Proceedings

Harnessing Technology to Support the National Drug Control Strategy

August 18–21, 1997
Chicago, Illinois

Sponsored by:

Executive Office of the President
Office of National Drug Control Policy
General Barry McCaffrey, Director
The Counterdrug Technology Assessment Center

and the

Department of Defense National Institute of Justice
Drug Enforcement Administration
Immigration and Naturalization Service
Federal Bureau of Investigation
Federal Aviation Administration
U.S. Customs Service U.S. Coast Guard
United Kingdom Home Office Revenue Canada

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1997 ONDCP International
Technology Symposium
Harnessing Technology to Support the
National Drug Control Strategy

August 18–21, 1997 Chicago, Illinois

INTRODUCTION

The Office of National Drug Control Policy (ONDCP) is pleased to have hosted its Fourth International Technology Symposium. Previous symposia have concentrated on technology advancements for counterdrug supply reduction, with a focus on support to drug law enforcement agencies. Our fourth symposium focused on Harnessing Technology for the Five Goals of the National Drug Control Strategy.

The opening video by Vice President Gore and the engaging opening sessions led by Director McCaffrey set the challenge and theme for the week. The audience was challenged to apply their minds and creative and organizational talents to the problem of reducing drug use through the Nation. In particular, the participants were encouraged to consider how technology can support the five goals and 32 objectives of our comprehensive 10-year National Drug Control Strategy.

The Symposium presentations addressed the five goals of the National Drug Control Strategy, a progress report on recent advances in medical and drug treatment technologies, a status report on the 10-year Technology Plan from the Science and Technology Committee, and 80 technical papers. These proceedings contain the technical papers presented at the symposium. The technical papers covered a broad array of topics. These included technology testbeds and test protocols, technologies and methodologies for nonintrusive inspection, communications, surveillance and tracking, information systems, chemical sensing for contraband and illicit substances, and technologies for chemical tagging and trace detection.

In addition to the technical presentations, the symposium provided an important opportunity to share the practical considerations and field experiences of law enforcement personnel and to discuss innovative approaches for integrating advanced technology into law enforcement applications. ONDCP and CTAC gratefully acknowledge the excellent contributions of the federal, state, and local U.S. law enforcement personnel who participated in a variety of discussions of these issues and opportunities, and of the foreign visitors who presented their countries' experiences. The many thoughtful and useful information exchanges developed by the symposium participants at the individual technical sessions are also appreciated. An incredible wealth of information was shared among the attendees and has been taken back to their respective communities within law enforcement, industry, and academia.

Dr. Albert E. Brandenstein
Office of National Drug Control Policy
Counterdrug Technology Assessment Center
November 1997

Harnessing Technology to Support the National Drug Control Strategy (Session 1B)

1

HARNESSING TECHNOLOGY TO SHIELD AMERICA'S AIR, LAND, AND SEA FRONTIERS FROM THE DRUG THREAT

Samuel H. Banks, Acting Commissioner of Customs
ONDCP International Technology Symposium
August 19, 1997

Thank you, General McCaffrey. Good afternoon, ladies and gentlemen. I'm very pleased to speak to you today on counterdrug enforcement operations at our borders, and in particular, on the array of technologies we currently use and our technology needs for the future.

Protecting our borders against drugs is an integrated team effort involving Immigration, Coast Guard, DEA, Defense, National Guard, and many other Federal, state, and local agencies. The Customs Service is at the center of that team, particularly with respect to the use of technology, and because it is the agency that I know best, I'm going to focus my remarks on how we use technology in support of Goal 4. Along the way, I may give you a totally new image of the Customs Service, which you may think of now as only the uniformed airport inspector who checks your bags and asks a few questions.

The Customs Service is at the center of border interdiction. Customs seizes 65 per cent of the cocaine, 60 per cent of the marijuana, and 84 per cent of the heroin that is seized by all Federal agencies in the United States. We also have a big hand in stopping the flow of money out of the country to pay for these drugs.

To achieve these results, we dedicate about 35 per cent of our budget to drug enforcement. The Customs personnel working on drug enforcement are not just the uniformed inspectors and canine officers at the ports, but also special agents working undercover and investigating drug cases; air crews flying radar-domed aircraft over South America; marine officers manning our sensor-equipped intercept and undercover boats in the Caribbean; and trained intelligence collectors and analysts.

Most of our technology is geared toward protecting America's borders from drugs, but it is also used for our other missions, like collecting $23 billion in revenues and protecting America from health and safety threats. We protect America's kids from unsafe toys and child pornographers, America's jobs from unfair trade practices, America's businesses from the theft of intellectual property rights, and America's consumers from unsafe foods, pesticides, and so on. Our mission is incredibly diverse, and although my focus today is drugs, we use technology to support all of our enforcement efforts.

Now let me focus on our enforcement operations and use of technology to support the first objective under the National Goal of shielding America's frontiers against drugs; that is, to detect, seize, deter, and disrupt drugs destined for the U.S.

The first thing you have to appreciate is the size of this job. The United States is a big country with open borders for the movement of commerce and people. There are over 300 international ports of entry to protect. The 431 million people using those ports last year was more than one and one-half times the population of the United States. The number of people crossing through our busiest land border port was more than the population of the United Kingdom. Did you know that a truck crosses from Mexico every 5 seconds and an ocean container is unloaded from a ship at Long Beach every 18 to 20 seconds? Do you realize that just during the 3 days of this Symposium, smugglers will have had almost 5 million opportunities to smuggle drugs into the United States hidden among the legitimate vehicles, people, and cargo moving through our ports?

Our frontiers also include over 10,000 miles of land and water borders, including the remote coastlines of Hawaii and Alaska. We've also got to contend with thousands of airfields and marinas within reach of the border. Even with Customs, Border Patrol, and Coast Guard working 24 hours a day, 365 days a year, protecting our borders is a very tough job. That's why we need technology to support us at every point along the way.

It is obvious that we cannot subject everyone and everything coming into the U.S. to a rigorous examination. Our first need is for technology to screen these millions of arrivals in order to select the bad guys -- that very small portion that are violators and a high risk for smuggling drugs into the country or for smuggling currency out of the country.

To give you an example most people can relate to, do you remember the scene at international airports only a few years ago? Everyone lined up first to clear Immigration and then, after you got your bags, everyone lined up again to clear Customs. With over 70 million passengers expected for FY97, we couldn't keep doing that -- and we don't. Today, automated information systems provide us with advance information on 50 per cent of the passengers arriving at our international airports. To make this happen, we've given passport readers and other information technology to the airlines so that when you check in at Heathrow, Norita, Bogota, and dozens of other overseas airports, a swipe of your passport through the reader starts a flow of information to Customs. We process this data through our computer lookout system and its links to INS, FBI, NCIC, and other lookout systems. We also analyze information from the airline reservation systems regarding your ticket and other pertinent screening indicators. By the time you arrive in the U.S., we know who we want to talk to in detail and who is more likely to move quickly through the entire inspection process.

At the airport, you now will encounter layered inspection systems that utilize aggressive-alert dogs and mobile X-ray vans to check baggage and cargo from the airplane. Once inside the inspection area, there are plain clothes rovers mingling with passengers and using behavioral analysis and other cues to detect potential smugglers, supported by passive-alert narcotics detection dogs and X-ray systems in the baggage areas. We're trying drug particle detectors at our airports to check both passengers and baggage. In addition, we'd like biometric and facial recognition technologies in order to provide more information on passengers and pedestrians, to verify identities against documents, or to identify persons on lookout lists. These technologies also are important for checking outbound passengers, baggage, and cargo as we look for currency.

Advance information on the 116 million cars entering the U.S. is essential if we are to quickly screen out the ones that deserve our closest scrutiny. Customs already has a nationwide database of suspect license plates that also is used by INS; the plate number is entered manually as you pull up to the inspection booth. This only takes a few seconds, but inasmuch as we have only 15 seconds on the average to decide whether a car proceeds or gets examined, we'd rather have the inspector use that time to observe the vehicle and its occupants for anything that arouses suspicion. As a result, Customs and INS have begun the installation of automated license plate readers for all of our inbound and outbound vehicle lanes on both the Mexican and Canadian borders. These will enter the license plates of the vehicle into our system automatically in lieu of the present manual entry. In addition, this is the first time we'll be capturing information on vehicles as they leave the country. While we probably won't be able to stop a car on its way out, we'll have ample time to check plate information against a variety of other data bases, so that we'll be very well prepared when that car returns. The Department of Defense has offered us help in developing an information system to utilize this outbound data in selecting inbound cars for attention, and we're discussing the details of that system right now.

In addition to this electronic technology, we also use our canine teams to screen suspect cars waiting to reach the primary inspection booth. Both dog and inspector are alert to signs of suspicious behavior as they roam the pre-primary lanes.

We also need enhanced screening systems to handle the millions of containers and trucks that enter the United States each year - almost 10 million in FY96 and the number is growing fast. We began a decade ago to automate the process of getting advance information on commercial shipments from the importers and freight forwarders. Then we built a variety of screening systems to process this electronic information against risk criteria, historical patterns, and trend analyses and to pick out the highest risk targets that our people and technology should concentrate on. Today, we get electronic information on about 98 per cent of the sea cargo that we receive. We're currently working on our second generation of automated targeting systems using rule-based analyses and artificial intelligence features to select sea containers and trucks that we should then run through our technology. Some of that work has been supported by ONDCP's Counterdrug Technology Assessment Center (CTAC) as well as the intelligence community. We're also involved in the many efforts going on in the U.S. to develop transponder-based electronic information systems for trucks crossing our Mexican, Canadian, and individual state borders.

By the way, although I've talked a lot about screening systems and automated targeting systems, it's very important that you realize why these are not the perfect answer against drug smuggling at our air, land, and sea ports. Advanced screening can't provide a lot of help against one of the most prevalent smuggling methods -- internal conspiracies. These involve the airport and seaport personnel who handle the aircraft, bags, containers, cargo, etc. In this smuggling scheme, traffickers place drugs in baggage, in cargo, in a container, or in a truck without the knowledge of the legitimate passenger, shipper, driver, or anyone else who would be checked by the targeting system. Upon arrival in the U.S., the drugs are removed before the item ever reaches Customs for examination. A targeting system focused on the innocent trucker or passenger won't stop this kind of smuggling, but as I'll describe soon, we hope to have other technologies that will.

Now let me mention some of the inspection technologies that we routinely use all around the U.S. These include the mobile X-ray vans that I've already mentioned as well as a variety of other X-ray systems for baggage, light cargo, and mail; handheld contraband detectors, commonly called the Buster, that utilize a small radioactive source and backscatter detectors to find drugs secreted in false walls, in tires, in car doors, and a multitude of other hiding places; fiberoptic scopes to look into gas tanks and the multitude of hiding places available in every vehicle; drug sprays and drug wipes to check for drug traces on clothes, baggage, and vehicles; laser range finders to look between or under cargo pallets to measure the inside of a truck and detect false walls; as well as the drug detection dogs previously mentioned to check baggage, vehicles, cargo, and mail.

We also make frequent use of less sophisticated equipment like power drills, needle probes, and other hand tools to check everything from trucks to briefcases. These "low-tech" items may not be as sophisticated as the high-tech ones, but that's not what's important. We will use anything that will help our inspectors find drugs.

To protect our borders against drugs, it is not enough to just detect and seize them at the ports, you have to get to the drug trafficking organizations and their transportation cells. When we detect a load of drugs being brought into the country, our Special Agents will often run controlled deliveries that allow the load to proceed under surveillance on up the ladder of the drug trafficking groups. These controlled deliveries take us to major distribution points like Detroit, New York, or Chicago. Most often the drugs are moved by car or truck, but they can also go by air or sea. Whatever the route, we can use our sensor-equipped aircraft and undercover boats to help us run these controlled deliveries without tipping our hand to the smuggler's counter-surveillance. The DEA has designated almost half of our 2,800 Special Agents to run drug investigations stemming from the borders and our investigative efforts often reach overseas to prevent drugs from entering the U.S. and to disrupt smuggling activities. For example, recent investigative work after the seizure of 2,522 pounds of cocaine in Newark, New Jersey, led to subsequent cocaine seizures in Spain, which was the source of the shipments to the U.S.

The technology used by Customs Special Agents is typical of most investigative organizations -- covert tracking systems, miniaturized video and audio surveillance systems, telephone wiretap equipment, night vision devices, secure communications, and so on. And like the other investigative agencies, we need new intercept technology to deal with the increasing use of cellular and digital phones, secure faxes, and the Internet; smaller and more reliable surveillance equipment; better power supplies for all of our devices; and communications capabilities that the criminals can not detect or disrupt.

Now let me highlight the operations and technology that particularly emphasize protecting the southern tier of the U.S.; i.e., the Southwest Border, Puerto Rico, and the Virgin Islands, in accordance with Objective Two of the national counterdrug goal of shielding America's frontiers.

The major drug smuggling threat in the 1980's was by small aircraft flying drugs into Florida, the Caribbean, and across our southwest border. With help from the Department of Defense, we built a fleet of sensor-equipped aircraft based all along the southern border supported by 15 radar-equipped tethered aerostats providing low altitude surveillance reaching from California into the Caribbean to Puerto Rico. The level of air intrusions dropped from more than 300 in fiscal 1988 to less than a dozen per year now.

Our success in disrupting the direct air route into the U.S. led the traffickers to land their aircraft short of the border in Mexico and to move their loads across the border between and through the ports. In response, the Border Patrol increased their resources and their efforts along the Mexican border, forcing more smuggling, and more violence, into the ports.

In the early 90's, drug traffickers simply put large loads of cocaine in private automobiles often without much attempt at concealment. When we'd make a move to inspect their vehicle, their means of escape was to just step on the gas, ram anything in their way, and make a high speed get-away onto the streets or highways beyond the port; a tactic we call port-running. As we shut down port-running, the traffickers increased their use of trucks, primarily empties, to carry concealed loads of thousands of pounds of cocaine at a time.

To cope with the increased smuggling through the Southwest border ports in cars and trucks, Customs instituted Operation Hard Line. Operation Hard Line emphasized unpredictable inspection methods, increased investigations, intelligence-driven operations, and changes in the flow of traffic through the port along with greater and innovative uses of technology. We also increased the use of the National Guard to assist us in operating many of our inspection systems and maintaining the controlled movement of vehicles and cargoes through our ports -- often the Guard would bring their own Busters and other devices to assist in this role. Today we have 620 National Guard troops augmenting our resources nationwide, with 300 of them concentrated on the Southwest Border.

The technology components of Hard Line are a mix of low, medium, and high-tech devices and systems. To stop the port-runners, we use concrete posts or bollards that we raise and lower hydraulically, stop-sticks dropped by inspectors in front of suspect cars to deflate tires, and concrete highway barriers to corral groups of cars and eliminate straight runs from the entry gate to the exit. As a result of these measures, port running dropped from 879 attempts in 1994 to about 330 attempts in 1997. To further reduce these numbers, Customs and INS are looking at additional ways to safely stop cars attempting to run through the port or make a U-turn back into Mexico.

Moving up the technology scale in support of Operation Hard Line, we increased our use of dogs and handheld inspection devices like the Buster, fiberoptic scopes, and range finders as part of a layered inspection process that encourages inspection of a car or truck at any point in its passage through the port. The automated license plate readers for cars and trucks are another element of the Hard Line technology improvements.

The high end of our technology scale is directed at smuggling in commercial trucks. As you can imagine, a truck provides a multitude of hiding places for drugs: tires, gas tanks, walls, roof, chassis, false walls, and many more. We get about 3.5 million trucks a year across the southwest border, and if we gave each a full narcotics examination we'd have trucks backed up clear to Mexico City within a matter of days. We'd also shut down the U.S. auto industry and other businesses depending on just-in-time deliveries from plants in Mexico. Instead, we employ an examination strategy stressing selective, flexible, and unpredictable inspections at every port; what we need now are examination technologies that support this strategy.

The first technology deployed specifically for examining trucks is the fixed site truck X-ray that scans the largest tractor-trailer rig in a single pass and provides transmission and backscatter images from both sides of the vehicle. It's not the biggest or most sophisticated truck X-ray system in the world, but for us it is practical, affordable, and most importantly -- very effective. Our first system has detected over 28,564 pounds of drugs since it began operation, along with 19 illegal aliens and a variety of other contraband. The prototype was developed for us by the Department of Defense Counterdrug Technology Development Program (CTDP); in just a little over a year we will have six more in operation, with an eighth system early in 1999.

The DOD program has also produced a mobile truck X-ray that provides many of the features of the fixed site system in a totally self-contained 32 foot truck capable of going to any port on the border. The first of these systems was backscatter only, but in October we will begin evaluating a prototype with both transmission and backscatter. This system can examine trucks of any size as well as cars and even some cargos. We have high expectations for this system for both counterdrug and anti-terrorism applications.

Checking for drugs placed in the load-carrying section of propane tankers and other thick-walled gas or bulk carriers is a particularly difficult problem. The gamma-imager for trucks is a joint effort of Customs, ONDCP's CTAC, and DOD's CTDP to solve this particular problem. The prototype system is relatively straight-forward in concept, operation, and appearance, and it has proven to be exceedingly useful and durable during several months of operational use by Customs. An improved version for scanning trucks is presently being funded by DOD.

Operation Hard Line and its supporting technology have been somewhat successful along the southwest border. Drug seizures are up, the ratio of inspections per seizure is down, attempts at port-running are down, and investigative cases and arrests are being made all over the country as a result of intelligence gained at the ports. Not surprisingly, the past 2 years have seen a resurgence of drug trafficking through Puerto Rico and the Caribbean. We have expanded Hard Line into that area and the Coast Guard, DEA, and FBI are increasing their resources as well.

To deal with the increased quantities of drugs we expect will be smuggled in sea and air cargo shipments, we are working right now with the DOD CTDP on a joint program to develop technology for use in seaports and airports in south Florida, Puerto Rico, and around the country. This program will produce a new generation of X-ray systems to examine bigger and heavier loads than we can currently handle, from LD-3 air cargo pallets to loaded sea-going containers. We also will be looking at how our new and existing systems can be used together to improve our overall effectiveness against drug smuggling in a "system of systems" concept. Many of these technologies will be mobile or relocatable so we can move our equipment between ports to meet changing threats and intelligence leads; this also means we can put the technology right at the point where the container or pallet is dropped off the carrier, helping us to detect internal conspiracies before anyone has a chance to remove the load. You will hear more about these new technologies in the next 2 days. We look forward to their successful deployment over the next 18 to 24 months.

Objective Two emphasizes intelligence and information-driven operations along the southern tier and we are linking technology to this aspect as well. Our intelligence teams along the borders utilize automated information systems, communications intercept equipment, drug particle detectors, the mobile truck X-ray, and other technology to learn what the smugglers are doing, including how they are reacting to our detection efforts. This enables us to react quickly to changes in smuggler tactics and reduce the smuggling opportunities available to the traffickers.

As you know, drug traffickers will change their tactics in response to our enforcement activities; a reality that again affects our needs and criteria for technology. The counter-measures employed by smugglers include shifting their operations to other locations or modes of entry and changing concealment methods to defeat our inspection equipment, just as they once tried hot pepper to discourage our dogs. They also spy on our operations, using spotters to assess our every move; they use communication codes and equipment that are difficult to intercept; and of course, they try to monitor our own communications. We defeat some of these countermeasures by our use of multiple inspection technologies, audio and video monitoring, counter-surveillance measures, and the Service-wide use of voice privacy radios, but we can still use new equipment that will make the smuggler's life even more difficult.

We also have enlisted American industry and businesses to help protect the U.S. against drugs. Our Carrier Initiative Program involves airlines, shipping lines, and truckers to assist us in stopping drugs from entering this country through their own use of inspection and security technologies. For example, 747's loaded with hundreds of boxes of cut flowers arrive daily from Colombia; these boxes were a serious smuggling threat until the airlines began their own X-raying of every box on arrival in Miami. One carrier even has closed circuit TV displays in Miami that monitor loading operations in Bogota, and others are considering buying their own large container and cargo X-ray systems. The Program currently has over 3,300 participants and has stopped thousands of pounds of drugs from reaching our shores or getting through our ports. Last year, we started a new partnership with U.S. businesses, the Business Anti-Smuggling Coalition, to combat the smuggling of drugs in goods shipped by these companies from Mexico and other countries into the U.S. The goal of these industry partnerships is to eliminate the use of legitimate business shipments and commercial carriers as a major opportunity for narcotics traffickers.

Objective Three under the goal of shielding America's frontiers stresses improving cooperation with Mexico, Caribbean, and other transit zone countries. We use technology in a number of ways to accomplish this objective, but I'd like to focus on our air and marine programs.

Many folks don't know that Customs has an air force of 136 aircraft, including surveillance and tracking aircraft that are flying over Colombia, Peru, Bolivia, and the transit zone. These long-range P-3's are equipped with radar domes just like AWACS; a technology program that many people thought was impossible until we went out and did it. Our air fleet also includes 26 Citation-II jet intercept/tracker aircraft that are equipped with the Air Force's F-16 radar and the Navy's FLIR; seven of these Citations are supporting counterdrug activities in Central and South America and two more are in Mexico. By the way, this was another Customs development program that provided the model for others to follow. We also operate other sensor-equipped fixed wing aircraft and helicopters in the U.S. to track smuggler aircraft and boats and to support controlled deliveries, covert surveillances, and apprehensions by Customs or other agencies. The technology needs for our air operations include satellite-based tracking systems, long-range optics, and improved interagency communications.

Our marine fleet of 84 vessels is a mix of high-speed intercept craft and unmarked small boats used for surveillance and undercover operations. Smugglers are making extensive use of air drops to boats waiting off the Bahamas and the Caribbean, and our aircraft and marine interceptors work together and in concert with the Coast Guard to disrupt these operations and intercept the load-carrying boats before they reach shore. Our boats have been rammed and shot at more than once by smugglers trying to avoid capture, and we could use a stun-gun or other method to stop smuggler boats trying such dangerous tactics. We also need marine radar and infrared and infrared sensors to detect low-profile vessels and jet-skis, underwater acoustic systems to detect unusual marine activity, and better devices to look for towed and parasitic concealments underwater.

The fourth objective under this goal is to support research and technology. I believe that no other agency in the world can match the extent and breadth of the Customs Service investment in interdiction technology. Our field troops are willing users of this technology and we are committed to its use in accomplishing our mission.

Our research and technology efforts are in lockstep with ONDCP's Counterdrug Technology Assessment Center and with the programs of DOD, FAA, DOE, and other domestic and international enforcement agencies. We are excited about the current efforts with DOD and the other development programs I've described, but we still have lots of unmet needs. There are almost 300,000 railroad cars coming from Mexico each year and Customs and the Border Patrol need better ways to examine them for drugs and aliens. We need ways to quickly check passenger vehicles for drugs without causing 5 hour delays or requiring everyone to get out. We need technology to find cocaine and heroin carried on or in the bodies of air passengers and pedestrians. We need technology to deal with cyber-smuggling -- the use of the

Internet by drug traffickers to conduct their activities and keep their records. The heart of our counterdrug enforcement strategy is a layered process that provides many opportunities to detect the smuggler and disrupt his operations; we want every smuggler to run a gauntlet that he doesn't even know exists, and we need technologies that support this concept.

I hope my remarks have given you an idea of how important technology is to the protection of America's borders against drugs. We are committed to the effective use of technology to satisfy Goal 4 of the National Drug Control Strategy. We know that the job of protecting our borders cannot be done solely by people, but neither can it be done solely by technology. There is no silver bullet. This job requires effective and affordable technology operated by and supporting trained and dedicated personnel -- and we intend to achieve exactly that. Our national success requires a full time effort from a coordinated, focused, and dedicated team, supported by the best available technology. That team includes American industry and I look forward to your continuing support.

Thank you very much.

2

Progress Reports on Key Medical and Treatment Projects (Session 1C)

Current Developments in Cocaine Monoclonal Antibodies

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Cocaine reinforces its self-administration the greater the rise and rate of rise to peak serum concentrations. Catalytic antibodies are artificial enzymes which could reduce serum cocaine concentrations, deprive the abuser of cocaine's reinforcing effect, and thus favor extinction of the addiction. Catalytic antibodies are elicited by immunization with a stable analog of a transition-state for a chemical reaction. Cocaine can be deactivated by hydrolysis of its benzoyl ester group and an analog of the transition-state for this ester hydrolysis will elicit antibodies which are highly specific esterases against cocaine. These artificial enzymes would bind and hydrolytically deactivate cocaine, thus freeing themselves for further binding. Through our new method for synthesizing phosphonate monoesters, we constructed several phosponate-based transition-state analogs of cocaine hydrolysis. Using these analogs, monoclonal antibodies were elicited and, thus far, nine anti-analog antibodies with hydrolytic activity against cocaine have been elicited. The activity of one of these antibodies, 15A10, is already sufficient to test its effect on cocaine-induced reinforcement and toxicity in animals models of addiction and overdose. We are also investigating novel strategies in analog design, and have undertaken structural analysis and mutagenesis studies of the most potent catalytic antibodies in hand, in order to optimize enzyme activity in preparation for antibody humanization and clinical trials.

Developing Medications for Drug Abusers

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Medications for opiate, nicotine and alcohol abuse are proven to be effective. They reduce drug use, improve the addict's health, relationships and productivity. However, there are no medications for methamphetamine, cocaine, or amphetamine addicts. Given that these drugs are now serious threats to the health, well being and safety of our society, the development of medications for these drugs, referred to as psychostimulants, is a national priority.

Many kinds of medications are needed. Just as there are many kinds of medications used to control cardiovascular diseases, we will need more than one kind of medication to treat methamphetamine addiction. We will need medications to control craving and "out-of-control" drug seeking, to reduce toxicity, and to prevent relapse. Because securing the addict to a treatment program is how treatment must begin, our group has been developing medications which are a first, critical intervention, which we expect will allow the addict to stop destructive behavior and begin treatment.

An obvious defining feature of drug addiction is out of control drug seeking behavior. This often leads to performance of crime and a series of self destructive episodes that can effect all aspects of an addict's life. Many addicts leave treatment because of the demoralizing, persistent strong urge to find, buy and take drugs. A medication that will stop this persistent strong urge to seek out illicit drugs is essential. This type of medication is the focus of the work of our group.

We are developing a medication that would be controlled and dispensed by the treatment physician, that would reduce craving for illicit drugs, and that would be a safe stepping stone in the overall process of withdrawing from drug use. The fact that the treatment center dispenses the drug will bind the addict to the center and give the treatment staff some control over the addict and the opportunity to set in place a program for detoxification. This type of approach, which is not a cure or the "magic wand", is proven to be effective as part of a larger program.

Our program began more than 10 years ago in collaboration with Dr Ivy Carroll at the Research Triangle Institute. Dr Carroll is a medicinal chemist and synthesizes the compounds which are tested by Dr Kuhar's team. We now have on hand more than 25 reasonable medication candidates which, with the support of ONDCP, are being tested further. Nearly 500 compounds have been synthesized and tested overall.

Every effective therapeutic medication has to have various properties. Besides the obvious need for safety and low toxicity, the compounds must also be potent and selective for their targets in order to reduce side effects, be orally active, and reasonably long acting. Some other technical needs must be met also. The compounds that we have developed have these properties, although detailed toxicity testing must be done. Of course ultimately they must be shown to be effective in the real settings of treatment centers. Our compounds are referred to as phenyltropanes.

Because it is unethical to test compounds in humans unless they are proven likely to be safe and successful, it is necessary to test these compounds in animals, particularly in animal models of addiction. A particularly effective and useful animal model is the self-administering animal. In this paradigm, an animal is given the opportunity to obtain an injection of a drug by pressing a lever. If the animal likes the drug, it will self administer it by pressing the lever again and again. This is an exceptionally good model in that almost all drugs that humans abuse are self-administered by these animals. Without this kind of animal testing, progress in developing medications of all types would be impossible or at least much more dangerous to people.

The compounds that we are developing can stop drug self administration by the animal. In other words, an injection of one of our candidate medications, will reduce or stop the subsequent self administration of cocaine. This is an important "proof of principle" that is necessary before these compounds can considered for testing in humans.

While we are some years away from testing in humans, we have produced excellent candidate medications that are badly needed.

These medications would be used in the following scenario. When an addict presents himself for treatment, whether it be voluntary or coerced, he/she is in a state where their behavior is out of control. The urge to seek, obtain and take the illicit drug is so great that the odds of failure of treatment are very high. However, the medication that we are trying to produce would reduce or stop these urges. The addict would return for more medication and be amenable to further treatment. Eventually it is hoped that all treatment would be stopped and the addict would return to normal life.

(As often happens in medical research, there may be other, unexpected uses for some of our compounds. While our focus is on medications for drug abuse, many of our compounds could be useful in treating depression, obesity, attention deficient hyperactivity and Parkinson's Disease. One of our compounds is being developed by a drug company as a diagnostic tool for early detection of Parkinson's disease; this compound is in Phase II testing which indicates that it is well along the path of drug development and could be marketed in a couple of years.)

The Drug Evaluation Network Study and the TRI-Net

An Electronic Information System to Track National Trends in Substance Abuse Treatment

Deni Carise, Ph.D.
Treatment Research Institute (TRI) at the University of Pennsylvania School of Medicine

And

A. Thomas McLellan, Ph.D.
Center for Studies on Addictions, University of Pennsylvania
and
Treatment Research Institute (TRI) at the University of Pennsylvania School of Medicine

Introduction

The Drug Evaluation Network Study (DENS) is a national, electronic data collection project that has recently completed an extensive pilot stage. During this pilot, the DENS information system (the TRI-Net) was installed in 5 cities; New York, San Francisco, Chicago, Philadelphia, and Albuquerque, and in over 40 treatment programs. The primary goal of the pilot was to evaluate the applicability of the TRI-Net information system for collecting and transferring data on the needs of patients presenting for substance abuse treatment across the country. Currently, an estimated 1 million Americans are undergoing some form of substance dependency treatment program (National Drug Control Strategy, 1997).

The data collected include Addiction Severity Index (ASI) interviews administered via laptop computers by trained interviewers at the programs. The ASI is the most widely used drug and alcohol assessment instrument in the field. The collected ASI's are transferred via modem to the Treatment Research Institute (TRI) on a bi-weekly basis. This insures rapid, timely, valid and useful data on the demographic make up and the nature and severity of problems presented by substance abuse patients entering the "network" of programs.

Ultimately, this system will include alcohol and drug treatment programs representatively sampled from all of the major metropolitan areas in the country. It will include public and private programs delivering various types of substance abuse treatments including residential and therapeutic communities, intensive outpatient, traditional outpatient, and methadone maintenance programs. Additionally, there are plans to include drug court programs. Collection of this type of information is consistent with the national funding priorities listed by the Office of National Drug Control Policy which demands a strategy that "contains the means to identify and monitor new drug use trends so that programs can address them proactively" (National Drug Control Strategy, 1997).

There has been no system of data collection focused upon the characteristics, nature and severity of problems of patients entering substance abuse treatment across the country. In the DENS TRI-Net, we are collecting ASI information on the nature, number and severity of patient's problems at the time of treatment admission in the following areas: medical, employment, drug, alcohol, legal, family, and psychiatric (Carise, McLellan, Kleber, & Petro, In Press).

DENS also collects information on length of stay, type of treatment, and discharge status, all of which have been shown to be important in evaluating outcome (Gottheil, McLellan, & Druley, 1992). Although this is very basic information, even this minimal data has not been available since the 1970's; and never in a form that could provide rapid reporting to state and federal policy makers. Consequently, policy makers at the federal and state levels have not had the information necessary to recognize important changes in the patient population and the introduction of new drug problems occurring over the past two decades. These trends have ultimately had profound influence on the treatment system (i.e.: the emergence of AIDS, the cocaine epidemic, the influence of managed care, etc.).

There is every indication of continued change within the substance abuse treatment field in the years to come. Thus, there will be an even greater need for "real time" information about patient characteristics, their problems, and the acuity of those problems in the planning and administering of the substance abuse treatment system. This information is essential to national agencies such as ONDCP, NIDA, NIAAA, CSAT, CSAP, NIJ, NIMH, the Veterans Administration and most state treatment systems. To be useful, the information should be relevant to the multiple clinical, administrative, fiscal, evaluative, and policy questions that so regularly arise, and the information should be available rapidly and continuously to enable observation of changes over time. Ideally the data should be suitable for presentation to many different audiences. Finally, the data must be useful and informative to treatment providers who collect it.

The DENS study and the TRI-Net system of data collection was designed around four separate principles:

1) Nationally representative sampling - After successful piloting of the TRI-Net system, DENS is ready to select a truly representative national sample of treatment programs. Programs selected will include publicly and privately funded programs from 26 major metropolitan regions of the country, and from all major treatment modalities. Just as television advertisers have developed the nationally representative set of "Nielsen Families" whose daily habits inform us about the trends in television watching - we propose that the patient characteristics and problems shown by admissions to the nationally representative sample of treatment programs will inform federal and state policy makers about current trends in the substance abuse field.

2) Reliable, valid and flexible information on clinically relevant patient characteristics. The Addiction Severity Index (ASI) will be the primary source for collection of patient information. The ASI will provide basic, valid, clinical and administrative information on all patients entering the national treatment system (Carise & McLellan, In Press). The ASI is a free, public domain instrument and is the most widely used instrument in the field. There are established training materials and the availability of a toll-free 800 number manned by trained staff to answer any questions regarding the instrument. Finally, information from the ASI is useful to programs' clinical staff in the initial assessment of prospective patients and to program administrative staff in providing basic descriptive information for reporting purposes. The ASI also provides information that can easily be used as a valid baseline in subsequent outcome evaluation efforts.

However, it is also clear that the ASI by itself will not provide information on the multiple and highly specific questions that continually face those in the national and state policy arena (e.g., How many pregnant women are in the system? Are more patients using amphetamines compared to last year? How many patients are referred directly from the criminal justice system? Is intravenous drug use increasing, and in what parts of the country?) To address these areas of interest **as they arise**, TRI-Net has the capability to add up to ten questions that may be included for a time-limited period (e.g., one to six months), and will allow collection of specific, timely information in a rapid time frame.

3) Collection of information by local staff - For economic reasons, and to maximize the local utility of the information to the treatment programs, the data collection is implemented by trained staff at individual treatment programs during the intake process. We train staff members of each participating program to administer the ASI and use the data transfer system. Also, lap-top computers and clinically useful software packages are provided to the programs in an effort to make the data collection beneficial at the program level.

4) Rapid transfer of all collected data on a timely basis to a central information system - The true value of this information to national substance abuse treatment and policy development efforts is the availability of "real time" information on patients entering the treatment system. To this end, the data collected at the program level are transferred to a central server unit via high speed modem. To protect client confidentiality no identifying information, including client's name, address, phone-number, social security number, etc, can be transferred. This process does not involve significant additional work by the treatment program staff, it is done twice a month, and takes approximately 5 minutes. Thus, when a report on the DENS is issued, it includes data on clients entering the system as recently as 1 week ago.

With these principles in mind, staff from 41 programs in 5 states were trained on the administration of the Addiction Severity Index and the DENS/TRI-Net system during the pilot phase of the project. At the time of this writing, approximately 1,700 cases have been collected from residential, outpatient, intensive outpatient, methadone maintenance programs and drug courts. This paper will discuss what and how data has been collected with the DENS system, what was learned in the pilot stage, implications of the study, and future expansion plans.

Note: Although pilot data on trends, comparisons of drug and alcohol problems between cities and areas of the country, differences over time, and differences between program types will be presented, programs participating in the DENS **pilot** stage are **not** randomly selected. This data should be viewed only as an indication of the **types** of inferences that can be drawn from the system **after** a random sample is employed.

Procedures

Both technical and administrative difficulties can be expected in the development of a project of this scope. For this reason, we decided to initiate the system in several phases. Our hope was to resolve difficulties as they arose at a manageable level and with minimal cost. The first phase of the pilot involved development of data collection technology and implementation of that technology in four programs in Philadelphia. The second phase involved responding to comments or problems from phase I and testing the system in 4 additional cities.

Admission Interview (ASI) – Client Data

As indicated above, the data collection efforts include the ASI provided in a computer software program. Our decision to focus on the ASI followed more than 20 years of replicated reliability, validity, and utility evaluation of the instrument with a very wide range of substance abusers (McLellan, Kushner, Metzger, & Peters, 1992, McLellan, Luborsky, Cacciola, Griffith, Evans, Barr, & O'Brien, 1985, McLellan, Luborsky, O'Brien, & Woody 1980). We have confidence based on this pre-testing that the data collected will be accurate and useful. The ASI data collected has immediate **clinical** value since we include a software package that prints out a six to nine page clinical narrative which may be used by programs as the admission note or evaluation summary. This narrative summary is also used by many providers to satisfy state requirements for an individualized intake evaluation, and provides a written springboard for the "biopsychosocial" assessment.

In the first phase of the pilot, data were collected on a pen-based laptop computer using MS Windows based software. This computer is an 8 1/2" by 11" tablet that receives input via a magnetic pen. It is an IBM compatible 386 system. The Addiction Severity Index was transferred to a software based version developed with FoxPro for Windows and additional support libraries. The system allows an interviewer to enter data directly into the laptop computer using the magnetic pen (rather than a keyboard) during the ASI interview. This allows the interviewer to establish good rapport with the client by maintaining appropriate posture, eye contact, and body language similar to that of a typical paper and pencil interviewing format. This version of data entry has been fully acceptable by patients and interviewers. We have not had a single case in which a patient refused to provide us with information using this format. Further, we have found very high correlation between the pen based system and the standard paper and pencil interview ASI.

All data are automatically screened for errors and inconsistencies during the interviewing process. The ASI computer software will not allow the interviewer to enter invalid values (i.e., entering a value of 5 for a question that has a range of 0 to 4). The cross-checking system also detects inconsistencies, such as contradictory coding (ex; the client reports in the medical section that s/he is receiving a pension for a medical disability, but does not report that as income in the employment/support section. These inconsistencies are "flagged" during the interview. This allows for immediate correction. When an error occurs, a built in ASI dictionary prompts the interviewer and s/he has the option of correcting the error immediately or at the end of the interview. Finally, at the end of the interview, there is an option to run a data check on all of the data entered. This check identifies blank fields or skipped questions and notes any errors that were flagged during the interview. Overall, the error and inconsistency checking system of the software produces a more accurate interview than the standard paper and pencil ASI interview. In fact, throughout all phases of the pilot, the "poor data" rate ranged from 3.0 to 4.5%, substantially better than our experience with pen and paper based ASI interviews. For the purposes of this study, poor data is defined as any intake ASI missing the data necessary to calculate at least 5 of the 7 composite scores, or any ASI missing data on the date of intake or date of interview. ASI composite scores are automatically calculated by the computer upon completion of each interview.

Program Description Form – Program Data

It is important for a number of reasons to develop useful and accurate descriptive information on the nature and organization of the treatment programs participating in the study. Therefore, a program description form was created based on earlier work completed by the Center for Substance Abuse Treatment as part of their National Treatment Improvement and Evaluation Study (NTIES); and based on the Drug and Alcohol Services Information System (DASIS), "Uniform Facility Data Set" (UFDS). It was important to build from this early work to insure maximal comparability with previous, large-scale data collection. The resulting Program Description Form, completed once each year by every program participating in DENS, includes extensive information on the treatment program, the services offered, and staffing and fiscal statistics. Examples of the types of questions included in the program description form include:

Type of program (Independent/Free Standing. part of a hospital, profit, non-profit, etc.)
Type of care offered (Inpatient, partial hospital, intensive outpatient, methadone, etc.)
Total Number of Beds Available/Length of Program, Average Length of Stay
Total number of treatment hours per week
Waiting list information
Staff Descriptors:
    Full-time, part-time, volunteer, Psychiatrists, Social Workers, Addictions Therapists, administrative, ethnicity, languages spoken, and recovering staff, etc.)
Reimbursement/Insurance Descriptors
    Private insurance, PPO, HMO or fee for service, Medicaid, Medicare, VA benefits, State, Federal funding, self-pay, or percent bad debt/charity.
Acceptable Reasons for Admission (Poly-drug, alcohol, heroin, cocaine problems, etc.)
Information on number of individual and group sessions.
Drug and Alcohol Services Offered at or by the program
    Number of educational, 12-step, relapse groups, etc. per week. Aftercare, medications for drug craving, (e.g. Desipramine), breathalyzer/urine testing, etc.
Medical Services Offered by the program (evaluation, HIV testing, prescriptions, etc.)
Employment Services Offered at or by the program.
Family Services (Childcare, couples counseling, parenting skills, etc.)
Psychological/Psychiatric Services Offered at or by the program (Relaxation/stress management, psychiatric medications, biofeedback, etc.)

Note: A complete copy of the Program Description Form is available from the senior author.

The TRI-Net System: An Electronic Information Transfer Protocol

Prior studies at the University of Pennsylvania Instrument Development Center have found that laptop computers offer real ease of use even for new interviewers. The current system includes an internal data transfer modem and a built-in protocol for the easy transfer of collected ASI interviews. Perhaps as importantly, the system allows for two-way transfer of information, thus permitting our central server to send up to 10 new questions to each of the program computers as the need arises. In this way, the system will continue to be current and streamlined, asking a few targeted questions of administrative and clinical significance, getting the answers rapidly and then discontinuing those questions in favor of other questions that will inevitably arise.

Once the data are checked and corrected at the program site, the interviewer sends the information via modem to the TRI-Net computing station where data from across the nation are received and stored. Transferring data via modem is an easy process. Each program participating in the TRI-NET study selects a convenient and regular time to transmit data. To transmit the data, programs simply connect the computer system to any telephone line using the modem located in the back of the computer and continue through the prompted commands. The software automatically dials and connects the system to the TRI-NET computing station. Data are downloaded in about 5 minutes, depending on the number of cases being transmitted.

The system is specifically designed **NOT** to transfer any identifying information (i.e., name, social security number, phone number, address, etc.). If there are any questions during the data transfer process, TRI-NET has a toll free number (1-800-335-9874) which provides technical support. Once data are transmitted, end-users receive a message indicating the transfer was successful. Data are then stored in an electronic folder dedicated to each agency. These data are merged with other folders to produce a national database we call the TRI-"Net". All programs have complete access to **their program** database and partial access to the full national data system, to permit comparisons between local and national trends. No program will receive data from another **identified** program.

Treatment Programs

Treatment programs from five cities across the country (Philadelphia, Chicago, New York, San Francisco, and Albuquerque) were asked to participate in the pilot in two phases. These programs continue to be the "laboratory" for us to develop a monitoring system that will be easy to use, provide clinical information to the programs, and have the capability to provide the needed data on a national scale. Like the larger sample of programs that will form the national system, these programs have been chosen to represent different modalities of treatment and populations of patients. They include methadone maintenance, inpatient residential, traditional outpatient, intensive outpatient program , and drug courts.

It is recognized that these programs are not necessarily representative of the greater population of all treatment programs; however, at this point, importance was placed on the development of a potentially useful prototype system in an atmosphere of cooperation and participation. The finished prototype will now be implemented in a larger, randomly sampled, and more representative network during the upcoming expansion.

Initial Training and Testing.

The following package of materials and training are provided to all programs:

1) A laptop computer with Windows® operating system and internal modem. The computers are chosen based on ease with which an interviewer can talk with a patient in a normal fashion (as they would with a clipboard and pencil) and to record information in a rapid and accurate fashion.

2) Pre-loaded software that permits collection of the ASI data (including notes and comments) and downloads to a central computer via modem. The full ASI (45-60 minute interview) is on the computer. It should be noted that this is **not a self-administered** version of the ASI.

3) Additional software is provided that uses the collected ASI data to provide clinical staff with a six to nine page clinical **narrative** suitable for use as an intake or admission summary, and to guide the initial treatment plan for each patient. This information is stored as a Windows® based word-processing document.

4) A training package describing the use of the computers, instructions for downloading the collected information, and instructions for using the clinical and administrative software. In addition, each program has access to a toll free, telephone information service that provides support on all aspects of the process.

5) Programs receive an annual stipend of $1,000 to partially offset any additional costs incurred by the program.

6) Programs receive extensive quarterly reports comparing all data collected at their site to the nationwide database. Program administration staff have placed a high value on these reports which they have used to justify funding, help with accreditation proceedings, and to reallocate staff. These reports, in the form of tables, statistically compare data in every area of clients functioning. Occasionally, programs will request and receive additional reports for specific purposes such as comparing their inpatient with their outpatient program, severity of problems of male vs. female clients, or for a site visit by an accrediting agency visit. A software program was developed to enable quick response to these requests, and the 10 page (Excel® based) report can be generated within 48 hours.

In **phase I** of the pilot, the four treatment programs located in the greater Philadelphia area were each individually trained in the use of an earlier pen-based computer. These programs included an intensive outpatient and traditional outpatient program located in a large, research oriented treatment center, a small inpatient program specifically for pregnant women and their children, and a Veteran's Administration based methadone maintenance program. All programs had previous training in the ASI, which we hypothesized would make implementation of DENS relatively trouble-free.

Overall, the most notable difficulties were with the pen-based computers. It should be noted that two of the programs were quite computer knowledgeable whereas staff at the other two programs described themselves as "computer phobic." Although staff at all four programs liked the idea of being able to write on the computer screen with the 'pen,' they were less than enthusiastic with the results. The translation of their writing from the pen computer screen to the printed ASI resembled notes taken by an elementary school student with a crayon. Regardless of the neatness of the writing, the print out appeared less than professional.

Because of staff complaints with this aspect of the computer, we altered the software to allow the counselor's notes to be entered directly from the keyboard. Additionally, changes were made to the computer and the software in an effort to decrease problems with the study. The computers were 386 MHz, windows based laptops with 8mg ram. The equivalent computer with Pentium technology would triple the cost. Because the speed of the computer functioning was the primary complaint, we added an additional 8 mg ram for a total of 16. This moderately increased the speed in running the ASI and crosscheck programs, and in printing the ASI.

<u>Phase II – Chicago and Albuquerque</u>

Shortly after completion of training in the Philadelphia programs, training commenced in Albuquerque and Chicago. Because extensive problems had not yet been identified with the pen-based computers, the study continued to include them. In Albuquerque, a large free standing residential program was chosen, as well as three other programs (methadone, intensive outpatient, and traditional outpatient), all housed within a large, research and university based facility. In Chicago, four facilities, most offering several modalities of treatment were approached with the expectation that two would be willing to participate. All four programs wanted very much to participate. Since we wanted to pilot this as extensively as possible, all four facilities were enrolled representing a total of 9 programs.

In Chicago, most programs had some level of computerization, but none were research-based facilities. The facilities include a large, private methadone treatment center and a primarily Hispanic center providing inpatient, outpatient and intensive outpatient services. There is also a community-based facility providing outpatient and intensive outpatient services, and a large free standing facility providing numerous types of treatment with inpatient, outpatient, and intensive outpatient programs. At the time of this writing, the programs have been collecting data for just over a year. All were recently approached about continuing participation for a second year, and every program agreed to continue. Interestingly, each of these facilities was large enough to necessitate a second computer, and all volunteered to forfeit their $1,000 site stipend for use of a second computer.

Although the Chicago programs have contributed extensive amounts of data (about 700 cases to date), and have all requested participation for a second year, there were some difficulties. These difficulties again revolved around the pen-based computers. The pen-based computers, made affordable because they were not new, but "refurbished", have not performed well. There have been problems with the modems, pens, power cords, and overall performance. One power cord had to be replaced due to excessive overheating. Three pen batteries (which were estimated to last several years) needed to be replaced, and one pen quit working. Several of the modems worked intermittently, and two ceased working altogether. Finally, one computer, after about 12 months of use, no longer worked at all.

Chicago is scheduled for a second training in October 1997. At this time, all pen-based computers will be replaced by newer, faster, and more reliable Pentium computers. Because **pen-based Pentium** computers would have increased the cost three-fold, the new Pentium computers will not support pen-based technology, but will utilize the more standard touch-pad or trackball technology. Recent developments in technology have driven the price of these computers down to about the same cost as the older, refurbished pen-based. Although a shorter "booster" training was budgeted for all continuing cities, the amount of staff turnover was underestimated, and there appears to be a need for more extensive training including the ASI training and site visits (Fureman, McLellan, & Alterman, 1994). Only 50% of staff originally trained are still working at the programs in the same jobs. This turnover rate approximates our experience in each of the pilot cities.

Difficulties in the research-based facility in Albuquerque were similar to those encountered in the two Philadelphia research based programs. This facility represented three program modalities; methadone maintenance, intensive outpatient, and traditional outpatient. They were given three of the pen-based computers. The staff appeared ambivalent about completing the ASI, viewing it as additional work in an already stressful environment. Initially, the facility assigned the evaluation staff to the task of completing ASI's and TRI-Net staff conducted training. The staff resisted this assignment, and administration of the ASI interview did not begin for a number of weeks or months. When ASI data was collected, it was done by staff other than the trained ASI interviewers. The study was delayed for various reasons over a significant amount of time.

The inpatient program in Albuquerque, despite difficulties with their pen-based computer, continues to participate and send data. This program has collected a significant amount of data and currently has approximately 300 cases in the study. It should be noted that problems with the pen-based computer including problems with two modems, total failure of one computer, difficulty printing, and two replaced batteries in the pen did require a significant amount of time, mostly phone consultation, on the part of the program. Programs continuing in DENS will be issued the newer, Pentium computers for their second year of participation.

Pilot Phase II continued – San Francisco and New York

Based on our experience in the first three pilot cities, some changes were made prior to implementation in San Francisco and New York. The ASI software was improved based on feedback from the earlier pilot programs. Changes were also made to the ASI narrative software. Staff at programs from the early pilots had noticed a number of syntax problems and incorrect linking of data to the narrative. These were reviewed and the narrative improved. Also, new Pentium based computers were ordered for all programs. In addition to being faster and more reliable, this also enabled programs to load the narrative software directly onto the laptop. The inclusion of this software would have slowed down the pen-based computer considerably and was previously only installed on program desktop PC's.

Finally, significant changes were made for implementation in the New York programs. Firstly, a decision was made to over sample New York programs due to the high percentage of individuals in treatment in the city. Secondly, the programs were **not** chosen because they had participated with us in other studies, or because a member of the TRI-Net staff had worked with the program previously. Although the programs were not truly randomly chosen, this is the first city where programs without prior knowledge of the study or its investigators were invited to participate. A list of programs in the New York area was received by the state, and each was "cold-called" and asked to participate. A total of eighteen provider facilities were initially contacted. Sixteen requested and received additional information packets. Six **facilities** declined participation citing "manpower problems" because they did not utilize the Addiction Severity Index in their intake and had no immediate plans to include it. Two **programs** from the interested facilities were ruled out because they did not meet selection criteria requiring a minimum of twenty intakes per month. Thirty-five staff members from 11 participating New York treatment programs have been trained and are collecting data.

Although DENS was only recently implemented in these cities, we currently have approximately 200 cases from the San Francisco programs, and approximately 300 from New York. Already, there has been some staff turnover in the programs, and additional training, while not budgeted, has been requested. There have been no computer, hardware, modem, or software problems reported from San Francisco. Clinical and administrative staff at these programs have expressed appreciation for participation in the study, particularly in light of recent statewide initiatives to use the ASI in California. Several other programs have heard about DENS and asked to participate, however, any additional programs included in the area will have to be randomly selected.

In summary, the DENS pilot sites include programs in five cities: San Francisco, Albuquerque, Chicago, New York, and Philadelphia. Sites in Albuquerque, Chicago, and Philadelphia beginning their second year of participation will receive additional on-site training and new computers. Currently, there are 41 programs actively participating in DENS and sending data. Fourteen traditional outpatient programs and 9 intensive outpatient programs are participating. There are 8 inpatient or residential programs participating. Nine methadone maintenance programs are included. Additionally, there is currently one drug court actively participating. Their estimated number of intakes per month are listed below.

Type of Program	Number of Programs	Projected Intakes Per Month	Projected Total for Next 12 Months
Inpatient/Residential	8	235	2,820
Traditional Outpatient	14	181	2,172
Intensive Outpatient	9	64	768
Methadone Maintenance	9	185	2,220
Drug Courts	1	20	240
TOTALS	41	685	8,220

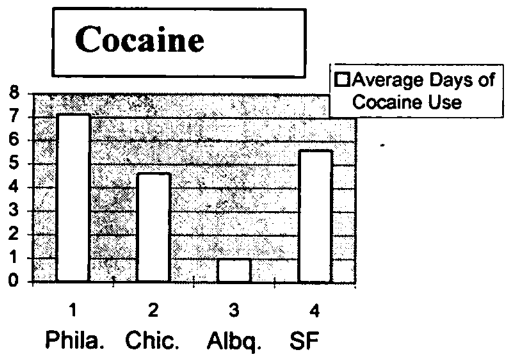
REPORTS FROM CURRENT DATA

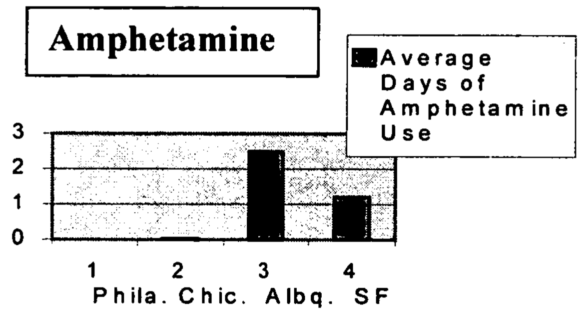
To illustrate some of the many issues that the DENS TRI-Net system will be able to address, we examined data from programs in the five pilot cities. The following represents information from over 40 treatment programs in 5 major metropolitan areas. It should be noted however, that the programs participating in the DENS **pilot** stage were not randomly selected, and this data should be viewed only as an example of the inferences that can be drawn from the data after a random sample is created.

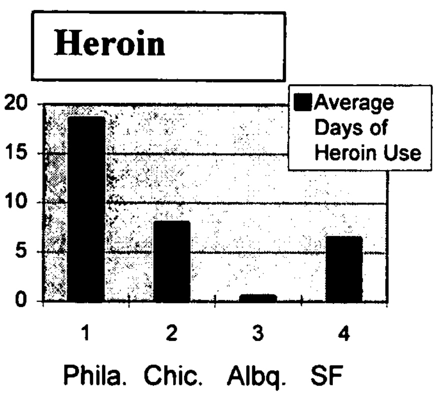
N=1,700 cases (July 1997)

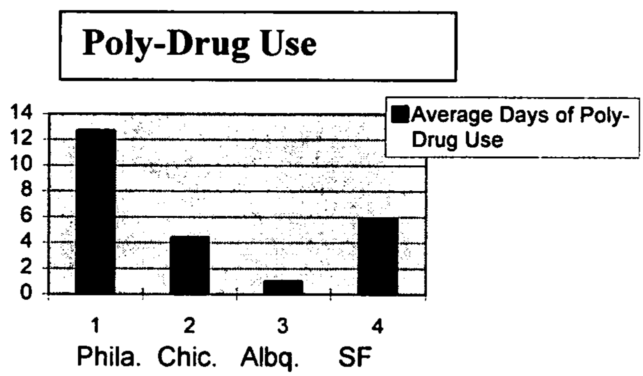
Comparison of Drug Use Across the Country

The following charts represent the average number of days that clients reported using amphetamines, cocaine, heroin, or more than one drug per day, in the 30 days prior to arriving at the evaluation.





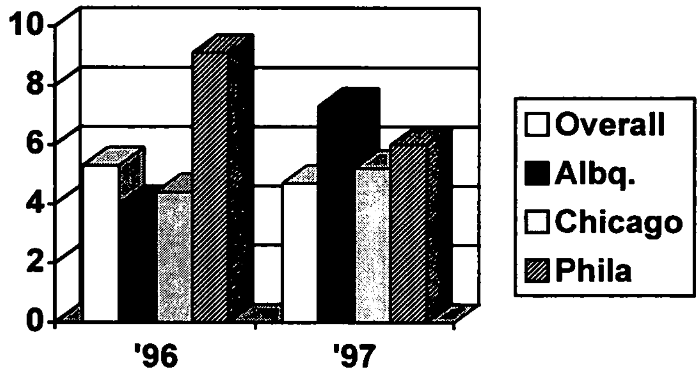




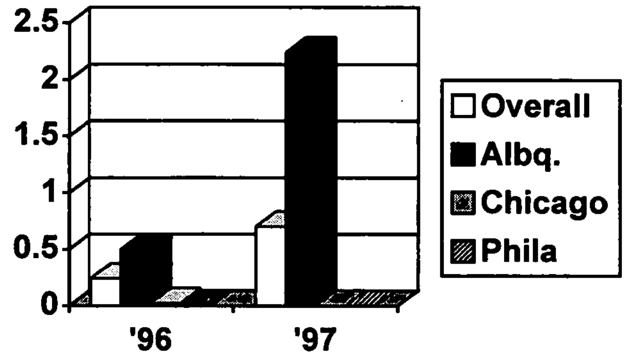
Comparison of Changes in Drug Use Across the Country from 1996 to 1997

Average number of days the clients reported using amphetamines, cocaine, heroin, or more than one drug per day, **in the 30 days prior to evaluation** in the last half of 1996 compared to the first half of 1997.

COCAINE



AMPHETAMINE

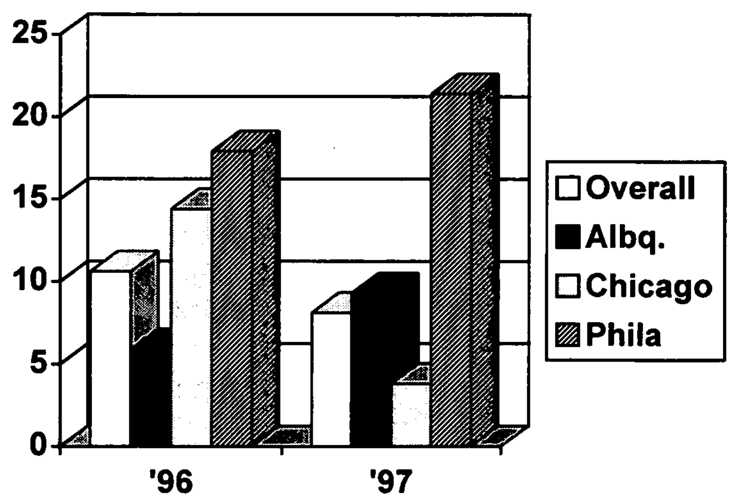


Cocaine: Overall, cocaine use is stable. There was a slight increase in use in Albuquerque and a slight decrease in Philadelphia.

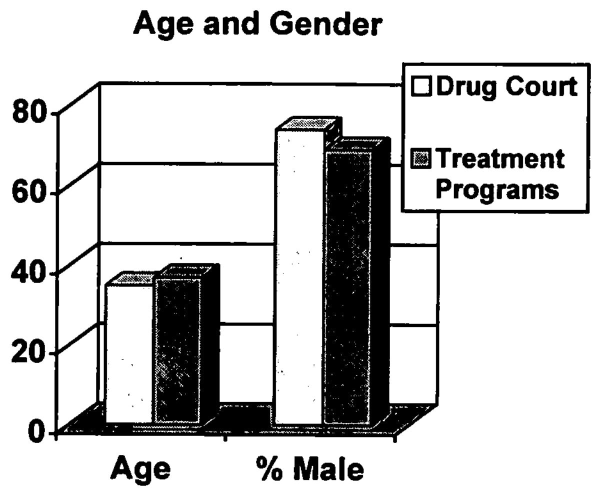
Amphetamine: Overall amphetamine use is low, however, there was a significant increase in amphetamine use in Albuquerque. There was little use in Philadelphia and Chicago.

Heroin: Overall, heroin use has not changed. There were slight increases in Albuquerque and Philadelphia, and a decrease in Chicago.

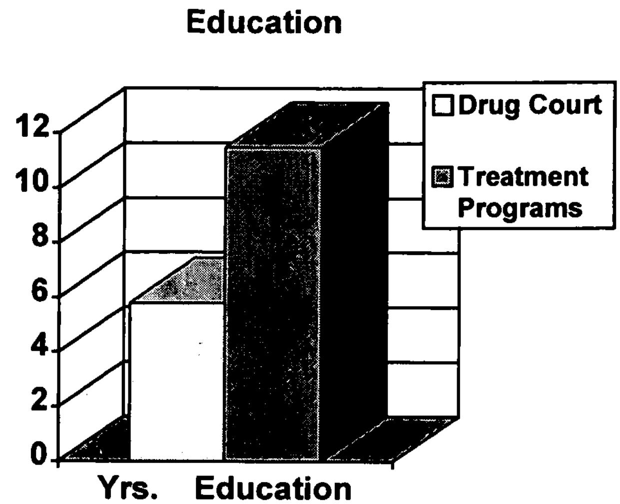
HEROIN



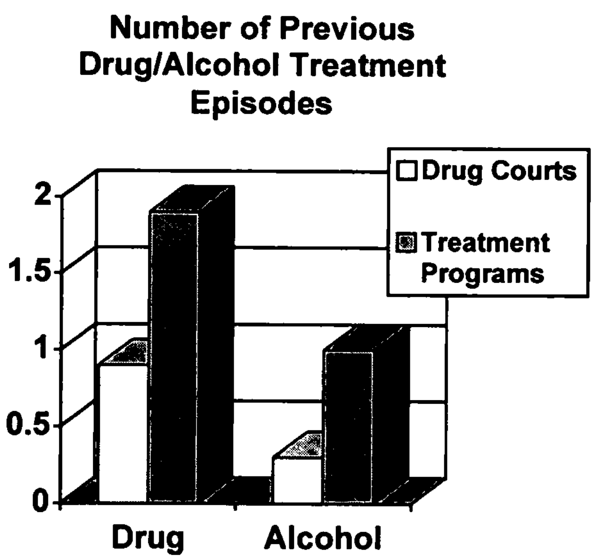
Comparisons of Drug Courts with Treatment Programs



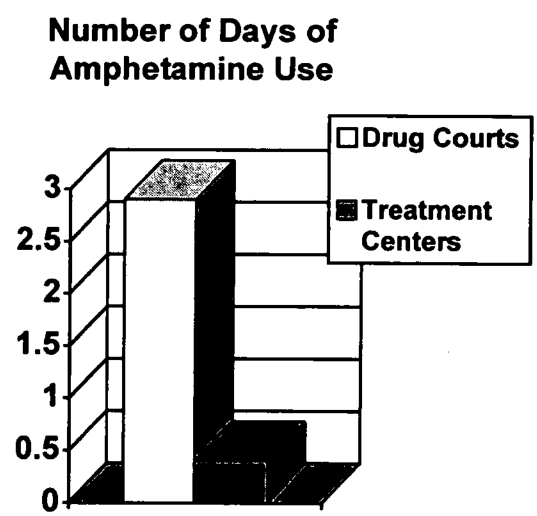
No significant differences were found in age or gender between the sample of clients from the drug courts and at treatment centers.



Clients from Drug Courts had 5.6 years of formal education whereas clients in traditional treatment settings averaged 11.3 years of education.

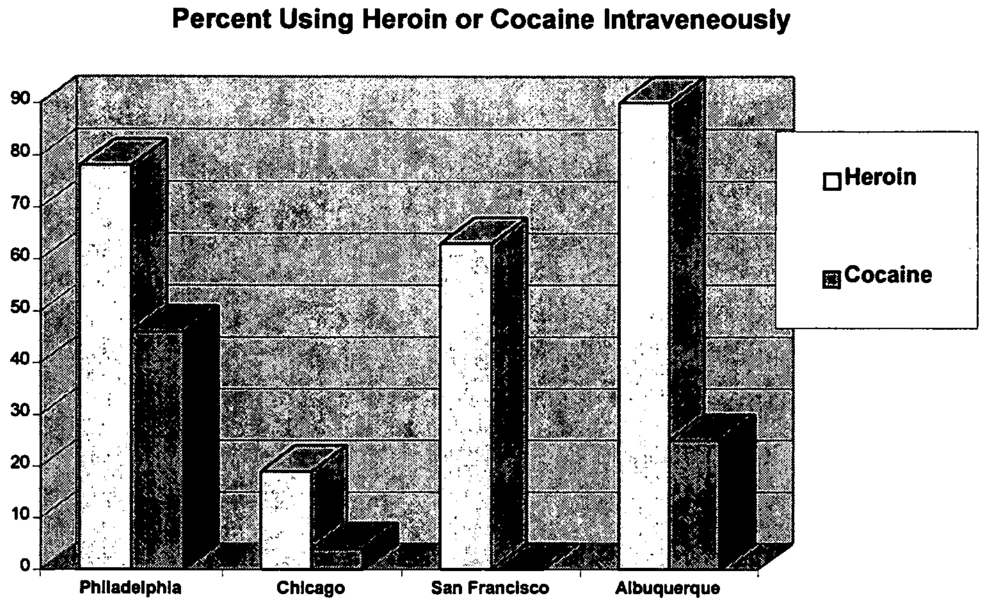


Clients referred by Drug Courts were significantly less likely than treatment center clients to have had previous drug or alcohol treatment.



Clients in the drug courts reported 7 times more amphetamine use than treatment clients in the 30 days prior to evaluation.

Usual Route of Administration



Philadelphia has the highest percent of intravenous drug use, with almost 80% using heroin and 45% using cocaine IV.

Interestingly, Chicago has comparably fewer IV drug users.

While Albuquerque and San Francisco have relatively high levels of IV heroin use, their rates of IV cocaine use is low.

Summary and Future Plans

How will this information system administered, who will have access to the information, will the programs and the patients be protected?

The TRI-net information system is a public domain system, implemented and operated by researchers at the Treatment Research Institute at the University of Pennsylvania and the Center for Alcohol and Substance Abuse at Columbia University. They are responsible for the continued training and monitoring of the treatment program personnel, the transfer of the collected information from the programs, and the maintenance and security of the information database (again - no **identifying** information on patients/clients are sent via modem to TRI). It is anticipated that continued funding for the administration of the network would come from annual grants from NIAAA, NIDA, ONDCP, VA, NIJ, CSAT and perhaps other agencies. No **single** agency will control the information collected - but all agencies can participate in the decisions regarding the types and numbers of questions that will be asked and the types of reports that will be generated and published. **This information/data will never be marketed or sold.**

Clinical, research and administrative information will be available for use by researchers, clinical personnel, and of course, policy makers. A Board of Directors comprised of representatives from the federal agencies, the programs that are participating and prominent clinical and research figures in the substance abuse field will monitor availability. This Board will have the power to grant database access to researchers and policy makers contingent upon a reasonable plan for using the information, and particularly, the agreement **not** to identify any participating programs in their reports. Requests for DENS data have already been received by several treatment programs, court systems, graduate students, state systems, one European country conducting a nationwide outcome study, and a group of European countries participating in collaborative use of the ASI.

How is the system designed and what are its operating characteristics thus far?

The system is designed for use at the program sites by trained intake staff. The information is collected in the ASI, which was chosen for its proven value in treatment and research with substance abusers. The system can automatically add or subtract as many as ten new questions at every data transfer occasion. The computers are Windows® based Pentium laptop computers using FoxPro software to present the ASI interview, collect and screen the data, and to transfer the data to a central server via modem.

The system has been piloted in five cities and all technical problems have been resolved to this point. Problems with data collection and transfer were solved with hardware upgrades and software improvements. The unanticipated rate of turnover of program staff will require more re-training and hotline support than was originally planned. User acceptability has been excellent with virtually all programs electing to continue participation. Data transfer has been easy and rapid. We are able to generate standard and specific statistical reports on the full system within 48 hours. This provides current information on admissions nationwide through the previous two weeks.

What are the immediate plans for expansion and their rationale?

The DENS is currently planning an expansion into forty randomly selected programs in ten new cities by June of 1999. In each city, four separate and distinct treatment programs will be randomly selected. In each city, participation will include one program in each of the following treatment modalities; residential, intensive outpatient, traditional outpatient, and methadone maintenance. The random sample will be drawn from a recently "cleaned" sample frame of public and private treatment programs that has been utilized in other nation-wide studies including NESAT (National Evaluation of Substance Abuse Treatment). Various methods of "weighting" the data to insure comparable samples will be explored. Cities will be chosen to participate based on size, location or MSA (Metropolitan Statistical Area), participation in CEWG's (Community Epidemiology Work Groups), and/or participation in other ongoing nationwide data collection efforts such as the Drug Abuse Warning Network (DAWN), Drug Use Forecasting (DUF), etc.

With the above consideration in mind, it is anticipated that programs will be sampled from among the following new cities: Los Angeles, Houston, Seattle, Miami, Portland OR, Washington DC, Denver, Minneapolis, New Orleans, and Boston.

How does this monitoring system satisfy the larger and more important goal of obtaining national data on the outcomes from treatment?

It should be clear at the outset that the present system, by itself, is **not** designed to provide **outcome** data on the sample of programs described. At the same time, this system is essential to have in place **prior** to the development of systematic and cost effective outcome reporting. In our view, the proposed system provides invaluable information that will, in the future, direct targeted outcome evaluations that can provide rapid, policy relevant and cost effective outcome information.

For Example: Once the larger system is in place, and information begins to accrue from the randomly selected programs, we believe that, consistent with the outcome goals of the ONDCP, particular groups of patients and types of treatments will become of specific and immediate interest. The DENS system data will point the way to the most efficient locations to find those patients and to initiate the outcome evaluation collection.

Targeted and specific questions will permit the design of a very rapid and cost effective outcome evaluation. Knowing the target population will enable sampling of patients from just those programs of interest - a significant savings in time and money in itself. The admission data will make it possible to **direct** the patient recruitment of a new sample to those programs that are most likely to admit the types of patients that will be the focus of the outcome study. Specific recruitment instructions to the program personnel can be delivered via the system, including an explanation of the study for the programs, an explanation for the patients, consent forms, and locator sheets for follow-up. Thus, instead of a large, slow, costly and fragmented effort at collecting outcome information on an unspecified sample, the proposed information system should permit the direction of more targeted, rapid and cost effective studies that will provide policy relevant information.

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Overview of the ONDCP-Supported Youth Diversion Program in Philadelphia

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Purpose: Federal data show that since 1980 there has been an increase of more than 165% in the numbers of individuals involved in the criminal justice system, whether incarcerated or on probation or parole. Much of the increase is due to the rapidly rising number of adolescents and young adults who are being sentenced for drug-related crimes. Since 1990, approximately 33% of new court commitments to state prisons have been for drug offenses, up from approximately 7% in 1980. Across the country, approximately one-third of young African American males ages 20 to 29 are under criminal justice supervision on any given day. In some communities, e.g., Washington, D.C., a majority of young African American males are under criminal justice supervision.

The criminal justice system across the country has been struggling to devise effective means of addressing drug-related crime while reducing the high rates of recidivism among drug offenders and reducing the burden to inner city communities that follows from incarceration of large proportions of its young men and women. Since 1989, some 200 jurisdictions have established drug courts or new court-related substance abuse treatment programs.

Our ONDCP-funded project for youthful offenders with substance abuse problems in Philadelphia is the first study to use random assignment of subjects to experimental and control conditions to evaluate a court-related treatment program. Random assignment is the 'gold standard' among methods for protecting against bias in program evaluations. However, implementing a random assignment design in connection with the processes of court adjudication and disposition requires highly complicated procedures. The Family Court of Philadelphia and its Administrative Judge, the Honorable Paul P. Panepinto, have offered exceptional cooperation with the project to enable random assignment procedures to be implemented.

The investigators hope to demonstrate that by offering intensive substance abuse treatment to adjudicated youth who are on probation and who have abused drugs and/or alcohol it is possible to reduce rates of criminal activities, drug and alcohol abuse, and repeat arrests and adjudications. The study expects to enroll 234 subjects, with 78 subjects assigned to each of the three study conditions. Enrollment of subjects is now projected to be completed around the end of December 1998.

Overview: To ensure unbiased evaluation, the study randomly assigns youth who face petitions in Family Court to three study conditions:

1. Comprehensive Treatment combines several treatment technologies (individual therapy, family therapy, social skills training, case management, monitoring by urinalysis, relapse prevention, and 'community meetings'). The goal of the combination of treatment methods is to maximize the efficacy of intervention for

substance abuse to the extent feasible in the current state of treatment technology. Participants receive 3 months of full Day Treatment (including schooling adapted to individual educational needs) followed by 6 months of Outpatient Treatment.

2. Substance Abuse Monitoring involves collecting urine samples daily and testing them for substances of abuse twice weekly on randomly selected days. A sanction is imposed from a scale of progressive severity after every instance of detected abuse. This intervention involves minimal staff resources and is designed to assess whether a 'punishment model' is effective in controlling substance abuse.

3. 'Treatment as Usual', a control condition in which subjects receive whatever services are arranged for them under procedures customarily followed by their probation officers.

Subjects are assigned to the three study conditions in approximately equal numbers. They are followed in the interventions for 9 months, then interviewed 6 months later for follow-up. Outcomes to be evaluated for subjects in all three study groups include substance abuse, recidivism, and change in psychological, attitudinal, and familial status. Our central hypothesis is that youth participating in the Comprehensive Treatment program will subsequently have substantially fewer rearrests and will have substantially less involvement in substance abuse than the followed in the 'Treatment as Usual' control condition.

In statistical projection of outcomes, we estimate that rates of rearrest among subjects in Comprehensive Treatment will be approximately 30% over 15 months post-baseline as compared with more than 50% among subjects in Treatment as Usual. Overall, we expect Comprehensive Treatment participants to show lower rates of substance use, engage in fewer crimes, have fewer arrests, and use fewer of the scarce resources of the criminal justice system. The lower rates of substance abuse, other crime, and recidivism should benefit the youths themselves, their families, their local communities, the city's criminal justice system, and the public at large. We expect Substance Abuse Monitoring subjects to have outcomes intermediate between Comprehensive Treatment and Treatment as Usual subjects.

Pilot Data: During the Spring and Summer of 1997, the Comprehensive Treatment condition was pilot-tested to ensure that the planned intervention services could be delivered with high quality before we initiated the random assignment experimental design. Fifteen subjects were enrolled following adjudication at the Family Court of Philadelphia and disposition to probation in order to pilot the Comprehensive Treatment package of interventions. Baseline data on the 15 subjects -- who will likely prove in many respects representative of subjects throughout the study -- are preliminary, but interesting in a number of ways. The data were collected with the Comprehensive Addiction Severity Index for Adolescents (CASI-A). Selected items from the CASI-A are shown in Tables 1 through 6 in the Appendix.

Demographic data are shown in Table 1. The subjects have been very predominantly male – 14 of the 15 individuals. Two thirds have been African American and one third of Caucasion backgrounds. The proportion who are African American is very close to the proportion of African Americans among youth processed at the Youth Study Center after arrest in Philadelphia. The mean age of participants was just over 16. The mean intelligence level on full scale IQ tests was 87.5, but with a large range of variation (SD=15.1). On average students were in the 10th grade, but with a mean achievement level 1.4 years lower. However, the range in achievement levels was relatively large (SD=3 years). A couple of students did well in school while others functioned far below their school years. Many of the youth had large numbers of absences from school prior to their enrollment in our program.

Self-reported legal charges, listed in Table 2, show that the participants had been charged with a wide range of crimes. Drug dealing was the most frequent of the 'current' charges, i.e., the charges which had led to enrollment in the program, while other drug charges (possession) were the next most frequent. Overall, burglary and related charges, vandalism, receiving stolen property, and auto theft were also among the more common crimes. One current charge and 7 past charges were for crimes, including robbery, simple assault, and aggravated assault, that are listed as exclusion factors for the study. In most of these cases, it was determined after a review of court records that the youths had likely been overcharged for their culpable behavior and had not been substantively violent in a sense covered by the exclusion criteria. In two or three cases, it is likely that the youths would have been excluded had all of the relevant information been available at the time of screening.

Table 3 shows lifetime self-reported substance use for the 15 subjects. All 15 subjects used marijuana regularly and had done so for a mean of 24.9 months. Among teenagers, two years of use suggests well established habits. Fourteen of the participants had used alcohol for a mean period of over two years as well. Thirteen had used tobacco for a mean period of two-and-a-half years. Six of the subjects had experimented with hallucinogens during the previous year or two, perhaps confirming recent reports that hallucinogen abuse is again becoming more frequent among youth in Philadelphia. Four subjects had used cocaine and 5 had used barbiturates or sedatives over a longer period. Two had experimented with amphetamines, 2 with over the counter drugs, and 1 with inhalants.

Table 4 reports the subjects' use of substances in the 30 days preceding admission to the program. Again, all 15 subjects had used marijuana. The mean days of use for marijuana was 14.1 with a standard deviation of 12.6. Thus, a number of subjects were daily or near-daily abusers. All 14 who reported lifetime drinking of alcohol were also drinking during the month before their admission, but with a much lower frequency of 3.9 mean days per month. All 13 who reported lifetime smoking of tobacco were also smoking during the month before admission. They reported smoking a mean of 27.4 days, indicating that a number were daily smokers. All 4 who reported lifetime cocaine use were current users with a mean of 5 days of use in the previous month. All 5 who reported lifetime use of barbiturates and/or sedatives were also using currently, although comparatively infrequently. The 1 subject who had reported lifetime inhalant abuse had used inhalants on 7 days in the previous month, a worrisome frequency. Examination of the individual profiles of substance use supports a worry that several of the program participants abused multiple groups of drugs (marijuana, alcohol, tobacco, cocaine, barbiturates/sedatives) and thus were at high risk of becoming long term polydrug abusers. It should be noted that, for most participants, the 30-day period preceding admission to our program for which they reported current use of substances was entirely or predominantly *after* the arrests that became the occasions for their placement with us. Thus, the reported substance abuse represents use that persisted despite whatever changes in their lives occurred following an arrest.

Table 5 shows the family living situations of the participants and the drug or alcohol problems of their parents. All 15 participants were living with biological relatives and 14 of them were living with at least one parent. However, only 3 were living with both biological parents. Four lived in households headed by a single parent, 3 lived with a parent but in a household headed by a grandparent, and 4 lived with a biological parent and a step-parent. Nine of the participants reported that one or both parents had drug or alcohol problems of their own.

Table 6 reports the high level of exposure to trauma that we have found among the program participants. The youth were first asked about general types of trauma to which they may have been exposed. Nearly three-quarters of the participants reported that they had directly witnessed an event resulting in personal injury to a family member. More than one-half had experienced a direct threat of serious personal injury or death. Two of the youth had been seriously injured (one had a number of notable facial scars). Six of the participants reported having been confronted in a traumatic way with information about the death or serious injury of a family member. *All* of the youth reported experiencing at least one of these categories of personal trauma.

The youth were also asked about specific traumatic events. Three (20%) reported being shot at, but not injured. Eight (53%) reported directly witnessing a shooting or stabbing. Six (40%) reported having been robbed or mugged. In response to these data, we have started to use a new psychological instrument with all program participants to assess psychological symptoms of post-traumatic stress disorder in more specific terms.

Conclusion: The pilot data confirm that the project is treating troubled youth. The youth are all 15 to 17 years of age, but most of them have been arrested two or more times. All of them have at the least problems of marijuana dependence that are seriously affecting family relations and progress in school. Some of them are well on the way toward established polysubstance abuse. A number of them are well behind grade level in and seriously disaffected from schooling. Their exposure to violence and risk of trauma reflects, in many chases, chaotic neighborhoods and/or families. We believe that our intervention programs have difficult challenges ahead in helping participants to reduce substance abuse and criminal involvement.

Table 1. Subject Demographics (n = 15)

Variable	n (%)
Male	14 (93%)
Race	
AA	10 (67%)
Caucasion	5 (33%)

Variable	Mean	SD
Age	16.3	0.8
Grade	9.8	1.0
KTEA Grade Equivalent	8.4	3.0
Full Scale IQ	87.5	15.1

Table 2. Self-Reported Legal Charges (n = 15)

Charge	Number of Subjects Reporting Past Charges	Number of Subjects Reporting Current Charges
Driving Violations (including DUI)	1	1
Vandalism, Criminal Mischief	3	0
Breaking & Entering, Burglary, Larceny, Theft	3	2
Robbery	4	1
Simple Assault	3	0
Aggravated Assault	2	0
Drug Charges (not dealing)	6	3
Drug Dealing	4	6
Criminal Conspiracy	0	1
Risk of Catastrophe	0	1
Truancy	1	0
Receiving Stolen Goods or Property	3	0
Auto Theft, Possession of a Stolen Auto	2	1

Table 3. Self-Reported Drug Use
Lifetime

Substance	Use		
	Number of subjects	Mean Months of Use	Sd
Tobacco	13	30.7	17.3
Over the Counter Drugs	2	12	0
Alcohol	14	24.9	22.6
Marijuana	15	24.9	13.3
Cocaine	4	7	4.6
Amphetamines	2	6.5	7.8
Barbituates, Sedatives	5	18.6	12
Inhalants	1	12	0
Hallucinogens	6	12.3	12.2
Opiates	0	--	--

Table 4. Self-Reported Drug Use
Last Thirty Days Prior to Admission

Substance	Use		
	Number of subjects	Mean days of Use	sd
Tobacco	13	27.4	5.1
Over the Counter Drugs	0	--	--
Alcohol	14	3.9	4.9
Marijuana	15	14.1	12.6
Cocaine	4	5	7.1
Amphetamines	0	--	--
Barbituates, Sedatives	5	2.2	1
Inhalants	1	7	0
Hallucinogens	0	--	--
Opiates	0	--	--

Table 5. Living Situation and Family Drug Use (n = 15)

Family Composition	Subjects
Two Biological Parents (with or without sibling(s))	3
Single Biological Parent (with or without sibling(s))	4
Biological Parent and Step-Parent (with or without sibling(s))	4
Biological Parent and Grandparent (with or without sibling(s))	3
Other Biological Relative	1
In Home Parent(s) with Past or Present Drug or Alcohol Problem	4
Out of Home Parent(s) with Past or Present Drug or Alcohol Problems	5

Table 6. Experience of Trauma (N=15)

Degree of trauma	n (N=15)	Percent
Experienced event involving serious injury to self.	2	13%
Experienced threat of death or serious injury to self. No physical injury.	8	53%
Directly witnessed event involving serious injury to family or significant other(s).	11	73%
Directly witnessed threat of death or serious injury to family or significant other(s).	1	7%
Confronted with information about an event involving death or serious injury to family or significant other(s).	6	40%
Any of the above.	15	100%
Specific Trauma	**n (N=15)**	**Percent**
Experienced being shot at. No injury.	3	20%
Directly witnessed a shooting or stabbing of another.	8	53%
Experienced being robbed or mugged.	6	40%

3

Science and Technology Committee Reports: A 10-Year Technology Plan (Status) (Session 2A)

THE NATIONAL COUNTERDRUG TECHNOLOGY STRATEGY
FOR
NON-INTRUSIVE INSPECTION TECHNOLOGIES

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August 20, 1997

Non-Intrusive Inspection (NII) Technologies are one of the four thrust areas of the ONDCP 10-Year National Counterdrug Technology Development and Acquisition Strategy. This report is an initial description of the direction and status of the NII Technologies strategy. It represents the combined efforts of the Coast Guard, Drug Enforcement Administration (DEA), Department of Defense (DOD), Immigration and Naturalization Service (INS), and the Customs Service.

NII TECHNOLOGIES OVERVIEW

The NII Technologies thrust area encompasses three types of devices or systems:

1. Equipment used to examine vehicles, aircraft, vessels, baggage, containers, cargo, persons, baggage, mail, and other means of transportation, without the physical search, disassembly, or damage of the item being examined.

2. Equipment utilizing information available at or prior to the inspection opportunity to aid in screening and selecting the items most likely to be of either high or minimal risk.

3. Inspection support equipment that improves the efficiency or safety of the inspection officers.

There are a variety of materials that are the detection targets for inspection technologies. The primary targets of interest for counterdrug NII technologies are drugs and other controlled substances, precursor solids and liquids, currency, and concealed persons. Additional NII targets of interest include concealed firearms, explosives, weapons of mass destruction, and other prohibited or controlled materials.

Non-intrusive inspection technologies fill a vital role in the National Counterdrug Strategy. The widespread use of NII equipment at the borders of the United States and in the transit zone is essential for the successful accomplishment of Goal 4 of the National Strategy, "Shielding America's Air, Land, and Sea Frontiers from the Drug Threat." This mission cannot be met by using only manpower or by using only technology. Protecting

America's borders against drugs requires a balanced combination of people and technology; i.e., NII technology that effectively and efficiently supports enforcement officers in the performance of their operations. When NII technologies are employed by cooperating countries to stop the movement of drugs within that country, they also contribute significantly to Goal 5 of the National Strategy, "Breaking Foreign and Domestic Sources of Drug Supply."

The principle users of NII technologies within the Federal counterdrug law enforcement community are the Coast Guard, DEA, INS, and Customs. Of these, Customs is the largest user in terms of the variety and quantity of current and planned NII equipment. However, these four agencies are only a portion of the potential market for NII technologies applied to counterdrug or other law enforcement applications. Other current and potential users of NII technology in the United States include Agriculture, Energy, Federal Aviation Administration (FAA), General Services Administration, Postal Service, and State Department; State and local law enforcement and correctional authorities; and companies responsible for transporting materials across U.S. borders such as businesses with overseas suppliers, freight forwarders and carriers, terminal operators, and international courier services. The corresponding entities in other countries also are part of the potential NII market.

NII technologies are most frequently thought of as being used at U.S. ports of entry to examine arriving persons, trucks, cars, and cargo. In reality, they are employed at many types of operational facilities and locations on land and at sea. In addition to being used on the inbound side of our ports, NII technologies also are applied to persons, conveyances, and materials that are departing the U.S., particularly to look for outbound currency, explosives, and weapons. They are used along the border between the ports and at interior checkpoints to examine vehicles, aircraft, or boats suspected of crossing the border illegally or of carrying illegal materials or persons. They are used aboard ships boarded at sea to check the vessel, cargo, and crew for drugs. NII technologies also are used at ports and checkpoints outside of the U.S. to search aircraft, vessels, trucks, and cargo for concealed drugs or for indications that drugs had been transported in a suspect conveyance.

CURRENT NII TECHNOLOGIES

Federal drug law enforcement agencies have been developing and deploying NII technologies for more than 20 years and a good many types of equipment are already in relatively widespread use. Additional new technologies and applications are being developed or are undergoing operational evaluation; this latter category includes improvements of equipment already in use and new operational applications of previously-exploited technology. Table 1 provides a listing of the major NII technologies currently being used, developed, and evaluated by the Federal counterdrug community.

TABLE 1

MAJOR COUNTERDRUG NII TECHNOLOGIES
IN USE, DEVELOPMENT, OR EVALUATION

TECHNOLOGY	IN USE	IN DEVELOPMENT/ EVALUATION
Automated targeting systems	X	X
Automated license plate readers	X	X
Closed Circuit TV for inspection	X	
Di-electrometers	X	
Drug and currency detector dogs	X	X
Drug particle and vapor detectors	X	X
Drug sprays and wipes	X	
Drug/contraband disposal systems		X
Fiberoptic scopes	X	
Gamma-backscatter devices (Busters)	X	
Gamma-imaging system for trucks		X
Handheld/portable computer terminals	X	X
Heavy cargo X-ray systems		X
Light cargo, baggage, mail X-ray sys.	X	X
Rangefinders	X	
Sea container X-ray systems		X
Side-scan sonar	X	
Truck X-ray systems	X	X
Ultrasonic sensors	X	X
Weigh-in-motion sensors		X

DEVELOPMENT STRATEGY

The existing and pending NII technologies listed in Table 1 address today's most urgent counterdrug inspection requirements. We have considerable confidence in the usefulness of the current equipment and in the successful completion of the development efforts that are currently underway. As a result, the first priority in the long-term development strategy is to continue the current development and evaluation projects. At the same time, we are aware that new inspection requirements will continually surface as our knowledge of smuggling methods improves and as smugglers react to our interdiction programs and successes. We also know that inspection technologies being developed by other agencies to detect explosives and other materials could have application to the detection of drugs, and that some of our deployed inspection systems and devices still could need refinement to make them more affordable, reliable, or user-friendly; especially if they are to be adopted by state and local agencies. Therefore, the long-term development strategy for counterdrug NII technology does not end with completion of the current development and evaluation programs; instead, the strategy is comprised of several continuing elements that are summarized below. The level of effort and time sequence of these elements depends on many external factors including the availability of funds and counterdrug interdiction priorities.

Continue current development and evaluation projects. The primary emphasis of these projects is on X-ray and gamma-imaging systems for sea/air containers, trucks, and heavy cargo; improved particle and vapor trace detectors; destruction systems for drugs and seized materials; and automated targeting/information systems for sea containers, trucks, and private vehicles.

Participate in related contraband detection projects by other agencies. Several Federal agencies have extensive development programs directed at detecting explosives, firearms, or weapons of mass destruction under scenarios similar to counterdrug applications. Agriculture is working on systems to examine baggage for prohibited materials and contamination. The customs and police organizations of Canada, England, and other countries also are working on NII technologies for various purposes. Our strategy for the development of counterdrug NII technology must utilize the information and achievements produced by these and similar efforts, either through direct participation or by sharing information of mutual interest.

Evaluate the application of current truck and container NII systems to the examination of railcars. Almost 300,000 railcars cross the Southwest border into the U.S. annually; they are of considerable concern to the Border Patrol and to Customs as a means of transporting drugs and people. Inspection facilities and equipment are limited and inadequate. Our first step in addressing this requirement is to determine if the NII systems developed for trucks and containers can be adapted to railcar inspection as either an interim or longer-term solution. Further actions to use these technologies or to consider other approaches will depend on the results of these evaluations.

Initiate new development efforts to meet requirements not satisfied by current programs. Despite our confidence in the success of the many development programs currently underway, we know they will not address all of our counterdrug inspection requirements. We anticipate new development efforts, for example, to provide handheld or portable devices to detect hidden compartments aboard ships; to find drugs or other materials hidden in bulk cargo, in liquids, and on or in people; to rapidly search aircraft and vessels, often under isolated conditions; and to detect underwater concealments attached to ship hulls, towed behind vessels, or sitting on the bottom. We also need mobile and fixed systems for the rapid examination of vehicles without requiring that the occupants leave the vehicle while it is being examined.

Optimize operational technologies to improve performance, utility, or cost. Our requirement to detect and deter drugs being smuggled into the U.S. is immediate. We need to put NII technologies into the field as soon as they are practical and affordable. However, if the state of the technology improves or our requirements change, we will need to consider investments in developing improvements either to modify existing systems or to provide new systems of greater value for our operational programs.

Respond to new threats. Drug traffickers have proven to be very ingenious in their tactics. As long as their incentives are high, they will try to bypass or defeat our defenses with new methods of concealment and new modes of entry. Our development programs and capabilities must anticipate these changes and respond to them with new and timely solutions.

ACQUISITION STRATEGY

Development programs alone will do little to protect America's borders against drugs. This goal will be satisfied only if the development programs are followed by acquisition programs to provide enough new equipment to meet operational requirements. Acquisitions must be followed by longterm maintenance programs to support the needed levels of operation. These acquisition and maintenance programs will be expensive, but they are essential not only for the Government to get a good return on its investment in technology development but also, and more importantly, they are essential if we are to succeed in our efforts to protect America's borders from the drug threat. At this time the key counterdrug agencies are beginning the process of estimating equipment and funding requirements that will utilize the NII technologies currently being developed.

4

Technology Test Beds and Test Protocols (Session 2B-1)

The DoD Counterdrug Technology Development Program

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ABSTRACT

The Naval Surface Warfare Center, Dahlgren Division, serves as the Executive Agent for the DoD Counterdrug Technology Development Program. The goal of the program is to develop technology and prototype systems to enhance the counterdrug capability of the Department of Defense and civilian law enforcement agencies consistent with the goals of the National Drug control Strategy and the DoD mission. The DoD Program primarily concentrates its efforts on addressing Goal Four (Shield America's air, land and sea frontiers from the drug threat), and Goal Five (Break foreign and domestic drug sources of supply) of the National Strategy.

The program employs four strategic thrusts: Non-Intrusive Inspection; Tactical Operations Support; Wide Area Surveillance; and Demand Reduction. Customers and users are involved from the beginning to identify problem areas and needs. We develop systems to address the needs, assess and demonstrate systems with the users at the field level, integrate the developed systems with existing systems employed by the, and transition systems to the user for purchase and deployment. Initial systems have been successfully installed and demonstrated, integration of customer technologies with those developed by the DoD Counterdrug Technology Development Program are underway, and successful transitions of many of the systems developed have been accomplished. The systems developed, which include mobile Truck X-Ray, Thermal Imagers, and the Relocatable Over the Horizon Radar (ROTHR) have been successfully used in the detection of illegal drugs and apprehension of drug traffickers. In addition, the systems developed have broad applicability for other purposes, such as the detection of contraband such as explosives, nuclear material, and chemical/biological weapons; and command, control, communications, computers, and intelligence (C4I).

1.0 BACKGROUND

In 1990, the Department of Defense (DoD) Coordinator for Drug Enforcement Policy and Support, appointed the Director of the Advanced Research Projects Agency (now the Defense Advanced Research Projects Agency, or DARPA) to be the Executive Agent for the DoD Counterdrug Technology Development Program.

In FY96, the Executive Agent responsibilities were transferred to the Naval Surface Warfare Center, Dahlgren Division, at Dahlgren, Virginia. The DoD Counterdrug Technology Development Program sponsors the research, development, testing, evaluation, demonstration and integration of prototype systems to satisfy shortfalls in current capabilities to detect, identify, monitor, locate, track, analyze, and disseminate information regarding illegal drug related activities. The projects are intended to have dual mission applications, supporting both general purpose and counterdrug military requirements. In addition, individual projects may also support the counterdrug needs of Domestic Law Enforcement Agencies (DLEAs). To that end, prototype demonstrations are conducted and coordinated with the United States Customs Service (USCS), Drug Enforcement Administration (DEA), Federal Bureau of investigation (FBI), and other law enforcement and regulatory agencies.

The DoD Counterdrug Technology Development program consists of four major thrust areas. These are Non-Intrusive Inspection (NII), Wide Area Surveillance (WAS), Tactical Operations Support (TOS), and Demand Reduction (DR). Each program area maps directly to the Office of the Secretary of Defense Counterdrug Functional Areas and the National Drug Control Strategy.

The strategy of the program is to employ systems engineering principles and concentrate on opportunities where technology can assist in the interrupt of illegal drug flow. To accomplish this, the program office conducts near-term developments and long-term research, early prototype demonstrations, and rapid transitions to DoD and DLEA customers.

2.0 NON-INTRUSIVE INSPECTION

This focus of the Non-Intrusive Inspection (NII) Program is to develop prototype equipment to rapidly detect operationally significant quantities of illegal drugs and other contraband without unnecessary delays in the movement of legitimate commerce. The technologies developed within this program area help support the achievement of Goal Four of the National Drug Control Strategy, "Shield America's Air, Land, and Sea Frontiers from the Drug Threat".

The application for the technologies resulting from these developments are to support National Guard and DLEA's primarily at border crossings and ports of entry, as well as High Intensity Drug Trafficking Areas. A number of technologies have been developed, evaluated, and demonstrated. They include: high and medium energy x-ray systems, pulsed fast neutron analysis, gamma-gamma resonance imaging, nuclear quadrupole resonance, acoustic, thermal neutron analysis, gas chromatographers, mass spectrometers, and canines. Supporting activities include a description of cocaine/heroin chemistry and a special vapor generator to support the testing of chemical sniffers. In addition, testbeds are constructed and operated in conjunction with our customers in order to evaluate the prototypes developed. The Non-Intrusive Inspection program is organized into three categories: Large Container Inspection Systems; Small Package Inspection Systems; and Handheld Inspection Systems.

2.1 LARGE CONTAINER INSPECTION SYSTEMS

The Large Container Inspection Systems developed by this office include High Energy X-Ray, Pulsed Fast Neutron Analysis (PFNA), Mobile Detection Systems, Simulations and Testbeds. The High Energy (8 MeV) X-Ray system was installed in a special testbed facility at the Port of Tacoma, Washington. Evaluations performed jointly with the United States Customs Service (USCS) were successful and demonstrated the systems capability to correctly identify the presence or non-presence of operationally significant quantities of hidden drugs 90 percent of the time. Although the demonstration and technical testing of this system were highly successful, the USCS expressed several major operational concerns, and has not deployed the system. The operational concerns expressed by the USCS included system affordability, equipment and facility size issues, and health and safety concerns. Lessons learned from the development of this system were applied to the fixed-site and Mobile Truck X-Ray systems.

2.1.1 FIXED SITE TRUCK X-RAY

A Fixed Site Truck X-ray system using transmission and side/backscatter imagery was developed, installed and evaluated in a testbed facility at the truck border crossing Otay Mesa, California. This system was specifically designed to detect drugs and other contraband hidden within compartments, structural cavities, walls, and other areas in small vehicles and empty trucks. The system uses two medium-energy x-ray sources (450 KeV each) to provide conventional transmission and low atomic weight side/back scatter detection modes. The system has demonstrated the effective and efficient inspection of cargo vehicles, including trailer trucks and trailer-mounted cargo containers, for illicit drugs, currency and other contraband.

When viewing the x-ray images, trained analysts can detect operationally significant quantities of hidden contraband, including drugs, within areas of the conveyance not normally visible to the naked eye. The system is capable of non-intrusively inspecting up to ten tractor-trailer rigs per hour. This fixed site system was installed at the testbed in July 1994, coincident with the completion of the new USCS border inspection station at Otay Mesa, California, and is currently operational. Evaluations conducted jointly with Customer personnel have been highly successful. It has been involved in over 125 drug and contraband seizures since becoming operational. These seizures have included drugs, Cuban cigars, and illegal immigrants. The USCS is in the process of purchasing additional systems for installation at other ports of entry.

2.1.2 PULSED FAST NEUTRON ACTIVATION, TIME OF FLIGHT (PFNA, TOF)

A Pulsed Fast Neutron Analysis (PFNA) System has been developed and evaluated at the contractor's plant. The system uses scanned 8.2 MeV pulsed neutron beams that interact with the nuclei of atoms in the cargo. The nuclei, excited from inelastic interactions with the neutrons, emit target-unique energy level gamma rays. The TOF measurement locates the target drugs in the cargo container. To discriminate drugs, such as cocaine hyrdrochloride, from benign materials, the system looks for amounts of oxygen and carbon at the same location or volume elements (voxels) inside the container. The system allows automatic elemental imaging to automatically detect operationally significant quantities of drugs concealed within the cargo or in hidden compartments inside the conveyance. Large cargo containers 8 feet high by 8 feet wide and 20-40 feet long can be inspected at a rate of several per hour. This technology has been transitioned to Eurotunnel, Israeli law enforcement, DOE, and FAA for explosive detection and other applications.

2.1.3 MOBILE DETECTION SYSTEMS

As a follow-on to the successful demonstration of the fixed-site truck x-ray system at Otay Mesa, development began on a new generation of mobile/transportable non-intrusive inspection systems. Multiple contracts were awarded for the development of several different conceptual designs. These concepts included a 450 KeV truck-mounted mobile system capable of inspecting cars and trucks with both transmission and backscatter x-rays, a shelter mounted high energy (2 MeV) transportable truck x-ray system, and a 1 MeV x-ray system capable of inspecting loaded pallets and aircraft size cargo containers. In addition, we are investigating image enhancement algorithms to automatically search the imagery and highlight suspected contraband for detailed examination by the image analyst. All of the x-ray systems are capable of rapidly inspecting trucks and other vehicles or cargo-laden pallets for illegal drugs and other contraband. They can be moved rapidly between different ports of entry in response to changes in the threat. A significant design feature of each of these mobile systems is that they are being designed and developed by the manufacturer to be certified as a "cabinet" x-ray system.

The Mobile Truck X-Ray prototype has been developed and has completed evaluation. Stream of commerce testing was successfully performed at the Port of Entry at El Paso, Texas. During that test, the system assisted in the detection of contraband in both a car and a truck. Initial system capability provides backscatter images only. A second system is being developed which will provide backscatter and transmission images.

2.1.4 HIGH ENERGY CARGO CONTAINER INSPECTION SYSTEM

One of the more challenging aspects in drug interdiction is the inspection of cargo containers, particularly at seaports. The DoD Counterdrug Technology Development Program Office has recently awarded a contract to develop a mobile inspection capability for 44-foot sea cargo containers. The system, a high energy 2-6 MeV X-ray integrated on a sea container transporter, will be totally self-contained and, if successful, will enable rapid inspection of the containers without impeding the flow of commerce

2.2 SIMULATION/TESTBEDS

Supplementing the system development projects within the NII program thrust is a series of support activities. These include the Thunder Mountain Evaluation Center, databases of drug physical and chemical characteristics, and simulation and modeling of the drug trafficking process including the effects of the introduction of improved inspection systems on the flow of traffic at the port of entry.

2.2.1 GENERIC PORT CONTAINER (GPC) MODEL

The Generic Port Container Model was designed to model and evaluate the effects of introducing advanced technology non-intrusive inspection (NII) devices for detecting illicit drugs and other contraband at ports of entry. The GPC is actually a series of computer simulations developed for eight major commercial cargo facilities at ports of entry along the Southwest border (Brownsville, Hidalgo, Laredo, El Paso, and Ysleta, TX; Nogales, AZ; and Calexico and Otay Mesa, CA). It represents the specific activities that take place at each of these locations, and allows analysts to assess the effects of inspection technologies as well as contemplated policy or operational changes on day-to-day activities of the port. The model demonstrates the impact of such changes on vehicle processing times, percentages of vehicles being inspected, volume of vehicles in the compound, and other parameters. Each port model uses actual operational data from that port, such as monthly, weekly, daily, and hourly volumes of vehicles by type of entry; times for loading and unloading vehicles for inspection; processing times; and staffing patterns. The model also allows the explicit representation of inspection technologies in terms of their probability of detecting drugs; probability of alerting when no drugs were present; and throughput (i.e., average time to process one inspection unit). The USCS is using this model to assess and improve operations at several of their ports of entry.

2.2.2 THUNDER MOUNTAIN EVALUATION CENTER (TMEC)

The Thunder Mountain Evaluation Center, located in Fort Huachuca, Arizona, provides a controlled operational test environment for NII systems prior to the introduction of the systems to operations at ports of entry on the border. The location provides facilities and personnel to support test, evaluation, technical analysis, and operator training and logistic support for the systems. Indoor and outdoor test space, storage space for test cargoes and vehicles, and data reduction facilities are available. The facility was opened in September, 1995, and has already been used to evaluate a small package x-ray, the mobile truck x-ray, a gamma ray detector, a hyperspectral infrared vapor detector, and a series of vapor and particle inspection systems.

2.2.3 COCAINE/HEROIN INFOBASE

The Cocaine/Heroin Infobase (CHI), was developed to fulfill the need for quick and efficient access to recent information on cocaine and heroin. Updated regularly, it is categorized into three main interest areas: identifiers and properties, synthesis and manufacture, and analysis and detection. It includes U.S. and foreign scientific and technical journal articles, patents and government-only documents. CHI includes a synopsis of the work, pertinent notes, references, and a full copy of the actual article, paper, or patent, if copyright permission was obtained.

CHI runs on many different platforms, including PC/Windows, PC/DOS, Macintosh, and Unix-based workstations. A compact disk (CD-ROM) drive is required, but all software, including drivers, search tools, and data, are provided on the CD.

2.3 SMALL PACKAGE INSPECTION SYSTEMS

The Small Package Inspection Systems are designed to inspect passenger baggage, expedited courier parcels, and break-bulk cargo. An evaluation was conducted of several commercially available state-of-the-art, small package x-ray systems to determine their ability to inspect smaller packages for the presence of illegal drugs and contraband. These x-ray systems are modifications of systems that were initially developed for explosive detection at airports and other locations.

Two advanced commercial x-ray systems have completed this evaluation. These systems include an advanced x-ray computer tomographic system, and a single energy x-ray transmission/backscatter imaging system. A third system, a dual-energy x-ray transmission/backscatter system is scheduled for assessment this year.

2.4 HANDHELD INSPECTION SYSTEMS

There are numerous chemical sensing technologies that are useful in the detection of drug contraband. Of these, we have investigated mass spectrometry, ion mobility spectrometry, gas chromatography, optical spectroscopy, canine olfaction, and vapor and particle preconcentrators. These techniques specifically identify the compounds of interest in the vapor or particle phase of the illegal drugs. Sensitivities in the sub-nanogram level have been demonstrated. Chemical sensing devices have the advantage of being portable, small in size, and compound specific, but have the disadvantage of requiring opening or venting the container in order to obtain a sample of the drug particle residue or vapor emissions.

2.4.1 CHEMICAL MICROSENSOR

An inexpensive, portable, rugged cocaine detection device has been developed and successfully demonstrated using a compact surface acoustic wave (Pyro-SAW) microsensor. The device is a hand-carried system used to detect drug particles. The suspect particles are collected on a disposable filter, heated (pyrolyzed) to decompose the particles into their chemical vapor by-products. A thin, selective coating that has an affinity for the target pyrolysis products covers the SAW transducer.

Upon a change in mass due to the target vapor absorption, a change in the SAW frequency propagation characteristics occurs which is sensed, processed, and used to trigger an alarm. The sensor has a wide variety of applications including screening cargo containers and searching ships by boarding parties. The entire system (collector, sensor, and processor) is battery powered, and weighs seven pounds. The system is capable of detecting 50 nanograms of cocaine.

2.4.2 ION TRAP MOBILITY SPECTROMETER

Ion mobility spectrometers are a classic means of analyzing and identifying chemical substances. The substance to be analyzed is broken down into ionized components, the components are accelerated through an electric and/or magnetic field, and the ions are physically dispersed according to their mass/charge ratio. Measurements of the dispersion identify the target substance. These types of instruments have inherent limitations in the areas of selectivity and sensitivity, but they are in general use, their performance has been improved over the years, and they are relatively simple, reliable, and inexpensive.

An improved Ion Trap Mobility Spectrometer has been developed under this program. A breadboard model has completed technical evaluation, and three prototype models of a handheld configuration have been completed. The handheld units weigh eight pounds each, including batteries sufficient for a one-hour mission. Sensitivity is in the one-hundred picogram range. The design features include a high-efficiency atmospheric sampling system with more turbulent flow, and improved trap geometry resulting in an improved ion collection efficiency, automatic calibration, and self-diagnosis.

2.4.3 CANINE SUBSTANCE DETECTION

Minimal scientific attention has been focused on fully evaluating the canine's biological and behavioral mechanisms, sensory capabilities, and effectiveness with regards to sensitivity, selectivity, collection/transfer efficiency, and the inherent "going-to-source" operation. The primary objective of this project is to conduct analysis of the complex aspects that contribute to the effectiveness of substance detection canines and provide procedures and techniques to achieve validated reliability and improved detection capabilities and establishment of documented standards of reference/calibration. Canine olfactory absolute detection thresholds and specific odor(s) signature discrimination for various drugs will be determined in a scientifically valid and non-invasive manner using advanced psychophysical operant conditioning techniques. Output will address the impact of environmental and physical variables, test conditions and confounding factors, and the effects of health, age, nutrition, exposure to toxic fumes/materials, attractants/detractants, target vapor and/or particle concentrations, signature phenomenology, specialized sample target collection techniques, candidate selection criteria, and training concepts. The project is structured to optimize leverage of on-going multi-agency sponsored canine detection/olfaction projects (DoD-Technical Support Working Group (TSWG), U.S. Secret Service, Federal Aviation Administration (FAA), the DoD Military Working Dog Program, U.S. Army (landmine detection), and the Defense Advanced Research Projects Agency (DARPA). Results will be provided to law enforcement agencies (DLEAs) to assist in the understanding and improving of our national canine assets. Furthermore, the results could augment the development of artificial biosensors for drug detection.

2.5 INTEGRATED SYSTEM DEMONSTRATION

Numerous technologies and systems have been developed and demonstrated under this program. Many of the technologies have been successfully demonstrated at Southwest Border Ports of Entry. These systems were demonstrated as they were developed. However, multiple systems developed under this program have not been demonstrated at a seaport and airport. Because increased emphasis is being placed on the threat at seaports and airports, the DoD Counterdrug Technology Development Program Office, in cooperation with the USCS and National Guard, will conduct an integrated system demonstration of the non-intrusive inspection systems developed under this program, as well as existing systems in place at the ports.

3.0 WIDE AREA SURVEILLANCE

The focus of the Wide Area Surveillance (WAS) program is to develop long-range standoff sensors and related signal processing and C3 capabilities for applications in the Detection and Monitoring (D&M) of the growth, manufacture, and transport of illegal drugs. The technologies developed provide methods of surveillance to support interdiction of trafficking activities in the source and transit countries and zones. In support of the National Drug Control Strategy, the technologies developed within this thrust assist in the achievement of Goal Four "Shield America's Air, Land, and Sea Frontiers from the Drug Threat", and Goal Five "Break foreign and Domestic Drug Sources of Supply".

A number of sensors have been developed, evaluated, and demonstrated as a result of this program thrust. They include Over-the-Horizon (OTH) Radar Enhancements, Foliage Penetrating Radar, and Modular Air-Air Radar.

3.1 OVER-THE-HORIZON (OTH) RADAR ENHANCEMENTS

Several years ago, Congress appointed the Department of Defense to detect and track illicit drugs flowing from countries outside of the continental United States (CONUS). At that time, systems at two sites (the ROTHR system in Virginia, and the OTH-B system in Maine) were providing long range coverage to the areas of interest. The OTH-B system was subsequently deactivated and ROTHR continued providing surveillance to the Counterdrug mission. A second ROTHR system is now operating in Texas, and a third is scheduled for installation in Puerto Rico in the near future. Because the existing Over-the-Horizon Radar Systems were originally designed to perform a military mission and not a counterdrug mission, enhancements to provide a better capability to provide surveillance are being developed by the DoD Counterdrug Technology Development Program. The enhancements include:

Impulsive noise reduction: Removing the effects impulsive noise events (lightning) from temporal data;

Improved target resolution: Using an enhanced dynamic algorithm to improve weak target detection and tracking;

Enhanced definition of land and sea interface. This enhancement will in turn improve the accuracy of target location;

Improved tracking of slow and maneuvering targets. This will be accomplished by improving tracking algorithms in the areas of Kalman filtering, track initiation, returns association, and peak detection;

Coordinated registration enhancement (range error) by dynamic optimization (CREDO). This will assist in achieving ionospheric definition and true target range;

Equatorial clutter reduction: We are investigating methodologies to minimize the impact of spread Doppler clutter that reduces the current OTH radar performance and creates range ambiguities;

Imbedded communications: Using a portable system to receive an OTH radar waveform, modify it to carry data, and retransmit the signal in time synchronization with the next incoming OTH signal;

Extended range coverage: The current range capability of the OTH radar will be enhanced to include 2000 – 2500 mile tracks;

Altitude readout: We are developing algorithms and technology to allow an accurate reading of the altitude of a tracked target;

Beacon-assisted Vectoring: We are testing to determine the effective use of repeater beacons and known locations to improve target location accuracy.

3.2 FOLIAGE PENETRATING RADAR (FOLPEN RADAR)

The DoD Counterdrug Technology Development Program Office completed the successful development and operational testing of a prototype foliage penetrating radar in October, 1996. The purpose of the foliage penetrating radar is to support operations of the U.S. Southern Command (SOUTHCOM) to detect and locate cocaine hydrochloride processing laboratories hidden under triple canopy jungle cover in South America.

The radar exploits ultra wideband (UWB) synthetic aperture radar technology that had been developed over the years by several U.S. Government agencies, including the Defense Advanced Research Projects Agency. Prior applications of the technology included tunnel and land mine detection in addition to foliage penetration. Special signal processing algorithms were developed for this latest radar to detect the man-made laboratories under the jungle foliage.

The radar was developed to operate on an existing U.S. Army airborne reconnaissance platform called Army Airborne Recce Low which is in routine operations supporting SOUTHCOM. The platform, a DASH-7 airframe, was modified by the addition of semi-covert transmit and receive antennas which were polarized in the horizontal and vertical modes. During the development of the radar, test data was collected at three test sites so that the signal processing algorithms could be refined and optimized for the drug lab detection mission. The technology has been transitioned to SOUTHCOM. The DoD Counterdrug Technology Development Program is developing enhancements to increase the effectiveness of the radar.

3.3 DETECTION AND MONITORING STUDY

This project is an in-depth analysis addressing the detection monitoring, and interdiction process for the Counterdrug transit and source zones (i.e., Central and South America and the Caribbean). This analysis provides an assessment of air and maritime interdiction operations in the transit zone with particular emphasis on the improved surveillance potential of the Relocatable Over-the-Horizon Radar (ROTHR). The study included a review of air, land, and maritime cocaine transport modes and quantities shipped from the source countries into the US; assessment of the performance of detection and monitoring resources in time and space; determination of response times; assessment of employment tactics; identification of current trafficking operations; and developing measures of effectiveness (MOEs) for detection, monitoring, and interdiction in the transit zone. The study results are used by the Joint Chiefs of Staff and the United States Interdiction Coordinator to improve the effectiveness of interdiction operations.

4.0 TACTICAL OPERATIONS SUPPORT

The focus of the Tactical Operations Support program is to develop prototype devices and algorithms to assist counterdrug forces in dismantling drug trafficking cartels. In support of the National Drug Control Strategy, the technologies developed within this thrust assist in the achievement of Goal Four "Shield America's Air, Land, and Sea Frontiers from the Drug Threat", and Goal Five "Break foreign and Domestic Drug Sources of Supply". In addition, the projects within this program address the Office of Secretary of Defense DLEA Support and Dismantling Cartels Counterdrug Functional Areas. The Tactical Operations Support program is organized into three categories: C4I; Interdiction Support Technologies; and Local Surveillance and Tracking.

4.1 C4I

The purpose of this program thrust is to enhance the effectiveness of the Command, Control, Communications, Computers and Intelligence (C4I) for DoD and DLEA counterdrug efforts. To that end, several information technology tools have been developed and demonstrated to assist in data analysis; computer media analysis, fax exploitation, and timeline analysis.

4.1.1 NEEDLES FROM HAYSTACKS

This text understanding project developed rule-based algorithms for recognizing key types of textual data in a multilingual environment (i.e., English and Spanish), and to extract named entities such as persons, corporations or organizations from large unstructured data sets. The technology was successfully demonstrated, achieving high scores in English with a relatively small training sample of under 100,000 words and a single external list containing 10,000 person names. The technology is now integrated into the counterdrug intelligence operations of SOUTHCOM and JIATF-E. A follow-on project, which will employ a learning algorithm to extract desired data from examples in documents, will further enhance the effectiveness of analysts evaluating data by decreasing the time and effort required to analyze information.

4.1.2 COMPUTER MEDIA ANALYSIS

This project provides the military and law enforcement communities, such as the Federal Bureau of Investigation, Computer Analysis Response Team, with a workstation capability to perform forensic computer analysis on seized digital computer media. Hardware is a conventional single-operator workstation. The actual use of this system is defined by the FBI and may change over time, however, one scenario could be as follows. When FBI field agents seize computer data, it will be provided to computer laboratory specialists at FBI Headquarters or to one of the fifteen field examiners for analysis. Along with the seized computer data, the field agent would also provide the laboratory with a description of critical data available for extraction, such as names, databases, and/or dates. After analysis, the laboratory would provide the agent with the desired data loaded on CD-ROM. This unaltered format should be useful in judicial proceedings. This system is nearing completion and installation at the Federal Bureau of Investigation.

4.1.3 TIMELINE ANALYSIS SYSTEM

This project was initiated to provide a visual analytical tool for analysts to track events in real-time or near real time as an adjunct to current technologies employed. It has been successfully demonstrated at SOUTHCOM and is currently being demonstrated at JIATF-E. It has also been utilized by police organizations to track the movements and transactions of persons engaged in illegal activities (i.e., serial killers).

Enhancements developed under this project will allow the system to operate on a variety of platforms, to allow greater flexibility and utility for operational commands.

4.1.4 COUNTERDRUG TECHNOLOGY INFORMATION NETWORK (CTIN)

The CTIN project developed an operating online database and bulletin board system dedicated to counterdrug technology and counterdrug activities. CTIN is unclassified, but access is controlled to registered users in law enforcement activities. Over thirty user agencies are currently registered. CTIN contains over 100 system descriptions and is designed to accept thousands more. CTIN is now maintained by the Army Material Command. Enhancements sponsored by this project will allow the placement of limited information on the World Wide Web in an effort to provide awareness to the law enforcement community and encourage dialogue among agencies and experts.

4.2 LOCAL SURVEILLANCE AND TRACKING

This program area supports DoD and DLEAs in conducting surveillance, identification, and tracking for counterdrug purposes. Several different technologies have been developed and demonstrated, including Facial Recognition; Uncooled Infrared Imaging; Tagging, Tracking and Locating; Tunnel Detection; and Navigation Studies and Enhancements.

4.2.1 FACIAL RECOGNITION TECHNOLOGY (FERET)

The objective of this project is to develop automatic face recognition systems with application to identify suspects in a booking station, and to identify suspected terrorists, smugglers, and criminals in public locations such as airports. To achieve this objective, the program supports research in face recognition algorithms; the collection of a large database of facial images; the integration of algorithms into a testbed; independent testing and evaluation of facial recognition algorithms; and construction of a real-time system to demonstrate face recognition in real-world situations. Excellent results have been achieved to date with over 90% accuracy in identification of faces. Several law enforcement agencies are interested in fielding a capability. Three system demonstrations are planned for both evaluation and community awareness purposes.

4.2.2 UNCOOLED INFRARED IMAGING

This project developed and fabricated low-cost prototype infrared thermal imagers that operate at room temperature. These infrared sensors detect thermal radiation emitted by all bodies and do not rely on radiation reflected from the scene as image intensifier systems operate (i.e., night vision goggles). The prototypes are used in military and non-military applications such as rifle sights, surveillance sights, driver's aids, reconnaissance sensors, security sensors, border security, preventative/predictive maintenance, and manufacturing process control. The major goal was to reengineer an earlier military system to significantly reduce the costs to increase affordability for non-military users. Twelve handheld units were delivered for law enforcement evaluation in August 1995. As a direct result of this and other DoD programs, the contractor has fielded commercial versions of the system. Unit cost is approximately $10,000, depending upon the exact configuration and quantity. Because of the reduced cost, the unit has been purchased by DLEAs and the military for use in their counterdrug and other operational requirements.

A follow-on project, the Helmet-Mounted Thermal Imager, sponsored in conjunction with the U.S. Army Special Operations Program, will engineer, demonstrate, and test prototypes for specific Counterdrug applications.

4.2.3 MICRO GPS

The micro-miniature global position system receiver program used multi-chip module (MCM) packaging technology to produce a six-channel C/A code receiver in a 1.4 inch square package with 1.2 watt power consumption, the world's smallest GPS receiver. This technology has been successfully transitioned to several activities including the Air Force HOOK-112 search and rescue radio, the Soldier-911 radio prototype currently in use in Korea and Macedonia, and several classified covert tags.

4.3.3 TUNNEL DETECTION/ GEOLOGICAL INFORMATION SYSTEM

This project will create a mechanism for monitoring surface and subsurface border conditions for evidence of illegal activities and provide the U.S. Border Patrol with an efficient data management scheme.

5.0 DEMAND REDUCTION

The focus of the Demand Reduction program is to develop technologies and procedures for chemical testing and improve detection thresholds; develop less invasive testing methods (e.g., sweat vs. urine); and optimize testing methods, equipment and procedures. In support of the National Drug Control Strategy, the technologies developed within this thrust assist in the achievement of Goal Three, Objective Three "Drug Free Workplace". The program has conducted studies utilizing the Naval Research Laboratory expertise and facilities, as well as those of other service laboratories. Efforts are leveraged with those of ONDCP and NIJ.

This program, in conjunction with the Navy Personnel Research and Development Center, San Diego, California, developed a PC-based drug policy analysis model to analyze alternative drug testing strategies and develop "optimal" testing strategies for military personnel. The model incorporates and integrates detection, deterrence, concept of optimization (trade-offs), and costs/benefits. The research strategy focused on two classes of drug user: the non-gaming user who selects day of drug use independent of drug-testing strategy and randomly chooses days of use; and the gaming user who selects the day of use to minimize probability of detection by testing. The following alternative drug wear-off patterns were developed: drugs detectable for fixed time frame with certainty; probability of detection based on time since last use; and probability of detection depends on pattern of use. Probabilities are calculated for a person being selected for testing, and the persons' drug use being detected in a period of time. A "survival" curve was described as the expected time until detection. Different testing strategies were examined: alternative monthly test rates; selection of test days (i.e., fixed number of testing days or a random number of testing days); selection of personnel (i.e., purely random or weighted probability of selection based on the risk of drug use or the date since last selected). In addition, the cost of drug abuse was analyzed in terms of productivity; health care; accidents; occupation (can vary); and replacement cost if users are discharged. The model has been transitioned to the Navy for use in changing and optimizing testing strategies.

To optimize urinalysis testing methods, equipment, and procedures, an improved specimen sampling process concept has been developed. The Specimen Sampling Automation Project consists of a new bottle concept which will greatly improve the integrity of urine sampling processes and an automated specimen bottle handling system to automatically identify/read the redesigned specimen bottle using bar code technology and automatically extract urine samples from the container for testing.

6.0 SUMMARY

The DoD Counterdrug Technology Development Program addresses the drug threat by aggressively pursuing high technology solutions. Many technologies have been developed, demonstrated, and transitioned to law enforcement and military users. The Program accomplishes its goals by working closely with industry, service and national laboratories, and academia to provide system solutions to real world operational problems.

THUNDER MOUNTAIN EVALUATION CENTER
THE ORGANIZATION AND THE SUPPORT

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ABSTRACT

This paper provides an overview of the services and capabilities provided by the Thunder Mountain Evaluation Center (TMEC), located at Fort Huachuca, Arizona, in support of the Department of Defense Counterdrug Technology Development Program Office, U.S. Customs Service, Office of Special Technology, Department of Energy, and the Drug Enforcement Administration.

TMEC, located in the high desert area of Arizona at Fort Huachuca, is ideally suited for the test and evaluation role, especially when dealing with counter-narcotic, counter-explosive, and counter-terrorist activity. The ready availability of contraband for use in evaluation of detectors, the proximity to actual Port of Entry sites for stream of commerce and field testing of non-intrusive inspection equipment, and the high security provided by TMEC combine to create an ideal environment for testing inspection, detection, surveillance, and tracking technologies.

TMEC has unique licenses and authority to possess, maintain and expend (if required) large quantities of various types of contraband in conducting evaluations. Thus, TMEC works closely with the various agencies and activities in assisting those agencies to evaluate the effectiveness of their prototype systems.

TMEC performs controlled operational tests at Fort Huachuca on various non-intrusive inspection systems, weapons, explosives, and personal detectors, and other drug and law enforcement-related systems. Those systems which appear to have significant merit can be transported easily to Ports of Entry in Arizona, California, New Mexico, or Texas and given more extensive stream of commerce tests.

TMEC provides management oversight of various test and evaluation programs using a combination of government, Arizona National Guard, and contractor personnel. TMEC has a large variety of "stream of commerce" cargo with appropriate vehicles to transport that cargo. These vehicles, some with false compartments, have been turned over to TMEC as "test and training aids."

1. Purpose and Facilities

The Thunder Mountain Evaluation Center was established by the Department of Defense Counterdrug Technology Development Program Office to provide facilities and personnel to support the management, testing and evaluation, technical analysis, operator training, logistics and maintenance support, and full life-cycle support for counter-narcotic and counter-terrorist system fielding to the Drug and Law Enforcement Agency Community.

Located in the high desert area of Arizona, TMEC is ideally suited for the test and evaluation role when dealing with counter-narcotic, counter-explosive, and counter-terrorist activity. The dry climate, mild winters, and clear summer skies of southern Arizona allow year round testing of systems with little danger of cancellation due to weather conditions.

TMEC is established on Fort Huachuca, an active army post which has a limited access perimeter with full time military and civilian constabulary. Fort Huachuca is home of the U.S. Army Intelligence Center and School and the U.S. Army Information Systems Command, both organizations very conscious of security. This presence significantly contributes to the security and confidentiality of the TMEC mission. The TMEC facility is, itself, surrounded by an eight foot high chain-link fence with electronic intrusion alarms and twenty-four hour visual monitoring. TMEC has a secure vault storage facility within the compound. There are strict guidelines established for the handling and accountability of security items by assigned personnel.

TMEC has unique licenses and authority to possess, maintain and expend, if required, various types of contraband in conducting evaluations. Through the auspices of the US Customs Service, the Drug Enforcement Agency, and the local Cochise County Sheriff's Department, supplies of common narcotics contraband such as cocaine hydrochloride and heroin, have been made available for use. This seized contraband is used in controlled tests to evaluate the effectiveness of prototype detector systems. Tests which are destructive of the contraband are among the tests which TMEC can readily support, as long as the exact quantity of contraband destroyed can be accurately documented. This ability to obtain and store narcotics clearly sets TMEC apart from other test and evaluation agencies and demonstrates one of the most valuable characteristics of TMEC.

Fort Huachuca itself is located at the foot of the Huachuca mountains just a few miles from the U.S. - Mexico border. Within a few hours drive, there are three U.S. Custom's Ports of Entry, the largest being Nogales, AZ., which provide sites where field testing can be performed in an actual operational environment. This points out another of TMEC's major advantages over other test and evaluation sites: the ability to do actual "stream of commerce" testing of equipment and procedures in addition to performing controlled testing in the Fort Huachuca environment. In addition, TMEC is well positioned to support testing at Ports of Entry from Brownsville, Texas to Calexico, California. Extensive field tests of new equipment have been conducted during the past few months at San Luis and Nogales, Arizona; and El Paso, Laredo, Pfarr, and Brownsville, Texas. As an example of the Office of National Drug Control Policy (ONDCP) sponsored technology at work, the Vehicle And Cargo Inspection System (VACIS), has been operating at the cargo Ports in Nogales, Arizona, and El Paso, Texas. The objective of the project was to demonstrate the concept that empty propane tankers could be thoroughly inspected by this gamma-ray system.

TMEC works closely with various agencies and activities, assisting in the conduct of evaluations by providing both personnel and materials support. The main requirement to obtain TMEC support is that the requesting activity be sponsored by the Department of Defense Counterdrug Technology Development Program Office, US Customs, or ONDCP.

Thunder Mountain Evaluation Center provides management oversight and test assistance using a combination of government, Arizona National Guard, and contractor personnel. Though not directly testing in all cases, TMEC can provide the assistance and facilities necessary for developmental and conceptual testing by independent developers sponsored by government or law-enforcement agencies. Also, TMEC can provide the experienced, qualified National Guard operators and evaluators to make improvement recommendations.

There are various vehicles available for test and evaluation which duplicate those encountered during "stream of commerce" inspections. These vehicles range from small automobiles to heavy duty trucks with trailers. Among the cargo containers, there are sea/land containers, aircraft cargo modules, and fuel trucks. The cargo itself can be simulated by wood products, stone, steel, aluminum, tires, paper, and various other materials expected at a Port of Entry. This availability provides the realism necessary to perform a meaningful and useful evaluation.

2. Mobile Truck X-Ray System (MTXR)

The Department of Defense Counterdrug Technology Development Program Office, with the US Customs Service has developed, and is now testing, a Mobile Truck X-Ray System. A medium duty truck contains an electrical generator, an X-Ray source, and the associated electronics necessary to perform an x-ray scan of a target vehicle. Rather than direct detection of the x-rays, as in a medical x-ray, the Mobile Truck X-Ray (MTXR) detection is performed by a process known as "backscatter" and is especially effective in detecting organic substances.

The MTXR requires a team of three people. Those are: a control room operator, a driver, and a ground guide. A target vehicle is positioned alongside the MTXR and is slowly scanned. This is accomplished by the MTXR driving the length of the target vehicle. The MTXR truck has an auxiliary, hydraulically operated transmission which moves the system at a constant rate of 6 inches per second. The real-time results of the scan are electronically processed and displayed to an operator in the control room. The control room operator can then examine the x-ray on a monitor and, if necessary, record it on the computer's hard disk as well as make a hard copy print. This operation takes less than ten minutes to accomplish.

As an example of the use of the MTXR, in examining the stream of commerce at an El Paso cargo Port of Entry (POE), a US Customs inspector's dog "hit" on a truck but the agents were unable to identify any contraband. The truck was unloaded without further evidence being uncovered.

Customs and National Guard personnel drilled into the front of the trailer from the interior. Though a false compartment was suspected, no evidence of contraband was found on the drill nor seen by peering into the holes. The truck was scanned by the MTXR and the false compartment at the forward end of the trailer became immediately evident. Also, the compartment was plainly shown to have something in it.

The agents, along with the assigned National Guard personnel, opened the forward end of the trailer and exposed numerous bales of marijuana.

Smaller vehicles can also be scanned by the MTXR system. In one case, a USCS inspector using a "Buster" determined that the density of an automobile fender was greater than expected. The inspector referred the vehicle to the MTXR operators for further inspection.

The vehicle, innocent appearing as it was on the outside, showed an entirely different picture on the inside. Some 53 pounds of marijuana was bundled and stowed behind the splash shields in each front fender.

3. Vehicle And Cargo Inspection System (VACIS)

The Vehicle And Cargo Inspection System (VACIS) has proven to be a valuable tool to the USCS. The development of a technical demonstration unit was sponsored by ONDCP. This unit is a transportable system which uses a shuttered and collimated isotopic gamma-ray source on one side of a vehicle and a vertical array of large gamma-ray detectors on the opposite side. The radiation source and the detector array are mounted on wheeled trolleys which move the length of the target vehicle. The movement is synchronized in order that the beam of radiation is intercepted by the detector on the opposite side of the vehicle. The detected signals are processed through an electronic scanning system and a computer generated image is produced depicting the inside of the vehicle, analogous to an x-ray. This is a real-time display and a trained operator examines the display on the console and makes a determination concerning the necessity for further inspection. The entire process takes approximately three minutes, including the time for the operator to view the results of the scan.

The system was tested at Fort Huachuca using the cargo materials and vehicles at the TMEC facility. It was further tested at Nogales, AZ POE in the "stream of commerce." This field test provided a greater mix of cargoes for testing and revealed situations not encountered at the TMEC facility. For example, the area set aside for scanning of cargo vehicles at Nogales POE was not level within system requirements. Although leveling devices are integrated on the rail system, it was not sufficient to counter the slope of the testing area. Blocks were devised and cut to bring the system within the manufacturers specified parameters. During the test, the VACIS did successfully reveal contraband. The field test at Nogales POE was followed by additional testing at Fort Huachuca and the system was then moved to the Ysleta Cargo POE, El Paso, TX., for further field testing.

The VACIS is capable of inspecting the vehicles expected at a typical POE. An extremely important capability of the VACIS is the ability to penetrate the thicker metal enclosures of propane tankers, which typical x-ray systems can not effectively do.

The prototype VACIS, designed for two hundred scans to prove the concept, is currently operational and being used in the stream of commerce at the Ysleta Cargo POE. To date, it has performed more than 3500 scans, proving not only the concept but the physical reliability as well.

As part of the continuing operation of VACIS, TMEC personnel install the system at a cargo POE, train the local Customs and National Guard personnel in its operation, assist in that operation for a short period of time, then leave the system at the POE for operational use. TMEC provides routine and emergency maintenance and moves the system from Port to Port at the direction of U.S. Customs.

4. BUSTER

When requested by government sponsors, TMEC has provided support to developers. As an example of TMEC support to equipment developers, Campbell Security Company, maker of a device called the "Buster", used extensively by US Customs Service, recently requested assistance in evaluating a concept for development of an improved version of the "Buster." The basic question to be answered concerned cocaine hydrochloride in water. In such instances, do the cocaine molecules combine with the water molecules, thus increasing the density of the resulting mixture, or does the cocaine simply dissolve in the water, thus increasing the volume of the mixture but not its density? The evaluation required a large quantity of cocaine hydrochloride in a specific volume of water. TMEC provided the test items, cocaine, and assistance in conducting the experiment. Campbell Security provided the "Buster" equipment. This evaluation was successful in that it provided an immediate answer to questions the developer had, which will ultimately result in a better "Buster" for Customs' use.

5. CO_2 experiment for INS.

TMEC also provided personnel and vehicle support in assisting INS officers in their evaluation of a "Human Occupancy Detector", which is basically a carbon dioxide concentration evaluation system. A team of TMEC National Guard personnel performed as "hidden illegal aliens" by hiding in cargo areas and false compartments in various TMEC vehicles while others, using the CO_2 detectors, inspected the vehicles for the presence (or absence) of occupation evidence. After a series of successful tests at Fort Huachuca, TMEC personnel assisted the INS officers in "stream of commerce" testing at the Nogales, AZ USCS POE.

6. Los Alamos experiment.

As another example of developmental assistance, Los Alamos National Laboratory recently requested assistance in evaluating one of their seismic detectors, designed to detect hidden compartments in fuel tanks, such as the saddle tanks used on large trucks. The Los Alamos developers had test experience only in their lab. When they reached the stage of system development where they needed a large variety of test objects, they contacted TMEC for assistance. TMEC provided a variety of barrels filled with various "stream of commerce" materials such as used motor oil and water and containing a variety of false compartments, some of which were empty while others contained contraband simulant. The array of test items provided by TMEC far surpassed the expectations of the scientists' and was sufficient for the Los Alamos developers to gain insight into further development requirements. The entire test took TMEC personnel only one day to prepare and one day for the test, yet contributed materially to the continued development of the sensor system.

7. Enclosed space detection system.

TMEC assisted in the evaluation of a system that would identify heartbeats inside enclosed spaces. This system relies on the ballistocardiogram effect, the process whereby a heartbeat produces small shock waves. The ballistocardiogram produces movement in the surfaces of a closed container, for example, the roof and sides of a vehicle. That movement can be measured by microwave sensor or velocity geophone. If the frequency component of the movement corresponds to the frequency of a human heartbeat, the presence of an intruder is suspected. This system was developed for the Department of Energy to assist in DOE inspection of vehicles entering nuclear facilities. However, there has also been a considerable amount of interest shown in the system by the prison systems of various states. Their interest, of course, lies in the detection of persons hiding in vehicles leaving the premises. During the course of this evaluation, TMEC made numerous suggestions for improvement of the system; almost all of which were adopted and implemented by Oak Ridge.

8. Conclusion

The Thunder Mountain Evaluation Center is a highly versatile evaluation support center that is fully capable of providing equipment and personnel to assist in the national efforts to combat drugs and terrorism. It has a high degree of flexibility and a wide area of expertise upon which to draw. These attributes, combined with a rapid response capability, make the Thunder Mountain Evaluation Center a highly successful and valuable member of the Drug and Law Enforcement Agency Community.

Performance Measurement of Non-Intrusive Inspection Systems

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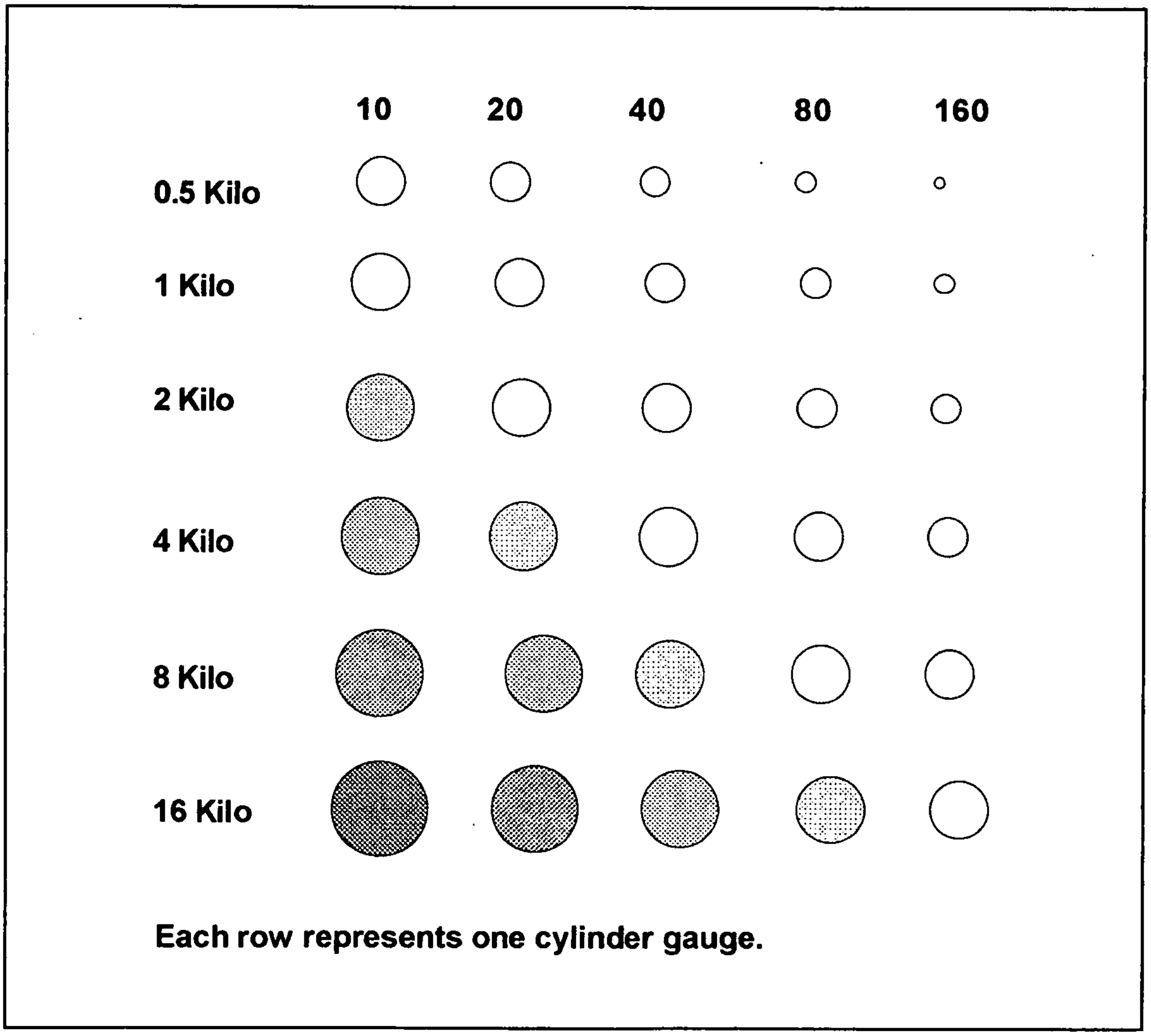

Abstract

A simple procedure has been developed which will allow the U. S. Customs Service to evaluate the performance of non-intrusive inspection system images presented to the operator. In principle, Customs wishes to know if a system can detect a given quantity of contraband and its ease of recognition. Typically these are x-ray or radiation based systems with video presentation to an operator. Theses systems may range in size and capability from small systems used for the inspection of passenger luggage to large systems used to inspect trucks or sea cargo containers. It is important to have a consistent procedure to quantitatively evaluate the performance of the whole range of inspection systems used by the Customs Service.

With regard to the performance level of inspection equipment, the following questions summarize the key issues:

1. What is the minimum quantity of contraband the inspection system can detect, and how well can the system detect various quantities of contraband?

2. Through what thickness of iron can this minimum quantity of contraband be detected?

The Penetration Image Quality (PIQ) gauges have been developed in order to answer these questions in a manner similar to that used in the ASTM gauges. The PIQ gauges simulate the density of typical contraband substances in various quantities within the context of surrounding material similar to the object being simulated. The PIQ gauges provide a quantifiable scale by which to assign performance ratings. This is the fundamental approach used for the new gauge design.

Discussion

Each parcel or container is unique and the range of contraband concealments is only limited by the smuggler's imagination. The challenge of detecting and identifying contraband is different for every package. In addition, the operators of the inspection equipment do not have identical levels of expertise. Because of these challenges, it is useful to have a performance measurement procedure which is as objective as possible.

The American Society of Testing Materials (ASTM) has developed the specifications for a series of standard gauges or penetrometers, which are used to specify the performance of x-ray machines. These gauges do not adequately solve the problem posed above. However, they do offer a valuable clue to the solution. The gauges have the important feature of nearly eliminating the subjective human element in the measurement of the performance of the equipment. Although the human element is essential, since humans ultimately observe the images, these gauges require only a simple yes or no answer as to the visibility of a small region (a "resolution element") within a uniform background in a x-ray image.

The procedure developed in this program allows personnel evaluating the x-ray inspection equipment to determine objectively the ability of the equipment to detect narcotics embedded in packages of specified thickness. In order to be user friendly, the gauge is only dependent on the visibility of single spots or resolution elements. This is similar to the ASTM penetrometer. The tester of the equipment simply chooses the appropriate gauge, processes the gauge through the x-ray inspection system, and determines a yes or no answer as to the visibility of spots on the resultant image.

This examination allows the user to:

1. Determine whether the equipment is operating up to specification, and
2. Determine the actual performance level of the equipment.

The procedure is simple. The user passes the gauge (as if it were a package being inspected) through the system, behind an iron absorber of a desired thickness. Other materials of interest may be used as the absorber. The user examines the gauge image. The positions of visible spots in the x-ray image determine the performance of the tested x-ray system.

The image on the title page represents a set of gauges sufficient to test virtually all operating NII inspection systems. Each row represents a single gauge. The rows are numbered 0.5, 1, 2, 4, 8, and 16 to correspond to weights in kilos of contraband. The relative sizes of the resolution elements for each gauge are shown together to illustrate the relationship among the gauges. Any single horizontal row represents a single PIQ gauge.

In the figure, the more dots that can be seen in the horizontal direction , the better a given quantity of drugs can be seen. The further the dots can be seen as one goes up the figure, the smaller the quantity of drugs, which can be detected. In practice, the quantity value is set when the gauge corresponding to that row is selected. The task then becomes the assessment of how well the NII system can detect the quantity of contraband represented by the gauge.

Detection of a specified quantity of drugs, behind a specified thickness of iron, is given on a scale of 1 to 5 corresponding to the 5 spots on each gauge. The weight of the specified drug package is specified in 6 categories: 0.5, 1, 2, 4, 8, or 16 kilos. This value is selected by selecting one of the six gauges. The figure represents a potential result, if all six possible gauges were passed through the system being tested. The darker the dots in the figure the more visible. From the illustration on the title page, the results may be described as follows:
16 kilos of cocaine can be resolved in 4 of 5 locations: a rating for 16 K of 4/5;
8 kilos of cocaine can be resolved in 3 of 5 locations: a rating for 8 K of 3/5,
4 kilos of cocaine can be resolved in 2 of 5 locations: or a rating of 2/5;
2 kilos of cocaine can be resolved in 1 of 5 locations: or a rating of 1/5;
0.5 and 1 kilo of cocaine are not seen at all.

The ratios noted above may be used in order to develop a database for comparison of systems and evaluation of their performance. For example the performance described above would be unacceptable for a low peak energy x-ray system (less than 150 KeV) behind 6 mm (.25") of iron. It might be barely acceptable for a medium peak energy x-ray system, (about 450 KeV) behind 6.31 cm (2.5") of iron. The performance would be acceptable for a 1 MeV system behind 10 cm (4") of iron. The performance would be outstanding for a 2 MeV system behind 15 cm (6") of iron. Performance levels for different systems can be compared accurately by testing each system with the same gauge.

In practice not all six of the possible gauges are necessary in order to test a given system. The majority of operating x-ray systems can be tested using the 4 kilo gauge and the 1 kilo gauge. These have been selected as the subject of this paper.

Description of the gauges

The simulant material used in the gauges is plastic. This material is in the form of rods, which represent a number of resolution elements (NRE). The chosen material mimics the absorption characteristics of cocaine (or cocaine hydrochloride) sufficiently accurately over the entire range of x-ray energies. The rods are embedded in a block of rigid foam with a density of 0.15 x $\rho_{cylinder}/\rho_{cocaine}$ g/cm^2, or 9 lb/ft^3. The foam simulates a surrounding material such as clothing in a suitcase.

There are five NRE values on each gauge. The NRE designations are the same for each gauge. From left to right they always read as follows: Gauge size such as "4 K" (or "1K") then 1,2,4,8, and 16 corresponding respectively to 10, 20, 40, 80 and 160 resolution elements.

The NRE values are labeled in two ways: lead characters directly below the corresponding rods on the front of each gauge, and plastic marker flags with brass characters. The lead characters may be sufficient when using thin absorber bars. The marker flags must be used when testing a system with a thick absorber bar. The marker flags are interchangeable for use with each gauge. Their order and position on each gauge is always the same.

The marker flags are located out of the x-ray shadow of the carefully positioned absorber bar. This ensures that the markers will be clearly visible even if very thick absorber bars are used to test the system. The centers for all sizes of the simulant rods are related to the markers and a constant distance up from the base to position all gauges in the same radiation field location.

Description of the absorber bars

The absorber bars are chosen to equal the thickness of iron (or other material) through which a system must detect a contraband substance. They must be customized in height, width, and thickness for each system to be inspected. There are two main configurations for the absorber bars: those used for testing a horizontal beam system, and those used for testing a vertical beam system.

To test a horizontal beam system, the absorber bar is positioned on the side of the tunnel, over the radiation beam entrance slot. It must block the portion of the beam that passes through the test gauge. The absorber height is determined by the angle formed from the x-ray source to the top of the foam block portion of the gauge. The absorber height must be such that the entire gauge is covered by the radiation shadow of the absorber, with the marker flags are outside this x-ray shadow. This angle will vary depending on the location of the gauge laterally within the tunnel. The thickness of the absorber bar will be the thickness of iron through which the system being tested claims to penetrate and image or of a material of interest.

As an alternate test in a horizontal beam system, a larger absorber bar may be placed at the far side of the conveyor completely covering the detectors subtending the gauge. Although this test might appear equivalent, this is not the case. Placing the absorber far from the gauge, in front of the detectors, is a far more challenging test of the x-ray system. Radiation scattered by the absorber or by the gauge may enter the transmission detector(s), effectively degrading the image. This test may produce dramatically different results.

For testing in a vertical beam system, the absorber bars are placed above/beneath the gauge on the conveyor, depending on the source location. In this case, the gauge and the absorber bar move through together stacked in a horizontal position. Because of this, the absorber must be as long as the gauge since it must cover all of the NRE rods in the gauge. They must be wide enough to cover the NRE rods but not the lead characters or marker flags. As in the side shooting system, the marker flags may or may not be used when testing a vertical beam system, depending on the thickness of the absorber bar used. Absorber bar sizes must be matched to the test gauge. Once this has been accomplished, testing itself is a simple procedure.

Reading the results

The presentation in the discussion covered most points. Returning to the image on the title page, the image is similar to what might be seen through an absorber bar. The open circles are an indication where unseen NRE are present. It could be expected that if a thicker absorber were used in this test, fewer and perhaps only the larger rods would be visible, resulting in a lower score.

Technical Discussion of the Theory Behind the PIQ Gauges

We assume that it is desired to perceive an object of weight, W, with sufficient precision to see its boundary through a thickness, XFe, of iron. This boundary must be seen while the object is embedded in surrounding material. We have defined the density of the surrounding material to be $\rho_{surround}$=0.15 x $\rho_{cylinder}/\rho_{cocaine}$ g/cm^2. This density has been chosen to be in the same ratio to the density of packed clothing as the ratio of the density of the cocaine simulant (the cylinder) is to cocaine. This is an appropriate choice of density for low energy systems. For higher energy systems, the density of the surrounding material varies widely. The same density material for high energy systems was chosen to ensure uniformity of the evaluations.

It is necessary to define the thickness of the suspicious object of weight W. For the purpose of this procedure, we make the assumption that the object is packaged with its thinnest dimension in the direction of the x-rays. A "kilo" of cocaine was chosen with dimensions of about 6" x 6" x 2" and a specific gravity of 0.8.

The spatial resolution of the inspection system, in the absence of any intervening absorber, is set smaller than the smallest measured resolution element in the presence of an intervening absorber. It is then permitted to replace the contraband object with a simulant of the same weight although of a different density, $r_{cylinder}$. This condition is always present.

In order for a given size of contraband parcel to be detected in the confused x-ray image, there must be sufficient "sharpness" in the image to perceive the outline of the parcel with reasonable clarity. If the image is too blurred, the parcel will not be identified. On the other hand, if the required sharpness of the image is established too stringently, the x-ray inspection system will be found to have much lower penetration than is in fact the case. Thus, it is important to establish this required sharpness conservatively, but not too conservatively. For the present, we define a parameter, NRE (number of resolution elements), which is the number of resolution elements in the image of the minimum cross-section of the minimum quantity of narcotics to be detected. NRE will be carried through the calculations as a parameter, which can be changed depending upon the results of actual testing in the field. It was assumed that a value of NRE = 10 may be too small and that a value of NRE = 160 may be too large. A matrix of values for NRE between these extremes was chosen.

The area of a resolution element should not be confused with the area of each pixel in the image. The number of pixels is determined by the electronic design of the imaging system. Even if the x-ray is completely dark because the parcel is much thicker than the x-ray system can penetrate, the number of pixels in the "image" remains the same. The pixels are simply empty. Nor should the area of a resolution element be confused with the cross-section area of a pencil beam. The area of each resolution element is measured by the "gauge" which is supplied. The better the quality of the inspection systems display, the smaller the measured area of a single resolution element is resolved.

The mathematics involved is elegant and can be developed by the reader. The reader can see the interrelation of the gauges in the illustration. Of note should be the careful matching of the attenuation coefficients of cocaine hydrochloride and the test material over the entire range of energies of interest. AnnisTech presented careful analysis showing the equivalence for transmission, backscatter and dual energy systems.

Conclusions

The benefit of these gauges include:

1. Many systems may be tested consistently.

2. Performance results can be measured against performance claims.

3. Results can be compiled and systems can be quickly compared.

Strategies for Biological Control of Narcotic Plants

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ABSTRACT

The USDA/ARS is developing bioherbicide products and technologies using plant pathogens (organisms which attack plants) for the control of narcotic plant production in the field. As a strategy for control of narcotic plant production, bioherbicides offer an alternative to chemical herbicides. Bioherbicides are environmentally safe and damage only the targeted plant species. The primary narcotic plant species being targeted are coca, poppy, and marijuana. These plants are distinctly different in growth requirements and habitats and therefore require distinctly different control strategies. Marijuana is often grown in small plots or even indoors making use of bioherbicides impractical. Opium poppy is grown as an annual crop, growing best under relatively cool conditions. For bioherbicides to be effective on poppy, they must be active under the proper growing conditions and aggressive enough to affect yield before the opium latex is harvested. Greatest success has been in the development of a bioherbicide for control of coca. Isolates of the fungus *Fusarium oxysporum,* which cause wilt of coca, have been formulated into stable bioherbicides which kill coca. The bioherbicide is slow acting but, since coca is a perennial persisting for 25 years or more, there is ample time for the bioherbicide to work. The potential effectiveness of the bioherbicide is further supported by studies of a natural epidemic of fusarium wilt which is currently damaging coca fields in Peru. We are continuing to evaluate new organisms and strategies for controlling narcotic plants with the goal of developing alternative control measures.

1. Biological Control - A Definition

In terms of this discussion, Biocontrol (13, 17, 21, 22) is defined as the field application of selective plant pathogens to unwanted plant species (narcotic plants) resulting in destruction of the narcotic production potential of the plant. Biocontrol strategies may, but not necessarily, include plant death. A similar definition could be applied to insects for biocontrol of weeds. Comparisons (28) to herbicide control methods (36, 37) are not appropriate and can restrict the potential of biological control methods. Biological control has many positive attributes including specificity, persistence, and the possibility of secondary spread which are well suited to the control of narcotic plants (22).

2. Major Positive Attributes of Biocontrol of Narcotic Plants

Specificity. The first and most important attribute of a biocontrol strategy is specificity (11, 13, 22, 39, 47) to a single plant species (i.e. narcotic crop). It is generally considered unacceptable to use plant pathogens which damage plant species, especially crops, other than the targeted plant species (12, 50). For example, a biocontrol agent applied to control coca should only attack coca, not tomato, beans or any other plant species. Interestingly enough, a pathogen's specificity to a single plant species often serves as a negative factor for biocontrol from a commercial standpoint (13). In a farmer's field there may be many weeds which must be controlled. Control of a single weed, unless of particular concern, may offer no commercial advantage. For the control of a narcotic plant species, specificity means the narcotic plant can be killed even if planted with other crops without damaging those other crops (39, 47).

Persistence. Because of their persistence (4, 7, 39, 50), plant pathogens may provide a nearly permanent solution to illicit narcotic crop production in a given area with a single application. Some plant pathogens produce resting structures designed for long term survival in the soil. Once a biocontrol agent has been released into an area, that area may remain unsuitable for the narcotic crop for many years (4, 47). This attribute may also be considered a negative from a commercial industry stand point where annual sales are sought (22).

Spread. Perhaps the most valuable attribute of using plant pathogens for biocontrol of narcotic plants is their potential for spread to untreated areas. Plant pathogens are self reproducing and are in many cases easily spread. Plant pathogens can be spread (20, 43) by animals including man, wind, rain, and plant parts such as seeds and cuttings. Consequently, a single treatment to a small area may ultimately result in control over entire regions. It is the potential for spread that makes pathogen host specificity a critical requirement for use with narcotic crops.

3. Development of a Biocontrol Agent

The initial task of a biocontrol strategy is the identification of pathogenic isolates with biocontrol potential (1, 42, 44, 47). This may require surveys for diseased plants over large areas to determine what pathogens attack a given plant species. In some cases this information may already be in the literature. Pathogens of related non-cultivated plant species can also be considered as sources of pathogens. This is a common strategy for identification of pathogens the specific plant species being targeted is unlikely to have resistance to. The conditions under which the pathogens are likely to cause disease must also be evaluated (10, 11, 12). Many pathogens will only cause disease under very specific environmental conditions which may differ from the optimal conditions for plant growth. An understanding of the plant species being targeted and the pathogen being evaluated is thus critical. The pathogen selected for evaluation ultimately determines the biocontrol strategy. Once a plant pathogen has been identified, collections of potential isolates are initiated and each these isolates must be evaluated. Evaluation of pathogenic isolates is greatly accelerated if a simple and rapid bioassay is available. The bioassay is a method that demonstrates pathogenicity using artificial infection techniques which accelerate disease development. The bioassay should not be too artificial so as to preclude determination of an isolate's relative virulence and pathogenicity (42). The specificity of the pathogen to the targeted narcotic plant species should initially be determined at this phase of development.

In order to use an organism as a biocontrol agent, a reproducible method must be developed for producing viable biomass of the organism (22, 24, 27, 29). Determination of the most efficient biomass production system requires extensive experimentation in the laboratory using various combinations of growing conditions. Under most conditions, biomass of the organism is produced through liquid or solid fermentation techniques where substrate, pH, oxygen content, and other growth factors are carefully monitored and manipulated. Many microorganisms can grow and reproduce on a wide range of organic materials. Inexpensive agricultural byproducts can often be used for biomass production (24, 29). The biomass should be stable in storage and maintain the isolates pathogenicity. Natural survival structures (often spores) of the pathogen can be produced in culture which may remain viable for many years in storage. This biomass will serve as a foundation for formulating the organism into an easily disseminated formulation.

The next step involves formulation of the biomass (22, 25, 34). In the case of a classical release (22), often used with pathogens that grow only on the target plant, the biomass might be used directly without extensive formulation. The exact nature of the formulation is dependent upon the organism being used, the plant species being attacked, and the conditions under which the pathogen is expected to cause disease. Liquid formulations may include oils and adhesives as well as nutritional components which promote growth of the organism. Solid formulations may be preferred especially where aerial application is required, since they allow application from high altitudes. Solid formulations can include, in addition to biomass of the pathogen, food sources for the organism, carriers to give bulk, stickers to bind the formulation together, and stabilizing agents to protect the organism or formulation from alterations which might limit performance. Once again, formulations often use inexpensive agricultural byproducts to reduce production cost which can be critical for large scale use of the formulation (25). As in the case of biomass production considerable experimentation may be required to produce the best formulation..

Once a formulation (or formulations) has been developed, it must be evaluated for efficacy (4, 5, 39). Although the amount of the target plant killed after application of a biocontrol formulation provides the ultimate measure of a formulation, many other characteristics must also be evaluated. In some cases 50% kill or less of the target plants may be considered excellent control while in some other cases anything less than 100% kill may be considered ineffective. A formulation may be expected to perform differently (18, 19) under different environmental conditions (moisture, temperature, soil type, plant age, plant genetic makeup, ect.). The timing of applications may be critical to the efficient use of a biocontrol agent since many plants become more resistant to disease as they get older. Time may be required after application for the disease process to be initiated and escalate to a point where the plant is seriously damaged. A formulation must have an affect on the target plant before crop yield is reduced (in the case of weeds in a typical crop) or before the crop is harvested (in the case of narcotic plants). Although initial evaluations of formulations may be carried out on a small scale in the laboratory, greenhouse, or field, the ultimate determination of a formulation's effectiveness must take place in a large scale field test where the target plant is grown under the production conditions for the narcotic crop.

A Summary of Procedures for developing a <u>biocontrol agent for control of narcotic crops.</u>

1. Outline the conditions under which the biocontrol agent must work
2. Identify the pathogen
3. Evaluate the pathogen
4. Produce biomass of the pathogen
5. Formulate the pathogen biomass
6. Field test the formulation

4. Production Systems for Narcotic Crops

Three primary narcotic crops are being considered: marijuana (*Cannabis sativa*), opium poppy (*Papaver somniferum*), and coca (*Erythroxylum coca* var *coca*). The most important factors in determining the success of a biocontrol strategy are the environmental and cultural conditions under which a target plant grows. Marijuana is grown as an annual species in warm climates around the world (14, 48, 52). It can be produced anywhere, including indoors, since the marketed product is relatively unprocessed leaf. Very small production systems can be profitable and production for personal use is feasible.

Poppy is grown as an annual or biennial and although it can be grown in many different environments, cool conditions with neutral to alkaline soils are preferred (30, 31, 33). The narcotic product is harvested as latex from flower capsules which must be further processed. Poppy can be produced on small to large acreages with the primary constraint being labor for harvest. Although originally an Asian produced narcotic, large acreages are now being grown in the western hemisphere.

Coca is grown as a perennial species being cropped for 7 to 25 years or more (8, 9, 45, 46). Coca requires warm tropical growing conditions and acid soil. The leaves are harvested 3 or more times a year. The leaf is processed to produce a paste which is further processed to produce the narcotic cocaine. Production of coca leaf is centered in South America (23, 46).

5. Biocontrol of the Narcotic Crop Coca

The Peru Epidemic. In the mid 1980s, coca plants began dying in a limited number of valleys within the upper Huallaga Valley of Peru (2, 42). The plant death was characterized by yellowing of the leaves, leaf drop, a browning of the stem tissue, and drying of twigs, branches and stems. *Fusarium oxysporum* was isolated from the stem tissue and the disease fusarium wilt was diagnosed by Peruvian scientist. The *F. oxysporum* which causes disease in coca has been named *F. oxysporum* f. sp. *erythroxyli* and is specific to Erythroxylum species.

Fusarium oxysporum is a fungus which causes host specific wilt diseases in many different plant species (3, 7). The fungus is found in soil world wide and can persist in the soil for many years by forming resting spores (chlamydospores) and grow saprophytically on plant residues. Although as a fungal species *F. oxysporum* can attack many plant species, specific isolates which cause wilts often cause disease in a single plant species or a group of closely related plant species (3, 12, 35, 39, 47). *F. oxysporum* causes disease in plants by invading the root system and colonizing the water transport system. *F. oxysporum* can produce toxins and limit movement of water to the above ground portions of the plant ultimately resulting in plant death.

Today, *F. oxysporum* f. sp. coca has spread throughout the coca producing areas of Peru east of the Andes resulting in fields being abandoned. Genetic analysis of over 200 isolates of *F. oxysporum* from Peruvian coca producing areas has revealed two major genetic strains of the pathogen (42). The lowest level of disease was observed in the southern areas around Cusco. Analysis of seed from Peru has revealed that the coca *F. oxysporum* can be spread by infected seed. *F. oxysporum* is also know to spread in runoff water and by movement of contaminated soil. The rapid increase in coca acreage continuing from the 80's has resulted in an epidemic characteristic of a plant monoculture system. In fact, the manner in which coca wilt has spread is characteristic of the spread of fusarium wilt in other plant species. For example, a new form of the tomato wilt pathogen is presently spreading in the United States where tomatoes are grown (38).

Biocontrol Development. The observation that *F. oxysporum* can cause severe disease in coca in field situations (2) provides a strong argument that *F. oxysporum* can function as a biocontrol agent for coca. In addition to the 200 isolates we have evaluated from Peru (42), *F. oxysporum* isolates from around the world have been evaluated for their pathogenicity to coca. These additional isolates were collected from relatives of coca (genus *Erythroxylum*) growing wild in both the Eastern and Western hemispheres. As a result of this work, a collection of over 100 *F. oxysporum* isolates pathogenic to coca has been identified. At present we do not have a method for evaluating the aggressiveness of the various isolates. Determining the most aggressive isolate will likely require field testing which is presently unavailable.

Isolate EN-4. In the 1980s studies of herbicide effects and growth habits of coca were initiated in Hawaii. To do this plants were imported from Peru and Bolivia. Soon after the plants were imported, the plants began dying of wilt symptoms. *Fusarium oxysporum* was isolated from the diseased plants. One of the isolates, EN-4, has been evaluated as a biocontrol agent (47, 51).

The initial studies concerning biomass production with isolate EN-4 indicated that dilute nutrient sources such as water extracts of soybean hull fiber were optimum for production of resting spores (chlamydospores) in liquid culture (24). It was known from the literature that *F. oxysporum* persists in soil for many years in the form of chlamydospores (7). Biomass production was carried out in 2.5 fermentors and then scaled up to 20 liter carboys. Each gram of biomass produced contained 10 million infective units (primarily chlamydospores as active ingredient) per gram. The biomass was stable in storage for over two years at 4 C. An unexpected benefit of this research was the finding that the same biomass production procedure were suitable for isolates of *F. oxysporum* other than EN-4.

Since *F. oxysporum* is a soil borne fungus and aerial application is preferred for coca control (i.e. ground application may be impossible), dry granular formulations were developed (25). Several standard formulations, alginate prill, and 'Pesta' (15), in addition to a new formulation formed by an extrusion method containing biomass of isolate EN-4 were prepared. All formulations were made of relatively cheap agricultural byproducts. These formulations were observed to sporulate when placed on moist soil. The spores produced from the formulations colonized the soil.

Due to the exotic nature of isolate EN-4 and the tropical nature of the target crop coca, field evaluations of the formulations were carried out in secured fields on the island of Kauai, Hawaii (4, 5). The major disadvantage of this test site was the level of background innoculum present in the test plots. These were the same fields from which EN-4 was originally isolated (47). Observations of uninoculated coca fields in Hawaii indicated that 50% of coca plants died within 2 years of planting. More extensive testing of the EN-4 formulations was limited by the unavailability of field sites free of the *F. oxysporum* pathogen.

The formulations were applied to the moist soil surface around coca plants at a rate of 33.6 kg/ha (4, 5). The fungus in the formulations sporulated and colonized the soil in the field. The population of EN-4 remained elevated in the treated soil for more than 7 months after application in all field tests. The formulations enhanced the rate of development of fusarium wilt in four of six field tests starting 4 to 7 months after treatment. In most cases, 4 to 7 months is much too long for a biocontrol strategy to work. However, coca leaves can be harvested for more than 25 years from a single planting, thus significant control of coca within 2 years of treatment should be considered a success. In addition, as is the case for the natural Peru epidemic, once the fungus is applied it should persist for many years and spread to neighboring fields. The most likely scenario for use of the bioherbicide would be to apply it aerially to a limited acreage and allow the disease to spread naturally. The more extensive the application area the more rapid the development of an epidemic of coca wilt.

A Summary Development of *Fusarium oxysporum* f. sp. *erythroxyli* as a Biocontrol Agent for Coca.

1. Outline conditions under which the biocontrol agent must work. Coca is a perennial with plantings being cropped for 7 to 25 years. The crop prefers warm acid soils and high rainfall,
2. Identify the pathogen. A soil borne pathogen, specific to coca, preferring warm moist acid soils to cause disease. The pathogen can persist in soils for years.
3. Evaluate the pathogen. The pathogen kills young and mature coca plants. Under conditions of natural spread, the pathogen can kill 50% of plants in 2 years. Isolates have been collected from around the world on coca and related species.
4. Produce biomass of the pathogen. Biomass containing spores is produced in liquid culture. The biomass remains viable for more than 1 year.
5. Formulate the pathogen biomass. Three dry granular formulations have been developed which sporulate when placed on moist soil resulting in soil colonization.
6. Field test the formulation. The formulations have been field tested in Kauai, Hawaii. The formulations increased kill of coca within 4 to 7 months of application.

6. Biocontrol of the Narcotic Crops Marijuana and Opium Poppy

Biocontrol of marijuana is more problematic than opium poppy or coca due to the nature of its culture within the United States (14, 48, 52). Small plots of marijuana hidden in backyards, state forests or grown indoors can be difficult to detect. Marijuana plots may not be localized to a central area thus making effective treatment difficult. The most efficient control method is immediate removal and destruction of the plants. In some areas marijuana is grown in easily identifiable large plots where biocontrol strategies may work. The concept of controlling marijuana using biocontrol methods has been considered for many years (39, 40). As in the case of coca, *F. oxysporum* may be a successful biocontrol agent. Isolate collections have been made around the world and considerable field testing of pathogenic isolate have been carried out. Formulations utilizing less technically sophisticated methods than for coca have been developed which cause considerable disease in marijuana (39, 40). Unfortunately, the annual nature of the crop, the long disease cycle associated with *F. oxysporum*, combined with the high value of the crop have made biocontrol impractical. Other plant pathogens have also been studied for their effectiveness as marijuana biocontrol agent, but further research is needed.

F. oxysporum has also been considered as a biocontrol agent for opium poppy. In many situations the culture conditions (30, 31, 33) for poppy (cool and dry with alkaline soils) limit the potential of *F. oxysporum,* which prefers warm, moist, acidic soils (7). *F. oxysporum* isolates which are pathogenic to poppy have been identified and evaluated but at present the same limitations experienced with marijuana control also apply to poppy. In addition to the biomass and formulation methods developed for coca, novel formulation methods including use of infected seed have been evaluated for biocontrol of poppy. These studies continue but more aggressive isolates are probably required to allow use of *F. oxysporum* for biocontrol of poppy. As with marijuana, other poppy pathogens (6, 16, 32) including bacteria are being studied as biocontrol agents for poppy.

More recently, research has been initiated to develop two other fungi, *Pleospora papaveracea* and *Dendryphion penicillatum* (16, 41, 43, 49), as biocontrol agents of poppy. These organism attack all parts of the poppy plant causing seedling and leaf blight and pod rots (16, 41). At present we have access to isolates of the two fungi from several countries world wide. The collection of pathogenic isolates of these fungi has been greatly accelerated since the fungi are seed borne (43). Field studies, using liquid formulations containing spores of the two isolates from the Beltsville area, were initiated in spring of 1997 at field sites in Beltsville Maryland. Granular formulation of the organisms are being developed from biomass produced by liquid fermentation (26). Some factors which must be overcome if these organisms are to be used successfully are: the pathogens prefer warm wet conditions which are not optimal for poppy production, the pathogen attacks older tissues, and younger tissue appear to be tolerant under field conditions. For effective control of poppy in the seedling stage, there must be very high kill rates. Regardless of these drawbacks, reports in the literature suggest isolates of the organisms exist which can function as effective biocontrol agents in many situations. Greatly reduced latex yields have been ascribed to disease caused by one or both of these organisms.

Summary of the Development of *Pleospora papaveracea* and *Dendryphion penicillatum* as Biocontrol Agents for Poppy.

1. Conditions under which the biocontrol agent must work. Opium poppy is grown as an annual. Opium latex is harvested from maturing capsules. The crop prefers cool neutral to alkaline soils and low rainfall during capsule development.
2. Identify the pathogen. Soil borne pathogens specific to opium poppy and a few closely related species, preferring warm moist conditions and mature to senescing tissue to cause disease.
3. Evaluate the pathogen. The pathogen causes seedling and leaf blight. The pathogen can attack all plant parts including capsules. Isolates have been collected from infected seed from around the world but collection continues.
4. Produce biomass of the pathogen. Spores are produced on solid media. Microsclerotia and modified mycelia are produced in liquid culture. Biomass stability must be evaluated.
5. Formulate the pathogen biomass. Spores of the fungi have been formulated in oil emulsion for spray application. Biomass has been formulated into dry granules but further improvement is required.
6. Field test the formulation. Liquid formulations have been field tested in Beltsville, Maryland with results being analyzed and further field tests being planned.

7. Conclusions

Biocontrol of narcotic crops remains an untried alternative to standard control methods. Whether used in a strategy of classical release or with inundative methods, biocontrol offers a highly selective means of removing the narcotic production potential of a field or region with low environmental impact. In some cases biocontrol may allow long term control with a single application. In the case of fusarium wilt of coca, presently the most advanced biocontrol strategy, the technology exists to produce a shelf stable formulation which will impact coca production which is compatible with the cropping system. Observations of ongoing natural epidemics in Peru provide a strong argument that the biocontrol strategy could be used to limit coca production under field conditions. Several other biocontrol strategies are being developed for marijuana and opium poppy. The major constraints to further development of biocontrol strategies are the lack of suitable field sites for testing, limitations in pathogen collection abilities due to the nature of the crop, and political constraints. Before biocontrol can be used extensively, further development is required to critically determine the environmental impact of use and to scale up formulation and application techniques. In addition, extensive discussions must be carried out between all of the governments involved to clear the way for their use if proven safe and effective. Considering the social and economic costs of narcotic crop production to the world society, the effort seems well worthwhile.

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RESEARCH AND APPLICATION OF SPEECH PROCESSING TECHNOLOGY FOR LAW ENFORCEMENT ACTIVITIES

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ABSTRACT

A Department of Defense leader in research and development (R&D) in speech and audio processing for over 25 years, Rome Laboratory's main thrust in these R&D areas has focused on developing technology to improve the collection, handling, identification and intelligibility of military communication signals. Since the designation of Rome Laboratory as the National Law Enforcement and Corrections Technology Center for sixteen (16) states in the northeast sector of the United States (NLECTC-NE) by the National Institute of Justice (NIJ) in 1995, Rome Laboratory has expanded its application of this expertise to additionally address law enforcement requirements.

Rome Laboratory speech and audio processing technology is unique and particularly appropriate for application to law enforcement requirements because it addresses the similar, military need for time-critical decisions and actions, operation within noisy environments, and use by uncooperative speakers in tactical, real-time applications. Audio and speech processing technology for both application domains must also deal with short utterance communications (less than five seconds of speech) and transmission-to-transmission channel variability.

Speech enhancement and speaker recognition will be the primary technologies discussed in this paper. Automatic language and dialect identification, automatic gisting, spoken language translation, co-channel speaker separation and audio manipulation technologies will be briefly discussed.

1. Law Enforcement Requirements for Speech Technology

Increasing levels of criminal activity and numerous budget-limiting factors have led to the need for more effective and efficient law enforcement operations. The application of advanced technologies can act as a 'force multiplier' and significantly reduce costs associated with increasing requirements. For example, according to a 1995 report by the Director of the Administrative Office of the United States Courts, the cost for the average wiretap in 1994 was approximately $49,000 [8]. With the expected increase in the number of wiretaps needed in the future, the cost is prohibitive with current technologies. Emerging technologies such as automatic speech, speaker, language, and dialect recognition could someday be used to automate parts of the monitoring process without overstepping bounds of personal privacy.

Military and law enforcement personnel are both dependent on time-critical decisions and actions. Audio and speech processing technologies for both application domains must deal with short utterance communications (between one-half to five seconds in length), transmission-to-transmission channel variability, and noisy signals. Rome Laboratory speech and audio technology is unique and particularly suited to address these requirements.

2. Speech Enhancement and Speaker Recognition

Rome Laboratory speech enhancement and speaker recognition technologies have already been applied to law enforcement requirements. These technologies and some of their applications are described in this section.

2.1 Speech Enhancement

A large number of different types of noises are heard on speech communication channels. Non-speech-like sounds affect speech intelligibility by masking fragments of speech sounds. To enhance speech that has been obscured by noise, it is necessary to remove the masking sound, or reduce its effect, without distorting the obscured speech sounds. Speech enhancement technology reduces noise and interference in a speech signal regardless of whether the signal is received by telephone, radio, or any other audio source, and independent of the language being spoken. Its use reduces listener fatigue and communication error rates.

Rome Laboratory's Speech Enhancement Unit (SEU) automatically detects and attenuates impulses, tones and wideband random noise using three signal processing algorithms. The impulse (IMP) algorithm, which virtually eliminates all impulse noises, static for example, operates in the time domain. The Digital Spectral Shaping (DSS) algorithm, which automatically detects tones and attenuates them to a minimum of 48 dB, operates in the frequency domain. The third algorithm, INTEL provides up to 18 dB attenuation of wideband random noise operating in the cepstrum domain. SEU users can select any combination of these noise attenuation processes. Input signals are processed in real-time with a maximum system time delay of 300 milliseconds.

Tape recorder noise, receiver noise, wire and radio link noise, automobile ignition noise, powerline hums, and the effects of other interference are reduced by this technology to allow recovery of noise-contaminated conversations.

Applied within the Air Force to clarify pilot communications, the speech enhancement capability has also been used to improve Office of Scientific Investigation (OSI), Federal Bureau of Investigation (FBI) and state and local police recordings, recovering conversations lost due to low level recordings, malfunctioning equipment, and ground loop connections.

For example, the SEU technology was applied in a drug surveillance case in which New York State Police used body wires and telephone wiretaps to collect incriminating conversations. Audio recordings, collected using standard recording devices, were of poor quality. A large portion of the collection was not audible, or had a noise level so high that the voices were not intelligible. Through the use of Rome Laboratory's Speech Enhancement Unit, the audio quality was significantly improved and provided necessary, additional information about on-going criminal activity. As a result, thirty drug activity participants were arrested. All thirty accepted plea bargains, saving tremendous court costs.

Another case involved the murder of three people. A videocamera recorded the presentation of Miranda Rights and the questioning of the suspect by police. Unfortunately, at times during recording, the investigator turned his back toward the camera and walked between the camera and the suspect, blocking sound to the videocamera's microphone. The suspect's lawyer complained that it was not evident from the poor sound recording that his client had been informed of his rights. The application of SEU technology to the recording allowed its audio contents to be transcribed, and presentation of the transcription to the suspect led to his full confession.

Speech enhancement can improve the intelligibility of monitored signals during wiretap surveillance, improve readability of audio evidence tapes, and improve the quality of police officer patrol communications.

2.2 Speaker Recognition

Automatic speaker recognition technology determines the identify of a speaker solely from a speech sample. Rome Laboratory's speaker recognition technology enables identification of a speaker using as little as four seconds of speech for system training, in contrast to the 30 - 120 seconds required by other speaker recognition systems. The capability is independent of the speaker's language and is indifferent to the speaker's choice of words. Identification decisions can be made on as little as one word (approximately one-third of a second).

Rome Laboratory's speaker recognition technique is unique in that it incorporates multiple feature sets (parameters representing speaker characteristics) and multiple classifiers (decision-making algorithms; each makes its own decision on the identify of the speaker). Each classifier is trained on each of the feature sets, and the results are then fused into a final decision on the identify of the speaker.

Automatic speaker recognition has two modes of operation: verification and identification.

2.2.1 Speaker Verification

Given a set of speech samples for which the identity of each speaker is known and another sample that is presumed to be from a particular speaker in the set, automatic speaker verification 'confirms' (or disproves) the presumed identity of the speaker.

There is significant military interest in using speaker verification technology to restrict access to areas such as flight lines and weapon storage areas to a limited set of individuals. Law enforcement application of speaker verification technology is similar, but could additionally include its use in booking stations - adding speech as a recognizable personal attribute along with fingerprints and picture identification.

Rome Laboratory's speaker verification technology was applied in a criminal case involving a series of false reports of fires. The goal was to determine if the false reports were made by a certain suspect. When a segment of speech from one of the false reports was compared with segments from the other false reports, the speakers were shown to be one and the same person.

IN-VEHICLE VOICE VERIFICATION SYSTEM (IVVVS)

Rome Laboratory is working with the New York State Technology Enterprise Corporation (NYSTEC) to evaluate and demonstrate the application of speaker verification for border control at the U.S./Mexican border.

The U.S. Department of Justice Immigration and Naturalization Service (INS) is supporting development of *biometric technologies* that will enable pre-registered motorists to obtain quick clearance through border stations when entering the United States. Biometric technologies are those that use one or more specific attributes or features of a person (i.e. voice, fingerprint, infrared facial image, hand geometry, etc.) to distinguish that individual from all others.

The In-Vehicle Voice Verification System (IVVVS) project is applying Rome Laboratory speaker verification technology as a means of verifying the identity of pre-registered border commuters. The IVVVS incorporates an infrared transmitter device, for communication from a moving vehicle, with a stationary computer workstation which receives the signal and performs voice verification utilizing Rome Laboratory's unique algorithms. Voice verification is expected to be performed in real-time when it is tested in the dedicated commuter lane at Otay Mesa, California.

2.2.2 Speaker Identification

Given a speech sample from an unknown speaker and a catalog of speech samples for which the identity of each speaker is known, automatic speaker identification matches the unknown sample against those in the catalog to find the closest match.

A recent example of the use of Rome Laboratory's speaker recognition technology in a law enforcement case involved the identification of a speaker whose voice was intentionally distorted to disguise his identity. The speaker's disguised voice was obtained from a VHS recording of a televised interview. A second VHS recording, made at an office party, contained speech samples of the five people that could have been the disguised speaker. Analysis of the interview tape determined that the audio had been distorted by increasing its speed. After normalizing the speed, speaker identification experiments were conducted. The experiments identified the television interview speaker as being most similar to speaker 'A' 67% of the time; forty percent (40%) more often than for any other speaker in the speaker set.

2.2.3 Other Applications of Speaker Recognition for Law Enforcement

Rome Laboratory's speaker recognition technology has been used by the OSI and police departments to identify telephone speakers in sexual harassment cases, false reports of fires, and other illegal activities. The technology has many other potential law enforcement uses, including tracking of individuals via wire and cellular telephone use, and voice "fingerprinting" for police sorting and booking operations. The technology could be applied to wiretap surveillance, providing a means of appropriately limiting the intrusion into private conversations. Applied to prisoner telephone access, the technology would limit the intrusion into private conversations while appropriately restricting access to unauthorized telephone contacts. Also, automatic computer supervision of in-home confinement programs, using randomly timed telephone calls, could apply speaker identification capabilities to ensure that a particular person is at his or her residence.

SPEAKER IDENTIFICATION FOR LAW ENFORCEMENT

A two-year project, "Speaker Identification for Law Enforcement," sponsored by the Federal Defense Laboratory Diversification Technology Transfer Program, was recently initiated at Rome Laboratory. The laboratory is working with a tightly organized consortium of technical specialists within the project to develop an automatic speaker identification capability for identifying suspects in law enforcement surveillance and booking operations.

3. Potential Future Technologies for Law Enforcement Application

Other Rome Laboratory speech processing technologies with potential for law enforcement application are: automatic language and dialect identification, automatic gisting, spoken language translation, co-channel speaker separation, and audio manipulation. Table 1 below lists the major law enforcement functions to which these technologies apply.

Rome Laboratory Technology	Applicable Law Enforcement Functions
Language/Dialect Identification	Surveillance, Booking
Gisting	Surveillance
Spoken Language Translation	Interrogation, Investigation, Booking
Co-Channel Speaker Separation	Surveillance
Audio Manipulation	Surveillance, Booking

Table 1: Other Rome Laboratory Speech/Audio Technologies Applicable to Law Enforcement

3.1 Automatic Language and Dialect Identification

Automatic language identification is a computer capability to identify the language (e.g. English, Spanish, Arabic) of a speech communication. The Rome Laboratory language identification algorithm works regardless of the identity of the speaker or the words that are being spoken. Other research laboratories have developed language identification algorithms, but the Rome Laboratory algorithm is unique in that it requires only a very short segment of speech, less than 4 seconds, to perform the identification task.

Using operational speech data (averaging 9 dB signal-to-noise ratio) and no more than 4 seconds of speech as a clue, the Rome Laboratory language identification algorithm has demonstrated an accuracy of 81% identification within a set of six (6) languages. A more recent experiment demonstrated 80% accuracy within a set of ten (10) languages.

The success of experiments with language identification technology has evolved into an investigation of the development of a 'dialect' identification capability. Recent activities in this research area have included speech database development (representing 11 Spanish dialects) and an evaluation of the applicability of existing language identification algorithms for dialect identification.

Language and dialect identification capabilities will be valuable for identifying suspects in law enforcement surveillance and booking operations.

3.2 Automatic Gisting

Automatic gisting is the computer capability to monitor speech communications for keywords that are indicative of certain activities. Gisting produces a 'gist' or synopsis of the information in the communications.

Rome Laboratory has developed a real-time prototype gisting system which, in monitoring communications between pilots and air traffic controllers, can maintain a list of aircraft flight identifications and the particular activities in which the aircraft are engaged (for example, takeoff, landing, ground control).

Automatic gisting of conversations may someday be a useful tool for law enforcement surveillance activities. Since the gist of conversations can be acquired by a computer without a human listener, telephone or in-person conversations could be monitored for indications of illegal activities without applying a high concentration of manpower and without interfering with the basic rights of privacy of citizens.

3.3 Spoken Language Translation

Spoken language translation technology accepts speech input in one human language and generates its computer-spoken translation in another human language.

Originally developed as a military interrogation screening aid for two-way translation between novice interrogators and non-English speaking informants, spoken language translation technology is of great interest to police departments for communication with non-English speaking members of their communities. Spoken language translation capabilities could reduce the complexity and inefficiency of collecting information at crime scenes, more quickly provide critical time-sensitive information, and make interrogation of crime suspects less difficult and costly.

QUICK REACTION SPOKEN LANGUAGE TRANSLATOR (QRSLT)

Rome Laboratory is serving as the technical program manager for a Defense Advanced Research Projects Agency (DARPA) Technology Reinvestment Project (TRP) effort titled, "Quick Reaction Spoken Language Translator (QRSLT)." Over the course of the two-year effort, a product prototype of a hand-held or body-mounted spoken language translator will be developed to assist military and law enforcement personnel in interacting with non-English speakers. The QRSLT will be an innovative advance over currently available "speaking translators" which produce speech based on typed inputs, cannot accept spoken input, and are not customized for military or law enforcement operations.

3.4 Co-Channel Speaker Separation

Co-channel speaker interference occurs when the voice of one speaker is superimposed over another speaker's voice on the same communications channel. The presence of co-channel interference in communications results in decreased intelligibility of both speakers. Rome Laboratory co-channel speaker separation technology attempts to recover the voices of all of the speakers in overlapping communications.

While humans can partially compensate for co-channel interference, the performance of automatic speech processing systems, such as speech recognizers and speaker recognition systems, deteriorates drastically in the presence of such interference.

Co-channel speaker separation capabilities will be imperative for identifying suspects in law enforcement surveillance operations.

3.5 Audio Manipulation

Audio manipulation capabilities assist users in 'manipulating' communications in order to improve their understanding and effective utilization of large volumes of speech communications . Users can simultaneously record on-going communications and playback previously recorded speech, time-tag portions of recorded communications for easier replay later, jump forward in recorded communications, jump back, and loop on segments of audio. Users can also vary the speed of the audio playback without altering its pitch and 'edit out' silence. These capabilities allow a user to listen to speech passages more than once to assure complete understanding, while enabling him or her to keep up with on-going, live communications.

Audio manipulation technology will improve law enforcement surveillance capabilities.

4. Summary

Since the mid-sixties, local, state, and national law enforcement agencies have sought the technical assistance of Rome Laboratory's speech processing group. This paper has described some of the activities that have applied laboratory speech and audio technology to law enforcement requirements. The recent designation of Rome Laboratory as a technical center of excellence for the National Institute of Justice will greatly assist in the transition of laboratory technology for law enforcement use.

New avenues for getting state-of-the-art, dual-use technology into civilian applications, particularly for medical and law enforcement uses, continue to become available. Rome Laboratory and members of its speech processing group continue to cultivate those further opportunities.

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TUNNEL DETECTION AND SITE CHARACTERIZATION

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ABSTRACT

To date, three tunnels have been discovered under the U.S./Mexico border; more are thought to exist. The U.S. Army Engineer Waterways Experiment Station (WES) assumed the Army's tunnel detection mission in September 1993 from the Belvoir Research, Development and Engineering Center after their dissolution by Congressional Act. After mission assumption with the Counter-Drug Research, Development and Acquisition (CD-RDA) office at AMC Headquarters, WES formed a tunnel detection team of engineers and scientists.

Numerous geophysical techniques and instruments have been evaluated at the Otay Mesa, CA and Douglas, AZ drug tunnel sites over a two-year time frame. (The Otay Mesa tunnel is currently under lease to WES as a laboratory proving ground.) Among those methods showing promise after considering necessary tradeoffs, is an electromagnetic induction instrument. After recent evaluation of an existing EM system, it is now believed to be theoretically possible to optimize such an instrument for tunnel searches in many border environments. The Department of Defense (DoD) funded the development of the new EM system during FY96-97. This paper discusses the development of that system and a generalized tunnel search strategy.

1. Introduction

1.1. Background

The U.S. Army Engineer Waterways Experiment Station (WES) assumed the Army's tunnel detection mission from the Belvoir Research Development and Engineering Center (BRDEC) at the beginning of FY 94. During the transition period, which ended on 31 December 1993, BRDEC completed an ongoing evaluation of some twenty plus geophysical techniques and associated hardware at the site of the Otay Mesa, CA drug tunnel. Those methods that successfully detected and located the tunnel included seismic (viz., high-resolution 3-D and crosshole), electrical resistivity, and surface and borehole electromagnetic (EM). It should be noted that ground-probing radar, which is also electromagnetic, was totally unsuccessful at detecting the Otay Mesa tunnel.

In January 1994, WES hosted a site characterization / tunnel detection workshop. Approximately thirty people attended the workshop; more than one third were law enforcement agents (LEA). Corcoran and Grau [1] compiled proceedings documenting presentations and open discussion. One of the primary accomplishments of the workshop was a realistic definition of border conditions which dictate operational procedures to be used by scientists performing investigative missions, i.e., full coordination must be maintained between LEAs and scientists and emphasis placed upon those techniques covert in nature. The LEA community suggested that future developments of hardware and methodology prioritize low visibility non-contact techniques that operate from the ground surface. This suggestion was not intended to ignore surface contact or borehole methods because in some instances they may be the technique of choice. However, emphasis and priorities should concentrate on development of rapid, covert tools that can be used in a low profile manner. In view of the results of geophysical technique evaluations at the Otay Mesa, CA drug tunnel test site, the electromagnetic technique was targeted for tunnel search optimization.

After preparation of specifications, Geophex, Ltd. of Raleigh, NC was awarded a contract in the fall of 1996 for development of a variable frequency EM induction system. Evaluation was scheduled for the summer of 1997 at the WES Otay Mesa, drug-tunnel test bed.

Funding has been provided for development of the EM system by the Department of Defense through the Counterdrug Technology Development Program Office located at the Naval Surface Warfare Center in Dahlgren, VA. The project is scheduled for completion during FY 98.

1.2. Objective

The objective of this study was to develop a realtime readout, one-man portable, variable frequency EM induction system capable of covertly detecting and locating clandestine tunnels under the U.S. / Mexico border. Secondly, the device was intended to be an optimized general purpose tool combining attributes of a wide variety of innovative and traditional EM hardware tested at the Otay Mesa test bed. When completed, the sensor should also be capable of vehicular mounting.

1.3. Scope

This program includes the development of a variable frequency EM induction system, testing under real world conditions, and documentation of its advantages and limitations.

2. Equipment Specifications

2.1. Considerations

As previously stated, LEAs input received strong consideration when the decision was made to pursue development of a tunnel-search geophysical tool. The primary criteria were:

- Effective to a search depth of at least 50 ft
- Non-contact, one-man portable (light weight)
- Rapid data acquisition; on-site interpretation
- Semi-covert operation
- Vehicular mounting capability
- High sampling rate
- Highly repeatable (for historical baselines)
- Reliable/durable under extreme field conditions

In today's R&D atmosphere, emphasis is strongly placed on short-term product development with research restricted to absolute necessity. After reviewing EM tools evaluated at the Otay Mesa test bed and commercially available products, it was thought feasible to build upon past experience to optimize a non-contact, variable frequency device — one which would meet sponsor expectations and LEA concerns. The EM system selected for optimization was the Geophex GEM-2.

2.2. GEM-2 Description

The GEM-2 is a hand-held, digital, multi-frequency electromagnetic sensor operating over a frequency band of 90 Hz to 23 kHz (Figure 1: Won et al., [3]). The unit is capable of transmitting and receiving any digitally synthesized waveform by means of the pulse-width modulation technique.

Figure 1. GEM-2 sensor being demonstrated.

The sensor, weighing about nine pounds, has built-in operating software that allows a surveyor to cover about one acre per hour at a line spacing of five feet. Along a survey line, the data rate is about one per foot, resulting in about 10,000 data points per acre per hour. Such portability, survey speed, and high data density are important requirements for economical geophysical surveys.

The GEM-2 sensor contains a transmitter coil and a receiver coil separated by about 5.5 feet. It also contains a third "bucking coil" that removes (or bucks) the primary field from the receiver coil. All three coils are molded into a single board, dubbed the ski, in a fixed geometry, rendering a light, compact, and portable package. The processing console is attached to the ski and is easily removed for battery charging and shipping.

The advantages of broadband, multifrequency, EM sensing are obvious. The idea of using multiple frequencies relates to the depth of exploration, which is inversely proportional to frequency. In other words, a low-frequency signal travels far through a conductive earth and, thus, sees deep structures, while a high-frequency signal only travels a short distance and thus, sees only shallow structures. Therefore, scanning through a frequency window is equivalent to depth sounding. Figure 2 shows a nomogram from which one may determine the penetration depth for a given frequency (Won [2]). For example, the theoretical skin depth for a ground conductivity of 0.1 S/m is approximately 10 to 200 m over the GEM-2 operating bandwidth.

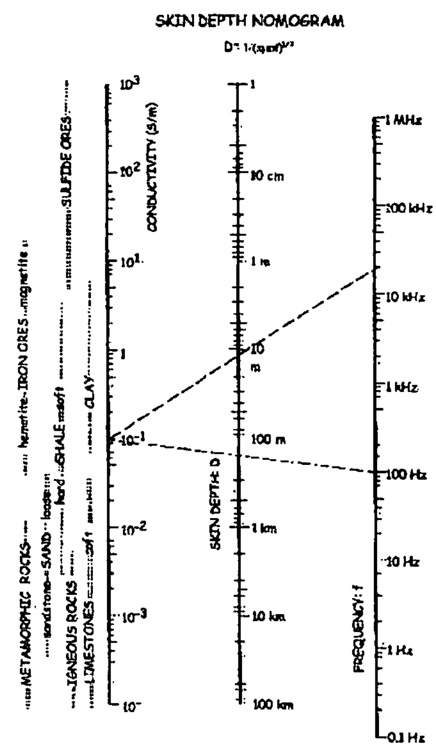

Figure 2. Skin depth nomogram. To find the skin depth, connect the ground conductivity (in siemen/m) on the left to the source frequency on the right (Won [2]).

GEM-2 has two recording channels: one from the bucking coil (called the reference channel) and the other from the bucked receiver coil (called the signal channel). Both channels are digitized at a rate of 36,450 Hz (half the transmitter rate) and at 16-bit resolution. To extract the in-phase and quadrature components, the measured time-series is convolved with a set of sine series (for in-phase) and cosine series (for quadrature) for each transmitted frequency. This convolution renders an extremely narrow-band, match-filter-type, signal detection technique. A single computer in a DSP chip coordinates all controls and computations for the transmitter and receiver channels.

The in-phase and quadrature data derived through the convolution are converted into a part-per-million, or ppm, unit defined as ratio of the secondary magnetic field divided by the primary magnetic field as observed at the receive coil.

The color-contoured ppm data, which represent the raw data logged by the GEM-2 sensor, are often sufficient to locate buried objects without elaborate processing. The target depth can often be estimated from these raw, multifrequency data. It is possible, however, to convert the data into "apparent conductivity" by assuming that the earth below the sensor is represented by a homogeneous and isotropic half-space (Won et al., [3]).

2.3. GEM-2 Data Example

Figure 3 is an example of a highly conductive linear underground anomaly. In this case, an 18-in.- diameter

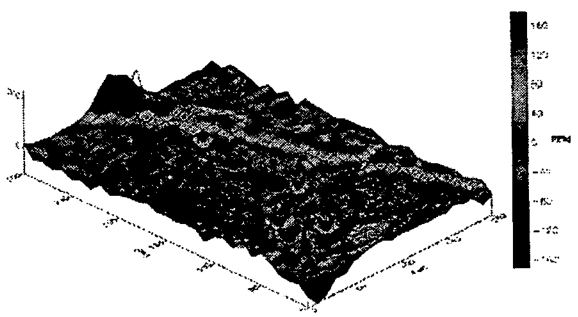

Figure 3. GEM-2 7,290 Hz in-phase data over an 18-in.-diameter stainless steel pipe buried at 30 ft below surface.

stainless steel pipe buried 30 ft below ground surface becomes a prominent target (Won et al., [3]). Similar response would be expected from a reinforced concrete-lined tunnel .

2.4. GEM-2H Description

The GEM-2H was designed to be an evolutionary advancement of the GEM-2, not a completely new, untested sensor. A comparison between the coil designs of the two sensors is shown in Figure 4. The desired modifications included a higher transmitting dipole moment for increased depth of penetration, a realtime LCD graphical display, the ability to sequentially step through a desired frequency band (one frequency at a time), and the option to operate in a passive mode (i.e., with the transmitter turned off).

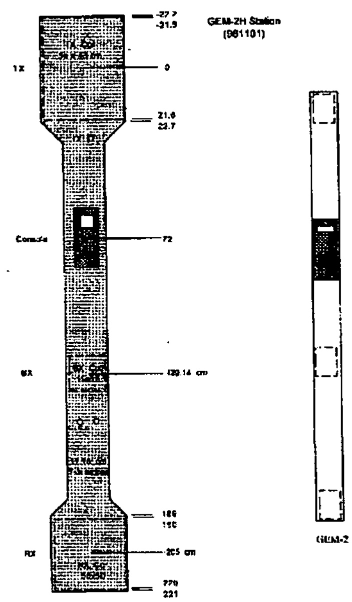

Figure 4. Physical layout for the GEM-2 and GEM-2H sensors.

One of the major goals for the GEM-2H is to achieve a transmitter dipole moment of 12 ampere·m^2 or higher. Increasing the transmitter moment, or the receiver moment, results in an increase in the signal-to-noise (SNR).

Figure 5 shows the computed currents and dipole moments for the GEM-2H sensor. The GEM-2H has the capability to employ a 12- or 24-turn transmitter coil configuration. The computed characteristics for both transmitter configurations are shown below. The maximum current through the transmitter circuitry is 5.5 ampere — thus limiting the maximum dipole moment as shown in Figure 5. For a single frequency operation, the GEM-2H will reach the maximum design current at about 2 kHz, with a corresponding moment of about 12 ampere·m^2 for the 12-turn configuration. For the 24-turn configuration, however, the single-frequency operation is possible down to about 470 Hz with a corresponding dipole moment of about 20 ampere·m^2.

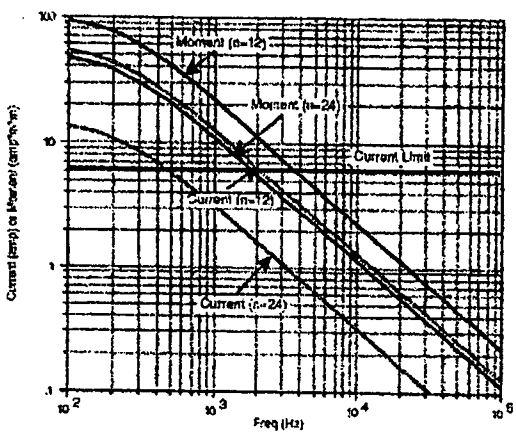

Figure 5. Computed current and dipole moments for GEM-2H sensor.

To maximize the SNR, the receiver area-turn product was increased approximately 3.5 times that of the GEM-2 sensor. These modifications result in a SNR increase of a 28 decibels (dB) over the GEM-2.

The GEM-2H was designed during the fall of 1996 and fabricated during the spring of 1997. Improvements to the GEM-2 electronics package include a 48-kHz analog-to-digital (A/D) converter and a LCD display. The faster A/D converter results in an operating bandwidth of 30 Hz to 24 kHz. An additional improvement to the electronic package includes a faster clock crystal that results in a 10-Hz sampling rate. The LCD display allows realtime analysis of the measured EM data.

The GEM-2H console is designed for easy field use (Figure 6). For example, all acquisition operations are controlled in the field by three pushbuttons - there are no cumbersome knobs. Additionally, a single plug is used for charging the internal nickel-cadmium battery pack and communications to a field computer. All connectors are keyed so that the ski, download cable, and electronics case cannot be assembled using the wrong polarity.

Figure 6. GEM-2H console.

The ski is constructed using kevlar-skinned foam core sheets. The housing material was chosen to be extremely strong, lightweight, and have a low thermal coefficient of expansion. The three-coil system is placed within the housing board at precisely calculated locations. Figure 7 shows a photograph of the GEM-2H during fabrication processes.

The prototype GEM-2H sensor is shown in Figure 8. During operation, it continuously acquires data as it is carried across the site at normal walking speeds. Alternately, it can send the measured data to an external

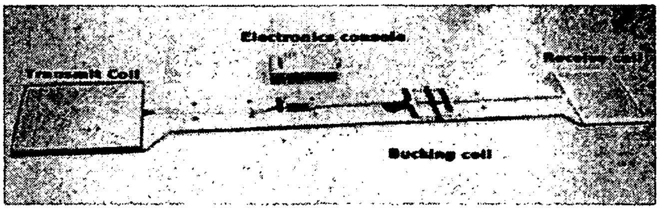

Figure 7. Photograph of the GEM-2H ski during construction. The ski is eight feet long. The gold console contains the drive circuitry and signal-conditioning electronics.

logger via an RS-232 data link (this allows the capability to become vehicular mounted and integrated into a GPS-based survey system). Under normal field conditions, the 10-Hz sampling rate results in a sample every foot along the survey line. A prototype GEM-2H tool will be fully tested at sites along the southwest border in the near future.

Figure 8. Prototype GEM-2H electromagnetic sensor during a demonstration survey.

3. Tunnel Search Strategy

The search for clandestine tunnels follows common sense reasoning. In practically every case, the suspected presence of a tunnel or tunneling activity originates from human intelligence information. In most instances, an exact location cannot be pinpointed. Rather, a general location becomes a target area. Law enforcement officials take great pains to protect sources of information. Ideally, considering that a LEA has been informed about tunneling, they approach Joint Task Force Six (JTF-6) to request assistance in detecting and locating the suspect tunnel. Military personnel assigned to JTF-6, working in conjunction with Project Alliance, contact WES (the army's tunnel detection proponent) for response to a tunnel detection mission. At this point, a detailed geologic reconnaissance is performed. Site specific information such as material type, depth to water table, underground and surface utility maps, site hazards, and geophysical parameters (conductive, etc) are obtained. Data are inserted into an existing Geographic Information System that catalogues southwest border site characteristics. A geophysical team is then briefed on site conditions and appropriate equipment is chosen for a site survey. Methodology is discussed and approved by the LEA. The survey is then performed and data are subjected to preliminary on-site analysis. First-look interpretations are discussed with LEAs and a final in-depth analysis is completed in the office culminating in a written report prepared for both JTF-6 and the LEA. At this point, WES is essentially out of the picture. The LEA has sought and received scientific corroborative evidence to support other evidence for presentation to the proper authorities for an action decision. That decision is his. The scenario discussed above is summarized in Figure 9.

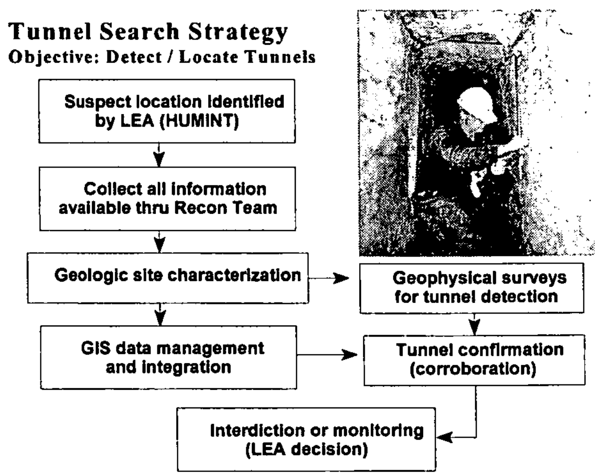

Figure 9. Tunnel detection search strategy flow chart.

4. Conclusions

The GEM-2H EM sensor has been successfully designed and prototyped. The two prototype sensors are performing to design specifications and possess a number of improvements over the previous GEM-2s. These improvements include a 28 dB increase in sensitivity, the capability to sequentially step through a frequency band (90 Hz to 23 kHz) one frequency at a time, the capability to operate in passive mode (viz., with the transmitter turned off), and a realtime graphical display. The battery-powered GEM-2H sensors are field efficient, easy to operate, and require minimal maintenance.

The prototype sensors are currently undergoing field-testing and evaluation. Although minor improvements are inevitable, the current sensors appear to be performing as designed.

Upon first stage evaluation, the GEM-2H appears to meet the LEAs primary objectives:

- Effective to a search depth of at least 50 ft (for realistic ground conductivities)
- Non-contact, one-man portable (light weight)
- Allows rapid data acquisition and near-realtime on-site interpretation
- Semi-covert operation
- Vehicular mounting capability
- High sampling rate
- Highly repeatable (for historical baselines)
- Reliable/durable under extreme field conditions.

5. Acknowledgments

The investigations described herein were funded by the DoD Counterdrug Technology Development Program Office (CTDPO), John J. Penella, Counterdrug Program Executive. Field work was performed by Joseph Dunbar and Maureen Corcoran, Engineering Geology Branch, Earthquake Engineering and Geosciences Division, Geotechnical Laboratory, WES. Tina Grau edited and prepared the layout of this manuscript. Permission was granted by the CTDPO and the Chief of Engineers to publish this information.

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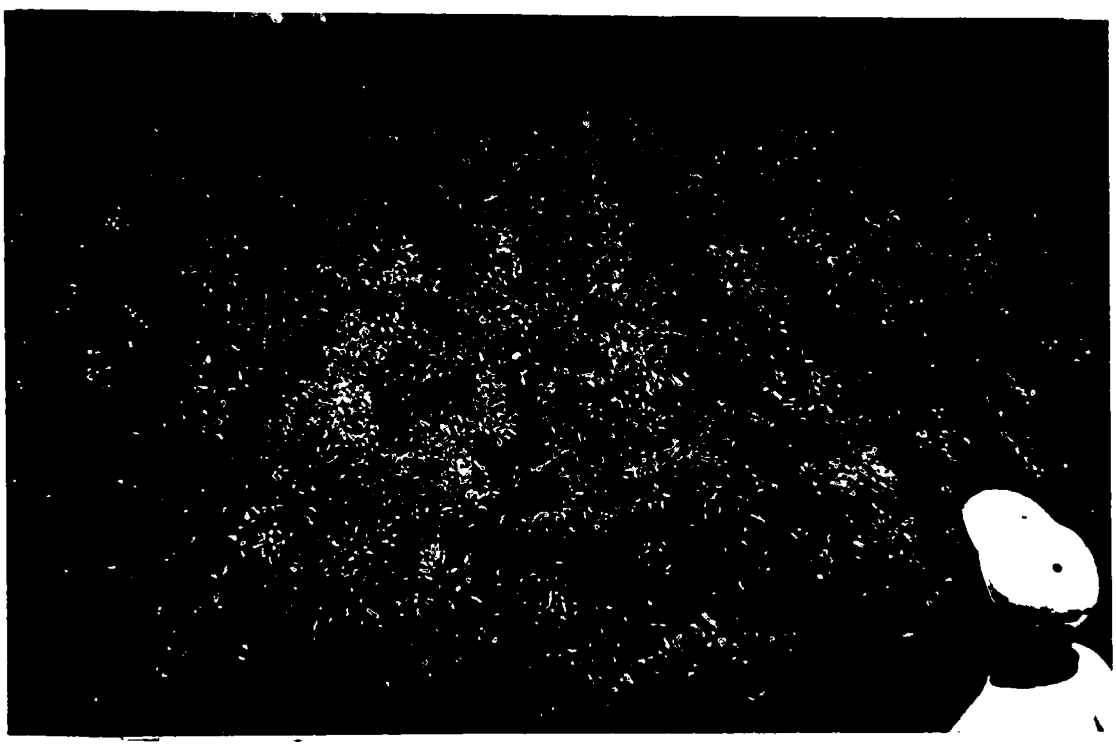
U.S. Department of Justice
Drug Enforcement Administration

Operation BREAKTHROUGH:

Coca Cultivation & Cocaine Base Production in Peru

Drug Intelligence Report

Intelligence Division



June 1997
DEA-97010

Cover Photograph: A well-maintained coca field in Tocache, Peru.

The Attorney General has determined that publication of this periodical is necessary in the transaction of the public business required by law of the Department of Justice.

Drug Enforcement Administration

Operation BREAKTHROUGH:

Coca Cultivation & Cocaine Base Production in Peru

Drug Intelligence Report

This report was prepared by the Latin America Unit of the Strategic Intelligence Section. Comments and requests for copies are welcome and may be directed to the Intelligence Production Unit, Intelligence Division, DEA Headquarters at (202) 307-8726.

June 1997

ADMINISTRATOR'S MESSAGE

The Operation BREAKTHROUGH study in Peru represents a continuation of the comprehensive Andean Ridge coca cultivation and cocaine base processing research project that began in Bolivia in 1993. The objective of this program, funded by the Office of National Drug Control Policy Counterdrug Technology Assessment Center, is to quantify cocaine production.

This report, *Operation BREAKTHROUGH: Coca Cultivation & Cocaine Base Production in Peru,* depicts the results of the effort to provide a reliable estimate of Peru's cocaine production. The key findings of the study are:

- the estimated average annual coca leaf yield for Peru is 1.83 metric tons per hectare;

- the average cocaine alkaloid content of the coca leaf is 0.71 percent for the Upper and Lower Huallaga and Ucayali Valleys. The average cocaine alkaloid content for the coca leaf grown in the Cuzco region is 0.75 percent;

- the efficiency rate (i.e., the efficiency with which the cocaine alkaloid is extracted from the coca leaf to produce cocaine base) is 44 percent.

These findings are supported by an unprecedented and comprehensive record of research and analysis in the field of coca cultivation and coca production. BREAKTHROUGH's research on production in Peru, coupled with the earlier Bolivia study, provides the most precise estimate of production levels for the Andean Ridge countries to date.

Upon completion of Operation BREAKTHROUGH in Colombia in 1996-1997, data will be available to U.S. policymakers that will enable greater precision in estimating total cocaine production. Subsequently, the evaluation of the domestic cocaine threat, the effectiveness of interdiction and counterdrug operations, and other issues fundamental to the formulation of national drug policy can be made with greater confidence.

Thomas A. Constantine
Administrator

CONTENTS

EXECUTIVE SUMMARY

For 1995, Operation BREAKTHROUGH estimates annual cocaine base production for Peru at 447 metric tons. This compares to official U.S. Government cocaine production estimates of 460 metric tons for Peru. This estimate of cocaine base production differs from the official U.S. Government estimate of Peru's maximum potential cocaine production. A maximum potential estimate, by design, assumes all mature coca cultivation in Peru—including licit Cuzco coca—is processed into cocaine. This study suggests a more concise estimation is possible. By clearly defining the critical elements of cocaine production, it offers a means for generating an estimate of Peru's actual, as opposed to potential, cocaine production. Operation BREAKTHROUGH's cocaine production model—incorporating actual assessments of the amount of coca leaf that is devoted to illicit cocaine production in each of Peru's coca growing regions—supports an estimate that best reflects Peru's cocaine production.

In addition to presenting the findings and conclusions, this report describes the research methodology used by the Peruvian agronomists and the DEA research team as they surveyed the coca fields, farmers, workers, and processors. For comparison purposes, this report incorporates findings from the 1993 BREAKTHROUGH study in Bolivia as illustrated below.

- **The estimated average annual coca leaf yield for Peru is 1.83 metric tons per hectare.**

  The estimated average annual coca leaf yield for Bolivia's Chapare region is 2.7 metric tons per hectare and for the Yungas region, 1.8 metric tons per hectare.

- **The average cocaine alkaloid content of the coca leaf is 0.71 percent for the Upper and Lower Huallaga and the Ucayali Valleys. The average cocaine alkaloid content of Cuzco leaf is 0.75 percent.**

  The average cocaine alkaloid content of the coca leaf in the Chapare region is 0.72 percent and for the Yungas region, 0.84 percent.

- **The extraction efficiency of the cocaine alkaloid in Peru was found to be 44 percent. Using this efficiency rate, approximately 400 kilograms (880 pounds) of coca leaf are required to produce 1 kilogram of 100 percent pure cocaine base.**

  The extraction efficiency of the cocaine alkaloid in Bolivia was found to be 45 percent. Roughly, 390 kilograms (860 pounds) of air-dried Bolivian coca leaf are necessary to produce 1 kilogram of pure cocaine base.

INTRODUCTION

BACKGROUND

Andean stone figure of a man

Coca has been grown in Peru for thousands of years and chronicled since the time of the Incan civilizations. Prior to the phenomenal increase in demand for coca, created in the 20th century by the illicit drug trade, coca was used as a medicinal and traditional herb. Beginning in the late 1970's, cultivation of the coca crop increased dramatically in Peru and Bolivia. The Huallaga Valley in Peru became the world's largest producer of coca leaf, the raw ingredient for cocaine. Tens of thousands of hectares (1 hectare is equivalent to 2.4 acres) of coca plants were cultivated in the Huallaga Valley region.

Coca cultivation is illegal in all areas of Peru with the exception of Cuzco, where legitimate coca leaf markets exist. A Peruvian Government regulatory authority, ENACO, controls all coca leaf sales in Cuzco.

More recently, coca cultivation has expanded significantly into other areas of Peru, namely the Ucayali and Apurimac Valleys. This expansion is due, in part, to large-scale disease and fungus affecting coca plants throughout the Huallaga Valley. Terrorist insurgency, which has created apprehension and fear in the region's coca growers, also has fueled the transition of coca cultivation into other areas of Peru.

OPERATION BREAKTHROUGH

Operation BREAKTHROUGH is a comprehensive coca cultivation and cocaine base processing research project, funded and undertaken on behalf of the Office of National Drug Control Policy Counterdrug Technology Assessment Center. The purpose of Operation BREAKTHROUGH is to establish precise estimates of Andean Ridge coca crop yields, coca leaf alkaloid contents, and the efficiencies of illicit laboratories in processing coca leaf to cocaine base and, in Colombia, cocaine base to cocaine hydrochloride (HCl). The goal of the project is to provide sufficiently detailed information, through the application of scientific field survey methodologies and laboratory analyses, to determine accurately the cocaine production threat for U.S. domestic and foreign policy decision makers.

The critical elements for producing an estimate of cocaine production (figure 1) are as follows:

- the number of hectares under coca cultivation;
- the percent of cultivation used for illicit purposes;
- the coca leaf yield per hectare;
- the cocaine alkaloid content within the leaf;
- the efficiency with which the cocaine alkaloid in the leaf is converted into cocaine base; and
- the efficiency with which cocaine base is converted into cocaine HCl.

Figure 1

Total Mature Coca Cultivation ▸ % Coca Cultivation for Illicit Use ▸ Coca Leaf Yield ▸ Coca Leaf Alkaloid Content ▸ Base Lab Efficiency ▸ Base to HCl Lab Efficiency = **Cocaine Production**

COCAINE PRODUCTION FLOW

The first and last elements of the cocaine production flow, coca cultivation and cocaine base to cocaine hydrochloride (HCl) processing efficiency, have not been addressed by Operation BREAKTHROUGH. The current methods used to measure the total number of hectares dedicated to coca cultivation are accepted by the U.S. Government and the counterdrug community. The chemistry of converting cocaine base to cocaine HCl is accepted as a 1:1 conversion. This aspect of illicit laboratory efficiency will be analyzed in detail in the third phase of the study in Colombia, allowing for an even more precise cocaine HCl production estimate.

Although the percentage of cultivation used for illicit purposes is difficult to estimate, U.S. Embassy personnel, who are thoroughly knowledgeable about coca cultivation in the areas where they are assigned, provided an estimate based on their experience. The goal of the operation was formulated to document scientifically three critical elements—coca leaf yields, coca leaf cocaine alkaloid content, and cocaine base processing efficiencies—necessary to model cocaine production. Prior to this initiative, these three elements were not defined clearly.

Operation BREAKTHROUGH completed studies in Bolivia ascertaining coca leaf yields, cocaine alkaloid contents, and illicit laboratory efficiency in processing coca leaf to cocaine base in 1993. The results are documented in DEA publication, *Operation BREAKTHROUGH: Coca Cultivation & Cocaine Base Production in Bolivia*, July 1994.

Using the valuable information derived from this research in Bolivia, research was expanded to Peru in 1994. During the second phase of Operation BREAKTHROUGH, coca leaf yields were measured in 10 major growing areas located in the three principal coca-growing regions: the Huallaga, the Ucayali, and the Apurimac Valleys over the course of 1 year. These areas were selected by U.S. experts and Peruvian agronomists familiar with coca cultivation. Coca leaf samples were collected in these 10 growing areas during each harvest and sent to DEA's Special Testing and Research Laboratory for analysis. Additionally, the efficiencies of cocaine base processing laboratories in the Huallaga Valley were measured through observation and sample collection during illicit laboratory processing of coca leaf to cocaine base.

The Operation BREAKTHROUGH study in Peru in 1994-1995 has allowed researchers an in-depth look at the spread of coca cultivation from the Huallaga Valley to the other growing areas in Peru, and the increased yield that has resulted from the new areas of cultivation.

COCA LEAF YIELD

The Operation BREAKTHROUGH coca leaf yield results have allowed the U.S. Government to revise the official estimates that were compiled from research studies conducted in the 1980's. As a result of this current study, the average annual coca leaf yield for Peru has been estimated at 1.83 metric tons per hectare.

Research Methodology
In Peru, 10 distinct coca-growing regions were identified and then studied to satisfy the Operation BREAKTHROUGH objectives. These 10 growing areas were identified through collaboration with Peruvian agronomists and coca cultivation experts from the U.S. Embassy in Lima. The areas, denominated as transects, are identified in figure 2.

The Operation BREAKTHROUGH team utilized a cooperative agreement titled *Agronomy Science Applied to the Studies of Narcotics and Other Associated Species of Plants* between the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), and the University of the Selva in Tingo Maria. The team made leaf yield measurements on a total of 77 farms, distributed among the 10 growing regions, with a minimum of 5 fields selected in each of the 10 growing areas (figure 3). Leaf yield measurements were made in all of the 77 fields over the course of 1 year during each of the 3 to 5 harvests.

The team selected coca fields according to the following three criteria:

- the field must be typical of the transect, i.e., disease, weeds, height, plant density, and lack of homogeneity;
- the field must have mature, approximately 90-day-old, coca leaf with the exception of Tingo Maria where 75-day-old leaf typically is harvested;
- the farmer must authorize the team to work in the field.

The five principal fields in each growing region were selected as follows:

- one field was to be a high-yielding field for the transect;
- one field was to be a low-yielding field for the transect; and
- three fields were to be average-yielding for the transect.

The team determined high, low, and average yield by comparing the yields of the neighboring coca fields in the transect based on interviews with the farmers.

Figure 2
Operation BREAKTHROUGH's 10 Growing Areas

Transect Number	Region	Valley
1	Tarapoto	Huallaga
2	Picota	Huallaga
3	Saposoa	Huallaga
4	Juanjui	Huallaga
5	Tocache	Huallaga
6	Pachitea	Ucayali
7	Aguaytia	Ucayali
8	Tingo Maria	Huallaga
9	Cuzco	Apurimac
10	Ayacucho	Apurimac

Figure 3

Coca growing regions in Peru

Figure 4

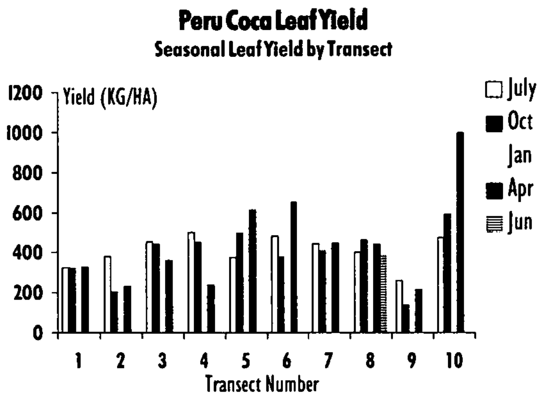


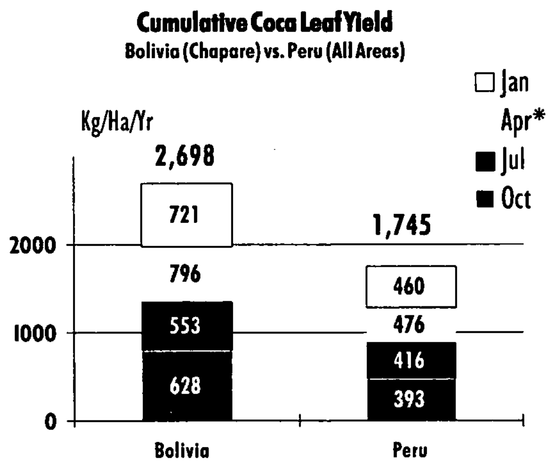
Figure 5

Peru Coca Leaf Yield
Annual Leaf Yield by Transect

Transect	Region	Official Yield (MT/HA/YR)*	Operation BREAKTHROUGH (MT/HA/YR)*
1	Tarapoto	1.14	1.44
2	Picota	1.14	1.11
3	Saposoa	2.3	1.67
4	Juanjui	2.3	1.51
5	Tocache	2.3	2.02
6	Pachitea	2.3	2.10
7	Aguaytia	2.3	1.72
8	Tingo Maria	2.3	2.15
9	Cuzco	1.14	0.91
10	Ayacucho	1.14	2.78
	Other	1.14	1.15
TOTAL AVG.**		1.80	1.83

*- Metric tons/hectare/year (air-dried weight).
**- Based on total cultivation (weighted average).

Figure 6



*April harvest in Peru includes 5th harvest in Tingo Maria

For each of the 10 coca growing areas, the University of the Selva selected field agronomists to conduct field measurements in the selected fields. Each field agronomist was responsible for all the measurements within his growing region. Physical measurements consisted of plant height, plant canopy diameter, stem diameter, plant row spacing, and leaf weight.

Additionally, soil samples were collected from the field for nutrient analysis. The samples were sent to the United States for analysis by the Spectrum Analytic Corporation's Agronomic Services Laboratory, Washington Court House, Ohio. (For results see page 8.)

In order to obtain an accurate leaf-yield measurement per area, the field agronomists measured a 50-meter by 30-meter area within the field (1500 m^2 area), and weighed all of the coca leaf from this measured area. Digital reading balances (Mettler Model #SB16000) were provided to accomplish this task. The balances are accurate to the nearest gram.

In some fields, the measured field area was smaller due to the layout of the field. The exact field measurements were reported by the field agronomist who was responsible for performing the field measurements. Smaller fields were either 30 meters by 30 meters or 30 meters by 40 meters.

In the surveyed fields, coca was to be of the same vintage planting; the coca plants were to be the same age; and the coca rows were to be oriented in the same direction. In the case of plants of different ages, plants that had been pruned, or plants that were at two different elevations in the same field, the coca field was divided into two separate populations and considered as two separate fields.

Survey Findings

Figure 4 shows the results of the leaf yield survey, and these are reported on an air-dried weight basis, which includes 16.4 percent water, for each of the harvests. In this report, all leaf yields are reported on an air-dried weight basis unless noted otherwise. In figure 5, the leaf yields estimated by Operation BREAKTHROUGH in Peru are compared with the U.S. Government estimated yields by the selected transects.

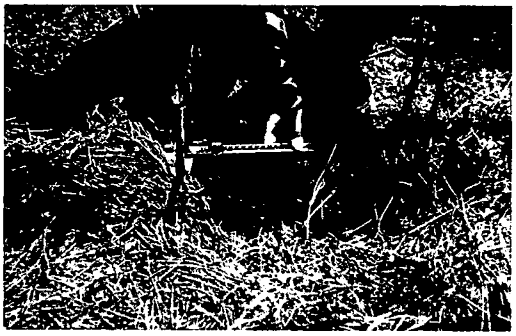
In figure 6, the Operation BREAKTHROUGH-measured leaf yields in Peru are compared to those found in the Bolivian research. The leaf yields are compared by growing seasons.

The average air-dried coca leaf yield for the 77 fields examined in Peru was 1.75 metric tons per hectare per year. The weighted average in Peru, based on total cultivation percentages, indicates an air-dried average coca leaf yield of 1.83 metric tons per hectare per year. This compares to an air-dried annual yield of 2.70 metric tons per hectare per year for the fields surveyed in Bolivia.

The leaf yield was found to vary by season in Peru as in Bolivia during each of the harvests. The seasonal effect of coca leaf yield emphasizes the importance of collection efforts during each growing season to obtain a reliable annual yield.

In addition to the leaf weight measurements, plant measurements were made within each of the fields. Ten areas, identified as plots, were selected in each of the fields by charting a diagonal spread across the field, and measuring out a 5-meter length in the selected row. USDA devised a research methodology prior to viewing the field that ensured random sampling. The coca plants in each of these 5-meter areas were counted and measured for height, canopy width, and stem diameter. During the measurement of the coca plants, the dead and living plants were counted. Also, the in-row spacing of the plants and the distances between planting rows were measured.

Coca plant height measurement



Coca plant stem diameter measurement

Figure 7

Peru Coca Field Description

	Cuzco	Ayacucho	**Tingo Maria
Number of Harvests	3-4	4-5	4-6
Plant Age (Years)	34	7.8	10.3
Living Plants (%)*	71/67	76/77	99/78
Plant Density (Plants/m^2)	2.3	8.8	5.3
Row Spacing (m)	0.9	0.54	1.15
In-Row Spacing (cm)	49	26	18
Plant Height (m)*	0.95/0.98	1.1/1.0	1.2/1.2
Canopy Diameter (m)*	60/67	46/52	70/69
Stem Diameter (mm)*	30.9/30.2	16.8/15.4	15.8/16.7

*Two Evaluations Performed (7/94 and 1/95)
** Tingo Maria considered separate from Huallaga due to unique planting

Figure 8

Peru Coca Field Description

	Huallaga Valley	Pachitea/Aguaytia
Number of Harvests	4	4
Plant Age (Years)	4.6	2.9
Living Plants (%)*	91 / 76	96 / 82
Plant Density (Plants/m^2)	2.1	3.7
Row Spacing (m)	0.95	0.98
In-Row Spacing (cm)	67	34
Plant Height (m)*	1.2/1.2	1.3/1.4
Canopy Diameter (m)*	66/72	82/89
Stem Diameter (mm)*	22.7/23.9	16.4/17.9

*Two Evaluations Performed (7/94 and 1/95)

Figure 9

Bolivia Coca Field Description

	Chapare	Yungas
Number of Harvests	4	3-4
Plant Age (Years)	8.4	6.4
Living Plants (%)	97	99
Plant Density (Plants/m^2)	2.7	16.6
Row Spacing (m)	0.9	0.9
In-Row Spacing (cm)	48	8
Plant Height	1.4	0.7
Canopy Diameter (m)	0.8	0.3
Stem Diameter (mm)	29	10

Researchers measured the plants at the beginning of the survey during the first harvest (July 1994) and approximately 6 months later during the third harvest (January 1995). The same 5-meter plots in the field were analyzed providing information on coca plant growth rates and coca plant mortality. The complete results are given in figures 7 and 8 and can be compared with the results obtained in Bolivia in figure 9. Researchers used the same methodology to measure 5-meter plots in both Peru and Bolivia.

The planting density in Peru was similar to the planting density of the Chapare region of Bolivia—roughly 2 to 3 plants per square meter (plants/m^2)—in most growing areas. The planting densities in Tingo Maria (5.3 plants/m^2) and Ayacucho (8.8 plants/m^2) were substantially higher, although they were not as high as in the Yungas region of Bolivia (16.6 plants/m^2). The higher planting densities in Peru were linked directly to higher coca leaf yields. Other factors such as fertilization or field management practices also may contribute to the higher yields in these fields.

Coca plant row spacing was found to be comparable to that in Bolivia with an average spacing between the rows of 95 centimeters. Ayacucho had coca rows spaced at 54 centimeters; Tingo Maria had coca rows spaced at 115 centimeters.

In some of the growing regions, fungus was widespread. This was observed in the percentage of living plants counted in the first and second evaluations conducted in July 1994 and January 1995. In coca fields in the Huallaga, Pachitea, and Aguaytia Valleys, nearly 15 percent of the plants died between the first and third harvests. This high rate of plant mortality was not observed in the Chapare region of Bolivia, and accounts for the large number of greater than 20-year-old plants customarily seen throughout the Chapare, as well as the higher average plant age (5.2 years in Peru versus 8.4 years in Bolivia).

Graphs document the physical dimensions found in the first and second evaluations to note the growing trend in the 6-month period between evaluations (figures 10-12). The results indicated an average increase of 5 centimeters in height, 5.25 centimeters in plant canopy diameter, and 1 millimeter in stem diameter. The average results are reasonable and consistent with those observed in plant growth models.

Other factors that were noted included the types of intercropping in the coca fields, the presence of burning and/or burned trees and/or burned stumps, and large areas of non-coca spacing. These factors directly influenced yield per area measurements and resulted in decreased yield numbers.

Farmers most commonly intercropped citrus trees (oranges, lemons, mandarins) and fruit trees (bananas and papayas). Coca farmers also intercropped mangos, tubers (yucca and potatoes), pineapple, cocoa, and sugar cane.

In 57 percent of the coca fields surveyed, the coca field was reported to be shaded. This was the result of the intercropping of citrus and fruit trees as well as the coca cultivation being planted in the midst of, or adjacent to, jungle areas that had not been cleared completely.

Figure 10

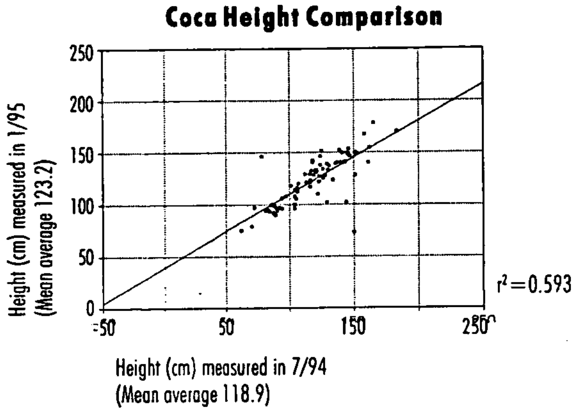


Figure 11

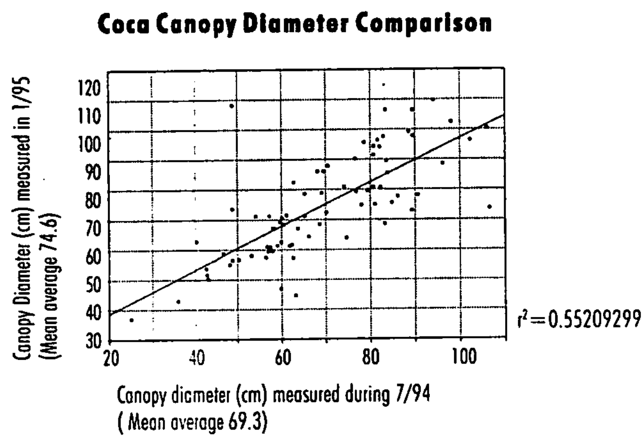
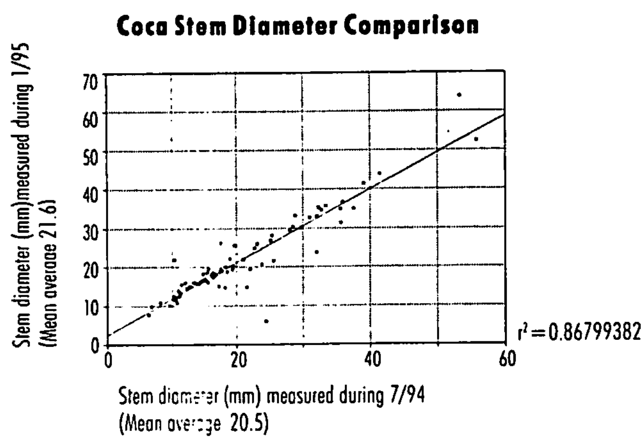


Figure 12

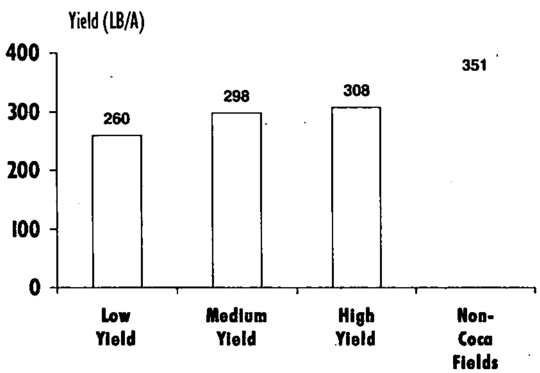


Slash-and-burn deforestation (Bolivia 1993)

Soil sample collection in coca field (Tingo Maria)

Figure 13

Peru Yield Comparison
Potassium Levels in Soil



In 28 percent of the fields, evidence of burned tree trunks and stumps were observed, indicating that slash-and-burn techniques were being used to expand coca cultivation. Operation BREAKTHROUGH researchers also observed slash-and-burn deforestation in Bolivia in 1993.

In each of the 77 surveyed fields, ten 1-pound soil samples were collected from the area adjacent to the plots where the physical measurements were taken. The samples were labeled and shipped to the United States where they were analyzed at Spectrum Analytic Corporation in Washington Court House, Ohio.

Analysis of soil samples from Peru indicated a higher average concentration of plant growth nutrients than those analyzed from Bolivia. However, in both countries the soil nutrients did not approach levels that would limit plant growth. A linear nutrient budget model was constructed for Peru like the one constructed for Bolivia. Results of the linear nutrient budget model indicated that sulfur, phosphorous, and potassium may be limiting nutrients to plant growth in the extended future (over 10 years).

As shown in figure 13, the average potassium soil nutrient levels were at reduced quantities in the lower yielding fields. The highest potassium levels were found in high-yielding fields or in control fields that were adjacent to the coca fields and used to grow other crops.

An interesting phenomenon in a coca field is that all coca leaf is harvested and removed from the field during the year—year after year—resulting in very little nutrient matter being returned to the soil from decaying biomass. This has negative implications for long-term growth of coca in the same growing area, as well as initiatives associated with crop substitution.

COCA LEAF WATER CONTENT

Research has determined that coca water weights are affected by growing conditions and geographic region. However, so far, researchers have not been able to provide a scientific explanation for these variations in water weights.

Analysis by the USDA-ARS of the water weight in coca plants grown in greenhouses showed a water content of 72 percent (Johnson 1995, 333). Two separate independent studies by the U.S. Army Topographic Engineering Center in 1991, and in 1994 by USDA-ARS at the same experimental coca field site in Hawaii, indicated a mature coca water leaf content of 70 percent upon analysis.

Operation BREAKTHROUGH researchers established the mean average water content for the South American BREAKTHROUGH studies to be 65 percent (64.5 percent in Peru and 64.7 percent in Bolivia). The same personnel who performed the Army Topographic Center and the USDA-ARS surveys conducted research in the first and second phases of Operation BREAKTHROUGH (Peru and Bolivia).

Since the same researchers were an integral part of all coca leaf water analyses performed, it appears that water content of coca leaf in different geographical locations may vary.

The value of 64.5 percent was used by Operation BREAKTHROUGH in all calculations to obtain dry weight values for Peru. Further research on leaf water weight will be conducted by USDA-ARS in Peru later in 1996, and by Operation BREAKTHROUGH in Colombia in 1996-1997.

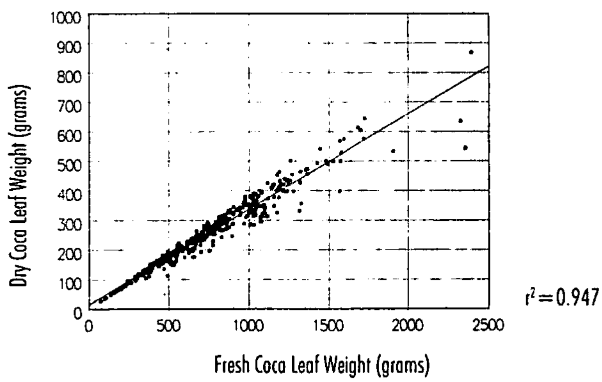
Research Methodology

In Bolivia (1993) coca leaf samples were collected for analysis to determine coca leaf water content. All coca leaf samples were dried at 70 degrees centigrade, consistent with standard agronomic practices. During Operation BREAKTHROUGH in Bolivia, researchers examined 380 coca leaf samples from both the Yungas and the Chapare. The average water weight for all 380 samples was 65.5 percent.

After eliminating the samples that were collected during periods of rain, the average water content in the coca leaf was determined to be 64.7 percent. In April 1994, ten samples were collected and analyzed from Tingo Maria and were found to be consistent with the results found in Bolivia (64.5%). The 64.5-percent coca leaf water weight found in Peru was used in calculations to obtain the dry weight of coca leaf for all regions of Peru.

Graphing fresh coca leaf weight versus the calculated dry coca leaf weight provided the basis for the study in Peru (figure 14). The correlation between dry weight and fresh weight (94.7 percent correlation) indicated that fresh coca leaf could be weighed and later converted to dry weight. The standard deviation for the water weight of all samples was 2.9 percent.

Figure 14 **Leaf Water Determination**



COCA LEAF ALKALOID CONTENT

Figure 15

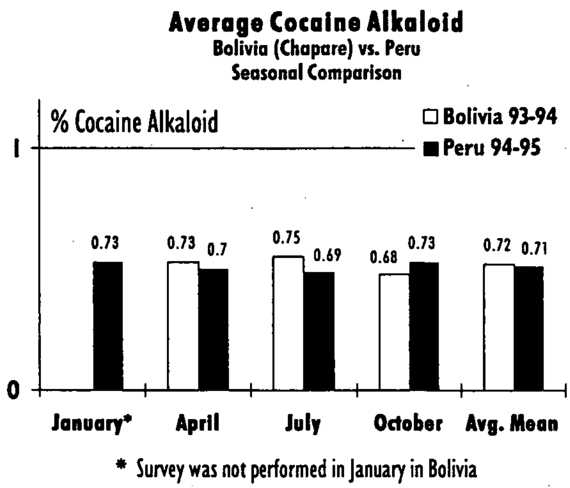
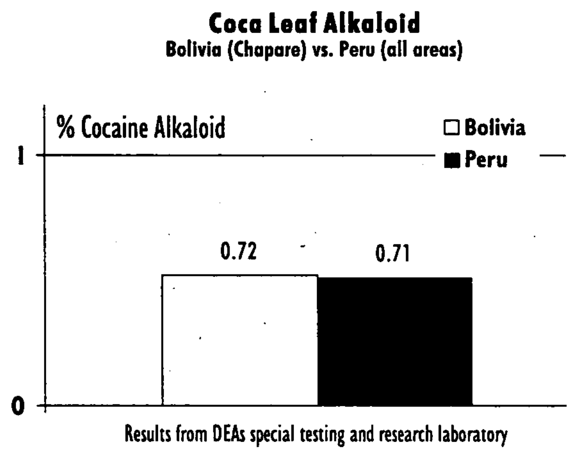


Figure 16



Operation BREAKTHROUGH survey results found little variance in the cocaine alkaloid values of the coca leaf samples analyzed. The average cocaine alkaloid content of leaf from the Upper and Lower Huallaga and the Ucayali Valleys was 0.71 percent; the average cocaine alkaloid content of leaf from the Cuzco region was 0.75 percent.

Research Methodology

Coca leaf samples from each of the 10 growing areas were collected for analysis. Samples were collected from 10 to 15 different farms from each transect and for each of the different growing seasons. A total of 875 coca leaf samples was collected.

Shortly after they were obtained, the samples were dried at 40 degrees centigrade at a central location in Peru. [Note: Extensive testing by DEA forensic chemists has shown that drying at higher temperatures effectively reduces cocaine alkaloid content. In fact, Operation BREAKTHROUGH analysis has revealed a 10-percent reduction in alkaloid from samples dried at 70 degrees centigrade from those dried at 40 degrees centigrade.]

After drying, samples were packed and sealed in zip-top bags along with a desiccant to prevent spoilage from moisture. The samples were forwarded to DEA's Special Testing and Research Laboratory for analysis by gas chromatography to determine cocaine alkaloid content.

After analysis of the coca leaf alkaloid by gas chromatography at DEA's Special Testing and Research Laboratory, correction was made for rehydration of water in the leaf (average 5.1 percent), so that all samples analyzed in Peru and Bolivia would be reported in the same manner.

In addition to the alkaloid analysis, the nutrient content for over 600 of the 875 coca leaf samples was analyzed at Brookside Laboratories in New Knoxville, Ohio. The analysis provided a more complete understanding of the chemical structure of the coca leaf. Also, USDA-ARS performed a flavonoid profile* on each of the coca leaf samples. The flavonoid profile has been used for coca leaf species identification.

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* Flavonoids are aromatic-based compounds found in plants, which are responsible for such functions as the determination of flower pigmentation, feeding deterence, and ultraviolet light filters for plant protection.

Survey Findings

The cocaine alkaloid values in Bolivia and Peru are reported in figure 15 with the average value written above the four harvests. As observed in Bolivia, the cocaine alkaloid variance between seasons was minimal in Peru. The overall cocaine alkaloid for the 875 samples analyzed in Peru was 0.71 percent and 0.72 percent for the Chapare region of Bolivia (figure 16).

Average seasonal figures on coca leaf alkaloid content in Peru are provided in figure 17. The range represents the standard deviation. A seasonal breakdown by transect is provided in figure 18.

Analysis showed that 84.4 percent of the samples were between 0.6 and 0.8 percent cocaine alkaloid. Previous estimates of cocaine alkaloid in coca leaf were listed between 0.3 and 1.3 percent in the scientific literature.

The wide range of reporting for cocaine alkaloid could be caused by the following reasons.

- Poor sample handling, which allowed for moisture to decompose the coca leaf, resulting in spoilage of the coca leaf.
- Incorrect analysis of *Erythroxylum coca ipadu* samples as *Erythroxylum coca coca.* (The *ipadu* coca leaf contains lower percentages—approximately 0.4 percent—of cocaine alkaloid).
- Incorrect reporting of total alkaloid contents as cocaine alkaloid. This would account for the higher percentages reported.

Although previous reports had identified at least four species of coca growing in Peru, *Erythroxylum coca coca (E. coca coca)*, *Erythroxylum coca ipadu*, *Erythroxylum novagranatense novagranatense*, and *Erythroxylum novagranatense truxillense*, the Operation BREAKTHROUGH research has identified only one species of coca, *E. coca coca* in Peru.

In the Chapare and Yungas regions of Bolivia, *E. coca coca* was also the only variety of coca observed. Research from the alkaloid content performed by DEA and the flavonoid and chemotaxonomic profile analyses performed by the USDA-ARS substantiate that all of the coca analyzed from Peru and Bolivia was *E. coca coca.*

Figure 17

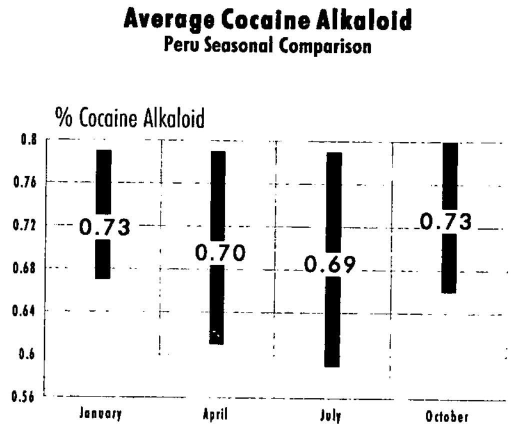
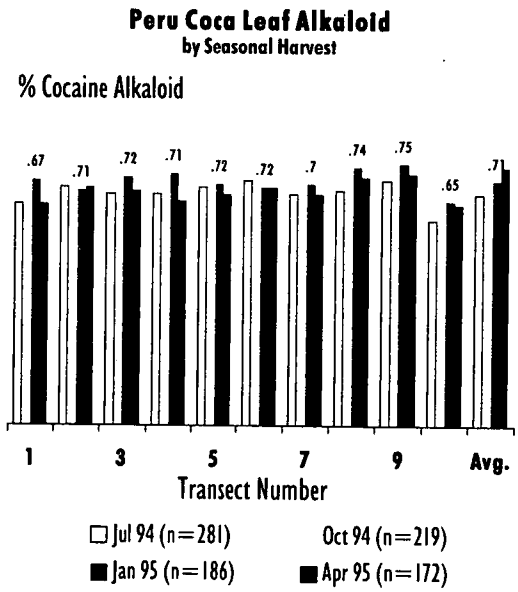
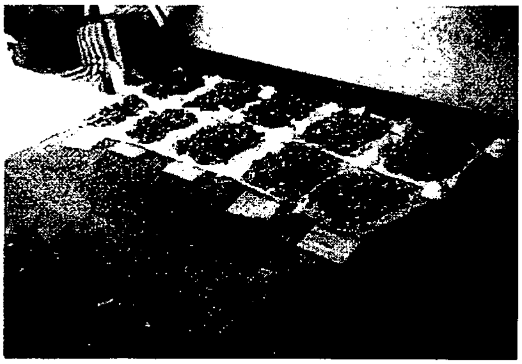


Figure 18



Farmers harvesting coca during one of four seasonal harvests



Coca leaf samples collected in Picota

Field agronomist measuring leaf weight

This is not to say that other species do not exist in Peru or Bolivia, but that in the large illicit growing regions of both countries targeted by Operation BREAKTHROUGH research, the primary species of coca grown is *E. coca coca*. When this initiative moves to Colombia, DNA research will be initiated on Colombian coca leaf and prior samples collected in both Peru and Bolivia to document further the number of different species of coca grown.

The study team focused on identifying any factors that may cause higher cocaine alkaloid contents. The plants in two regions were of particular interest: the Cuzco region in Peru, with a cocaine alkaloid content of 0.75 percent, and the Yungas region in Bolivia with 0.85 percent cocaine alkaloid content. These two areas had the highest cocaine alkaloid contents.

Two obvious similarities exist between the fields of Peru's Cuzco region and the Yungas region of Bolivia: 1) the plants are cut back to the ground every 6 to 7 years, and 2) both of these areas are at higher altitudes—an average of 1,200 meters for those fields surveyed in Cuzco and 1,450 meters for fields surveyed in the Yungas.

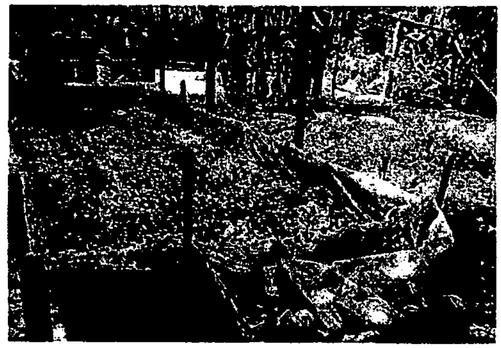
Coca leaf researchers have theorized that cocaine alkaloid production in the plant occurs as a reaction to plant stress. Higher altitude plants would be subject to greater stresses due to colder weather and climate.

A slight correlation of alkaloid associated with leaf yield was observed in Peru. In very high-yielding fields such as those in Transect 10 (Ayacucho), a decrease in alkaloid was noted. However, researchers could not establish a direct correlation between coca leaf yield and alkaloid content.

No single factor from elemental soil composition, soil pH balance, method of cultivation, fertilization, plant age, or other factor could be linked directly in every case to high or low alkaloid content of the coca leaves.

COCAINE BASE LABORATORY PROCESSING EFFICIENCY

Operation BREAKTHROUGH found the efficiency rate (i.e., the efficiency with which the cocaine alkaloid is extracted from the coca leaf to produce cocaine base) was 44 percent in Peru. In practice, approximately 400 kilograms (880 pounds) of coca leaf are required to produce 1 kilogram of pure cocaine base. In Bolivia, the extraction efficiency of the cocaine alkaloid was found to be 45 percent. Roughly, 390 kilograms (860 pounds) of air-dried Bolivian coca leaf are necessary to produce 1 kilogram of pure cocaine base.



Pozo filled with coca leaf

Research Methodology

Operation BREAKTHROUGH's survey of cocaine processing in Peru required a detailed approach to ensure that illicit cocaine base laboratory processing could be described thoroughly and accurately. A DEA team, consisting of a special agent, a forensic chemist, and an intelligence analyst, debriefed cooperating individuals knowledgeable of cocaine base processing in Peru. From February to July 1994, the 3-member team interviewed 31 illicit laboratory processors in Peru about cocaine base processing.

Filtering the cocaine base after precipitation

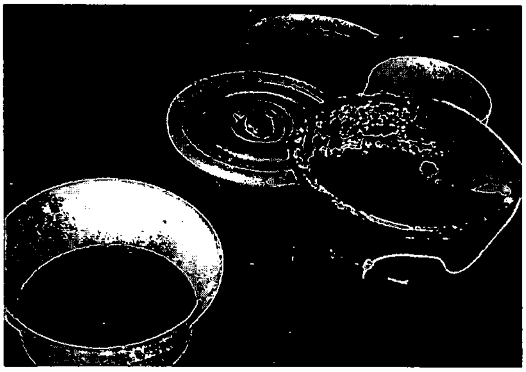
Based on the information learned from the interviews, a select sample of 10 of the 31 cooperating individuals who were debriefed were chosen to process coca leaf to cocaine base in the same manner to which they were accustomed.

The simulations were conducted in a controlled setting, with the processors being allowed the ability to process coca leaf to cocaine base independently with no outside interference from law enforcement or government authorities.

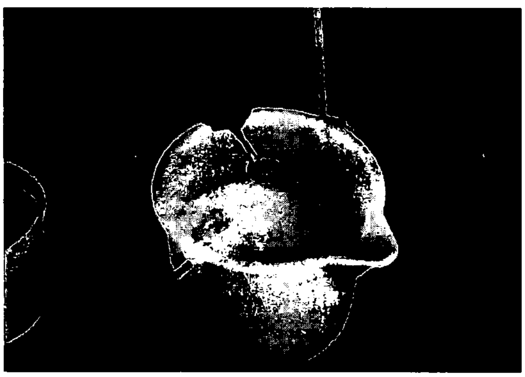
Cocaine base on drying table

During August 1994, a five-member team, including two DEA forensic chemists, observed cooperating individuals process coca leaf to cocaine base on four different occasions at the Peruvian National Police's Santa Lucia base camp. At all stages of processing, DEA forensic chemists took samples that were later analyzed for purity and chemical composition at DEA's Special Testing and Research Laboratory. Unforeseen circumstances delayed and eventually canceled the remainder of the laboratory processing simulations in Peru.

Bucket of lime used to process cocaine base



Chemicals and labware used to produce cocaine base



Precipitation of cocaine base with ammonia

Survey Findings

Key findings from Operation BREAKTHROUGH research in Peru with a comparison to findings in Bolivia are given below.

- Coca leaf is processed immediately without drying in the Huallaga Valley and some areas of the Ucayali Valley (Pachitea). In virtually all areas of the Chapare in Bolivia, coca leaf is sun dried prior to processing.

- The "classic acid extraction" technique is used almost exclusively in all areas of Peru and Bolivia.

- Laboratory processors typically process from 200 to 400 kilograms of coca leaf at one time in Peru, although in Pachitea from 400 to 600 kilograms are processed at one time. This compares to 230 kilograms that are processed in Bolivia.

- Analyses of the cocaine alkaloid-rich intermediate solution, known as *agua madre* in Peru, determined that 17 liters of *agua madre* yields 1 kilogram of cocaine base. However, in Bolivia, 40 liters of a similar solution known as *agua rica* yields 1 kilogram of cocaine base.

- The cocaine base produced in Peru, as in Bolivia, is impure. Purity of cocaine base samples in Peru averaged 84 percent and in Bolivia they averaged 82 percent. As a result of the impure nature of cocaine base samples produced in Peru and Bolivia, further oxidation of these samples is performed at re-oxidation laboratories set up solely to accomplish this task. Re-oxidation laboratories are known to exist in Peru, Bolivia, and Colombia.

- Typical chemicals used in illicit processing to obtain 1 kilogram of cocaine base are listed in figure 19.

A primary difference observed between Peru and Bolivia is that in at least half of the coca-growing regions in Peru, coca leaf is processed immediately upon picking, eliminating the requirement for drying. This procedure requires that the processing area be located in close proximity to the coca field, since transportation of the large weight volume of coca leaf in the treacherous jungle terrain would be prohibitive.

The final cocaine base product in Peru is dried on large drying tables assembled from local materials. Heat is provided by kerosene heaters placed underneath the table. In Bolivia, the final product is sun dried.

Analysis of cocaine base processing showed an average of 44-percent extraction efficiency of cocaine alkaloid from the coca leaf. See figure 20 for the results of Peruvian laboratory processor efficiency and analysis of cocaine base purity. Results of Bolivian illicit laboratory processing are given in figure 21.

Operation BREAKTHROUGH research has shown that it takes approximately 400 kilograms (880 pounds) of air-dried Peruvian coca leaf to obtain 1 kilogram of pure cocaine base.

Leaf maceration pits, called *pozos* in both Peru and Bolivia, are built on a much larger scale in Peru. Peruvian *pozos* are often large enough to produce 2 kilograms of impure cocaine base. Typical amounts of coca leaf processed at one time are 20 to 40 *arrobas* (227 to 455 kilograms) depending on the processing region.

Interviews of illicit laboratory "chemists," inspection of photographs taken at operational laboratory sites, and the observation of actual cocaine base processing demonstrated the primary use of a single illicit processing technique in Peru and Bolivia. This technique is referred to as the "classic acid extraction" technique, based on the methodology of stomping coca leaf in a dilute sulfuric acid water mixture to extract the cocaine alkaloid from the coca leaf.

Routinely, coca leaf is processed directly to cocaine base in a single processing operation. This differs from previous reports of processing first to paste with subsequent processing to cocaine base. In some regions, however, the preparation of cocaine paste (*bruta*), is done by precipitating an unoxidized dilute acidic solution, *agua madre*, containing concentrated coca alkaloids with sodium carbonate. This results in a crude cocaine base that contains more impurities than a cocaine base precipitated with ammonia.

Operation BREAKTHROUGH found two variations of the illicit laboratory processing technique in Peru. Both utilized the classic acid extraction technique for cocaine alkaloid extraction; however, the techniques differed in the removal

Figure 19

Chemicals Used in Illicit Processing

Chemicals	Bolivia	Peru
Sulfuric Acid (Concentrated)	3 Liters	3 Liters
Lime	10 Kilograms	15 Kilograms
Kerosene or Substitute	60 - 80 Liters	80 - 100 Liters
Potassium Permanganate	200 Grams	50 Grams
Ammonia (Concentrated)	1 Liter	1 Liter

Figure 20

Peru Laboratory Efficiency
Observation of Illicit Laboratory Operators

Simulation Number	Illicit Laboratory Efficiency (%)	Cocaine Base Purity (%)
1	47	84
2	52	88
3	41	86
4	36	77
Average	44	84

Figure 21

Bolivia Laboratory Efficiency
Observation of Illicit Laboratory Operators

Simulation Number	Illicit Laboratory Efficiency (%)	Cocaine Base Purity (%)
1	33	65
2	57	94
3	49	88
4	49	70
5	39	93
6	44	84
Average	45	82

Figure 22

Bolivia Cultivation*

Region	1994 Mature Coca Cultivation (HA)	1995 Mature Coca Cultivation (HA)
Apolo	1,100	900
Yungas	13,100	12,800
Chapare	28,100	26,300
Total	42,300	40,000

* Provided by Counter Narcotics Center, U.S. Department of State

Figure 23

Peru Cultivation*

Region	1994 Mature Coca Cultivation (HA)	1995 Mature Coca Cultivation (HA)
Tarapoto	2,000	3,250
Picota	3,500	3,250
Saposoa	2,500	3,250
Juanjui	2,500	3,250
Tocache	12,900	12,900
Pachitea	8,300	7,100
Aguaytia	8,300	17,800
Tingo Maria	16,000	16,000
Cuzco	9,400	9,400
Ayacucho	12,800	14,300
Other Regions	13,400	10,900
Total	91,600	101,400

* Provided by Counter Narcotics Center, U.S. Department of State

of impurities from the cocaine base. The techniques are described below.

- Chemical separation—Impurities are removed from the *agua madre* through precipitation with potassium permanganate. The impurities are contained in the precipitated product.

- Physical separation—Impurities are removed from the *agua madre* by precipitation with sodium carbonate, boiling the resulting mixture, and skimming the impurities from the boiled solution.

According to laboratory processors, boiling the *agua madre* is a new technique that was introduced in the past 3 or 4 years. The laboratory processors noted in interviews that this technique generally results in a less pure product.

The boiling procedure probably originated because of difficulty in obtaining potassium permanganate due to chemical regulations, shortage of supply, or the cost associated with obtaining the chemical.

Interviews of illicit processors suggest that the boiling method is used predominantly in Tarapoto and Pachitea. It is estimated that currently 10 to 20 percent of laboratory processors use the boiling method.

The research team observed simulations by laboratory processors using the boiling method in November 1996. Definitive results on the boiling method have not been obtained yet. Based on the prior Operation BREAKTHROUGH research, however, it is believed that there will not be a significant change in total laboratory efficiency.

1995 COCAINE PRODUCTION MODEL

The 1995 cocaine production model uses 1995 official U.S. Government estimates for mature coca cultivation in Peru and Bolivia in combination with the data collected from Operation BREAKTHROUGH research on coca leaf yield, coca leaf cocaine alkaloid content, and illicit laboratory efficiency. These estimates and data elements are depicted in figures 20 through 25.

Each region in Bolivia and Peru was considered a distinct entity with the coca leaf yield and alkaloid content for that particular transect used in the modeling process. Estimates concerning the total amount of coca cultivation used for illicit purposes was provided by the U.S. Embassies in Peru and Bolivia. It is important to note that this is an estimate and is extremely difficult to predict because of domestic consumption (chewing, herbal tea use), waste after harvest (spoilage and residual loss), undocumented enforcement actions, and cases where harvests are neglected (unpicked) because of economic or other factors.

From the DEA model, the 1994 and 1995 total cocaine base production figures for Peru and Bolivia are shown in figure 26. Again it should be noted that the DEA model utilizes a percentage of cultivation that is used for illicit purposes, and this number is based on U.S. Embassy guidance.

For Peru, 95 percent of all cultivation was estimated to be used for illicit purposes except in Cuzco, a legitimate selling market, in which 50 percent was believed to be diverted for illicit purposes. In Bolivia, it was estimated that 10 percent of coca cultivated in the Yungas region and 95 percent of coca cultivated in the Chapare and Apolo regions was used for illicit purposes. Figure 27 shows the effect on total cocaine production estimates by varying the percentage of coca cultivation used for illicit purposes.

Figure 24

Bolivia - Operation BREAKTHROUGH Measured Results (1993)

Region	1993 Measured Leaf Yield (MT/HA)	1993 Coca Leaf Alkaloid Content (%)
Apolo	1.8	0.85
Yungas	1.8	0.85
Chapare	2.7	0.72

Figure 25

Peru - Operation BREAKTHROUGH Measured Results (1994-1995)

Region	1994/95 Measured Leaf Yield (MT/HA)	1994/95 Coca Leaf Alkaloid Content (%)
Tarapoto	1.44	0.67
Picota	1.11	0.71
Saposoa	1.67	0.72
Juanjui	1.51	0.71
Tocache	2.02	0.72
Pachitea	2.10	0.72
Aguaytia	1.72	0.70
Tingo Maria	2.15	0.74
Cuzco	0.91	0.75
Ayacucho	2.78	0.65
Other Regions	1.15[1]	0.71

[1]- These are small, low-yielding fields distributed throughout Peru. Average yield is calculated from the averages in the three lowest yielding transects (1,2,9).

Figure 26

Operation BREAKTHROUGH Model Results Cocaine Base Production (metric tons)

ESTIMATES	BOLIVIA	PERU
1994	194	398
1995	198	447

Figure 27

Total Cocaine Base Production (1995)
Based on Percent Cultivation Used for Illicit Purposes

Percent Illicit Cultivation	Bolivia [1]	Peru [2]
100%	208	470
99%	206	464
98%	204	461
97%	202	456
96%	200	450
95%	198	447
94%	196	442
93%	194	436
92%	192	433
91%	190	429
90%	188	424
80%	168	379

[1]- 10% cultivation for illicit purposes in the Yungas.
[2]- 50% cultivation for illicit purposes in Cuzco.

Examples of the calculations used to determine the overall cocaine yield for Peru and Bolivia in 1995 are given in figures 28 and 29.

Figure 30 examines the 1995 cocaine base yield per hectare for each region in Peru. This number is derived using the assumption that 95 percent of all cultivation is utilized for illicit production of cocaine base (50% in Cuzco). In the Chapare region of Bolivia, the 1995 cocaine base yield is 7.03 kilograms per hectare.

Figures 28 & 29

Peru Production Model[1]
(Sample Calculation for Ayacucho)

Total Mature Coca Cultivation		% Coca Cultivation for Illicit Use		Coca Leaf Yield		Coca Leaf Alkaloid Content		Base Lab Efficiency		Base to HCl Lab Efficiency		Total Coca Cultivation
14,300 Ha	x	.95	x	2.32 MT/Ha	x	.0065	x	.44	x	1.00	=	[redacted]

[1] - Oven-dried weights used for calculation.

Bolivia Production Model[1]
(Sample Calculation for Chapare)

Total Mature Coca Cultivation		% Coca Cultivation for Illicit Use		Coca Leaf Yield		Coca Leaf Alkaloid Content		Base Lab Efficiency		Base to HCl Lab Efficiency		Total Coca Cultivation
26,300 Ha	x	.95	x	2.30 MT/Ha	x	.00715	x	.45	x	1.00	=	[redacted]

[1] - Oven-dried weights used for calculation.

The DEA Investigative Technology Section has developed a computer model that allows variations in all critical elements used in the DEA's cocaine production model. This model is available on request from DEA's Investigative Technology Section, which can be reached on (703) 541-6578.

Figure 30

Peru Cocaine Base Yield/Year 1995

Region	Kilograms/hectare	Metric tons/year
Tarapoto	3.38	11
Picota	2.77	9
Saposoa	4.31	14
Juanjui	3.69	12
Tocache	5.12	66
Pachitea	5.35	38
Aguaytia	4.21	75
Tingo Maria	5.56	89
Cuzco	1.28	12
Ayacucho	6.01	90
Other Regions	2.84	31
Total		447

MODELING NOTES:

- For total production calculations, only mature coca cultivation data was used. Total production calculations did not include seedling and new cultivation.

- The model used coca leaf weights with water removed (oven-dried weights). The leaf yields were air-dried weights, which included approximately 16.4-percent water, based on samples collected in Bolivia at Chapare coca markets.

- The average cocaine alkaloid for each respective coca growing area was used. Small variances between growing areas were observed, and the DEA model attempted to portray the scientific data accurately.

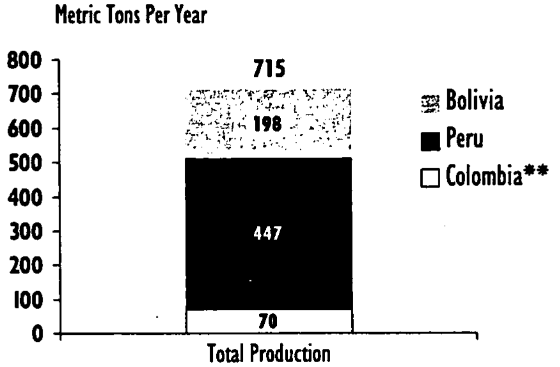
- The efficiency of laboratory processors was found to be 44 percent for Peru and 45 percent for Bolivia based on actual observation of illicit laboratory processing. Interviews of at least 30 processors in each country from different localities, along with confirming documentation, indicate that the processing techniques in the two countries were virtually identical.

- Currently, the accepted rate of converting cocaine base to cocaine HCl efficiency is a 1:1 conversion. This will be examined in detail when Operation BREAKTHROUGH moves to Colombia. With the acceptance of the 100-percent conversion efficiency, the values reported here for cocaine base production can be extrapolated to cocaine HCl production.

- Theoretically, if 100-percent conversion is achieved, 1 kilogram of cocaine base would yield 1.12 kilograms of cocaine HCl. (This is due to the molecular weight differences between cocaine base—303 grams per mole (g/mole) and cocaine HCl—339 g/mole.

Figure 31

Worldwide Cocaine Base Production
Operation BREAKTHROUGH Results*



* Based on U.S. estimate of % cultivation used for illicit purposes
** Estimated. Operation BREAKTHROUGH has not completed its study in Colombia

CONCLUSIONS

The findings and analysis presented herein represent the most precise understanding of cocaine production in Peru now available. In place of the historically fragmented and anecdotal reporting on cocaine production in Peru, Operation BREAKTHROUGH has established a clear understanding based on scientific evidence. This evidence displaces earlier, cumbersome intelligence efforts to catalog and assess cocaine production. This initiative thoroughly analyzed the key elements determining Peru's cocaine production that, to date, had been only vaguely understood: coca leaf yields, coca leaf cocaine alkaloid contents, and cocaine base processing efficiency. Based on this research, Operation BREAKTHROUGH confidently offers a method for estimating cocaine production that--when adapted to incorporate actual assessments of the amount of coca leaf from each of Peru's coca growing regions that are devoted to illicit cocaine production--best reflects Peru's actual cocaine production capacity.

Total worldwide cocaine base production for 1995 was 715 metric tons (figure 31). Operation BREAKTHROUGH's cocaine base production estimate for Peru of 447 metric tons for 1995 represented an increase of 49 metric tons over the 1994 estimate of 398 metric tons. The fundamental reason for the increase in Peru from 1994 to 1995 was an increase in the total mature coca cultivation from 91,600 hectares in 1994 to 101,400 hectares in 1995.

Upon completion of this program in Colombia in 1997, repeating the same research effort there, the U.S. Government will be able to provide a precise estimate of Colombia's cocaine production. And, in so doing, Operation BREAKTHROUGH will be able to generate a precise assessment of the Andean Ridge's total cocaine production.

U.S. policymakers, armed with reliable cocaine production estimates, will be allowed greater precision in assessing the domestic cocaine threat, the impact of interdiction efforts, and other issues fundamental to the formulation of national drug policy. More specifically, by enhancing our understanding of coca cultivation in Peru, Operation BREAKTHROUGH provides insight into the economics of coca growing and suggests potential approaches for improving eradication and crop substitution strategies. In addition, host nation governments in conjunction with the U.S. Government now can identify the major cocaine base producing areas and concentrate enforcement, eradication, and interdiction strategies accordingly.

APPENDIX: FARMER SURVEY

In addition to performing measured leaf yields, field personnel conducted at least 50 farmer interviews in each coca growing transect. A total of 533 farmer interviews were conducted and information was obtained regarding fertilizer, herbicide and insecticide usage; harvest and cultivation practices, coca field sizes; and coca leaf yield.

Of the 533 farmers interviewed, 494 were the owners of the coca field, 19 were workers, 10 were tenants, and 7 were managers of the coca field.

Results of the farmer interviews concerning coca leaf yield directly substantiated the measured coca leaf yields (figure 33). Graphing the average measured leaf yield versus the farmer survey leaf yield results in an r^2 correlation of 62 percent. Yield data of any crop are extremely difficult to obtain and yield data for illicit crops nearly impossible. However, the farmer interviews appear to provide a reliable approximation of yield for future research studies.

Farmers were questioned about average field age and it was found that field ages as reported by the coca farmers were representative of the neighboring coca fields in each transect. Excluding fields in Cuzco, a traditional growing area with field age averaging 34 years, it was determined that the average field age for all other coca growing areas in Peru was 5.15 years.

Coca plants were generally planted as seeds in small 8 by 8 inch square holes, called "golpes." Customarily seeds are planted in each corner of the golpe. In other cases, the farmer would transplant seedlings into the golpes. The golpe most likely is used as an aid in irrigation to collect rain which otherwise would run off the sloped terrain. The average number of stems in the golpes for mature coca plants is two. Obviously, farmers have learned over the years the facts about the mortality rate for young coca plants. It was also learned that plants become mature enough for harvest between 15 and 20 months.

The number of harvests per year was identified conclusively at four for the majority of the coca growing areas (figure 32). There were 16 responses indicating 3 harvests, which all came from Transect 9, Cuzco. Annual harvests of five per year were reported from Transect 8, Tingo Maria (73% of Transect 8 responses), and Transect 10, Ayacucho (57% of Transect 10 responses). Harvests of six per year were reported from Tingo Maria, (8% of the responses from Transect 8). The consequence of picking at

Figure 32

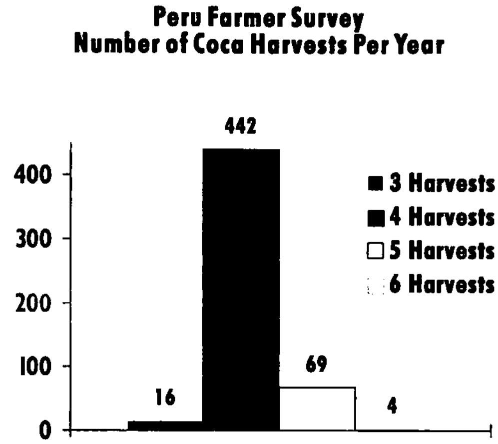
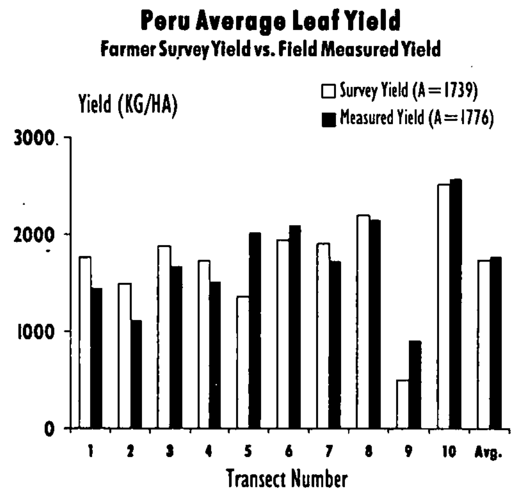


Figure 33



Seedlings planted in "golpes" in Upper Huallaga Tingo Maria

Figure 34

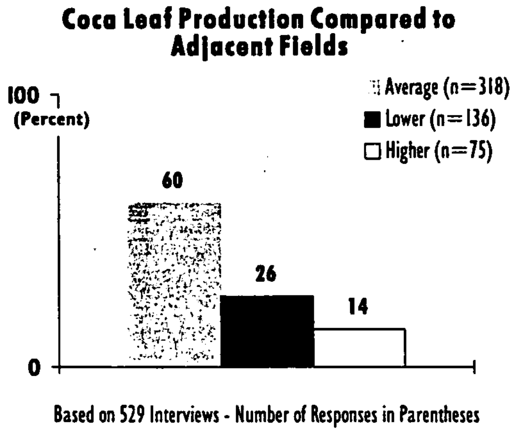


Figure 35

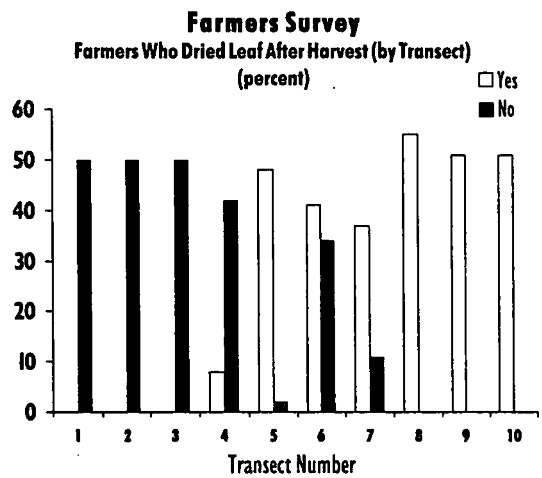
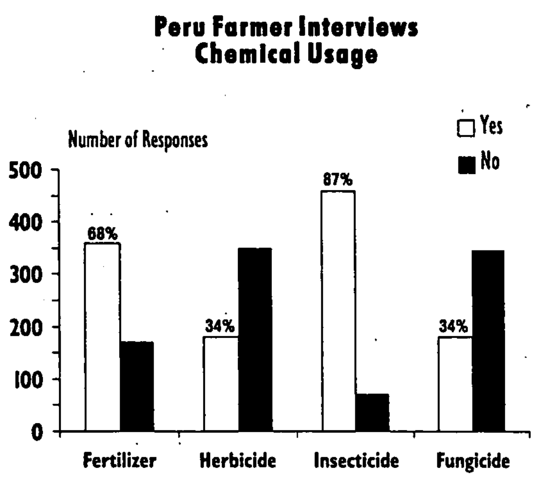


Figure 36



this frequency is that 60 to 75 day coca leaf is being harvested, a less mature coca than is harvested traditionally.

Farmers were asked about how the coca yields from their farms compared to other farms in the coca growing transect during the last 3 years. An overwhelming 86 percent of the farmers responded that their fields were average or lower yielding when compared with adjacent farms. The results are shown in figure 34. Lower yielding fields may be the result of plant disease, insect damage, a decrease in farmer management (weeding), a decrease in chemical input (fertilizer and insecticide usage), or neglect resulting from low prices paid for coca and cocaine base products.

It was found through the interviews that in half of the growing areas, coca leaf is processed immediately following the harvest, eliminating the necessity of drying on patios. Survey results are shown in figure 35.

Farmer use of chemicals in coca fields is reported in figure 36. Insecticides were the chemicals most applied by the farmers in their fields. Chemicals used by coca-growing farmers in Peru are identified in figure 37. The field agronomists reported that farmers were reluctant to use chemicals for fear of spreading fungus, which they believed had been put into the fertilizers, insecticides, herbicides, and fungicides by Peruvian or U.S. Government authorities.

Figure 37

Chemicals used by coca-growing farmers in Peru

Fertilizers	
Extrafoliage	Profoliar
Nitrofoliage	Nitrofosca
Vitafoliage	Agricola
Fertifoliage	Fertrilon
Nutrifoliar	Bayfoliar
Fertucombi	Urea
Harvestmore	Lonzin
Herbicides	
Gramoxone	Gramoxone Agro Kling
Herboxone	Herbox
Reglone	Hedonal-6
Super Herbox	Roundup
Gramoxone Super	Malesil
Insecticides	
Barbasco	Larvin Farmex
Sevin/Sevin 85	Belmark Shell
Antracol	Malathion
Stermin	Belmark
Thiodan	Titan Plus
Lannate 90	Extermin
Mirex/Mirex 450	Parmex 85
Tamaron/Tamaron 600	Decis
Fungicides	
Cobox/Cobox 6	Vitigran
Cupravit	Activol
Manzat	Roxicorp
Oxichlorino	Cuprex
Kocide/Kocide 101	


Plant fungus "seca seca"


Plant lichen


Coca leaf eating grub (gusano)

Plant disease was widely reported by the coca farmers. The two most widely reported diseases affecting the coca plant were "escoba de bruja" and "seca seca." Literal translations for escoba de bruja and seca seca are "witches broom" and "dry dry." Seca seca is the fungus that was reported as affecting the Huallaga valley in the late 1980's and early 1990's, and was responsible for decimating large numbers of coca fields. Lichens also were observed on the stems of the coca plants. This generally occurs in older plants as observed in both the Peru and Bolivia Operation BREAKTHROUGH research. In the 77 Peru coca survey fields, lichen was found on all plants older than 5 years.

Insect damage was evident in many of the fields surveyed. One prevalent insect, "Malunya," a moth-like flying insect, was responsible for much of the coca leaf damage as noted by Peruvian field agronomists. Large smoke producing fires were often used to eliminate the Malunya during periods when it was most active. Other insects that were noted to cause the coca-growing farmer problems included ants, crickets, and grubs.

Farmers were asked to rate various items related to coca cultivation as being very important, important, or not important at all. Of particular note was that altitude or location of the coca field, slope or slope direction of the field, origin of the seedstock, and use of herbicide were rated by more than 50 percent of the farmers as being not important at all. Agronomists generally recognize these factors as being very important to achieving large and high-quality harvests.

The five areas perceived by the farmers as being important or very important in affecting yields and the positive response percentages are:

- *Rainfall* 99%
- *Coca plant age* 94%
- *Field planting density* 92%
- *Weeding/cultivation* 90%
- *Use of insecticides* 87%

Plant fungus "Escoba de Bruja"

Figure 38

Chemicals used by coca-growing farmers in Peru

	Very Important	Important	Not Important
Fertilization	234	186	104
Herbicides	72	147	304
Insecticides	250	208	68
Fungicides	108	237	153
Plant Age	214	280	29
Row Spacing	94	341	82
In Row Planting	92	350	74
Plant Density	124	357	43
Seed Stock	47	200	263
Soil Quality	203	229	91
Weeding	221	259	45
Rainfall	257	265	4
Field Location	46	217	254
Field Slope	57	225	233
Slope Direction	24	158	321
Field Elevation	11	138	345
Method of Planting	118	320	73
Cultivation	210	246	62
Phases of Moon	20	107	312

533 Farmers Interviewed

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5

Nonintrusive Inspection Technologies (Session 2B-2)

U. S. CUSTOMS SERVICE NARCOTICS DETECTION TECHNOLOGY ASSESSMENT STATUS UPDATE - PERFORMANCE ASSESSMENT OF COCAINE / HEROIN DETECTION SYSTEMS

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Abstract

At the October 1995 Counterdrug Law Enforcement International Symposium, the Narcotic Detection Technology Assessment Program sponsored by ONDCP/CTAC accessing the performance of commercially available and emerging prototype cocaine/heroin detection systems was presented. Performance specification tests, double-blind target response tests, and quasi-controlled simulated field examinations were discussed. Three assessment cycles have now been completed, assessing 12 different detection systems. This paper describes the results of these assessments in general terms, since these data are considered law enforcement sensitive. In addition, this update describes changes to the program that are under consideration for subsequent assessments, including expansion for marijuana/ hashish, amphetamine and methamphetamine systems and narcotics vapor detection systems.

Introduction

The United States Customs Service (USCS) Applied Technology Division (ATD), of the United States Treasury Department, has been conducting independent ongoing technology evaluation studies of illicit substance detection devices. These USCS directed studies are aimed at evaluating both commercially available and emerging prototype *chemical* detection systems in *laboratory and field simulation scenarios*. The USCS has continued to conduct these evaluation studies to provide information to interested federal, state, and local law enforcement agencies (LEAs) regarding the performance of illicit substance detection technologies. Individual test reports describing the results of each system evaluated are intended to be distributed only to the individual system manufacturers and law enforcement agencies, on a "For Official Use Only" basis.

The test program was designed and organized by USCS with contributions from Revenue Canada Customs Excise and Taxation (RCCET, *i.e.,* Canadian Customs) in accordance with the June 15th, 1983 Memorandum of Understanding between the two agencies. The USCS enlists the aid of the Narcotics Detection Technology Assessment (NDTA) Team to perform these evaluation studies. The active participating members of the NDTA Team supporting these studies consist of the USCS, the United States Coast Guard (USCG), the Department of Defense (DoD), RCCET, the Houston Advanced Research Center (HARC), and Argonne National Laboratory (ANL). Other agencies that have been involved in the program include the Federal Aviation Administration (FAA), the Federal Bureau of Investigation (FBI), and the Drug Enforcement Administration (DEA).

The Office of National Drug Control Policy (ONDCP), Counter-drug Technology Assessment Center (CTAC), directed by Dr. Albert E. Brandenstein, is sponsoring these on-going independent evaluation tests.

To date, three rounds of tests have been completed, resulting the assessment of 12 different particle detection systems. The most recent round of assessment tests conducted at the Houston Advanced Research Center, near Houston, TX was completed in November 1996.

Instrument manufacturers are informed of NDTA activities through periodic announcements published in the Commerce Business Daily (CBD) and can apply for participation in the program by responding to these sources sought notices which are generally published at least 60 days prior to the anticipated test dates.

Respondents to the CBD notice are provided with a general cover document that outlines the instrument requirements and test procedures. Interested manufacturers are then asked to provide information on their system's performance and certain design specifications. This information is reviewed by the NDTA team to verify that all candidate systems meet the minimum requirements outlined in the cover document. At this point, responsive manufacturers are asked to commit to participate and the test schedule is finalized.

Acknowledgments And Special Thanks

Test support teams were comprised of personnel from the following groups:

- United States Customs Service (USCS),
- Revenue Canada, Customs, Excise and Taxation (RCCET),
- United States Coast Guard (USCG),
- Houston Advanced Research Center (HARC),
- Argonne National Laboratory (ANL), and
- Support Contractors.

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Objectives

The primary objective of the Narcotics Detection Technology Assessment (NDTA) Program is to *quantitatively evaluate the detection performance of chemical based narcotics detection equipment.* The secondary objective of the NDTA program is to *provide qualitative information on normal operational aspects* of the participating narcotics detection systems. This "Law Enforcement Sensitive" information is distributed in an evaluation report to interested LEAs on a "For Official Use Only" basis. These independent evaluation tests are currently scheduled to be conducted approximately twice per year; the level of testing and frequency of testing will be adjusted as the USCS deems appropriate based on the advances in state-of-the-art drug detection technology.

Since the requirements, applications, and utility of narcotics detection systems are quite diverse, assessing the performance of detection systems in each of the many *"real world"* scenarios and conditions typically encountered by law enforcement agencies is impractical with the limited resources available. Furthermore, the *real world* is not a constant reference point that can be quantitatively defined because it changes with time and location. In order to eliminate the varying *real world* testing conditions, segments of the NDTA performance evaluation studies are confined to a controlled environment. In this manner, a measurable and repeatable test target is established as an accurate reference standard eliminating subjective results.

To accomplish the primary objective of *quantitatively* evaluating each instrument's narcotics detection performance, the assessment tests were divided into three main segments:

- Manufacturer's Specifications Verification Tests,
- Standard Target Response Tests, and
- Luggage Tests.

These tests were designed to gain information to help understand the potential field utilization of narcotics detection systems. Specifically, these tests focused on evaluating each individual instrument's capability to detect *cocaine and heroin.* The NDTA team believes the most generally comprehensive and useful test results are obtained from fundamental standard tests completely divorced from detection strategy. Therefore, the tests were also designed to eliminate *detection strategy* by system operators. To eliminate detection strategy from the tests, the locations of all test samples was made obvious. Additionally, the Manufacturer's Representative (MR) operated their respective systems for the duration of the tests. This also allowed the MR to select the optimum sampling method for his or her system.

To accomplish the secondary objective of providing *qualitative* information on operational aspects of the systems, the independent NDTA team members observed the operation of each detection system by the respective manufacturer's representative. Subsequently test team members formed opinions addressing:

- Portability,
- Ease of Operation,
- Operator Qualifications,
- Support Requirements, and
- Recurring and Operating Costs.

No conclusions or recommendations will be issued based on the quantitative or qualitative test results. The independent NDTA evaluation team holds the opinion that conclusions and recommendations cannot be adequately formulated without relating the performance evaluation results to specific user applications, and user applications are simply too varied to address in their entirety. However, these *Law Enforcement Sensitive* reports provide system-specific performance data which can be evaluated by individual law enforcement agencies within the framework of their own particular applications.

Standards Development

Solid Standards

The key to obtaining meaningful and applicable data from this performance assessment program has been the development of comprehensive test standards. As early as 1991, the difficulties in designing repeatable and reproducible solid narcotics standards in the range of nanograms to micrograms was discussed.[1,2] Further the use of standard chemical solutions as an adjunct for solid standard was dismissed because of the inability to simulate actual dynamic forces on particles, as well as environmental effects of humidity and temperature on actual narcotics particles. Pilon et al [3] developed the procedures for coating sand particles with solutions of cocaine and heroin in methanol and was the basis for the round 1 NDTA tests. However limitations for these standards were apparent as instruments with greater desorption temperatures tended to outperform their competitors, but instruments with responses independent of temperature were unaffected by these standards. This lead the NDTA team to investigate a series of different solid standards based on the following criteria:

1) The standard must enable accurate and repeatable dispersal of cocaine and heroin in sub-nanograms.
2) The standard must be repeatable.
3) The standard itself must not affect the test results.

Ulvick et al[4] looked at solution deposited substrate standards, solution deposited substrate-free standards, vapor deposited standards, suspension standards developed by the FAA[5], and dry mix standards. The latter are solid phase narcotics homogeneously mixed and sieved to a known particle size distribution and then mixed with a particulate filler, and the standard is transferred to the target surface as a solid powder. Silver coated nickel particles were used for cocaine; silanized glass spheres were used for heroin. Not only were these standards determined to be the most independent of IMS desorber temperature, they had the longest shelf life of any solid standard studied, most significantly when purged with dry nitrogen gas.

Vapor Standards

A description of the Idaho National Engineering and Environmental Laboratory vapor generator was given at the 1995 ONDCP symposium in Nashua, New Hampshire. This system, developed originally for the FAA is capable of a calibrated and controlled discharge of cocaine and heroin vapor in the picogram to low nanogram range. It consists of three components, a pneumatic system, a controller and a sampling head. Narcotics solutions are dissolved on quartz wool housed in the sampling reservoir, with the vapor saturation level established by the reservoir temperature such that a known quantity of vapor can be emitted with each pulse. This system was used to generate narcotics crystals on glass slides in the preceding discussion of solid standards development. Experience over the past year with the NDTA team in the evaluation of several vapor based narcotics detection systems have demonstrated the value of the INEEL vapor generator.

Calibration curves for cocaine base have been generated for both gas chromatography / mass spectrometer and ion mobility spectrometer instruments with the resulting output linear over temperature ranges of 25°C to 55°C and flow rates of 50 to 250 cc/min. Temperature fluctuations at the output caused by heated instrument inlets let to the design of a heat independent vapor generator output nozzle. Calibration curves remained linear for this tip redesign.

Testing Methodology and Measures of Effectiveness

The first two sets of tests are performed in a well controlled laboratory environment with standard testing procedures. The third test is aimed at simulating actual field applications and conditions by examining a simulated luggage queue. The standard target response tests and the luggage tests were performed as double blind tests.

In the first round of NDTA tests reported in October of 1995, there was also an enclosure test where standard targets were placed in concealments onboard a pleasure yacht and a recreational vehicle. These tests were designed to assess the functionality of detection system in common search scenarios. The system operators were made aware of all target locations prior to the test so search strategy was still not a mitigating factor in the performance evaluation. However, following the completion of the November 1994 (round 1) test the NDTA team decided that the results of the enclosure tests did not contribute significantly to the usefulness of the data. Therefore, the enclosure test was not continued into the following 2 rounds of tests.

It should also be noted that in the initial round of tests, the majority of testing was not conducted with the MR as the system operator. The NDTA team tried to assess training requirements by requesting the MR to train an operator provided by U.S. Customs Field Operations Support Division and that trained operator would serve as the system operator for the majority of the testing. The MR was allowed to operate the system for one of the three series of Standard Target Response Tests for both cocaine and heroin and the trained Customs operator conducted the remainder of the tests. For subsequent rounds of tests, the NDTA team determined that the optimum system performance could be assessed by allowing the MR to operate their own system for the entire test.

The tests were performed in the order listed above. That is, generally, the performance verification tests were conducted first, the standard target response tests second, followed by the luggage tests. ***The MR set the narcotic loading range for both the Performance Verification Tests and the Standard Target Response Tests. However, the loading range was set by the independent NDTA evaluation team for the Luggage Tests, and this range was constant for all devices tested. The independent NDTA evaluation team set these narcotics loading ranges at the selected values based on extensive field testing experience.*** The MR was informed of the target narcotic (heroin or cocaine) mass loading in all tests. The MR set the system alarm threshold response level(s) *before* starting the standard target response tests. Subsequently, the MR was then allowed to set the alarm level(s) before the ensuing luggage tests; no changes were allowed during the tests. Only a DETECTION or NO DETECTION result was recorded for the system response to heroin, cocaine, or blank targets. Quality assurance and quality control (QA/QC) personnel observed all tests and a data recorder recorded all test results.

All tests were conducted in series form. That is, no simultaneous or parallel testing of different detection systems was performed. A standard response form was employed to document any test equipment malfunction. The performance verification tests, standard response tests, luggage tests, and their respective measures of effectiveness, are briefly described in the following sections.

<u>Performance Verification Tests:</u>

The performance verification tests consisted of four distinct tests. Each individual system was evaluated for:

- Response Limits for Cocaine and Heroin (*i.e.,* the minimum detection limit and saturation limit),
- Total Analysis Time per Sample,
- System Recovery Time from a Saturated Response, and
- System Warm-up Time.

These tests were performed in a laboratory setting with the MR. When possible, known calibration standards of a narcotic methanol solution were injected directly onto the sampling device of the system. This procedure helped eliminate sample transfer or sampling efficiency from the process. *The MR specified the narcotic mass loading ranges for these tests.*

Standard Target Response Tests:

The standard target response test consisted of testing clear anodized aluminum plates pre-loaded with narcotics. The test targets were designed to simulate, to a practical degree, fundamental detection targets typically encountered in the field. The aluminum plates (9" square by 1/8" thick) were machined flat and sanded to a predetermined roughness. The plates were then loaded with a known calibration standard. These calibration samples, as discussed above in the section on standards development, consisted of 10 mg of substrate mixed with 5 ng to 10 μg of narcotics in the solid state. The substrate mixed with cocaine was silver-coated nickel powder (63 μm diameter average particle size), and the substrate mixed with heroin was 80 μm diameter silanized glass beads. *All heroin and cocaine target mass loadings were within the response range specified by the MR.*

Three (3) repetitions were run in the laboratory environment for both cocaine and heroin (*i.e.,* 6 runs total). Generally, each repetition consisted of 15 individual tests (*i.e.,* 45 tests for cocaine and 45 tests for heroin, totaling 90 individual tests).

Luggage Tests:

The luggage tests consisted of testing two sets of *real world* luggage. The luggage is *real world* luggage in terms of being subjected to a typical search environment (i.e., air terminal baggage areas and aircraft baggage holds). One set was loaded with cocaine standards and silver-coated-nickel blanks; the other row with heroin standards and silanized glass bead blanks. The cocaine and heroin standards are the same as those used in the standard response tests described above. *The independent NDTA evaluation team specified the narcotic loading range for these tests based on extensive field testing experience.*

Generally, each set consisted of 16 pieces of luggage (32 pieces of luggage were tested for each system). Of the 16 pieces of luggage in each set, generally, 8 pieces were loaded with a narcotic (again, cocaine standards applied to one set, heroin standards applied to the other set); the remaining pieces of luggage were loaded with blanks (*i.e.,* controls). Of the 8 pieces of luggage spiked with loadings of a narcotic, 2 were loaded at the 0.05 μg level (*i.e.,* 50 ng), 2 were loaded at the 0.5 μg level (*i.e.,* 500 ng), 2 were loaded at the 1 μg level (*i.e.,* 1,000 ng), and 2 were loaded at the 10 μg level (*i.e.,* 10,000 ng). For clarity, the following tables summarize the narcotic loadings for these luggage tests. When possible, the luggage was placed in a vertical or upright position with the handles pointing up. The narcotic samples and blank sand samples were deposited on the uppermost horizontal surface, usually near the handles, in clear view of the system operator. Again, this procedure eliminated any sampling strategy by the operator. These luggage tests were performed only once; they were not repeated.

Luggage Loading Distribution (Cocaine and Heroin Sets)	
Loading (μg)	Number of Luggage Pieces
Blank	8
0.05	2
0.5	2
1	2
10	2
	Total 16

Assessment Results

As indicated above, complete results for each individual system have been distributed to the respective manufacturers and full reports of all systems tested have been distributed as *Law Enforcement Sensitive* documents to interested Federal, State and local law enforcement agencies For Official Use Only. The NDTA team, has also honored requests of foreign governments, upon case-by-case approval of the U.S. Customs Service, to provide these reports to law enforcement agencies in other countries.

To avoid disclosure of individual system data in this paper, the performance results discussed here have been averaged by technology category. The down side of this approach is that some of the averaged data may not accurately reflect the state-of-the-art technology capabilities in each category. However, this approach does accurately portray the overall trends as well as the general strengths and weaknesses of the systems assessed.

The 12 different particle detection systems assessed to date have been separated into the following three categories:

- Ion Mobility Spectrometry Systems
- Biological Based Systems, and
- Other

The "other" category consisted of four systems: Three front-end gas chromatograph systems, and a prototype surface ionization detector. There were five IMS systems and three biological based systems.

It should also be noted again that the manufacturer's representatives had the option to select the range of the target mass loading for both the Performance Verification Tests (including the minimum detection limit test) and Standard Target Response Tests. In some cases the manufacturer's representative chose wide ranges of targets, varying by 2 or 3 orders of magnitude, while in other cases the target range varied by less than an order of magnitude. There was no attempt by the NDTA team members to change any selected range nor was there any attempt to determine the dynamic range of any instrument. In some cases the manufacturer's representative was relatively conservative, selecting a target range well within the instrument's capability for detection, while other times, the opposite was true and the instrument was challenged.

Performance Verification Test Results:

As can be seen in the performance verification results table, the minimum detection limit for the IMS systems was lower, indicating greater sensitivity than the other two types of systems. However, the newer biosensor technology has been masked by the results of some of the older systems in this data set and is actually much closer to the IMS data. The data also show that the IMS group and the "other" group were more sensitive to cocaine than heroin. Quantitatively, cocaine sensitivity for the IMS was about 1 ng and the numbers for heroin sensitivity were anywhere from 2 to 5 times higher. The minimum detection numbers for biological systems ranged from 10's of ng to 10's of μg for both cocaine and heroin. The largest range for minimum detection limit data was seen in the "other" systems, ranging from hundreds of picograms to around 100 ng for cocaine and from 1 ng to 500 ng for heroin.

Typical analysis time, including sampling time was on the order of minutes (averaged) for all systems, although individual times varied from less than 30 seconds to several minutes. Saturation recovery time was on the order of 5 to 10 minutes for cocaine and heroin respectively for IMS systems, while recovery time for the "other" systems averaged out to about an hour. Saturation recovery times this long would not be practical for field use. Saturation recovery times for biological systems were not applicable, since the biological systems tested were disposable kits and were not reusable.

Initial purchase costs varied greatly. Biological "kit" systems (disposable components), on average, were about $10.00 each, whereas, the GC systems were in the hundreds of thousands of dollars. The IMS systems were around $50,000.00.

Recurring costs ranged from $300.00 to about $5000.00 per year for the IMS systems, and even higher for the biological systems. These costs, however, may be more accurately measured in terms of the number of samples collected and analyzed over a given time period. At $10.00 to $12.00 per sample for a biological kit, the average annual cost would be about $7100.00 per year, assuming 50 samples per month. That figure could easily be much higher since separate kits

Performance Verification Results Averaged by System Type

	Minimum Detection Limit (μg)		Typical Analysis Time (h:mm:ss)	Saturation Recovery Time (h:mm:ss)		Approximate Initial Purchase Cost	Approximate Recurring Cost
	Cocaine	Heroin		Cocaine	Heroin		
IMS	0.00135	0.00520	0:01:10	0:05:34	0:11:46	$48,240.00	$1,575.00
Bio*	3.66917	2.00500	0:01:45	0:00:00	0:00:00	$675.17	$7,100.00
Other	0.06281	0.15150	0:03:28	0:51:16	1:01:28	$98,000.00	$700.00

*Recurring Cost for Bio systems is based on 50 samples per month. Cost can vary with Quantity. Kits are not reusable (1 kit per test, per drug). Some newer immunoassay kits are capable of MDL < 1μg.

are required for heroin and cocaine, and tests for each drug have to be carried out separately.

Standard Target Response Test Results:

When analyzing the standard target response data it should be noted that there is a direct relationship between the true positive percentage (TPP) and the false negative percentage (FNP) as well as between the false positive percentage (FPP) and the true negative (TNP) percentage.

TPP + FNP = 100%
FPP + TNP = 100%

The IMS and the biological systems exhibited significantly higher true positive percentages than the "other" systems. The IMS results, however, were tempered by the much higher false positive percentage than the biological systems (over 20% for cocaine, compared to only 1% for the biological systems performance for cocaine). Generally, the false positive percentages for cocaine were higher than for heroin for both IMS and biological systems.

A true negative percentage of 100% would exist where the instrument indicated no narcotic was present for all cases where, in fact, no narcotic was present. This level of results was achieved by the biological systems for both cocaine and heroin, and for the IMS and "other" systems only for heroin. Both the IMS and "other" systems had a 75% true negative ratio for cocaine and the corollary of which was a false positive ratio of 25%. This could indicate instrument carryover where a previous hit would register positive on a negative sample.

False negative percentages were high for both IMS and biological systems, around 20% on average (cocaine and heroin) for IMS systems and up to 33% for biological systems (average for heroin). The false negative percentage for biological systems against cocaine was down to about 8%.

The target response characteristics for the "other" systems was rather poor in comparison to systems in the other two categories. The true positive percentages for "other" systems were over 50% for cocaine and over 30% for heroin. False positive percentages were about 25% for cocaine and zero in the heroin tests. True negative percentages for the "other" systems were comparable to the IMS and biological systems at around 75% for cocaine and near 100% for heroin. The false negative results for the "other" systems, of course, complement the true positive results at 45% for cocaine and 66% for heroin.

The poor results of the "other" systems in these tests may be attributed, in part to instrument malfunctions. In several instances the respective manufacturer's representatives indicated that they felt their instrument was not functioning properly and declared a system malfunction. In most of these cases the vendors ended up aborting the tests after declaring a malfunction. The data collected up to the point of a malfunction is reported. In other cases, the manufacturer's representative may not have fully understood the significance of the target loading range he or she selected for the tests. As discussed above, some manufacturer's representatives were much more conservative than others in their selection of the target loading range.

The cocaine and heroin loadings were deposited on a silica substrate for the first round of these tests (conducted in November, 1994) and subsequently prepared as a dry mix, as described above for the last two rounds of tests. The test standards were representative of what the NDTA team members had experienced in field exercises, but may have been quite different from laboratory standards used in product development and manufacturer's testing.

One possible advantage that the biological systems may have over the other two types of systems against these standards, lies in the fact that the system response for the biological systems is the result of an antibody-antigen

Standard Target Response Test Results Averaged by System Type

	STRT True Pos % (within range set by MR)		STRT False Pos %		STRT True Negative %		STRT False Negative %	
	Cocaine	Heroin	Cocaine	Heroin	Cocaine	Heroin	Cocaine	Heroin
IMS	83.72	75.8	21.12	0.86	78.88	99.14	16.28	24.2
Bio	91.67	66.67	1.00	0.00	99.00	100.00	8.33	33.33
Other	54.63	33.33	24.63	0.00	75.37	100.00	45.37	66.67

reaction and is less affected by the substrate matrix. On the other hand, a particle detection system would have to rely on particle desorption and the better performing instruments would characteristically, have higher desorption temperatures. Again, the manufacturer's representative's choice of the target load range may also have contributed to these results. In some cases, the range was from 10's of ng to 10's of μg, while in other cases the range was much less.

Luggage Test Results:

There was a decrease in the performance of the IMS and biological systems in the luggage tests as compared to the standard target response test. The true positive and false negative percentages for IMS against cocaine in the luggage tests was very close to the performance in the standard target response test, indicating that in this case, the sampling surface didn't appear to significantly impact the instrument's performance against cocaine. The IMS performance against heroin, however, decreased significantly in the luggage tests compared to the standard target response test.

The biological systems experienced a much more drastic decrease in performance against both cocaine and heroin targets in the luggage tests compared to the standard target response test. The true positive percentage for the biological systems against cocaine dropped from over 90% in the standard target response test to just over 30% in the luggage test. The decrease in performance numbers against heroin in the luggage test was also significant decreasing from over 66% true positive percentage in the standard target response test to under 40% in the luggage test. The performance decreases in true positive percentages for the bio systems were, of course, accompanied by off-setting increases in the false negative percentages. The biological systems' performance in the luggage test with respect to false positive and true negative percentage remained relatively unchanged compared to the standard target response test as did the IMS systems.

The "other" systems' performance in terms of true positive and false negative percentages was relatively unchanged between the standard target response test and the luggage test. In fact, performance actually increased slightly in the luggage test for these two measures of effectiveness. The false positive and true negative data, however, shows a significant decrease in performance in the luggage test compared to the standard target response test.

Conclusions

The development of repeatable narcotics particle and vapor standards has been completed. To date, the optimum cocaine standard is a dry mix of sieved cocaine particles and silver-coated nickel particles. For heroin, the optimum standard, is a dry mix of sieved heroin particles and silanzied glass beads. Currently the only vapor standard in use by the NDTA team is the INEEL vapor generation for cocaine and heroin. Other vapor generators have been developed but have not been as throughly investigated, by the NDTA team, as the INEEL system.

Three reports, subject to *Law Enforcement Sensitive* distribution, have been published which have evaluated 12 different narcotics detection systems in a variety of laboratory and quasi-operational environments. Three types of tests have been conducted; performance verification, target response and a quasi-operational test of a luggage queue. Approximately 20 different field tests have been conducted over the past seven years, evaluating some of these same devices in a variety of field conditions. These conditions have included hot dry climates typical of the US/Mexico border, hot humid climate of South

Luggage Test Results Averaged by System Type

	Luggage Test: True Pos %		Luggage Test: False Pos %		Luggage Test: True Negative %		Luggage Test: False Negative %	
	Cocaine	Heroin	Cocaine	Heroin	Cocaine	Heroin	Cocaine	Heroin
IMS	**81.25**	**50.00**	**20.10**	**23.23**	**79.90**	**76.78**	**18.75**	**50.00**
Bio	**33.33**	**37.50**	**0.00**	**0.00**	**100.00**	**100.00**	**66.67**	**62.50**
Other	**56.25**	**37.50**	**57.15**	**25.00**	**42.85**	**75.00**	**43.75**	**62.50**

Florida and Puerto Rico, more moderate climates of San Diego and Los Angeles, to other extremes of temperatures in Canada. One common theme noted in most of these tests was the difficultly, in applying the results of laboratory tests to field conditions. Many times, although the equipment performed admirably in the laboratory, the inability to overcome logistical and environmental factors such as weather, contamination, and power constraints, diminished the system's utility in the field. Another equally significant implementation issue for these detection systems has been the difficulty in providing adequate training and resources to field operations and end-users.

Throughout the preliminary planning leading up to the first NDTA test, a critical decision was made not to rank any of the devices and not provide any conclusions or recommendations, but rather to report out only the raw results of each of the tests. The rationale for this, was that end user applications and requirements are simply too varied to address in their entirety and a larger number of agencies and end users would be able to benefit from the data if it was presented in a raw form that each agency could then evaluate in the context of their own application.

These tests were designed based, largely, on the extensive field testing experience of the independent NDTA team members. The NDTA team is convinced that the loading ranges selected in the simulated field tests are representative of the "real world" conditions.

The independent NDTA evaluation team holds the opinion that the most important measures of effectiveness, *without regard to system costs*, are the minimum detection limit, hit percentage (note that miss percentage equals 100 minus the hit percentage), and false positive percentage. Clearly, a system operator wants to have a sensitive drug detection capability that detects a high percentage of hits, but does not produce a large number of false positives. These features must be seriously considered based on the intended application, environment, and available resources.

All NDTA assessments to date have considered only cocaine and heroin hydrochloride targets. These drugs were and are considered by U.S. Customs as the highest priority in the interdiction efforts. This was not meant to lessen the impact of other drugs, but, during the NDTA planning stage, it was felt that other drugs, especially marijuana were more readily detectable by canines, and not very well detected by instruments. In response to the recent rapid introduction of other designer drugs, often made domestically but now seen as smuggling threat, the NDTA team is considering expanding the assessments to include marijuana, hashish, methamphetamine, amphetamine as well as others. There are no plans at this time to include drug precursors in any of the upcoming NDTA evaluations.

Future Plans

The independent NDTA team intends to conduct these assessment tests approximately twice per year. Announcements soliciting interested parties with applicable technology will be published in the Commerce Business Daily (CBD). Respondents will be given a documentation package outlining the specific details and operational procedures of the testing cycle and will be able to submit questions or comments on the program. The NDTA Team will consider the respondents' concerns and finalize a test documentation package. The test documentation package will be mailed to the responsive candidates well in advance of the test date. The tentative biannual testing schedule may be adjusted based on advancements in state-of-the-art technology and availability of funding. Additionally, field tests have been, and will continue to be, conducted with selected devices to better assess the utility of the technology.

Currently, the standard tests outlined in *the Testing Methodology and Measures of Effectiveness* section of this report are expected to be conducted with only minor changes. That is, *quantitative* standardized tests will be conducted to determine minimum detection limit, hit percentage, miss percentage, false hit percentage, true negative percentage, and examination rate. Also, *qualitative* tests will be performed to gauge portability, ease of operation, operator qualifications, support requirements, user manual utility, and recurring and operating costs. Prior to conducting a planned forth round of tests for particle detection systems, the NDTA team plans to conduct an assessment based on similar quantitative and qualitative MOE's for vapor detection systems.

Probably the most glaring weakness of most approached to narcotics detection is the lack of understanding of the basic dynamics of

Laboratory Tests

Round 1 Testing (Particle Systems) - November 1994	**4 Systems**
Round 2 Testing (Particle Systems) - January 1996	**5 Systems**
Round 3 Testing (Particle Systems) - November 1996	**4 Systems**

Field Tests

Over 20 different field tests have been conducted at the following locations, incorporating emerging detection systems into real operational scenarios.

Argonne National Laboratory, IL
Dulles International Airport, VA
El Paso, TX
Ft. Huachuca, AZ
Houston, TX
JFK International Airport, NY
Miami/Ft. Lauderdale, FL
New Brunswick, Canada
Otay Mesa Cargo Facility, CA
San Juan, Puerto Rico
San Ysidro Border Crossing, CA
Wilmington, NC

vapor/particle/aerosal transport phenomena. Present narcotics particle-based systems rely on trace contamination involved in the drug processing, shipping and distribution network. Newer vapor detection systems may be able to detect processing compounds and decomposition products, as well as the parent drug itself. But how these compound vapors including aresols interact with the parent compound in a myriad of packaging techniques, under varying environmental conditions in a variety of conveyance is not well understood. In a further attempt to define some of these basic parameters, efforts relating to the utilization of vapor and particle generation techniques are underway and will continue in order to assist in understanding the basic particle/vapor interactions.

Operationally the basic assumption of separating sample detection strategy from the NDTA assessment in an attempt to reduce a variable that was essentially uncontrollable may have over simplified conditions. The NDTA team is planning to investigate several novel detection strategies and determine whether or not these strategies can be quantitatively assessed. Additionally the team wants to reassess the non-quantitative detection output, including parameters that are operator related. In particular, the training and maintenance requirements of each instrument need to be better defined in order to integrate the best suited technology based tools for a particular application and achieve the maximum performance and life span of each specific instrument as well as maximum return on the technology investment overall.

Research and development efforts aimed at improving sampling protocols for narcotics particles, aerosols and constituent vapors need to continue. In addition to the need for smaller, faster, better detection systems, efforts must also continue in areas such as sampling methods, sampling efficiency, and collector types, including effective pore size for each narcotics detection scenario. Ground truth determinations have yet to be developed in the area of understanding of the dynamics and transport phenomena of the constituent narcotics and associated breakdown products that may be useful for standoff detection.

There is a need to evaluate new narcotics detection systems that may be in the developmental phase, as well as existing systems with improved modifications.

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EFFECTIVENESS INDICATORS FOR DRUG INTERDICTION TECHNOLOGY

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This paper is a progress report of the U.S. Customs Service's effort to establish measures of effectiveness of the advanced technology being developed and deployed for drug interdiction.

OBJECTIVE

Customs drug interdiction mission is twofold. First and foremost is to stop drugs from entering the country and second, to minimize the affects of narcotic inspections on innocent commercial traffic.

Within this mission there is a need to determine the effectiveness of the devices that technology is bringing to bear on the problem of contraband detection. This study will try to find performance effectiveness indicators of the technology contributions to the inspection process and seizures, which can be quantified. The commitment of resources, personnel, funds and management requires a to determine the value that new devices make to drug interdiction. As the cost, space, and training for these new technologies grows, the importance of measuring their effectiveness grows too.

The primary objective of this study is to develop the means to quantify the effectiveness of the inspection devices developed by the USCS for the interdiction of drugs concealed in commercial cargo conveyances such as trucks, cargo containers, and railcars. Secondary objectives are to develop analysis tools that would contribute to decisions that could increase the quantity and quality of inspections, facilitate inspections of innocent vehicles, and reduce the need for intrusive damaging examination techniques. A by- product of this work is expected to provide guidelines for the data collection of the operations of new devices and equipment in the field for use in future evaluations.

GENERAL APPROACH

There are a number of possible measures of effectiveness. There are some that can be categorized as seizure-based measures of effectiveness. These are measures that use the number of seizures made and the amount of contraband seized as part of a yardstick. In various forms they are presented as success if seizures go up and failure if seizures go down. There is a basic conceptual error inherent in these indicators. That is that there is no way to determine whether these numbers are meaningful since the amount of drugs that entered the country and could have been seized is unknown. Attempts to estimate this quantity have included production estimates, hospital statistics, and the street price. However none can be accepted as valid estimates.

There are a large number of factors that can affect performance and many are beyond Customs control. Any Customs response to smugglers choice of route, conveyance type, entry point or concealment technique is quickly observed and countered. The Truck x-ray in Otay Mesa has been the only operational truck x-ray along the Southwest Border (SWB) until recently. A smuggler can alter routes to non truck x-ray equipped POEs (port shopping), use alternate transportation means (cars, vans, air, people, and rail), or time of day to fit the x-ray's operations. With the expansion of the Truck x-rays to other POEs, a smuggler's alternatives will be reduced along the SWB.

Seizure reports frequently, but not always, contain information that allows the role of each inspection device in contraband detection to be separately analyzed and can therefore contribute to technology effectiveness measurements. However much of this information is contained in the narrative portion of seizure reports (as opposed to the formatted portion). It is now being captured and incorporated into a seizure database tailored to the issue of performance. It is expected that any analysis would closely represent the actual inspection process that leads up to each seizure. One outcome of this effort will be suggestions for modification of the seizure report format.

A second set of possible measures of effectiveness can be categorized as inspection-based. These relate to the inspection process used on many vehicles. Inspections cause delays and in some cases damage to innocent vehicles. Customs' objective is to maximize the number of threat vehicles inspected while minimizing delays and damage to innocent vehicles. Inspection effectiveness is judged by this objective. This effectiveness category focuses on finding performance characteristics that provide high quality examinations in a minimum amount of time and are non-intrusive. Quantifiable characteristics are examination time, examination quality and damage affects on vehicles and cargo.

To determine the effectiveness of a particular device, such as the Truck x-ray, data is needed that separates one device's performance from the performance of others. This information, as indicated previously, is frequently but not always, in seizure reports, including references to the tools used to find the drugs, how they were used, the inspection sequence, the concealment location of the drugs, and the reasons the vehicle was originally targeted for inspection. For inspections that do not result in a seizure, this information is not generally recorded nor is it a Customs requirement. It is at the discretion of each POE to record inspection data for its own use. Otay Mesa has maintained excellent records of all inspections and this data is being computerized for application to effectiveness indication calculations. It is desirable to compare inspection data before and after the introduction of a new device. However this type of data has not been found.

Inspection based effectiveness is the analysis of a number of possible measures of effectiveness using these detailed inspection records. Databases of this information are being built now. The selection of Otay Mesa for the initial study of effectiveness was partially based on the extensive records that have been kept for each type of inspection, Block Blitzes, intensive exams and truck x-ray exams. These records are handwritten and require extensive data input. Several months of data have been procured for a trial test of this approach. These records will also be used to determine the feasibility of collecting data in daily operations.

It is recognized that each POE has its own unique attributes such as its commercial cargo traffic (land, sea or air), the type and quantity of vehicles to be inspected, the types of cargo to be inspected, the Customs resources available, the inspection procedures in use, the data collection methodology, and the targeting methods employed. Otay Mesa has been selected for the initial case study because:

1. It has had the truck x-ray in operations for two and one half years. The truck x-ray has recently been installed at Calexico and is being procured for other Southwest Border POEs.
2. It uses all the advance technology devices in all drug inspections
3. Its inspectors are trained and have experience in the use of all devices
4. It has records of the selection (targeting) process for each inspection.

5. It has extensive records of each type of inspection performed for several years and the targeting methods used.

Subsequent to Otay Mesa analysis the plan calls for the analysis of each POE receiving a truck x-ray on a before and after basis. Inspection data collection that is currently ongoing is being investigated at these POEs. Instituting modifications will follow this, if needed, when the truck x-ray is installed.

INSPECTION PROCESS

This is an explanation of a typical inspection process conducted to detect contraband at the Southwest Border. Each POE is responsible for its own inspection process within guidelines provided by U.S. Customs Service Headquarters.

TARGETING

The first step in the inspection process is the selection (or targeting) of a conveyance to be examined. Customs has developed several types of analysis teams that provide targeting capabilities at POE. In addition automated information systems that analyze information about shipments, shippers, country of origin, importers and exporters and recommend candidates for examination are employed at several POEs. These systems require that shipping information be available in advance of arrival of the vehicle at a POE. Therefore automated systems have been applied, initially, to seaports where manifests are available days before ship arrival. Any study of inspection effectiveness must consider the targeting process.

The Customs targeting teams include the Intelligence Collection and Analysis teams (ICAT), Cargo Analysis research Investigative Teams (CARIT), Document Analysis Units (DAU), Operational Analysis Staff (OAS) and Contraband Enforcement Teams (CET). The automated analysis systems include the Automated Targeting System (ATS), the Cargo Container Targeting Information System (CCTIS), and the Target Information Management System (TIMS).

INSPECTIONS

When a truck arrives at the primary gate of a land border POE, the primary inspector is responsible for the targeting decision for a narcotic examination. He uses visual observation, behavioral analysis, the TECS Lookout list, results of the targeting process, or has received information from sources outside of the POE. (Customs refers to this externally generated information as "Prior Information"). The Primary Gate Inspector can randomly target a vehicle at any time. A vehicle can be sent to a dock for an intensive narcotic exam, released to the exit or, if it is Otay Mesa or Calexico, sent to the truck x-ray. Vehicles released to exit may be stopped while still in the POE and subjected to a STOP (Southwest Border Team Oriented Processing) examination described below.

NARCOTICS INSPECTIONS

The conduct of narcotic exams varies between POEs, depending on the perceived threat, and available inspection resources. However there is a Narcotics Interdiction Guide that provides a uniform standard of enforcement in the performance of narcotics examinations. An exam consists of two parts; the vehicle itself, loaded or empty, and the cargo if the vehicle is loaded. The Guide specifies a "six-point" inspection plan for all trucks that covers all parts of a truck and requires a canine inspection. If there is a cargo, part of the cargo must be devanned in order that the inside of the truck can be examined.

For loaded trucks, at least 20% of the cargo is required to be unloaded and physically examined, non intrusively if possible, or opened, drilled, probed, weighed, and viewed if not. The 100% exam is the ultimate inspection that requires the devanning of the entire cargo and the inspection of 100% of it. Variations on these examinations are at the discretion of each POE.

In order to adequately represent the different levels of inspections, Customs has defined a set of requirements for each type of inspection. There are "100% Narcotic Exams" that require 100% cargo inspection if loaded with a six point examination of the truck itself. There are "Enforcement Narcotic Exams" that require a minimum of 20% cargo inspection if loaded, and a six point examination. Truck X-ray examinations of empties fall into this category. Any exam that does not meet the full six-point exam requirement is termed a "Narcotic Screening".

A STOP Examination is typically used on a group of 10 to 20 trucks, randomly stopped as a group and quickly inspected. With an inspection rate of about 2 minutes per trucks, examinations are conducted by teams of inspectors who can use busters, canines, visual inspections, mallets, distance measuring range finders, fiber optic scopes and drills. Inspectors conducting these exams can direct a vehicle, deemed suspicious, either to an intensive dock for an exam or to the truck x-ray. A typical team consists of four inspectors including a canine handler. This process has various names such as Stop Blitz, BLOC Blitz, Secondary Express, Pre Primary, and Post Primary, etc. They are conducted somewhat differently at various POEs but are essentially similar.

Trucks sent to the Truck X-ray from the Primary Gate, Bloc Blitzes or occasionally from an intensive dock are examined in about 10 minutes, excluding waiting time. The x-ray images are quickly scanned and results determined. The process is completely non-intrusive. Detection of any suspicious cargo is cause for the vehicle to be sent to an intensive dock for a physical search. The Truck X-ray was originally intended to detect contraband in truck structures, loaded or unloaded, excluding the cargo. A x-ray of an empty truck is equivalent to a six- (6) point exam without a canine team. Approximately 50% of the trucks entering the U.S. from Mexico are empty and have been a major smuggling vehicle. There are a limited number of locations in an empty truck where large quantities of drugs can be concealed and the truck x-ray examines them all. With the accumulation of concealment location information from seizure reports, examinations of trucks have become more effective.

Trucks sent to an inspection dock for an intensive exam are physically searched inside and out. Cargo is devanned and examined. The duration of an intensive exam is dependent on whether it is empty or loaded and if loaded what the cargo is and the cargo examination process. The unloading and loading is done by crews hired by and paid by, the shippers or brokers and are not Customs employees. Palletized cargo can be devanned quickly. If appropriate the pallet x-ray is used to inspect the cargo. All tools are used including canine teams, pallet x-rays, busters, range finders, fiber optics, mallets, drills and the truck x-ray.

The exam definitions vary for empty and loaded vehicles. For instance a six- point exam of an empty vehicle is a "narcotics exam" and is reported as such. However for a loaded vehicle, unless the cargo is at least partially unloaded and examined, the inspection of the vehicle itself is not sufficient to be counted as a "narcotics exam" and is not included in examination statistics. This differentiation is important and bears directly on performance measurements when applied to such devices as the truck x-ray. A x-ray of a loaded vehicle is not a narcotics exam. The introduction of the Truck x-ray has made it apparent that the current inspection definitions require review

POSSIBLE EFFECTIVENESS INDICATORS

There have been many suggested measures of effectiveness. The following list is solely intended as a starting point.

Seizure-based indicators are included with the understanding of their shortcoming. The inspection effectiveness indicators that appear to have the best chance of utility are associated with the quality of examination, rate of examination, and level of intrusiveness. As seizure-based effectiveness measures are generally accepted, this study focuses on inspection-based technology effectiveness indicators and POE effectiveness as affected by Technology. However in a broader sense changes in POE inspection effectiveness may be indirectly reflected in changes in smuggling characteristics such as changes in transportation methods and changes in routes. The Seizure database being developed will be able to provide some insight into this issue.

Technology Utilization (each type of fixed or mobile device)

- Equipment Usage (number procured, number in use, number maintained, frequency used)
- Use in seizures (# of inspections, amount seized, target process, initial detection/confirmation/location
- Thruput (examinations per unit time, affect on facilitation)
- Quality of inspections per unit time
- Conveyance sections accessibility for inspection
- Inspection cost per examination
- Amount and category of cargo examined
- Hazardous cargo inspections.
- Damage to conveyances/cargo

Inspection Process (integrated inspections)

- Targeting Methods affects on Technology Effectiveness
- Inspection Sequence effectiveness (detection vs. confirmation vs. location)
- Seizures per number of inspections (technology affects)
- Seizures by type of inspection
- Number and type of claims/torts caused by inspection tools
- Cost per inspection

POE Specific

- Variations in technology utilization and results
- Traffic pattern changes related to inspection technology effectiveness
- Inspections (targeting, type, number, examination duration, tools used)
- Seizures (amount seized, # of seizures, concealment locations, technology used)

PRELIMINARY RESULTS

The following section presents some very early results of analysis that is possible in the near term. It is preliminary due to the data collection problems encountered the lack of adequate information in seizure reports and the time needed to define and create the databases. The data is actual data recorded at Otay Mesa. However the amount of data thus far entered into the databases used for the results shown is very small in comparison to the amount that has yet to be entered.

Southwest Border Cargo Traffic

To put the results in context, a description of the cargo carrying traffic entering the U.S. from Mexico is presented. Traffic from Mexico has increased greatly. In 1994, 2,714,667 commercial cargo vehicles (trucks and railcars) entered the United States from Mexico, 48% of which were loaded with cargo. By 1996 this had increased to 3,545,839, an increase of 30%.

Southwest Border Inspections.

Along the Southwest Border, in FY94, Customs conducted 668,698 cargo vehicle (empty and loaded) examinations. That year there were 8 seizures made (cocaine and marijuana) weighing 3,998 pounds. The Inspection to Seizure ratio was 83,587 exams per seizure. By FY 96 there were 812,038 examinations conducted that resulted in 56 seizures, weighing 39,741 pounds. The Inspection to Seizure ratio had decreased to 14,500 exams per seizure, an improvement of almost 600%. In spite of a huge traffic increase of 830,000 more vehicles, Customs was able to examine 143,000 more trucks in FY 96 than in FY94 and increase the number of seizures by 700%. During this period Customs was changing inspection procedures, such as Operation Hardline, and increased the use of technology such as busters, pallet x-rays and the truck x-ray.

Otay Mesa Inspections

The number of commercial cargo vehicles entering the U.S. through Otay Mesa increased from 331,045, in FY94 to 516,384 in FY96, an increase 185,339 or 56%. In FY96, Otay Mesa was able to conduct examinations on 3% of the loaded vehicles and 38% of the empties. The truck x-ray contribution was about 10% of all inspections. More definitive information will be available on the truck x-ray performance in the future.

The Truck X-ray started operations in Otay Mesa in FY95. Using seizure data as a measure of effectiveness, that year Otay Mesa made 27% of all seizures along the Southwest Border. This decreased to 13% in FY96. However in the first nine (9) months of FY97, there have been 53 seizures in cargo vehicles along the SWB and Otay Mesa made 21 of them. The truck x-ray is credited with 15 of the 21 Otay Mesa seizures (70%) and almost 30% of all SWB seizures. Interestingly, in FY94, the California POEs (Otay Mesa, Calexico & Tecate) accounted for 75% of all SWB seizures. By FY96 this was down to 11%.

To explore the truck x-ray's effectiveness, SWB FY96 seizure reports provided the contraband concealment locations. A grouping of the concealment locations is shown in Fig 1. Of the 56 seizures 10 were made in cargo, while 42, or 75% were found in the tractor/trailer itself. Since the truck x-ray was originally intended to detect contraband concealed in trucks, whether empty or loaded, it is likely that the truck x-ray will be successful along the SWB. This is particularly valid for empties and for loaded vehicles including some cargoes estimated at 20% of the laden vehicles x-rayed.

From the Otay Mesa Cargo Daily Summary Reports, an initial database of Cargo Facility Daily Statistics for April 1995, April 1996, January 1997 and February 1997 has been created. These reports are summaries of the number and type of inspections conducted each day. During these four months 78,120 laden vehicles and 83,377 empties entered Otay Mesa.

There were 3,295 intensive narcotic examinations conducted on laden vehicles and 1,626 on empties. Another 2,422 laden vehicles were x-rayed and 9,853 were examined in Block Blitzes.

Of the 83,377 empty vehicles entering through Otay Mesa 1,751 were given intensive exams, 4,672 were x-rayed and 31,357 were examined at Block Blitzes, a total of 37,780 empty vehicle examined.

There are several inspection devices developed by Customs that are in use at Otay Mesa. These are a truck x-ray, pallet x-rays, range finders and fiber optic scopes. Each inspection at Otay Mesa is detailed in a record that includes the tools used and results. This data is now being entered into an inspection tool database. It is too early to for any final determination of which Measures of Effectiveness are needed. However the usage of any device can now be calculated. Usage is one indication that inspectors believe that a device is effective. The data is in the Otay Mesa Intensive Examinations records, detailed handwritten inspection records of each inspection. This data are being entered into a computer database. A much more detailed analysis of the use of technology is planned.

INITIAL CONCLUSIONS

The use of seizure reports to measure the effectiveness of technology will require a significant change in the level of detail describing the inspection process that led to each seizure and the contribution that each inspection device made. Present seizure reports contain some of the information needed. However the information is in the narrative portion of the report and is not consistently included. Modification of the seizure report is required to assure that the required information is recorded. It is likely that the contribution each device makes can be separated into meaningful categories such as initial detection, detection confirmation, and concealment location(s) resolution. It is expected that with seizure report modification, seizure-based measures of technology effectiveness will continue to be used with that caveat that the amount of drugs that did get through will not be known.

Examination time can be a direct determinant of effectiveness between various inspection methods if quality is assumed to be equal. If not, examination time is valuable in association with inspection quality. There is no data available that rates examination quality for any device or combination of devices. Testing, to determine quantitative value of inspection technology relative to other inspection methods is desirable but may be impossible to conduct. A survey of inspectors to obtain subjective opinions as to the relative value of each inspection technique or combination techniques is being implemented. The third measure is the measure of the level of intrusiveness imposed by each examination method. Technology has greatly reduced the amount of damage caused by inspections but this has not quantified. The damage caused by intrusive examinations, such as drills, can only be estimated, is rarely reported and is non-quantifiable. But non-intrusive inspections, of a quality equal to the devanning, opening and reloading of cargo, or the drilling of a wall or tire, would improve the acceptance of inspections by innocent drivers and shippers.

Effectiveness based on inspection quality; examination time or non-intrusiveness requires a great deal of data. At the present time detailed inspection records are not a Customs requirement but are kept at the discretion and for the benefit of individual POEs. Standardizing and formalizing this type of data is a future requirement. Specific data recording requirements will be recommended as the need becomes apparent.

Usage, as a measure of effectiveness is a valuable indicator of the confidence that inspectors place in technology. The truck x-ray, the buster, and the range finder are in constant use at Otay Mesa as revealed in inspection records. The pallet x-ray provides a non-intrusive means to examine cargo and records are now available to the frequency and under what conditions it is used.

Otay Mesa has detailed records of all inspections. Their sufficiency for effectiveness calculations will be determined after the data has been computerized and applied to various effectiveness measures. Preliminary results are encouraging. These records may be a model for the records for other POEs.

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ABSTRACT

U.S. Customs technology development efforts in counter-drug activities are well-known. What is not as well-known are the uses of counter-drug technologies for other non-intrusive inspection missions of the Customs Service.

Customs missions are many and varied. Customs inspectors at U.S. border locations enforce 400 laws for as many as 40 government agencies. Their activities support non-intrusive examiniation of both inbound and outbound cargo, passengers/pedestrians, and a variety of conveyances including rail, aircraft, and land border corssing vehicles. Since volumes of traffic are immense an personnel resources limited, technologies developed for counter-drug pruposes are greately enhanced in value for border search if they have other applications as well.

Among the many missions of Customs are the following:

- Drug Interdiction
- Anti-Terrorism
- Duty Assessment
- Nuclear Nonproliferation
- Enforcement of Currency Laws
- Export Controls (Exodus)

This paper will discuss Customs recent effort to develop and field technology that has multiple applications and is aimed at informating the R&D/scientific community that the develoopment of equipment with multiple applications will be viewed positively by the Customs Service in its' procurement actions.

MULTI-USE TECHNOLOGIES TO SUPPORT U.S. CUSTOMS MULTIPLE MISSIONS

U. S. Customs technology efforts in the area of non-intrusive inspection date to the late 1960s with the introduction of X-ray technology into mail examination. Today, as then, Customs technology emphasis is aimed at the detection of drugs. This is the mission which is most familiar to the public and to those in attendance at this technology symposium.

The purpose of this presentation is to familiarize attendees with other missions of Customs, some of which have come about in the past two years, and the technology initiatives that are underway to support those mission responsibilities.

The primary focus of Customs efforts at the borders is the detection of contraband. Chart 1 depicts several examples of the types of contraband of interest in border searches. As noted, Customs responsibilities are both inbound and outbound. Of particular note in this list are the entries "nuclear materials" inbound and "explosives" outbound; types of contraband which are receiving renewed emphasis not only in the United States, but world-wide.

Chart 2, "The Environment," illustrates several operational "facts of life" that constrain Customs efforts in the search for and detection of contraband.

o Customs has many other responsibilities; e.g. clears commercial shipments; collects tarriffs.

o Customs enforces 400 laws for as many as 40 government agencies.

o Inspectors number approximately 7000; contraband enforcement team members number about 700.

o Legal requirements may constrain Customs from conducting searches; e.g. outbound mail.

o Immense traffic volumes require targeting techniques.

There are numerous ways to smuggle prohibited materials into the U.S. Chart 3 shows the potential contraband conveyances that Customs must screen before entry into the country. Coupled with this diversity of conveyances is the increasing volume of traffic that enters the country annually. Chart 4, "Windows of Opportunity," shows inbound traffic statistics for FY9 6.

With volumes of traffic so immense and personnel resources so limited, the developers of technologies in support of Customs should consider the various missions of Customs (in addition to the drug detection mission) and propose practical and affordable equipment with multiple detection capabilities. Chart 5 portrays many of the missions of Customs today and the technologies that Customs is pursuing for non-intrusive detection purposes; particularly X-ray, radiation and chemical detection.

It becomes immediately apparent that a given technology class, such as X-ray, has application across many mission areas of Customs. The same observation can be made for radiation and chemical detection. Likewise, for a given mission class, more than one detection method may be brought to bear. For example, drug interdiction can be aided by all three technologies. Each of the technologies cited brings its own capabilities: X-ray with its transmission and backscatter imagining, radiation detection with visual and audible alarms of the presence of radiation and maybe the identification of the isotope or class of isotope (i.e. medical, industrial, special nuclear material) and chemical detection with its spectrographic analysis which leads to particle or vapor identification.

For the balance of my presentation I will be discussing the technology initiatives underway at Customs aimed at applying multiple technologies to Customs various missions or one or more technologies to satisfy multiple missions. Many of those initiatives will be aimed at satisfying the requirements of the two most recent congressionally-mandated tasks: Anti-Terrorism and Nuclear Non-Proliferation.

The Anti-Terrorism task deals with assisting the FAA in examining baggage and cargo exiting U.S. Airports. The Nuclear Non-Proliferation task arises from Presidential Decision Directives 39 and 41, which mandate a national effort to reduce the danger of nuclear smuggling and the associated potential for nuclear terrorism.

Customs is in the process of developing and fielding a multi-mission "Super Van." The impetus for this development is the Anti-Terrorist funding provided to Customs in the wake of the TWA 800 tragedy. Chart 6 depicts the new larger mobile X-ray van with its usual transmission and backscatter X-ray technology, both useful in imaging explosives, drugs, currency and other contraband. To be mounted in the rear of the van is a chemical detector, an ion mobility spectrometer, capable of detecting minute explosive or drug particles. This technology has been tested extensively by Customs and other law enforcement agencies (including FAA) with good results. The FAA has certified the instrument that Customs intends to install as an effective explosives detector.

Finally, Customs will add a gamma ray radiation detection capability to the van. This added capability responds to the Nuclear Non-proliferation concerns of Congress embodied in the Defense Against Weapons of Mass Destruction Act of 1996, often referred to as the Nunn-Lugar Bill. The detector being added to the van, and other X-ray equipment as well, uses sensitive sodium iodide crystals to detect radiation emanating from nuclear weapons, special nuclear materials and other radioactive material.

While the new mobile X-ray van is being given a nuclear detection capability, Customs is in the process of upgrading its existing X-ray van fleet, and other X-ray screening equipment with the same capability. Also, as illustrated in Chart 7, Customs employs X-ray systems at passenger arrivals locations, cargo examination facilities, and mail facilities. Each of these systems will be outfitted with gamma ray detectors. When examining baggage, parcels or cargo for drug or other contraband, the inspector will be alerted to nuclear contraband at the same time with little or no extra effort involved.

While Customs has X-ray capabilities at its numerous mail facilities (and will soon have a radiation detection capability as well), action is underway to provide the mail facilities and the various consignment carriers with a chemical detection capability to detect explosive or drug particles. Chart 8 illustrates this capability. An ion mobility spectrometer mounted on a cart will afford inspectors at mail and consignment carrier facilities the ability to screen outbound parcels for explosives and inbound parcels for drugs. The dual capability is made possible by the "cart" capability which allows the chemical detection system to be wheeled to 'Inbound" or "Outbound areas. Also, the detector has the ability to convert from the explosive to the drug detection mode in seconds with the push of a button.

Finally, Customs is developing a portal radiation detector which will have the multiple capability of being able to detect weapons of mass destruction and special nuclear materials (U-235, U-233, Pu 239), other illegal radioactive material, as well as quantities of plant-derived drugs. The drugs which would be detectable include marijuana and hashish. Chart 9 shows an artist's concept of how the system would be configured. A previous pilot study conducted by Customs supported the proposition that Potassium 40 which concentrates within certain plant materials during the growing cycle, is detectable with sensitive sodium iodide detectors. This prototype system will be fielded along the Southwest Border for a period of test and evaluation in early 1998.

I have described how counter-drug, nuclear non-proliferation and anti-terrorist missions of Customs are being integrated into contraband detection systems with multi-technology capabilities. I would like to present a little more detail on how we are undertaking the nuclear proliferation task.

Chart 10 shows that Nuclear Proliferation is considered a prime National Security Threat at high levels of the U.S. Government. At U.S. borders nuclear smuggling becomes a major issue for Customs. "It is likely that front line inspectors will be the first Customs personnel to encounter radioactive materials."

The specific requirements for a detection capability at U.S. borders is shown on Chart 11:

o To detect special nuclear materials and weapons of mass destruction.

o To ensure safety of Customs personnel.

o To interdict hazardous radioactive materials.

Chart 12 shows the general approach we are using in our radiation detection program:

o Non-interfering with normal operations.

o Minimal technical challenge to use.

o Screen out innocent alarms.

o Call in experts.

The approach shown translates into tiers of radiation detection actions. These tiers are outlined on Chart 13:

o Initial detection of Gamma-Ray emitting materials
  - -- Radiation pager
  - -- Portal add-on to X-ray systems

o Isotope identification.
  - -- Hand-held, portable spectrometer

o Action per SOP.
  - -- Release object/person
  - -- Call in experts

Chart 14 describes the Radiation Pager, which was developed by a DOE laboratory. Customs has selected this instrument as the primary means to detect gamma rays. The concept for its use by Customs is to have it issued like a weapon or radio and to leave it powered on at all times. Customs inspectors, in the course of performing their many duties, would be screening persons, baggage and cargo for emitted radiation at all times.

Finally, technology has been identified to allow identification of radioactive isotopes in the field. A hand-held device (Chart 15) has been developed for use by non-technical personnel that will have a library of isotopes of interest to Customs. This instrument will allow Customs to make decisions in the field on whether to release an object/parcel/person based on the class of isotope or to call in the appropriate expert.

In summary, owing to the many missions of Customs (including recent added missions in antiterrorism and nuclear non-proliferation) , a fairly static work force, and increasing traffic volumes, it is essential, that where possible, technology systems satisfy as many missions of Customs as possible. This presentation has been meant to inform the R&D/scientific community that the development of equipment with multiple applications will be viewed positively by the Customs Service in its future procurement actions.

Chart 1

CONTRABAND

Examples

Inbound:

- Drugs
- Agricultural Products
- Child Pornography
- Trademark/Copyright Violations/IPR
- Nuclear Materials

Outbound:

- Currency
- High Technology
- Weapons of War
- Stolen Cars
- Explosives

Chart 2

U. S. CUSTOMS SERVICE OPERATIONAL ENVIRONMENT

- Contraband Detection is one of many duties
  - Tariff Collection, Import, Export Clearance, etc.
  - Other Agencies' Enforcement
- Personnel Constraints
  - Inspectors
  - CET
- Legal Constraints
- Inbound Traffic Volume

Chart 3

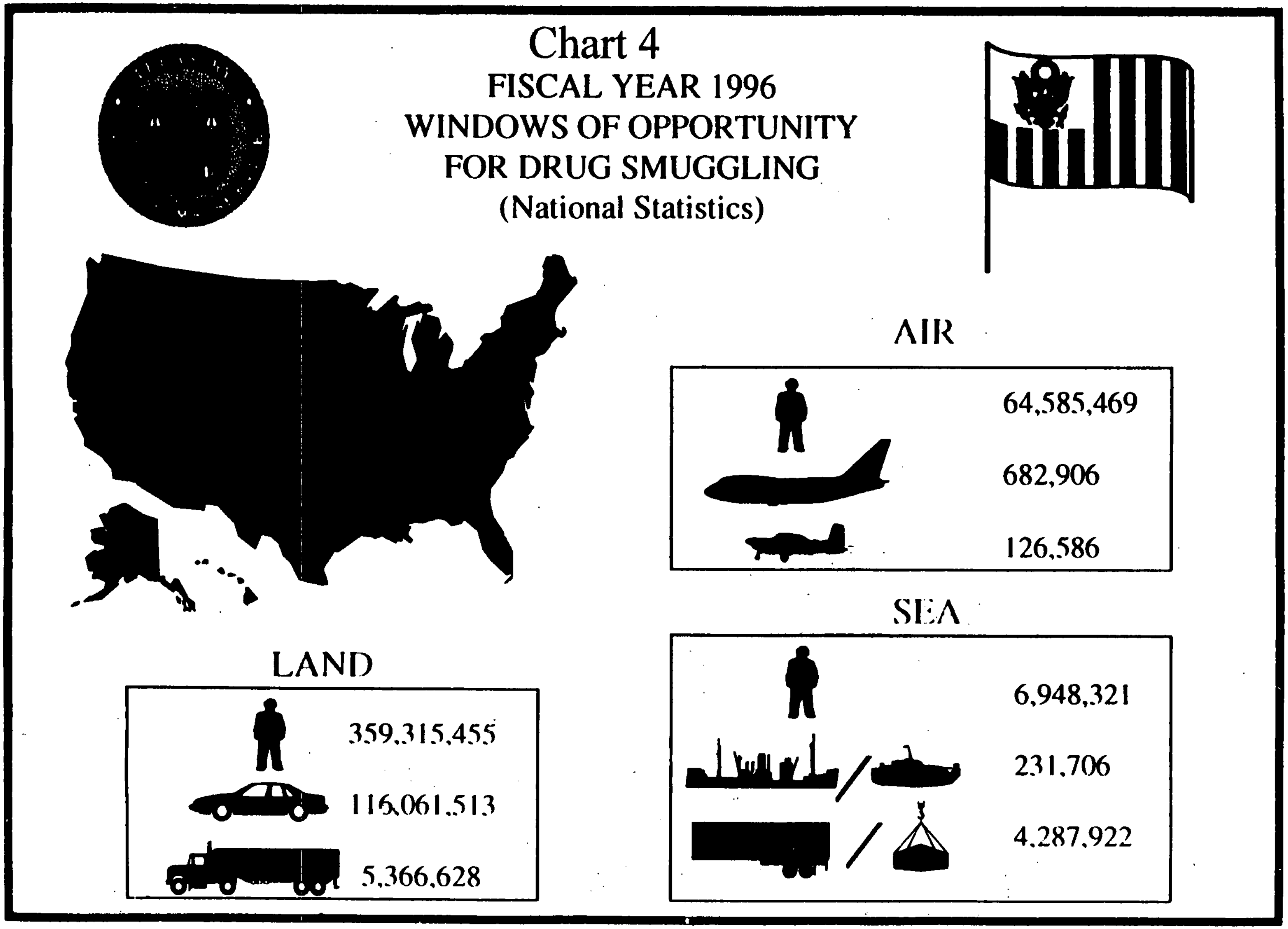
U. S. CUSTOMS SERVICE

In Search of

- Drugs
- Currency
- Other Prohibited or Controlled

In/On

Cargo Containers
Break Bulk Cargo
Vehicles
Aircraft
Vessels
Persons
Mail
Baggage
Rail



** Data Source: OMR Data Warehouse (November 4, 1996)

Chart 5

APPLICATION OF TECHNOLOGY TO CUSTOMS MISSIONS

Detection Technology

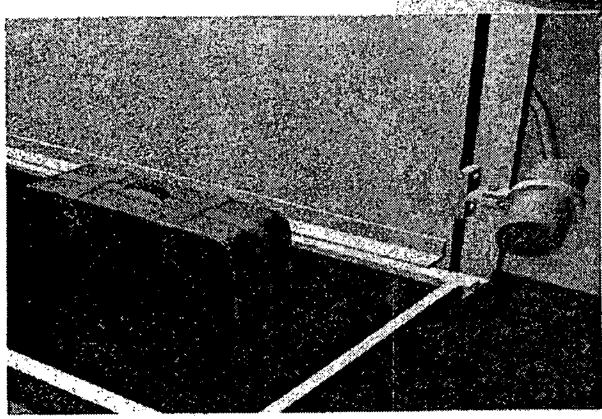
Mission:	X-RAY	RADIATION	CHEMICAL
Drug	X	X	X
Anti-Terrorism	X	X	X
Duty Assessment	X		
Nuclear Non-Proliferation	X	X	
Currency Law Enforcement	X		X
Export Controls	X	X	
Mail/Parcel Exam.	X	X	X

Chart 6

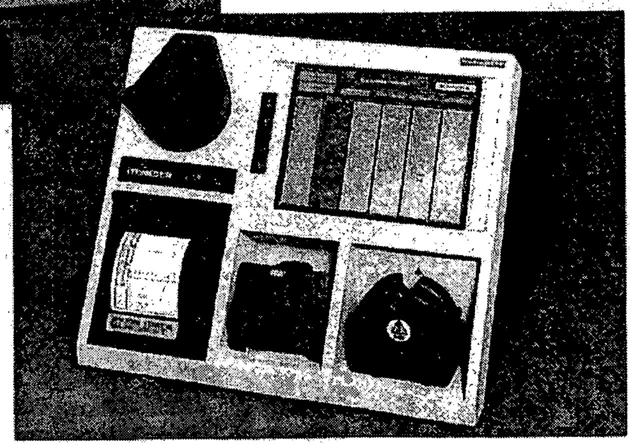
Customs "SUPER" Van

X-ray:
*Transmission
*Backscatter

Portable TECS



Radiation Detection

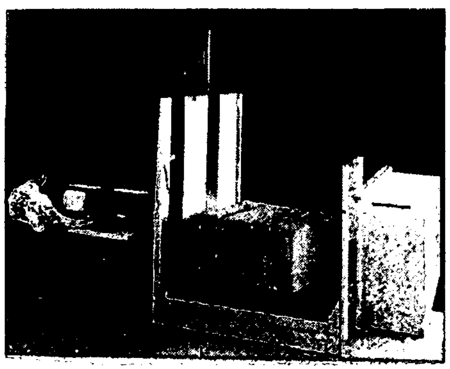


Chemical Detection

Chart 7

Upgrade To Fixed Site X-rays

Mail



Cargo

+

=

X-ray/ Radiation Detection

Airport

Chart 8

Mail/Parcel Examination

- Customs Mail Facilities
- Consignment Carriers:
  - Fed Ex
  - UPS
  - DHL
  - Emory
  - Burlington
- Drug Detection (Inbound)
- Explosive Detection (Outbound)

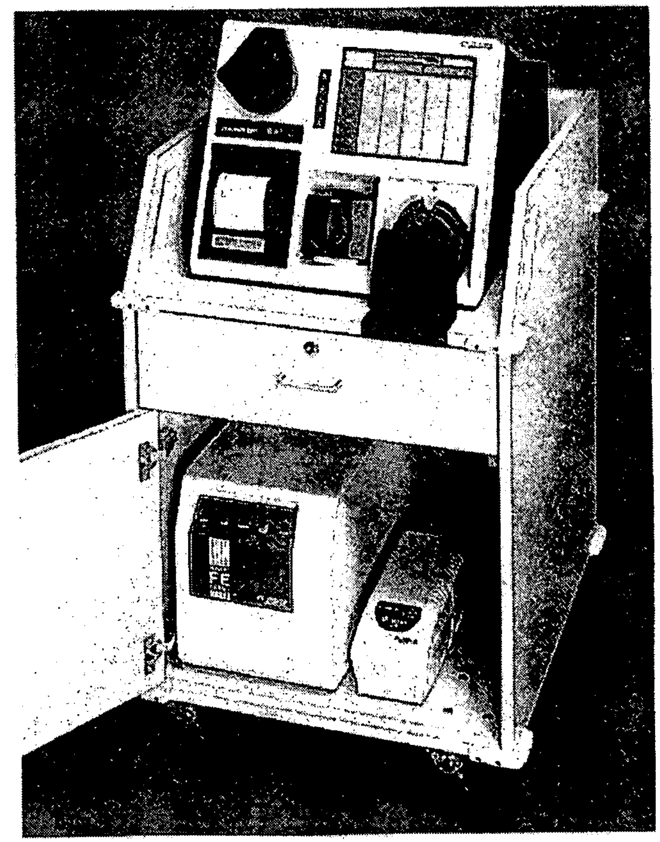


Chart 9

PORTAL RADIATION DETECTOR

- WMD/SNM
- Radiation Contaminated Products
- Plant Derived Drugs

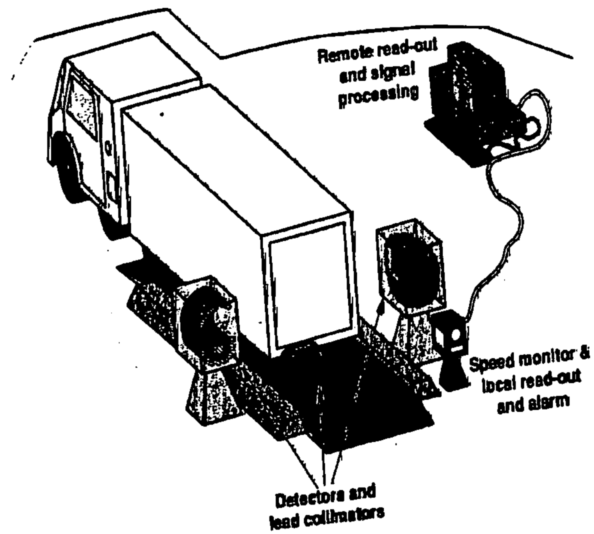


Chart 10

Prime National Security Threat

Nuclear Proliferation

- Nuclear Smuggling
- Nuclear Terrorism

"It is likely that front line inspectors will be the first Customs personnel to encounter radioactive materials."

Chart 11

Requirements for Detection Capability at U. S. Ports of Entry

- To detect special nuclear material and weapons of mass destruction
- To ensure safety of Customs personnel
- To interdict hazardous radioactive materials

Chart 12

Radiation Detection Program

U. S. Port of Entry

- Non-interfering with normal operations
- Minimal technical challenge to use
- Screen out innocent alarms
  - medical isotopes in people
  - known/labelled radioactive materials
    - lantern mantles
    - smoke detectors
    - ceramic glazes
    - camera lenses
    - irradiated gemstones
- Call in experts

Chart 13

Tiers of Radiation Detection Activity

I. Initial detection of Gamma-Ray emitting materials

- Radiation pager
- Portal add-on to x-ray systems

II. Isotope identification

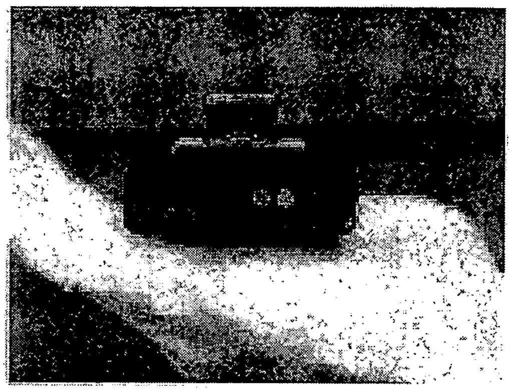
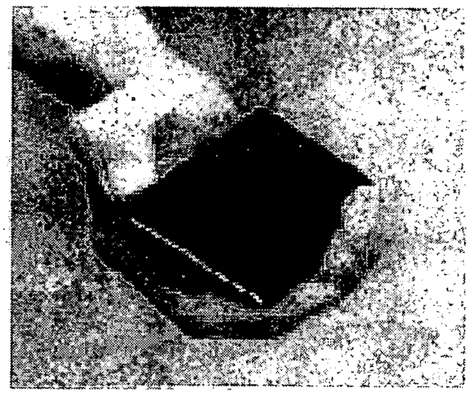
- Hand-held, portable spectrometer

III. Action per SOP

- Release object/person
- Call in experts

Chart 14

Radiation Pager

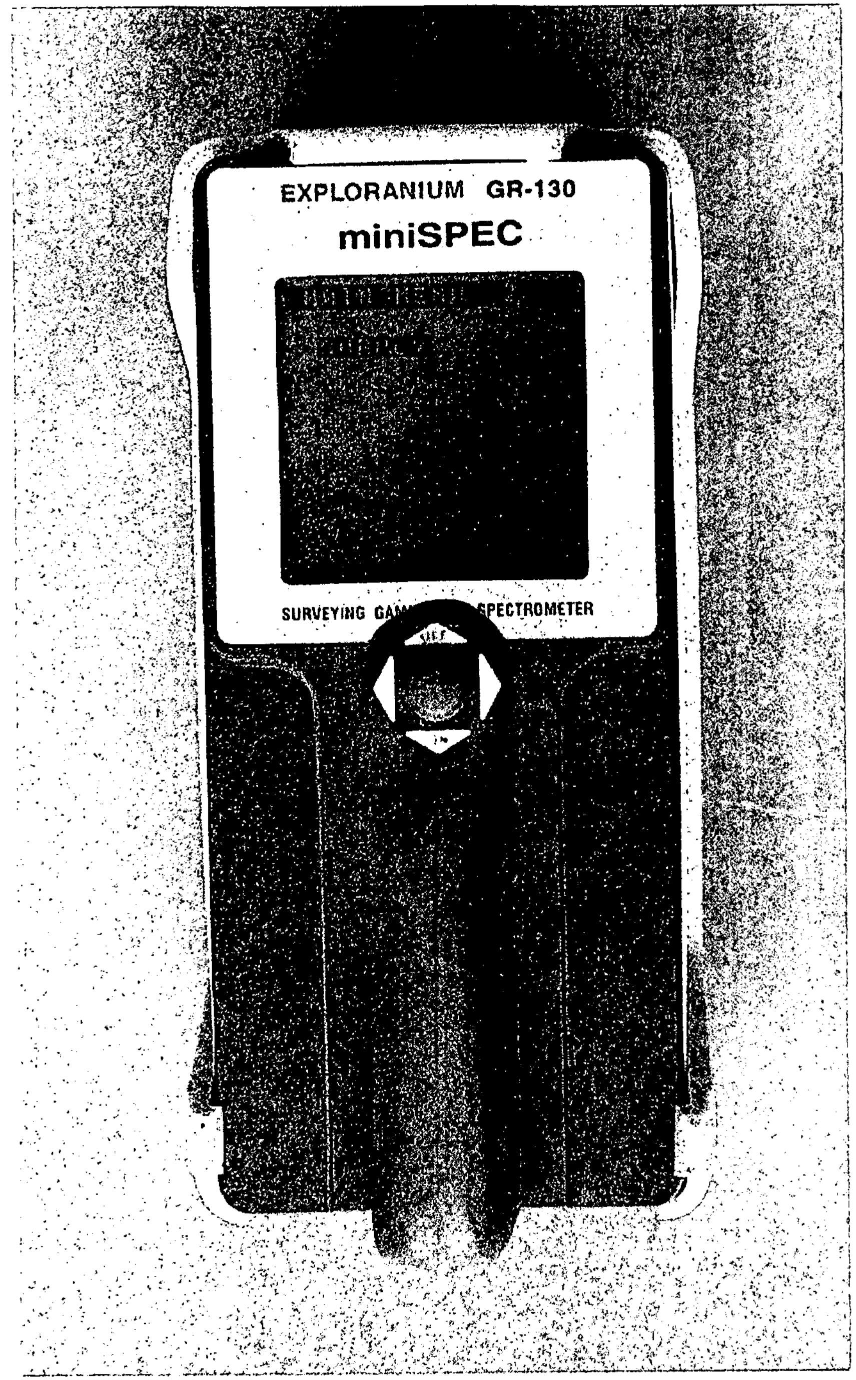
- Most sensitive radiation detector, for its size, known to be commercially available.
- Detects gamma or X-rays at 2-4 times background level.
- Alarms by flashing LED, vibrator or audio tone.
- Hands-off operation; carried in pocket or clipped to belt.
- Operates continuously for one year, using AA alkaline batteries.
- Localizes source of alarm with single digit LED, flashing LED or audio tone.

Chart 15

Radscan

Hand-held Gamma Ray Spectrometer

Model 100 Mini Ident



PERFORMANCE ASSESSMENT OF CABINET X-RAY SYSTEMS FOR NARCOTICS DETECTION

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ABSTRACT

As part of the Narcotics Detection Technology Assessment (NDTA) program sponsored by the Counterdrug Technology Assessment Center (CTAC), the performance of six different cabinet-size x-ray systems was evaluated quantitatively for the detection of cocaine packets in luggage and small boxes. The evaluations consisted of two parts. The first measured objective parameters such as resolution, contrast, and penetration using standard test fixtures. The second part measured operational performance using a series of quasi-operational tests. In these tests, packets of cocaine simulant were placed in randomly selected luggage and boxes. The objects were then scanned and a determination made as to the presence or absence of the simulant. Over 400 packages were tested with each x-ray system. The results were characterized in terms of the number of true positives and false positives. The results of the quasi-operational tests reflect a complicated combination of system and operator performance that make detailed comparison of individual systems complicated. We have used Receiver Operator Characteristic (ROC) curves to evaluate the performance of individual systems and in assessing the overall performance capability of these systems.

1. Introduction

The United States Customs Service (USCS) Applied Technology Division is coordinating independent technology evaluations of illicit substance detection systems. These studies, named the Narcotics Detection Technology Assessment (NDTA) Program, are sponsored by the Office of National Drug Control Policy (ONDCP) Counterdrug Technology Assessment Center (CTAC). The NDTA studies are intended to evaluate commercially available and prototype narcotics detection systems in both laboratory and field-simulation scenarios. These studies are conducted on a regular basis to provide interested federal, state and local law enforcement agencies (LEAs) with information regarding the performance of narcotics detection technologies.

This paper reports the results of a series of technical and quasi-operational tests of cabinet x-ray systems. The purpose of these tests was to assess the performance capabilities of x-ray scanners for narcotics detection in cargo and passenger effects at US ports of entry. In particular, luggage (suitcases, etc.), artifacts contained in airline luggage or carried by airline passengers, and small cargo containers (boxes and bags) were the subject of this assessment.

This evaluation was initiated by publication of an announcement in the Commerce Business Daily (CBD) dated February 1, 1995 seeking cabinet x-ray systems for narcotics detection. Respondents were provided copies of a management plan developed by the USCS. Comments and questions on the test procedures were invited, and a final management plan [1] was distributed to interested parties in March 1996. The test procedures, preparations, standards, and facilities for the current evaluation are described in that document.

Based on the management plan, a test plan was developed by Argonne National Laboratory (ANL) and USCS. The evaluations were conducted at ANL in two sessions during the period June 17 to July 19, 1996. Dr. Siraj Khan (USCS) was the x-ray assessment program manager. Dr. Bradley Micklich (ANL) served as the test manager. Test team members were provided by USCS, ANL, Revenue Canada Customs Excise and Taxation (RCCET), US Department of Agriculture (USDA), US Marshals Service, Federal Bureau of Prisons, Houston Advanced Research Center (HARC), and CTAC.

2. Objectives

The primary objective of the NDTA program is to quantitatively evaluate the detection performance of commercially available or prototype narcotics detection equipment. The results [2] of the present assessment are available to interested LEAs from CTAC on a "Law Enforcement Sensitive / Official Government Use Only" basis. The scope and frequency of future testing will be determined by ONDCP/CTAC and USCS as deemed appropriate based on advances in state-of-the-art narcotics detection technology.

The applications, requirements, and utility of x-ray systems for illicit substance detection are quite diverse. All of the x-ray systems evaluated are used to detect explosives, weapons, agricultural products, and a variety of other items in addition to narcotics. Inspection can take place under a wide range of operational and environmental conditions. Thus assessing the performance of x-ray systems for each application and under all the scenarios and conditions typically encountered by LEAs is impractical. Therefore, specific quantitative tests are carried out under controlled conditions. These results may then be extrapolated to a particular application and operational environment. Care must be taken in this extrapolation, however, since results obtained in a test for narcotics detection under one set of conditions may not be applicable to detection of other substances under different conditions.

To accomplish the objective of quantitatively evaluating each instrument's narcotics detection performance, the assessment tests were divided into two main segments. One segment involved the measurement of objective parameters such as resolution, contrast, and penetration using standard test fixtures developed for x-ray system evaluation. The second segment of the evaluation involved quasi-operational tests in which a cocaine simulant was placed in randomly selected luggage and boxes which were passed through each x-ray system. A large number of trials (> 400) were run to estimate the effectiveness of the systems in detecting different amounts of the simulant in varied backgrounds.

Examination of a package by an x-ray machine does not yield an unambiguous signature for the presence of narcotics. The image produced by an x-ray system requires a judgment to be made either explicitly (by operator determination of a threat) or implicitly (by use of a human-generated computer algorithm). It is not possible to completely separate the device from the operator. Therefore, the results of quasi-operational testing reflect the performance of the combination of the system, data acquisition and image processing algorithms, and the operator. Vendors were asked to provide operators for their own systems in order to avoid having operators who were unfamiliar with the equipment.

Periodically, the USCS has issued solicitations which establish requirements and operational performance criteria for cabinet x-ray systems to be used for narcotics detection at US ports of entry. It was not the objective of this evaluation to determine whether technical and operational specifications of a given x-ray inspection system meet or exceed those requirements and criteria, but rather to quantify a system's performance capabilities in a particular set of tests. Furthermore, no conclusions or recommendations were drawn on the relative or absolute merits of the systems evaluated based on the test results described in the evaluation report. The assessment team believes that conclusions and recommendations cannot be adequately formulated without relating the performance evaluation results to specific user applications, and user applications are simply too varied to address in their entirety. For example, in addition to narcotics detection, x-ray systems are also used for detection of explosives, weapons, agricultural products, and a variety of other items. Inspections can also take place under a wide range of operational and environmental conditions. While it is not practical to assess the performance of x-ray systems for each application and under all the scenarios and conditions typically encountered by LEAs, the results of these studies could aid a potential purchaser in the selection of a system appropriate for their application.

3. Technical Performance Tests

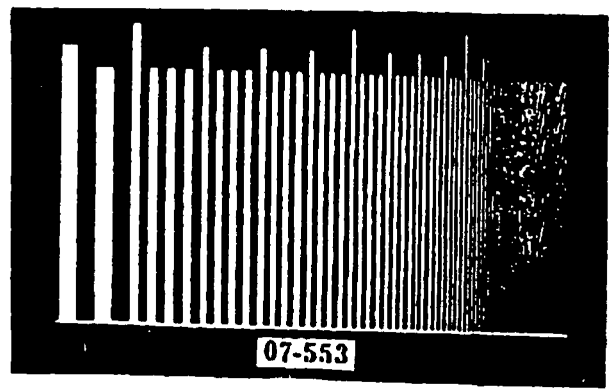
Testing Methodology

The technical performance tests consisted of a series of measurements of each system's resolution, contrast, and penetration. While all of the systems evaluated have a large variety of image enhancement features, in routine use the display should not require frequent adjustment of contrast and brightness. For the purposes of these tests, therefore, the operators were required to "normalize" the system settings to their satisfaction, and no further adjustments were allowed for the remainder of the test. The operators were provided with the test fixtures and were given the opportunity to use these fixtures to determine the settings they wished to use for the tests. Additionally, the magnification for each test pattern was that needed to give a full view of the total test object.

Resolution tests were used to determine the smallest detectable line details. Contrast tests were used to determine contrast dynamic range, to determine minimum detectable voids, and to determine contrast resolution for various densities. Penetration tests were used to measure the ability to see through thick objects. All tests used direct transmission x-ray images. Further information on the test fixtures employed is contained in Reference 3.

Resolution

This test used the medical line pair test pattern number 07-553 (Figure 1) and the wire gauge and shim penetrometer test pattern (Figure 2). For the line pair test pattern, the pattern was passed through the system, elevated six inches above the inspection table. The resulting image was analyzed to identify the line



Group	LP per mm	Group	LP per mm	Group	LP per mm
1	0.25	9	1.7	17	7.0
2	0.5	10	2.0	18	8.5
3	0.6	11	2.4	19	10.0
4	0.7	12	2.9	20	8.5
5	0.85	13	3.5	21	7.0
6	1.0	14	4.2	22	6.0
7	1.2	15	5.0		
8	1.4	16	6.0		

Figure 1. Medical line pair test pattern.

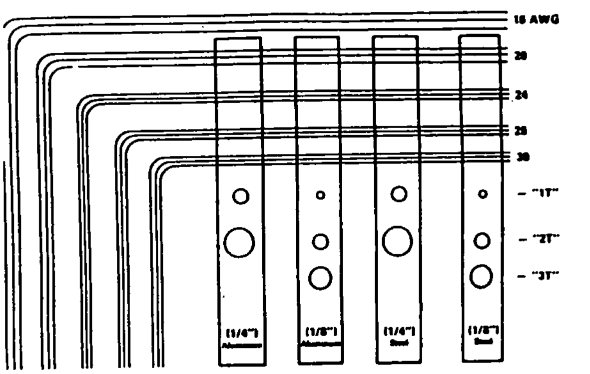


Figure 2. Wire gauge and shim penetrometer test pattern.

pair by group number which could be clearly discerned. This translates into the number of line pairs per millimeter which can be resolved, as indicated in the table accompanying. The wire gauge test pattern was used to identify the smallest wire gauge size for which the triplet wire pattern could be resolved. This was recorded separately for the horizontal and vertical directions. The wire sizes are given in AWG (American Wire Gauge), with higher numbers corresponding to thinner wires.

Contrast

Contrast tests used the ASTM F792 step wedge (Figure 3), the wire gauge and shim penetrometer test pattern (Figure 2), and the contrast test fixture (Figure 4). An image of the ASTM F 792 step wedge was acquired and, for each wire size, the number of the last step in which it was visible was recorded. Higher numbers mean that the given wire was visible through thicker steps. The shim penetrometer was used to determine which hole was visible in all four shims (a 1T hole has diameter equal to the shim thickness). The same test fixture was used to determine the wire gauge visible through the 1/4" aluminum and 1/8" iron shims. The contrast test fixture consists of a wood block in which are drilled three holes. One hole was left empty, one was filled with sugar (higher density than the wood), and the remaining hole was filled with tea leaves (lower density than the wood). For this test fixture, determinations were made as to whether the empty hole was clearly visible and whether or not the

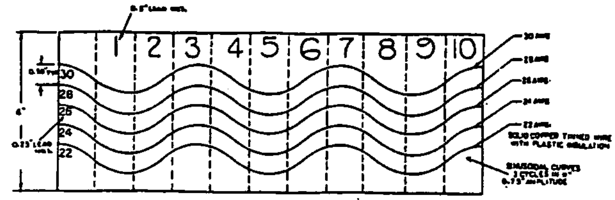


Figure 3. ASTM F-792 step wedge.

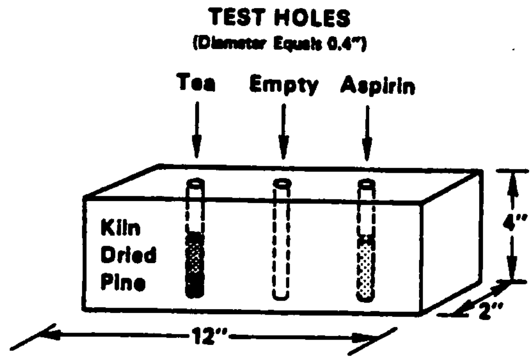


Figure 4. Contrast test fixture.

interfaces between the tea and wood and between the sugar and wood were visible.

Penetration

Penetration tests used the 3M/PH-10 plastic step wedge (Figure 5), a lead beam stopper, and a series of 1/8"-thick steel plates. For the plastic step wedge, the

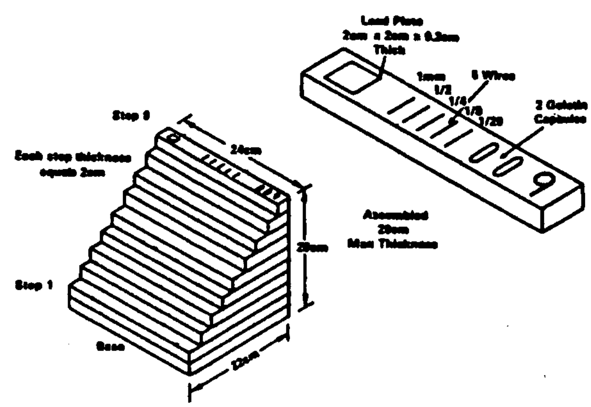


Figure 5. 3M/PH-10 plastic step wedge.

highest discernible step was recorded, as well as whether or not the 2-cm square lead artifact in the top step was visible. The steel plates and lead beam stopper were used to determine the number of plates required to render the beam stopper invisible.

4. Quasi-Operational Tests

Overview of Testing Methodology

The quasi-operational tests measured the ability of each machine to detect the presence of a cocaine simulant in luggage and in small boxes containing cargo. The suitcases and their contents were obtained from the Federal Aviation Administration (FAA) from a stockpile of unclaimed luggage and luggage contents. Additional items such as books, toiletries, candy, and other foodstuffs were randomly added to the suitcases to further simulate real-life luggage. The boxes contained produce and other foodstuffs, dishes and glassware, and surplus electronics and computer equipment. The suitcases had an average density of 0.2 g/cm^3 and the boxes an average density of 0.4 g/cm^3. The contents of each bag were shuffled several times during the test to provide a different x-ray image to the operator. Approximately 400 items were inspected during each of the two sessions. The same set of test items (approximately 26 suitcases and 15 boxes) was used for both sessions except for a few that had to be replaced because of damage.

The quasi-operational tests were conducted using a red/blue/silver team model. The red team, composed of USCS and ANL personnel, packed the suitcases and boxes. Packing was done in a secure cage that was visually isolated from the testing area. A computer program, using a random number generator, decided which suitcase or box was used, and whether or not that item would contain a simulant. Approximately 35% of the items inspected contained a simulant. The red team made the decision as to location of the simulant inside the luggage or box. The amount and position of the simulant within the luggage or box was recorded. After packing, the red team placed the test item on a cart outside the secure cage.

Handlers for each machine were used to move the suitcase/box between machines for inspection. A handler would bring the suitcase/box to the inspection station, load it per the instructions of the machine operator, unload it after inspection, and transfer the suitcase/box to a staging area where it would be collected by the handler for the next machine.

The blue team for each machine consisted of a machine operator (provided by the x-ray system vendor) and a data recorder, who was a volunteer from one of the participating LEAs. The machine operator was responsible for making the decision as to the presence or absence of a simulant. Each operator had approximately 60 seconds to reach this decision and could use any of the enhancement capabilities of the machine. No communication occurred between the operator and data recorder until a decision had been reached by the operator. The data recorder noted the orientation of the object relative to the scan direction, the operator's threat determination and the position of the simulant on the computer screen (if present). Data recorders spent approximately a half day with each machine. The recorders did not have any knowledge as to the presence or absence of simulants in the test items. In addition, the operators were not told the percentage of items containing simulants or the physical form/shape of the simulant being used in these tests.

The silver team served as quality control inspectors and monitored the entire test operation. Their tasks were to verify that test procedures were being followed, to resolve ambiguities that arose, and to answer questions.

Use of Cocaine Simulants

The use of a cocaine simulant for the quasi-operational tests was dictated by the amount of substance required for the test and the logistical difficulty of handling such a large quantity of actual narcotics. Simulants may be used in this type of evaluation because, unlike for chemical detection, the x-ray systems do not generate a signal which is unique to the presence of cocaine. The signal is based on photon transmission and scattering, and would be the same for any substance having identical photon interaction properties. Two substances were used to simulate the presence of cocaine hydrochloride ($C_{21}H_{22}NO_4Cl$) inside the luggage. The first, referred to here as pseudo-cocaine, was provided by USCS. It consisted of a mixture of 72.81% cinnamic acid ($C_9H_8O_2$), 8.83% urea (CH_4N_2O), and 18.36% PVC (polyvinyl chloride, C_2H_3Cl). The mixture had a net molecular formula of $C_{21}H_{22}N_{1.5}O_{4.75}Cl$. Double-wrapped plastic packets were prepared in ¼, ½, and 1 lb sizes. A ½-lb packet sample had been provided to the vendors prior to the test.

The second simulant consisted of a mixture of 87.5% sugar and 12.5% salt (NaCl) by weight. The composition of the simulant was chosen so that its x-ray attenuation characteristics were as close as possible to those of cocaine hydrochloride. This simulant could be formed into packets as well as a variety of other shapes and configurations, such as a thin sheet of cocaine attached to a false bottom of an attaché case, or used to fill jars and cans.

The total mass attenuation coefficients and the Compton scattering coefficients of photons in the energy range 10-200 keV were calculated using the PHOTCOEF [4] code for cocaine hydrochloride, pseudo-cocaine, and the sugar/ salt mixture. The results are shown in Figure 6 and Figure 7. The figures show good agreement between the curves corresponding to the three substances. Sugar, however, has a significantly smaller total attenuation coefficient because of the lack of the higher-Z component. The salt/sugar mixture would be a much better narcotics simulant than sugar in cases where large quantities are needed.

An operational test of the simulants was performed by preparing packets of equal size and weight containing granulated sugar, flour, the sugar/salt mixture, and the pseudo-cocaine. These packets were taped to a thin plastic sheet and inspected with the four x-ray machines present during Session 1. The transmission images on all four systems indicated the same density for each of the packages. Each system was able to distinguish the two cocaine simulants from the flour and sugar. However, none of the systems was able to

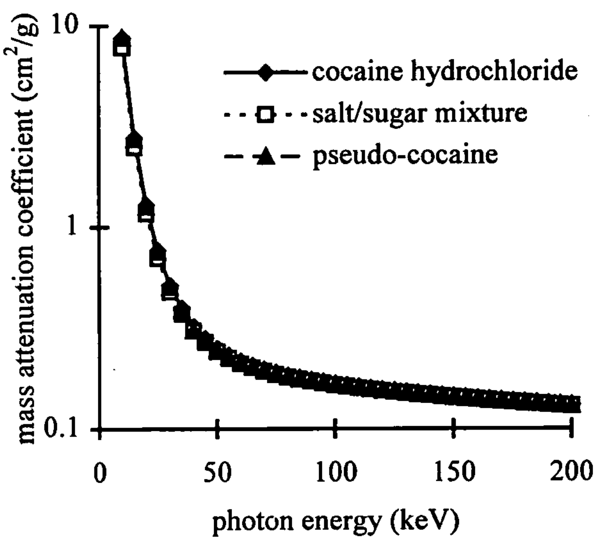


Figure 6. Total mass attenuation coefficients.

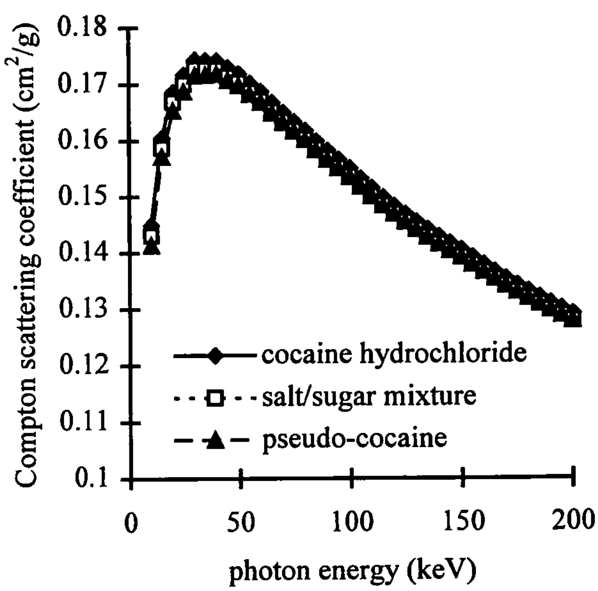


Figure 7. Compton scattering coefficients.

distinguish between flour and sugar or between the salt/sugar mixture and the pseudo-cocaine.

A simulant for heroin hydrochloride ($C_{21}H_{24}NO_5Cl$) was also developed. This pseudo-heroin is composed of 78.26% cinnamic acid, 7.05% urea, and 14.69% PVC, and has the molecular formula $C_{22.75}H_{23}$

N_1O_5Cl. However, because of the similarity of photon attenuation in heroin hydrochloride to that in cocaine hydrochloride, any system capable of detecting one substance would be able to detect the other. Thus, there was no need to consider both substances. Another factor to consider is that only half of the heroin entering the United States is in the hydrochloride form. The remaining half, in the free base form, would have a different attenuation coefficient because of the absence of the chlorine atom. The chlorine atom is responsible for the difference in effective Z between standard objects found in luggage and the hydrochloride forms of cocaine and heroin. Absence of the chlorine atom would change the signature of the narcotic and negate some of the advantages of dual-energy systems over those using just a single energy in trasmission.

Quasi-operational Test Description

Table 1 provides a summary of the tests conducted for Sessions 1 and 2. Approximately 400 items were examined in each session, with approximately 150 items containing a simulant. Because it was believed that the detection of 1/4 lb packets would be difficult, only a few of these were included in the test.

Table 1. Test parameter summary for sessions 1 and 2.

	Session	
	1	2
Total number of trials	407	432
Number discarded	10	3
Number used in analysis	397	429
Total number of suitcases	251	262
Number with ¼ lb. simulant	12	16
Number with ½ lb. simulant	33	31
Number with 1 lb. simulant	52	46
Number with ~1.75 lb. simulant	0	3
Number with ~4 lb. simulant	2	1
Total number with simulant	99	97
Number with no simulant	152	165
Total number of boxes	146	167
Number with ¼ lb. simulant	16	9
Number with ½ lb. simulant	21	17
Number with 1 lb. simulant	23	31
Total number with simulant	60	57
Number with no simulant	86	110

Measures of effectiveness

The main results of the quasi-operational tests have been expressed in terms of true positive percentage and false positive percentage. A True Positive (TP) is defined as an indication of the presence of a simulant in an inspected item when a simulant was present. A False Positive (FP) is defined as indicating the presence of a simulant in an inspected item when no simulant was present. The True Positive Percentage (TP%) is defined as the total number of True Positives divided by the total number of items with simulants. Similarly, the False Positive Percentage (FP%) is defined as the total number of False Positives divided by the total number of items without simulants.

Similarly, one can define false negatives (FN) and true negatives (TN) and their corresponding percentages (FN% and TN%). Since the TP% + FN% and the FP% + TN% must each sum to 100, there are only two free parameters available to describe system performance. The standard choice in diagnostic evaluation is to use the TP% and FP%.

Test results were analyzed separately for boxes and suitcases, and for all items combined. Within each category, the TP% was calculated for the ¼, ½, and 1 lb simulant packets, and the FP% for all cases without simulants. Comparison of the TP% between packets of different sizes for either boxes or suitcases can provide information on the minimum detectable quantity of simulant. Similarly, a comparison of the FP% between boxes and suitcases can provide some information on the effect of density on detection capability.

The uncertainties calculated for FP% and TP% were obtained by assuming that the number of FPs or TPs were obtained from a binomial distribution (B) of the form B(x,n,p). Here x is the measured number of false or true positives, n is the total number of TP or FP, and p is probability for obtaining either a FP or TP. The probability p is assumed to be given by x/n.

For any given device, there is a relationship between TP% and FP% as a function of the decision criteria used by the detection algorithm or by the human observer in assessing the presence of a simulant. This relationship can be expressed as a Receiver Operator Characteristic (ROC) curve. Since it is not generally easy to set the decision criteria for a given machine or to equalize the decision criteria for a group of machines, it is typically difficult to compare machine performance. However, by assuming a simple model for generating a ROC curve, it is possible to obtain a single number (k) that can be used to characterize and compare system performance even if different decision criteria are used. References to ROC curves [5,6] and their application to substance detection problems [7] are in the literature.

Receiver-Operator Characteristic (ROC) Curves

The purpose of many diagnostic systems is to make a decision as to the presence of a signal within a background of noise. In contraband detection using x-ray systems, the signal is due to the narcotic and the background noise is due to the image clutter from other items located inside the object being inspected. Comparing the relative performance of different x-ray systems, or the same system used by different operators, is difficult because of biases present in the diagnostic. These biases correspond to different decision criteria that are used by the different operators or by the different detection algorithms in the detection process. The use of Receiver Operator Characteristic (ROC) curves provides one method of characterizing system performance independent of these biases.

Consider a diagnostic device used by two different operators. Assume that the first operator is very concerned with not missing the signal. This operator will use a lenient decision criterion (low detection threshold) in declaring the presence of the signal. A second operator may not be as concerned about missing the signal and will use a more critical criterion (higher detection threshold). The first operator will have a higher TP% than the second operator. However, the second operator will have a better FP% value than the first. Different detection thresholds will produce different TP% and FP%. If all these measurements are plotted on a graph of TP% vs. FP%, then the resulting curve (a ROC curve) will describe the system performance independent of the detection threshold used. Since it is not usually easy to compare different curves, the ROC curve for a diagnostic is often reduced to a single parameter.

With a few simple assumptions, it is possible to develop a model that describes the measured relationship between the TP% and FP% in terms of a single parameter, which has a simple theoretical interpretation. Consider the case in which images from a series of objects without signals and a series of objects with signals are presented to the diagnostic system, which may or may not include a human operator. The diagnostic system processes these images and produces a signal response, whose magnitude is indicative of the presence of a signal. A completely automated system would produce a number that is proportional to the likelihood that the image contains a signal. A human operator would provide a degree of confidence value for each image. After a large number of images have been processed, there will be a probability distribution that describes the system response of the diagnostic device when the signal is present and a corresponding probability distribution that describes the system response to objects with no signal present.

Figure 8 shows an example of a diagnostic output. In this figure, the dashed line corresponds to the distribution of signals when no drugs are present, and the solid line corresponds to the signal distribution when drugs are present. It is assumed that the probability distributions for the no-drug and drug cases are Gaussians with equal standard deviations σ. The distance between the peaks of the two curves is defined to be k, where k is measured in units of σ. The arrow labeled "detection threshold" corresponds to a particular value of the signal response such that if the measured response is larger than the detection threshold, it is assumed that drugs are present, and if the measured response is below the detection threshold it is assumed that no drugs are present. The TP% corresponds to the area of the drugs-present distribution lying above the detection threshold, and the FP% corresponds to the area of drugs-not-present distribution above the detection threshold. As the detection threshold is raised, both the FP% and TP% decrease; as the detection threshold is lowered both the FP% and TP% increase. A ROC curve is obtained by varying the detection threshold for a fixed set of signal and no-signal distributions. Figure 9 shows a series of ROC curves for selected values of the separation *k* between the two measured distributions.

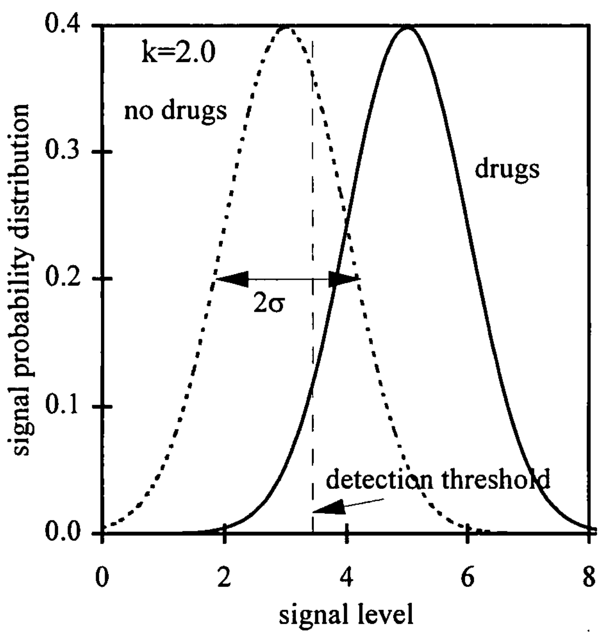


Figure 8. Model describing signal response from a simple diagnostic system.

A single measurement of the TP% and FP% is sufficient to obtain a value of *k*. If more points are available, then a least-squares fit can be performed. In the present case, the errors in *k* were estimated by using the uncertainties derived from the Binomial distribution. In general, they probably underestimate the actual variation in *k*. It is also possible to relax the assumption that the variance of the signal response

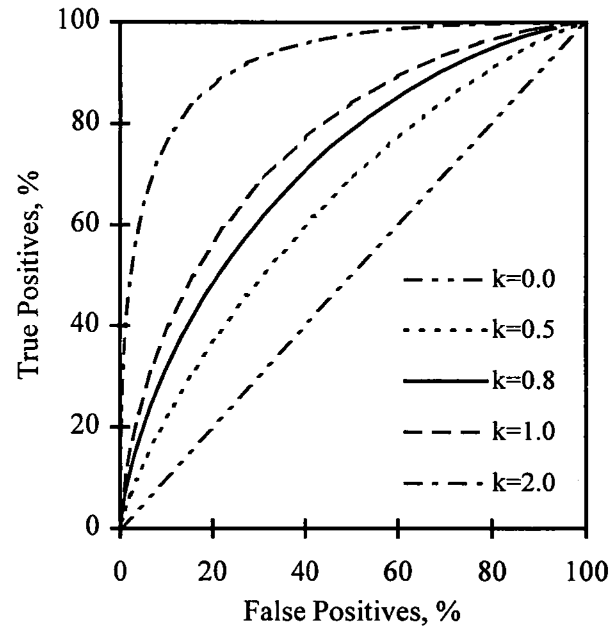


Figure 9. ROC curves for selected values of the parameter k.

distributions are the same, although usually there are not enough data to justify this procedure.

5. Future Plans

At this time, it is not known when another assessment of cabinet x-ray systems will be conducted. Generally, announcements soliciting interested parties with applicable technology are published in the Commerce Business Daily (CBD). Respondents will be given a documentation package outlining the specific details and operational procedures for the proposed tests. Respondents will be asked for questions, comments, and opinions regarding the test procedures. The test team will consider the respondents' concerns and finalize a test documentation package. The test documentation package will be sent to respondents well in advance of the actual system testing.

Future testing would involve both technical performance tests and quasi-operational tests as described in this report and in Reference 1, although the specific tests to be performed may change. For example, measurements will still be made of the systems' resolution, contrast, and penetration, but these may be performed using different test fixtures than those described here. The results of quasi-operational tests will continue to be analyzed in terms of true positive percentage and false positive percentage. Also, qualitative measures may be introduced to gauge the systems' ease of use, operator training, image quality, etc.

The evaluation team will continue to develop new testing protocols for x-ray inspection systems. In particular, efforts will be made to develop alternate testing procedures for the quasi-operational tests which better control for the variability in sensitivity of the operator or automatic detection algorithm. Also, research will continue on simulants for narcotics other than cocaine hydrochloride, and which can be made into a variety of shapes (e.g., flat packs).

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7. Acknowledgments

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U. S. Customs Strategy for Deploying High Technology Non Intrusive Inspection Equipment for Cargo Examinations at U. S. Land Border and Seaports

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INTRODUCTION

The goal of the Applied Technology Division of the U.S. Customs Service is... "To provide the Customs Officer with the right technology to support their mission". The "right" technology may not be the most expensive or the most advanced, but rather that technology which takes into account all of the operational, environmental, and human factors that must be considered for a Customs Officer to do his job. This paper outlines these factors and defines and describes the Customs strategy to deploy non-intrusive inspection (NII) technology for the inspection of inbound cargo at U.S. ports of entry. We will focus on the land and seaports, but the approach described can be applied to other environments as well.

CUSTOMS INTERDICTION STRATEGY

The overall strategy for Customs drug interdiction can be summed up in the three words: Detection, Displacement, and Deterrence. What do we mean by this? We know that drug smuggling organizations are applying effective business principles in their operations, e.g., to obtain maximum profits at minimum cost. This implies that they are selecting locations where our defenses are weak and are using techniques that are sufficiently effective to beat our existing search methods a majority of the time. They can also afford to lose a small percentage of their shipments to Customs seizures - the cost of doing business. But there is a point that increasing the detection probability, through technology or other means, makes this cost too high, and the result is the organizations seek safer means to smuggle in their product. The existing smuggling method has been displaced by a newer method, which is invariably more expensive for the same degree of risk. By maintaining a high probability of detection of the older smuggling method, a deterrent effect is obtained. A larger number of smuggling attempts will turn up in other locations or with different methods, and the process repeats itself.

DRUG SMUGGLING AT SEA AND LAND BORDER PORTS

There are many different ways to smuggle contraband into the United States: over land, sea, air, the mails, between ports of entry, etc. To conceal it in containers and conveyances at seaports and land border ports are but two. The opportunity to conceal it in a large enclosed space either within the cargo itself or in a false compartment within the space is easy to do, and has the reward of shipping very large amounts, if undetected. Since over 9 million commercial trucks and containers will enter the U.S. next year, it will be impossible to inspect them all. Nor would we want to even if we could, for the concept of selectivity and targeting has been a policy of Customs for the last 20 years.

Our objective in this paper is to identify the defining characteristics of cargo importations at sea and land ports of entry, and to determine what types of non-intrusive inspection technology best fit these characteristics. We will look at threat and logistical factors first, followed by those criteria against which we evaluate alternative technologies.

Figure 1 lists the major cocaine seizures (over 500 pounds) made in commercial cargo, which in this case also includes air cargo, for FY1996. Only one seizure in FY1996, at New York's JFK, was by air; all of the others entered by land or sea. It is clear that a real threat exists through this mode of smuggling.

Although the threat of smuggling in land and sea containers is large, the nature of the threat and the logistics of Customs response can differ significantly at the two locations, resulting in a significant difference in the technology to be deployed. Table 1 identifies some of there similarities and differences of how contraband can be secreted in cargo containers.

Table 1
Contraband Location Comparison: Sea Cargo vs Land Cargo

Contraband Location	Seaports	Land Border Ports
Not hidden	yes	rarely
False compartment	yes	yes
In conveyance	rarely	yes
In cargo	yes	yes

A few explanations are in order. A significant difference between seaports and land border ports is that the Federal government generally owns the land on which the border port is located, and Customs controls the security of the facility itself, as well as the laborers that work there. Seaports are owned by municipal or state port authorities, or in some case private companies, and Customs is just one tenant on the property, along with steamship companies, brokers, freight forwarders, etc., and we have little control of the security of the facility or the labor workforce, which is unionized, mostly as ILA or Teamsters. Another significant factor that affects the threat at the two types of cargo sites is the flow of the containers/conveyances that enter and leave the facility. At land border ports, all commercial trucks must present themselves at a primary inspection booth before they are allowed entry into the inspection facility. Once in, their movement is controlled and under surveillance by Customs until their release at a Customs controlled exit booth.

Seaports, on the other hand, are much less controlled; the off-loading of containers from ships can usually be made at several locations (piers), and Customs must specifically request that unlading be done under Customs supervision, otherwise the containers will be removed from the vessel, and only those containers targeted by Customs beforehand will be presented for Customs examination. In addition, the exit out of the cargo lot check is not controlled by Customs. The overall result is that there are many opportunities for drugs, that are thrown or casually hidden in a container of an innocent importer, to be removed by dock workers before (or if), the container is presented for Customs examination. We estimate that upwards of 50% of all smuggling attempts are accomplished by this method in some seaports. This is the reason that in Table 1 there is a "yes" in the "not hidden" contraband location block. Our method for combating this form of smuggling, which is called "internal conspiracy", is through surveillance, or more frequently, by the monitoring of the unloading and checking of virtually every container from a targeted vessel. This latter technique is called landed quantity verification, or LQV.

There are two other major differences between sea and land cargo smuggling. The first is that significant smuggling is found in the land conveyances themselves: the cab, engine compartment, tires, and undercarriage of the trailer being favorite locations. Although some sea containers are shipped on wheeled carriages, and then rolled on and off the vessel with tug tractors, (hence the name ro-ro's), there has been little noted smuggling in the carriages or tires. The second difference is that a significant percentage of trailers and tankers coming across the Southwest border are empty; up to 50% in some locations. Since we often find smuggling in empty tankers, and in the conveyance itself, the examination rate for empties is high, both from the historical results and in the speed with which a thorough examination can be made. Empty containers also enter at seaports, but the evidence of smuggling by this mode is not as large as land border ports.

Table 2 lists some other logistical factors that separate the examination process between sea and land border ports, and impact the type of technology to be deployed.

Table 2
Comparison of Logistic Factors: Seaport vs Land Border Ports

Factor	Seaports	Land Border Ports
Number of containers/year (FY1996)	160K - 1,500K	150K - 1,000K
Physical size	large (100's of acres)	small (10's of acres)
Time for cargo clearance	hours - days	minutes - hours
Information available for targeting	1-2 days before entry	0-4 hours before entry
Number of container entry locations	multiple	single
Number of container exit locations	single	single

Note that in the first two factors that even though the number of containers/conveyances for sea and land border ports is comparable, the two locations differ significantly in physical size. This implies that distances between examination points are also significantly different. At some seaports, Customs officers and associated NII equipment must travel distances of up to a mile to do an LQV on a targeted vessel. At land border ports, walking distances between examination sites are the norm, and with the additional control Customs exercises over the containers and conveyances, this implies that fixed site technology can be employed, and the target can be brought to the system with a high degree of security, with minor inconvenience to both shipper and Customs.

The third logistical difference is that the time estimated for cargo clearance by brokers at land border ports is on the order of minutes to hours. Mexican drivers often make 2-3 round trips a day with a tractor just to bring in another container to a local importer. Perishables, such as fruits and vegetables require fast Customs processing if an enforcement examinations is not warranted. This is not the case at seaports, where the containers have already been on board ship 2-3 days, and the release of the contents is generally not as time-critical. Lastly, the information available to the Customs officer to conduct a targeting analysis, either through the automated targeting system (ATS) or through manifest review unit (MRU) targeting, differs significantly. Currently sea manifests are available to Customs 1-3 days prior to vessel arrival, allowing ATS or MRU targeting, which is ample time for Customs to designate containers in advance to the importer/broker for examination. (Note that this type of targeting is useless against internal conspiracies, which use importers that will not often be targeted.) The ATS is currently in operation in Newark, where it has been responsible for several large seizures in containerized cargo. It is planned for expansion to other seaports in the next two years. Miami and Port Everglades will receive it next year. The requirement to have advanced manifests for land based shipments is only being employed in Laredo, where a Southwest border port version of ATS has just been implemented. The reporting requirement is 4 hours before entry, with which the local brokers are understandably unhappy, not just because of the added paperwork, but because of the extra turn-around time of their conveyances and drivers.

TECHNOLOGY CRITERIA

Customs evaluates new technology that may be deployed for operational use against criteria that have proven to be significant in defining requirements and in determining the feasibility and eventual success of the technology application. These criteria are listed in Table 3. The requisite values for each of these criteria are based on the specific operational application and environment being considered for the technology.

Table 3
CRITERIA FOR TECHNOLOGY EVALUATION

- Safe for the user, public and target
- Legal and proper in the intended use
- Reliable response; useable in court
- Appropriate selectivity and sensitivity
- High availability and maintainability
- User-friendly
- Robust and multi-purposed
- Affordable
- Cost effective over life cycle
- Improved utilization of Customs resources
- Difficult to thwart

Most of these factors are self explanatory, but I will expand on one. By affordable, we mean the initial capital outlay and O&M costs of the technology acquired and deployed. Customs is not seeking a "silver bullet", where silver also implies cost, unless that bullet can indeed stop drug smuggling for multiple smuggling modes. No current high technology system or any in the horizon even comes close to meeting that requirement in our estimation. Consequently, we are seeking what may be called several "copper" bullets, that are sufficiently successful in detecting contraband in one mode to force the smuggler to displacement methods, but not so expensive as to be prohibitive in maintaining a strong deterrence later.

CONCLUSIONS - THE STRATEGY

What conclusions can we draw from all of these assumptions and observations?

- Targeting Customs has maintained for two decades that we cannot afford to examine every package and container presented for entry as was done in the past. The concept of "selectivity" for commercial compliance was introduced in the 70's, and enforcement targeting was implemented a decade later. There is no question that enforcement targeting increases the probability of contraband detection in consignee smuggling attempts, regardless of whether the targeting is the product of the manual manifest review unit, or the automated targeting system, ATS, which is the automated version of MRU output. Customs is committed to expanding the ATS to all seaports, land border ports, and airports over the next years. The receipt of advanced manifests is critical to this concept, and there will have to be some legislative and regulatory changes required for this to be a reality in some cases.

- Technology performance Virtually all of the NII technology that is currently available or being developed now is a candidate for application to the detection of contraband in containers and conveyances, subject to the restrictions listed in Table 3 and those discussed below. This includes x-rays, nuclear systems (e.g., gamma ray imaging), trace detectors in all their forms, ultrasonics, and EM spectrum sensors, both passive and active. At seaports, for the radiographic systems, there is a requirement to have sufficient energy to inspect the full contents of the target, e.g., container or pallet, for commercial quantities of drugs. This is also desirable at land border ports, but since the density of the cargo and thickness of the container walls are generally less than at seaports, the energy levels can be lower. Similarly, trace detection systems must be capable of detecting the commercial amounts of drugs that are being smuggled. A high P_D and low P_{FA} is always desireable. Higher throughput capability is generally required at land border ports because of the need for faster cargo clearance.

- Mobility and/or relocatibility The requirement to bring NII systems to the vessel off-loading site for an LQV examination is critical in the seaport environment. Fixed site equipment may be suitable for some applications, e.g., pallet and 55 gallon drum examinations. In land border environments, since the size, flow, and security of commercial traffic within the port is controlled by Customs, fixed site installations may be feasible at the larger border ports, causing the smuggler to divert to less frequented ports. It becomes critical, therefore, that mobile or transportable NII technology be deployed to augment the fixed site systems at those neighboring ports that do not have fixed systems.

• <u>Technology mixture</u> Customs has concluded that there is no single NII technology that is so attractive in detection performance, cost, operational flexibility, and user acceptance as to consider its exclusive use. There are, however, several technologies that when used in series with each other, may produce results that approach the detection probabilities we require. One of the objectives of the Florida Integrated Non-Intrusive Inspection Technology (FLINT) operation in South Florida is to identify how and where such technologies can be augmented in a layered or phased, and hopefully synergistic, manner.

These are the four strategy factors that Customs has selected to be applied to the implementation of NII technology at seaports and land border ports: Targeting, Performance, Mobility and Mixture. The final section describes how Customs is employing this strategy in our short and long range plans.

CUSTOMS NII DEVELOPMENT, EVALUATION & DEPLOYMENT PLANS

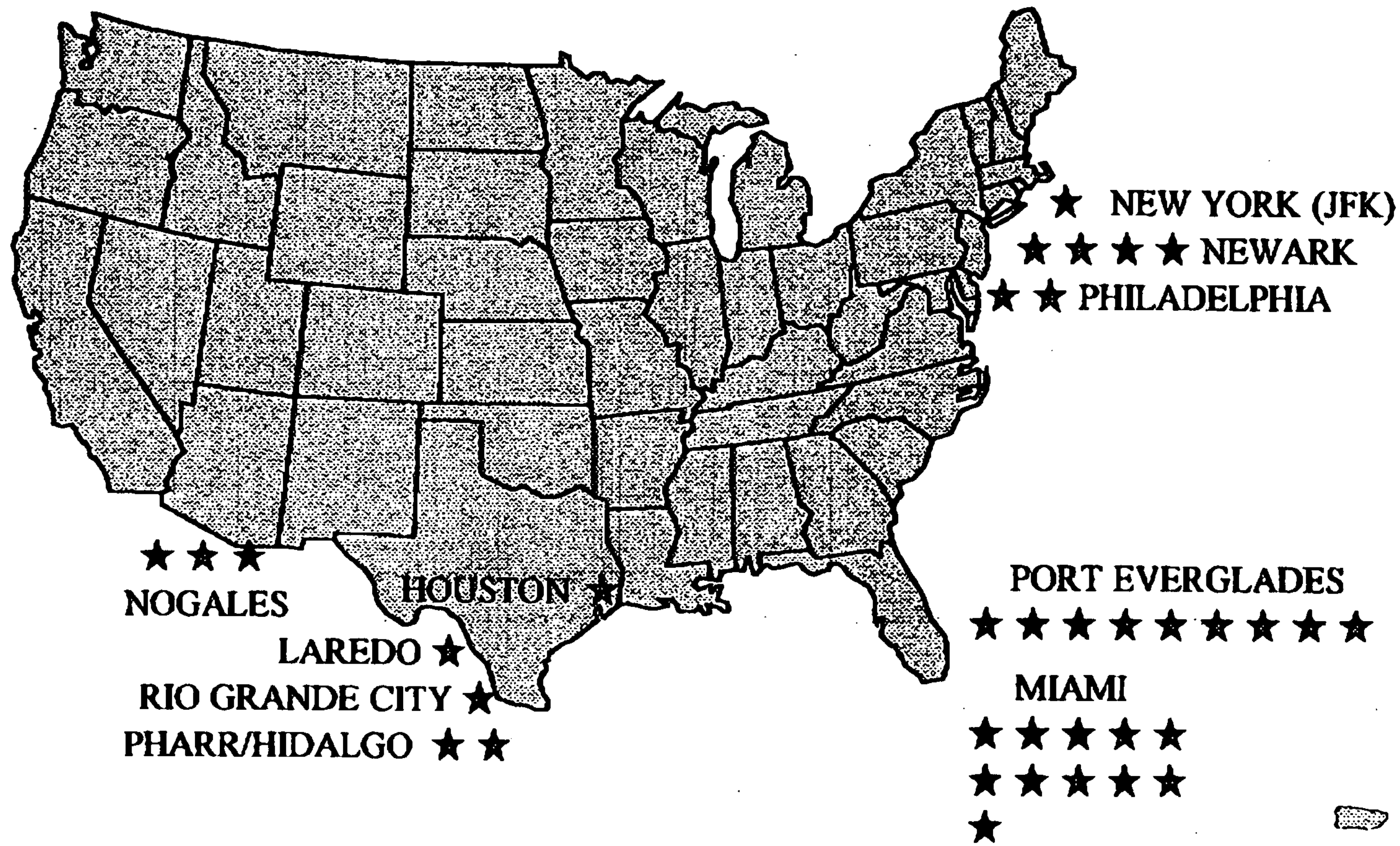
The U.S. Customs Service has been on the forefront of non-intrusive inspection technology for over 20 years. We introduced x-rays into our mail and baggage operations in the early 1970s, backscatter x-rays for cargo exams in the late 1980's, the gamma ray densitometer, or Buster, in the mid 1980s, and with the support of the Department of Defense and the Office of National Drug Control Policy are pushing the state-of-the-art in NII into the 21st century. Some of the technologies that we have evaluated for our operations include: low-energy x-rays (120-160 KeV) for baggage, mail and small containers; medium energy x-rays (450 KeV) for empty and lightly loaded containers and conveyances; high-energy x-rays (10 MeV) and Pulsed Fast Neutron Analysis (PFNA) for fully loaded containers; gamma ray imaging for empty tankers and other conveyances; nuclear magnetic resonance for drug swallowers; ultrasonic sensors for hazmat and contraband detection in 55-gallon drums; and the entire spectrum of vapor and particle trace detection systems technology, from ion mobility spectrometry, to surface acoustic wave devices, to biological sprays and drug wipes. We are continuing to review the capabilities of existing and new technologies for our operations, and have developed a plan to deploy the following types of technology at our land and sea ports of entry, both in an operational mode and for prototype evaluations. Table 4 lists these applications.

Table 4
Existing and Developing Technologies for Cargo Detection

Technology	Application
Mobile & relocatable high energy (2-6 MeV) transmission and backscatter x-ray	Seaport loaded containers
Relocatable medium-high energy (1 MeV) transmission +backscatter x-ray	Seaport and airport loaded containers
Fixed site backscatter (160-360 KeV) + dual-energy x-ray.	Seaport and land border port small containers
Fixed site medium energy (450 KeV) transmission + backscatter x-ray	Land border port empty and lightly filled containers, conveyances and tankers
Mobile medium energy (450KeV) transmission + backscatter x-ray	Land border empty and lightly filled containers, conveyances and tankers. Sea and air containers, possibly.
Transportable gamma ray imaging system (1 - 2 Curie source)	Land border tankers and trucks. Sea containers. Railroad cars.
Passive portal radiation detector	Land border trucks and tankers.
Narcotic vapor & particle detectors	Land border and seaports. Everything.
Ultrasonic sensors	Land border and seaports - 55-gal drums.
Gamma ray densitometer (Buster)	Containers, conveyances - everywhere
Laser rangefinder	Containers at land border and seaports.
X-ray Vans (160 KeV B/S)	Small cargo packages at land, air and seaports

Customs will evaluate other technologies as they mature; however, these are the only ones that meet the strategy factors as outlined above, and are the only ones we are considering for land border and seaports at this time.

U.S. CUSTOMS SERVICE
MAJOR COCAINE SEIZURES IN COMMERCIAL CARGO
FISCAL YEAR 1996
(500 Pounds or More)



(Seizures indicated above are listed in pounds)

Strategic Problem Solving in the Customs Service

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ABSTRACT

The Customs Service has adapted community-oriented policing principles to a national law enforcement agency. Our program is called Strategic Problem Solving (SPS). Its focus is on the four main categories of enforcement violations that Customs has statutory responsibility to enforce. They are narcotics smuggling, trade fraud, outbound violations and money laundering. Our local offices identify which problems they want to attack and put together cross-functional teams to do so. The teams use analytical tools to dissect the problem and then use their creative talents to craft action plans to deal with the problem. SPS includes prevention, deterrence and displacement as acceptable outcomes along with more traditional law enforcement responses. This allows the teams to have a wider variety of options to consider in combating problems. There have been 100 teams established since instituting the SPS concept a little over a year ago. In addition to Customs officers, the teams have included numerous other Federal, state and local law enforcement agencies, major foreign and domestic airlines, a manufacturer, U.S. and District attorneys, a hospital, the Postal Service, small package couriers, and port authorities. The work of the teams is captured in a national database that will be part of a knowledge base of methods, techniques and technology developed by experienced officers.

The nation is beginning to see the benefits of Community Oriented Policing techniques employed at the local level. Recent news reports about the downward trend in the crime rate gives substantial credit to these techniques. The techniques involve using non-traditional police methods to reduce crime or to displace it from a community. The central tenet in this type of effort is to look beyond the incident by incident response that law enforcement agencies have always done. By studying the underlying characteristics of the trend or pattern of violations, police agencies can often create ways to prevent, reduce or deter criminal violations. This is a major deviation from the traditional law enforcement responses of arrest, seize, indict and prosecute.

BACKGROUND

The Customs Service was facing a situation of increasing violence in our ports of entry along the border with Mexico in 1994. Drug smuggling organizations were employing young people to drive large loads (600-800 lbs.) of cocaine and marijuana through our ports. They attempted to fit in with the millions of other vehicles crossing the Southwest border. However, if they were challenged in any way they were instructed to accelerate through the port area without regard for people or property. They were well compensated by the smuggling organizations. We were having our officers and innocent civilians injured in these episodes. We were also averaging a shooting a month when these "port runners" would drive at our inspectors. At this point we decided to organize a serious attempt to address the problem. As we gathered information on the smugglers and their methods it became clear that we would have to take steps to prevent or deter this activity rather than construct methods to catch the violators. The latter approach would have only increased the violence. We developed a combination of structural changes to the ports along with operational changes that significantly reduced the number of "port runners" (by 60%). This lesson along with some previous Customs experience with developing methods to deter criminal activity led us to seriously study the community-oriented policing work that was occurring in many localities. This also came at a time when there was strong philosophical commitment within the management of Customs to involve the front line officers more deeply in decision-making. After reviewing the efforts of the local police organizations and talking with leading thinkers on this topic, such as Professor Herman Goldstein of the University of Wisconsin, we realized we would have to make some adaptations to the local police methods. One of the major differences is that our approach is team oriented. We also stress that the team should be multi-functional in order to maximize the creativity of the solutions. Community oriented policing is driven more by the individual patrolmen. The result of this effort is called Strategic Problem Solving (SPS).

METHODOLOGY

We began training field officers in SPS techniques in January 1996. The method we teach is a six-step logical approach that is similar to the four-step method used in police agencies. The steps are:

1. Problem identification. The team collects and analyzes data on the problem from both within Customs and from outside sources. They look for trends in terms of four categories: persons, location, time and behavior. This is the key step in the process.

2. Objective/Expectation. The team decides, based on the nature of the problem, what they want to achieve. Deciding to displace a problem will lead to different solutions than trying to maximize arrests and prosecutions. They develop measures of impact that go beyond the traditional law enforcement measures. These measures should be able to tell the team whether they achieved their objective or not.

3. Analyze situation and develop alternatives. Based on their analysis of what they collected in step one, the team brainstorms a long list of alternatives to the problem. This step is where the benefits of a multi-disciplinary team are realized.

4. Analyze and select alternatives. The team compares the alternatives against some criteria to try to determine the impact on other Customs processes, the people using the Customs facilities, and, most importantly, the impact on the problem.

5. Implement. The team assembles the selected alternatives into an action plan that says what needs to be done and who will do it. The plan may also include staged actions if technology acquisition, legal opinions or capital changes will take some time. The team will also share this plan with managers who were not involved in its development.

6. Monitor. The team devises a monitoring plan using the impact measures developed in step two. This plan lays out who will collect the data and how often the team or management should review it. Teams generally are finished after this step. However, many find it beneficial to reconvene six months or so later to look at lessons learned.

GOALS

It is our plan that Strategic Problem Solving will help the Customs Service achieve several goals. The first is to improve our enforcement results. The second is to foster greater teamwork among the various disciplines within Customs and with the other law enforcement agencies that deal with us. The third is to create partnerships with private industry on issues of enforcement when our interests intersect. Finally we also want to push creativity in dealing with our enforcement responsibilities.

We believe this creative aspect resulting from the multi-functional team will lead to more focused use of existing technologies and will lead to demand for new technologies. Our Office of Applied Technology is seeking a greater role in working on some of the SPS project teams or in consulting with them. Most of our officers are not aware of what range of technologies is available or will soon be available. Conversely, having our technology specialists involved in analyzing the enforcement problems and helping to craft solutions will lead them to a greater understanding of the challenges and needs of our field officers.

PROJECTS

Our local ports of entry or our local investigation offices choose the problems that they wish to address. The National office developed the training course and provides support for implementation when the local budgets fall short but does not direct the local offices on which enforcement problems to work on. We are attempting to create a system for front-line officers to nominate problems, however most of the projects so far have been nominated by local managers. The projects fall into the four broad categories of Customs enforcement responsibilities. Those are drug smuggling, money laundering, trade fraud and outbound smuggling. Since the first project began in February 1996, there have been approximately 100 SPS projects in almost all areas of the country. Some of these are finished and some are ongoing. The following list is a sample of the variety of locations and problems:

Brownsville, Tx - Drug smuggling by shark fishing boats into South Padre Island.

New Orleans, La - Movement of stolen vehicles out of the country through the seaport.

Miami, Fl - Internal conspiracy among seaport workers (longshoremen) to remove drugs concealed in legitimate cargo by seaport workers in Colombia.

New York, NY - Internal conspiracy among ground personnel to remove drugs secreted on Avianca aircraft.

Chicago, Il - Diversion of international mail before Customs can inspect it.

Louisville, Ky - Shipment of restricted high technology out of the country in express courier shipments.

Los Angeles, Ca - Heroin smuggling by vessel crew members.

El Paso, Tx - Smugglers adapting to a device used to slow down port runners.

Roma, Tx - Method for inspecting long haul busses was inadequate.

Laredo, Tx - Drug smuggling via freight trains.

Anchorage, Ak - Drug smuggling in express courier shipments from Asia.

Blaine, Wa - High-risk Asian cargo discharged in Vancouver arrives at the border with little information for targeting/sorting.

Nogales, Az - High speed pursuits through the congested port of entry by various Arizona law enforcement agencies endangers the officers and civilians at the port.

The various teams that worked on these projects and many others often included members from outside Customs. The Brownsville shark fishing boat project involves the local county sheriff's office, the Coast Guard, the Texas National guard, Customs Air Branch, the National Park Service, and the Border Patrol. In the New York project, the team includes airline personnel. The Laredo project includes security personnel from different railroads. The El Paso project included the manufacturer of the device.

SPS project teams have also included, hospital personnel, U.S. and district attorneys, steamship lines, the RCMP, Canada Customs, many local law enforcement agencies, the U.S. Postal Service, Federal

Express, American Airlines, INS and GSA.

The types of technology that the teams have chosen to use in their implementation plans are: tracking devices for controlled deliveries; very small cameras for internal conspiracy investigations; large-scale camera arrays for monitoring counter-surveillance by the smuggling organizations; different kinds of non-intrusive drug detection devices; and communication devices.

LESSONS LEARNED

Introducing new ideas into any culture meets with resistance. The concept of deterring illegal behavior rather than diverting resources to arrest and prosecute the criminals is alien to traditional law enforcement. Many law enforcement agencies count enforcement success by the number of arrests they make, or the amount of drugs they seize. However, the communities in which these agencies operate are really more interested in living in safer environments. Consequently, the law enforcement agencies need to consider the desires of their communities. Spending scarce resources to deter drugs from entering a locality or to deter criminals from operating in a locality may be more in line with what the residents want than spending those resources only on ways to catch the criminals.

Despite the resistance in some quarters to SPS, we are pleased with the results of our efforts so far. We believe we will achieve the goals listed previously in this paper.

1. We have improved our traditional enforcement results. The Miami internal conspiracy project has netted us over 100,000 lbs. in marijuana and cocaine. The Brownsville shark fishing boat project has netted us over 30,000 lbs. in drugs. The New Orleans stolen car project has recovered over 70 vehicles and resulted in 60 arrests.

2. We are seeing more inter-disciplinary teamwork. As noted previously we have involved a substantial number of outside entities. Initial resistance to involving other parts of Customs and outside agencies has been melting away as the different disciplines train and practice SPS together.

3. We are slowly involving private industry on some of our teams. Avianca and American Airlines are deeply involved in two projects. The manufacturer of the Stop Stick worked with our officers to redesign it. Achieving this goal will take a couple years because of the strong resistance to involving civilians in law enforcement efforts.

4. We are starting to see SPS projects foster creativity. Many of the action plans put together by the teams initially were fairly routine. However, there have been a couple that were innovative. These usually involved technology. A project in Arizona started out with each of the three main ports of entry looking for ways to monitor the counter-surveillance activities of people known as "spotters". Spotters are positioned outside the port of entry to watch our operations. The Arizona project has grown from just putting up a few video cameras to an ambitious project that will tie all the areas of the ports, the investigative offices and the Customs Management Center in Tucson into one digital network. This video network will also be tied into some ground sensors between the ports that will record vehicle intrusions out in the desert.

We hope that as we publicize the work of the various teams within Customs that more teams will look for creative, innovative ways to address enforcement problems.

Nonintrusive Inspection Technologies (Session 2C-1)

6

Developments in Contraband Detection Using X-ray Technology

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ABSTRACT

The broad application of X-ray technology to the detection of explosives, weapons and drugs will be reviewed. PSDB's development programme has been addressing the problems of finding explosives in quantities considered to be a threat in cargo and luggage. The technologies yielded by this programme will be described and their application to drug detection discussed.

The detection of specific substances, whether they are explosives or drugs, requires accurate and repeatable physical measurements to be made. It also requires that the human operator be provided with a high quality representation of the item to give correct confirmation or denial. To these ends the application of fibre optic CCD based technology and depth information using stereoscopic imaging is discussed.

An X-ray system that makes material measurements purely on a single set of transmission data will encounter problems when classifying thin layers of material. Low angle X-ray scatter is presented as one potential solution to this problem.

X-ray systems, capable of material discrimination at X-ray energies of around 160 keV, are in routine use throughout the world for screening luggage. These systems exploit photoelectric absorption and Compton scattering. A technique that exploits Compton scattering and pair production is discussed, this has allowed material discrimination at X-ray energies of around 10 MeV. This has applicability for screening large cargo items such as shipping containers and aircraft luggage containers.

1. Introduction

During the 1970s and early 1980s the threat to civil aviation came from terrorist hijackings. The need to screen passengers for weapons was the main concern of the aviation security industry and consequently the detection systems were chosen to find metallic items effectively.

After the early 1980s the *modus operandi* of the terrorist changed to placement of improvised explosive devices (IEDs) on aircraft either by the terrorist themselves or by a dupe. The devastating effects of such a device were witnessed with the destruction of Pan-Am flight 103 over Lockerbie. Although an event of this nature was not unique, it could be considered as marking a period of change within the aviation security industry.

The manufacturers of security equipment shifted the focus of detection equipment away from metal items to explosive substances, with particular attention being paid to commercial and military plastic explosives based on PETN and RDX. The technology employed in standard monochrome baggage X-ray systems was improved so that items were colour coded according to their elemental make-up. Further improvements have been made to the technology over the last five years or so to allow more accurate determination and indication of threat substances. This can now be done with such reliability that in some cases the operator's role is that of validating the decision made by the machine.

Recent UK Department of Transport (DoT) legislation, in line with International Civil Aviation Organisation (ICAO) recommended practices "Safeguarding International Civil Aviation Against Acts of Unlawful Interference" Annex 17, has meant all items carried on an aircraft need to be security screened. These include cabin and hold baggage and any items of cargo. There are different requirements depending on what the systems are screening, but X-ray technology has been applied to them all.

PSDB, with funding from the DoT, have an ongoing programme of work to improve available X-ray technology, both for baggage and cargo applications. This programme has primarily been addressing the detection of explosives but the technology also has the inherent capability to detect drugs once they have been characterised. These pose no threat to aviation, however their detection is of a major concern to law enforcement agencies across the world.

PSDB are also responsible for testing the performance of commercially available baggage X-ray systems, both conventional systems and those employing automatic threat recognition (ATR).

2. PSDB's Baggage X-ray Programme

Metallic items with distinctive shapes can, on the whole, be easily recognised by baggage X-ray system operators. Employment of this technology, providing grey scale images, was effective for finding weapons that could be used in a hijacking scenario.

Systems employing dual energy technology became available in the 1980s, which gave the operator added information - the broad material type of objects. The ability to be able to discriminate between organic materials and metals gives operators a better chance of spotting an IED [1] or a package of drugs and also has the benefit of reducing the number of false or nuisance detections.

PSDB's development programme for baggage X-ray systems has been tailored to address three key areas: -

1 Detection of bulk materials (materials which are 6 mm thick are greater)
2 Detection of sheet explosive (materials which are thinner than 6 mm)
3 Provide the operator with a high quality image.

1 and 2 above are concerned with developing techniques to provide the operator with either an automatic or semi-automatic indication of contraband being present. The operator still needs to determine whether the alarm is legitimate or not and presenting them with a high quality image enables them to carry out this task more effectively and so reduce the number of potential false alarms.

There are seven current projects, each addressing one or more of these areas and the following sections cover this work in more detail.

3. Fibre Optic Intensified CCD Technology

PSDB have been working with Cambridge Imaging Ltd. (CIL) for the past seven years on X-ray detection technology. The CIL fibre optic/CCD technology was first reported on at the ONDCP symposium in 1992 [2]. The aim of the development programme was to produce a baggage X-ray system that gave a high quality image and good materials discrimination allowing threat recognition to be implemented. This system, marketed by EG&G Astrophysics as the E-Scan 200, has been commercially available for the last two years.

System Description

The system employs dual range X-ray sensors to accomplish material discrimination. As with many of the commercially available baggage X-ray systems a folded linescan array is used for image acquisition. Thallium doped Caesium iodide crystals convert incident X-rays to visible light. This material was chosen for its high conversion efficiency, but has the disadvantage of long lived persistence which PSDB and Hilger Analytical hope to quantify and address in the near future. The line array consists of about seven hundred crystal pairs, with the crystals in each pair arranged one in front of the other in the line of incident X-rays. Each of the crystals is coupled to an optical fibre. The optical fibre bundle, leading out from all the crystal pairs, is attached to the front end of a three stage intensified CCD camera.

An area CCD chip is employed so the straight-line array image is mapped onto this, then re-mapped as a line for display purposes.

The colour display pallet employed has been chosen to be consistent with those of other commercially available systems in order to avoid operator confusion.

Materials Discrimination

The arrangement and dimensions of the sensor crystals has been chosen to allow X-ray detection in two energy bands; the thinner front crystals measure incident X-rays with energies up to 80 keV and the back crystals above 80 keV to the tube maximum, typically 140-160 keV.

Measurement in these two energy ranges allows exploitation of the physical processes of X-ray attenuation to determine the effective atomic number of the medium the X-rays have passed through which, if sufficiently accurate, can determine if explosives or drugs are present. The two main mechanisms for X-ray attenuation at baggage X-ray energies are the photoelectric effect and Compton scattering. The following formulae give the linear mass attenuation coefficients for these two processes respectively.

$$\mu_{pe} \propto Z^4 E_\gamma^{-7/2}$$

$$\mu_{comp} \propto Z E_\gamma^{-1}$$

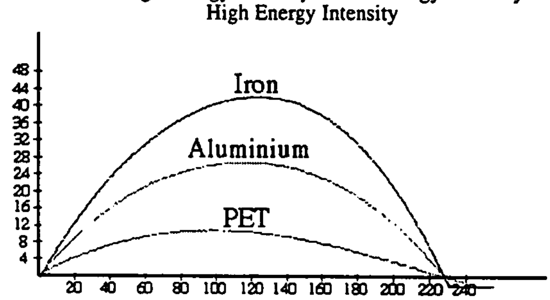
Z is the atomic number

E_γ is the X - ray energy

X-ray photons with energies below 80 keV are strongly absorbed by the heavier elements, but not by lighter elements. The effective atomic number of a given region can thus be measured by determining the low and high energy absorption ratios once the system is calibrated for known materials.

The system is calibrated for three known materials: - Polyethylene terephthalate polyester (PET), aluminium and iron. Calibration images of step wedges made from each of the materials are acquired and stored. The step wedges for each material have increments that cover the range from almost 100% down to 0% X-ray transmission. The following plot shows a set of calibration curves for a particular crystal pair. The scale on the x-axis is the grey scale value in the range 0-255 and on the y-axis the difference in the grey scale values between the high and low intensity images.

Plot of High Energy Intensity – Low Energy Intensity vs. High Energy Intensity



Curves such as these are calculated for each of the crystal pairs and these are then used to colour code the image according to the material type.

Threat Recognition

In order to implement effective threat recognition, either automatic or operator assisted, on transmission based X-ray systems it is necessary to measure the effective atomic number of an object of interest to a high degree of accuracy. The system built in conjunction with CIL is capable of measuring the effective atomic number to one unit at the single detector level. The accuracy of this measurement increases when it is aggregated over the area of an object on the display.

It is relatively straightforward to determine the effective atomic number of a single homogeneous object on the belt of an X-ray system. In a real suitcase the object of interest might have a variety of different materials overlaying it. The effect of these overlying materials has to be subtracted in order to classify the object correctly.

Future Development

X-ray systems used to screen carry-on bags typically have a conveyor belt speed of 0.2 ms^{-1} and those used to screen checked bags about 0.5 ms^{-1}. CIL, under contract to PSDB, have developed a patented evolution of the fibre optic CCD based technology, which allows image acquisition at conveyor belt speeds up to 1 ms^{-1} but still maintains the high image quality of the slower system. This has been accomplished by developing a new intensified camera. At high acquisition rates the resultant CCD image can be significantly degraded by frame shift smear. This effect occurs when the CCD is still illuminated during its readout phase. To prevent this the image intensifier is gated off during this phase so no illumination of the CCD occurs.

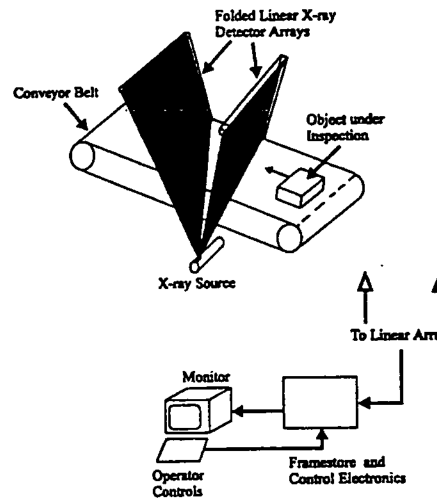
An operator would not be capable of viewing bags at the imaging rate of this fast system. A buffer memory card has been developed which will cope with this acquisition rate; the images are buffered onto the PCI bus of a standard PC and can be accessed by any other device on that bus system. This gives the potential to multiplex these images to a number of discrete workstations where they can be subject to threat recognition and to operator interrogation.

4. Stereoscopic Baggage X-ray System

An image from a standard baggage X-ray system is wholly two dimensional, there is no information regarding the relative position in depth for the various objects in a luggage item under inspection. PSDB and the 3D imaging Group from Nottingham Trent University have produced a baggage X-ray system capable of displaying an X-ray image of a bag in 3D [3]. Operators can easily see the relationship of objects and clear bags that may have appeared to have contraband items present when viewed in 2D so reducing the false alarm rate.

Prototype System

The figure below shows a schematic configuration of the stereoscopic baggage X-ray system.



Depth Relief Model

This year PSDB will be building a further stereoscopic system, which is part funded with US, money. The system will employ intensified CCD technology which will give a high resolution stereo image.

A fixed geometry stereoscopic system, such as the one being built, can be used for finding range or depth information. The range of a point, which is present in both images, can be calculated by the shift in its position from one image to the other. This fact has been exploited to determine the depth within the baggage X-ray system cavity of a given object.

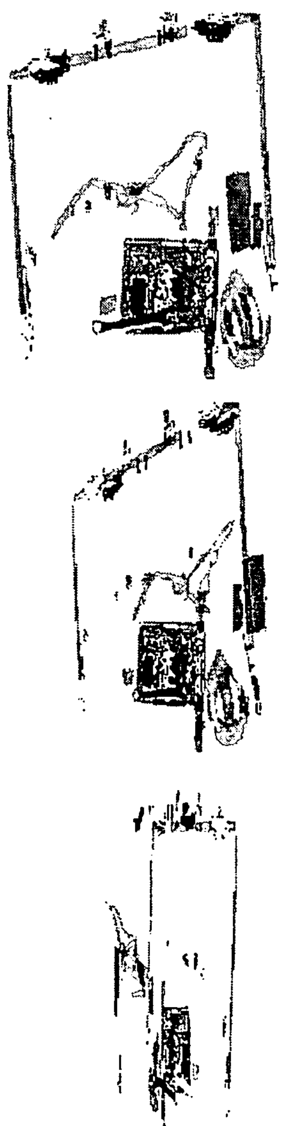
PSDB have developed an automatic technique to correspond objects between the stereo pair images and from the shift in position calculate the depth co-ordinate. The system's fixed geometry allows a simplified matching technique to be used, which gives more robust results in a shorter time.

During the matching process a depth relief model file is written and the original image is draped over this and displayed. These depth relief model images can be rotated to allow the operator to view the spatial relationship between the different matched objects without the need to wear special glasses. This image is available to the operator in addition to the two 2D images and the 3D viewable image and results in the operator getting further information to make an more informed decision.

The more accurate materials measurement of the intensified CCD system will be exploited in the matching routine and indications are that it will result in a more accurate depth relief model image.

This form of imaging could also be applied to screening large cargo where it can often save a great deal of effort to know exactly where the object of suspicion is located.

The figure below illustrates three views from a model sequence. The 3-D database for this sequence has been derived manually to demonstrate the principle of operation, but the code to do this automatically will be ready within the next three months.



5. Coherent X-ray Scattering

Specific materials information can be obtained from X-ray diffraction; a well understood technique for the study of small samples. Such techniques have been applied to the problem of screening for contraband in baggage [4]. PSDB, in conjunction with St Bartholomew's Hospital and University College London, has been working on using the technique of low angle scattering for the detection of contraband. An energy dispersive X-ray diffractometer has been developed that allows characterisation of material from an extended target to be addressed. The current state of the research is described in more detail elsewhere [5]. Essentially, for a given scattering angle, unique diffraction spectra can be obtained in realistic timescales.

The technology is going to be applied to the detection of thin sheets of explosives in the lining of suitcases. Some characterisation work has already been carried out on drugs and the technique will also work for them.

This technology has now matured to a level where PSDB will be incorporating it into a system that will be built next year. It will be used to compliment the capabilities of the intensified CCD technology and stereo view system.

6. Materials Discrimination X-ray for Large Cargo

Materials discrimination baggage X-ray systems are now common place at international airports throughout the world. The extra information contained in the material coding can help the operator locate potential contraband items and also discard items that may previously have caused a false alarm.

PSDB have actively supported and funded CIL in achieving this level of coding for high-energy (up to 10 MeV) cargo inspection X-ray systems. This is the first time that materials discrimination images have been acquired by using the dual energy approach in the 1-10 MeV region.

At the lower baggage X-ray energies the photoelectric effect and Compton scatter attenuation mechanisms are exploited. In order to implement materials identification at higher energies, it is necessary to exploit Compton scattering and pair production. This requires more complicated detector elements than those in the baggage X-ray system. Each detector element consists of a number of specially designed scintillation crystals and, in addition, various absorber materials and shielding components were also employed. The system was calibrated for materials in a similar way to the baggage X-ray system and, once calibrated, was capable of producing images of real items colour coded according to their broad material type.

The demonstration system used a 0.5 m high array, which is one eighth of the height of a full size system. A purpose designed rail and platform system was constructed to move objects in front of the detector array at the required speed. This set-up gave a demonstration of the practicability of the technique. The detection system can be synchronised with the linear accelerators in use at cargo inspection installations today and make use of the existing infra-structure. This is an exciting development and has demonstrated broad materials identification. In common with the baggage X-ray system aggregating over an object in the image will give finer measurements which will make it possible to tag contraband substances so increasing the probability of detection and reducing the number of false alarms. This reduction in the false alarm rate will mean less time consuming and costly de-vanning of cargoes.

The technology is now ready for the next phase - the construction of a full size system and demonstration on real cargo. This requires substantial funding (£5m) which might well only be found if there is some form of multi-agency co-operation. This technology is fully protected by international patents owned by CIL. The results of feasibility trials are described in an accompanying paper at this symposium[6].

7. Conclusions

A number of different technologies have been discussed here, each addressing one or more of the key areas outlined in the introduction.

Some of the technologies have now reached maturity and are produced commercially, such as the fibre optic intensified CCD technology, and others are still under development and awaiting market interest. PSDB's aviation security programme, funded by the Department of Transport, is continuing to address these areas with the aim of successfully demonstrating and deploying more effective contraband detection technology.

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High Energy Material Discrimination (HEMD) in the X-ray Imaging of Cargo Containers at Linac Energies.

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ABSTRACT

Cambridge Imaging Ltd (CIL) has successfully developed and demonstrated a new technique for achieving material discrimination with the imaging of large objects such as cargo containers, which require high energy X-rays (above 1 MeV) for their examination. The use of images color-coded with information on material composition is well known for low-energy (~ 150 keV) X-ray baggage scanners as a means of helping operators to identify threats and illicit objects at airports. However, this technique cannot be extended to high energy X-rays in a straightforward way because the physics of X-ray interactions is very different at low and high energies.

A key feature of the project has therefore been the unique design of X-ray detector arrays to achieve High Energy Material Discrimination (HEMD). Using a 10 MeV Linac at DERA, Fort Halstead, UK we have obtained high quality images of moving objects. These images have been color coded according to the material composition of the object, as with baggage scanners, and show separate identification of metals (Fe), light metals (Al) and organic materials according to their mean atomic number.

The main performance features demonstrated with a 0.5 m detector array are:- penetration of Fe to a depth of about 400 mm; visibility of Cu wires down to 370 micron diameter; material discrimination permitting organic-Fe separation with 1.6 g of material with 99.99% certainty; a separation of about 90 g of materials differing by one unit of Z, equivalent to separating explosives from narcotics and from harmless materials, can be achieved at 95% certainty.

This work has been carried out with the active support and financial assistance of the UK Department of Transport and Home Office.

1. Introduction

The imaging of trucks and cargo containers using high-energy X-rays for detection of contraband and threats is a well established and valuable technology. However the images of such large objects are often complex and require extensive operator interpretation. The detection of contraband hence depends critically upon the level of training and alertness of operators and their ability to interpret overlapping objects with conventional black and white (or false color) images.

The use of images color-coded with information on material composition is well known for low-energy X-ray baggage scanners, such as those used at airports, as a means of helping operators to identify threats and illicit objects. However, this technique cannot be extended to high energy X-rays in a straightforward way because the physics of X-ray interactions is very different at low and high energies.

For the past 5 years, Cambridge Imaging (CIL) has been carrying out an R & D program to achieve high-energy X-ray imaging of large moving objects with material discrimination. Our approach has recently been successfully demonstrated in trials with a 10 MeV Linac at DERA, Fort Halstead, UK. We have obtained high quality images which have been color coded according to material composition of the object, as with baggage scanners, and show identification of metals (Fe), light metals (Al), and organic materials according to their atomic number (Z).

Our demonstration of the feasibility of the **high-energy material discrimination (HEMD)** technique required the design and development by Cambridge Imaging of a new type of detector array, incorporating special arrangements of scintillation crystals and other components. The system design included careful attention to the high-energy X-ray beam profile. For these demonstration trials, we used the proprietary fibre-optic/CCD read-out system developed by CIL. We would emphasise, however, that the HEMD technique is not limited to any particular crystal read-out means, and should be feasible with alternatives such as photodiodes.

In the final phase of this R & D development since March 1995, the project has been supported financially by the UK Department of Transport and Home Office. This proprietary technique of high-energy material discrimination (HEMD) is the subject of international patents filed and owned by Cambridge Imaging Ltd. In this report we describe briefly the system as finally tested in late 1996, and we summarise the performance of the system, including in particular its capability for obtaining information on the material composition of objects at high energy.

2. Realization of HEMD

2.1 Physical Basis

Just as with low energy X-ray baggage scanning, the capability for performing material discrimination in the MeV energy range depends on an ability to sample separately the high and low energy components of the X-ray beam, since those components are affected differently by objects of different atomic number Z. If we write the attenuation coefficient for X-rays of energy E in material of atomic number Z as $\mu(E,Z)$, then we show in Figure 1(a) the scaled ratio $R(E,Z) \equiv (\mu(E,Z) / \mu(1,Z)) / (\mu(E,1) / \mu(1,1))$ plotted against E for various elements. This ratio R(E,Z) is normalized to have the value 1 at E = 1 MeV; it shows that above 1 MeV there is an almost linear dependence on E and also a linear dependence on Z at fixed E.

To show the Z dependence more explicitly we present in Figure 1(b) the quantity $R(E_1, Z)/R(E_2, Z)$ for two chosen energies E_1 = 6 MeV, E_2 = 1 MeV appropriate to high energy cargo scanning, and it is seen to be linear in Z. Shown for comparison in this figure is the same quantity for E_1 = 60 keV, E_2 = 100 keV appropriate to baggage scanning, where the dependence on Z is now seen to be highly non-linear, and only slowly dependent on Z at low Z values, which makes separation of organic materials relatively difficult at low energies. For ease of comparison both curves in Figure 1(b) have been normalized to unity for the case of carbon, Z = 6.

This simple linear dependence on Z in the MeV energy range arises from the fact that the absorption of X-rays around 1 MeV is dominated by Compton Scattering ($\propto Z$), whereas, at high energies there is a growing contribution from pair production ($\propto Z^2$), so that the ratio R(6,Z)/R(1,Z) is growing linearly with Z.

This means that material discrimination at Linac energies should in principle be straightforward and easy to interpret, using measured values of quantities like ratios of R(E,Z) values.

To achieve material discrimination in a baggage scanner using transmission imaging, a detector element (dexel) usually comprises a thin front scintillating crystal which preferentially absorbs the softer X-rays, followed by a thicker crystal that responds to the harder X-rays that have passed through the front crystal (and sometimes through additional absorber placed between front and back crystals).

Unfortunately this technique cannot be straightforwardly extended to HEMD for reasons that will now be summarized.

2.2 Practical Considerations

Among the challenges confronting realization of an HEMD cargo scanner are the following:

1. The high and low energy components of the X-ray beam in the MeV energy range that have penetrated the object under examination have to be separately identified and measured. This is difficult when these components are in the MeV energy range because the energy deposited in detector material by the X-rays has large spatial spread (~ millimetres) depthwise, and the attenuation coefficients are small

This is to be contrasted with the baggage scanner case where the X-rays (of energy typically ~50-100 keV) are mainly losing energy by photoelectric effect and the energy deposited in a detection crystal is confined to a tiny spatial region (~ microns).

2. X-rays in the MeV range will Compton scatter upstream of the detector array, in beam collimator components, and in the detector array itself, leading to a large background radiation level. It also makes it difficult to identify separately the low and high energy components of the beam. For these reasons, the detector array and X-ray beam geometry have to be carefully designed.

3. The material discrimination effect itself is much smaller (~1-2%, see Section 5 below) at Linac energies than at baggage scanner energies, where it is a ~10-20% effect.

At the ONDCP Conference held in Washington DC in October 1992, Cambridge Imaging announced [1] that it was in the process of demonstrating a new technique for material discrimination for containers and cargo examination using X-rays of energy above 1 MeV. A key feature was to be the unique design of the X-ray detection sensors and imaging set-up to achieve HEMD. Since then Cambridge Imaging has undertaken a program of research and development to show feasibility of the technique. The early phase of the program (1992-93) was financially supported by British Rail with a view to examining rail freight entering the Eurotunnel. Throughout 1995-96 the project has been financially supported by the UK Department of Transport and Home Office. At the onset of the work Cambridge Imaging applied for and has since been granted international patent coverage for HEMD.

We now describe the system used for feasibility tests that were performed in late 1996 at DERA, Fort Halstead, UK. This led to the successful imaging of moving objects and implementation of HEMD with color-coded images.

3. Test system for demonstration of HEMD

The system comprised the following elements:

- Linac X-ray source and beam collimators
- Conveyor system
- Test detector array
- Read-out system and electronics for control and data acquisition
- Test objects

X-ray source

The 10 MeV Linac at DERA was utilized that is capable of delivering about 3000 R min^{-1} at 1 m at 300 Hz pulse rate. A beam collimation set-up was constructed to deliver a clean fan beam with good alignment to the 0.5 m prototype detector array which was 6.7 m from the linac internal target.

Conveyor

A test track and hydraulically powered transporter was placed about mid-way between Linac and detector array. The transporter had a flat deck area 1 m (wide) x 2 m (deep), set approximately 1 m above floor level consistent with beam height, so that test objects up to this size could be transported across the beam. The transporter could be operated remotely from the Linac control room, viewed by closed circuit television, and moved in either direction at constant speed while the deck area crossed the beam, typically at about 25 mm s^{-1}.

0.5 m Detector Array

Early versions of this array with several different module designs were first optically tested using a 300 keV X-ray set and then performance tested in the Linac beam at DERA to make a final selection of module design. The final detector test array was made up of 100 detector elements arranged in 10 modules each containing 10 detector elements. Each detector element presented an area of 5 x 5 mm^2 to the fan beam, and consisted of a number of scintillator crystals, each read out by plastic optical fibres. Various absorber materials and shielding components were used. For beam monitoring purposes, a block of reference crystals was utilized, each crystal read out by the its own optical fibre, which could be placed in the beam in front of the object under test.

Read-out System and Electronics

For these trials we used the proprietary fibre optic/CCD read-out system [1] developed previously by CIL for container and baggage scanning. Optical fibres coupled to each crystal of the detector array received the light signals produced in each crystal by absorbed X-rays and transported these signals to an electronic camera. This was a 200 Hz intensified CCD camera, together with Frame Grabber and a 12-bit FADC for read-out of the CCD.

The camera unit and electronics were contained in an electrically screened unit, which was placed next to the detector array, and the optical fibres from the detector array were bundled and passed into the box for mounting on the camera. When the Linac was in use, the system was operated remotely through a cable link and drive unit to the Linac control room. Control electronics were developed to allow a delayed camera frame sync pulse to be used to trigger the Linac.

Test Objects

Step wedges of Fe and PTFE, 600 mm high with steps of width 20 mm, were constructed with thicknesses chosen to yield between approximately 90% and 10% transmission when used with the Linac at 10 MeV. The densities of these materials were 7.25 g cm^{-3} and 2.2 g cm^{-3} respectively. An Al step wedge (35 mm plus 9 steps 5 mm thick) used previously for baggage scanner trials was also available. A steel resolution grid was constructed, consisting of sets of 4 bars of various widths between 8 and 3 mm, each bar being about 12 mm deep in the beam direction. A test chart comprising Cu and Fe wires, paper clips and other items to check system performance was used, together with a variety of other objects.

4. Data Acquisition Method and Software

The detector array contained 100 detector elements or "dexels", each read out by a number of optical fibres. The block of reference crystals, each read by a single fibre, accounted for further readings. Groups of CCD pixels away from the fibre ends were arranged to give dark field readings. Up to 12000 camera read-out cycles could be recorded, and since the system operates at 200 Hz the corresponding acquisition time was 60 s, somewhat greater than the time (~ 40 s) taken by the transporter to cross the field of view.

The image files were processed off-line, using a specially assembled software suite. The following types of calculation were performed:

(a) Dark level subtraction

In the absence of beam the recorded FADC counts have a background offset. An average dark level was obtained before Linac switch-on this value was subtracted from the values subsequently obtained when the beam is on.

(b) Normalisation

For many reasons, and in particular because of differences in channel output, normalisation of the counts is essential. A technique was developed to obtain calibration curves to be used to convert measured counts to normalized counts in generating images. A final normalization was done using the reference crystals to take out changes in Linac intensity, both periodic variations and long term drifts.

(c) Material Discrimination calibration

The curves used for this calibration ("banana curves") were obtained for each dexel as described in Section 5 below.

5. Details of Feasibility Trial and Implementation of Material Discrimination Color Images

A trial of the full system described above took place at DERA in late 1996. This led to the successful imaging of moving objects and implementation of HEMD with color-coded images. Most data were taken with the Linac running at 10 MeV though some data were also taken at 8 MeV. Data taking was started just before objects on the transporter deck entered the beam line, usually with movement in the same direction (from left to right when viewing the object in the direction from source to detector). A thin metallic absorber was placed early in the X-ray beam as a means of hardening the beam to optimize material discrimination. A series of images was obtained, in most cases as a black and white image together with the corresponding color coded image to indicate material composition.

The first step in obtaining material discrimination coded images was to generate "banana curves" using the step wedges of PTFE (representative of low Z materials), Al and Fe described above.

A banana curve takes the form of a plot for each dexel of a Derived Signal (DS) versus transmission T. The DS is a measure of material discrimination being calculated from the signals in the crystal components in a dexel and is expressed as a percentage of bright field signal (ie with zero thickness of absorbing materials in the beam). (For a baggage scanner, DS is usually just the difference between the signals in front and back crystals, and is hence a measure of the extent to which low and high energy components of the beam are affected differently by materials of different Z in the beam). The transmission T is normalized to bright field.

In Figure 2(a) we show plots of DS versus T for a typical dexel obtained at 10 MeV with smooth curves drawn through the data points. We see that the greatest separation between PTFE and Fe data is at about transmission 0.5, where DS is measured to be of magnitude (1.50 ± 0.224)%, where the error(σ) in DS comes from the statistics of the X-rays interacting in a dexel. The material discrimination is therefore measured here to be a $1.5 \div 0.224 = 6.7\ \sigma$ effect. A banana curve for Al (Z = 13) might be expected to lie roughly one third of the way between the curves for PTFE (Z = 8.3) and Fe (Z = 26) on the hypothesis that the material discrimination effect is linear in Z as stated in Section 2.1, and the data for Al for a limited transmission range shown in Figure 2(a) are seen to be consistent with this expectation.

In Figure 2(b) we show equivalent data obtained with the Linac at 8 MeV. The PTFE-Fe separation is now seen to be of magnitude 1.2%, ie about three-quarters of that at 10 MeV.

We have developed a computer model of our detection system, making plausible assumptions about the Linac X-ray energy spectrum (a "thick target" bremstrahlung spectrum), and the processes of energy loss and transfer in a dexel, leading to digital signal values. This has enabled us to predict by Monte Carlo calculation the banana curves to be expected at 10 MeV and 8 MeV. There is found to be excellent agreement between our experimental curves and the theoretical predictions as to both shape and absolute magnitude.

Using these experimental banana curves a 3-way color coding of image elements may be made, to produce color-coded HEMD images.

6. Performance of Prototype HEMD X-ray Screening System

6.1 Data aggregation for performance assessment

Our data was acquired at 200 Hz, using a 0.5 m detector array with 5 x 5 mm^2 dexel size placed at a distance of 6.7 m from the Linac target. The Linac was triggered at 2/3rds of its standard pulse rate (300 Hz) and hence we were using 2/3rds of the 3000 R min^{-1} available.

We need to present our data in a form consistent with a practical cargo scanning situation. We could assume a 20 m long cargo item requiring 200s imaging time, and hence moving at 100 mms^{-1}. Since we have a dexel size of 5 mm, this implies a speed of 20 dexels s^{-1} and since we acquire data at 200 Hz, this implies 10 cycles/dexel. We have therefore aggregated our data over 10 cycles in quoting results and we refer in the following to this time period. (Note that since the transporter moved at about 25 mms^{-1} instead of 100 mms^{-1} this is equivalent to using one quarter of the test data available).

To screen full size objects we could assume a 4 m high detector at a distance of 12 m from the source, which should be a full scale Linac delivering, say, 5000 R min^{-1} at 1 m. Compared with the current trial the interaction rate would then differ by a factor

$$(5000/3000) * (6.7/12)^2 * (300/200) = 0.78$$

where the last factor assumes use of a 300 Hz data acquisition system to match the Linac. The current trial is therefore a reasonably good predictor of what would be possible with a full scale system under these assumptions.

6.2 Absorption Curve and Penetration

Using the Fe step wedge described above, plus additional thicknesses as appropriate up to a total thickness of 350 mm, we have obtained the absorption curve for Fe as shown in Figure 3. The values plotted are for a typical dexel, per 10 cycles.

In defining penetration, and based on experience with baggage scanners, it is reasonable to say that a signal of magnitude 0.7 σ over a number of adjacent dexels is appropriate to estimate the limit of visibility, where σ is the standard deviation on the dark level. The value of 0.7 σ is shown as 'Noise' on Figure 3, from which we see that the penetration is about 375 mm of Fe for a single dexel.

As an alternative means of estimating the penetration, we could consider aggregating 100 dexels (ie. 5 x 5 cm^2) which reduces σ by a factor of 10 and so leads to a penetration of 450 mm of Fe at the 1 σ level, or 425 mm of Fe at the 2 σ level.

6.3 Wires and Spatial Resolution

From our measured bright field signal we can estimate the diameter of Cu wire that will just be visible, and we estimate a value of about 0.30 mm. We find from our image of a test chart of wires that the thinnest Cu wire of diameter 0.37 mm is clearly visible.

In the image of the Fe resolution grid described in Section 3 we are able to see the smallest gap of 3.2 mm which is consistent with the dexel size of 4 mm at the object, allowing for the fact that we are averaging over 10 cycles in presenting the image.

6.4 Material Discrimination

Using the measured banana curves presented in Figure 2(a) we can predict the ability of our system to do material discrimination in different situations. We saw that we had a 6.7 σ effect in separating PTFE from Fe, a Z difference of 17.6 units, at T=0.5. This can be summarized by stating that our measurement error in Z is σ_Z = 17.6/6.7 = 2.6 units. It is of interest to consider the separation of organic material (eg. cocaine) from Fe. In general Z_{eff} for chemical substances will be different at MeV energies than at baggage scanner energies, the change resulting from the different Z dependence of X-ray interactions at different energies; thus cocaine at baggage scanner energies has Z_{eff} = 9.4 whereas in the MeV range it has Z_{eff} = 6.75. Separation of cocaine from Fe, a Z difference of 19.25 units, would therefore lead to an effect of magnitude (19.25/17.6) * 6.7=7.3 σ. Since from our step wedges we know that T=0.5 is associated with about 21 g cm^{-2} of material, the mass on a dexel (area 4 x 4 mm^2 at the detector) is 21 g cm^{-2} * 0.16 cm^2 = 3.4 g. It follows that at the 5 σ level this mass would be $(5/7.3)^2$ * 3.4 = 1.6 g.

An alternative way of expressing this material discrimination capability is to say that two slabs producing images of the same (50%) greyness, one of PTFE of thickness 21 g cm^{-2} ÷ 2.2 g cm^{-3} = 9.5 cm, the other of Fe of thickness 21 g cm^{-2} ÷ 7.25 g cm^{-3} = 2.9 cm, will be distinguished at the dexel level as a 7.3 σ effect.

We can predict how this separation capability would be affected by intervening material which would attenuate the X-ray beam before (or after) traversing the unknown object. This is shown in Figure 4(a), in the form of the mass of organic/Fe that can be separated at the 5 σ level, ie. with 99.99% certainty, for increasing thicknesses of intervening water. We see that behind 1 m of water the mass has increased to 560 g, and behind 1.5 m to about 11 kg.

In discriminating between different organic materials, one is comparing materials having only a small difference in effective Z, such as explosives from narcotics and from harmless materials. In Figure 4(b) we show the mass of two materials differing by one unit of Z that can be separated. At the 1 σ level this is 23 g, increasing to 8.4 kg with 1 m of intervening material (water). At the 2 σ level (95% certainty) it is 92 g, increasing to 33.6 kg behind 1 m of water.

We note that although the resolution in Z is 2.6 units, for the large objects in a cargo scanner one could aggregate 100 dexels and still have 4 cm x 4 cm spatial resolution with $\sigma_Z = 0.26$ units, a comparable Z resolution to that of baggage scanners.

Although these idealizations are very different from practical situations, they nonetheless point to the performance to be expected in real scanning situations.

6.5 Summary of Performance of System

These results for our HEMD scanner are summarized in Table 1. They are compared in Table 2 with the performance of a typical low energy X-ray baggage scanner.

7. Summary

High Energy Material Discrimination (HEMD) has been demonstrated to be suitable for high quality imaging of cargo at 10 MeV.

Black and white images and color coded HEMD images have been obtained using a 0.5 m detector array of new design. Performance details are summarized in Table 1. The main features are: penetration of Fe to a depth of about 400 mm; visibility of Cu wires down to 370 μm diameter; material discrimination enabling one to distinguish organic materials from Fe in a single dexel corresponding in principle to a mass of 1.6 g with 99.99% certainty. One could also in principle separate ~100 g of materials differing by one unit of Z, such as explosives from narcotics or from harmless materials, with 95% certainty.

One could summarize the HEMD performance (see Table 2) by stating that the Z resolution, for the same ratio of imaging area to area scanned, is as good as or better for the cargo scanner ($\sigma_Z = 0.8$ units) as for a baggage scanner ($\sigma_Z = 1\text{-}2$ units).

The feasibility of HEMD has therefore been demonstrated. This means that at every pixel in a container image, the operator will have information as to how much inorganic or organic material is in the cargo being scanned. The operator would therefore be able to inspect either a black and white image of projected material densities, or an image color coded to indicate the identity of material at every location. A color image indicating the amount of either organic or inorganic material at every pixel (ie material stripping) would also be available. We expect that this additional information will greatly assist operators in interpreting complex images, and hence improve the detection rate for contraband and other materials. Such information has proved invaluable for baggage scanning, and it is highly plausible that container scanning would benefit likewise.

Cambridge Imaging has applied for and been awarded international patents for its HEMD technique described here.

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Table 1

Summary of Measured Properties of High Energy Material Discrimination X-ray Cargo Scanner

Property (*)	Value
Penetration in Fe ($\rho = 7.25$ g cm^{-3}) - from visibility criterion - from 2 σ in 100 dexels	 375 mm 425 mm
Cu **Wire** visibility (diameter)	370 μm
Material Discrimination organic/Fe (99.99% certainty) - no intervening material - behind 1 m of water materials differing by 1 unit of Z (95% certainty) - no intervening material - behind 1 m of water	 1.6 g 0.56 kg 92 g 34 kg

(*) These estimates are appropriate to scanning a 20 m cargo in 200 s, moving at 100 mm s^{-1} (see Section 6.1), using dexel size 5 x 5 mm^2, corresponding to approximately 4 x 4 mm^2 at the object.

Table 2

Comparison of Performance of HEMD Cargo Scanner with a typical Low Energy Baggage Scanner

	Typical baggage scanner (approx values)	HEMD Cargo Scanner
X-ray peak energy	140 keV	10 MeV
Area scanned	1 m^2	80 m^2
Dexel size at object	1.5 x 1.5 mm^2	4 x 4 mm^2
Penetration of Fe (thickness)	25 mm	400 mm
Cu wire visibility (diameter)	120 μm	370 μm
Material discrimination resolution (σ_Z) at ~50% transmission in equivalent area (ie same ratio of imaging area to area scanned)	1 - 2 units (in 1 dexel)	0.8 units (in 11 dexels)

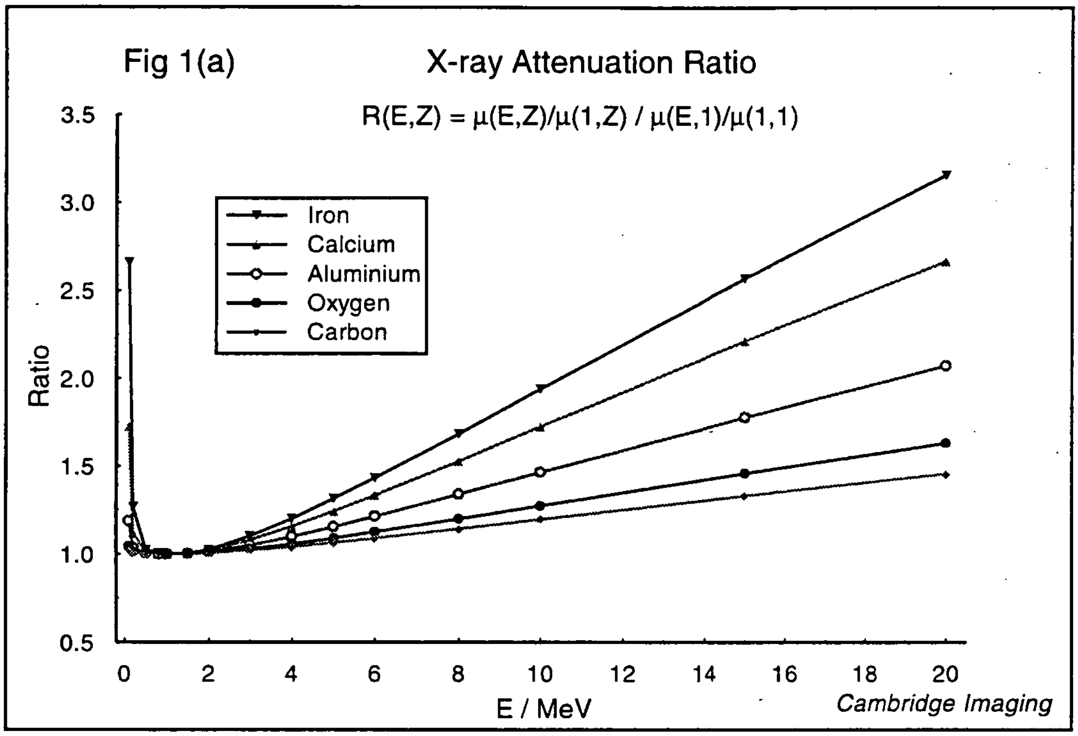


Fig 1(a)
X-ray Attenuation Ratio
R(E,Z) = μ(E,Z)/μ(1,Z) / μ(E,1)/μ(1,1)
Iron
Calcium
Aluminium
Oxygen
Carbon
Ratio
E / MeV
Cambridge Imaging

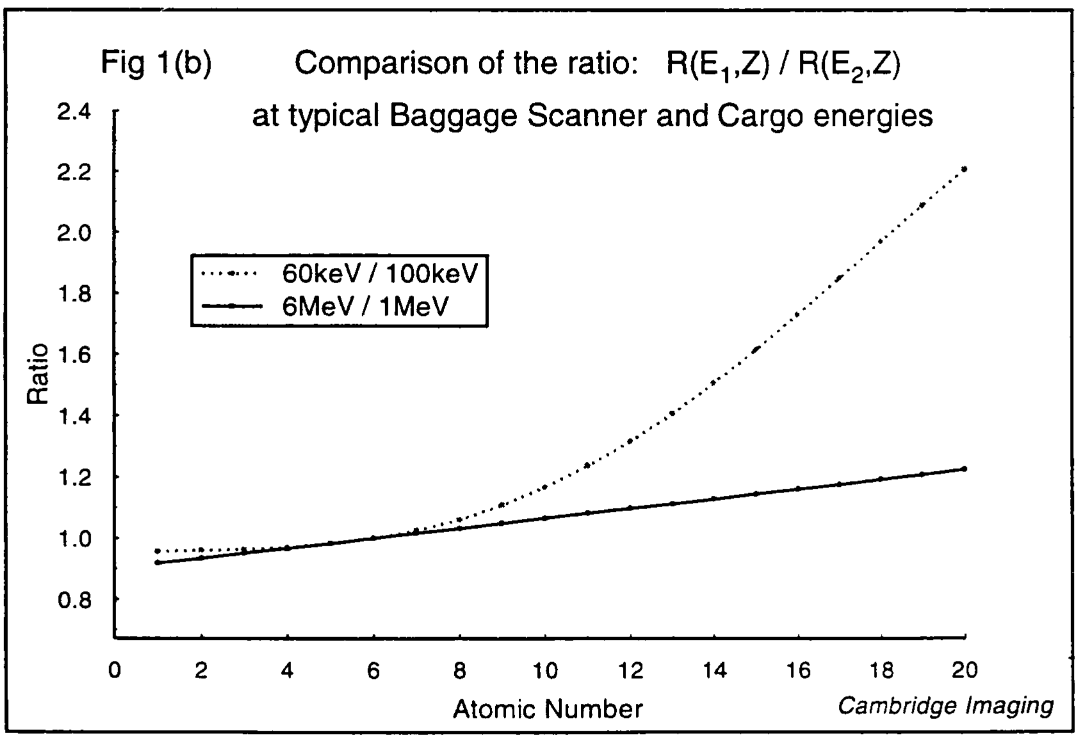


Fig 1(b)
Comparison of the ratio: R(E1,Z) / R(E2,Z)
at typical Baggage Scanner and Cargo energies
60keV / 100keV
6MeV / 1MeV
Ratio
Atomic Number
Cambridge Imaging

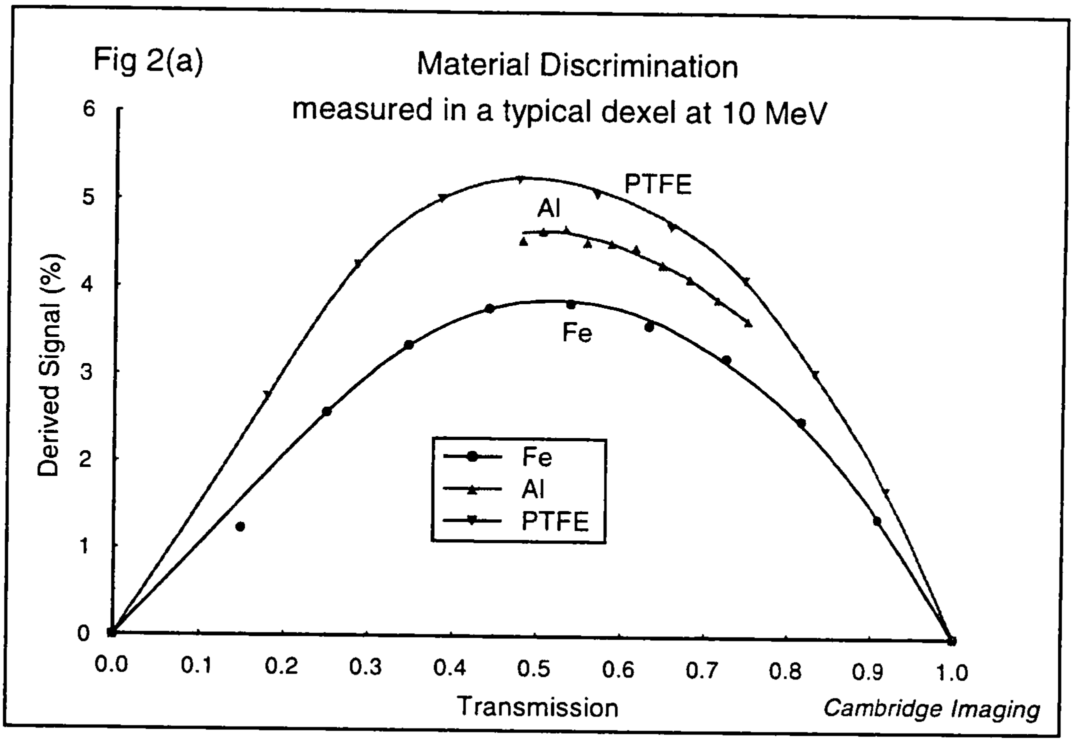


Fig 2(a)
Material Discrimination
measured in a typical dexel at 10 MeV
PTFE
Al
Fe
Fe
Al
PTFE
Derived Signal (%)
0
1
2
3
4
5
6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Transmission
Cambridge Imaging

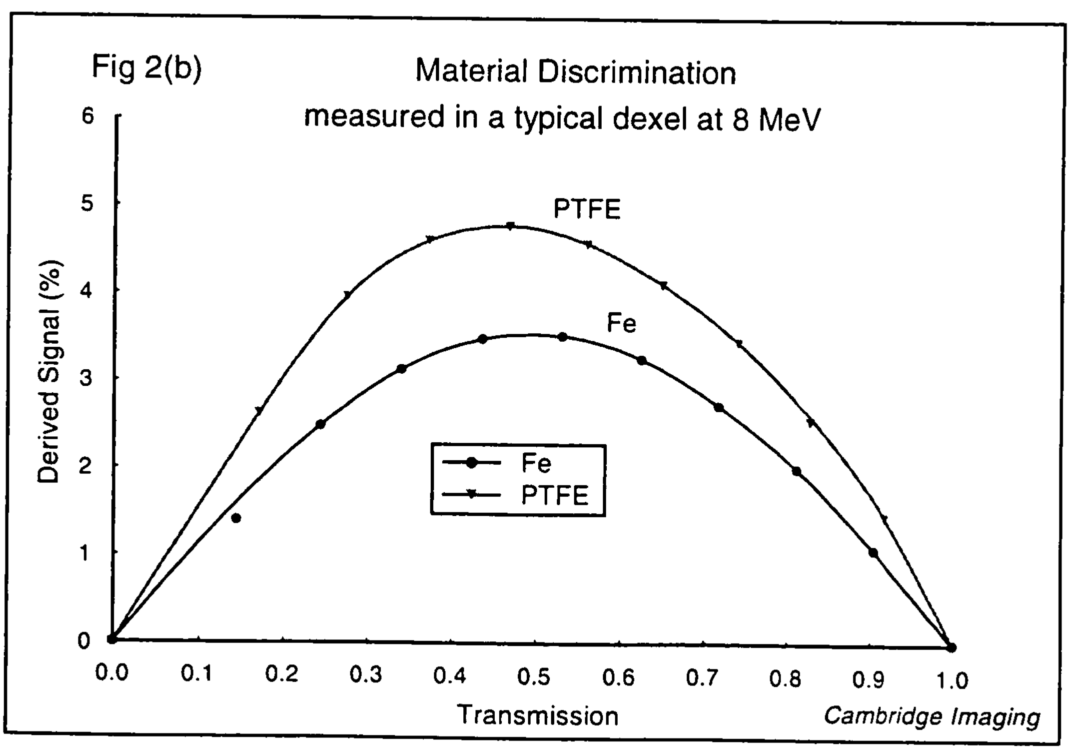
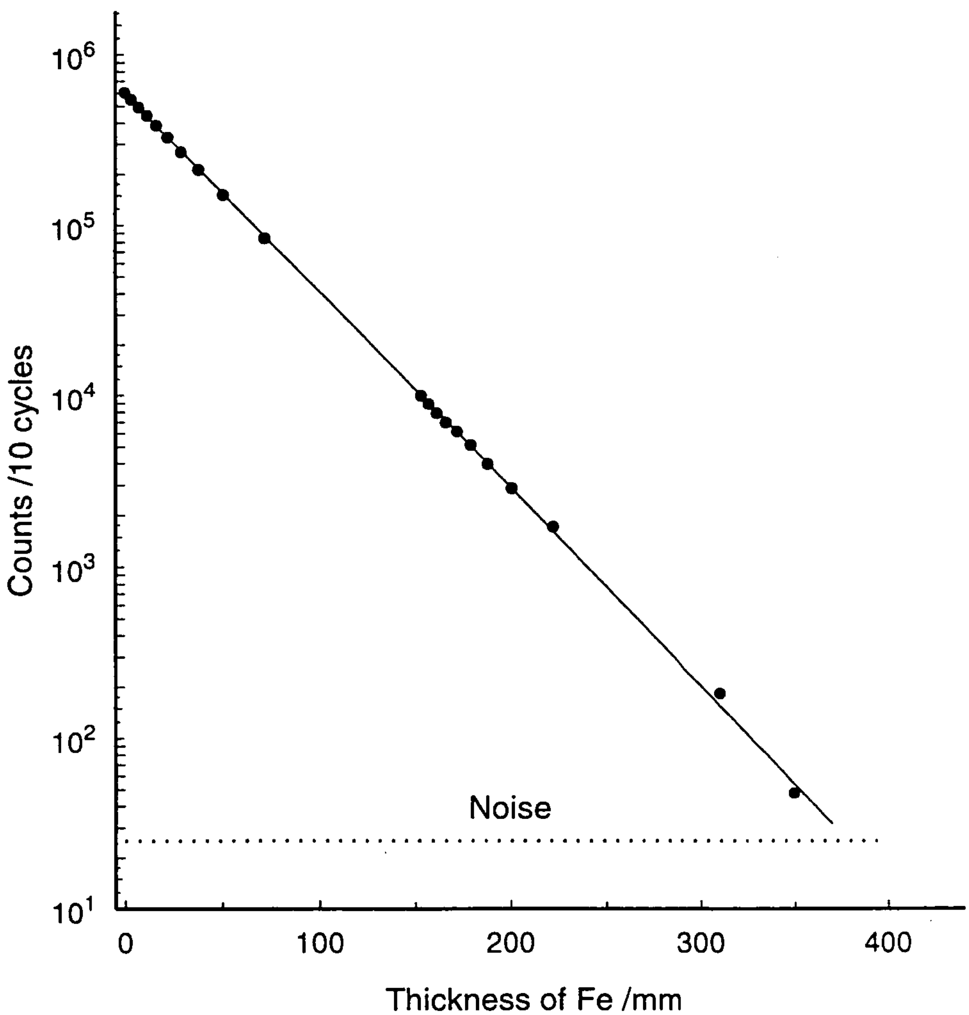


Fig 2(b)
Material Discrimination
measured in a typical dexel at 8 MeV
PTFE
Fe
Fe
PTFE
Derived Signal (%)
0
1
2
3
4
5
6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Transmission
Cambridge Imaging

Fig 3 Absorption in Fe measured for a dexel at 10 MeV



Cambridge Imaging

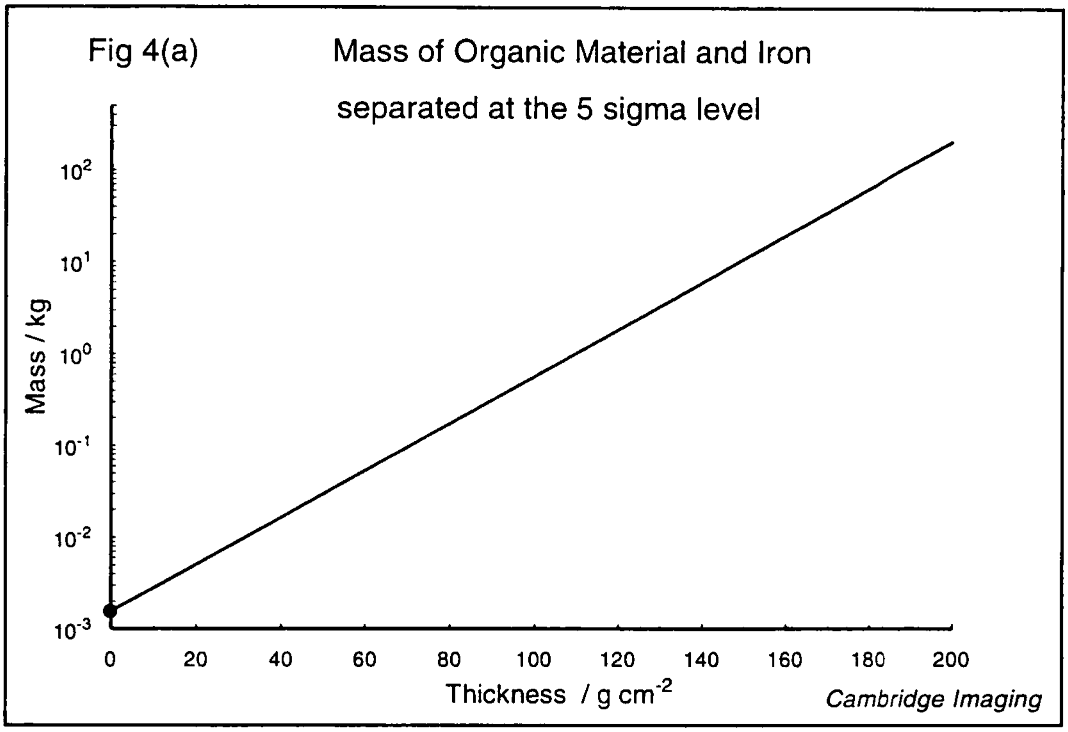


Fig 4(a)
Mass of Organic Material and Iron
separated at the 5 sigma level
Mass / kg
10^2
10^1
10^0
10^-1
10^-2
10^-3
0
20
40
60
80
100
120
140
160
180
200
Thickness / g cm^-2
Cambridge Imaging

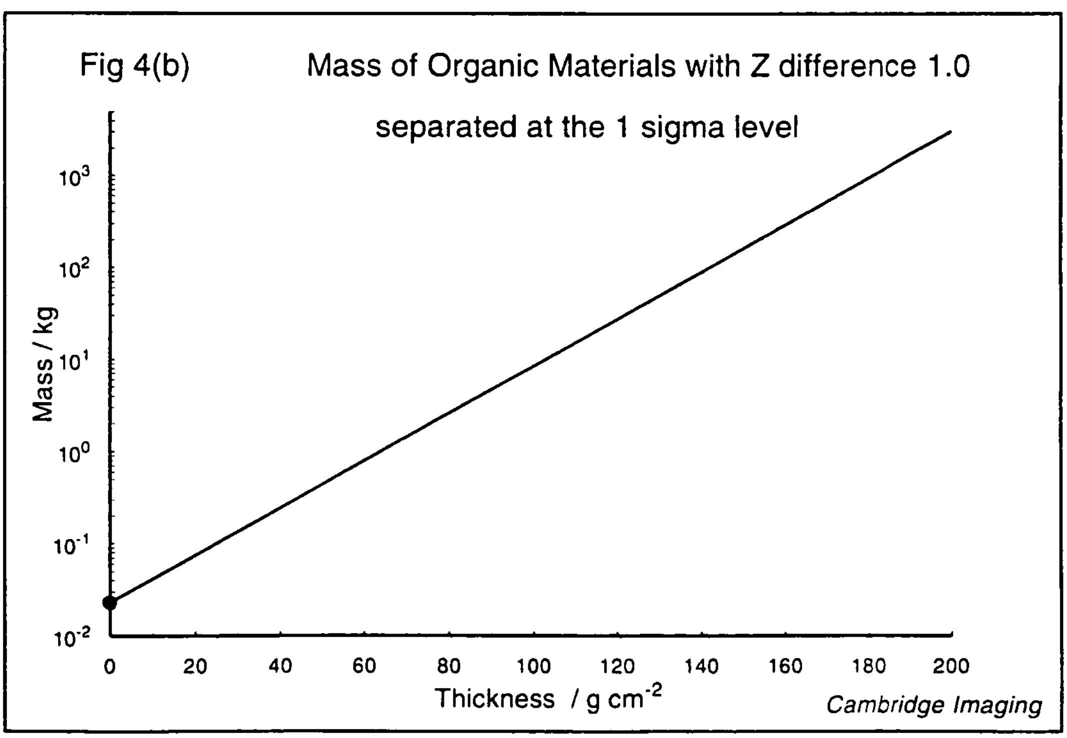


Fig 4(b)
Mass of Organic Materials with Z difference 1.0
separated at the 1 sigma level
Mass / kg
10^3
10^2
10^1
10^0
10^-1
10^-2
0
20
40
60
80
100
120
140
160
180
200
Thickness / g cm^-2
Cambridge Imaging

Title of Paper: A Pulsed Fast-Thermal Neutron Probe for Contraband Detection

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ABSTRACT

Elemental characterization of an object through the utilization of neutrons as a probe is a well established technique. Neutrons are widely employed for, among others, oil exploration[1], bulk coal analysis[2], cement analysis[3], and mineral exploration[4]. Furthermore, several neutron-based methods have been under development in the last few years for the detection of hidden explosives and drugs[5].

Based on previous measurements[6], we have proposed to construct a probe prototype for contraband detection in-situ within pallets of materials utilizing the neutron technique of Pulsed Fast-Thermal Neutron Analysis (PFTNA). We will present the principles of PFTNA as well as some of the features of the prototype. The prototype will be ruggedized and man-portable; sizes and dimensions will be discussed. The probe has been designed to be inserted between sacks of material on a pallet. The detector in the probe is arranged such that it has a preferred directionality. The prototype will be self-calibrating or easily calibrated to meet specific environmental conditions with a spectral deconvolution algorithm to increase sensitivity. Detection limits versus depth of surveillance for this probe will also be described. Finally, a description of how this device will be employed in the field will be given.

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1997 ONDCP INTERNATIONAL TECHNOLOGY SYMPOSIUM
Applied Counterdrug Law Enforcement Technology

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1997 ONDCP INTERNATIONAL TECHNOLOGY SYMPOSIUM

Applied Counterdrug Law Enforcement Technology

Personnel Screening Systems for Aviation Security

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ABSTRACT

Personnel Screening Systems for Aviation Security

The Federal Aviation Administration has been working on Personnel Portals to screen for weapons and explosives since 1989. Two systems are currently under development. They are the millimeter wave detection portal and the dielectric detection portal. Both systems are able to see objects hidden on the body and to present an image to an operator on a computer monitor. The idea is to discover hidden objects that could be weapons (either metallic or non-metallic) and/or explosives. Issues that will be discussed include those of privacy, search and seizure, health, and safety. In addition, the recent National Research Council's report entitled "Airline Passenger Security Screening - New Technologies and Implementation Issues" that examined both the technologies and issues will be addressed.

4/11/97

An X-ray Imaging Alternative for Interdiction of Weapons and Contraband Concealed on the Body

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ABSTRACT

In an effort to avoid detection, smugglers and terrorists are increasingly using the body as a vehicle for transporting illicit drugs, weapons, and explosives. This trend illustrates the natural tendency of traffickers to seek the path of least resistance, as improved interdiction technology and operational effectiveness have been brought to bear on other trafficking avenues such as luggage, cargo, and parcels. In response, improved technology for human inspection is being developed using a variety of techniques. AS&E®'s BodySearch™ X-ray Inspection System uses backscatter x-ray imaging of the human body to quickly, safely, and effectively screen for drugs, weapons, and explosives concealed on the body.

This paper reviews the law enforcement and social issues involved in human inspections, and briefly describes the AS&E BodySearch system. Operator training, x-ray image interpretation, and maximizing system effectiveness are also discussed. Finally, data collected from operation of the BodySearch system in the field is presented, and new law enforcement initiatives which have come about due to recent events are reviewed.

INTRODUCTION

Due to a rising concern over terrorist activities and the continuing vigor of the drug trade, law enforcement agencies are being challenged to tighten their security measures. Cooperative efforts between government and industry over the last several years have led to improvements in inspection technologies deployed in the field, making it more difficult for smugglers and terrorists to get past installed security measures. The main focus of these developments, though, has been in the area of parcel, luggage, vehicle, and cargo screening. Similar development and deployment of technology for performing human inspections has lagged behind, making the human body a more attractive vehicle for passing illegal drugs, weapons, and explosives through security check points. This is a gap that must be filled, as any truly comprehensive and effective security program must address all of the possible avenues by which it might be penetrated. New technological tools for human inspection which have recently become available now face the challenge of meeting the requirements for deployability. Note that in most cases it is the public at large that becomes subject to these security inspections. Also, the overwhelming majority of people subjected to searches are honest, law-abiding persons whose searches turn up negative. This reality requires that any human inspection method intended for routine use must meet standards of public acceptance. Issues of privacy, intrusiveness, inconvenience, and legality are therefore every bit as important as technical performance and effectiveness.

There are several methods available for performing human inspections, and they vary widely in their trade-offs between effectiveness and intrusiveness. The most widely practiced methods are also the least intrusive: Walk-through metal detectors and pat-down searches. Because these types of searches are relatively unobtrusive, the barriers to implementation are low. However, their ability to detect a wide range of concealed materials is limited. The far more intrusive strip-search is probably the most effective search technique available, but for obvious reasons it is only practicable in a restricted number of environments. This technique is not only intrusive and degrading to the subjects, but it also places the security agents in close quarters with the subjects, exposing them to the personal risk of disease transmission and bodily violence. These issues force security agents to be very restrictive in their use of strip-searches, relying instead on profiling and intuition as a means of pre-screening individuals. Naturally this very selective process drastically reduces the effectiveness of the interdiction effort. New technological tools such as X-ray imaging, electromagnetic imaging, and trace detection are now becoming available to increase effectiveness while limiting intrusiveness. Of course each of these technologies has its advantages and disadvantages. American Science and Engineering, Inc. (AS&E®) has developed what it believes to be the best solution available to date in its BodySearch™ X-ray Inspection System. BodySearch uses backscatter X-ray imaging to quickly and safely acquire high resolution images sensitive to both high atomic number (high-Z) metals and low-Z organics and explosives concealed on the body with minimal inconvenience and intrusion to the subject.

WHERE SECURITY INSPECTIONS ARE NEEDED

There are varying objectives among the different environments where security check-points are employed. In the international customs service and border control environment, searches of parcels, cargo, and people focus on interdiction of illegal drug trafficking and smuggling of valuables to avoid import duties. In the prison environment, drug interdiction is again an objective but so too is the search and seizure of weapons or materials from which weapons can be fashioned, which includes both metals and plastics. Other security-controlled installations such as high-level government buildings, military installations, and nuclear facilities seek to prevent the unauthorized entry of weapons and explosives as well as the removal of valuable or controlled materials. One further application for human inspection that has recently gained much exposure is civil aviation security. Recent world events have forced a re-evaluation of such security measures world-wide, and inspection methods considered too aggressive only a few years ago are now receiving consideration. With such a diverse set of interdiction needs, the equipment that is currently used to supplement manual searches, namely metal detectors, fails to provide the operator with comprehensive and specific information about the threat materials being carried. For example, metal detectors cannot distinguish normal metal objects such as zippers in clothing from threats such as metallic weapons. In addition, the need to detect non-metallic objects such as plastics, explosives, and drugs defeats the standard metal detector as a comprehensive deterrent. The BodySearch system was designed specifically to provide detection of all of these materials, sensing not only the presence of objects but providing images of both metallic and non-metallic objects on the body. These images can be used by the

Figure 1. The AS&E BodySearch X-ray Inspection System

operator to locate concealed items and quickly differentiate between normal non-threat items and contraband.

THE AS&E BODYSEARCH SYSTEM

To perform a scan, the subject is asked to stand relatively still on an external stage for several seconds while the system acquires two-dimensional raster-scanned image data. The electronic image of the subject is formed using the intensity of X-rays scattered from each location on the body via Compton scattering interactions. This X-ray scatter intensity is a function of both the atomic number and density of the materials probed by the primary X-ray beam, in this case either the body itself or items worn on the body. Note that since hair and clothing have very low densities, very few

Figure 2. Front and back X-ray images taken with the BodySearch system. Concealed metallic and organic contraband can be seen.

X-rays interact with these materials and they effectively vanish from the image. Denser objects such as metals, explosives, plastics, and packed drugs interact more strongly and so appear in the image along with the body itself. This can be seen in Figure 2, which shows examples of both metal and organic items on the body imaged with X-rays. The tight collimation of the X-ray beam results in high spatial resolution in the acquired images, making identification of the objects on the body easier. Note, however, that this technique only images materials on the surface of the body. It is not effective for seeing through the body or detecting materials which are concealed within body cavities. Because of this fact, two scans (front and back) are typically required for a routine inspection. Additional scans can in some cases be beneficial for identifying objects on the body. This is an area where the training and experience of the system operators can be important in maximizing system effectiveness.

MAXIMIZING SYSTEM EFFECTIVENESS

In the majority of cases, a simple front and back view of the person being inspected is sufficient to determine the presence or absence (and in many cases the identity) of contraband on the body. Extracting that extra percentage of detection sensitivity, though, requires slightly more. As is the case with virtually all X-ray imaging systems, the operator interpreting the acquired images is a vital component in the overall performance and effectiveness of the system. This is clearly the case with the BodySearch system. For maximum effectiveness, the operator must know not only how to interpret the images but how best to position the subjects being scanned for the best view of potential contraband. This is not a difficult task to learn, but is simply a matter of operator training. First comes an understanding of how different materials appear in an X-ray image when placed against or alongside of the body. As a rough rule of thumb, materials with high atomic number (high-Z) such as metals are good absorbers of X-rays, and so appear in the image as dark areas corresponding to few scattered X-rays. Conversely, low-Z materials (drugs, explosives,and the body itself) are good sources of scattered X-rays, and so appear as bright areas in the image corresponding to a large number of scattered X-rays. Since objects show up best when presented with a contrasting background, the most revealing view of dark, high-Z objects occurs when they are positioned in front of the bright signal from the body. Figure 3 illustrates the contrast of metals against the body. Likewise, bright, low-Z objects are easiest to detect when imaged alongside the body so that they are contrasted against the dark air background. These are ideal conditions which produce the greatest detection sensitivity. However, the

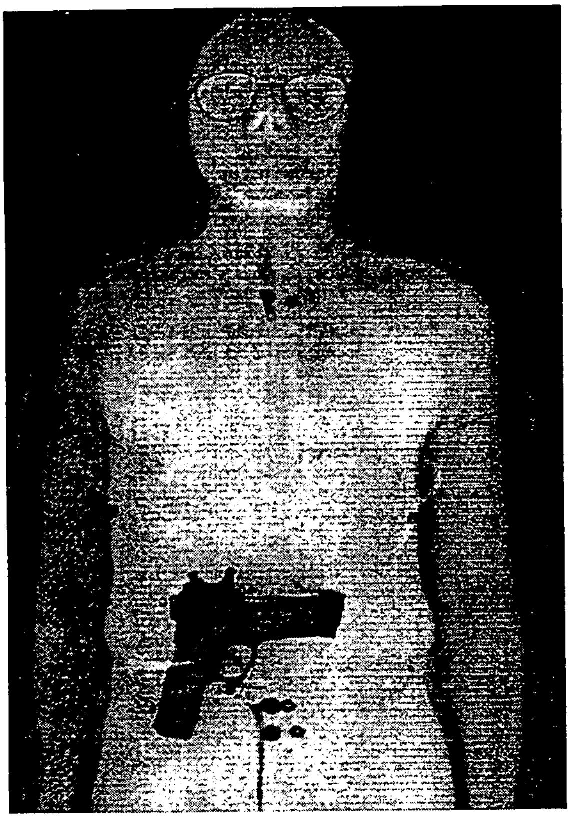

Figure 3. Metallic contraband imaged in front of the body appears with high contrast.

operator can not always expect these conditions to occur. This is where operator training becomes so important. When low-Z objects are imaged against the body, that is, white-on-white, there are still fairly obvious indications in the image if one knows what to look for. Changes in brightness level often reveal areas that are distinguishable as foreign materials on the body. Many low-Z threats appear this way because they have a density that is different from that of the body, resulting in a difference in grey-scale in the image. Even more useful is a "shadowing" effect which usually outlines a foreign object. Because of the very small spatial extent of the primary X-ray beam, X-rays which scatter from the body immediately next to a foreign object are somewhat shielded by that object, resulting in a darker grey-scale in the image for that given pixel. This occurs all around the object and tends to outline its shape with a "shadow." Figure 4 shows an organic threat placed against the body and illustrates the shadowing effect around the object. Operators using the BodySearch system quickly become accustomed to what a normal body without contraband looks like in X-rays, such that these visual cues are easy to recognize. This is facilitated by the fact that many foreign objects on the body such as packets of drugs,

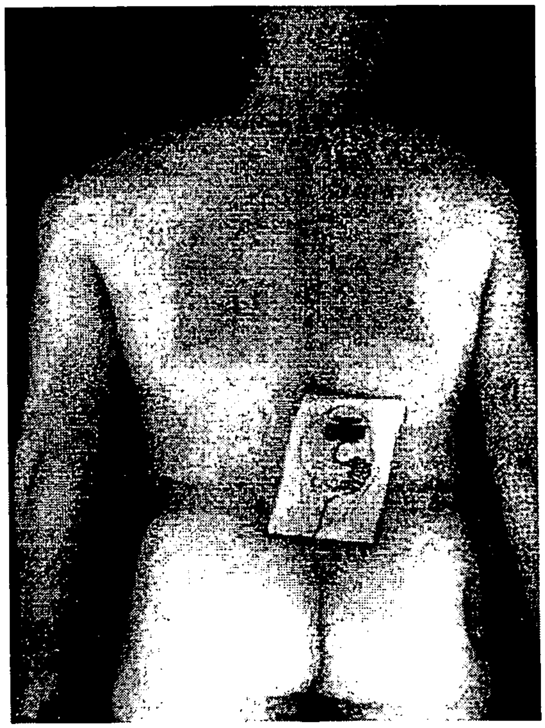

Figure 4. X-ray image showing a 372gm plastic explosive simulant. Note the shadowing effect at the edges. Also visible are wire leads and metallic components of the battery and detonator.

molded explosives, and plastic items usually have straight edges, right angles, or uniform curvatures to their shape. These shapes are not natural on the human body and immediately draw the attention of operators who know what to look for. Once operators are trained to look for these signs, even small, subtle objects in the image can be detected which might otherwise have gone unnoticed. A skilled operator will then re-position the person being inspected so that potential low-Z threats will be presented to the system in silhouette against the air background, permitting more certain detection and identification.

This same procedure can be exercised for high-Z materials imaged alongside the body against a poorly-contrasting air background. While air produces little X-ray scatter, it produces enough to contrast against metal objects, given the right tools with which to view them. The BodySearch system is equipped with image enhancement features which, among other things, allow the operator to enhance regions of the image containing very low signal levels. This helps to take advantage of the small but useable contrast between metals and the air background making it easier to distinguish the presence of metal items. A skilled operator will use this tool and in these cases re-position the subject for imaging of the object using the body as a backdrop.

HEALTH AND SAFETY

As stated earlier, the BodySearch system exposes the subject being scanned to 5 μrem (0.05 μSv) per scan, which is an extremely low exposure. By way of comparison, the typical natural background radiation exposure (at sea level) that we are all exposed to is approximately 550 μrem per day, or the equivalent of 110 BodySearch scans per day. Another interesting comparison can be made to the radiation exposure received during air travel. The exposure received during a round-trip flight from New York to Los Angeles is roughly equivalent to 1000 BodySearch scans. The safety of the BodySearch system for general use even in applications where multiple scans are performed on persons as an everyday routine has been confirmed by independent health physicists, and the BodySearch system has met all of the compliance requirements set forth by the U.S. FDA for entry into commerce.

DETECTION CAPABILITIES

The detection capabilities of the BodySearch system are naturally dependent on the skill of the operator interpreting the images and can vary depending on the body type of the subject. Because of this difficulty in creating repeatable controlled test conditions, it is not as easy to quantify absolute detection limits for the BodySearch system as it is for other types of X-ray inspection systems. To address this, AS&E has performed a series of tests to make the best determination possible of realistic detection capabilities under given conditions. These conditions are: a) the operator viewing the images has a reasonably good understanding of how different materials appear in the X-ray image, is reasonably skilled at detecting the visual cues in the images indicating the presence of contraband, and generally knows how to pose the subjects for effective imaging, b) the operator viewing the images has sufficient time (~10-20 sec) to study the images, c) the operator makes use of the standard set of image enhancement tools available on the system, d) the subject has a build representative of the norm in the U.S. population, and e) contraband items are worn on the surface of the body, not within body cavities or enclosed by tissue. Under these conditions, the BodySearch system has been found capable of detecting metallic (high-Z) threats down to a resolution of 28 AWG, making small blades, bullets, pins, and hypodermic needles detectable. Further, for organic (low-Z) threats of reasonable density (>0.7 g/cc), the BodySearch system is capable of detecting from sub-10gm quantities under ideal conditions to approximately 60gm quantities under the toughest conditions.

DEPLOYMENT, PRIVACY, AND PUBLIC ACCEPTANCE

Human inspection technologies in wide use today have changed little over the past few decades. Driven by the civil aviation security environment, most of the deployed technologies still focus on finding metallic weapons. This is not for lack of realization that the nature of the threat to both airliners and sensitive installations has expanded to include explosives that are undetectable by simple metal detectors. Rather, deployment of new technologies that can detect these threats has been hindered by very real issues of privacy, legality, and public acceptance. As evidenced by the images presented in this paper, imaging systems capable of detecting organic and other low-Z threats concealed on the body also reveal graphic details of the body itself. This is difficult to avoid given the similarity of elemental composition between the body and low-Z contraband.

Last year, the National Research Council (NRC) published findings and recommendations of a study regarding airline passenger security screening. A significant part of this report focuses on new technologies such as BodySearch and the non-technical aspects of implementation and deployment of these devices. Primary issues considered by the NRC include health, legal, operational, privacy, and convenience issues, with privacy and legality identified as two of the most important. The legal issue raised is one that revolves around the right to conduct a search. In an airport security environment, for example, the right to search persons is restricted to a search for items which may pose a threat to the traveling public. There is no right granted to search for illegal but non-threatening items. This poses a problem, since many of the new technologies available will permit detection and identification of both threatening and non-threatening items. It is possible that a change in legislation will be required to address this issue. The issue of privacy is a more obvious one. Again, an imaging system that has a high detection sensitivity will by necessity reveal more information about an individual than he or she might be comfortable with. There are a number of ways to alleviate this issue. Procedural solutions are the easiest to develop and put in place. Use of same-sex operators, availability of alternative search techniques, and operational discipline to prevent abuse of image data can all be used to help address the privacy issue. The difficulty with these solutions, however, is that they require constant vigilance and enforcement in order to be effective. A cleaner solution from an operational point of view would be one that pre-filters the image data so that only contraband information is displayed with no private bodily image data presented to the system operators. Algorithms that either restrict the search areas on the body or that localize and mask private areas of the body help in this regard. The challenge of this approach is to mask out private body parts without sacrificing detection effectiveness. Unfortunately, the private areas of the body are also the most common areas where contraband is concealed, precisely because it is reasoned that this is the last place that security officers would be willing to search. This challenging development task is receiving attention, but a deployable solution that will fully defuse the privacy issue through system functionality rather than through operational procedures is still some way off. It is noted that in the area of public acceptance, possibly the most insightful and enlightening comment made in the NRC report is that the amount of intrusion and inconvenience that the public will tolerate is directly dependent on the level of threat (real or perceived) and the effectiveness of the efforts to deter the threat.

SUMMARY

It is clear that in present day society there are environments in which effective screening for concealments on the human body is needed. Conventional pat- and strip-searches, while effective, are not suitable for addressing the security and drug interdiction needs that we now face due to their intrusiveness and inconvenience. Application of new techniques to this problem can help to alleviate many of the difficulties associated with human inspections. High-resolution X-ray imaging with the BodySearch™ system has been found to serve this function well. Increasing public protection from terrorist threats and enforcing the illicit drug laws that so greatly affect our society is made possible through fast, safe, and effective X-ray screening. Unfortunately we live in a world where the need for security screening of persons is likely to continue rising. Through continued development and refinement of new tools for screening, improved security need not carry such a high cost in inconvenience and invasion of privacy for the public at large.

CARGO SCREENING:
THE EFFECT OF USING DIFFERENT ENERGIES

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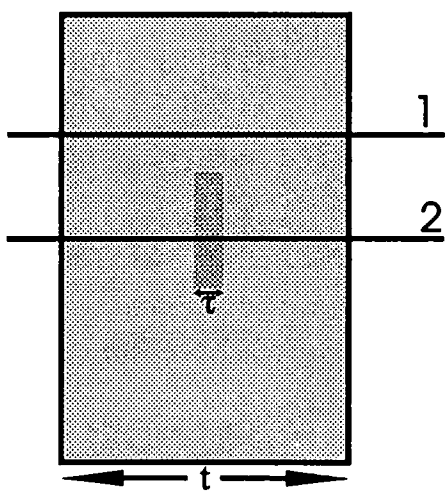
Introduction

There are several different systems proposed for use in cargo screening using different x-ray energies. Each manufacturer makes claims about the virtue of their particular configuration. This talk is intended to establish some objective criteria to compare these claims. The signal to noise in a simple model is computed for various energy photons and the results compared. This is clearly a simplified calculation but it is useful as a starting point for discussion. As will be seen, there is significant advantage in imaging at the highest energy possible. Eight to ten MeV gives the best image at any dose to the object.

Estimation of Required Dose

Consider the very simple object shown below:



Here there are two paths through a container filled with water. The first path only goes through the water and the second path goes through the water and an additional substance. One can compute the signal seen by a detector from the following equation:

$$\int_0^\infty N(E)\cdot e^{-\int \mu\rho \cdot dt}\cdot E\cdot dE$$

Where $N(E)$ is the number of photons per unit energy in the incoming x-ray spectrum, $e^{-\int \mu\rho \cdot dt}$ is the negative exponential of the integral of the mass attenuation coefficient along the optical path, and E is the energy of the photons. In order to approximate this integral one usually replaces the integral over the energy spectrum by using simply the mean energy of the spectrum and total number of photons in the spectrum. This is not completely accurate but usually sufficient to be able to draw the major conclusions. In that case the transmitted signal along optical path one is:

$$N_{total}\cdot E_{mean}\cdot e^{-\mu_1\cdot\rho_1\cdot t}$$

and the detected signal along integral path two is:

$$N_{total}\cdot E_{mean}\cdot e^{-\mu_1\cdot\rho_1\cdot(t-\tau)}\cdot e^{-\mu_2\cdot\rho_2\cdot\tau}$$

The signal related to the detection of the object is simply the difference of the detected energies along the two different integral paths. The noise is simply the fluctuation in the number of detected photons (square root) times the energy of the detected photons. Therefore the signal to noise ratio for the detection of this object is:

$$\frac{N_{total}\cdot E_{mean}\cdot e^{-\mu_1\cdot\rho_1\cdot t}\cdot[1-e^{-(\mu_2\cdot\rho_2-\mu_1\cdot\rho_1)\cdot\tau}]}{\sqrt{N_{total}}\cdot E_{mean}\cdot e^{-\mu_1\cdot\rho_1\cdot\frac{t}{2}}}$$

If the object to be imaged has similar x-ray contrast to water (i.e., their products of mass attenuation coefficient and density are approximately equal) then the signal to noise simplifies to

$$\sqrt{N_{total}} \cdot \sqrt{T} \cdot (\mu_2 \cdot \rho_2 - \mu_1 \cdot \rho_1) \cdot \tau$$

where T is simply the transmission along integral path 1. This simply states that the signal to noise ratio for the image is the product of the square root of the number of photons used in the image times the square root of the transmission of the object at the energy of interest times the radiographic contrast of the object to be detected. Of these factors only the transmission can be affected by the energy of the photons used to create the image. Now lets look at a specific example: Assume the radiographic contrast is 1% and we require a signal to noise ratio equal to or greater than 5 for detection (This is a common assumption in imaging calculations. A smaller or larger signal to noise will not affect the conclusions). In that case we require that the square root of the product of the number of photons used times the transmission of the object exceeds 500. Now assume that the object being imaged is water one meter thick. Then we can compute the transmission at any given energy and from this the minimum number of photons that are required for a signal to noise ratio of 5. For a photon energy of 1 MeV this is 2.74×10^8 and for 5 MeV this is 5.02×10^6. About 55 times as many photons are required for the same imaging capability at 1 MeV as compared to 5 MeV. If one takes into account the fluence rate, then the dose required at 1 MeV is still 17.4 times that required at 5 MeV. This is shown in figure 1.

The above calculation has ignored the relative efficiency of detection of the photons as a function of energy. But the large advantage of high energy will always be important. Even if one could have 100% efficiency of detection at 1 MeV it would only require a 6% efficiency at 5 MeV to achieve equal results. Typically the efficiency of detection at these high energies is approximately equal.

Computation of Required Dose

The calculation above is really an estimate sufficient to obtain the general characteristics as a function of energy. It ignores the real spectral shape of the x-rays to simplify the calculation. One can also do a numerical integration to obtain more accurate results. To do this we used realistic Linatron spectra, the known attenuation and density of water. The transmitted photon spectra was computed numerically along both optical paths and normalized to a constant dose. Using the computed signals and noises along each path, a simple image was simulated for each energy spectrum. This is shown in figure 2.

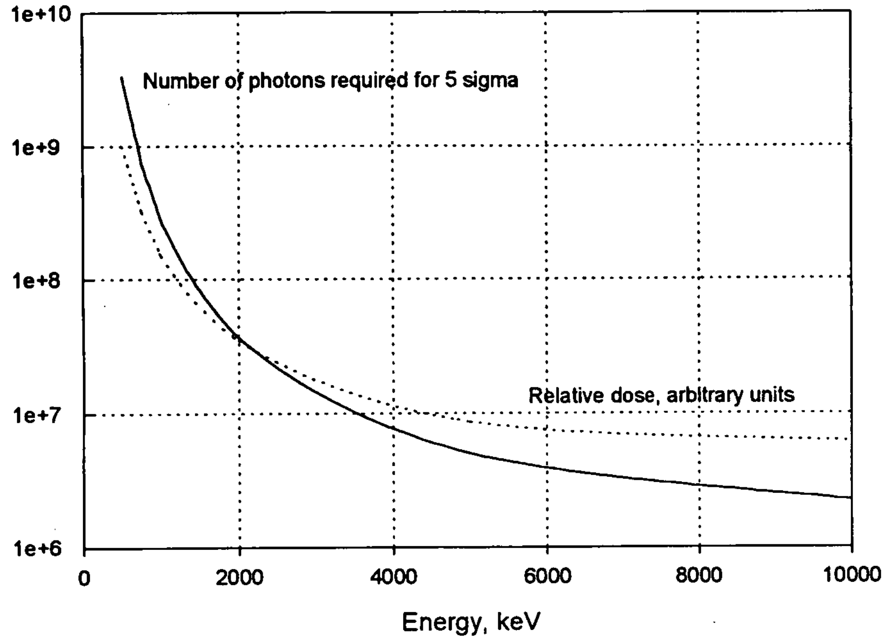


Figure 1: Photons required for five standard deviations per pixel and relative dose for that number of photons as a function of energy. Note that the dose axis is logarithmic. The increase at low energies is very dramatic.

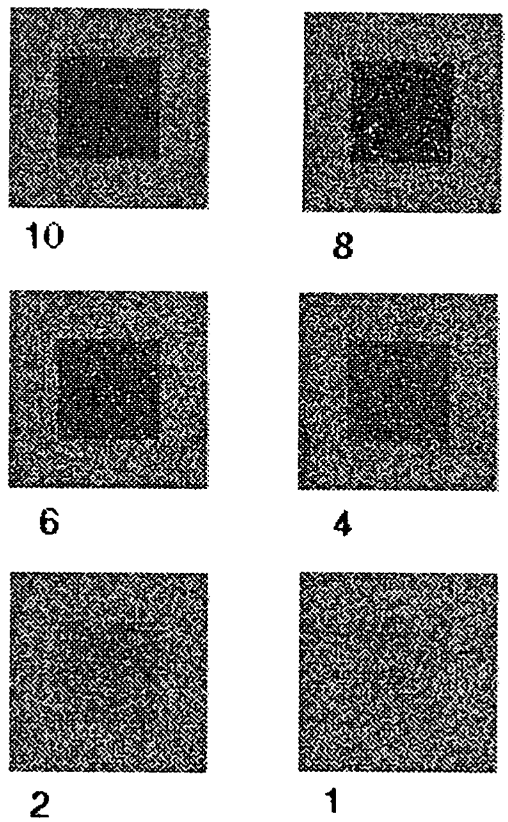


Figure 2: Simulated images using the results of a numerical integration of the transmitted spectra for various energies at a constant dose. Note that below about 6 MeV the contrast drops dramatically.

Conclusion

Both the estimate and the numerical integration clearly show the strong advantage of imaging at higher energy. The estimated dose required for an equivalent image is 17 time smaller at 5 MeV than at 1 MeV. Even if one cannot make detectors as efficient at 10 MeV as at 2 MeV the large dose advantage will clearly still leave a dramatic advantage at the higher energy.

7

Communications, Surveillance, and Tracking Technologies (Session 2C-2)

Multiple Agency Interoperable Communications (MAGIC)

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ABSTRACT

As we approach the new millenium there are several forces at work that will radically change the future of law enforcement communications. These forces include frequency spectrum constraints, budget and manpower constraints, the introduction of major technological advances in computer and communications related disciplines and the continuing need for real-time cooperation and interoperability among federal, state and local law enforcement agencies.

In both anticipation of, and in reaction to these forces of change the United States Customs Service has embarked on a process to research, develop, evaluate and test what could become a significant part of the Public Safety Wireless Network being developed by the federal government. Known as "MAGIC" (Multiple-AGency Interoperable Communications), this initiative consists of developing and implementing radically new telecommunication concepts, in two phases: initially through an innovative 64kb transmission medium utilizing existing hardware, and eventually utilizing ATM/frame relay technologies. The ultimate goal of this revolutionary system is to automatically transmit, receive and route digitized, narrow-band RF communications interoperably among members of the border enforcement community. This paper will provide the background that led Customs to seek out this process, the changing telecommunications environment in which it was conceived and finally the process that Customs is using to develop this initiative.

PART I – Background: The Need for Change

Several mandates and recommendations by the federal government's legislative and executive branches have influenced the push towards a more efficient and effective law enforcement communications technology.

On October 27, 1992, Congress enacted Public Law 102-538, known as the "Telecommunications Authorization Act of 1992". In this act Congress mandated that "... the Secretary of Commerce shall adopt and commence implementation of a plan for Federal agencies with existing mobile radio systems to use more spectrum-efficient technologies that are at least as spectrum-efficient and cost-effective as readily available commercial mobile radio systems. The plan shall include a time schedule for implementation".[1] Under the authority of this Act, the National Telecommunications and Information Administration (NTIA) implemented regulations mandating that the Federal Government replace all

[1]Telecommunications Authorization Act of 1992 (Public Law 102-538)

of its Very High Frequency radios (VHF band – those using 162-174 megahertz frequencies) with radios that use narrowband (12.5 kHz) technology by January 1, 2005. [2]

In September of 1993 the Vice President's National Performance Review succinctly outlined many of the problems currently facing federal, state, and local law enforcement agencies when it wrote "Whether they are responding to a natural or technological disaster or performing search-and-rescue or interdiction activities, federal, state, and local law enforcement and public safety workers must be able to communicate with each other effectively, efficiently, and securely. Most of this communications occurs over tactical land mobile radio systems. However, interoperability across these radio systems is difficult to achieve. Federal, state, and local law enforcement agencies operate in different parts of the radio spectrum. Complicating this problem is the lack of security on most systems, leaving them open to interception and monitoring. When security is applied to radio systems—as is done with many federal radio systems-interoperability depends on having the correct key to communicate. Moreover, every federal, state, and local law enforcement agency operates separate tactical networks in every metropolitan area in the country. Often, there are several independent network control centers operating within the same federal building with no interoperability. This expensive duplication of effort prevents the use of spectrally efficient equipment and results in less-than-optimum coverage for many agencies. In addition, technical and administrative support is duplicated throughout the federal government". The report when on to say, "over the next 10 to 15 years, all federal government radio systems will be replaced with digital technology. If this is done on an agency-by-agency basis—as was done in the past—the cost will be enormous and the same problems with interoperability will occur, resulting in costly redundancies of equipment and staffing. Current budget conditions make it critical that the federal law enforcement, public safety, and disaster response agencies coordinate the transition to digital narrowband systems." Finally the Review recommended the establishment of "a National Law Enforcement/Public Safety Wireless network for use by federal, state, and local governments". [3]

On June 25, 1995, in response to a Congressional request by House Appropriations Subcommittee Chairman Harold Rogers, the Federal Communications Commission and the National Telecommunications and Information Administration established the Public Safety Wireless Advisory Committee (PSWAC). The purpose of this committee is "to provide advice on the specific wireless communications requirements of Public Safety Agencies through the year 2010 and make recommendations for meeting those needs".[4] PSWAC, in its final report, stated that "The nation's Public Safety agencies face several important problems in their use of radio communications:

First, the radio frequencies allocated for Public Safety use have become highly congested in many, (especially urban) areas. Usable spectrum for mobile operations is limited, and Public Safety agencies are not able to meet existing requirements, much less to plan for future, more advanced communications needs. Not only does the shortage of spectrum jeopardize the lives and heath of Public Safety officials; it threatens their ability to fully discharge their duty to protect the lives and property of all Americans.

Second, the ability of officials from different Public Safety agencies to communicate with each other is severely limited. Yet interoperability is key to success in day-to-day operations, joint task force and mutual-aid operations, and many other intra- and inter-jurisdictional activities.

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[2] *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration, 1995.

[3] *Reengineering Through Information Technology. Accompanying Report of the National Performance Review, IT04: Establish a National Law Enforcement/Public Safety Network*, Office of the Vice President, September 1993.

[4] *Final Report of the Public Safety Wireless Advisory Committee to the Federal Communications Commission and the National Telecommunications and Information Administration*, September 11, 1996

Interoperability is hampered by the use of multiple frequency bands, incompatible radio equipment, and a lack of standardization in repeater spacing and transmission formats.

Finally, Public Safety agencies have not been able to implement advanced features to aid in their mission. A wide variety of technologies—both existing and under development—hold substantial promise to reduce danger to Public Safety personnel and to achieve greater efficiencies in the performance of their duties".[5]

The citations listed above point out the need for major improvements in law enforcement communications technology and present a challenge to that community. That challenge, in its most basic terms, is threefold:

First, to make more efficient use of the available frequency spectrum;

Second, to make more efficient use of the network infrastructure, including personnel assets, and

Third, to significantly improve, and ideally expand, secured interoperable communications among law enforcement agencies.

One approach to meeting these challenges is the system presently being developed and tested by the U.S. Customs Service, "MAGIC".

PART II – Evolutionary Changes in the Customs Radio Network

The Network in 1990

In 1990, the U.S. Customs radio communications organization was totally decentralized (Illustration 1). Each of the seven Customs Regions (New York, Northeast, Southeast, North Central, South Central, Southwest, and Pacific) had a fully autonomous Sector Communications Center that organizationally reported directly to the local Assistant Regional Commissioner (Enforcement). The national headquarters Communications Management Division provided operational guidance to these Communications Centers. Each of the Sector Communications Centers operated and maintained an isolated portion of the Custom's VHF radio network, a network which consisted of landlined base stations, non-wired base stations, wired repeaters, non-wired (RF) repeaters, and base repeater stations. These fixed radio sites were strategically located to provide optimum communications coverage throughout that particular region. The network terminated at the Sector Communications Center console where Sector Enforcement Specialists provided 24 hour a day, seven day a week tactical law enforcement communications and data support to field units. The network was designed for mobile radios (30-mile radius) while providing limited support for portable or hand-held radios. The radio network was capable of using the Data Encryption Standard (DES) voice privacy encryption keys that were manually loaded into the radios by means of a Key Variable Loader (KVL). Interoperable communications with other agencies on the network was extremely limited and was usually the result of loaning another agency Customs radios for use during any given operation.

Although there were inherent inefficiencies in both organization and technology in the Customs Radio Network of the early 1990's, it should come as no surprise that even with these limitations the Customs communications system was held out by many within the federal community as an example of a progressive, resourceful organization. This view notwithstanding, a forward looking management team made up of communications professionals addressed the problems and came up with some exciting and innovative solutions. These solutions, in the final analysis, would be proven to have been necessary steps towards developing the "MAGIC" concept.

Introduction of Over-The-Air Rekeying (OTAR) in the Early 1990's

One of the inherent inefficiencies noted above was the requirement to manually load voice privacy keys in each individual radio through the use of a Key Variable Loader (KVL). With thousands of radios in the field each key change became a manpower intensive evolution taking months to

[5] Ibid.

successfully complete. More important, it was difficult during fast moving enforcement operations to locate a Key Variable Loader and, if located, to manually re-enter the voice privacy key if one of the members of the group lost their key. In reality, when this occurred many groups would just revert to unencrypted voice to facilitate group communications, jeopardizing the security of the operations and the safety of its participants.

partnership with Motorola to develop a system that would allow radios to be rekeyed, over the air, using the existing radio infrastructure. The U.S. Customs Service became the lead federal agency working with Motorola on this project. The product resulting from this partnership was the Motorola Advanced Securenet System™. This system incorporated two significant enhancements for law enforcement communications. First, it succeeded in its mandate to be able to securely

US Customs Service VHF Sector Radio System
Seven Sector Configuration

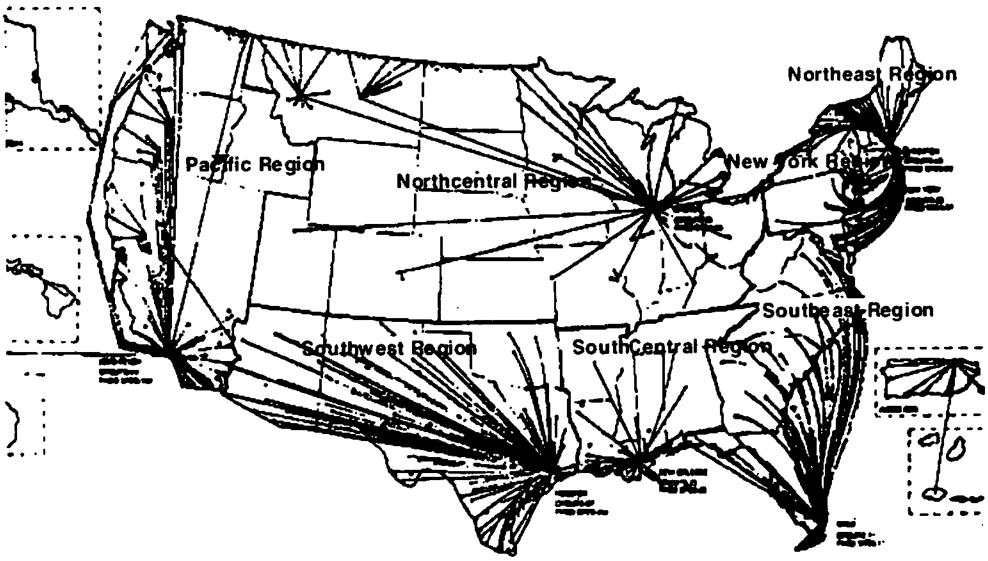

Illustration 1.

In 1988, the National Drug Policy Board (a forerunner to the current ONDCP) established a multi-agency government commission known as the Communications Interoperability Working Group (CIWG), to look into this and other voice privacy matters. This commission formed a send voice privacy keys to radios, over-the-air, using an existing VHF network infrastructure. The centerpiece of this system was the Key Management Controller (KMC)™. From this computer, located in the Sector Communications Center, operators could immediately restore lost keys to a radio anywhere on the network, change or update keys for literally thousands of radios in a matter of minutes, schedule key changes on a periodic basis, and regroup one or more radios (remap the voice privacy keys) on the fly as the operational situation dictated. Second, and equally important, the Advanced Securenet System™ introduced multi-key for use in the new generation of OTAR radios. Multi-key, in addition to other features, significantly enhanced interoperability by allowing field units to have not only their own agency key but also a number of additional keys for use in joint/combined operations.

In spite of the significant enhancements generated by this new system, funding and manpower constraints precluded it from being implemented in all areas of the country. In order to take full advantage of these new possibilities, a consolidation of Sector personnel, operations and their concomitant funding was necessary.

The Consolidation and Relocation of Regional Sector Communications Centers: December, 1993 – December, 1995

In the fall of 1993, and after several years of study, it was readily apparent to the U.S. Customs Service's communications management team that in order to meet the challenges outlined above, an entirely new way of doing business had to be found. By December, 1993, Customs already operated the largest protected, coast to coast, radio communications system in the nation. Its primary responsibilities were to assist law enforcement officers at all government levels with the interdiction of narcotics and other contraband material entering or leaving the United States. In fact, the network even then supported literally dozens of federal agencies as well as hundreds of state and local law enforcement offices.[6] Because of this breadth of scope and responsibility, it is not an understatement to assert that most officers who accessed this network recognized its importance as oftentimes the only viable lifeline to field associates working in dangerous situations. Unfortunately, by this point in time the individual communications centers were faced with this substantially expanding user base and its resulting significant increase in workload without the wherewithal to meet the challenges with their existing workforce. Government downsizing precluded the possibility of meeting the increased workload with additional staffing. Without some action, new users could not have been given full access to the radio network and existing services would have had to be significantly curtailed or eliminated. Thus, after a lengthy and careful period of analysis, it was determined that consolidation of all network and sector activities into a single center would greatly enhance officer safety as well as day to day operations while providing a considerable savings to the Government. After an extensive search for a suitable location, a building at the Naval Training Center in Orlando, Florida was identified. The timing could not have been more fortuitous, as the Training Center was on the 1993 Base Closure List. Thus, in 1994, the then Assistant Secretary (Enforcement) of the Treasury had delivered appropriate correspondence to the Secretary of the Navy requesting the transference of this building to Customs. Moreover, in preparation for the revolutionary plan to consolidate all seven of the Sector Communications Centers scattered throughout the country into one state-or-the-art facility, a number of working partnerships with numerous federal agencies, private vendors such as Motorola, Rockwell and Sprint, as well as the Navy had to be established. Additionally, these partnerships allowed the communications program to develop requisite organizational structures and policies which complied with Vice President Gore's National Performance Review as well as Custom's own reorganization objectives.

Given the magnitude of these challenges, it is truly amazing to consider that within an 18 month period (and six months ahead of schedule) all seven regional Sectors, the program's Headquarters staff and message center, more than 500 fixed site radio stations wirelined to the Sectors, as well as the Program's well respected long range HF program – Customs Over the Horizon Enforcement Network (COTHEN) – were consolidated into a state-of-the-art facility

[6] See Attachment (1), *U. S. Customs Service Communications Network Subscribers*, July, 1997

(Illustration 2). [7] Perhaps even more impressive than these achievements, this consolidation was accomplished with:

- No reported adverse impact on any field operation;
- No service interruption and virtually transparent to the end user community;
- Annual savings to Customs in space (rental) costs of approximately $1.75 million;
- Additional savings of approximately $250,000 annually due to differences in locality pay between Orlando and higher rate areas such as New York, Los Angeles and Washington;
- An improved supervisor to employee ratio, from 1:6 to greater than 1:11;
- An opportunity to fully develop the OTAR and KMC technologies, pioneered at the federal level via blanket interagency agreements and implemented on a national scale;
- More than $2 million in cost avoidance which would have been required to upgrade seven separate Sector facilities;
- (perhaps most importantly) More than $3+ million annual salary and benefit cost savings due to reductions in the program's staff size as organizational redundancies were eliminated and other efficiencies were realized.

The Customs consolidation initiative allowed for a more efficient use of the existing workforce and resulted in a substantial saving of personnel. This saving was reinvested in a manner that permitted the consolidated communications center to successfully accommodate both the expanding customer base and the increased workload without the necessity to augment staff or funding. Most importantly, it allows the Program to convert their entire network, including its user's mobile and portable inventories, into compliance with digital and narrow-band mandates. While this massive

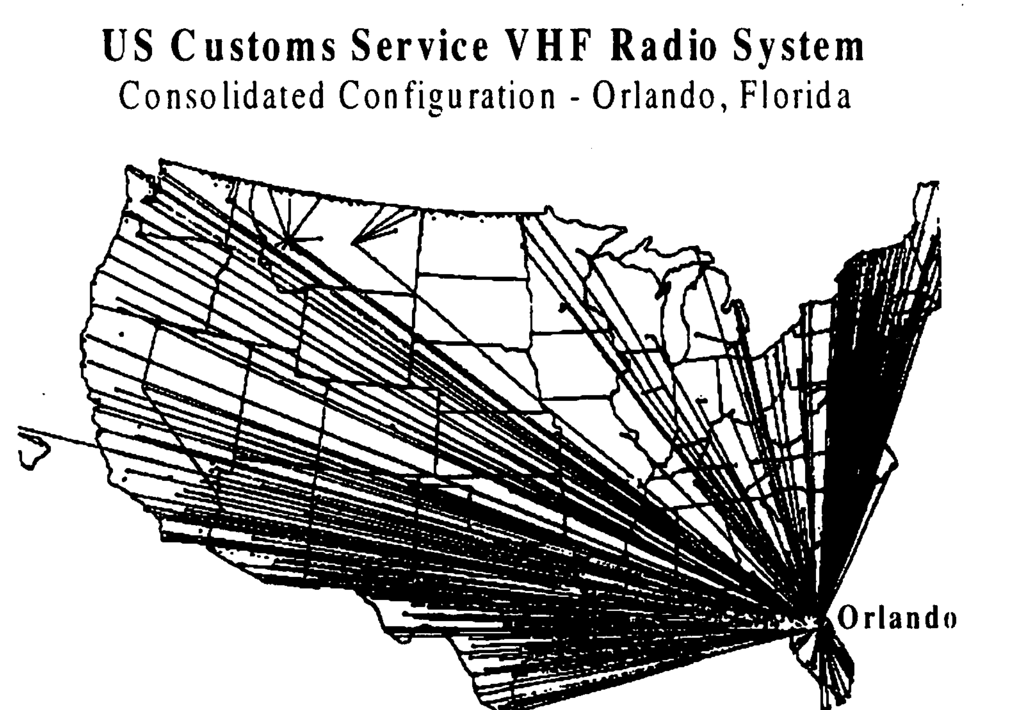

Illustration 2.

[7]Facility Brochure, *U.S. Customs Service National Law Enforcement Communications Center*, June, 1997.

undertaking alone will take a minimum of four years (which is indicative of how expansive this network has become), upon its completion Customs will be finally and uniquely positioned to undertake MAGIC.

PART III - The MAGIC Concept – A Shared Infrastructure Communications System

MAGIC is envisioned as a means for allowing multiple source VHF/UHF transmission/reception connectivity between numerous agency/jurisdiction dispatch centers through one fixed site; in other words, to allow for elimination of redundant transmission sites (or circuits) within a common geographical area, supported by organizations with a common agenda. Although truly significant savings within the federal law enforcement community should be realized, its greatest strength is that MAGIC has been conceptually designed to increase communications efficiency and usability through network and system re-engineering as well as to facilitate and encourage real-time cooperation and interoperability among federal, state, and local law enforcement officers.

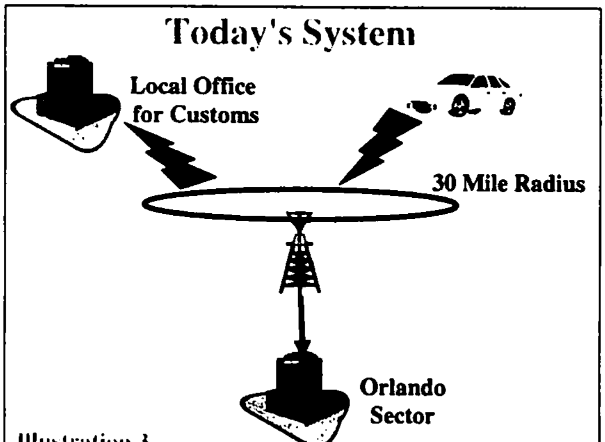

Illustration 3.

Not unlike most other network configurations, the current Customs radio network architecture has a single site with a single repeater which uses a single voice grade line to connect to the Sector Communications Center in Orlando (Illustration 3). There are currently over 450 of these sites and associated repeaters and transmission lines supporting the field users. These sites are intended to provide continuous communications coverage throughout the United States to the area of operations for which the Customs Service has responsibility. Users of this system manually select a "channel" or frequency that is known to provide coverage for an area in which they intend to work. All users who wish to communicate with each other must know what frequency the other users are on and must be on that frequency in order to communicate. Everyone on the same channel, and when present, on the same voice privacy encryption key, will hear all transmissions that occur on that particular repeater. If one user is transmitting on the channel and another user wishes to transmit, the second user must wait for the first user to finish their communications before they can transmit; otherwise the second user will "step on" the first user's transmission and there is a good probability that that transmission will not be heard as intended. The Sector Communications Center monitors and hears each transmission on each of the repeater channels.

Under the MAGIC concept, major changes will be made in various stages:

In the first iteration of MAGIC (Illustration 4), several repeaters, or frequencies, supporting a particular area would be co-located on the same antenna ("stick"). These frequencies would be multiplexed to a single 64kb specially conditioned telephone line ("pipe") that would terminate at the Sector Communications Center. Since this single 64kb pipe would replace several voice grade lines, an approximate three to one savings in leased landline costs for these co-located repeaters could be achieved. This stage is required to begin the necessary pilot testing preparatory for the final phase of MAGIC, which will ultimately be a true shared infrastructure.

Second, users would be assigned to "talk groups" based on common job function, office type or, perhaps, location or other similar criteria. A talk group controller would manage the assignment of these groups and would be able to dynamically re-assign groups "on the fly". When a user wishes to establish communications with another individual the user would select a particular talk group with which to communicate rather than selecting a channel or frequency on which to establish communications. The user now decides whom communications is desired with rather than on which channel should communications be established. This is a much more user-friendly system. The user only cares about with whom he wishes to communicate, not how that communications is to be routed. A system controller constantly monitors the location of each radio on the net and the talk groups to which that radio is assigned and routes communications accordingly.

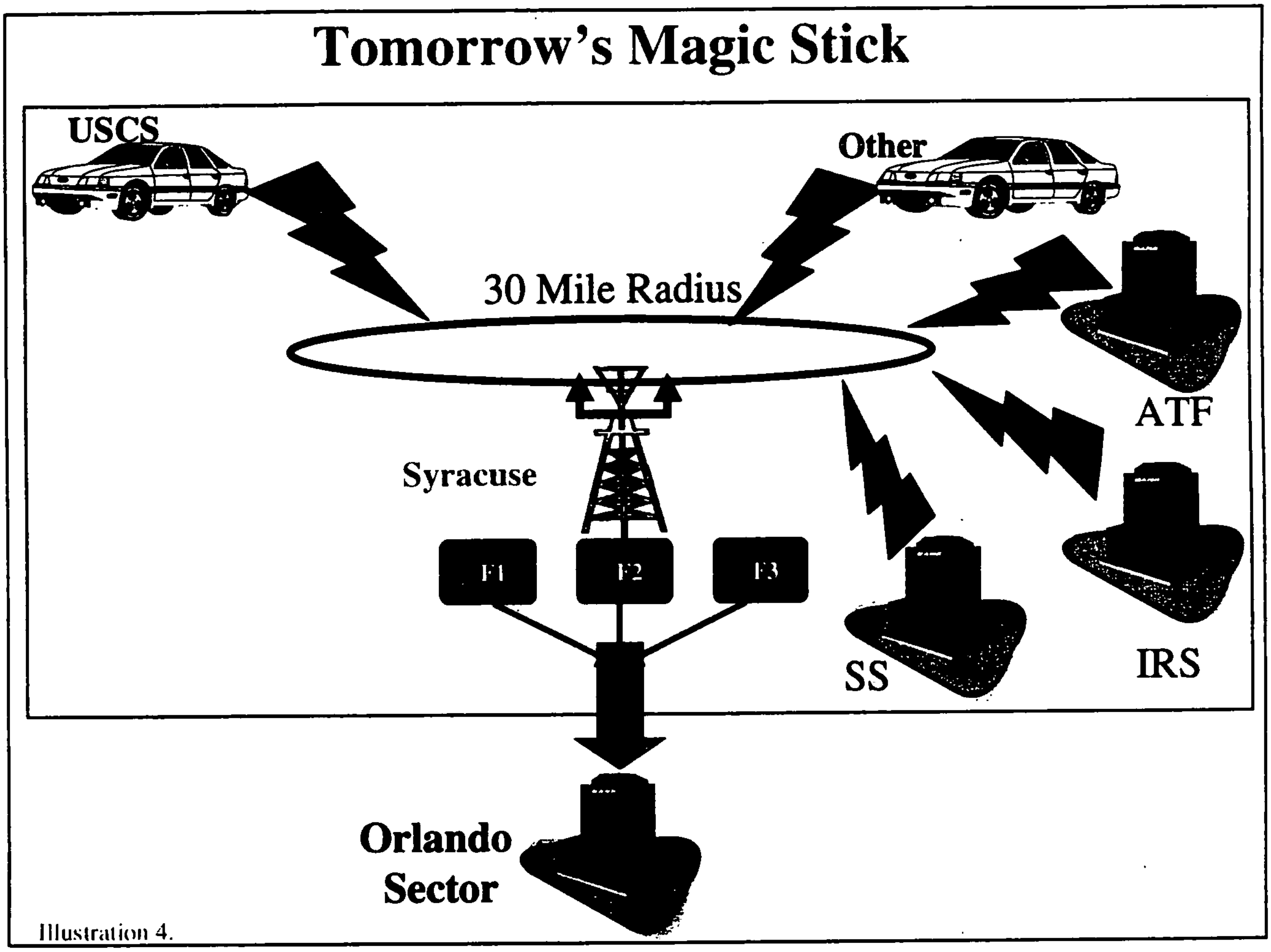

Illustration 4.

Third, the frequencies in a particular area would be "pooled' and would be available for assignment by the system controller based on the selection of a particular talk group by the user. If all of the available frequencies were to be in use, the use would get a "busy signal", and would have to wait for a free frequency. This is similar to the situation described above on a single stick. However, unlike the single stick, this would be much less frequent since there would be more than just one frequency available for use. In the case of emergency or priority traffic this system allows you to override non-priority traffic; a feature we do not enjoy at the present time.

Fourth, significant improvements in interoperability would be realized. There are currently over 40,000 "other agency users" on the Customs radio network. Many of these users have radios that operate primarily on their own agency network and their own frequencies/spectrum segments. However, they may also have Customs frequencies loaded in their radio and an interoperable voice privacy key for use during common operations. In still other configurations, agencies may also have a need for a second radio due to incompatible radio hardware. Assignment of these "other agency users" to appropriate talk groups would make establishing and maintaining real-time interoperable communications much more simple than under the current system.

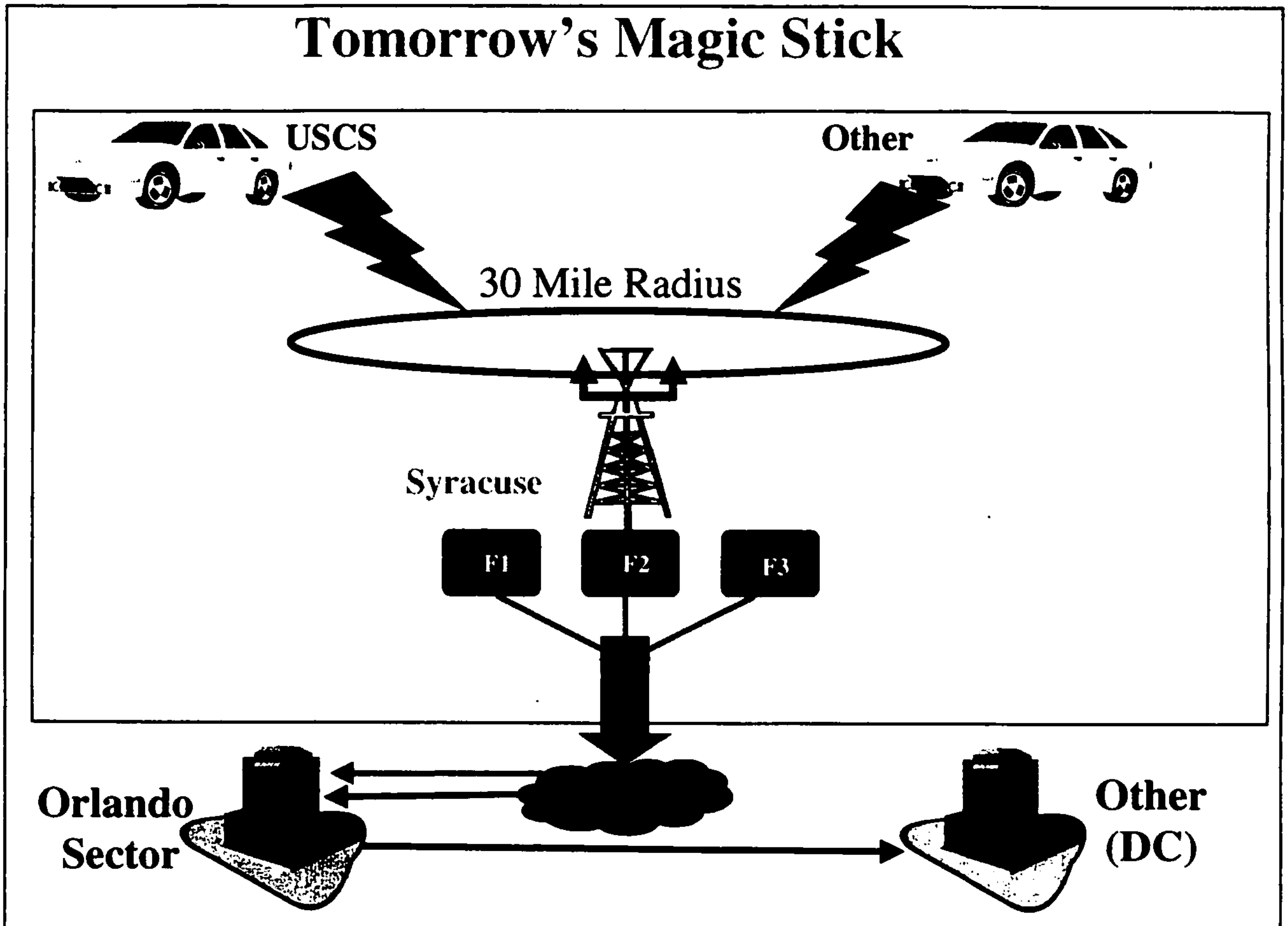

Illustration 5

MAGIC continues to be refined and improved as technological limitations are resolved and more efficient means of data compression and transport are designed and tested. Still in the conceptual stage is a multi-band switch ("the cloud") that will represent a quantum leap forward in interoperable communications (Illustration 5). Recent advancements in the area of Asynchronous Transfer Mode (ATM), frame relay technologies and Packet Data Network (PDN) transports are also being investigated. This research is being undertaken to determine how these technologies can be used to facilitate the routing and transport of voice (and eventually data) traffic in a more intelligent and flexible wide-area communications network. This switch will serve as an easy interface between VHF radio networks, such as Customs, and the UHF and 800 MHz systems widely used in federal, state and local law enforcement. Under this concept all users, regardless of the frequency band on which they operate, would be assigned to specific talk groups. The traffic originating from one band-type, such as an 800 MHz system, destined to a talk group member in another band-type, such as a VHF system, would be routed through this switch and would be received, in real-time, in the appropriate band-type at the destination. Such a switch would allow the existing disparate law enforcement networks to be linked into a truly national law enforcement system. The end result would be real-time interoperable communications between all federal, state, and local law enforcement officers.

Both phases of the MAGIC concept would be designed to "TIA 102" standards. Designed components would be backward compatible, would support both audio and many of the emerging data capabilities, may support Over The Air programming and would include such features as remote diagnostics. Since it is still in the conceptual stage many refinements and many new features can be expected.

PART IV – In Conclusion

Throughout the process of the Sector consolidation initiative, there were many critical challenges that had to be met in order to ensure success. As outlined in this paper, each of these challenges were accepted, and the obstacles they presented were overcome.

Many similar challenges face the law enforcement communications community as it moves into the 21st Century. These challenges include:

- The development of digital, narrowband communications technology and systems;
- Greater efficient use of existing communications infrastructures and resources, both personnel and budgetary;
- Secured, real-time interoperability.

These challenges are all embodied in the concept of MAGIC; the first steps towards implementing that process have already been taken by the Customs Service. The vision is attainable. The Customs experience in consolidating its regional communications centers is ample proof that with good planning, team support, a dedicated staff, strong perseverance and ... perhaps ... with just a little bit of luck ... MAGIC can be achieved.

ATTACHMENT (1)

U. S. Customs Service Communications Network Subscribers, July, 1997

The National Law Enforcement Communications Center has formal Memorandums Of Understanding (MOU) with, and/or has issued Letters of Authorization to, the following federal, state and local law enforcement agencies in order to utilize U.S. Customs owned radio frequencies. These agencies are authorized to receive varying services from the Center, ranging from the most basic after hours emergency radio support up through full tactical, time-sensitive law enforcement data and network support, similar to the level of service enjoyed by U. S. Customs officers.

AGENCY

Department of Justice (AUSA)
Civil Air Patrol
Department of Justice (FBI)
Department of Defense (Air Force)
Department of Defense (Army)
Department of the Treasury (ATF)
Department of Transportation (USCG)
Department of Justice (DEA)
Department of Agriculture (Forrest Service)
Department of Agriculture (APHIS)
Department of State (Embassy Nassau)
Department of Justice
Department of the Treasury (OIG)
Department of Commerce
Department of Defense (DCIS)
Environmental Protection Agncy
Environmental Protection Agency (CID)
Federal Aviation Administration
U.S. Fish and Wildlife
U.S. Food and Drug Administration
U.S. Food and Drug Administration (OCI)
U. S. General Services Administration
Department of Housing and Urban Development
Department of Justice (INS)
Department of the Treasury (IRS)
Department of the Treasury (IRS CID)
Department of the Treasury (IRS ELD)
Department of Justice (Marshals Service)
Department of Commerce (National Marine Fisheries)

Department of the Interior (National Park Service)
Department of the Interior (Bureau of Land Management)
Department of Defense (Navy NIS)
U. S. Postal Service
Department of the Treasury (Secret Service)
Department of Commerce (NOAA)
Arizona Department of Agriculture (Animal Division)
California Bureau of Narcotics Enforcement
New York District Attorney (NY Dist)
New York District Attorney (Queens Dist)
California District Attorney (San Diego Dist)
New York District Attorney (Nassau Dist)
Florida Marine Patrol
Massachusetts Environmental Police
Arizona National Guard
Florida National Guard
Hawaii National Guard
New Jersey National Guard
Texas National Guard
Puerto Rico National Guard
New York & New Jersey Waterfront Commission
Pennsylvania - Allentown Airport Police
Georgia - Atlanta Police Department
Massachusetts - Boston Police Department
California - Culver City Police Department
New York - East Orange Police Department
California - El Segundo Police Department
Puerto Rico - Fajardo Police Department
Florida - Ft. Lauderdale Police Department
Florida - Hialeah Police Department
Florida - Homestead Police Department
Texas - Houston Police Department
Florida - Jupiter Police Department
California - Laverne Police Department
California - Long Beach Police Department
California - Los Angeles Police Department
Puerto Rico - Mayaguez Police Department
Florida - Dade County Police Department
Louisiana - New Orleans Police Department
New York - New York Police Department
New Jersey - Newark Police Department
Florida - North Miami Beach Police Department
New York - Plattsburgh Police Department
Puerto Rico - Ponce Police Department
Puerto Rico - National Police

California - San Diego Police Department
California - Santa Ana Police Department
Florida - Tampa Police Department
Texas - Tomball Police Department
Virgin Islands - Police department
Puerto Rico - Vasquez Police Department
California - Westminister Police Department
Pennsylvania - Bureau of Narcotics Interdiction
Florida - Broward County Sheriff
North Carolina - Cascade County Sheriff
Arizona - Cochise County Sheriff
New Jersey - Essex County Sheriff
Texas - Jackson County Sheriff
North Carolina - Jones County Sheriff
California - Los Angeles County Sheriff
Florida - Monroe County Sheriff
New York - Nassau County Sheriff
New Jersey - Passaic County Sheriff
Pennsylvania - Philadelphia County Sheriff
Arizona - Pima County Sheriff
California - San Bernardino County Sheriff
Arizona - Santa Cruz County Sheriff
New York - Suffolk County Sheriff
New Jersey - Union County Sheriff
Pennsylvania - State Police
Texas - State Police
Virginia - State Police
Florida - Department of Law Enforcement
Arizona - Department of Public Safety
New Mexico - State Police
Southwest - Department of Public Safety
Southwest - Sheriff's Offices
Mississippi - Highway Patrol
New York - State Police
Illinois - State Police
New Jersey - State Police
Texas - Beaumont County Narcotics Task Force
New Jersey - Bergen County Narcotics Task Force
Florida - Florida Joint Task Force
Florida - HIDTA Joint Task Force
California - Joint Task Force
Southwest - Joint Task Force
Texas - Alcohol Control Board
Texas - Parks and Wildlife
Texas - Texas Ranger

Southern California Integrated Communications Network (SCICN)

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ABSTRACT

This paper proposes a concept for the development of a regional communications "utility" that will transparently interface all federal, state, and local public safety agencies (law enforcement, fire/hazardous material, and emergency medical services) and the military for critical information exchange. The proposed Southern California Integrated Communications Network (SCICN) will be a shared public safety radio system that will solve many of the incompatibility, channel congestion, and lack of system functionality problems that currently exist in San Diego and Imperial Counties. San Diego and Imperial Counties have made significant advances towards "partnering-up" for radio compatibility among state, local, and federal law enforcement, public health, and public safety organizations. They would be an excellent choice for the development of a "showcase" system to serve as a model for other communities nationwide. This paper outlines the limitations of current public safety systems in the two counties, the existing shortfalls in interagency communications, the desirable requirements/attributes for the proposed SCICN, and the benefits to be gained from the SCICN shared communications utility. Sophisticated trunking systems currently offered by vendors appear to be able to meet or exceed the expected near-term SCICN requirements. The paper proposes a phased approach in implementing the SCICN, where any new technologies/radio systems acquired would be totally backward-compatible with existing systems to avoid any incompatibility or existing service disruption.

1. INTRODUCTION

1.1 Purpose

This paper presents a concept proposal for developing a regional communications "utility" for San Diego and Imperial Counties, California. The ultimate goal is a state-of-the-art digital communications network that will transparently interface all federal, state, and local public safety agencies [law enforcement, fire/ hazardous material (HazMat), and emergency medical services], and the military for critical information exchange.

Immediate access to information is essential to the ability of these agencies to protect life and property. Effective communications between law enforcement agencies (LEAs) is particularly critical in combined task force counterdrug operations. For personnel in the field, mobile radio communications is the primary and sometimes only link to vital information during both routine and emergency operations.

However, lack of radio interoperability, channel congestion, aging equipment, and limited system functionality often cripples the ability of LEAs and public safety entities to effectively communicate between themselves and other agencies. Lack of effective communications can result in delayed response times, duplicate efforts (wasting time and resources), increased risks to officer and civilian safety, and sometimes an inability to perform the primary mission adequately: the protection of life and property.

This paper proposes the development of a Southern California Integrated Communications Network

(SCICN). The SCICN will be a shared public safety radio system that will solve many of the incompatibility, channel congestion, and lack of system functionality problems that currently exist between law enforcement and public safety/service agencies in San Diego and Imperial Counties. The SCICN will incorporate the newly developed phases I and II of the San Diego InterCAD (Computer-Aided Dispatch) system as the basic foundation for the shared network. SCICN with InterCAD will enable agencies within the region to automatically exchange incident-related data in near-real time to avoid dependence on telephone coordination between agencies.

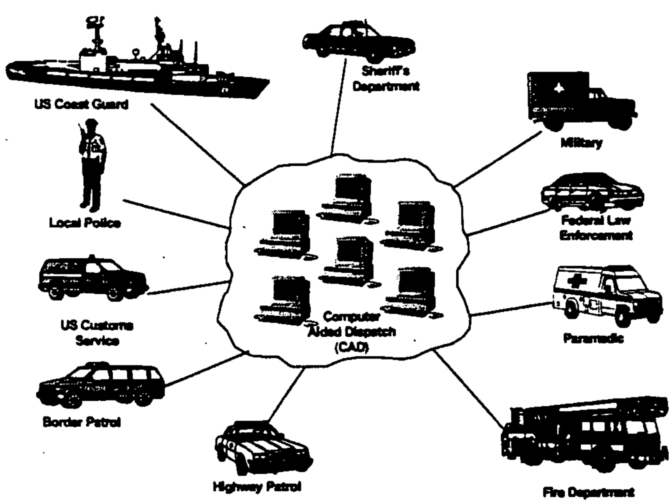

Figure 1. SCICN shared public radio system.

Phase I of InterCAD has been completed and involved the interface of the California Highway Patrol (CHP), San Diego Police Department (SDPD), and San Diego County Sheriff's Department (SDCSD) CAD systems. Phase II is in the development stage and is scheduled for operation in October 1997. Phase II will involve approximately 11 additional agencies from the federal, state, and local levels, including the incorporation of the new CHP/CalTrans Transportation Management Center (TMC).

A third InterCAD phase is proposed that will use the four TMCs in the Southern California region as the connecting conduit to enable agencies within the San Diego region to communicate with other agencies throughout the Southern California region.

Like the San Diego InterCAD system, the proposed SCICN outlined in this paper will be developed in phases. SCICN hardware and infrastructure will be selected to allow almost immediate seamless interoperability between agencies in the initial phases without massive expenditures to replace existing radio systems. This seamless interoperability will increase the effectiveness of coordinated LEA anticrime/counterdrug activities and the ability of LEAs and public safety entities to effectively communicate in emergency or disaster operations. It will be like a "utility" in that agencies can tap into resources as required while maintaining their "regional" nets and existing equipment. In later phases, as more and more of the aging radio equipment is upgraded to the new proposed systems and digital radios, the reduction of channel congestion and the achievement of the new enhanced functionalities can be realized both at the local user level and throughout the proposed SCICN.

1.2 San Diego County/Imperial County

San Diego and Imperial Counties are excellent candidates for the development and implementation of a regional communications utility. The combined counties encompass both high-density metropolitan areas and sparsely populated rural areas, plus share an extensive border with Mexico. San Diego has a major port of entry, a commercial seaport, and several Navy bases. In addition to crime, immigration, and drug smuggling concerns, the area has a moderate-to-high risk for natural disasters (wildfires, floods, mud slides, and earthquakes). The counties have special and immediate needs for comprehensive coordination between law enforcement (federal, state, and local), public service, public health, the military, disaster/emergency relief organizations, and public safety entities.

San Diego County and Imperial County will also ultimately form the westernmost leg of the planned Southwest Border Communications Network, an "electronic fence" linking state, local, and federal law enforcement along the border with Mexico to help combat crime, illegal immigration, and drug smuggling. This network of interoperable communications between LEAs will stretch along the border through the states of California, Arizona, New Mexico, and Texas.

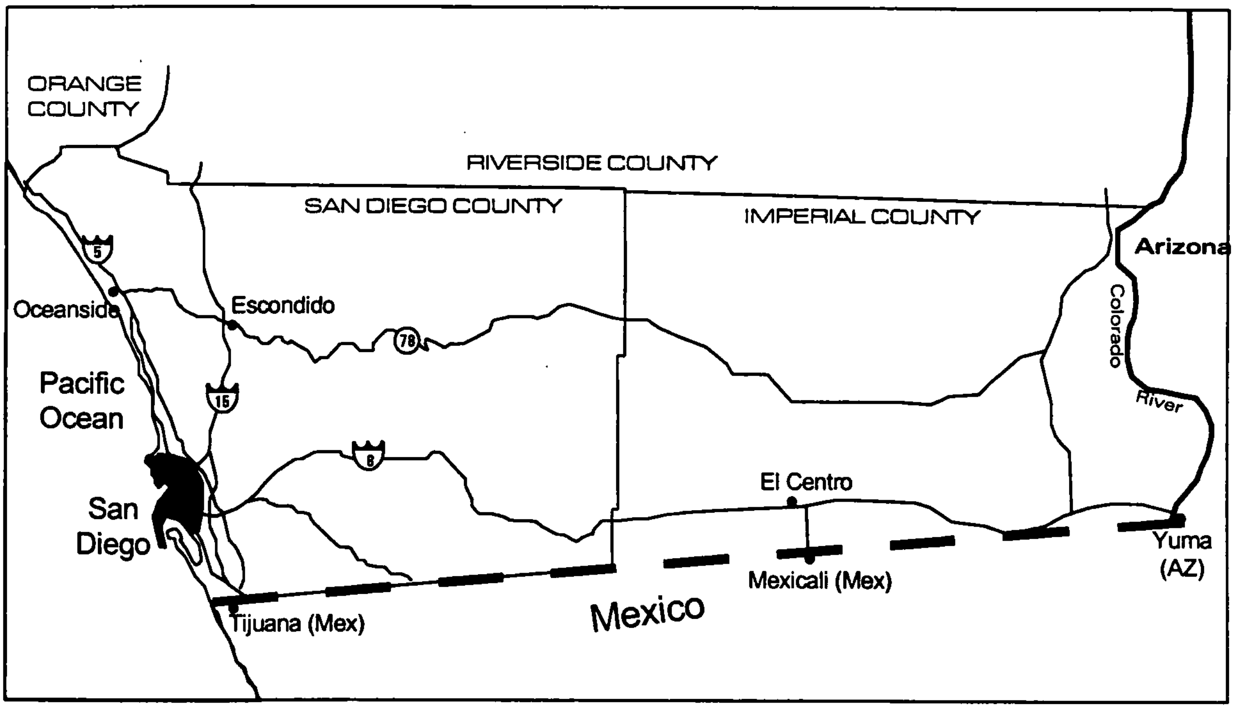

Figure 2. San Diego and Imperial Counties–excellent candidates for "regional communications" utility.

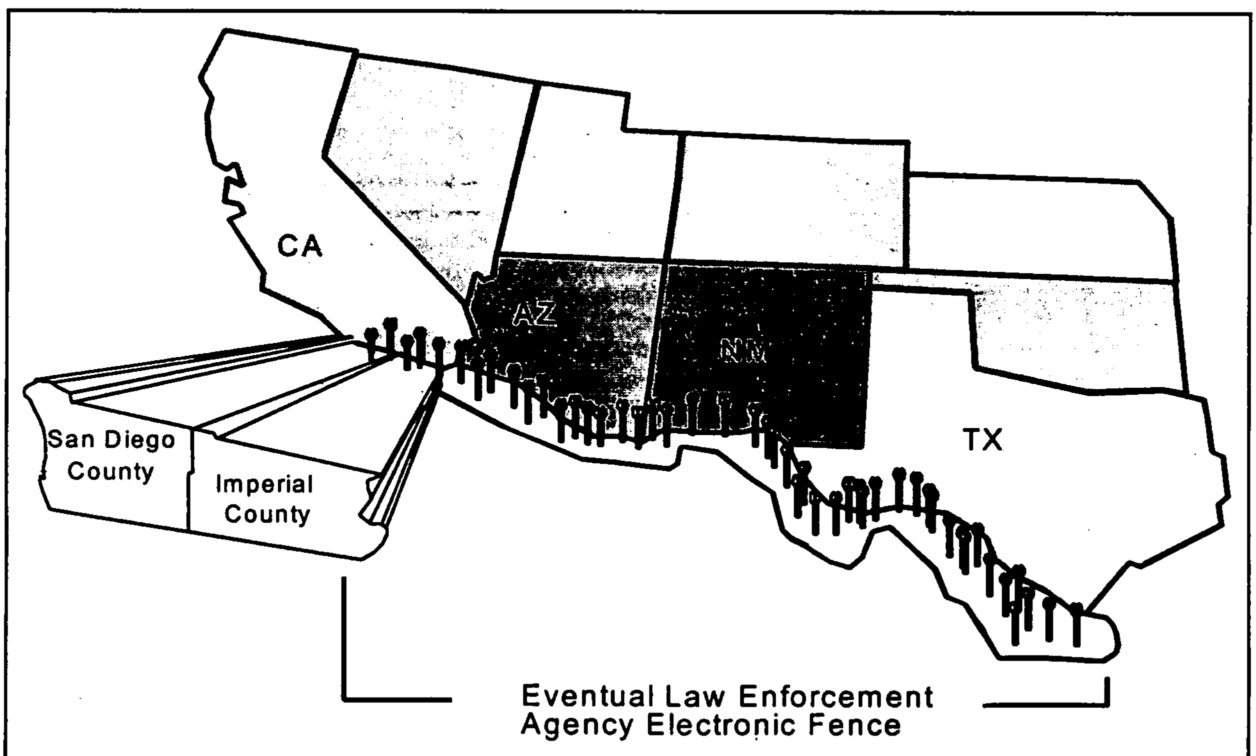

Figure 3. San Diego and Imperial Counties, westernmost leg of electronic fence along the border.

The development and successful implementation of the SCICN regional communications utility in San Diego/Imperial Counties can serve as both a showcase and a model for the development of 21st century shared communications systems for other communities nationwide.

1.3 Significant Advances to Interoperability

San Diego County and Imperial County have already made significant advances toward the SCICN goal of a regional communications utility. Within San Diego County, programs have been initiated to achieve improved public services with existing resources by embracing and promoting the federal initiative for *National Performance Review & Reinventing Government* through personal responsibility and initiative. The concept of Partnering-up in San Diego has been developed to create "One Radio for Public Safety."

Partnering-up for radio interoperability among state, local, and federal law enforcement, public health, and public safety has made significant advances and resulted in the creation of major programs toward the goal of seamless radio interoperability between agencies. The significant programs already initiated or completed in San Diego County and Imperial County include:

- Consolidated Area Radio Trunking System (CARTS): In 1992, the Navy implemented a 10-channel, 400-megahertz (MHz) Motorola Smartnet Trunking System (which has an additional 10 channels assigned for expansion purposes). CARTS is available for use by any federal user in the San Diego area. The area of coverage is from the Mexican border to the Camp Pendleton Marine Base, Oceanside, California. CARTS has recently expanded operation to include an interface for the San Diego Wireless Testbed (SDWTB) project. SDWTB is a communications architecture which allows more efficient and effective communications among selected public safety agencies. The testbed also ensures that each agency retains control of its own communications system. Currently, the SDWTB consists of 14 federal, state, and local public safety agencies.
- San Diego Transportation Management Center (TMC): An integrated facility that includes CalTrans Traffic Operations, Caltrans Maintenance, and CHP in a unified, co-located communications and command center. The TMC is an existing capability that provides the communications, surveillance, and computer infrastructure necessary for coordinating transportation management on state highways on a 24-hour basis and during special events and major incidents or accidents.
- Regional Communications System (RCS): A co-operative communications effort between San Diego County and Imperial County, expected to be operational in 1998. RCS will be developed based upon the concept of a shared regional communications utility available to law enforcement and public safety agencies from both counties.
- Western Wireless Emergency Communications System (WWECS): A model communications utility for four western states (Arizona, California, Nevada, and Utah), but open to other states. WWECS is an on-going effort between 13 federal, state, and local agencies to develop a seamless interoperable communications system to meet nationally mandated changes in radio spectrum utilization, to be implemented by the year 2005.

Although there is still a long way to go in achieving seamless interoperability between the respective law enforcement and public safety entities, the various agencies and county officials realize the need for this interoperable public safety utility. The dialogue, agency interaction, and planning have begun.

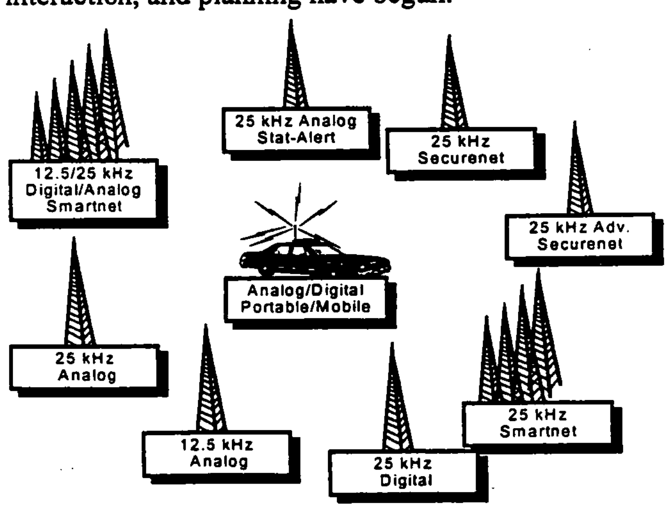

Figure 4. New radios will be backward-compatible with existing systems

1.4 Phased Development

The proposed SCICN will be developed in phases. New technology will be integrated with the old as planning and available funding dictate. Any new technology, SCICN communications infrastructure, or new radios will need to be totally backward-compatible with existing systems to avoid any incompatibility or existing service disruption.

The following anticipated SCICN phases will work in conjunction with the on-going partnering-up programs in the realization of the integrated communications network for San Diego/Imperial Counties:

Phase 1 – Planning:

- Identify existing communications resources.
- Review current capabilities.
- Identify current and future needs.
  - Current and projected user population, talk group requirements.
  - Number of radios, duty cycles, and current holding times.
  - Timeliness requirements, priorities, and acceptable delays.
- Identify duplicate infrastructure.
- Assist agencies in strategic communications planning.

Phase 2 – Technology Review/Initial Implementation:

- Review current technologies.
- Recommend state-of-the-art hardware, software, and communications infrastructures to meet the identified regional communications system needs.
- Comply as much as possible with industry- accepted communications standards [such as the Association of Public Safety Communications Officials, Inc., Project 25 (APCO 25)] to ensure compatibility of new systems and allow for competitive procurement from various vendors.
- Provide that new systems be user friendly and easy to operate with minimum training.
- Provide that new systems be backward-compatible with existing systems and yet have a flexible architecture for future expansion.
- Integrate new systems gradually into the existing communications infrastructures.

Phase 3 – Define and Procure Next-Generation Public Safety Radio:

- Define requirements/capabilities for Next-Generation Public Safety Radio to meet the anticipated needs and utilities for the future.
- Work with communications vendors toward the development, evaluation, and ultimate procurement of the Next-Generation Public Safety Radio.
- Integrate Next-Generation Public Safety Radio into the San Diego County communications infrastructure.

2. COMMUNICATIONS NETWORK "PARTNER" USERS

In the age of cost-conscious government, even the largest agencies can no longer afford the cost or luxury of developing comprehensive radio solutions alone. Partnerships between agencies need to be established for the mutual benefit of services, sharing of existing communications infrastructure, and spreading the cost of acquisition of new technologies. For the proposed SCICN, the partners or users of the system will initially be federal, state, and local LEAs; public safety entities (fire departments and paramedics); and the military (law enforcement and public safety forces). As a minimum, agencies listed in the following paragraphs will be part of the initial SCICN.

2.1 Local, County, and State Public Safety Agencies

- California Highway Patrol (CHP)
- San Diego Police Department (SDPD)
- San Diego County Sheriff's Department (SDCSD)
- Chula Vista Police Department (CVPD)
- San Diego Fire Department (SDFD)
- County and local fire departments
- Paramedics

2.2 Federal Public Safety Agencies

- US Navy Regional Security
- US Customs Service (USCS)
- Federal Bureau of Investigation (FBI)
- Drug Enforcement Administration (DEA)
- US Border Patrol, San Diego (SDBP)
- US Forest Service (USFS)
- US Navy Federal Fire Department (FFD)
- US Coast Guard (USCG)

This initial list is by no means comprehensive or exclusive. The SCICN will be designed to be an open system, with an adaptable architecture able to serve new or additional users with their varying requirements as the network expands and grows to maturity.

3. EXISTING COMMUNICATIONS CAPABILITIES

3.1 Partnering Agencies' Current Communications

Phase 1 in the development of the regional communications utility will be a comprehensive survey of the existing capabilities and communications infrastructures of the partnering agencies. For each agency, a determination will be made of the type of radio frequency (RF) communications system, the number of radios currently in each system today, the number of radios expected in the system in 15 years, console type, number of repeater sites, number of microwave links, and number of supporting telephone circuits. Available systems/procedures for interfacing to other agencies will also be determined. Table 1 is a partial listing of the proposed SCICN partnering agencies' current RF communications systems.

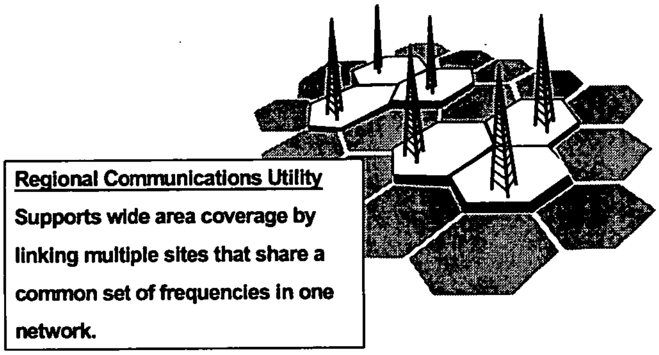

Figure 5. Partnering-up for mutual benefits

Table 1. Partnering Agencies' Communications Capabilities

Agency	System Type	Current No. of Radios	No. of Radios Expected in 15 Years	Console Type	No. Of Repeater Sites	No. of Microwave Links	No. of Landline Circuits
San Diego County RCS	UHFTrunked,						
County Agencies*	Simulcast	4519	5536				
All Other Cities		5439	6663				
MDTs and AVL		1847	1883				
CHP (statewide)	Low Band	14000		Console System	14	10	4
Includes Contract Cities		25805	14082				
San Diego City	Trunked						
Federal Agencies							
DEA	UHF Conv	400		CENTRACOM II**	14	1	12
DEA (New)	UHF Conv						
FBI	VHF Conv	400		CENTRACOM II	15	0	20 (est)
USFS	VHF High Band	200	300	Mod-U-Com***	12	1	0
Border Patrol	VHF Conv	3400		CENTRACOM II	7	0	3
Border Patrol (New)	VHF Voting						
US Coast Guard	VHF Conv	10		Command Comm II	0	1	13
Treasury							
Federal Fire Dept.	VHF Voting	150		CENTRACOM II	6	0	20
Federal Fire Dept. (New)	UHF Trunking	150		CENTRACOM II	1	0	2
Navy Security Agencies	VHF Conv	800	900	CENTRACOM II			
Navy Medical Agencies	VHF Conv Voting	40	60	CENTRACOM II			
				***By Motorola*	6	0	20
				****By Modular Communications Systems*			

RCS - Regional Communications System; CHP - California Highway Patrol; UHF - ultrahigh frequency; Conv - Conventional
MDT - Mobile Data Terminal; DEA - Drug Enforcement Administration; FBI - Federal Bureau of Investigation
AVL - Automated Vehicle Location; VHF - very high frequency; USFS - US Forest Service

Only limited information on the partnering agencies was available for compilation in this paper. In general, however, the majority of the partnering agencies operate their own independent conventional broadcast radio network. For conventional broadcast, the radio operation is half-duplex; communications go both ways but only one way at a time; one radio at a time broadcasts while all other radios receive. Most of the systems are primarily for unsecure analog voice, with limited data capability to 2400 bits per second (b/s) or 4800 b/s with a suitable external modem.

Most of the current systems rely on 30-year old technology with much of the infrastructure installed over 10 years ago. It is estimated that over one-half of the existing partnering agencies' mobile, fixed, and portable radio systems are at or nearing the end of their useful life and will require replacement within the next 4 years.

There are three notable exceptions: (1) the San Diego County RCS, which is in the phase of implementation of a new digital 800-MHz trunking system; (2) the city of San Diego, which is operating an existing analog 800-MHz trunking system; and (3) the federally owned CARTS system, which consists of a 10-channel, 400-MHz, Motorola Smartnet Trunking System.

Trunking systems, such as Motorola Smartnet, allow for the generation of subnets with individual radio addressing. More information is required on the two trunking systems to determine their compatibility with other agency radio systems and the current trunking systems' remaining useful life spans.

The frequency coverage for the partnering agencies includes every available band allocated for public safety use: very high frequency (VHF) low and high bands, ultrahigh frequency (UHF) Conventional and Trunking, and 800-MHz frequencies. Currently, radio users in one band cannot talk directly to users in another band on the same radio without special "voice patches" manually made by a dispatcher. Without the voice patches, communications between agencies can require the operator to carry multiple radios to cover the various frequency bands of other agencies.

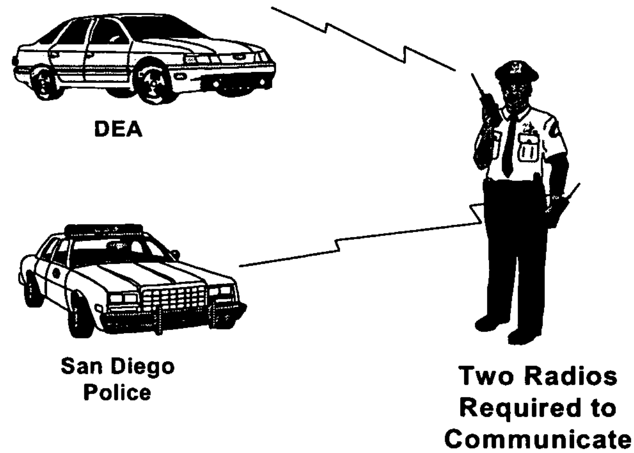

Figure 6. Existing interagency communication often requires two radios at a site

3.2 Interagencies' Current Communications

There is currently no single system that provides complete public safety interagency communications service for San Diego and Imperial Counties. Most agencies operate their own systems, where radios from one system are generally incompatible with other systems.

The need for interagency communications has existed for many years. An early solution was to dedicate several frequencies throughout the United States explicitly for interagency use. These frequencies are known as the National Law Enforcement Mutual Aid Frequency (155.475 MHz) and the State Mutual Aid Frequencies for Fire Fighters (154.290, 155.085, 154.295, and 154.265 MHz). Many of the radios used in Southern California can access these frequencies. However, these frequencies are intended for emergency use only, and can support only a very limited number of users within a geographic area. These channels quickly become saturated during a major regional situation.

Another set of national mutual aid frequencies exists for LEAs: 866.0125, 866.5125, 867.0125, 867.5125, and 868.0125 MHz (and the corresponding frequencies 45 MHz lower). The lowest frequency, 866.0125 MHz, is the "calling" channel, which is used to initiate a call. At this time, very few of the public safety agencies in southern California have radios that can access these frequencies.

California also has an interagency system called the California Law Enforcement Mutual Aid Radio System (CLEMARS). This system provides three channels (two in VHF, one in "800 MHz"). Several state and local agencies, including the CHP, use this system. However, many of the federal public safety agencies along the southern border cannot use the system because their radios are incompatible.

The CARTS, which was established by the US Navy Public Works Center in 1992, provides some interagency communications in the San Diego area for federal users. CARTS is a 400-MHz Motorola trunking system, and provides joint service to federal users at 13 military installations as well as surrounding areas. In addition, an effort called the Western Wireless Emergency Communications System (WWECS) is proposed that will interconnect federal, state, and local trunking systems between (but not limited to) California, Arizona, Nevada, and Utah.

To add interagency capabilities between CARTS and the local and state public safety agencies in the San Diego area prior to the implementation of WWECS, a "patching" capability was added to the federally owned and operated 911 Public Safety Answering Point (PSAP). The patching is not automated. Manual intervention is required to establish a patch through channels between agencies. This patching is done at the audio baseband level. None of the extended capabilities of any of the systems being patched together (e.g., talk groups, encryption) is supported by the patch.

As discussed in the preceding, none of the solutions implemented to date is complete. No single system provides communications between all of the LEAs that might be involved simultaneously in anticrime/counterdrug operations, much less all the LEAs and public service agencies that would be involved in a regional catastrophe. The RCS is currently being developed to provide such capability for state and local agencies within San Diego and Imperial Counties. The RCS is a trunked, simulcast, analog/digital (IMBE voice coder), 800-MHz Motorola Smartzone radio system using digital encryption for appropriate users. The RCS will use frequencies supplied by the local agencies that will eventually become the users of the system. Upon completion, more than 60 frequencies will be used by RCS to support separate voice and data infrastructures.

The federal government has substantial investment in 400-MHz trunking systems such as CARTS. In the four-state area of coverage for the WWECS, there are 28 existing systems operating today. In California alone, there are 18 systems which, if reengineered properly, could be a Wide Area Trunking System for California. The federal systems, which operate in the 400-MHz range, are incompatible with RCS. Therefore, achieving effective interagency communications between all southern California local, state, and federal agencies would require an electrical interface between the existing federal systems and the RCS. A properly engineered SCICN could provide the solutions to the current interagency communications problems.

4. LIMITATIONS

In general, the communications system of each agency described previously is limited to conventional analog frequency modulation (FM) voice and is limited to operating within its own agency. (Exceptions include radio trunking systems operated by RCS, San Diego City, and CARTS.) The following paragraphs discuss limitations common to most of the agencies which will comprise the SCICN.

4.1 Outmoded Half-Duplex Operation

This is basically 30-year old technology. For each frequency, there is two-way communication, but only one radio at a time broadcasts and all other radios in the net receive.

4.2 Inefficient 25-30 kilohertz (kHz) Bandwidths

The 25-kHz bandwidths are not spectrum efficient for analog voice. Newer radio systems operate on the 12.5-kHz narrowband channels, which allows for more efficient use of frequency allocations (twice the capacity in the same bandwidth).

4.3 Outmoded Analog FM

This is old technology. New systems operate in a digital FM mode for voice or data transmission. FM digital for voice provides better intelligibility for cases of "noisy" or weak reception.

4.4 Lack of Seamless Interoperability with Other Agencies

The interagency communications require either a separate radio on the other agencies' frequency or special manual voice patches installed at the central office to patch communications across the nets.

4.5 Lack of Full-Featured Interagency Communications

The existing interagency communications described do not support talk groups or user (radio) addressability.

4.6 Lack of Security

Most communication performed by the agencies is "in the clear"; i.e., voice transmissions over simple analog FM radios without encryption. These transmissions are easily intercepted by commercially sold scanning radios. Although this does not usually present a problem, sensitive interagency operations, such as counterdrug activity, could be compromised if the wrong people are monitoring the conversations.

4.7 Lack of Efficient Digital Data Transfers

Most of the current systems were designed for voice traffic only. Sending data over the systems usually requires some type of modem equipment at each end and is typically limited to a data rate of 2400 b/s, or perhaps 4800 b/s under ideal conditions.

4.8 Aging Radio Hardware

Almost one-half of the current fixed, mobile, and portable radios are nearing their useful life span and will require replacement within the next 4 years.

With limited spectrum resources and already congested channels, there is little or no room for future expansion with the existing systems. Many of the systems are already operating at, or exceeding, available capacity. Without additional spectrum resources or a migration to newer spectrum-efficient technologies, these systems will be unable to support future requirements. The above limitations will become more and more apparent as further demands are placed on public safety communications.

5. REQUIREMENTS OVERVIEW

The proposed SCICN should be designed to meet the current unique needs of the partnering agencies as well as the common requirements to communicate between agencies. The system should also be flexible and adaptable to future expansion to meet public safety needs well into the 21st century. The proposed overall requirements for the SCICN are summarized as follows:

- Provide more effective use of the limited radio spectrum through spectrum efficiency plus comply with expected federal, state, and local communications mandates of the future.
- Enhance command and control by minimizing (or eliminating) channel congestion for faster, more reliable communications.
- Enhance or expand usable geographical coverage and reliability of short- and long-range communications systems through shared infrastructure assets.
- Provide blanket coverage over a defined area without holes for mobile and portable operation with 95 percent in-building coverage for dismounted officer safety.
- Provide an infrastructure for emergency operations with a hierarchy of user priorities for day-to-day use, as well as during small- and large-scale incidents or disasters.
- Enhance functionality to include individual user (radio) addressability, trunking concept for talk groups plus retain conventional broadcast capability.
- Provide the capability for communications between federal, state, and local agencies (when required) in a seamless, transparent manner.
- Provide for easy, "over the air" regrouping for special situations or emergencies requiring multiple departments or agencies working together.
- Provide for the integration of emergency and operational location of mobile units and personnel by Automated Vehicle Location (AVL)/Global Positioning System (GPS) tracking of users reported back over the network.
- Provide for effective encryption and security for both voice and data with the ability to transmit both digital

voice and data on the same channel. Digital data transmission would include items such as computer case files, graphical images, and electronic mail.

- Provide individual radio unit IDs to enhance office safety by improving response times in officer crisis situations.
- Enhance officer safety plus provide for risk management accountability for suspected rogue officers through the ability to monitor situations via open mike.
- Ensure that new systems are backward compatible to be completely interoperable with existing systems during transition.
- Use existing LEA and public safety communications infrastructure, equipment, and frequencies whenever possible and practical.
- Ensure minimum (if any) impact on the environment by using existing transmit and relay sites whenever possible–avoid new "bristling antenna farms" cluttering the skyline or mountain tops.
- Have ample reserve capability for future expansion for new users plus be easily upgraded or expanded to new technologies and/or user requirements.
- Comply, as much as possible, with industry-accepted standards to ensure compatibility of new systems and allow for competitive procurement from various vendors.
- Provide common console(s) for dispatch operations and easy to operate radios which would require minimum operator training.
- Ensure system reliability–a paramount requirement because public safety agencies operate 24 hours a day, 7 days a week and often deal with life and death situations.
- Provide fault tolerance–necessary so that if problems arise, the system will degrade gracefully with minimal interruptions.
- Be a turnkey operation and easy to maintain to the maximum extent possible.

6. BENEFITS

It is clear that significant investments in San Diego County and Imperial County public safety communications systems are required to rescue the currently overburdened and deteriorating systems. Partnering-up for the SCICN and making coordinated investments in shared radio systems represent a dramatic departure from today's approach to public safety communications. There are many benefits to be gained by partnering-up in a shared communications utility.

The main benefits from the proposed shared communications utility for San Diego/Imperial Counties are to resolve the current limitations/problems with the existing system in terms of channel congestion, inefficient channel utilization, lack of seamless interoperability with other agencies, lack of efficient data transfer capabilities, and aging radio hardware. Seamless communications interoperability between LEAs is critical in effective interagency counterdrug operations. Other benefits are apparent from the desired new functionalities for the SCICN as outlined in the previous section. Overall the proposed SCICN will provide public safety agencies with enhanced communications tools and capabilities to better protect life and property

Shared communications systems also will provide many secondary benefits. Besides providing the most reliable means of achieving direct interoperability among agencies, large numbers of shared users make implementing enhanced features such as mobile data more cost effective. Shared systems also offer greater opportunities to achieve cost efficiencies through the reduction of duplicate infrastructure, streamlined maintenance structures, and greater leverage in competitive equipment procurement.

Partnering-up for shared communications is a "win, win" proposition for everyone. The individual agencies lose nothing. Each can maintain its own "autonomous nets" and operations but gain tremendously in reduced channel congestion, improved communications, and enhanced functionality. The biggest winners, however, are the people of San Diego and Imperial Counties, who will benefit most from the improved public service that the shared SCICN communications utility can help provide.

7. AVAILABLE TECHNOLOGIES

Advances in communications technology can provide a wealth of new capabilities to substantially aid public safety personnel in the performance of their duties. In particular, new sophisticated trunking systems are currently being offered by vendors which *can meet or exceed* the requirements for the proposed SCICN as outlined in Section 5.

The basic building block for these systems is the trunking concept in which a pool of radio channels is made available to any user when required and returned when not in use. Current vendor systems use sophisticated trunking coupled with new over-the-air programmable radio systems to greatly enhance spectrum efficiency and reliable message throughput. New vendor multisite trunking systems can integrate communications over large geographic areas such as region, county, state, or even country.

Vendor systems support not only traditional trunking functions such as group calls, selective calls between two radios, and priority channel monitoring but many new capabilities like emergency/alarm, call alert, dynamic regrouping, telephone interconnect service, selective radio inhibit, and console dispatch. In much the same manner that cellular telephone systems choose the optimum cell host(s) for a call from a moving vehicle, some trunking systems can constantly choose the best repeater site(s) to maintain the highest quality communications for vehicles on the move.

Some of the enhanced features offered by vendors with their systems could be very useful for both officer safety and increased operational capabilities. Typical new vendor-offered system features are described in the following paragraphs.

7.1 Radio Identification Display

Each mobile and portable unit sends a unique ID code with a call. The radio's name is displayed on the radio dispatch management terminal with the operator's assigned name or ID.

7.2 Emergency/Alarm

Allows the user to press a single button to transmit an emergency signal with the user's ID back to the central dispatch. Emergency flashes in red with an audible tone at the radio dispatch management terminal to gain attention.

7.3 Dynamic Regrouping

Allows a dispatcher to reassign talk groups without activity on the part of the mobile or portable operator. Prearranged situational talk group assignments, or storm plans, can be preprogrammed into the system. When the situation occurs, the plan can be activated automatically.

7.4 Telephone Interconnect Service

Allows a mobile or portable unit to operate as a half-duplex telephone to both make and receive telephone calls during an emergency when a connection to a landline is imperative.

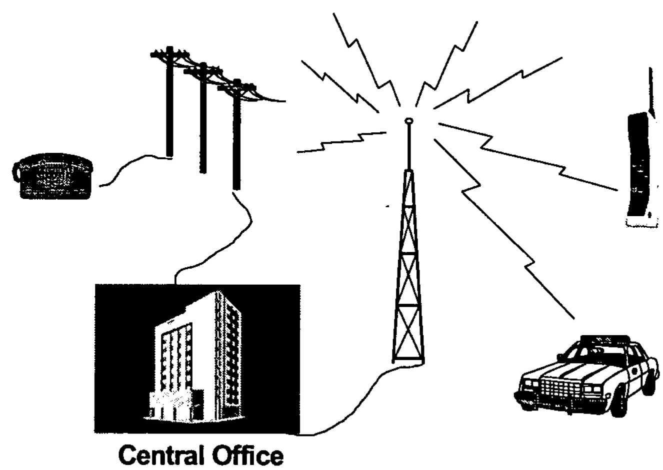

Figure 7. New technologies allow direct seamless telephone calls for mobile users

7.5 Physical Radio Security

If a mobile or portable radio is lost or stolen, the Systems Administrator can prohibit the radio from operating on the system, rendering the unit virtually useless. The central dispatch can even initiate a "hot mike" on the radio, causing it to transmit to aid in direction finding for recovery of the unit.

7.6 New Network Management Tools and Capabilities

Many of the new vendor systems offer enhanced network management capabilities, including network configuration software tools to aid in the basic configuration, network monitoring, and communications statistics determination. Fault management tools can provide near-real-time monitoring of the infrastructure components and real time traffic loading of the system. The network manager can become aware of real or potential problems on the system before users can even notice any degradation and initiate the appropriate corrective actions.

Vendors currently offer new, intelligent trunking systems and smart radios that can achieve these enhanced capabilities and yet are totally backward compatible to both conventional radio systems and older trunking systems.

The new systems and radios can be integrated into the existing infrastructure a few at a time, many at a time, or with a complete switch over with no loss in current system functionality or capabilities. There are virtually no fleet size restrictions to the number of radios that may be assigned to the new, available, sophisticated trunking systems. There are solutions existing today which can make the San Diego/Imperial County SCICN a viable working reality.

8. NEXT-GENERATION PUBLIC SAFETY RADIO

Although there are excellent vendor systems and smart radios currently available which can provide solutions to San Diego and Imperial Counties' public radio needs well into the 21st century, the strategic direction for public safety communications must constantly be focused on the future.

Emphasis must be placed on defining the next generation of public safety radio systems. This is a continuing process that includes (1) defining new desirable or needed features for public safety radios, (2) building on current technology or researching new technologies to meet the requirements, and (3) working with hardware manufacturers to incorporate new features into cost effective designs and viable hardware.

Figure 8 shows an example of a next-generation, portable public safety radio that is totally "doable" using current technology. This radio basically combines a secure FM radio with a built-in GPS receiver for automatic tracking and reporting of the unit's location back to the central dispatch office. The unit would incorporate additional desirable features such as a gunshot overpressure sensor, a 911 "panic" button, and special interface ports to Class II or III special ballistic vests with integrated biological and vertical sensors (officer shot or down), and a chest-mounted 911 "panic" slap button.

If any of the sensors are activated or the officer presses or slaps the 911 emergency buttons, the radio would automatically send a distress call back to the dispatcher indicating the unit's ID number and physical location (via GPS). Emergency response to the officer's known location would be immediate.

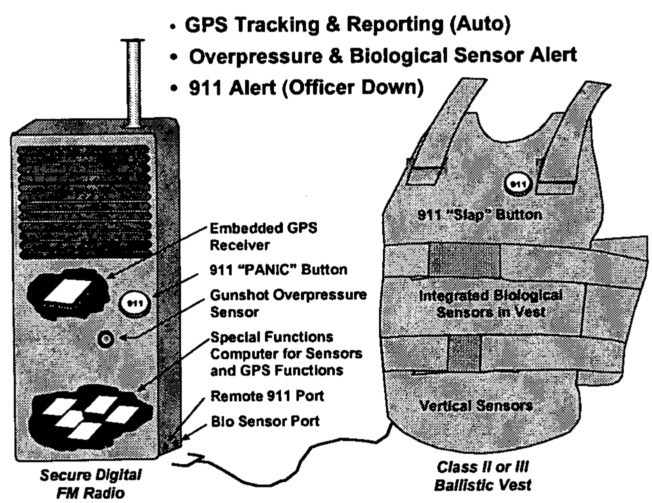

Figure 8. Next-Generation Public Safety Radio

Another desirable feature not shown in the figure is an expanded LCD display for the portable radio. Some currently available portables have a small two-line display to show unit IDs, called numbers, and limited paging messages. It is well within current technology to expand this display to be able to send more information, such as suspect description, wants and warrants, or simple graphical maps for travel to a given suspect location.

9. RECOMMENDATIONS

An initiative should be started to begin the development and implementation of the proposed SCICN for San Diego and Imperial Counties, California. The current individual conventional systems in these counties are based on aging technology and are in need of replacement. With limited spectrum capacity and congested channels, these systems are already operating at or exceeding available capacity. Without additional spectrum resources or the migration to new spectrum-efficient technologies, these systems will be unable to adequately support future requirements. Public safety as well as officer safety will continue to be degraded unlessnew, reliable communications systems are acquired to meet the future needs of the community.

A shared system based upon new trunking technologies offers the best opportunity to solve the existing system problems and improve interoperability among LEAs for counterdrug operations and other combined law enforcement activities. A shared system can provide the infrastructure for large-scale combined LEA and public service activities during emergencies and disasters and support normal day-to-day operations. The sophisticated trunking systems coupled with new smart radios currently offered by vendors can not only meet all the requirements of the proposed SCICN for today but are also flexible enough to meet the two counties' public safety communications requirements well into the 21st century.

Airborne Tracking and Coordination System (ATCS)

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ABSTRACT

With the distribution of narcotics being a lucrative business, the individuals involved have become cognizant of the efforts by law enforcement agencies to curtail their operations. Distributors and dealers now routinely assume that they are being followed by ground vehicles and make numerous course and speed changes in order to throw off or detect surveillance units. As a result, the law enforcement community is turning progressively towards airborne surveillance.

The Airborne Tracking and Coordination System (ATCS) is designed to be used mainly by an observer in an airborne unit and in a limited way by the pilot. The ATCS comprises a touch screen operated computer integrated with a radio modem for tracking suspect as well as ground surveillance vehicles; a GPS for self tracking; an FM beacon for real-time differential correction of the air and ground sensors and an optical high brightness map display for the pilot. Additionally included is a ground base station capable of tracking and communicating with the airborne as well as ground surveillance units.

Additional features include relaying tracking data from the airborne unit to the mobile units below; two-way digital message transmission; post process differential correction for tracking data; general map orientation and map overlay features.

The ATCS is presently an integral part of the operations of the State Patrol Aviation Section (SPAS) of the Minnesota State Patrol, whose mission it is to provide airborne law enforcement support throughout the state. Narcotics related flights comprise a significant number of their special operation missions.

With the ATCS capabilities in place, State Patrol aviation officers will be able to execute and coordinate surveillance operations while airborne, using the provided capabilities to self-track while simultaneously and covertly tracking suspects on the ground.

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Biographies

Trooper Mark Dunaski is assigned to the Minnesota State Patrol Aviation Division as a command pilot. He has extensive experience in law enforcement operations and holds many pilot ratings in addition to his helicopter role with the MSP. He is a graduate of the University of Minnesota with a BA in Sociology.

Yukie Novick is President of Integrated Systems Research Corporation (ISRC) and earned a BS in Electronics from Jerusalem College of Technology.

Morris Levine holds a MS in Aerospace Science from USC and has an extensive background in military and intelligence operations.

Introduction

For the past several years, Integrated Systems Research Corporation (ISR) has been developing and integrating software and hardware technologies that are being applied by different drug and law enforcement agencies for mapping, tracking, surveillance, communications, and information exploitation. At the base of these technologies is ISR-MAP, an elaborate mapping system that runs on different platforms, including DOS, MS-Windows, UNIX, X and Windows 95. ISR-MAP is used as a common background for the display and exploitation of:

- Real-time tracking using remote position sensors
- Self-tracking in air and ground vehicles
- Unattended tracking and data gathering, and off-line display and analysis
- Local and remote map overlays
- Message exchange between surveillance units and a base station.
- General purpose database management applications for law and drug enforcement
- Bi-directional data exchange with commercial relational database management systems
- Case management, mission deconflicting, dynamic personnel management linked to mapping and tracking

The background of this program is a good indicator of the evolution of technology and the transfer and technology re-use from earlier efforts. The basic capabilities represented by the ATCS Program were also employed in a program developed under DARPA (Defense Advanced Research Projects Agency) known as "Korea 911" and a similar program funded by ONDCP in conjunction with the Mayo Clinic in Rochester, MN for use in their airborne medevac helicopters. The latter program (ASINC) provided a testbed for the development and application of an airborne sensor program. Both the Korea and Mayo programs enable the self-tracking of the helicopter/aircraft using GPS and a mapping program. Both programs demonstrated the utility of such capability and suggest a straightforward transition to the needs of the drug enforcement community when operating in an airborne mode.

MSP Aviation Division has a long and successful history of employing airborne assets to support law enforcement operations, including surveillance of criminal suspects. The MSP experience and that of other aviation sections throughout the community show that airborne elements are a valuable adjunct to police surveillance and tactical operations. It is expected that the ability to provide self-tracking in conjunction with input from a covert, remote sensor on the suspect vehicle as well as the capability to tie in to a base station command and control function will greatly enhance the overall effectiveness of airborne operations.

Airborne Tracking and Coordination System (ATCS)

The use of airborne assets to support surveillance and tactical operations extends both the eyes and ears of enforcement officers and agencies. In the counterdrug and general law enforcement context, pilots are able to surveil a much larger area in a broader visual context than ground personnel and do so in real-time. Airborne units can be hampered by the absence of on-board mapping systems, location sensors, and effective communications.

ATCS will assist pilots directly and ground personnel indirectly by providing the systems support derived from mapping programs, databases, GPS and DGPS technologies, current computing and display systems, and two-way digital messaging. When covert sensors are employed to track suspect vehicles, the air unit will be able to stand off out of both visual and audible range while still maintaining precise position information on both the aircraft and the suspect.

HARDWARE

- Flat panel 586 computer for helicopter. This off-the-shelf, ruggedized and flight qualified system will provide the basic compute power to support the air use of the ATCS system. The basic features will be similar to those of laptop/notebook systems currently available, including serial and parallel connectors and PCMCIA slots.
- Touch screen in the rear of the helicopter for use by the non-pilot flight crew or co-pilot. This will be used for real-time observation of the helicopter and suspect location, along with map information such as FAA flight sectionals and street vector maps.
- Hi-bright display and touch screen for the pilot will provide GPS-derived position information of the airborne unit and the suspect(s).
- An off-the-shelf GPS unit will be used for self-tracking.
- Differential beacon to correct ground position for derivation of differentially corrected GPS data.
- Radio modem to track multiple ground suspect units.
- Cellular phone based sensors for emplacement on suspect vehicles.
- Covert VHF radio tags for tracking suspect vehicles.
- The development of a future plan to relay self-tracking and tracked targets to a ground-based command and control or base station.
- The system will be designed for airborne operations by police units.
- As designed, the ATCS could be as easily used in a ground mode as well as in the air.
- Tracking of ground-based suspects could be extended to water or air targets.
- The design approach of ATCS is to use an open and modular architecture with a very short learning curve.
- The sensors to be employed or that could be employed, include:
    - SPM 2000 VHF radio tags
    - Orion systems cellular tracker
    - Newcomb satellite relay of data
    - TraPS cellular-based covert sensor
    - Other TraPS-based sensors as may be provided by ONDCP.

The hardware approach has been tested and proven in the field by both the Korea 911 program and the Mayo Clinic airborne medevac program.

Base station

The base station will have the ability to display the operational environment based on a centralized location provided by the position of the tracking helicopter. The underlying mapping software for the base station will be essentially similar to that of the aircraft. Hardware includes:

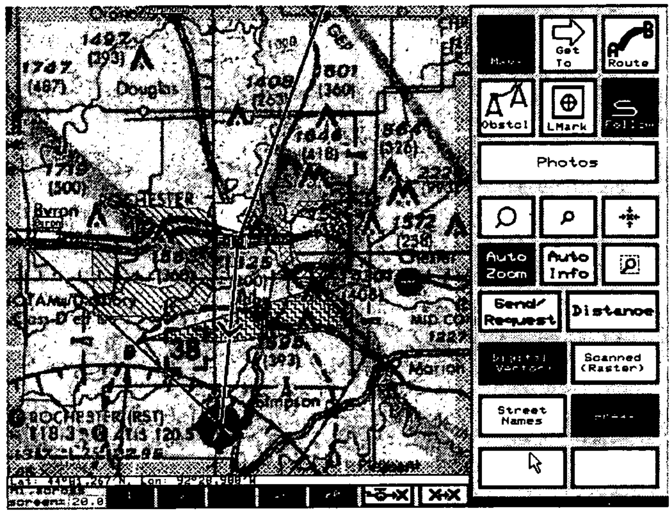
- A COTS Pentium-based PC with large screen display for use in situational monitoring and command and control.
- DGPS unit to provide the basis for software based differential

Software

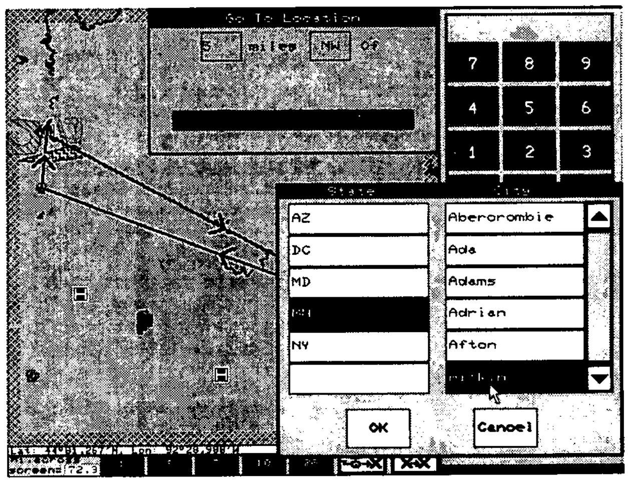
Airborne

The airborne software combines the lessons-learned and operational experience from the two prior airborne programs, Korea 911 and Mayo Clinic. In addition, it combines remote tracking and surveillance elements from the NavTrack program, which is in extensive use throughout the federal law enforcement community. The new ATCS software combines these capabilities into a new program designed to support airborne self-tracking, airborne remote tracking of ground-based suspects, and base station display capabilities. Following are the general capabilities of the software:

- Simple to use. The interface being developed for ATCS will employ an intuitive screen display designed to be used in touchscreen mode, with all commands and capabilities being obvious and straightforward.

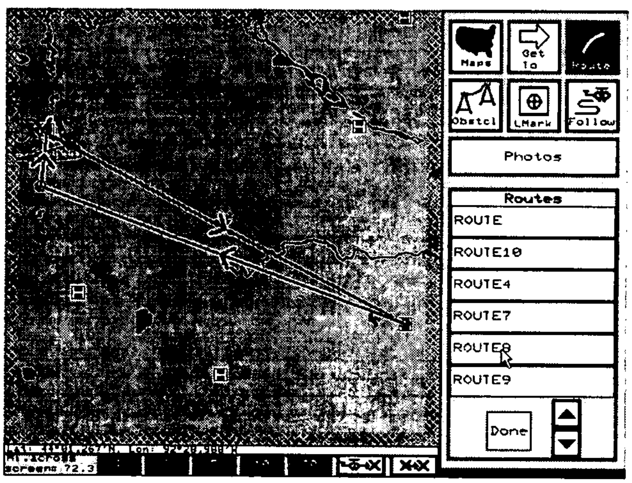


- Designed for pilots and for use in an airborne environment. The key features of the program will provide the pilot with the kind of map displays and "go to" information required to respond rapidly to developing tactical situations and to track covertly suspects on the ground.

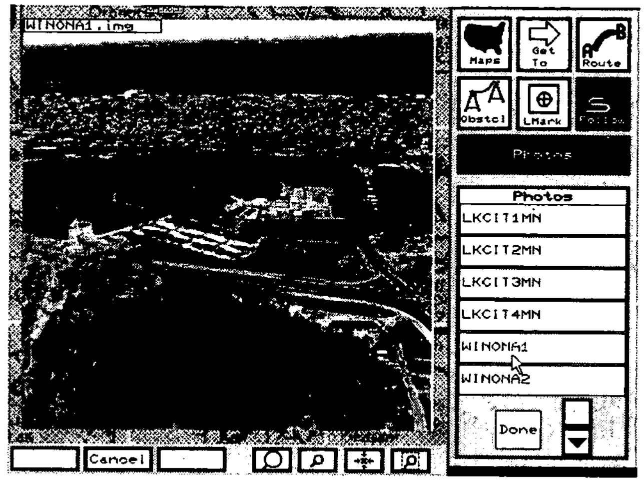


- Used in a related program by military pilots in Korea for use in DMZ border patrol operations. The lessons learned in Korea 911 will transfer to ATCS.
- Capable of dual-screen display and can be used by pilots and a spotter at the same time
- A full mapping system with complete GIS capabilities and full map display attributes in conjunction with industry standards.

- Capable of tracking multiple ground targets from the airborne platform and displaying all or selected tracks on the spotter or pilot display.
- Able to perform real-time DGPS correction in the airborne unit using hardware to receive the broadcast DGPS signals.
- Able to receive pseudo ranges from SPM-2000 to provide post-processed DGPS information.
- Will incorporate the software hooks to enable future capability to relay information to a ground-based monitor.
- Flight route upload from a base station to the airborne unit will be provided, and will include all the route waypoints and "leg" information for a track or route. If the pilot needs a route from an existing location to a new but unknown location, the route can be developed on the ground and passed to the aircraft.



- Images of landing zones. The software provides a capability to link to an image database that might incorporate, for example, approach images for landing zones throughout the unit's area of operations.



- Overlays, including polygons and icons which form part of a local database for use by the unit or individual pilot, showing case information or other significant information.
- Selective display of obstacles based on altitude or other landmark or location information produced from locally-generated databases that will display on vector maps that information, such as obstacles and height-above-ground.

Base station

The base station software will be a Windows-based program that will serve as a situational display, as well as a full-featured GIS program to support command operations. All mapping capabilities provided in prior law enforcement programs will be used in the ATCS program. The base station design will be largely based on the Korea 911 and MayoAir programs.

The base station will be capable of generating flight routes and flight route segments and maintaining these in an integral database for archiving purposes or to upload on-demand to the airborne unit.

The image database will also be maintained at the base station and will provide all images desired to be stored and used by the aviation division to support routine and tactical operations. These images will include landing zone information and key target information as it is developed throughout a case investigation.

All operational data, including flight route information, friendly tracks and suspect tracts will be archived by the base station software and can be replayed at a later date. Archived information will also include native data pertinent to operations, such as unique polygon and icon data for a given case.

Tracks that have been archived can be replayed for subsequent analysis. Replay modes can be selected for different speeds (e.g., proportionate track movement), as well as for time and area windows.

All software includes the ability to include scanned maps, such as flight sectionals as well as digitized flight maps produced by various vendors. This flight map information can be used by both the flight and ground segments of the ATCS program.

Multiple sensors are included in the program, including at least one VHF tracker and two cellular phone-based systems.

At the conclusion of the program, another standard product will be available for widespread use by the drug and law enforcement communities. The ATCS application will have wide applicability to mobile operations in general and to airborne operations in particular.

Summary

ATCS will provide the law enforcement community with a product to support simultaneous air and ground tracking operations, focused on the airborne unit. The major components of ATCS will build on the successes of prior programs and tailor their applications to the counterdrug operational environment.

The major components rest on a firm foundation of operational testing and developed sensor products that can be integrated into the ATCS program.

The open architecture and modular approach to software design and hardware integration provide a clear path to future expansion and provides an unusual degree of flexibility for the introduction of new capabilities.

1997 ONDCP INTERNATIONAL TECHNOLOGY SYMPOSIUM

Applied Counterdrug Law Enforcement Technology

ABSTRACT

Eagle Eye Mobile Messaging PLuS
Personal Locating Service via Satellite

Eagle Eye is currently developing a satellite based mobile messaging and tracking system that can track an ankle or wrist-worn mobile communicator. Applications include tracking parolees and communicating with law enforcement officers. Consumer applications include tracking children and people afflicted with Alzheimer's disease. Advantages include wide area tracking directly via satellite, two-way messaging and paging, and long battery life. Additionally, unlike GPS based tracking solutions, Eagle Eye's patent pending tracking solution penetrates buildings. Building penetration is required for tracking of people, since people spend their time indoors.

To date, Eagle Eye has built prototype antennas, RF front-ends, and has selected and tested a single chip DSP/ASIC for its miniature mobile communicator. In addition, Eagle Eye has tested its design using a U.S. Navy satellite. The results of the tests have proven the ability to send a receive packet data messages via low Earth orbiting satellite. Eagle Eye is continuing to finalize its design, and plans to introduce its messaging and tracking service in the first quarter of 1998.

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Law Enforcement Applications of Time Modulated Ultra-Wideband RF Technology

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ABSTRACT

Time Domain is the world's only developer of Time Modulated Ultra-Wideband radio technology. From the perspective of law enforcement personnel, Time Modulated Ultra-Wideband RF systems have many unsurpassed qualities. These qualities include: an ultra-covert RF signature; ultra-fine ranging/positioning capability; ultra-low RF output power levels; and immunity to multipath fading.

Time Modulated radio technology allows construction of "bugs" that are nearly impossible to detect (even with sophisticated intercept equipment), radios that that work exceptionally well within building and in urban environments (with milliwatt and sub-milliwatt emitted RF power levels), tracking devices that are both undetectable and work in environments where GPS is not available; building imaging radars, and robust, covert intrusion and proximity sensors.

Introduction

Law enforcement organizations have a tremendous appetite for wireless communications. Generally, law enforcement's radio communication links are neither secure nor covert, i.e., the communications being transmitted are not encrypted and the transmissions are easily detected. Time Domain Corporation has developed an RF communications technology that is inherent covert and encrypted.

The security of message transmission can be a significant issue. It can be embarrassing to have television reporters beating law officers to crime scenes, but of greater concern is the advantage gained by criminals who intercept law enforcement communications. Fortunately, modern digital radio systems can incorporate highly effective encryption subsystems. However, secure communications are insufficient for some law enforcement activities, where signal detection can be a life and death issue. A detectable signal from a "bug" that has been placed on an informant endangers the informant and can spoil the operation. Traditional radio technology is highly detectable and even the most advanced military RF communications technology is detectable by today's sophisticated and well financed crime organizations.

Time Domain Corporation's Time Modulated Ultra-wideband ("TM-UWB") RF technology is demonstrably the most covert RF technology ever developed. With TM-UWB one can construct tiny transmitters that are undetectable to even the best signal intelligence teams. For example, Time Domain has constructed a prototype wireless microphone that occupies less than 2 cubic centimeters, has a range of approximately 100 meters, and cannot be detected by standard "bug" detectors even when those detectors are in direct contact with the device.

The technology can also be used to implement precision tracking systems and building imaging systems capable of accurately resolving the location of people within buildings.

RF Signal Detection

In order to detect a RF signal, a measurement device – an intercept receiver – must be able to distinguish between the signal of interest and other signals – noise. Noise is composed of other RF signals from such sources as (1) sparking motors, radio transmitters, and computers, ("ambient" noise) and (2) from signals generated within the receiver itself ("thermal" and "self-generated" noise).

In the absence of ambient and self-generated noise, thermal noise ultimately limits the sensitivity of an intercept receiver. Thermal noise is noise generated by the random motion of electrons within a receiver. Any signal below the thermal noise threshold of the intercept receiver is undetectable. Therefore, to minimize the potential to be intercepted, all low probability of detection (covert) signals are made as noise-like as possible.

Range also plays an crucial role in signal detection. The greater the distance between a transmitter and a receiver, the less detectable the signal. Signal power falls off with the square of the distance; thus, just as the light of a flashlight is one-fourth as bright when one doubles the range, so would be the power of a RF signal.

By minimizing the range between a transmitter and an intercept receiver, one maximizes the probability of detection.

A primary goal of engineers of covert communication systems is, therefore, to make the transmitted signal as noise-like as possible and to emit as little power as possible.

Time Modulated (TM) Radio

Time Domain Corporation has developed Time Modulated RF technology, which has proven to be the most covert RF technology every demonstrated.

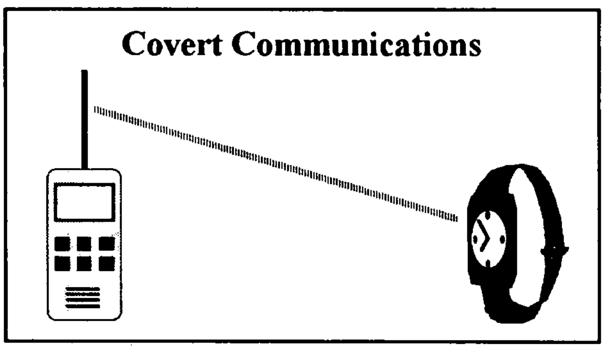
Time Modulated radio is an ultra-wideband RF technology.[1] By using "time domain" techniques rather than traditional "frequency domain" techniques, time modulation radio transmits noise-like RF signals over multiple gigahertz of bandwidth. Traditional radios have "narrowband" frequency channel assignments, e.g., a 30 kHz wide channel in the 900 MHz UHF band. Time Domain's "UHF band" radios operate over the entire UHF band – from below 300 MHz to over 1 Ghz – a 700 MHz wide channel. And Time Domain's "2 GHz" microwave band radios operate over the band from 1 GHz to 3.5 Ghz – a 2.5 GHz wide channel.

Time modulated ultra-wide bandwidth radio signals have inherently ultra-low probability of detection signals. Moreover, TM radios have another extremely valuable quality: it is inherently immune to multipath fading, the bane of narrowband radio within building and urban areas (fading of cellphone calls and televison ghosting are the result multipath). The traditional technique for overcoming multipath is to transmit extra power, making narrowband signal more detectable. In the cluttered in-building and urban environment, time modulated signals can be transmitted at significantly lower power levels – typically 1/100th to 1/1000th that of a narrowband radio.

TM Radio is Inherently Covert

A few years ago, Time Domain demonstrated transmitting 156 kilobits per second (kbps) to over a kilometer. During the demonstration a highly sophisticated signals intelligence team attempted to detect the signal. After the demonstration, an observer stated the detection range was insignificant – it was within "bayonet range".

Time Domain regularly demonstrates transmitting the equivalent of two ISDN channels (e.g., 128 kbps) several hundred feet through its office suite with an effective emitted power of less than 100 microwatts (millionths of a watt). Since digital compression can reduce the bit rate requirement for voice communications to less than 4.8 kbps, we should be able to transmit compress voice over the same path with approximately 10 microwatts.

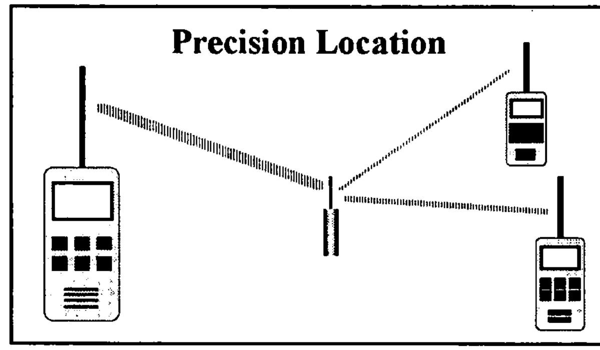


In comparison, consumer cordless telephones, which transmit the equivalent of about 32 kbps, typically emit about 100 milliwatts (thousandths of a watt) or about 1,000 to 10,000 times that required by a TM-UWB system.

Tests indicate that radio detection devices commonly used by sophisticated criminals are incapable of detecting any of these time modulated signals.

Precision Ranging

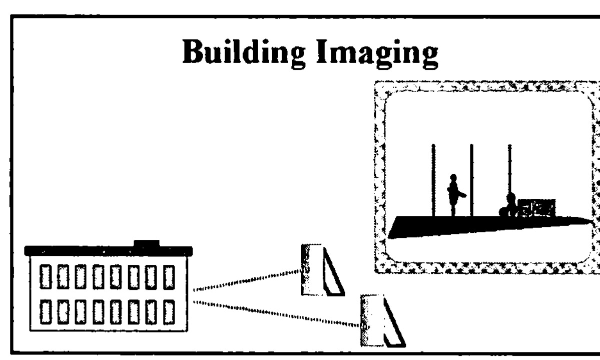
Time modulated radios are "synchronous" radios. Each radio has an internal clock; when one time modulated radio is communicating with another, the clocks in the two radios are synchronized to within 30 trillionths of a second (picoseconds or ps). Knowing that the speed of light is 300,000 km/sec. one can calcuate the distance between the two radios to less than one centimeter, i.e., 30 ps x 300,000 km/sec = 0.9 cm. This means that Time Domain could build covert tracking systems with unprecedented accuracy.



Building Imaging

For this same reason, one can also construct an extremely high performance radar – a radar that can image buildings and its contents. With a sub-centimeter ranging limit, it has an inherent resolution that would allow visualization, in real-time, of small moving objects.

There are several valuable applications of a building imaging system. Fire fighters could use such a system to image buildings to both look for people who might be trapped and to observe the location of fire fighting personnel. Similarly, hostage rescue teams could use an imaging system to determine to location of terrorists and hostages.



In proof-of-concept testing, Time Domain engineers have demonstrated the ability to locate a 15 cm x 15 cm metal plate in a house and may even be able to detect heartbeats.

With the addition of a moving-target identification software, it would be possible to focus only on even the slightest movements within the structure.

Security and Proximity Sensors

Related to the imaging radar is a proximity sensor – a device for determining if something has penetrated into a protected zone. In radar engineering terminology, Time Domain has constructed a "range-gated radar". Unlike infrared sensors and doppler radars, a time modulated proximity sensor cannot be triggered by large objects outside of the preset range. This can reduce false alarms dramatically. Moreover, a time modulated proximity sensor cannot be faked as can an infrared sensor (for example, by draping a damp towel over oneself, one can get around IR sensors).

One prototype that Time Domain has built incorporated a digital memory that allow the system to "remember" the location of objects within the protected space. The addition or removal of objects would then trigger an alarm.

Technology Status

Time Domain has been developing its Time Modulated radio technology for nearly ten years. The technology was first conceived in the late 1970s and the initial patents were issued, first in the USA and later in other countries, in late 1980s and 1990s.

Time Modulation technology is on the forefront of radio research and development. With no technological antecedents, Time Domain has had to fund basic research into this field.

Time Domain has produced many proof-of-concept prototypes that have demonstrated signal characteristics and allowed us to gain expertise in the construction of more advanced time modulated radios. Time Domain has just completed a 2.0 GHz center frequency with a 2.0 GHz RF bandwidth full duplex voice (8 kbps) and data (32 kbps to 128 kbps) concept system.

Conclusions

For communications applications requiring covertness, time modulated radio is the only truly stealthy radio communications technology. Additionally, the factors that make time modulation a covert signal also give it other unique capabilities. Time modulated radios offer the potential to create precision and covert tracking systems that operate well in cluttered environments such as those found in buildings and urban areas. TM radio technology can be used to image buildings, giving law enforcement officers vital information of the location of people and critical objects. TM radio can also be used to create sophisticated proximity sensors that have a much lower probability of false alarms.

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[1] For a mathematical description of time modulated ultra-widband technology, see R.A. Scholtz, Multiple Access with Time Hopping Impulse Modulation (Invited Paper), Proceeding of the IEEE Milcom'93, Bedford, MA, Oct. 11-14, 1993.

Magnetic Loop Based LORAN Receiver for Urban Canyon Applications, 1997 Update

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ABSTRACT

During the summer of 1996, the Office of National Drug Control Policy, the British Home Office, and the Defense Advanced Research Projects Agency funded the development of a digital H-field LORAN receiver and joint United States / United Kingdom radionavigation experiments to determine the accuracy, repeatability, and availability of LORAN in urban locations. The data measured in this experiment were taken using an H-field LORAN receiver. This decision was made based upon the results of an experiment performed in New York City during the summer of 1994 where it was determined that H-field LORAN significantly outperforms E-field LORAN in an urban environment. Details will be presented of the USCGA developed all digital H-field LORAN receiver that accepts a precise oscillator input to produce a two station time-of-arrival (TOA) fix if three stations are not available.

The first experiments were performed in London utilizing a van supplied by the United Kingdom and outfitted by a joint U.S. / U.K. team. The London data collected over a two week period indicated the LORAN receiver could consistently provide fixes with accuracy comparable to GPS SPS. The second set of experiments were performed in the New York City area utilizing a van supplied by ISRC and outfitted by USCGA, SAIC, and ISRC personnel. The New York data collected over a two week period also indicated the receiver could consistently correctly acquire and provide fixes of accuracy comparable to GPS SPS.

Preliminary details of a proposed low power implementation of the design are also presented.

Introduction

In 1994, the Defense Advanced Research Projects Agency (DARPA) funded the USCGA to conduct a comprehensive study of radionavigation signals in the New York City area. The study was performed in cooperation with several corporations including SAIC of Arlington, VA, and ISRC of Englewood Cliffs, NJ. Reference [1] presents the results of this study. The study showed that LORAN H-field signals are highly available in all areas tested, the E-field LORAN signal is less available than the H-field signal, and LORAN is more available than GPS in all areas tested. Considering these findings, the USCGA is building an H-field LORAN receiver that can be used to track vehicles or personnel in an urban environment.

In 1996, the Office of National Drug Control Policy (ONDCP), the British Home Office, and DARPA funded the USCGA development of a digital H-field LORAN receiver and coordinated a joint United States / United Kingdom radionavigation experiment to determine the accuracy, repeatability, and availability of that H-field LORAN receiver in urban locations and to compare its performance against GPS and integrated GPS/GLONASS. Two sets of experiments were conducted--one in London, England in August 1996 and one in New York City in November 1996.

This paper describes the equipment suites used in each experiment, the LORAN receiver hardware, the LORAN receiver software, the various scenarios in the experiments, the methodology in analyzing the data and presents examples of plots, preliminary details of a proposed low power implementation of the design, and conclusions.

Hardware Description

This section contains a brief synopsis of the two equipment suites and provides a detailed discussion of the H-field LORAN receiver hardware. In both London and New York, equipment was installed in an experiment van which was driven over each scenario route. Each data collection device, e.g. laptop computers, GPS receivers, LORAN receivers, was synchronized to UTC time to within a few seconds. This allowed a comparison of the different data collected based on time. The equipment used to collect data in London differed slightly from the equipment suite used in the New York City scenarios. The main differences were the ground truth collection system and the GPS receivers. Figure 1 is a block diagram of the key data collecting hardware systems in London and New York City.

Equipment Suite

The Marconi Inertial Navigation System (INS) was used for ground truth in the London scenarios. It was reinitialized every 10 minutes which produced about 1 meter circular error probability (CEP) accuracy. The ground truth data was time tagged with UTC time so that it could be used to determine fix accuracy for the GPS, GPS/GLONASS, and LORAN receivers. The Ashtech Z-12 was the 12 channel GPS receiver used in the experiment. It functioned as a stand-alone receiver--no DGPS corrections were used. The Ashtech GG24 (GPS/GLONASS), an integrated 24 channel receiver (12 GPS and 12 GLONASS), was used to determined the benefit of a combined GPS/GLONASS receiver over a GPS only receiver in urban environments. The data collection van contained two USCGA Digital H-field LORAN receivers. They could calculate a fix in either the traditional three station time-difference (TD) mode or in a two station time-of-arrival (TOA) mode when using the cesium frequency reference. The receivers were connected to H-field antennas mounted on the van. A cesium standard or rubidium standard was used as the clock reference for the USCGA LORAN receiver. The ISRC UniTrack Map Display / Data Collection System was used to record the DGPS, GG24, and LORAN data for playback on map overlays.

In the New York experiments an ISRC UniTrack Map Display / Data Collection System with Ground Truth was used to record the DGPS, GG24, and ground truth data. A RAC-2000 device was utilized to supply the ISR UniTrack with distance information from the experiment van's electronic transmission. Based on the RAC-2000 input, the ISR system calculated the ground truth position. In the New York experiment, a Magnavox MX9212 DGPS provided real-time DGPS position.

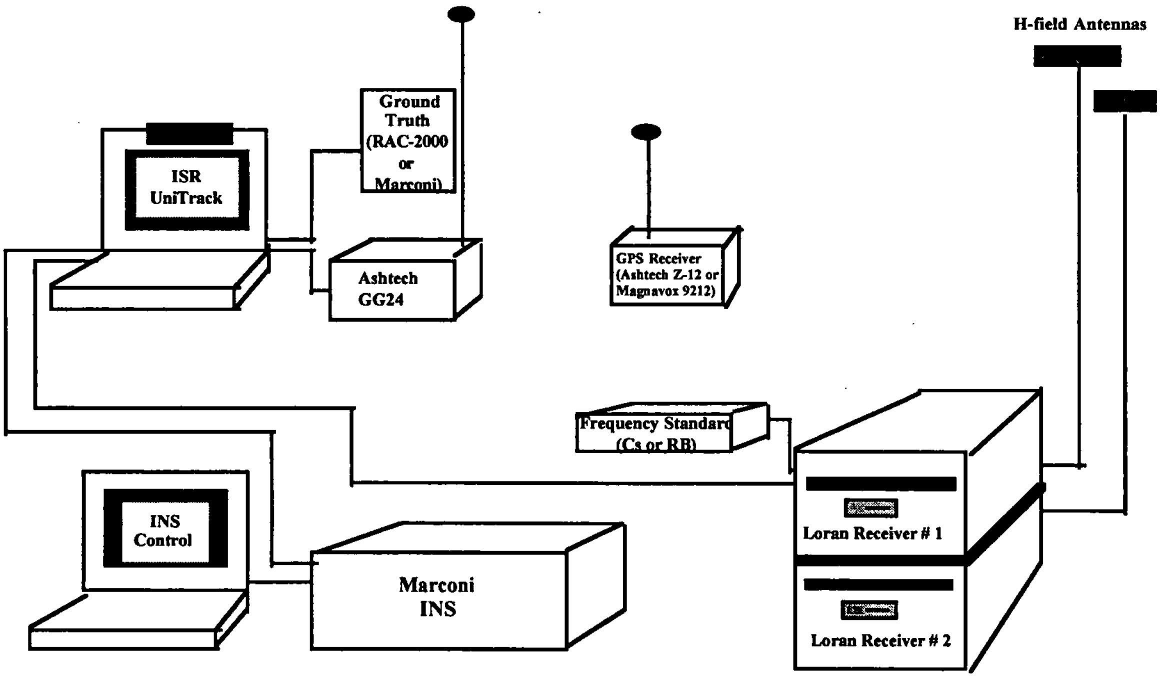

Figure 1 Block Diagram of Key Data Collecting Hardware Systems

LORAN Receiver Discussion

The H-field LORAN receiver consists of an H-field LORAN loop antenna, a pre-amplifier/band pass filter module, a Spectrum ISA board in a Pentium portable computer, and a stable clock. Figure 2 shows a block diagram of the receiver.

A stable frequency standard was required, especially for the LORAN receiver to operate in a two TOA mode. The rubidium or cesium frequency reference was used to produce this stable clock signal. The signal was used to trigger a synthesizer which produced a 150 kHz signal of appropriate magnitude and duration to trigger the convert on the analog to digital converters.

The computer used to process the LORAN signals was a Pentium portable computer with a minimum of 32 megabytes of RAM. A TMS320C30 system board (ISA format) by Spectrum Signal Processing, Inc. was used to perform digital signal processing. Two models of computers were used during the tests. In London, both computers were BSI portable computers, using a 90 MHz Pentium processor and 32 Mbytes of RAM. In New York, one BSI computer was replaced with a DFI notebook, using a 120 MHz Pentium processor and 32 Mbytes of RAM, with a docking station. The computer retrieved and analyzed LORAN data from the TMS320 board. It calculates a heading, TOA's, TD's, and position information. The computer records the LORAN data and sends NMEA-0183 position information out the serial port to the NavTrack computer.

The TMS320C30 system board is made by Spectrum Signal Processing, Inc. The TMS320C30 Digital Signal Processor contains an integer and floating point arithmetic units. It operates from a 33.3 MHz clock, performing 16.7 million instructions per second. When parallel instructions are used, 33.3 million instructions per second may be achieved. The board contains 64K words of dual port memory which can be accessed by the computer or TMS320C30. It also contains 128K of additional memory for general storage. Dual channel 16 bit A/D and D/A systems are included on the board. Sampling rates of up to 200 kHz are supported.

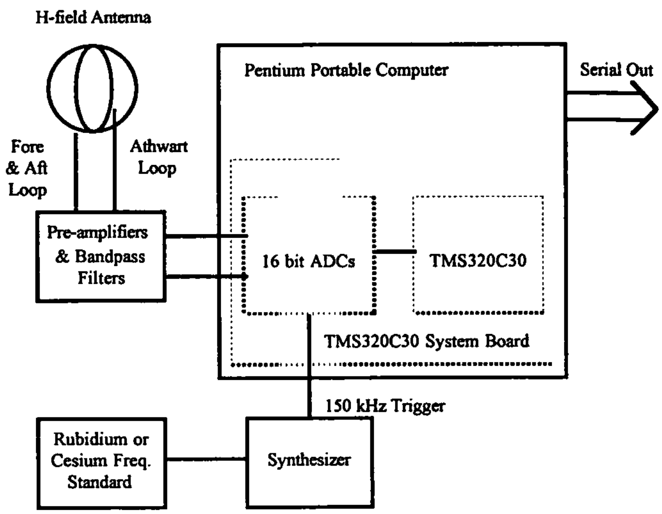

Figure 2. Block Diagram of H-field LORAN Receiver

Antenna Issues

Several models of H-field LORAN antennas were tested and used. Manufacturers of the LORAN antennas included Megapulse, Starlink, and Cambridge Engineering Inc.. The antennas contained two magnetic loops oriented 90 degrees apart. The loops are referred to as the fore and aft loop and the athwart loop. Each antenna included its own pre-amplifier. These preamplifiers have second order responses with a -3 dB bandwidth of approximately 30 kHz.

During the tests, it became obvious that there were cross coupling problems between the two loops of the antennas. Figure 3 illustrates these problems. To collect this data, a local magnetic field was created using a one meter diameter loop antenna driven with a 100 kHz sinusoid. Figure 3 shows plots of magnitude and phase of the two crossed loops as the receiving antenna is rotated through 360 degrees. The nulls in amplitude are not very deep and when at the amplitude minima, the phase is 90 degrees from its value at the maxima due to a voltage induced by the current flowing in the crossed loop. This cross coupling causes problems in that the received phase or TOA becomes a function of the orientation of the loop resulting in position errors. Figure 4 illustrates a preliminary attempt to model and eliminate these errors in software. In Figure 4 for the Starlink antenna, the solid lines were calculated using Loop1 -0.09j * Loop2 and the dashed lines using Loop2 + 0.13j * Loop1, where j = $(-1)^{\wedge 0.5}$.

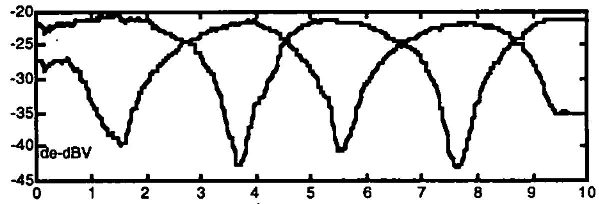

Figure 3. Response at 100 kHz as Starlink loop is rotated through 360 degrees in a local magnetic field. (Horizontal axis is time in arbitrary units.)

The RF signals from the fore and aft loop and the athwart loop of the magnetic loop antenna are amplified and filtered. Several types of pre-amplifiers and filters were tested during the experiments. Manufacturers of these pre-amplifiers/filters included Frequency Electronics and Stanford Research Systems, Inc. A Frequency Electronics D68H8E high pass module followed by a D68L8E low pass module were cascaded to perform the required filtering. Each module is an 8 pole, 6 zero elliptic filter. The filters are well enough matched so that they are almost identical. The overall magnitude response has a -3 dB bandwidth of approximately 24 kHz and is 30 dB down at 60 and 160 kHz. At 100 kHz, the phases of the two channels agree to within 0.25 degrees or to about 7 nsec.

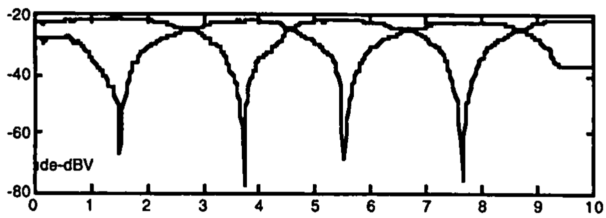

Figure 4. Elimination of cross coupling in software for Starlink antenna

Software Description

The software to implement the magnetic loop LORAN Receiver was written in three different languages. The code for the TMS320C30 board was written in the TMS320C30 assembly language. The assembly language code collected, filtered, and stored the sampled signals from the magnetic loop antenna. The code that allowed the host computer to communicate with the TMS320C30 board was written in C. The C code included routines to load the TMS320C30 board, change parameters on the board, and read data from the board. The host computer code that processed the data retrieved from the TMS320C30 board was written in MATLAB. The MATLAB processing included filtering the data, finding the start of the LORAN pulses of the appropriate stations, calculating the heading of the antenna and beamforming the signals, calculating the zero crossings, time of arrival (TOA), and time differences (TD's), and calculating position.

Figure 5 is a block diagram of the digital signal processing algorithm that the TMS320C30 board is running. The RF signals from the fore and aft loop and the athwart loop of the magnetic loop antenna are amplified and filtered by an analog, sixth order bandpass filter with a center frequency of 100 kHz and a bandwidth of 24 kHz. The two signals are connected to channel 1 and 2 of the Spectrum TMS320C30 board where the signals are sampled at 150 kHz and 16 bits.

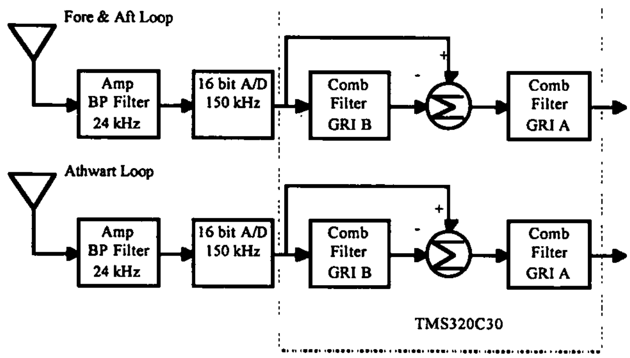

Figure 5. Block Diagram of TMS320C30 Processing.

Reference [2] presented a digital signal processing algorithm for the TMS320C30 that used a series of comb filters to notch out two LORAN GRI's and track one GRI. The TMS320C30 code uses the same algorithm, except only one GRI is notched and two channels are processed by one board. Each of the comb filters is an exponentially weighted average of the last number of phase code intervals. The transfer functions of the comb filters are of the form:

$$H_c(z) = \frac{1-a}{1-az^{-N}}$$

where $\frac{1}{1-a}$ is the time constant of the comb filter in Phase Code Intervals (PCI) and N is the length of a PCI in samples. The TMS320C30 code uses (1-a) as the multiplier of the input and (a) as the multiplier of the output which is delayed N samples. These variables are calculated and passed from the host. The output of the first comb filter (GRI B) is subtracted from it's input to form a notch filter at the GRI's harmonics. The notch filter transfer function is:

$$H_n(z) = \frac{a\left(1-z^{-N}\right)}{1-az^{-N}}$$

Reference [2] illustrates the theoretical and actual responses of this type of system.

In London, GRI 7499 was tracked and GRI 8940 was notched. The time constants and lengths of the comb filters can be easily changed by the host computer to change GRI's or adjust time constants. At a sampling frequency of 150 kHz, the maximum length N of any GRI would be 30,000. The Spectrum DSP board is limited to 64 k 32 bit words of dual port memory which is easily accessible by both the TMS320C30 and the host computer. The data from GRI A, including both antenna loops (channel 1 and 2), is stored in the dual port memory (60,000 words) along with variables to control the algorithm such as N and the time constants related variables (1-a) and (a)

The host computer routines to process the LORAN signals are written in MATLAB. The program has two parts - (1) the signal acquisition, and (2) the signal tracking. During the signal acquisition, the program initializes the TMS320 board and retrieves data from the board. The program also allows the user to do additional notch filtering on the LORAN signals. The user can either manually set the filters or have the program calculate the best filter. Figure 6 shows the typical 7499 LORAN signals from the TMS320C30 board. Both loops are shown. Only one half of the PCI is shown in the figure. Figure 7 illustrates the actual spectrum, the ideal spectrum, and the filtered spectrum.

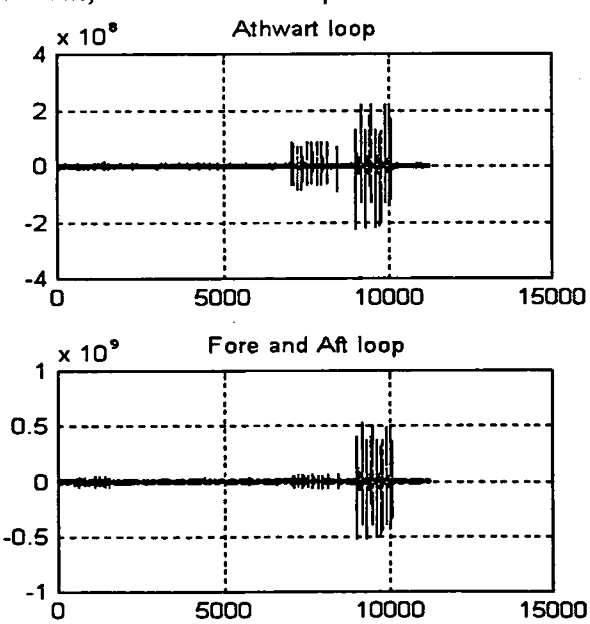

Figure 6. Typical 7499 LORAN Signal

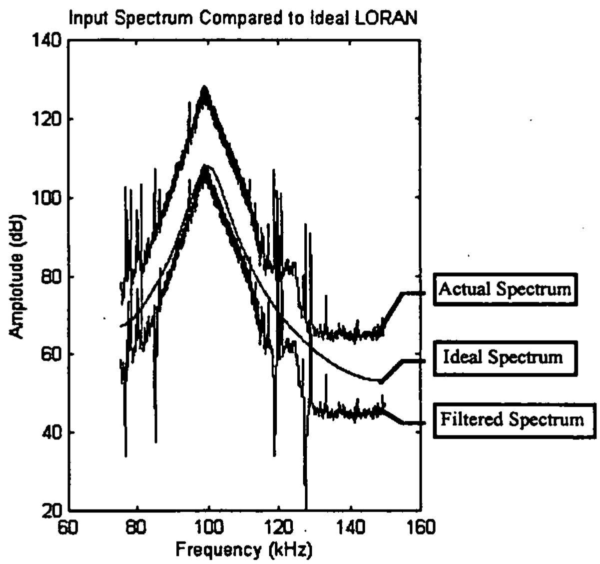

Figure 7. Actual, Ideal, and Filtered LORAN Spectrum

The start of the master LORAN signal is found by match filtering the two LORAN signals added in quadrature with an ideal master LORAN signal. This is done in the frequency domain using a 65,536 point FFT. Likewise, after the start of the master LORAN signal is found, the secondary signals are found using a match filter of the two LORAN signals added in quadrature with an ideal secondary LORAN signal. Figure 8 shows a typical matched filter for 9960. Once the start of the pulses is identified, one composite master and several composite secondary pulses are formed by adding the individual pulses of the LORAN signal multiplied by the appropriate phase shift. The vector size that stores the individual LORAN pulse is 64 points and starts 106 microseconds (or 16 points) before the actual start of the pulse. At 150 kHz sampling frequency, that corresponds to 426 microseconds or 42 LORAN cycles. The measurements of the start of the pulses are later used to calculate the TOA's of the pulses.

The program uses two methods to find the correct cycle zero crossing of the LORAN pulses. The first method involves calculating the envelope of the pulse and then the envelope ratio. When the envelope ratio equals a predetermined threshold, and the Envelope to

Cycle Difference (ECD) is taken into account, the cycle zero crossing should be the nearest zero crossing. In a receiver using an E field antenna, this works well because the LORAN signal always has a positive phase. It requires that you must be able to calculate the correct cycle zero crossing within a half a LORAN cycle or 5 microseconds.

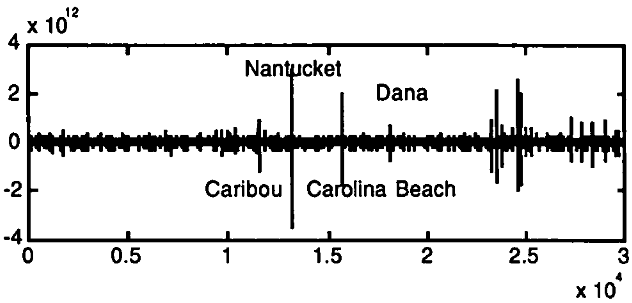

Figure 8. Matched Filters for 9960.

In the H field magnetic loop antenna, the signals may have either a positive or negative phase depending on the direction of the transmitting station from the antenna. This requires that, for at least one station, you must be able to calculate the correct cycle zero crossing within a quarter of a LORAN cycle or 2.5 microseconds. Once the zero crossing for one station is found, the heading can be calculated, and beamforming of the loops can be used for the remaining stations and ensuring that they all have a positive phase. During acquisition, this method is used to find zero crossing of strongest loop of the strongest station. Once the zero crossing of the strongest signal is found, a portion of its envelop is saved as a template. This template is used later to find the cycle zero crossing on the other stations by performing a least squares fit with each LORAN pulse envelope.

Since the sampling rate is 150 kHz, the LORAN signal that is centered at 100 kHz has only three samples every two LORAN cycles. The sampling rate can be expanded by performing a 64 point FFT and zero padding in frequency domain by a factor of 8 or 512 points. This produces a signal sampled at 8 times the sampling frequency or 1.2 MHz. Reference [2] discusses this algorithm in detail. Figure 9 shows the template and an "expanded" LORAN signal.

After acquisition of the LORAN signal and the start of the pulses are identified, the tracking of the zero crossing and navigation phase is done. This is the main loop of the program in which the TOA's are calculated. Once the TOA's are calculated, TD's and finally latitude and longitude are calculated.

During the tracking phase, the LORAN signals are retrieved from the TMS320 board, filtered, and expanded. Next, the strongest LORAN station is identified. The envelope template formed earlier is used to find the initial guess to the cycle zero crossing. The strongest loop of this strongest LORAN station is also identified.

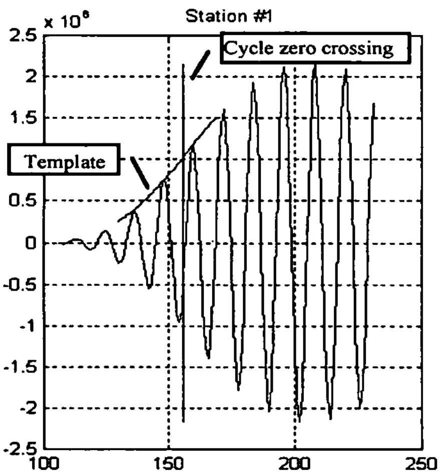

Figure 9. Expanded LORAN Pulse and Template.

The first time this routine is used, the phase of the strongest signal must be determined to perform beamforming correctly. Using the strongest loop, the closest zero crossing to the initial zero crossing guess is found and used as the correct cycle zero crossing, adjusted for the ECD. This is the TOA of the strongest LORAN station. The slope of this zero crossing gives the phase of the signal. The closest positive zero crossing of the composite signal for the strongest signal is found next. The phase difference between this point and the correct cycle zero crossing is used to calculate the relative bearing of the antenna to the strongest signal. The antenna heading can easily be found from this. In subsequent loops in this routine, the fore and aft loop and athwart loop signals are correlated with the previous beamformed signal and a new beamformed signal is found. Using the beamformed signal, the closest positive zero crossing to the initial zero crossing guess is found and used as the correct cycle zero crossing (TOA of strongest LORAN station). As before, the heading can be calculated.

The remaining LORAN stations are processed by first beamforming the athwart loop and fore and aft loop signals. Once the beamformed signal is found, the envelope template is used to find an initial guess of the correct cycle zero crossing. After adjusting for ECD, the closest positive zero crossing to the initial guess is found and used as the correct cycle zero crossing (or TOA) of the LORAN station

Signal strengths are checked to see if a loss of signal has occurred. If a loss of signal has occurred for a length of time, such as would occur if the LORAN signals were blocked by interference for a time period, a flag would be set to reacquire the LORAN signal once the strengths returned. The ECD's are also checked. If the ECD of a station remains greater than 5.0 or less than -5.0 for length of time, the tracking point cycle is adjusted. Finally the position is calculated. The user can select one of three methods - calculation of latitude and longitude by (1) TD's, (2) weighted least squares of the TOA's (described in reference [3]), and (3) TOA's of the strongest two stations only.

Scenario Descriptions

London

In London we used the 7499 chain with master at Sylt, Germany and secondaries at Lessay, France and Vaerlandt Norway, Because both the Vaerlandt and Sylt stations are northeast of London, the fix geometry is rather poor. Furthermore, because Vaerlandt is more than 600 nautical miles from London, the signal strength and hence the SNR is very poor further degrading fix accuracy. Future plans call for the addition of a new station at Loop Head in southwest Ireland which should result in both excellent fix geometry and signal strength in all of England.

There were four scenarios used in London. The first scenario involve a drive from a rural area into the city of London. Moderate to high van speed is a characteristic of this scenario. The scenario was expected to last about 40 minutes. The second scenario involved a drive through London. This scenario represented a urban environment. It contained tall buildings, parks, vehicles, and a noisy frequency spectrum. Slow van speed is a characteristic of this scenario. Each scenario run was expected to take about 2 hours to complete. The third scenario involved a drive trough the urban canyons of London. The purpose of this scenario was to measure LORAN and GPS performance in a highly urban environment with many tall buildings. Slow van speed is a characteristic of this scenario. Each scenario run was expected to last about 30 minutes. The fourth scenario involved the drive from London back to a rural location This scenario followed the reverse route of the first scenario. Moderate to high van speed is a characteristic of this scenario.

New York City

There were several scenarios in the New York City experiment. However, most of the data collected was from the Urban Canyons and Suburban scenarios. Since no ground truth data was collected on the other scenarios, absolute accuracy of the radionavigation systems cannot be determined. However, fix availability was measured. The first scenario consisted of approximately a 5 city block by 5 city block rectangular grid in the Wall Street area. Slow vehicle speed, narrow streets, and tall buildings were the main characteristics of this scenario. It took about 15 minutes to complete one scenario run. The second scenario consisted of travel trough the Bronx. Power lines, two and three story buildings, and an elevated train were attributes of this scenario. A typical scenario run took about 15 minutes to complete. The third scenario was run in the vicinity of West

Point in New York. It was used to determine the effect of mountainous terrain on DGPS, GPS/GLONASS, and LORAN receivers. About two hours of data were collected in this environment. The fourth scenario involved a suburban to urban run. Every morning and evening the experiment van traveled between suburban New Jersey and urban New York City. Data was collected from these runs and is typical of a person commuting to and from work each day in an urban environment.

Data Analysis

Extensive analysis was performed on the collected data to determine the availability, accuracy, and repeatability of H-field LORAN in urban locations. Envelope-to-cycle difference (ECD) plots were generated to determine LORAN signal availability. Plots of differences between LORAN and ground truth position are presented to show accuracy. Scatter plots of the position errors along with the cumulative distribution of errors are also shown. Actual and predicted TOA's are plotted (this is an indication of both availability and accuracy). Plots of TOA's from multiple scenario runs verses distance into the scenario were generated and indicate the LORAN repeatability. For the Suburban scenario in New York City, the DGPS position is plotted versus the ground truth position for comparison. The following describes the various plots. An example of each is given.

LORAN ECD verses Time

The H-field LORAN receiver calculated and stored the ECD for each LORAN signal. The ECD is the difference in microseconds between the actual tracking point zero crossing of the LORAN signal and the tracking point measured by the envelop alone. In optimum conditions, the ECD is less than 2.5 microseconds and is stable. If the signal is weak, the measurement will jump in multiples of 10 microseconds (5 microseconds for the strongest station). The receiver software continuously examines the ECD and will adjust the cycle selection. If the ECD jumps momentarily, it is an indication of interference. The ECD for each LORAN signal is an excellent indication of the LORAN signal availability. If the LORAN signal is acquired and tracked, the ECD will remain constant. Figure 10 shows a typical plot of the ECD's from the New York experiment. Note that the last two ECD's are fairly stable. The first ECD from the Seneca station shows one jump.

Figure 10. Example Plot of LORAN ECD verses Time. ECD's are plotted relative to nominal values.

Latitude and Longitude Verses Time

Figure 11 shows an example plot of the LORAN latitude and longitude and ground truth latitude and longitude verses time. This is an indication of the accuracy of the LORAN signals. Figure 12 shows an example plot of the LORAN position verses ground truth.

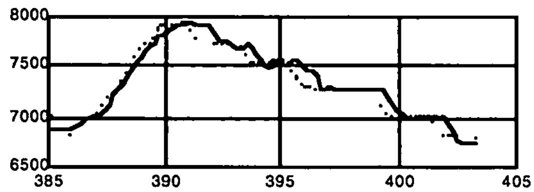

Figure 11. Example Plot of LORAN and Ground Truth Latitude and Longitude verses Time

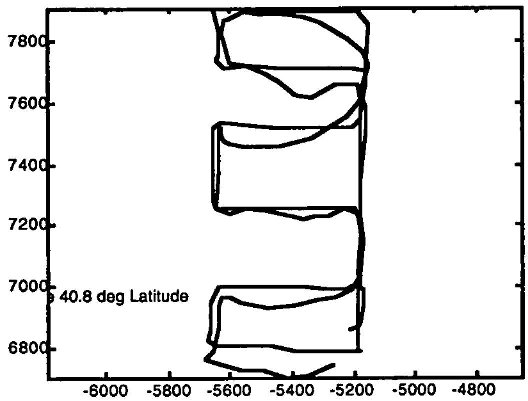

Figure 12. Example Plot of LORAN verses Ground Truth Fix Accuracy Plots.

Figure 13 shows a typical scatter plot of the error between the LORAN positions and the ground truth positions for the London urban scenario. The cumulative distribution of the error is shown in figure 14. What these plots show is that approximately 60% of the fixes were within 150 meters of ground truth in London. With the Loop Head station transmitting resulting in both better fix geometry and signal to noise ratio, fix accuracy should improve significantly. Figures 15 and 16 show comparable data for the Bronx and Wall St. scenarios in New York City.

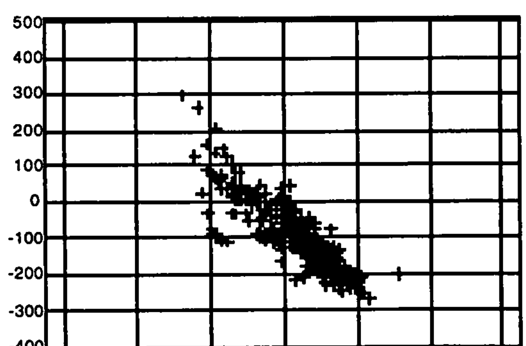

Figure 13. Example Scatter Plot of LORAN Position Error for London urban scenario.

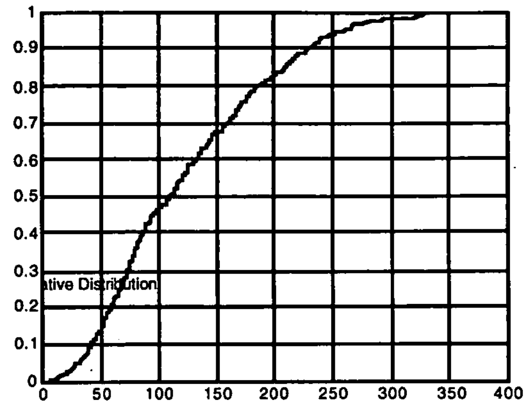

Figure 14. Example Plot of Cumulative Distribution of LORAN Position Error for London Urban Scenario.

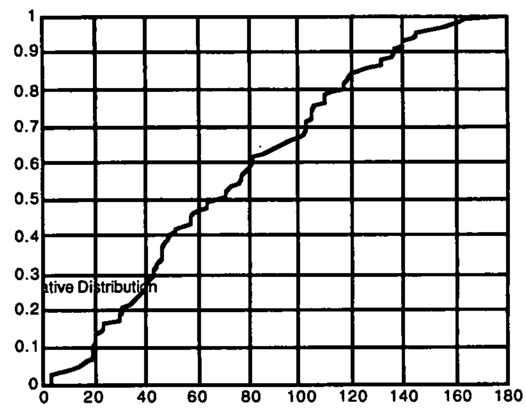

Figure 15. Example Plot of Cumulative Distribution of LORAN Position Error for Bronx Scenario.

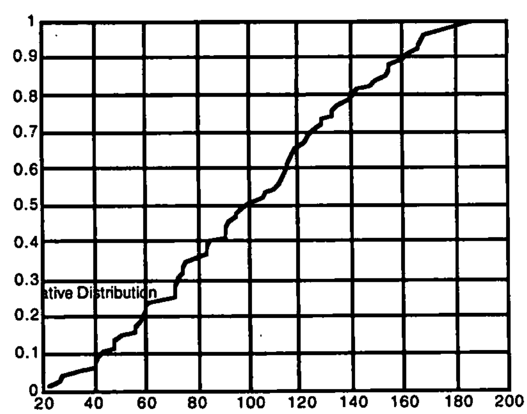

Figure 16. Example Plot of Cumulative Distribution of LORAN Position Error for Wall St. Scenario.

TOA's versus Distance into Scenario

Figure 17 shows a plot of difference between predicted and observed TOA's from multiple Bronx scenario runs verses distance into the scenario. In this example, the positive spikes occur on the left edge of figure 14 or under an elevated train. The propagation path from the Wildwood transmitter is along the train direction. For Nantucket with propagation perpendicular there was not the same phase shift. Also, the attenuation of the Wildwood signal was 10-15 dB under the train but the Nantucket signal was attenuated much less.

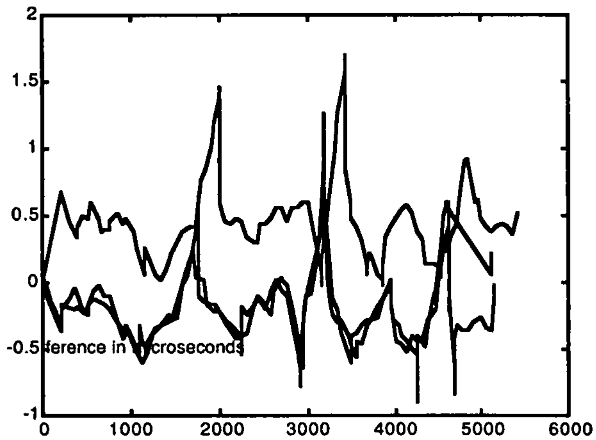

Figure 17. Example Plot of Multiple LORAN TOA's verses Distance into Scenario.

Proposed Low Power Receiver

At present ISRC and the Coast Guard Academy are cooperating in a proposal to reduce the size and power consumption of the receiver for use in urban warfare and law enforcement applications. The receiver would be packaged using the industry standard PC104 bus technology. Figure 18 shows a block diagram of the proposed H-field LORAN receiver. The three basic functions needing to be reduced in size and power and how this is to be accomplished are listed below. It is envisioned each of these functions will initially occupy one PC104 card.

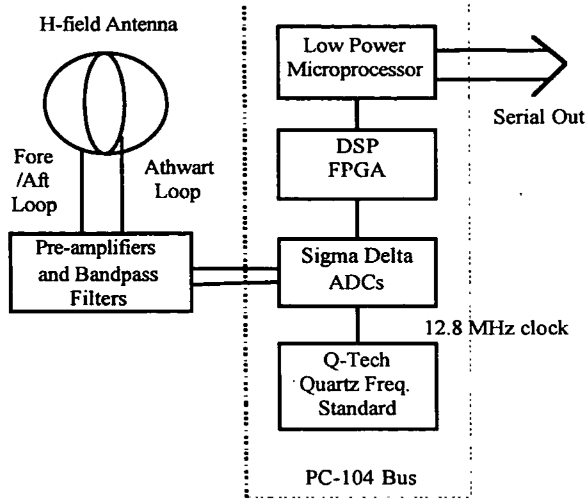

Figure 18. Proposed Low Power H-field LORAN Receiver

The Antialias Filtering and A/D Conversion

In the initial phase the combination of the high order analog antialiasing bandpass filter and the 16 bit successive approximation A/D converter will be replaced with a commercially available, low power, Sigma Delta A/D converter. The signal will now be sampled at one bit and 12.8 MHz which means the low order bandpass pre-amp need only filter out those frequencies above 6.4 MHz. This one bit data is then decimated and lowpass filtered in a series of two Finite Impulse Response (FIR) filters to produce 12 bit samples at 400 kHz and a cutoff frequency of 196 kHz.

The DSP Functions of Cross Rate Canceling/Comb Filtering

The 12 bit, 400 kHz data from the A/D conversion will then be mixed with the sine and cosine of 100 kHz. The mixer outputs will be lowpass filtered and sampled at 50 kHz. Figure 19 shows a block diagram of the antialias filter, Sigma Delta A/D Converter, and I & Q demodulator. This 50 kHz data will then be averaged with cross rate interference removed just as was done on the 150 kHz data in the 1996 version of the receiver. Present plans are that this will initially be done with a Field Programmable Gate Array (FPGA) and later phases will transition from FPGA to an Application Specific Integrated Circuit (ASIC) to further reduce size and power. In addition, the function of the commercially available lowpass A/D converter in the section above will be incorporated into this ASIC (or ASIC's) with the lowpass FIR filters replaced with logic to go directly to the 50 kHz I and Q samples.

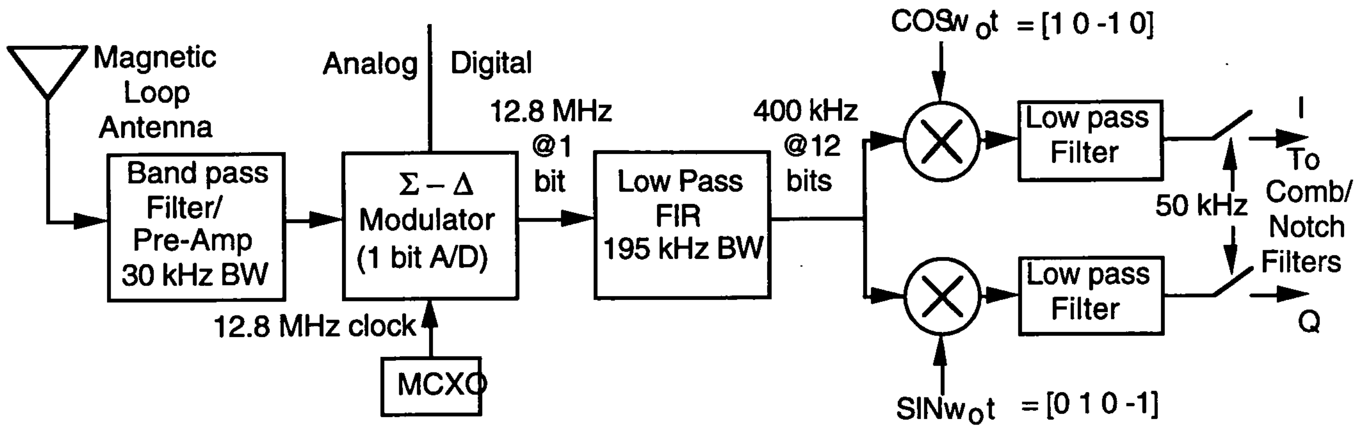

Figure 19. Block Diagram of Antialias Filter, Sigma Delta A/D Converter, and I & Q Demodulator. Repeated on each of two channels.

The Host Functions of Converting an Averaged PCI Waveform First into TOA's and then Latitude and Longitude

In the 1996 version of the receiver, these functions were performed by a program written in MATLAB and ran on a 90 Mhz Pentium computer. Initially these functions will be converted from the present MATLAB version to C++ and performed on a low power microprocessor. Whether the development of an ASIC for these functions is feasible is still being studied.

Conclusions

We have presented the design of the US Coast Guard Academy developed all digital H-field LORAN receiver which accepts a precise oscillator input to produce a two station time-of-arrival (TOA) fix if three stations are not available. In addition, the results of extensive LORAN testing in urban canyons was presented.

The first experiments were performed in London utilizing a van supplied by the United Kingdom and outfitted by a joint U.S. / U.K. team. Ground truth to an accuracy of one meter circular error probability was obtained via a combination of frequent stops at precisely surveyed locations and post processing of inertial navigator data. The London data collected over a two week period indicated the LORAN receiver could consistently provide fixes with accuracy comparable to GPS SPS.

The second set of experiments were performed in the New York City area utilizing a van supplied by ISRC and outfitted by USCGA, SAIC, and ISRC personnel. The New York data collected over a two week period also indicated the receiver could consistently correctly acquire and provide fixes of accuracy comparable to GPS SPS.

A preliminary design of a proposed low power implementation of the digital H-field LORAN receiver was also presented.

Acknowledgments

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MATLAB to communicate with the TMS320C30 were developed by LCDR Chris Kmiecik of the Coast Guard Academy. The Coast Guard Electronics Engineering Center operated the 9960T transmitter specifically to support the New York City tests and provided monitor data. Megapulse Inc. provided a loop antenna on loan and some of the ideas for modeling cross coupling in magnetic loop antennas were based on conversations with Bill Roland, the President of Megapulse.

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[2] Peterson, B. B., K. C. Gross, and E. A. Bowen, 'LORAN Receiver Structure to Cross Rate Interference Cancellation,' Proceedings of 22nd Annual Wild Goose Association Technical Symposium, Santa Barbara, CA, October 1993.

[3] Peterson, B. B., "Electronic Navigation Systems", in The Electronics Handbook, J. C. Whitaker, Editor, pp. 1710-1733, CRC Press, Boca Raton, 1996.

Information Systems Technologies (Session 2C-3)

8

WIDE AREA INFORMATION SERVERS IN SECURE ENVIRONMENTS

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ABSTRACT

Software tools used on the Internet for dissemination of information on the World Wide Web (WWW) have been adapted to enable separate law enforcement jurisdictions to share information in a secure environment. In the West Florida Counterdrug Investigative Network (WFCIN), a test site for advanced networking technologies sponsored by the U. S. Office of National Drug Control Policy's Counterdrug Technology Assessment Center (CTAC), the Data Miner provides an overlay of existing text databases and supports full-text and structured field search and retrieval. The Data Miner is being used by the participating agencies for full-text search and retrieval of incident reports, retrieval of image files associated with cases, and data organization for wiretap transcripts. At one agency, the Data Miner manages access to 500,000 cases by over 1,000 users. The Data Miner adapts database software from the WAIS-sf package, utilizes standard encrypted web client/server communications protocols implemented in the Stronghold secure web server, and implements access control by case, user, and groups of users to enable agencies to share information on a case-by-case and user-by-user basis while maintaining ownership and control of the data. The technologies are compatible with existing Internet protocols and can be used on both private intranets and the public Internet. The Netscape Navigator web client is used for Data Miner access, information retrieval, and configuration management on PC, Macintosh, Sun, and other platforms.

1. Introduction

Counternarcotics law enforcement agencies collect substantial bodies of information about their jurisdictions e.g., descriptions of people who are arrested, investigators' narrative reports of their involvement in cases, vehicle descriptions, crime scene images, and mug shots are a few examples. Much of this information is often stored in computer databases, which are typically collections of records containing fields of information filled in by the investigators. As with any law enforcement investigation, not everything fits within a set of pre-defined fields, so there can be a large collection of additional information (computer-based or not), such as newspaper stories, witness' statements, and narrative summaries of incidents written by the officers involved.

Databases are quite good at storing and retrieving information indexed by one or more fields in the records of a file, but what about all of the information that doesn't fit in these records? An officer's narrative summary of his or her actions at a crime scene is an example that is typically a rich source of information about the *modus operandi* of a crime, but is not easily accessible using traditional databases. Since these narrative summaries are typically stored as word processor documents attached to a database record, it is not generally possible to search the contents of the narratives for information that may be relevant to the investigation at hand.

A primary goal of the West Florida Counterdrug Investigative Network (WFCIN) has been to enable cooperating counternarcotics agencies to share computer-based information in a secure manner. Much of the information that is of interest comes from narrative summaries, as well as the traditional fields of the case management databases. It made sense to introduce technology that enables investigators to search across all available data sources rather than restrict them to the features of the existing systems. A full-text search and retrieval system was adopted. This system digests arbitrary text files and constructs large indices that allow rapid identification of documents that match an investigator's query. There is a trade-off in this approach: The indices tend to be large; however, disk storage space is quite inexpensive.

To implement a strategy for sharing information among cooperating counternarcotics agencies, we adapted commercial web client/server technology. This approach provides very good security (assuming the implementation is carefully engineered) using 1,024 bit RSA public key cryptography with symmetric (private) 128 bit session keys generated randomly each time they are needed. An interface between a web server and a full text search and retrieval engine was built, and this server configuration was replicated at each participating agency.

Commercial off-the-shelf web client/server technology only provides a portion of the solution; the remaining components had to be developed. First, a critical component of the success of this approach is local ownership and control of all data sources is maintained. Typical web server applications are not concerned with what resources a client may access. (There are exceptions, such as web-hosted stockbrokers.) Normally, clients may be authenticated, either using a username and password or a client certification, and once this is done, they have access to all web server resources. This is not satisfactory in counternarcotics applications, where access is granted on a case-by-case basis to the individuals or groups who are involved with that case's investigation or prosecution. A user privileges database was developed (WHOSINIT) and is discussed elsewhere in this Proceedings.

A second component implements distributed web server access by authorized clients. The standard method for web client/server interaction is one-to-one. A client requests information from (or provides information to) a web server, specified by a Uniform Resource Locator (URL), and the server replies. This is not suitable for secure applications because it is feasible for a web server's administrator to compromise encrypted traffic passing through a local server when it is acting as a proxy for a client's access to another server.

A Netscape Navigator plug-in has been implemented which provides distributed and simultaneous access to multiple web servers and mimics the response a user would expect to see from a single server. This allows users to transparently query multiple distributed and secure data bases from a client.

The result is a system, which is on-line at the agencies that are participating in the WFCIN test bed, which allows investigators to access any WFCIN web server-based databases from any client machine running Netscape Navigator and logically connected to the network. Users are able to issue queries composed of boolean search expressions and arbitrary text. The results are filtered and rank ordered according to how well they match the search criterion, and are returned as URL links used to retrieve the documents. The system also supports storage and retrieval of digital images, which may be scanned from film or acquired with a digital camera. Each image has an associated file of annotations which is also searchable. Any investigator with appropriate access privileges can append additional comments to this file. The following pages provide a brief discussion of the technologies which have been used to implement these capabilities and examples of their use. A short discussion of issues involved in transferring these technologies to other sites is included at the end.

2. Problem Formulation

Counternarcotics law enforcement data systems must take all reasonable measures to protect the information they contain. This is not only a legal requirement derived from citizens' rights to privacy; release of these data can place lives at risk. This work focuses upon operational data – data that is being developed and utilized to support ongoing law enforcement operations. Data are associated with open cases, and organizational policies control the rights of individual investigators to access data, usually on a case-by-case basis.

All law enforcement organizations, and especially counternarcotics organizations are reluctant to share data with outsiders. The counternarcotics community is typically tightly knit, and investigators share information as required and usually only to people they know and trust. The design of information systems to support multi-agency investigations must take these facts into account. It is not feasible, for example, to transport data to a central site in order to share information. This project adopted the following design philosophy, which imposes constraints upon the solution that is offered:

1. Data are owned by their respective organizations and are not moved away from those sites.

2. The organization which owns data for a specific case has complete control over access rights to that data.

3. Compromise of personnel at one agency must not compromise sensitive data at other agencies.

Given these constraints, software installed on a computer network is desired which allows any individual at any participating agency to search and retrieve information that he or she is authorized to access across organizational boundaries.

To simplify the investigators' learning process, a standard interface was adopted for all tools (wherever possible) developed under the WFCIN project. The World Wide Web (WWW) client browser paradigm was selected, in part because it is already familiar to many people, and in part because it provides a very natural way for people to interact with computers. The web browser displays "pages" of information to a user after each operation. Some regions of these pages, usually highlighted, represent links to additional pages of information. In some cases, a page requests a user to enter textual information in visual fields within a page and submit this information by "pressing a button" on the page with the computer mouse. Typically, it takes a and formed WAIS, Inc., developed the first WAIS indexing and search engine in 1988. The WAIS protocol was designed for searches across the Internet; it is implemented by a protocol server running on the database host machine which listens for requests for service from remote (or local) hosts. The protocol is based upon ANSI standard Z39.50 version 1.

A WAIS system is composed by clients, which issue search and retrieval requests, and servers, which process these requests. The clients and servers can be on multiple computer hosts; however, these hosts must have access to the server hosts via network connections. The servers maintain indices of documents they are able to send clients upon request. The indices are inverted word indices; for each word encountered by the index construction process, a list of all documents containing that word and pointers to the location of the word in these documents is maintained. These indices can be quite large, occupying as much as half of the space of the source files. Their advantage, however, is the speed with which documents can be located that contain arbitrary combinations of text.

Some example queries which are acceptable to WAIS, and their meaning, are listed below. These examples are from the freeWAIS-sf online web documentation available with the software.

Query	Meaning
information retrieval	Free text query.
information or retrieval	Same as above.
ti=information retrieval	The word 'information' must be in the title field.
information and retrieval	Both words must be present.
py==1990	The 'py' field value must be numerically equal to 1990.
py<1990	Numerically less
py>1990	Numerically greater
soundex salatan	Words match which sound like 'salatan' (such as 'Salton').
"information retrieval"	Search for the phrase in quotation marks.
information system*	Wild-card search.
nuclear w/10 waste	'Nuclear' and 'waste' must both occur (in either order) and be located within 10 words of each other.
nuclear pre/10 waste	Proximity search, but order is important.
atleast 20 clinton	'Clinton' must occur at least 20 times in the document. ('atleast' must be all lower case and one word.)

The freeWAIS-sf software was developed (based upon freeWAIS) by the University of Dortmund in Germany. It is freely available and is redistributable. The '-sf' suffix stands for "structured fields"; databases can define fields, which are parsed from the original documents to be indexed, and searches can be restricted to these fields by prefixing the query with a field code, as in 'address=(montvue or montview)'. This search would look for documents which contain an address field containing either of the words 'montvue' or 'montview'. The web server interface we are currently using does not directly support these fields, although they can be embedded in a query manually. Field codes will be used in future versions of the web server interface (Data Miner) to support query forms.

The freeWAIS-sf software was developed with minimal emphasis upon security. Security features were defined; however, not all of them worked. As part of the WFCIN project, we have made modifications to freeWAIS-sf to enhance its ability to protect information from unauthorized release. It is not advisable to utilize freeWAIS-sf new user about five minutes to become comfortable with use of a web browser.

The Netscape Navigator web browser was selected for this project. A competing browser, the Microsoft Internet Explorer, was not used because of its emphasis of ActiveX. ActiveX can be used to defeat the security of the client machine and does not offer strong protection against malicious software modules which can be downloaded from the Internet or other sources. Internet Explorer had additional flaws that did not allow it to recognize server security certificates that are issued by a certificate authority not recognized by Microsoft. A typical WFCIN home page is shown in Figure 1.

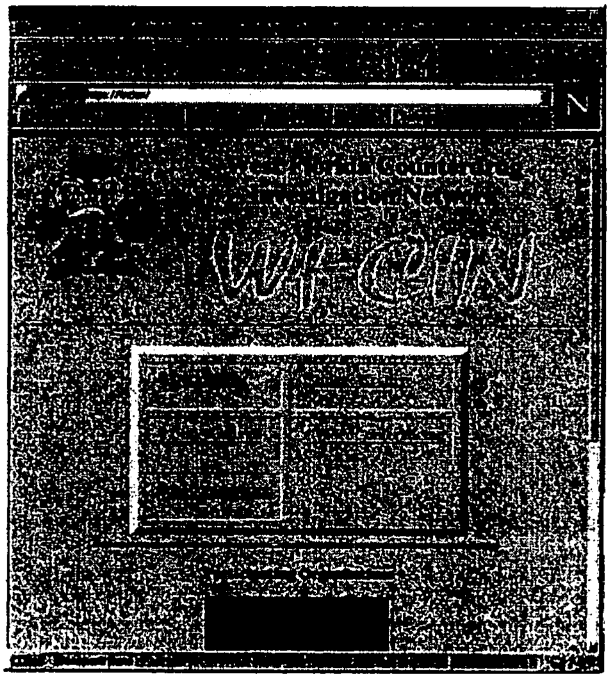

Figure 1. Typical WFCIN home page.

Several items are worth noticing in the home page. First, all underlined blue areas of text are links to additional pages. The Data Miner is the top-level page of the full text search engine's user interface, and the Image Archive is a direct link to groups of images by case identifier (if that is known). The documentation for the system is available on-line as hypertext links. A web-based PGP key server is also supported, which enables the use of encrypted e-mail using the very popular PGP (Pretty Good Privacy) encryption program. Finally, the small blue key icon in the bottom left corner indicates that this document was received over a secure (encrypted) link from a server that supports SSL, the Secure Sockets Layer encryption protocol developed originally by Netscape. This page was retrieved using Netscape's client software, Navigator 3. Any version of Navigator (or Communicator) at or above 2.02 will work with the WFCIN servers; versions lower than 2.02 do not offer effective security and are not authorized to use the servers.

3. Full Text Search Engines

A full text search strategy is employed. Rather than designate specific fields to be searchable and thereby improve the efficiency of the search process, all text contained in the data can be searched. Searches can be composed of:

1. One or more words separated by white space (space, tab, line feed, or punctuation), in which case the occurrence of any word in a document is a match,

2. Words grouped by enclosure in parentheses,

3. Either (1) or (2) joined by the Boolean operations AND, OR, and NEAR, and

4. A word or a group of words enclosed in parentheses preceded by the unary operator NOT.

Additional features are supported but are used infrequently; these include stemming (a wildcard, '*', at the end of a word) and synonyms (defined by a dictionary optionally associated with each database).

Several full text search engines are available; some of the more popular are eXcite (used by the Yahoo! web site), isearch (Center for Networked Information Discovery), and several versions of WAIS. We have adopted freeWAIS-sf, a derivative of freeWAIS (originally developed by WAIS, Inc. as a free introduction to their commercial version and later maintained by CNIDR). WAIS stands for Wide Area Information Servers; scientists at Thinking Machines, Inc. (TMI), who subsequently left TMI distributions from other sources for sensitive applications.

4. Secure Web Server Interface

The freeWAIS-sf software is configured to communicate with software executed by a web server on the local machine in the WFCIN environment. WAIS clients, such as those from CNIDR and MCC, do not work with WFCIN freeWAIS-sf servers. Rather, an interface to the WAIS search and retrieval capabilities is defined by the web servers, which perform these additional functions:

1. Authenticate users using assigned usernames and passwords,

2. Encrypt all network traffic between the client and the web server, including username and password information,

3. Filter search results to allow users access only to information they are authorized to see. This is done on a case-by-case basis, and

4. Log all client/server transactions with the client machine's hostname and/or IP address, the username, and the URL requested by the user.

These functions are transparent to the user, who is presented with a simple web-based form to fill out in order to request searches of the databases. This interface is called the Data Miner, and is shown in Figure 2. The user selects one or more databases to be searched using the check boxes at the top of the form, and enters a legal freeWAIS-sf query in the text box. Clicking on the "Submit Request" button with the mouse transmits the search request to the secure web server. Note that the Distributed Data Miner's form has the same format, but allows the user to simultaneously query secure web servers residing on several hosts.

The results of the search are returned as a form with hypertext links to request the server to retrieve a selected document. The results of the search request shown in Figure 2 are displayed in Figure 3. These documents may or may not be viewable by a user, depending upon that user's access rights to each document. If the user has the right to view the document, a mouse click on the document's name causes the web server to retrieve the document from the freeWAIS-sf database and display it on the client's workstation, as in Figure 4. Figure 5 shows a typical form where a search has returned URLs to documents which the user has the right to know exist but can not view.

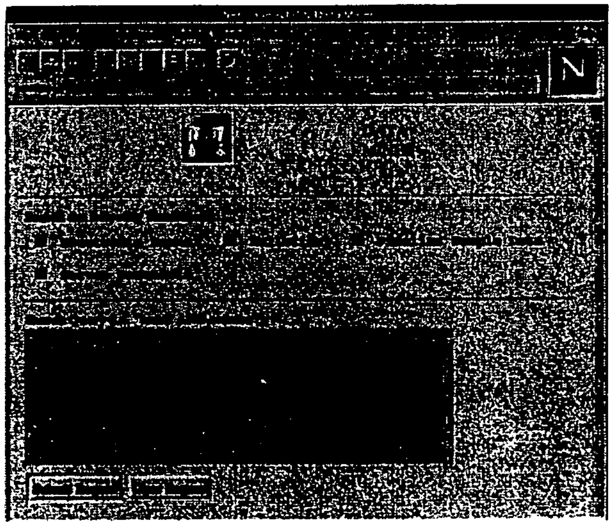

Figure 2. Data Miner query entry.

When a user clicks on a restricted document with the mouse, a form appears asking the user to fill out a request to the person who has been designated as point of contact (POC) for the case linked to the document. The filled-in form is e-mailed to this POC upon submission. Since the web server generates the e-mail, the user can not determine from any information available to him or her who the POC is.

The stars to the left of the document's URL give an indication of the document's relevance to the search query. All versions of WAIS satisfy search requests by computing a numerical score of relevance of the database documents to the search request. A list of documents that satisfy the search request and have high relevance scores is returned, up to a site-dependent maximum number of documents (usually 40). The Data Miner converts this score to between zero and five stars, with documents having more stars being more relevant to the search query.

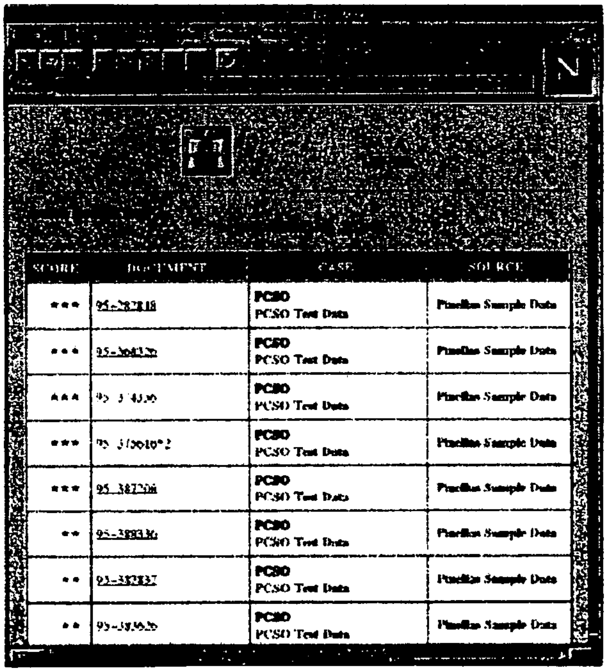

Figure 3. Results from a Data Miner search request.

Search requests can be both large and complex; in fact, it is possible to identify a document which is very close to what an investigator desires, and search for all documents which "match" the contents of that document. A series of words in a query is equivalent to the statement "match documents which contain one or more words from this list", and relevance can rank order all other documents with respect to their similarity to the document used for the query. Those matches with the highest relevance score are then returned. This approach to database search and retrieval is called "relevance feedback" and is very effective in assisting investigators who are trying to find similar incidents to a current investigation. Relevance feedback can be utilized in the Data Miner by selecting and copying "relevant" portions of retrieved documents to the search query text box and re-submitting the search.

Consider an example of the use of relevance feedback. A woman calls 911, reporting that a man has broken into her home and held her at knife point with a hunting knife while waiving a whiskey bottle (of one of the lesser-known brands) and demanding money. The responding officer takes a statement that includes a description of the items stolen and the incident. Several days later, a stolen car is recovered; in the glove compartment is a hunting knife, and an empty whiskey bottle is in the rear floor. The Data Miner is used to search for reports containing "hunting knife whiskey bottle". A report is immediately returned which describes the break-in and theft due to the match to the weapon. This provides a description of the suspect, which can be copied into the search query. A new search generates several reports of robberies in which a person fitting the woman's description is a suspect. A pattern begins to emerge that allows investigators to make an arrest.

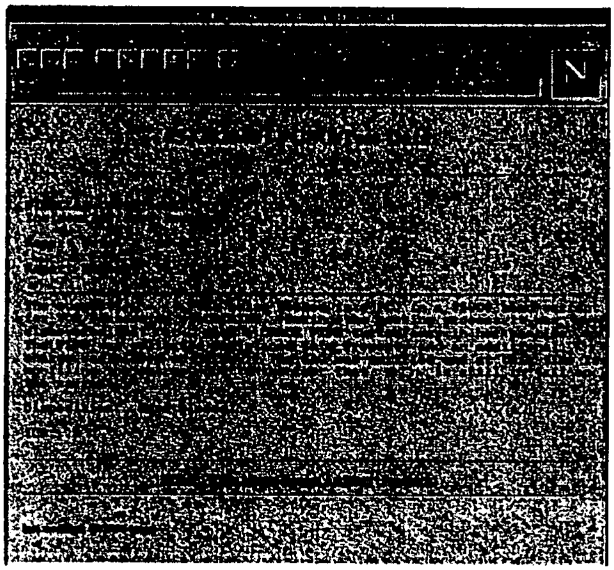

Figure 4. A document retrieved by the Data Miner.

A related application involves transcripts of wiretaps. As with a narrative report, all monitored conversations are transcribed and become a word processing document, which can be indexed using freeWAIS-sf. Several weeks into an investigation, a conversation may be heard which relates a code phrase, such as "cigars", to deliveries of drugs. A search of all transcripts made up to that time for "cigars" reveals 23 times when the suspects may have been referring to shipments of drugs.

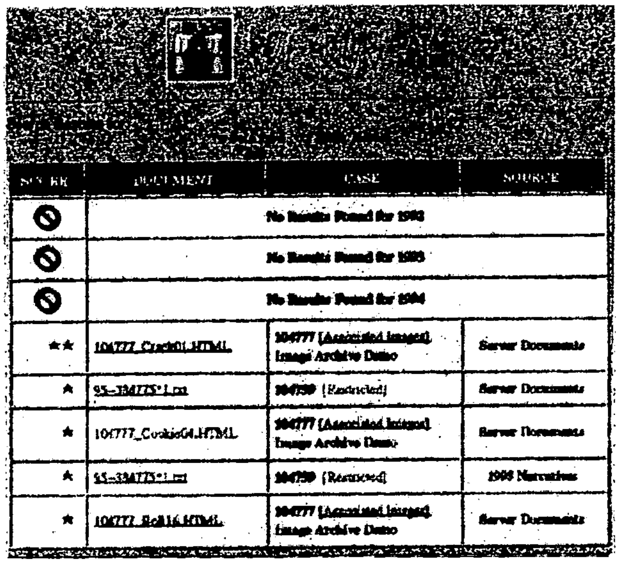

Figure 5. Search results which return URLs to restricted files.

5. The Image Archive

A second component of the secure web server is the Image Archive. Digitized images can be stored on the web server, along with a text file containing information about the image and investigators' notes about its contents. All images are stored in JPEG format and are associated with a case. Images may be retrieved by referencing the case identifier, using the form shown in Figure 6, or by freeWAIS-sf matches to the contents of the associated text files, in which case they appear as references in the CASE column of the search results form, as shown in Figure 5.

The first entry in the search results page of Figure 5 is an image of a sample of crack cocaine. Clicking on this reference with a mouse retrieves the image, which is similar to the one shown in Figure 7. A page of associated images can be displayed, as in Figure 8, either by clicking on the reference to "Associated Images" on the search results form, or by entering a case number, as in Figure 6. The page of thumbnail images can be used to order hardcopy prints of selected images. Checking the small boxes below the images the user wishes to have printed and clicking "submit" does this. Each web server's site administrator is responsible for defining the point of contact to receive photo orders, which are delivered by e-mail.

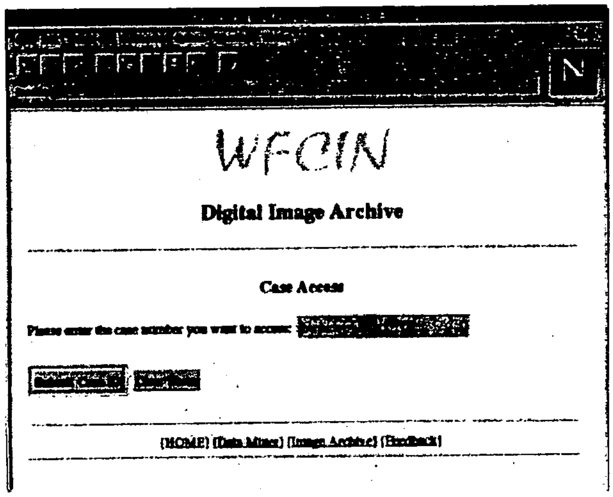

Figure 6. A request for images associated with a case.

6. The WFCIN Environment

The WFCIN environment is unique in law enforcement, and rare in any discipline. All WFCIN sites are interconnected using an Asynchronous Transfer Mode (ATM) network over fiber optics with a minimum bandwidth of 30Mbps. This effectively removes any restrictions on the exchange of information among client/server or distributed applications. The technologies which are described in this paper can be utilized in less exotic (and less costly) networks, although some minimum level of network bandwidth is required to avoid user frustration with slow response times. This minimum level depends upon the size of the user population, but two rough guidelines are that slow speed (56Kbps or 64Kbps) frame relay is not enough for more than occasional use, and T-1 service (1.544Mbps) is more than sufficient for most organizations. Of all of the WFCIN software tools, the exceptions to these guidelines are videoconferencing and link analysis, which are not covered in this paper.

Several of the participating agencies have been using computer-based case management systems for a long time and have established procedures which minimize the errors and inconsistencies that are typical of most information systems. The Pinellas County Sheriff's Office utilizes specially trained individuals to transcribe reports called in by officers and a computer system that ensures that fields are correctly filled in for each report type. The consistency of the data that is captured makes the task of the Data Miner much easier – problems such as spelling errors and invalid field entries are seldom encountered. The disadvantage of pre-existing systems is the Data Miner, and perhaps the Image Archive, must be interfaced to the legacy data stored in these systems. This is always a customization effort, and can be non-trivial. Four of the WFCIN sites use the ACISS information system, which runs on UNIX platforms and was reasonably easy to interface to the Data Miner. Of these sites, three did not require hardware modifications to the servers used for ACISS.

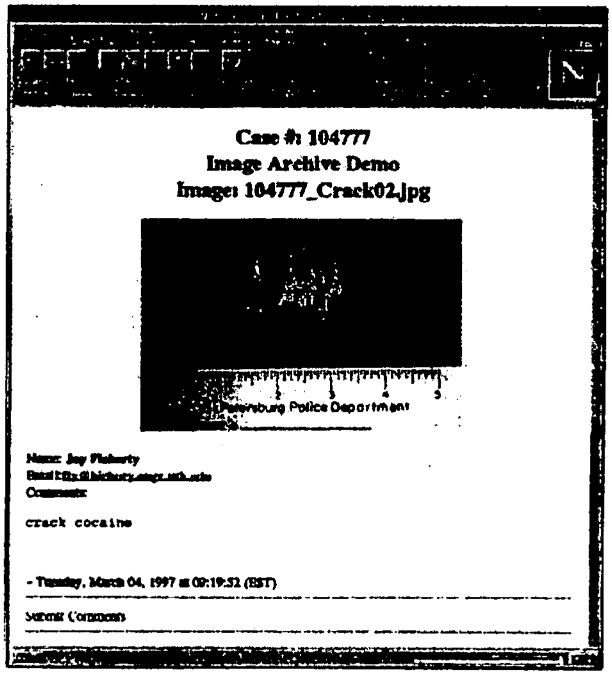

Figure 7. An image retrieved from the Image Archive.

Additional valuable information can be made available using secure server technology. Images, such as drivers license photos, are a natural fit. One tool that has been developed for the WFCIN test bed is a web-based reverse telephone number database. Other databases are under development, including a distributed "pointer" database which allows an investigator at any participating agency to check the files of all other agencies to determine if a suspect is known to any of those agencies.

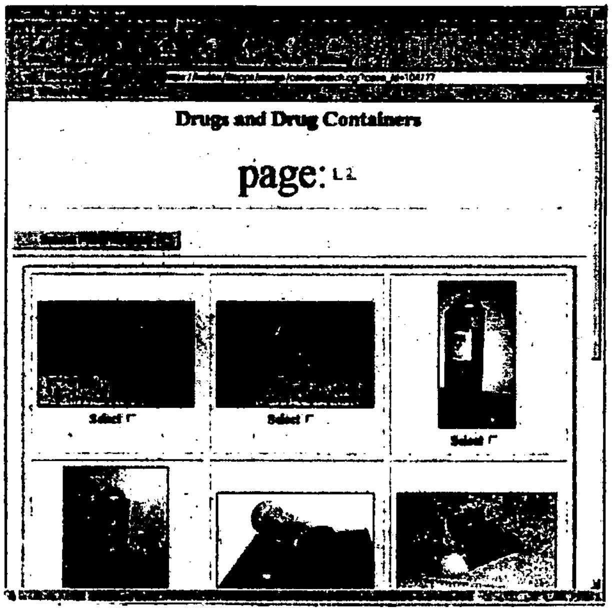

Figure 8. A page of images associated with a search result.

7. Summary

There is little doubt that the WFCIN network will be connected to other law enforcement networks within, and perhaps outside, Florida. The response of the law enforcement communities that have received briefings on the project has been overwhelmingly enthusiastic. It is clear that use of secure web technologies is the correct choice to enable independent law enforcement agencies to share information. The cost advantages of utilizing commercially available off-the-shelf software, such as the Netscape browser and Stronghold secure web server, are substantial. Adoption of these technologies allows law enforcement to ride the rising tide of applications development associated with the deployment of the National Information Infrastructure.

The use of freeWAIS-sf was the correct choice for the WFCIN project. It provided the needed capability, was modifiable to satisfy the security requirements, and offered features which combine the advantages of free text search and more traditional databases (structured fields). This is not, however, the only option, and the field of advanced search engines is rapidly evolving. Other approaches, such as eXcite, isearch, and Alta Vista, are viable alternatives. With the development of digital libraries, this field will continue to evolve.

This project has concentrated upon free text search to offer investigators a lantern to find their way in the forests of collected information. Our experience has found that this first step is much more important than refinements such as natural language processing and message understanding. Once these first steps are taken, however, more advanced methods can begin to be employed, and a "natural" next step is incorporation of machine intelligence, such as message understanding. It is important to maintain the perspective, however, that the computer exists as a tool to assist investigators in solving the puzzles presented in their cases and make them more efficient at what they do best.

Adoption of web server technologies provides a standard protocol for communications among independent law enforcement agencies. There is a cost associated with custom interface development to link web services to legacy information system; however, a portion of this is also born by the commercial sector because developers such as Oracle, Microsoft, and Sybase are rapidly moving to upgrade their products to support web services. The underlying TCP/IP networking protocols have already overtaken many older proprietary networks, and a benefit of TCP/IP is the physical network layer is abstracted – point-to-point services such as T-1 and DS-3, local area networks based upon Ethernet and Fast Ethernet, and wide area networks using ATM interoperate as a single logical network. The future coin for exchange of information among independent peer computers has to a large extent already been decided: HTTP (web services) and SSL (secure services) across TCP/IP networks.

Many problems remain to be solved. The software tools deployed for the WFCIN project are not off-the-shelf reusable items. For some time to come there will be significant costs and investments of time in transferring these technologies to new sites. Much of the reason is there is not an exact match between the requirements of the Internet community and the requirements of law enforcement. An example is the Distributed Data Miner capability – public client/server applications on the Internet do not have a large demand for multiple and simultaneous secure connections. A second example is the Java programming language, which is advertised as the safe and secure way to develop applications which are independent of the computing platform. Java does not as yet implement SSL (although a third party Java package is available); it is not viewed as a high priority compared to the market for Java in, for example, animated web-based advertising.

The WFCIN test bed will continue to evolve. Applications development in this environment is very much like rapid prototyping – every software tool that is placed in service is a prototype which elicits feedback from investigators that can improve it. The continued success of WFCIN and other similar test beds is critically dependent upon the close working relationships between developer/implementers and the investigators. To date this relationship has been successful, and we hope to see it continue to evolve.

8. Acknowledgements

Many people in law enforcement, academia, and government have contributed toward the success of the WFCIN project. There is not sufficient space to do justice to their efforts, other than to offer our thanks. This work is funded by the Office of National Drug Control Policy / Counterdrug Technology Assessment Center through the Tennessee Valley Authority under agreement TV-94549V. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of ONDCP or TVA.

The Face Recognition Technology (FERET) Program

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ABSTRACT

The mission of the Face Recognition Technology (FERET) program is to develop automatic face recognition systems from the development of detection and recognition algorithms in the laboratory through their demonstration in prototype real-time systems. Since 1993, the FERET program has funded the development of a number of recognition algorithms, conducted numerous database collections, created one of the most extensive collections of readily available facial images, and conducted several rounds of independent testing and evaluation of recognition algorithms. The FERET program has collected a standard database for algorithm development, established baseline performance for face recognition algorithms, and established a testing protocol that is the de facto standard in the face recognition community. Currently the program is funding the development of several prototype face-recognition systems, which will demonstrate complete real-time video face identification for access control scenario. This paper gives an overview of the FERET program, presents recent performance results of face recognition algorithms evaluated, and describes the real-time face-recognition systems with preliminary performance results.

1. OVERVIEW

The objective of the FacE REcognition Technology (FERET) program* is to develop face-recognition systems that can assist intelligence, security, and law enforcement personnel to identify individuals from a database of facial images. A number of potential "missions" exist in which face-recognition technology could be useful in assisting security and law enforcement personnel including:

- Automatically searching mug books using surveillance photos, other mug shots, or artists' sketches;
- Controlling access to restricted facilities or equipment;
- Checking the credentials of personnel for background and security clearances;
- Monitoring areas (e.g. airports, border crossings, secure manufacturing facilities, doorways, hallways, etc.) for particular individuals; and
- Finding and logging multiple appearances over time of individuals in surveillance videos (live or taped).

Possible government and commercial uses of

* This work funded by the DoD CounterDrug Technology Development Program Office.

this technology include:

- Identity verification at ATM machines;
- Identity verification for automated driver's license issuance;
- Searching photo ID records for fraud detection (applying for multiple driver's licenses, collecting multiple welfare benefits, etc.).

Before the FERET program, there was no way to accurately evaluate or compare published face-recognition algorithms, because no standard database or standard method of evaluating recognition algorithm performance existed. Researchers collected their own databases under conditions relevant to the problem they were investigating. Often these databases were limited to less than 50 individuals. Two notable exceptions were, Alex Pentland of the Massachusetts Institute of Technology (MIT) [1], who used a database of ~7500 images collected in a highly controlled environment with controlled illumination; images had the eyes in a registered location and were full frontal face views and, Christoph von der Malsburg of the University of Southern California (USC) [2], who used a database of ~100 images that were of a controlled size and illumination, but included some head rotation.

In order to focus FERET recognition algorithm research, the program has concentrated on two related scenarios.

The first scenario, searching an electronic mug book and identifying a individual from a large group of recorded images. The mug book is a collection of images of known individuals–a gallery. The image of the individual to be identified (called a probe image or probe) is presented to the algorithm, which reports the closest matching image from the gallery. The performance of the algorithm is measured by the ability to correctly identify a person in a probe image. For example, an image from a surveillance photo is the probe, and the system displays the 20 people from the gallery that most resemble the unknown individual in the surveillance photo. The user can then quickly examine these 20 images to determine if the surveillance photo is anyone in the database.

The second scenario seeks to identify a small group of specific individuals from a large population of unknown individuals. This system could be used for access control. As an individual approaches a doorway, a video image is captured, analyzed, and compared to the gallery of individuals approved for access. Alternately, the system could monitor points of entry into a building, border crossing, or airport jetway to search for smugglers, terrorists, or others attempting to enter surreptitiously. In both situations, a large number of individuals not in the gallery will be presented to the system. The important system performance measures in this scenario are the probability of a false positive (the incorrect identification of the individual as being in the gallery – a false alarm) and the probability of a missed recognition.

Since 1993, the FERET program has focused on four primary goals:

- Establishing an imagery database for training and testing;
- Establishing uniform testing procedures and test sets;
- Pushing the state of the art in recognition algorithms through the funding of algorithm research; and
- Funding construction of demonstration hardware incorporating promising recognition algorithms.

As technical agent on the FERET program, the Army Research Laboratory's (ARL's) first tasks were to obtain a large database of facial images, and to identify recognition approaches on which to fund research. Section 2 of this paper reviews the FERET program. Section 3 reviews details of the database collection effort. Section 4 covers our testing protocols. Section 5 briefly introduces the recognition algorithms tested to date and section 6 details the results of the most recent round of comprehensive testing. Section 7 covers the current status of the program, with concluding remarks in section 8.

2. THE FERET PROGRAM

The FERET program was initiated in September 1993 as part of the DoD's Counterdrug Technology Program. ARL was asked to be technical monitor for the effort. A three-phase program was envisioned. In Phase 1, initial contracts were awarded to develop as many approaches as funding allowed, ending with government testing of the funded efforts. Funding limited support to 5 approaches. Contracts were awarded for one-year efforts, with follow-on options for successive years (phases 2 and 3). Also during this time, a contract was awarded for the collection of a facial image database for development and testing purposes.

In August 1994, we tested the FERET funded algorithms. These first tests established a performance baseline for face recognition algorithms using a gallery of 316 individuals. This round of tests was designed to measure performance of algorithms that could automatically locate, normalize, and identify faces from the database. Results from this test also identified areas where research needed to focus to improve performance: creating larger databases for development and testing, improving performance on images of the same person taken months apart, and dealing with pose variations.

At the beginning of the second year, three research efforts were chosen to continue under government funding. The facial image database collection effort also continued. During this time the Counterdrug Technology Program Office also asked for an evaluation of infrared (IR) imagery for face recognition. A small joint effort between ARL and Rutgers University was funded to evaluate IR imagery and compare its usefulness to visible imagery. Encouraging results have been reported in Wilder et al[3].

In March 1995, we conducted the phase 2 algorithm tests. For this round of testing, we extended the gallery to 817 individuals. One emphasis of the test was on duplicate images – an evaluation of performance on probe images taken weeks, months and in a few cases, a year after the gallery image. Test results were encouraging, and funding continued for the program into 1996 (for the results of the 1994 and 1995 tests see Phillips et. al. [4]).

Until March 1995, development had been conducted on single frame images in a laboratory/research environment. Questions of whether difficulties would arise when using video or requiring real-time performance were raised. To address these issues, the FERET demonstration project was initiated to construct demonstration/experimental systems (section 7).

During 1996, work also continued on the recognition algorithms, and in September 1996, a third round of FERET testing took place. The testing protocol substantially enhanced to allow us to collect more useful information on the algorithm performance, as detailed in section 5. A version of the test was also created that included eye coordinates enabling face recognition researchers outside of the FERET program to also take the test. The main goals of the September 1996 test were to measure progress in FERET algorithm development since the 1995 test, and to provide feedback to the non-FERET funded algorithms tested. Again this test, as the previous test, provided valuable information by identifying for us and for the algorithm developers weaknesses in the algorithms and by pointing out gaps in the database (Phillips et al. [5]).

3. FERET DATABASE

To evaluate and compare recognition algorithms it is necessary to have a common database of images for development and testing. It is obvious that the database must exist to test algorithms, but it is equally important that a database is provided to researchers to develop and tune their algorithms. For the evaluation procedure to produce meaningful results, the development database must consist of images similar to those on which algorithms are to be tested. The development and testing data sets must be similar in both quality and quantity. For example, if the test consists of a gallery of 1000 individuals, it is not appropriate for the development database to consist of only 50 individuals. The algorithms tested will only be as good as the database from which they are developed.

To build the necessary databases, Harry Wechsler of George Mason University (GMU), in conjunction with ARL, has collected imagery for the FERET program. The images for the FERET database are initially acquired with a 35-mm camera, placed onto a CD-ROM via Kodak's multi-resolution technique for digitizing and storing digital imagery, and finally converted into 8-bit gray scale images. Each image was assigned a unique file name that encodes the image ground truth. Further details can be found in Phillips et al [4,6].

Images of individuals are collected in sets. A set consists of 5 to 11 images taken at different angles, always including two frontal images, called fa and fb. The fa image is the first image taken, the fb image generally the last collected for the set. Figure 1 shows an example of a single image set.

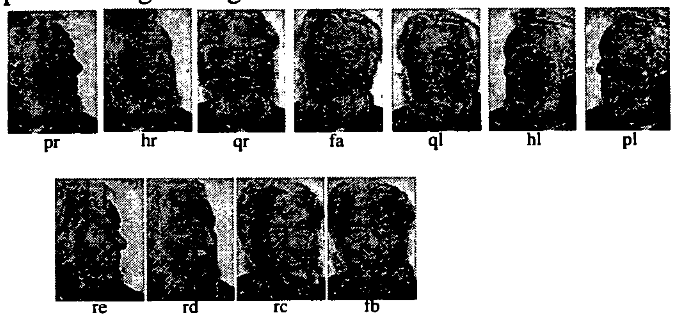

Figure 1. One set of images from the FERET database. Image labels indicate face aspect and are not the image file names. Note expression change in fb image

One of the objectives of the collection process is to have multiple images of the same individual collected over a period of time; these image sets are called duplicates. A number of individuals have been photographed several times (see Figure 2). Some individuals have images in the database spanning more than a year. Another objective of the collection process is to have as many individuals in the database as possible. Collections have been primarily conducted at GMU, with several collections done at ARL facilities at Ft. Belvoir, VA, and Adelphi, MD.

Figure 2. Variation in images from different collections.

At present, the FERET database consists of 1546 sets of images of 1199 individuals. There are 365 sets of duplicate images. From this database, 503 sets, including a number of duplicate sets, have been designated the development data set and are made available to algorithm researchers. The remaining sets are sequestered by the government for testing purposes.

4. TESTING PROTOCOL

As mentioned earlier, 503 sets of imagery were given to each participant as the development data set. Each set consisted of the complete image set of one individual. Some sets were duplicates of individuals – images collected on different dates. Along with the development images, we supplied researchers with the ground-truth information for each image, which consisted of the aspect of the image and any post processing information (illumination or scale changes). With this data, the researchers developed, trained, and tested their algorithms.

The remaining images are held by the government as the sequestered set. The development images are added to the sequestered images to create the government testing set. For the September 1996 test, the gallery consisted of 3320 frontal images. The probe set consists of the 3320 gallery images, plus 496 other images, for a total of 3816 images. As we have only collected image sets of 1199 individuals there are obviously a significant number of individuals with 2 or more images in the test set.

To conduct an algorithm test, a government representative goes to the developer's site to administer the three-day test. The government representative takes the data tape to the developer's site. The tape contains the 3816 images and a list of the 3320 images to use as the gallery for the test. If the algorithm required eye coordinates to perform, a file containing the eye coordinates for each image is also included on the tape. All images are processed while the government representative is present. Results from the tests are recorded and the government representative takes the results back to the government facility for scoring. At the conclusion of the test, both the gallery and probe data are removed from the developer's computer system, and the data tape returned to the government representative. To ensure that matching does not occur with the use of any of the ground truth in the image file names, the images are each given random file ID numbers. The government keeps the links between the file names and ID numbers secure from the developers, supplying only the random ID number of the images for the test. The random file name also includes the pose, or aspect, of the image, because this information was expected by the recognition algorithm to be supplied by a the hypothetical "face detection" front end, supplying the localized faces to the recognition algorithm.

Computation time of the algorithms is not measured and is not considered a basis for evaluation. However, the algorithms should be able to perform the tests on a few standard workstation-type computers over three days. The rationale for this restriction is to ensure that an algorithm is not so computationally intensive as to preclude it from being fielded.

The output from an algorithms identification of a probe image is a file which contains the comparison score for every gallery image (3320 entries). These scores are ransked from the smalles, or closest matcht, to the largest, or worst match, With this output format we can perform a large number of different evaluations of the algorithms.

The testing protocol, for the September 1996 test was designed so that algorithm performance can be computed for a variety of different galleries and probe sets. The key property of the new protocol is that for every probe image a similarity score for every image in the gallery is generated and recorded, allowing for greater flexibility in scoring. From the output files, algorithm performance can be computed for virtual galleries and probe sets. For further details see Phillips et. al. [5].

5. RECOGNITION ALGORITHMS

The following groups took the September 1996 FERET test:

- The Media Lab at the Massachusetts Institute of Technology (MIT), led by Alex Pentland [1],
- Excalibur Technologies Corporation, Carlsbad, CA,
- Michigan State University (MSU), led by John Weng [7],
- University of Maryland (UMD), led by Rama Chellappa [8], and
- Rutgers University, led by Joe Wilder [9]

In addition, in March 1997 two addition groups took the same test given in September 1996:

- The Computational Vision Laboratory at the University of Southern California (USC), led by Christoph von der Malsburg [2], and
- University of Maryland, took the test a second time

The MIT and USC efforts are part of the FERET program. The other algorithms were developed outside of the FERET program and voluntarily agreed to take the test. ARL also internally implemented the basic eigenface technique (ARL eigenface) found in the literature as well as a simple normalized correlation technique (ARL NC), in order to establish a baseline.

6. TEST RESULTS

Having limited space we will only report on several of the more interesting results from the 1996 test. The September 1996 version of the FERET test has been administered on two separate occasions, September 1996 and March 1997. Table 1 shows participants and testing dates for FERET testing to date. For a more detailed discussion of the results of the September 1996 test see Phillips et. al. [5].

	Aug 94	Mar 95	Nov 95	Aug 96	Sept 96	Mar 97
Fully automatic: No Eye coordinates given.						
MIT(Pentland)	X	X		X	X	
Rockefeller(Atick)			X			
Rutgers(Wilder)		X				
TASC(Gordon)	X					
USC(Malsburg)	X	X				X
Not Fully Automatic: Eye coordinates given.						
Excalibur Technologies Corp.					X	
Michigan State U. (Weng)					X	
MIT(Pentland)					X	
Rutgers(Wilder)					X	
U. of Maryland (Chellappa)					X	X
USC(Malsburg)						X
ARL Eigenface					X	
ARL Normalized Correlation					X	

Table 1. Shading indicates the three versions of the FERET test: August 1994, March 1995 and September 1996. Column label is actual date of test.

The results shown in the figures 3 to 6 are plotted as cumulative match versus correct result rank. Rank indicates where the correct match occurred in the results list: cumulative match score indicates the percentage of correct results in that particular rank or higher. For example in figure 3 the curves indicate that for all the algorithms tested, the correct answer was in the tenth position or higher (ranks 1–10) for 89% of the probe images submitted. The highest performing algorithm had the correct answer at the top of the list (rank 1) for 96% of the probe images, and in the top ten for 99% of the probe images submitted.

Figure 3 shows recognition rates using the second frontal (fb) image from a set as the probe image, and evaluating how well the algorithms match it against the fa image in the gallery. Here we see that all the algorithms perform well. This is a very restrictive test where performance is expected to be high. If an algorithm cannot perform well under this condition, it is unlikely to do well under the other conditions.

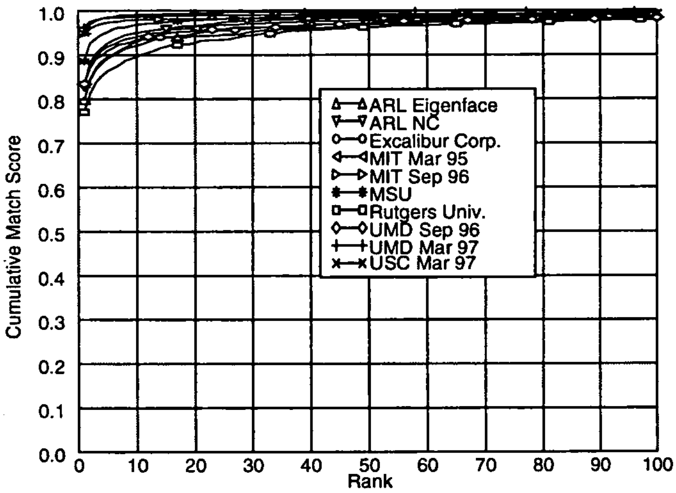

Figure 3. Algorithm performance on fb images. Test taken in Sept. 96 unless otherwise noted. Gallery contained 1196 images. Probe set contained 1195 images

Figure 4 shows the performance graded only for duplicate images (duplicates are probe images collected on a different date than the gallery image). These results are for only frontal probe images. Here, we see a significant performance drop between the fa versus fb test and the duplicates test. The duplicate test represents a more realistic condition under which face recognition systems will be expected to perform if they are to be used extensively

.Figure 5 shows an even more challenging condition. The gallery images were taken in early 1995, or earlier, and the probe images were taken during the June and July 1996 data collections. There is a significant drop in performance.

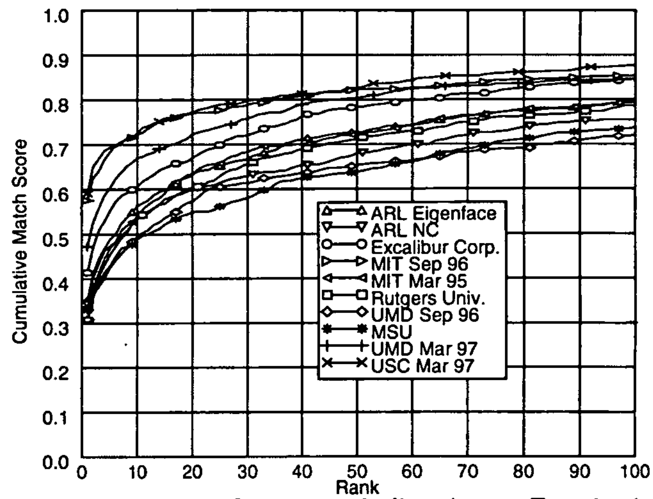

Figure 4. Algorithm performance on duplicate images. Test taken in Sept. 96 unless otherwise noted.Gallery contained 1196 images. Probe set contained 722 images

We are not discouraged by this because, as shown in figure 6, continued effort can improve performance. Figure 6 shows a comparison between the MIT algorithm as it existed in 1995 and as it exists today. Both versions of the algorithm were tested with the September 1996 data.

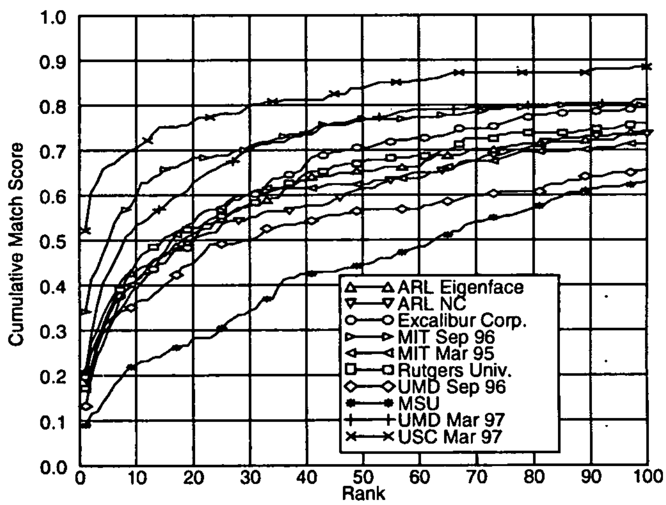

Figure 5. Performance on duplicates at least one year apart.Test taken in Sept. 96 unless otherwise noted.Gallery contained 864 images. Probe set contained 234 images

Also shown in figure 6 are results from the UMD algorithm, showing reasonable improvement with only modest effort over six months. This illustrates one of the key benefits of this type of testing: feedback for further algorithm improvement. We expect similar and continuing improvements could be made in all the algorithms with continued development.

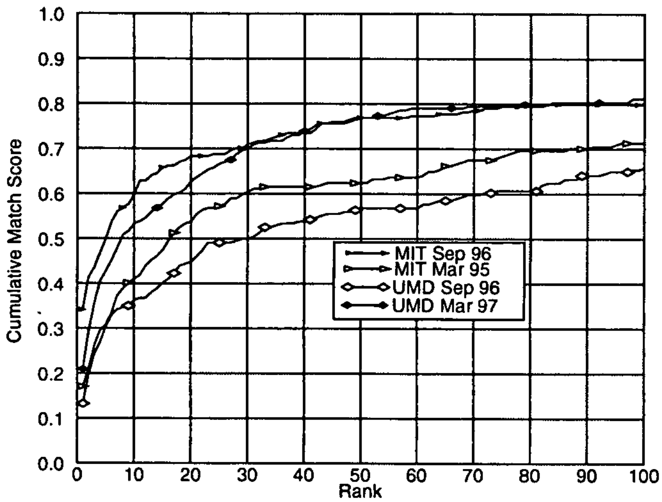

Figure 6. Examples of improvements over time on performance on duplicates separated by a year.

Another important aspect of algorithm performance is how well algorithms perform when the majority of the individuals in the probes are not in the gallery. For this test, which examines performance on duplicates, the gallery consists of 100 individuals, and the probe set contains 2927 images (2618 are false alarms). The results for this test are presented as a receiver operator curve (ROC) in figure 7. The horizontal axis is the

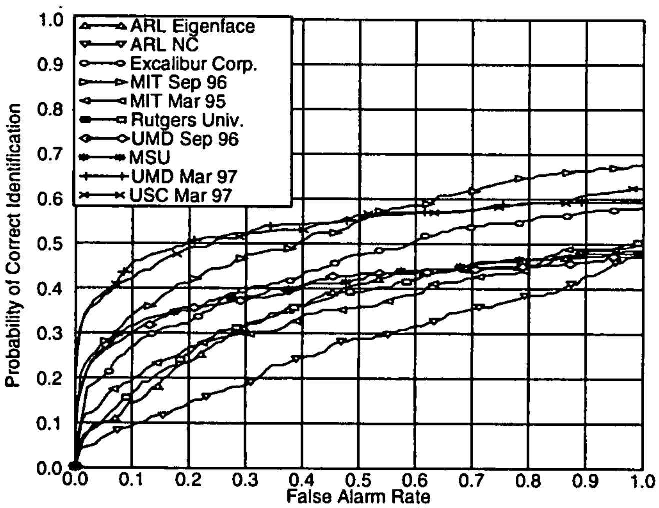

Figure 7. ROC for duplicates.

probability of a false positive and the vertical axis is the probability of correct identification. Here we see that in this more realistic scenario, a high false alarm rate would have to be accepted for even a modest level of recognition. One encouraging point here is the improvement that is apparent between the March 1995 and September 1996 MIT curves and between the September 96 and March 97 UMD curves. The improvement in the these algorithms is encouraging and we believe further significant improvements are possible.

Finally, from a statistical point of view, a face recognition algorithm estimates the identity of a face. Consistent with this view, we can ask about the variance in performance of an algorithm: for a given category of images, how does performance change if the algorithm is given a different gallery and probe set?

In tables 2 and 3, we show how algorithm performance varies if the people in the galleries change. For this experiment we constructed 6 galleries of approximately 200 individual, in which each individual was in only one gallery (the number of people in each gallery is in the table). Table 2 ranks each algorithm by performance on FB probes for each of the 6 galleries.

Algorithm ranking by top Match						
Gallery Size/ Scored Probes	200/ 200	200/ 200	200/ 200	200/ 200	200/ 199	196/ 196
Algorithm	gallery 1	gallery 2	gallery 3	gallery 4	gallery5	gallery 6
ARL Eigenface	9	10	8	8	10	8
ARL Correlation	9	9	9	6	9	10
Excalibur Corp.	6	7	7	6	7	6
MIT Sept. 96	4	2	1	1	8	3
MIT March 95	7	5	4	4	5	7
Michigan State U	3	4	5	8	4	4
Rutgers Univ.	7	8	9	6	7	9
UMD Sept. 96	4	6	6	10	5	5
UMD March 97	1	1	3	2	2	1
USC March 97	2	3	2	2	1	1
Average Score	0.935	0.857	0.904	0.918	0.843	0.804

Table 2: Variation in performance eon 6 different galleries on FB probes. Images in each gallery do not overlap.

Also, include in the table is average performance and number of probes scored. Table 3 is organized in the same manner as table 2, except that duplicate probes are scored. In this table, mean age refers to the average time between images in the gallery and corresponding duplicate probes. No scores are reported for gallery 6 because there are no duplicates.

Algorithm ranking by top Match					
Gallery Size/ Scored Probes	200/ 143	200/ 64	200/ 194	200/ 277	200/ 44
Mean age of probes (months)	9.87	3.56	5.40	10.70	3.45
Algorithm	gallery 1	gallery 2	gallery 3	gallery 4	gallery5
ARL Eigenface	6	10	5	5	9
ARL Correlation	10	7	6	6	8
Excalibur Corp.	3	5	4	4	3
MIT Sept. 96	2	1	2	2	2
MIT March 95	7	4	7	8	10
Michigan State U	9	6	8	10	6
Rutgers Univ.	5	7	10	7	6
UMD Sept. 96	7	9	9	9	3
UMD March 97	4	2	3	3	1
USC March 97	1	3	1	1	1
Average Score	0.238	0.620	0.645	0.523	0.687

Table 3. Variations in performance on 5 different galleries on duplicate probes. Images in each gallery do not overlap

The information found in these figures demonstrates the strength of this type of algorithm testing. With this testing we have been able to identify strengths and weaknesses of each algorithm, and to provide feedback to the developers to allow continued improvement and generalization of the algorithms. This strategy has led to performance improvement every 6 to 12 months.

7. CURRENT STATUS

Based on the 1995 test results, as well as the test results shown in section 6, we believe that to make significant progress in moving this technology into the field, two steps must be taken. First, many applications require recognition using a video camera as the imaging source. Also, near-real-time processing will be necessary for many user applications. We have recently awarded contracts for prototype face recognition systems to Facia Reco Associates, USC, and Visionics Corp. Facia Reco Associates is integrating the MIT detection and recognition processes. USC is building a real-time implementation of their FERET algorithm. Visionics Corp. is implementing the recognition algorithm of Joseph Atick of the Laboratory of Computational Neuroscience at Rockefeller University, NY. The Rockefeller algorithm took the FERET test in November 1995 and performed well, which led to discussions and finally this contract for a prototype system.

These systems are to be complete real-time stand-alone face recognition systems using video as input. These systems will be stand-alone stations configured for the access control mission. They will require acquisition and detection of faces in the video; localization of the face; pose (aspect) estimation; transfer of facial clips to the recognition module; and recognition of the face and recording of results. The systems are composed of commercial-off-the-shelf (COTS) hardware. Each system must use video to detect and recognize faces of individuals approaching the camera. The software suite must allow enrolment and removal of individuals into the gallery database. Because these are prototype systems, each system records the results of each recognition attempt, so that the systems performance can be evaluated.

The format of the recorded results will be based on the September 1996 FERET test results format, thus allowing us to use the same evaluation techniques. This is significant because it will allow us to characterize any performance changes performance due to migration from the laboratory to a complete system. Each system will be extensively tested in a series of acceptance and performance tests, culminating in a large-scale performance test where attempts will be made to have 200 to 300 volunteers pass through the systems each day for about 2 weeks. Figure 8 shows a diagram of the proposed setup to be used for the large-scale tests.

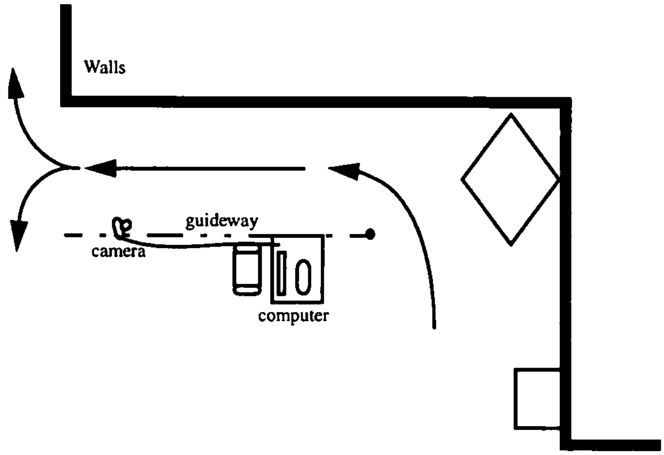

Figure 8. Proposed setup for testing prototype systems in open area. Arrows indicate flow of subjects through system. Unmarked boxes are existing obstacles in area.

The test and evaluation program for each system will consist of several stages. In stage 1, the contractor will deliver the system to our site. At our site the contractor will set up the hardware. The contractor will instruct us in the assembly of the hardware and the use and operation of all the software.

The second stage will see several of us enrolled into the system, while the contractor is still on site, so we can ensure the system functions correctly and the output formats are correct.

In stage 3, after the contractor has left, we will begin limited test runs to familiarize ourselves with the system and finalize our SOP for the tests. At this time we will score some of the output for the system to insure the scoring algorithms will perform as planned.

Stage 4 will see the system moved into an open area of the building and the recruitment of our volunteers for the large test. Volunteers will sign a release form and be enrolled into the system. The test protocol is designed so that we can drop any individual from the gallery to form a virtual gallery off-line, to evaluate false alarm performance, without actually unenrolling and reenrolling individuals.

To evaluate system performance of these prototypes, ground truth will be collected by hand as subjects pass through the system. This will allow us to monitor any detection misses and to evaluate recognition performance. Using the ground truth and the systems output, we will score performance and generate results curves.

Also, to continue to improve the performance and robustness of the algorithms, more data must be collected, especially duplicate images. To this end, we are continuing to support the GMU contract to collect static imagery. They will also begin to collect video segments, which will be used to generate development and testing databases similar to the static image sets.

8. CONCLUSION

Face recognition in a world of billions of people is a difficult problem since researchers have only a few thousand images of individuals, and only a small number of images for each individual. Many variations in personal appearance occur naturally and appear normal to a human observer, but they can produce large discrepancies and, therefore, problems for face-recognition algorithms. It is this overall problem of facial recognition that the FERET program is addressing.

ARL has been supporting and monitoring the algorithm development and facial database development portions of the FERET program. Recently, ARL's involvement has expanded into coordinating the design and construction of prototype face-recognition systems that incorporate the current FERET recognition algorithms. This program is addressing the complex issues of facial recognition that have direct and daily applications to the intelligence, security, and law enforcement communities. The FERET program is currently investigating techniques and technologies that show significant promise in the area of face recognition. The long-term goal of the FERET program is to transition one or more of these algorithms into a fieldable face-recognition system.

Prior to the FERET program, most research efforts that addressed the issue of facial recognition used database images that were carefully registered when collected. The FERET database was, and continues to be, collected to help address real-world problems. As such, the FERET database was created to be more realistic, while, at the same time, providing some control over the type and nature of the images collected. A database of more than 14000 images has been assembled, requiring many collection activities and a large-scale effort to catalog the images into a database. This database has been requested by and distributed to approximately 70 research groups, and is presently assisting researchers in the development and performance evaluations of their algorithms. To date, the FERET test has been administered 17 times since 1994, to 8 different organizations, 5 of which are not presently funded under the FERET program. The development database, as well as the FERET testing protocols, are the de facto standard for the face recognition community.

Accomplishments of the FERET program include:

- For the first time in face recognition algorithm development, the establishment of a common baseline for comparison of different algorithms.
- The advancement of the state-of-the-art in the area of face recognition.
- The establishment of a database of facial images that represents some real-world conditions.
- The identification of areas for future research, such as
  - Increasing the size of the database and
  - Increasing the number of duplicate images.

Recent tests have shown that the overall performances of the MIT and USC algorithms have reached a level requiring their inclusion in an experimental/demonstration system. The goals of these systems are to:

- Develop large-scale performance statistics requiring a large statistical database taken from a realistic scenario;
- Demonstrate the capabilities of the system to potential end users; and
- Identify weaknesses that have not been identified in the laboratory or represented in database collection efforts to date.

The FERET test results demonstrate the strength of our approach; pursuing multiple technical paths and performing regular rigorous algorithm evaluations. This methodology is now being applied to the real-time systems being developed under the FERET demonstration project. These systems will demonstrate that face recognition system technology has matured enough for development into fieldable systems.

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ANOMALY DETECTION USING SIGNAL PROCESSING AND NEURAL NETS

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ABSTRACT

In order to detect hostile penetrations of information systems, a method has been developed to identify unusual events that may be intrusions, misuse of computing resources, or other threats to the security of the computing system. The technique consists of clustering to reduce the volume of data, periodicity analysis to extract repeating patterns, and neural net classification to detect anomalous events. After training a neural network with patterns of normal computing activity, subsequent data samples are classified as similar or dissimilar.

Because many of the activities of an intruder are the same as those of legitimate users, intrusion detection has been difficult. Intruders execute many of the same commands and can rename files to hide abusive activity. Thus methods are not effective which merely monitor activity or rely upon criteria that is obvious to the intruder. The method described here identifies patterns of resource usage in terms of parameters that are not obvious nor easily manipulated. The method would not be easily countered or spoofed because it does not rely upon directly observable patterns. Also, the reduction of the data by clustering makes it feasible to analyze the considerable volume of events taking place in a computer operating system in time to respond to the abnormalities detected.

This approach to anomaly detection uniquely combines signal processing, nonparametric clustering, and machine learning. It has been applied to data collected from computer workstations for intrusion detection, and it may be applicable to other areas of detection research.

1 Detecting Misuse of Computing Systems

Computer misuse has proliferated despite measures to deter it. Forms of misuse range from denying service to other users to destroying data. It includes worms and viruses, Trojan Horses, trapdoors, bombs, password attacks, browsing, eavesdropping, scavenging, and exploiting covert channels.[17][15] In 1988 the Internet Worm brought networks to a standstill and captured the attention of the computing world.[18] More recently, threats associated with networking have surfaced such as packet sequencing attacks[1] and hostile applets.[16]

While preventative protection measures such as authentication and access controls are a first line of defense, they are not sufficient for many forms of misuse. As an example, suppose an intruder gains access to a privileged account, either because the intruder was able to break the password or because the privileged user forgot to log out. The intruder can use that login session to act with all the authority of the privileged user, having bypassed authentication and access controls. Similarly, if a privileged user executes a file that is a Trojan Horse, the subversive hidden components run with the authority of that privileged user. Since preventative measures are not sufficient and because intruders continually invent new methods to attack weaknesses in operating systems and uncover human lapses in vigilance, detection of threatening activity is needed.

Detection can be directed at recognizing events that are known to be malicious or at recognizing all unusual events. Intrusion detection, which recognizes events similar to past intrusions, serves the purpose of screening activity and preventing recurrences of devious activity. It does not detect instances where an intruder alters behavior or devises a new way to circumvent security. Anomaly detection identifies *any* unusual event. False alarms occur when valid users change their activity patterns, but they are tolerated in the interest of identifying instances when uncharacteristic behavior is security-threatening.

Presumably the patterns exhibited by intruders differ from those of normal users.[1] Once normal activity patterns are col-

[1] In an early paper on intrusion detection, Dorothy Denning stated, "Ex-

lected, unusual events can be identified by comparison with this profile. Responses to the events include destroying the miscreant, logging the activity, slowing the response time to discourage the activity and lessen the damage, and notifying the system manager.

2 Methodology

This paper describes a means of extracting the salient features of user activity and for automating their analysis. Resource usage parameters such as memory size, disk I/O, and cpu time provide a rich source of patterns that can be used to characterize typical activity and to distinguish abnormal activity. The method used for anomaly detection consists of nonparametric clustering, periodicity analysis, and neural network classification. As shown in Figure 1 data points are collected by monitoring a computer system. Each event (command or program execution) is considered a point in the resource usage space of parameters such as those listed in Table 1.

Figure 1: **Training**

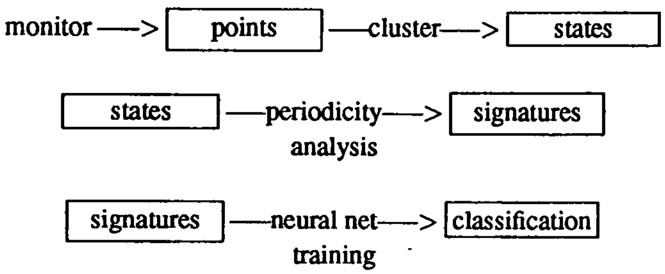

Table 1: **Resource Usage Parameters**

accumulated cpu time (microseconds)
combined memory and stack segments (kilobytes)
real memory size of process
disk I/O (pages in)
ratio of elapsed time to cpu time
ratio of real memory size to cpu time

Clustering reduces each data point to one of a finite set of states. Periodicity analysis is applied to sequences of these states to identify characteristic repeating patterns. These signatures, representing typical activity for the particular computing system, are used for training a neural network. Essentially, clustering reduces the data to a more manageable form while retaining essential information. Periodicity analysis is used to identify repeating patterns, and a neural network is used for classifying the patterns as normal or unusual. Once the network has been trained, later activity can be classified as similar or dissimilar to normal activity.

ploitation of a system's vulnerabilities involves abnormal use of the system; therefore, security violations could be detected from abnormal patterns of system usage."[4] This has proven true in past intrusions.

2.1 Nonparametric Clustering

Traditional parametric statistical methods such as clustering or linear discriminant analysis do not produce groupings of similar activities when applied to resource usage data. They make assumptions about the underlying distribution of the data, usually assuming Gaussian distributions. The performance of these methods depends upon the conformity of the actual distribution of data to the assumed underlying distribution. Because the distributions of resource usage values are non-Gaussian, the results are not satisfactory.[2][14][7]

Considering an event as a vector $X_i = (x_1, x_2, \ldots, x_d)$ of resource usage in a d-dimensional space, clustering permits evaluation of classes of behaviors rather than treating every event separately. Using the nonparametric k-nearest-neighbor *knn* clustering reported in [12], an event is grouped based on the distributions observed for each of the resource usage parameters. Instead of using a uniform distance metric for clustering, each event is clustered with k of its nearest neigbors, where k is a function of the distribution of the data. For a sample of n points and a reduction to r clusters, each X_i is clustered with $k = n/r$ of its nearest neighbors.

For example, resource usage for twelve consecutive events from a sample are listed in Table 2. The first command is represented as data point $(0.12, 56, 360, 0, 0, 3000)$ in the 6-space whose axes are cpu time, combined memory, real memory, disk I/O, the ratio of elapsed time to cpu time, and the ratio of real memory to cpu time.

The reduced values for the commands are displayed in Table 3. The *ls* command with resource usage values (0.12, 56, 360, 0, 0, 3000) becomes state (001001). The names of the commands are included for illustration purposes, but the command names were stripped from the data and not used since the name can be easily changed by an intruder.

Because the clustering is based upon the distributions of resource usage parameters, data points are grouped with activity that is similar. Each cluster or state is a collection of similar resource usage on the particular computing system. It is not necessarily a homogeneous set of commands; it is the resource usage that is similar.

The nonparametric *knn* method has been demonstrated to be effective for anomaly detection in separate projects utilizing data from two different operating systems. [11][12][13] A number of measures have been used for the analysis of these patterns, including entropy, transition frequencies, and periodicity analysis with neural nets to automate the classification.

Table 2: Events

time of day	cpu time	com mem	real mem	disk I/O	ratio elap cpu	ratio mem cpu
13:32	0.12	56	360	0	0	3000
13:32	0.07	56	360	0	14.3	5142
13:32	0.12	56	360	0	0	3000
13:33	0.24	152	552	41.7	23	2300
13:36	1.37	192	632	61.3	11	461
13:36	0.44	368	808	6.8	6	1836
13:36	0.56	160	552	6	171.4	985
13:36	0.17	160	440	1	5.9	2588
13:41	0.21	56	328	4	4.8	1561
13:41	0.08	40	232	2	0	2900
13:41	0.18	56	368	0	0	2044
13:41	0.61	192	608	4	31.2	996

Periodicity analysis to produce signatures for input to a neural network is described in the sections that follow.

2.2 Periodicity Analysis

Considering the resource usage data associated with events in an operating system as a signal, each event is one state of that signal. Periodicity analysis can be used to determine whether patterns exist in the sequence of states. It provides a means of identifying repeating states which characterize the normal activities. These pattern signatures are expressed in terms of the periodicity in the signal and the signal strength.

The Fourier Transform of Equal Symbols (FTES) described in [9] identifies the states with significant spectral densities by applying an autocorrelation function to matching states. The contribution of each state to the spectral density is measured at different sequence lengths. This is important because user actions vary greatly, and the length of repeated sequences of actions cannot be determined *a priori*. For a window size of τ, the autocovariance of the occurrence of any string at position t and its occurrences at sequence $t+\tau$ is defined as $C_k(\tau)$ where

$$C_k(\tau) = \frac{1}{N-\tau} \sum_{t=1}^{N-\tau} U_{k(X_t, X_{t+\tau})}$$

X_k is the current state under consideration as the window of size τ moves across the entire sequence of N states in the data set. U_k is a binary indicator function defined as shown below.

$$U_{k(X_t, X_{t+\tau})} = \begin{cases} 1 & X_t = X_{t+\tau} \\ 0 & \text{otherwise} \end{cases}$$

Table 3: Reduced Resource Usage Parameters

event	parameters	state
ls	0.12, 56, 360, 0, 0, 3000.00	001001
ls	0.07, 56, 360, 0, 14.29, 5142.86	001011
ls	0.12, 56, 360, 0, 0, 3000.00	001001
repl	0.24, 152, 552, 23, 41.67, 2300.00	111110
vi	1.37, 192, 632, 11, 61.31, 461.31	111110
post	0.44, 368, 808, 6, 6.82, 1836.36	111100
repl	0.56, 160, 552, 6, 171.43, 985.71	111110
repl	0.17, 160, 440, 1, 5.88, 2588.24	011101
ls	0.21, 56, 328, 4, 4.76, 1561.90	100100
ldd	0.08, 40, 232, 2, 0, 2900.00	000101
ls	0.18, 56, 368, 0, 0, 2044.44	001000
vi	0.61, 192, 608, 4, 31.15, 996.72	111110

C_τ is an averaged count of the autocovariance.

$$C(\tau) = \sum_{k}^{K} C_k(\tau) = \frac{1}{N-\tau} \sum_{k}^{K} \sum_{t=1}^{N-\tau} U_{k(X_t, X_{t+\tau})}$$

The signal $\hat{g}(f)$ is then computed for a given window size, summing the contribution at all frequencies. Signal $\hat{g}(f)$ is the normalized spectrum of $U_{k(X_t)}$ from time $t = 1$ to $N-1$ where frequency $f = t/N$.

$$\hat{g}(f) = 2\left\{1 + 2\sum_{t=1}^{N-1} C(\tau)\cos(2\pi f \tau)\right\}$$

FTES is applied to subsequences selected randomly from a sample. For deriving the signature, short range correlations proved more useful because at longer range the sum reflects an accumulation of signals that is less representative.

Many of the sequences within a signal would not be significant in defining a signature because sequences of routine, acceptable activity exist in any computing system, even one in which an intruder is active. States with the greatest contribution to the signal are selected for the signature.

2.3 Neural Network Classification

The FTES method yields signatures which are expressed in triples of the form (state, periodicity, amplitude). These signatures are input to a neural network with the architecture shown in Table 4 and a Gaussian threshold function. The data sets used for training and testing are described in the next section.

Once a neural network has been trained with typical activity, current activity can be tested. Using the predetermined clusters identified during training, subsequent data samples can be converted quickly to a reduced form; thresholds are

Table 4: **Neural Network Architecture**

input layer	3 input neurons and 1 threshold neuron
hidden layer	5 neurons
output layer	2 classifications

used to assign points to one of the states. Periodicity analysis is used to obtain signatures, and these are classified using the trained neural net.

3 Results

The method was applied to four sets of data samples referred to as A, B, C, and D. Each sample is a collection of consecutive events from a Unix workstation. Collectively, the samples span a six-month period of time; individually they range from two hours to five days. The number of events for each sample is shown in Table 5. The only prior knowledge of the data was that set A contained typical events for a computing system. It was not revealed whether sets B, C, and D were similar or dissimilar.

Table 5: **Number of Events**

Data Set	Sample	Number of Events
A	1	7,399
	2	3,928
	3	11,496
	4	9,206
	5	12,824
B	1	3,363
	2	12,994
	3	11,856
C	1	13,480
	2	9,390
D	1	16,740
	2	16,738
	3	16,742
	4	16,744
	5	20,088
	6	20,090
	7	30,568

After the experiments, the data sets were identified as follows:

A: from a single multiuser workstation, representative of the normal activity on that system

B: from the same workstation at a later point in time but with similar activity occurring

C: from the same workstation at a later point in time with different activity occurring

D: from different users on separate workstations (but the same platform)

The patterns from sets C and D should be recognized as different from those in A while those from B should be recognized as similar. Data from set D would be the most indicative of suspicious activity since different users were sampled.

For training, samples were randomly selected from data sets A1 and D1, reduced by nonparametric clustering, and analyzed for periodicity. The neural network was trained with the signatures produced, correctly classifing 98.64% of the cases during training. Test cases were then randomly selected from all the samples for classification.

Table 6 shows the results from testing randomly selected samples. Samples from A were classified as normal in 98%, 98.7%, 82%, 60%, and 86.7% of the cases. During the period of time for these samples (six weeks), the activity changed somewhat from the training set A1, but most of the events were recognized as normal. Likewise, most of the events taken from the next three months, set B, were classified as normal.

Only 64.4% and 77.8% of the samples from C were classified as normal, and there would be cause for scrutiny by a person monitoring the system. For D, there would be an even stronger indication of unusual activity since only 1.2% to 43.3% of the events in the samples were classified as normal.

The method used here correctly classifies the activities in sets C and D as abnormal, despite the fact that many of the events in those sets were the same as those in the training set. For the samples of data set D, even though they are from different users on different workstations, from 91% to 100% of the commands executed were in the training set from A. Detection methods relying upon command names would not differentiate the events in the D samples from normal activity as our method did. This distinction is important because intruders execute many of the same commands as normal users and can rename files to hide misuse.

In conclusion, after training a neural network with a sample of the resource usage from a particular workstation and a sample from a different environment, the network was used for classifying additional samples. The classification successfully distinguished unusual activity from that which was similar to the training set.

Table 6: **Test Results**

Data Set	Sample	Percent Recognized as Class A (Normal)
A	1	98.0
	2	98.7
	3	82.0
	4	60.0
	5	86.7
B	1	87.3
	2	88.7
	3	92.7
C	1	64.4
	2	77.8
D	1	1.7
	2	43.3
	3	6.7
	4	11.7
	5	5.0
	6	10.0
	7	1.2

4 Background

The theoretical foundations of intrusion and anomaly detection are presented in [8], and a survey of current approaches to the problem are given in [6]. The most fully developed system has been SRI International's New Intrusion Detection Expert System (NIDES) which evolved from IDES, originally described in 1987 in [4] and more recently in [10]. The NIDES system builds a statistical profile for each application program and uses baselines of acceptable behavior.

A prototype neural network system was reported in [5] using an architecture based on a Kohonen Self Organizing Feature Map. Parameters such as cpu utilization, paging activity, mailer activity, number of users, failed logins, and average session time were used. Another neural network model was presented in [3]. Numerous models exist for neural networks, and further work is needed to determine how they can be best applied to the problem of anomaly detection.

Our work is an effort to further improve anomaly detection methods. Currently, our work is focused on the use of periodicity analysis after data is reduced by nonparametric *knn* clustering. Our neural network was trained with samples that contained both positive and negative examples. We plan to investigate training the network using only positive examples.

5 Contributions of this Work

Anomaly detection is intended to be used along with preventative measures and to detect threatening situations which occur in spite of other security measures.

Some of the activities of an intruder will be the same as those of normal users. This adds to the difficulty of recognizing suspicious behavior. An intruder might first observe a legitimate user's activity and then mimic it, embedding abusive behavior in activity that appears normal. Or the intruder can rename files to hide misuse. Detection should not be based on observable features such as the names of the commands. The method described here is not based upon observable criteria. It treats the events occurring in an operating system as a stream of data much like a signal. After reducing the data by nonparametric clustering, periodicity analysis is applied to the signal to extract characteristic patterns. Because the patterns analyzed with this approach are not obvious, it will be more difficult for the user to circumvent detection.

Because the users of a computer system exhibit a variety of behaviors, many of which are routine and some of which are transitions between activities, it is important to identify the repeating patterns that characterize activity. The occurrence or non-occurrence of an event, or even counting the number of events, is too rough a measure for the kind of discrimination desired. FTES periodicity analysis provides a means of identifying repeating patterns. Only the predominant patterns are extracted; small differences do not receive equal attention. Moreover, consideration is given to sequences of events of different lengths, overcoming the problems that neural nets have in dealing with variable length input streams.

Because the method does not filter the content of user messages, it is not as threatening to individual privacy as methods which filter particular textual strings. Only those events that use system resources in an unusual manner are examined.

Clustering provides some smoothing of data distortions due to factors such as system load. Factors such as system load and shared memory usage affect resource usage values. The same command executed at another point in time can produce different values for cpu time or I/O. These differences are consolidated when data points are clustered.

A difficult aspect of anomaly or intrusions detection is analyzing the considerable volume of events taking place in an operating system in time to respond while an intruder is active. [14] If the data points were not reduced in some manner, the data would be ill-suited for storage, periodicity analysis, or for any real-time treatment. Rather than unbounded values, each data point is reduced to one of a fixed number of states. Patterns of user activity are concisely represented as a series of these states. The reduction in the range of data improves the time and space requirements for analyzing the occurrence of events. If anomaly detection can be performed in real time so that intervention is possible, it will be useful for various types of misuse. And it has potential for other areas where the detection of unusual patterns is needed. An automated detection process is needed, both to reduce human monitoring and to provide real time data analysis of an active system.

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PRACTICAL APPLICATIONS OF LINKAGE ANALYSIS TECHNOLOGY IN THE INTERNATIONAL COUNTERDRUG LAW ENFORCEMENT ARENA

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ABSTRACT

This paper documents how computer-aided Linkage Analysis—the study of interrelationships between people, organizations, etc. (particularly applicable to international trafficking organizations)—has evolved from being a highly-specialized, R&D technology into an easily-accessible, practical law enforcement tool through the creative application of common, client/server software technologies. The paper will concentrate on proven applications of the linkage analysis paradigm to desktop, PC-based software packages that directly assist analysts and investigators in understanding the complex intricacies of international trafficking organizations.

The paper covers the following key subject areas:

- an overview of the linkage analysis paradigm,
- a general history of computer-aided linkage analysis,
- lessons learned/experience gained by early efforts, and
- practical applications of computer-aided linkage analysis in counterdrug law enforcement.

1.0 Linkage Analysis

Linkage analysis is the study of the interrelationships between entities. Entities, to use an example related to international narcotics trafficking, can be people, organizations, credit cards, companies, telephone numbers, addresses, precursor chemicals, boats, aircraft, passports, or any other 'thing' that is related to the supply or distribution of illegal narcotics. Any relationships that exist between these entities are referred to as links. To illustrate these definitions with an example, let's say that George, a narcotics trafficker, is known to conduct business with a suspect shipping company, Acme Shipping. In this case, George and Acme Shipping are two separate entities. They are linked together by a business connection. If Steve is an employee of Acme Shipping, then Steve and Acme Shipping are entities, and the link between them is an employment link.

The power of linkage analysis in assisting the international counterdrug law enforcement effort becomes overwhelmingly apparent when a) a large volume of 'linkable' information is available, and/or b) the linkable information is derived from multiple, possibly unrelated sources. Imagine a narcotics money laundering investigation where a large volume of bank transaction data is available from multiple banks—the vast majority of it meaningless. An investigator could carefully follow the flow of money from one known account number owned by a suspect company into three other accounts, and then from those three into another twelve, and from those twelve back to another single account owned by a different company. The investigator is able to identify connections between two companies that might otherwise have gone unseen. The reality of this analysis, however, is that reaching the conclusions above is nearly impossible given realistic time and resource constraints. It was because of this problem that analysts first turned to computers to assist in making these connections.

2.0 Computer-Aided Linkage Analysis

In the early days of computer-aided linkage analysis, computers assisted analysts in primarily two ways: 1) by providing a means for visualizing links—i.e., for drawing simple link diagrams (see Figure 1), and 2) by attempting to sort through and manage large volumes of data. Using computers to assist with manually drawing links provided (and continues to provide) some assistance—although minor—to analysts. In fact, many of today's systems now integrate automatic link visualization capabilities.

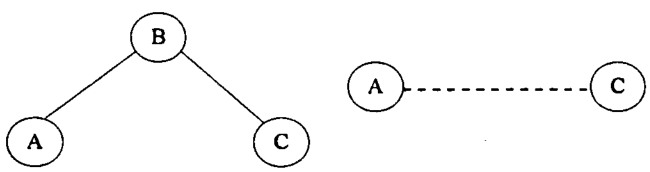

Figure 1 - An example of computer-aided link visualization.

In attempting to sort through large volumes of data, early analysts and system designers looked towards ideal solutions. Given a set of instructions, computers are extremely adept at finding the "needle in the haystack" that may elude a human for weeks—i.e., the flow of illegal money through bank transfers. Understanding this, early system designers attempted to utilize powerful technology to automatically extract entities and links from sets of data. Once this data was extracted, it was theorized, searching, sorting, and analyzing the entity and link information would become simple. Unfortunately for these early systems, the ability to automatically identify entities and links was hampered by the capabilities of a computer to read, understand, and extract information from the raw data provided.

3.0 Lessons Learned

To the eventual frustration of both system developers and analysts, early attempts at utilizing computers to perform linkage analysis focused primarily on automatically identifying and extracting entities and links from a given set of data. For example, if documents were seized from a business known for narcotrafficking, a computer system would be employed to search all the documents, identify possible entities and links, and then analyze the link information for the analyst. The challenge here was that in order to identify entities and links, the computer system needed to be able to read and understand written language. Even with the powerful computers of today, it is still difficult to teach a computer to read and comprehend the English (let alone any other language that the seized documents may have been written in) language. Several years ago, this technology was in the infancy stage.

The area of study where computers are taught to comprehend textual passages is known as natural language processing. Natural language processing attempts to mimic the human brain's ability comprehend the written word. This capability has eluded researchers for decades, in part due to the incredible complexity of the English language. In addition, humans are far more capable of reading 'between the lines' than computers seem to be. The result in the computer-aided linkage analysis systems that attempted to utilize automatic data extraction was that entity and link information was either under- or over-extracted. In the case of under-extraction, valuable and needed link data would wind up missing from the analysis portion of the system, thereby minimizing the value-added of the system. In the case of over-extraction, either links were identified incorrectly, leading analysts to erroneous conclusions, or the extracted data so overloaded the system that useful analysis could not be performed at all. Early linkage analysis systems therefore failed to succeed because they were never able to accurately obtain the linkage data they needed.

Once the problem of automatic link extraction was identified, law enforcement analysis moved in the direction of manual extraction for linkage analysis systems—i.e., having a human read, identify, and extract entities and links from a document. Once information was extracted, a human would then enter the information into a structured database. This database, then, could be analyzed and reported on by a powerful, stand-alone computer system. This concept proved successful until two things occurred over a period of time: 1) the volume and complexity of the data stored grew too large, and 2) multiple analysts needed access to multiple sets of data directly from their desktops.

4. Practical Applications of Computer-Aided Linkage Analysis

Modern day computer-aided linkage analysis systems currently in use by international counterdrug law enforcement analysts have built upon the lessons learned in the early link analysis systems. Today's systems are PC-based (or even network-based), desktop systems that track very few, very specific entities and links to simplify data entry. Data entry is comprised of assisted processing (i.e., numbers and names are identified in a document for verification by a data entry person) in combination with manual data entry. Software is built upon standard, common client/server technologies (like Microsoft and Sybase products) and is specifically designed to integrate seamlessly with standard PC office applications. Link information is now made available to all system users through a Windows interface that can be sorted, viewed, filtered, and arranged in nearly any format imaginable. All of this is made possible by 1) the availability and flexibility of client/server system development tools, 2) affordable, more-powerful computers, and 3) a highly-simplified data structure (see Figure 2) that is now understood to be extremely important for analyzing large sets of data.

Entity	Link	Entity
Acme Shipping	is connected to	George
Acme Shipping	employs	Steve
Fred	is employed by	Acme Shipping
Henry	is brother of	Steve
Acme Shipping	is owned by	Henry

Figure 2 - A simplified data structure like this one has assisted with the advancement of computer-aided link analysis tools.

The simplified data structure above has also provided analysts with a capability not previously provided—the ability to drill down from link to link (this is particularly important in larger, more realistic data sets). For example, given the data structure and contents in Figure 2 above, if a search was conducted on Henry, the results would be:

Henry is brother of Steve
Henry is owner of Acme Shipping

(Note that the reverse linkage—Henry is owner of Acme Shipping—is automatically provided to the user.) If an analyst wanted to know more about Acme Shipping and it's relationship (or links) to other known traffickers, he or she could simply click on "Acme Shipping". The result would be a search for links to Acme Shipping:

Acme Shipping is owned by Henry (the reverse link)
Acme Shipping employs of Fred
Acme Shipping employs Steve
Acme Shipping is connected to George

When the two result sets are viewed side-by-side (as today's link analysis tools allow), it becomes obvious that both Steve and Acme Shipping are entities that may require further investigation. Today's analyst can continue 'drilling down' level after level to develop a complete understanding of the complex, international relationships between narcotrafficking persons, organizations, and other entities.

In addition to being able to handle larger volumes of data, technology has also advanced in the field of link visualization. Now, instead of using a computer to draw entities and links, linkage analysis systems can automatically send data structured as above to a visualization tool. This tool translates the textual data into graphical representations, as illustrated in Figure 3 below. This ability to view linkage data in both textual and graphical manners has proven to be extremely useful in understanding the incredible complexities of today's international narcotics trafficking organizations.

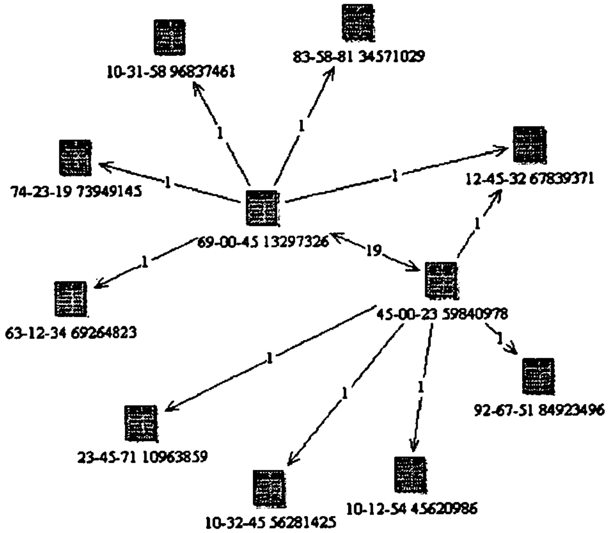

Figure 3 - Today's link analysis systems have the capability of automatically sending textual data to a graphical link visualization tool.

As development tools and computers become more and more powerful, the trend in computer-aided linkage analysis will likely be towards laptop-based and/or Internet-based computer-aided linkage analysis software. This type of technology will bring computer-aided link analysis tools to agents at border crossings, to investigators at the scene of major crimes, or to analysts investigating the financial ties of a corrupt narcotrafficking corporation. With tools like those available today, linkage analysis will undoubtedly continue to play a growing role in the international counterdrug law enforcement arena.

LINK DISCOVERY TOOL

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ABSTRACT

The Link Discovery Tool is a general-purpose visualization/exploration program that displays typed data links as a three dimensional graph. The tool is tailored for use on data collected during criminal investigations involving associations such as relatives, criminal contacts, telephone toll data, and financial transfers including the analysis of communication data, investigation of the flow of resources, identification of the direction and extent of control influences, and discovery of clusters of subnetworks in data.

1. Introduction

The scenario is common. The counternarcotics investigator is already overload with cases and is busy gathering data about a criminal network. Analysis of the data to extract potentially useful information is difficult (and slow), so it waits until time can be found to understand what information the data may actually contain and the layout of relationships between people and groups covered by the data. Meanwhile, the criminal activities continue.

Criminal investigation requires discovering relationships buried in tremendous quantities of data about loose associations among individuals, organizations, and activities. Technological innovation has allowed the collection of large amounts data to become routine in an investigator's work, but analysis of the accumulated data has resisted attempts at automation and is still a tedious and time consuming task. One reason for this barrier to the automation of analysis is that association data inherently require interpretation in order to extract significant information about relationships contained in the data. This means that the human investigator must remain in the analysis loop so that abstract or subtle associations represented by the data may be discovered.

Key to understanding the collected data and making maximum use of its information content is discovering groups of individuals and organizations that work together and are closely connected. A major problem to gaining this understanding is the shear quantity of data that must be analyzed.

The Link Discovery Tool is built to handle large amounts of data and allows an investigator to interactively explore relationships contained in a data set. The tool has been designed, from the ground up, to allow an investigator to display data involving associations in a manner that organizes data into clusters based upon associations and relationships between individuals in the data set. A design constraint was to use only algorithms which have linear (or at worst small order polynomial) complexity. This means that the computational capabilities of the computer platform running the tool must only grow linearly (or as a small power) with the data set size.

This design philosophy allows the Link Discovery Tool to take a *top-down*, rather than a *bottom-up*, approach to link analysis. Traditional link analysis activities in criminal investigations seek to build link charts which diagram known associations, or links, between individuals, businesses, or other entities. New entities and linkages to them are added as they are discovered by investigators.

The Link Discovery Tool, in contrast, utilizes a snapshot of all the data available to an investigation and discovers clusters of individuals or other entities which are strongly related by the associations contained in the data. The data may come from a variety of sources, including associations among entities in a case management database, telephone pin register logs, and financial transaction logs. The advantage of this top-down approach is all of the entities that can be tied to a cluster of criminal activity using the available data are discovered and included in the link chart. This feature has been clearly demonstrated in tests of the Link Discovery Tool where comparisons of clusters with investigators' knowledge of their activities have quickly identified new individuals who are active participants in the criminal activity.

The top-down approach of the Link Discovery Tool necessitates the requirement for linear or small polynomial complexity. The data sets used for analysis can be quite large when all information is made available to the tool. In one case a database of approximately 28,000 individuals known by counternarcotics investigators to have links to criminal activities was analyzed. In another case, telephone pin register data documenting over 300,000 calls were utilized.

The Link Discovery Tool has been successfully applied to data sets in use in ongoing criminal investigations. The sizes of these data sets have ranged between 10,000 associations and 300,000 associations. A consequence of the volume of data is the difficulty of presenting an understandable picture of the discovered relationships and pattern on a two-dimensional graph. As a result, the data are presented in three dimensions, and the user is able to rotate and scale the image around the axes of a three dimensional coordinate system. We have found that the three dimensional presentation and rotation of the results dramatically improves the user's ability to interpret the results of Link Discovery.

This paper describes the Link Discovery Tool, providing a brief description of its graph theoretic foundation and presenting examples of many possible applications for the analysis tool in the investigation of criminal networks.

2. Link Discovery Tool Foundation

The Link Discovery Tool is a general-purpose graph visualization/exploration program that represents directional data as a three dimensional structure. The graph structure is displayed as nodes, which can represent individuals, telephone numbers, bank accounts, or other entities, and links between nodes, which represent one or more specified relationships between the nodes. Nodes may have associated information, either textual or graphical, that annotates the displayed graph and provides context for understanding the graph structure.

The theoretical underpinning of the tool rests upon mathematical graph theory. The program generates and displays one of several graphs of the association data set. Algorithms in the program can produce the following types of graphs: component, bi-component, strongly-connected component, quotient, and articulation. Display of the generated graph begins at a given node, or *focus*, and provides directional views of the data displaying nodes reachable from the focus by following edges in their forward direction, backward direction or either direction.

The program makes available a variety of filtering methods for reducing the complexity of the displayed graph, as well as a collection of visualization tools, or *graphical objects*, by which data can be viewed as different graphs, each emphasizing a unique aspect of the underlying interconnection information. Graphical objects provided in the program include minimal length paths, hierarchical analysis, and the locations of sources, sinks, and choke points. Graphical objects operating upon one or more graph types generated from association data allow rapid visualization of clustering information.

3. Applications

Applications for the Link Discovery Tool cover a broad range of criminal investigations. These include investigations involving typed links such as crime families, telephone toll data, and financial transfers. Other analyses well suited for application of the Link Discovery Tool are analysis of communication data, investigation of the flow of resources, identification of the direction and extent of control or influence, and discovery of clusters or subnetworks in data.

3.1 Family Members in Crime

Links based upon immediate family member and extended family connections form one set of possible associations for criminal networks. Relationships displayed as links between individuals may be coded by color to show an organization's structure and how family members fit within the network. Parent-child (red) and sibling (yellow) relationships are shown in Figure 1 to indicate a single family's influence on criminal activity.

As may be seen, the family network displayed in Figure 1 not only forms its only criminal group, but also has connections to several other groups represented in the data.

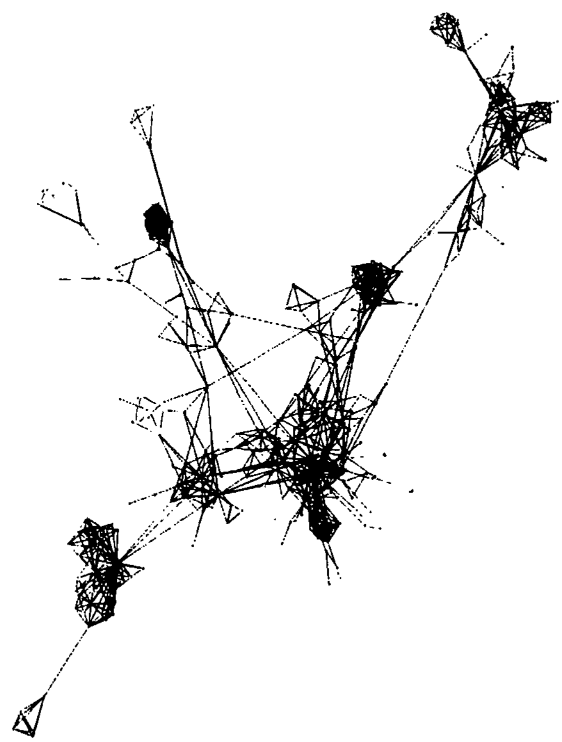

Figure 1. Family members in a criminal organization.

3.2 High Activity Individuals

Individuals who are very active in a criminal network tend to have many associations with other individuals. By restricting the display to nodes with large numbers of links, only high activity individuals are represented in the displayed graph.

The display in Figure 2 is restricted to only those individuals with more than ten known criminal associations from and to other individuals in the database. Several other restrictions can be specified.

Data sets normally contain names of individuals. This paper uses graphs from real data, but individuals are labeled with an identification number in the figures instead of actual names. The structure of each graph in the figures is correct, only node labels are changed.

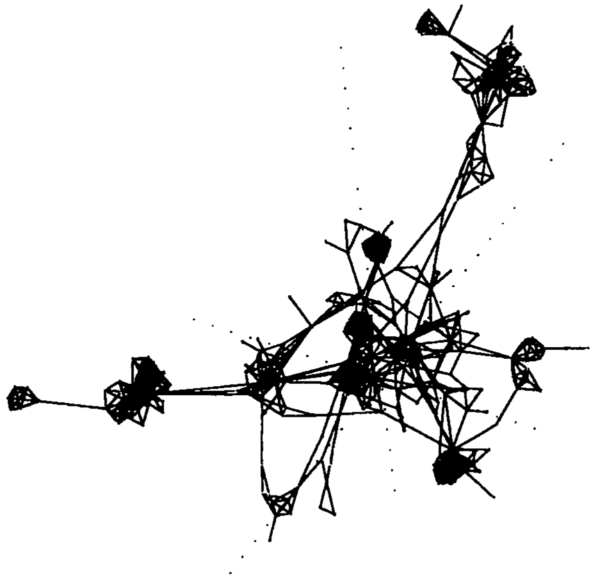

Figure 2: Individuals with High Activity

3.3 Wiretap Analysis

Wiretap and pin register data are a natural fit for the Link Discovery Tool. These investigation methods can produce exceptionally large amounts of association data, and the tool is designed to handle large data sets.

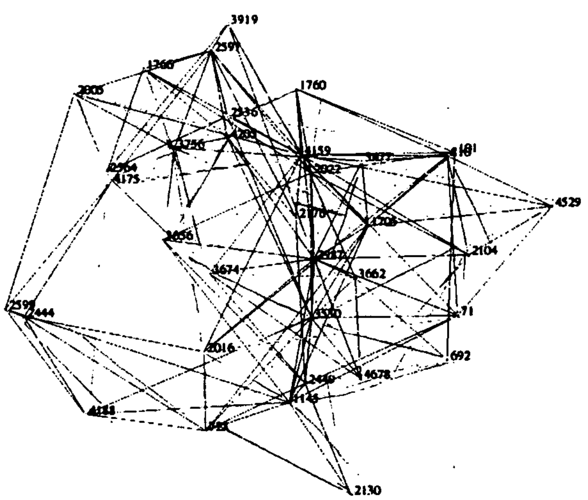

Figure 3: Wiretap Analysis.

Figure 3 is a graphical representation of a database of telephone traffic collected using wiretaps. Each node with yellow (outgoing calls) and blue (incoming calls) links represents all calls placed from or to a wiretapped phone and other monitored telephones.

An interesting detail to note is the relative balance between the number of incoming and outgoing calls at certain nodes. Node number 2564 shows a phone that receives many incoming calls (yellow links) but very few calls are made from that number, and nodes 2449 and 22987 have mostly outgoing phone calls (blue links). This may indicate a phone number that receives orders (2564) and phone numbers that place orders (2449 and 2987). In the figure, it may be difficult to discern the graph structure, but when running the tool on a computer, the display may be rotated in 3D and the details mentioned above are easily recognized.

3.4 Shortest Paths Between Nodes

Collaboration among criminal groups is often difficult to track. Relationships between groups depend upon associations of individuals in the groups, but investigations may not reveal direct links between group members. The tool can display link paths between nodes in the data set that may guide an investigation into criminal groups and their cooperative activities.

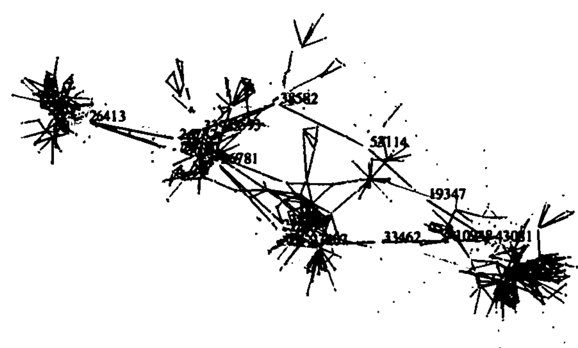

Figure 4: Shortest Paths Between Individuals.

Shown highlighted in red in Figure 4 are all paths of shortest length between two individuals (at opposite ends of the graph). This type of graph can be used to rapidly determine the relationships between two organizations that on the surface appear to be independent. The organizations shown in the figure are family crime groups: green links show parent-child associations and magenta links show sibling associations.

3.5 Hierarchical Relationships

Determining leaders within a criminal network can prove to be a difficult task. Individuals issuing orders that are carried out by subordinates attempt to mask their involvement by constructing a command hierarchy within their organization. Evidence and details of the hierarchy are buried in data associations.

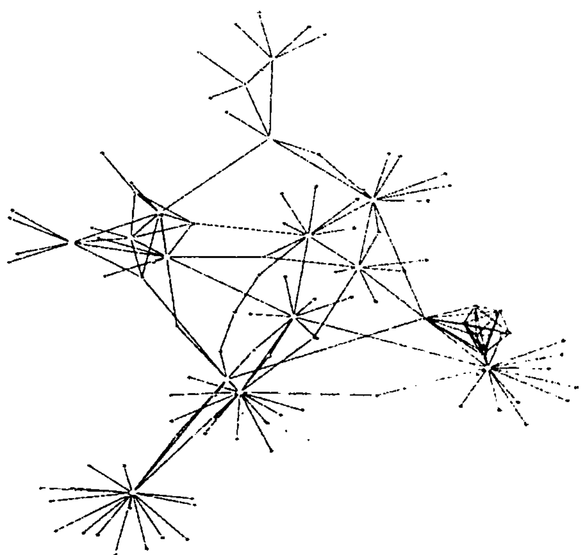

Figure 5: Hierarchical Relationships.

As shown in Figure 5, the Link Discovery Tool can be used to identify and display those individuals who are at the top level of the hierarchy of criminal associations. This figure shows a strongly-connected component graph with links representing associations in either direction.

3.6 Individual in Multiple Crime Groups

Individuals who are active in several criminal groups are valuable targets for investigation. Because they are members of multiple crime groups, these individuals can provide important information for the investigator either directly or indirectly through surveillance. Identifying such individuals is an important task.

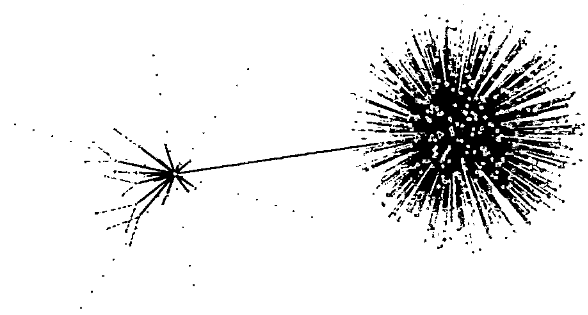

Figure 6: Individuals in Multiple Crime Groups.

In the graph shown in Figure 6, edges represent individuals who are members of more than one group, and nodes are groups. This graph can be used to target assets against the individuals whose absence will cause maximum disruption to their organizations. Shown in Figure 6 is association data displayed as an articulation graph. Links highlighted in blue represent an individual who is the only link between nine subgroups

4. Conclusion

The Link Discovery Tool allows the investigator to explore large data set of associations. The tool displays the associations in a self-organizing structure that shows clusters of closely linked individuals. Using its built-in graphical objects and graph types to display data reduces the complexity of the displayed graph.

The tool expands the investigator's capabilities by providing interactive manipulation of large amounts of data. Because the tool takes over the tedious and error prone tasks of sorting and plotting typed relationships represented by the data, the investigator is free to concentrate on his/her primary role which is abstract analysis on patterns of criminal activity contained in the collected data. Guiding the investigation process becomes a more efficient and manageable task, and the investigator is likely to produce tangible results in a more timely manner.

Timeline Analysis Tools for Law Enforcement

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ABSTRACT

The Timeline Analysis System (TAS) was developed by Rome Laboratory to assist intelligence analysts with the comprehension of large amounts of information. Under the TAS program data visualization, manipulation and reasoning tools were developed in close coordination with end users. The initial TAS prototype was developed for foreign command and control analysts at Space Command in Colorado Springs and was fielded there in 1989. The TAS prototype replaced manual paper timeline maintenance and analysis techniques and has become an integral part of Space Command's information infrastructure. TAS was designed to be domain independent and has been tailored and proliferated to a number of other users. The TAS program continues to evolve because of strong user support. User funded enhancements and Rome Lab funded technology upgrades have significantly enhanced TAS over the years and will continue to do so for the foreseeable future. The DoD and national counterdrug community has become a significant user of and investor in TAS. Recently the DoD Counterdrug Technology Development Program Office (DCTDPO), Naval Surface Warfare Center Dahlgren Division has begun to fund several TAS counterdrug initiatives. The DCTDPO objective is to enhance and make TAS available to a wide range of counterdrug users within DoD and Law Enforcement. TAS was recently provided to the New York State Police (NYSP) for evaluation using actual case data. Timeline analysis it turns out is a popular methodology used in law enforcement. The evaluation has led to a more comprehensive application and evaluation project sponsored by the National Institute of Justice (NIJ). This paper will briefly describe the capabilities of TAS, its counterdrug user community, results of the initial NYSP evaluation and plans for the future.

1.0 TAS DESCRIPTION

TAS was originally developed for the intelligence community analysis of foreign command and control activities. The program began as a prototype to automate the manual pencil and paper timeline maintenance and analysis process. The manual process consisted of reading message traffic and annotating a paper timeline with interesting events derived from the messages. From the timeline the analysts would try to discern activity patterns and trends and attempt to predict events based on historic activity patterns. The manual process greatly inhibited the analyst's ability to search, compare and comprehend even simple event patterns. Historical analysis would require analysts to think about when he or she may have seen a particular pattern before and search through file cabinets of timelines for the elusive pattern. The goal of the original TAS prototype was to provide tools to: easily enter event data into a relational data base; represent events visually as meaningful icons using icon shape and color to represent event type; manipulate and filter events on flexible timeline displays for data visualization and analysis. It was also required that the tools developed be domain independent so they could be applied to a myriad of timeline analysis domains. While TAS was originally applied to foreign command and control analysis, its flexibility to be tailored to other domains has been proven by its subsequent use in counterdrug, counter terrorism, space and other analytical domains. In addition to events, TAS also has the capability to build profiles of individuals and organizations. The TAS tool set now consists of the following tools: timeline, map, dictionary, event sequence modeler and event sequence assessment. These tools are described in further detail below.

1.1 TIMELINE TOOL

The timeline tool allows the user to view data as meaningful icons over time scales ranging from minutes to decades. The user can scroll through time at selected rates. The zoom feature allows the user to resolve events at higher resolution. Since timeline displays can become cluttered, many filters are available to the user to help focus the analysis. The user can filter on specific icon types and colors i.e. just show the red dollar sign icons (check cashing events) and the blue telephone icons (pay phone events). Area of interest filters allow the user to display on the timeline only the those events which occurred in specified geographical areas. Events can be tagged and filtered by tags. Country code and other filters are also available. Events that are related, for whatever reason, are connected on the display with white dashed lines. Tan lines represent duration of events. Clicking the mouse on an icon displays hypermedia information (image, video, text, etc.) associated with the event. Parent child event relations can be displayed as red dashed lines. Child events and their dashed lines can be hidden. The user can overlay text and geometric annotations on the timeline display. Using the "classics" function the user can save interesting timelines for later reference. Event data can be imported from external data bases to the timeline and can like wise be exported from the timeline to external data bases.

1.2 MAPPING TOOL

Within TAS we have recently incorporated the Air Force Common Mapping Tool Kit (CMTK) [1] to provide access to a wide variety of mapping products available from the Defense Mapping Agency (DMA). Map resolutions from displaying the entire world to resolutions down to 1:50,000 and better are available along with digital terrain data and many other products. Event icons are displayed over selected map backgrounds. The map display has a user definable time window which time filters events displayed on the map. The user can step through time on the map at selectable rates. All of the filtering features described in the timeline description above are available on the map display as are connectivity lines and parent child lines. Map "classics" can also be used to save interesting map and event data. The user can also overlay text and geometric annotations on the map. On line time distance and other tools are available. The user can also import and export data to and from the map. Interfaces for commercial-off-the-shelf mapping tools are currently being considered.

1.3 DICTIONARY TOOL

The dictionary tool provides the capability for the user to maintain a lexicon of words, definitions and synonyms. It is also used to maintain information on persons (and aliases), equipment or other entities.

1.4 MODELING TOOL

With the modeling tool the user can easily build graphical models of event sequences. The models are used to define anticipated event sequence patterns in timeline data and present the results to the user. The modeling tool utilizes Temporal Transition Modeling (TTM) [2] technology developed under the TAS program. TTM is a combination of concepts from decision trees and Augmented Transition Networks (ATN) used in natural language processing [3]. Associated with the TTMs is a graphical specification language which allows analysts, who are experts in the analysis domain but have no artificial intelligence expertise, to manipulate and maintain the knowledge base. TTMs consist of event states and transitions. The analyst can specify an event state type and required attribute field values to be modeled. Transitions are analyst specified time durations between events. The analyst can also assign importance weighting to transitions. Importance weighting is propagated using MYCIN confidence techniques [4]. Transitions include AND-OR branching between states. The advantages of the TTM representation over other types of knowledge representations are many. The state-transition concepts found in ATNs combined with the capability to define AND-OR branch specifications, allow TTMs to closely match the methods the analysts use in manually performing situation assessment. Model states can aggregate discrete events i.e. state is fulfilled when three or more Boeing 727 aircraft take off from Washington National airport. This state will look for three or more separate events involving take off of Boeing 727 aircraft from Washington National airport. Geographic zones can also be used as an event state attribute. The user can specify for example a telephone call from john from the geographic zone of Rome NY. The user builds the geographic zones within the map tool.

1.5 ASSESSMENT TOOL

The assessment tool also referred to as KPASA (Knowledge based Predictive Analysis and Situation Assessment) is used by the analyst to find modeled event sequences in the timeline event data. To run an assessment the user selects a group of events from the timeline display through simple point and click mouse operations. The user then selects the models from the data base to run against the events selected from the timeline. A rank order of models matched will then be presented to the user. The user can then mouse click on the model from the list to get a detailed explanation of the assessment of that model. Assessment results are displayed in three ways. A graphical display shows the model with the matched states filled in with red shading. Partial state matches are indicated by lighter red shading. The user can mouse click on the event state icons to see which attributes of the state have been satisfied. A second display shows all of the events that satisfied the model states. These events are displayed as icons on a filtered timeline. A mouse click on an icon displays further information for that event. The third display consists of a textual explanation of the assessment. This explanation is built automatically using natural language generation techniques [2].

At this point the user can run a prediction to determine what events to expect next. The prediction is based on the remaining states in the model. To perform a prediction the user specifies a period for prediction usually starting with the time of the last matched event in the model. Upon running the prediction the same graphical display of the model will appear with the predicted state icons circled in yellow. Also a textual rendering of expected events will be displayed.

1.6 QUERY TOOL

This tool provides a dynamic method for analysts to build complex queries without having knowledge of Standard Query Language (SQL) or the data base schema. The query panel provides an interface by which an analyst may select the object to be queried from a list of available entities. Once the object class has been chosen the available attributes associated with that object are displayed in a list. The user may build a query by selecting as many attributes as necessary for refining results. The results of the query can be displayed in several ways. The results can be sent to a histogram where event occurrence over time can be displayed on various chart displays. The user can display event occurrences by year, quarter, month, day, day of week, and hour of day. This display is particularly useful in looking for trends. Query results can also be displayed tabularly and on a map background.

1.7 DOMAIN EDITOR

This is the most recently developed tool within TAS. With the domain editor the user can site tailor the event types, facility types and other entity types handled by TAS. For example, if a new user wanted to create a new event type to capture telephone surveillance information a new event type called telephone surveillance could be created. This new event type might contain attributes labeled "caller name", "caller number", "time", "telephone type" or whatever else the user wants to specify as attributes of the event type. This is all done through an intuitive user interface and does not require programming experience. When a new event, facility or other entity type is created the data dictionary is automatically modified and propagated throughout the TAS tools.

1.8 OPERATING ENVIRONMENT

TAS currently operates in the Sun OS, Solaris, DEC Ultrix and DEC Unix operating system environments on standard workstations with no special hardware requirements. TAS currently requires the Sybase data base management system. An effort has begun to design and implement a web browser based TAS to include a port to the JAVA programming language. This version of TAS will be capable of operating on any platforms that support standard web browsers. Also data base middle ware will be incorporated to facilitate interfaces to other data base management systems.

2.0 COUNTERDRUG APPLICATIONS

TAS is currently in use at several DoD and national sites supporting counterdrug and other applications. Among the counterdrug users are: US Southern Command, Joint InterAgency Task Force South, Joint InterAgency Task Force East, 12th Air Force and others. TAS is primarily used to perform trend analysis, situation assessment and provide needed information to decision makers in support of source country and transit zone interdiction. TAS serves as a common medium for these organizations to share information and analytical results.

2.1 LAW ENFORCEMENT INITIATIVE

TAS was provided to the New York State Police (NYSP) for evaluation in July 1995. A three thousand event case was imported into TAS from the NYSP data base so that the evaluation could be performed in a familiar context. The timeline data imported was that of a suspected child abductor. The events in the timeline were broken into several categories for icon assignment. These categories included: financial transactions (dollar sign, red for check cashing, green for check writing); vehicle events (traffic tickets, registration, etc); legal (incarceration, questioning); family related events (marriage, divorce, etc.); open cases of missing persons (victim found, victim not found); offender location. With the data imported the power of visualization could now be demonstrated. Rather than looking at long uninspiring lists of events in tabular form the analyst can now see the same data as icons on the timelines and maps. Red inverted triangle icons representing when the offender was absent from work or class could easily be correlated with open case icons. Work and class attendance patterns become obvious. Incessant driving patterns were observed. Check cashing patterns appear to radically change on the same day and shortly following an abduction event. Once an apparent pattern is found it can be annotated and saved as a classic for future reference and comparison.

As a result of the evaluation the National Institute of Justice has provided funding to support a more in-depth evaluation of TAS at NYSP Troop B located near Lake Placid NY. TAS was installed there in October 1996 and user training provided. Over the next several months TAS will be tailored for specific event types required by Troop B. Ongoing case data will be manually entered and imported from existing files. TAS enhancements will be provided based on user feed back. The evaluation will attempt to determine TAS suitability for law enforcement use and if suitable how it should be transitioned.

3.0 TAS THE NEXT TWO YEARS

Several TAS enhancements are planned to occur over the next two year period. As DoD funded enhancements are made to TAS they will be included in baseline upgrades to be made available to the counterdrug and law enforcement communities. Enhancements include; World Wide Web browser interface; port to JAVA programming language; machine learning techniques to discover activity and behavior patterns; data sharing and collaboration tools. The goal is to have a machine independent, browser based TAS fielded by late summer 1998. Interface to commercial mapping packages will also be investigated.

4.0 CONCLUSION

TAS has become an established capability in the intelligence community. Its success is attributed to its ability to be tailored to new domains and to the fact that timeline analysis is a ubiquitous analytical methodology within the intelligence community. It is these attributes that also render TAS a good candidate for transition to counterdrug and law enforcement applications. TAS has proven its value in DoD and national counterdrug applications. Initial steps have been taken to demonstrate its suitability to law enforcement. Over the next several months a more rigorous field evaluation will take place in conjunction with the NYSP. TAS enhancements will continue into the foreseeable future and will be incorporated into the software baseline. If TAS is transitioned to law enforcement that community can receive tremendous leverage from DoD funded enhancements.

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Chemical Sensing Technologies (Session 2C-4)

METHAMPHETAMINE VERSUS NICOTINE DETECTION ON THE BARRINGER ION MOBILITY SPECTROMETER

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ABSTRACT

The South Central Laboratory has been using the Barringer portable Ion Mobility Spectrometer to support federal, state, and local drug cases for over four years. In the course of hundreds of field operations, difficulty has been encountered in detecting methamphetamine when nicotine is present. The two substances have similar reduced mobilities, and therefore interfere with the detection response. This interference is greatly enhanced when the two substances are present in amounts that overload the detector. Problems occur mainly with data interpretation in a critical field operation where methamphetamine is the target controlled substance and the target individuals are cigarette smokers. The South Central Laboratory has encountered numerous situations where methamphetamine and nicotine are present, which includes warehouses, vehicles, large trucks, residences, and other real property. The samples taken are always confirmed by Gas Chromatography-Mass Spectrometry. However, the operator must be able to recognize the potential interference of the two substances in a field situation.

1. Background and Theory

The Barringer Ion Mobility Spectrometer is an invaluable tool used in the law enforcement field for detecting trace amounts of controlled substances. However, this instrumentation is merely a field test and does not produce a conclusive response. Ionization by Ion Mobility Spectrometry depends on factors such as the carrier-gas matrix, concentration of the sample, the method of sample introduction, and the temperature in the drift tube.[1] More specifically, when there are multiple reactant ions, such as methamphetamine and nicotine together, there is a competition between the two ions. This competitive nature of charge-exchange ionization prevents Ion Mobility Spectrometry from being a suitable technique for some multiple compound analyses.[2] The qualitative measurement of a specific ion is referred to as the reduced mobility constant (K_o). This value is very similar to the retention time on a gas chromatograph. Barringer defines the reduced mobility of a target compound for their portable IMS using the equation below, where K_{otarg} is the reduced mobility for the target ion, K_{ocal} is the reduced mobility for the calibrant (nicotinamide), t_{cal} is the drift time for the calibrant, and t_{targ} is the drift time for the target ion.[3]

$$K_{otarg} = (K_{ocal} \times t_{cal}) / t_{targ}$$

The reduced mobility can be slightly different from instrument to instrument depending on the parameters and conditions. The published K_o values for methamphetamine are 1.63 and 1.66 cm^2/Vs, where cm is the length of the drift tube, V is the potential drop across the drift tube, and s is the drift time in seconds.[4] There were no published reduced mobility figures for nicotine. Values obtained from laboratory experimentation for methamphetamine and nicotine were 1.62-1.63 and 1.57-1.58 cm^2/Vs on the IMS 250 and 1.59-1.60 and 1.54-1.55 cm^2/Vs, respectively on the IMS 350. The 0.05-0.06 cm^2/Vs

difference in K_o is extremely small and is an indication that resolution may be a problem. These experimental values were obtained using IMS parameters located in Table I.

Due to the similar reduced mobilities, use of the IMS in field operations to detect methamphetamine, in the presence of nicotine from cigarette use, produced unreliable results. The resulting response from the IMS varied, depending mainly on the matrix effects, other competing drugs, such as cocaine, and the concentration. The IMS responds to a detected substance by producing an audible alarm. A computer generated plasmagram, indicating the peak drift time and reduced mobility, can also be obtained. The IMS for samples collected in field operations resulted in a variety of responses. First, a false negative occurred when the audible alarm did not sound, however, the corresponding plasmagram indicated two unresolved peaks. Second, a false positive was produced when the audible alarm and display indicated only methamphetamine or nicotine, however a large peak with a smaller shoulder was present in the plasmagram. In both examples, the methamphetamine peak is larger, with a slightly higher drift time, and the nicotine appears as a shoulder peak on the down slope of the methamphetamine (Figure 1). This can be a potentially serious problem for IMS operators that rely on the LCD screen and alarm, as opposed to the personal computer, for interpretation of results.

Table I. Ion Mobility Spectrometer parameters.

Ion Mobility Spectrometer	Barringer IONSCAN 200, 250, 350
Drift Tube Temperature	235°C
Inlet Temperature	280°C
Desorber Temperature	250°C
Drift Gas (air) Flow	300cc/minute
Sample Gas (air) Flow	200cc/minute
Exhaust Gas Flow	502cc/minute
Desorber Time	4.4 seconds
Drift Tube Length	6.9 centimeters
Scan Period	20 microseconds
Calibrant	Nicotinamide

2. Experimental

The South Central Laboratory conducted numerous studies to address the IMS detection of methamphetamine and nicotine including linearity studies, concentration, and various heater temperatures. Unless otherwise specified, the parameters listed in Table I were used. IMS has limited linearity capabilities, therefore the linear concentration values listed are an approximation.[5] Methamphetamine detection in solution has a linear response on the IMS 350 from approximately 0.4 nanograms to 4 nanograms (Figure 2). Nicotine, on the other hand, is linear from approximately 1 nanogram to 20 nanograms (Figure 3). However, the two drugs combined in solution give a variety of detection responses on the IMS 350. The detection response on the Barringer IMS, in addition to an audible alarm, is called amplitude and is recorded in digital units (du). First, the amount of methamphetamine remained a constant value of 4 ng and nicotine was varied from 0 to 100 ng (Figure 4). All audible responses produced accurate results until the amount of nicotine reached 20 ng. Unreliable results were obtained between 20 and 40 ng of nicotine. In this range, the IMS would produce a random audible alarm on methamphetamine, nicotine, both, or none. However, the peaks were always present on the corresponding plasmagram (Figure 5). The only time there was inadequate resolution of both peaks was due to an overload of either drug. An overload can occur when the target drug has reached a plateau in its amplitude response (Figure 2 and 3). This produces a broad and distorted peak, which can shift the drift time and reduced mobility, and therefore cause an unreliable response on the IMS.

After confirming the detection limits, the drift tube temperature was altered from 100°C to 280°C to determine its effect on the detection response of methamphetamine and nicotine. The optimal drift tube temperature for detection of a solution of 4 ng of nicotine and 4 ng of methamphetamine was in the range of 230°C to 260°C. At higher and lower temperatures, the reduced mobilities were altered and the IMS amplitude response low or none. However, the original drift tube temperature setting (240°C) was found to be optimum for the audible detection of both compounds.

Finally, the desorber temperature was varied to evaluate its effect on resolution and sensitivity. The same standard solutions used for drift tube evaluation were tested by altering the desorber temperature from 80°C to 300°C. Optimum sensitivity was achieved between 250°C and 300°C, while response was reduced below 170°C. Therefore, the usual desorber temperature of 290°C produced audible detection for 4 ng of methamphetamine, 20 ng of nicotine, and an equal mixture of 4 ng each.

3. Field Situations

The data and study presented above is ideal due to the controlled laboratory environment, known solutions, and time for analysis interpretation. However, 90% of the IMS teams' work is in uncontrolled law enforcement field situations. A typical field situation has factors such as extreme heat, poor ventilation, excessive dirt and debris, large search areas and inadequate lighting to interfere with IMS sample collection and analysis. In addition, vacuum sweep sample collection introduces a variety of contaminants not normally encountered in a laboratory setting. As a result of this environment, it is not always feasible to change temperatures, parameters, concentrations, and collection methods. Even at the optimum temperatures and parameters confirmed in this experiment, optimum concentration with no matrix interferences is rarely achievable in the field. For example, the IMS 350 was used at a warehouse location on a hot summer day with little ventilation. The IMS team was asked to search critical areas of a warehouse for the presence of controlled substances, mainly methamphetamine. The violators were also known cocaine and cigarette users. Numerous vacuum samples were taken and tested on the IMS. Most of the samples did not produce an audible alarm, however the corresponding plasmagram on the personal computer showed a large peak in the methamphetamine area with the nicotine shoulder peak (Figure 6). The reduced mobilities and drift times were shifted. Furthermore, a few samples detected methamphetamine, but not nicotine, and vice versa. Some samples also indicated the presence of cocaine, usually with an alarm. These substances were later confirmed by GCMS. In field situations, it is advantageous to understand the potential for nicotine interference, learn to recognize the response, and how to interpret the IMS plasmagram.

4. Discussion

Once the IMS parameters are optimized, a few steps can be taken in field situations to minimize inaccurate responses for methamphetamine detection when nicotine is present. First, obtain a nicotine standard and establish a channel on the IMS so it can be detected. Second, another channel can be made titled "meth high" to detect an overload of methamphetamine. This channel can be set at a wider search window. Barringer has implemented this in the IMS 400 for an overload of cocaine. However, setting another channel to detect a methamphetamine overload may overlap with the nicotine channel, or other substances with similar reduced mobilities, producing a false positive. Third, use the computer purchased from Barringer to analyze every vacuum sample. This will insure a corresponding plasmagram, containing peaks, to interpret. Soley relying on the LCD screen and audible alarm may lead to false positives or false negatives. Fourth, confirm all samples collected by conventional laboratory analysis, for example GCMS. Finally, evaluate standards of methamphetamine and nicotine to observe the large peak with a tail, an overloaded peak, or a shift in the K_o value.*

5. Conclusion

The South Central Laboratory's experimentation with the portable IMS in the laboratory, as well as their experience in the field, has proven that false positives and false negatives are prevalent when detecting methamphetamine in the presence of nicotine. These inaccurate responses can occur from a sample containing two unresolved peaks, an overloaded peak, and a shift in drift time and reduced mobility. Furthermore, in field situations, it is almost impossible to control the concentration of the target compound (methamphetamine), interfering compound (nicotine), and the matrix contents. Hence, as a precaution, the plasmagram from the personal computer should be interpreted before any presumptive conclusions are drawn. In addition, all samples should be confirmed by conventional laboratory analysis.

6. References

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[2] Eiceman, p.49.

[3] Barringer Instruments Manual for the IMS 250, p.7/21.

[4] Eiceman, p. 154.

[5] Eiceman, pp. 129-132.

*In addition to the above helpful hints, there is another approach to this problem that involves a process called neural networking. This data signal processor was introduced to the South Central Laboratory by Dr. Pierre Pilon of Canadian Customs, Ottawa, Canada. Please reference Dr. Pilon's research in the journal from the "Third International Workshop on IMS" held in Galveston, Texas in 1994. The author would like to thank Dr. Pilon for reproducing some of the data provided in this research, as well as experimenting with neural networking to research the methamphetamine and nicotine problem.

Figure 1. Plasmagram of a standard solution of nicotine and methamphetamine with no IMS alarm.

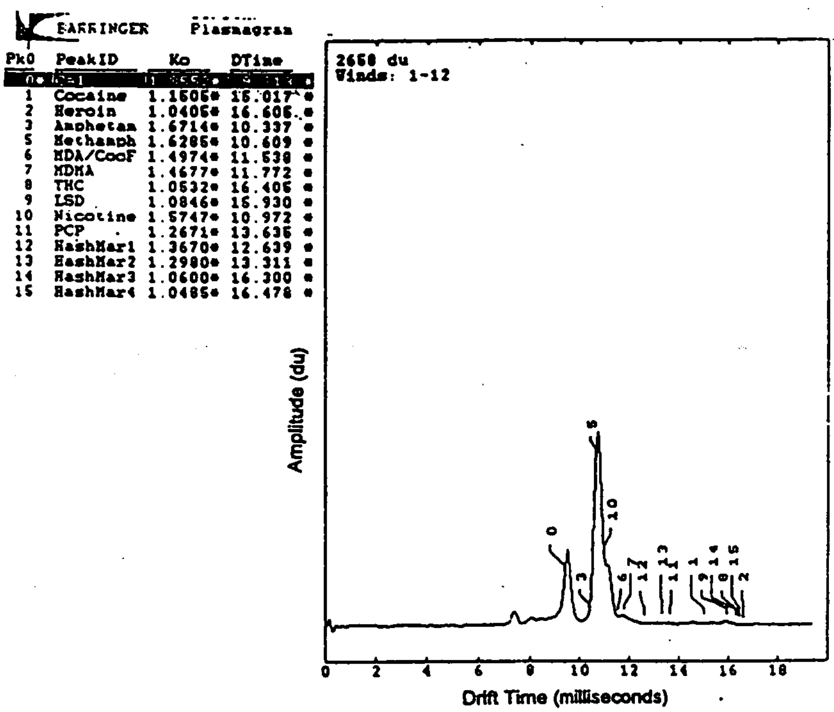


Figure 2. Methamphetamine response on the IMS 350.

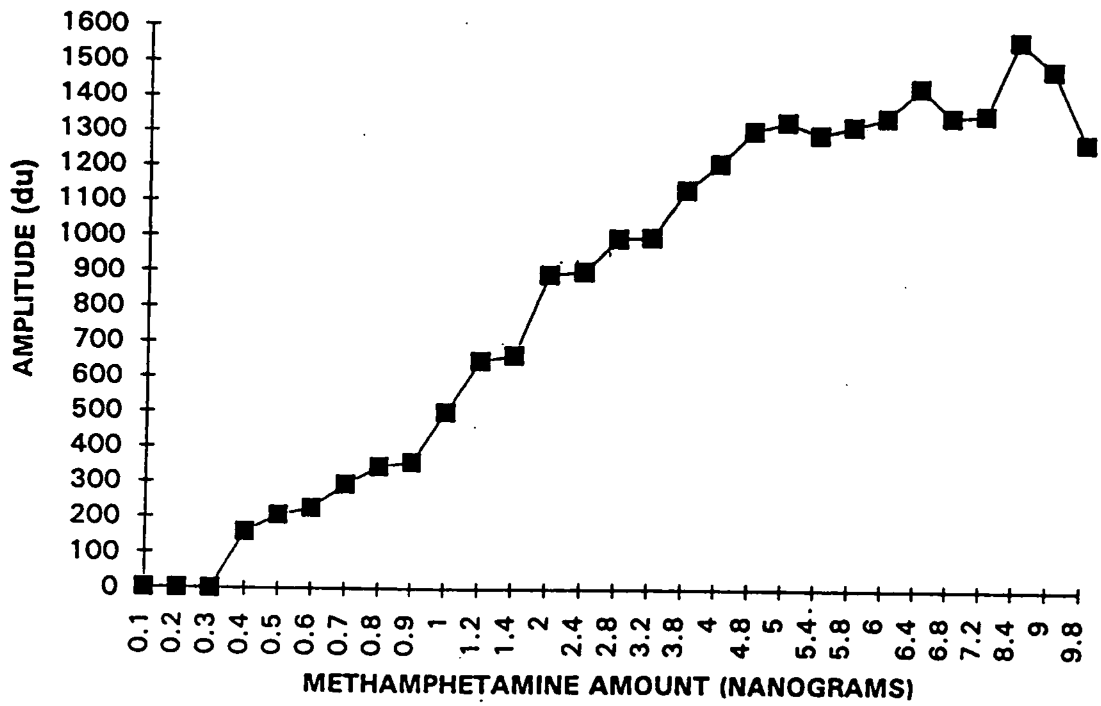


Figure 3. Nicotine response on the IMS 350.

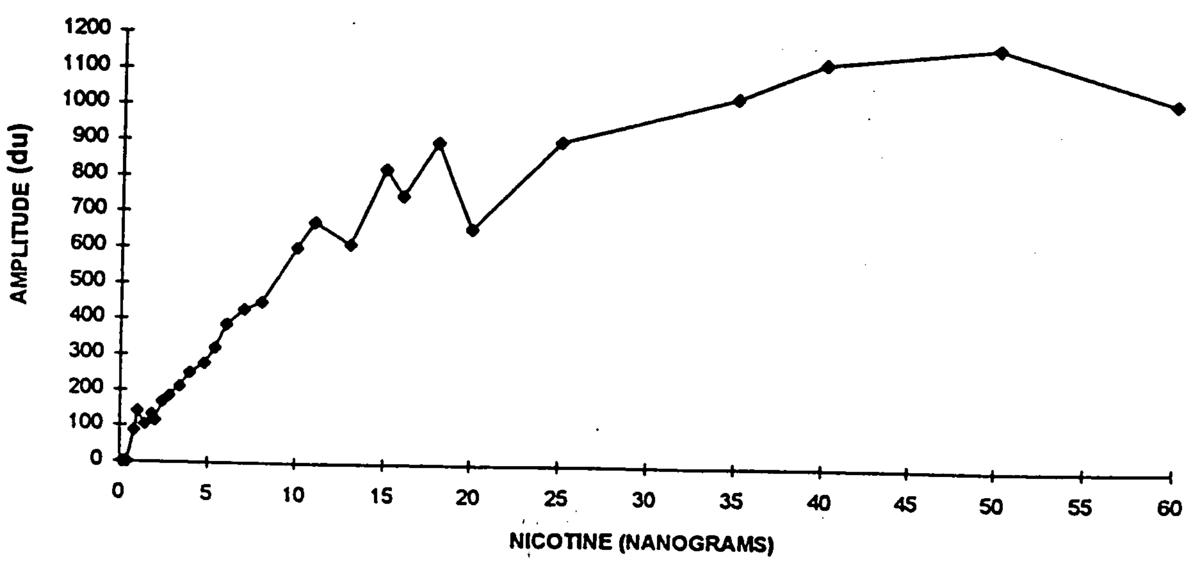


Figure 4. IMS 350 response for a fixed amount of methamphetamine versus varying amounts of nicotine.

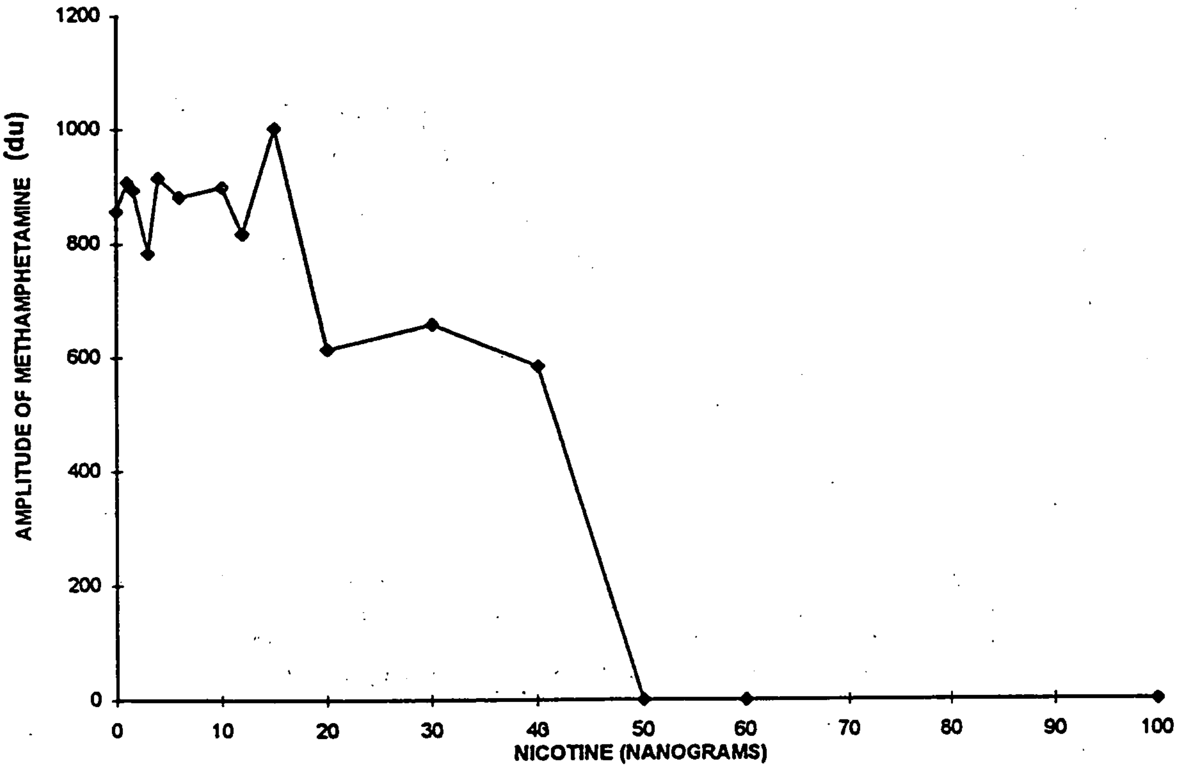


Figure 5. Plasmagram for a solution of 4 ng of methamphetamine and 20 ng of nicotine.

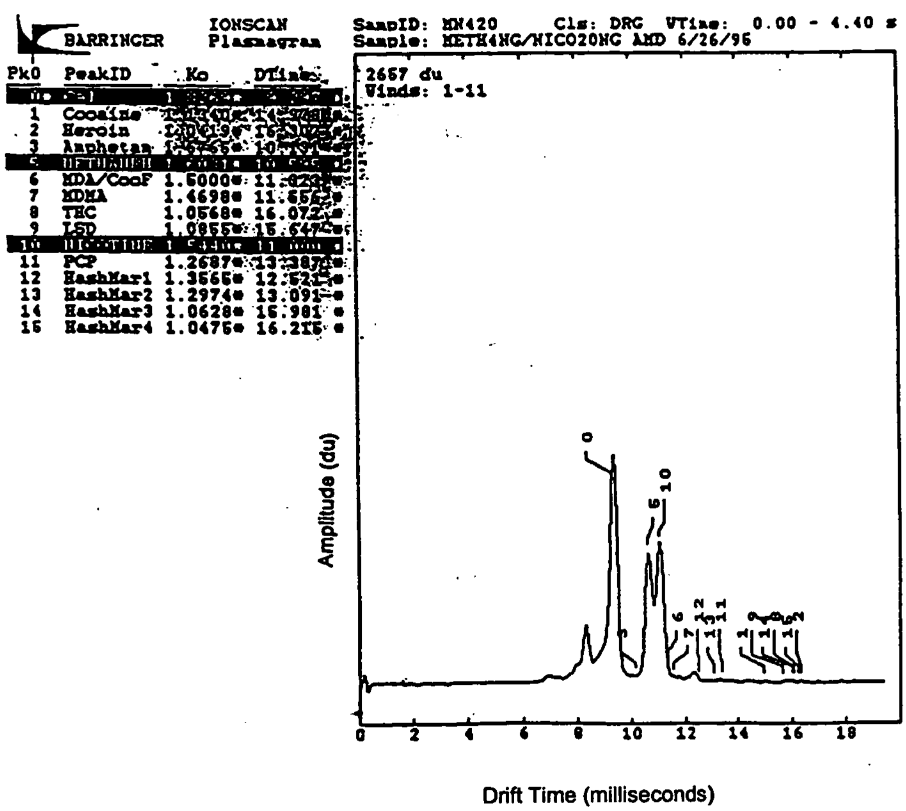
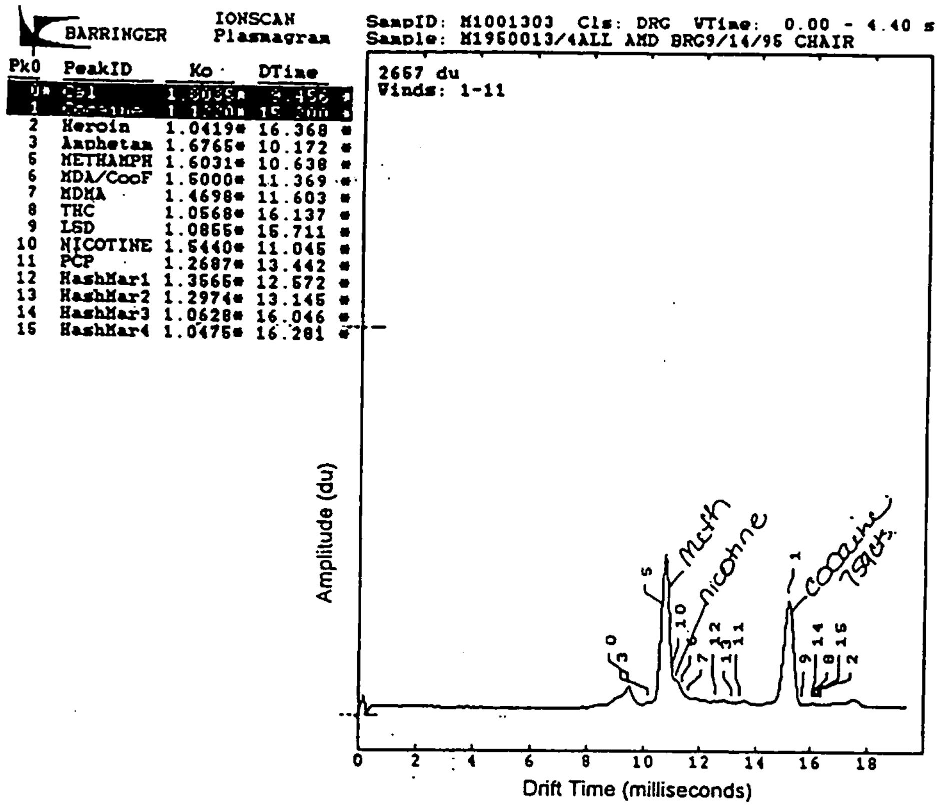


Figure 6. Plasmagram from a scan of a warehouse where cocaine was the only audible alarm present.



AN INTEGRATED OPTIC SENSOR FOR DRUG DETECTION AND IDENTIFICATION

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ABSTRACT

The use of illegal drugs and substances of abuse is exacting a devastating toll from personal lives, the business world, and society in general. The development and deployment of highly sensitive and portable drug monitoring equipment offers a valuable tool to aid in the effort to reduce drug trafficking. This paper describes a prototype integrated optic (IO) sensor system applicable to drug detection and identification. The sensor technology is based on an integrated optic (IO) interferometer (i.e. an optical system on a chip) that has proven to be extremely sensitive as a chemical sensor. The unique design of the integrated waveguide interferometer provides a system capable of detecting picograms (femtomoles) of an analyte or alternatively concentrations in the part-per-billion range. Furthermore, the technology offers multi-channel (13) sensing capability on a common chip. From a systems perspective the IO sensor offers a compact package applicable to a variety of drug monitoring/detection scenarios. Estimated cost for volume quantities, is projected to be in the $200 range. The current activities are focused on the detection and monitoring of methamphetamine. The sensor technology and experimental results are discussed in this paper.

1.0 INTRODUCTION

The use of illegal drugs and substances of abuse is exacting a devastating toll from our personal lives, the business world and society in general. The economic losses are large, estimated at $67 billion in the United States alone, with approximately 70% of this cost related to crime. Additionally, over 20,000 deaths per year are drug related [1]. To counter these devastating losses, the Office of National Drug Control Policy (ONDCP) through its *1996 National Drug Control Strategy* has identified five specific strategic goals and objectives. Among those goals was to "Shield America's air, land, and sea frontiers from the drug threat" [1]. The objectives cited as part of this goal included "the use of science and technology to improve the effectiveness of law enforcement" as a means of preventing smuggling using international air, maritime, and land cargo shipments.

To realize the ONDCP goal of countering drug trafficking, highly sensitive, portable and versatile monitoring equipment will be required. Furthermore, drug detection/monitoring instrumentation should operate non-intrusively and, in many instances, should be capable of functioning in a covert fashion.

Towards these objectives, an advanced integrated optic (IO) sensor system designed for drug detection and identification is currently undergoing development. The IO sensor offers a chemical laboratory-on-a-chip capable of detecting volatile components serving as drug markers or alternatively detection based on particulates. The same basic sensor has the capacity, with a slightly modified chemistry, to detect metabolic by-products indicating drug usage through breath analysis or analysis of bodily fluids. The sensor was developed and patented by the Georgia Institute of Technology [2,3] and is currently being developed for environmental and food safety applications [4,5]. In the following sections of this paper, the IO sensor technology is described, experimental results are presented and system configuration is described.

2.0 BACKGROUND

The ONDCP goal of countering drug trafficking requires highly sensitive, cost effective, and portable instrumentation to cover the many varied application scenarios that will be encountered in the effort to limit the influx and use of illicit drugs. Potential applications for monitoring and inspection encompass the following:

- **Cargo at ports-of-entry** - incoming/outgoing cargo containers require rapid non-intrusive inspection.
- **Shipping bays of maritime, air and land transportation systems** -suspicious cargo may be continuously monitored during shipment using very small monitoring systems hidden within a vessels shipping bay and tied in with a satellite based global positioning and information system.
- **Packages and luggage** - non-intrusive and rapid inspection of mail packages handled by U. S. Postal Service and private handlers as well as luggage at airports.
- **Automobiles and other forms of personal conveyance** - covert monitoring of personal automobiles at routine traffic stops .
- **Buildings and private homes** - inspection, sometimes covertly, of suspected drug distribution and synthesis sites.
- **Crime Scenes** - inspection at crime scenes for presence of illicit drugs.

These applications place special demands on the utility and versatility of a drug monitoring and detection system. Sensitivity is key in practically all situations because non-intrusive inspection of sealed cargo containers, packages and luggage is required. Only trace levels of drug marker species existing in vapor or particulate phase will typically exist for these situations. Multi-analyte detection capabilities are required to detect and identify specific drug species, thus instrumentation with analytical capabilities is required in many instances. Rapid response is essential in many instances to minimize impact on operations. In most instances a highly compact and low power consuming system is required. Ideally the detection system should be in the form of a small hand held package. This aspect is particularly critical in law enforcement operations where covert operation is important.

Current state-of-the-art chemical sensing technologies including surface acoustic wave (SAW) devices [6], chemical field effect transistors (ChemFET) [7], fluorescence based sensors [8], and ion based spectroscopic techniques [9] fail to meet some or all of these requirements. Of these technologies, only the surface acoustic wave (SAW) transducers [6] and ion mobility spectrometers [9], have been developed for illicit drug detection. The SAW technology relies on detection of a mass change or a change in the viscoelastic constant of a polymer coating deposited on a quartz crystal. Adsorption of an analyte of interest onto the polymer surface effectively increases the mass at the surface of the acoustic transducer and alters the frequency of the surface acoustic wave. Chief limitations of this technology include sensitivity and specificity. The specificity issue occurs because the SAW device measures mass changes; thus adsorption of any molecular species onto the non-selective polymer device surface will generate a signal. The ion mobility spectroscopy systems rely on pyrolyzing particulates that are collected by air sampling or wiping methods. The volatile products are then detected and correlated with drug species. This system exhibits limited sensitivity (400 to 800 nanograms) and tends to be fairly cumbersome as it involves a suitcase-sized package [9]. To be truly practical, a drug detection system should be capable of detecting picograms of material and exist as a hand-held device, as will the proposed sensor.

2.1 IO Interferometric Chemical Sensor

The Georgia Tech drug detection and identification sensor system is based on an integrated optic (IO) interferometer [2,3] (i.e., an optical system on a chip) that has proven to be extremely sensitive to chemical changes occurring on the surface of a functionalized waveguide [4,5]. The unique design of the integrated waveguide interferometer provides a system capable of routinely measuring refractive index changes of $\leq 10^{-6}$. Sensors with this level of sensitivity are able to monitor refractive index changes associated with reversible chemical interactions involving only picograms (femtomoles) of material [3]. This capability opens up a totally new approach to chemical sensing that offers enhanced sensitivity, chemical selectivity and versatility, all based on surface chemistry interactions previously only observable using sophisticated analytical laboratory instrumentation.

The IO sensor technology is currently being developed for environmental monitoring, agricultural and food safety applications. Water quality monitoring probes capable of detecting benzene, ethylbenzene, toluene and xylene at the parts-per-billion in ground water have been demonstrated. A gaseous ammonia sensor designed to detect ammonia at concentrations of 100 ppbv has been developed for agricultural applications [3]. The IO sensor has demonstrated detection sensitivities at the picogram/milliliter level for biosensing applications based on immunoassays [4].

The IO chemical sensor technology exhibits several key advantages that make it attractive. These advantages include:

- **Multichannel sensing capabilities:** provides multiple drug detection capabilities from a common chip.
- **Particulate and vapor phase detection capabilities:** trace analyte detection from airborne particulates or vapor phase analytes
- **High sensitivity:** detectable concentrations levels of part-per-billion to parts-per-million by volume range (ppbv to ppmv range) or picograms on a mass basis.
- **Chemical selectivity:** enhanced chemical specificity through tailored reversible chemical reactions and molecular shape/size recognition.
- **Real time operation:** reversible reactions providing rapid response and concentration dependent measurements.
- **Compact system package:** configurations ranging in size from pen light to hand held calculator size typical.
- **Cost effective:** low cost, estimated to be as low as $200.
- **Low voltage/low power:** Low power consumption and low voltage (5 vdc) permitting battery operation.

2.2 IO Sensor Description.

The basic IO sensor structure (Figure 1), consists of a supporting substrate, a central waveguide film, and a covering superstrate film designed to interact with the species of interest. The optical source is typically a solid-state diode laser, with its output coupled into the waveguide by means of a surface grating coupler. The grating coupler eliminates the precise mechanical alignment normally required using edge coupling and only requires a relatively simple low-tolerance angular alignment to ensure a practical instrument for real world applications. Figure 2 is a photograph of a fully packaged four channel sensor system designed for environmental monitoring and detection of food-borne pathogens.

In a typical sensor configuration, the waveguide is a thin layer (< 200 nm) of a higher refractive index material deposited on the surface of an optically transparent substrate. The chemically selective layer on the waveguide surface may be a protein that binds with a specific antigen or antibody, a chemically active layer that undergoes a reversible reaction with the species of interest, or a selective film that undergoes a physical change such as swelling. In operation, a guided optical wave has associated with it, an evanescent electric field that penetrates the waveguide interface and into the chemically selective surface film. As a result of the evanescent field interaction, the phase of the guided wave is sensitive to any changes in thickness or refractive index of the chemically selective film. Chemical reactions on the waveguide surface typically introduce a phase shift (due to an index change associated with an electronic perturbation) that is easily detected by interfering the sensing guided wave with an unperturbed reference guided wave, and monitoring the resulting movement of the interference fringes with a suitable detector system. The observed phase shift or fringe motion is directly proportional to analyte concentration.

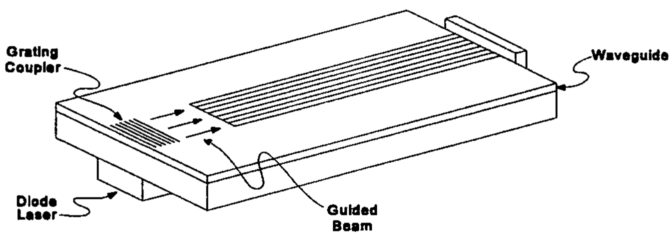

Figure 1. Multi-channel Integrated-Optic

3.0 INTEGRATED-OPTIC DRUG SENSOR DETECTION CHEMISTRY

The chemical selectivity and sensitivity of an IO sensor is dependent on the surface chemistry at the waveguide surface. To maximize chemical selectivity and provide concentration dependent measurement capabilities, functionalization chemistries are chosen that will react strongly but reversibly with analytes of interest. Acid/base reactions (*i.e.* proton transfer) have proven to be very effective for IO chemical sensing applications [3]. Dipolar changes caused by these reactions can be optimized to dramatically increase the effective index changes observed by guided optical waves. For chemical sensing applications such as drug detection and drug identification, an acidic or basic sensing surface is utilized. The acidic or basic strength of a sensing surface can be controlled to interact with a specific basic or acidic analyte. For example, it is has been shown this technique can be utilized to chemically discriminate between ammonia and amines, while detecting either of these species at ppbv concentrations [3].

A versatile drug detection system must be capable of detecting drugs based on volatile emissions from the drug in the free base form or alternatively as trace drug particulates in the acid salt form. In most cases there may be little volatile components other than associated precursors or solvents. The precursor components, however, tend to be highly volatile so they quickly dissipate and these volatile components also tend to be fairly common and may vary depending on drug synthesis techniques. This aspect makes discrimination from background sources more difficult and identification of drug type more complicated.

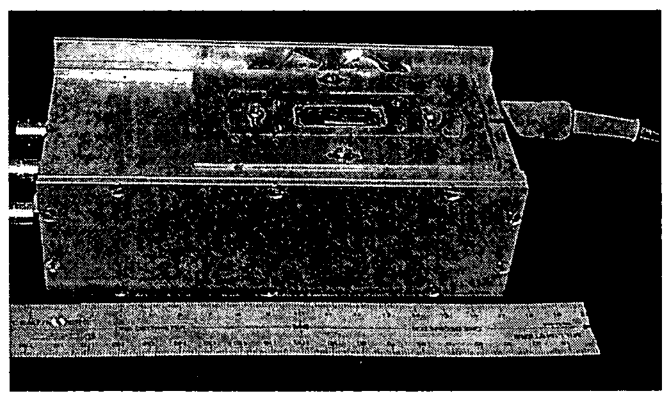

Figure 2. A Four-Channel IO Interferometric Sensor Package.

Because reliance on volatile components emanating from a drug sample is not dependable in all situations and for all drugs, detection based primarily on trace particulates must be utilized for a reliable and versatile detection and identification system. The non-volatile component of all the drugs in question is usually an acid salt (cocaine hydrochloride, for example). The acid salt can, however, be converted to a more volatile free base for detection purposes and subsequently detected using acid/base sensing films. The conversion process is accomplished by introducing particulates generated through air sampling or by swab samples into a thin matrix of a strongly basic ion exchange resin. These inexpensive, commercially available resins are by nature hygroscopic and will therefore provide the aqueous medium needed to effect conversion from the acid salt to the free base. The resulting free bases have minimal solubility in water, therefore, once neutralized the free base will volatilize out of the resin. Increased selectivity as well as interferant removal could be accomplished, if necessary, by the incorporation of a second ion-exchange resin (having somewhat different properties than the first), mounted in series with the first resin. For example, a proper choice of resins might allow cocaine and heroin to pass but retain stronger bases such as amphetamines and contaminants such as ammonia and alkylamines. A continuous air flow will draw the sample into the matrix and carry the volatile bases to the sensing surface. Detection time from the drawing of the sample, including volatilization and interaction with sensor surface, will be seconds or faster depending on flow rates.

Because heroin, cocaine, and methamphetamine have different base strengths (pKa = 7.9, 8.4, ~10 respectively), interferometric sensing channels functionalized with acidic sensing groups that bracket the pKa of each target analyte may be utilized to discriminate and define the drug species. In this case, each drug vapor will cause a strong differential response between adjacent channels. Only interferometers with pKa channels that lie on either side of the analyte will show a response. Interferometers with both pKa channels lying above or below the base strength of the analyte will react almost equally and therefore will optically cancel. Target analytes will give rise to unique response ratios between adjacent interferometers. Comparison of these response ratios from adjacent interferometers will allow for interferant subtraction and for the identification of the target analytes (or mixtures of analytes).

3.1 Experimental Results

To generate experimental results, a four channel integrated optic sensor was utilized in a package similar to that illustrated in Figure 2. The sensing channels on this device were functionalized with appropriate sensing chemistries for the selected drug simulates. The test analytes or surrogates selected for the laboratory testing were phenethylamine and N-methyl phenethylamine. The dimensions of the sensing channels on the IO structure were 10 millimeter length and .35 millimeters in width. The waveguide system consisted of a BK-7 glass substrate with a 0.14 micrometer silicon nitride film serving as the actual waveguide. The actual layout of an interferometer channel is illustrated in Figure 3. An IO interferometer consists of signal and reference guided wave arms that are interfered to generate the two optical signals. The waveguide total internal reflecting (TIR) mirror and beam splitter (BS) provided the beam combining functions. These elements and the grating couplers are etched into the waveguide film.

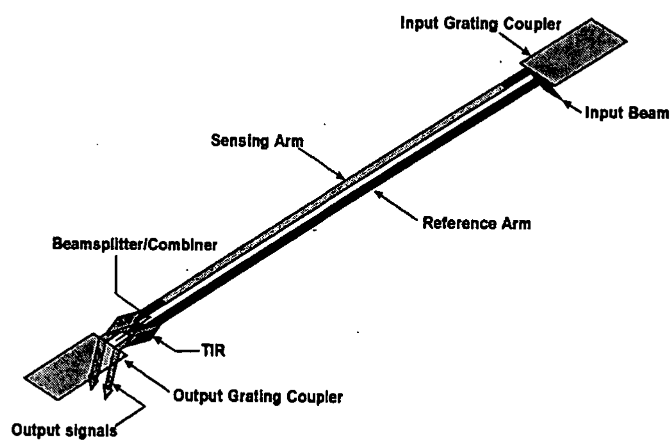

Figure 3. Single Interferometer Channel with Dual Output

Experimental results have been generated using both vapors and particulates. The vapor phase tests were performed using phenethylamine and N-methyl phenethylamine. These analytes were selected because they represent volatile vapor phase analogs to methamphetamine. To test these analytes, known quantitites were injected into a moving air stream flowing onto the sensor chip surface. The time dependent response was recorded. Current detection limits for the N-methyl phenethylamine are in the tens of part-per-billion by volume range. To date no test have been performed to evaluate potential interferant effects.

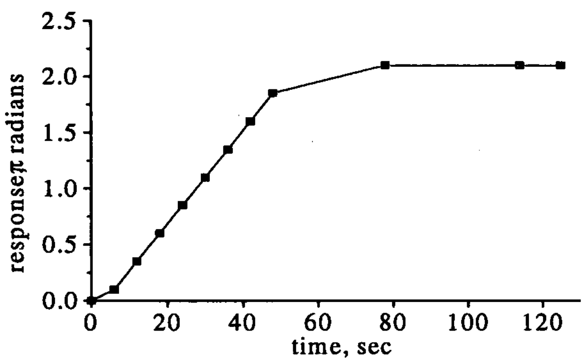

Figure 4: Sensor Response to 6 ppmv N-methyl phenethylamine

To evaluate particulates, phenethylamine hydrochloride was used as a surrogate for the non-volatile acid salt, a common form of non-volatile component for drugs (cocaine hydrochloride for example). To convert the acid salt to a more volatile free base, a strongly basic ion exchange resin was used. The HCl salt of phenethylamine is swept into a bed of the resin being held in a syringe. The volatile contents of the syringe were injected into the carrier air stream and introduced to the waveguide surface. Within seconds a response was observed with a signal to noise ratio of 40:1. A similar experiment in which vapor of phenethylamine was directly added to the in line air flow produced comparable results. These experiments show that the ion exchange resin efficiently converts the acid salt to the free amine, which can be subsequently detected by the proposed sensor.

4.0 SENSOR SYSTEM CONFIGURATION

A block diagram of a multi-channel analytical sensor is outlined in Figure 5. Key system components include the following elements:

- diode laser
- IO chip
- detector array
- signal processing electronics
- data storage
- display.

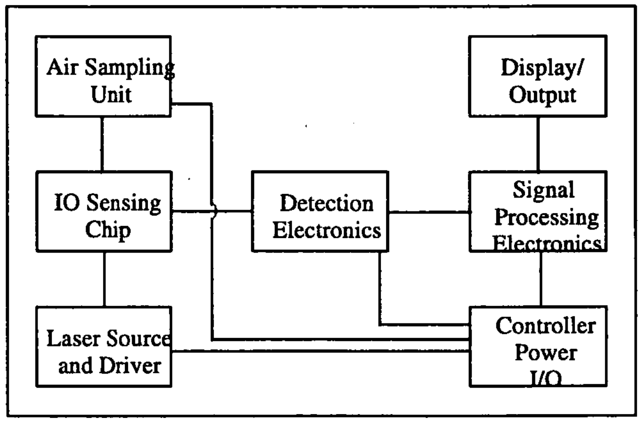

Figure 5. Block Diagram of multi-channel IO sensor system

Critical cost element components are the diode laser and signal detection electronics. Currently, diode lasers of the type used in compact optical disk read heads are utilized as the optical source. Component costs for these elements are approximately $7 per piece (Sharpe LTO 22MD) in lots of 10 or more. The detector array is a 128 element self scanned diode with 50 micrometer pixels on 63.5 micrometer center-to-center spacing available from Texas Instruments for under $10 per piece (TSL 401). This is a self scanning photodiode array with scanning rates in excess of 10 KHz. The TSL 401 is particularly attractive as it only requires 5 vdc power as does the diode laser. The IO sensor chip is based on a glassy material substrate and its projected cost varies from $1 to $10 depending on number of sensing channels (and production volumes). Projected cost for a simple threshold detector system indicates it can be produced for component cost of less than $100. More sophisticated instruments designed to function as an analytical tools exhibit projected cost of a few hundred dollars with actual cost dependent on processing and data storage capabilities.

Signal processing and data storage capabilities can be configured as desired based on the type of system. A simple threshold detector system would require very little in the way of electronics. A more complicated identification device would require processing power as well as some onboard memory. One option would be to include a "credit-card computer" (for example an S-MOS Cardio-486 available from S-MOS Systems, Inc.) which includes memory and processing capabilities in a single unit. Alternatively signal could be output to a portable computer with software for data analysis and display. Use of a portable enables a more permanent record which could be later used as documentation. It would also be possible to integrate the latter two options into a system which could store data on the run and be downloaded at the end of a day for example.

The current IO sensing chip incorporates four 350 micrometer (μm) wide interferometric sensing channels. The actual chip size is approximately ½ inch by 1 inch. The number of interferometric sensing channels on a common chip is currently being increased to 13 channels. This increase will not require any change in IO chip dimensions, the detection electronics or the overall package dimensions. Each interferometric sensing channel may be used for detection of a specific analyte, as a back up channel for redundancy or as a sensing channel to identify and remove signal resulting from interferant species that might be present. The practical limit on the number of sensing channels is in the range of 24 to 28 channels. That limit is currently imposed as much by the ability to discretely functionalize the individual interferometric sensing channels as by the available detection electronics. In all cases, the waveguide is constructed from a high index thin film deposited on a glassy substrate material; tantalum pentoxide or silicon nitride are typically used for the IO sensor waveguide systems.

5.0 SUMMARY

The IO sensor technology provides an attractive inexpensive and unique way to detect illicit drugs either in their volatile free base form or as particulate acid salts. In line pretreatment converts the analyte of choice to its free base form for detection. Judicious choice of sensing films allows the sensor to distinguish the various drugs from each other using their differing base strengths while canceling out interferants. Sensitivities can range from parts-per-million to parts-per-billion for a real-time reversible sensor. Added sensitivity can be achieved by tailoring the chemistry to act as an integrating sensor, where the collection time determines the lower detection limit. The multiple sensing channels allow for multiple analyte detection on a single sensing chip. This compact, low powered sensor will find use in a variety of applications especially where covertness is required. Finally the low cost of the sensor increases its availability to all levels of law enforcement.

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Mini-Lidar for Non-contact Chemical Identification

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Abstract

Brookhaven National Laboratory (BNL) is developing a compact, portable mini-Lidar system for *in situ* optical fingerprinting of unknown liquid and/or solid mixtures, such as liquid in a tank or powders on surfaces. This compact system, when fully developed, will allow either short-range non-contact (i.e. one to few meters distance) or contact (i.e. via fiber-optics) detection and identification of drugs or chemical/biological agents related to weapons of mass destruction.

I. Introduction

The compact mini-Lidar system that is being developed, will be a small, rugged, mobile instrument capable of rapid chemical identification. It is designed specifically for scenarios where liquid or powder chemicals are identified in-situ either on a surface, on the ground, or mixed with water or other solvents. The current technology for unknown chemical identification, whether on a surface or mixed with water/solvent, requires that samples (liquid, powder, or soil) be collected in a BIDS-type of sensor truck and then analyzed. These procedures can be complex, time-consuming, and potentially hazardous, depending on the chemicals. The portable mini-Lidar system will simplify the process by enabling non-contact or near-contact (with fiber-optic attachment) *in situ*, real time analysis of unknown chemicals and biologicals by using Raman, pre-resonance Raman, or the resonance Raman finger-printing technique.

In recent years, several types of compact, portable Raman spectrographs have been developed. Data collection techniques include contact microscopy with a fiber optic probe [1], detection of trace gases adsorbed on an alumina substrate [2], surface-enhanced Raman [3], and near-IR Raman using a fiber optic probe [4]. While there are some similarities between these instruments and the one we are going to construct, the fundamental difference is that the BNL mini-Lidar system will be capable of *stand-off* (non-contact) detection; the contaminants can be analyzed *in situ* at a distance without being touched. The detection can be done even through windows (glass or quartz) so that a protective barrier can be maintained between the operator and the contaminated area. In contrast, the other spectrographs [1-4] require that the sample be collected or come into contact with a probe.

Portable Raman Mini-Lidar

II. Scientific Basis

The mini-Lidar system will exploit the phenomenon of Raman scattering. Raman scattering is a coherent, two-photon process that conveys information about the vibrational mode-structure of the scattering molecule. In normal Raman scattering, an incident photon of frequency hv excites a molecule from its ground electronic level to a "virtual" state. If the energy of this virtual state is sufficiently different from that of a nearest real level, the molecule decays quickly back to its ground level; a second photon is emitted almost instantly. If the emitted photon has the same energy as the incident one, the process is called Rayleigh scattering. However, interaction of the incident photons with vibrational modes of the molecule can shift the frequencies of the scattered photons. The shifts are proportional to the energies of the discrete vibrational modes of the molecule. This unique set of frequency-shifts, called Raman shifts, produces a spectrum that is a unique vibrational fingerprint of the interacting molecule.

Some characteristic vibrational motions of a molecule can also be observed via its infrared (IR) spectrum. But Raman has many unique features. The Raman line positions and their relative intensities, i.e. Raman fingerprint of the chemical, are not extremely sensitive to the physical states (essentially having the same fingerprint for solid, liquid and gaseous state) and the surrounding environment. For example, atmospheric gases and water vapor have no interference effects on the Raman process. This is not true for fluorescence and IR absorption. The Raman fingerprint is also independent of the excitation frequency, a feature unique to Raman spectroscopy. Finally, Raman lines are typically fewer in number and narrower than IR and fluorescence spectra, thereby providing better identification of compounds in mixtures and solutions.

It is understood that normal Raman scattering is a weak process, and the cross-sections are smaller than those of absorption and fluorescence. Consequently, the stand-off distance of a Raman system cannot rival that of absorption or fluorescence system based on scattering/absorption alone. But the unique features of Raman certainly make it a viable technique for short range applications, especially for incident response and on-site investigations. It can yield more molecule-on-surface information than absorption or fluorescence. Furthermore, Raman spectra can yield quantitative information based on signal strength.

For detecting chemical warfare (CW) and biological warfare (BW) related chemicals, the preferred Raman excitation wavelengths are in the ultraviolet (UV). Using a UV source has four distinct advantages:

(1) First, there is a ν^4 dependence of the Raman scattering intensity on excitation frequency. For example, the scattered photons increases by a factor of sixteen whenever the excitation frequency is doubled.

(2) There is a potential of additional pre-resonance or resonance enhancement of the Raman cross-sections (2-4 orders of magnitude) as the excitation photon energy approaches that of an allowed electronic transition, as occurs in the UV for many chemical/biological species. The combination of the ν^4 dependence and the potential of pre-resonance or resonance enhancement of the target chemicals indicate the overwhelming advantage of using UV excitation.

(3) Third, the usual degrading effects of background light on signal-to-noise ratio in day-time operation can be eliminated when the system is operated in the UV solar blind region (λ<300 nm).

(4) Finally, the availability of optical multichannel analyzers in the visible and ultraviolet permits full capture of Raman fingerprint for every laser pulse. In this way, there is no need to operate the spectrometer in a scanning mode; hence, no parts need to move during data acquisition of a Raman spectrum.

III. System Architecture

The mini-Lidar system consists of a compact Nd:YAG laser (wavelength selectable from 266 nm, 355 nm, 532 nm, and 1.06 µm), a 74 mm single grating “predisperser”, a 0.25 m single grating spectrometer, an intensified CCD (ICCD) array detector, and a compact receiver-telescope. A Macintosh power-book lap-top computer both controls the equipment and acquires and analyzes the data. The mini-Lidar system presently runs on line voltage and eventually can be run on batteries. All of the Lidar components fit into a rolling cart approximately 40 inches high with a footprint about 30 inches by 24 inches. [See Photo 1] The upper deck contains the laser, receiver-telescope, and spectrometer/detector. The middle section houses the roll-out lap-top computer, and the lower section contains power supplies and electronics. The electronics can be reduced to a smaller package at a later date.

The laser beam is coaxial with the receiver-telescope, so that the illuminated surface is always within the field-of-view of the telescope, regardless of the distance to the target. Pointing and steering are accomplished by moving the entire upper deck. This technique preserves the relative alignment of all of the optical components. The signal collected by the receiver-telescope is sent into the predisperser, which acts as a sharp-cut-off filter to pass the Raman signal and block the much stronger elastic backscattering (Rayleigh scattering) into the spectrometer. The latter is a 0.25 m single-grating spectrometer, which disperses the signal light onto the ICCD array detector at the spectrometer’s exit port.

While the emphasis thus far has been on the development of a stand-off chemical/biological sensor, it is possible for the mini-Lidar to perform contact detection as well using a fiber-optics probe attachmant. The probe would have two channels: one to guide the laser light to the targeted spot for interrogation, and the other to collect the return signal and send it back to the spectrometer. The probe would replace the telescope in situations where there is no clear line of sight to the contaminated area (such as an underground storage tank). The ability of the mini-Lidar to do contact as well as stand-off detection would give it a versatility unrivaled by other techniques.

The mini-Lidar system described above will be tested in the coming months for its functionality at short-range. The size and weight will be reduced later as appropriate. The ultimate goal is to have a system easily maneuverable and portable for field applications.

IV. Laboratory Measurements

To gain insight into the performance of the mini-Lidar chemical sensor, we have conducted several laboratory simulation experiments and an actual system test. Some results will be presented here. Since the mini-Lidar system has been assembled from readily-available components, it is not the optimum system. The primary objective has been to demonstrate its novelty and potential as a useful instrument for on-site chemical detection and identification. Once this has been accomplished, the mini-Lidar will be optimized to achieve the highest sensitivity possible in a smaller package.

Figure 1 shows a Raman spectral fingerprint of a few drops of nitrobenzene on a rock taken from Battery Park in NYC. This spectral fingerprint was collected with 3600 laser pulses (<0.5 mJ/pulse), 250 nm wavelength, and at a distance of about 1.5 m from the spectrometer. The intent of this experiment is to demonstrate that the Raman fingerprint technique can capture both chemical as well as biological signatures at the same time, should they be present together. Here, Raman signatures of nitrobenzene and the naturally occurring mold spores/pollen are clearly evident. The N_2 Raman peak comes from the atmospheric nitrogen near the sample. It should be noted that resonance Raman is the preferred optical technique in studying the spectral as well as dynamic behavior of biological species.

Figure 2 is another example of Raman fingerprinting of biological species - E-Coli. It was placed onto a freshly cleaved surface from the same NYC rock. Its signature matches to that of the published data [5] shown in Figure 3, labeled ECO.

A preliminary test of the mini-Lidar chemical sensor system is shown in Figure 4. The cyclohexane solution is contained in a small quartz cell, two meters away from the mini-Lidar. Data collection time was 7 seconds, and the laser wavelength was 532 nm. The numbers on the graph are the approximate shifts in wavenumbers of the Raman lines from the Rayleigh line. The system was not optimized before this very preliminary test.

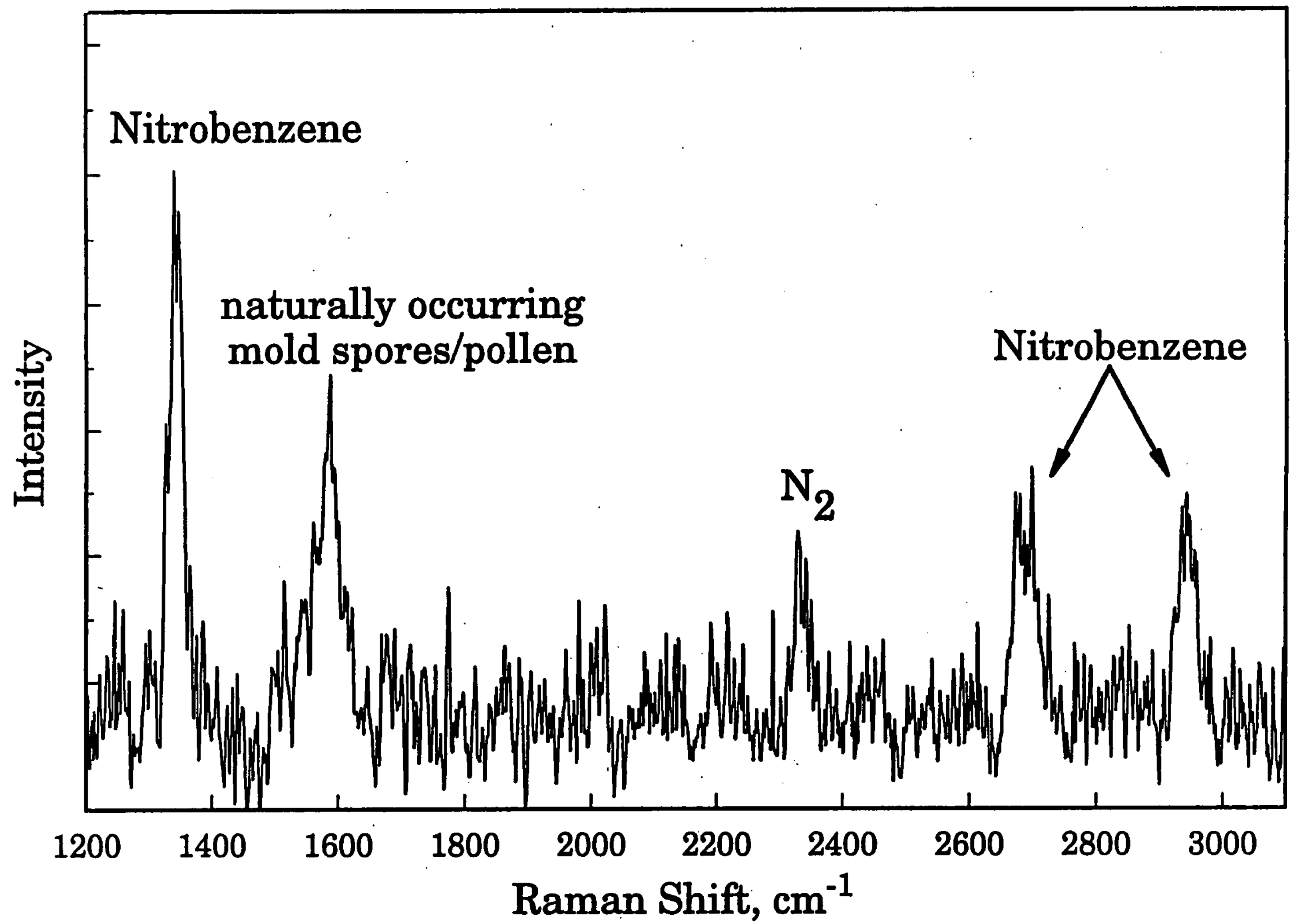

Figure 1. Raman spectral fingerprints of naturally occurring mold spore/pollen and nitrobenzene on NYC rock. N_2 peak is atmospheric nitrogen.

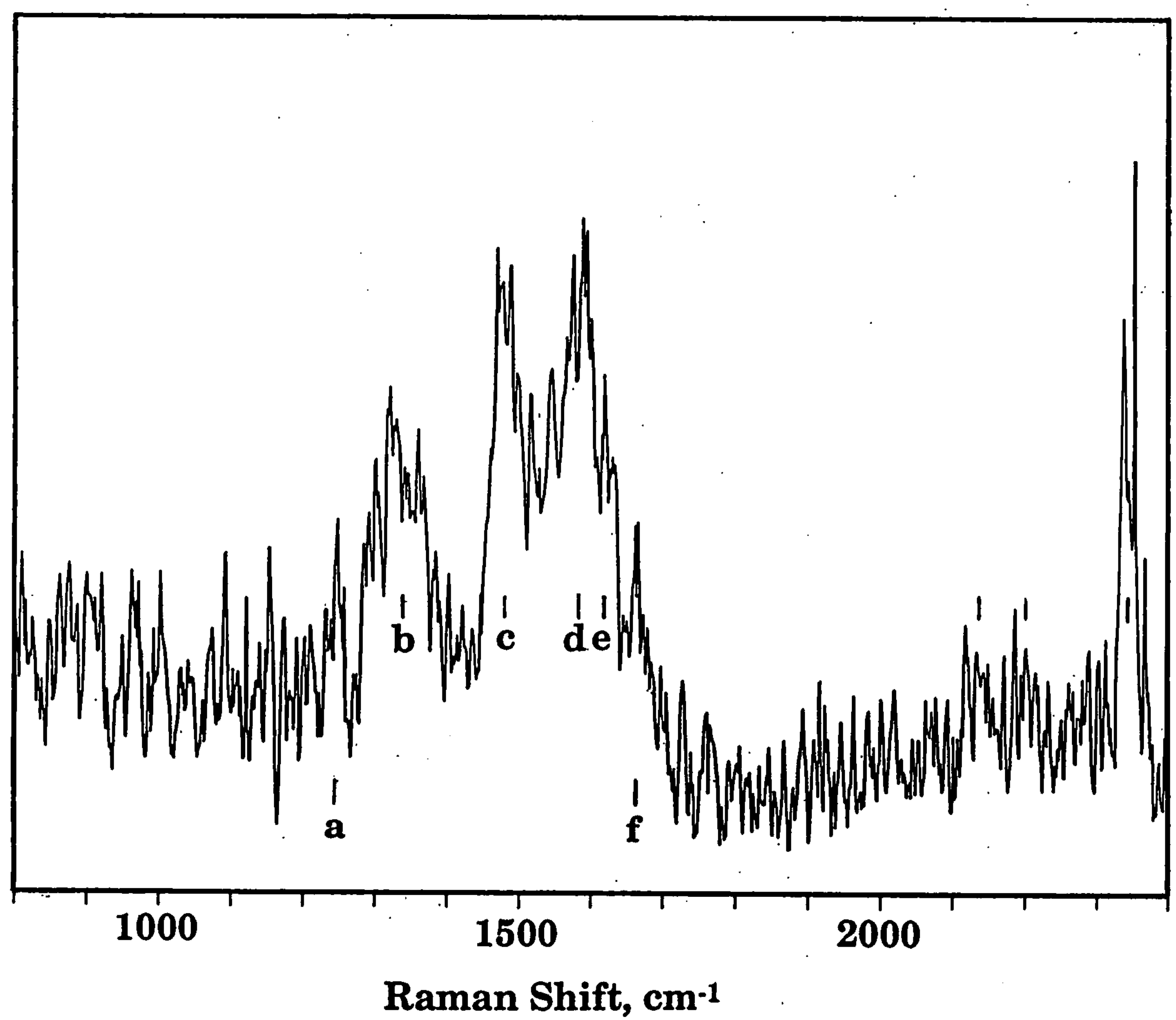

Figure 2 Raman spectral fingerprint of E-Coli on NYC rock.

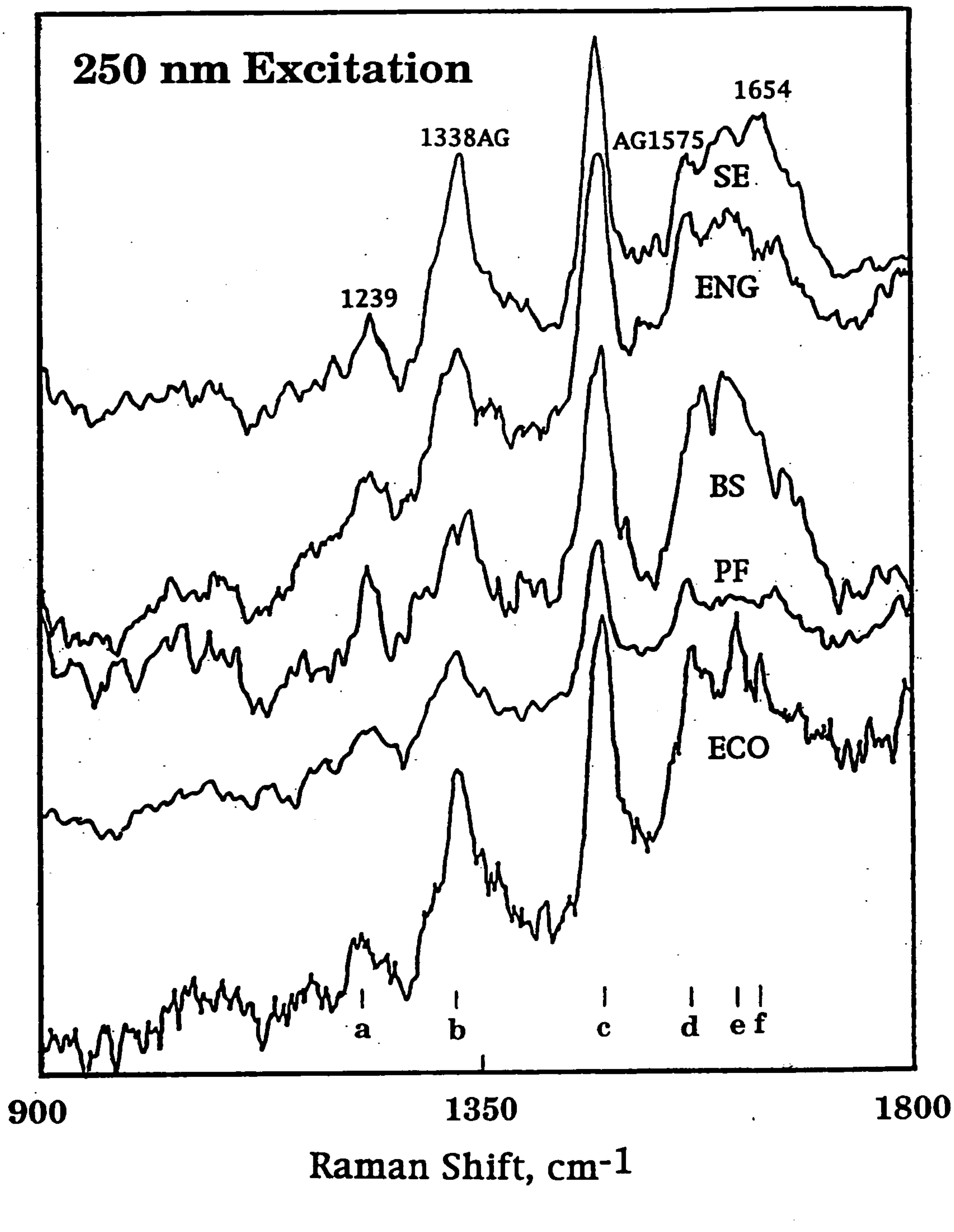

Figure 3 E-Coli Raman spectral fingerprint measured by W. H. Wilson [Ref. 5].

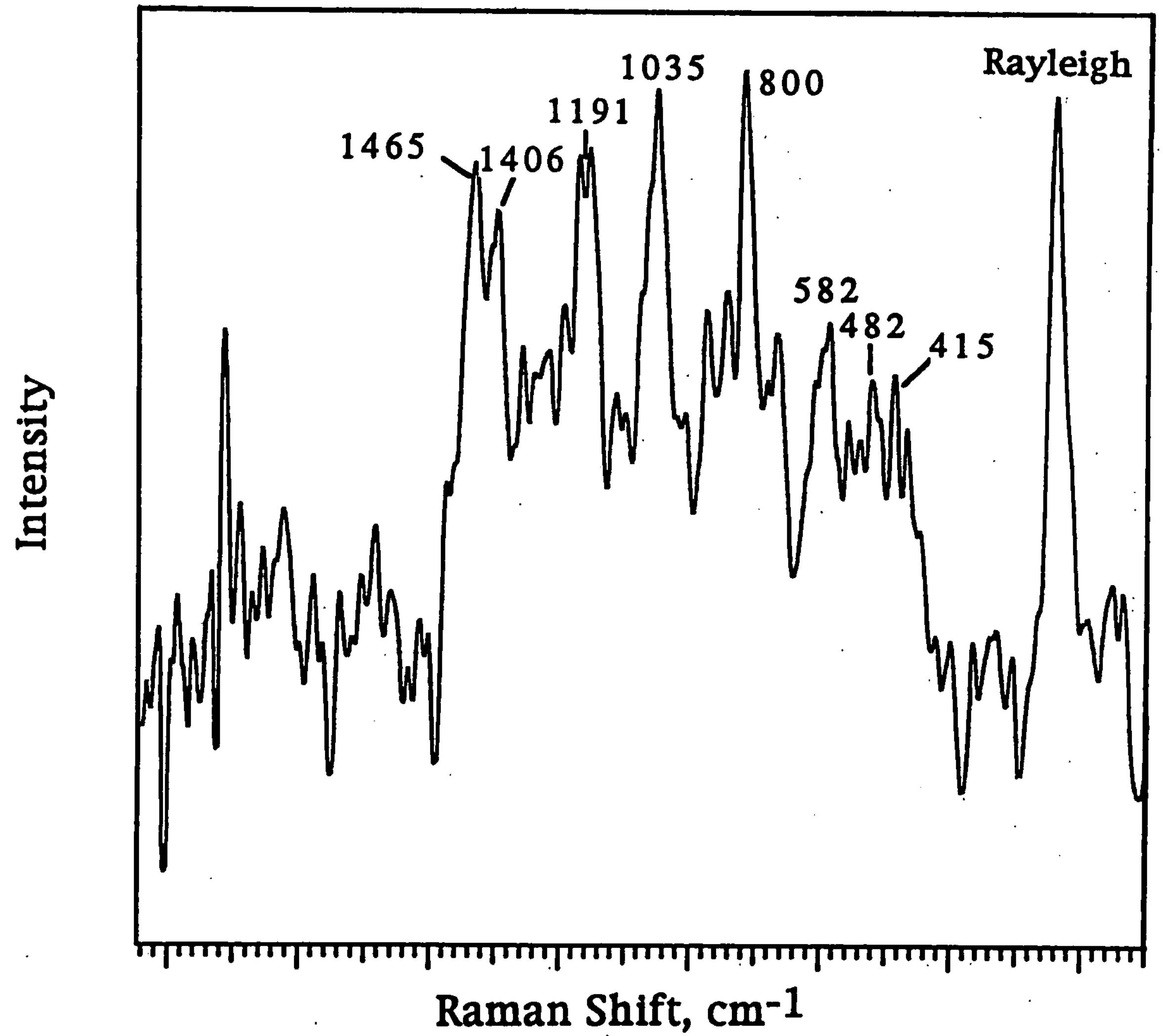

Figure 4 Nitrobenzene Raman spectral fingerprint as measured by the mini-Lidar chemical sensor at a distance of two meters.

Therefore, we are confident that the system, once it is properly tuned and aligned, would perform much better than what is shown here. For comparison, a normal Raman spectrum of cyclohexane is shown in Figure 5. This spectrum was taken with a FT-Raman spectrometer at 1.064 micron.

V. Conclusion and Discussion

Brookhaven National Laboratory has been developing Raman, pre-resonance and resonance-enhanced Raman LIDAR as a means of remote detection of chemical effluents. The work has been funded by the Department of Energy (DOE). As a result, we measured for the first time many chemical Raman fingerprints. We have also built and tested two mobile Lidar systems, outfitted with state-of-the-art frequency-tunable-lasers, receiver-telescopes, spectrometers, detectors and computer hardware/software. In data processing, we have applied pattern recognition for chemical identification. Other novel techniques such as Rayleigh line suppression, and broad-background removal (FreMERS - a frequency modulation technique) have been tried successfully in the laboratory. The mini-Lidar is the third system in the series of development and is solely for short-range applications. We expect that this mini-Lidar sensor will be useful for law enforcement and incident response.

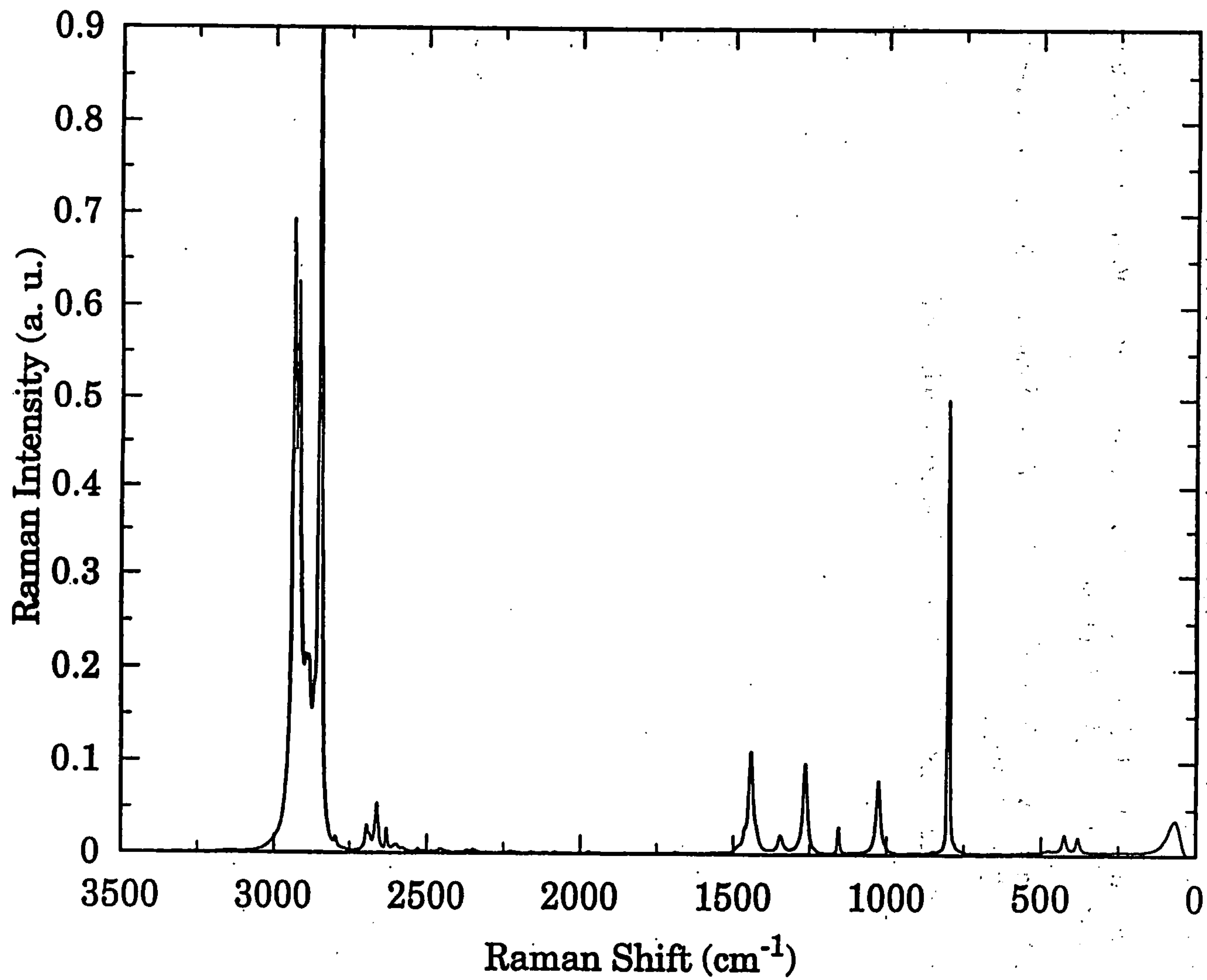

Figure 5 Nitrobenzene Raman spectral fingerprint as measured by FT-Raman spectrometer at 1.064 micron.

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Immunochemical Detection of Drug Vapors

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ABSTRACT

An immunoassay film badge (IFB) system provides a versatile means of detecting the presence of drugs such as cocaine and heroin via highly sensitive and specific detection of vapors. The IFB is made by spotting (3 mm diameter spots) monolayers of antibody toward the intended target compounds on a special semimirror. The area covered by a spot transmits less light, in the normal direction, than the bare mirror. When antibody binds its target compound, further diminution of transmission occurs. A photometer, which is the other component of the system , measures the effect. A comparator spot is used to compensate for nonspecific environmental effects.

The IFB has been shown to detect the vapors of several drugs at the parts-per-trillion level in ambient air. By detecting caffeine on the breath, it has also been shown capable of breath testing. The fact that the IFB is able to rapidly detect drugs at very low concentrations has recently been independently confirmed.

This paper describes the technical status of the IFB and its further likely applications, such as the detection of couriers who have ingested drug-filled condoms via breath analysis. The potential for this application is suggested by indications that substances leach from the latex rubber into the digestive tract and find their way into the breath.

1. Introduction

Inasmuch as drugs are not high molecular weight compounds, they have measurable vapor pressures. Detection of drugs by means of their vapors offers certain advantages, as for example the finding of a drug's presence prior to finding its exact location. Also, as in the case of the breathalyzer, detection of selected compound vapors, including drugs, on the breath may eventually be applied in the field.

Among the many means of detecting vapors, the immunoassay film badge of Diametrix Detectors is unique in its combination of high specificity, sensitivity, and simplicity of operation such that it provides a potential for a low cost system with high performance capabilities. This paper discussses the device, its performance, its current status, and its applications for the detection of drugs.

2. The Immunoassay Film Badge (IFB)

The immunoassay film badge (IFB) is comprised of 3 mm diameter monomolecular layers of antibody attached to an indium semimirror and, as such, is a unique combination of biosensor (the antibody) and transducer (the semimirror). The semimirror (hereafter called the mirror) is made by vacuum deposition of a < 500 angstrom layer of indium on a transparent substrate (usually a microscope slide cover glass). The indium exists as small, non-contiguous islands that exhibit the surface plasmon and polariton effects when illuminated by visible light. A typical mirror transmits and reflects about equal portions of incident light. A spot on the mirror that is covered with a monolayer of a poor conductor, such as antibody, becomes visible because it significantly modulates the plasmon/polariton effects. Such a spot appears darker than the surrounding mirror when illumination and viewing are approximately normal to the plane of the mirror, as is the case throughout this work. The decrease in optical transmission for a given IFB is proportional to the thickness of the organic material, and binding of target molecules to the antibody further darkens the spot.

Consider the optical densities of the bare mirror, the antibody spot before exposure to the antibody's target vapor, and the post-exposure antibody spot (antibody plus target compound) to be OD1, OD2, and OD3, respectively. That OD2 is greater than OD1 can be seen with the unaided eye. That OD3 is greater than OD2, although not usually visible to the eye when the target compound is of low molecular weight, can be measured with a photometer.

It has been found that cocaine will bind to its spot from the vapor phase when the temperature is between 1 and 52 degrees C and the relative humidity is between 10 and 100%. It appears that water mediates the binding of the target vapor to its antibody on the IFB.

A typical IFB has one or more sensor spots that target one or more comopounds plus a comparator spot. A protein that has no specific affinity toward any vapor likely to be in the environment is used as the comparator, which serves to compensate for non-specific environmental factors, such as dust, that will change the OD of a sensor spot. Thus, the key datum for a given sensor is the change in OD ratio, sensor to comparator, when the IFB is exposed to air, breath, or other sample material.

The sensors have excellent specificity and sensitivity. The antibody collects target molecules from the air with concomitant changes in OD. Special sample collection and processing methods are absent. Use of the IFB is extremely simple, since special sample collection and processing methods are absent. In most of the work reported here, a Macbeth densitometer was used to measure pre- and post-exposure OD, and exposure to saturated target vapor took place in a closed 100 ml Coplin jar.

A brassboard reader has been constructed that draws air samples past, and measures optical transmissions of, a 4-spot IFB and passes the data to a laptop computor for instant ratio analysis.

The reader, which enables real-time detection of target vapors, is currently under test. When fully operational, the reader will greatly facilitate data acquisition.

3. Detection of Drug Vapors with the IFB

Cocaine, morphine, heroin and THC vapors in ambient air have been detected by IFBs. Given good batches of mirrors, it is possible to make IFBs that respond very rapidly, and the rate of change, R, of optical transmission ratios can be measured from a sequence of short exposures. It has been shown (1) that R is related to the time of exposure, t, by the expression:

$$R = bt^m, \qquad \text{(eqn.1)}$$

where b and m are constants.

In that work, m and b, calculated with t in minutes and data averaged from four cocaine IFBs, were -0.8085 and 2.8109, respectively. The standard deviation of data points about the line was +/-37% relative. The noise level of the densitometer was such that a ratio change of 0.15%, relative, indicated detection with a 95% probability, given sensor and comparator pre- and post-exposure data sets of 9 readings each. This level of change was reached, according to eqn.1, and the constants given above, in 0.04 minutes, on the average. As can be seen these IFBs gave extremely rapid detection of cocaine vapor at ambient temperatures.

An independent test of several multispot IFBs targeted toward cocaine was recently carried out by D.Hoglund et al (2). They used a vapor generator direct puffs of cocaine vapor, lasting from less than a second to a few seconds, across the IFBs and found that 75% of the sensor spots detected puffs containing from 115 to 500 picograms of cocaine. Thus, an IFB with 3 cocaine sensor spots had a 98.4% probability of detecting cocaine vapor. In the test, there were no false positives and none of the IFBs failed to detect cocaine when present. Further such tests are planned.

4. Breath Testing and the Detection of Couriers

As may be inferred from the fact that the IFB operates well in warm, humid conditions, it is able to detect substances in breath. This was shown to be the case by the ready detection of caffeine on the breath of a person who had consumed coffee (3). The passage of a single breath over an IFB was enough to produce a positive response. Like alcohol, when caffeine is in the blood, a portion of it appears in the breath. Thus, it is likely that the IFB can detect the presence of drugs in the body via breath testing.

A technique for smuggling drugs is for a courier to swallow drugs packaged in latex condoms. There are numerous compounds in latex that could serve as indicators, on the breath, of swallowed latex. In addition to cogeners of natural rubber (amino acids, low molecular weight isoprenoids, sugars, and so forth), additives are used to assure the desired final quality of rubber. Such additives include soaps or surfactants, dispersing agents, antioxidants, vulcanizing accelerators, thickeners, and heat sensitizers. A typical latex formulation will include natural rubber, a thiazole accelerator (such as 2-mercapto-benzothiazole), a secondary accelerator (such as diphenylguanidine, a stryenated phenol antioxidant, sulfur, potassium hydroxide, zinc oxide, and stearic acid.

Isoprenoids, thiazoles, and guanidines are likely candidate indicators for detecting latex in the body Their vapor pressures should be acceptable, and the production of antibodies toward these compounds would be straightforward. They can be expected to leach from the latex and appear on the breath either directly from the gastrointestinal tract or, after absorption into the blood, from the lungs.

5. Present Status of the IFB and Discussion

As can be seen from the foregoing, the IFB can rapidly detect target vapors at very low concentrations. However, as the data show, there has been considerable performance variability among IFBs. This has been traced to variability of mirror microstructure. Until recently, Diametrix has acquired mirrors from outside vendors, and control of this variable proved to be elusive. Diametrix has recently acquired its own vacuum coater, and improvements have already been obtained. For example, the standard deviation of optical densities within a batch of mirrors is now about one-third that of mirrors from outside vensors. Although Diametrix is still in the process of determining the preferred parameters for producing mirrors, early IFB data indicate that improved performance consistency will result from reduced variability among mirrors.

6. Acknowledgements

We wish to thank the U.S.Customs Service for its support of this work. We also wish to thank C.Coats and S.Kulhanek for their participation in the most recent IFB work.

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Evaluation of Three Prototype Cocaine Vapor Detectors Under Controlled Operational Conditions

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Abstract

The Department of Defense Counterdrug Technology Development Program has sponsored the evaluation of three prototype vapor detectors for their ability to detect cocaine vapor emanating from seized cocaine hydrochloride (HCl) bricks. The detectors were based on ion mobility spectrometry, field ion spectrometry, and fast gas chromatography with surface acoustic wave detection. Evaluations were conducted using environmentally sustained laboratory and controlled operational conditions, the temperature range of 77–158 °F (25–70 °C) with relative humidity in the range of 5–20 percent.

For controlled operational studies, a 1400 ft^3 intermodal shipping container loaded with 4 to 76 kg of seized cocaine HCl bricks was incubated in an environmental chamber for a minimum of 48 hours. Vapor samples were collected for analysis through a port in the side of the shipping container. The cocaine HCl bricks were loaded into the shipping container on a wire screen table designed to maximize exposed surface area. Two of the three detectors successfully detected cocaine vapor at 158 °F, 20 percent relative humidity. Cocaine vapor was not detected consistently at 158 °F, 5–6 percent relative humidity, and was not detected by any detector at 122 °F or 77 °F. Vapor samples at each test condition were also collected onto sorbent tubes for GC/MS analysis.

Preliminary laboratory tests indicated that the detectors could successfully detect low levels of cocaine HCl vapor. However, under controlled operational conditions, the amount of cocaine vapor available was insufficient for consistent detection. This paper will also provide the results of the sorbent tube analyses and discuss other chemical signature candidates suitable for vapor detection.

(Paper not available at time of publication)

Anomalies in the Detection of Contraband Drugs Using Ion Mobility Spectrometry

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ABSTRACT

The use of ion mobility spectrometry (IMS) for the detection, identification and semiquantitative analysis of contraband drugs and their decomposition products is well documented. Challenges in using IMS include the possibilities of obtaining anomalous results due to factors such as the limited dynamic range of the method, masking effects by interferences, competition in the ion chemistry, decomposition of the target compounds during analysis, differences in the heat conduction and sorption properties of sample holding materials, and variations in instrument performance. This paper describes two of several IMS studies we have performed in which unexpected results were obtained. In one study, an attempt was made to use IMS for the identification and analysis of two known decomposition products of cocaine i.e., anhydroecgonine methyl ester (AEME) (methyl ecgonidine), and ecgonine methyl ester (EME) (methyl ecgonine) in the presence of each other. These compounds exhibit ion mobility values which are relatively close (reduced mobility constants, K_o: 1.505 and 1.485 cm^2V^{-1} sec^{-1}, respectively). Our studies with various mixtures of AEME and EME standards led to a single peak which could not be resolved. It was also found that amounts of either AEME or EME may be underestimated when the other compound is present. Furthermore, IMS does not appear to be useful in estimating total AEME-EME. Caution needs to be taken in reaching conclusions in compound identification and analysis when both AEME and EME may be present. In another study, amounts of 6-acetylmorphine were examined for effects on the IMS detection and signal amplitude of heroin. 6-Acetylmorphine is a known hydrolysis product of heroin. IMS studies with various mixtures of 6-acetylmorphine and heroin hydrochloride (from 25-100 ng each in different ratios) showed that the intensity of the main heroin peak decreased as much as 62 percent, depending on the amount of 6-acetylmorphine present. Clearly, the amount of heroin in a sample may be underestimated if 6-acetylmorphine is also present.

1. Introduction

The use of ion mobility spectrometry (IMS) for the detection, identification and semiquantitative analysis of contraband drugs and their decomposition products is well documented [1-5]. IMS involves gentle ionization of target analytes followed by measuring the velocity of the product ions in a drift tube.

Historically, this technique has been called gaseous electrophoresis and plasma chromatography [6]. The analytes are ionized and the product ions pass through a drift tube. Characteristic ion mobility peaks are displayed as peak intensity vs. drift time. Analysis involves use of peak amplitudes and ion mobilities (reduced mobility constants, K_o, $cm^2\ V^{-1}\ sec^{-1}$). The amplitude is directly proportional to the amount of sample present, and the K_o value can be used to identify target analytes. Several excellent reviews of IMS are available [7-11].

There are many challenges in attempting to use IMS for analytical applications as outlined in the abstract. The present paper describes two of several IMS studies related to cocaine and heroin in which unexpected results were obtained. In one case, it was found that IMS peaks of certain mixtures of two common reaction products from cocaine (AEME and EME) could not be resolved. In another case, it was found that the presence of 6-acetylmorphine, a hydrolysis product of heroin, led to significant decreases in the IMS amplitude of the heroin peak.

2. Experimental

Reagents

Anhydroecgonine methyl ester standard in acetonitrile (1.0 mg/mL), Radian International, Catalog No. A-034, 99% purity; ecgonine methyl ester standard in acetonitrile (100 µg/mL), Radian International, Catalog No. E-008, 99% purity; heroin hydrochloride standard in methanol (100 µg/mL), Sigma Chemical Co., Catalog No. H5144, 99% purity; and 6-acetylmorphine standard in acetonitrile (1.0 mg/mL), Radian International, Catalog No. A-009, 99% purity.

Instrumentation

Barringer IONSCAN ion mobility spectrometer, Model 400 settings: Mode - positive ion; analysis time - 8 seconds; drift tube: 233 °C; inlet: 275 °C; and desorber: 288 °C. The sample membranes were Barringer Teflon™, 50 µm pore size.

The instrument software allows calculation of peak amplitudes as either maximum, cumulative or average (obtained from a Gaussian fit of a peak) values. Average amplitudes were utilized for the calibration curves and semiquantitative analyses described in the present paper.

Procedures

Anhydroecgonine methyl ester (AEME) - ecgonine methyl ester (EME) IMS calibration curves

Calibration curves were obtained using 1 µL each of acetonitrile solutions: 0.2, 0.5, 1, 5, 10, 25, 40, 50, and 100 ng/µL (AEME) and 0.5, 1, 5, 10, 20, 25, 30, 40, 50, and 100 ng/µL (EME). The aliquots were applied individually to Teflon™ membranes using a 1 µL syringe. The syringe was cleaned before each deposition first with acetonitrile or methanol, then with the particular test solution. In each deposition, the solution was spread evenly on the membrane with the tip of the syringe needle. The solvent was allowed to evaporate for approximately one minute before the IMS analysis. The IMS analysis was repeated, usually one or two times, until no residual sample was detected on the membrane. Though all results were recorded, only results from the first run were used for the calibration curve. Each sample was analyzed in triplicate.

IMS of anhydroecgonine methyl ester (AEME) and ecgonine methyl ester (EME) mixtures

Appropriate volumes of 100 µg AEME/mL acetonitrile, 100 µg EME/mL acetonitrile and acetonitrile were pipetted (Eppendorf™ pipettes) into vials making up solution volumes of 100 µL for each mixture. Aliquots (1 µL) were deposited on Teflon™ membranes as described above. The ratios by weight (AEME/EME) for individual samples were: 10 ng/10 ng, 10 ng/20 ng, 10 ng/40 ng, 10 ng/60 ng, 10 ng/80 ng, 20 ng/10 ng, 40 ng/10 ng, and 60 ng/10 ng.

IMS of heroin hydrochloride and 6-acetylmorphine mixtures

The analysis of heroin hydrochloride and 6-acetylmorphine by IMS was accomplished by applying 1 µL aliquots of heroin hydrochloride to Teflon™ membranes using microcapillary pipettes followed by aliquots of solutions containing different amounts of 6-acetylmorphine. Each solution was spread evenly on the membranes using the tip of the microcapillary pipette. The solvent was allowed to evaporate prior to analysis.

The heroin hydrochloride methanolic solutions contained 25 ng, 50 ng, 75 ng or 100 ng heroin freebase per µL. Each amount of heroin was analyzed in the presence of 25 ng, 50 ng, 75 ng and 100 ng of 6-acetylmorphine. These amounts of 6-acetylmorphine were contained in 1 µL, 2 µL 3 µL and 2 µL acetonitrile solutions, respectively. Each combination was analyzed in triplicate.

3. Results and Discussion

Anhydroecgonine Methyl Ester (AEME) and Ecgonine Methyl Ester (EME)

AEME appears in IMS plasmagrams of high purity cocaine freebase and cocaine hydrochloride samples due to cocaine decomposition during thermal desorption [12]. AEME has also been noted in seized cocaine samples [3], and in the air from cargo containers containing cocaine [13]. EME is a hydrolysis product and a metabolite of cocaine [14]. Benzoylecgonine is a related metabolite [15].

We have been involved in studying the chemistry of cocaine and have found IMS to be a convenient tool to detect and identify reaction products. K_o values for cocaine and its common reaction products are given in Table 1. The compounds can be differentiated based on K_o values though sensitivity may vary widely. Our cocaine reaction studies required differentiation of AEME and EME as products. We were also interested in semiquantitative information. Calibration curves for AEME and EME are shown in Figures 1 and 2. It appears that analytical information can be obtained using pure compounds from less than a nanogram to approximately 30 ng. Above 30 ng, saturation of the system becomes evident.

An unexpected finding was that IMS peaks from AEME and EME mixtures could not be deconvoluted using the instrument software. The K_o values and average amplitudes for these mixtures are given in Table 2. The peak amplitudes from AEME/EME mixtures were about 50% lower than expected by adding amplitudes of individual components using their calibration curves. This is not surprising with higher amounts because of saturation effects but was unexpected for AEME-EME totals of 30 ng and below. It is possible that amounts of either AEME or EME may be underestimated when the other compound is also present. This is probably due to effects of peak shape but was not investigated further. AEME shows higher sensitivity to IMS than does EME (Figure 1 and 2) but this is of little consequence in attempting to analyze total AEME-EME.

It is clear from the data in Table 2 that K_o values cannot be used to differentiate AEME from EME in their mixtures. (It may also be difficult to identify these compounds using IMS in the presence of other substances which have similar ion mobilities.) Identification of AEME and EME requires use of an independent technique such as gas chromatography-mass spectrometry (GC-MS). In some applications, it may be very important to differentiate AEME from EME. In such cases, IMS will not be useful.

Table 2 shows K_o values for combinations in which one component is held at 10 ng and the other is varied up to 80 ng. As EME amounts are increased (holding AEME at 10 ng) the K_o values decrease. The K_o of EME is nearly reached at an AEME/EME ratio of 10 ng/40 ng. The K_o values continue to decrease slightly until the K_o of EME of EME is reached. This

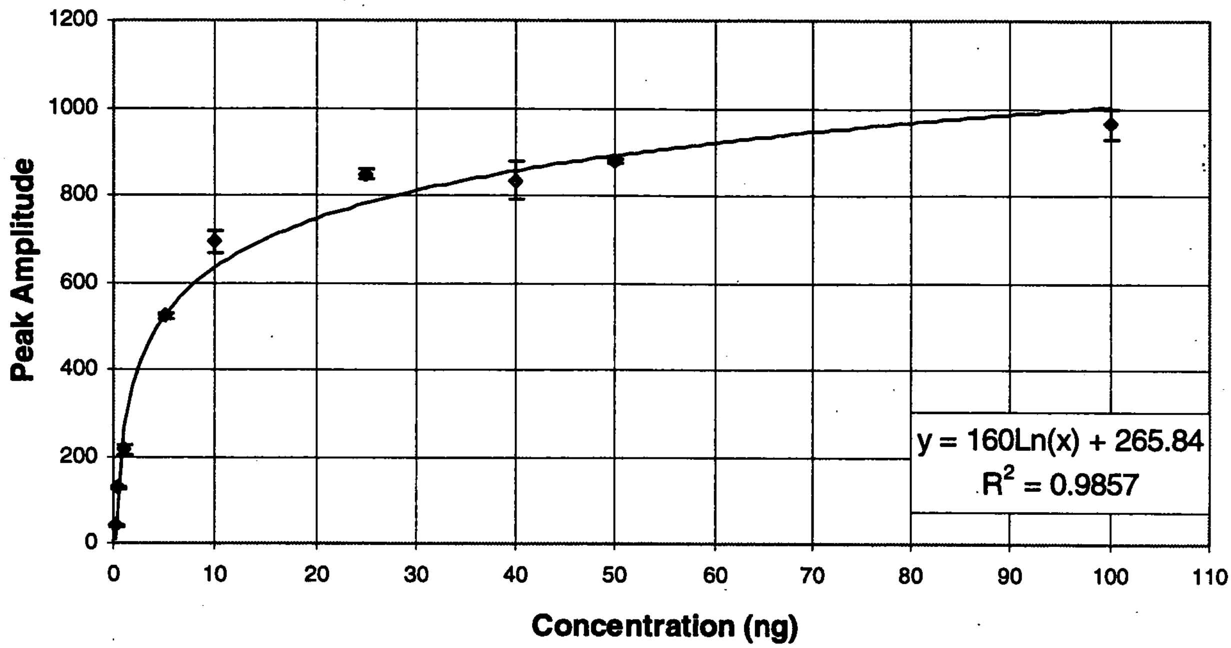


Figure 1. Ion mobility spectrometry calibration plot for anhydroecgonine methyl ester (AEME) (0 -100 ng)

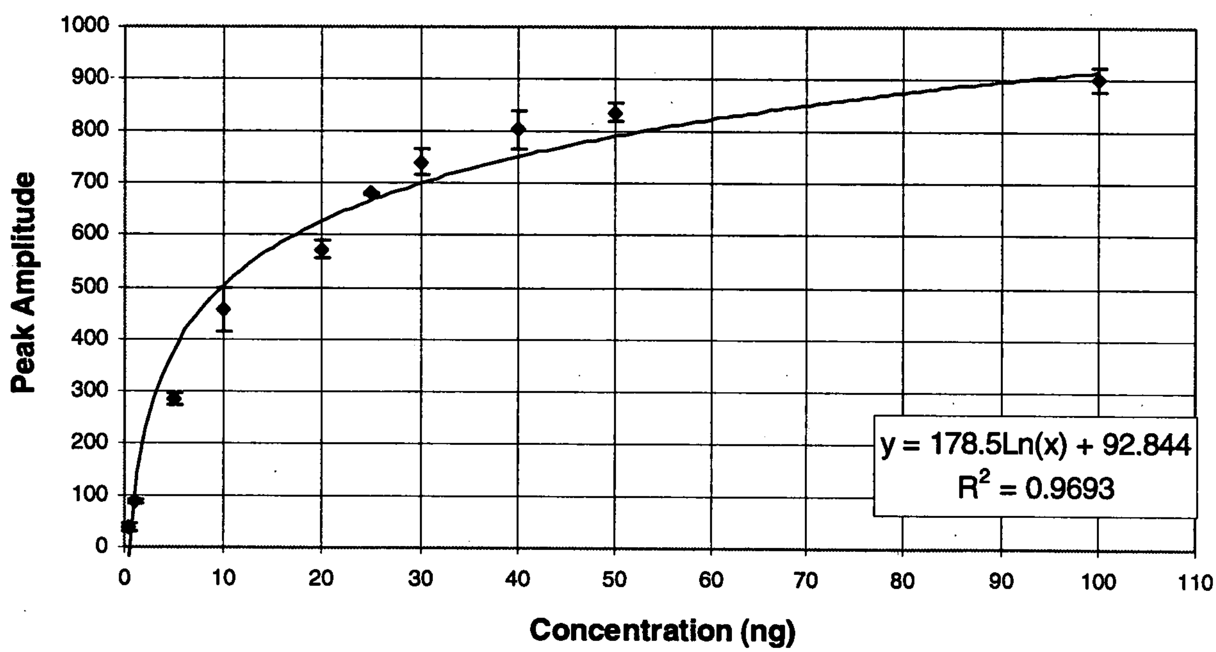


Figure 2. Ion mobility spectrometry calibration plot for ecgonine methyl ester (EME) (0 -100 ng)

Table 1. K_o values for cocaine and its common reaction products [16]

Compound	K_o $cm^2 V^{-1} sec^{-1}$
Cocaine	1.160
Benzoylecgonine	1.184
EME	1.483
AEME	1.504 [17]
Ecgonine	1.550

Table 2. Ion mobility spectrometry results using mixtures of anhydroecgonine methyl ester (AEME) and ecgonine methyl ester (EME)

Weight Ratio ng AEME/ ng EME	K_o $cm^2 V^{-1} sec^{-1}$	Average Amplitude
10 / 0	1.504 ± 0.000	692 ± 25
10 / 10	1.502 ± 0.002	531 ± 13
10 / 20	1.490 ± 0.003	547 ± 27
10 / 40	1.485 ± 0.000	692 ± 27
10 / 60	1.484 ± 0.000	815 ± 25
10 / 80	1.483 ± 0.000	856 ± 7
0 / 10	1.485 ± 0.001	406 ± 22
10 / 10	1.502 ± 0.002	531 ± 13
20 / 10	1.493 ± 0.001	684 ± 19
40 / 10	1.495 ± 0.000	750 ± 12
60 / 10	1.494 ± 0.000	772 ± 7
80 / 10	1.496 ± 0.000	801 ± 24

decrease appears real in view of the high precision. The same operator performed all of the experiments and was well experienced in the technique.

The peak amplitude decreases for AEME/EME ratios of 10 ng/10 ng and 10 ng/20 ng, and then increases. The observed decrease may be due to factors such as the lower sensitivity of IMS to EME (Figures 1 and 2), peak shape, and/or instrument variability.

As EME amounts are increased (holding EME at 10 ng), the highest K_o value was found at an AEME/EME ratio of 10 ng/10 ng. At higher AEME/EME ratios the K_o values are lower, but close to AEME. An interesting finding is that at a 10 ng/10 ng weight ratio of AEME/EME, the K_o values indicate the presence of AEME.

A K_o value at or close to that of AEME may mean that as much as 50% of EME is also present. A K_o value at or close to that of EME indicates a high probability that at least 75% of the sample is EME.

Heroin Hydrochloride and 6-Acetylmorphine

Heroin produces two IMS peaks (Figure 3), as does 6-acetylmorphine (Figure 4). One peak of heroin

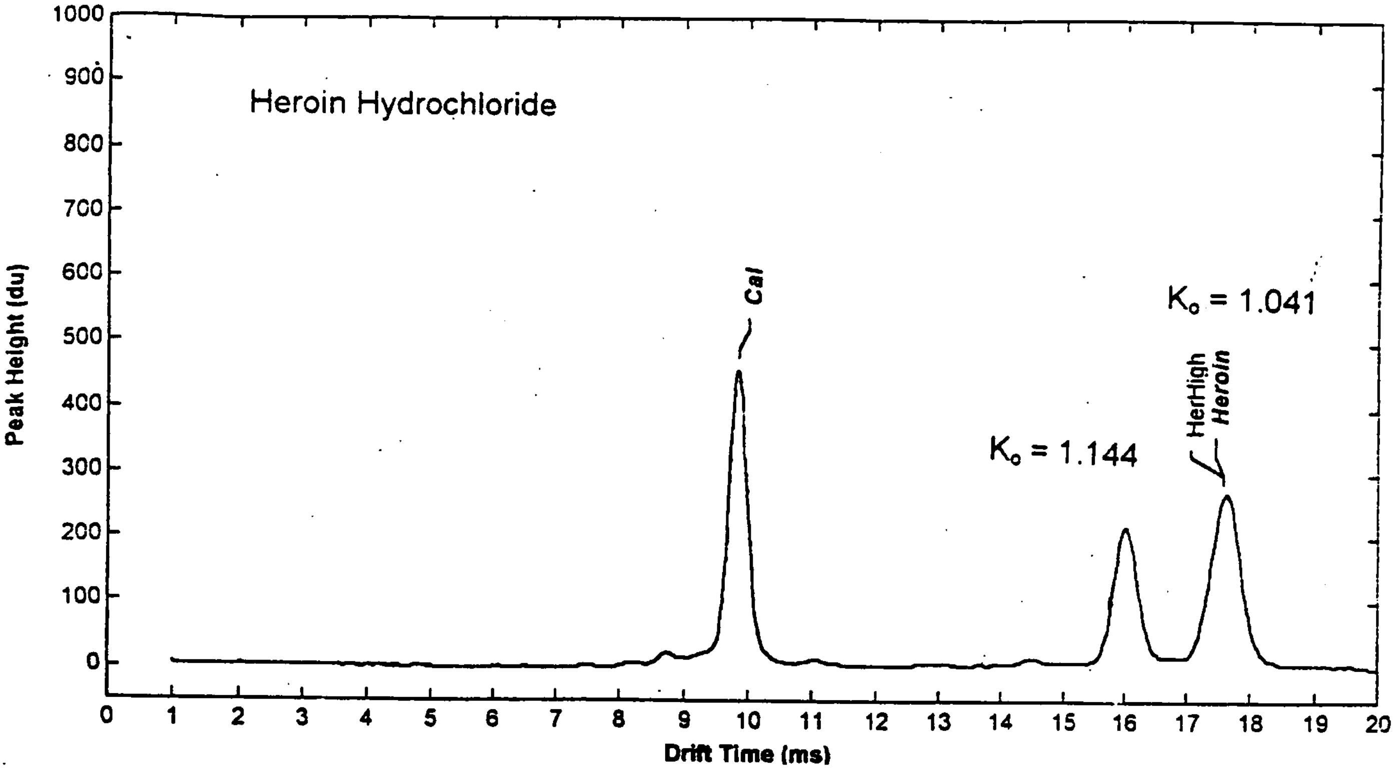


Figure 3. Ion mobility plasmagram of heroin hydrochloride. 75 ng deposited on Teflon™ membrane from methanol.

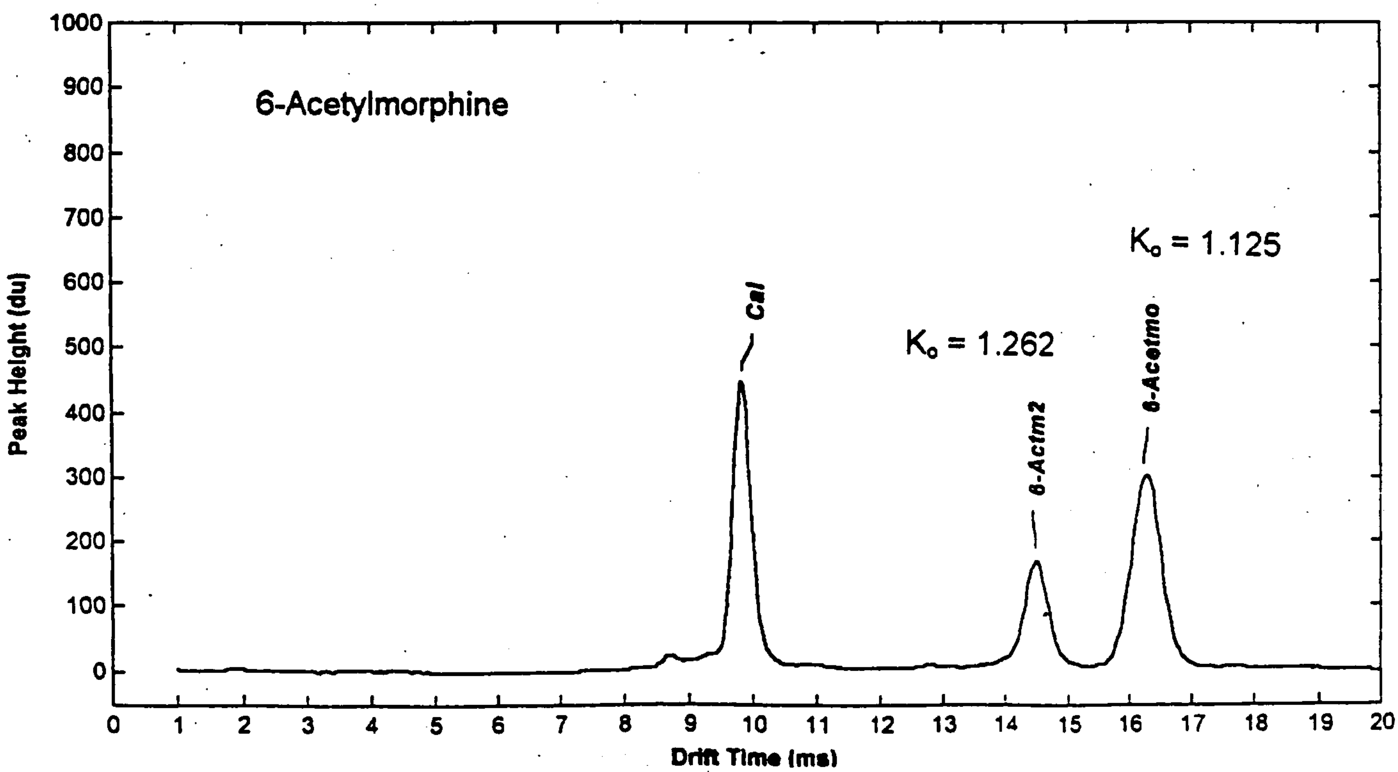


Figure 4. Ion mobility plasmagram of 6-acetylmorphine. 75 ng deposited on Teflon™ membrane from acetonitrile.

(K_o=1.144 $cm^2V^{-1}sec^{-1}$) appears very close to one of 6-acetylmorphine (K_o=1.125 $cm^2V^{-1}sec^{-1}$). This overlapping needs to be taken into account when analyzing samples that contain a mixture of heroin and 6-acetylmorphine. More specifically, the main IMS peak of 6-acetylmorphine (K_o, 1.125 $cm^2V^{-1}sec^{-1}$) cannot be used alone to either identify or analyze 6-acetylmorphine when heroin is also present. One must use the K_o, 1.262 $cm^2V^{-1}sec^{-1}$, peak.

The effect of various amounts of 6-acetylmorphine on the IMS detection and analysis of heroin hydrochloride was examined. One peak of heroin (K_o, 1.041 $cm^2V^{-1}sec^{-1}$) was evident irrespective of the amount of 6-acetylmorphine present. However, the amplitude decreased as the concentration of 6-acetylmorphine increased. The percentage decrease also depended on the amount of heroin hydrochloride. The trends are shown in Figure 5. For example, with the largest amount of 6-acetylmorphine (100 ng), the percent decreases in IMS peak amplitude (K_o, 1.041 $cm^2V^{-1}sec^{-1}$) for different amounts of heroin hydrochloride were found to be: 62% (25 ng heroin), 57% (50 ng heroin), 48% (75 ng heroin), and 32% (100 ng heroin).

It was interesting to note that as IMS saturation levels are being approached (above 50 ng heroin hydrochloride), appreciable amplitude decreases were still apparent for the heroin peak (K_o, 1.041 $cm^2V^{-1}sec^{-1}$). For example, with 75 ng heroin hydrochloride, the amplitude measured in the presence of 100 ng 6-acetylmorphine indicates only 25 ng heroin as determined from the heroin IMS calibration curve (not shown). The results imply there is competition between heroin and 6-acetylmorphine for charge with 6-acetylmorphine showing higher proton affinity. Using the same data but processing it differently allows one to examine the possible effects of varying amounts of heroin hydrochloride on the amplitude of the 6-acetylmorphine peak (K_o, 1.262 $cm^2V^{-1}sec^{-1}$). The amplitude of the changed slightly from sample to sample within a series. However, when the amplitudes from all four samples in a particular series were averaged, the values remained approximately the same, regardless of the amount of heroin hydrochloride present.

4. Conclusions

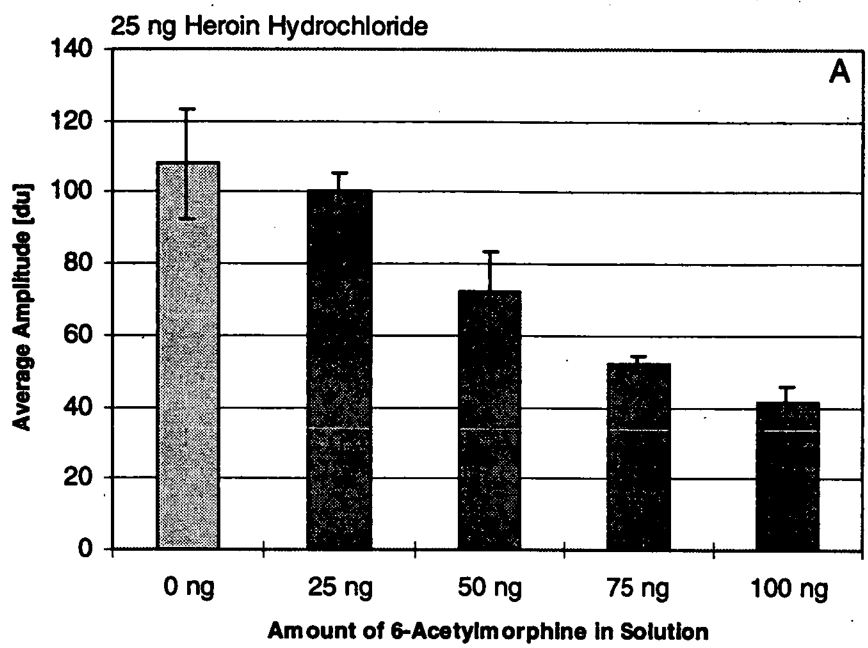
It is clear that IMS will continue to be an important tool for the detection, identification and semi-quantitative analysis of contraband drugs and their reaction products. However, it is apparent that use of IMS in semiquantitative analysis may be limited depending on the specific circumstances. Also, identification of target compounds may not be possible. Specific conclusions relative to mixtures of the cocaine reaction products AEME and EME, and mixtures of heroin hydrochloride and 6-acetylmorphine follow.

Anhydroecgonine Methyl Ester (AEME) and Ecgonine Methyl Ester (EME)

Mixtures of AEME and EME standards led to a single IMS peak which could not be resolved. Amounts of either AEME or EME may be underestimated when the other compound is present. IMS does not appear to be useful in estimating total AEME-EME. Caution needs to be taken in reaching conclusions on compound identification and analysis with IMS when both AEME and EME may be present. Unexpected results described in this paper can be explained on the basis of the close K_o values for AEME and EME, differences in IMS sensitivity, and differences in proton affinity.

Heroin Hydrochloride and 6-Acetylmorphine

6-Acetylmorphine was found to interfere in the IMS semiquantitative analysis of heroin hydrochloride, but not in its detection and identification. The presence of 6-acetylmorphine significantly decreases the IMS amplitude of the heroin peak (K_o, 1.041 $cm^2V^{-1}sec^{-1}$) leading to an underestimation of the amount of heroin hydrochloride actually present in the sample. The effects of heroin hydrochloride on the detection of the 6-acetylmorphine peak (K_o, 1.262 $cm^2V^{-1}sec^{-1}$) are minimal. The same amount of 6-acetylmorphine is detected in those samples that contain heroin as those that do not. Semiquantitative analysis of heroin hydrochloride when 6-acetylmorphine is present may not be possible using IMS. Alternative methods of analysis need to be considered.



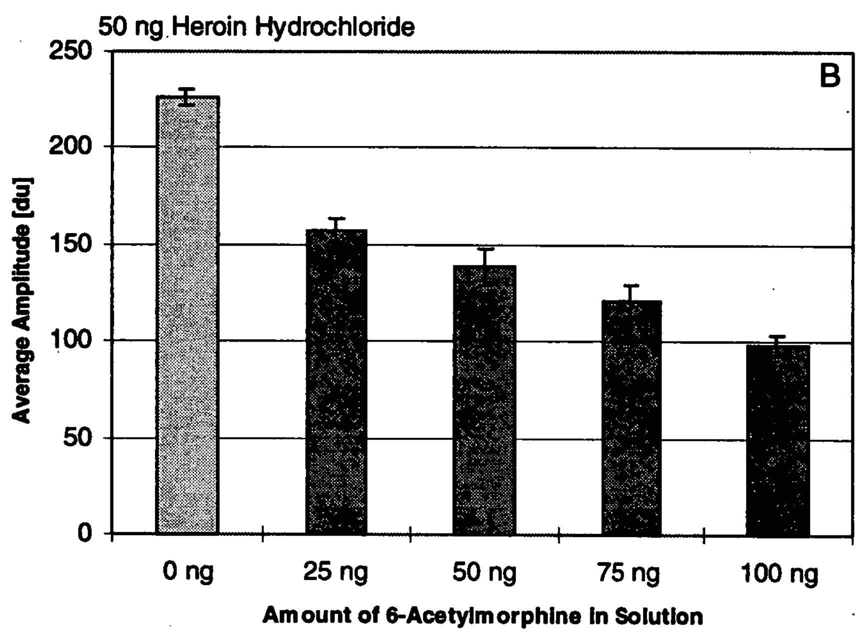


Figure 5 (A and B). Average amplitude of the K_o, 1.041 $cm^2V^{-1}sec^{-1}$ peak of heroin hydrochloride in the presence of 6-acetylmorphine

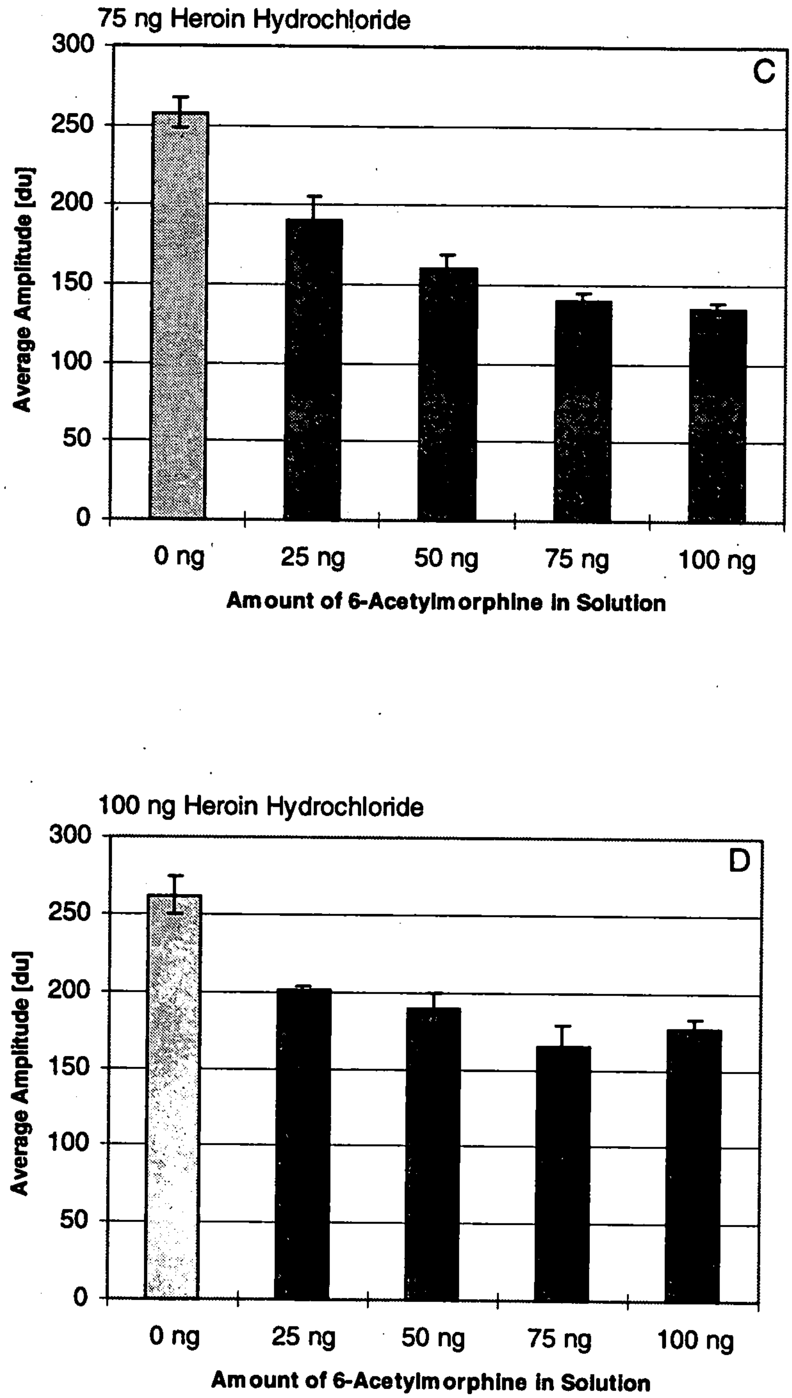


Figure 5 (C and D). Average amplitude of the K_o, 1.041 $cm^2V^{-1}sec^{-1}$ peak of heroin hydrochloride in the presence of 6-acetylmorphine

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COCAINE METAMORPHOSIS STUDY

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ABSTRACT

In an attempt to provide better information on an efficient and effective sampling method for cocaine, several tests were performed studying the physical properties of cocaine when subjected to different environmental conditions. The goal of the study was to provide the field officer with information concerning the physical state of cocaine under different environmental conditions so that the officer may make better choices concerning the sampling method to be employed at any given time. The first phase of the experiment determined combinations of temperature and humidity at which cocaine hydrochloride changes from the solid to the liquid phase. The second phase of the experiment concentrated on monitoring the characteristics of cocaine hydrochloride as it changed from the solid to the liquid phase while placed on several materials commonly encountered in the real world. All experiments were observed and recorded under 120X magnification. A discussion of the experiment, as well as a video detailing the results, will be presented.

1.0 INTRODUCTION

For several years, law enforcement agencies have been conducting research and associated field studies for the purpose of evaluating new and existing nonintrusive narcotic detection instruments. The successful development of nonintrusive inspection systems will both automate and greatly increase the rate at which suspect conveyances such as vessels or containers can be searched. The end result will be an increase in the number of targets searched in a reduced amount of time.

With all the effort that has been dedicated to the assessment of these instruments, one unknown that still exists is the effect of the environment on the target compound prior to analysis. Varying environmental conditions may affect both the chemical and physical properties of narcotics. Given the ability to predict at a high confidence level the physical and chemical state of the target analyte, an efficient and effective sampling system or strategy can be developed. Additionally, knowing the physical state of the narcotic to be sampled will facilitate the use of the most effective procedure and/or device.

2.0 PURPOSE OF STUDY

In an attempt to provide better information on an efficient and effective sampling method for a target analyte, several tests were performed studying the physical properties of cocaine when subjected to different environmental conditions. Cocaine hydrochloride (i.e., cocaine salt) is the main form of smuggled cocaine. It is a well documented fact that cocaine is extremely hygroscopic. Preliminary experiments conducted at the U.S. Coast Guard Research and Development Center (CGR&DC) indicated that varying temperatures and humidities will affect the physical state of cocaine hydrochloride. By providing information concerning the physical state of cocaine under different environmental conditions, better choices may be made by the officer concerning which sampling method should be employed at any given time.

It must be stressed that only the physical properties of cocaine were monitored in this study. A study of the chemical properties would require a separate research project.

3.0 TEST OBJECTIVES

This experiment was organized into two phases. The objective of the first phase was to provide information on the physical state of cocaine to varying combinations of temperature and humidity. The second phase concentrated on utilizing the results from the first phase and applying them to different surfaces that are typically encountered in the field (wood, fiberglass, etc.). The goal was to monitor the characteristics of cocaine on each of these surfaces at different environmental conditions.

4.0 METHODOLOGY

4.1 INSTRUMENTAION

In order to properly investigate the metamorphic properties of cocaine, solid samples were placed in a BMA, Inc. Model TH-64C environmental chamber capable of maintaining temperature and humidity to within 5% of set conditions. The conditions inside this chamber were monitored with a Panametrics Hygrometer with an accuracy of ±2% RH and ±0.56°C.

To observe the samples during testing, a translation stage to move the sample, along with a Panasonic GP-KS-102 color video camera was placed in the camber. This camera was adapted to a Canon 2X zoom extended lens mounted on an Edmund Scientific 15-60X zoom inspection microscope. The camera was connected to a Panasonic AG1960 SVHS video cassette recorder and all tests were recorded on high quality 3M SVHS tapes. Samples were illuminated using a CUDA 3200°K color temperature quartz halogen light source and fiber optic light guide. The translation stage, the light source and the magnification of the video camera were operated by controls outside the chamber. This allowed for easy three dimensional positioning, zooming, and focusing on any portion of the test sample without disrupting the test.

4.2 MATERIALS

Test samples were pharmaceutical grade cocaine hydrochloride and cocaine base obtained from Sigma Chemical Co. For convenience of observation, these samples were categorized into 3 approximate size categories. These sizes are not precise, as they were determined by viewing through an eye loupe with an etched graticule. "Small crystals" were defined to be clumps of crystals measuring approximately 65 microns (0.0025"), "medium crystals" were defined to be clumps of crystals measuring approximately 125-200 microns (0.005"-0.008") and "large crystals" were defined to be clumps of crystals measuring 375 microns (0.015") and larger. Figure 1 shows typical "crystals" from each category.

5.0 EXPERIMENTAL

Preliminary studies conducted at the CGR&DC indicated that cocaine hydrochloride will liquify when subjected to specific combinations of temperature and humidity. A series of tests, described in the following paragraphs, were performed on cocaine hydrochloride. During each of these tests, records were kept on temperature and relative humidity (RH) in the chamber along with pertinent comments.

5.1 PHASE 1

A series of tests to determine the combinations of temperature and humidity at which cocaine hydrochloride changes from the solid to the liquid phase were conducted. The samples were placed on thin plastic squares which allowed for easy set up and viewing. These tests were conducted by keeping the temperature nearly constant at 4.4°C, 10.0°C, 15.6°C, 21.1°C, 26.7°C, 32.2°C, 37.8°C and 43.3°C while manually stepping the relative humidity until liquification of the cocaine hydrochloride crystals occurred. During this stepping process, and after an RH greater than 60% was reached, the RH was increased in 2% increments and left to stabilize for approximately 5 minutes before increasing to the next level. The purpose of this series of tests was to quickly determine optimum conditions for phase 2.

Another test involved keeping the temperature constant and cycling the RH above and below the known liquification point. The purpose of this test was to determine if the point of liquification and solidification would remain the same after repeated phase changes.

A final test involved keeping a sample at a constant temperature and a constant RH approximately 10% below the known liquification point to determine if long term exposure had any additional effect.

5.2 PHASE 2

Another test series was conducted for the purpose of monitoring the characteristics of cocaine hydrochloride as it liquified on different materials commonly encountered in the field. This test was accomplished by holding the temperature constant while ramping the humidity. These tests were conducted at 32.2°C. The cocaine hydrochloride crystals were placed on various materials such as unfinished lightly sanded and cleaned teak, wood finished with polyurethane, denim, aluminum, like new and worn dollar bills, Ziploc™ plastic bag material, and sand. The final state of the cocaine (i.e., absorbed into the material or still residing on the surface) was monitored.

6.0 TEST RESULTS

6.1 PHASE 1

After several attempts to liquify cocaine hydrochloride crystals failed, it was discovered that the area directly under the light (cold light) had a temperature 3°C higher and RH 10% lower than the chamber. Due to this effect, data gathered to this point was not accurate. To overcome this problem, the light was only turned on for a period of 5 seconds once every minute for recording and observation. Any portion of the study that had been previously completed was repeated.

Observations recorded during the test phase indicate the cocaine hydrochloride existed in 3 distinct states. The first state is when the samples are still crystalline or solid as shown in Figure 1. The second state is when the samples are beginning to "clear". As shown in Figure 2, this phase is defined as when the cocaine hydrochloride begins changing from a solid to a liquid. The third state is when the cocaine hydrochloride becomes completely liquified as shown in Figure 3.

As a result of performing the series of RH ramp tests, a direct correlation between the RH and temperature at which cocaine hydrochloride begins to clear can be established. This correlation is shown in Figure 4. Due to the limitations of the environmental chamber, results obtained at temperatures lower than 4°C were not reliable. Therefore, results down to 4°C are the only ones reported. It must be noted that each data point in Figure 4 is a single data point, not an average of several runs. Additional work to conduct multiple trials is certainly necessary to better define these lines. Another note of interest is, on several occasions when reaching the desired point, the RH would overshoot the set point. This phenomenon is relatively common in instruments with heating capabilities. In most cases this overshoot was slight and kept within the specifications of the equipment.

6.1.1 HUMIDITY RAMP CYCLING

A test was conducted to determine the characteristics of cocaine hydrochloride as the relative humidity was cycled around the known liquification point. As part of this test, some of the puddles were touched with the fine point of a needle to determine at what RH a crystal would be reformed. This test was performed at 32.2°C and the actual step increase time was not a critical matter . Liquification began at 77.6% with the largest crystal becoming totally liquified at 82.0%. At this point, the RH was lowered and the large areas of the puddle began to crystallize at 74.8%. When the RH reached 40%, the areas that were small crystals were touched with the needle with no apparent change. The areas where the large crystals had been were then touched and crystallization was observed. The RH was then again raised and liquification began at 84% with complete liquification at 89%. The RH was then slowly lowered. The area that was the large crystal was touched at 79.8% RH, 51.8% RH and 40.2% RH with no crystallization. At 39.4%, the area was again touched with crystals forming. At 35%, the area was touched once more and the area had completely solidified. The large crystals in the liquid state and in the recrystallized state are displayed in Figure 5

6.1.2 LONG TERM EXPOSURE TEST

A test was conducted to determine if a lower RH over a long period of time has any effect on the liquification point of cocaine hydrochloride. A long term exposure test was performed with one sample placed in the chamber at 32.2°C and the RH at approximately 10% less than when the smallest crystals liquified in previous tests at this temperature. This test was conducted over a period of four hours with no observable changes to the test sample.

6.2 PHASE 2

Further tests were performed with the cocaine hydrochloride crystals on various types of material commonly found in the field. Because the liquification point had already been determined in Phase 1 of this study, this series of tests only observed the characteristics as liquification occurred on these materials. For ease of controlling the environmental chamber, it was decided that these tests would be performed at a near constant temperature of 32.2°C. The following paragraphs give a brief description of the observations made during the tests.

6.2.1 SANDED AND CLEANED TEAK

Two separate tests were performed on the teak. The first test used cocaine hydrochloride crystals similar to those used during the ramp tests. The small crystals began to liquify at 84.3% RH. The medium crystals began three minutes later with an RH of 89.4% with the large crystals following at 88.3%. As soon as the crystals turned into liquid, they were absorbed into the wood. Observing the solution through the video system showed little, if any, cocaine crystals left on the surface of the wood. However, when examined after the wood was removed from the chamber, there appeared to be a wet spot where the crystals had been placed. Figure

6 displays the cocaine on the teak before and after liquification.

The second test performed on the teak was with a much larger cocaine hydrochloride crystal. The crystal used for this experiment was measured to be 1168 microns. The purpose was strictly to observe the behavior of the crystal as it liquified and was absorbed into the wood. As noted in the previous test, as liquification occurred the solution appeared to soak into the wood. After the crystal was about 75% liquified, the RH was dropped so observation could be made of crystallization. When the wood was removed from the chamber the area around the location of the crystal, as before, appeared to be wet or have formed a type of coating over the wood. Figure 7 displays the large cocaine crystal on the teak before and after 75% liquification.

6.2.2 FINISHED WOOD

One test was performed to determine the characteristics of cocaine hydrochloride as it liquified on a piece of finished wood. Ten minutes elapsed from the time the smallest crystals began to change until the largest crystal liquified. Observations of the sample during this test were much like that of tests performed on the standard plastic sections used during the ramp tests. Figure 8 displays the cocaine on the finished wood before and after liquification. Even after lowering the RH, the cocaine appeared to remain in the liquified state.

6.2.3 DENIM

Two separate tests were performed on small squares of standard denim material. The first test used cocaine hydrochloride crystals similar to those used during the ramp tests. The liquification of the crystals was similar to that observed in previous tests. However, as liquification occurred, the liquid was absorbed into the fibers of the fabric with no visual indication of any residue left on the surface of the fibers. Even after removal from the environmental chamber, there was no evidence of a stain or anything that would indicate the presence of cocaine. Figure 9 displays the cocaine on the denim before and after liquification.

The second test performed on the denim was very much like that of the second test on the teak. A much larger crystal was placed on the denim and observations were made during the liquification. As noted in the previous test on the denim, the liquid was absorbed into the fibers of the fabric with no indication of any residue. Figure 10 displays the large cocaine crystal on the denim before and after liquification.

6.2.4 SAND

The purpose of this test was to observe the characteristics of the cocaine hydrochloride crystal as it liquified on a bed of sand placed in an aluminum tray. This sand had been previously measured to be between 5 and 100 microns in size. As liquification of the crystal occurred, it was observed that the liquid did soak into the sand to some extent. However, a meniscus formed and the liquid remained in a droplet form rather than dissipate throughout the sand. After the crystal had totally liquified, the sample tray was turned over to remove all excess sand. All that remained on the tray was the droplet and any sand that had been submerged in the liquid. This liquified cocaine was observed while the RH was lowered and crystallization occurred 43 minutes later with an RH of less than 50%. Figure 11 displays the cocaine on the sand before liquification, after liquification and after recrystallization.

6.2.5 MONEY

Two separate tests were conducted using two US one dollar bills. The first test was with a dollar bill which was in "like new" condition and the second test used an older well worn dollar bill. The purpose of this test was to determine the characteristics of the cocaine hydrochloride crystals as they liquified to determine if the solution would pool on the surface of the bill or be absorbed into the money's fabric.

During the first test with the "like new" bill, an elapsed time of fourteen minutes from the time the smallest crystals began to liquify until the largest crystals became completely liquified was required. As the crystals began to liquify it was observed that the solution was absorbed into the fabric of the dollar bill. However, enough cocaine remained on the surface of the bill to still be visible under the microscope. As the RH was lowered, slight crystallization was noticed with the solution on the surface of the bill. Figure 12 displays the "like new" bill before the test as well as the cocaine on the bill before and after liquification.

During the second test with the worn dollar bill, an elapsed time of eight minutes from when the smallest crystals began to liquify until the largest crystals become completely liquified was required. Observations during this test were very much like that of the previous test. The only noticeable differences between the two bills was the cocaine had a tendency to slide around on the surface of the new bill much more easily than that of the worn bill. Also, the liquified cocaine appeared to be absorbed into the older bill more readily than the new bill. Figure 13 displays the cocaine on the worn bill before and after liquification.

6.2.6 ZIPLOC™ BAG

One test was performed with cocaine hydrochloride on plastic material similar to that which might be used for transportation. The total elapsed time from when the smallest crystal began to liquify until the largest one became liquid was nine minutes. The liquified cocaine was very similar in appearance to the liquified cocaine on the plastic squares in Phase 1 of this study. After liquefaction, the RH inside the chamber was lowered to 25.9% over a period of two and one half hours. The final observation of the sample showed one round clear crystal formation resulting from the liquid mass that was observed earlier. Figure 14 displays the cocaine on the Ziploc™ bag before liquification and after crystallization.

6.2.7 BASE COCAINE

An initial test with cocaine base was performed to determine its characteristics when the relative humidity was increased. The cocaine base reacted differently from the cocaine hydrochloride in that it did not liquify. The duration of this test was two hours with a peak RH of 99.9% with no effect on the base cocaine with respect to relative humidity.

Another test was performed to determine the characteristics of the cocaine hydrochloride when mixed with the cocaine base. The crystal size of the base cocaine was much smaller than the cocaine hydrochloride which made it relatively simple to distinguish under the microscope. The cocaine hydrochloride liquified, as in previous tests, at roughly 80% RH. Cocaine base did not appear to liquify. Some cocaine base was "sucked" into the liquified cocaine and was engulfed in the liquid but did not appear to dissolve. As the RH was lowered the liquified mass crystallized with the base inside. With the addition of the base cocaine inside the super saturated solution, it appeared that crystallization was easier than that of a pure solution. In a sense, it appeared that the base cocaine crystal acted like a seed crystal. Figure 15 displays the cocaine base/hydrochloride mixture before and after liquification.

7.0 CONCLUSIONS

The results from both phases of this study indicate that cocaine hydrochloride is extremely hygroscopic. It absorbs water to the point that a supersaturated solution is formed. The results from phase 1 indicate that there is a linear relationship between the temperature and humidity at which cocaine hydrochloride liquifies. The lower the temperature, the higher the required humidity. Further testing found that cocaine that has been liquified and recrystallized requires a higher % RH to liquify than initially. The long term exposure test indicates that there is a definite lower limit of RH at which cocaine will liquify for a given temperature. Long term exposure to even slightly lower levels of RH at the given temperature will not result in the cocaine liquifying.

The results from phase 2 of this study indicate that, depending on the porosity of the real world material, liquified cocaine hydrochloride may or may not be absorbed into the matrix of the material. The ease of cocaine being absorbed by the worn dollar bill compared to the "like new" one could be one of the main contributing factors in explaining the observations reported by Ulvick, et. al. [1], on the currency contamination study. On material that cocaine hydrochloride is not absorbed, a droplet or pool is formed on the surface. As expected, cocaine base does not liquify under our experimental conditions. This holds true even when in the presence of cocaine hydrochloride.

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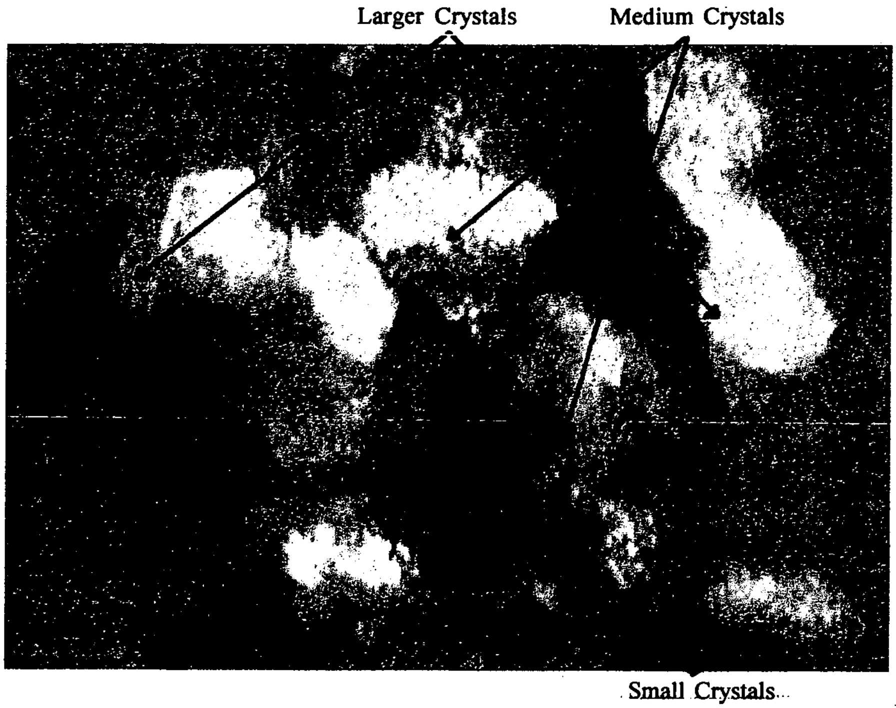


Figure 1 - Size Classification of Cocaine Crystals

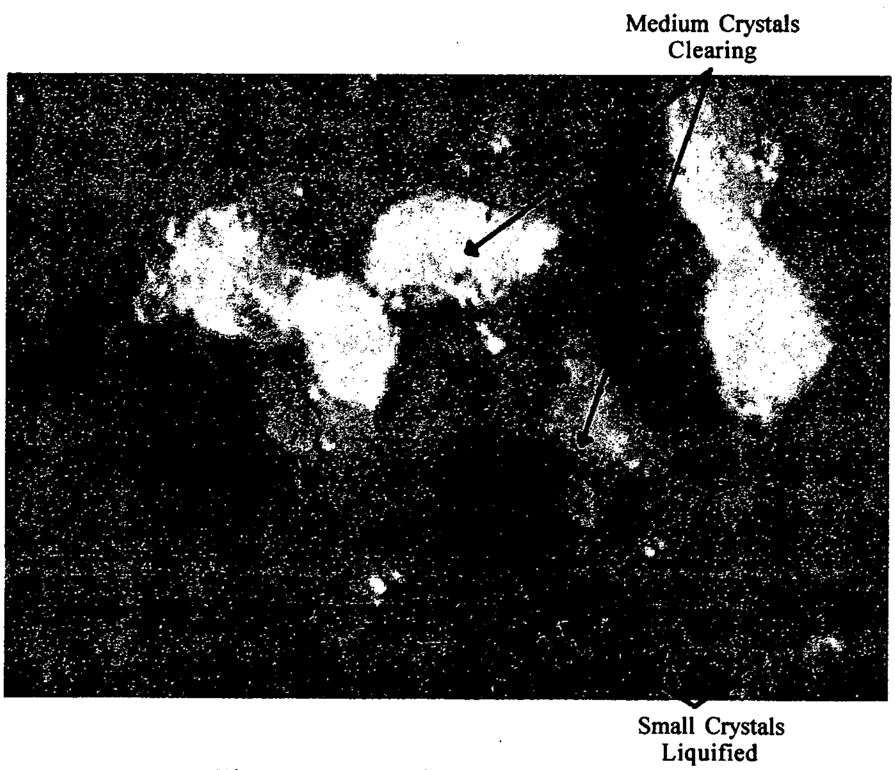


Figure 2 - Crystals Beginning to Clear

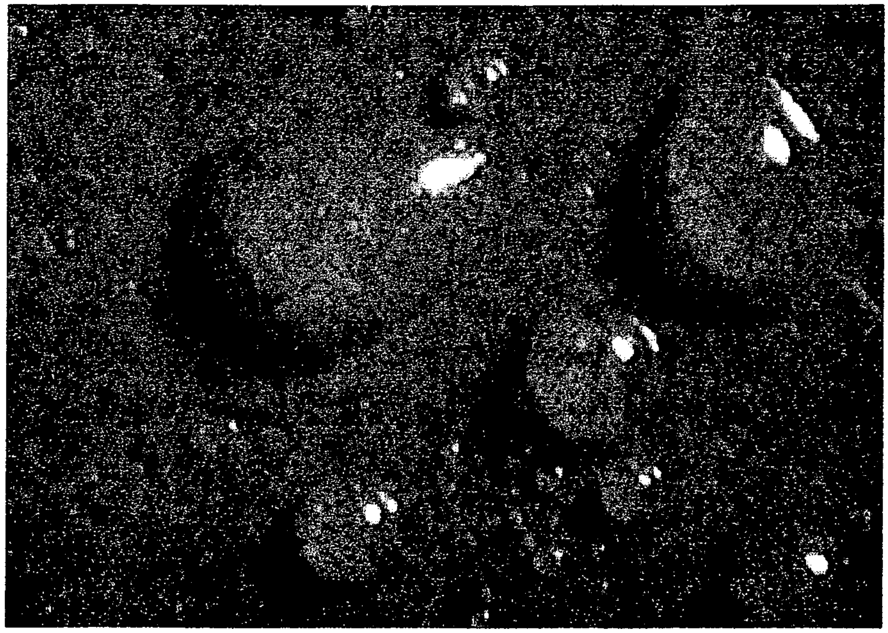


Figure 3 - All Crystals Liquified

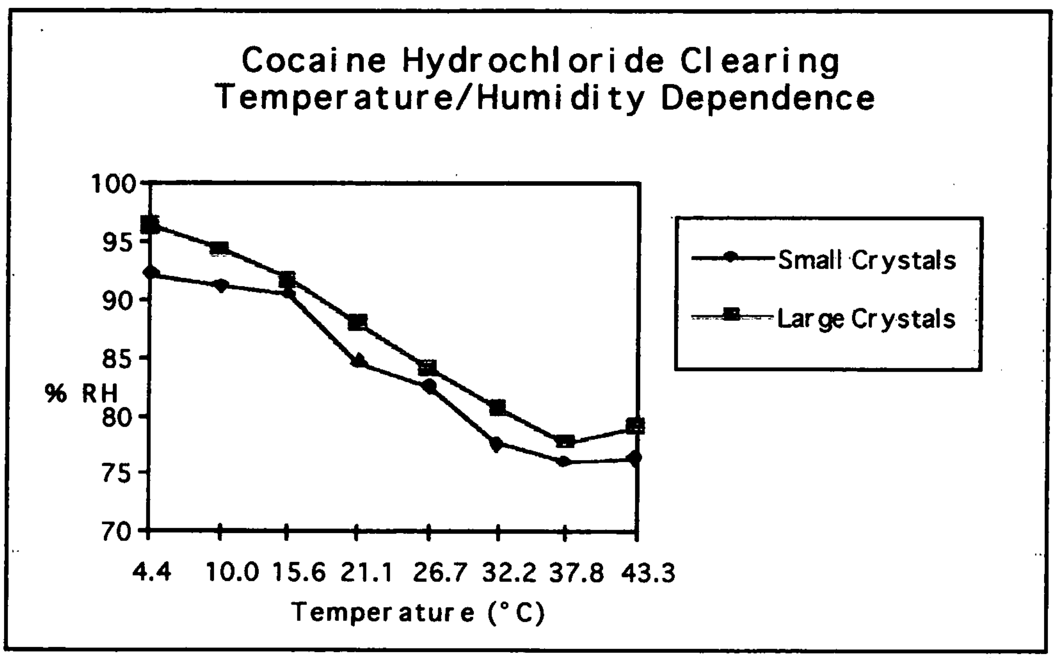


Figure 4 - Temperature/Humidity Dependence of Cocaine HCL Liquification

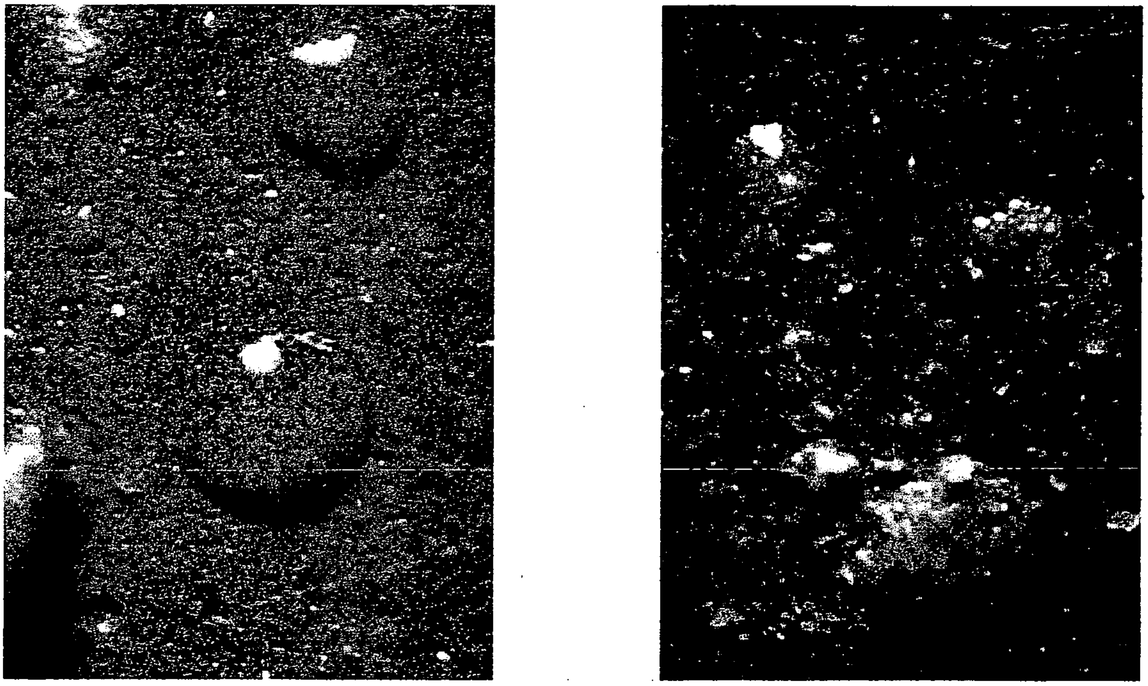
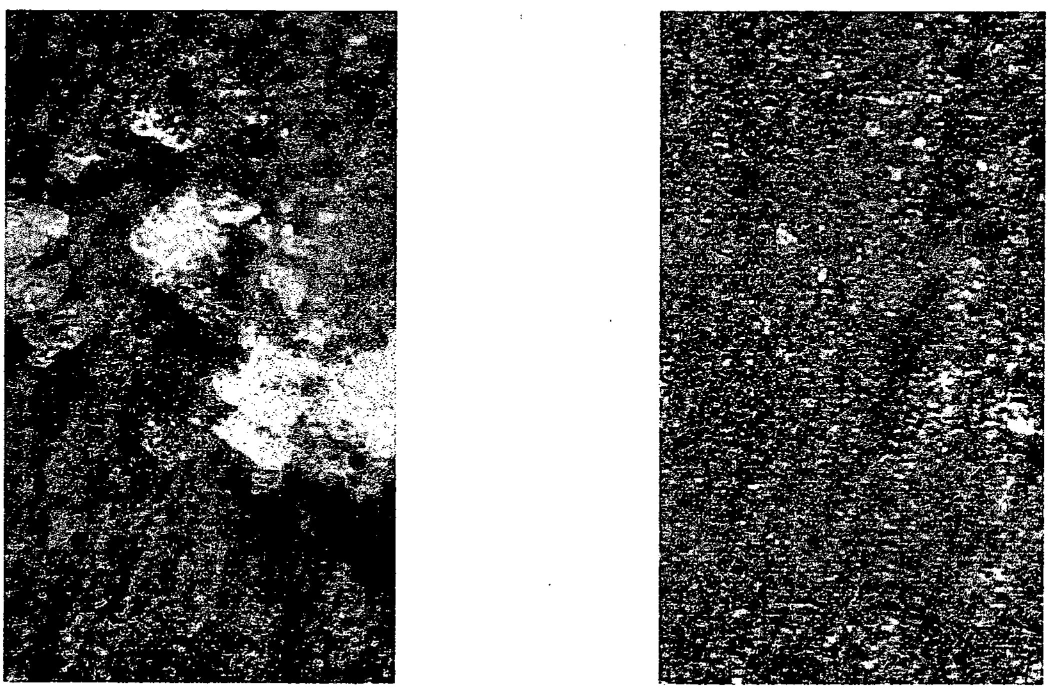


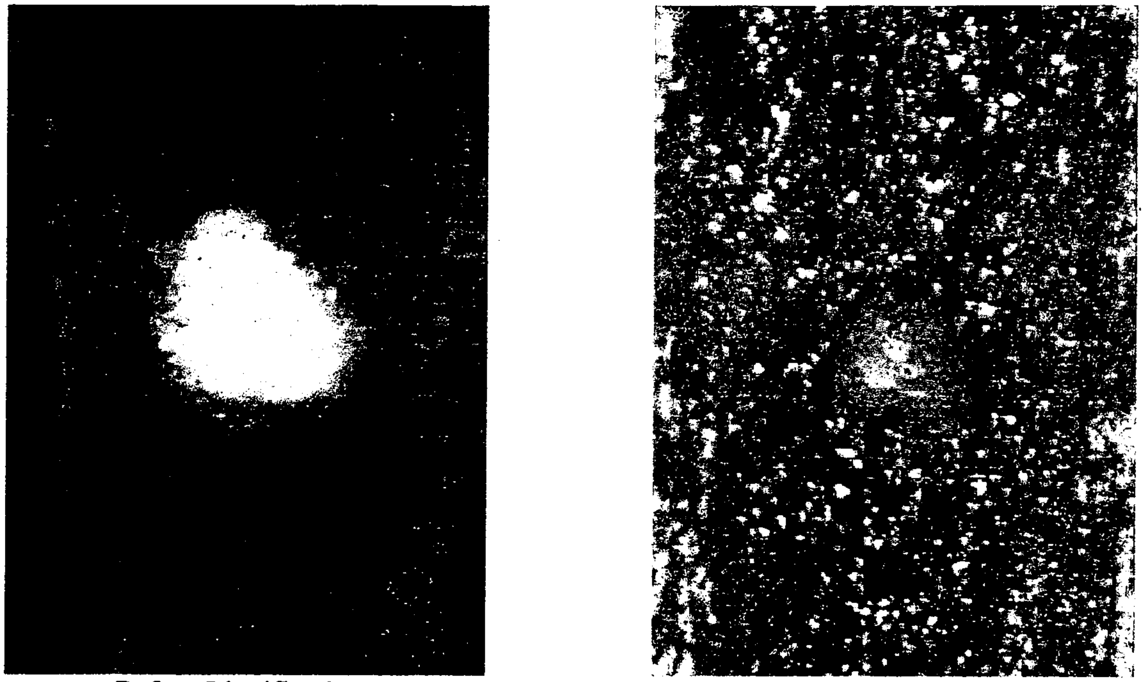
Figure 5 - Large Crystals in the Liquid and Recrystallized States



Before Liquification

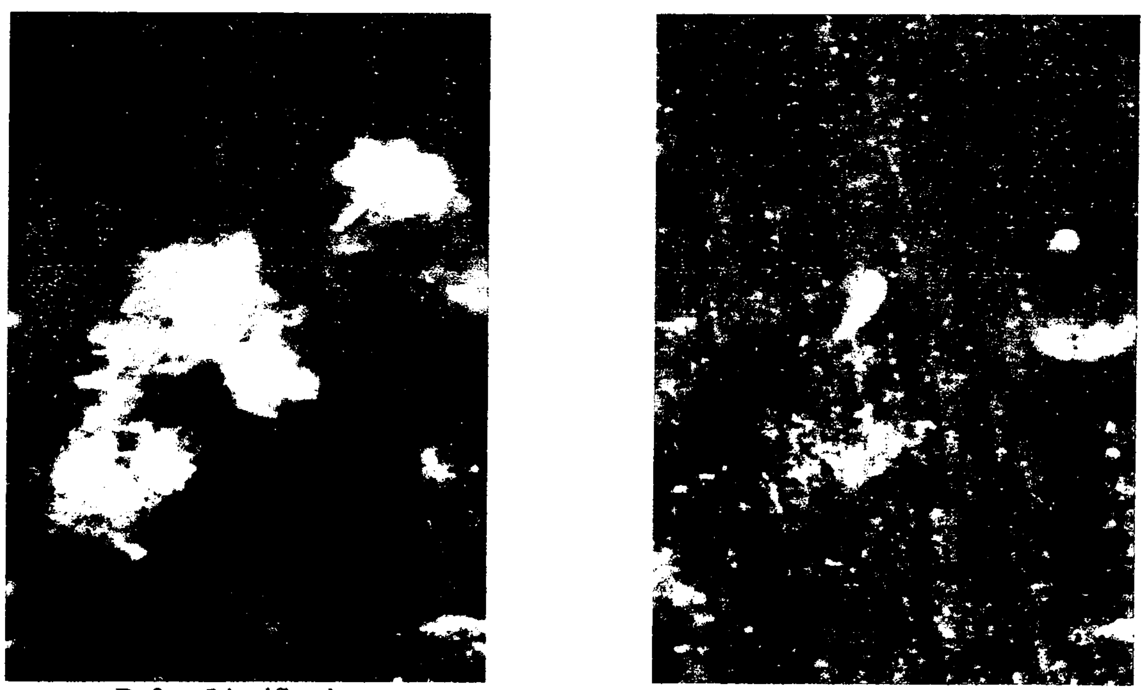
After Liquification

Figure 6 - Cocaine on Teak



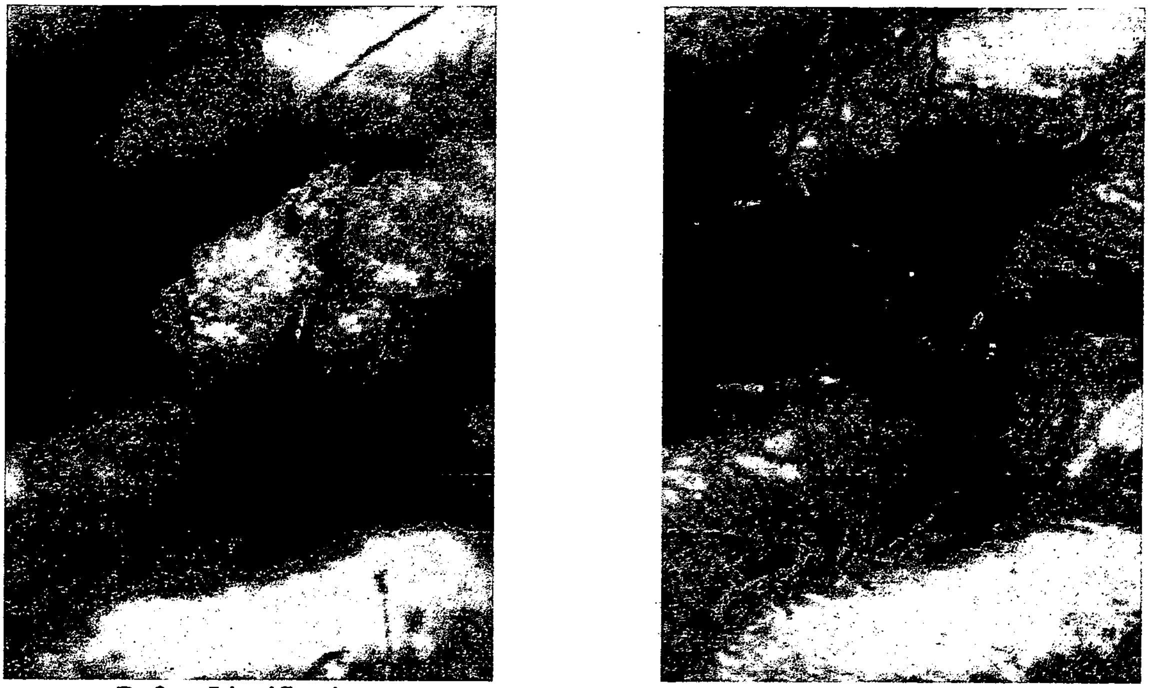
Before Liquification | After 75% Liquification

Figure 7 - Large Cocaine Crystal on Teak



Before Liquification | After Liquification

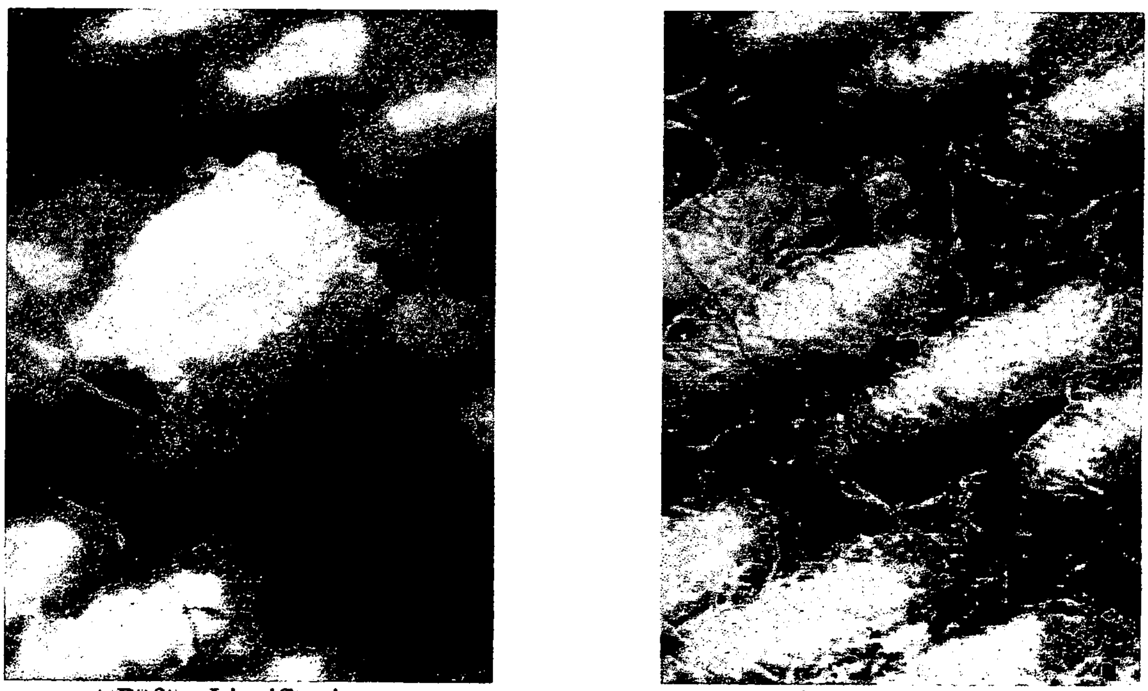
Figure 8 - Cocaine on Finished Wood



Before Liquification

After Liquification

Figure 9 - Cocaine on Denim



Before Liquification

After Liquification

Figure 10 - Large Cocaine Crystal on Denim


Before Liquification


Liquified Sitting on Sand

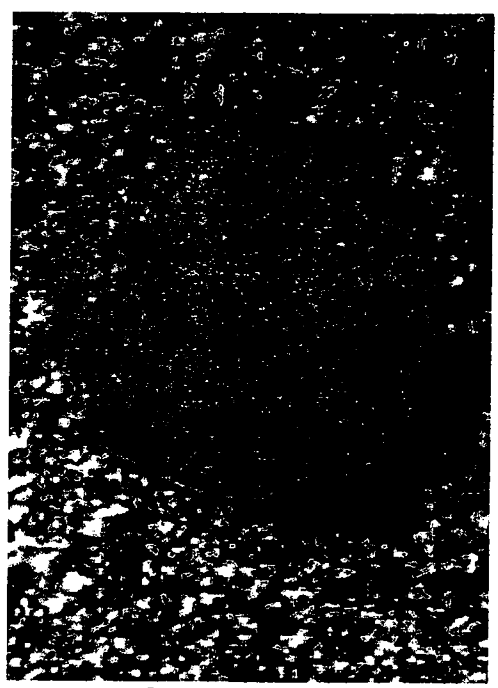
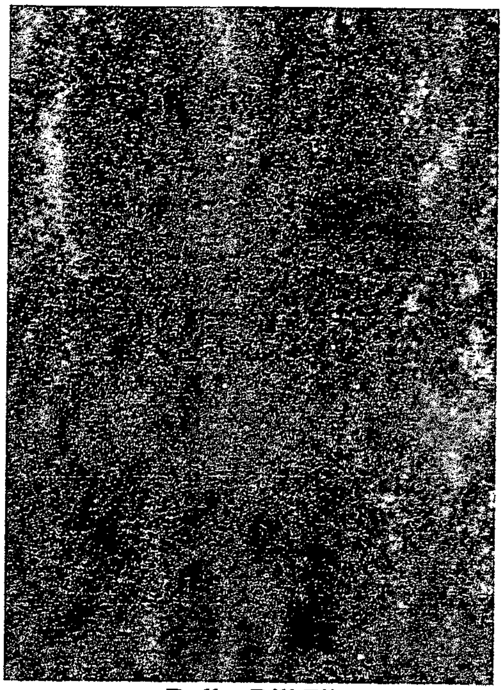

After Crystallization

Figure 11 - Cocaine on Aluminum Tray

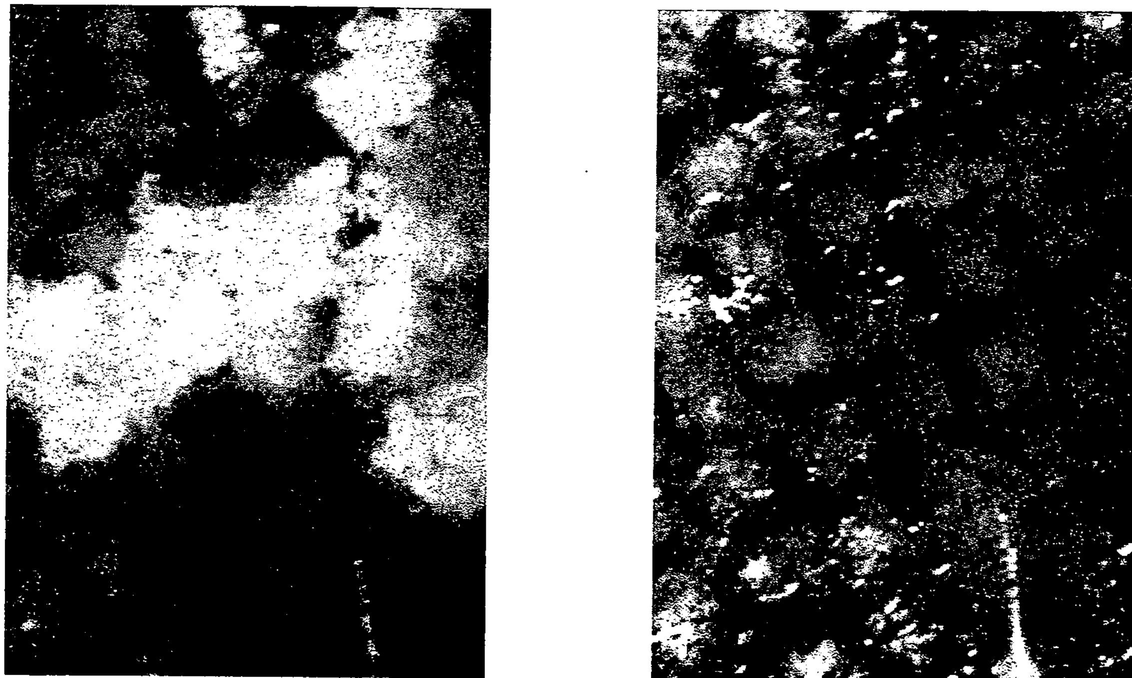


Dollar Bill Fiber

Before Liquification

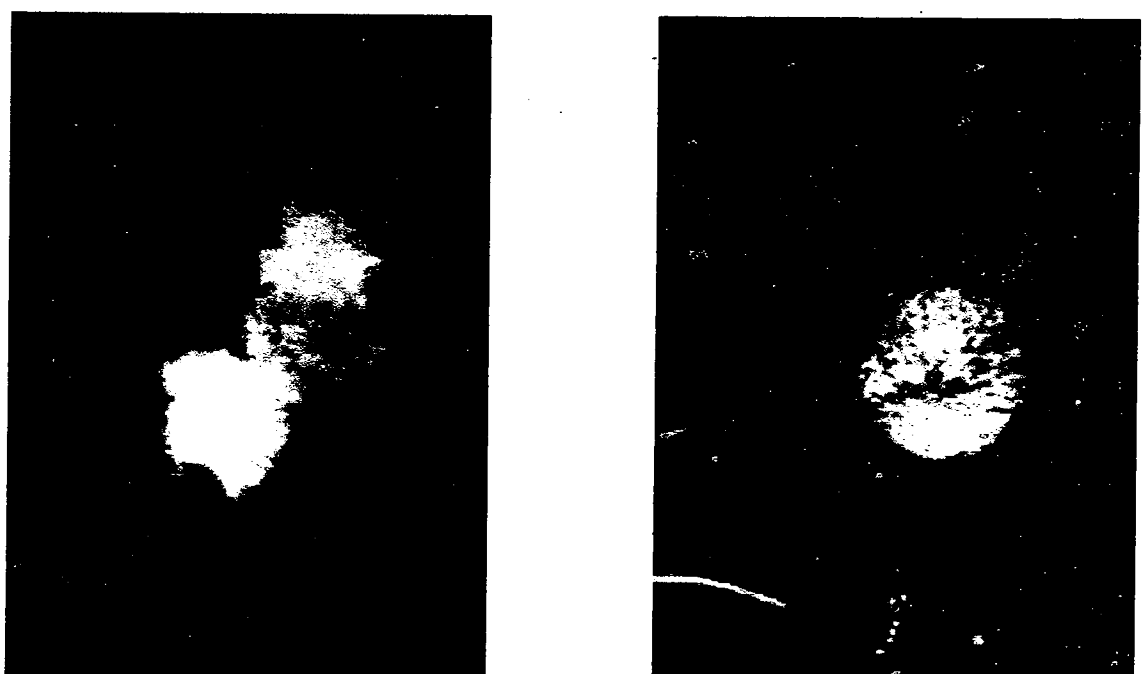
After Liquification

Figure 12 - Cocaine on a "Like New" Dollar Bill



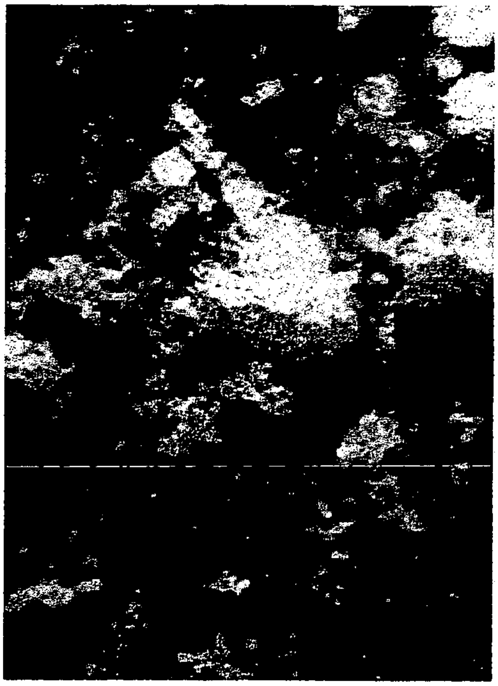
Before Liquification After Liquification

Figure 13 - Cocaine on a Worn Dollar Bill

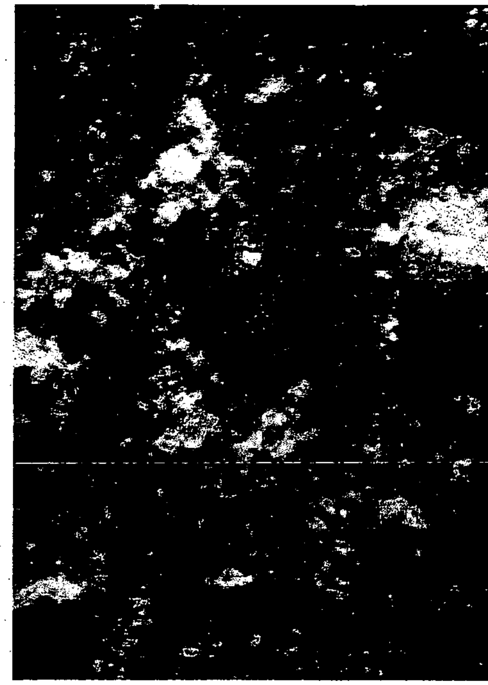


Before Liquification After Crystallization

Figure 14 - Cocaine on a Ziploc™ Bag



Cocaine Salt/Base Before Test



Cocaine Salt/Base After Liquification

Figure 15 - Cocaine Base/Hydrochloride Mixture

10

Nonintrusive Inspection Technologies (Session 3A-1)

Contraband Detection in Cargo Containers using K-40 Natural Gamma ray Emissions: Field Test at a US-Canada Border Crossing

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ABSTRACT

A passive radiation detection system based on measuring the natural K-40 gamma ray emissions from plant contraband such as tobacco, marijuana, and hashish was field tested at the Philipsburg land border crossing between Quebec and Vermont in October 1996, for a 2 month period. The monoenergetic K-40 gamma rays of 1.45 MeV were detected using large-volume sodium iodide (NaI) crystals mounted on either side of the inspected cargo container. Data was collected for a wide range of cargo materials. As well, control measurements of contraband simulant and real contraband, tobacco and marijuana, were performed. Numerical analysis of the spectral data and the appropriate selection of key spectral features from the energy spectra has shown that the cargo can be classified into several categories based on the presence of a radionuclide in the cargo, as well as from the attenuation of the normal background radiation due to the cargo itself. The field test results indicate a high success rate for positive detection of K-40 simulant and the true contraband.

1. Introduction

Recent statistics on drug seizures indicate that smuggling in containers is carried out in bulk-quantity shipments. Of these container seizures, a large proportion was found to be marijuana and hashish in several thousands of kilogram quantities. These findings draw attention to the importance of routine non-invasive inspection of containers, rail cars, and tractor trailers at the various ports of entry, to detect concealed shipments of plant contraband. As such, Canada Customs[1] has been involved since 1994 in the development and testing of a truck inspection system based on the detection of *passive radiation* naturally emitted from the plant contraband.

Contraband such as marijuana, hashish, and tobacco that are produced from dried plant material contain small amounts of potassium in concentrations of about 1-3% by weight. This potassium is absorbed from the

[1] Canada Customs has collaborated on this K-40 based plant contraband detection project with its industrial partner, Exploranium G.S. Limited, 264 Watline Avenue, Mississauga, Ontario, Canada L4Z 1P4.

ground by the plant and tends to get concentrated in the leafy part of the plant, more so than in the stems. This fact is a plausible reason for the higher potassium concentrations in plant contraband, on average greater than most other agricultural produce. The radioactive potassium-40 (K-40) nuclide occurs in potassium with an isotopic abundance of 0.012%, and decays naturally by emitting single-energy gamma rays at 1.45 MeV.

The application of passive radiation detection methods, namely the detection of K-40 emissions, as a plant contraband detection technique was first investigated by the US Customs and Lawrence Livermore National Laboratory in 1992 [1]. These tests were performed on an empty trailer and a pick-up truck that was parked in a stationary position. Revenue Canada investigated a detection system employing both plastic detectors and sodium iodide (NaI) detectors in 1994 [2], and conducted the first field test with a similar system at the Lansdowne border-crossing at Thousand Islands between Ontario and New York in 1995 [3]. In this field test, inspections were performed on moving trucks. The detection system used in this field test comprised of two NaI detectors (10 x 10 x 40 cm^3) and four PolyVinylToluene plastic scintillation detectors (30 cm x 104 cm x 2.5 cm^3), mounted on either side of the truck. Three optical sensors served in providing an estimate of truck speed. The detectors were shielded from background radiation by a detector housing only 2.5 cm thickness of steel. The test procedure was simple and required no personnel at the inspection site: the drivers were asked to drive the trucks past the detectors at a low speed, which triggered the data acquisition system to acquire and save the measurements. No real-time data analysis or feedback on the inspection result was provided, since the main objective of the test was to build a data base for a variety of cargo loads. The lack of an operator in these preliminary field test led to some problems with regards to the matching of manifests (to determine the declared cargo) to the recorded detector measurements, and resulted in a partially useful database. This fact, as well as the low sensitivity of the *dynamic* detection system, influenced the decision to conduct another field test with an improved detection system.

2. Philipsburg Field Test

2.1 Passive Radiation Detection System

The field test at the Philipsburg border-crossing between Quebec and Vermont was performed during October-November 1996. The detection system was made up of 8 NaI crystals, each of dimension 10 cm x 10 cm x 40 cm. The detectors were mounted at a height of 1.8 m with four crystals on each side of the truck. The spacing between the two sets of detectors was 4.5 m. Two detector outputs were obtained by summing the individual outputs of the four crystals from the right and left crystal packs, and fed into the Exploranium[1] GR-820 spectrometer. This spectrometer was capable of automatic gain stabilization of each individual crystal to reduce spectral drift caused by temperature changes at the detector. The stabilization was performed on the background Thorium peak at 2.6 MeV. The GR-820 was interfaced to a computer for data acquisition. The data acquisition software was coded using Labview, and provided instantaneous feedback on the measurement process by displaying on a single screen the averaged energy spectra for the right and left detectors, the total counts for pre-selected spectral regions of interest (ROI), and the time varying outputs of the five optical sensors from which the truck profile can be discerned. The spectrometer and associated high voltage supplies, and the data acquisition system computer were housed in a van adjacent to the detectors as seen in Figure 1. Also visible in the figure are stands for 5 pairs of optical sensors at intervals of 3.6 m, and located at the same height as the detectors. The detectors and associated hardware was supplied and installed by Exploranium[1].

2.2 Background Radiation Reduction

A detection system that is designed to be highly sensitive to K-40 in the cargo unfortunately becomes vulnerable to the reception of unwanted background radiation emanating from the surrounding soil, construction material, and vegetation. Since this background radiation also contains K-40 emissions, to obtain a high contrast for K-40 containing cargo, the background radiation has to be drastically reduced by suitable ground shielding and a combination of detector shielding and collimation. For the field test, ground shielding with a steel plate of 2.5 cm thickness, 3.6 m width between the detectors, and a 6 m length was used. The detectors were shielded from behind with a 2.5 cm thick steel back plate of width 165 cm that extended from the ground to the tops of the detectors. The combined result of the steel ground plate and detector back panel shielding was to reduce the background radiation in the K-40 channel by about 60% (as recorded by an Exploranium GR-130 hand-held spectrometer at a height of 1.8 m).

The test setup used in the Lansdowne field test did not employ detector collimation, and resulted in relatively poor contrast for K-40 simulants. Therefore for this test, steel collimators of 5 cm thickness which approximates about 2 mean-free-paths of 1.45 MeV radiation was placed around each crystal pack. Each collimator measured 90 cm x 60 cm on the detector sides and 60 cm x 60 cm at the detector base. The collimator extended 60 cm from the rear of the detectors so that the actual width of the passage for the trucks was reduced from 4.5 m to 3.3 m. The background count rate measured by the detector system in the K-40 window reduced from 63 cps (per 4 crystals) to 27 cps after collimation, which was an improvement of 53%. The collimated detector enabled segmented inspection of the 12 m length of the cargo container, where the field-of-view (FOV) of the detector corresponded to about a 2.4 m truck length.

Figure 1. Passive radiation system installed for the field test at the Philipsburg border-crossing.

2.3 Container Inspection Process

Unlike the Lansdowne tests that were aimed at automated inspection of a moving truck, the test procedure for these tests were to record both dynamic and static measurements for each truck. Also, a dedicated operator was present for the entire duration of the tests to ensure consistency and reliability for the data collected. The static and dynamic modes of operation were selected by the operator using a hand-held control box. Three static measurements were obtained for each truck corresponding to the front, center, and rear of the truck. Except for the case of some control tests with contraband simulant, all other measurements were acquired over a 60 sec time period. The duration of a typical dynamic measurement was about 30-45 sec.

Background measurements were acquired daily throughout the tests, during idle times, and was used for compensating the spectral measurements for variations in background due to weather (mostly rain).

Control tests were conducted with the contraband simulant hay which had 1.2% potassium, loaded into an empty tractor trailer. Different simulant quantities and distribution configurations inside the trailer were tested: eg. front wall, floor, side wall. Similar tests with 614 kg of tobacco (115 kg in cans and 499 kg in cartons) and 566 kg of marijuana provided by the Royal Canadian Mounted Police were also tested. The potassium concentration in tobacco is 2.9% [2], and for the marijuana used in the test was 1.9%. In addition, a concentrated potassium source of KCl fertilizer (50.7% potassium) distributed in pipes, each 6.25 cm diameter by 180 cm length and weighing 29 kg, were also tested inside loaded and empty containers.

3. Results for Real Contraband and Simulant

For the K-40 window centered around 1.45 MeV a Contrast Factor was defined as the ratio: (net counts in contraband spectrum - net counts in background spectrum) over the (net counts in background spectrum), where a background spectrum refers to the case where there was no truck present. The net counts in the K-40 window were obtained by subtracting from the total counts an estimated background count due to the detector wide response. This contrast factor yielded better results than when traditional peak stripping was employed, where the magnitude of the counts stripped was proportional to the intensities of higher energy nuclides such as Uranium and Thorium. Figures 2, 3, and 4 plot contrast factor vs. contraband weight for the contraband simulant hay, tobacco, and marijuana.

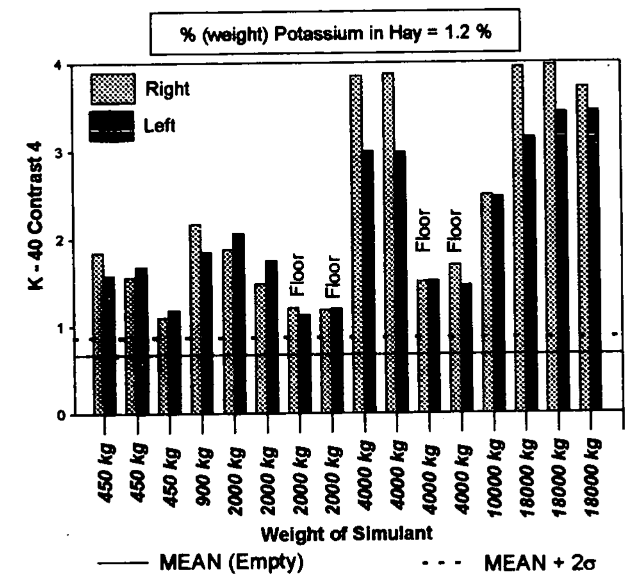

Figure. 2. K-40 contrast for contraband simulant, hay.

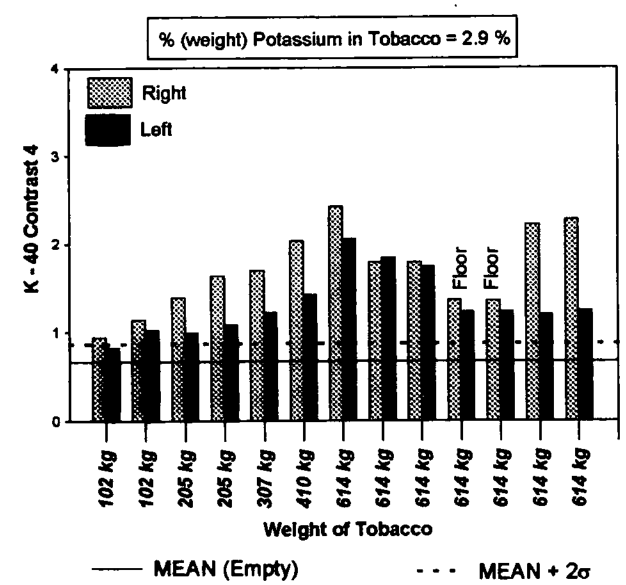

Figure 3. K-40 contrast for contraband, tobacco.

For a detection threshold based on the mean + 2σ of an empty truck, it can be seen 230 kg of marijuana, 200 kg of tobacco, and 450 kg of hay, with a potassium concentration (1.2%) similar to that of hashish (1%), are detectable when loaded in the front of the truck. For contraband spread across the floor, the detectable contraband weight is higher and is due to the absence of a. detector looking upwards towards the truck floor.

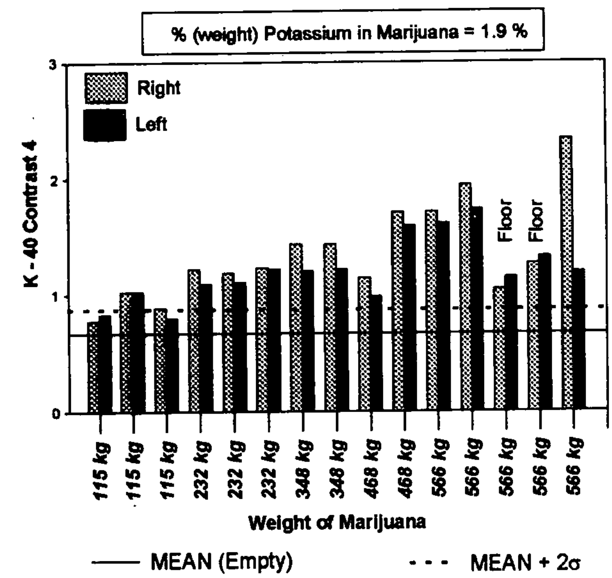

Figure 4. K-40 contrast for contraband, marijuana.

4. Spectral Data Processing

If the K-40 signature as detected in the K-40 window was unique to plant contraband cargo alone, then a simple detection technique that applied a global threshold to the K-40 window total counts would suffice as shown in the results of Figures 2, 3, and 4. However, cargo can vary over a wide range. From an emission perspective, the cargo can contain small amounts of radionuclides that decay emitting K-40 and/or other gamma rays such as Thorium (Th), Uranium (U), and Radium (Ra) decay products, or the cargo may not contain any radionuclides at all. The bulk of the cargo falls into the latter class, and are the empties, paper, textile, lumbar and wood products, chemicals, electronics, metal (bulk, heavy machinery, recycled metal) etc. It is because of this smaller class of cargo which contain gamma-ray emitters that further spectral analysis of the NaI energy spectrum is required. Even if none of the radionuclide containing cargo emissions were K-40, spectral processing is still required because of the intrinsic nature of the detector wide response function that can cause an increase in the K-40 window count rate. Table 1 lists potassium weight concentrations for contraband and a few agricultural products, and some interference inorganic cargo.

Table 1 Percent weight concentrations of potassium in contraband and other cargo

	% Potassium
Marijuana	1.9%
Hashish	1.0%
Tobacco	2.9%
Straw	1.03%
Hay	1-1.2%
Corn powder	1.1%
Corn-dried kernels	0.27%
Whey powder	1.6%
Canola meal	1.0%
Soybean-powder	1.8%
Cow feed	2.0%
Chocolate	0.42%
Potato chips	1.0%
Glass	0.97%, 1.3%
Cement mix	1.44%
Limeash	1.66%

For this study, several energy windows corresponding to Thorium and Uranium, and at very low-energy were examined for their ability to cluster the data into distinct classes. Also, several Contrast factors that accurately estimate the emission signals were investigated. These contrast factors differed based on the manner in which the contribution from higher energy radionuclides in the window of interest was compensated. A partial result of this analysis is summarized in Figure 5 for the three estimators, C4(K40), C1(Th2), and Att(Th1+U1), where contrast factor C4(K40) is the background normalized net peak counts in the K-40 window, C1(Th2)+1 is the background normalized gross stripped counts of the U2 window centered at 1.12 MeV, and Att(Th1+U1) is the background normalized gross stripped counts from the Th1 and U1 windows centered at 2.61 MeV and 1.76 MeV, respectively. The figure shows the data being classified into 4 categories: non-radionuclide containing cargo (empty, metal, paper, etc.), contraband cargo, Th/U/K-40 containing interference cargo (inorganics such as sand, cement, glass, etc.), and K-40 containing interference food cargo. The latter class is separable from the contraband cargo based on bulk-density differences as estimated by contrast factor Att(Th1+U1). It should be noted that cargo classification using spectral data is a multivariate problem that should utilize all spectral features (in addition to the above three shown in Figure 5) that reinforce the overall classification solution. Additional features such as C1(Th1), C1(U1), C1(U2), and C1(low-E) were also seen to have properties that characterize the data, and could be included in the feature set. In particular, the (low-E) window at 0.1 MeV will be beneficial in identifying cargo that has radionuclides other than K-40, Th, or U.

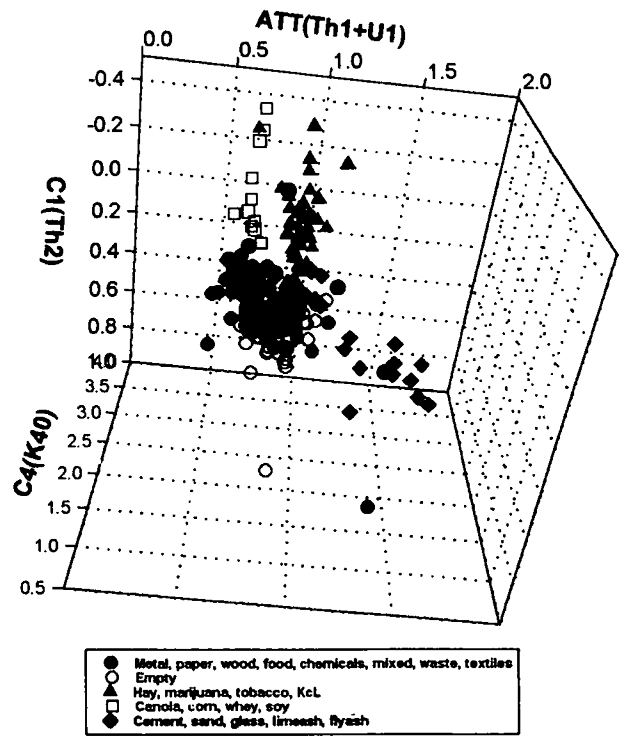

Figure 5. Results of spectral processing of estimators taken from three energy windows

A sub-classification of the non-radionuclide category of cargo not visible in Figure 5 can be obtained using an un-normalized C4(K40). This contrast factor which estimates the attenuation of the natural background K-

40 due to the cargo, and therefore is proportional to the bulk cargo density, enables sub-classification into at least 2 groups: low and high density cargo. An estimation of cargo density could aid in manifest verification.

5. Future Work

Key to the success of plant contraband detection in a real field environment where there is an abundance of different cargo types, is cargo classification. Data analysis performed in this work indicates the use of a multivariate feature set derived from the detector energy spectral response for cargo classification. A neural network approach, that can learn the probability distributions and decision boundaries for the various cargo classes by training with a spectral feature set obtained for a wide range of cargo types, will be attempted with the data from this field test. This automatic cargo classification and decision making software will be implemented and incorporated in the next field test, so that a Customs Inspector with minimal technical training can execute the tests and make decisions when provided with an output screen similar to Figure 6 that shows the results of classification for the inspected container segments.

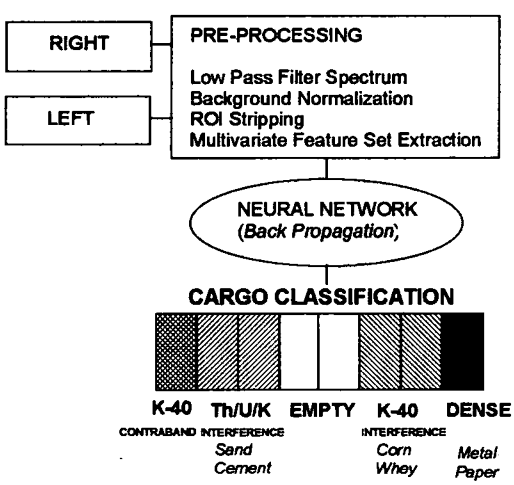

Figure 6. Conceptual design for cargo classification and operator readout.

6. Summary and Conclusions

A passive radiation detection system comprising of NaI detectors were tested at the Philipsburg border-crossing. Since K-40 is also present in the background radiation, detector shielding and collimation plays an important role in enhancing the detection sensitivity: detector collimators providing an attenuation of about 2 mean-free-paths to 1.45 MeV photons, with a restricted field-of-view allowing segmented inspection of the container, was used in the tests. Results of control tests with marijuana, tobacco, and the simulants, hay and KCl fertilizer, showed that quantities less than 500 kg were detectable. In addition to plant contraband cargo, there exists a smaller percentage of benign cargo that interfere with the detection process due the presence of K-40 in them. To classify this interference cargo multiple features derived from the energy spectra from Th, U, and other low-energy windows were examined. Preliminary analysis has shown that the data can be classified into low- and high-density non-radionuclide cargo, Th/U containing interference cargo, K-40 containing high-density interference food cargo, and K-40 contraband cargo.

7. Acknowledgments

The support and cooperation of the Philipsburg border-crossing team for their participation in the field test is greatly appreciated. Special thanks also go out to Mr. Frank Lohmann for his role in data collection at the test site, and to the RCMP for their vital role in providing seized contraband for testing on two occasions. Many thanks are also due Mr. Gerry Drolet of the Enforcement Directorate for his strong support and efforts in promoting this test.

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VACIS, A Versatile Gamma-Ray Vehicle And Cargo Inspection System

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ABSTRACT

A versatile, gamma-ray imaging system is described in which individual photon counting is utilized to achieve an image rapidly, yet with a low-level radiation field. The choice of Cs-137 or Co-60 gamma rays provides penetration capability corresponding to 2 and 4 MeV x-rays, respectively. The use of the largest detectors possible, consistent with the resolution required for the image, makes it possible to achieve scan speeds of 1-60 mph; Very high-speed electronics have been developed for the high gamma-ray count rates and the high-frequency sampling times that are required for the high-speed range.

The variety of inspection systems under development and/or proposed, as described below, are high-throughput systems; capable of being easily transported in some of its configurations; of presenting clear, unambiguous images; and of being economical and highly reliable.

1.0 Introduction

The Vehicle and Cargo Inspection System (VACIS) is a gamma-ray imaging system that utilizes a narrow slit-shaped gamma-ray beam to irradiate a linear array of detectors. Either the source-detector system moves to scan a fixed vehicle (see Figure 1) or the source-detector system is fixed and the vehicle to be scanned moves. With the use of single-photon counting, plus the largest detector size possible (consistent with the required image spatial resolution), the scan speed can be high (1-60 mph or 1.6-96 kph) with the use of a relatively weak and very penetrating radiation field.

The initial configuration, VACIS-I, was designed to scan some of the 350 thick-steel-walled, high-pressure tanker trucks that shuttle from Mexico nearly empty but still under pressure. One such tanker was interdicted with about 8000 pounds of cocaine (see Figure 2). Utilizing a Cs-137 gamma-ray source (equivalent to a 2-MeV x-ray source), it easily penetrates the 1-inch or so of steel and can presently scan a typical 40-foot tanker in about 45 seconds. A VACIS-I system is being used at the El Paso, Texas Port of Entry (POE), inspecting nearly 200 cargo trucks and tanker trucks a day, after extensive use at Nogales, Arizona earlier this year.

Other VACIS configurations include:

- The VACIS-II, a higher-resolution system. This system has a taller detector tower and a longer source-detector "trolley-track" system so as to scan the taller and longer cargo vehicles in a single scan (perpendicular viewing, or "oblique"). It also features zoom capability for more precise inspection of highly suspect areas.

- Another configuration has a fixed source-detector system that utilizes a radar vehicle-velocity measurement to correct for changing velocities (i.e., for obtaining the correct image "aspect ratios") of the vehicle to be scanned.

- A similar system, without velocity measurement, anticipates the cargo vehicle's acceleration after leaving the checkpoint.

- A system with a very small "footprint", and with the source under the vehicle (to inspect sealed cargo containers for stolen automobiles).

- A system for inspecting automobiles with still higher resolution and zoom capability.

- A system for 100% inspection of long trains from Mexico at 1-15 mph, is in the planning stage.

Some of these may utilize a Co-60 gamma-ray source (equivalent to a 4 MeV x-ray source) for greater cargo-load penetration.

Section 2 presents some of the test results obtained with the VACIS-I system that is now in use at El Paso, Texas, inspecting nearly 200 cargo containers per day. Section 3 presents the design features of VACIS-II, a ruggedized and more capable version of VACIS-I. In Section 4, the features of the proposed AUTOMOBILE VACIS are presented. Section 5 describes the RAILROAD VACIS configuration designed for the Nogales, Arizona POE, and Section 6 presents the three different STAR (STolen Automobile Recovery) configurations of the basic VACIS system. Section 7 presents a summary of the advantages of the VACIS approach to high-speed, "flow of commerce" inspection either as an ultimate inspection tool or as a preliminary-screening type of inspection system.

2.0 VACIS-I Performance Capabilities

The VACIS-I system is shown in Figure 3, ready to scan a thick-steel-walled tanker truck. The Cs-137 gamma-ray source, on the source trolley is on the right and the detector tower is on the left. Both are ready to roll down the trolley tracks to inspect the tanker. A typical tanker image is shown in Figure 4, with a stash of simulated cocaine inside (bottom image), and without a stash (top view, REFERENCE) Note that the stash is easily detected, even without the REFERENCE image. Figure 5 shows a stash secreted along one of the tanker's structural ribs, just to the left of the ladder. If such stashes were carefully placed along all the ribs, they would not be easily detected without the REFERENCE image above. The computer can store up to 32,000 such reference images, and they can be called out by tanker type, or even by tanker identification number for those tankers that are constantly shuttling across the USA-Mexico border.

Figure 6 shows a cargo van about to be inspected. The contents of the van can be seen in Figure 7 (top, REFERENCE and bottom, loaded) with the load showing a stash in the second container from the left; top center of the palette. Figure 8 shows a cargo van with a false compartment empty (top), and with a stash (bottom). The VACIS-I images clearly reveal such hidden compartments. The system is currently generating nearly 200 such images per day at the El Paso, Texas POE.

3.0 The VACIS-II Configuration

The VACIS-I system was initially designed as a demonstration system to show the feasibility of inspecting thick-steel-walled tanker trucks. It is now performing well in inspecting cargo vans as well. The van and cab are appreciably longer and higher than the tanker trucks, so that up to 4 scans are required for 100% inspection of the vans (or cab plus cargo container on a flatbed): a high and a low scan for each of the front and rear sections. Therefore, VACIS-II is being made taller and the trolley-track length greater so as to be able to complete a 100% inspection in a single sweep. This capability is shown in Figures 9 and 10, top view and end view respectively.

With the taller detector tower, the van can now be placed about halfway between source and detector, rather than close to the detector tower. This modification, plus a closer spacing of the detectors, will improve the image resolution to about 1-1/4" (3.2 cm) per pixel (picture-element), vertically, from about 3" (7.6 cm) for inspecting nearly 200 cargo trucks and tanker trucks a day, after extensive use at Nogales, Arizona earlier this year.

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VACIS-I was designed as a demonstration unit, capable of conducting at least 200 demonstrations. It has performed well, generating 10,000 to 20,000 images with only minor repairs. VACIS-II will be ruggedized and weather-proofed for the ability to operate for a much longer time without major replacements and to withstand salt-air environments such as at Miami, Florida.

4.0 AUTOMOBILE VACIS

An image of a station wagon is shown in Figure 11 with a stash of simulated cocaine hidden in the passenger seat behind the driver's seat. The proposed AUTOMOBILE VACIS system will improve on this VACIS-I image in three ways. First, the image will be able to scan lower portions of the vehicle, as shown in the schematic diagram of Figure 12. This way the floor and tires can be inspected. Second, the image resolution will be improved from about 1-1/2" (3.8 cm) to about 1/4 - 3/8" (0.6 - 0.9 cm). Third, zoom capability will be added to enhance the inspectability of suspicious areas, including the stuffed toy shown in Figure 12.

Figure 13 presents the results of a camper inspection, showing items placed on the table and chairs behind the driver's seat. It is clear that, for both these items and the stuffed toy of Figure 12, a much higher resolution system with "zoom" capability would greatly enhance the detectability of hidden drugs in such packages. The US Customs Service R&D staff members have suggested that a resolution of 1/4 - 3/8" (0.6 - 0.9 cm) would be adequate.

The proposed AUTOMOBILE VACIS system can be used as a high-throughput ("flow of commerce") inspection system providing rapid inspection of a significant fraction of the automobiles crossing the USA-Mexico border. In addition to rapid screening of suspect vehicles in the normal flow of traffic, there is also need for periodic (unannounced) checks of registered vehicles traveling in the dedicated commuter lane. Such checks should greatly reduce the flow of drugs through the many POEs.

5.0 RAILROAD VACIS

Figure 14 shows a conceptual scale drawing of the RAILROAD VACIS system for the Nogales, Arizona POE. This system will be designed to inspect railroad cars entering USA. It can inspect every railroad car of the 100 or so cars of each train, and would do so at the normal entry speeds of 1-10 mph (1.6 to 16 kph). Thus, this preliminary-screening inspection can be conducted without delays, since each of these long trains ties up both foot traffic and automobile traffic in Nogales, Mexico and, to a lesser degree, in Nogales, Arizona.

SAIC has recently developed the necessary high-speed data processing electronics to handle the ultra high gamma-ray count rates and data-communications sampling rates to generate the gamma-ray images for these railroad car speeds. With this system, the normal flow of commerce is not impeded. Any suspicious-looking railroad car or cargo container is immediately flagged for downloading at the Rio Rico railroad inspection site about 10 miles north of the border.

The US Customs Service railroad inspectors at Nogales pointed out that a large volume of automobiles, automobile sheet-metal products and upholstery entering the USA require inspection for hidden drugs. The most difficult of these to inspect is, perhaps, the automobile. Figures 15 and 16 show images of an empty automobile in a cargo container (top image of each figure), and one with a simulated stash of cocaine in the trunk, on the floor just behind the driver's seat, and on the hood. Similar stashes hidden in either a load of upholstery or sheet metal products could also be detected.

It is clear that RAILROAD VACIS can perform a useful inspection of railroad cars and stacked containers, and can carry out this screening on every single railroad car without impeding the normal "flow of commerce."

6.0 STAR (STolen Automobile Recovery) Inspection Systems

Three different STAR systems are being developed to inspect sealed ("unopenable") cargo containers leaving the Port of Miami and other POEs for stolen automobiles. These systems are of vital interest to insurance companies as well as law-enforcement agencies, both of whom would like to reduce these costly losses (estimated to be in the $100 million to $200 million range, per annum).

A major problem in such areas as the Miami POE is the footprint of the VACIS system. One of the STAR-VACIS configurations addresses this problem uniquely, since it eliminates both the large width and length of the conventional trolley-track inspection system.

Figure 17 shows a cargo container being inspected with the Cs-137 source underneath and the detector array above the container. This is probably not a good viewing angle when looking for drugs, but when looking for a massive and easily identifiable object such as an automobile, it works well. The cluttering of the picture due to the undercarriage of the cargo vehicle will not "hide" a stashed automobile. This viewing angle solves the width-problem of the STAR-VACIS footprint.

As for the length-problem, we have produced good VACIS images of trucks with the source and detector stationary and the truck moving. By anticipating the acceleration rate of the truck (i.e., the "velocity profile"), we were able to vary the sampling time (as the velocity changes) so as to achieve a distortion-free image. That is, it was adequately distortion free to facilitate positive identification of a stashed automobile within the container.

The second configuration utilizes the standard horizontal viewing of the cargo container, but with source and detector fixed (the cargo truck moves instead, as discussed in the paragraph above), and with the source-detector separation much smaller than for the VACIS-I and VACIS-II configurations. The resulting image quality is much too poor for drug inspection, but is entirely adequate for detecting the presence of a stashed automobile.

The third configuration is much like the second, except that it is quite portable, enabling it to be moved from one inspection lane to another by simply "wheeling it about". Note that the computer display in Figure 17 shows both the gamma-ray radiographic image of the container and above this, a TV-camera image of the ID number taken from the side of the container. Both the TV and the radiographic image will be sent to a central inspection station by means of wireless transmission, from whence interdiction procedures will be initiated. Only with such positive identification, facilitated with this non-intrusive inspection system, can these sealed containers be confiscated.

7.0 Summary and Conclusions

The flexibility of the basic gamma-ray radiography is apparent from some of the possible variations on the basic (source and detector trolleys) configuration discussed above. As mentioned in Section 6, a useful image can be obtained even for an accelerating (from stop) cargo vehicle. This was first accomplished by anticipating the velocity profile during acceleration. It can be done with much improved image quality by actually reading into the image-generating computer the measured velocity at each instance: A Doppler-radar system was developed for SAIC that will read velocities accurately down to 1 mph (1.6 kph).

SAIC has recently upgraded the detector signal-processing/signal-communicating electronics to achieve gamma-ray count rates of nearly 2 million counts/sec and to transmit detector reading at up to 600 samplings per second (for each detector, up to 50 detectors at this rate). This 1-60 mph (1.6 to 96 kph) capability makes VACIS uniquely adaptable for solving a large variety of inspection problems, and for potentially inspecting at rates that allow for screening every vehicle without impeding normal "flow of commerce".

The detectors are chosen to be as large as possible, consistent with the image-resolution requirements for the particular mission. This, along with the high-speed electronics recently developed, allows for high-speed image generation with very low (walk-through) radiation fields.

The radiation source is small, portable, inexpensive, and never runs out (within the half-life of the source, of course). The choice of sources (Cs-137 or Co-60) is such that excellent penetration power is achieved (equivalent to 2 MeV and 4 MeV x-ray sources, respectively).

A VACIS system can be virtually "made to order", be it for drug interdiction, stolen automobile recovery or armed forces protection.

It is basically an economical system, and is not plagued with high source (e.g., x-ray) costs, high source-power requirements, great source weight and size, long warm-up times, and high and frequent replacement costs.

8.0 Acknowledgement

The effort described in this paper was sponsored and supported, in part, by the office of National Drug Control Policy (ONDCP), and the DoD Counterdrug Technology Development Program.

The U.S. Customs Service is presently operating VACIS-I at the El Paso, Texas Port of Entry.

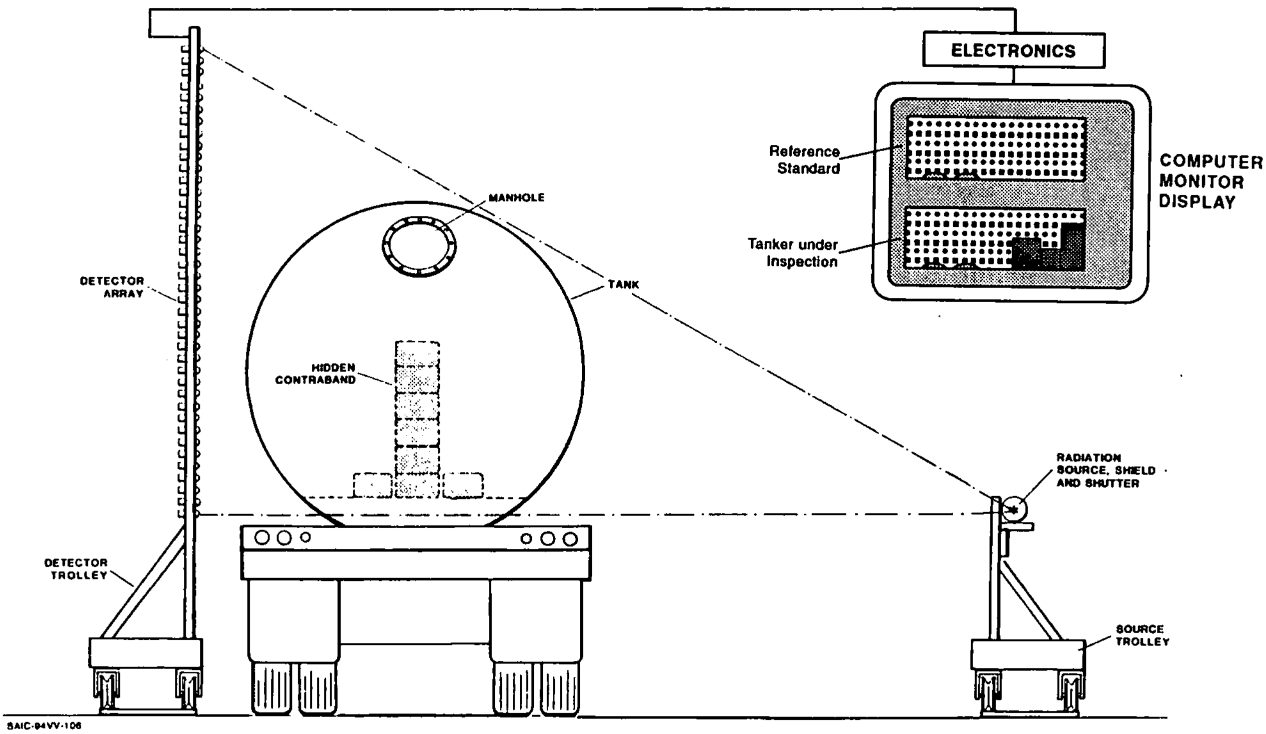

Figure 1. VACIS-1 gamma radiographic system for cargo trucks: Precursor for VACIS-II.

Figure 2. Tanker truck, confiscated with 8000 pounds of cocaine, undergoing preliminary study with Cs-137 source and NaI detectors prior to development of VACIS-I system.

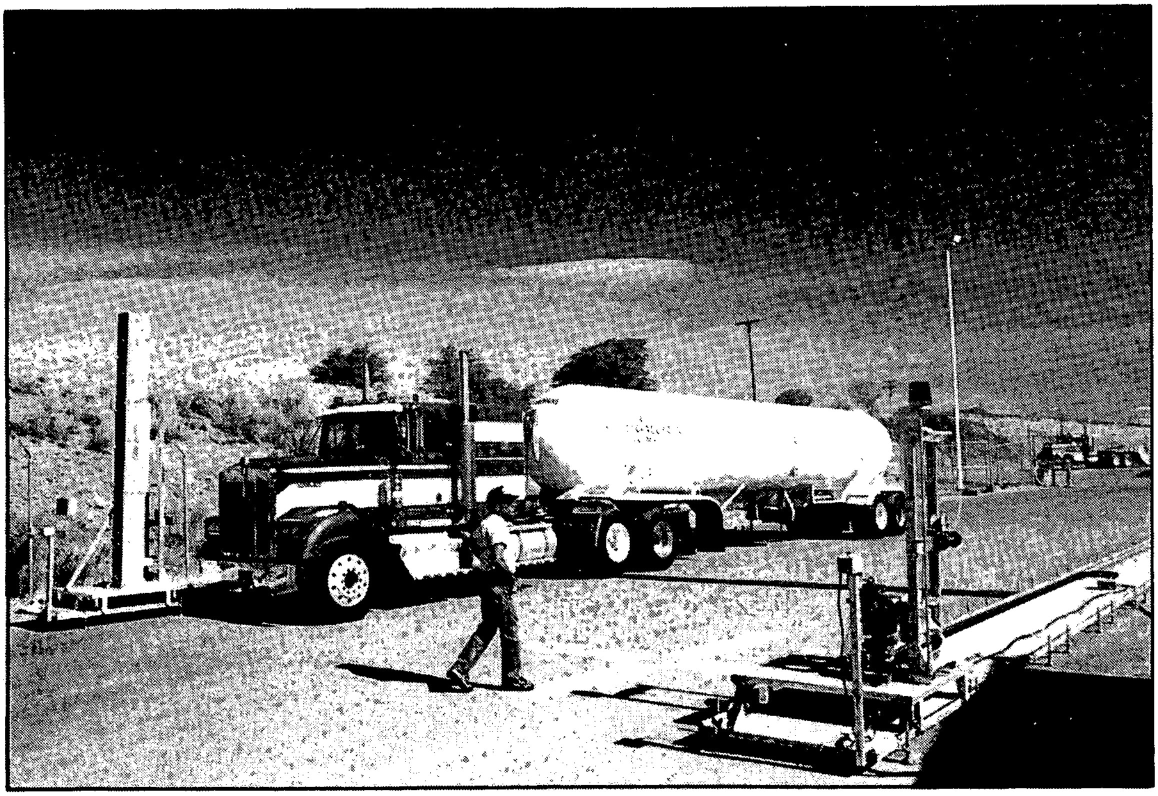

Figure 3. VACIS-I system ready to inspect high-pressure tanker: source is at right, detector tower at left, and US National Guard inspector in front of truck.

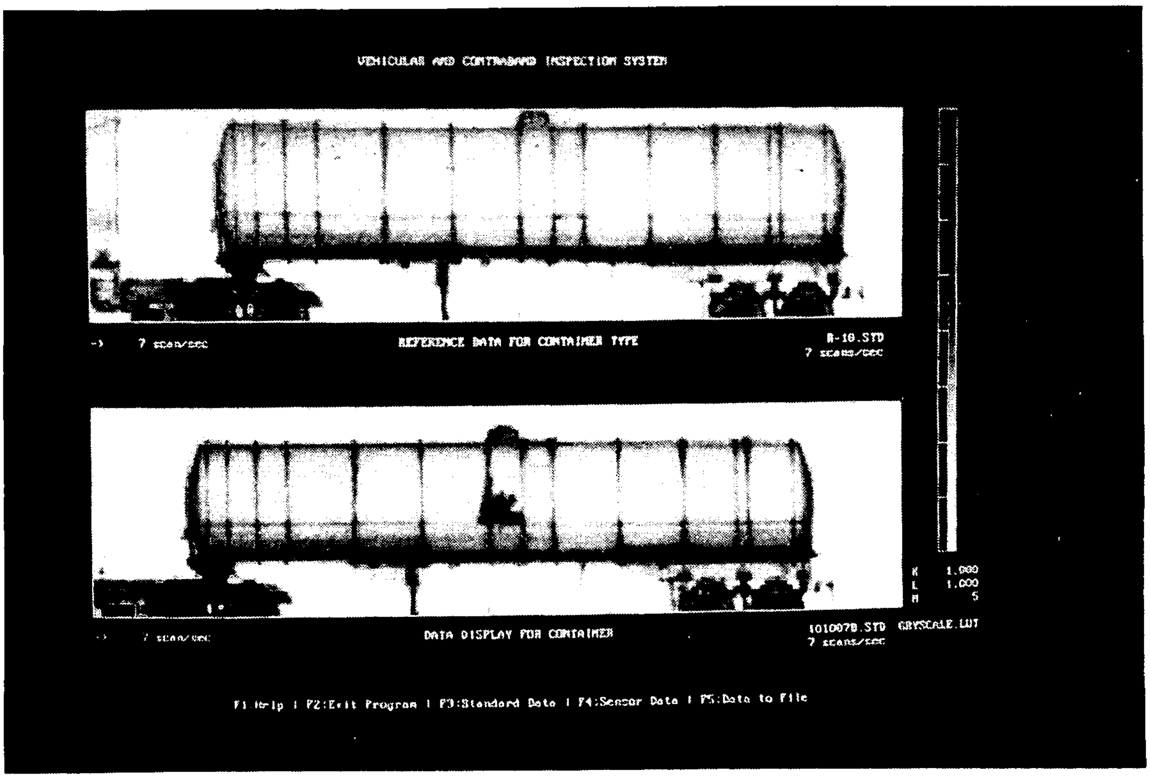

Figure 4. Image of reference tanker at top and tanker with stash of simulated cocaine inside, at bottom.

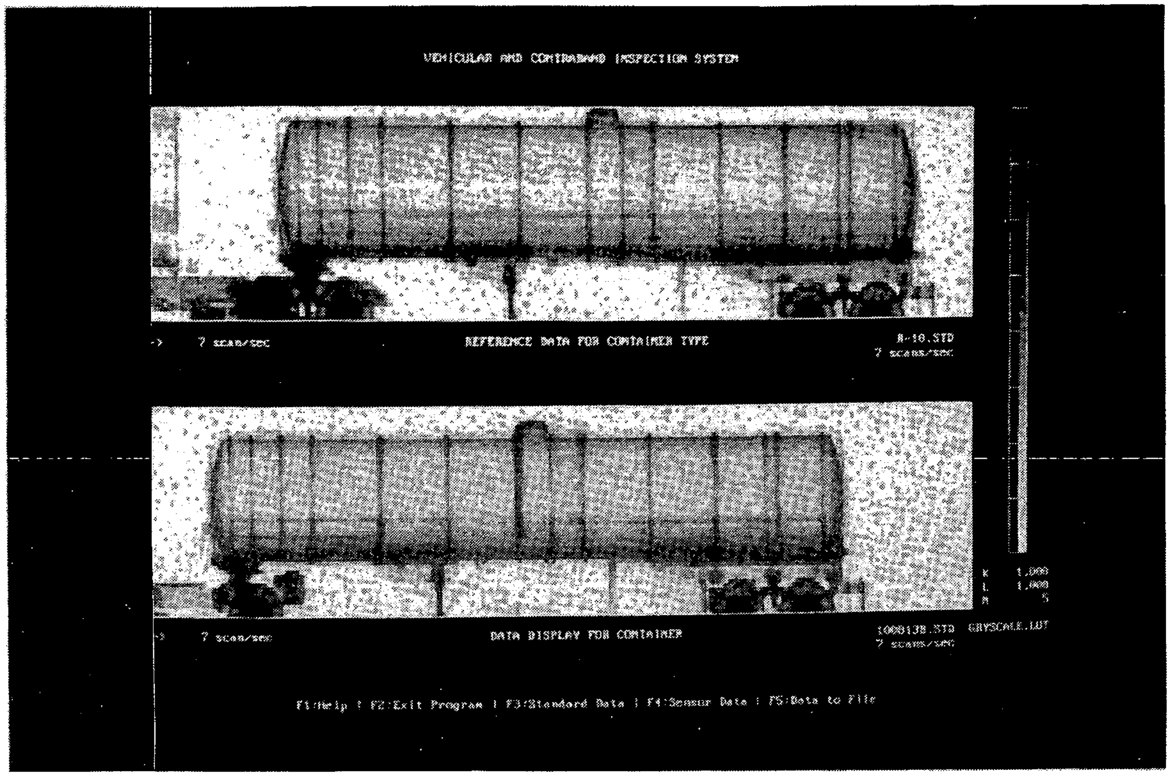

Figure 5. Image of tanker (bottom) with simulated cocaine along rib just to the left of the ladder near the center of the tanker.

Figure 6. Truck with cargo container in VACIS-I inspection lane.

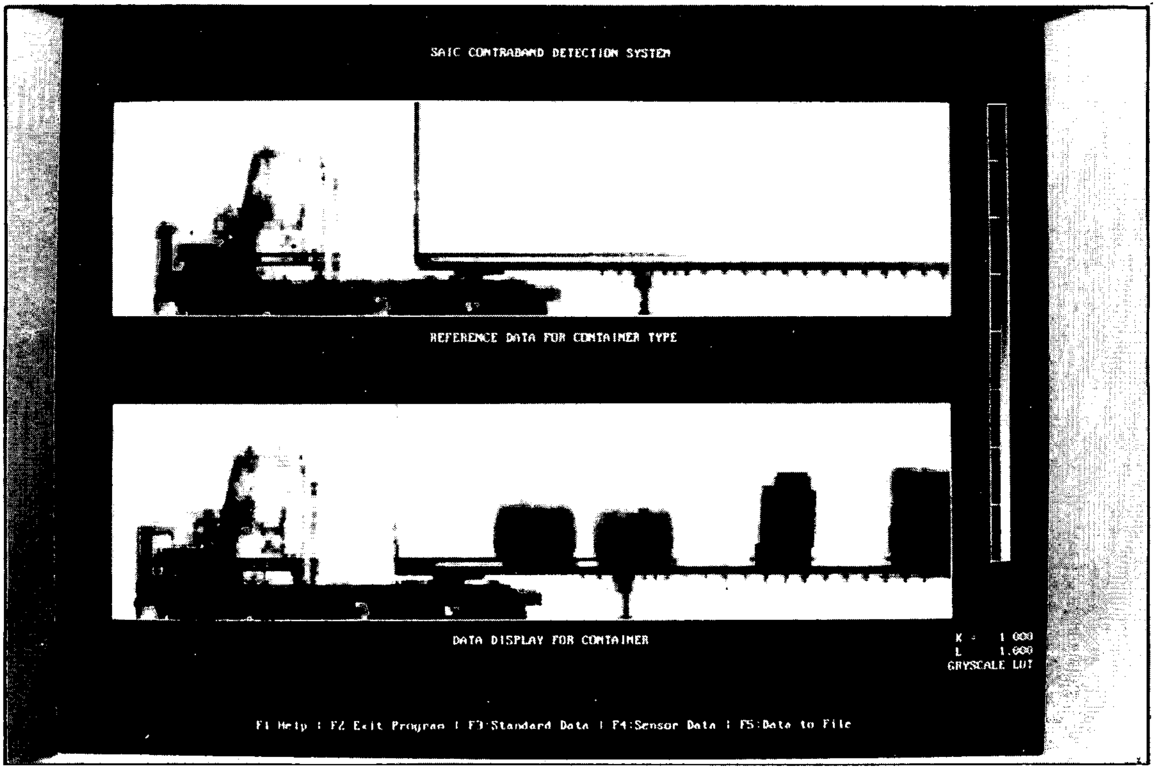

Figure 7. Contraband hidden in one of two 4' x 4' pallets of crushed, highly compacted plastic bottles.

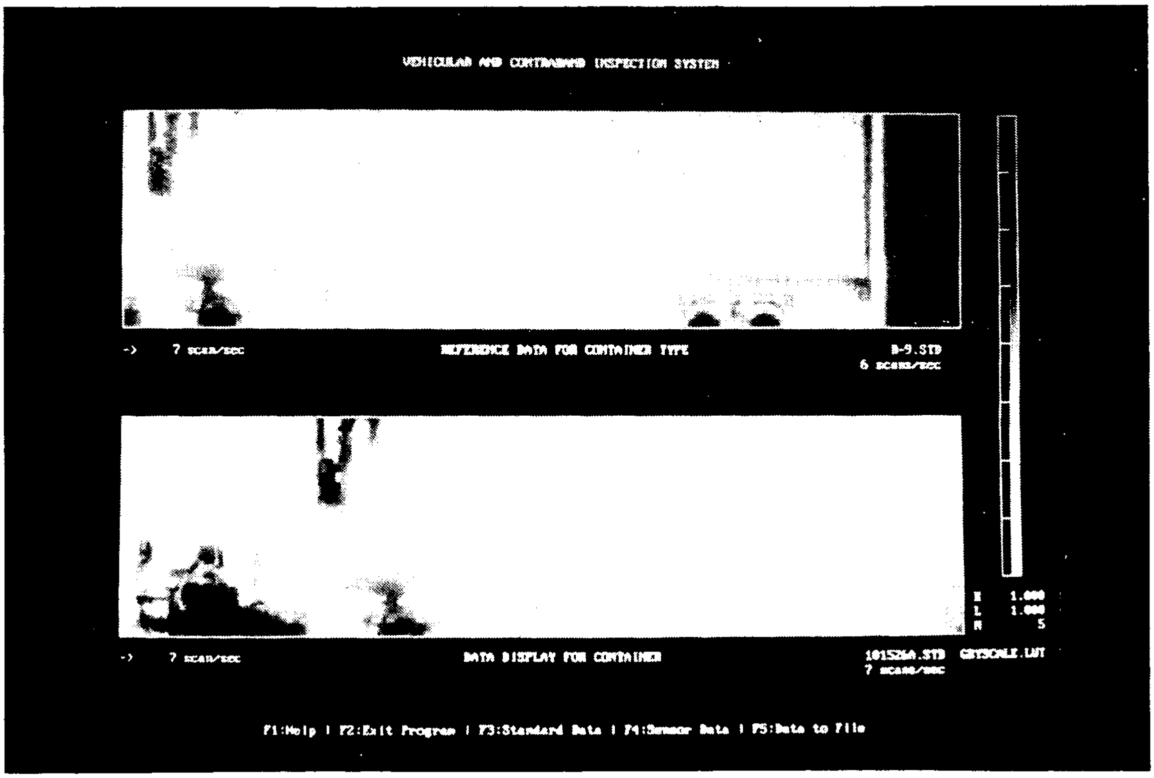

Figure 8. Cargo van with false compartment empty (top) and with hidden simulated cocaine stash (bottom).

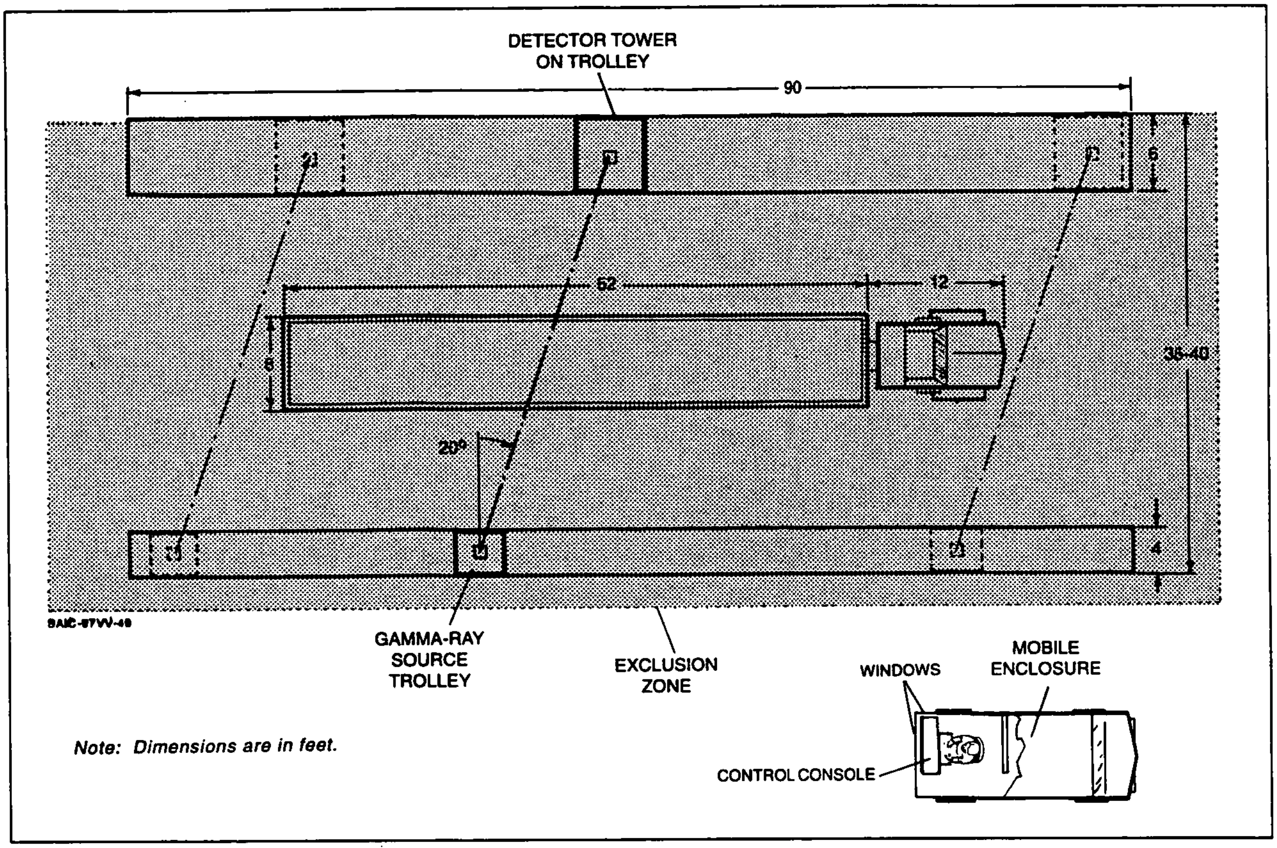

Figure 9. Top view of VACIS-II.

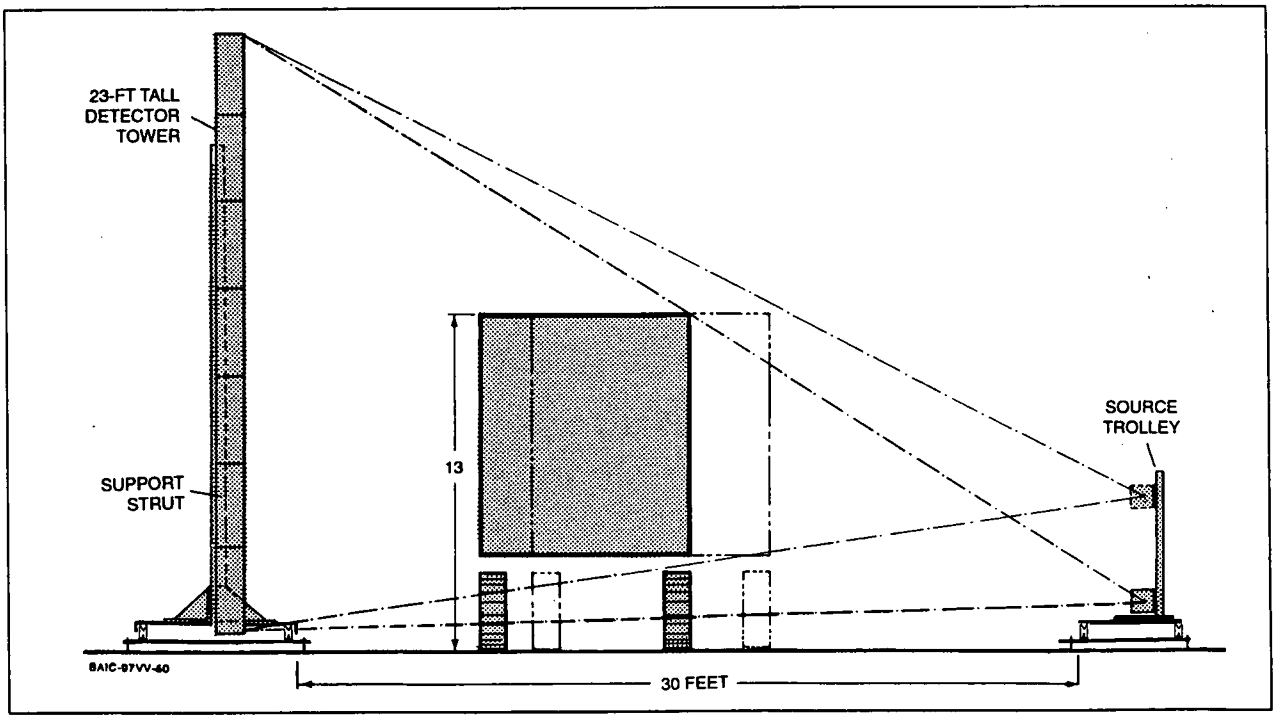

Figure 10. VACIS-II set-up, showing alternative cargo-van/radiation source positions.

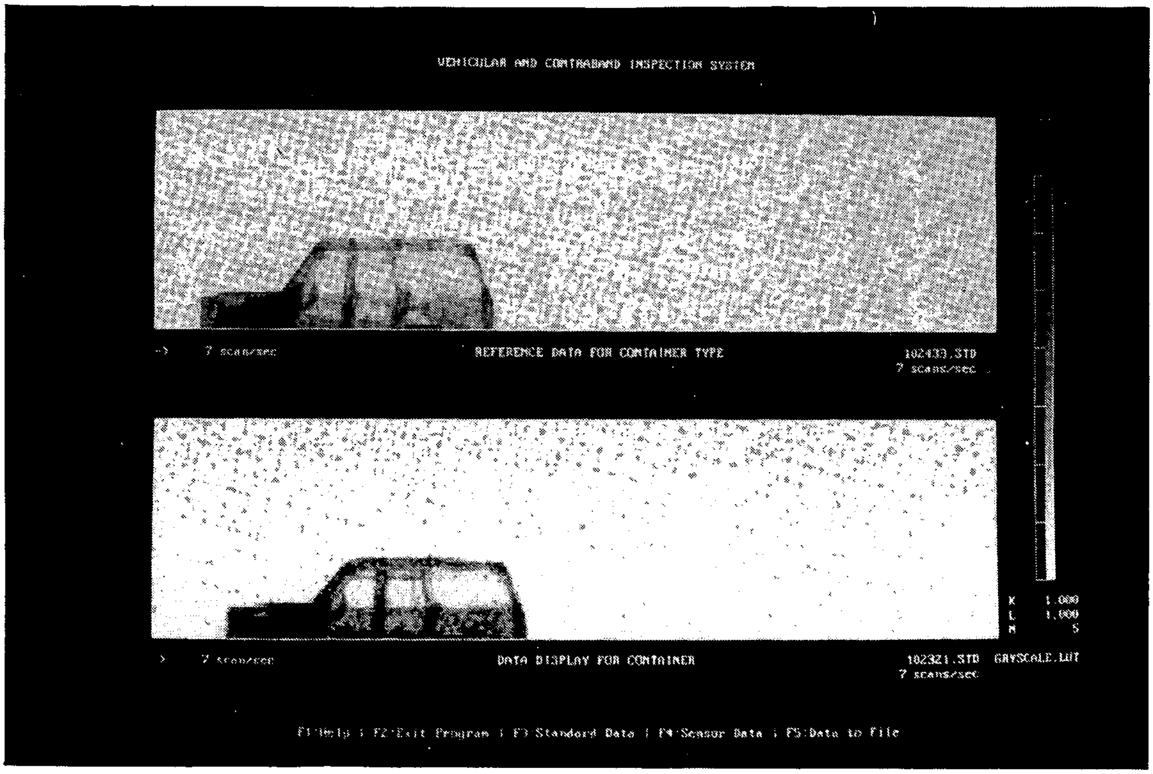

Figure 11. VACIS-II images of station wagon without (top) and with (bottom) simulated drug packets hidden in the passenger's seat behind the driver's seat.

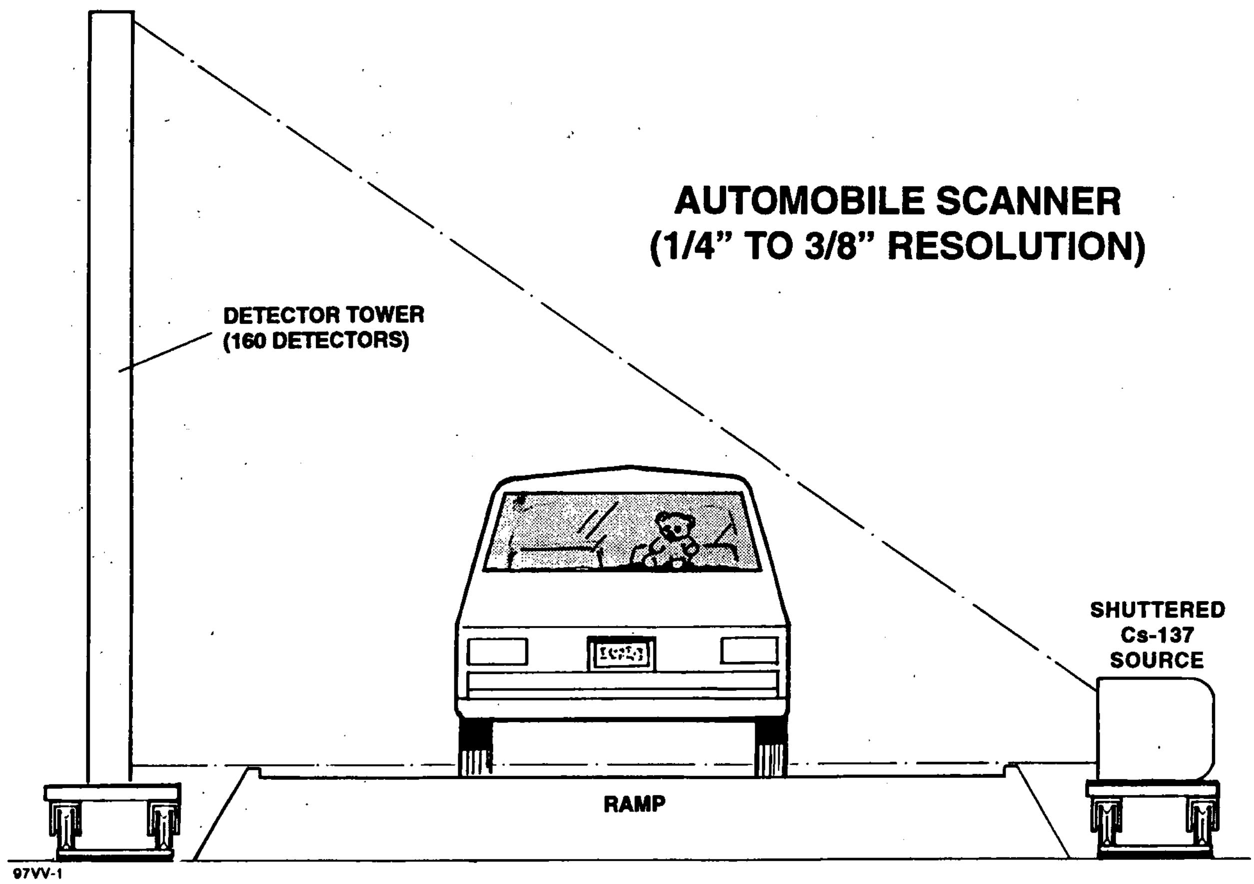

Figure 12. Schematic drawing of automotive VACIS scanning from tires to rooftop.

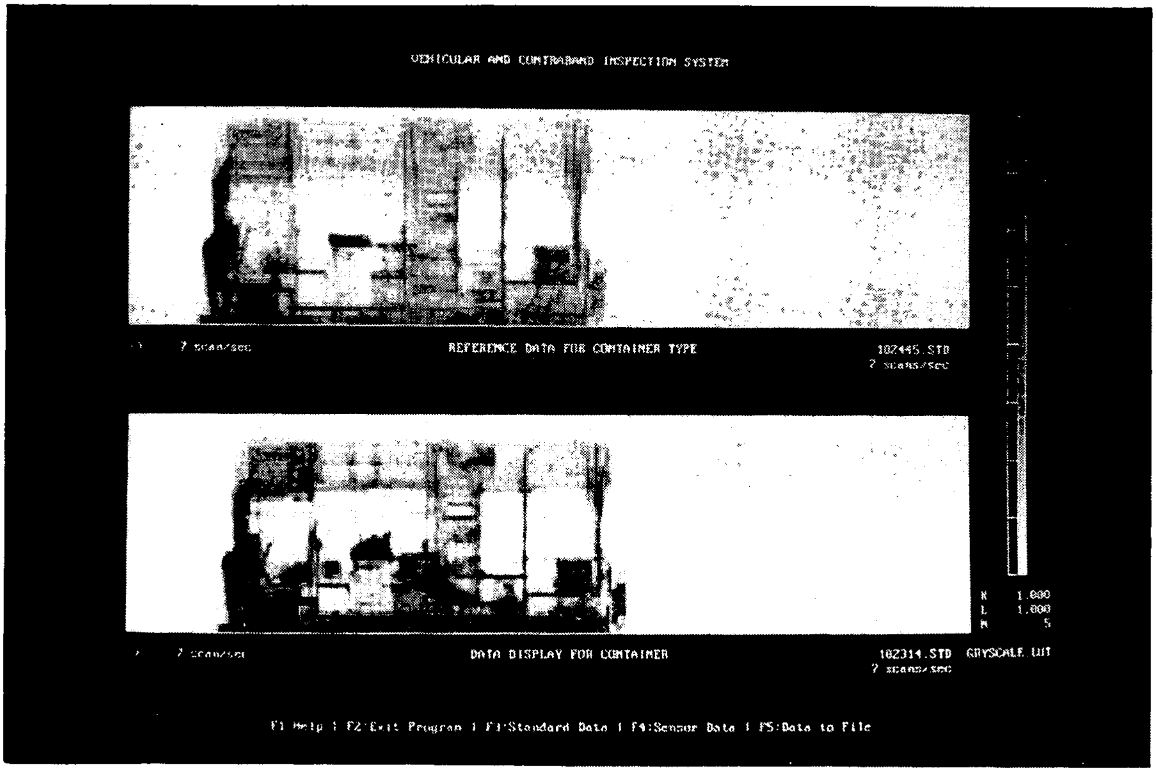

Figure 13. VACIS-I image of camper with simulated drug packets on chairs and table behind the driver's seat.

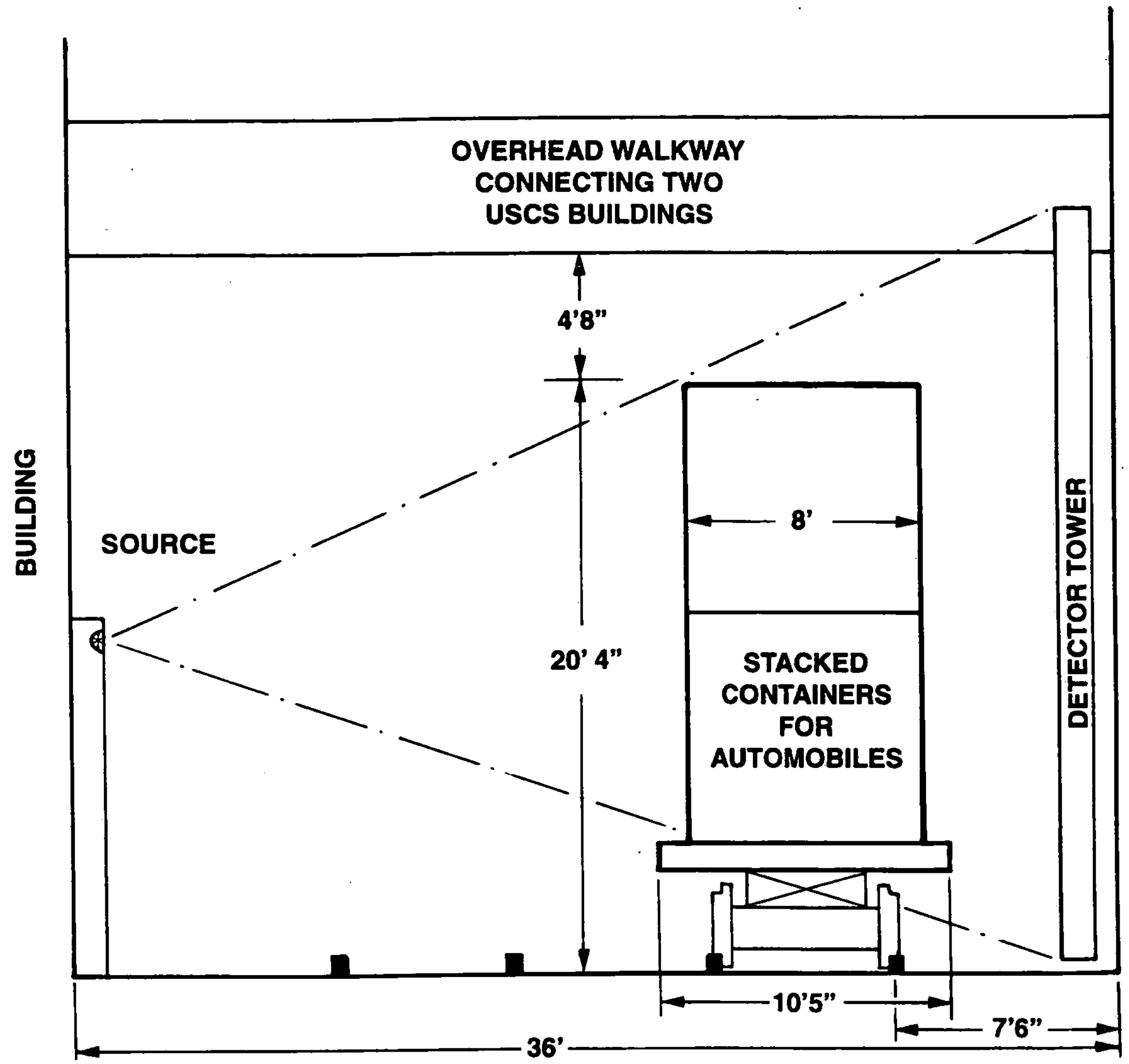

Figure 14. Proposed RAILROAD VACIS configuration for Nogales, Arizona railroad port of entry.

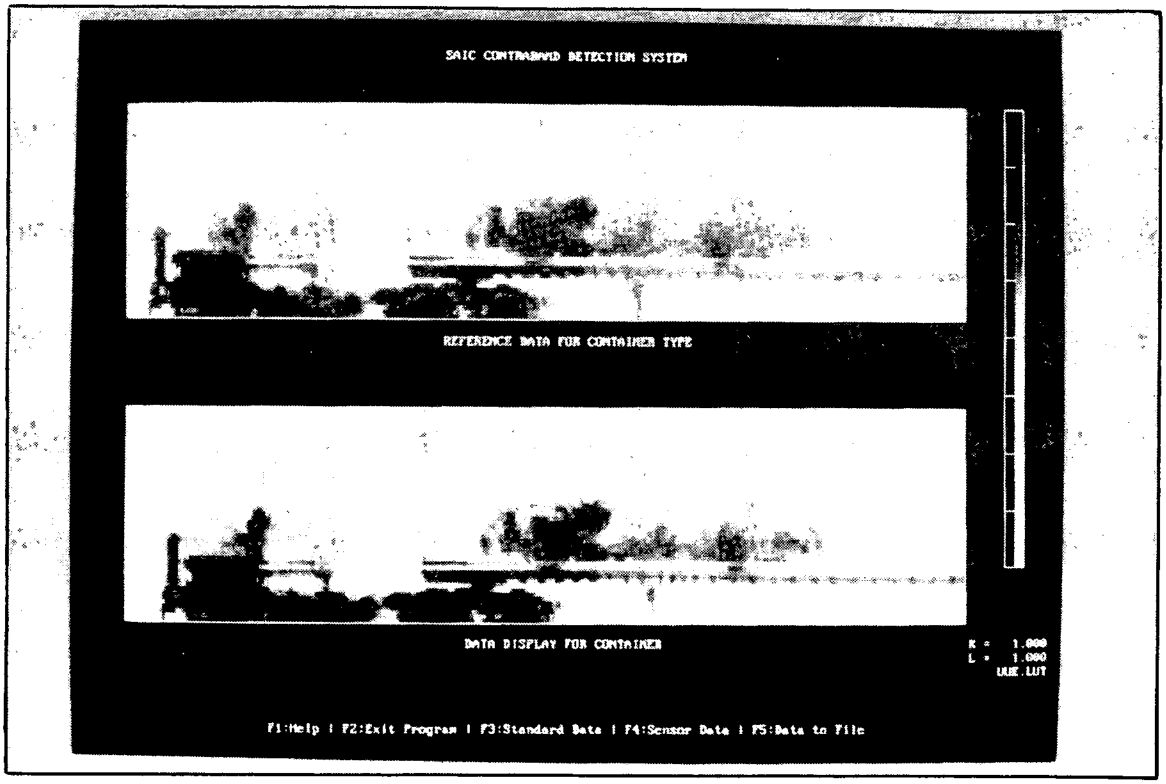

Figure 15. Automobile in cargo container with drugs on hood, on floor behind driver's seat, and in trunk (bottom): without drugs (top).

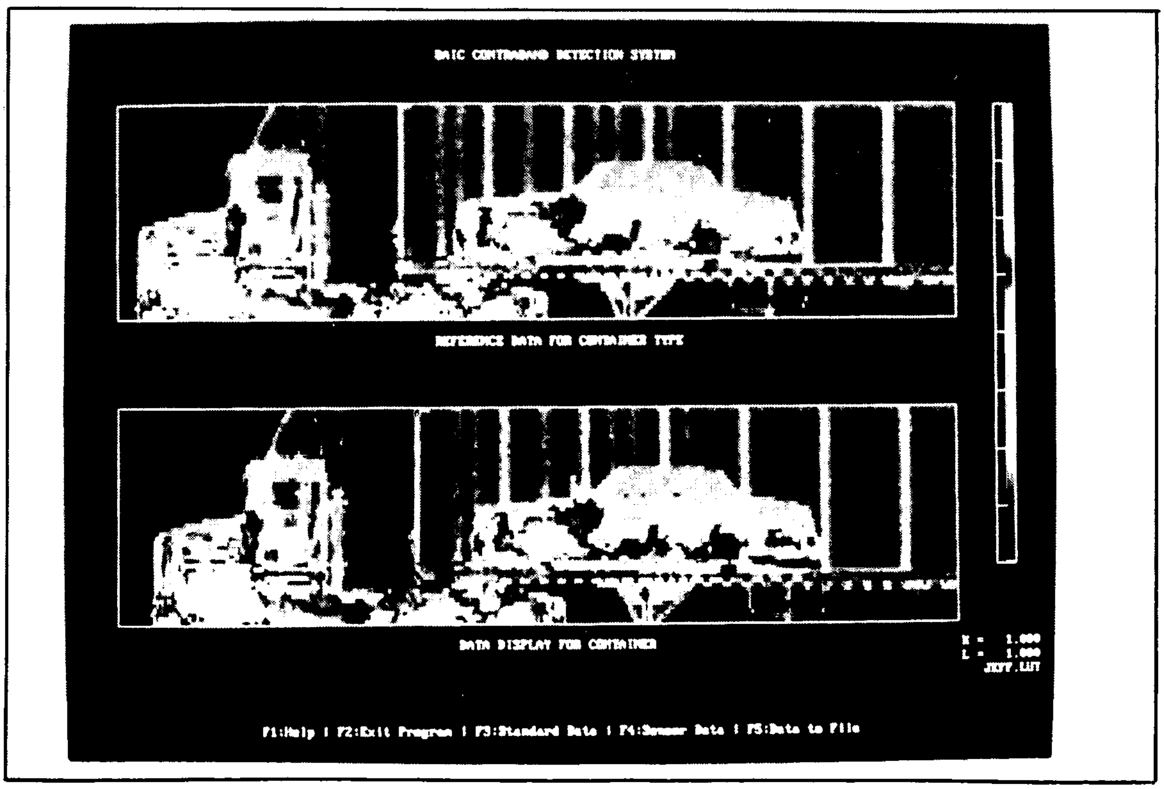

Figure 16. Contrast-enhanced image of car in cargo container. Drugs on hood, on floor behind driver's seat, and in truck (bottom): No drugs (top).

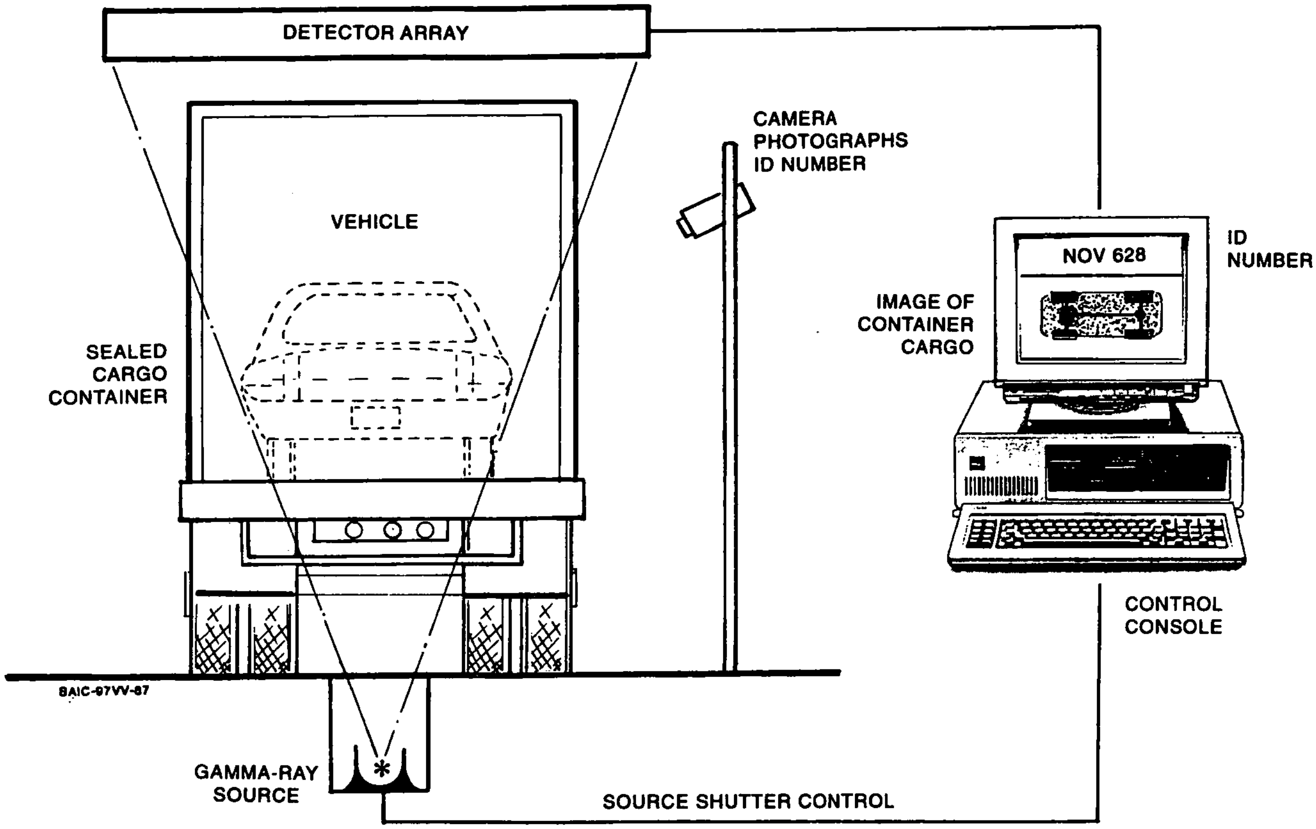

Figure 17. STAR-VACIS system: Stolen automobile recovery system with small "footprint".

Performance Assessment of Prototype Gamma-ray Imager for Illicit Drugs

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ABSTRACT

The Department of Defense Counterdrug Technology Development Program has addressed the development and demonstration of technology to enhance non-intrusive inspection of cargo-empty commercial vehicles such as liquid and compressed gas tankers. A controlled operational performance assessment of a prototype, relocatable, transmission gamma-ray (1-Ci Cs-137) imaging inspection system has been conducted at the Thunder Mountain Evaluation Center. This prototype system was developed through funding provided by Office of National Drug Control Policy. The target material for this assessment was bulk quantities of a radiographically appropriate, cocaine hydrochloride simulant in brick form. This program involved the use of a Red/Blue Team test concept and was conducted in accordance with an approved assessment protocol. The results of the analysis were returned for evaluation and data compilation by an unbiased observation team. It is currently being tested by United States Customs Services at various ports of entry. This paper includes a basic description of the prototype, transmission gamma-ray imaging non-intrusive inspection system and its operation, development of the assessment protocol, summary results of the performance assessment, and recommendations for future system modifications and operational utility.

1. INTRODUCTION

The Department of Defense (DoD) Counterdrug Technology Development Program Office has supported the controlled performance assessment of the Science Applications International Corporation (SAIC) Vehicle and Cargo Inspection System (VACIS). This prototype radiographic inspection system was developed by United States Customs Service (USCS) under funding provided by the Office of National Drug Control Policy (ONDCP). It was originally developed for the non-intrusive inspection of empty tanker trucks. The extensive performance assessment described in this paper was conducted after a successful initial system demonstration by Thunder Mountain Evaluation Center (TMEC) in March 1996.

Controlled contraband detection tests for this system were conducted during the months of September and October 1996. The tests used a land border crossing scenario and the test vehicles, cargo and contraband simulants available at TMEC.

Technical information for this system has been presented in previous ONDCP and SPIE conference proceedings.[1],[2] This paper will highlight the inspection system and present the available results for the related assessment program and its subsequent operational utility.

2. SYSTEM OPERATION OVERVIEW

The VACIS is an engineering prototype for a relocatable, commercial vehicle-class non-intrusive inspection system, see Figure 2. The system requires a relatively flat area, such as a parking lot, for its operation. An area of approximately 55' by 85' is required for system placement. This area does not include any necessary vehicle approach/exit lanes, nor does it include space for the inspection control station.

The inspection system uses transmission mode gamma-ray imaging technology to provide images to an operator. The system is comprised of a gamma-ray source, transmitted gamma-ray detectors, the source/detector trolley and rail system, and an operator's computer console and control panel. The physical footprint of the system are defined by a pair of 4-foot wide parallel aluminum tracks 35 feet apart and approximately 55 feet long. The vehicle to be inspected is parked between the parallel tracks.

The source is comprised of 1 Curie of cesium-137 which produces monochromatic 662 keV gamma-rays. The shutter of the source housing (Ohmart model SHF1) is electronically actuated. Gamma-rays are directed through a single vertical stationary slit producing a collimated beam. The shielded source is placed on a trolley which moves (1.2 ft/sec) in synchronization with a vertical linear array of NaI scintillation detectors placed on another trolley on the second track. Both trolleys have a hand winch that allows the source and detector to be raised or lowered. In the current configuration, the detectors and source were raised so that the top portions of especially tall vehicles could be scanned.

The system operates on 220 VAC and can also use a gasoline-fueled generator. A single scan takes approximately 45 seconds to complete. Single scans are sufficient for short vehicles. However, taller and lengthier vehicles may require as many as four scans to cover the extent of the vehicle.

The system power and electric motor power are controlled by the on-off switches located on the control panel. The cycle control moves the trolley and opens the shutter on the source. With the cycle control in manual, the forward and reverse switch determine the direction that the trolley will move. The jog button moves the trolley. With the cycle control on automatic, the start button opens the source, and moves the trolley down the rails. The direction is controlled with switches located on the track. The stop button and the emergency stop button stops the trolley and closes the source.

The control and image analysis software ran on a Pentium-class personal computer with a high-resolution 17 inch color monitor and a keyboard. The software takes the input from the 25 pin cable from the detector array and subtracts the raw count values from the normalization data. This data were contoured from the color bar and displayed on the screen. The color bar represents a density scale. The screen is divided into three windows: the top and bottom windows contains the reference image and the scanned image, respectively, and the vertical window contains the color bar. The images in the top and bottom windows are 240 pixels by 900 pixels.

The image analysis tools are controlled from the computer keyboard. There are three tools for analyzing data after the run is completed: contrast, gain, and color bar. The contrast and gain shifts the data with respect to the color bar. The color bar included two gray scale look-up tables and six color look-up tables. The vertical window displayed the color bar with the most dense material at the top of the bar and the least dense at the bottom.

3. ASSESSMENT SITE DESCRIPTIONS

The assessment was conducted at the Thunder Mountain Evaluation Center (TMEC) at Fort Huachuca, Arizona. The following mission/capabilities information was provided by the TMEC Overview Document.[3]

> "The mission of the Thunder Mountain Evaluation Center (TMEC) located at Fort Huachuca, Arizona is to provide facilities and personnel to support management, testing and evaluations, technical analysis, operator training, logistics, and full life-cycle support for system fielding to the Drug Law Enforcement Agency community.
>
> A portion of TMEC is designed to simulate a USCS Port of Entry and will use authentic target vehicles, cargo, and packages in evaluating new mobile Non-Intrusive Inspection (NII) systems and other technologies as they are developed."

Due to inspection system size, the assessment could only be conducted outside of the TMEC's main building, see Figure 1.

The inspection system was successfully used to scan vehicles ranging from tractor/trailer truck combinations to pick-up trucks with only minor re-alignment of the detector and source.

4. ASSESSMENT DESCRIPTION

4.1. Objectives

One objective of this activity was to determine the ability of the system to detect specified quantities of contraband or contraband simulant in tankers and cargo-less commercial trailers and tractors. This was addressed through the use of a controlled performance assessment border crossing scenario. Stream-of-commerce cargo laden and empty vehicles were also examined as part of a separate test conducted concurrently by the USCS.

These assessment activities consisted of four phases. System specification activities were conducted as Phases I and II. Acceptance testing under Phase I was directed toward verifying that the equipment met radiological safety standards. The Phase II Technology Performance Assessment was conducted per various performance standards to determine spatial resolution, depth of penetration, and imaging quality performance for each inspection system. These activities include the scanning of various test fixtures.[4] This phase was also conducted to insure operator familiarity and confidence in the performance of each inspection system. In addition, comparison scans were made to ensure that the selected contraband simulant material accurately mimicked the imaging properties of the actual contraband material. The presentation of detail results of the Phase I and II assessment activities are beyond the scope of this paper.

The Phase III activities were directed to determining the ability of the inspection systems to distinguish the presence of target/contraband simulant material secreted in various vehicles.

The Phase IV activities were to include a selected stream-of-commerce vehicle inspection operational assessment to be conducted by USCS.

4.2. Assessment Team Participants

A Red/Blue/Silver Team arrangement was employed during both tests. The Red Team members worked at off-site warehouse facilities and emulated the smuggling element. Within the controlled environment of the tests, they would attempt to smuggle contraband simulant "into" the U. S. concealed aboard test vehicles and/or cargo. The Blue Team members worked at the sites of the X-ray inspection system and emulated the law enforcement inspectors/image analysts. The Silver Team worked at both sites and acted as official observers and data collectors. This test breakdown structure separated the vehicle preparation from the vehicle inspection process and added a sense of realism.

A Red/Blue/Silver Team arrangement was employed during both controlled performance assessment activities. Three separate teams involving contractor (non-vendor) and government personnel were used to conduct this assessment and to ensure that the assessment and its collected data were complete, correct and concise. The Red Team members worked in separate laboratory space and emulated the criminal smuggling element. Within the controlled environment of the tests, they would attempt to smuggle contraband simulant through the inspection system concealed aboard test vehicles. Digital scan images were captured and analyzed by another separate team, known as the Blue Team. This team emulated the law enforcement inspectors/analysts and attempted to determine if target material was present through the utilization of the imaging inspection system. A third team, known as the Silver Team, was present during the assessment-related activities to represent the interests of the Government client in an unbiased manner and to act as a data collector. Assessment results were shielded from all participants except for the Silver Team members until later times, so as not to impart bias to the assessment results. This work breakdown structure separated the vehicle preparation from the inspection process and added a sense of realism to the field assessment.

4.3. Assessment Protocol

In order to conduct the controlled performance assessments under reasonably realistic operational conditions a number of assessment elements were adopted, including a continuous assessment activity schedule, the use of standard performance fixtures, and the use of scan image analysis procedures observed at USCS commercial ports of entry and other security check-points. The assessments were nominally conducted by the Assessment Teams eight hours per day, five days per week throughout the assessment period. This consistent structure provides a basis for comparison of assessment results from other systems.

The assessment was conducted in accordance with test protocols prepared and approved by a Test Review Panel prior to test initiation.[5] The protocol contained the objectives, the responsibilities of the participants, procedures, analysis and reporting requirements, and instructions for both the Red and Blue Teams. Copies of the protocols were shared with the Team Leaders and the members of the various teams prior to the start of the assessment. Variations to the protocol were only allowed with the approval of the Test Director. The approved assessment protocol was loosely based upon the protocol developed for previous DoD sponsored vehicle inspection system assessments. Additional resources, technical papers, and accepted standards were also utilized during production of the current protocol.[6],[7],[8],[9]

4.4. Scenario

The border crossing scenario simulated the inspection of tankers, shipping containers, and vehicles at the Canadian/Mexican--U. S. border prior to their movement to locations throughout the continental United States. In this scenario, the container and its contents, as well as the tractor and chassis, were all subject to inspection.

Results reported for the border crossing scenario include only those results obtained for containers specified as empty and for the various vehicle zones regardless of the contents of the cargo container zone.

4.5. Analyst Training

One of the first tasks related to the testing at TMEC was to train site personnel on how to use the inspection system. The Phase III assessment activities utilized three analysts throughout the schedule. Attempts were made to ensure that each analyst saw similar training opportunities prior to the assessment. In fact, each of the analysts (Arizona National Guard) had operated numerous imaging inspection systems at USCS ports of entry on a consistent basis during the two years prior to this assessment. They have also participated in a number of controlled assessment programs as part of their assignment at TMEC. All of the analyst/operators were able to assist in the preparation of special training vehicles, and then scan and interpret the available imagery for comparison. In addition, the use of test fixtures which contained the target materials provided valuable insight to the operators. No special aptitude tests were given to screen operator/analysts' capabilities. Battelle has accepted the TMEC Site Director's assertion that these individuals were proficient in the utilization of this inspection system and representative of the capability of current image inspectors.

4.6. Target Material Properties

The key material properties for the radiographic imaging community are bulk density and chemical composition of cocaine hydrochloride. Both terms appear in the equations that govern the attenuation and scatter of X-ray energy.

According to the DoD Cocaine Handbook [10], the chemical formula for cocaine hydrochloride is $C_{17}H_{22}O_4NCl$, molecular weight of 339.82. The Handbook does not provide a reference for bulk density. However, Battelle has recently conducted an investigation using a quantity of seized material for simple mass and volume measurements. The bulk density of the seized bricks was determined to be approximately 0.73 g/cc. Simulant material was formulated from legal materials to have a reasonably comparable molecular weight and packaged in such a manner to have a comparable bulk density. The simulant material was radiographically verified using this inspection system.

4.7. Vehicle Zones and Simulant Placement

The following types of vehicles were provided for use in the Phase III portion of the assessment: liquid-tankers, compressed gas-type tankers, flatbed trailers, and commercial cargo trailers. Tractors appropriate for use with each trailer were provided, and several of the vehicles were unitary type.

A computer program was used to randomly determine whether or not the vehicle zone would be used as a concealment for contraband simulant and how much simulant would be used. This program has been used in previous assessment activities.[11],[12] Each document carried a unique computer-generated run number so that all documentation could be uniquely identified for each run.

During the border crossing scenario the Red Team was authorized to place contraband simulant in the various areas of the vehicle and container. Zone 1 comprised all of the driver accessible regions of the tractor cab, including any sleeper and equipment storage compartments. Zone 2 was all of the tractor's engine and drive train related space, including the wheels, battery box, fuel tanks and exhaust stack. Zone 3 comprised all of the trailer chassis, jack stands and rear axles. Finally, Zone 4 was the tank/cargo container itself. If contraband was to be placed in any of the four zones, the Red Team Leader would also prepare a vehicle configuration sheet to indicate the location, size and form of contraband placed onto the vehicle.

4.8. Phase III Assessment Results Summary

The system operators have two options when they complete an image interrogation: release the vehicle or request an intensive inspection ("intensive") for contraband. In previous sections it was been noted that target material was placed inside the vehicles based on the result of a random selection process. The operator's decision was scored in a consistent manner where True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN) are defined as follows:

- True Positive - The analyst correctly declared that there was contraband concealed in the vehicle.
- True Negative - The analyst correctly declared that there was no contraband concealed in the vehicle.
- False Positive - The analyst incorrectly declared that there was contraband concealed in the vehicle.
- False Negative - The analyst incorrectly declared that there was no contraband

concealed in the vehicle.

The sum of True Positives and True Negatives divided by the total number of runs provides the overall fraction of correct decisions. Similarly, the sum of False Positives and False Negatives divided by the total number of runs provides the overall fraction of incorrect decisions. Inspection times presented are relevant only in terms of the assessment and may not be indicative of the values experienced in a stream-of-commerce environment.

As previously noted, assessment of the VACIS transmission gamma-ray imaging inspection system was conducted at the Thunder Mountain Evaluation Center, Fort Huachuca, Arizona in September/October 1996. This system was operated in its standard human interpretation mode. As designed, the operator had access to historical reference "clean" vehicle images. During the Phase III assessment of the inspection system a total of 2140 vehicle zones were inspected, approximately 100 zone inspections per day. Results reduced from the available data correspond to an overall percent of correct inspections of 85% and percent of incorrect inspections of 15%. The average total time required to conduct a single vehicle inspection during Phase III was 6:20 minutes and leads to an inspection rate of approximately 6-8 vehicles per hour. This value includes time required for the scan process, manual interpretation of the available scan imagery, and declaration of decision. It does not include the time required to position the vehicle which is a function of both operator and vehicle driver skill.

5. OBSERVATIONS FOR TESTING

The following observations were made by the Battelle authors as a result of participation in this assessment program:

- Pretesting of newly developed systems should be conducted, when practical, to minimize system down-time due to mechanical, electronic and software difficulties during controlled tests.
- A design study should be conducted for methods of improving spatial resolution, increasing the overall scan angle for the detectors, improving the environmental engineering of the system to field quality, improving image analysis tools, and identifying other source materials for increased penetration.
- User community should continue to develop/monitor Concepts of Operations which address radiation safety and practice.
- Test and evaluation community must remain in contact with user community for controlled performance assessments to remain operationally significant.

6. OPERATIONAL USAGE

The VACIS is currently in operation at various USCS ports of entry. Standard operating procedures have been developed and utilized during the training, including radiation safety, and deployment of the system. Since the system uses a radioactive source, radiation safety and monitoring have been important considerations.

The operators of the system have been able to inspect up to 100 vehicles per day, which is consistent with the previously noted inspection rate of 6-8 vehicles per hour. A wide variety of vehicles (tankers, tractor-trailers, flatbeds, refrigerated trailers, pick-up trucks, etc.) have been inspected. In one instance, the operators used the system to discover an illegal alien hiding inside a tractor. On other occasions the operators have discovered hidden compartments in a trailer and in a propane tank in a pickup truck.

After the test period, a number of operational and performance enhancements (see Section 5) were addressed by USCS and DoD.

7. SUMMARY

Although the unit tested was considered an engineering prototype unit, this assessment has demonstrated the capability of the inspection system in the imaging of illicit substances. In addition, recommended improvements to the system are being addressed. The engineering prototype continues to serve USCS during deployment to various ports of entry.

8. ACKNOWLEDGMENTS

The Battelle authors participated in these test activities under contract support provided by the Office of Special Technology (OST) contract number DAAD05-93-D-7021, Task 91. OST serves as a technical agent for the Counterdrug Technology Development Program Office. We extend our appreciation to Mr. John J. Pennella of the DoD Counterdrug Technology Development Program Office and Mr. James A. Petrousky of OST for their comments and direction during this task.

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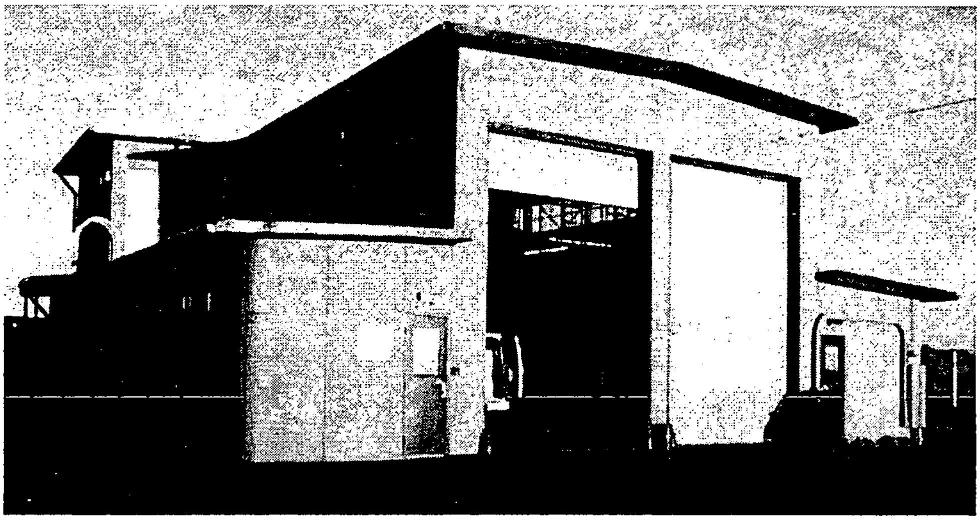

Figure 1. TMEC Main Building

Figure 2. Gamma-ray Imaging Inspection System for Tankers

Non-intrusive Detection of Drugs Using Neutron Transmission Utilizing Cone Beam Geometry *

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ABSTRACT

A pulsed fast neutron transmission spectrometer has been used to determine the presence of contraband drugs in sealed suitcases. A pulsed 'white' neutron source was created by allowing a pulsed beam of 5 MeV deuterons to impinge on a thick beryllium target. The neutron intensity was measured from about 0.8 MeV to about 7 MeV, first with the sample out of the beam and then with the sample in the beam to determine the neutron attenuation as a function of neutron energy. Trained neural networks using either 'shape' or 'regression' techniques are used to identify contraband drugs in sealed containers. Initially, collimated beam experiments were employed to determine the presence of contraband drugs within a slender column of a sealed container, but this work has now been extended to examine a complete suitcase using cone beam geometry, where the single detector has been replaced by a 99 detector array. Hence, each detector in the array examines a small solid angle through the sample. The sensitivity of the technique has been further increased by using multipass (tomographic) techniques.

1. Introduction

The detection of substances using neutron transmission techniques has proven to be a valuable tool. Miller [1, 2] has previously reported a series of measurements on the use of collimated neutron beams to determine the presence of contraband drugs in sealed containers. In these publications, it was shown that hard drugs such as cocaine and heroin have a distinct signature that allows them to be distinguished from other common suitcase items. In this paper the work is extended to cone beam geometry where a complete suitcase is probed at a single exposure to the neutron beam. Both single pass and multipass (tomographic) options are available. The contraband detection system is labeled the MDNR for Multi-Dimensional Neutron Radiometer since two and three-dimensional information can be obtained.

The technique used is now called Pulsed Fast Neutron Transmission Spectroscopy (PFNTS), and has been described previously [3, 4]. The technique is similar to optical spectroscopy, where a white light beam is passed through a gas sample and the unknown gases are determined by comparing the measured attenuations to attenuations found in the literature.

In the case of neutron attenuation, a 'white' beam of neutrons, a beam of neutrons covering a broad energy spectrum, is passed through a sample. By

*Research funded by the Federal Aviation Administration

measuring the intensity of the neutrons first with the sample out of the beam and then with the sample in the beam, the resulting neutron attenuation is determined as a function of neutron energy. Miller [1] has used regression theory along with the measured neutron attenuation curve and the measured cross sections to determine the number densities of H, C, N and O in the neutron beam. Certain other number densities, such as aluminum, silicon and iron are now determined by including their respective cross sections in the database.

The pulsed 'white' neutron source was produced by allowing a pulsed beam of 5 MeV deuterons to impinge on a thick beryllium target. This reaction has been shown to produce an excellent 'white' neutron source from about 0.75 MeV to about 4 MeV. The reaction produces neutrons up to about 8 MeV, but the intensity of the neutrons drops dramatically above about 4 MeV for 5 MeV deuterons. Neutron energy was measured by use of neutron time-of-flight techniques.

2. Experimental Setup

The PFNTS cone beam experiments were performed at the 8 MeV Van de Graaf accelerator at the University of Kentucky (UK). Fig. 1 shows a schematic view of the experimental setup at the UK Van de Graaf Accelerator Laboratory. As seen from fig. 1, the UK Van de Graaf is a vertical accelerator and a 90 degree bending magnet and several quadrupole focussing magnets are used to bring the beam to the beryllium target. The beryllium target is a disk that is 0.030 inches thick. The accelerator is usually run at 5 MeV. The deuteron pulse width is about 1.5 nsec (FWHM) and has a period of 533 nsec. The Be target is held in a water-cooled "snout" which is 1.5 inches in diameter and comprises the last 23 inches of the beamline. The neutron angular distribution of the Be(d,n) reaction is forward peaked, but does emit neutrons at all angles. A large shielding tank with a specially designed collimator is employed to shield the detector array against neutrons other than those heading toward the detector array. The shielding tank was constructed from an upright polyethylene cylindrical agricultural chemical tank. The shielding tank and the specially designed collimator have been described previously [5].

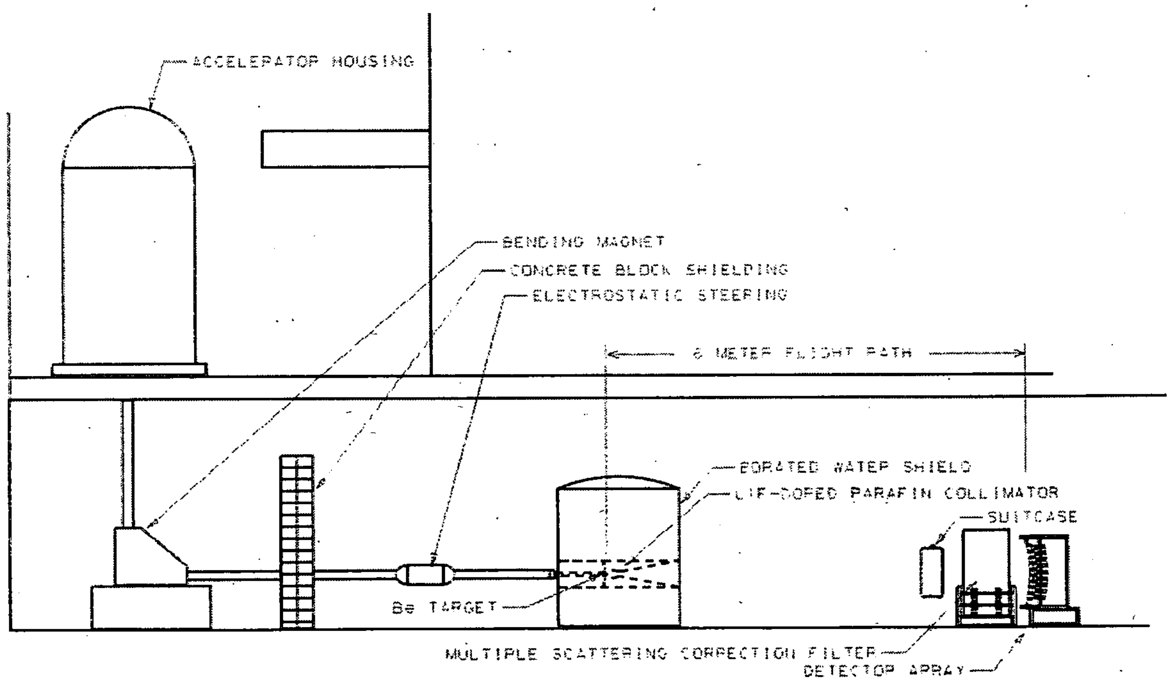


Figure 1 *Illustration of the major components now installed at the University of Kentucky.*

The detector array is placed 6 meters from the neutron source. Each detector is 8 centimeters by 8 centimeters and is 2 centimeters thick. The detectors are BC 404. Each scintillator is attached to a Hamamatsu H3690-2 photomultiplier tube via a plexiglas tapered light pipe. The center of each scintillator is 6 meters from the neutron source; hence the surface of the scintillator array forms a portion of a sphere that has a radius of 6 meters. The energy of each detected neutron is determined by measuring its time-of-flight over the 6-meter flight path. The data acquisition system uses state of the art electronics and has been described previously [6].

3. Experimental Procedure

In a typical measurement of neutron attenuation, a background run is first made for a predetermined amount of integrated charge. The suitcase is then inserted into the beam path and the run repeated for the same amount of integrated charge. After correcting for dead time the neutron attenuation is determined by dividing the two spectra, channel by channel, and then taking the natural logarithm of the ratio on a channel by channel basis. The number densities of the elements in the neutron beam (atoms per square cm) is then determined by solving the series of equations:

$$\left(Ln\frac{N_O}{N}\right)_{C_i} = \left(\sum_j \sigma_j \alpha_j\right)_{C_i} \qquad \text{Eq. 1}$$

where

N_0 = Neutron Spectra without suitcase
N = Neutron Spectra with suitcase
C_i = ith Channel of the Multi-channel analyzer
σ_j = Total cross section of the jth element in the neutron beam
α_j = Atoms per square cm of the jth element in the neutron beam

Neural networks are used to determine the presence of contraband in sealed containers. Two different neural network techniques are used and they have been described in previous publications [7]. One technique uses the shape of the neutron attenuation curve (the left side of Eq. 1) to determine the presence of explosives. The other option uses regression theory to solve Eq. 1 directly for the number densities of the various elements, using the total cross sections of the elements. At the present time the elements H, C, N, O, Si and X are included in the regression database. The element X [8] is a fictitious constant cross section of 3 barns used to account for certain heavy elements and constant background that could be in the neutron attenuation spectra. In the future certain other heavy elements such as aluminum and iron will be added to the regression database.

The neural networks are trained from actual suitcases, some with contraband and some without contraband. The suitcases are usually positioned in front of the detector array so that the neutrons traverse the suitcase through the narrowest dimension. The detector arrays contains 99 detectors (9 by 11) and usually 1/2 to 3/4 of the detectors are behind the suitcase and result in neutron spectra to be analyzed. The neural network is trained using spectra from individual pixels, hence a suitcase without explosives could yield up to 99 training pixels. A suitcase with contraband could yield several pixels with contraband pixels and the rest would be non-explosive pixels for training. Using this technique, a neural network is trained to recognize a contraband pixel as distinguished from a non-contraband pixel. A suitcase of unknown contents is then placed in front of the detector array and attenuation spectra accumulated for each detector. Each pixel spectrum is presented to the trained neural network to determine the presence of contraband in that particular pixel. A computer printout indicates which pixels (and hence which portions of the suitcase) contain contraband.

4. Results

The presorted data were obtained using 51 suitcases supplied by the Federal Aviation Administration for explosives detection experiments. These suitcases consisted of lost international luggage having a broad variety of contents. A database of suitcase information was generated, including the identification number, the dimensions, and the weight of the suitcases. A

Suitcase Thickness (cm)	Number of Suitcases
10-20	7
20-30	19
30-40	13
40-50	6
50-60	5
>60	1 (81cm)

Table 1 *Breakdown of suitcases supplied by the FAA Technical Center for Test Series 5 by suitcase thickness.*

breakdown of the number of suitcases of various thickness is presented in table 1.

For these tests, two contraband drugs were available for testing: cocaine and marijuana. These drugs were supplied by the Kentucky Department of Motor Vehicles. The cocaine was contained in a cylindrical thin aluminum can 10.3 cm in diameter and 6.5 cm thick. The mass of the cocaine was 325.3 grams and was 96 % pure. The marijuana was also contained in the same sort of can as the cocaine, but the mass of the marijuana was 193.3 grams.

Sample Spectra

Fig. 2 shows several neutron attenuation spectrum including (a) a neutron attenuation spectrum of cocaine alone, (b) a spectrum of a suitcase alone and (c) a spectrum of cocaine

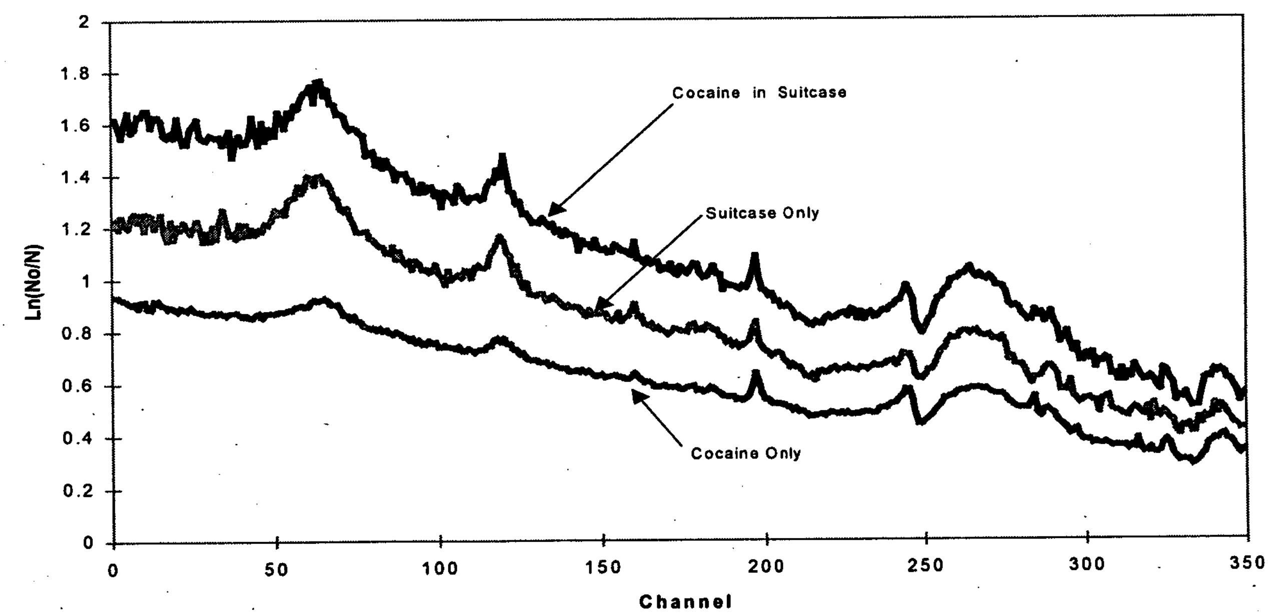


Figure 2 *Sample neutron attenuation spectra for cocaine.*

imbedded in a suitcase. It should be noted that these spectra represent a single pixel of the suitcase — the pixel where the cocaine was placed.

SINGLE PASS RESULTS

In order to determine the usefulness of PFNTS to detect contraband drugs in luggage, probability of detection versus probability of false alarm curves were constructed from experimental data. It would be preferable to perform hundreds of runs to train the neural network and then to perform hundreds of runs to test the neural network. It was not possible to spend that much time during this test series so a technique was used which simulated hundreds of suitcase loadings, each containing varying amounts of contraband drugs.

The neural network training and testing proceeded as follows: All fifty-one suitcases were run without contraband. The suitcase spectra were roughly divided into halves, the first half would be used for training the neural network and the second half would be used for testing the trained neural network. The neutron attenuation spectrum was then obtained for the can of cocaine.

Training and testing the neural network with limited data requires suitcase pixel spectra both with and without contraband drugs. For each training cycle, successive Monte Carlo random draws are employed. The first determines whether the next simulated attenuation curve used in the training/testing data set will contain contraband drugs. If the resultant requirement is for a non-contraband suitcase, a second random draw selects a measured pixel attenuation spectrum of a non-contraband suitcase. If the first random draw calls for the attenuation curve of a suitcase containing contraband drugs, the pure drug attenuation curve is scaled by a random fraction and added to a randomly selected non-contraband suitcase attenuation curve. The validity of this method is apparent when one considers equation 1: an attenuation curve is the linear superposition of contributions from the j elements, and the scaling of the drug attenuation curve allows for the simulation of varied quantities (or number densities α_j) of the drug in the pixel. Using this technique, the neural networks were trained to recognize the contraband drugs, cocaine and marijuana.

After training, the neural network was tested using the second half of the suitcases' pixel spectra choosing pixel spectra with and without contraband as in the neural network training. A plot was then made of threshold versus missed explosives and threshold versus false alarms for each of the contraband drugs tested. Fig. 3 shows a plot of threshold versus false alarms for missed cocaine. By integrating under the curves of Fig. 3 and remembering that probability of detection is defined

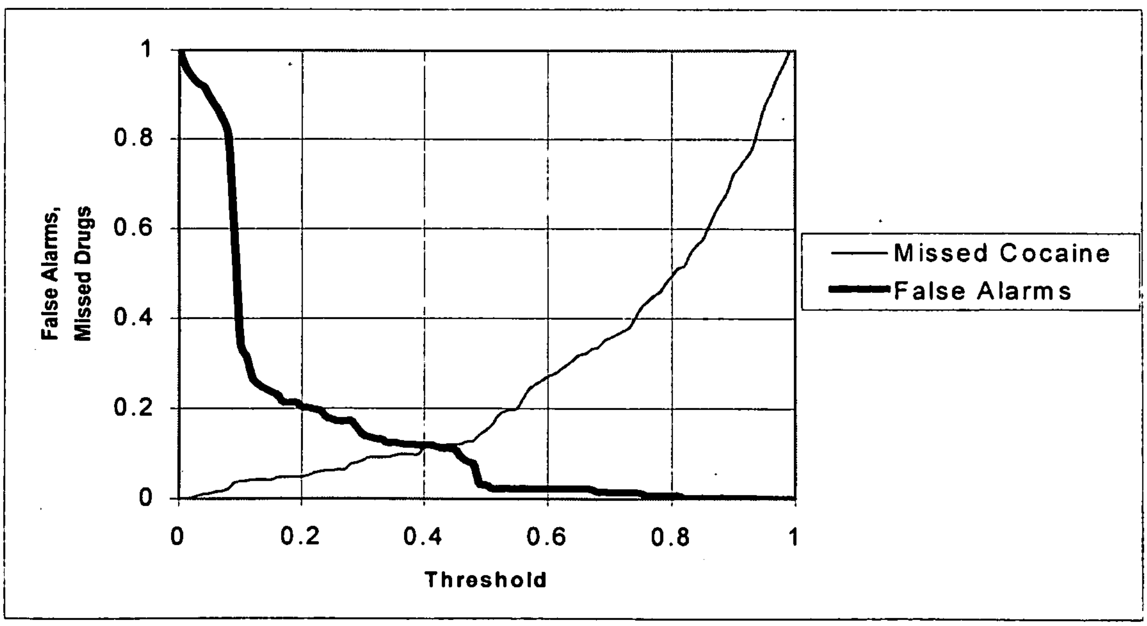


Figure 3 *Plot of threshold versus false alarms/missed drugs for cocaine.*

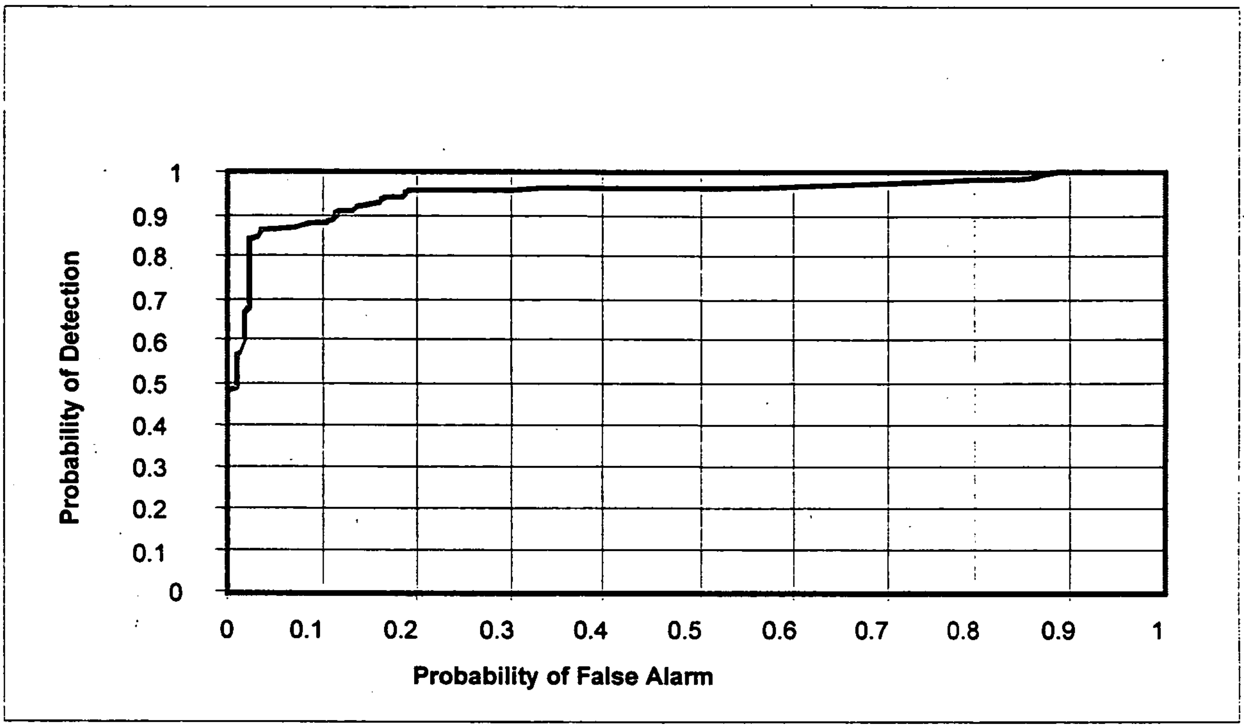


Figure 4 *Pd-Pfa curve for cocaine.*

as 1- "minus" missed explosives, one obtains the operating curve of probability of detection versus probability of false alarms (Pd-Pfa). Fig. 4 shows the Pd-Pfa curve for cocaine for the conditions of this study. Fig. 5 shows the Pd-Pfa curve for marijuana for the conditions of this study.

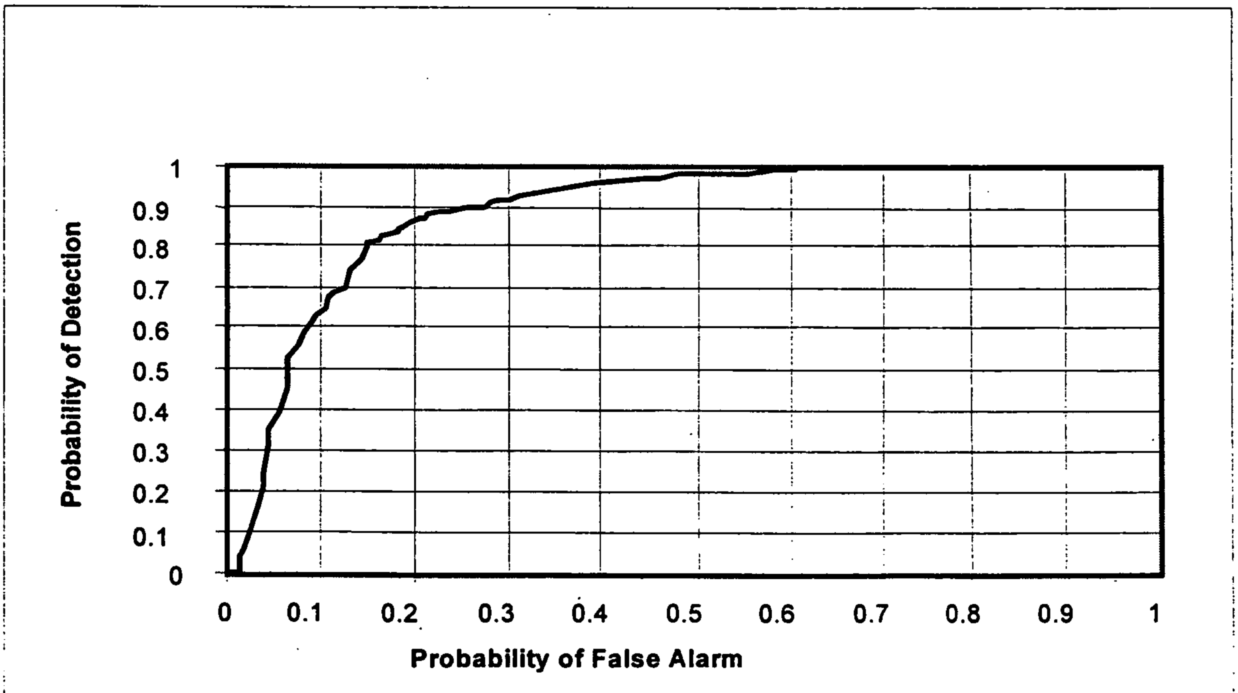


Figure 5 *Pd-Pfa curve for marijuana.*

MULTI-PASS (TOMOGRAPHIC) RESULTS

Previous simulation studies [4] have indicated that the sensitivity for detecting contraband in sealed suitcases could be increased by the use of neutron tomography. During the test series several tomographic runs were made to determine the sensitivity of the tomographic technique.

Fig. 6 shows a view of the suitcase chosen for the tomographic run to be described here for illustration. From Fig. 6 it can be seen that the 320 grams of cocaine were placed in one corner of the suitcase and a thin slab of explosive was placed in the opposing corner of the suitcase. Detail "A" shows the position of the cut where the tomographic reconstruction was made. The technique for explosive detection using tomographic reconstruction has been described previously [4].

In order to perform the tomographic reconstruction, a turntable was constructed so that passes could be taken at several different angles through the suitcase. For this example, passes were taken at 17 different angles. The Donner algorithms [9] were converted to c++ and adapted

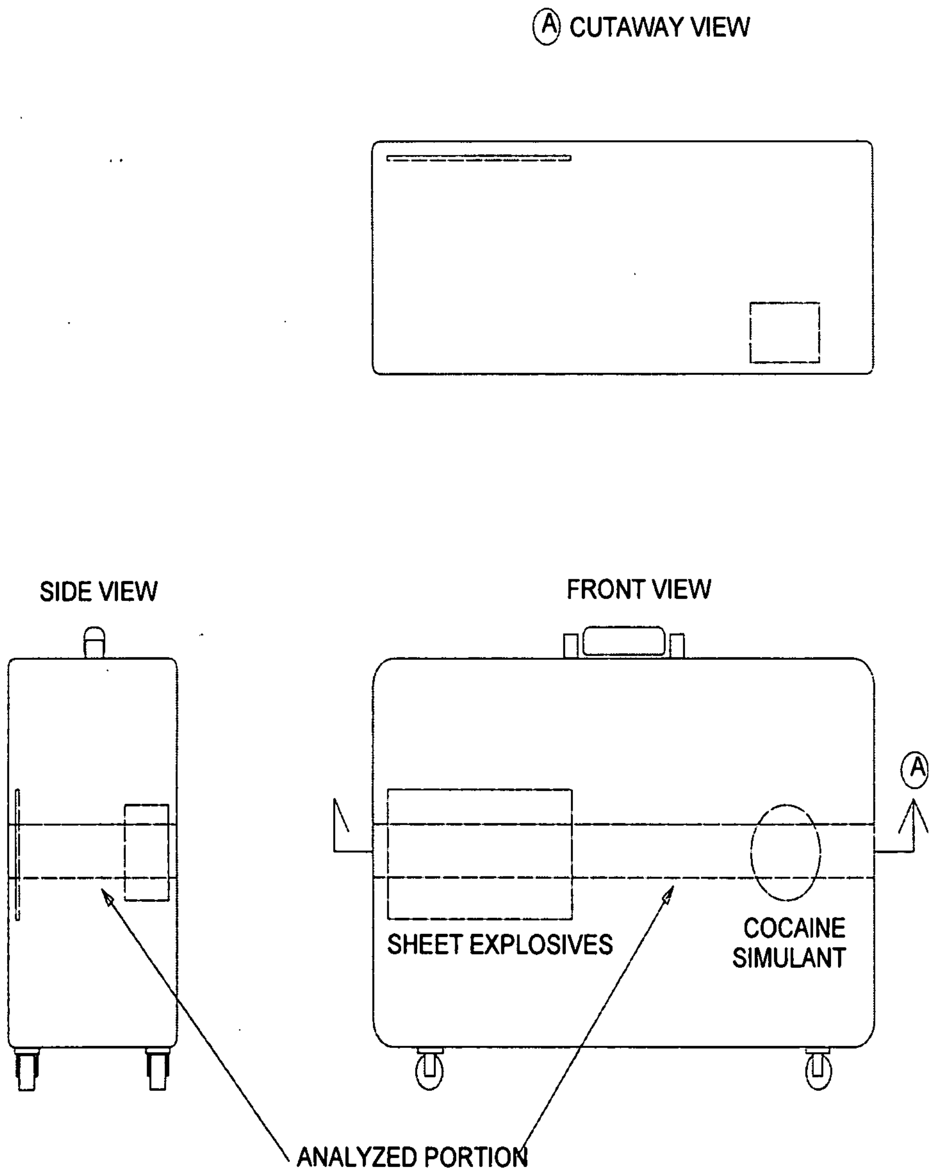
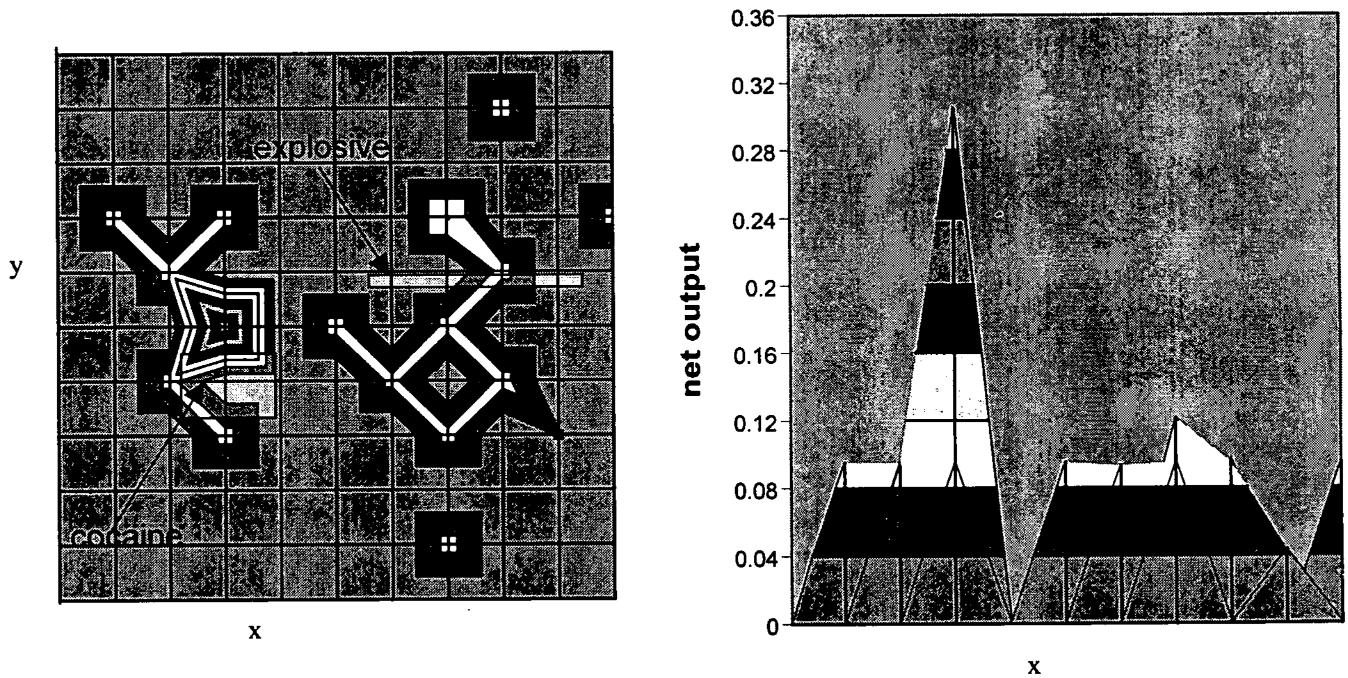


Figure 6 Placement of sheet explosive and cocaine for tomographic experiment.

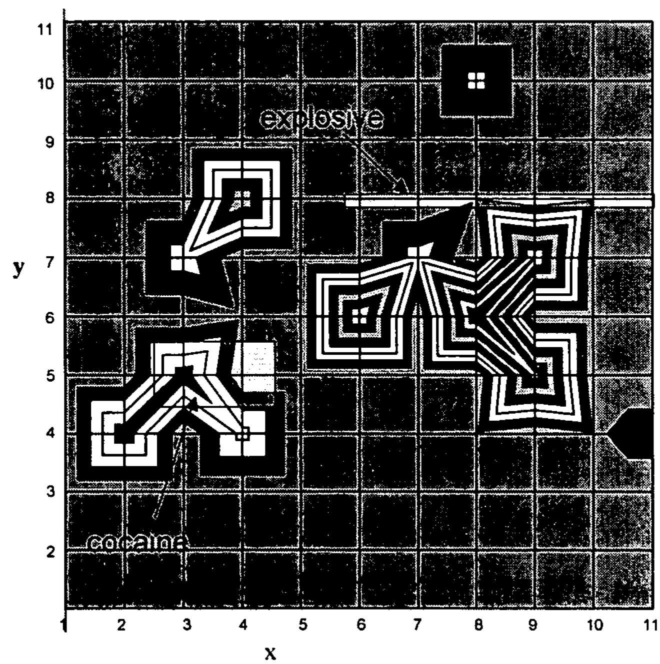
for the reconstruction. The technique used for detection of explosives has been described previously [4]. The technique involves reconstructing the number densities at the cut for each of the elements used in the regression calculation. Hence, for each pixel at the cut, one has the number density of each of the elements. The trained neural network is now used to determine the presence of explosives for each of the volume cells, or voxels, defined by the pixel areas and the plane of the suitcase of detail "A".

Fig. 7(a) shows a contour plot of the neural net output when the net searches for cocaine. 7(b) shows a cut indicating the magnitude of the neural net predictions for cocaine. The tall peak in 7(b) with a net output of above 0.3 is the cocaine peak. Hence a bias level of 0.2 would eliminate all false alarms in the search for cocaine. From these plots one can see that one can 'find' 320 grams of cocaine in a rather thick suitcase. It should be noted that single pass runs did not detect the drugs. Fig. 8(a) shows a contour plot of the neural net output when the net searches for explosives. Fig. 8(b) shows a cut indicating the magnitude of the neural network prediction for explosives. The two large peaks on the right side of 8(b) are due to the sheet explosive. Hence a bias of 0.7 would eliminate all false alarms for this particular suitcase. It should be noted that single pass runs did not detect the piece of sheet explosive.

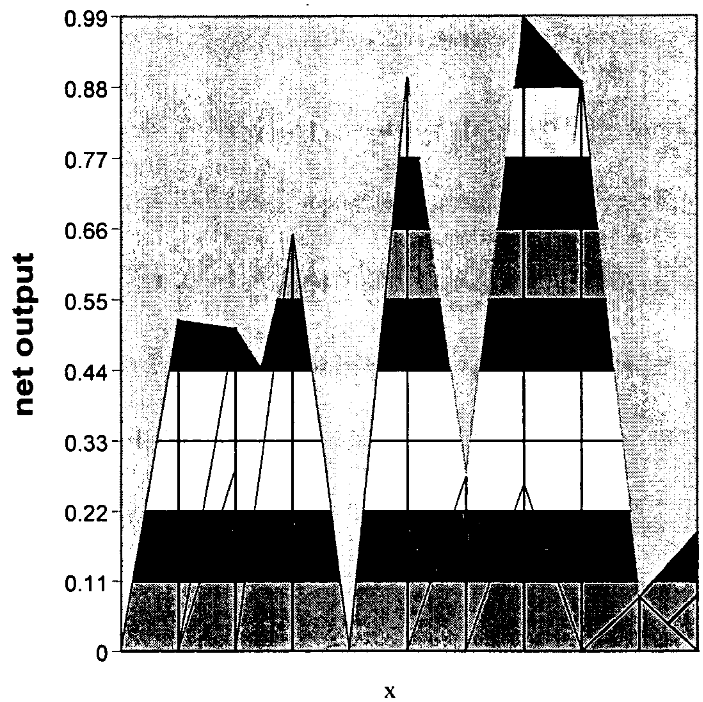


(a) (b)

Figure 7 *(a) Contour plot of Neural Network for tomographic reconstructed suitcase phantom for cocaine, (b) relative heights of peaks for 7(a).*



(a)



(b)

Figure 8 *(a)Contour plot of Neural Network for tomographic reconstructed suitcase phantom for explosives,(b) relative heights of peaks for 8(a).*

5. Conclusions

Probability of detection versus probability of false alarm curves have been run for cocaine and marijuana for a wide variety of suitcases. Drugs are somewhat more difficult to detect than explosives, probably because drugs do not contain an appreciable amount of nitrogen as compared to explosives. Neutron tomography runs were made and this increased the sensitivity of PFNTA to detect drugs. Initial results indicate that neutron tomography increases the sensitivity of PFNTA to detect drugs and sheet explosives by a factor of about four to ten. It should be noted that the Neural Network was trained on single pass data. It is expected that the sensitivity of the tomographic option could be substantially increased by training on tomographic data.

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APPLICATION OF PROBABILITY OF DETECTION CONCEPTS TO PERFORMANCE CHARACTERIZATION OF CONTRABAND DETECTION SYSTEMS, PROCESSES, AND PERSONNEL AT BORDER CROSSINGS

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ABSTRACT

The use of nonintrusive inspection systems for contraband detection at border crossings has fostered a need for assessment of current performance in order to better direct future development of these technologies. The similarities between the nondestructive detection of flaws in engineered structures and the nonintrusive detection of contraband at border crossings provides the underlying rationale for the use of the probability of detection (POD) concepts already developed for aerospace and medical applications. This paper outlines the application of these POD concepts to the border crossing scenario, and includes a discussion and demonstration of applicable POD concepts and methods to a representative problem.

INTRODUCTION

The examination of suspicious truck and cargo containers for contraband illegally crossing our borders is a critical function of the U.S. Customs Service. Manual inspection is difficult, frustrating, and time consuming. To meet this challenge, the DoD Counterdrug Technology Development Program, in coordination with the Customs Service, is developing and demonstrating a full range of Non-Intrusive Inspection Systems to rapidly inspect these conveyances for the presence of illegal drugs and other contraband.

As one would expect, the real world inspection problem is very complex, with a wide variety of conveyances (truck/container types, sizes, and shapes) and a wide variation in the amount of contraband (from tens to thousands of pounds of illegal drugs, for example) which the smuggler attempts to transport. Because of this, no attempt is made to objectively assess the performance of these Non-Intrusive Inspection Systems over the full range of target classes and contraband amounts encountered by the Customs inspectors. Assessment data sets are usually limited to only a few target classes and usually to a very narrow range in the types and amounts of contraband assessed. The Non-Intrusive Inspection System community needs concepts and methods for assisting in this objective assessment.

BACKGROUND

Similarities Between Flaw Detection and Contraband Detection

The use of nonintrusive radiographic inspection methods for the detection of contraband in the stream of commerce passing through a border crossing is analogous to the use of a variety of nondestructive inspection (NDI) methods for the detection of flaws in engineered structures, e.g., the radiographic examination of girth welds in gas-transmission pipelines. The similarities are as follows:

- the inspection process is indirect or instrument-based.
- flaws and contraband appear infrequently.
- the process is dichotomous in nature.
- cost-effectiveness requires a high true-positive detection rate with a concurrent low false-call rate.
- although motivated, the operator's performance is degraded by fatigue, distractions, lack of training, and other well known human-factor issues.

Organizations in which the detection of flaws in engineered structures is a routine concern (e.g., the aerospace, nuclear power, and gas-transmission industries) have developed and routinely use the concept of probability of detection (POD) as one measure of inspection performance. In these applications the collected data are analyzed to generate the intuitively expected sigmoidal or S-shaped POD curve. With respect to flaw size, such POD curves asymptotically approach 0 and 1 very slowly and change relatively rapidly through the region corresponding to flaws of an intermediate size. This is expected, since once the process drops below the detection threshold for small flaws, there is no further deterioration of performance with diminishing flaw size. Similarly, for large flaws there is no expected increase in performance once the flaw size is large enough to always be detected. These upper and lower thresholds are indistinct in practical situations, and so real POD curves change more gradually, which gives a smoother S-shaped POD curve. In border crossing inspections for contraband and in the NDI for flaws (e.g., in airplanes, power plants, and pipelines), the amount of contraband and flaw length have analogous roles. Consequently, there is sufficient reason to apply POD technology in both areas.

Dichotomous Data and the Log-Odds Model [1-4]

Border crossing inspection is one of the many interesting problems that are inherently dichotomous in nature. Either the operator detects the contraband or the operator does not detect the contraband as each vehicle, package, or person is inspected. Such dichotomous problems are discussed in the literature under the headings of binary, quantal, hit/miss, and categorical. The categorical response in such problems is the dependent or Y-variable associated with an explanatory, independent, or X-variable. For the border crossing scenario, the categorical response variable is whether the contraband was detected or not, and the associated explanatory variable is the corresponding quantity of contraband. If sufficient data are available, the response variable can be expressed in terms of fraction detected or proportions. In the border-crossing scenario, this is the ratio of successful responses to opportunities.

The problem is now one of developing a model for the border crossing scenario that examines the effect of the explanatory variable (i.e., quantity of contraband) on the categorical response variable (i.e., the probability of detecting that amount of contraband). Such models are important because they help illustrate the interactions and structural relationships between the variables, determine the strength and importance of the relevant effects, and provide parameters that can be used as figures-of-merit or other performance-assessment measures.

As is detailed in the references, practitioners have found for both theoretical and practical reasons that the logistic or log-odds model is a useful description of the relationship of a categorical, hit/miss, binary, etc., response variables and their associated explanatory variables, such as the amount of contraband. In terms of the probability of detection, this model is written as

$$\pi(x) = \frac{\exp(\alpha + \beta \ln x)}{1 + \exp(\alpha + \beta \ln x)} \quad (1)$$

In Eq. (1), $\pi(x)$ is the probability of detection of x amount of contraband and α and β are fitting parameters estimated from the data set. An alternative form for Eq. (1) is the log-odds form, written as

$$\ln\left(\frac{\pi(x)}{1 - \pi(x)}\right) = \alpha + \beta \ln(x) \quad (2)$$

The mean, μ, and the standard deviation, σ, in terms of the fitting parameters are written as

$$\mu = \frac{-\alpha}{\beta} \quad (3)$$

and

$$\sigma = \frac{\pi}{\beta\sqrt{3}} \quad (4)$$

Figure 1 shows the influence of α and β on the general shape of the curve, and Figure 2 shows the relationship between specific points on the curve and the values of α and β. In Figure 1, the values of α and β are selected so all three curves pass through the same point, i.e., $\pi(x) = 0.50$. With reference to Figure 1, the value of $\pi(x)$ lies between 0 and 1 as required for a probability function. For $\beta > 0$, $\pi(x)$ is a monotonically increasing function of x, which is consistent with the intuitive view of the behavior of a probability of detection function. The magnitude of β determines the rate of change of the curve with increasing x. If β is large, there is a sharp transition from minimal to maximal probabilities of detection. Of course, if $\beta = 0$, the probability of detection curve is flat, which indicates its independence from x. With reference to Figure 2, the ratio $-\alpha/\beta$ is the value of ln x for which $\pi(x) = 0.5$ or $\exp(-\alpha/\beta)$ is the value of <x> for which $\pi(x) = 0.5$, and $(-\alpha/\beta \pm 1/\beta)$ is the approximate value of ln (x) at $\pi(x) = 0.73$ and $\pi(x) = 0.27$, respectively. That is, $\exp(-\alpha/\beta + 1/\beta) \cong x$ for $\pi(x) = 0.73$ and $\exp(-\alpha/\beta - 1/\beta) \cong x$ for $\pi(x) = 0.27$.

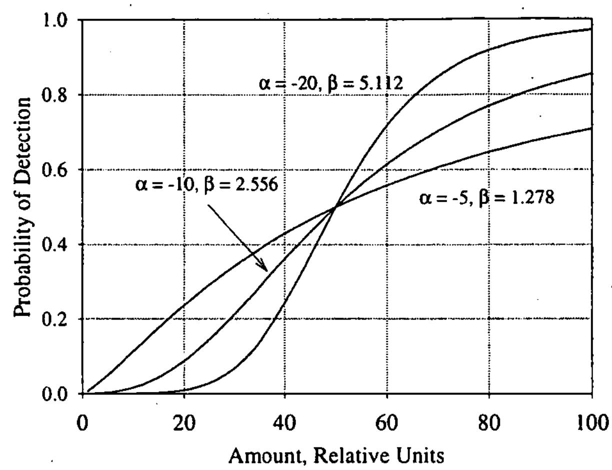

Figure 1. Influence of α and β on POD curve shape.

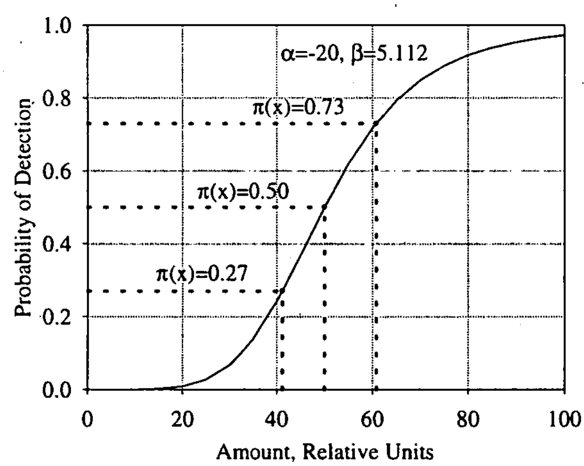

Figure 2. Relation of α and β to points on POD curve.

These points roughly define the "straight line" portion of the log-odds probability of detection curve and are indicated by the dropped lines in Figure 2.

Another important point regarding the fitting parameters α and β is the shape of the curve. Hence, the location of commonly used reference points or performance measures, such as $\pi(x) = 0.50$ and $\pi(x) = 0.90$, are quite sensitive to these values. The point $x = -\alpha/\beta$ is the more stable point with regard to small changes in α and β. However, in moving away from this point and toward another point like $\pi(x) = 0.90$, for example, relatively small changes in the value of β cause rather significant shifts in the lateral position of $\pi(x) = 0.90$ and, hence, the corresponding value of x. Although a performance measure based on a 0.90 probability of detection is much more reassuring than one based on a 0.50 probability of detection, for many purposes the 0.50 value is preferred and should be used.

PARAMETER ESTIMATION

Data Preparation

The following methods for estimating the log-odds parameters require the data to be in a certain format. Data sets of interest come in two varieties, namely the fraction detected as a function of the amount of contraband, and as hit/miss, binary, 0-1, etc., data sets that are also a function of the amount of contraband. The fraction detected is the ratio of the number of successful attempts to the number of opportunities.[1] Data sets of this nature can be used directly by either of the following methods for calculating estimates for the log-linear log-odds parameters.

Unless maximum likelihood methods are used, hit/miss data sets have to be grouped before they are used for calculating the log-odds parameters. Data sets consisting of 0's and 1's as a function of the amount of contraband must be transformed into an equivalent set of "fraction detected" values or proportions. One way is to smooth the hit/miss data set in the following manner.

The moving average for calls which generates the fraction detected values from the hit/miss data is written as

$$<p(j)> = \frac{1}{N} \sum_{i=j}^{j+N} c_i \ , \qquad (5)$$

where N is the number of values over which the average is calculated. Similarly, the moving average for the corresponding amounts of contraband is calculated as the average of the two end values over the selected range and is expressed as

$$<x(j)> = \frac{1}{2}\left[x_i + x_{i+(N-1)}\right] . \qquad (6)$$

Grouped detection ratios resulting in 0's and 1's cause mathematical difficulties in the subsequent algorithms and, hence, are replaced as follows:

$$0 \Rightarrow \frac{1}{2N} \text{ and } 1 \Rightarrow 1 - \frac{1}{2N} . \qquad (7)$$

where N is the number of opportunities in the group. Other methods can be used for the smoothing of hit/miss data sets.

Real data sets are small and messy, and the estimation of the log-odds parameters is moderately sensitive to relatively small changes in one or more values in the data set. Where possible, the log-odds parameters should be calculated for various configurations of the available data sets, including rounding off the values, excluding questionable or suspect data, and similar data analysis practices. Particularly troublesome are rogue points or outliers, which if present can drastically alter the calculated values for the log-odds parameters. There are diagnostic methods for identifying, understanding, and, as possible, reducing or eliminating such troublesome data from the reported results [5, 6]. These should be explored as appropriate in any application of these methods.

The principal ways to generate estimates for the log-odds fitting parameters α and β are regression and maximum likelihood. The simplest and most direct method for using either of these methods is to use any of a number of software packages that are available for the personal computer. Linear regression routines are available in essentially all the widely used spreadsheet and solver-type software packages, and can be applied in the form of Eq. 2 to generate the values of α and β along with some

[1] Although false positives or false calls are recognized as important, the log-odds approach does not handle them in a direct manner, so other methods must be used.

low-level regression diagnostics. Other more specialized programs with nonlinear regression routines can handle the data as shown in Eq. 1. At various times we have used Excel®, SigmaPlot®, and Mathcad® for these applications.

Routines for generating maximum likelihood estimates for the fitting parameters are in the more specialized statistical software packages such as SAS® (Statistical Analysis System), and GLIM\MLP (Generalized Linear Interactive Modeling /Maximum Likelihood Program). Reference to these and similar programs can be found via most of the Internet search engines. An alternative is to use software packages like Mathematica®, Mathcad®, or MatLab® for solving the set of simultaneous equations found in Berens [3]. Estimating the fitting parameters by maximum likelihood offers the advantage that individual detection opportunities involving 0 and 1 responses can be analyzed without any data grouping or smoothing.

EXAMPLE

The above concepts are applied in the following manner to the analysis of field data. In most field evaluations practical considerations limit the number of data points. In this hypothetical example, we have taken fraction detected data for three amounts of contraband. In terms of relative units, the observed performance was as follows:

Amount, Relative Units	Hypothetical Fraction Detected
3	0.075
5	0.52
7	0.90

A log-linear logistic regression, i.e., Eq. 1, was performed on this hypothetical data set and the graphical results are shown in Figure 3. The open circles are the hypothetical data points and the solid line is the fitted log-linear log-odds POD curve. For this data set $\alpha = -9.095$ and $\beta = 5.725$. For these values of the fitting parameters $\pi(x) = 0.5$ is equivalent to $x = 4.9$ units of contraband. The values for other performance measures such as $\pi(x) = 0.9$ can be measured directly from the curve or derived numerically.

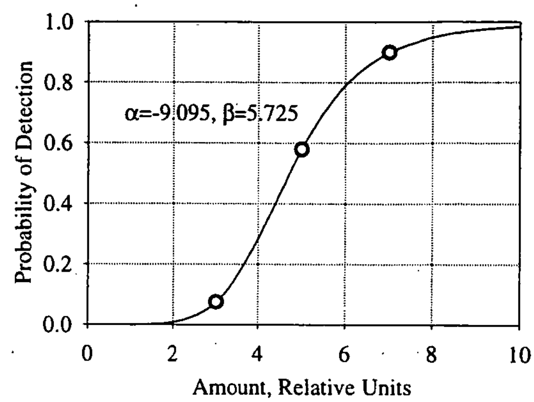

Figure 3. Logistics regression POD curve for hypothetical field data.

CONCLUSIONS

We have shown a similarity between the nonintrusive inspection for contraband at border crossings and the nondestructive inspection for flaws in engineered structures. In addition, we have demonstrated that probability of detection methods developed for the characterization of the nondestructive inspection process are directly applicable to the characterization of the nonintrusive inspection for contraband at border crossings. Thus, probability of detection methods provide a means for assessing and comparing the performance of a diverse population of systems, processes, and inspectors, albeit an imperfect one. Given the success of this approach, the exploration of the transfer of other related methods seems warranted.

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Applicability of Counterdrug Nonintrusive Inspection Systems to Alternative Applications

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Abstract

The large number of vehicles, containers, and persons crossing the US border each year has fostered a need for the development of nonintrusive inspection technologies which can efficiently increase the number of inspections conducted without impeding the flow of legitimate traffic. The Department of Defense Counterdrug Technology Development Program has actively addressed the development of advanced systems and technologies to enhance mobile, relocatable, and fixed-site nonintrusive inspection of variously sized packages and containers, commercial vehicles, and palletized cargo. The operational intent of these systems covers the full range of counterdrug inspection environments. Once sufficiently developed, performance assessments and demonstrations of those systems are conducted in controlled operational environments by the Program Office.

This paper addresses the application of nonintrusive inspection systems (bulk/imaging and trace detection) originally designed and employed for counterdrug purposes to the detection of alternate contraband materials (i.e., explosives, weapons, contraband tobacco, and vehicles) which are of interest to the broader inspection and Force Protection community.

(Paper not available at time of publication)

Biography:

Michael Spradling is a Principal Research Scientist within Battelle's Ordnance Systems and Technology Department. He is currently assigned as Counterdrug Project Manager for the Office of Special Technology Engineering Support Program. Recent research activities have involved the conduct of extensive contraband detection assessments for nonintrusive inspection systems in support of the DoD Counterdrug Technology Development Program. He received a B.S. in Aeronautical Engineering and a M.S. in Mechanical Engineering from The Ohio State University. He has completed Ph.D. courses in Aeronautical Engineering at The Ohio State University.

NARCOTICS DETECTION WITH A PIEZO-ELECTRIC RINGING (PER) DETECTOR.

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ABSTRACT

It has been recently recognized that cocaine hydrochloride exhibits piezoelectric resonance (PER) characteristics which may be used as an indicator of concealment. PER has been tested on commercial (smuggler's) grade cocaine hydrochloride with littler or no success to date. The initial preliminary responses were unrepeatable and are still not understood. Careful lab work has determined that frequency response in the 2 Mhs range is likely. This is a discussion of its USCS application and the reasons for the new frequency of interest.

Quantum Magnetics has recently carried out studies on the PER signal with the support of the US Army, US Customs Service, and the Office of National Drug Control Policy. Results will be discussed from recent DEA and US Customs Service trials.

1. Introduction

The concealment of contraband within cargo poses a constant challenge for law enforcement authorities worldwide. Manual investigation has proven to be extremely time consuming and expensive, and is ultimately ineffective as a technique for stemming the flow of contraband over international borders. U.S. Customs has long supported the development of non-invasive, automated detection technologies which could be used to reduce the expense and manpower effort required to screen the enormous number of items that pass through ports of entry on a daily basis.

The most commonly implemented technology for non-invasive screening of cargo is the X-ray. While extremely effective at detecting a wide range of materials very quickly, X-ray systems possess a key operational disadvantage in that they require the constant presence of a specially trained operator. Although automated X-ray systems are becoming more widely available, they are still very expensive and complex to operate in a high-volume setting. Other technologies that have been used in the past for non-invasive screening include Thermal Neutron Analysis (TNA) and vapor particulate analysis. These technologies, however, have proven to be somewhat impractical, due to high cost and complexity of operation.

Over the past eight years, Quantum Magnetics (San Diego, California) has developed a number of advanced contraband detection systems based on two variants of magnetic resonance technology, Quadrupole Resonance (QR) and Nuclear Magnetic Resonance (NMR). QM has an exclusive license with the Naval Research Laboratory (NRL, Washington DC) covering all aspects of QR and PER based contraband detection technologies. NRL developed the first prototype QR explosive and narcotic detector and discovered the piezo-electric effect from CHCl. QR is a phenomenon associated with the inherent molecular properties of the atomic nuclei in crystalline and amorphous solids. Nuclei with nonspherical electric charge distributions possesses electric quadrupole moments. QR originates from the interaction of these inherent electric quadrupole moments with the gradient of the electric field in the vicinity.

The QR response is characterized by a precessional frequency which depends upon two parameters: 1) the electric quadrupole moment of the nucleus, and 2) the nature of the electric field gradient experienced by the nucleus due to its molecular environment. For narcotics applications there are three significant quadrupolar nuclei: nitrogen-14 (^{14}N), chlorine-35 (^{35}Cl), and chlorine-37 (^{37}Cl). Another important detection factor is linewidth, or resonant quality. All of these parameters depend on the purity and manufacturing process of the sample.

Some contraband materials such as cocaine hydrochloride (CHCl) are difficult to detect using magnetic resonance techniques, due to their electric and magnetic properties. In 1995, Quantum Magnetics designed and built a QR-based, conveyorized system for the detection of narcotics concealed within blocks of frozen seafood cargo. The detector consists of two separate detector heads having an active 170-liter volume (24" x 24" x 18"). The detector heads tuned to two different quadrupole resonance frequencies: 3.719 MHz for cocaine base (CB), and 0.961 MHz for cocaine hydrochloride (CHCl). In testing, however, it proved difficult to integrate the detection of CHCl into the large scale device described above, due to the fact that CHCl gives a very weak QR signal, necessitating a prohibitively long scan time when using a large scale coil (170 liter). CHCl, like most of the other contraband materials of interest, is based on natural products and is notoriously impure. Precessional frequencies are low, coupled with poor resonant quality (i.e. very broad linewidths), making the preferred magnetic resonance detection technique known as induction detection very difficult.

However, other physical properties can be used as a basis for detection. It has recently been discovered that CHCl is piezo-electric due to its particular crystal structure. Piezo-electric materials can, under certain circumstances, be made to produce a distinctive Piezo-Electric Resonance (PER) signal. The PER signal from certain narcotic materials can be detected and used as a basis for a non-invasive detection system. Piezo-electricity is quite common among crystalline materials and may be exhibited by other contraband materials such as methamphetamine (MA).

2. PER Detection System Description

The PER detection system implements a series of radio-frequency pulses (5 MHz for the U.S. Customs Thunder Mountain test). The electric field generates piezoelectric signals in the crystallites in a powder. These signals are detected by a large copper plate capacitor encompassing a volume of 10 liters. The time domain voltage data are recorded by computer and Fourier transformed into the frequency domain. The frequency-space data is compared to the spectrum of the statistical/thermal noise level in the system to determine the presence of crystal substances, in particular cocaine hydrochloride. Figure 1. shows a block diagram of the PER detection system.

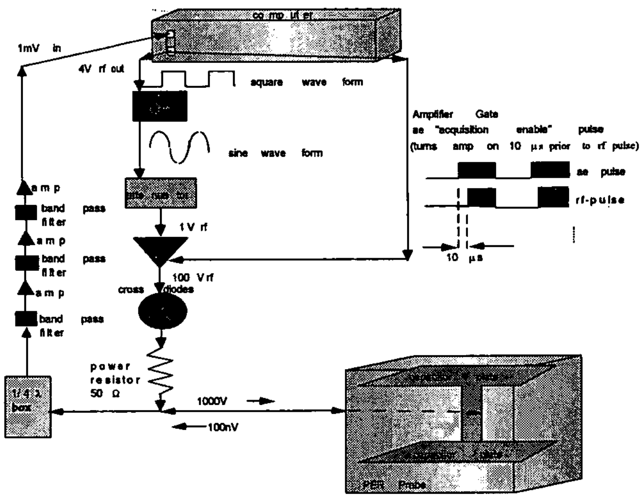

Figure 1. Schematic of the PER device. The detector head is shown together with the main system interconnections. The computer contains the necessary electronics to generate a rf pulse and detect the PER signal.

3. The Crystal Diameter Dependence Of PER Signals

A PER signal is easily detected from sodium nitrite ($NaNO_3$), providing the crystal diameter (L) is of sufficient size to accommodate the wavelength of the first harmonic of the perturbing rf - pulse.

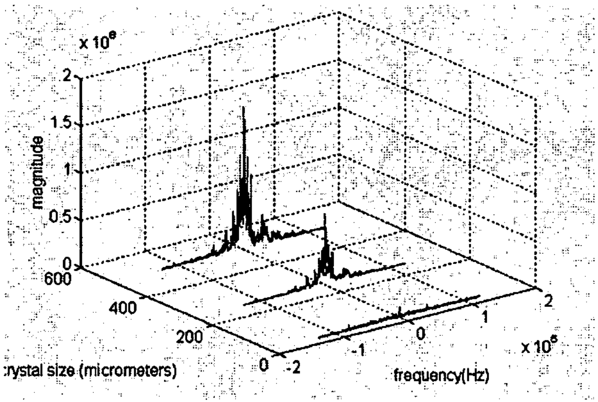

Figure 2. The largest PER signal at 5 MHz is produced by $NaNO_3$ crystals ~ 500μm diameter.

The relation between resonant frequency and physical characteristics of the crystal are:

$$f = \frac{v}{\lambda} \quad (v = \text{velocity of sound in crystal medium}) \qquad [1]$$

where f is the frequency and λ the wavelength.

$$\lambda = \frac{2L}{n} \qquad [2]$$

$$v = \left(\frac{Y}{\rho}\right)^{\frac{1}{2}} \quad (Y = \text{Young's modulus},\ \rho = \text{density.}) \qquad [3]$$

substituting [2] and [3] in [1],

$$f = \left(\frac{n}{2L}\right)\left(\frac{Y}{\rho}\right)^{\frac{1}{2}} \quad n = 1,3,5\ldots \qquad [4]$$

For the crystal sizes described in Figure 2, the mode n=1 resonant frequencies calculated for sodium nitrite are given in Table 1.

Crystal Size (μm)	Resonant Frequency (MHz)
25.4	72.85
254	7.285
500	3.7

Table 1. The inverse relationship between crystal size and resonant frequency (mode n=1). Calculated with $\rho = 2.19 g/cm^3$, and $Y = 3 * 10^{11}$ $dynes/cm^2$

Within any sample there is a distribution of crystal sizes that produce a band of PER frequencies. Recent data obtained from the Idaho National Engineering Laboratory indicates the agglomerate and aerodynamic particle sizes of cocaine hydrochloride (CHCl). With this data, the resonant frequency band of CHCl are calculated according to equation [4]:

Agglomerate particle size range = 50μm to 150μm
Agglomerate frequency range = 14 MHz to 36 MHz.
Aerodynamic particle size range = 4μm to 10 μm.
Aerodynamic frequency range = 182 MHz to 460 MHz .

A glance at this data shows that a PER device should operate at a frequency above 14 MHz to successfully resonate CHCl crystals.

4. Thunder Mountain Evaluation Center Test: Fort Huachuca, Arizona

A field test of the equipment was performed to study the feasibility of using piezoelectric resonance (PER) at 5 MHz to detect the presence of CHCl. (At the time of the test agglomerate data for CHCl was not available.) A number of CHCl were tested as confiscated. with negative results. Calculation of the mechanical resonance spectrum of CHCl shows that the lowest-frequency resonances probably lie above 14 MHz for common crystallite sizes well above the system operating frequency. Work is in progress to implement PER detection at a higher frequency (≥20 MHz) to match the natural frequency of commonly occurring CHCl crystallites which should vastly improve the probability of detection.

5. Future Work

Quantum Magnetics is proposed *a* program to improve the performance of the PER-based contraband detection system. The first phase will involve intensive study of the PER responses of various narcotic substances, in particular cocaine hydrochloride at different operating frequencies and with different samples. The second phase will entail the development and testing of a prototype PER system. Using information obtained from the intensive study on cocaine hydrochloride, this prototype will first be rebuilt and tested.

The third phase will consist of modifications to make the PER system suitable for deployment and use by unskilled personnel. For this final phase, Quantum Magnetics hopes to build and install three of the prototype units and install them for long-term testing and evaluation at various U.S. ports of entry through June 1999.

6. Acknowledgments

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Communications, Surveillance, and Tracking Methodologies (Session 3A-2)

IMPROVED ROTHR DETECTION AND TRACKING USING THE MLANS ALGORITHM

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ABSTRACT

An advanced detection and tracking system is being developed for the Relocatable Over-the-Horizon Radar (ROTHR) to provide improved tracking performance against small aircraft typically used in drug smuggling activities. The development is based on Nichols Research Corporation's Maximum Likelihood Adaptive Neural System (MLANS), a model-based neural network that combines advantages of neural network and algorithmic approaches. The objective of the MLANS Tracker development effort is to address user requirements for increased detection and tracking capability in clutter, and improved track position, heading, and speed accuracy. The MLANS Tracker is expected to outperform other approaches to detection and tracking for the following reasons. It incorporates adaptive internal models of target return signals, target tracks and maneuvers, and clutter signals, which leads to concurrent clutter suppression, detection, and tracking (track-before-detect). It incorporates super resolution spectrum estimation techniques exceeding conventional maximum likelihood and maximum entropy methods. The unique spectrum estimation method is based on the Einsteinian interpretation of the spectrum as a probability density of signal frequency. The MLANS neural architecture and learning mechanism are founded on spectrum models and maximization of the likelihood, allowing knowledge of the physical behavior of both targets and clutter to be injected into the tracker algorithms. The paper describes the addressed requirements and expected improvements, theoretical foundations, engineering methodology, and results to date.

1. Introduction

Two ROTHR systems are currently being operated by the Navy, located in Virginia and in Texas. Their mission includes detection, tracking, and assisting in the intercept of drug trafficking aircraft, typically small aircraft. The current ROTHR systems can reliably detect and track targets with signal-to-noise ratio, SNR, above 12-14 db. But, small aircraft typically used in drug trafficking activities cannot be reliably detected and tracked. This is a recognized deficiency of the current ROTHR systems and improvement of the detection and tracking performance in low SNR has been identified as a priority by the ROTHR users. The program performed by Nichols Research Corporation under contract to the USAF Rome Laboratory addresses this deficiency, with a goal of detection and tracking in low SNR environments down to 5 db. This paper discusses the development of this enhanced detection and tracking capability for ROTHR by application of the Nichols Research innovative Maximum Likelihood Adaptive Neural System (MLANS)[1]. MLANS detection and tracking algorithms have been previously developed and demonstrated for many different types of sensors[2,3,4]. For example, a successful development and evaluation of MLANS for target detection and location with active sonar systems has resulted in the MLANS algorithm being evaluated as a replacement for the current operational sonar tracker. This example is particularly relevant because the current operational sonar tracker is similar to that used for the current ROTHR tracker.

The technical difficulty of the ROTHR system in detecting and tracking low SNR targets can be explained as follows. The current ROTHR detection and tracking subsystem operates in a two step process. First, peaks are detected and potential target peaks that exceed a predetermined threshold are identified. Second, these potential target peaks are then used to initiate tracks. This two-step procedure is a current state-of-the-art approach; most operational radar systems use this approach. The limitation of this procedure is clearly determined by the detection threshold. The detection threshold, in turn, is determined by the nature of the signal and by processing requirements of the tracker. If the threshold is reduced, the number of detected peaks grows quickly (roughly speaking, tenfold with each 1 db decrement). This growth cannot be countered simply by increased computer power, because the processing requirements of the tracker at low SNR are combinatorial in terms of the number of peaks, so that a tenfold increase in the number of peaks results in millions-fold increase in the required computer power.

The technical capability of the MLANS algorithm for reliable performance in low SNR is based on an adaptive fuzzy association logic, which associates all the data bins in a time window of data scans with a number of possible tracks. Fuzzy association eliminates a need for combinatorial search, making it possible to initiate tracks on multiple scans using all the data, without peak thresholding. In addition, this approach adapts to clutter properties for better clutter suppression. Thus, MLANS superior performance is due to a combination of three factors: (1) simultaneous detection and tracking, which combines information in multiple ROTHR dwells, (2) fuzzy association logic, which lets MLANS process all the data bins without thresholding, and (3) concurrent estimation of target and clutter characteristics, which permits better detection.

The paper describes the MLANS technology, algorithmic approach to ROTHR tracker development, and current results. The next section describes the foundation of MLANS model-based approach in the Einsteinian concept of the spectrum being a distribution function of the signal frequency. Section 3 describes further development of this concept, introduces the MLANS models, and describes the operational approach for the ROTHR tracker. Section 4 then presents examples of current detection and tracking results, and Section 5 contains a summary discussion.

2. Einsteinian Model For Spectrum Estimation

Einstein interpreted the electromagnetic spectrum as a probability density function (pdf) of the photon frequency[5]. This interpretation leads to a new formulation of the likelihood structure for spectrum estimation, different from conventional likelihood expressions, which are based on statistical assumption of signal properties and ignore the physics of electromagnetic scattering and propagation. The Einsteinian likelihood accounting for the physics of electromagnetic spectrum is derived in [6]. The likelihood, in terms of the properly normalized empirical spectrum $S(\omega)$ and spectral model $F(\omega)$, is given by

$$L = \prod_{\omega} [F(\omega)]^{S(\omega)}; \quad \ln(L) = \sum_{\omega} S(\omega) \ln(F(\omega)) \quad (1)$$

According to the ML principle, the likelihood or its logarithm should be maximized in the estimation process.

The specific shape of the parametric model for $F(\omega)$ can be determined based on the physics of the process under consideration[7], or a general type of flexible parametric model can be selected as in [8] as discussed below. For ROTHR, the received signals can be considered as being produced by incoherent contributions from several sources. In such a case, the spectrum is a sum of individual source contributions,

$$F(\omega) = \sum_{m} F(\omega|m), \quad m = 1,..., M. \quad (2)$$

Such a model for a pdf is called in statistics a mixture model, and we call each mixture component, $F(\omega|m)$, a sub-model corresponding to source m. In many cases, conditional pdf modeling individual sources can be modeled using Gaussian densities. Gaussian models are widely applicable, because a superposition of Gaussian models can be used to model any function. The Gaussian model is given by

$$F(\omega|m) = A_m G(\omega|m), \quad m = 1,..., M;$$

$$G(\omega|m) = (2\pi)^{-1/2}(\sigma_m)^{-1} \exp\{-0.5 (\omega - \omega_m)^2 / \sigma_m^2\}. \quad (3)$$

In the above equations, A_m is a sub-model weight, ω_m is the sub-model mean frequency and σ_m is the sub-model frequency standard deviation. Each sub-model $F(\omega|m)$ models the energy from the source m at frequency ω, and $G(\omega|m)$ is interpreted as the conditional pdf of the photon frequency from source m. Wide applicability of the above model is due to the fact that Gaussian functions form an overcomplete set of functions so that any function $S(\omega)$ can be modeled using eqs. (2) and (3).

The mixture model specified by eqs. (2), and (3) is characterized by three parameters per Gaussian sub-model: the weight, the mean, and the standard deviation. The ML estimation equations for these parameters are derived by maximizing the likelihood L in eq. (1), resulting in the following ML equations:

$$A_m = N_m / N, \; N_m = \sum_{\omega} P(m|\omega) S(\omega), \quad N = \sum_{\omega} S(\omega), \quad (4)$$

$$\bar{\omega}_m = \sum_{\omega} P(m|\omega) S(\omega)\, \omega / N_m, \quad (5)$$

$$\sigma_m^2 = \sum_{\omega} P(m|\omega) S(\omega) (\omega - \omega_m)^2 / N_m. \quad (6)$$

The term $P(m|\omega)$,

$$P(m|\omega) = F(\omega|m) / [\, \sum_{m'} F(\omega|m')\,], \quad \sum_{m} P(m|\omega) = 1, \; m = 1,... M, \quad (7)$$

has the meaning of the a posteriori Bayes probability that a photon at frequency ω has originated from the source (or sub-model) m. Thus, N_m is proportional to the number of photons from the source m, and N is proportional to the total number of photons.

The ML estimation eqs. (4) through (7) do not yield an immediate estimate of the model parameters, because the probabilities $P(m|\omega)$ in the right-hand side of eqs. (4) through (6) depend on the unknown parameter values, according to eq. (7). These equations define an iterative system: beginning with an initial estimate for values of the parameters, the sub-models $F(\omega|m)$ and probabilities $P(m|\omega)$ are computed according to eqs. (3) and (7); on the next iteration, the parameter values are recomputed according to eqs. (4) through (6), etc., until convergence. The convergence is determined by requiring that parameter changes are small from iteration to iteration. The convergence is always attained; this is a consequence of the estimation-maximization (EM) algorithm[9].

It is shown in [8], that the above estimation procedure can be interpreted as a relaxation to equilibrium of the photon ensemble comprising the observed spectrum, leading to a relationship between the "Einsteinian" likelihood and entropy. Also, the estimation can be interpreted as maximization of the information contained in the internal MLANS model about the signal. Therefore, Eisteinian likelihood maximization is equivalent to maximizing the information extracted from the data.

In [10], this technique was compared to superresolution spectrum estimation techniques based on classical maximum likelihood and maximum entropy principles. The technique was shown to be superior, especially for short duration spectra important for ROTHR target detection and tracking.

3. MLANS Tracker Models And Estimation

ROTHR data are four-dimensional spectra in the Doppler-range-azimuth-time domain. This section extends the results of the previous section to this more complicated data. MLANS ROTHR tracker models are developed using known phenomenology of the ROTHR signals. They are modifications of Gaussian models considered in the previous section. The unknown parameters of these models, including target positions, velocities and course are estimated by maximizing the Einsteinian likelihood, similar to eqs. (4) through (7). This section contains a discussion of the specific models and the estimation process applicable to ROTHR.

3.1 MLANS Models

The Nichols Research MLANS Tracker for ROTHR incorporates three types of sub-models: (1) target-track sub-models, whose purpose is to capture moving targets such as aircraft, (2) ocean/ground clutter sub-model, whose purpose is to capture the near zero-Doppler ocean/ground return and, (3) noise/background clutter sub-model, whose purpose is to capture the residual background noise and clutter observed in the data across all Doppler values. The total model incorporating all the submodels is given by

$$F(X_n) = A_b \mathrm{pdf}(X_n \mid \mathrm{background}) + \sum_m A_{c,m} \mathrm{pdf}(X_n \mid \mathrm{clutter}) + \sum_m A_{t,m} \mathrm{pdf}(X_n \mid \mathrm{target}) \qquad (8)$$

where A_b, $A_{c,m}$ and $A_{t,m}$ are the amplitudes of the noise/background clutter sub-model, ocean/ground clutter sub-model, and target-track sub-models, and $X_n = (\omega_n, R_n, AZ_n, t_n)$ are the coordinates of the n^{th} bin: Doppler, Range, Azimuth, and time. The sums are taken over the corresponding sub-models.

MLANS model parameter estimation is accomplished through maximization of the Einsteinian log-likelihood function, given by:

$$\ln(L) = \sum_{n=1}^{N} S_n \ln[F(X_n)] \qquad (9)$$

The sum is taken over all data bins {n} (that is, over all values of range, Doppler, azimuth and time) within a time window.

3.1.1 Noise/Background Clutter Sub-Model

Noise and clutter is expected to appear randomly throughout all data bins; therefore, it is modeled using a uniform distribution.

$$\mathrm{pdf}(X_n \mid \mathrm{background}) = (\Delta R \cdot \Delta\omega \cdot \Delta AZ)^{-1}, \qquad (10)$$

where ΔR is range extent, $\Delta\omega$ is Doppler extent, and ΔAZ is azimuth extent.

3.1.2 Ocean/Ground Clutter Sub-Model

Ocean/ground clutter distribution in Doppler is modeled as a superposition of several Gaussian distributions. Each Gaussian distribution corresponds to a propagation mode of the radar signal refracted by the ionosphere. Usually, two modes ("1-hop" and "2-hop") are needed to model clutter with sufficient accuracy. In range and azimuth, ocean/ground clutter distribution is modeled as uniform, and the shape of clutter return in Doppler is modeled independently in every range-azimuth cell. The pdf of the clutter mode m, for the n^{th} data cell, is thus given by

$$\mathrm{pdf}(X_n \mid \mathrm{clutter}, m) = (2\pi)^{-0.5}\left(\Delta R \cdot \Delta AZ \cdot \sigma_{\omega,m}\right)^{-1} \exp\left[0.5\left(\frac{\omega_n - \bar{\omega}_m}{\sigma_{\omega,m}}\right)^2\right], \qquad (11)$$

where pdf(Xn|clutter,m) is the pdf for the n data cell to belong to the m^{th} clutter model, $\sigma_{\omega,m}$ is the estimated Doppler standard deviation, $\bar{\omega}_m$ is the estimated mean Doppler, and $A_{c,m}$ is the estimated amplitude for clutter model m.

3.1.3 Target-Track Sub-Models

Since the target size is much smaller than the ROTHR range-azimuth-Doppler cell, (that is, since the targets are unresolved) the shape of the target return is determined by the radar ambiguity functions, which we model using Gaussian shapes in range, azimuth and Doppler. Since the targets are expected to move through the data in a deterministic manner according to the equations of motion, the target-track sub-models incorporate this expectation and their parameters are estimated not at each range and time, but over all ranges and times within each time window. The explicit form of a target-track sub-model is

$$\mathrm{pdf}(X_n|\mathrm{target}) = (2\pi)^{-1.5}\left(\sigma_{\omega,m}\sigma_{R,m}\sigma_{AZ,m}\right)^{-1}$$

$$\exp\left[-0.5\left(\frac{\omega_n-\bar{\omega}_m(t)}{\sigma_{\omega,m}}\right)^2\right]$$

$$\cdot\exp\left[-0.5\left(\frac{R_n-\bar{R}_m(t)}{\sigma_{R,m}}\right)^2\right]\cdot \tag{12}$$

$$\exp\left[-0.5\left(\frac{AZ_n-\overline{AZ}_m(t)}{\sigma_{AZ,m}}\right)^2\right],$$

in which $\bar{\omega}_m(t)$ is the estimated Doppler mean, $\bar{R}_m(t)$ is the estimated range mean, and $\overline{AZ}_m(t)$ is the estimated azimuth mean for target mode m.

3.2 Model Parameter Estimation

Parameters are estimated by maximization of eq. (9) with respect to model parameters: A_m for the noise/background clutter sub-model, (A_m, $\sigma_{\omega,m}$, $\bar{\omega}_m$) for the ocean/ground clutter sub-model, and A_m and track state parameters for the target-track sub-models.

3.2.1 Estimation Of Noise And Clutter Parameters

Maximization of eq.(9) with respect to A_m, $\sigma_{\omega,m}$, and $\bar{\omega}_m$ leads to the following parameter estimation equations for the noise/background clutter and the ocean/ground clutter sub-models:

$$A_m = \langle 1\rangle, \tag{13}$$

$$\bar{\omega}_m = \langle\omega_m\rangle / A_m, \tag{14}$$

$$\sigma_{\omega,m} = \left\langle(\omega_n-\bar{\omega}_m)^2\right\rangle \Big/ A_m, \tag{15}$$

where the angular brackets are defined as

$$\langle\bullet\rangle = \sum_{n=1}^{N} S_n P(m|n)(\bullet). \tag{16}$$

Using Einstein's interpretation of the spectrum as a probability distribution of the ensemble of photons, the P(m|n) are interpreted as a-posteriori Bayesian probabilities of a photon with frequency ω, originating from sub-model m [7], which is defined according to eq. (7)

$$P(m|n) = A_m \mathrm{pdf}(X_n|m) / \sum_{m'=1}^{M} A_{m'} \mathrm{pdf}(X_n|m'), \tag{17}$$

where the m' refer to all sub-models: ocean/ground clutter, target and noise/background clutter.

3.2.2 Target-Track Sub-Model Parameter Estimation

The following equations of motion are used for accelerating and turning targets in range and linear tracks in azimuth

$$\omega_m(t) = \omega_{0,m} + \omega_{1,m}t$$

$$R_m(t) = R_{0,m} + \omega_{0,m}t + \frac{1}{2}\omega_{1,m}t^2 \tag{18}$$

$$AZ_m(t) = AZ_{0,m} + AZ_{1,m}t$$

The estimation equations for range and Doppler parameters $(\omega_{0,m}, \omega_{1,m}, R_{0,m})$ are

$$\begin{bmatrix} \langle 1\rangle+\alpha\langle t^2\rangle & \langle t\rangle+\frac{\alpha}{2}\langle t^3\rangle & \alpha\langle t\rangle \\ \langle t\rangle+\frac{\alpha}{2}\langle t^3\rangle & \langle t^2\rangle+\frac{\alpha}{4}\langle t^4\rangle & \frac{\alpha}{2}\langle t^2\rangle \\ \langle t\rangle & \frac{1}{2}\langle t^2\rangle & \langle 1\rangle \end{bmatrix} \begin{bmatrix} \omega_{0,m} \\ \omega_{1,m} \\ R_{0,m} \end{bmatrix} = \begin{bmatrix} \langle \omega\rangle+\alpha\langle Rt\rangle \\ \langle \omega t\rangle+\frac{\alpha}{2}\langle Rt^2\rangle \\ \langle Rt\rangle \end{bmatrix}, \quad (19)$$

where

$$\langle\cdot\rangle=\sum_n S_n P(m|n)(\cdot) \ ; \ \alpha=\sigma^2_{\omega,m} \ / \ \sigma^2_{R,m} \ .$$

And, the estimation equations for azimuth track parameters $AZ_{0,m}$, $AZ_{1,m}$ are similarly

$$\begin{bmatrix} \langle 1\rangle & \langle t\rangle \\ \langle t\rangle & \langle t^2\rangle \end{bmatrix} \begin{bmatrix} AZ_{0,m} \\ AZ_{1,m} \end{bmatrix} = \begin{bmatrix} \langle AZ\rangle \\ \langle AZ\cdot t\rangle \end{bmatrix} \quad (20)$$

3.3 Track Declaration

The MLANS Tracker processes ROTHR data using a sliding window approach for target propagation and track declaration. This section presents the algorithm which is used for preliminary track declaration, so that potential targets are propagated in time to subsequent windows. The process described below is performed for each target-track sub-model. In this discussion, a "window" of data consists of a specified number of radar scans (typically 6), which is moved through the data set as new scans become available, so that the data in these new scans can be associated with previously propagated potential targets, and track state parameters estimated and updated in time.

The MLANS Tracker declares target-tracks using the ML criterion. Log-likelihood is computed for every target-track sub-model. First, the most likely sample X_n for track k is determined for time t_n using the log-likelihood ratio for one sample:

$$LLR_{k,t} = \max_{\omega_n, R_n, AZ_n} \ln(\mathrm{pdf}(X_n|\mathrm{track},k) / \mathrm{pdf}(x_n|\mathrm{background}) \quad (21)$$

Second, the log-likelihood ratio for the track (LLR_k) is computed and compared against a threshold, which we call the Target Propagation Threshold (TPT),

$$LLR_k = \sum_t LLR_{k,t} \ ; \ LLR_k > TPT \quad (22)$$

This declaration algorithm is based on concurrent detection and tracking. The threshold value to be used in the operational ROTHR system will be determined so that the number of false declarations is below an acceptable level.

3.4 MLANS Tracker Operation

3.4.1 Data Sequence Estimation

The concept of operation of the Tracker is illustrated pictorially in Figure 1. Input to the MLANS Tracker are data image temporal sequences composed of data scans, also called dwells, similar to the one shown in the figure. Using a time sequence of data scans, but for sixteen azimuth channels, the MLANS Tracker software forms an estimate of the temporal data structure, iterating between associating the data from each range-Doppler-azimuth bin with each of the sub-model types and estimation of the model parameters, including the state vector parameters for potential sub-target models. Upon convergence, a maximum likelihood estimation of the image data sequence is formed.

An example of the MLANS Tracker estimation is shown in the center of the lower rectangle in Figure 1. This image estimation is for the sample input data scan for a single azimuth channel as shown in the upper left portion of the figure. Note that the MLANS Tracker has converted the Doppler bin number to radial velocity. MLANS has accurately estimated the ocean/ground clutter at near-zero Doppler for all range values, and represents the residual noise/background clutter with a constant value across all Doppler bins. Most important to note is that the MLANS Tracker has selected four spectral structures as potential targets. We use the term 'potential target' since we have not yet performed target nor track declaration. As discussed in Section 3.3, a log-likelihood ratio test is then performed on the data for target declaration, and declared targets are then propagated into the updated data temporal sequence for sliding-window tracking as described below in the next section. For the example in Figure 1, the only potential target structure declared for propagation into the next time window is the target moving toward the radar (positive Doppler) at a Dwell Illumination Region (DIR) range of approximately 790 km with a radial speed of about 90 m/s.

It is of interest to examine the MLANS spectral estimation. A plot of the range-Doppler spectrum for the range bin at approximately 790 km is shown in the left side of the lower rectangle in Figure 1. Here, we plot the received signal strength, shown as the solid dark line, as a function of the Doppler velocity. The MLANS Tracker model estimation of this data spectrum is also plotted. The strong ocean/ground clutter structure at near zero Doppler is seen to be well represented by the two-modal Gaussian model. The residual noise/background clutter is estimated for all Doppler values as a constant amplitude representative of the lower bound of the spectrum. Most important is the single Gaussian model that MLANS has fit to the spectral structure near 90 m/s. This specific spectral structure was selected by the MLANS Tracker as having a temporal motion through the entire data sequence representative of that expected of an aircraft target.

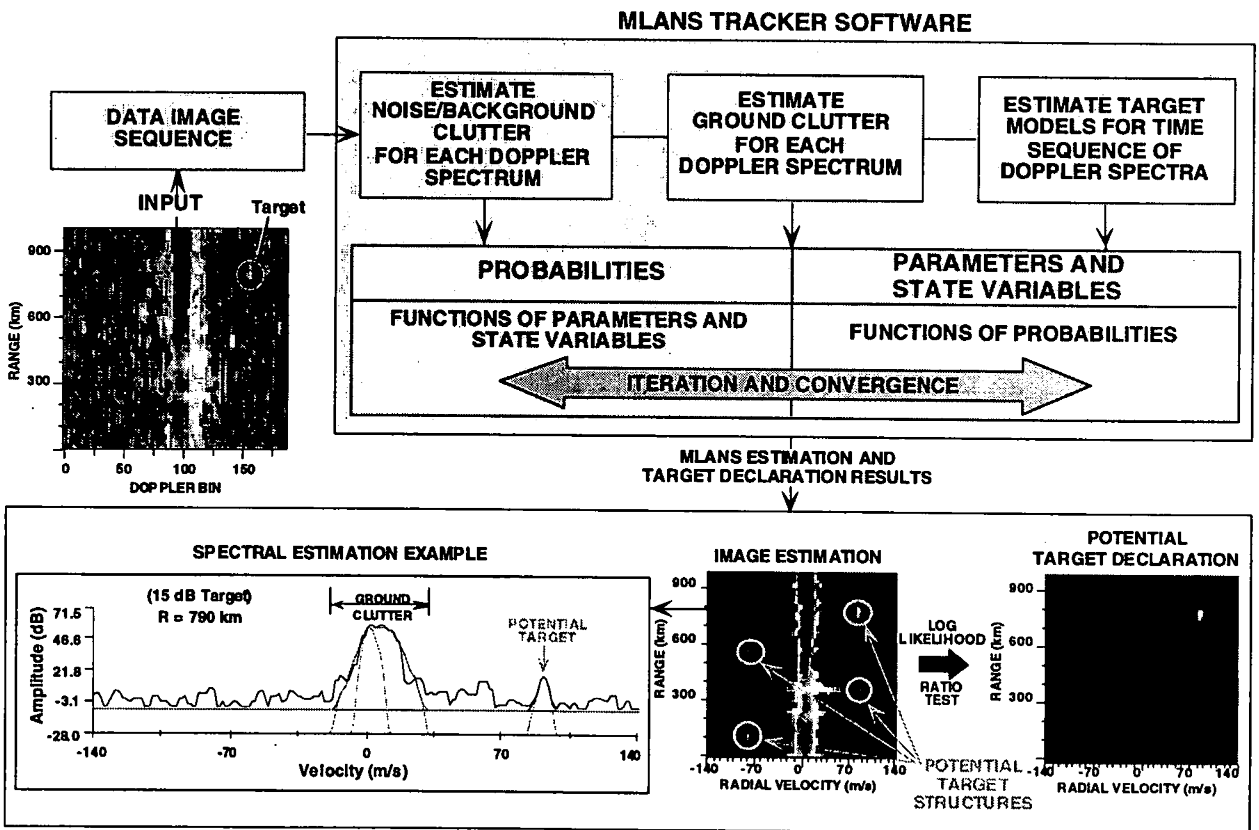


Figure 1. MLANS Tracker Concept of Operation

It is important to note that the MLANS Tracker does not go through a peak-picking process with a predetermined threshold on SNR to select spectral structures as potential targets, as does the current ROTHR operational tracker. The strength of the Nichols Research approach is that MLANS searches out all the data in range, azimuth, and Doppler for spectral structures that are consistent with the target-track sub-model, with all range-Doppler-azimuth data bins partitioned among all three sub-model types in a statistically optimal manner. The key point is that targets exhibit a time-evolution consistency between the data and the target-track sub-model while statistically random noise and clutter events do not. The MLANS Tracker goes through this process using all of the data, resulting in detection and tracking performance at lower SNRs than approaches such as 'peak picking' that thresholds the data.

In the next section, we discuss the process used by the MLANS Tracker for target propagation in time and track declaration.

3.4.2 Sliding Window and Target-Track Propagation

The MLANS Tracker initiates target tracks and declares potential targets using a temporal sequence of several data scans for all sixteen azimuth beams within a DIR. The sliding-window process is illustrated in Figure 2. Here we pictorially show a temporal sequence of data scans for a single azimuth channel. In the sliding-window process, the MLANS Tracker processes a temporal sequence of data scans, searching for data structures that are consistent with the target-track sub-model as discussed previously. When a particular DIR is revisited by the radar, the oldest data scan in the current sliding window is discarded and the new data scan is included in the time window to produce an updated window. Thus, in this manner, the sliding window temporal sequence of data always has the most current data as the last scan, i. e., for a six scan window, the most current data is always the sixth scan.

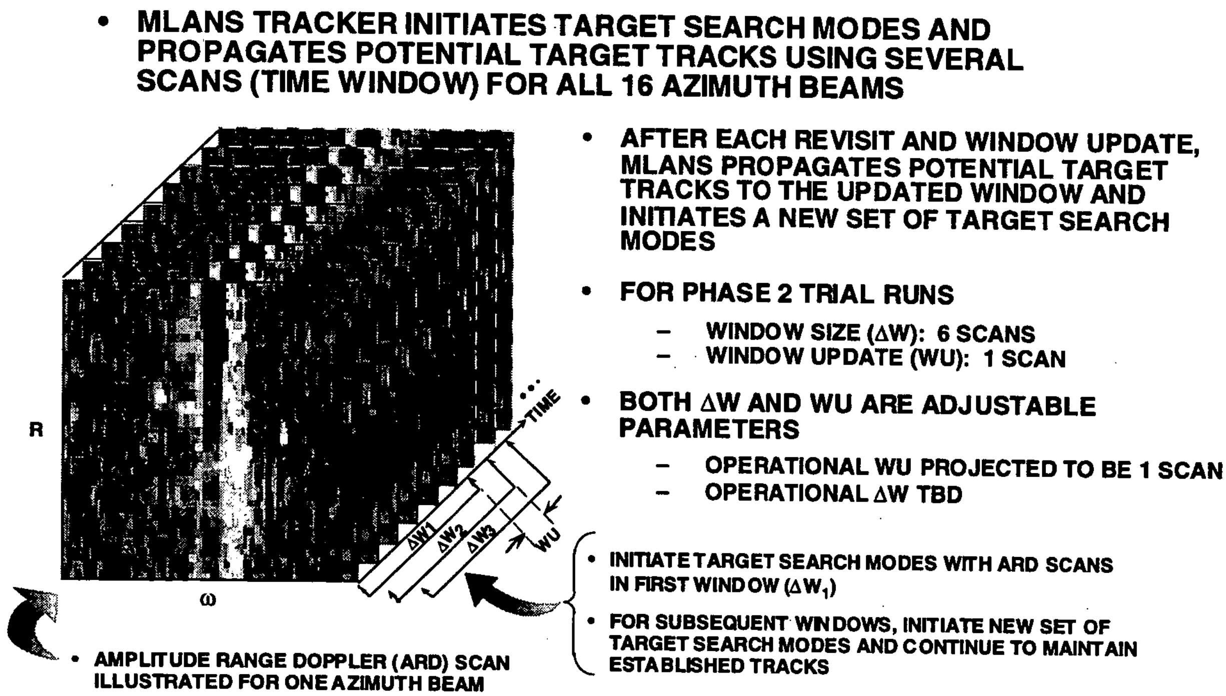


Figure 2. Sliding Window Implementation

One of the variables for control of the MLANS Tracker is the number of data scans in the sliding window. Through analysis of trial tracking case runs with various window sizes from three scans to twelve, we selected a value of six scans as the nominal window size for the MLANS Tracker. This selection was made based on a trade off between computational run time and having sufficient data over time to detect and track low - SNR targets. The final operational window size is yet to be set, and may differ from the value of six scans.

4. Test Target Flight Profile And MLANS Tracker Performance

4.1 Test Flight Profile and Data Set

We used data recorded by the Texas ROTHR for the P-3 test flight of 18 May 1995 as a test data set. The flight profile and Texas ROTHR DIR laydown is illustrated in Figure 3. The aircraft was a P-3 Orion aircraft in a flight that departed from Jamaica, flying on a south by south west course over Panama, making turn maneuvers over the Pacific Ocean off of Columbia, and then returning to Jamaica back over nearly the same route in reverse. The total duration of this test flight was nearly seven hours, and GPS truth data was recorded aboard the P-3. Illustrated in Figure 3 are the Texas ROTHR dwell illumination regions, TX DIRs 1137 and 1140 which covered the northern portions of the flight.

The ARD data for all sixteen azimuth channels from 17:40 UT to 18:25 UT covers the P-3 flight through DIR 1137 and likewise, the DIR 1140 covers the P-3 flight from 18:13 UT to 19:12 UT. The P-3 target test aircraft is rapidly crossing azimuth beams for both DIRs. The sixteen azimuth channels are schematically indicated in Figure 3 by the dashed lines for DIR 1140. Similarly, sixteen azimuth channels also exist for DIR 1137.

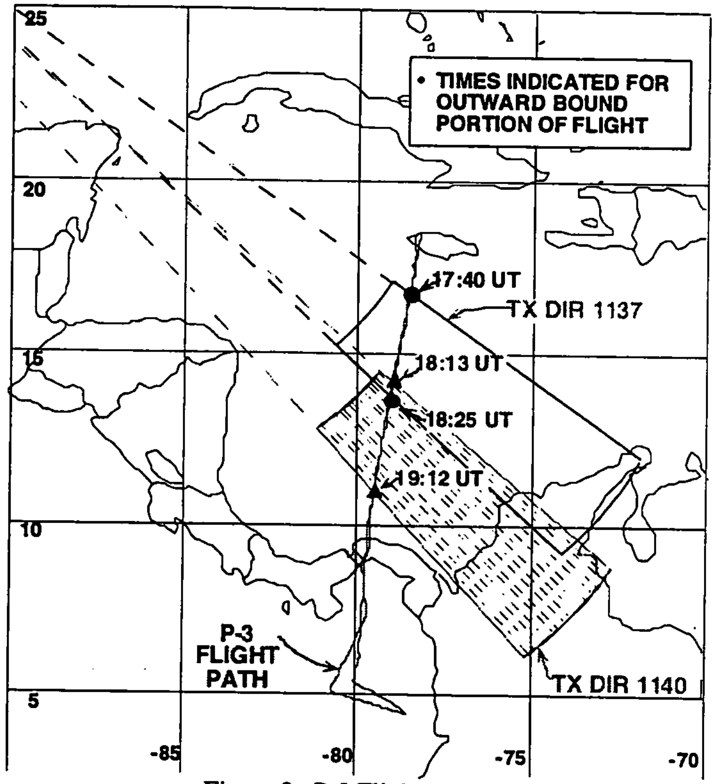


Figure 3. P-3 Flight Profile

4.2 MLANS Tracker Analysis Results

Figure 4 contains the consolidated results of trial runs of the MLANS Tracker performed independently for DIRs 1137 and 1140. In Figure 4(a), the slant range is plotted for the target-track sub-models propagated forward in time by the MLANS Tracker software, and the slant azimuth track component is likewise plotted in Figure 4(b). The target-track sub-models (two total) associated with the P-3 target are plotted as solid circles and triangles, while all other potential target-track sub-models are plotted as open circles. This simultaneous detection and tracking of the P-3 was performed automatically by the MLANS Tracker software; no manual assistance nor operator inputs were provided to facilitate the detection and tracking process. The MLANS Tracker consistently tracked the target through the two DIRs until it exited DIR 1140 at 19:12 UT.

For DIRs 1137 and 1140, the TPT (target propagation threshold for the window cumulative log-likelihood ratio) was set at low values of 3000 and 0 correspondingly. These low TPT values allow for the propagation of very low signal-to-clutter targets as well as potential false alarms. Despite these low thresholds, the number of false alarms is not prohibitive: we are able to clearly distinguish by eye the P-3 target-track sub-models from other potential tracks and false-alarms. The window cumulative log-likelihood ratio for the two sub-models associated with the P-3 target shown in Figure 4 (a) and (b) are generally in the range of 10E+4 to 10E+5, significantly above the TPTs of 3,000 and 0.

The SNR for the propagated models associated with the P-3 target goes through large variations, to which the MLANS tracker successfully adapted. This include regions of extremely low SNR of less than 10db, through which the MLANS Tracker successfully continued track on the P-3.

The results for the radial speed track results are contained in Figure 4(c) along with the radial speed as estimated from the GPS truth data. These results show that the potential target track identified in Figures 4(a) and (b) is that for the P-3 test aircraft.

Also, in Figure 4 we see that the MLANS Tracker results in a very smooth transition between the two DIRs. Track in slant range, slant azimuth, and radial speed are consistent between the two separate DIRs.

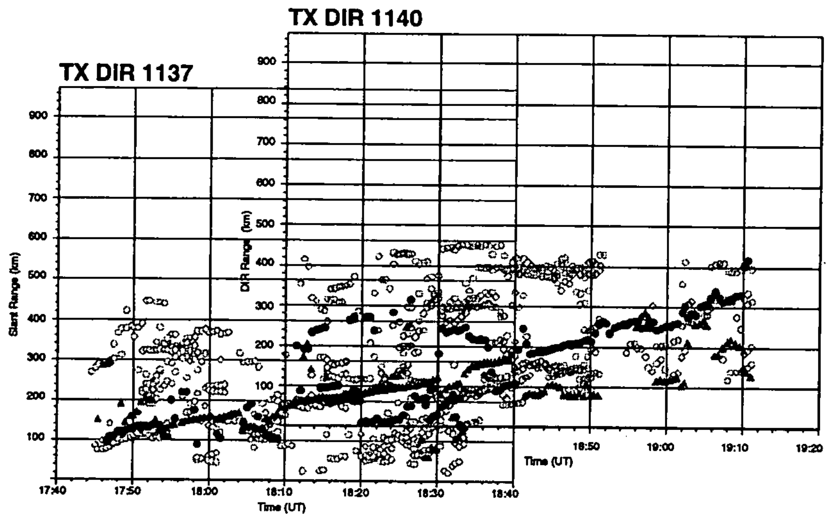
5. Summary And Discussion

The model-based maximum likelihood analysis technique presented here in leverages off Nichols Research Corporation's extensive experience in development and application of the MLANS neural network in other detection and tracking programs. MLANS is a model-based neural network: its architecture and learning mechanism incorporate a signal model. This internal model is composed of multiple sub-models that account for targets, clutter and noise in ROTHR data. Sub-models are adaptive, their properties are estimated from the signal in real-time. Model-based signal processing is an innovative and advanced processing concept, it combines the knowledge of signal models with adaptation to the unknown aspects of signals, and thus utilizes all the available information. The current ROTHR tracker, like all trackers, utilize models of target motion, but do not utilize models for peak detection. The MLANS tracker utilizes models for detection and tracking. By performing the maximum likelihood estimation, the MLANS algorithm achieves the Cramer-Rao bound on learning speed [11]. Coupled with its parsimonious use of parameters, it is thus ideal for application as a detection and tracking algorithm for the ROTHR system. For ROTHR detection and tracking, MLANS models have statistical, spectral, spatial, and temporal aspects.

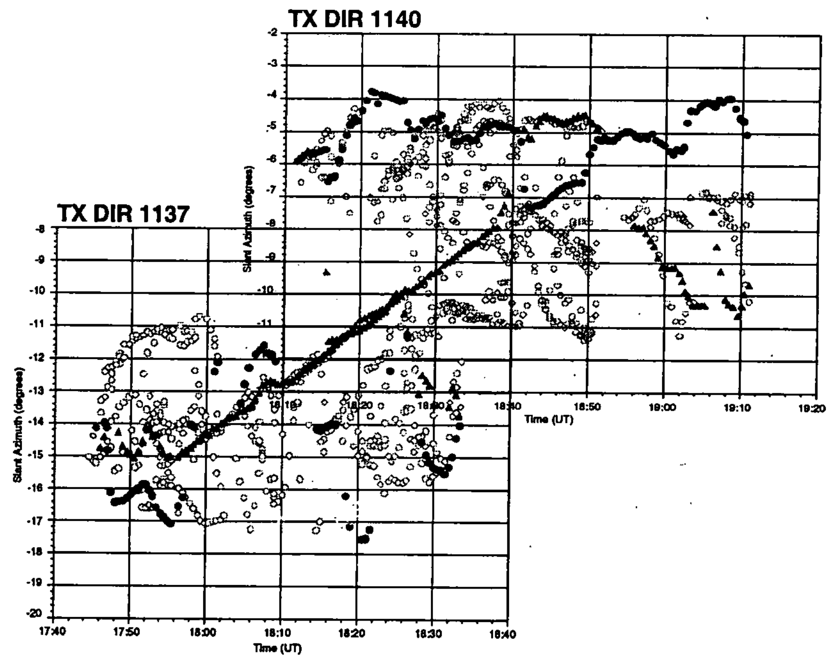
MLANS provides for improved ROTHR detection and tracking and clutter characterization performance over conventional techniques by (1) utilizing physical and phenomenological multi-modal spectral models, (2) adapting to the fast changing clutter environment, and (3) performing concurrent clutter estimation, detection and tracking by fusing data from multiple radar scans. Each of these aspects is discussed below.

Clutter observed during ROTHR operation is likely to vary quickly, both spatially and temporally, and, in addition, background noise and clutter with varying properties is always present for all Doppler values. This results in complicated Doppler spectra. Conventional techniques of high-resolution and super-resolution spectrum estimation, both neural network and algorithmic, rely on a large number of parameters to estimate such spectra. Such estimation techniques can result in confusion between clutter and targets, interfering with clutter and target separability. These other techniques are not optimal for ROTHR detection and tracking[12]. MLANS utilization of physical and phenomenological models permits accurate and robust estimation of the complicated ROTHR Doppler spectra in stressing clutter environments. Since clutter is constantly, and at times rapidly changing, fast adaptation of clutter statistics improves target detection and tracking performance. MLANS has been shown to achieve the fastest possible adaptation limited only by the information-theoretic bound on the speed of learning, the Cramer-Rao bound, resulting in the best possible performance in a changing environment[1]. In addition, the superresolution nature of MLANS estimation, exceeding performance of classical techniques, will be useful for low-Doppler target detection and tracking.

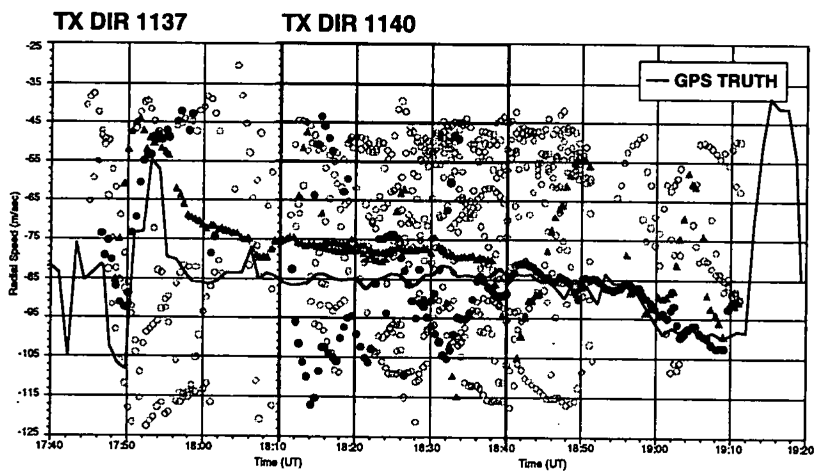
MLANS' most significant improvement in detection and tracking is achieved by performing concurrent clutter and target detection, and tracking. Simultaneous detection and tracking allows utilizing data from multiple scans to be used for the detection decision without using any predetection threshold. This approach reduces the chance of missing a low-signal target that does not pass a peak threshold, thereby enhancing the detection and tracking function, especially in the presence of clutter and noise and for low-Doppler targets. ROTHR will benefit significantly from concurrent detection and tracking, providing for optimum performance. MLANS performs this



(a) Range Track Transition Results



(b) Azimuth Track Transition Results



(c) Radial Speed Track Transition Results

P-3 Test Flight
May 18, 1995

▲, ● – Target-Track Sub-Model Modes Associated with P-3 Test Aircraft

○ – All Other Potential Target-Track Sub-Model Modes

Figure 4. Consolidated Track Results, DIRs 1137 and 1140

task by concurrently estimating target-track sub-model parameters while associating data from multiple scans, thus allowing simultaneous detection and tracking of targets in low SNR conditions.

The MLANS neural network, by parameterizing the large number of neural weights in terms of a relatively small number of model parameters, is able to adapt in real time to changing conditions and use all available information contained within the ROTHR data. Thus, the MLANS tracker does not have to perform the detection function using a 'peak picking' threshold and can thus better detect and track low signal strength targets in clutter.

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RECENT ADVANCES IN COUNTERDRUG OTH RADAR SHIP SURVEILLANCE

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ABSTRACT

The alarming increase in the use of ships, fishing vessels, and go-fast boats to transport drugs to points within Mexico and the United States has spawned renewed R&D in the use of high-frequency (HF) over-the-horizon radar (OTHR) for enhanced detection and tracking of these seaborne vessels. This work is sponsored by the USAF Rome Laboratory in support of the DoD Counterdrug Technology Development Program Office, which is improving the performance of U.S. Navy Relocatable OTHR (ROTHR) systems currently located in Texas and Virginia. Recent improvements to ship detection and tracking (SDT) have demonstrated more reliable, routine tracking of large ships, as well as the first demonstrated detection of a go-fast boat, which was operated in December 1996 by U.S. Customs in Puerto Rico, in cooperation with ROTHR. Ship targets have been tracked in the Gulf of Mexico, the Caribbean, and along the west coast of Mexico. R&D goals include improving OTHR operating practices, signal processing, detection, tracking, and display. Of considerable interest is a capability to track specific vessels to destination.

This paper provides a brief historical perspective of OTHR ship surveillance R&D, illustrates recent improvements in ship and go-fast boat detection and tracking, and discusses new modern spectral analysis techniques (MSATs) that allow OTH radars to detect ships with minimal impact on aircraft surveillance. Recommendations and plans for technology transfer to ROTHR also are discussed.

1. Introduction

High-frequency over-the-horizon radar has been used for long-distance land-based radar applications for several decades [1, 2]. As with overseas shortwave broadcast, OTHR makes use of ionospheric bending of the radar waves to circumvent the earth's curvature. Effective radar ranges vary from 400 to 2000 nmi, and sometimes beyond, depending on ionospheric conditions. A paper presented by Barnum at the 1993 ONDCP/ CTAC Tactical Technologies and Wide Area Surveillance International Symposium [3] summarized OTHR characteristics, described specific developments and applications for counterdrug (CD) surveillance of small private aircraft, and presented a description of SRI's Wide Aperture Research Facility (WARF) OTHR testbed, along with examples of detection and tracking of small aircraft.

In 1994, the U.S. Navy Relocatable OTHR (ROTHR) (AN/TPS-71) was chosen as the primary CD wide-area surveillance asset, and is now fully operational from locations in Virginia and Texas. Figure 1.1 illustrates the nominal coverage areas of the WARF testbed and the two ROTHRs. A third, south-looking ROTHR is now being planned for installation in Puerto Rico. The ROTHRs are concentrating on aircraft detection in source and early transit zone regions.

WARF coverage using new antenna arrays was established over the southwest U.S. border in 1992 in response to early CD surveillance objectives. The WARF capabilities were assessed by the Joint Electronics Warfare Center (JEWC) in 1992 [3]. From 1993 through 1996, the WARF was used periodically to develop and test improvements that have been or will be transferred to the ROTHR by means of the engineering change process. The U.S. Air Force Rome Laboratory has served as the principal sponsor of ROTHR enhancement R&D, while the U.S. Navy approves, sponsors, and tests all new system modifications.

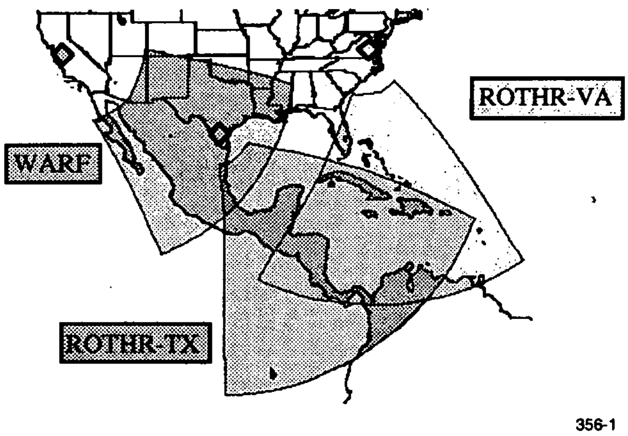

Figure 1.1 WARF and ROTHR nominal radar coverage sectors.

The WARF and ROTHRs are capable of automatic detection and tracking of all varieties of aircraft. However, a validated and predictable operational capability for automatic ship detection and tracking at ROTHR remains a high-priority requirement. The detection of ships by OTHR is much more difficult than aircraft detection, because ship echoes have very low Doppler shift (on the order of ±1 Hz), and are thus difficult to separate from ocean surface radar clutter returning from moving ocean waves. Ship detection and tracking by OTHR was first demonstrated in 1967 by the Naval Research Laboratory (NRL) using the MADRE OTHR on Chesapeake Bay [1]. Although this early OTHR design had relatively poor spatial resolution, a new Doppler processing capability had been recently developed to separate targets from sea clutter. With the use of long coherent integration times (CITs) to achieve sub-Hertz Doppler resolution, MADRE was able to detect and track large, fast ships, such as aircraft carriers.

Shortly after the MADRE ship detection demonstration the Advanced Research Projects Agency (ARPA) and the Office of Naval Research (ONR) sponsored the development at Stanford University of the world's largest HF receiving antenna array, 2.55 km in length, known as the Wide Aperture Research Facility (WARF) OTHR. (The WARF and associated staff transferred to SRI International in 1970.) It was believed in 1968 that the use of very high spatial resolution (half-deg in azimuth and 1000 m in range) might enable ship detection without the use of Doppler processing. Many WARF experiments, coupled with new measurements of ship target radar cross section and sea clutter radar cross section per unit area [4, 5] clearly demonstrated the need for high Doppler resolution. The improved spatial resolution, however, improved radar sensitivity to smaller ships against both first- and second-order sea clutter [4]. An overview of OTHR ship detection R&D between 1970 and 1985 was given by Barnum in Reference [2]. Methods for automatic detection and tracking were developed at WARF and demonstrated during operational Navy exercises. Hundreds of ships were tracked in WARF's Pacific Ocean coverage area (not shown in Fig. 1.1).

The ROTHR antenna system, radar waveform, and basic Doppler processing were patterned after WARF, so in principal the ROTHR should be capable of predictable and reliable ship surveillance. Indeed, large and fast ships have been tracked at ROTHR using the same computer algorithms employed for aircraft detection and tracking. However, ROTHR also detects and reports numerous false target echoes from sea clutter. It has been estimated that the number of false ship tracks exceeds the number of real tracks at ROTHR by a factor of ten. Analysis indicates that the ROTHR has operated at inappropriate radar frequencies for ship detection, or under ionospheric and sea clutter conditions that temporarily prohibit detection of certain ships, particularly small vessels traveling relatively slowly in the direction of the prevailing winds (in the vicinity of the largest Doppler-shifted sea clutter component). In summary, three principal areas for ship detection improvement are being pursued at ROTHR:

- Improved operating practices
- Improved performance monitoring
- Improved signal processing and display.

We shall summarize here recent developments in improved ship detection and tracking in the above areas. Perhaps of most operational interest has been a ROTHR demonstration of the detectability of the so-called "go-fast boat" often used in drug transport operations. Another new development involves the use of very short radar dwell times and modern spectral analysis techniques (MSATs) to allow ship detection using the very short CITs normally used only for aircraft detection.

2. Ship Detection With Improved Operating Practices and Signal Processing

Improved radar operations at ROTHR have been achieved with the use of better frequency selection, wider operating bandwidth (25 kHz), and more frequent target revisits (every 2 min). An experimental ship tracking exercise was conducted on 21 March 1996, for the purpose of gathering a variety of data for research. Figure 2.1 illustrates the ROTHR-VA radar coverage area south of Puerto Rico (PR), in which an outbound 16-knot ship target was located and tracked for several hours. The ship was not identified, but its echo strength suggested a fairly large cargo vessel. This illustration shows results from a new computer algorithm that measures the sea clutter Doppler spectrum and predicts the detectability of an average ship target (adjustable) as a function of radial speed. The illuminated area is shaded from white to black, in proportion to minimum detectable ship radial speed (white best, black worse). Two radar frequencies were used in this example to compare detectability for different ionospheric propagation conditions. The display shows that minimum detectable velocities were lower for the higher radar frequency, and that outbound targets could be seen down to 8 knots radial velocity (indicated as -8 knots). The sensitivity for detection of inbound targets was much less, however (closer to +15 to +18 knots), because the wind-driven sea was traveling toward the radar, causing the clutter to be much stronger on the positive Doppler side [4]. The geographic location of the target of interest is shown by the small circle.

Figure 2.2 illustrates a 52-min detection history of this ship target of opportunity, with signal processing improvements. References 1, 2, and 3 discuss various aspects of this type of OTHR display. The basic format is grayscale (or color) echo intensity as a function of Doppler and time, which is segmented into range and azimuth bins. Here we have shown a single range bin (about 6 km deep) and four contiguous azimuthal beams. (The target echo actually spans three range bins due to spectral weighting, so the display of a single range bin here is sufficient.) Zero Doppler is located in the center of each display panel in Figure 2.2. Approaching targets, with positive Doppler (or negative range rate), are displayed to the left, and receding targets to the right of zero Doppler. On the left panel is seen the bright sea clutter echo, with the ship target on the right, at negative Doppler. A new normalization technique was then applied to remove the sea clutter from the range Doppler display (on the center panel), and an automatic detection scheme was applied to locate and track the ship echo peaks (on the right panel). This process has improved ship detection and tracking, while reducing false alarms.

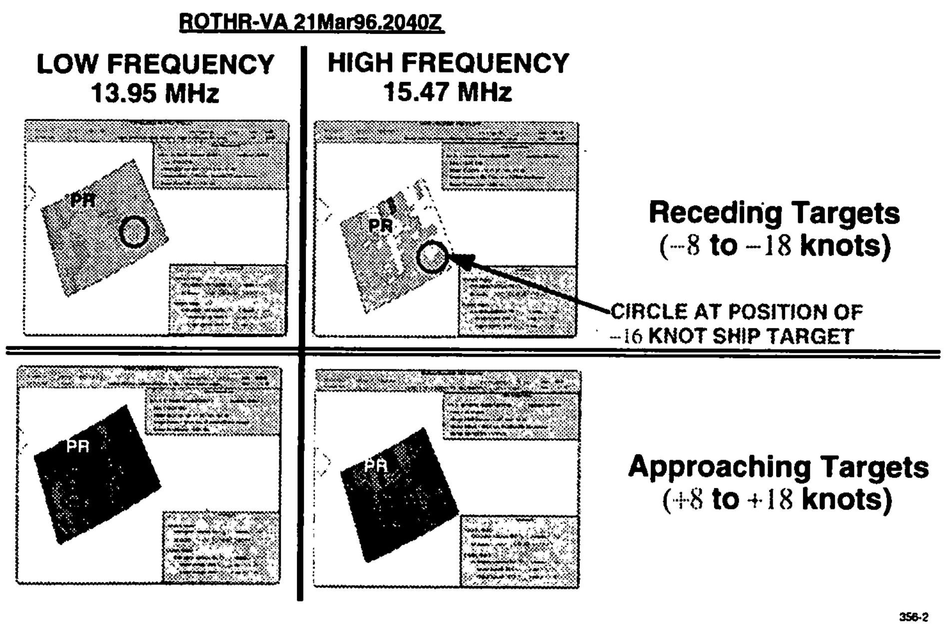

Figure 2.1 ROTHR ship detection performance monitoring display. Examples for ship tracking experiment on 21 March 96. Capability for outbound ships much better in this example, due to sea clutter characteristics at the time. The higher radar frequency performed better than the lower frequency.

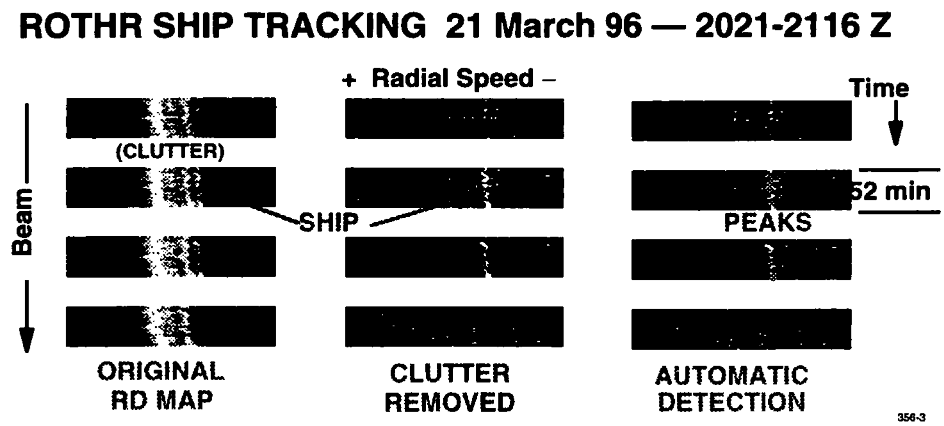

Figure 2.2 ROTHR ship detection histories that demonstrate new clutter normalization and automatic peak detection/association algorithms. False alarms from unnormalized clutter have been reduced.

3. Go-Fast Boat Detection

A contemporary interdiction concern that can be resolved with use of OTHR is depicted in Figure 3.1. A smuggling aircraft has been tracked from a source location by OTHR, and a maneuver is detected when the aircraft is ready to drop its cargo to a go-fast boat. This maneuver is detected on a range-Doppler detection display similar to the ship-target display shown in Figure 2.2, using techniques similar to those discussed by Barnum [3], and as described for remote airfield surveillance by Ciboci at the 1995 ONDCP/CTAC International Technology Symposium [6]. The final surveillance task, heretofore believed to be difficult or impossible for OTHR, is to detect and maintain track of the go-fast boat so as to enable interception and interdiction by authorities.

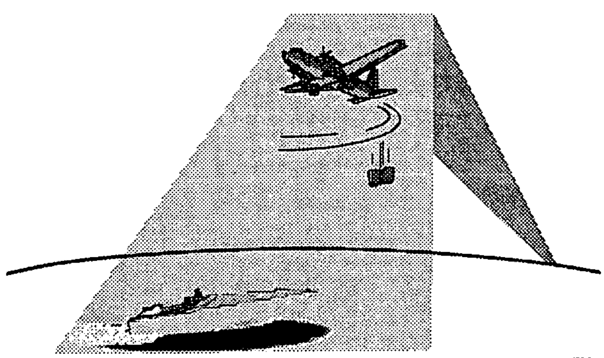

Figure 3.1 Contemporary Drug-Smuggling Scenario Depicting an Air Drop to a Go-Fast Boat

In this regard, new techniques were devised to enable detection of a go-fast boat by ROTHR-VA. On 3 and 4 December 1996, a U.S. Customs 36-ft speedboat (Figure 3.2) was operated south of Puerto Rico in the area shown in Figure 3.3. Mr. Serafin Rodriques of the Naval Research Laboratory (NRL) organized and coordinated the experiment. The boat made four round trips at about 30 to 35 knots along the track shown. RCS modeling revealed that the HF antenna aboard the boat would modify its echo, so half the trips were made with the whip up, and half with the whip down. An HF repeater located at the northwest end of the island was operated between the boat runs to provide absolute geographic position location. The selection of radar operating parameters was unique for an OTHR target.

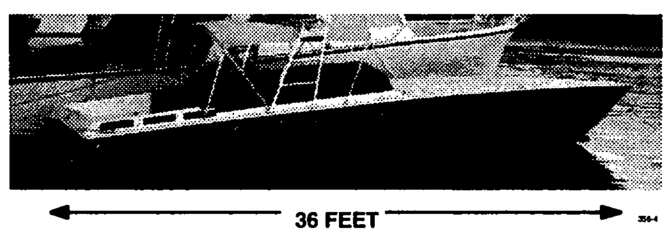

Figure 3.2 Photograph of U.S. Customs "go-fast" boat used in ROTHR detection experiments on 3-4 December 1996.

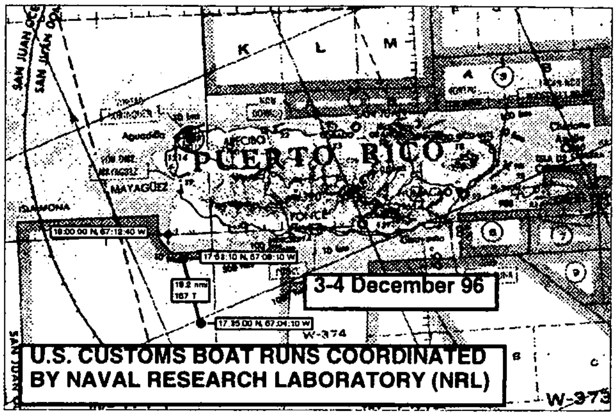

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Figure 3.3 Map showing go-fast boat operations southwest of Puerto Rico and the HF repeater location at the northwest corner of the island.

Figure 3.4 illustrates the NEC-modeled RCS response of the 36-ft go-fast boat as a function of radar operating frequency. Approximate radar operating frequency ranges for night and day are indicated. Three types of wire models were employed: (1) a single wire extending from the propeller to the bow, accounting for the electrical circuit up to the bow running light; (2) the single wire plus additional wires near the center of the boat to account for radio wiring; and (3) the above wires plus a 20-ft HF radio whip. Notice that the RCS exhibits resonant peaks in both day and night operating regimes, and that the HF whip is expected to enhance the boat RCS. Clearly, radar frequency selection is critical.

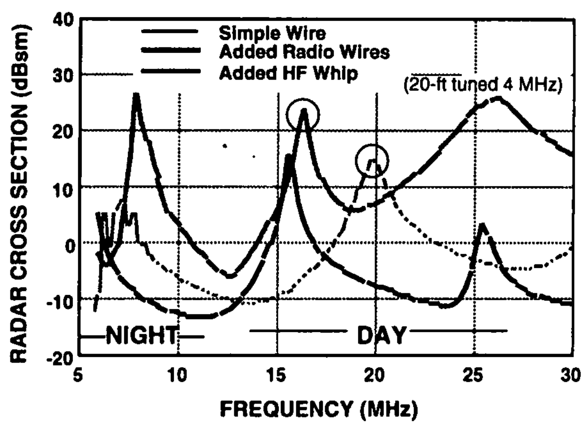

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Figure 3.4 NEC-modeled RCS response vs. radar frequency and vertical polarization for 3 electrical wiring assumptions. Significant improvement in RCS is seen when a 20-ft HF communications whip is installed.

The radar operating format used four different radio frequencies in rapid succession (every 12.8 s), with the hope that at least one frequency would make a detection. The primary constraint was that the ionosphere would support propagation to the boat at each frequency. Detections were made using this format on approximately two-thirds of the runs. As it turned out, since the runs were comparatively close to shore, antenna sidelobe echoes from automobile traffic and some radio interference were observed at Doppler frequencies equivalent to those of the boat echo. The highway traffic actually helped to pinpoint the expected boat echo location in the radar data.

Figure 3.5 illustrates the boat echoes on two different frequencies, one labeled "non-resonant" because the echo was very weak and unclear, and the other labeled "resonant" because it was seen clearly. These particular data were taken with the HF whip down on the boat, and the resonant frequency, 19.6 MHz, was close to that predicted in Figure 3.4 for the simple wire (probably by coincidence). The boat was returning to port at this time, which explains the positive Doppler shift, and the data reflects an acceleration (near the arrow labeled "boat") that was documented in the boat log. The normalizer and automatic detection algorithm illustrated in Figure 2.2 successfully located this boat echo, but very low detection thresholds were necessary and false alarms from echoes and clutter surrounding the island were high. It has been tentatively concluded that operator assistance, using displays similar to that in Figure 3.5, will be necessary for detection and tracking of go-fast boats by OTHR.

4. Modern Spectral Analysis With Short CITs

Doppler processing for OTHR ship detection requires CITs of at least 12.5 s. ROTHR typically requires 25 s to separate the target from the very strong sea clutter return. For example, the ship echo in Figure 2.2 was achieved using a 25-s CIT, but this echo would not be routinely detected at ROTHR with a 6-s or 12.5-s CIT. These dwells must be repeated every 2 min, for 20 min, without changing radar parameters, to form a ship track under reasonably stationary ionospheric conditions. This "10-look" rule is necessary in part to collect enough ship detections, and in part to distinguish the echoes from temporarily unnormalized sea clutter patches. Effectively, each ship "dwell illumination region" (DIR), which represents the ocean area surveyed at .

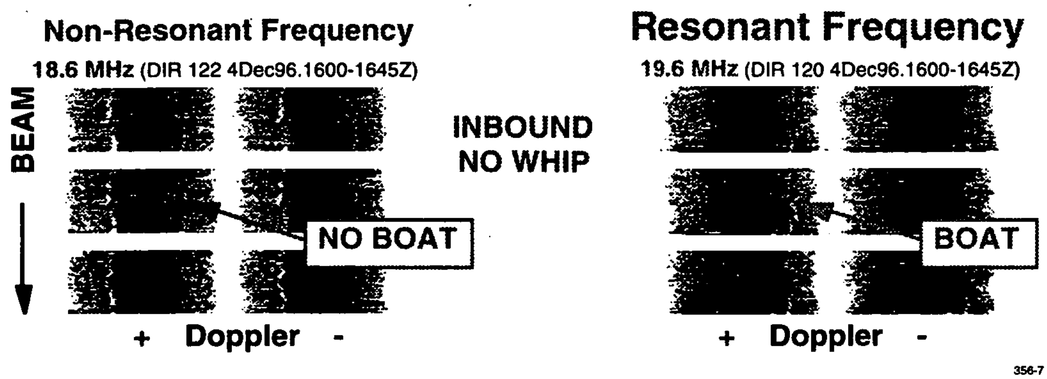

Figure 3.5 Go-fast boat detection data at two radar frequencies. The frequency on the right-hand side was resonant with the boat RCS, yielding positive detection, while the other frequency was not. Results can be compared with the RCS predictions in Figure 3.4 with the HF whip down.

any given time by the radar transmitter and receiver, consumes 25% of the radar resources. By comparison, aircraft dwells require only 2 to 3 s per CIT, or an order of magnitude less than the time normally required for ships. Without ship surveillance, ROTHR normally maintains 10 to 12 aircraft DIRs, using a 2- to 3-s CIT for each, which are revisited every 30 s to maintain track. Therefore, since aircraft targets are the primary ROTHR mission, ship detection operations can be considered a significant interruption. The use of only two ship DIRs either (a) reduces the air DIR revisit time to 1 min, which is considered poor for tracking purposes, or (b) dramatically reduces the number of viable air DIRs (nominally two air DIRs are possible with a 30-s revisit interval).

Fortunately, the application of MSATs, or "super-resolution" algorithms, has led to a factor of 4 to 8 reduction in the time required to separate ship echoes from sea clutter. The sea clutter Doppler spectrum is largely dominated by two coherent sinusoidal signals produced by first-order Bragg diffraction of the radio wave with the ocean wave frequency spectrum. For the backscatter direction, the Bragg-resonant ocean wavelength is equal to one-half the radio wavelength, modified slightly by factors to account for non-zero radar wave elevation angle and the bistatic radar geometry. The Doppler frequency shift of the Bragg scatter is well-known and fixed, by virtue of the dispersion relation for deep water gravity waves [e.g., 4, 5]. These so-called "Bragg lines" are produced by ocean wave traveling in all directions, with an amplitude peaked in the direction of the prevailing winds and minimum in the direction against the wind. The stronger and weaker Bragg lines have opposite Doppler shifts, and the ratio of the Bragg line amplitude can even be used to estimate wind direction for the purpose of weather monitoring and hurricane tracking [7, 8, 9]. The key to ship detection is that this strong sea clutter echo can be minimized by Doppler frequency resolution, rather than by brute-force clutter cell reduction, which makes the MSAT processing so attractive.

Numerous approaches to enhanced spectral resolution with short CITs have been surveyed, beginning with studies using OTHR data in 1984 by Cooley et al. [10]. The MSAT work recently has converged on a fully viable approach, although it involves a series of fairly complicated signal processing and estimation steps. The basis for the work is the Tufts and Kumaresan [11] autoregressive (AR) model, using a truncated singular-value decomposition [12] via the Akaike Information Criterion [13] and Minimum Description Length (MDL) to minimize false-alarm peaks [14]. A new linear power estimator is employed to produce smoothed Doppler spectra. Using a preprocessing step in the time domain, it is easier to identify the sea clutter Bragg peaks and to distinguish these echoes from nearby ships. The ship peaks likewise are clustered in time for enhanced recognition and use for removal of the ionospheric Doppler (IDOP) bias. Mathematical details of the current MSAT approaches can be found in Reference 15.

Figure 4.1 illustrates the application of this AR technique to a single radar dwell CIT of the data used to produce the detection display of Figure 2.2. On the left side of Figure 4.1 is a simple Fourier transform of backscatter amplitude as a function of Doppler shift (now plotted with outbound ships

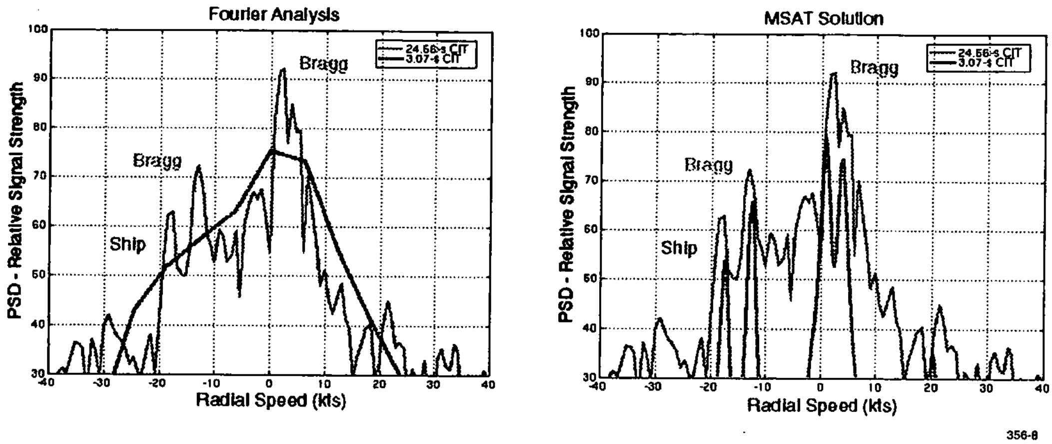

Figure 4.1 MSAT processing enabling use of a 3-s radar dwell to detect the 21 March 1996 ship target. This represents a factor of 8 improvement in ROTHR operating efficiency for ship surveillance.

on the left of the clutter), showing the sea clutter Bragg lines and ship echo. The solid line was achieved using a 25-s CIT, and it shows the ship clearly. The dotted line used only 3 s of data, and the ship is now blended with the Bragg scatter. On the right, the 25-s FFT is compared with a 3-s MSAT, which cleanly resolves the ship from the Bragg lines.

Figure 4.2 illustrates the results of MSAT processing of sea clutter Bragg lines and ship echo over a 55-min tracking period that contains the 53-min period processed using normal 25-s FFTs shown in Figure 2.2. Compared with the latter, the MSAT data are plotted in a more traditional "waterfall" range-Doppler format. Figure 4.2 shows the Doppler spectrum as a function of time for nine range bins at a single azimuth, which confirms target spatial localization in range. Figure 2.2, on the other hand, plotted the Doppler spectrum at the strongest range bin as a function of time on four of the available sixteen receive azimuths. The latter format illustrates target spatial localization in azimuth. Both types of display formats can be made available for operator selection.

For the MSAT processing, pole clustering was applied to identify persistent clutter and target echoes. In Figure 4.2, the poles for the ship are plotted atop the linear power spectral density to permit easier target recognition. During the pole-clustering process, not only was the strongest set of Bragg lines identified, but a second set was discovered to have been returned via a second ionospheric mode (called multimode clutter). This second set of pole clusters was visually identified and the poles removed from the plot. An automatic algorithm for removing the additional clutter Bragg lines is currently under development.

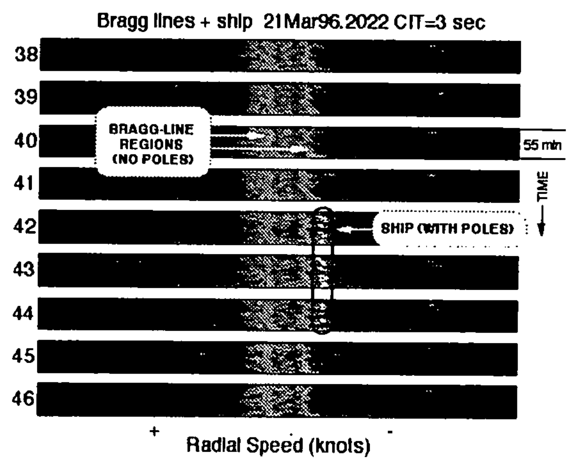

Figure 4.2 MSAT range-Doppler display showing pole-enhanced ship echo and resolved Bragg clutter.

Figure 4.3 illustrates a different approach being taken by Ben Root of NRL [16, 17] to reduce the CIT required for ship detection. The data and ship target are a 10-min subset of that shown in Figures 2.2, 4.1, and 4.2. Sixteen panels of amplitude vs. Doppler and time are shown at a single range bin and azimuth, which is a similar format to Figure 2.2, except that the Doppler scale is reversed. Each panel of Figure 4.3 shows an interim result of attempting to model and cancel a sinusoidal Bragg line echo from the data by iterative subtraction of an equal and opposite digital sinusoid. A mere 6-s Fourier transform was used as the frequency analysis tool, which clearly does not resolve the ship in the upper left panel, before any cancellation is applied, whereas the ship becomes highly visible and discrete after 12 iterations. This technique therefore also shows promise for improving ship detection efficiency at ROTHR, and experiments are now being planned to combine the Bragg-line canceller (BLC) and MSAT algorithms to reduce possible second-order effects of Bragg lines on ship echo pole frequency estimation.

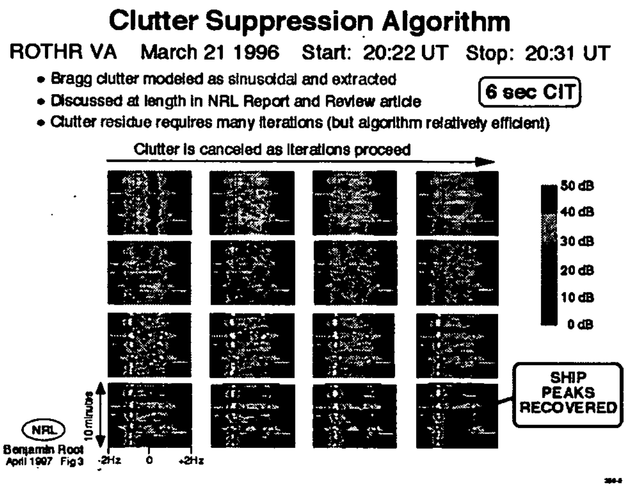

Figure 4.3 Alternative approach to modern signal processing using an adaptive, coherent clutter cancellation algorithm that clearly reveals the Figure 4.1 ship using only 6 s of data. This ship was also detected using this technique with only 3 s of data (similar to Figure 4.1).

5. Conclusion

New methods for enhancing ROTHR ship detection performance and reduction of false alarms have been devised. Additionally, the time required for ship surveillance can be reduced dramatically through the use of MSATs or BLC, or both methods in tandem. It is likely that medium to large ships can be tracked using aircraft wave codes with 2- to 3-s CITs, or with new, comparatively short ship waveform codes using approximately 6-s CITs.

A go-fast boat was periodically detected south of Puerto Rico using the ROTHR-VA radar under average to good ionospheric conditions. This was an OTHR "first" that was made possible by careful experiment planning, boat scheduling, and radar operations. The results demonstrated primarily that preplanned radar frequency management is essential to locating boat RCS resonant peaks. Go-fast boat RCS values are too low to permit detection otherwise.

Overall, a valuable set of capabilities for detecting and tracking medium to large ships to destination, or to way points en route, and cued detection of go-fast boat operations can be implemented at ROTHR. It is well understood that ship detection and tracking is not a 24-hour, routine capability of OTHR, primarily due to sea clutter variations with sea state and wind direction, and more subtle effects of ionospheric multipath on clutter broadening [2]. Rather, this capability is desirable for its intelligence value. The new performance monitoring displays will enable quick determination of usable or unusable ionospheric and clutter conditions for tracking so that time is not unnecessarily taken from routine CD air surveillance. In general, OTHR ship surveillance should be viewed as a cued asset.

A transfer of the new, advanced ship detection and tracking technologies to ROTHR is planned by route of a new facility called the ROTHR Enhancement Demonstration System (REDS), which is located at the ROTHR Operations and Control Center (OCC) in Virginia. The new algorithms and operator interactive displays will first be recoded as necessary to match the extant ROTHR computer operating systems, including those evolving with the current OCC architecture upgrade. Following satisfactory testing and adjustment, the algorithms will be incorporated in an engineering change process led by the ROTHR system prime contractor.

Acknowledgments

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Improved Over-The-Horizon-Radar Detection for the Counter-Drug Mission in the presence of Range-Folded Spread Doppler Clutter

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ABSTRACT

This paper describes the results of a demonstration investigating a technique to mitigate a certain type of interference encountered by Over the Horizon Radar. Over the Horizon Radar often experience unwanted return, referred to as Range-Folded Spread Doppler Clutter (SDC_{rf}). This clutter originates from disturbed ionospheric equatorial and auroral regions, and arrives at the radar receiver through range-ambiguous returns. Returns from these regions fold directly back into a desired surveillance area. The net effect is a masking of targets within this area, and a resultant desensitization of detection and tracking attainment. The program involves the application of a nonrecurrent waveform with quadratic phase shift, herein referred to as the NRWF, at an Over the Horizon Radar located in Virginia, operated by the Navy's Fleet Surveillance Support Command. Utilizing the NRWF lessens the performance degradation caused by SDC_{rf} by controlling where range-ambiguous returns fold. The idea is to set the control such that the return(s) corrupted by this clutter have minimal effect on the desired surveillance area. After the NRWF was installed, testing was done to prove that the waveform: (1) Does not introduce Radio Frequency Interference, (2) Mitigates SDC_{rf}, and (3) Improves detection and tracking performance.

I. INTRODUCTION

Over the Horizon Radar are safe, cost effective, land based, pseudo monostatic (receiver slightly separated from transmitter) radar systems. They provide long range detection and tracking of targets in selected geographic regions.

The Over the Horizon Radar that is used in this program is called the Relocatable Over the Horizon Radar (ROTHR). ROTHR is operated by Raytheon personnel, under the Navy's Fleet Surveillance Support Command (FSSC). FSSC was established in 1987 to support US fleet units in selected regions worldwide. This unique radar system was originally designed to provide battle group commanders with tactical warning of air and surface threats at long ranges to allow time for responsive engagement. In fact, the prototype system in Amchitka, Alaska surveilled the eastern coast of Russia twenty-four hours a day, seven days a week, from April 1990 to March 1993. With the end of the Cold War, the Amchitka system was dismantled. Chesapeake, Virginia became home to the first production system that was operational in a counterdrug role in support of US Atlantic Command.

To increase the surveillance of known drug smuggling routes, a second system was installed in Texas and became operational in July 1995. A third system is proposed for Puerto Rico. These three ROTHRs will make up a Counter-Drug Surveillance Net.

As illustrated in Figure 1, the first part of the net, located in Virginia, covers Florida, part of central America, the Caribbean, portions of the Atlantic, and northern areas of Columbia, Venezuela, and Guyana.

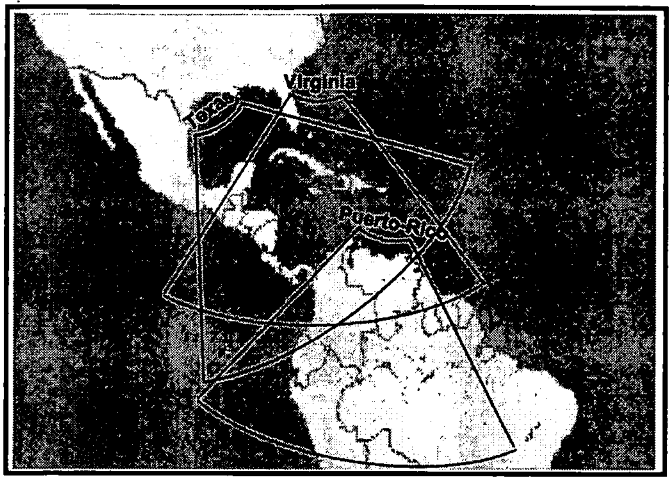

Figure 1
Counter-Drug Surveillance Net

The second part of the net, located in Texas, covers the southeast area of Mexico, the gulf of Mexico, part of the Caribbean, Central America, and the northern part of Equador, Columbia, and Venezuela. Finally, the third part of the Counter-Drug Surveillance Net proposed for Puerto Rico, will cover Equador, Columbia, Venezuela, Peru, the northern parts of Bolivia and Brazil.

Each pie shaped area, referred to as the Extended Coveragè Area (ECA), covers approximately 5 million square miles for the interdiction of drug smuggling activities. When all sections of the net are operational, virtually all the traffic over the Caribbean and northern half of South America will be monitored. This is where most of the world's cocaine originates.

From a historical standpoint, the first drug related event utilizing ROTHR happened on 1 May 1989. During testing of the production ROTHR in Virginia, the system provided the Joint Coast Guard/Customs Center in Miami with critical detection information that led to an involved chase and seizure of an aircraft carrying drugs to the Bahamas [1]. Today, ROTHR systems in Virginia and Texas operate as part of the National Counter-Drug Strategy and have contributed to the seizure of over 50,000 kilograms of narcotics and tens of millions of dollars in cash and assets since 1992 [2], [3].

Figure 2 [4] illustrates the ROTHR concept. ROTHR sequentially illuminates multiple sections within the ECA with high frequency radio waves of 5-25 MHz. These waves reflect off the ionosphere, an electrically charged, multi-layered, medium in the atmosphere.

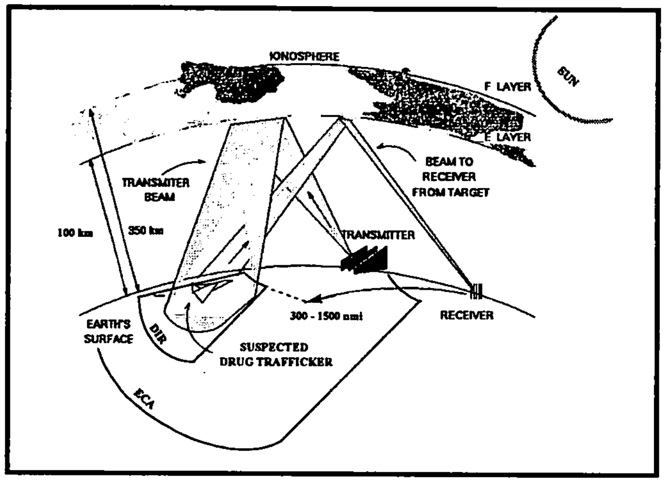

Figure 2
ROTHR Concept

The multiple sections within the ECA are each referred to as a Dwell Illumination Region (DIR). A DIR is illuminated every Revisit Time (typically 30 seconds). A typical DIR covers a Range Extent of 534 nautical miles (615 miles) with an 8.8 degree azimuth. Figure 2 illustrates only a single DIR for simplicity.

The illuminated objects within the DIR (the Earth's surface, land and air targets) reflect the transmitted energy, scattering it in all directions. Some of this energy reflects again off the ionosphere back in the direction of the receiver. Here it undergoes range and doppler processing for target detection. The doppler effect is a shift in the frequency of a wave radiated, reflected, or received by an object in motion [5]. ROTHR detects a target's doppler and converts it into a corresponding radial velocity.

The main advantage of ROTHR is that it uses this "look down" approach to minimize the hiding places for drug-ferrying vehicles. With conventional line of sight technology, drug traffickers are able to elude detection and tracking by flying low or by maneuvering between land masses such as mountains and islands. Such scenarios do not escape detection under ROTHR.

II. BACKGROUND

a. *Propagation*

Propagation of these high frequency radio waves, referred to herein as waveforms, is a complex subject. This section provides a simplistic description of one aspect of waveform propagation necessary for a fundamental understanding of SDC_{rf}.

Building upon the ROTHR concept as described in Figure 2, ROTHR relies on the ionosphere as kind of a "backboard" to bounce its waveforms off of. As depicted in Figure 3, when ROTHR illuminates a DIR, some of the reflected waveform continues down range. Just as with the original transmitted signal, this waveform reflects off the ionosphere, and illuminates a second region (kind of a second DIR, even though it is not referred to as such). This in turn reflects the waveform scattering it in all directions. Some of this waveform reflects again off the ionosphere back in the direction of the receiver where it is processed. Depending on the state of the ionosphere, this process occurs for a third, fourth time, creating multiple returns.

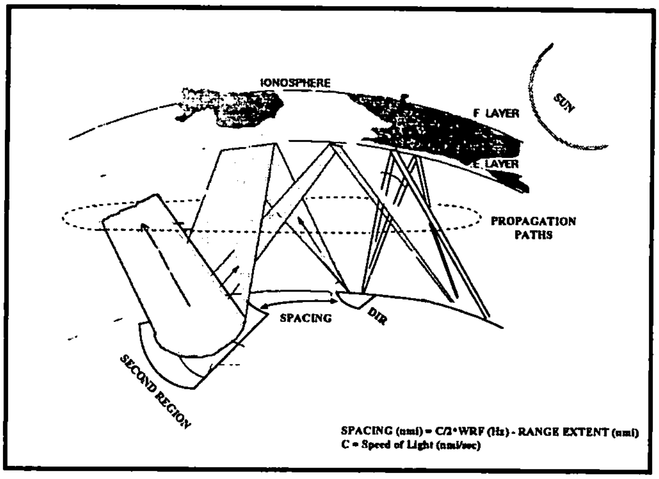

Figure 3
Waveform Propagation Paths

The spacing (in range) between the DIR and the second, third, fourth region is equivalent. The spacing value is a function of the Waveform Repetition Frequency (WRF), and Range Extent. The significance of the WRF is discussed in part d of this section entitled, "Effect on Radar Return".

The main point is that the radar return is really a direct composite summation of the DIR return and the multiple return(s). All returns are directly folded on top of one another.

The DIR's return is referred to as the range-unambiguous return. The multiple return(s) are referred to as range-ambiguous returns. Individually, the range-ambiguous returns are referred to as range-ambiguity interval #1, range-ambiguity interval #2, range-ambiguity interval #3, etc.

Generally speaking, the signal strength of range-unambiguous return is dominate. However, this may not be the case when the range-ambiguous return(s) contain SDC_{rf}.

The NRWF can control where the range-ambiguous returns fold in doppler. The control is set such that their effect on the desired surveillance area within the DIR is minimized.

b. *Ionosphere*

The ionosphere effects the propagation of waveforms. The ionosphere is a region of ionized gas which starts about 100 km above the earth extending out to approximately 350 km. The source of this ionization is the sun. The amount of ionization changes with altitude, time of day, time of year, sunspot cycle, and geographic location.

In regions located both north and south of the geomagnetic equator, disturbances often build in the nighttime equatorial ionosphere (more so than other sections of the ionosphere). These disturbances also change with altitude, time of day, time of year, and sunspot cycle. This is the source of SDC_{rf}.

When a propagation path (as described above) from an range-ambiguous return intersects these geographic locations, the problem of SDC_{rf} may occur.

c. *Range-Folded Spread Doppler Clutter*

Imagine traveling down a long, straight, stretch of road on a hot sunny day. Up ahead a mile or so is another car. Road glare distorts your view of this car. Sometimes, this glare is coming off of the road in front of the observed car. At times this glare is coming off of the road between your car and the observed car. From time to time its both. In this analogy, SDC_{rf} is the glare coming off of the road in front of the observed car which in turn distorts your view.

Picture yourself sitting at table with a group of friends in a crowded restaurant. You cannot hear the interesting conversation between your friends because of the loud chatter coming from other tables within the room. Sometimes, you cannot hear because too many people at your table are talking. From time to time you cannot hear for both reasons. In this analogy, SDC_{rf} is the chatter coming from other tables within the room.

These two analogies are meant to point out that SDC_{rf} is an unwanted return originating from *beyond* the observation area. The NRWF seeks to control these returns.

From a technical point of view, SDC_{rf} is a type of noise that originates from disturbed ionospheric equatorial and auroral regions. It arrives through range-ambiguous returns and is spread in doppler. This doppler spreading, which may be observed on the radar's "Range-Doppler Map" display, can cause targets traveling up to approximately 250 knots (288 miles per hour) radially toward and/or away from the radar to become invisible. The exact extent depends on the magnitude of the doppler spread. A typical drug-trafficker is well within the velocities corrupted by SDC_{rf}.

The extent of the "problem" caused by SDC_{rf} is a function of several variables. The major variables are the actual state of the ionospheric equatorial and auroral regions and subsequent propagation through these regions, and the choice of WRF. Also included, but at a lower level, are the DIR location, frequency of operation, and desired surveillance area.

The following discussion relates these variables to the occurrence of SDC_{rf} in ROTHR Virginia, where the waveform is installed.

As illustrated in Figure 4, range-unambiguous coverage to the south propagates via a relatively undisturbed ionosphere. Range-ambiguous propagation paths intersect regions of the equatorial ionosphere. In these regions, located both north and south of the geomagnetic equator, disturbances often build in the nighttime equatorial ionosphere. As certain layers in the ionosphere dissipate, propagation is observed occurring to/from these regions. These returns often arrive spread in doppler due to interaction with the disturbed equatorial regions.

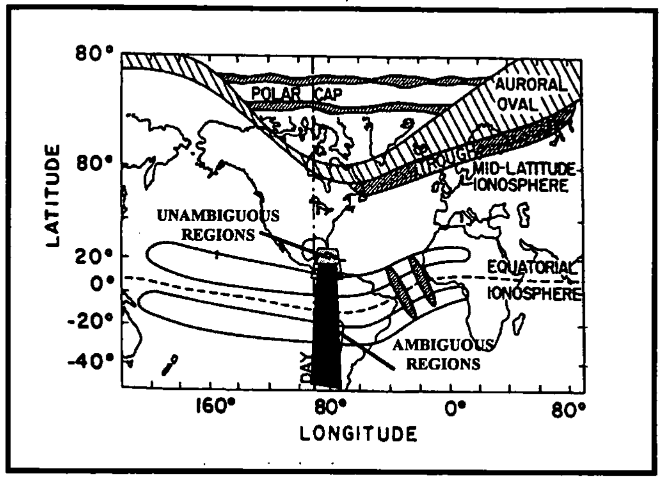

Figure 4
Geographical/Ionospheric Perspective

A clutter map provides a view of these disturbed regions. A representative nighttime clutter map showing expected range and doppler profiles of clutter is illustrated in Figure 5. The clutter map is basically each of the returns (range-unambiguous and range-ambiguous) unfolded.

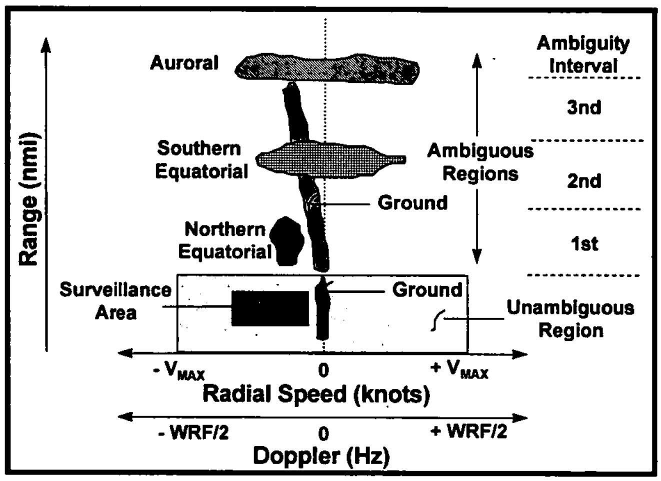

Figure 5
Typical Nighttime Clutter Map

In a hypothetical DIR (unambiguous region), ground clutter is observed with little doppler spread. In addition, a typical surveillance area is shown. This area defines speeds of interest for inbound (northbound) drug-traffic. At ranges beyond the DIR (ambiguous region), ground clutter is observed with narrow spread and is shifted (drifts) slightly in doppler. The sense of this shift varies from a negative shift in the early evening hours, to a positive shift after midnight (shown is a negative doppler shift).

This is followed by regions of spread doppler clutter associated with anomalous regions located north and south of the geomagnetic equator. Returns from the southern anomaly frequently have a wider spread. At very long ranges, wide spread is noted from the auroral region.

The actual spreads and doppler shift define the state of the ionospheric equatorial and auroral regions. This state is the first major variable defining SDC_{rf}. As mentioned above, these regions vary with time. However, the general relationship of each one of the regions depicted remains consistent.

d. *Effect on Radar Return*

This section discusses the second major variable defining SDC_{rf}, namely the choice of WRF. ROTHR uses recurrent, Frequency Modulated Continuous Wave (FM/CW) waveforms. These waveforms are characterized by parameters such as Waveform Repetition Frequency (WRF), operating frequency (fo), Bandwidth (BW), and Coherent Integration Time (CIT).

The WRF parameter controls the unambiguous range and (along with the operating frequency) unambiguous velocity measurements. These two measurements define the maximum range and radial velocity at which a target may be detected without uncertainty. When FM/CW waveforms are used, range-ambiguous returns are aliased (folded) back into the DIR and often mask returns from desired targets within the desired surveillance area. This reduces the detection and performance of the radar. The exact extent of this degradation depends on the spread and location of the clutter, the value of the WRF, the frequency of operation, and the desired surveillance area.

The performance of a high WRF FM/CW waveform in the presence of long range clutter is as follows. The higher the WRF, the lower the unambiguous range measurement and the higher the unambiguous velocity measurement. The lower the unambiguous range, the more range-ambiguous returns (range-ambiguity interval #1, #2, etc.) fold back into the DIR and often mask the surveillance area.

Given the typical clutter map in Figure 5, Figure 6 illustrates what the radar would see by using such a high WRF FM/CW.

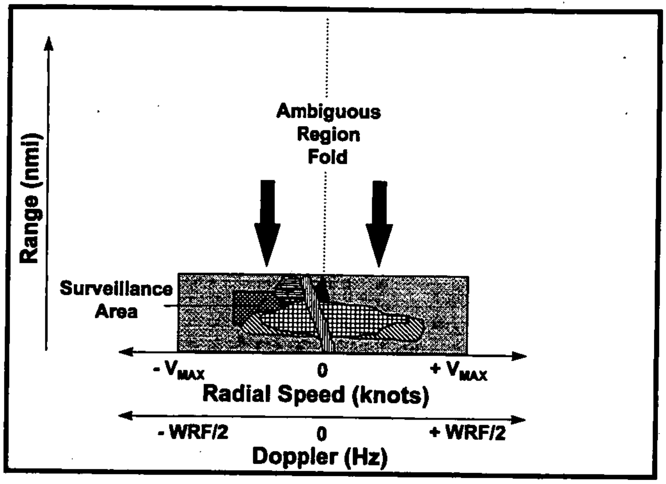

Figure 6
Response to a single high WRF FM/CW

Notice that much of the surveillance area is masked by SDC_{rf} which directly folds in from the ambiguous regions. One advantage of the high WRF FM/CW is that it is doppler unambiguous, meaning that it is able to detect and track higher speed targets without uncertainty. However, even with this advantage, the high WRF FM/CW is highly vulnerable to SDC_{rf}.

An approach to combat this vulnerability is to use a low WRF waveform. The performance of a low WRF FM/CW waveform in the presence of long range clutter is as follows. The lower the WRF, the higher the unambiguous range measurement and the lower the unambiguous velocity measurement. The longer unambiguous range of the low WRF would fold in little range-ambiguous returns. However, the use of a low WRF waveform introduces problems in the doppler domain due to doppler ambiguities. Surveillance of both slow and high speed targets is degraded by both blind speeds and doppler folding that occurs with a single, low WRF. A blind speed is simply a speed or range of speeds which the radar cannot detect. A suspected drug trafficker traveling at this speed cannot be detected.

Given the typical clutter map in Figure 5, Figure 7 illustrates what the radar would see by using such a low WRF FM/CW. Notice that little of the range-ambiguous returns have effected the surveillance area. However, part of the surveillance area is lost due to blind speeds.

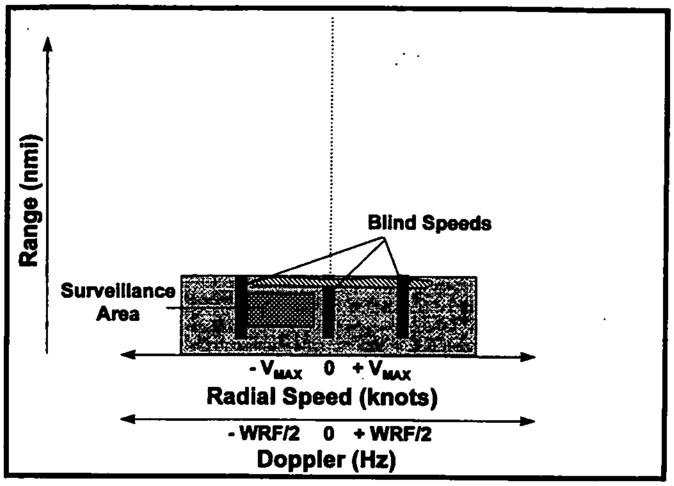

Figure 7
Response to a single low WRF FM/CW

With both the single high WRF waveform and single low WRF waveform producing undesirable results, another solution is sought.

One solution is to use a multiple set of low WRFs. A multiple set usually consists of three low WRFs. WRF #1 is used the first time the DIR is illuminated, WRF #2 the second time, WRF #3 the third time. The series then repeats. Each WRF contained in the set has certain associated blind speeds. The WRFs are chosen so as to not have the same blind speeds. As the WRFs are used sequentially to illuminate the DIR the blind speed changes (moves).

Given the typical clutter map in Figure 5, Figure 8 illustrates what the radar would see by using a multiple set of low WRF FM/CW.

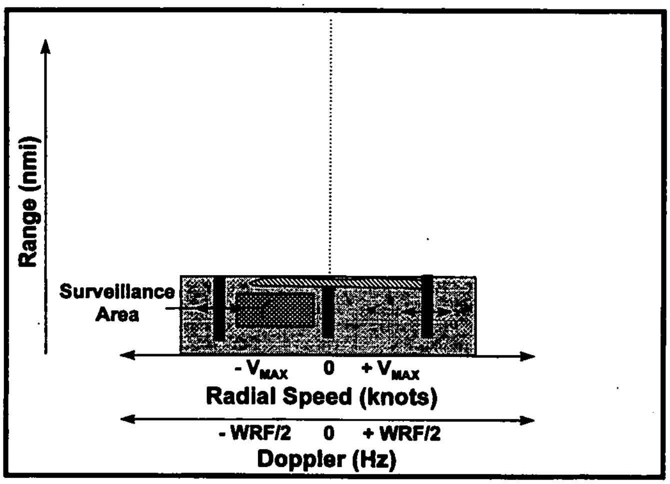

Figure 8
Response to a multiple low WRF FM/CW

The blind speeds exist "part-time" so they are more like "vision impaired" rather than blind. A suspected drug trafficker traveling at a certain speed may be blind at one of the WRFs but will be seen at the other WRFs. This mode of operation helps minimizes the blind speed problem and is effective in dealing with SDC_{rf}. However, the fact remains that some blind speeds may exist in the desired surveillance area. This may cause a reduction in the hit rate of the tracker, which may reduce tracker performance measures such as Time to Initiate.

The obvious desired mode of operation is to obtain an invulnerability to SDC_{rf} (low WRFs) with no blind speeds (high WRFs). This mode is not obtainable in the strict sense of the word, and thus a compromise must be met with the use of the recurrent FM/CW waveforms. This basic problem led to the investigation of alternative waveforms to deal with SDC_{rf} while minimizing blind speeds. Waveforms that have this potential are nonrecurrent waveforms. This class of waveforms seeks to control returns from ambiguous regions. The investigations initiated in this project focused on a nonrecurrent waveform that readily fit into the ROTHR with minimum modification, namely the NRWF.

III. NRWF

A NRWF is a train of pulses with an additional modulation applied to each pulse repetition interval. The modulation is a quadratic phase code (C_n) which is imparted pulse to pulse, on a FM/CW pulse train. Figure 9 illustrates a mathematical breakdown .

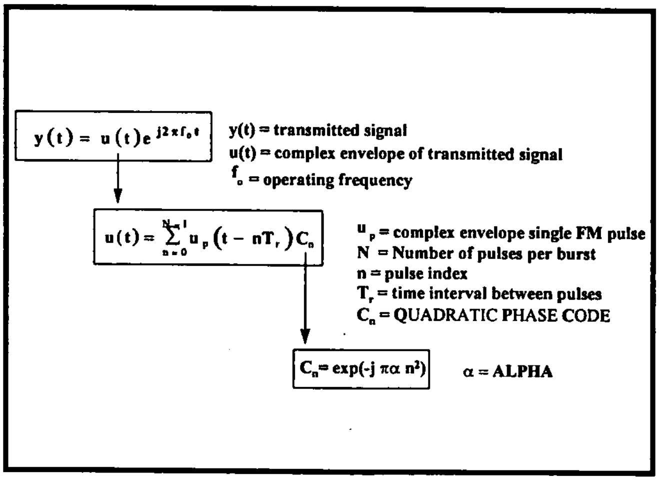

Figure 9
Mathematical Breakdown of the NRWF

A variable referred to as Alpha within the quadratic phase code controls the magnitude and direction of the doppler shift. The result is a doppler shifting of the returns from range-ambiguous regions.

Given the typical clutter map in Figure 5, Figure 10 illustrates what the radar would see by using the NRWF with a certain Alpha setting.

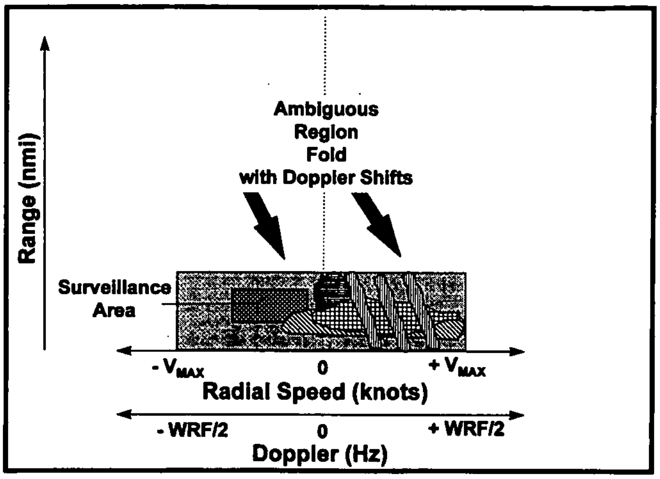

Figure 10
Response to a single high WRF NRWF

The NRWF uses a single, high WRF with Alpha set to shift range-ambiguous returns. In this example, Alpha is set such that range-ambiguous returns shift to the positive side of the doppler spectrum. Some clutter in Figure 5 is range-ambiguous, coming from 1st, 2nd and 3rd range-ambiguous intervals. The range-ambiguous returns fold in range just as with the FM/CW waveform. However, the difference here is they are now shifted in doppler. The range-unambiguous return is not shifted by the NRWF.

The doppler shift of range-ambiguous return is a function of the range-ambiguity interval (N = 1, 2, 3), the value of Alpha, and the WRF, as given by:

Doppler Shift (Hz) = N*Alpha*WRF(Hz)

Notice that the ground return in Figure 5 extends through multiple range-ambiguity intervals. The NRWF breaks this return up because the Doppler Shift it imposes is a function of the range-ambiguity interval (N). The ground return in each range-ambiguity interval has a slightly different shift.

By proper selection of the Alpha and the WRF, the surveillance area can be clear of range-ambiguous clutter folding. This assumes that there are regions of doppler space that are of lower interest and large enough to handle the shifted clutter.

Figure 11 compares the receiver response of (a) a single high WRF FM/CW, (b) multiple low WRF FM/CW, and (c) a single high WRF NRWF. Notice the multiple low WRF FM/CW and high WRF NRWF both mitigate SDC_{rf}. The major difference is that some blind speeds may exist in the desired surveillance area for the multiple low WRF set. However, they do not exist with the higher WRF NRWF. This contrariety will show up in detection and tracking attainment.

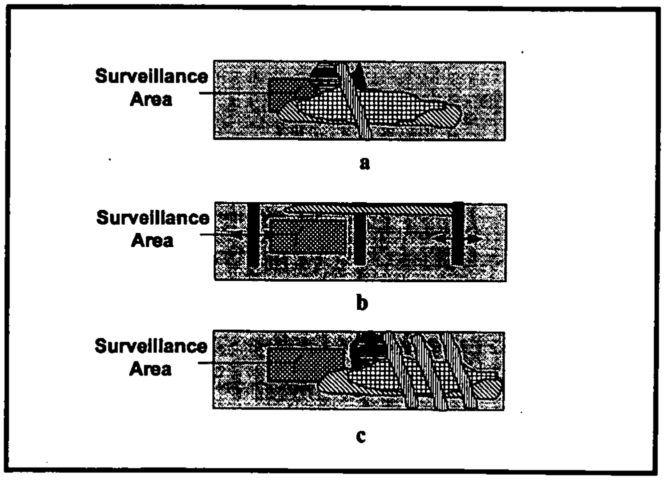

Figure 11
Response to FM/CW and NRWF

IV. INSTALLATION

To install the waveform in ROTHR Virginia, hardware and software modifications had to be made. Mainly, modifications were made to the Exciter Hardware Module at the transmit site, the LO Generator Hardware Module at the receive site, as well as Control Software. These modifications were performed by Raytheon. Testing was done to make sure that the modifications did not effect the prior performance of the radar and that the ROTHR Operators could control the NRWF.

A DEC/Alpha workstation was attached to the real-time radar return. This enabled NRWF data collection, analysis, and parameter (WRF and Alpha) suggestion tool development to be done on a non-interfering basis.

V. EVALUATION

The paragraphs to follow illustrate a small sampling of the testing done to prove that the NRWF: (1) Does not introduce Radio Frequency Interference (RFI), (2) Mitigates Range-Folded Spread Doppler Clutter (SDC_{rf}), and (3) Improves detection and tracking performance.

a. *RFI*

One of the concerns with the NRWF was to make sure that it could operate in the crowded High Frequency (HF) spectrum at nighttime when the SDC_{rf} problem occurs. Additionally, at the same time, minimize RFI to other users of the HF band.

At the transmit site, the Radio Frequency (RF) spectrum of the NRWF waveform was measured and compared to that of the FM/CW waveform using a external probe attached to an RF spectrum analyzer. The in-band and out-of-band spectrums were compared for all possible permutations of the operating frequency, WRF, and Alpha listed below in Table 1.

Table 1

Parameter		
f_o	5 MHz	15 MHz
WRF	31 Hz	52 Hz
Alpha	+/- 0.1	+/- 0.5

Figure 12 illustrates one representative example at a f_o = 5 MHz, WRF = 31 Hz, and Alpha = - 0 .5. The doppler spectrums of the NRWF and FM/CW are plotted.

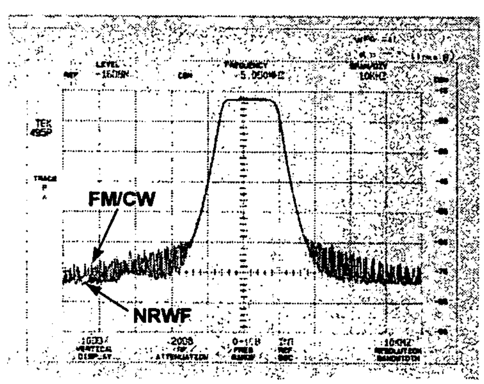

Figure 12
NRWF and FM/CW RFI Comparison

The results of the RFI tests concluded that the NRWF did not cause RFI to other users of the HF band.

b. *MITIGATION*

One of the first concerns testing the NRWF and its effect on SDC_{rf} was to actually find the occurrence of SDC_{rf}. As described above, the ionospheric disturbances that cause SDC_{rf} change with altitude, time of day, time of year, sunspot cycle, and geographic location. There is no SDC_{rf} detector in ROTHR to alert the usage of clutter mitigation techniques. Multiply this probability by the fact that mitigation testing was done on a non-interfering, part time basis (2 Hrs./night, 1.5 nights/week, 16 weeks). Therefore, to combat locating SDC_{rf}, a display was developed on the DEC/Alpha workstation to view in real-time the Range-Doppler Maps of all of the DIRs illuminated within the ECA. With this display a visual inspection of the DIRs could be performed to look for SDC_{rf}.

The NRWF was tested during 24 nights over the months of Dec. 96 to March 97, for approximately 2 Hrs. per night. SDC_{rf} was observed and found to degrade performance 29% of the time, according to Table 2.

Table 2

SDC_{rf}	% of nights
Observed during the night	66 (14/24)
Effect on performance	29 (7/24)

It should be noted that the remaining times when SDC_{rf} was observed and did not degrade performance was when the desired surveillance speeds of interest, coupled with the shape of the clutter and subsequent fold did not degrade tasking. In other words, the SDC_{rf} landed out side of the surveillance area.

Note that these SDC_{rf} occurrence findings are not meant, nor should be interpreted, as a measure of how much of a problem SDC_{rf} is at ROTHR Virginia. The findings are based only on a small sample.

Figure 13 is a representative real clutter map example of when SDC_{rf} degrades the performance of the radar. This clutter map was taken with a 10 Hz WRF waveform.

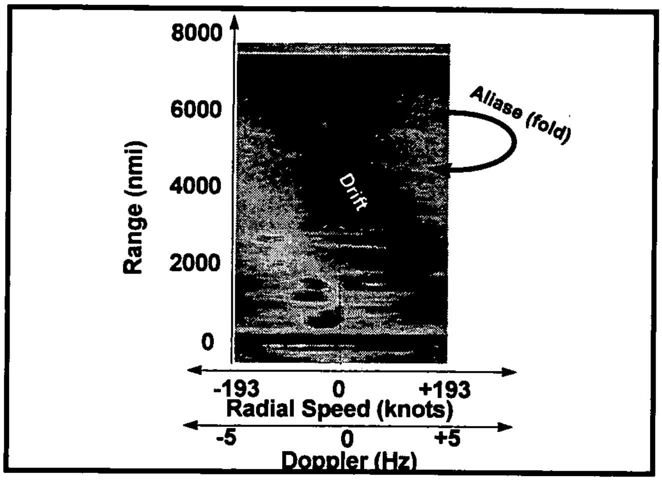

Figure 13
Clutter Map

This figure is "sort of" the real world example of the typical clutter map shown previously in Figure 5. The reason being is that the clutter map of Figure 5 is both range and doppler unambiguous, while the 10 Hz waveform is range-unambiguous and doppler-ambiguous. In this example, the equatorial, auroral, and ground clutter regions are difficult to separate. Observe the clutter drift to the left and subsequent aliasing (fold).

With this as the clutter environment, the ROTHR system was in a mode of operation that did not allow for any blind speeds. The Range-Doppler Map display for the radar's return is illustrated in Figure 14a.

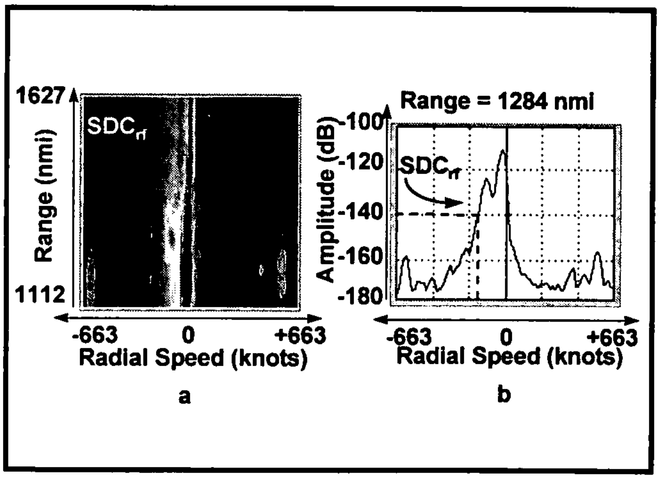

Figure 14
FM/CW Range-Doppler Map
Doppler Profile

Notice the SDC_{rf} masking speeds of interest for inbound targets (left side of zero doppler) of up to 220 knots. The masking of the inbound surveillance area makes sense because the clutter map shows a left drift. Figure 14b illustrates a doppler profile for a range of 1284 nmi. Notice the shoulder area to the left side of zero doppler caused by SDC_{rf}. Also highlighted is a speed of 132 knots with a return of -140 dB.

The Range-Doppler Map display for the radar's return when operating the NRWF in an overlapping DIR is illustrated in Figure 15a. Notice the shifting of the SDC_{rf}, unmasking speeds of interest for inbound targets. Figure 15b illustrates a doppler profile for a range of 1284 nmi. Notice the reduction of the shoulder area to the left side of zero doppler. Also highlighted is a speed of 132 knots with a return of -160 dB. This is a 20 dB improvement at this speed.

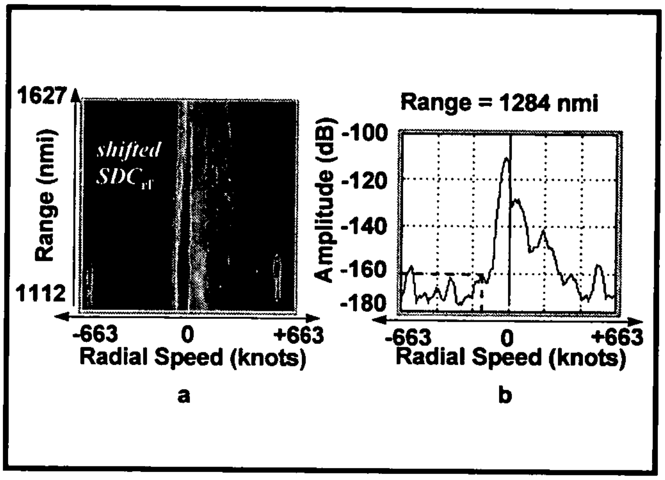

Figure 15
NRWF Range-Doppler Map
Doppler Profile

The results of mitigation tests concluded that the NRWF mitigates SDC_{rf} from a desired surveillance area. The amount of this mitigation is directly proportional to the amount of SDC_{rf}. The NRWF does not mitigate clutter that does not originate from range-ambiguous returns. Furthermore, successful mitigation is dependent upon having regions of doppler space that are of lower interest, and large enough to handle the shifted clutter.

c. *TRACKING*

At the time of this publication, the tracking tests with the NRWF were ongoing. This section contains the results of initial tests. Just as with the mitigation tests, locating the problem of SDC_{rf} was the first step. Little SDC_{rf} was encountered. A significant reduction over that encountered during mitigation tests. This highlights the fact that ionospheric disturbances change with time.

Before running NRWF to observe tracks, a baseline was needed for comparison. Two overlapping DIRS were used. One running the NRWF looking for inbound targets, and the other running a low WRF triplet. The low WRF values used in this triplet were 9.4, 10.4, and 11.4 Hz. These values were chosen because each of them mitigates SDC_{rf} rather well. Note that the ROTHR system would probably not select these WRF values because they have some common blind speeds. ROTHR would most likely select something like a 7.4, 11.4 and 26 Hz triplet, so as to not overlap the blind speeds. However, also note that the WRF of 26 Hz would not mitigate SDC_{rf} as well and blind speeds would still exist.

The basis of the initial tests was to compare tracking performance of FM/CW waveforms that provided SDC_{rf} mitigation as well as the NRWF.

Figure 16 depicts the results from such a scenario. One DIR was running the low WRF FM/CW waveforms. The low WRF values used were 9.4, 10.4, and 11.4 Hz. Another DIR was placed on top of the original DIR. This DIR was running the NRWF with an Alpha value set to look for inbound targets. Both DIRs produced separate peak displays with track overlays.

Figure 16 is a picture of the displays placed on top of one another. Highlighted are the low WRF tracks. The remaining tracks are from the NRWF. Notice first, that the NRWF picks up more inbound (negative slope lines) targets than does the low WRF triplet. Further analysis showed that the speeds of these missed targets where at or near a blind speed region of the low WRF Triplet.

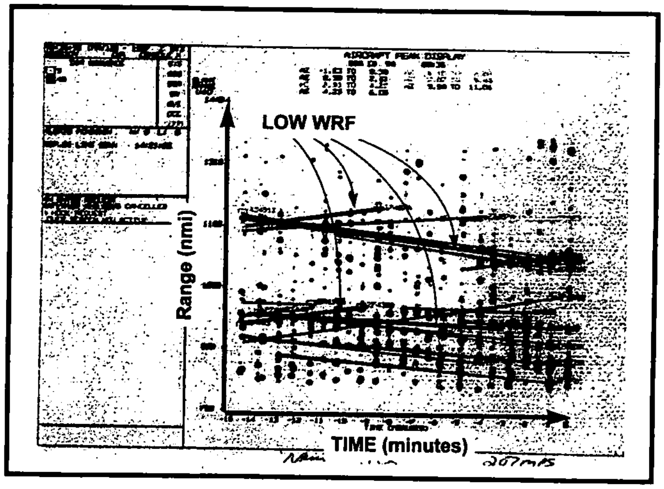

Figure 16
Peak Display with Track overlays
for
NRWF and low WRF Triplet

The NRWF does not pick up outbound (positive slope lines) targets because these regions have been blanked. The exception is when an outbound target is traveling at a greater velocity than the NRWF's unambiguous velocity measurement. This causes the target to fold in doppler, appearing on the inbound side that has not been blanked.

The results of tracking tests are incomplete due to the lack of SDC_{rf}. However, one conclusion is that the NRWF will provide better tracking than a set of low WRF triplets that mitigate SDC_{rf} just as well. Testing is ongoing, with hope to obtain more results during moderate to severe SDC_{rf}.

VI. CONCLUSIONS

The payoff for ROTHR with the use of NRWF includes improved detection and tracking performance of potential drug targets in the presence of SDC_{rf}. Depending on the magnitude of SDC_{rf}, the NRWF causes 15 dB (nominally) of SDC_{rf} rejection. This mitigation capability, coupled with the fact that the NRWF uses high WRFs, will increase the probability of the seizure of narcotics during SDC_{rf} events.

Although the current state of NRWF at ROTHR Virginia has proven itself beneficial, there is still more work to be done. Obviously, the application of the NRWF at the remaining sites with the Counter-Drug Surveillance Net (Texas and Puerto Rico).

Furthermore, at a high level, 1) the NRWF waveform parameters (WRF and Alpha), which are currently set by the ROTHR operator, need to be automated and presented as an operator tool to facilitate the ease of use. This automated waveform selection and optimization procedure would use low radar occupancy for all ROTHR waveforms necessary to deal with the variety of ionospheric conditions experienced by ROTHR. 2) Methods need to be developed/tested to combine SDC_{rf} mitigation techniques with impulsive noise (cause by lighting strikes) and meteor excision as well as Beacon-assisted Coordinated Registration (another R&D development program at ROTHR). 3) Under the current configuration, the NRWF allows for the detection of inbound *or* outbound targets during one Revisit Time. Advanced NRWF operation would allow for detection of inbound *and* outbound targets during one Revisit Time.

ACKNOWLEDGMENTS

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THE USE OF RADAR TECHNIQUES FOR REMOTE HEARTBEAT, RESPIRATION AND HUMAN PRESENCE DETECTION THROUGH WALLS

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ABSTRACT

Researchers at the Georgia Tech Research Institute (GTRI) have developed a radar that will detect heartbeat and respiration of individuals without any physical connection being required between the subject and the radar located up to 10 meters from the subject. This paper explores the use of this technology for the biometric identification of personnel who work in a highly secure environment. The system, used in this application, would use the heartbeat signature as a novel biometric identification system, a detector of a human presence behind a door or wall, a sensor system used to detect the ballistocardiogram of persons hidden in closed areas of a vehicle for entry point screening, and as two channels of information in a non-intrusive polygraph.

1. History of System Development

The systems to be described are representative of a technology developed during several research projects conducted at GTRI over the past 10 years to detect respiration and heartbeat in individuals at a distance. An early system was patented in the mid-1980s under sponsorship of the United States Department of Defense (DoD). The frequency modulated (FM) radar was a battlefield vital signs monitor. It would be used during live fire situations to determine if a wounded soldier was alive before risking a corpsman's life to treat him. The design goal of that system was a capability to detect heartbeat and respiration at distances of 100 meters. That system was also tested on soldiers wearing a chemical or biological warfare suit to allow vital signs to be monitored without opening the suit and risking contamination of the subject. The latest system developed by the author was intended for use in the 1996 Olympics held in Atlanta, Georgia (also the location of GTRI). A variant called the RADAR Flashlight was developed for use by law enforcement personnel. Each system is addressed in the remainder of this paper.

2. Olympic Application

Specifically, it had been proposed that some Olympic archers and rifle competitors can sense their heartbeats (which cause an approximate 5 milliradian movement of the arms and body). By shooting between heartbeats, better accuracy is achieved. It was proposed that a heartbeat monitor radar would be built to demonstrate the finely honed skills of the

Olympic competitors. It was envisioned that the demonstration system would be of interest to the television networks covering these competitions. Several system requirements were developed. The operation of the system could not distract the competitors. To meet this challenge, the radar was designed to be located at least 10 meters from the competitors, under a radome, and mounted on a pan-tilt positioner. The system was built, tested and was in final preparation for mounting on a pan and tilt head when the television networks chose not to broadcast the archery and rifle competitions in prime time. Since that time, slightly over one year ago, other applications of the heartbeat radar have been explored. Medical and security applications are being pursued. The security applications that are being considered are the topic of this paper.

3. Security Applications

If it could be demonstrated that the radar signature produced by the heartbeat is unique to a single individual, then the system could serve as a biometric identification device. While development of this function is admittedly ambitious for the system, no supporting medical research has yet been performed by GTRI to determine the unique nature of an individual's heartbeat signature. Assuming that an individual's heartbeat signature is unique, the next research objective would be to determine over what period of time the unique heartbeat remains "unique." The effects of heart disease and other biological changes that occur naturally with age may affect an individual's heartbeat signature and should be investigated.

A less ambitious research objective with security applications, believed immediately achievable, is the use of the radar heartbeat monitor to sense changes in an individual's heartbeat and respiration rate over short periods of time. This capability has been demonstrated using the current version of the system. This capability would allow the current system to be used as a two channel polygraph to detect the point at which a subject has an emotional response to a question. For example, using a radar system at a border crossing would allow the heartbeat and respiration rate of suspicious individuals to be monitored during secondary inspection without their knowledge while undergoing questioning. It is postulated that a neural network could be trained to recognize deceptive behavior on the basis of changes in heartbeat and respiration rate alone.

It is thought that the radar heartbeat monitor could serve as a non-intrusive duress alarm while monitoring persons in a highly secure environment. This application is based on the assumption that duress situations cause rapid acceleration in heartbeat and respiration in the person under duress.

The system also has potential applications for prison population monitoring. The system could be used to monitor an inmate with suicidal tendencies. During periods when the inmate is moving around in the cell, there would be a very large radar signature caused by body motion which is easy for the system to monitor. However, when the inmate is not moving, the radar could monitor respiration rate (as a minimum) and heartbeat rate when the inmate's body is positioned so that the thorax region is visible to the radar.

A variant of the Olympic radar has already been tested by GTRI in collaboration with Oak Ridge National Laboratories, to sense the presence of a human hiding in a vehicle by sensing the ballistocardiogram (shock wave induced into the vehicle by the beating heart). The shock wave generated by the heart is a very small impulse, but it can be sensed using the GTRI radar and the Oak Ridge National Laboratories' signal processor developed to detect the ballistocardiogram of a subject hiding in an enclosed space. The advantage of detecting heartbeat and not movement or respiration for these applications is that heartbeat is not a function that can be controlled at will by an individual.

The RADAR Flashlight to be discussed was designed as a law enforcement tool. It can detect the respiration signature of an individual standing 8 feet away with an 8 inch concrete block wall in between. Wooden doors are almost transparent to the system. It could be used to conduct bed checks in prisons to assure that an inmate (as opposed to a dummy) was in his bed by detecting the respiration signature. The use of the

RADAR Flashlight allows this function to be performed without the requirement that a prison guard enter a cell. It could also be used by those law enforcement personnel serving warrants to determine if someone is standing behind a door without a requirement that the door be opened. (If someone is behind the front door by not answering a knock, this is valuable information to the warrant server.) It can also be used to inspect a closed space such as an interior closet. The closet would not have to be opened to determine if someone was hiding inside. The RADAR Flashlight will be discussed in more detail in a later section.

4. The Radar System Design

Figure 1 shows the heartbeat radar system developed for the long range Olympic monitoring function. Referring to Figure 1, a hole in the dish allows a charged coupled device (CCD) camera to view the area illuminated by the dish antenna. The CCD camera image is used to align the near field antenna beam on the subject's thorax. A dot is placed on the monitor to indicate the area of approximate antenna beam center. For most applications, the radar vital signs monitor (RVSM) is operated in the near field of the antenna.

A well behaved near field antenna beam was required for successful Olympic event monitoring. A focused lens antenna was initially considered, but later rejected due to the high cost and long delivery lead times. Sensitivity to antenna beam issues were raised when it was determined that event judges would be allowed to walk near the competitors while the radar was monitoring their heart rate. Because the Olympic prototype system has no range gate, it is very sensitive to radar clutter from motion at all ranges. Fortunately, during testing of the 0.6 meter dish system, it was found that the 3 dB beamwidth was extremely narrow in the near field and the sidelobes were down considerably from those expected for the far field case. During testing, a subject at a range of 10 meters from the radar could be approached by a second subject to within 0.5 meters without creating objectionable clutter levels.

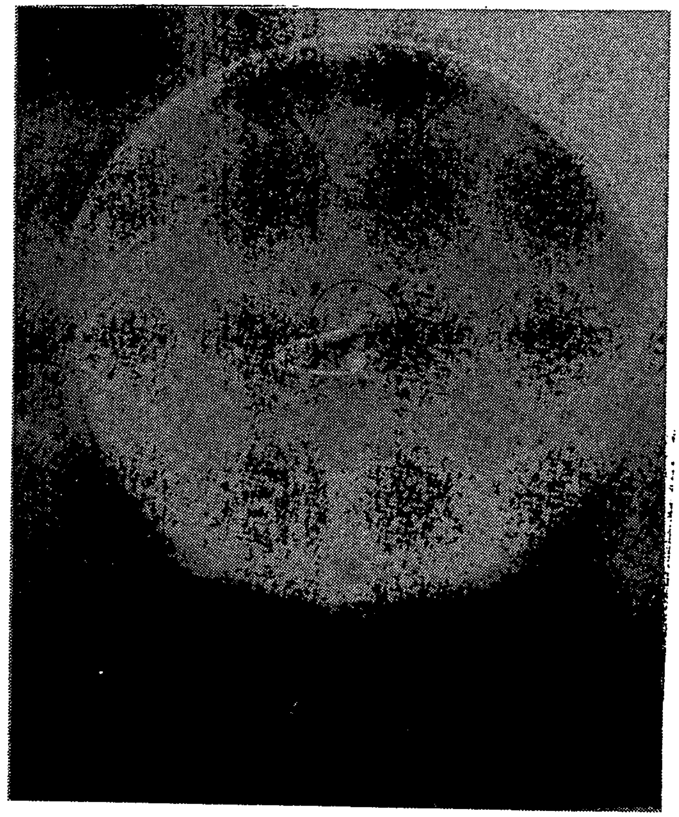

Figure 1. Front view of the RVSM developed for use in the 1996 Olympics.

5. Signal Processing

The radar signal processing scheme also contributes to clutter rejection. Figure 2 shows the printed circuit board on which the signal processing circuits are mounted. The microwave signal source is also mounted to the printed circuit board. There are two channels of information produced simultaneously by the two channel radar system: (1) heartbeat, and (2) respiration. The signal processing technique to recover the heartbeat signal employs a matched filter approach, the response of which was determined after analysis of the distribution of the frequency domain energy of the radar heartbeat signature in the laboratory environment. The respiration channel is injected into a low-pass filter that cuts off below the heartbeat signal. The heartbeat channel is injected into a band pass filter that is wide enough in frequency response to recover most of the heartbeat energy while eliminating the respiration signal.

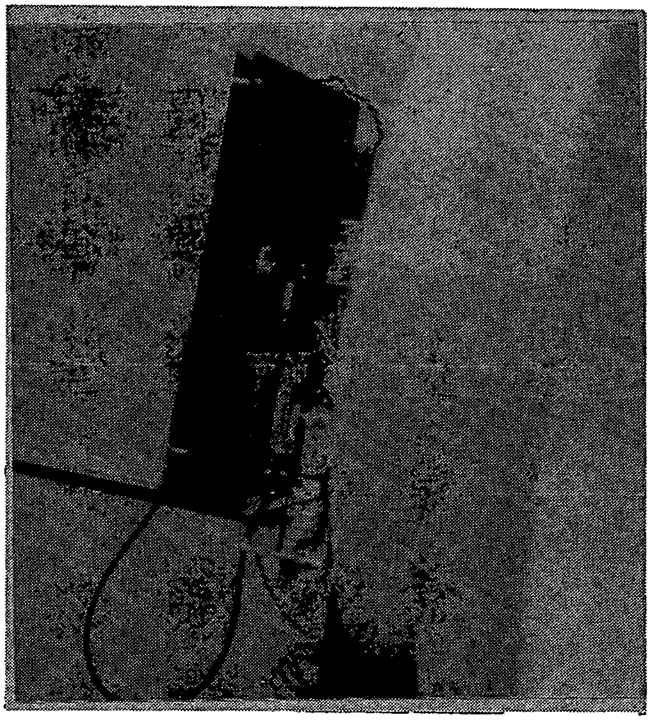

Figure 2. Power converter, transmitter/receiver module.

The radar heartbeat monitor can achieve detection of a heartbeat signal on a subject 10 meters from the radar without heroic signal processing measures when operating within the design parameters shown in Table 1.

Table 1. Operational Characteristics of a Radar Vital Signs Monitor

Frequency of Operation	24.1 GHz
Transmitter Power Output	30 milliwatts
Antenna Type	parabolic, 0.6 meter dish
Antenna Gain	≈40 dB (operation in near-field)

6. Data Supporting Security Applications

Figure 3 is a heartbeat signature taken in the laboratory with the male subject approximately 4 meters from the radar, seated in a frontal stationary position. The main beam was centered on the thorax area of the chest. Time increases from the left side of the plot to the right side of the plot. Each division in time represents approximately 100 milliseconds. Each heartbeat starts with three major sinusoidal cycles followed by additional cycles at a smaller amplitude. Direction of movement of the chestwall cannot be determined with the Olympic prototype because in-phase and quadrature data are not available. Referring to Figure 3, there are 800 milliseconds between the start of each complex which corresponds to 75 beats per minute. A shift in heartbeat rate as small as 50 milliseconds is possible to sense, given the high signal to noise ratio. A 50 milliseconds change in heartbeat rate corresponds to a difference in heart rate of 3.75 beats per minute when the subject has an at rest heartbeat of 75 per minute. Given this sensitivity, it is thought that it would be possible to measure an increase in heart rate due to an emotional reaction to questioning at a border crossing or in a person suddenly finding themselves under forced duress by another individual. Thus, the application of the system as a two channel polygraph and duress monitor appears to be achievable in the short term.

In a previous paragraph, it was speculated that a heartbeat signature might be used as a biometric identifier of individuals. No feature set has yet been developed to allow comparison between two sets of radar heartbeat data in a similar manner to the feature set used in fingerprint matching. It is thought that heartbeat signature matching using simple time domain data would be difficult due to the variations that occur in the time domain signal. For example, Figure 4 is a radar heartbeat signature taken under similar conditions to the signature shown in Figure 3. Referring to Figure 4, the time between the major heartbeat complexes is approximately 600 milliseconds. This corresponds to an at rest heartbeat rate of 100 per minute. Figure 5 shows data taken on the same individual very recently, approximately one year after the data in Figure 4 were taken. Both plots are time domain data and time increases from the left to the right of each figure. Each minor division along the 'X' axis represents 100 milliseconds. Analysis of the data in Figure 4

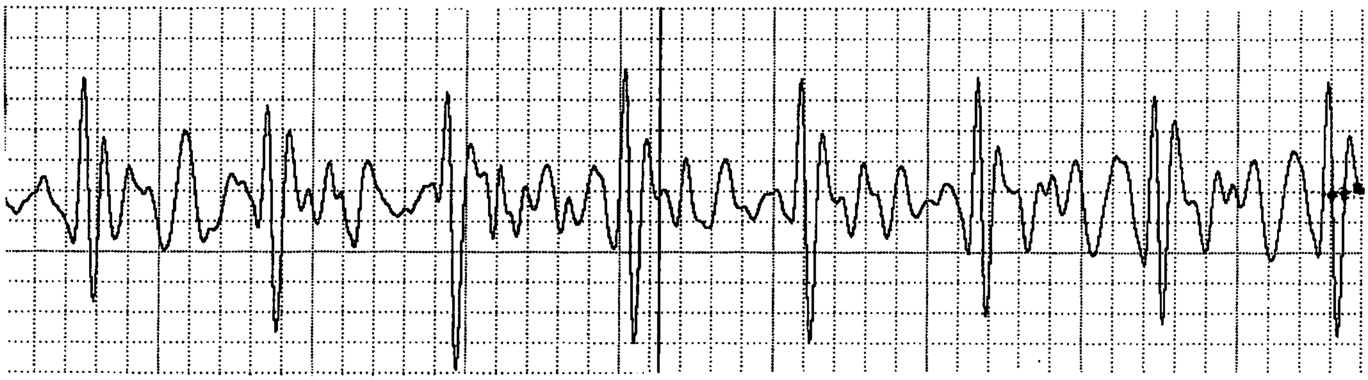

Figure 3. The radar cardiogram of subject 1 showing the fine resolution of the data.

Figure 4. Radar cardiogram of subject 2 showing the differences in the heartbeat signature between test subjects.

shows the at rest heartbeat rate of the subject one year later was approximately 85 beats per minute. The bottom trace taken in 1997 does not appear to correlate with the top trace taken in 1996 when a cursory examination is made of time domain data only. Given this background, it appears that additional research is necessary to determine how best to process the heartbeat signal to develop a feature set that can be correlated over time.

7. The Radar Flashlight

The RADAR Flashlight was developed as a variant of the Olympic radar. It was designed to be portable and used by law enforcement personnel to search for human life signs through a wall or door. Referring to Figure 5, the RADAR Flashlight prototype is contained in a housing similar to a large flashlight. Presently, the prototype signal processor is housed on a separate board. One research objective is to miniaturize the signal processor and house it in the flashlight enclosure so that the entire system is self contained. A second research objective is to develop a simplified display to allow rapid signal analysis by a user in the field.

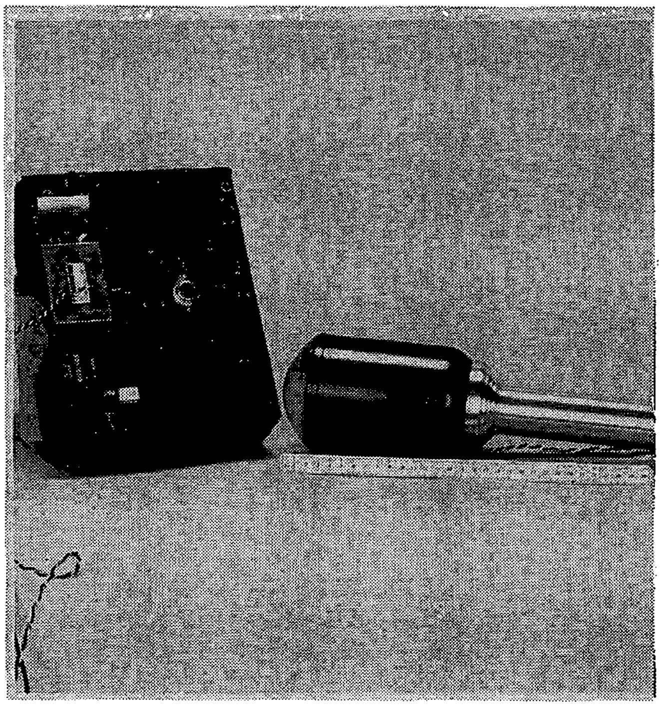

Figure 5. RADAR Flashlight shown with signal processor.

There are several law enforcement applications. In Cobb County, Georgia, over 250,000 warrants are served annually. This number is thought to be typical of those served in each metropolitan county annually. A certain percentage of these servings have ambush potential. One inch solid wooden doors like those used on the front or rear entrance of most homes in the United States are almost transparent to the system. The RADAR Flashlight would be helpful to determine if a subject is behind the door but not responding. In this situation, the warrant server would be given a warning of a potential problem. The system's capability of penetrating doors and particle board walls would allow interior closets to be searched from the outside without exposing law enforcement personnel to an armed person located within the closet.

The RADAR Flashlight has been demonstrated to be capable of detecting the respiration signature of an individual standing 4 feet behind an 8 inch concrete block wall. Figure 6 shows the respiration signature of a subject behind an 8 inch hollow block wall. Referring to Figure 6, time increases from left to right. Each minor division represents 0.67 seconds of elapsed time. The subject changed his respiration rate to show the sensitivity to the respiration rate that can be detected.

Given this capability, it is thought that the RADAR Flashlight could be used to locate persons in a room during a hostage situation on the basis of movement. In the case of immobilized victims, the RADAR Flashlight could locate them by their respiration signature alone. The RADAR Flashlight is also thought useful as an aid to conduct bed checks in prisons to assure that an inmate (as opposed to a dummy) was in his bed by detecting the respiration signature. The use of the RADAR Flashlight allows this function to be performed without the requirement that a prison guard enter a cell.

The RADAR Flashlight may be capable of locating victims in a building collapse who are trapped under thin layers of rubble. Another application of the system that is being explored is to locate subjects hiding in tall grass or behind vegetation.

8. Additional Research

A goal that GTRI is currently pursuing is the development of a signal processing technique to reduce the radar "clutter" that is generated by body motion during data collection. This is a challenge. The amount of signal returned from the chest area of a moving body, front aspect, is approximately 30 to 40 dB above the heartbeat signature. Applications that require body motion be tolerated during measurement requires that a technique be developed for body clutter suppression. GTRI is seeking collaboration with members of the medical community to pursue a better understanding of the source of the radar heartbeat signal.

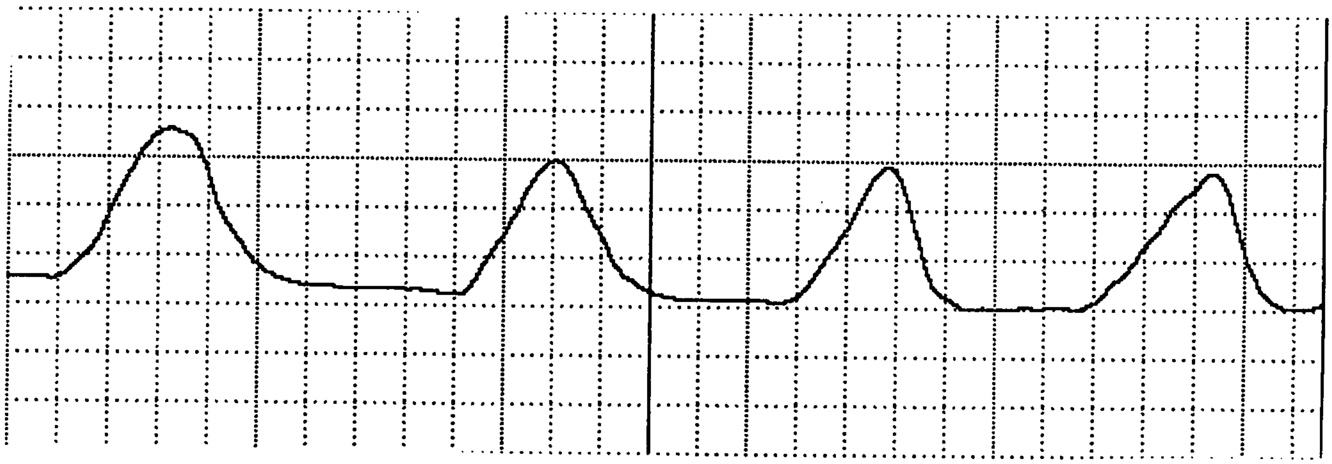

Figure 6. Respiration signature of subject standing behind cinder block wall observed by RADAR Flashlight.

9. Microwave Exposure Levels

Electromagnetic radiation exposure of the RVSM was measured to be almost an order of magnitude below the voluntary one milliwatt per centimeter standard on radiation exposure observed in the United States. Techniques are being developed to reduce the 100% duty cycle of the system so that a subject's radiation exposure will be reduced to even lower levels. An FM version of the system that was patented by GTRI earlier will allow further reduction in radiated power levels over the current Olympic prototype due to that system's inherent sensitivity.

10. Summary

Measurement of the radar cardiogram at a distance is achievable using inexpensive microwave components, if matched filter signal processing techniques are used to extract the time domain signal. Law enforcement applications are also being pursued for the RADAR Flashlight. It is thought that the data produced by the system may be unique and yet similar to the information produced by a doctor's stethoscope. The challenge remains as to how best to process the data that the system produces for the various applications that have been developed for the basic technology.

HISAR: An Advanced Multi-Application Surveillance and Reconnaissance System

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ABSTRACT

In response to the growing need for an affordable surveillance and reconnaissance system for multi-applications by U.S. and international customers, the Hughes Aircraft Company (HAC) has recently developed a state-of-the-art multi-mode airborne radar system, called Hughes Integrated Synthetic Aperture Radar (HISAR). HISAR provides day or night and all-weather capabilities for ground, sea, and air surveillance at a stand-off distance in a nonintrusive and nonprovocative manner. The baseline HISAR system has been flight tested on a demonstration aircraft, is now operationally available, and can be tailored and upgraded to meet specific customer needs.

The baseline HISAR system contains a Moving Target Indicator (MTI) mode for detecting ground moving targets at user-selected revisit times. In addition, it contains a strip Synthetic Aperture Radar (SAR) mode with a moderate resolution and a spotlight SAR mode with an ultra-high resolution. The system is also equipped with a mode for detecting small boats and a mode for detecting low-altitude aircraft. This wide range of surveillance capabilities provided by HISAR are indispensable for various drug control enforcement applications.

This paper will overview the HISAR system, describe technical capabilities of each radar mode, present concept of operations, and discuss future upgrade plans.

(Paper Not Available at Time of Publication)

12

Information Systems Methodologies (Session 3A-3)

Learning to Extract and Classify Names from Text

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1. SUMMARY

Extracting vital information from unformatted text has only been possible to date by having the text read by human analysts and manually entered into databases. At HQ US SOUTHCOM counterdrug analysts read unformatted SANDKEY message traffic to identify important names (e.g. ships, persons and locations), dates, relationships, and events and create structured event templates for updating the database of an analytical tool entitled the Temporal Analysis System (TAS). By simultaneously displaying significant events on TAS timelines and maps, counterdrug analysts are able to support such tasks as maritime tracking and drug interdiction. In order for the TAS software to be effective, however, it requires timely, structured data templates as input for the timeline and spatial analysis applications. With a volume of nearly 2,500 messages arriving daily, a gap is often created by the fact that manual intervention is required and it simply takes too long for the data to get entered into the TAS system.

"One of the biggest problems is getting the important information out of the free-text and into the database" said a former SOUTHCOM Intelligence Information Systems Chief. Instead of having personnel performing purely analytical functions, counterdrug analysts often spend as much as 50% of their time reading and interpreting unformatted messages. Coupled with this problem is the fact that with the overall downsizing of the DoD, intelligence centers typically employ fewer analysts. Over the last few years natural language processing (NLP) technology, has matured enough to provide automated assistance for these kinds of tasks. While fully automated data extraction with 100% precision and recall is not yet practical, NLP applications can provide for effective automated extraction of certain kinds of information. Such processing can save analysts time and reduce the errors inherent in un-automated data entry tasks.

The DoD Counterdrug Technology Development Program Office, in conjunction with Rome Laboratory and BBN Corporation, has developed a new law enforcement technology to bridge this gap between data buried in text and the requirement of producing structured data for input to analysis applications like TAS. The technology is licensable under the name IdentiFinder™ and utilizes statistical learning algorithms to "learn from examples" how to find data that is important in text. IdentiFinder™ is currently able to identify person names, organization names, locations, dates, times, monetary amounts, and percentages. It could be trained to find other locally spottable data, such as facilities, product names, phone numbers, ship names, military units, addresses, social security numbers, etc.

Ongoing research will enhance The approach to perform a "deeper" level of

extraction, such as extracting relationships. The end goal of this research is to extract complex events from text of the form "who", did "what", to "whom", "when" and "where".

The technology has several advantages over conventional knowledge engineering approaches which utilize manually constructed finite state patterns. The most obvious advantage is that a system implementer does not have to handcraft and maintain large knowledge bases of pattern matching rules and on-line lexicons. The system implementer annotates a corpus of text with the information to extract and the system automatically trains on the examples by applying statistical methods to the annotated data. In addition, whenever a new domain of messages is encountered rule-based systems require tailoring (e.g. new or modified rules must be generated) by highly skilled computational linguists.

The technology is based on learning, and therefore, the only knowledge of the language or specific domain required is examples of the correct output. A knowledge engineering approach of manually writing rules is generally a much more tedious, labor intensive task, and one that is performed by a group's most talented and high priced personnel.

Another attractive feature of the technology is that it is language independent. Just as examples are annotated from text for new domains within the same language (English), foreign language text may be annotated with the correct answers and used for training purposes. The same software was applied to both English and Spanish texts made available as a result of Government evaluations and achieved results approaching the best manual knowledge engineering approaches. The software is currently implemented in C++ and runs under Sun Solaris, SGI Irix, Windows NT, or Windows 95.

2. THE PROBLEM

Entity recognition and identification has been recognized as a core problem and has been part of Government evaluations, such as the Sixth Message Understanding Conference (MUC-6, 1995) in November, 1995 for English and in the recently held Multi-lingual Entity Task (MET) (Merchant and Okurowski, 1996) for Chinese, Japanese, and Spanish. An example for English and in Spanish appears in Figure 2-1.

We have developed technology that:

- Learns to handle new languages by generalizing from examples marked in documents.

The delegation, which included the commander of the U.N. troops in Bosnia, Lt. Gen. Sir Michael Rose, went to the Serb stronghold of Pale near Sarajevo, for talks with Bosnian Serb leader Radovan Karadzic.

Este ha sido el primer comentario publico del presidente Clinton respecto a la crisis de Oriente Medio desde que el secretario de Estado, Warren Christopher, decidiera regresar precipitadamente a Washington para impedir la ruptura del proceso de paz tras la violencia desatada en el sur de Libano.

- Locations
- Persons
- Organizations

Figure 2-1: Named Entity Task. *Examples of the named entity task for English and Spanish.*

1. MATSUSHITA ELECTRIC INDUSTRIAL CO. HAS REACHED AGREEMENT ...

2. IF ALL GOES WELL, MATSUSHITA AND ROBERT BOSCH WILL ...

3. VICTOR CO. OF JAPAN (JVC) AND SONY CORP. ...

4. IN A FACTORY OF BLAUPUNKT WERKE, A ROBERT BOSCH SUBSIDIARY, ...

5. TOUCH PANEL SYSTEMS, CAPITALIZED AT 50 MILLION YEN, IS OWNED ...

6. MATSUSHITA EILL DECIDE ON THE PRODUCTION SCALE. . .

Figure 2-2: English Examples. *Finding names ranges from the easy to the challenging.*

- Has been evaluated on finding named organizations, named persons, named locations, dates, times, monetary amounts, and percentages.

Nothing about our approach is restricted to the named entity task; other kinds of data could be spotted with similar techniques, such as ship names, product names, addresses, and military units.

Figure 2-2 exemplifies difficulties involved in entity recognition, using corporation names for illustration. All of the examples below are taken from on-line newswire text in DARPA's TIPSTER program. The first example is the easiest; a key word (*CO.*) strongly indicates the existence of a company name. However, the full, proper form will not always be used; example 2 shows a short form, an alias. Many shortened forms are algorithmically predictable. Example 3 illustrates a third easy case, the introduction of an acronym. Examples 1-3 have been well-handled in the state of the art. Examples 4-6 are far more challenging. For instance, in examples 4 and 5 there is no clue in the names that they are company names; the underlined context in which they occur is the critical clue to recognizing that a name is present. In example 6, the problem is an error in the text itself; the challenge is recognizing that *MATSUSHITA EILL* is not a company, but that *MATSUSHITA* is.

Technical problems in developing a system arise from the following:

1. Recognition of names that are not known by the system is required since it is infeasible to have a dictionary listing all person names and all corporation names, since new person and organization names continually come into use.

2. Errors in the input arise from many sources. People produce many spelling, typographical, and grammatical errors. If material is automatically entered via OCR, the frequency of errors can be quite high. Also, there can be variation in the spelling of foreign names.

3. Languages other than English must be covered. An analyst may not have the luxury of dealing only with material written in English. Critical evidence may be in Spanish, German, Italian, Arabic, Chinese, or any of a host of other languages. Therefore, a technology that will increase productivity should not be limited to English documents. Since little data may be available in other languages, the algorithms should not require volumes of data.

3. APPROACH

A learned approach is represented in Figure 3-1. As the diagram shows, there are four requirements to this approach.

1. A set of *training data* must be provided; training data consists of sentences and annotations that represent correct output, i.e., an answer key.

2. A *model* must be defined that states the mapping from words to the annotations.

3. A *training algorithm* or module must estimate the parameters of the probability model to be learned from the example

data, that is, from the sentences with their correct annotations.

4. A *recognition algorithm* or module must apply the probabilistic, learned model to new sentences to provide their annotations.

Under separate DARPA funding, we developed the underlying software which was later applied to the NE problem for English and for Spanish. Government supplied data in MUC-6 and in MET serve as the training data. In our most successful version, the probabilistic model employed is in the general class of hidden Markov models (HMM), though the HMM used currently is more complex than those traditionally used in speech recognition and in part-of-speech tagging. Since the SGML-marked text can be straightforwardly aligned with the answer keys, the training algorithm simply counts the frequency of events and normalizes with respect to the event class to estimate the parameters of the model. For the recognition algorithm, the Viterbi algorithm, which is typically used in hidden Markov models, is applied.

The selection of features to include in a probability model, which features can be assumed independent (e.g., to minimize the training data required), which of several training algorithms to employ, what back-off procedure is appropriate, etc. are all empirical issues that depend on the problem. Since a statistical approach to language understanding is so new, many cycles such as that depicted in Figure 3-2 have been required. In each cycle at least one variation in the probability model is investigated, e.g., different features, different independence assumptions, different training algorithm, different decoding algorithm, etc. Then one retrains the learning algorithm and tests the learned model on test data, using an automatic scoring procedure, such as the MUC scoring software. Following a test, analysis must be performed to understand the resulting performance; that analysis will suggest a new round of variations in the overall probability model to try.

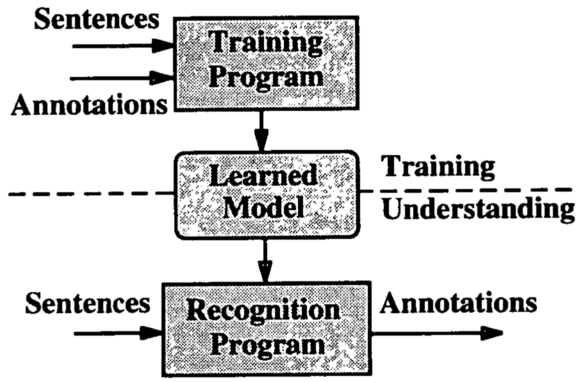

Figure 3-1: Components of a Learning Approach. *The language understanding system is trained via example sentences and answers (annotations); as a result of training, a model is learned; the model is then used to understand new sentences and produce answers for them.*

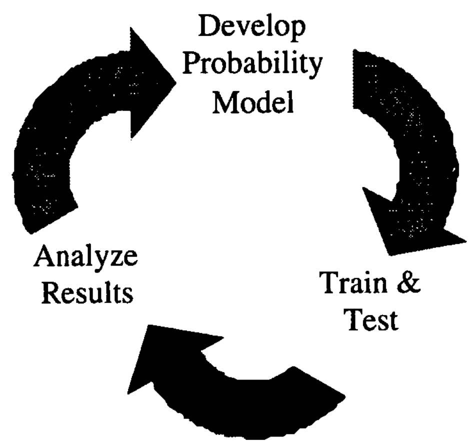

Figure 3-2: Process of Developing Effective Probability Models. *Developing a model requires cycles of hypothesizing and implementing a model, training and testing it on annotated data, and analyzing the model's deficiencies.*

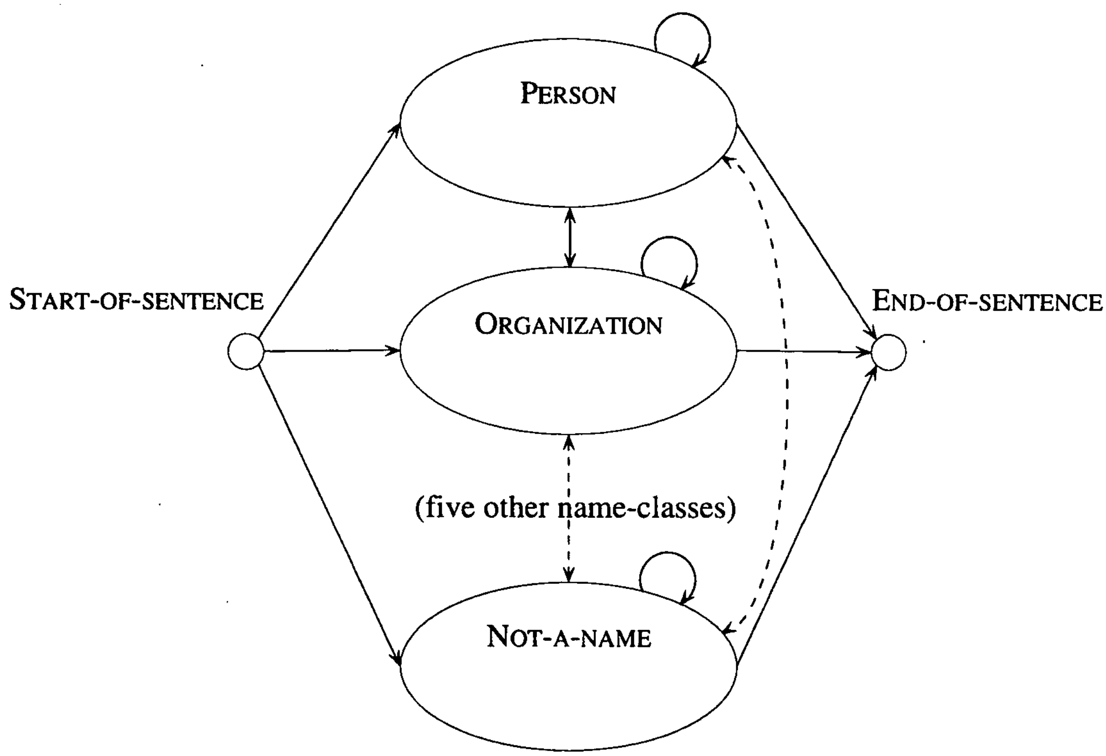

Figure 3-3: Pictorial representation of conceptual model.

3.1 Recognition

Processing a sentence corresponds to assigning a label to each word of the sentence. The labels include the seven types of data sought (in our experiments, named organizations, persons, named locations, dates, times, monetary amounts, and percentages) and noise (anything not sought). The algorithm in principle considers all possible assignments of labels that maximize the probability of assignments, given the input sentence. Figure 3-3 shows the correct labels; all unmarked words in that figure are labelled as "Not-A-Name".

3.2 Conceptual View of Probability Model

Figure 3-3 is a pictorial overview of our model. Informally, we have an HMM with only eight internal states (the name classes, including the noise class called NOT-A-NAME), with two special states, the START- and END-OF-SENTENCE states. Within each of the name-class states, we use a statistical bigram language model, with the usual one-word-per-state emission. This means that the number of states in each of the name-class states is equal to the vocabulary size, $|V|$.

Details of the probability model may be found in (Bikel, et al., 1997). Informally, the construction of the model in this manner indicates that we view each type of "name" to be its own language, with separate bigram probabilities for generating its words.

While the number of word-states within each name-class is equal to $|V|$, this "interior" bigram language model is ergodic, *i.e.*, there is a probability associated with every one of the $|V|^2$ transitions. As a parameterized, trained model, if such a transition were never observed, the model "backs off" to a less-powerful model, as described below.

Word Feature	Example Text	Intuition
twoDigitNum	90	Two-digit year
fourDigitNum	1990	Four digit year
containsDigitAndAlpha	A8956-67	Product code
containsDigitAndDash	09-96	Date
containsDigitAndSlash	11/9/89	Date
containsDigitAndComma	23,000.00	Monetary amount
containsDigitAndPeriod	1.00	Monetary amount, percentage
otherNum	456789	Other number
allCaps	BBN	Organization
capPeriod	M.	Person name initial
firstWord	*first word of sentence*	No useful capitalization information
initCap	Sally	Capitalized word
lowerCase	can	Uncapitalized word
other	,	Punctuation marks, all other words

Table 3-1: Word features, examples and intuition behind them

3.2.1 Words and Word-Features

Throughout most of the model, we consider words to be ordered pairs (or two-element vectors), composed of word and word-feature, denoted $\langle w,f \rangle$. Initially in our development, all words were uppercased, and there was nothing to distinguish capitalized and non-capitalized words, nor was there anything to distinguish different types of numbers. The word feature is a simple, deterministic computation performed on each word as it is added to or looked up in the vocabulary. It produces one of the fourteen values in Table 3-1.

These values are computed in the above order, so that in the case of non-disjoint feature-classes, such as containsDigitAndAlpha and containsDigitAndDash, the former will take precedence. The first eight features arise from the need to distinguish and annotate monetary amounts, percentages, times and dates. The rest of the features distinguish types of capitalization and all other words (such as punctuation marks, which are separate tokens). In particular, the firstWord feature arises from the fact that if a word is capitalized and is the first word of the sentence, we have no good information as to why it is capitalized (but note that allCaps and capPeriod are computed before firstWord, and therefore take precedence).

The word feature is the one part of this model which is language-dependent. Fortunately, the word feature computation is an extremely small part of the implementation, at roughly twenty lines of code. Also, most of the word features are used to distinguish types of numbers. The rationale for having such features is clear: in Roman languages, capitalization gives good evidence of names.

4. EVALUATION METHODOLOGY

The goals in evaluating this new approach were to:

- benchmark the progress of the research
- identify problems, so that possible solutions can be sought.

An automated evaluation procedure is essential. Such "scoring software" is of direct benefit to the development of the learned models and statistical algorithms, since that is the software that measures progress. Because such software exists already through the DARPA-sponsored Message Understanding Conferences (MUC), we leveraged off of that existing work.

Figure 4-1 illustrates the evaluation design. The component software to be tested is provided with test data which has not been previously used to train the system. Assume

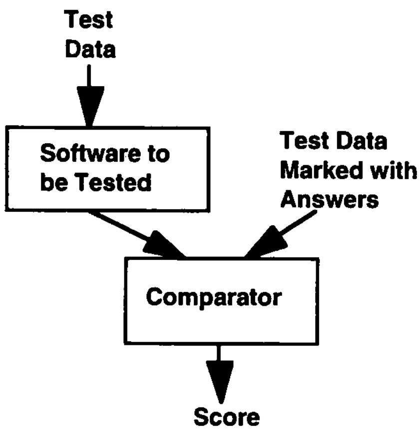

Figure 4-1: Testing/Evaluation. *Given test data and a separate key of answers for that test set, a procedure can score a system's performance.*

that the test set has been previously annotated by the correct answers. Then the scoring software (a comparator) compares the system output on the test data versus the answer key, building a table as shown in Figure 4-2. We count the cases that both the system and the answer key ("truth") label as an example ("a" in the diagram); these are correct system output. We also count the other three categories: the cases where the system misses an example ("b" in the diagram), cases where the system gives a false positive ("c" in the diagram), and cases where both the system and answer key (truth) agree that there is no example ("d" in the diagram).

Score Dimensions:

Truth \ System	Example	Not Example
Example	a	b
Not Example	c	d

$$\text{Recall (R)} = \frac{a}{a+b}$$

$$\text{Precision (P)} = \frac{a}{a+c}$$

$$F = \frac{2*R*P}{R+P}$$

Figure 4-2: Evaluation Metric of the Name-Finding Software

Given those definitions of correctness, three measures are typically computed: recall, precision, and F. Recall measures how much information is found; precision measures how reliable the output is (independent of how much information is found). F is a way of converting those two measures into a single dimension. Recall and precision have long been used in evaluation of information retrieval systems, and have become the accepted standard for evaluating information extraction systems.

4.1 English Results

We used several test sets. One test set is the 30 articles that formed the Named Entity (NE) test in the Sixth Message Understanding Conference (MUC-6). These articles were obtained by the government by an information retrieval query designed to get articles from the Wall Street Journal about change in corporate officers. In Figure 4-3 results of the learned system are compared against BBN's name finding program using manually constructed rules. This is the only test in English where a number of systems have been evaluated on the named entity information extraction task. Note that the learned system is almost equivalent to the handcrafted system on mixed case, and far outperforms the manual system on uppercase text. A detailed breakdown of the performance of the learned system by each category and by text versus headlines is provided by Table 4-1.

Category	Recall	Precision
Organization	96	93
Person	96	93
Location	99	96
Date	98	98
Time	none	none
Money	99	89
Percent	100	65
Headline	90	83
Text	97	93

Table 4-1: Detailed analysis of the learned system performance on English by component and by headline versus prose

	Manual Rules	Learned
Mixed Case	93.6	94.5
Upper Case	87	93

Figure 4-3: Results on the MUC-6 Named Entity Task. *On the only benchmark for the named entity task in English, the learned system is already performing close to the level of one of the top handcrafted systems, and outperforms some of the handcrafted systems in MUC-6.*

By this comparison in English, it is clear that the learned system is already performing comparable to the state-of-the-art of handcrafted systems on the named entity tasks. It is interesting to note that the learned system is performing at about the level of human performance as well, since informal experiments at BBN show that comparing human annotators on this task will yield an F of from 92 to 95.

4.2 Spanish Results

The Spanish test materials are a collection of documents distributed by the government for the named entity task. The documents were drawn from AFP newswire and were obtained by an information retrieval query designed to get documents pertaining to press conferences. In this case we compared the learned system on Spanish against BBN's system with handcrafted rules.

It is important to remember that the learned system for Spanish uses the same probability model and the same feature set as the learned system for English. Nothing was changed to bring the system up on Spanish except that the training data it was given was Spanish rather than English. By contrast, several person weeks were invested in handcrafted rules for the rule-based system that was used in the comparison. Table 4-2 shows results for each of the categories. Both Spanish systems performed equally well, about four percent worse than for English.

One of the striking characteristics of the Spanish data is that the headlines were totally in uppercase; therefore, capitalization could not help at all in recognizing names in the headlines. One of the advantages of the learning system is that we could train the system on uppercase text merely by converting the text and answer keys already supplied in mixed case to uppercase and then training a model on the uppercase text only. Therefore the run time system employed two models: one for the headlines and the second for the prose in the body. Note that one set of training data only was required for the two different types of text.

Category	Recall	Precision
Organization	88	83
Person	92	94
Location	85	88
Date	96	99
Time	97	97
Money	78	88
Percent	100	100
Headline	76	89
Text	89	90

Table 4-2: Detailed results for Spanish for each category and for text versus headlines.

4.3 The Amount of Training Data Required

With any learning technique one of the important questions is how much training data is required to get acceptable performance. More generally how does performance vary as the training set size is increased or decreased? We ran a sequence of experiments in English and in Spanish to try to answer this question for the final model that was implemented.

For English there were 450,000 words of training data. By that we mean that the text of the document itself (including headlines but not including SGML tags) was 450,000 words long. Given that maximum size of training available to us during this effort, we successfully divided the training material in half until we were using only one eighth of the original training set size or a training set of only 50,000 words for the smallest experiment. To give a sense of the size of 450,000 words, that is roughly half the length of one edition of the Wall Street Journal.

The positive outcome of the experiment is that half as much training data would have given almost equivalent performance. Had we used only one quarter of the data or approximately 100,000 words, performance would have degraded slightly, only about 1-2 percent. Reducing the training set size to 50,000 words only would have had a more significant decrease in the performance of the system; however, the performance is still impressive even with such a small training set.

For Spanish we had only 223,000 words of training data. We also measured the performance of the system with half the training data or slightly more than 100,000 words of text. There is almost no change in performance by using as little as 100,000 words of training data.

Therefore the results in both languages were comparable. As little as 100,000 words of training data produces performance nearly comparable to handcrafted systems.

5. CONCLUSIONS

The statistical approach to learning to recognize information to be extracted was demonstrated successfully in both English and Spanish. The results of the evaluation are so promising as to suggest that we have achieved the first steps towards a breakthrough in software to extract information from text. This is based on the following results in the following dimensions:

- *Performance* in being able to find and extract named entities from text is nearing both the best in the state-of-the-art of handcrafted information extraction systems and is also nearing human performance.
- *The data required* is the type already required in the state-of-the-art in handcrafted systems and represents the answers that the domain expert would extract from the text.

Several important dimensions must be addressed to take this early result from a promising one to a technology that is ready to transfer to the DoD.

The performance of the system in extracting information from text can be improved further, we believe; there are several concrete ways that should improve the model's ability to recognize the desired information.

Though our experiments show that as little as a hundred thousand words of annotated data may be adequate, we believe that the cost of annotating that amount of data can be reduced dramatically by focusing on techniques that bootstrap the preparation of data by semi-automatic means. Part of that cost reduction will be the development of tools and graphical user interfaces for use by the customer; such tools will not only reduce the cost of annotation but also help the customer assess the quality of annotation, support the maintenance of the system, and provide for the evolution of the definition of the data to be extracted.

Thus far, there has not been sufficient time or effort to evaluate carefully the degree that the algorithms are sensitive to the training data. A careful evaluation of sensitivity and experiments with well known techniques from probabilistic algorithms in continuous speech recognition should drastically reduce any sensitivity of the algorithms to the training material.

Two additional research dimensions are 1) to apply the technology to other languages that are quite different from European languages and 2) to extend the technique to find not just a single level of information such as dates and organization names but also to find relationships among such entities, such as who is holding a given office in an organization at what time.

6. ACKNOWLEDGEMENT

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Automation of Temporal Pattern Detection in Financial Crime Analysis

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ABSTRACT

In the detection of financial crimes such as money laundering, there is a need to identify underlying temporal patterns and trends within complex data sources. We describe a platform-independent Java-based application designed to address this problem using special algorithms and visualization techniques. The system may be configured by the user to read in data from multiple sources containing temporal information. Data extractions derived from these sources are parsed and passed to temporal filters. A temporal pattern is defined as a relationship among object events (e.g., people, organizations, locations, accounts), occurring with regularity. Three types of patterns have been targeted: absolute patterns which occur across measurable time intervals as defined by the user; contiguous patterns showing the co-occurrence of two or more events within user-defined time intervals; and hybrid patterns for which the interval between events can vary depending upon the behavior of the object being reviewed. Once these temporal patterns and relationships are extracted, the data are passed to display modules which allow the user to control the positioning and visualization of the data using numerous clustering, kiviat, and grid display routines.

Key terms: Money laundering, datamining, absolute time cycle event; contiguous time cycle event; visualization

INTRODUCTION

The United States Government has recognized the need to design, develop, and integrate advanced technologies to detect financial crimes and sustain related drug enforcement interdiction activities. There are many databases that contain information on financial transactions, money transfers, and currency exchanges. This article describes our efforts to develop a system that can detect temporal patterns and trends contained within these complex data sources by using special programs, heuristics, and visualization techniques.

All of the methods described in this paper are applicable to multiple domain areas concerned with the detection and monitoring of financial crimes to include, for example, analysis of communication events, port-of-entry surveillance, and transshipment route disclosures (e.g., container tracking). The application area with the biggest payoff and the one of most interest to law enforcement agencies, especially state and local units, is in the detection of money laundering activities and related financial crimes.

Money laundering is a term applied to any process that is used to take the monetary proceeds of illegal activities and transform them into assets that appear to have been obtained by legitimate means. Profit is the principal motive in such criminal activities, and the majority of these ill-gotten gains are based on cash transactions. In today's marketplace, money laundering is most easily detected at the point in which the funds enter a legitimate financial system.

It is estimated that 100 to 300 billion U.S. dollars are laundered each year throughout the world. Various local, state, federal and international agencies have been tasked with the detection and identification of those people and organizations actively involved in laundering money. To date, these agencies have approached this difficult task with the enlistment of advanced computational and analytical methodologies which may be used to discover a variety of money laundering activities. These methodologies often capitalize on the interactions and relationships that are represented in financial databases, for example, those created as a result of the Bank Secrecy Act (BSA). When specified volumes of cash enter or exit a legitimate financial system, forms must be filed by the institution conducting the transaction. Various types of information about the activity are recorded including names, addresses, identification numbers, accounts, and amounts involved. These data include documentation of critical relationships, patterns of interactions, and volume of cash flow.

There are, however, other implicit types of data contained in these filings that are not being fully exploited. For instance, every form filed contains the date of the transaction, which can serve as a temporal flag. Analysts need methods for presenting temporal data so that the patterns and trends of activity become explicit. Under contract to the Counter Technology Assessment Center at the Office of National Drug Control Policy, UIS is developing a data visualization system which will aid analysts in temporal data mining.

Temporal patterns represent activities or relationships based on a specified cycle of events that recur over a period of time. To illustrate, the filing patterns (deposits/withdrawals) of a suspect over time might be correlated with other events (such as narcotics transactions or border crossing) occurring in the same time frame. By observing such temporal patterns, an analyst will be better able to discover cause-effect relationships and forecast future events based on historical behavior. Some examples of how temporal analysis can be used include:

- Identifying the number of deposits made over time by different BSA occupational codes to look for seasonal adjustments;
- Identifying the withdrawal demand for certain time periods in specific regions of the country;
- Calculating the patterns of minimum (maximum, etc.) activity in a suspect's account;

- Calculating the patterns of deposits in an account over different periods of time;
- Exposing high velocity accounts within predefined time frames; and
- Showing the progression of loan-back schemes and related events.

TEMPORAL PATTERN DETECTION

The key to detecting a temporal pattern is to determine the cycle in which the pattern occurs. Many systems define *cycles of convenience*. These cycles tend to fall within structures that we find easy to interpret. Convenient cycles include abstract temporal representations such as minutes, hours, days, weeks, months and years. We understand, accept, and work within these cycles, and are therefore often predisposed to look for patterns within them. However, criminals will often try to disguise their behaviors and may not engage in traceable activities (phone calls, money transfers, travel) within convenience cycles, but may instead alter behavior patterns to avoid detection. This will disguise the cycles of convenience that are typically addressed by conventional analytical methods. What is required are techniques that can be used to detect and expose the *hidden* patterns.

Our work addresses this issue through the definition of cycle events. A cycle event can be defined as a particular association between two objects (e.g., people, organizations, locations, accounts), which occurs with a certain frequency. Our development efforts have mainly focused on the detection of two classes of patterns, absolute time cycle events and contiguous time cycle events. The value of an absolute time reference equates to the amount of elapsed time between two occurrences of the same cycle event. Contiguous time cycle events are those in which two or more independent events occur within a given time interval and may be associated based on that fact.

Absolute Time Cycle Events. To initiate a search, the user defines the trigger event which forms the basis of the pattern match. This event may be a simple representation such as the occurrence of a certain object with a particular attribute value (for example, cash transactions of more than $50,000). Alternatively, the user may define a more complicated trigger event made up of a composite representation as defined by more than one attribute across one or more object classes (for example, cash transactions of more than $50,000 reported from money exchange houses within a particular zip code). To the degree that the trigger for the time cycle event is made more complex, the user increases the granularity of the search, giving it more resolution and focus. The user then defines the boundaries of the search and the size of the time cycle to be inspected by the temporal filter.

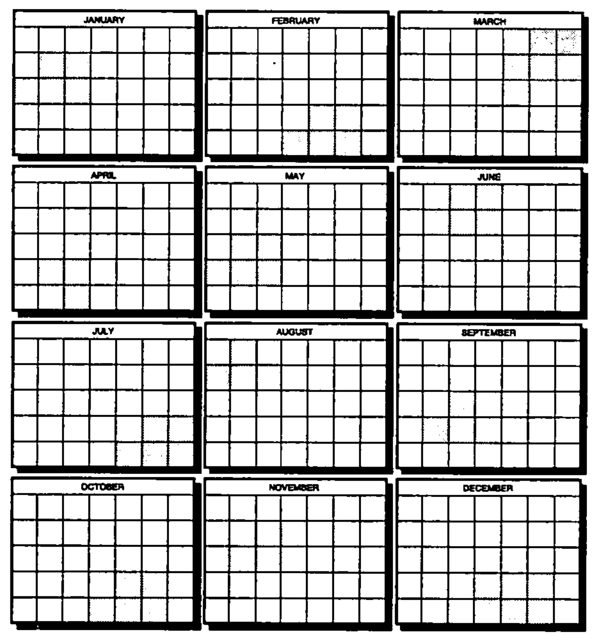

Figure 1- Absolute Time Cycle Event

The heuristics implemented to detect absolute time patterns decompose the cycle specified into a series of discrete time segments of equal length. For each segment, the heuristics determine whether the trigger event specified by the user has occurred. The algorithm is repeated on successively smaller (or larger) time intervals, finally stopping at the boundary defined by the user. Patterns are reported for a given run if the number of time intervals in which the trigger event occurs exceeds the reporting threshold set by the user (i.e., 50%, 75%, etc.). The user may then inspect these findings, run the filter again with a more refined trigger event, and so on as desired. Any patterns detected can then be used to forecast events and establish relationships to other activities. Figure 1 shows an example of a pattern that fits an absolute time cycle model, where the pattern is occurring every month.

Contiguous Time Cycle Events. In the algorithm just described, the user is looking for the recurrence of a particular event across a measurable interval of time. Rather than searching on the amount of time passing between occurrences of a single event, however, the user may be more interested in detecting the co-occurrence of two or more events within a nonstandard time interval. Thus the contiguous time cycle event is a simple extension of the absolute time cycle event in which the search is directed towards patterns of two or more events occurring across a series of time intervals. Contiguous pattern detection examples might include successive occurrences of telephone conversations, meeting contacts, or transactions in associated bank accounts.

As before, the user defines the trigger to be used in the search. The trigger is composed of the initial event and the user specifies the boundaries of the time intervals to be searched and the increments or decrements in interval size on each successive pass through the data. For every detection of the initial event, the algorithm gathers all data fitting within the bounds of the subsequent interval. This interval may be defined by the user as an interval following the trigger event, and interval before the trigger event, or both. Once a complete pass is made through the data, the algorithm searches for events contained in common across all intervals included in the pass. A pattern is defined as the repeated recurrence of an event in conjunction with the initial trigger event across the defined time intervals. Patterns are reported when the number of trigger events across intervals exceeds the threshold set by the user.

Figure 2 shows a sample diagram of a contiguous time cycle event. In this figure, there are a series of shaded time intervals for which the trigger event is depicted by an upward triangle symbol. Each event has a corresponding time/date stamp that can be used to determine whether it belongs in the interval following the trigger event. In this example, a pattern has been detected in that the trigger event is consistently followed by two other events (circle symbols) that both fall within the shaded time interval.

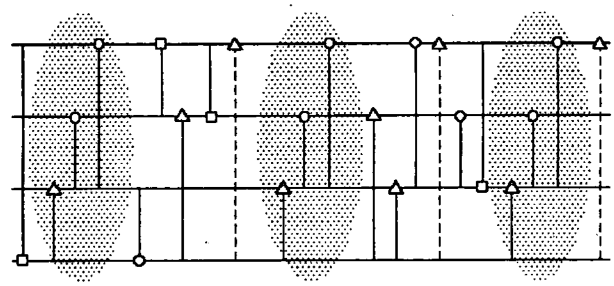

Figure 2 - Contiguous Time Cycle Event

Hybrid Time Cycle Events. There may be certain applications for which the user may wish to establish an interval as the period of activity between two cycle events or until the end of a cycle. We are in the process of developing temporal pattern detection algorithms for this purpose. All specification mechanisms defined for contiguous time cycle events can be used for configuring the hybrid time cycle events. However, the interval between events will be of varying duration that can be long or short in nature depending on the behavior of the object being reviewed. For example, when a certain amount of money is deposited into a specific account, it is observed that money is also removed from a different account within some specified time interval or preset number of observed events.

VISUALIZING TEMPORAL PATTERNS

Several methodologies have been developed for the display and analysis of outputs resulting from the temporal pattern detection routines described above. All of these are implemented as display modules in UIS's Generic Visualization Architecture (GVA), which is a nonproprietary system written in Java and which runs on virtually all computing platforms.

3D Grid Display. One of the visualization modules currently being developed displays the results of the temporal filtering process in a 3-

dimensional grid format. The functionality for this display module includes 3D rotation, drill-down and profiling of underlying data objects, user selection of data variables and ranges, as well as control over a host of other display features.

An example of how this type of display might convey temporal pattern information is shown in Figure 3. In this example an absolute time cycle event filtering operation has been conducted based on a trigger event of suspicious financial transactions (cash transactions over $10,000) within a group of participants on certain days of the week. The interesting aspect of the data presented in Figure 3 is the pattern of suspicious deposits occurring largely on Mondays across this group of participants. The pattern is stronger for certain individuals shown in brighter blocks within the grid.

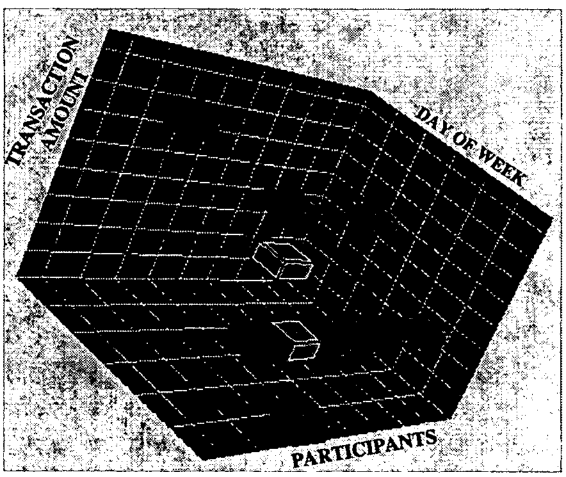

Figure 3 - Grid Display

Kiviat Display. Special circular histogram displays, called "kiviats" (or radar diagrams) can also be used to present high level summaries of the data reported from a temporal search. In these displays the user can present data from multiple dimensions (including the z dimension) with the values normalized against the mean of the data set if desired. The user selects all dimensions to be included in the display and these may be displayed either by value or by frequency. Values may be displayed when the user wishes to see the range of all possible values of a variable contained within a data set. On the other hand, one might with to display by frequency in order to ascertain the distribution of values across a database. This is particularly revealing in the case of discrete variables.

Figure 4 shows a temporal kiviat diagram in which the set of participants is represented in 2D and days of the week are represented along the z axis. The shape of the 2D kiviats indicates the frequency with which they participated in banking transactions for each given day. The reader will see immediately that more suspicious transactions occurred in this data set on Mondays than on any other day of the week. Using 3D kiviat diagrams, the user can visually inspect the data for important changes across the interval presented. Kiviats are ideal for illustrating trend-related information or correlations among a large number of seemingly unrelated events or observations.

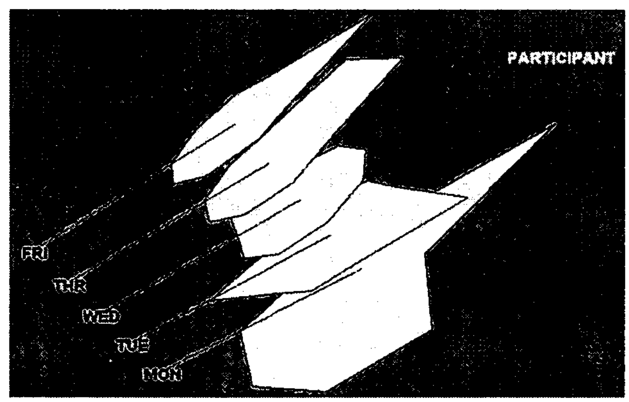

Figure 4 - Temporal Kiviat Diagram

CONCLUSION

To summarize, UIS has developed a facility in which analysts can do datamining and visualization of financial databases in order to observe temporal patterns that might not be readily detected otherwise. Algorithms have been developed to detect recurring patterns across absolute time intervals as well as contiguous patterns of events co-occurring within a given time frame. Because this work has been supported by ONDCP, government users may obtain the system free of charge to use in their own analyses.

Office of the Attorney General
State of Texas

DAN MORALES
ATTORNEY GENERAL

E.S.P.E.R.

A
Relational Database Analytical Tool

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Abstract

Data mining is a necessary and frequently underutilized aspect of financial crimes investigations. Often the investigator is faced with seized data sources (i.e. databases, spreadsheets, electronic documents, etc.) that are not easily or readily integrated with current law enforcement data tracking systems. In many instances the investigator does not possess the expertise necessary to integrate previously undefined data sources with currently available analytical tools. In a best case scenario an "expert" may be available to lend technical assistance where needed. This is not often the case. Tools for the average investigator are needed that will lend themselves to versatility and adaptability. These tools must be sophisticated enough to ***enable*** the investigator to perform data analysis that would have previously required technical expertise not typically available to the average investigator. This paper describes a system envisioned by the Texas Office of the Attorney General. Electronic Surveillance of Patterns of Entity Relationships (ESPER) is a system designed to allow the average investigator insight into the entity relationships, or relational structures, that may exist between seemingly disparate data sources.

INTRODUCTION:

The Texas Office of the Attorney General has had great success with its utilization of Bank Secrecy Act (BSA) data. Currency Transaction Reports (CTRs) prepared by Texas financial institutions or by financial institutions outside the state on behalf of Texas residents are maintained in a database that makes them readily available to investigators via a dedicated Novel[tm] server. Tight security is maintained while allowing maximum access to authorized users. Access is password protected. A sophisticated front-end package, the Financial Crimes Targeting System (FCTS), has been developed to allow non-technical users full access to the BSA data contained in the database. Investigators are able to search the database on any field, or piece of information, collected concerning financial transactions that have been captured by the system.

Often, other data sources are found that can conceivably be tied in with BSA data using fields such as Social Security Number, Address, etc. The data structures used within the Texas Financial Artificial Intelligence Targeting (TXFAIT) database lend themselves to these types of queries. Occasionally, however, a database is collected from a system seized during a search warrant execution. Obviously, such a database will not fit the TXFAIT model, and will not readily lend itself to analysis using standard query tools.

It is anticipated that those in charge of organized criminal enterprises will alter their tactics in response to the increased use of BSA data by law enforcement as current investigation techniques become common knowledge. To counter such developments, investigators will need a tool like ESPER. It will provide the versatility needed to continue productive analyses of relational data and enhance innovative approaches to financial as well as other types of crimes.

TECHNICAL SPECIFICATIONS:

ESPER is intended to be a "Smart" Data Mining Tool. It will be useful in any situation where a need for analysis of existing relational data exists. It is not intended as a database management tool, but may prove useful in some aspects of this area. It is intended to become the primary targeting system for investigators utilizing electronic data. It will greatly enhance the tools available to the typical investigator. Seemingly disparate data sources can often be inter-related using common data fields such as names, addresses, etc. ESPER will facilitate this process for the average investigator.

TXFAIT Support:

The TXFAIT database is the on-line system designed by the Texas Office of the Attorney General to store BSA data. This database is designed with security, versatility, and accessibility in mind. Specially designed procedures, or algorithms, must be followed to gain access to the tables. Support is being designed into ESPER to allow the user to open, search, and browse the supporting tables that comprise the TXFAIT database. Connectivity will be provided only after the user enters his or her unique TXFAIT password.

Query Designer:

This screen is the meat and potatoes of the ESPER system. In this screen all database query criteria are completely configurable by the investigator. Options exist to translate the request into Standard Query Language (SQL) code or a Quick Copy, cursor manipulation request. Query Designer sessions can be saved in a user specified file and retrieved at a later date for modification or execution. Information is stored with this file to allow ESPER to restore aliased connection to the necessary tables to perform the documented request.

SQL Code Generation: SQL requests can be generated from the Query Designer session. These requests can be executed within the ESPER environment, or passed to a native SQL engine if desired. Standard SQL constructs are provided through Graphical User Interface (GUI) menus designed to facilitate the query process. Support is provided to the investigator to introduce non-standard constructs into a query. An example of a non-standard construct would be to request the output of a function as a field, such as the FoxPro^tm TRANSLATE() function. This will allow the investigator to "massage" the data into a more desirable format. This functionality is provided to allow maximum flexibility during data mining sessions.

1. Quick Copy or Cursor Manipulation: This is often the fastest way to get at the data pertinent to the current investigation. When available it will beat traditional SQL engines for speed. ESPER will attempt to set up all necessary relationships, both one to one and one to many, using existing tags, or indexes. If Cursor Manipulation can be accomplished within the guidelines provided by the investigator then the Quick Copy and Quick Browse features will become enabled. This approach allows the investigator some control over the query method used.

   - *"Quick Copy"* is a term coined by the Texas Office of the Attorney General to describe a Cursor Manipulation scheme which allows the requested data to be quickly copied from a group of tables which have been properly inter-related. This method is the fastest way to extract data, but only works if the appropriate indexes exist. An SQL query will look at the complete database contents when determining what rows, or records, to extract. A Quick Copy is accomplished by first performing a binary search (a very fast database search algorithm) to locate the first row in the desired output. The data can then be copied while records fall within the stated search parameters. This allows the system to look at, virtually, just the rows being requested. Once the Quick Copy is completed the investigator will have access to a table containing information pertinent to the case.

- *"Quick Browse"* is a term coined by the Texas Office of the Attorney General to describe the Cursor Manipulation scheme which allows the requested data to be browsed or viewed. This is very similar to Quick Copy, but no data is actually extracted. Quick Browse is useful when the investigator wants to know if a target exists in the database(s).

Data Manipulation:

1. Importation: ESPER will provide full data importation features. Data can be directly imported from application files such as spreadsheets and external databases, as well as word processor files. If the source application can place the data in tabular or delimited format and export to an ASCII file or if an appropriate ASCII file exists, the data can be imported into a table for use in an ESPER query.

2. Exportation: As would be expected, ESPER can also export data in the formats identified above. In addition, extensive support will be provided to interface ESPER query results with NETMAP^tm^, a preferred visual data mining tool produced by Alta Analytics. A Graphical User Interface will be provided to the investigator to define, to ESPER, any externally selected fields. This will allow the automatic generation of Link Definition and Node Definition Files. These files are used by NETMAP^tm^ to generate a session.

3. Extraction: ESPER will provide the investigator with an extracted data set (database table), if desired. The extracted data set can then be imported into other database systems or spreadsheets for further analysis.

Presentation Generation:

1. Reports: Once a subset has been selected from ESPER a report can be generated. The report generator will be completely user configurable using the Windows^tm^ GUI environment. Standard Windows fonts will be available. Support will be made available to incorporate bitmaps and OLE objects into the reports.

2. Graphs: ESPER will directly interface with graph generating packages including MS Graph^tm^, Excel^tm^, and others.

3. Spreadsheets: ESPER will posses the ability to export directly to Excel^tm^ and other spreadsheet applications.

ODBC Support:

Open Database Connectivity (ODBC) is an evolving standard database access paradigm. The ODBC environment allows standardized access to most available commercial database packages. ESPER will support ODBC requests. Initially this support will be extensively tested with FoxPro[tm] and SYBASE[tm] databases. Eventually dynamic support will be provided to allow connectivity to previously unavailable database systems.

Applications:

ESPER will have many applications in addition to Financial Crimes Investigations. Interest in ESPER has already been expressed by the Texas Department of Banking. The versatility being built into the ESPER system virtually eliminates specialization of the product. The ESPER system will prove extremely valuable in all data mining attempts against standard relational data structures.

1. Financial Crimes Investigations: The primary goal of ESPER is to provide a versatile surveillance tool to aide in the investigation of financial crimes. Special support will be provided, as an option, to connect to the existing TXFAIT database system. The TXFAIT data dictionary will be adopted as the ESPER standard to aide in the automation of certain features, such as the exportation of a query to NETMAP[tm], that will be provided to the investigator.

2. Regulatory Agencies: ESPER will lend itself to a plethora of data mining applications. The Texas Department of Banking (DOB) has requested the Texas Office of the Attorney General's help in utilizing the regulatory data they maintain. ESPER will be provided during beta testing. This will fulfill the DOB's needs and, at the same time, provide the OAG with a valuable end-user testing environment.

Portability:

ESPER is being designed with maximum portability, within the PC environment, in mind. Network support will be built in as an available option, where appropriate. It is envisioned that ESPER will be made available to investigators in the field. In such a case ESPER will be loaded on a stand-alone notebook or compatible. Specific support will be provided to allow utilization of the TXFAIT database. TXFAIT does not have to be available to enable access to ESPER.

SUMMARY:

In today's world of technical sophistication it becomes increasingly difficult to stay on top of the often more inventive criminal element. The criminal investigator often lacks the degree of technical expertise available to the "crooks". ESPER is intended to be a non-specialized, innovative, versatile, and highly adaptable analytical tool. It is intended to interface with other existing tools including the TXFAIT database and NETMAP^{tm}. ESPER will provide the Financial Crimes Investigator with a standard GUI for easy access to seemingly disparate data sources. ESPER is a system that can be produced using existing technology.

Sharing is VITAL

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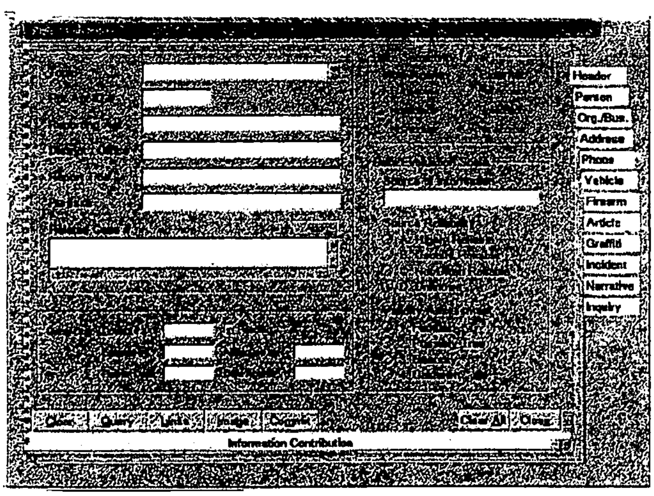
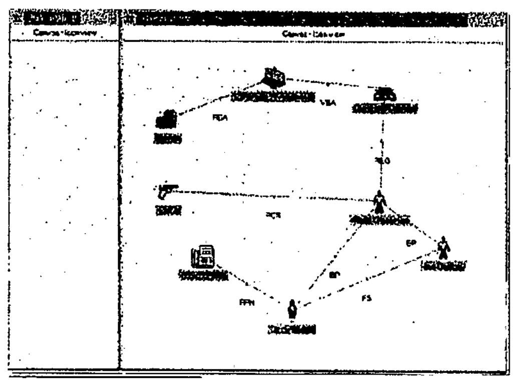
Current and emerging technologies have created unprecedented opportunities for the law enforcement community to share information for crime solving and crime prevention. **VITAL**, (Violent crime Information Tracking And Linking) the Illinois State Police's intelligence reporting system, has been developed to exploit those technologies. VITAL is a powerful on-line intelligence reporting system of robust tools built on a central-resident database for sharing by potentially all Illinois law enforcement agencies and law enforcement partners in contiguous states.

Among VITAL's collection of tools is the ***Information Notebook.*** The notebook has been designed



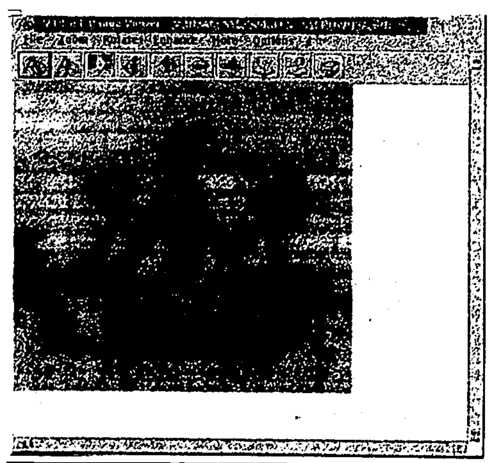
to allow for easy entry and query of intelligence data. The notebook design fosters compliance with federal guidelines for collection and dissemination of intelligence information.

The ***Links Canvas*** graphically depicts relationships between information in the database by interconnected icons showing those affiliations.

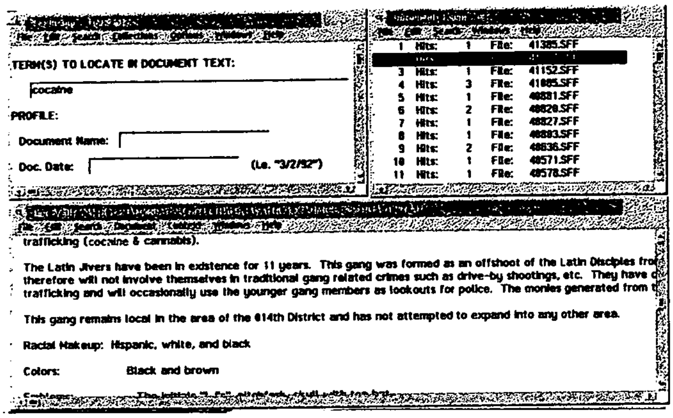


These graphical associations will become more crucial to the analyst and investigator as the database is increasingly populated.

The ***Image Viewer*** allows associations to be made between images and information in the database. These images include photographs of persons or items, official documents, maps, blueprints, etc. Building these associations especially renders the system a powerful crime fighting tool.

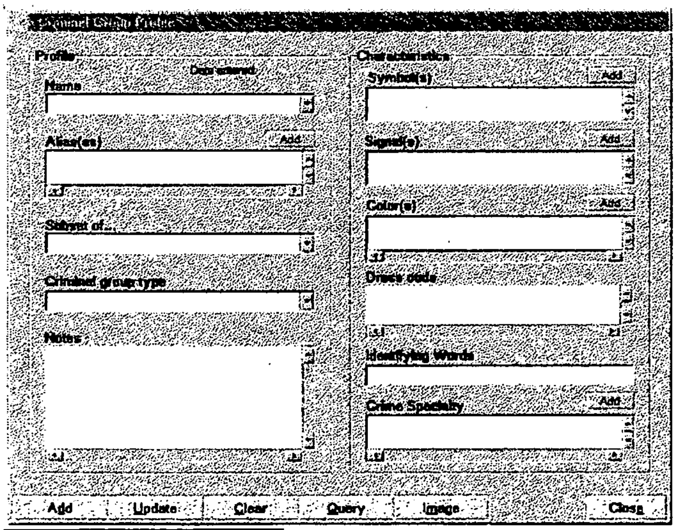


The *Text Indexing and Searching* tool provides



capability to search any computerized text file for any word or phrase. Documents containing the searched criteria are instantly revealed for users' review.

The ***Gang Database*** contains pertinent information about established gangs, and can be linked to associated images. This includes gang colors, signals,



signs, dress codes, etc. VITAL users can take advantage of this tool to learn more about gangs and how they operate.

Recent establishment and statewide deployment by the Illinois State Police of Resource Support Centers will facilitate sharing of information and resources, with **VITAL** as the hinge pin to intelligence information sharing among partner law enforcement agencies. These support centers have been strategically placed throughout Illinois, bringing analytical support directly to the field.

Support center personnel, consisting of employees from contributing agencies, are challenged to bring about a safer community by facilitating a free exchange of assets and information through enhanced coordination and communication. The centers are open to all law enforcement agencies, educational institutions and appropriate community and private agencies to share information and resources within the confines of the law. The support centers are designed to help law enforcement meet challenges of the future by encouraging a cooperative effort to build a solid coalition and help citizens reestablish ownership of their communities.

Counterdrug Mapping, Tracking and Databases Position Data Gathering (PDG) System

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ABSTRACT

As the nation's war against drugs approaches the 21st century, law enforcement agencies (LEAs) are seeking to incorporate increasingly advanced technologies into their operations. One major area of focus has been the integration of vehicle tracking linked with geographic and textual databases for case tracking, pointer index and database technologies which will support the inclusion of non-traditional sources of data needed for demand reduction, which in turn will be linked to active efforts focused on supply side reduction operations.

The Counterdrug Mapping, Tracking and Databases program, sponsored by CTAC and currently underway at the Yonkers Police Department, will produce a low cost law enforcement integrated package offering a scaleable product providing such capabilities.

The package, when completed, will comprise a palmtop computer based GPS tracking and data logger; micro-controller based GPS tracking and data logging devices equipped with a Motorola radio modem operating on the GE/Ericsson RAM network; a cellular based GPS tracking device designed for covert tracking; mapping and tracking application software capable of tracking sensor-equipped vehicles; analysis of active tracking data; real-time and post process differential correction of stored or transmitted tracking data; geo-coded databases for demand tracking with input forms to enter demand information; ability to display demand status using Pin Maps and Thematic Maps; geo-coded pointer index database able to display leads in textual forms, images and Pin and Thematic Maps.

An additional innovative feature proposed for integration into the project relates to community involvement. Information relating to drug sale and consumption locales unknown to the police, provided by the community and incorporated into linked demand-reduction/supply side reduction databases, would greatly enhance the system's capability to target critical areas for enforcement operations.

Biographies

Detective Lieutenant Josh Landers is the commanding officer of the Narcotics Division of the City of Yonkers Police Department. He entered the police service twenty four years ago and has an extensive background in narcotics, organized crime and technical investigations. He is presently enrolled in a BSc/MSc Criminal Justice program with a concentration in geo-location and information systems at Mercy College in New York State.

Yukie Novick is President of Integrated Systems Research Corporation (ISRC) and earned a BS in Electronics from Jerusalem College of Technology.

Morris Levine holds a MS in Aerospace Science from USC and has an extensive background in military and intelligence operations.

Introduction

For the past several years, Integrated Systems Research Corporation (ISR) has been developing and integrating software and hardware technologies that are being applied by different drug and law enforcement agencies for mapping, tracking, surveillance, communications, and information exploitation. At the base of these technologies is ISR-MAP, an elaborate mapping system that runs on different platforms, including DOS, MS-Windows, UNIX, X and Windows 95. ISR-MAP is used as a common background for the display and exploitation of:

- Real-time tracking using remote position sensors. This is accomplished primarily by covert emplacement on suspect platforms.
- Self-tracking in air and ground vehicles. A GPS unit installed on the vehicle provides self-position data which can be displayed on a laptop PC.
- Unattended tracking and data gathering, and off-line display and analysis. This is the "data-logger" approach, i.e., the continuous gathering of position data and information retrieved periodically via remote link.
- Local and remote map overlays. All associated software provides complete mapping in vector format, and the capability to overlay other map data as required.
- Message exchange between surveillance units and base takes place either through the exchange of analog messages, text, or the commanding of the remote unit by the base station software.
- General purpose database management applications for law and drug enforcement. These tend to be relational programs tailored for use by the particular jurisdiction.
- Bi-directional data exchange with commercial relational database management systems, which take full advantage of such tools as ODBC or, more recently, DAO standards.
- Case management, mission deconflicting, dynamic personnel management linked to mapping and tracking. These approaches provide a common GIS theme and overlay to multiple sources of information.

Position Data Gathering (PDG) System

YPD has long sought to employ a suite of navigation, surveillance and command systems which would reduce or overcome several of the operational problems faced by our investigators and supervisors. As local law enforcement officers, they have limited assets which must be continually reused. These assets, nondescript vehicles and undercover officers, must be deployed in geographically small and densely populated areas, increasing the probability that the subject/defendant will quickly discover a surveillance or the presence of an undercover officer.

Combining the latest mapping and geographic databases with high-technology tracking devices enables the investigators to surveil and track suspect targets without physically following the suspect. Using these technologies, precious resources are not quickly compromised; moreover, these same costly resources can be freed up for assignment to other tasks. In addition, officer safety is enhanced, since for many surveillance situations the suspect may be observed remotely.

The PDG system has answered the pressing need of YPD narcotics investigators to organize tracking and surveillance data gathered by many different investigators and to display that information in the context of other, relevant investigations. The information is displayed in "overlays," "symbols" and "icons" of known or suspected drug trafficking sites, or remote database information such as property ownership and other attribute information.

The program was divided into two phases. Phase I was to focus on rapid prototyping a position data logger that would be installed in vehicles conducting surveillance and extracting the data files into a base station for analysis purposes. In Phase II we intended to further enhance the system, adding communications to the data logger and possibly integrating covert tags as well as related databases.

A major emphasis of this program was to exploit commercial off the shelf (COTS) and Government of the Shelf (GOTS) hardware and software in an effort to make the system affordable, yet modular and scalable for any small, medium or large organization involved in drug and law enforcement

The Phase I system is deployed, and we are currently in the final stages of Phase II where the system is iterated and further enhanced based on lessons learned from actual system use to a point where at the end of the program, a well thought out tracking, surveillance and analysis product will emerge that will be made available to the drug and law enforcement communities.

Phase I - DOS based prototype system

In order to achieve our main goal of prototyping a system that will be truly affordable to a small to medium-sized police department and at the same time offer a modular and open approach to system expansion for the medium to large police organization, it became clear that our system had to have an architecture that would permit a configurable system supporting low cost (under $1000) position logging devices and at the same time the more sophisticated and more costly remote position sensors (ranging in price from $3,500 to $11,000) that could be installed as covert tags on suspect vehicles. Furthermore it was clear that the software had to be simple to use and at the same time offer full GIS capabilities with accurate street maps, map overlays, archive and replay capabilities for analysis purposes. To achieve these goals ISR and YPD conducted an extensive analysis of available hardware devices that could be installed in the surveillance vehicles without any significant modifications and would allow quick integration with the ISR-MAP product.

The primary criteria used for this analysis included:

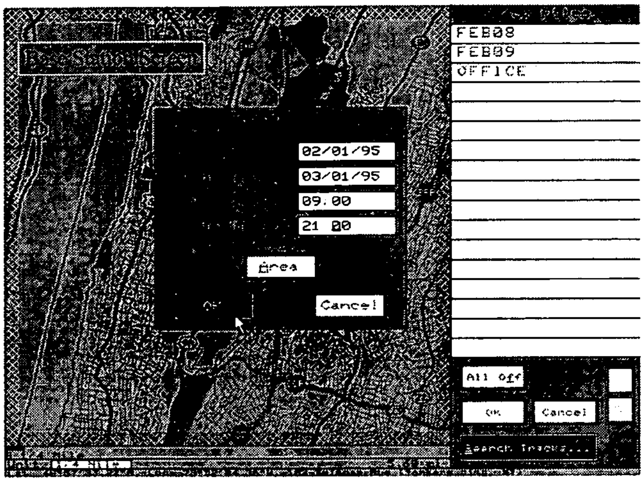
- Very low cost, commercially available
- Device Accessories and repair readily available
- Run on standard batteries found in any drug store
- Require minimum to no training
- Could be left unattended in the vehicle
- Operate for several days without changing batteries
- Small , lightweight and not draw attention
- Store position data for at least one week. This requires sufficient microprocessor memory and good microcode implementation, along with low power needs to optimize battery life.
- Simple to upload files to base station. Good implementation enables an ability to retrieve remotely all stored information.

Phase I Hardware

After the review of many mobile computing devices we determined that the best choice for our device would be an HP Palmtop computer. These palmtop computers were originally designed as a programmable pocket personal organizer. As a result, their design incorporated extremely low power components that operate standard AA batteries that could last for weeks without charge. Furthermore, they were lightweight, very small and available in most electronics stores.

Phase I - Software

Base station software :



The Base Station software is based on the NavTrack program, which has been in use by various Federal Law Enforcement agencies for many years. In this way, the YPD program gained uniformity with other programs in use throughout government, but with a customized interface for the YPD operations.

The program has full mapping features and can be used not only to display data derived from the PDG system, but can also be used as a general GIS to support YPD operations. Detailed vector and raster maps are provided to display the surveillance area and replay of information gathered by the PDG devices.

In Phase I, all information was gathered on the HP Palmtops and GPS information reflected the time/location of the surveilling YPD teams assigned to the case. Upon return to the office, all information is easily downloaded from the Palmtop to the base station PC. Once downloaded, tracks can be replayed and case information can be entered directly on the PDG application display.

Overlays can be developed by the case officer and these become part of a local database for the PDG system. The case officer might want to overlay a shaded and colored polygon, for example, to denote a high-crime area or area of operations or interest. Likewise, identifying icons are easily placed on the display to denote key aspects of the surveillance situation. These also become part of the local database and provide a visual information display to aid YPD personnel in developing case information and details.

All case information is archived, including track information. The archives permit track replay and reconstruction, as well as recall of all local database information containing comments, overlays, and other information.

Position Data Gathering (PDG) software

The PDG software included the development of software to drive the data-gathering capabilities of the HP Palmtop, as well as simulating palmtop operation and displays on a PC. This provided the ability to gather data effectively while in the field, and then to retrieve and display information on the PC in a manner minimizing interface capabilities. A Palmtop communications driver was developed to provide the bi-directional interface required for Palmtop-PC integration. A special upload protocol was developed to enable easy transfer of data to the PC for analysis.

Throughout Phase I, the GPS units interfacing to the Palmtops were off-the-shelf Garmin 75's. These provided the necessary accuracy and other performance criteria needed to provide effective position fixes and data gathering in support of surveillance operations. The Garmin-75 proved to be an effective piece of hardware with excellent performance characteristics. GPS position information gathered by the Garmin was only stored in the Palmtop when the vehicle was moving.

PHASE II

The Phase II program is designed to build upon the successful field use and implementation in Phase I. Improvements will include the addition of new sensors and other capabilities to further enhance operations and to better support actual field operations.

The main goals are to:

- Increase position accuracy through use of DGPS technologies.

  The well-known inaccuracies of Selective Availability cause nominal position inaccuracies of up to 100 meters (>300 feet). For urban operations, errors of this magnitude can cause surveillance problems and particularly during real-time tracking and surveillance may well indicate the wrong location for the suspect. To overcome the inaccuracy problem, Differential GPS (DGPS) may be employed. There are two basic approaches to implementing DGPS. The first is through the use of hardware or subscription to commercial DGPS services. Both of these are costly alternatives, requiring special equipment and adding to the overall cost of operation. The second approach is to implement DGPS through software processing, requiring only the establishment of an accurately surveyed reference point and then the implementation of the software to permit processing of undifferentiated GPS data and correcting the information. This can provide an order of magnitude improvement (on the order of 10m) in position accuracy. Phase II PDG will provide this software DGPS capability.

- More robust PDG (SPM-2000)

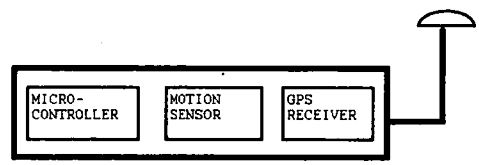
Significantly greater capability (than the HP Palmtop) will be provided by the inclusion of a very robust sensor, the SPM 2000. The unit is contained in a 4.4" square metal box, only 1.3" high and houses the following components:

1 A smart microcontroller board

2 A GPS receiver (including an external connection to a GPS antenna).

3 A motion sensor

A block diagram of the SPM 2000 basic unit is shown below.



The SPM 2000 microcontroller board is based on a state-of-the-art single chip Hitachi microcontroller, which includes the following main features:

- 2 -5 MIPS processor
- 2 RS232 ports
- 8 A/D inputs
- 16 digital I/O lines
- Internal counter/timers
- Very low power consumption

The board also includes:

- Motion sensor
- 128K RAM
- 1 MB Flash ROM for position storage and software
- Low power AC/DC conversion
- Power switching to GSM and GPS units
- Option for two line LCD display units

Option for an additional RS232 port

A new generation Windows mapping capability will be provided as well. The transition from an earlier DOS environment to Windows will provide a more powerful mapping and tracking software tool than was possible with the first generation program. Much more powerful tools to construct overlays and incorporate additional mapping features are provided. In addition, the use of a Windows-based application, provides the opportunity to employ such standard Windows programming tools as DDE links to external databases. This will allow YPD to employ RDBMS applications in support of their operations and link directly with the map application for visual display of data.

A covert cell phone-based sensor will also be provided to YPD in Phase II. This will be a version of the TraPS sensor which is in widespread use by the law enforcement community. Among the advantages of cell phone-based sensors is the very ubiquity of cell phone coverage, which allows very wide areas of coverage for ongoing operations. In addition, the TraPS sensors have an option to enable audio surveillance in conjunction with GPS-based tracking.

At the conclusion of Phase II, a product with many different software and hardware components will be available to the overall law and drug enforcement community. Agencies should be able to pick the components they need for counterdrug surveillance operations and implement them at relatively low cost.

Phase II Hardware

The Phase II hardware will introduce additional capabilities as described above, but will also be backward compatible with the Phase I system. The Palmtop PDG will continue to be supported by the Phase II system, as well as the ability to employ the more advanced SPM-2000 sensor.

The Base Station will be enhanced not only with newer software, but will include the DGPS capability for improved GPS accuracies. The software-based DGPS computational capabilities also provide differentiated information at a lower implementation and operating cost than conventional means.

The other major addition will be the use of the TraPS cell phone sensor for remote position monitoring. These types of system sensors employ cell phone technology as the means for bi-directional exchange of data between the sensor and a base unit.

Phase II Software

The Windows-based software, described above, will provide enhanced capabilities not present in the Phase I system and will include integration/interface with the new SPM sensor.

A major portion of the work will be the development of the software-based DGPS differential correction capability. This has only been done a few times in the industry and never done, to our knowledge, to support real time law enforcement operations. The usage of differentially corrected data will significantly enhance the operational utility of the program, particularly in crowded urban areas.

In addition to the support of the SPM sensor and the integration of the DGPS capability, the Windows-based program will be designed to work with additional sensors, e.g., the TraPS units that will be supplied.

The Phase II system will also provide the capability to interface to many different kinds of database applications as well as to additional mapping capabilities, such as a Thematic Map program and Deconflicting, which provides both a database record as well as map displays of operations occurring between multiple agencies in the same space/time.

This phase of the program will also deal with databases incorporating non-traditional data sources in an effort to analyze and deal with supply side reduction efforts and tie those to the more traditional demand reduction efforts.

At the conclusion of the Program, there will exist essentially a product that can be employed throughout the drug and law enforcement communities that will provide a GIS capability, mapping and tracking, remote surveillance and covert sensors.

Summary

The YPD PDG hardware and software is a total concept for the application of geographic technologies tied to RDBMS applications, focused on counterdrug efforts. Phase II is designed to build on the foundations of the first part of the program and deliver new capabilities for remote and covert tracking, as well as more accurate position-fixing and improved database capabilities. Everything developed and delivered in Phase II will be backward-compatible with Phase I components.

The architectural approach provides a modular design and an open architecture that enables the addition of new capabilities with minimum development. The design approach also permits linking to various database applications to further aid the investigative and analysis processes.

The completion of this program will provide a "product line" of capabilities for the law and drug enforcement communities based on solid technologies and tested in a harsh operational environment.

Data Collection during Operational Deployment of Explosive Detection Equipment for the White House Commission on Aviation Security and Safety

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ABSTRACT

The White House Commission recommended the procurement of $144M of aviation security equipment to be installed and operated at many of the nation's major airports. Congress approved a supplemental appropriation of $144M and an Integrated Product Team (IPT) was established within the FAA to procure, install, and provide for the operation of this equipment. This presentation will address the methods being used to collect from a central location the data acquired by this equipment and the safeguarding of the computer systems to prevent unauthorized disabling actions. The collected data will be analyzed to measure systems performance. Equally important is the task of training and retaining the operators of this equipment. Data on the performance of individual operators will allow the aviation security community to assess the validity of training and longevity in the job. The centralized collection system is currently being developed and is anticipated to go on line in early 1998.

1. Introduction

On July 19, 1996 TWA flight 800 crashed into the Atlantic as it ascended out of New York's JFK Airport. In response to the uncertainty surrounding the cause of the crash, President Clinton formed the White House Commission on Aviation Security and Safety. In their initial report issued September 9, 1996, the commission cited shortcomings in the security of the nation's airports. In particular, the commission cited the lack of modern baggage inspection equipment despite the fact that much of it was manufactured in the U.S. and it was being installed in airports in other countries around the world.

At the end of FY 1996, in response to the commission's report, Congress appropriated $144M for acquisition and installation of explosives detection equipment at United States Airports. The monies were designated for Trace inspection equipment at the checkpoints, for operator training systems, for operator testing equipment to be retrofit to existing X-ray systems, and for state of the art checked baggage inspection systems, particularly the CTX 5000SP.

Given the responsibility of acquiring this equipment, the FAA decided that it was necessary to collect as much data as possible about the operability of these systems as they were deployed. Because of the number of systems and

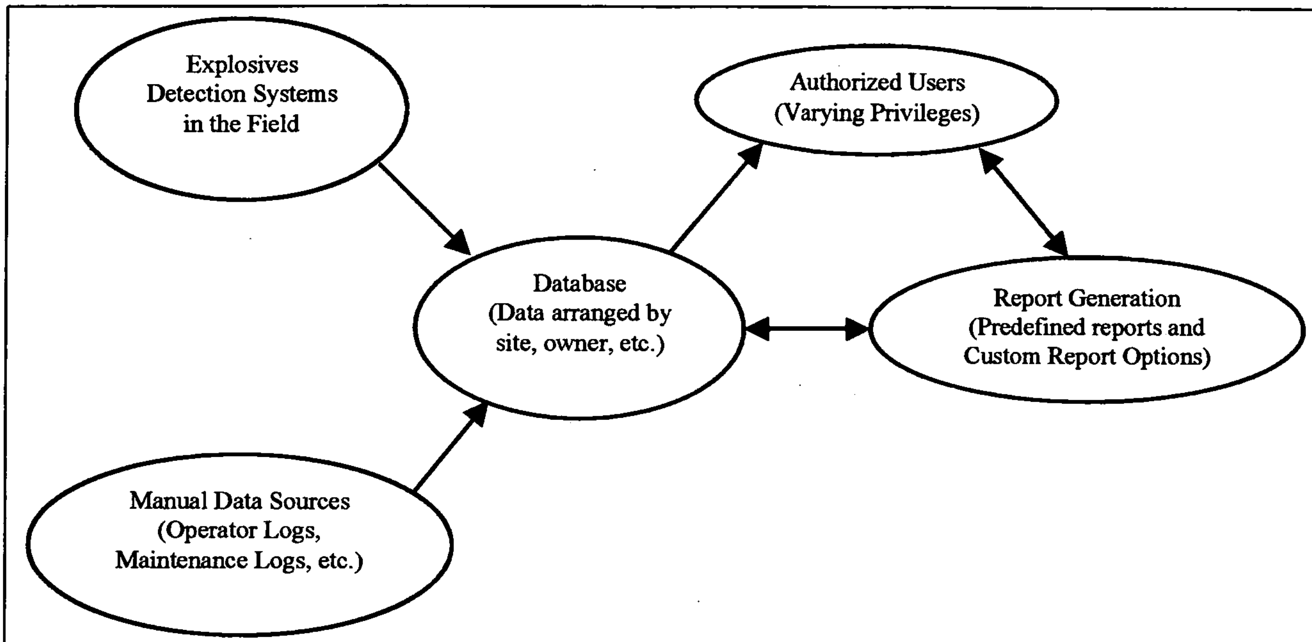

Figure 1: Data Flow

the geographical spread of the installation sites, manual collection of such data was expected to require a significant level of manpower. In order to manage this problem and reduce the manpower requirement, the FAA decided to develop a centralized data collection system, to collect automatically generated data wherever possible. Initially, this database will collect data from those machines that can most easily accomplish automated export. Eventually, all data of interest to the FAA would be collected in this database, though some manual collection may still be required.

2. Data Flow

The intent of this database is to allow each authorized party to monitor the operations of equipment for which they are responsible. Data would be generated at the inspection sites in both automated and manual forms. Inspection equipment would be modified to collect data where appropriate. Remaining data that the systems can not reliably record (system down time, maintenance records, search results, etc.) would be collected through manual logs. These would include both those collected on paper and in some cases on a computer terminal. The database system must be designed to assure efficient collection of this information.

Data access is also fairly demanding. The FAA intends to allow each airline's corporate office access to all data on their systems, but not those of other airlines. Additionally, each local airline office will have access to their local sites, but not other sites. FAA officials would need access to data on all systems. Consequently, the data must be segregated in the database such that inappropriate access does not occur.

The users will have access to both their raw data and analyzed results through a report generation capability. The report generation is expected to have some predefined reports the user requests. Depending on efficiency, the reports could be generated off-line based on previous user requests. If possible, the user would be offered a custom report option as well. This would be used to do analysis of particular interest to that user.

In summary, the database system must allow the user to download raw data, produce predefined reports, and design custom reports. The next section discusses some of the measures that might be included in reports.

3. Data to be Collected

The FAA and airlines are interested in collecting a wide variety of data on the systems' operability. In particular we are interested in operational effectiveness, system efficiency, system health, system utilization, and system reliability, maintainability, and availability (RMA). Operational effectiveness refers to the system's ability to provide protection against the introduction of improvised explosives devices (IEDs) onto the airplane. It would include measures of the machine's ability to alarm in the presence of an IED as well as the operator's tendency to remove IED containing bags from the baggage stream (either by referring them to hand search or turning them over to local law enforcement). System efficiency refers to the system's ability to process bags quickly. It includes measures of false alarm rate and baggage throughput rate. System health refers to the condition of the system. Are any components malfunctioning? Has the system slipped out of calibration? System utilization is a measure of how often the system is used (hours per day, bags per day). Finally, the system RMA is a measure of the reliability of the machine. How often was it down? How long did it take to repair?

All of this data is available for each of the baggage inspection systems being deployed by the FAA. Its potential for automation, however, varies depending on each specific technology. As an example, we will discuss the InVision CTX 5000SP that has been modified to automatically collect much of the raw data necessary for calculating the measures cited above.

4. CTX 5000SP Data Collection Capabilities

As part of the FAA's airport testing of the CTX 5000SP, the InVision system was modified to automatically export operational data to a networked workstation. The idea was to minimize the data collection workload of the participating airlines. The workstation was equipped with a database designed to collect, store and reduce the raw data from the CTX, automatically producing reports on the measures listed in the previous section. The CTX exported a record for each bag it processed. The record contained timing data on when the system requested its next bag, when it received it, when it rendered a decision, what that decision was, and in the case of alarmed bags, when the operator started and finished examining a bag. These data allowed for the calculation of the system efficiency statistics (throughput, false alarms, etc.) and the system utilization statistics (number of bags processed per time period, fraction of time in use, fraction of time spent waiting for a bag, etc.). The code for collecting the data worked reasonably well. Unfortunately, due to significant problems with the export code and the database, much of the data was lost.

Since the code for collection did function adequately, it was retained and modified for the next generation of data collection. In the new system, the CTX still generates a record for each bag processed. It does not, however, export them individually. Instead, it writes the records to its own disks for retrieval at a later date. These local records are to be maintained for 1 year regardless of the number of times they are exported. This provides redundancy in the data storage to minimize the potential for data loss.

System effectiveness data will be provided through a second modification to the CTX. Through a FAA grant, InVision developed a Threat Image Projection (TIP) capability for their system. TIP is used to both keep the operators' interest and to measure their effectiveness. The TIP images are produced offline by creating an IED, inserting it into a bag, and recording all possible CT slices to disk. On a random interval, the TIP system substitutes an image from the TIP library for the image of the current bag. The operator is unaware that this is a test image and inspects the image as they would any alarm image. Their response is monitored by the system and recorded. This provides a measure of each operator's ability to differentiate between real threats and false alarms. For our purposes, the data is exported by the CTX as it is for any other real bag. In this case the bag record contains a flag indicating that it was a TIP bag. The TIP bag records can be accessed independent of the regular bag records allowing us to compile data on each operator's effectiveness.

System health data will be collected as results from a daily image quality test. At the beginning of the day, the operators will put the machine into a test mode and run a specially designed bag. The system uses this bag to test its ability to accurately reconstruct an image. The bag contains phantoms for checking the system resolution, CT number generation, belt registration, etc. The system calculates measures for each of these phantoms and then verifies that the result is within the acceptable range. If it is, the operator is told to continue with operation. If not, the operator is told to call for maintenance. Regardless of the overall result, the individual results are written to disk and kept there for a minimum of one year. This data would be down loaded as a separate file from the bag data. By collecting the individual results of each of these tests, we hope to determine if certain aspects of the system are subject to degradation. It will also tell us if some of the machines are significantly different from the rest.

Currently, this collection is strictly limited to storage on each CTX system's disk. As part of this effort, the CTX will be modified to allow for automatic exporting of the files. On a yet to be determined interval (daily, weekly, etc.), each CTX would make contact with the central collection system to dump accumulated data. This modification should be fairly straight forward as the data is already being collected into files. As we deploy other equipment, we anticipate that they will be modified to export appropriate data as well.

5. Access and Security Issues

One of the greatest challenges of this database system development will be to provide access to all appropriate parties while keeping the information secure. As we stated previously, the system must prevent users from accessing data for which they are not authorized. At the same time, we must prevent terrorists from accessing the data to prevent them from identifying potential weak spots, as well as protect the data and hardware from potential tampering. This will require multiple levels of access authorization. It also requires selection of hardware and access protocol that discourages unauthorized access.

The CTX 5000SP are the most important part of this system. They are providing the actual security against IEDs. Consequently, we can not allow tampering with these systems. If a CTX were configured to wait until called by the central system, it would be open to mischief. An unauthorized party could intercept the data by "hacking" their way in and requesting it. Worse yet, and more probable, an unauthorized party could access the machine and render it useless by tampering with key files. Instead, we anticipate configuring the CTX systems to call the central system at predetermined intervals. This should prevent unauthorized access to the actual inspection systems.

For users accessing the central system, we are considering both Internet access and modem access. Internet access is attractive because of its popularity; however, it has both security and speed drawbacks. First, the database would be widely advertised. As we only expect a small pool of authorized users, this provides little benefit while exposing us to a wider range of potential intruders. Second, access is hard to trace. It is fairly trivial for a hacker to create a non-existent machine address or to access the system through several intermediate machines in order to cover his tracks. Further, most Internet users are familiar with the delays associated with accessing data on web sites. The delivery speed would be dependent on the current loading of the Internet, which can vary widely during the day. On the positive side, security protocols are being developed for conducting business on the net. One of these "off the shelf" protocols may prove adequate. Also Internet access is wide spread and the FAA's William J. Hughes Technical Center currently has a large bandwidth connection for its normal operations. This connection could be augmented to handle the average load of the database system. Excess bandwidth would be shared by the database and the normal operations to handle peak loads in either.

Modem connectivity also has plusses and minuses. Since it is likely that the data would be collected via modems, we would already have a bank of modems available. It is likely however, that we would need additional units to accommodate the user calls as well as the machines. Further, we would need to have enough modems to accommodate the peak load rather than just the average. Consequently, we would have a large initial investment or suffer more busy signals than we would like. A bank of modems is no secure fortress either, but it has some advantages. First, the system could be set up to shut down after a few missed logins. Second, the system could be set up to only accept calls from traceable (caller ID) numbers. Incoming numbers would be recorded, providing a trail back to anyone causing mischief. These measures can also be circumvented, but require more resources than similar measures on the net.

6. Conclusions

Collecting data on the deployment of security equipment to airports is critical in determining their value and in optimizing deployments in the future. Due to the large quantity of data, the wide geographic area, and tight manpower restrictions, we must automate the collection wherever possible. This is particularly true in the collection and distribution of the information extracted from the data. Access to the data will have to be controlled to prevent tampering. The final product of this development will have to address each of these concerns while remaining user friendly enough to encourage continued use.

Chemical Sensing Methodologies (Session 3A-4)

DETECTION AND IDENTIFICATION OF DRUGS AT CRIME SCENES

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ABSTRACT

Tackling the drug's problem by targeting and prosecuting dealers and those involved in trafficking is one of the National Policing Objectives for UK Police Forces. Nottinghamshire Police have developed and applied a comprehensive field test service for the detection of drugs at crime scenes and on suspects, and to the identification of suspicious substances. We use Ion Trap Mobility Spectrometry (ITMS) for trace work and a combination of ITMS, NIK chemical tests and TICTAC CD ROM for identification of substances and tablets. ITMS has proved to be sensitive, rapid, reliable and transportable. Our results are reported during the operation and before the first interviews with suspects and this has given the investigators a vital edge. ITMS evidence has been presented, challenged and accepted in the UK Magistrates and Crown Courts.

1. INTRODUCTION

To effectively support Police operations against dealers and traffickers we need to be able to quickly test suspicious substances and detect and identify traces of drugs on various surfaces. Vehicles and property belonging to known dealers can be quickly tested for traces to determine what drugs are being handled. Suspects can be charged and prosecuted expediently if investigating officers know the identity of the substance prior interviewing the suspect. When a test purchase has been made the investigators need to know if the suspicious looking white powder is an illegal drug before considerable police resources are spent on surveillance and investigation. We have been encouraged by other Drug Enforcement Agencies [1,2,3,4,5], who have either successfully applied Ion Mobility Spectrometry (IMS) to operational work or have conducted extensive benchmark evaluations on IMS instruments. These portable analysers have been designed to be extremely sensitive, robust and reliable under operational conditions and they are simple and quick to operate. They can detect traces of drugs and can simultaneously screen for a large number of different drug compounds.

A CD ROM image library of pharmaceutical and illicit tablets is commercially available and provides a method for verifying the identity of a tablet or capsule by its general appearance and weight.

The NIK Chemical polytest system provides a multi stage colourmetric presumptive test for a range of commonly encountered drug types and it is very convenient for field testing substances.

In Nottinghamshire we have applied all the above methods to operational police work.

2. EQUIPMENT

An ITI Cambridge Itemiser Ion Trap Mobility Spectrometer operating in both positive and negative ion modes was used for this work. Samples are collected onto filter papers using a hand held vacuum pump. With this device only the sample trap paper comes into contact with the subject.

A description of the theory of ITMS can be found elsewhere [3,6].

Initially we used a Suzuki Supercarry van as a mobile laboratory but have more recently progressed to a Ford Transit. This vehicle is fitted with a laboratory bench, flooring and a thermostatically controlled electrical heating system. The Itemiser is not switched off. By remaining active the instrument can decontaminate and achieve excellent stability. A 12v/250v voltage converter allows the vehicle alternator to be used to generate sufficient current to power the Itemiser during operations.

The Becton Dickinson NIK System employs a series of colourimetric comparisons for presumptive identification of Cannabis, Heroin, Amphetamines, Opiates, Methamphetamine, Barbiturates, LSD, Cocaine, Methadone, PCP(Phencyclidine), Morphine, Codeine, Methaqualone, Pentazocine, Propoxyphene, Diazepam and Ephedrine. Each test pack contains the chemical required to perform the desired test in pre-filled, hermetically sealed glass ampoules. This eliminates the need for measuring, mixing and dispensing of reagents. It is safe, quick, and very easy to use. The identification is based upon a polytesting procedure whereby a suspect substance is subjected to a series of progressively discriminating screening tests. Suspect substances, tablets and capsules can be tested. The tests do require mg quantities of sample and can therefore not be used for trace work.

TICTAC (The Identification CD-ROM for Tablets and Capsules) is a software package containing an extensive library of 25,000 images for 11,000 tablets, capsules and patches. This includes illicit tablets and capsules received at the Forensic Science Laboratory and designs of various LSD squares. The database is updated every 3 months by the supplier, Chapman & Hall Electronic Publishing Division. The software was operated from a portable lap top computer. The operator selects options for the physical description of the suspect tablet i.e. markings, logos, shape, colour, dimensions, weight. This information is searched against the database and a list of images that match the criteria is produced for viewing. Other useful information such as legal status, street slang, chemical structure and details of suppliers is also given. It is also possible to search using names of ingredients or product names. A set of accurate (+/- 0.05mm) engineering callipers for measuring tablets and an accurate (+/-0.01g) electronic balance for weighing were used.

3. ITEMISER ANALYTICAL METHOD

3.1 Itemiser Conditions

Methylene chloride reactant ion gas is used for negative ion detection mode and Ammonia is used for positive ion mode. In general a 2 second pre-integration time delay followed by 4 seconds integration time was used for data acquisition.

3.2 Itemiser Calibration

Standards purchased from Sigma/Aldrich Company are used to provide reference materials.

3.3 Preventing Contamination

The Itemiser is not taken into scenes but operated in the clean environment of the Mobile Laboratory. Experience has shown that in dwellings where people have smoked drugs the narcotic vapours and particulates have covered nearly every surface in the scene. For this reason one operator enters the scene area to collect specimens while the other team member remains in the vehicle to receive specimens and operate the Itemiser. Operators wear sterile suits and powder free gloves and their gloves and suits are sampled and tested to ensure they are free from contamination prior to starting the examination. An instrumental blank level is obtained, and recorded, prior to each sample analysis.

3.4 Sampling

Powders and Crystalline Substances:

Wooden cocktail sticks are used to pick up microgram quantities of the powder. The stick is simply inserted into the powder, or used to crush a few crystals, and the loaded end is then gently smeared onto the centre of a filter paper which is then placed into the Itemisers vaporisation unit. Care must be taken to avoid overloading the sample trap as this causes lengthy instrument clean out times.

Cannabis Vegetation/Herbal Matter:

A small quantity of the leaf/flower material is placed on to a clean sheet of paper and the sample vegetation is vacuumed onto a filter paper for about twenty seconds.

LSD Squares and Rizla Papers:

An LSD Square is mounted directly onto a filter paper sample trap by inserting the four end corners of the square into four slots cut into the paper. The mounted filter paper can then be then inserted into the vaporisation unit. The same approach was used for pieces of Rizla papers and other forms of paper i.e. till receipts, notepad paper.

Traces from Surfaces of Artefacts:

The target surface is wiped several times using a hand held vacuum pump fitted with a filter paper. For drug taking paraphernalia such as burnt residues on spoons, pipes and bhongs an ethanol wetted swab is used to remove a portion of the residue and to deposit it onto the centre of the filter paper.

Traces from Clothing:

The item of clothing is placed onto a sterile sheet of paper. All outer surfaces and pocket areas are wiped with a filter paper fitted to the hand held vacuum pump. If a positive result was obtained then specific areas i.e. front left pocket, back right pocket etc., were sampled to identify the location of the most significant response.

Prisoners:

Using a hand held vacuum pump fitted with a filter paper the outer clothing followed by the hair and then hands were sampled for a total of one minute.

Solvent Extraction on Cut Amphetamines and Tablets:

The bulking or cutting agents which form the major constituent of tablets or cut amphetamines are often sugar based compounds such as glucose, dextrose, mannitol, sucrose, lactose, or other compounds such as citric acid, calcium carbonate, sodium carbonate. The latter two compounds have do not have any adverse effect but the sugar based compounds and citric acid produce a chemical matrix effect. To overcome this problem the following solvent extraction method was used to remove the interfering matrix.

Approximately 50-100mg of powdered sample (or crushed tablet) is placed into a 5ml glass vial. 1ml of deionized water and 3 drops of concentrated ammonium were added to convert the drug compounds to their basic form. 1ml of diethylether (DEE) is added to extract the drug compound from the aqueous solution. The vial is capped and shaken for half a minute and then allowed to stand for a few seconds so that aqueous and organic solvents separated to form two distinct layers . The top DEE layer contained the drug compounds. while the cutting agents remained in the bottom aqueous layer. 5µl of the top DEE solution is injected onto the centre of a filter paper. The DEE evaporates in seconds leaving a dry residue of sample analyte ready for inserting into the ITMS sample port.

4. ASSESSMENT OF ANALYTICAL PERFORMANCE

4.1 Accuracy Tests on Historical Casework

40 samples which had been sent to the Forensic Science Laboratory for analysis were re-examined using ITMS. For items known to contain Cannabis, MDEA, Ephedrine, Ketamine, Cocaine and Heroin, the ITMS results consistently agreed with the Laboratory results. Amphetamines of strengths above 50% also agreed with the Laboratory result but substances containing between 0.5% and 10% amphetamine could only be reliably tested once the solvent extraction method was used. NIK test method (A) - Marquis Reagent - provided a distinct orange to brown colour change for this range of amphetamine materials.

The problems associated with producing accurate concentrations of standard reference materials while using only sub ug quantities of solids are considerable. Consequently, quantitative analysis is not feasible by ITMS and drug strengths can not be determined to the degree of accuracy required for forensic work. However, the experienced operator will be able to immediately distinguish between a cut or uncut amphetamine.

4.2 Range Of Substances

We have been able to identify 52 different drug related substances. This figure includes all of the common drug types, adulterants and cutting agents. Table 1 gives a list of reference standards tested in this work and the detection modes used. Reports from other workers [4,5] indicate that there is potential to increase the total number of drug types by a further 18. Anabolic Steroids can be detected and identified by ITMS and this is particularly useful as there are no chemical methods available.

4.3 Itemiser Sensitivity

The sensitivity of ITMS is impressive. 1µg of most drugs will yield a plasmagram peak with relative intensities in the region of 500 to 5000 above background. Taking into consideration the background level of approximately 1000. The theoretical limit of detection, based on a signal three times the standard deviation of the background, is approximately 20 to 200ng. However in practice some of this sensitivity is traded in by setting a more cautious alarm level. In general the instrument has demonstrated a capability of working at a peak height alarm level of 50 but in practice to avoid false positives we have used alarm levels much higher at 500 and 1000.

4.4 Instrument Clean out Times

A typical clean out time is 5 minutes for the majority of compounds. Only LSD has proven to be an exception to this. LSD is far more persistent and requires almost twice as long to decontaminate.

5. OPERATIONAL WORK

At the time of writing this report, 75 cases involving 205 jobs have been the subject of ITMS examinations. 9 of these cases were major trafficking offences, 11 were for dealing/supply offences and 55 were for possession. A total of 12 scenes, 26 vehicles, 16 prisoners, 75 artefacts, 114 substances and 26 different tablets were examined.

9 cases have resulted in convictions and there have been no acquittals. 2 of these cases involved major trafficking offences, 3 were dealing/supply cases and 4 were possession only cases.

In 14 cases which involved suspicious substances the items were eliminated as not containing drugs. 5 cases were for intelligence purposes only. In the remaining 24 cases suspects have been charged and are awaiting trial.

Our statements have been served on the defence in 25 cases. In 8 of these cases our evidence was accepted in both the Magistrates and Crown Courts. In 5 cases admissions were secured. Our evidence has been challenged on only one occasion.

In 96% of all cases ITMS results were confirmed by other analytical methods or by admissions. Those which were not confirmed were predominantly for traces in vehicles and on artefacts. Such analyses require the forensic laboratory methods to be optimised so that sufficient sensitivity (ng limits of detection) is achieved. Operating GC/MS instruments in single ion mode, or peak jump mode specifically for the drug compounds detected in field test, and optimising the extraction and derivatisation methods are amongst some of the essential requirements of this work. In general excellent results were obtained. Here are some specific examples which demonstrate the usefulness of our service.

5.1 Analysis of a Suspects Clothing

A suspect was seen leaving a vehicle and during the pursuit the suspect ran round a corner and was out of sight. A small deal bag of white substance was dropped at this stage. When the suspect was arrested and searched no other substances were found. He denied possession of the deal bag but the front right hand pocket of his jeans gave large response for Cocaine and Heroin (Figure1). The suspect was charged with possession of these substances. Later the laboratory confirmed the presence of cocaine and heroin in the pocket.

5.2 Examination of a Vehicle

A vehicle believed to have been used for dealing was examined. A bag of white powder was found in the one of the footwells and a small piece of brown material was found in a glove compartment. These substances were identified as cut amphetamine and cannabis resin. Also traces of cocaine were detected on the drivers controls, the drivers seat, on the door sill, and on a knife which was recovered from the drivers door pocket (Figures 2-5). The vehicle was transported to the Forensic Science Laboratory together with copies of our reports. The Laboratory confirmed our findings. The suspect was charged with possession of class A and B drugs with intent to supply. This was the first case that was subject to a full defence examination of the ITMS evidence. A good standard of documentation and thorough compliance with disclosure of evidence is essential.

5.3 Drugs Raid

During the first hours of a large operation seven prisoners were tested and three dwelling house scenes were examined. Positive results were obtained from all of the prisoners and many artefacts such as chopping boards, work surfaces, knives, bags implicating all members of the group.

After being tested, one detainee admitted to carrying a concealment. At one scene police dogs were particularly interested in a number of items. These items were not taken until ITMS results confirmed the presence of cocaine. All prisoners were arrested and charged and the three main suspects were remanded. Throughout the operation close analytical support was given to drugs Squad officers and this provided better focus during the scene searches. The Laboratory confirmed our findings. Five suspects pleaded guilty to trafficking offences, two pleaded not guilty and one of these specifically challenged the ITMS evidence. This was the first case in which ITMS evidence has been presented, challenged and then accepted in a UK Crown Court. The two challengers were convicted.

Cross contamination and the reliability of the results are common lines of defence cross examination and it is important that the prosecution is well briefed on such issues before the trial and that statements contain sufficient detail on working protocols that ensure the integrity of field tests.

5.4 Traces of Cocaine on a Suspect

The house of a suspect believed to be dealing crack cocaine was raided. Many locations inside the house proved positive i.e. microwave oven, foil, cling film, tables and a box which once contained scales. A police dog also gave indications but no real physical quantities of cocaine was found. We detected traces of cocaine on the suspects hands (Figure 6). The suspect was taken into police custody and during interview, confessed and confirmed the handling of crack cocaine. Previous to this case the suspect would not have been arrested and the investigation would have been aborted at an early stage. Here the more rigorous examination of the suspect and the scene yielded initial evidence which was sufficient grounds for arrest and charge.

5.5 Analysis of an Illicit Tablet

A suspect was searched and found carrying a bottle of white tablets bearing a smiley logo. After carrying out a DEE extraction a peak identified as MDMA was obtained. Figures 7A and 7B show the Plasmagram for MDMA reference standard and suspect sample respectively.

NIK chemical tests (A) to (L) were also used to confirm these findings. NIK test (A) gave a dark purple colour indicating opiate or MDMA and eliminating amphetamines which give a orange then brown colour. Test (B) gave a yellow/green colour. This eliminated amphetamine which would be colourless, heroin which would give a yellow colour that changes to green, morphine which gives orange to red then yellow and codeine which would have gone from orange to yellow. Test (K) gave a dark green colour which eliminated MDA and Codeine which both give a dark blue colour and morphine which would have given a blue colour which turns to grey. Test (L) produced a plum colour on breaking the first ampoule which darkened to almost black when the second ampoule was broken. This indicated the presence of MDMA and eliminated Heroin which would have given a green colour.

The physical dimensions and design of tablet was searched on the TICTAC CD ROM database and a match was obtained to an illicit MDMA tablet.

The suspect was charged with Intent to Supply. The Laboratory confirmed this tablet to contain 25 to 33% MDMA.

This case serves as a good example of how the three methods of identification can be used collectively to enhance the reliability of the evidence.

A number of such cases have been treated in a similar fashion for possession only offences. Guilty plea cases for possession only are dealt with in our Magistrates Courts and under these circumstances a field test result is sufficient and a Laboratory confirmation is not required. Such admissions are more readily forthcoming if the field test results are presented to the suspect during interview and in this way the prosecution process is expedited saving police time and avoiding costly Laboratory analysis. Reliability of the test results is vital.

6. CONCLUSIONS

The Ion Track Itemiser Ion Trap Mobility Spectrometer has worked successfully under all operational conditions providing a sensitive and reliable method of analysis for both routine substance identification and detection of traces at scenes. All commonly encountered drugs can be tested simultaneously to trace (20ng to 10ug) levels on artefacts such as money, work surfaces, scales, documents, knifes, spoons, cellophane, cling film, polythene bags, steering wheels, window winders, gear sticks, car seats, footwells, car boots, clothing and footwear. The Itemiser is robust, easy to maintain and user friendly. The analytical procedures involved are quick with a sample time typically being about 2 minutes for both sample collection and analysis.

With Forensic Laboratory techniques such as Gas Chromatography coupled to Mass Spectrometry (GC/MS) analysis, the suspect substance is first separated into its various compounds by the gas Chromatograph and then the structure and mass of each of these compounds is determined by the mass spectrometer. In this way the identity of the substance can be determined with a great degree of certainty and the possibility of an erroneous result is almost eliminated. ITMS identification relies only on the position of a suspect peak. The possibility of obtaining an erroneous false positive result from another unknown substance which yields a peak at the same position as a controlled substance can not be overlooked. However ITMS does possess sufficient resolving power to discriminate between all of the commonly encountered drug types and the plasma chemistry limits the number of types of chemical compound that can produce peaks in the plasmagram. The ITMS operator becomes more accomplished with experience. For these reasons, and in the light of our experiences, we consider ITMS to be reliable. However, unlike GCMS, ITMS can not provide an unequivocal method of identification and it is not a quantitative technique. Consequently confirmation analysis by a Forensic Laboratory will provide the main forensic evidence for Crown Court purposes and ITMS trace analysis results will only be presented on occasions where there is useful corroborative value, when called upon by the defence, or if there is a need to confirm an admission. The use of chemical tests and searchable CD ROM libraries assists in enhancing the reliability of ITMS results for substances.

ITMS results on traces can be used to justify an arrest, seizure and confiscation of vehicles and property, support an application for a search warrant and substantiate a charge and assist in securing a remand. Testing the hands of detainees has had a dramatic positive effect on the outcome a several cases. The results can also be used at suspect interviews and provide useful intelligence to the investigators. In this way our Scenes of Crime Department has been able to provide useful and effective support to the Nottinghamshire Police Force and help in the fight against drug related crime. Our findings and recommendations for wider use of this technology within the Police service and changes to law and Police Powers have recently been published [6].

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We also wish to thank Ion Track Instruments for providing first class technical support.

Table 1. List of substances, detection modes used, detection limits and legal status according to the Misuse of Drugs Act 1971.

Substance	*Itemiser Detection Mode*	*Detection Limits*	*Classification*
MDMA	+ ion mode	10 - 100ng	A
MDA	+ ion mode	10 - 100ng	A
D9 Tetrahydrocannabinol	+ ion mode	10 - 100ng	B
L-Amphetamine Free Base	+ ion mode	100ng - 1ug	B
Amphetamine Sulfate	+ & - ion modes	100ng - 1ug	B
Methamphetamine	+ ion mode	100ng - 1ug	B
Epherdrine	+ ion mode	10 - 100ng	Not a controlled substance
Ketamine	+ ion mode	10 - 100ng	Not a controlled substance
Methadone	+ ion mode	10 - 100ng	A
Phencyclidine	+ ion mode	10 - 100ng	A
Methaqualone	+ ion mode	10 - 100ng	B
Heroin	+ ion mode	100ng - 1ug	A
Opium Powder	+ ion mode	10 - 100ng	A
Cocaine	+ ion mode	10 - 100ng	A
Temazepam	+ ion mode	100ng - 1ug	C
Chlorodiazepoxide	+ ion mode	10 - 100ng	C
Codiene	+ ion mode	100ng - 1ug	B
Diazepam	+ ion mode	100ng - 1ug	C
LSD	+ ion mode	10 - 100ng	A
DextroPropoxyphene	+ ion mode	10 - 100ng	C
Barbitol	- ion mode	10 - 100ng	C
Phenobarbitol	- ion mode	10 - 100ng	C
Pentobarbitol	- ion mode	10 - 100ng	C
Hydrocodone	+ ion mode	100ng - 1ug	A
Hydromorphone	+ ion mode	100ng - 1ug	A
Lysergic Acid	+ ion mode	10 - 100ng	Not a controlled substance
Amylbarbitone	- ion mode	10 - 100ng	C
Dipipanone	+ ion mode	10 - 100ng	A
Phenazocine	+ ion mode	10 - 100ng	A
Phendimetrazine	+ ion mode	10 - 100ng	C
Pentazocine	+ ion mode	10 - 100ng	B
3-Hydroxy-4-methoxy-Phenethylamine	+ ion mode	1ug - 10ug	A
Benzocaine	- ion mode	100ng - 1ug	A
Caffeine	- ion mode	100ng - 1ug	Not a controlled substance
Secobarbitol	- ion mode	10 - 100ng	C
Glucose	- ion mode	10 - 100ng	Cutting agent
Fructose	- ion mode	10 - 100ng	Cutting agent
Dextrose	- ion mode	10 - 100ng	Cutting agent
Mannitol	- ion mode	10 - 100ng	Cutting agent
Citric Acid	- ion mode	10 - 100ng	Cutting agent
Starch	+ ion mode	10 - 100ng	Cutting agent
Lactose	- ion mode	10 - 100ng	Cutting agent
MDEA	+ ion mode	10 - 100ng	A
Morphine sulfate	+ ion mode	10 - 100ng	A
Mescaline	+ & - ion modes	1ug - 10ug	A
19-Nortestosterone	- ion mode	1ug - 10ug	C
Mesterolone	- ion mode	10 - 100ng	C
Stanozolol	- ion mode	1 0 - 100ng	C
17 a-Methyltestosterone	- ion mode	10 - 100ng	C
Fluoroxymesterone	- ion mode	10 - 100ng	C
Bolasterone	- ion mode	100ng - 1ug	C
Secobarbitol	- ion mode	10 - 100ng	C

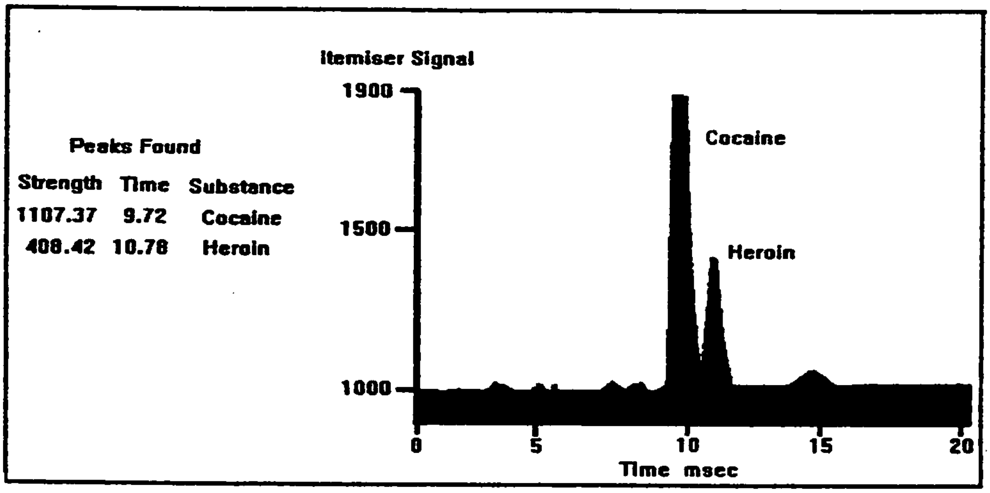

Figure 1. Plasmagram from sampling inside a pocket from a pair of jeans taken from a person suspected of dealing Heroin and Cocaine. Vacuum sampling for 30 seconds onto a pre-conditioned sample trap.

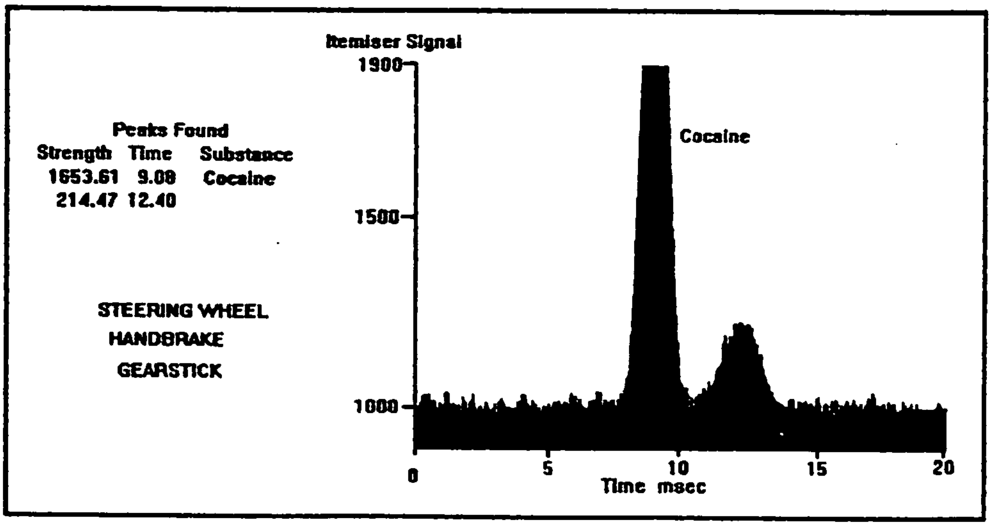

Figure 2. Examination of a suspects vehicle. Response from vacuum sampling the steering wheel, handbrake and gearstick.

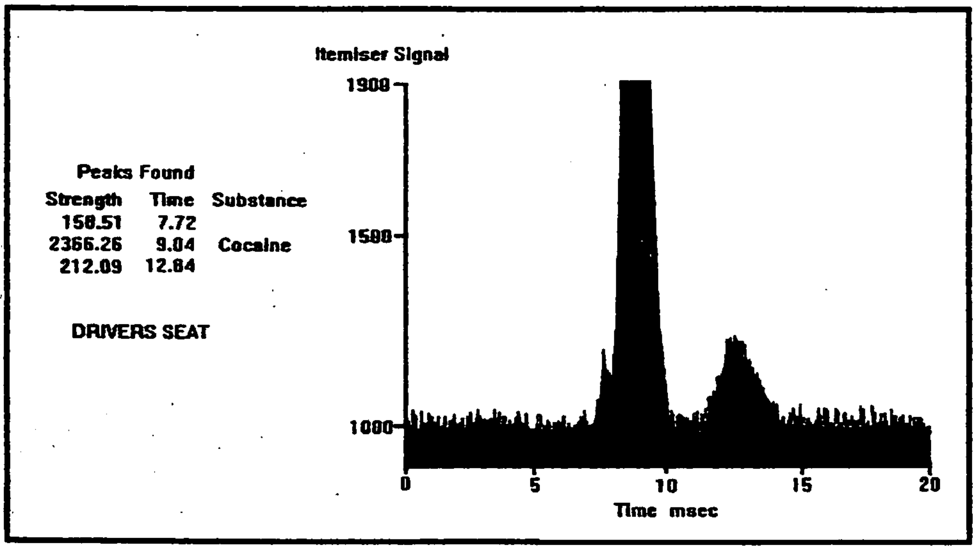

Figure 3. Examination of a suspects vehicle. Response from vacuum sampling the drivers seat.

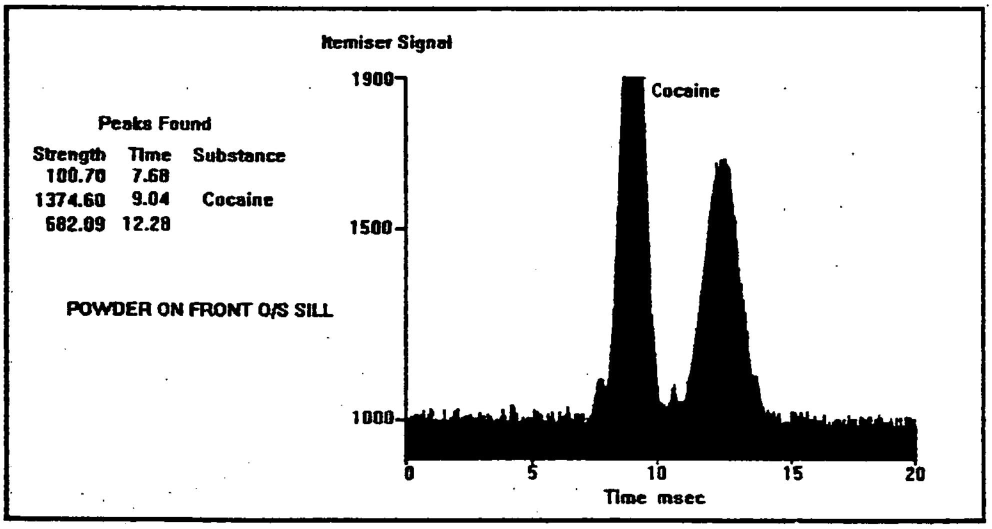

Figure 4. Examination of a suspects vehicle. Response from vacuum sampling the door sill.

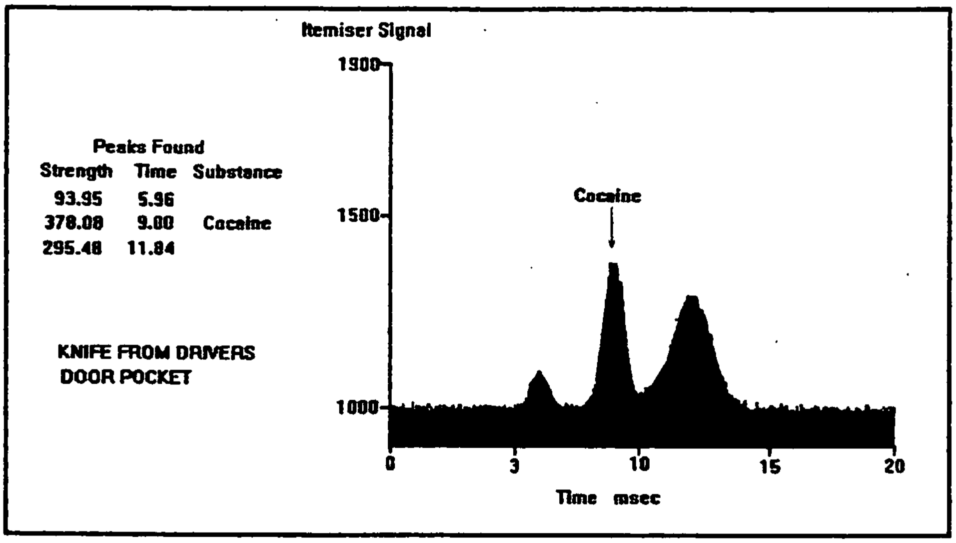

Figure 5. Examination of a suspects vehicle. Response from sampling the blade of a knife found in the door pocket.

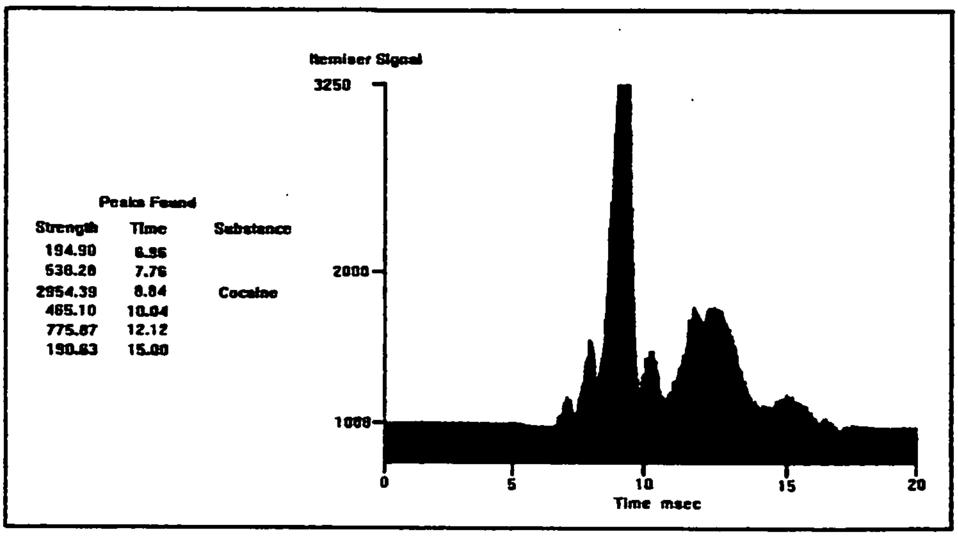

Figure 6. Plasmagram from vacuum sampling a detainees hands who later admitted to possession of crack cocaine.

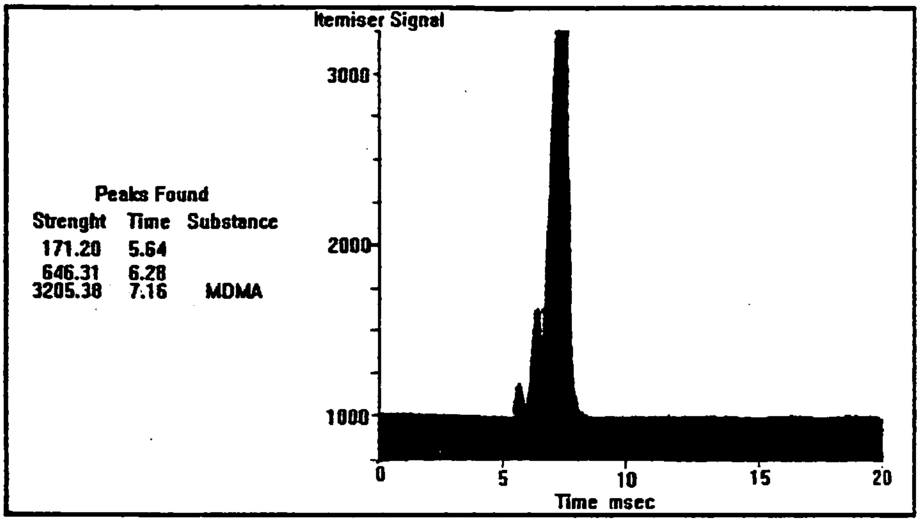

Figure 7a. Plasmagram of MDMA Reference standard.

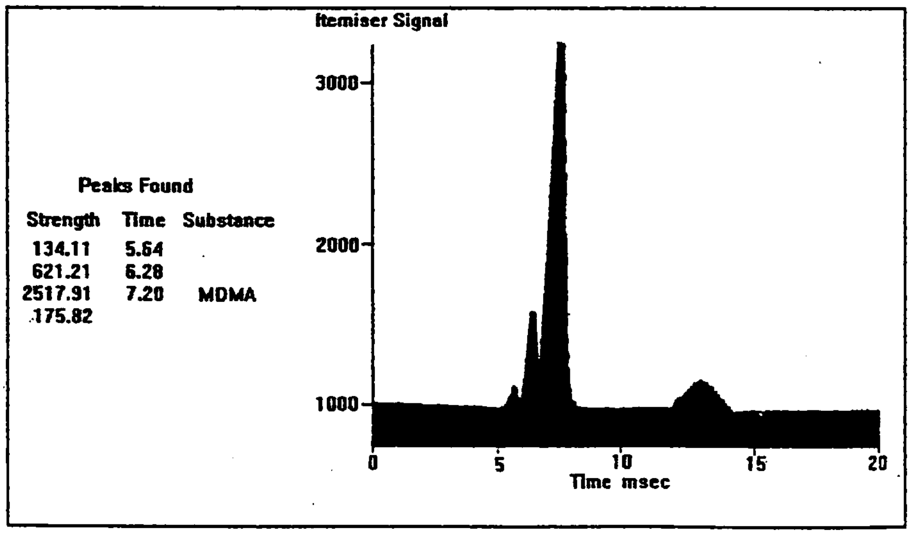

Figure 7b. Plasmagram for tablet believed to be MDMA. DEE/aqueous extraction method on small fragment of tablet. 5μl injection from DEE phase onto pre-conditioned sample trap.

DETECTION OF COCAINE ON CURRENCY

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ABSTRACT

The Office of the Texas Attorney General, Financial Crimes Division (FCD) is using an enzyme immunoassay surface drug detection kit during money laundering investigations to determine the presence of cocaine contamination on the surface of currency in Texas.

The examination utilizes the AccuPRESS Surface Drug Test Kit, available from DETEC, Inc. Subsequent to the field test of the currency, the evidence is submitted to Quest Diagnostics Incorporated, Baltimore, Maryland for an independent gas chromatography/mass spectrometry (GC/MS) analysis. A qualitative and quantitative confirmation for cocaine, heroin, or other narcotics contained in the evidence sample is subsequently received

The FCD has been using this field test method for the past three years. The examinations were performed in nine criminal/civil cases that resulted in the seizure of approximately $1,381,000 and subsequent convictions. This enforcement activity has reduced the number of money laundering businesses known as *giro* houses in Houston from 81 to eight, and the amount of money sent to Colombia from $450 million to $10 million. Additionally, tests have been performed in other cases that are still ongoing. Background level determinations of drugs on currency in general circulation have also been accomplished utilizing this methodology for comparative purposes. The background test results were, on average 18 times less than the levels of drug residues on the suspect currency.

Keywords: cocaine, drugs, evidence, GC/MS, heroin, immunoassay, money laundering, seizure, test kits, warrants

The war on drugs is fought on many fronts. Although the subject of illicit drugs/substance abuse is addressed in terms other than "war", the word is appropriate due to the magnitude of the effort necessary to solve this devastating problem. The layperson's image is of the typical narcotics officer busting the dealer on the street corner, or the discovery of a large quantity of contraband hidden in some compartment or container. This is a true picture in many instances, but there is also another side in this war. What has not been in focus is the sophistication of the drug organizations that must be able to deliver the profits of street level sales back to their suppliers in Mexico or South America.

This activity, commonly referred to as money laundering, gives rise to a new battlefield, that of money.

Smuggling currency to other countries has proven burdensome to the narcotic dealers. Therefore, new methods of sending these proceeds had to be developed. New "industries" which do nothing but provide a means by which these illegal funds are sent south have emerged. Many of these businesses appear to be created for legitimate purposes, but their true nature is revealed following a closer examination. Up to 80 percent of the cocaine entering the United States each year crosses the Texas-Mexico border, and an estimated $35 billion in illegal drug money is laundered in the state each year.[1]

In 1991 the Texas Legislature enacted the first in a series of laws aimed at these suspect money laundering businesses. The Currency Exchange Act was passed to regulate the activities of these "non-bank financial institutions" who conducted electronic wire transfers and currency exchanges. The regulations included an application process, bonding requirement, and audit provision. The original act was later amended to include the regulation of currency transported in Texas.

In 1993 the Texas Legislature passed a law under the Texas Penal Code which made it a felony crime for a person to be involved in money laundering. The law outlines each element of the offense and how the funds derived from such criminal activity are subject to forfeiture under Chapter 59, Forfeiture of Contraband, in the Texas Code of Criminal Procedure(CCP). Additionally, Chapter 34 authorized assistance by the Attorney General in the prosecution of these cases.

In response to these new laws, Attorney General, Dan Morales, formed the Financial Crimes Division(FCD) under the supervision of Drew T. Durham, Deputy Attorney General for Criminal Justice. The mission of the Financial Crimes Division is to interrupt the flow of illegal proceeds, seize the proceeds under CCP Chapter 59, and prosecute those individuals responsible for the criminal activities.

The FCD began by initiating investigations into the Colombian controlled currency transmission industry in Houston. These businesses, known as "*Giro* Houses" (pronounced *hero*), purport to provide services to the foreign immigrant communities with currency transmittal, cargo shipment, long distance telephone access, pagers, and other services. In 1991, it was estimated that as many as 81 *giro* houses were in operation in Houston processing more than $450 million per year in wire transfers, mostly destined for Colombia.[2] The Currency Exchange Act was specific that a business had to be licensed in order to provide wire transfer activities. Several unlicensed *giro* houses were closed by the FCD following the execution of search warrants. Other *giro* houses that learned about the enforcement actions, voluntarily closed their doors.

Elements of these early investigations included the use of narcotics dogs trained to alert on cocaine contaminated currency and Ionscan examinations of currency, which was deposited into local banks by the unlicensed *giro* houses. The use of canines in a bank became impractical due to the necessity of having a dog handler and dog available and, normal banking activities were disrupted due to the dog's presence. Additionally, Ionscan technology proved to be a logistical challenge and was discontinued except for special circumstances.

The investigations by the FCD spread to businesses which were licensed but appeared to be fronts for money laundering activities. Texas became the pilot state for a new program with the Financial Crimes Enforcement Network(FinCEN) when Attorney General Dan Morales signed a memorandum of understanding with the Department of the Treasury. This agreement provided the FCD, with full access to Bank Secrecy Act data. The data which is accessed directly by the FCD is used to identify *giro* houses with the highest volume of cash deposits. These lengthy investigations included examinations of the licensee's bank records, analysis of the wire transfer records, cash deposit activity, surveillance of the business location, and evaluation of data received from their annual audit reports.

These investigations established that the businesses' banking activities showed characteristics of money laundering. However, there was still a need to develop a "drug" connection to the money the businesses were receiving. Since the drug dealers and money laundering fronts began to employ more sophisticated techniques, the FCD decided to utilize a portable, practical field test that would give an immediate indication for the presence of narcotics on currency. The ability to obtain a laboratory test on the same sample for confirmation purposes was essential. The laboratory confirmation would be available for use in search warrant affidavits as well as courtroom presentation. Combined with the other investigation techniques, this type of analysis would provide the evidence necessary to close down the suspected money laundering businesses.

The FCD found that an enzyme immunoassay surface drug detection kit was commercially available that tested for cocaine and heroin. This kit available from DETEC, Inc. is known as the AccuPRESS Surface Drug Test Kit (AccuPRESS). The kit is portable enough to be carried in the palm of your hand, and is a cost-effective product to meet the field indication needs as well as the laboratory confirmation requirement. The kit costs approximately $17.50 when purchased in quantity. A color change occurs to indicate a field positive detection.

The AccuPRESS kit consists of four components: a sample bottle and swab, a test module, a wash ampule, and a reagent ampule. One kit is used for each sample examined, and the kits are not reusable. The sample bottle contains a liquid preservative and a swab assembly attached to the cap. The test module is a clamshell type configuration with a sample well and a color readout disk.

The FCD began using AccuPRESS as a field test method about three years ago. Local bank officials cooperated with the FCD by segregating the targeted deposits from other currency received for deposit. The use of the AccuPRESS kit proved less disruptive and tests could be conducted during normal business hours. All of the agents assigned to the FCD are trained and certified in the use of the AccuPRESS field test kit. A strict protocol is followed for each test conducted. A sample is collected from the surface of three currency bills removed from each targeted deposit. This collection is accomplished by wiping the bill surface with the swab. Time constraints detailed in the AccuPRESS manual are strictly followed. The test takes approximately five minutes to complete. Each positive test sample is maintained with the proper chain of evidence criteria in mind. The test vials are sealed and labeled for shipment to the laboratory. A written report is prepared detailing the test particulars.

The positive sample obtained during the field test is sent to Quest Diagnostics Incorporated (QDI), Baltimore, Maryland for an independent gas chromatography/mass spectrometry (GC/MS) analysis. A qualitative and quantitative confirmation in nanograms per milliliter (ng/mL) for narcotics contained in the sample is subsequently received. Sample storage by the laboratory is under strict chain of custody guidelines. The laboratory supplies the FCD with a written laboratory report of the confirmation results for the investigation file.

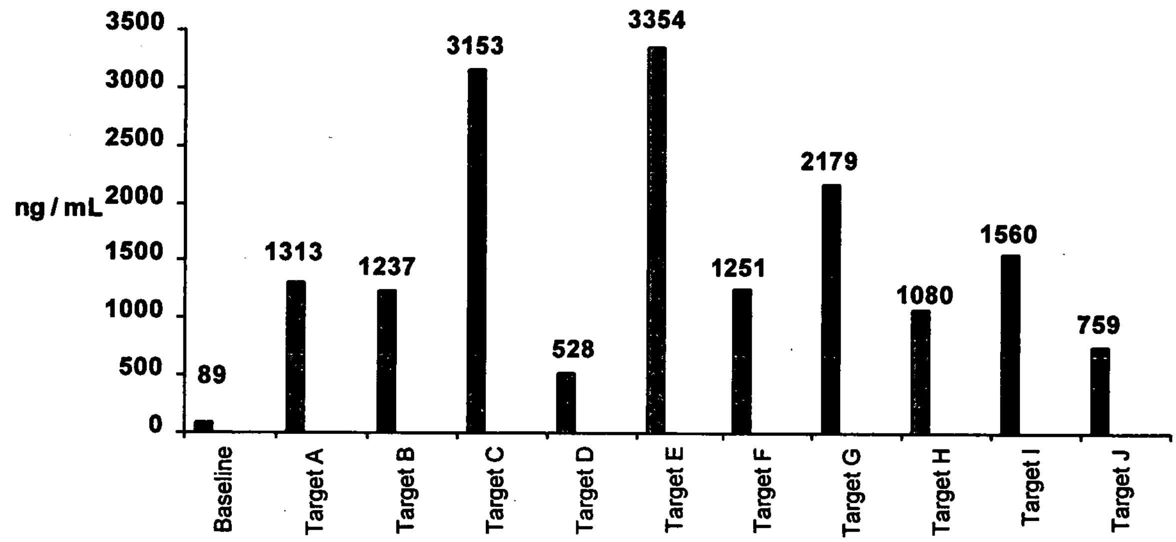
Many defense attorneys will argue that all currency is contaminated with drugs. In order to determine the true level of drug contamination on local currency, the FCD conducts tests of money in general circulation in the investigation area. The same protocol standard is followed to conduct the background level tests. These tests will normally indicate a negative response in the field. The test vials are sent to QDI for confirmation testing. The laboratory conducts the same GC/MS analysis, and provides a written report to the FCD. In Houston the level of cocaine contamination on currency in general circulation was found to be on average 89 ng/mL. The comparison of these levels in general circulation with those of samples submitted from an investigation target will indicate that the targeted currency contains levels of narcotics in higher concentrations. The graph below shows some of these comparative results. These results show that the average level of contamination on targeted samples is 18 times greater than the baseline average.

TIMES GREATER THAN AVERAGE

Target A = 15	Target F = 14
Target B = 14	Target G = 24
Target C = 35	Target H = 12
Target D = 6	Target I = 18
Target E = 38	Target J = 9

The FCD has submitted 81 samples to the laboratory for confirmation testing. To date, none of the submissions which indicated a positive field test failed to be confirmed by the laboratory at substantially higher levels for narcotic contamination.

Comparison of Confirmation results to Baseline Average



The evidence obtained throughout the investigation is used to develop probable cause for the issuance of a search warrant. This warrant is obtained from a State District Court. The AccuPRESS data is used in the search warrant and the results are summarized as follows.

"....AFFIANT believes based upon the positive indications for cocaine obtained from the field tests and the laboratory confirmations received, that the currency being deposited into the target account is consistent with the nature of proceeds that are generated during narcotics-related activities."

The FCD has executed nine search warrants using the AccuPRESS data as probable cause. These warrants have resulted in the seizure of approximately $1,381,000. Three individuals were convicted on state money laundering charges and two individuals agreed to cooperate in future investigations in lieu of indictment. Also, two individuals and a corporation were indicted in state court and are pending trial, and another individual was indicted on state charges and remains a fugitive.

These statistics appear impressive but don't tell the rest of the story. The impact these investigations have had on the *giro* house industry reflects the true bottom line.

A recent count of *giro* houses lists eight (down from the original 81) and the total amount of money wired to Colombia annually has dropped to $10 million (down from approximately $450 million).[3] This reduction in the number of businesses can be linked directly to the investigations conducted by the FCD in conjunction with the Houston HIDTA Money Laundering Initiative.

The FCD continues to use this field test and confirmation method to provide valuable investigative information in the most cost effective, least invasive manner available. Other investigations are continuing that are expected to lead to additional forfeitures and arrests in the future.

[1] Attorney General Dan Morales, Laredo Morning Times, July 30, 1996.
[2] Houston 1996 Threat Assessment, Houston Joint Drug Intelligence Group
[3] Ibid.

Signature Profiling of Trace Components in Illicit Cocaine Samples for Tactical and Strategic Law Enforcement Purposes

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ABSTRACT

This laboratory has recently developed several methodologies for gas chromatographic signature profiling of illicit cocaine samples. Profiles of trace components, coupled with pattern recognition computer programs, can chemically match exhibits whose relationship was previously unknown or only suspected. These relationships can be used as intelligence for tactical and strategic law enforcement. Capabilities currently being used for tactical intelligence include sample-to-sample and sample-to-database comparisons. Sample-to-sample comparisons are performed for ongoing conspiracy investigations and eventual adjudication. Profiles from apparently unrelated samples are searched against a large database for matches by a computerized neural network. Drug investigators are thereby given new investigative leads for developing conspiracy cases. Our strategic intelligence initiatives include two main objectives: 1) determination of primary solvents utilized for converting cocaine base to cocaine hydrochloride, and 2) development of a "region-of-origin" profile. Conversion solvent determination enables monitoring and control of essential solvents used by clandestine laboratory operators. This initiative has had a dramatic impact on the final processing stage of illicit cocaine. In addition, preliminary results from several new chromatographic methodologies indicate that a "region-of-origin" (Bolivia, Peru and Colombia/Ecuador) profile may be possible for illicit cocaine.

INTRODUCTION

One of the major goals in forensic drug research of cocaine is the development of chromatographic signature profiling methodologies which can be utilized for comparative purposes. Chromatographic profiles typically determine trace to ultra-trace level components (10^0 to 10^{-6} %) found in illicit cocaine. These components include: 1) alkaloids that are co-extracted from the coca leaf, 2) manufacturing by-products from the chemical manipulation of cocaine, and 3) impurities from the processing chemicals.

Signature profiling of these trace components can provide law enforcement both tactical and strategic intelligence data. Profiling includes: 1) comparison of two or more cocaine seizures to determine if they were derived from a common source; this data can be used in development of conspiracy cases for criminal prosecution; 2) tracing drug distribution routes; 3) determining what solvents were used in converting cocaine base to cocaine hydrochloride, thus enabling diversion investigators to monitor essential chemicals imported by cocaine hydrochloride - producing countries; 4) differentiation of illicit from pharmaceutical cocaine; and 5) determination of a cocaine exhibit's geographic origin [1].

METHODOLOGIES

We have developed six separate chromatographic signature methodologies for comparing cocaine samples (CISPA, Trimethoxy, Truxilline, N-Nor, CHEMCON, and BAR). Each of these methods examines different classes of impurities found in illicit cocaine. The CISPA method determines major impurities such as the cinnamoylcocaines, tropacocaine, and hydrolysis products [2]. The Trimethoxy method examines trimethoxy-substituted and other ion-pairing alkaloids [3]. The Truxilline method examines truxillines [12] and their hydrolytic by-products[4]. The N-Nor method determines N-demethylated and hydroxy-substituted alkaloids [5]. CHEMCON examines solvents which are occluded in cocaine hydrochloride from the illicit conversion process [6]. Finally, the BAR method examines ultra trace-levels of 2-carbomethoxy-3-alkyloxy- and heteroaroyloxy- substituted tropanes [7].

TACTICAL INTELLIGENCE

The aforementioned methods are used for both sample-to-sample and sample-to-database comparisons. Sample-to-sample comparisons are performed on ongoing conspiracy investigations and can be instrumental in successful prosecution of these cases [8]. In such cases, comparative analyses of two or more samples can determine if the samples are chemically related or not; that is, are they from the "same batch" or possibly manufactured as separate batches, but concomitantly. Examples illustrating chromatographic signatures of two cocaine samples from the same batch and differing batches using the CISPA methodology are illustrated respectively in Figures 1 and 2. Data from these chromatographic signatures are entered into and searched against a database using a computerized neural network pattern recognition program [9,10]. This neural network program is referred to as SNIFFER. It can rapidly autosearch a large number of CISPA signatures, thus giving an output of possible matches against specific samples as well as any other samples in the database that may possibly be related. We've had excellent

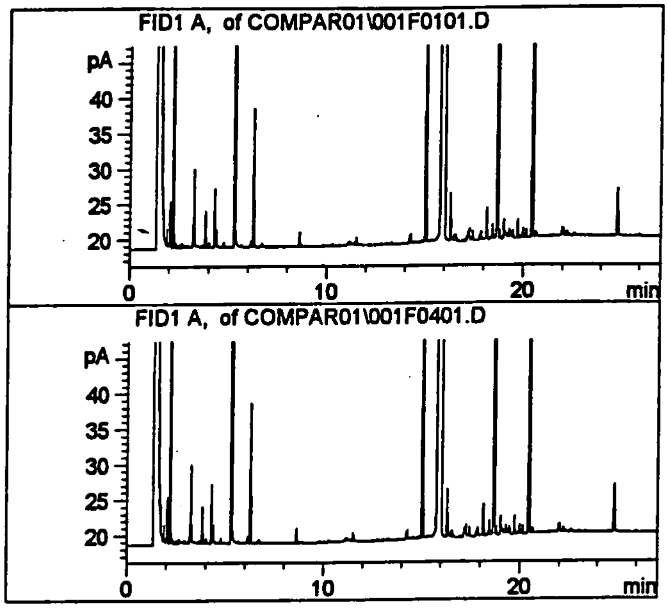

Fig. 1. CISPA chromatographic signature profiles of two cocaine HCl samples from a common batch.

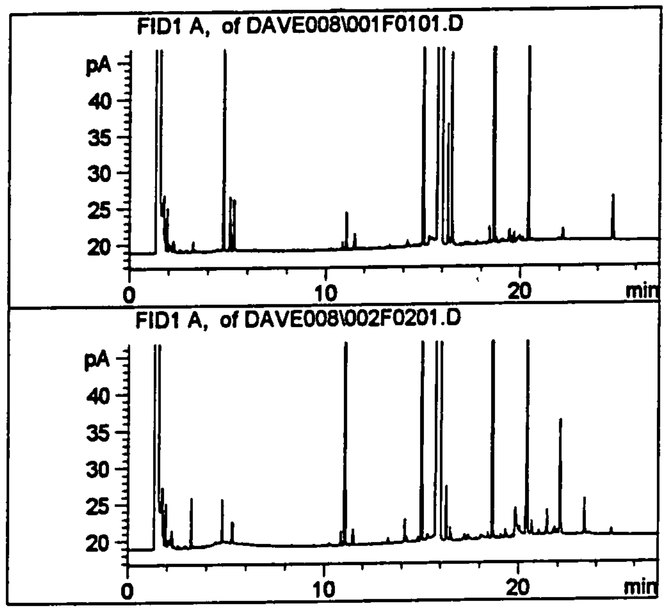

Fig. 2. CISPA chromatographic signature profiles of two cocaine HCl samples from differing batches.

success using these techniques in these comparisons. It should be noted that these methodologies can be used to differentiate legitimate from illicit cocaine in pharmaceutical cocaine diversion cases.

For sample-to-database comparisons we primarily utilize CISPA, CHEMCON and SNIFFER. Random samples from all cocaine seizures of 10 kg or more which are submitted to the DEA laboratories are routinely analyzed by these methods at the DEA Special Testing and Research Laboratory. Data from new samples are searched against a large database using SNIFFER. An example of a SNIFFER search is illustrated in Figure 3. As seen, the reference

SNIFFER IMPURITY ANALYSIS
Pattern Name: C0173B
Run Date: 10/11/96 10:08:41

FILES USED
Reference pattern: JFK.ref
Database: Chemcon.dbx (1784)
Results: JFK.snf

TRAINING PARAMETERS
Learning Rate = 0.20
Training Iterations (Limit/Calc.) = 500/222
Momentum = 0.80
Sum Square Error (Limit/Calc.) = 1.000/0.996

Rank	%Error	Probability of Match	Name	Alert Setting = 0.2 Warning Setting = 0.1
				C0173B Reference Pattern
1	0.000	1.000	C0173B	(ALERT)
2	0.028	0.975	C0167Q	(ALERT)
3	0.137	0.895	C0022F	12 (0.516)
4	0.178	0.876	C0167P	14 (0.186)
5	0.184	0.874	C0167T	8 (0.116)
6	0.221	0.857	C0167J	
7	0.225	0.855	C0177B	
8	0.246	0.845	C0173A	
9	0.262	0.839	C0051A	
10	0.294	0.824	C0157A	

Fig. 3. SNIFFER results printout. See ref. 10 for discussion of the neural network and training parameters.

sample (C0173B) found itself in the database as a perfect match and an ALERT (possible match) was found for another sample (C0167Q). Several other samples have a high probability of match and may be related, but were not "ALERTS" because certain impurity values were above the warning setting (e.g., for sample C0022F, impurity #12 has an absolute difference of 0.516% from C0173B). The ALERT must be verified by a forensic chemist visually comparing the two chromatograms. Without a computerized neural network for pattern recognition, it would be virtually impossible to visually compare new signatures against a database of thousands of samples. When two or more samples are determined to be related, the investigating officers are notified, thus giving them an investigative lead towards conspiracy investigations or potentially new cases. This data may also be useful in determining and tracing cocaine distribution routes. The sample-to-sample and sample-to-database programs have not only benefitted DEA but other federal agencies as well as many other more localized joint task force operations. For example, in North Carolina, this program helped a local task force develop a conspiracy case against three cocaine dealers and was led to a fourth suspect who might not otherwise have been implicated.

STRATEGIC INTELLIGENCE

Our strategic enforcement initiatives include two main objectives: 1) determination of primary solvents utilized in the conversion of cocaine base to cocaine hydrochloride; and 2) development of a "region-of-origin" profile for illicit cocaine.

Conversion solvents are determined by the CHEMCON methodology [6]. This method provides simultaneous qualitative and quantitative data on volatile conversion solvents which are occluded in the cocaine hydrochloride crystal matrix. Individual components from complex solvent combinations can be identified and determined relative to each other and to cocaine hydrochloride. This allows differentiation of primary solvent(s) from trace level solvent impurities. Examples of chromatographic profiles from cocaine hydrochloride using ether/acetone and MEK/petroleum ether are illustrated in Figure 4. Data from this program has allowed diversion investigators and policy makers to control distribution of certain chemicals imported into cocaine HCl - producing countries. This initiative has had a dramatic impact on the final processing step of illicit cocaine. Historically, ether and acetone were the two primary conversion solvents. Beginning in the mid-1980's, controls on these solvents were tightened in South America, and traffickers were forced to use alternative solvents at higher costs. The CHEMCON program began identifying these new solvents, most notably methyl ethyl ketone (MEK), and controls were tightened on

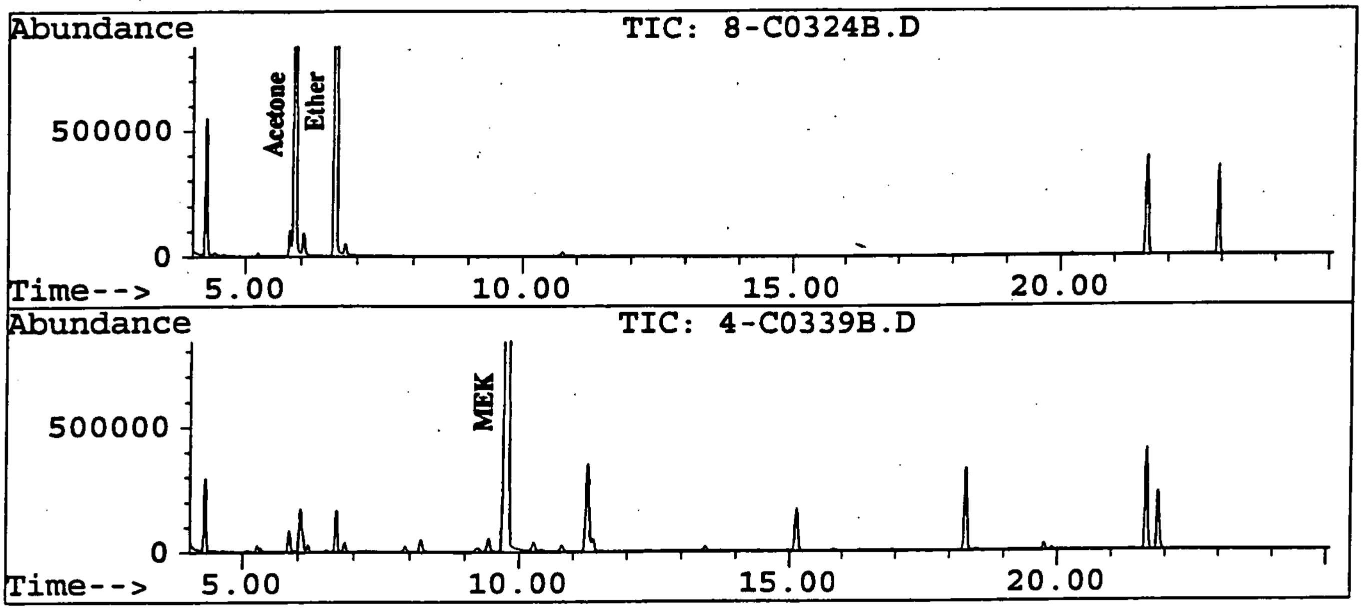

Fig. 4. CHEMCON chromatographic profiles of cocaine HCl containing trace levels of ether and acetone (upper), and MEK and petroleum ether (lower). Each chromatogram also contains internal standards.

this solvent as well. Since that time, many more alternative solvents have been utilized by the traffickers, only to be controlled a short time later in South America because of data obtained from CHEMCON.

We are currently developing a new computerized neural network pattern recognition program which can be applied to CHEMCON data. With this program it may be possible to relate differing batches of cocaine hydrochloride produced from the same clandestine cocaine hydrochloride conversion laboratory, based on unique solvent combination profiles. Chromatographic profiles from two cocaine hydrochloride samples from the same clandestine cocaine hydrochloride conversion laboratory are illustrated in Figure 5.

We are also developing chromatographic methods towards a "region-of-origin" signature for cocaine. Two factors must be considered in this regard: 1) where the leaf was grown and where the cocaine base was produced, and 2) where the cocaine base was converted to cocaine HCl. There are four major areas of coca cultivation in South America. These are the Chapare Valley of Bolivia, the Huallaga Valley of Peru, the Putumayo Region of Ecuador/Colombia, and central Colombia. There are two major cultivars of coca grown in these regions. *Erythroxylum coca* var. *coca* (ECVC) is the only cultivar found in the Chapare and Huallaga Valleys, while ECVC and *Erythroxylum novogranatense* var. *novogranatense* (ENVN) are found in central Colombia. ECVC is found in the Putumayo Region and it is suspected that some ENVN may be grown there as well. We have found significant differences in the trace alkaloid composition of these two cultivars [11] and believe these variations may eventually be utilized in differentiating illicit cocaine produced from these two cultivars.

Currently, our research efforts are directed towards a "region-of-origin" to determine where the leaf was grown and processed into cocaine base. In this regard, we are examining the patterns of trace and ultra-trace level alkaloids found in coca leaf and refined cocaine from these areas. Four of our methods (Truxilline, Trimethoxy, N-Nor, and BAR) show some promise in solving this complex puzzle.

We have been able to determine differences in truxilline content of coca leaf and refined cocaine HCl from different countries [1,12]. As seen in Table 1, there appears to be some discrimination of truxilline content between Bolivia/Peru and Ecuador/Colombia. The elevated values of truxillines in Colombian leaf may be attributed to the ENVN cultivar. The low value for Colombian cocaine HCl may be because of

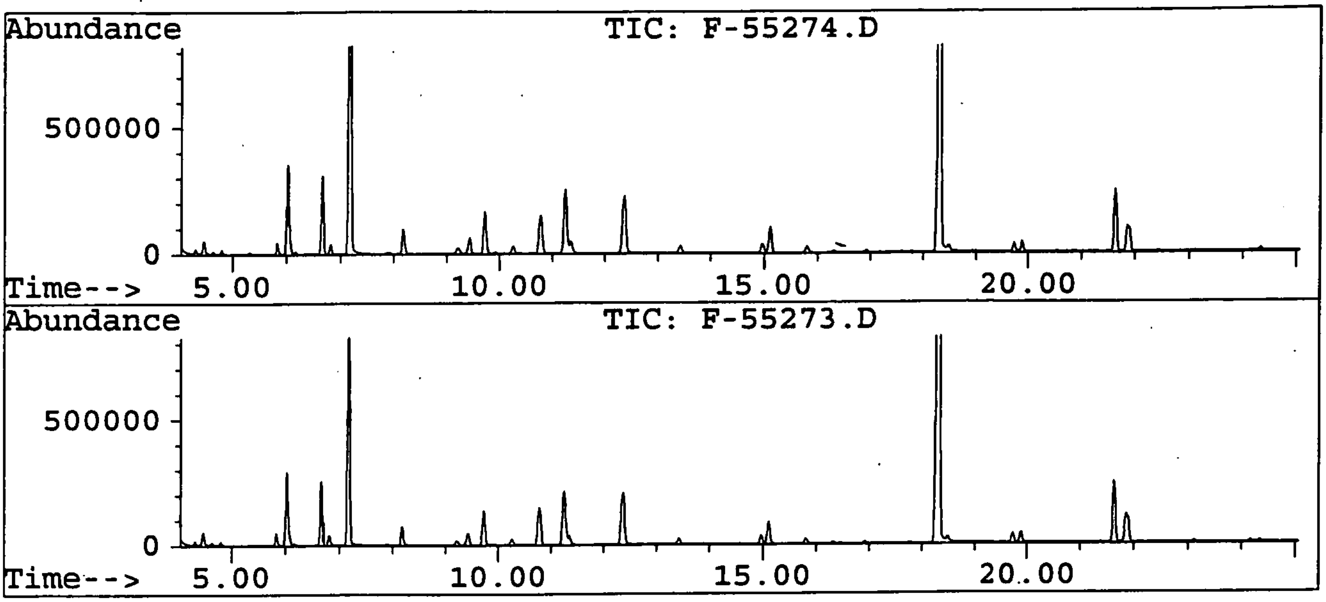

Fig. 5. CHEMCON chromatographic profiles of two cocaine HCl samples produced in the same clandestine laboratory. Each chromatogram also contains internal standards.

Table 1

Total truxilline content of South American coca leaf and refined cocaine HCl.

Matrix	Bolivia	Peru	Ecuador	Colombia
Coca leaf [a]	2.53	2.99	13.04	61.20
Cocaine HCl [b]	1.66	1.38	3.66	4.01

All data presented as % (w/w) relative to cocaine.
[a]N=1 for each country.
[b]Bolivia (N=19), Peru (N=16), Ecuador (N=16), and Colombia (N=52).

Table 2

Trimethoxy-substituted alkaloid content in South American coca leaf [a].

Country	TMT[b]	TMC[c]	cTMCC[d]	tTMCC[e]
Brazil	-	1.12	-	0.15
Colombia	-	-	-	-
Bolivia	-	0.22	0.11	0.95
Peru	0.18	0.24	0.16	0.83

All data presented as % (w/w) relative to cocaine.
[a]N=1 for each country.
[b]3',4',5'-Trimethoxytropacocaine
[c]3',4',5'-Trimethoxycocaine
[d]3',4',5'-Trimethoxy-*cis*-cinnamoylcocaine
[e]3',4',5'-Trimethoxy-*trans*-cinnamoylcocaine

transhipped base from other regions.

The Trimethoxy methodology has shown variances in the trimethoxy-substituted alkaloid content in coca leaf. The quantitative data for a limited number of coca leaf samples from Peru, Bolivia, Brazil, and Colombia are reported in Table 2. As seen, there are striking differences in the relative content of the trimethoxy-substituted alkaloids in coca leaf. The Colombian leaf did not contain detectable amounts of any of the four trimethoxy-substituted alkaloids, and is therefore easily differentiated from Brazilian, Peruvian and Bolivian leaf.

The N-Nor Methodology has shown some promise in differentiating two different cultivars of coca. We have found that ECVC has much lower levels of 1-hydroxytropacocaine relative to cocaine than ENVN. This work is promising since ENVN is exclusively cultivated in certain areas of Colombia, while ECVC is cultivated in all four major regions of Bolivia, Peru, Ecuador and Colombia.

The BAR methodology has also shown promise in differentiating refined samples derived from leaf cultivated in Bolivia, Peru, Ecuador, and Colombia. This sensitive method determines a new class of cocaine related alkaloids at levels as low as 10^{-6} % relative to cocaine. A selected chromatogram of a sample from each country is illustrated in Figure 6.

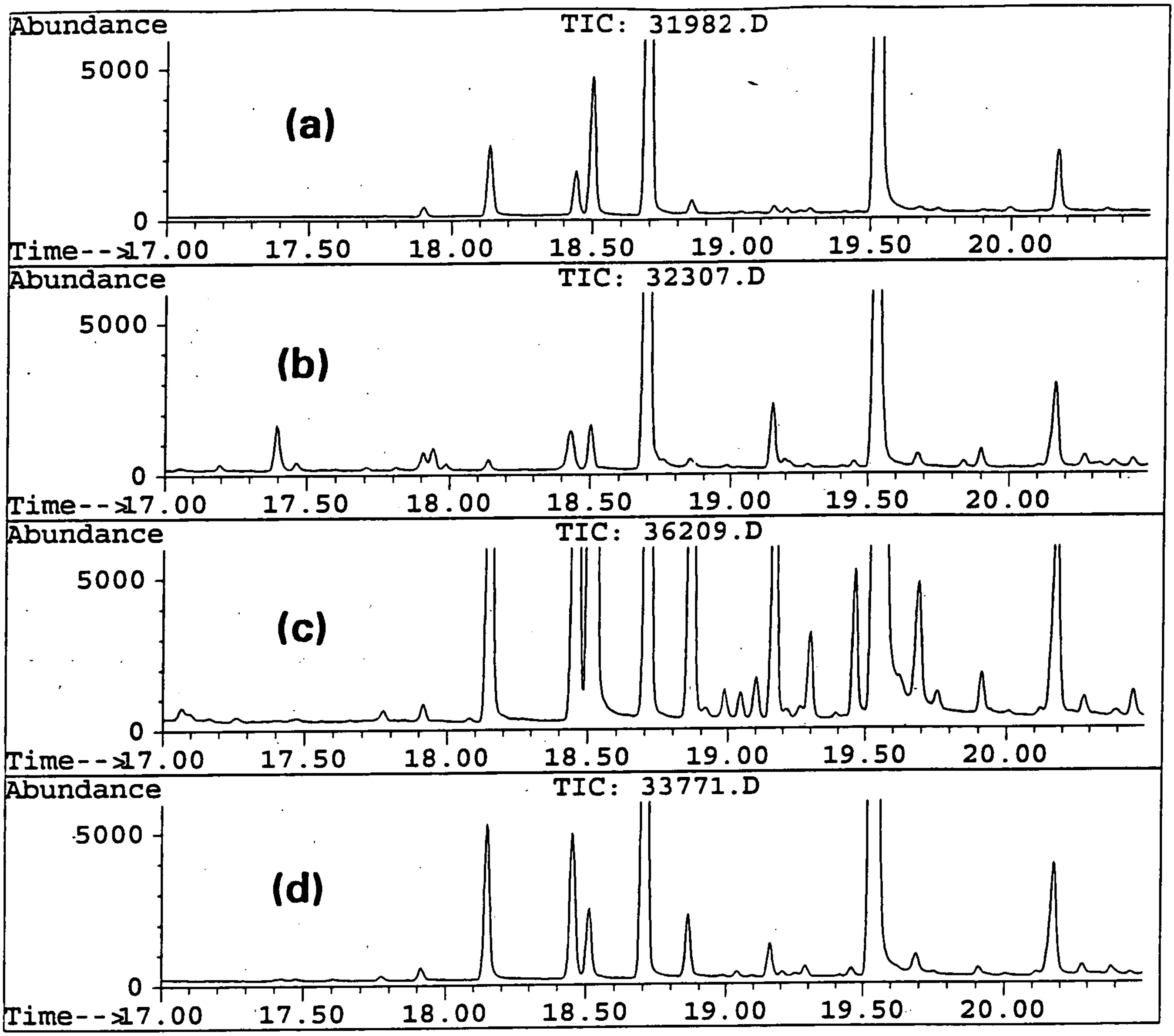

Fig. 6. Partial reconstructed single ion chromatograms (m/z 182) of illicit refined cocaine from: (a) Colombia, (b) Bolivia, (c) Peru, and (d) Ecuador.

Although the methodologies described herein show promise, origin classification may require a combination of methods that determine all classes of coca alkaloids. At this time, determination of leaf origin using these methodologies is uncertain, due to limited databases of authentic samples.

SUMMARY

This laboratory has developed several methods for chromatographic signature profiling of trace components in coca leaf and illicit cocaine samples. These methodologies can be utilized for tactical law enforcement applications such as providing corroborative evidence in conspiracy investigations. These methods have also given strategic intelligence for conversion solvents utilized in clandestine laboratories and may eventually give region-of-origin data as well.

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COCAINE PYROLYSIS DEGRADATION STUDY

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ABSTRACT

The presence of methyl ecgonidine via the pyrolysis of cocaine as a field confirmation method for cocaine detection has been reported by the U.S. Coast Guard Research and Development Center. It has also been reported as an indicator of existing cocaine in cargo containers via air sample collection by the Canadian Customs Service. These investigations compelled us to further examine the mechanism of, and products from the catalytic pyrolysis of cocaine. After selecting silica gel powder as the catalyst, a number of experiments were conducted to assess the effects of heating temperature and duration as well as the solvent used to pyrolyze the cocaine. The results from each set of tests are presented along with discussions. A significant result was that the catalytic pyrolysis of cocaine to methyl ecgonidine can be accomplished at temperatures as low as 150°C for 6 minutes by using simple laboratory glassware.

1. INTRODUCTION

The U.S. Coast Guard (USCG) has been utilizing ion mobility spectrometry (IMS) technology since 1992 to assist the boarding officer in the search for illicit drugs. In support of efforts to improve the operating effectiveness of IMS devices, the USCG Research and Development Center (R&DC) presented a field-level confirmatory method in 1994 [1]. The glass fiber filter was used in that method to catalyze the cocaine hydrochloride (HCl) degradation. Methyl ecgonidine (MeED) was found to be the major pyrolysis product detected by IMS.

The identification of MeED as a major pyrolysate of cocaine has been presented in numerous papers. Lukaszewski et al. [2] detected MeED in their analysis of impurities of illicit cocaine, but cautioned its presence could be due to the thermal degradation of cocaine in the gas chromatograph (GC) injection port at 250°C. Martin et al. [3] reported that only three compounds, unreacted cocaine, MeED, and benzoic acid, were identified after the pyrolysis of free base cocaine at temperatures ranging from 150°C to 650°C and airflow rates ranging from 100 mL/min to 400 mL/min. They found that the conversion of cocaine to MeED was predominant at 650°C. At this temperature, over 80% of the cocaine was converted to MeED. Nakahara et al. [4] carried out the thermal degradation of cocaine in crack (cocaine hydrochloride and sodium bicarbonate) under 400-500 mm Hg suction at temperatures ranging from to 170°C to 420°C. MeED was the predominant pyrolysis product at over 255°C. By heating cocaine in glass ampules at different temperatures (180-200°C). Jindal et al. [5] reported that MeED and cocaine were the only two nitrogen-containing products detected by GC/MS.

None of the cocaine pyrolysis procedures examined have been adapted to MeED synthesis. All reported MeED synthesis methods involved time consuming and multistepped processes. Zirkle et al. [6] and Lukaszewski et al. [2] prepared MeED by refluxing cocaine hydrochloride with hydrochloric acid to ecgonidine which is then reacted with methanol under acid catalysis. The MeED was then purified by a sequence involving acid extraction, alkali neutralization and ether extraction. The complete processes required more than 5 days. Jindal et al. [7] reported MeED as a minor product (6%) in the preparation of methyl ecgonine by refluxing ecgonine and methanol with drops of thionyl chloride followed by evaporation to dryness for thin-layer-chromatography separation. Zhang et al. [8] was the only group that synthesized MeED without using reflux apparatus. After a reaction of the mixture of methyltriphenylphosphonium, hexamethylphosphoric triamide and ecgonine methyl ester in a microvial at 50°C for 4 hours, they conducted a sequence involving acid extraction, base extraction, and organic solvent extraction to separate the MeED.

Neudorfl et al. [9] reported the detection of MeED during high-volume vapor sampling of evidence storage vault or cargo containers that once held smuggled cocaine, and suggested that MeED could be used as an indicator for the presence of cocaine in an enclosed compartment.

These four time consuming and labor intensive methods of MeED synthesis in conjunction with the proposal of Neudorfl et al. [9] for using the detection of MeED for cocaine searches led the USCG R&DC to develop a more simplified laboratory procedure for MeED synthesis.

Since the vapor pressure of cocaine is extremely low, its analysis using IMS or GC methods requires relatively high desorption and oven temperatures, respectively. The higher the operating temperature required for analysis of cocaine, the more difficult it is to miniaturize the detection instrumentation. Due to the high vapor pressure of MeED, further studies to understand the catalytic pyrolysis reaction at low temperatures may therefore help to miniaturize some of the existing detection instruments. Such studies may also help to implement the portable GC as a field instrument in cocaine detection. This report describes an investigation into the catalytic pyrolysis of cocaine. Experiments were carried out to identify pyrolysis products and the effects of temperature and heating duration on their formation as well as possible reaction mechanisms.

The silanol (Si-OH) group, one of the active sites on a glass filter surface, was proposed as the catalyst in the pyrolysis of cocaine in the Ionscan desorber [1]. An increase in the glass surface area or in the number of silanol active sites should enhance the pyrolysis degradation of cocaine. Silica gel, widely used as the absorbent in liquid chromatography because of its highly porous structure (i.e., large surface area) and its characteristic silanol functional group, was therefore selected as the pyrolytic catalyst.

2. EXPERIMENTAL

2.1 Reagents and Chemicals

Cocaine HCl and cocaine base standard in methanol (1 mg/mL) were obtained from Alltech-Applied Science or prepared from pharmaceutical grade cocaine HCl or cocaine base purchased from Sigma Chemical Company. Less concentrated standards were prepared by further dilution of this standard with methanol. Benzoic acid and methyl benzoate were graciously donated by Dr. J. Stuart of the University of Connecticut. EM Science's OmniSolv Methanol and Baker Resi-analyzed Acetone were used for standard preparation and washing. Silica gel powder (60-200 mesh) was obtained from Baker.

2.2 Materials

All lab glassware was purchased from Ace Glass Inc. unless otherwise noted. Final sample concentrations were performed using 10 mL centrifuge tubes from Kimble. Supelco clear glass 4 mL and 7 mL, or I-Chem 40 mL vials with Teflon-lined screw caps were used for sample storage. Distilling columns were Snyder type with floating balls in three sections. Pyrolysis glassware included Hickman still heads with a side port (capped with a Teflon septum) and 14/10 inner and top-threaded outer joints and 25 X 200 mm tubes with ground glass 24/40 joints.

2.3 Instrumentation

GC/MS analyses were performed on a Finnigan MAT Model INCOS 50 quadrupole mass spectrometer and data system coupled to a Hewlett-Packard Model 5890A gas chromatograph. A J&W Scientific DB-5ms capillary column (60 m X 0.25 mm and 0.25 μm film thickness) with a 6 m guard column were used for sample separation. The column was operated at a head pressure of 7.5 psi of helium. Temperature settings were 280°C for the injector and 249°C for the transfer line and transfer nozzle. A Restek uniliner was inserted into the GC injector. After sample injection, the oven temperature was maintained at 40°C for 2 min., ramped to 300°C at 14°C/min., and then held at 300°C for 4.5 min. The mass spectrometer was operated in positive EI mode with the electron energy at 70 eV and emission current at 750 μA. The ion source was maintained at 150°C. The mass spectrometer was programmed to scan over the m/z range 45-650 at a data rate of 1 scan/sec.

3. METHODS

3.1. Preparation of Samples of Cocaine Coated Silica Gel

The results of GC/MS analyses of concentrated methanol extracts from heat treated, methanol-washed silica gel and unwashed silica gel revealed similar background spectra. Therefore, silica gel direct from the jar was used for all tests.

Both cocaine salt (cocaine HCl) coated silica gel (CsCSG) and cocaine base coated silica gel (CbCSG) were prepared by adding silica gel to the corresponding cocaine standard solutions in the ratio of 1 mg cocaine to 2 g of silica. Each slushy mixture was blown down under a gentle nitrogen stream at room temperature until visibly dry and without any clumps.

In order to distinguish whether methanol or acetone was used in the preparation of CsCSG or CbCSG, the prefix of MeOH or Atn are used, respectively.

3.2 Pyrolysis of CCSG

3.2.1 Quick Procedures to Study the Temperature Effects on Cocaine Pyrolysis and Degradation

An aliquot of MeOH-CsCSG was weighed and placed in a 25 mL Erlenmeyer flask with a ground glass outlet. This flask was joined to two Hickman still heads in tandem. The flask/Hickman set was then placed on a hot plate at a preset temperature and intermittently swirled to prevent vigorous degassing due to the superheating of MeOH-CsCSG. After the first 1 to 2 minutes of heating, an aluminum foil jacket was placed around the flask to increase the temperature of the flask wall and thereby evaporate chemicals condensed on the inside wall of the flask. The heated MeOH-CsCSG was placed in a column chromatograph and eluted with methanol to extract the reaction end products. The methanol extract was then blown down under a gentle stream of pure nitrogen for GC/MS analysis. Rapid evaporation of the solvent or evaporation to dryness caused the loss of most volatile products including the MeED.

3.2.2 Pyrolysis of CCSG in a 25 x 200 mm Test Tube

About 1 to 2 grams of MeOH-CsCSG, MeOH-CbCSG, Atn-CsCSG, or Atn-CbCSG was added to a 25x200 mm test tube with a ground glass outlet joint connected to a Snyder distilling column. The test tube was then inserted into the slot of a heating block which was preheated to about 130°C. The amount of CCSG placed in the test tube never exceeded the top surface of the heating block. The pyrolysis duration was 1.5 to 3.5 hours. After the pyrolysis, the test tube was removed from the heating block to cool to room temperature. The silica gel was then transferred to a Soxhlet extractor and subsequently extracted with acetone for at least 4 hours. Finally, the acetone extract was blown down under a gentle stream of pure nitrogen to a desired amount.

3.3 GC/MS Analysis of Pyrolysis Products

The GC/MS in scan mode was used to analyze the end products of the pyrolysis reaction. Targeted compounds analyzed in selected ion mode (SIM) and their corresponding fragments were: methyl benzoate (77, 105, 136), benzoic acid (77, 105, 122), carbomethoxycycloheptatrienes (CMCHTs) (91, 119, 135), cocaine (82, 182, 303), MeED (152, 181), and tropinone (82, 96, 139). For semi-quantitative comparisons, the intensities of selected single ions were recorded for 105 (benzoic acid), 105 (methyl benzoate), 82 (tropinone), 91 (CMCHTs), 152 (MeED), and 82 (cocaine) at the corresponding retention time.

4. RESULTS AND DISCUSSIONS

4.1 Pyrolysis Products of MeOH-CsCSG

Figure 1 shows the typical peaks detected by GC/MS of the methanol extract of MeOH-CsCSG pyrolyzed in an Erlenmeyer flask for the quick study of the temperature effect on pyrolysis. Methyl benzoate and MeED were the two major pyrolysis products. When cocaine salt was pyrolyzed under reduced pressure (400 - 500 mm Hg), Nakahara et al. [2] observed that carbomethoxycycloheptatrienes (CMCHTs) were the main pyrolysis products, and the total amount of CMCHTs initially increased with increasing pyrolysis temperatures from 170°C to 255°C and then subsequently decreased. Figure 1 shows that CMCHTs were generated in trace amounts in the pyrolysis of MeOH-CsCSG from 122 - 190°C. CMCHTs were identified by comparing their mass spectra to that reported by Nakahara et al. [4]. Figure 2 shows the mass spectrum of one of the CMCHTs.

Tropinone (Figure 3) was also detected in this study. None of the previous cocaine pyrolysis studies reported any presence of tropinone. Tropinone was identified by comparison with the retention time and mass spectrum of an authentic standard.

4.2 Temperature Effect on Pyrolysis of MeOH-CsCSG

The GC/MS peak height intensities of selected ions for each pyrolysis product versus temperature are plotted in Figure 4. For convenience, the peak height of the largest CMCHT value was used. All intensities were corrected for 1 gram of CsCSG. Figure 4 clearly indicates that the cocaine was almost completely decomposed at 155°C. With an increase in the reaction time, this temperature requirement could have been even lower. A concurrent, though unexpected, observation was that the dramatic decomposition of cocaine HCl from 120°C to 155°C did not reflect a corresponding substantial increase in either methyl benzoate or MeED. The additional unreacted cocaine at 191°C compared to that at 155°C may be due to the increased amount of MeOH-CsCSG used at 191°C.

During two tests performed with MeOH-CsCSG under similar test conditions except for a 10°C difference in heating temperature, a pronounced difference in cocaine and MeED levels was noticed in the resulting GC/MS RICs, Figure 5a and 5b. It is evident that a moderate temperature increase can significantly impact the level of degradation of the cocaine.

4.3 The Mechanism of Methyl Benzoate Formation in the Pyrolysis of MeOH-CsCSG

It is well known that methyl benzoate is one of the compounds associated with smuggling cocaine. Methyl benzoate is a natural product of the plant Erythoxylon coca, and it has also commonly been accepted as a cocaine degradation product in the real world environment without consideration as to the availability of the external methoxy group.

In the preparation of MeOH-CCSG, it has been observed that the final weight of silica gel was increased by about 10 to 20% of its original weight. This increase was observed after the methanol had been evaporated and the nitrogen had dried the silica gel to its original powdery form. The extra weight was due to the methanol trapped inside the silica gel. Therefore, the methoxy group associated with methyl benzoate formation during the pyrolysis of MeOH-CsCSG (Figure 6a) could have been obtained from the cocaine molecule itself or other adjacent cocaine molecules, or from methanol trapped inside of the silica gel. By using the acetone as a solvent in the preparation of CsCSG, the methoxy group from a non-cocaine molecule was removed. The GC/MS RIC in Figure 6b shows that the benzoic acid and MeED were the two major Atn-CsCSG pyrolysis products. These observations in conjunction with the lack of methyl benzoate in the pyrolysis products, indicates that the elimination of benzoic acid from the cocaine molecule to form methyl ecgonidine was the major reaction during silica gel catalyzed cocaine pyrolysis without methanol. Whether the benzoic acid was eliminated via a concerted or stepwise mechanism cannot be ascertained with the existing information. When methanol was available, as in tests with MeOH-CsCSG, benzoic acid eliminated from cocaine can then react with methanol to form methyl benzoate.

4.4 Pyrolysis Products of CbCSG

Martin et al., Nakahara et al., and Jindal et al. reported that MeED and benzoic acid were the main products of cocaine base pyrolysis [3, 4, 5]. Figures 7a and 7b show that MeED was one of the major products of pyrolysis of MeOH-CbCSG and Atn-CbCSG. The other major product, methyl benzoate or benzoic acid, depended on the solvent used in the preparation, methanol or acetone, respectively.

Trace amounts of CMCHTs and tropinone were also detected in the pyrolysis products of all four reactions.

Except for some minor variations in the unreacted cocaine residue, there were no distinguishing differences among the GC/MS RICs of CsCSG and

CbCSG (Figures 6 and 7). A common silica gel catalytic pyrolysis mechanism is therefore shared between cocaine HCl and cocaine base.

4.5 Isolation of MeED

It has been observed that the relative peak ratio of methyl benzoate to MeED decreased substantially during the storage of the pyrolysis products of MeOH-CsCSG and MeOH-CbCSG in methanol. This was due to the high vapor pressure of methyl benzoate in comparison with that of MeED. Figure 8 illustrates that by taking advantage of this phenomena via carefully controlled evaporation, it may be possible to separate the MeED from the remaining pyrolysis products without the commonly applied sequence of acid extraction, neutralization with an alkali, and extraction with an organic solvent.

5. CONCLUSIONS

This study demonstrated that MeED was one of the major reaction products of the silica gel catalyzed pyrolysis of both cocaine salt and base. A predominant conversion of cocaine to MeED was observed at temperatures as low as 150°C for 6 minutes. The MeED can therefore be synthesized by this method which required only common laboratory glassware and heating devices. Not only was the synthesis procedure simple, requiring no acid reflux steps or complex, multisolvent extractions, but also short, requiring no overnight processes.

ACKNOWLEDGMENTS

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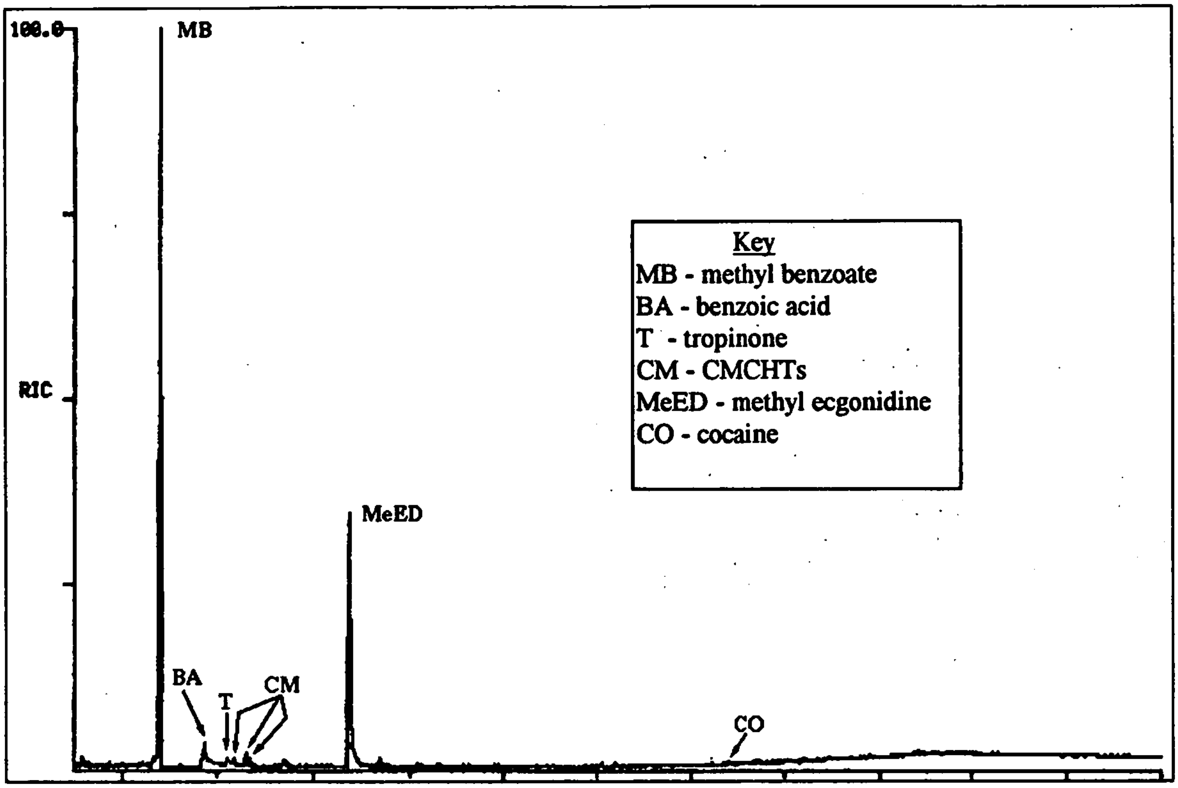

Figure 1 - GC/MS RIC of the Methanol Wash from
1.74 g MeOH-CsCSG Heated at 155°C for 4 min

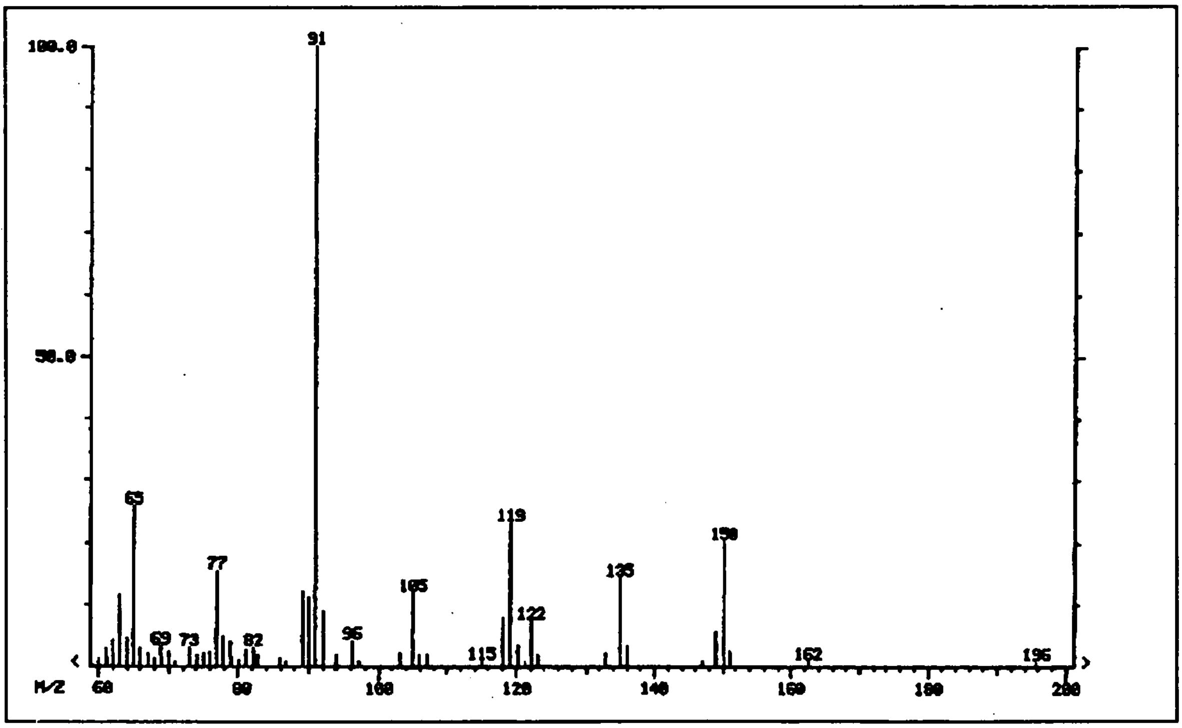

Figure 2 - GC/MS Spectrum of a Typical CMCHT from Figure 1

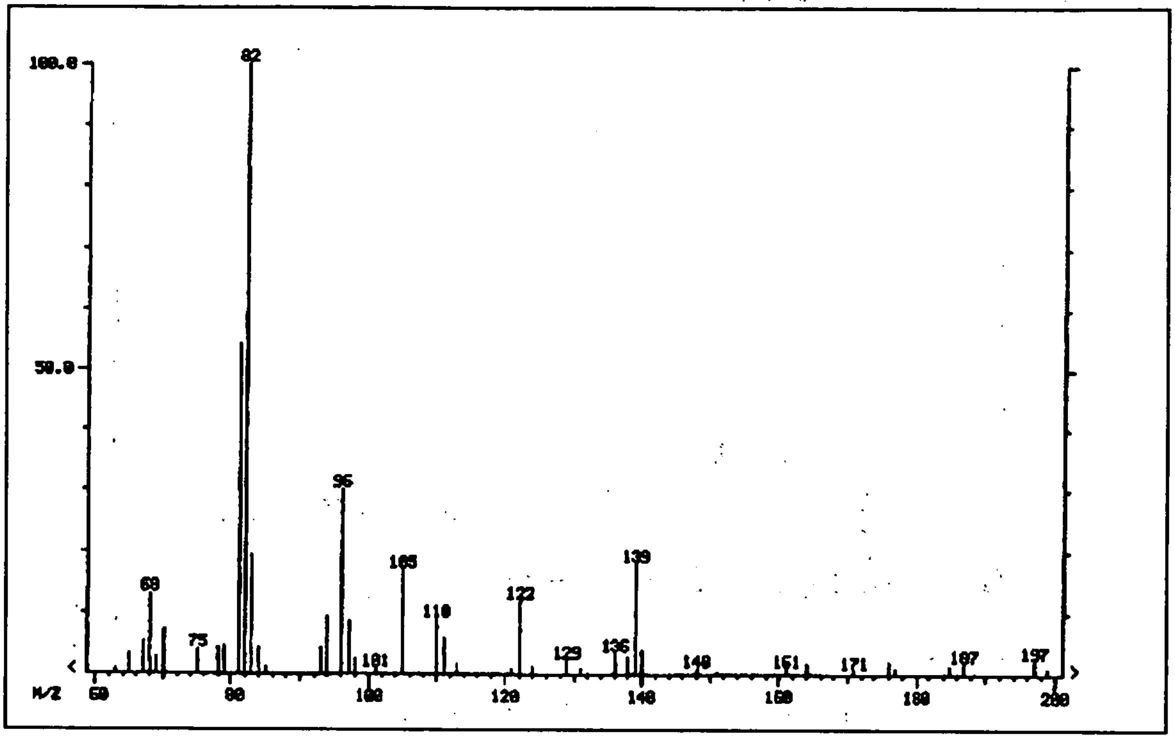

Figure 3 - GC/MS Spectrum of Tropinone from Figure 1

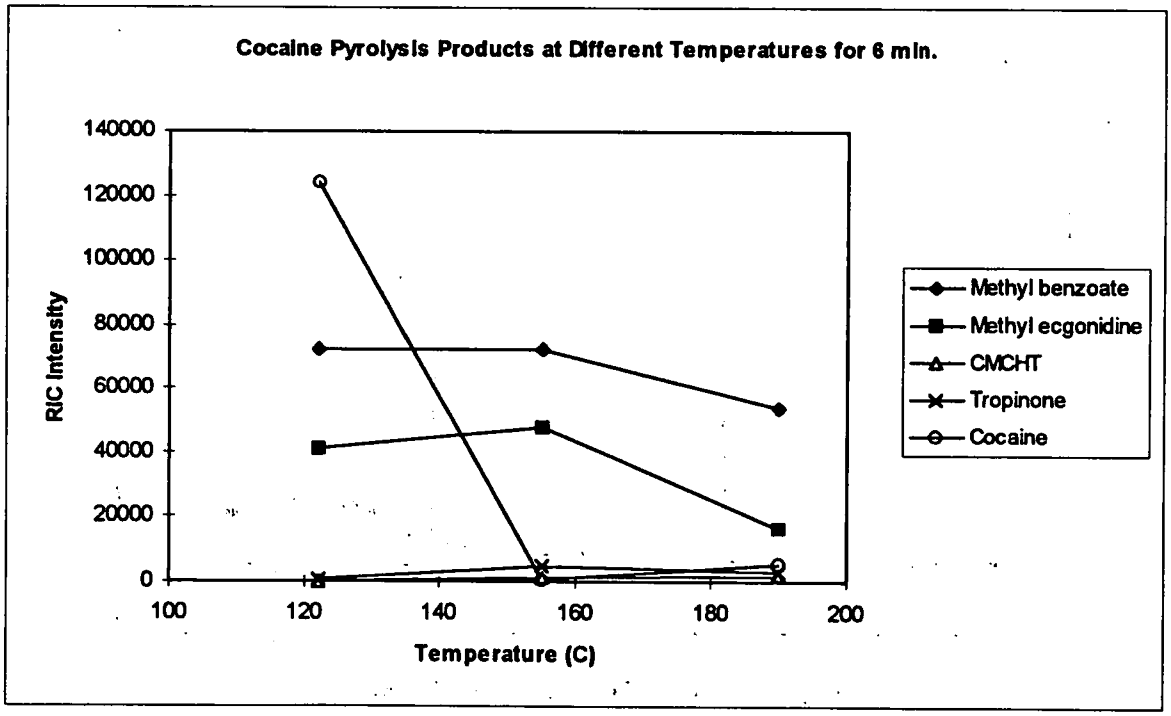

Figure 4- GC/MS Selected Ion Intensity of each Pyrolysis Product at Different Temperatures for 6 Minutes

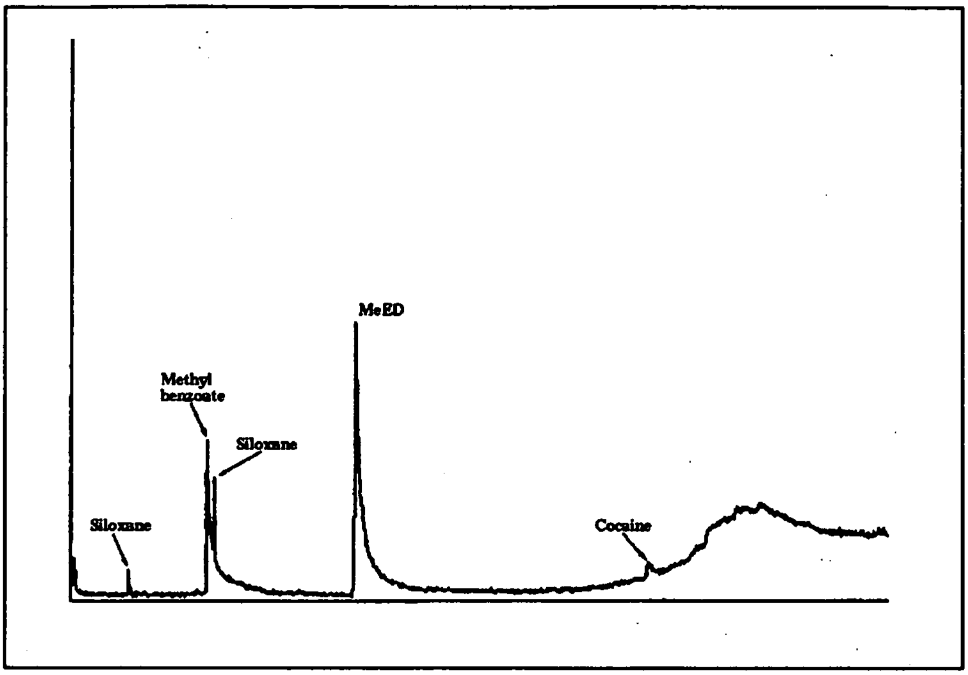

Figure 5a- GC/MS RIC of Methanol Wash from
2 g MeOH-CsCSG Heated at 135°C for 90 Minutes

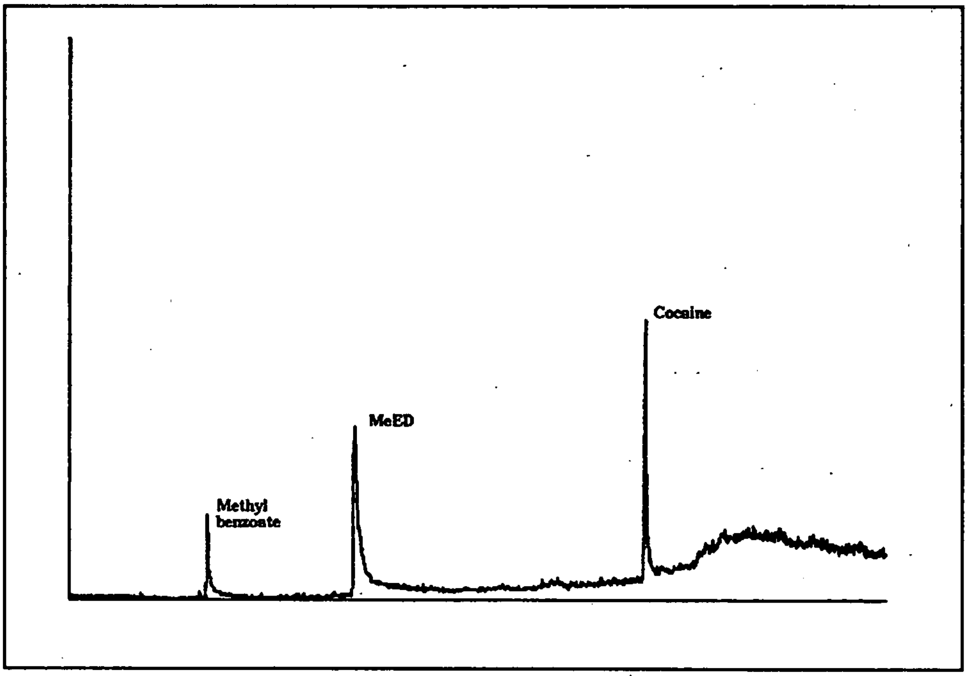

Figure 5b- GC/MS RIC of Methanol Wash from
2 g MeOH-CsCSG Heated at 125°C for 90 Minutes

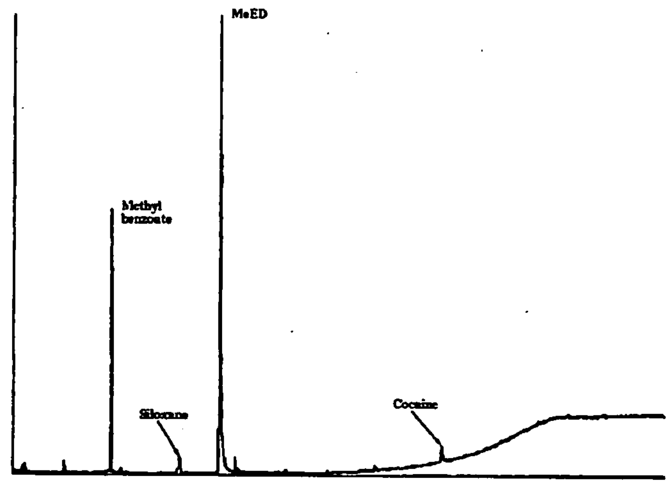

Figure 6a - MeOH-CsCSG

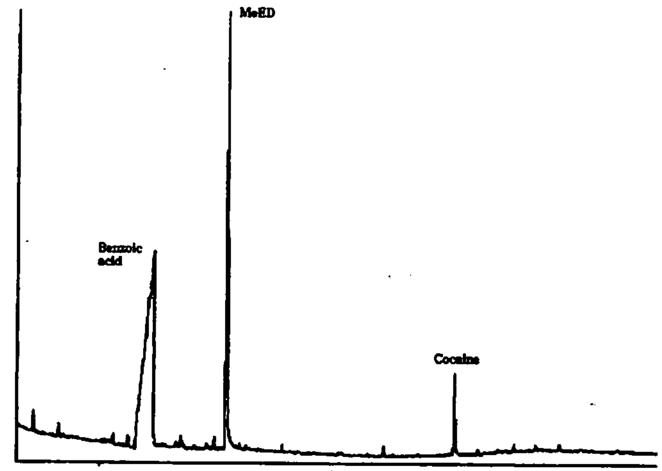

Figure 6b - Atn-CsCSG

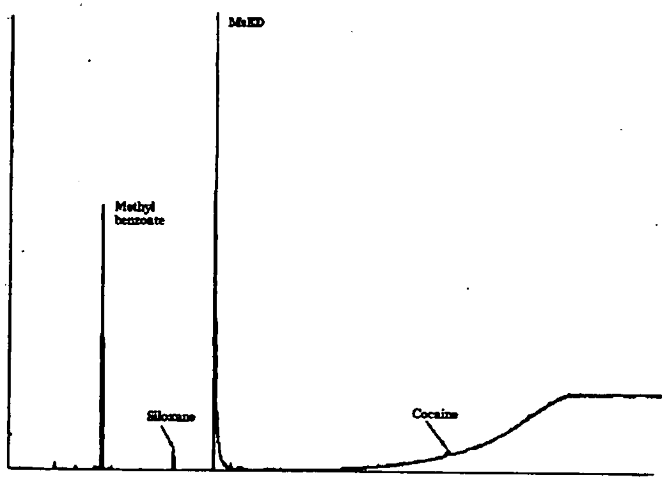

Figure 7a - MeOH-CbCSG

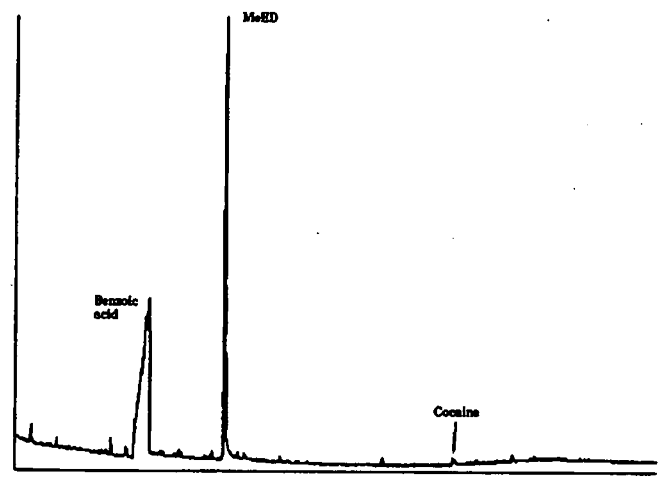

Figure 7b - Atn-CbCSG

GC/MS RICs of Concentrated Solvent Extracts from Pyrolyzed CCSG Heated at 130°C for 90 Minutes

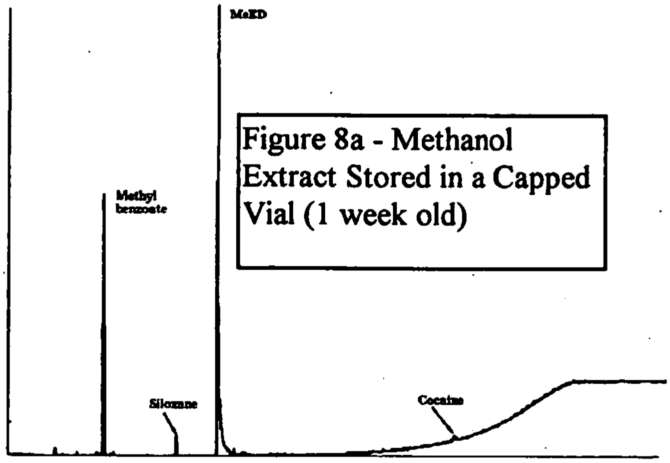

Figure 8a - Methanol Extract Stored in a Capped Vial (1 week old)

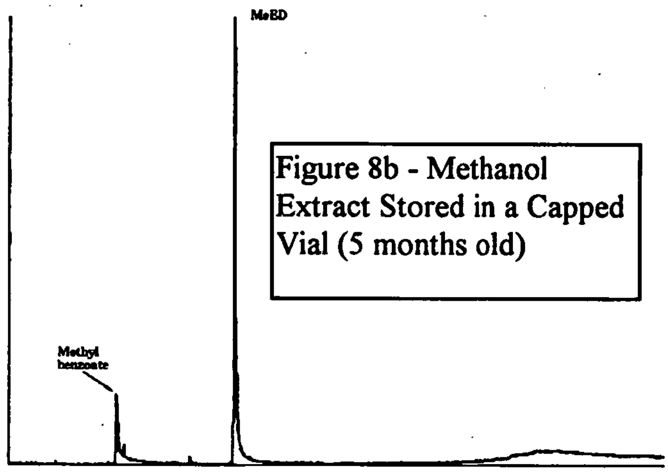

Figure 8b - Methanol Extract Stored in a Capped Vial (5 months old)

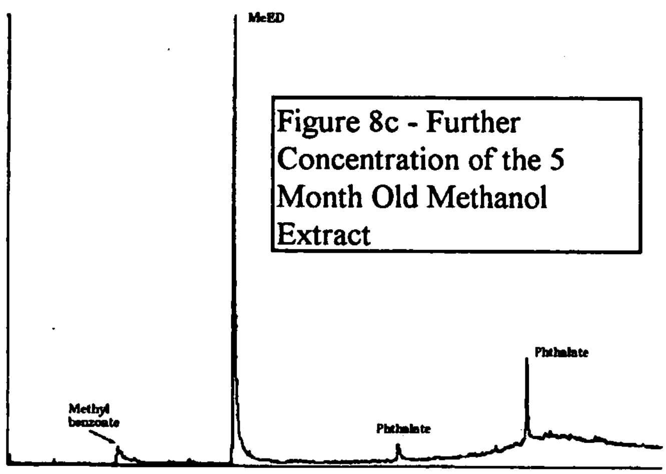

Figure 8c - Further Concentration of the 5 Month Old Methanol Extract

Loss of Methyl Benzoate in a Closed and Open System

Value Assessment of Chemical Markers for Cocaine Hydrochloride

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ABSTRACT

In efforts to curtail the supply of illicit cocaine hydrochloride, there is nothing as useful as cocaine hydrochloride itself for a detection target compound. Due to the nature and physical properties of cocaine hydrochloride, it is sometimes not detectable using instrumental methods of analysis. In addition, there are instances when cocaine hydrochloride itself is not easily accessible as in cargo containers. A number of compounds have been proposed as markers for cocaine hydrochloride. Some of these compounds are traceable in structure to cocaine hydrochloride while others are not. In this paper, a list of the chemical compounds and the origin of these compounds will be provided and discussed. The detection method and the relative significance of each compound to cocaine hydrochloride detection are described.

Introduction

Cocaine hydrochloride is an illicit drug that has been widely distributed and widely used in the streets and neighborhoods of America resulting in destroyed lives and violence. The Supply Reduction element of the National Drug Control Strategy includes the detection and interdiction of illicit drugs at Ports of Entry into the U.S. A number of government agencies cooperate in this effort. However, the enormous volume of commerce through these ports dictates a requirement for efficient and effective non-intrusive inspection of shipment vehicles and containers. One of the approaches that have been attempted is to understand the chemistry of cocaine hydrochloride when it is in the environment and use the information gained to identify target compounds for the detection scheme for cocaine hydrochloride.

Battelle has been involved in the study of the chemistry of cocaine hydrochloride. In this paper, the information we have gathered is consolidated in order to create an encompassing picture of cocaine hydrochloride and the substances that are related/associated to it. A list of compounds is presented in this paper and the relationship of these compounds to cocaine hydrochloride is established. The analytical methods used to detect these compounds are mentioned.

Discussion

The following discussion is based on the compounds listed in Figure 1. There are three concentric circles in Figure 1 that establish the relationship of the compounds to the target drug, cocaine hydrochloride.

Compounds outside the Concentric Circles

The compounds methanol, methyl ethyl ketone, acetic acid, 2,2,4-trimethylpentane, 2-methylpentane, dichloromethane, isopropyl alcohol, acetone were observed in illicit cocaine hydrochloride samples provided by the Drug Enforcement Agency in

Chicago. The illicit cocaine hydrochloride was analyzed for headspace constituents using cryogenic trapping and GC/MS analysis (1). Among the compounds listed, methanol and methyl ethyl ketone were consistently found in the three illicit samples.

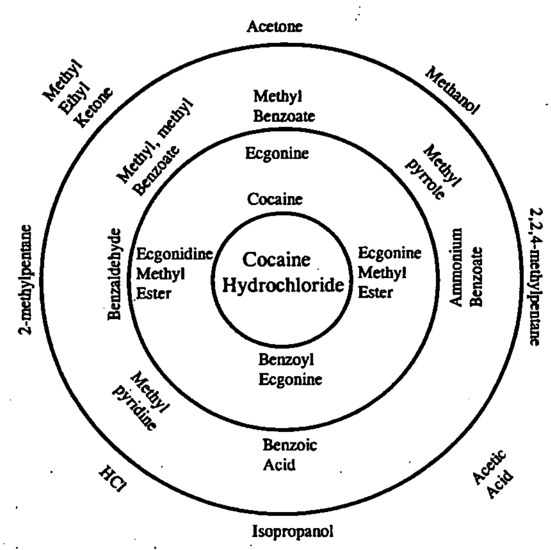

Figure 1. The three concentric rings describe the relationship of the listed chemical compounds to cocaine hydrochloride.

Because these compounds are commonly found as solvents in chemical laboratories, their significance is defined by the following qualifications:

a) if found in large quantities in shipping containers, it is either indicative of chemical mishandling (EPA violation) or failure to declare the cargo (Custom Duties violation)
b) not necessarily indicative of cocaine hydrochloride because they are not structurally related to cocaine
c) when found in illicit cocaine, they may indicate the process used in the manufacture of the drug
d) surveillance of manufacturing operation.

The surveillance value of these solvent chemicals would consist of tracking and tracing the movement of large quantities from origin to destination. Disruption of the supply of processing chemicals has some effect, though limited, upon illicit drug manufacturing operations.

Although we did not observe HCl in our headspace determination, this compound is included because it could be released by cocaine hydrochloride in the same way as in the dissociation of ammonium chloride to form ammonia and HCl. However, the significance of finding trace amounts of HCl in a cargo container is nil.

Compounds in Between the Outer and Middle Circles

The compounds listed include methyl pyrole, methyl pyridine, benzaldehyde, methyl benzoate, ammonium benzoate, benzoic acid and methyl benzoate. Methyl pyrole and methyl pyridine were observed not as neutral compounds but observed when cocaine fragments inside the mass spectrometers. Since the formation of the two compounds proceeds via a radical reaction, their observation implies that cocaine may undergo decomposition into methyl pyrrole or methyl pyridine if it is exposed to strong light which is known to initiate a reaction proceeding through the formation of radicals.

On the other hand, benzaldehyde, methyl, methyl benzoate, ammonium benzoate, benzoic acid and methyl benzoate were observed when cocaine hydrochloride was heated in a glass tube around 190°C. All of these compounds are related to cocaine via the benzoate functional group attached to the azabicyclo ring system.

Because the formation of the compounds listed above requires special conditions, their significance as target compounds is diminished.

However, methyl benzoate is a special case. It has also been observed in the storage experiments performed at Battelle (2). A known amount of cocaine hydrochloride was exposed to different temperatures (between 27°C and 40°C) and humidities (dry and 80%RH). Methyl benzoate was observed in different amounts in all these experiments. We also found that temperature and high humidity promotes formation of methyl benzoate.

What is most interesting about methyl benzoate is that it was found in test shipping containers which were loaded with seized cocaine hydrochloride in Fort Huachuca, Arizona and Montreal, Canada. This result suggests that methyl benzoate is expected to be present where cocaine hydrochloride is stored.

Compounds in Between the Middle and Inner Circles

Cocaine, Ecgonine, ecgonine methyl ester, benzyl ecgonine and ecgonidine methyl ester are compounds directly related to cocaine hydrochloride. All of them have the azabicyclo ring, which is the main backbone of the cocaine molecule. By law, these compounds are Schedule II. This means that people possessing them legally should have the required authorization.

Cocaine is not differentiable from cocaine hydrochloride in gas phase analytical techniques. They can however be differentiated from each other by ion chromatography. That is, the chloride signal is expected in cocaine hydrochloride but not cocaine. Cocaine is listed in Figure 1 because cocaine hydrochloride can dissociate to form cocaine and HCl.

Ecgonine, ecgonine methyl ester and benzoyl ecgonine are compounds that we detected using LC/MS technique (PE-Sciex triple quad mass spectrometer) when pharmaceutical grade cocaine hydrochloride was soaked in water. All of these compounds are hydrolysis products of cocaine hydrochloride. In the case of ecgonine, the methoxy and benzoate functional group of cocaine are hydrolyzed. In ecgonine methyl ester, the benzoate group is hydrolyzed. In benzoyl ecgonine, the methoxy group is hydrolyzed. Although these compounds are expected to form, it appears in our experiment that they don't have high volatility and hence their likelihood to be collected in the gas phase diminishes.

Interestingly enough, we also found methyl benzoate in the mixture. This confirms the result in the storage experiments.

In another series of experiments, we were able to establish the origin of the egonidine methyl ester (EDME) which had been observed in analyses by ourselves and other investigators. By varying the inlet temperature of a GC/MS, we were able to demonstrate that EDME is a thermal degradation product of cocaine, with the relative abundance a function of temperature. To confirm the EDME formation site, we then analyzed cocaine by LC/MS technique (a colder technique) and found that no EDME was formed. Therefore, we conclude that where sufficient cocaine vapor is available, a high temperature detection system will indicate ecgonidine methyl ester.

Conclusion

Figure 1 summarizes the relationship of the listed compounds to cocaine hydrochloride. Among the compounds, methyl benzoate holds the promise of being a good indicator for cocaine hydrochloride considering that it is volatile and proven to be easily formed when cocaine hydrochloride is exposed to humidity even at room temperature.

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PERFORMANCE AND APPLICATIONS OF A NEW PORTABLE DETECTION SYSTEM FOR DRUGS AND EXPLOSIVES

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ABSTRACT

A new hand-held portable vapor detection system is presented. Based on Ion Track Instruments' patented Ion Trap Mobility Spectrometer (ITMS), this new instrument is shown to be capable of detecting picogram levels of vapors from drugs and explosives in the laboratory. Data is presented on the limits of detection for cocaine, heroin, RDX, TNT, and PETN. Other properties of the instrument, such as the sampling system, computer interface, and battery performance, are summarized.

Preliminary results from container sampling for drugs and bunker sampling for explosives are presented. A model for the distribution of vapor concentration from low volatility compoundsinside a container was presented and compared with some preliminary empirical results.

1 INTRODUCTION

The United States Government has taken several steps that demonstrate its commitment to eliminating the flow of contraband substances within and across American borders. The acquisition of new technology for this effort, such as trace explosives detectors for airport security, has been widely publicized. Modern narcotics related crime scene investigations, however, often still rely on the collection of possibly contaminated articles and suspected bulk drugs for later forensics laboratory analysis.

Although reliable methods for these analyses, such as gas chromatography-mass spectrometry, are available, there are many drawbacks to remote sampling methodology. Several recent high-profile cases have raised concerns with the general concept of remote sample collection: the possibility of evidence contamination during or after collection, the destructive sample preparation often necessary for the analysis, and the possibility that other evidence will be disturbed during sample collection. In fact, up to 80% of the error in the data for any sample is caused by loss or contamination between sample collection and analysis.[1]

The detection of bulk drugs or explosives in vehicles and cargo containers is another application that requires "instant" results. The use of canines and x-ray technology, no matter how successful, can only meet a small fraction of the demand for drug and explosives detection and new more innovative, lower cost solutions are needed. For example, eight million cargo containers cross U.S. borders each year and presently only about 2% of these containers are checked. Checking vehicles for explosives by the residue analysis techniques being installed at airports becomes problematic where personnel have legitimate contact with explosives, such as at military installations. A sensitive, portable instrument for the non-destructive identification of multiple narcotic or explosive substance vapors would not only solve the problems associated with remote sampling in narcotic crime scene investigation, but would increase sample throughput for container analysis and help to eliminate nuisance alarms resulting from trace residues.

Ion Track Instruments, Inc. (ITI, Wilmington, MA) has developed a hand-portable instrument that is capable of detecting picogram levels of vapors or particles from both explosives and narcotics. The VaporTracer vapor detector (Figure 1) uses the same patented ITMS technology that is used in the ITEMISER, the ITI benchtop detector being installed in airports across the country. The atmospheric sampling system provides a several fold increase in sensitivity as compared to wipe/residue analysis methods, decreases the detector's susceptibility to negative and positive interference, and reduces nuisance alarms caused by ultra-trace levels of illicit substances that may be present for legitimate reason. Performance characteristics, such as calibration response curves and minimum detectable quantities for heroin, cocaine, RDX, TNT, and PETN are presented. The sampling system, portability characteristics (including battery life), computer interface, and other instrument properties are summarized. Preliminary results from container sampling for drugs and bunker sampling for explosives are presented. A model for the distribution of cocaine vapor concentration inside a container was developed and is compared with the empirical results obtained from container tests.

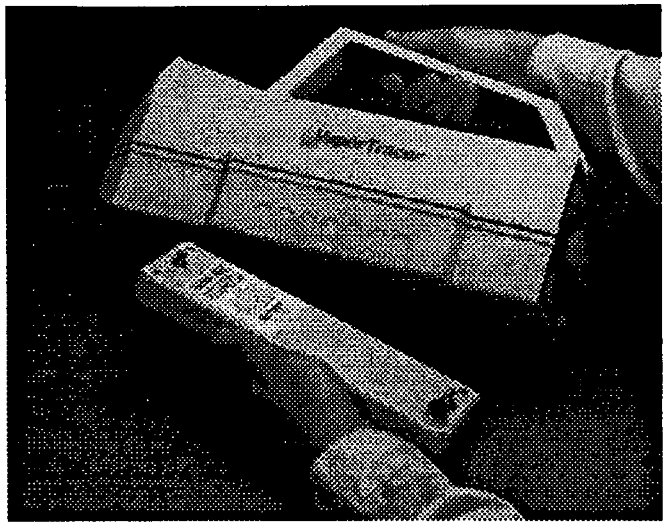

Figure 1. Photograph of the VaporTracer narcotics/explosives vapor and particle detection system and rechargeable battery pack.

2 EXPERIMENTAL

2.1 Instrumentation

The patented ITMS detector used in the VaporTracer offers a 100-fold sensitivity increase over conventional ion mobility spectrometry (IMS) detection. The principles of ITMS technology have been described extensively elsewhere. [2,3,4] Figure 2 is a picture of the LCD dot matrix screen. Up to six substances can be displayed on the screen. A bar-graph and number appear when a substance is detected, corresponding to the relative "strength" of the signal. The LCD screen, five button control panel, and sample introduction nozzle are seen in Figure 3. The trigger button is located on the handle. The instrument weighs about eight pounds and is packaged into a convenient "man portable" design. Two rechargeable batteries, a compact 90 minute battery (shown in Figure 1), and a six hour battery belt, as well as a detachable extension cord are available.

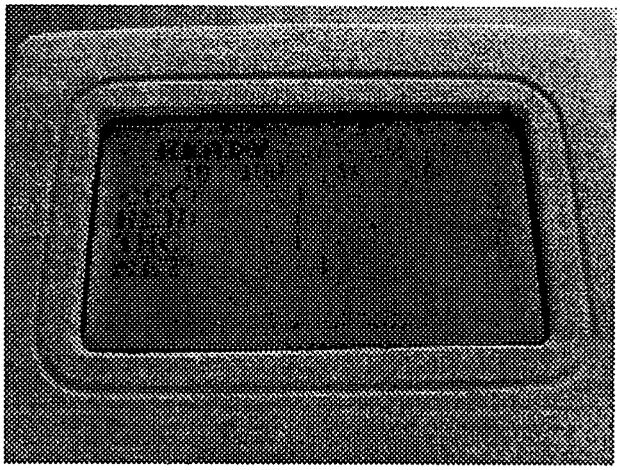

Figure 2. VaporTracer LCD dot matrix screen for narcotics mode. The "COC", "HER", "THC", and "MET" readouts stand for cocaine, heroin, THC, and methamphetamine, respectively. The numbers under the "READY" signal are the logarithmic bar-graph scale. Numeric values for detections are displayed at the right of the screen.

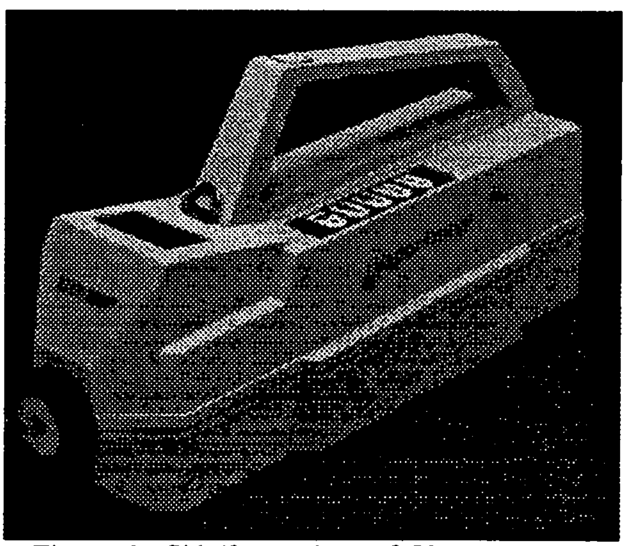

Figure 3. Side/front view of VaporTracer showing nozzle(at left), five button control panel (next to handle), LCD screen (in front of handle), and start trigger (on handle).

An imbedded 486DX66 computer controls sampling time, data analysis, calibration, and instrument cleardown. Pre-set one touch trigger activation, or variable collection time (requiring one trigger for activation and another to stop acquisition) can be selected. Plasmagrams are collected at a rate of 50 Hz during the adjustable integration time. The instrument has six substance capability during stand-alone performance. Connecting the VaporTracer to a laptop PC with a standard RS232 cable allows the user to detect forty substances at once, as well as to analyze plasmagrams more thoroughly using ITEMISER software. The VaporTracer is simply calibrated using an internal substance without the need for external vapor sources or computer support. Plasmagrams can be displayed directly on the LCD screen.

The sensitivity required for true vapor detection, a several fold increase over wipe/residue analysis methods, is achieved by discrete atmospheric sampling through a membrane that is selectively permeable to organic compounds. The detector and membrane are kept at approximately 200° C. When a one-touch trigger is activated, sampling pumps cause sample air and vapor to impinge upon the membrane at approximately 5 liters per minute. The air flow cools the membrane to approximately 100° C, causing it to become an effective vapor and particle preconcentrator. When sampling stops, the membrane temperature rises again, releasing the vapors into the detector.

The interface between the sampling membrane and the detector has been altered from the prototype design [2,3,4] so that the membrane temperature is close to that of the detector. Other thermal design changes have been made in order to extend battery life. The instrument is switched between narcotics and explosives detection mode by changing a small power-brick that is accessed through a door in the bottom of the unit. Mode change requires less than two minutes, in which time the internal heated components do not cool enough to require additional warm-up time.

2.2 System Performance

Explosives and narcotics vapors were produced using an INEL Vapor Generator (Idaho National Engineering Laboratories, Idaho Falls, ID) with a TNT, RDX or PETN head as appropriate. The sampling time of the VaporTracer was varied to correspond to the length of the vapor pulse produced by the generator in all experiments. An imperical optimization was performed with each of the vapor heads to ensure accurate quantitative calibration. Figures 4 and 5 show the response curves for cocaine and heroin respectively. Figure 6 shows the response curves for RDX and TNT. Figure 7 shows the response curve for PETN.

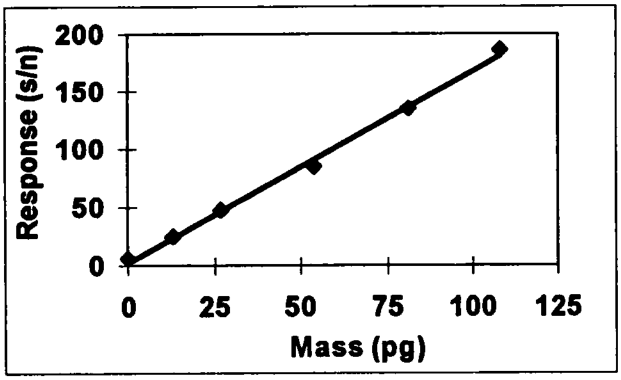

Figure 4. VaporTracer calibration response curve for cocaine vapor generated using an INEL generator.

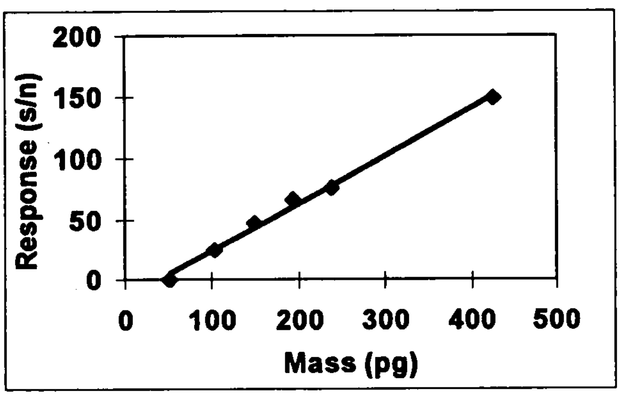

Figure 5. VaporTracer calibration response curve for heroin vapor generated using an INEL generator.

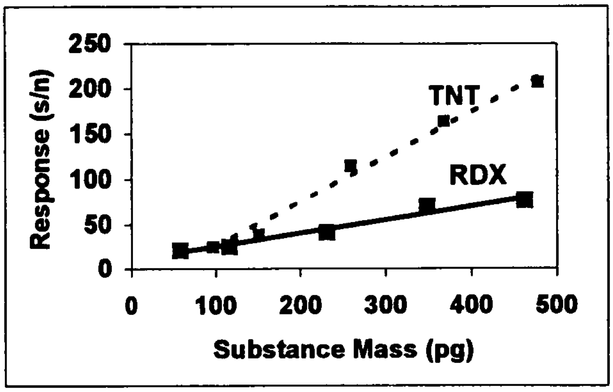

Figure 6. VaporTracer calibration response curves for RDX and TNT vapors generated using an INEL generator.

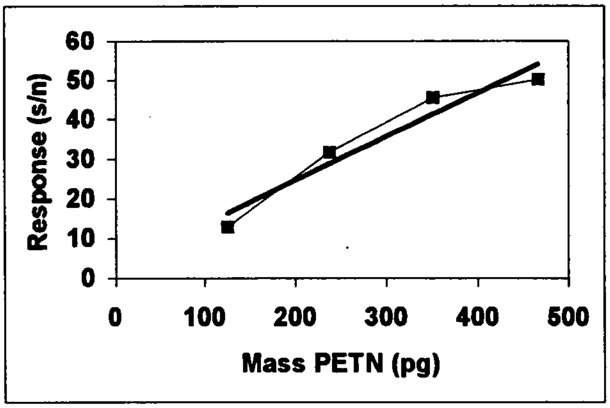

Figure 7. VaporTracer calibration response curve for PETN vapor generated using an INEL generator.

2.3 Model of the Vapor Concentration in a Cargo Container

A model was developed in order to describe the probable vapor distribution of cocaine in the cargo container. Although several factors have probably not been accounted for, the model was an attempt to begin to define the real world problem of sampling vapor from an external port. The assumptions that were made in developing the model were: the vapor concentration profile was at equilibrium (i.e. $\delta C/\delta t = 0$ (1), where C is concentration and t represents time), the walls of the container were infinite vapor sinks (the vapor concentration dropped to zero at the walls), and that the emission source (the cocaine) was a three foot cube on the middle of the floor. Since the cocaine is a continuous source of vapor, a net flow of vapor from the source to the infinite sink (the walls) is assumed to occur. The vapor flow would be analogous to heat flow from a source to a sink. The container was divided into 6 inch cube volume test elements for the purpose of modeling. The equation that was solved for each volume element in the container volume is described by LaPlace's Equation

$$\nabla^2 C_{(x,y,z)} = 0 \qquad (2)$$

Where the indices x, y, and z are the coordinates of the test element, and $C_{(x,y,z)}$ represents the concentration in a particular volume element. Equation (2) expands to

$$(\delta^2C/\delta x^2) + (\delta^2C/\delta y^2) + (\delta^2C/\delta z^2) = 0 \qquad (3)$$

Where,

$$0 < C_x < C_{0x}$$
$$0 < C_y < C_{0y}$$
$$0 < C_z < C_{0z} \qquad (4)$$

Here C_{0x}, C_{0y}, and C_{0z} are the initial concentrations at the surface of the source. Figure 8 is a computer modeled vapor concentration profile of a cross section of the container at the surface height of the source that was produced using Equation (3). The model predicts a rapid decrease in concentration with distance from the source.

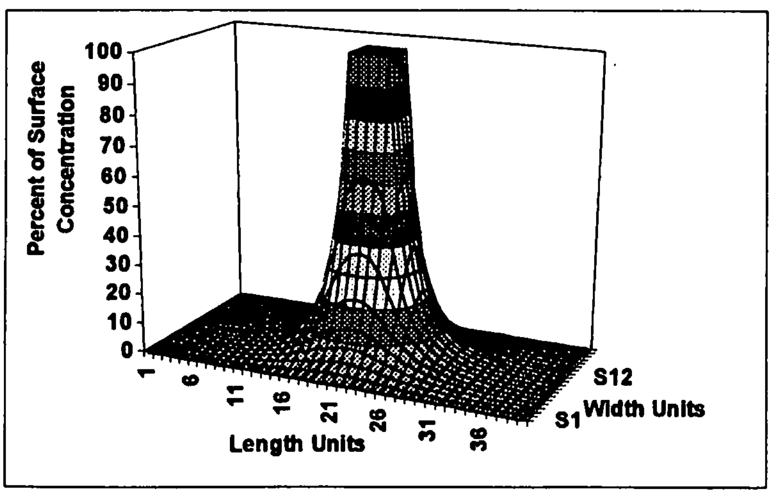

Figure 8. Computer modeled concentration profile for a low volatility compound generated using Equation (3).

The profile closely resembles the profile for heat flow for the case of a spherical source inside a hollow spherical heat sink. In the latter case, which has been definitely solved, the profile is only dependent on the distance from the source, the starting conditions, and the ratio of the surface area of the source to the surface area of the sink. The added complexity of the container model stems from the asymmetry of the container. Figure 9 is a two-dimensional contour line plot of the predicted vapor concentration in a cross section of the container two feet above the surface of the source. A high resolution contour line scheme was used to enhance the clarity of the profile distortion.

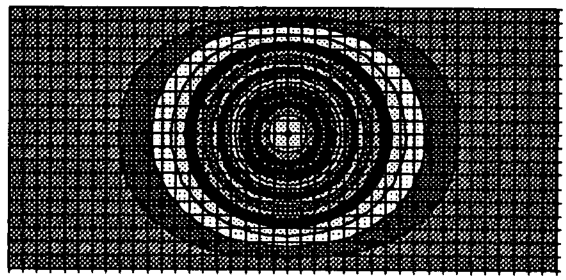

Figure 9. Two dimensional contour plot of the vapor concentration of a low volatility compound showing profile distortion due to container asymmetry. The cross section shown is two feet above the surface of the source.

The equilibrium vapor concentration of cocaine in cocaine base saturated air is approximately 0.89 ng/L. If the assumption is made that the air at the surface of the source in the model was saturated with cocaine vapor, then the vapor concentration in the six inch cube volume element centered next to the closer wall at the height of the source surface had a predicted cocaine vapor concentration of 25 pg/L. The concentration of cocaine in the volume element centered next to the further wall at the height of the surface of the source had a predicted cocaine vapor concentration of 0.84 pg/L.

3 RESULTS AND DISCUSSION

3.1 Limits of Detection Using INEL Generator

Table 1 shows the calibration functions and correlation coefficients for RDX, TNT, PETN, cocaine, and heroin. Minimum detectable quantities were calculated as the mass of vapor required to produce a change in response equivalent to 3 signal to noise units. The minimum detectable quantities for RDX, TNT and PETN were 20, 6, and 27 pg respectively. The minimum detectable quantities for cocaine and heroin were 2 and 8 pg respectively. Calibration intercepts were not considered in the calculation of minimum detectable quantities because they are primarily artifacts of sample leak from the INEL generator and random error, and would therefore artificially enhanced or reduced the calculated minimum detectable quantities.

Substance	Calibration Function	Correlation Coefficient
RDX	y = 0.151x + 9.94	0.9639
TNT	y = 0.500x - 25.4	0.9873
PETN	y = 0.111x + 2.34	0.9385
Cocaine	y = 1.65x + 2.81	0.9964
Heroin	y = 0.389x – 14.5	0.9925

Table 1. Calibration functions and correlation coefficients for RDX, TNT, PETN, cocaine, and heroin.

3.2 Preliminary Field Results

A standard 20 foot long x 10 foot high x 8 foot wide cargo container that contained several kilograms of cocaine on a pallet on the middle of the floor was sampled. Samples were drawn from a hole drilled in the center of one of the 20 foot walls at the height of the surface of the source. Cocaine has not yet been consistently detected in the several liter air samples drawn from the container. It can be assumed, based upon the predicted 25 pg/L cocaine vapor concentration in the sampled volume element and the VaporTracer's 2 pg minimum detectable quantity for cocaine vapor, that the vapor attenuating factors of the cocaine packaging must have a significant effect upon the surface cocaine concentration. The results from recent testing are still being evaluated for the further development of testing methodology. More effective sampling may be achieved by either finding a way to take samples from closer to the source, or by first mixing the volume of the container to redistribute the vapor concentration and therefore increase the vapor concentration in the volume elements next to the walls Although the findings thus far do not negate the general percentage based model for the distribution of cocaine vapor in the container, the starting conditions (i.e. the cocaine vapor concentration at the surface of the source) should be set at a more realistic, attenuated value.

Four bunkers were tested for explosives mode sampling. Two of the bunkers contained explosives, including RDX, PETN, and TNT. The other two bunkers did not contain explosives, but were used to store explosives five months prior to the testing. Blanks were obtained outside the bunker, and the instrument was allowed to clear down after each detection was achieved. The VaporTracer was set to sample for 30 s. for all samples. Atmospheric samples were taken outside, outside around door seams, inside, and through the vents of the bunkers that contained explosives. Samples were taken outside and inside of the empty bunkers.

The first bunker tested contained the largest quantity of explosives out of all the bunkers tested. Several samples were acquired from outside of the bunker. Small quantities of RDX (23 to 88 pg) were detected when samples were taken from outside the bunker door, but the results were not reproducible. It was determined that air currents were stirring some of the vapors so that the vapor concentration in the sampled air was not consistent. Explosives vapor was detected on 6 out of the eight samples drawn from vents on the bunker, with an average signal equivalent to 68 pg RDX detected. Explosives (102 pg and 94 pg RDX) were detected in both of the two samples taken from vents that were known to be located near the largest amounts of explosives (the back two vents). This was consistent with the assumption that the vapor concentration would be higher nearer to the emission source.

The second bunker tested contained approximately 40% of the amount of explosives that were stored in the first bunker. Explosives were not detected from the outside of the bunker. The first two samples taken inside the bunker gave signals equivalent to 57 pg and 36 pg RDX. The third sample was taken after a box of TNT was opened in the bunker: 34 pg TNT were detected.

No explosives were detected in the samples taken from outside of the "empty" bunkers. Samples taken from outside of the open door and from inside of one of the empty bunkers yielded 45 pg and 47 pg RDX detections, respectively. No explosives were detected in the second empty bunker.

4 CONCLUSIONS

The VaporTracer's minimum detectable quantities for the explosives and drugs investigated were an order of magnitude or better than commercial wipe test instruments. Bunker testing was done to demonstrate the power of the vapor detection system in discriminating between bulk explosives and trace residues. The model for the distribution of low volatility vapor in a cargo container should prove a useful tool in understanding the problems associated with real sampling applications. The development of container testing methods for cocaine vapor is ongoing at ITI.

Further applications development for the VaporTracer should also focus on demonstrating the inherent advantages of vapor detection over wipe testing methodology. Interfering compounds that are often sampled from surfaces during wipe testing, as well as trace residues that may be present for legitimate reason, should not produce nuisance alarms or false negatives because they are not significant vapor emission sources. Vapors or particles from a concealed illicit substance, however, could be detected at extremely low concentrations without the need for physical contact with evidence.

5 ACKNOWLEDGMENTS

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AUTOMATION OF "POURING" IN DoD DRUG TESTING LABORATORIES

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ABSTRACT

The Department of Defense conducts random drug testing of military personnel as a means of deterring and detecting drug use in the military. Reductions in the rate of usage within the military since the drug testing program was instituted indicate that random drug testing is an effective deterrent. DoD operates and maintains military drug testing laboratories (DTLs). Because of potential severe consequences (dishonorable discharge or imprisonment), DoD drug testing laboratories heavily emphasize forensic integrity within the drug testing process.

In an effort to reduce the cost of the drug testing program and improve its effectiveness and efficiency, the DoD Office of the Coordinator, Drug Enforcement Policy and Support (OCDEP&S) has initiated several projects. One such project is investigating the feasibility of automating the "pouring" of urine specimens within the DoD DTLs. Currently, specimens which are received at DTLs from collection sites are manually poured from specimen collection containers into test tubes. Automation of pouring would not only reduce operating costs but would provide other enhancements including improved working conditions, enhanced forensic integrity of specimens, improved data capture, and increased throughput.

In the first phase of the specimen automation pouring project, Battelle is conducting a study to determine the feasibility of automating the pouring process. As part of the feasibility study Battelle has designed a specimen collection bottle that will integrate with current DoD collection and testing protocols; interface with existing drug program systems; and operate with a new system which Battelle has designed to automatically extract urine specimens from the new collection bottle. A key benefit of Battelle's bottle and extraction system are their ability as a system to comply with DoD's stringent requirements for forensic integrity in an automated "pouring" environment.

This paper will describe the Battelle specimen bottle and extraction system designs, explain how they comply with the stringent DoD performance requirements, and describe how the system can be implemented into drug testing laboratories to achieve reduced cost, improved efficiency, and enhanced forensic integrity.

Introduction

The Department of Defense conducts random drug testing of military personnel as a means of deterring and detecting drug use in the military. All members of the Armed Forces on active duty or reserve training are subject to the drug testing program. Currently the military operates a total of six drug testing laboratories with an annual testing volume of approximately 3 million specimens.

This paper will provide useful background to the DoD narcotics Demand Reduction Program (drug testing program), explain DoD's ongoing efforts to maintain the effectiveness and forensic integrity of its drug testing program while improving efficiency, and present a concept developed for DoD for automating the accessioning area (where incoming specimens are logged in and poured off into test tubes for subsequent testing) of its drug testing laboratories.

Department of Defense Drug Testing Program

The military drug testing program had its inception in 1971 during the Vietnam War. During that time, military drug programs emphasized prevention and treatment. In 1982 the military acquired the ability to conduct disciplinary action based on drug testing results. Currently that disciplinary action includes actions up to dishonorable discharge and in some cases imprisonment. Since 1980, drug use among military personnel has dropped dramatically (by 89 percent). The effectiveness of the Military's program of drug deterrence, detection, and education can be measured over time. In 1980, 27% of all uniformed military personnel reported that they had used some illegal drug in the preceding 30 days. This was determined through the 1980 Worldwide Survey of Nonmedical Drug Use and Alcohol Among Military Personnel [1]. In comparison, the 1995 survey reported an estimate of 3.0% using drugs in the last 30 days.

DoD Drug Testing Program Organization

The DoD drug testing program is primarily operated by each military Service with a high degree of coordination at the DoD level. The drug testing program within each Service (Army, Navy, Air Force) reports to the surgeon general. Each Service has its own laboratories and slightly different implementations of regulations and standards established by the DoD Office of the Coordinator Drug Enforcement Policy and Support (OCDEP&S). The key responsibility of OCDEP&S is to coordinate and oversee the entire DoD drug testing program and to ensure that acceptable quality (forensic integrity), uniformity, and efficiency apply throughout.

DoD has implemented one of the first comprehensive, regulated, drug testing programs, and considers its program to be more stringent than those programs implemented by other government agencies and/or commercial entities for several reasons. First, the frequency of testing is typically greater than other programs. For example, the random testing program in the Marine Corps is such that the number of random specimens collected each year is about 2 ½ times the number of active duty members of the Marine Corps. This is in contrast to civilian drug testing programs which typically have a 50% random testing rate. Second, the DoD program typically tests for a larger panel of drugs, thus increasing the likelihood of detecting drug abuse. Finally, the consequences of a positive drug test in the DoD program is typically loss of ones military career, separation from the service with a dishonorable discharge, or felony conviction at court martial. For this reason, the custody and control and forensic integrity of the DoD drug testing program is of the utmost importance.

Drug Testing Protocols

As mentioned before, DoD places a greater emphasis on custody and control and forensic integrity than other government and civilian drug testing programs because of the military's potentially severe consequences of a positive test result. Following are examples of collection and testing protocols within the DoD drug testing program that represent particular emphasis on ensuring both the custody and control and the forensic integrity of the program:

- Unlike most civilian programs, all specimen collections are observed
- Random testing is conducted more frequently
- Selection protocols such as those embodied in the Navy Drug Screening Program (NDSP)

system are designed to be unpredictable by the donor population

- Two positive screening tests are required for a specimen before it is sent for confirmation testing

- Consequences of a positive test result include penalties up to dishonorable discharge and court martial

Drug Testing Laboratory Automation

In fiscal year 1992, the Office of the Assistant Secretary of Defense, Health Affairs began a comprehensive examination of the DoD drug testing program and its associated activities, including the the possible automation of various functions within the DoD drug testing laboratories. The objective of this initiative was to reduce costs and improve the efficiency of laboratory operations. A fundamental requirement of this initiative has been that none of the enhancements diminish the existing level of forensic integrity. Ideally, the forensic integrity of the process will be increased as a result of this initiative. Some of the automated functions that have been implemented include a laboratory information management system (LIMS), automatic assay equipment for first screens (Olympus AU 800), and a donor selection protocol system known as the Navy Drug Screening Program (NDSP) system.

Acting on behalf of OCDEP&S, the DoD Office of Special Technology (OST) has initiated several projects to assist in this automation effort. Funding for the project has been provided by the DoD Counterdrug Technology Development Program Office.

In a study conducted for OST in 1994, Battelle assisted OCDEP&S in identifying requirements for the next generation Laboratory Information Management System (LIMS) and in identifying potential enhancements that would improve the effectiveness or reduce the cost of overall DoD drug testing laboratory operations. One such recommended enhancement was the automation of the accessioning process (where incoming urine samples are processed and poured for subsequent testing). In follow-up to the study, OST requested that Battelle develop a concept for automating the accessioning process within the DoD drug testing laboratories.

Requirements for Automatic Accessioning:

Four major operational parameters were considered during the formulation of the concept for automating the accessioning process: 1) performance measures; 2) forensic integrity; 3) system operations; and 4) interfaces.

Performance measures are the measurable qualities the pouring device must possess such as throughput, reliability, extraction capacity, and setup and maintenance time. Forensic integrity relates to those operational parameters that support the use of test results as evidence in court. Forensic integrity of the container or the automated process requires that no cross contamination occur between different specimens during the accessioning process or as a result of the design of the container. The pouring device must also have secure access control and run data integrity. System operation parameters include use of existing test tube racks, bar code reading and printing capabilities, autonomous operation from the LIMS, and provisions for audit trails. System operation parameters also include the objective of being compatible with point-of-collection systems and procedures. Interface parameters include interaction with the DoD form 2624, LIMS, AU 800 test tube racks, and the NDSP collection administration system.

Battelle Concepts

To meet the above requirements, Battelle developed a conceptual system consisting of three elements: a special urine specimen collection container, an automated device for extracting aliquots from the collection containers for testing in the laboratories' automated analysis equipment, and a system for logging in specimens as they are received in the laboratory.

To be considered feasible the system was designed with the following performance objectives. The system must:

- Reduce labor costs within the labs

- Maintain current level of forensic integrity (at a minimum)

- Have minimal, if any, impact on current specimen collection and testing protocols

- Work in conjunction with current and future enhancements to the drug testing process including interfacing with an updated LIMS, automated assay equipment and ongoing bar coding efforts

- Minimize manual pouring of urine.

Each of the concepts for the system is described below.

Specimen Collection Container

Battelle developed design objectives for the specimen container that would meet DoD requirements. They include:

- A specimen container with two chambers, one small and one large, separated but filled to the same level at collection time

- A cap, which when mated with the container creates the two chambers. The cap design includes a membrane for extracting aliquots and features which resist tampering and provide evidence should tampering occur prior to first extraction

- A large chamber design that includes a pour spout with a removable or resealable cap which resists tampering and provides evidence should tampering occur prior to first pouring

- Dedicated space for two bar code labels, one for a Social Security Number bar code applied at the collection site, and one for a laboratory accession number bar code applied during the accessioning process

- A keyed or indexed shape for consistent placement in the pouring system

- Construction material that is polymer, non-absorbent, slightly opaque, and non-leaching

- An overall design which meets International Air Transport Association (IATA) standards for biological specimens.

Based on these design objectives, Battelle developed a conceptual design for the specimen container as shown in Figure 1, Proposed Specimen Colleciton Container, below.

Dual Chamber - The inner chamber of the container is designed to hold a 20 ml sample for first screening, and the outer chamber is designed to hold 65 ml for second screening and confirmation testing. The container must be filled to a level slightly above the inner wall, so that

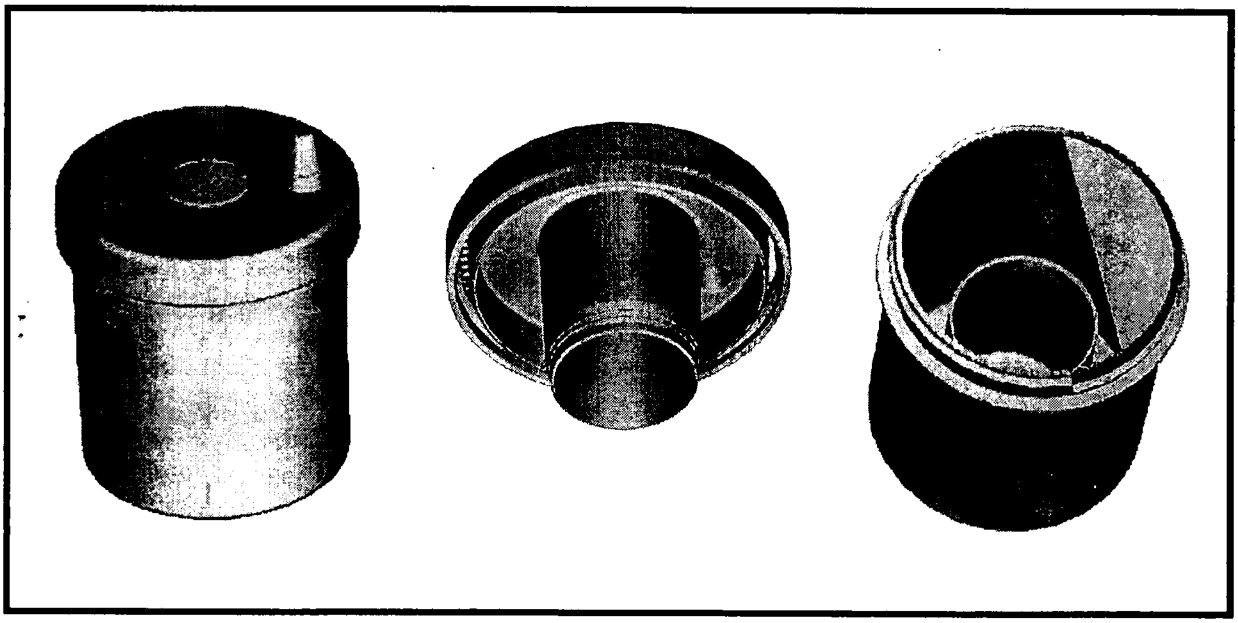

Figure 1 Proposed Specimen Collection Container

liquid fills approximately half of the container. When the cover is installed, a seal is formed at the inner wall to separate the sample into two parts. The cover also seals against the outer wall of the container to prevent leakage from the outer chamber. A skirt around the underside of the cover displaces liquid from the container if the container is overfilled. This maintains an air space in the container to allow for expansion of the sample if it were to freeze. The relatively large air volume under the cover also minimizes the compression of the air as the cover is screwed on.

Plastic-on-plastic seals (without additional elastomers) have been used in the design to minimize cost. The seal between the chambers has two circular ridges that contact a slightly conical surface. When the cover is screwed on, high pressure is obtained at the interface to deform the plastic, forming a tight seal. The seal on the outer chamber is a similar radial seal. The sealing force is obtained from interference fit designed in the diameter of the container wall and the cover seal. This seal is independent of the cover position, so that the two seals perform independently.

Automatic Extraction - The inner chamber of the container is designed for automatic extraction of the sample using the automated pouring device. The center of the cover contains a butyl rubber septum for sampling with a probe. Since the septum is in the center of the container, no rotational positioning is necessary to sample with automated equipment. The inner chamber is also relatively tall and thin to allow almost all of the liquid to be extracted with the probe. An off-the-shelf septum may be used. Butyl rubber does not react with the sample, requires fairly low puncture forces, and seals well even with repeated puncturing.

Manual Pouring - A spout on the cover allows the sample to be poured from the outer chamber of the container. The design of the spout is similar to that found on caulk or glue tubes. The tip must be cut off to open the spout. A special tool will make cutting the tip safe and quick. A disposable blade will eliminate the possibility of contamination. After pouring, the spout can be resealed with a small snap-fit cap. As required by DoD legal staff for reasons of forensic integrity, this cap will be part of the original container.

This pour spout design was chosen because it is very inexpensive and it cannot leak during shipment. More elaborate designs were not considered necessary, especially since manual pouring should be needed on only a small percentage of the containers (specimens that test positive on the initial screen thus requiring "pour off" for a second screen and confirmation testing).

Material - The container and cover are designed to be fabricated using a polyolefin material. Current specimen containers are usually made from this material because it minimizes the possibility of absorption of drugs from the specimen and releases no contaminants into the specimen. It is reasonably rigid, yet soft enough to deform to make a leak-proof seal. Polyolefins are inexpensive and are appropriate for injection molding.

Security - Tamper-evident features in the container design make it difficult to alter the sample by removing the cover or disturbing the septum. Teeth on the container and cover deform and lock as the cover is screwed on. The design of the teeth prevents removal of the cover without large forces that would visibly damage the container or cover. The septum is covered with a heat sealed foil or plastic film that would show evidence if the septum were pierced or removed

Bar Code Checker

The second element of the system required for automation is a device for logging in specimen containers (bar code checker) as they are received in the laboratory and automatically assigned a unique LAN in conjunction with the laboratory's LIMS.

The bar code checker automatically reads the social security number on Form 2624 [chain of custody (COC) form] and, in conjunction with the LIMS, writes the Laboratory Accession Number (LAN) assigned by the LIMS on to Form 2624 in bar code readable form. Later in the automated pouring process, this same LAN which has been associated with the specimen's social security number in the LIMS is bar coded onto the specimen container and onto the test tube in which the aliquot is deposited.

An ordinary desktop page scanner, in combination with off-the-shelf data entry software, will be used to scan all information from the Forms 2624 into the LIMS during the receiving process, concurrent with loading the containers into their transport racks. After the COC has passed through the scanner, it is automatically inserted into an ordinary desktop inkjet printer where the LANs are printed in plain english and barcoded form in the appropriate form fields.

Automated Pouring Device

The third element of the system required to achieve automation of the accessioning process is a device to automatically extract ("pour") aliquots of urine from the specimen container and to deposit them into the test tubes utilized by the Olympus AU 800 automatic testing device utilized by the laboratories. Battelle developed design objectives for the automated pouring device in order to meet DoD requirements:

- A throughput of 400 specimens per hour
- Setup and maintenance time of no more than 1 hour at the beginning and end of a 2 shift operation
- Extraction capacity of 1.5 - 2.0 ml
- Elimination of cross-contamination from aerosolization, particle or protein adhesion, or drug absorption onto probing surface
- Bar code reading and printing capability
- Keying system to assure proper specimen container orientation for extraction
- Ability to accept test tubes 12 mm x 75 mm or 10 mm x 75 mm
- Ability to accept Olympus AU800 test tube racks
- Minimum up time of 95%
- Capability of autonomous operation, that is, it must be capable of working off-line from the LIMS.

Current Technology and Options

In designing the automated pouring device, as with the bar code checker, every effort was made to utilize commercial off-the-shelf (COTS) products in the concept designs.

Most COTS aliquoting systems are designed to transfer fluids between test tubes, micro plate containers, and bulk reservoirs but not between specimen container and test tubes.

Based on the review of current technology and options, a system was conceived based on COTS subsystems and components that could be integrated into a reliable final product compliant with DoD requirements as shown in Figure 2, Automated Pouring Device, on the following page.

The conceptual design consists of separate conveyors to advance specimen containers and test tube racks, a robotic pipette device to extract aliquots and deposit them in test tubes at stationary transfer stations, and bar code reading and printing equipment to read, verify and print LANs on the specimen containers and test tubes.

Individual components of the extraction device are as follows:

Robot - A COTS laboratory robot was selected for the core of the sample transfer motion system. The robot is a 6-axis, two-arm, Cartesian-style robot. The two-arm robot easily achieves the desired throughput and provides several other benefits. Besides a significant reduction in machine wear and tear, two arms raise the system's level of reliability and utility. If one arm is out of operation the system can operate in single-arm mode, which will slow but not stop sample processing.

Pipette/Washing - The DoD design requirement for the system is that there be no crossover contamination between samples. One approach to meeting this objective would be to use disposable pipettes. However, to pierce the butyl rubber septum during sample extraction, an expensive disposable pipette would have to be used. To reduce cost, while achieving the zero crossover objective, a washable pipette approach was adopted. Battelle investigated the potential for crossover contamination using a reusable/washable pipette system. As a useful

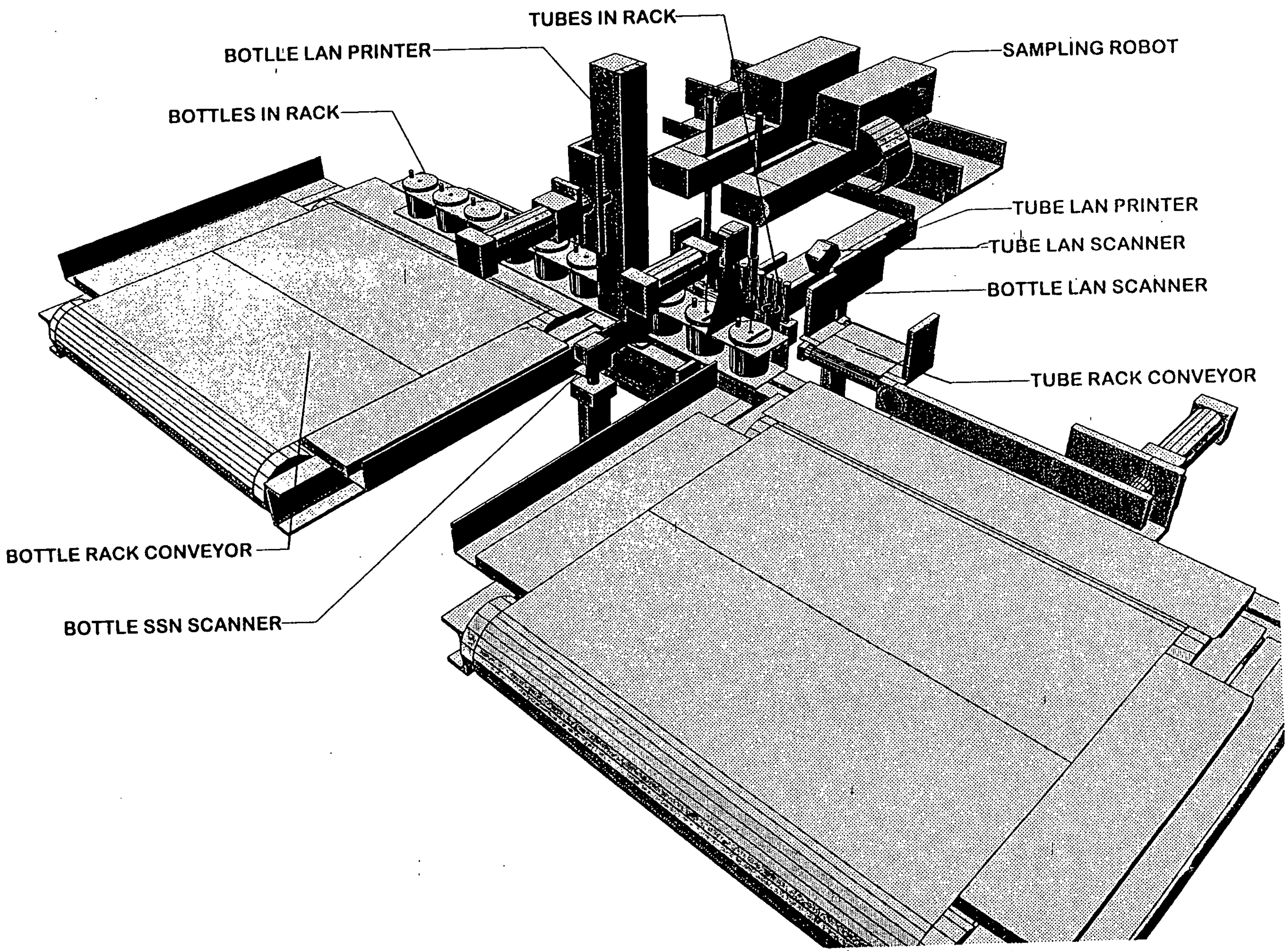

Figure 2 Automated Pouring Device

point of reference, we identified a similar concern for crossover of infectious disease in blood which has existed for the American Red Cross. To address this concern, a study had been conducted which confirmed the suitability of a reusable/washable pipette for critical specimen handling.

The selected robot includes a fluid handling hardware interface as standard equipment. A variety of probe tips and accessories are supported. The system will be adaptable to different sized test tubes/racks to accommodate the possible use of different automatic analyzers. A washable, cap-piercing probe was selected. This probe is good for approximately 10,000 penetration cycles of a Vacutainer-type septum. It is also the sensor for the liquid-level-following feature of the robot. This feature allows the tip to be submerged at a desired level in the sampled fluid. As fluid flows in or out of a container and the surface level drops, the tip will track and maintain the desired submersion level.

Fluid Handling and Tip Washing - The fluid handling components of the robot are used for both sample handling and tip washing. The fluid path is such that there is always a clean, non-contaminating interface between the working fluid (in this case, water) and the sample fluids. An air bubble barrier can be introduced between the two fluids during the sampling process. After the sample is deposited in the target container, the working fluid is used to flush out the tip in preparation for the next sampling cycle. Thus, fresh working fluid is present for each sample. Because the tip is flushed in a well, the outside of the tip is cleansed as well as the inside.

Bar Code Reading/Printing - Bar codes are an integral part of specimen tracking within the laboratory and are an important contributor to the forensic integrity of the system. Bar code reading and printing are utilized in several ways within the concept system.

A social security number (SSN) bar code label is attached to the container on the outside at the time of collection, and the same SSN bar code is printed on the Form 2624 (DoD chain of custody form). When containers and COCs are received in the laboratory accessioning area, the bar coded SSN is scanned on each container and the corresponding block on the COC is scanned. When this process is completed, each SSN is transmitted to the LIMS. The LIMS assigns a laboratory accession number (LAN) to each SSN. Later in the automatic pouring process, this same LAN is bar coded onto the specimen container and onto the test tube into which the aliquot is deposited.

A COTS laser bar code scanner was selected for all bar code reading within the automatic pouring device. A total of three are used: two to read SSN and LAN bar codes from the specimen containers, and one to monitor the target test tube during specimen sample deposit.
Two ink jet type printers are used for applying the LAN bar codes to the containers: one for the containers and one for the test tubes. Permanent, dye-based ink, compatible with the container and tube materials, will be used.

Container Rack Conveyors - Motorized, belt-type conveyors are proposed for the entrance and exit queues to the rack transport systems for both the specimen containers and the test tubes.

Transport System - Ball screw, stepper-motor powered, linear slides are proposed as the basis for the transport system for the container racks and for the test tube racks. They will provide quick, consistent, and precise motion of the container and test tube racks through the sampling station. Pneumatic cylinders and vacuum containers are used for seating the racks properly into the transport system and for ejecting sampled container racks to the exit queue.

Concept of Operations

To visualize how the specimen collection container and the automatic pouring device interact with existing DoD procedures and equipment, a concept of operations must be understood.

Following specimen collection, the specimen container is sealed and locked in the presence of the donor. The social security number (SSN) barcode label which is attached to the container front is verified by the donor. The same SSN bar code is printed on the 2624 chain of custody form by the Navy Drug Screening Program (NDSP) system. The collection specimens and accompanying Forms 2624 are batched in a shipping container and sent to a DoD drug testing laboratory.

When the shipping container is received in the laboratory, each Form 2624 is scanned using the desktop scanner discussed above. Specimen donor information is coded on the form in both plain english text and bar code formats. Optical character recognition (OCR) and bar code recognition (BCR) software decodes the scanned image. Individual donor records are parsed out from this data. Verification that the forms match the actual contents of the shipping container proceeds as the container's SSN information is entered. After scanning and accounting, a LAN is sequentially and uniquely assigned to each donor/sample set by the LIMS. Next, each Form 2624 passes to the desktop inkjet printer, also discussed above, where the specimen's LAN is printed in both text and bar code formats on the 2624. Thus the LAN and SSN for each donor/sample set are linked in two distinct places: within the LIMS and on the Form 2624.

Concurrent with the processing of Forms 2624, the specimen containers are removed from the shipping container and have their SSN bar codes scanned by a point-of-sale type vertical bar code scanner. The SSN is read into the LIMS, and the shipping container contents are automatically cross-checked against the forms. When an individual SSN has had its existence verified on both the container and the form, the LAN described above is assigned. Specimen bottles are then placed in racks and loaded on the automatic pouring device.

Once bottle racks are loaded on the automatic pouring device, the initial processing step is to determine the identity of each container as it enters the sample transfer station. A bar code scanner scans the SSN from the side of the specimen container. This bar coded SSN is passed to the LIMS, where the corresponding pre-assigned LAN is retrieved and passed back to the device. The LAN is then printed onto the container lid with the first ink jet printer and simultaneously onto the test tube with the second. There are now three distinct links between SSN and LAN: Form 2624, the LIMS, and the specimen container.

The final data coordination check occurs at the accessioning station. Two bar code scanners simultaneously scan the source container and the target test tube to ensure that they have identical LANs. Passing this test, the sample is transferred between the two.

Following this, the specimen container racks and test tube racks advance to the exit conveyor where they are collected for temporary storage and processing in the automatic analyzer, respectively.

Conclusions

Based on this project, Battelle determined that automation of the pouring aspects of DOD drug testing laboratories was feasible.

Automation would require new or revised elements of the system, including the specimen collection container and the automated pouring device. These revised elements of the overall DoD drug testing program would not adversely affect current selection protocols, collection procedures, or analytical testing processes.

Automation of the accessioning activity at DoD drug testing laboratories would have numerous benefits in addition to cost reductions.

Benefits

Numerous benefits are anticipated from installation of the automated pouring system. These benefits are briefly characterized below:

Cost Reduction - Substitution of the automated pouring system for manual pouring (including the semi-automated log-in system) will result in significant cost reductions in the DoD drug testing laboratories.

Enhanced Forensic Integrity - Key features of the proposed system enhance the forensic integrity of the DoD drug testing process. These features include: Increased automation minimizes the potential for human error; security features of the container minimize the potential for tampering throughout the collection/testing process and provide a means for detecting tampering, and barcode features enhance the chain of custody tracking.

Improved Working Conditions for Accessioning Staff Automation of the "pouring" process, including extracting first screen samples from a chamber sealed by a septum, minimizes exposure of accessioning staff to urine samples.

Improved Turnaround Time - The automation of the accessioning portion of the laboratory will improve the turnaround time for processing and reporting the results.

Improved Data Capture - Implementation of the proposed system will incorporate automatic data capture and tracking at log-in and automated pouring. Such automatic data capture will interface with the laboratories' LIMS.

Further Potential Labor Reductions - The labor reductions assumed in the feasibility study for DoD have been stated conservatively. Further potential labor savings include the minimization of manual paperwork through increased use of bar codes and the potential for second shift reductions based on ability to handle all first screen testing (possibly including surge conditions) during the first shift.

Potential for Future Enhancements - Implementation of the proposed system provides the basis for implementing future enhancements to the DoD drug testing laboratories including the direct transfer of first screen samples to the automatic testing equipment, full inventory automation, and increased flexibility in varying test panels from sample to sample.

Commercialization

Battelle has applied for a patent for the specimen container. Based on Federal Acquisition Regulations, any use of the patented container would be royalty free to the U.S. Government.

Reference List

[1] Bray, R., et. al., *1995 Department of Defense Survey of Health Related Behaviors Among Military Personnel*, 1995.

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Nonintrusive Inspection Methodologies (Session 3B-1)

CONTAINER INSPECTION SYSTEM OPERATION

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ABSTRACT

As of today, **Heimann Systems** and **Europ Scan** have delivered and are maintaining six Cargo Inspection Systems, named HI-CO-SCAN and Sycoscan, operated world-wide by Customs and Security operators for the inspection of trucks, containers and pallets.
By the end of this year, a further eight systems will be under construction throughout the world.
This paper will present the results from the various user's perspectives, of the experience gained as a result from these unique achievements.
It will highlight the current evolution of the user's requirements, both technically and operationally.
Therefore, the detailed topics addressed are :

- Operational systems technical features and integration requirements;
- System operation results in terms of seizures in all fields, as well as reactions of the people involved with the systems;
- Market situation and potential developments.

1. General Presentation

On-going political pressure on law enforcement agencies to improve general traffic controls.

For the past few years, political organizations have asked for an improvement of the fight against the various diseases of our society. By desease is meant all smuggling which generates social and economic distortion. This includes items from drug and weapons to incorrectly declared commercial goods which create local competition distortion or even world-wide ecological and sociological discrepancies.

Based on this requirement, enforcement agencies have followed various methods from social and economic actions, to in-bound operations using the police or targeted actions in the producing countries, to border controls.

As a result, the enforcement of transit as well as export traffic controls is being given a greater priority.

Clear pressure from the economic word to soften the controls on commercial exchanges.

It is today accepted that all the three methods have to be followed. The border controls aspect has always been considered the most difficult in relation to the political position which requires a growth in economic exchanges.

The Customs are today intimately involved in the economic world. Given the economic growth imperative, the border control requirement is studied in depth by ports, borders users and authorities. Their approach is mainly to increase the efficiency and image of their border, so as for these controls.

Thus, not only the control itself, but also the procedures used to effect the control, have to be fast and require the minimum resources for effective operation.

With regard to the required limitation of work-forces, only technical equipment can achieve both requirements.

Extra cost cannot simply be imposed on the border users by new regulations.

The flow of goods will continue to show a steady growth for the next few years. As the Border Control Administration cannot, in general, increase their work-force because of economic constraints, and the port is not willing to accept additional costs for the border users, the only feasible solution is to make use of technology equipment and solutions.

This equipment must achieve the following control objectives :

- Be fast enough so as not to disturb the flow of goods;
- Have high reliability and a low false alarm ratio, which generate manual searches, so that all government agencies provide their acceptance;
- Complete integration with the border logistic system providing EDI (Electronic Data Interchange) facilities for manifest information and targeting, if available.

This paper will present, from our point view, the results of policies in the countries where our systems are operating, as well as from information gained through our various world-wide contacts.

2. Systems technical presentation

Road border configuration

Captive trucks - Fast targeting or random

In this case, typically as at the Eurotunnel or Shenzhen, the trucks present themselves at the border without any prior notice. The targeting is either based on a quick decision or on random basis. The inspection can be done by comparison to the manifest and has to be completed within a short period of time.

Results and system description

Eurotunnel and Shenzhen are high energy systems and are operated at close to their maximum throughputs of 25 trucks per hour with four image operator workstations.

The Eurotunnel system is used primarily for detecting bombs and thus the drug seizures made are only a result of the image analysis, thanks to its high quality. These two systems, one at each end of the Channel Tunnel linking France and the United-Kingdom, were the first high energy systems for truck inspection in the world in 1993.

In Shenzhen, border between China and Hong-Kong, the Chinese Customs controls are mainly oriented on commercial and art smuggling.

They have achieved their objectives by realizing many seizures, from drug to electronic goods smuggling for instance, up to maintaining security for the Channel Tunnel.

Airport configuration

Captive pallets

In this case, typically as at Roissy-Charles de Gaulle, the pallets can be inspected for both law enforcement and security. Both aspects must of necessity utilize targeting as the airport logistic chain cannot tolerate any disruption.

Long term / fast targeting

The inspection is done against the manifest which is received via EDI from the airport and shipping companies. The general inspection throughputs must be as high as possible while having a high success ratio for load recognition.

The Pallet Loading/Unloading system, as well as the temporary storage system for the inspected pallets, must be carefully planned.

Results and system description

In Roissy, the system, paid for by the French Civil Aviation (DGAC), but operated by the Customs, is mainly used for security controls and law enforcement purposes. It is a single-view 2.5 MeV system with a maximum throughput of 60 10 foot pallets per hour. This system was the first high energy system for pallet inspection in the world in 1991.

Port configuration

Stand-by containers

In this case, typically as at Hamburg and Le Havre, the containers are stacked at the terminal.

On average, the majority to be inspected enter or leave the terminal by trucks on the road, while the balance are transshipment or rail-bound containers.

Targeting policy - Legal aspects - manifest handling - typical container procedure planning

The Customs services is able to target import and transshipment containers in advance using EDI.

The equipment are also used for inspecting export containers as well as trucks on nearby roads selected by the in-bound enforcement agencies.

The inspection is done by associating a manifest, either EDI or printed, or scanned, with the X-Ray image. This helps to reduce the paperwork and achieve an average total inspection time of 17 to 18 minutes per truck. The general throughput of 14 to 20 trucks per hour meet the need for fast control whilst having a high success ratio in load recognition.

Results and system description

Because of the excellent integration with the port logistic systems, French and German Customs have extended their use of the inspection equipment to include general road traffic and export containers.

Hamburg - Container terminal and road hub location

Hamburg was the first dual-view high energy system in operation in the world in 1996.

The system is located at the exit of the main container terminals, under the highway hub at the Köhlbrand bridge, which allows easy access to and from the highway.

Being within the customs area, an automatic ticketing system associated with a traffic management system is used to check the containers status at the exit from the site and terminal. This system informs the driver to either exit the terminal, or to go to an adjacent building (packing hall) where a manual search is done using the recheck operator station. It is composed of a remote printer of the images, including the 3D coordinates of the suspicious areas, and of a workstation supplying all information regarding the container manifest and identification. This recheck workstation receives automatically the data related to the suspicious truck from one out of the four image operators workstations.

From a technical viewpoint, the dual-view 10 MeV imaging HI-CO-SCAN has achieved close to 100% satisfactory inspection, with very few images which cannot be fully interpreted.

Finally, the German Customs, after less than a year of operations, are claiming that they have already paid off the total infrastructure investment, as a direct result of significant and numerous seizures.

Le Havre - road exit location

Le Havre was the first single-view high energy system in operation in the world for container inspection in 1994.

The system is located at the exit of the port four container terminals, outside the customs zone and close to the highway hub of Normandy bridge. This location has resulted in some specific procedures to legally take care of the targeted containers from the customs area up to the inspection facility.

From a technical viewpoint, the single-view 5 MeV imaging Sycoscan has achieved almost 97% satisfactory inspection, with very few images which cannot be fully interpreted.

3. Systems operational results

Private sector reactions

From a firstly negative to a positive image and use

All border operators were keen to criticize any new measure, and thus any new equipment. After years of operations, none of this remains and, on the contrary, the entire private sector supports this kind of installation. Moreover, insurance and private industries are requesting the use of the equipment for certain special missions.

No border or port is complaining of traffic re-routing and are keen to think that this type of equipment is promoting the image of the Customs and of the entire port, border or airport. No operator, from the truck driver to the shipping company, is complaining or has any doubts about the system's abilities or their own total safety.

From our experience, we have learnt that a number of months are required to fully integrate such a system into the port logistics and targeting procedures. This is even more critical during interruptions, such as strikes (from the dockers for instance).

Operator's reactions

From curiosity to ownership

All operators are now fully confident in the capabilities of "their machine" and are proud of the results achieved. No Unions or personnel are afraid of the functioning of such an installation.

Moreover, the use of this equipment enables discrete inspection and surveyed deliveries operations. This increases the effectiveness of the law enforcement agencies.

The same development has been perceived with all the systems installed and operated.

Seizures realised - knowledge of flows - return on investment

Other aspects of these installations are that :

- The payback period, in the field of law enforcement, can be measured in months (or years depending on usage). The number of fruitless manual searches and complete unloadings is decreased significantly.
- By controlling a large percentage of all border's flows, it has given to the administration considerable new information on them.
- A modern image and therefore renewed motivation is created for the law enforcement agencies, some going as far as to consider that this equipment is the only tool that can help them to achieve their mission.

It must be pointed out that, even where a system has been in operation for a number of years, the smuggling offense figures are not declining.

Summary

Everyone, from user to freight operator, is satisfied with the results from the use of this equipment.

The equipment has resulted in the seizures of drugs, weapons, alcohol, cigarettes, ivory and smuggling of commercial goods to such an extent that the investment cost has been paid off.

4. Market situation

Today's situation in Europe, USA, Asia

The European parliament has recently made a recommendation that all main ports and border points use this kind of equipment. Each country would be responsible for it's own policy and investment in this regard in order to achieve the minimum European commission control ratio. The commission is also considering a small tax on all imported containers to cover the cost of moving the containers to the inspection facility. To date, this cost is carried by the port economy or, partially, by the Customs.

Evolution

The advantages of the dual-view high energy systems are three fold :

1. The second view enables a clear identification of suspicious areas located in the first view, as well as the location of small objects which could be difficult to identify or discover with only one view;
2. Enables the precise location in 3D coordinates of suspicious objects;
3. By increasing the global efficiency, it results in fewer false alarms, thereby justifying the additional investment cost.

The tender presently being issued world-wide are basically for dual-view high energy systems.

The basic requirement for an high energy system is that it is capable of a minimum steel penetration of 34 cm or 2.5 m of water. The result is that almost 100% of the containers can be fully inspected. Only one or two containers per day (assuming more than 200 are passed through the facility daily) would have to be manually inspected.

A mobile system creates problems with integration into the port logistics and targeting procedures. The main application and locations for mobile systems is, based on our information, at major road hubs. A mobile system could also be shared between several secondary ports, being aware of the well-known adaptability and speed of reaction of the smugglers' logistic.

Border control authorities are, we have noticed, attempting to develop corridors for trucks where fixed high energy systems will be deployed.

Current and short term projects

Europ Scan and Heimann Systems have joined their experience to create, in Paris, the Group Center of Competency for Cargo Inspection Systems.

Thanks to this unique experience, the Heimann group has been able to optimize the available and proven technology to your specific needs and constraints.

We have secured the contracts for five high energy fixed systems, namely one Rotterdam dual-view system (Netherlands), three Djakarta and one Surabaya systems (Indonesia).

A clear world-wide market evolution is taking place as many countries have allocated funds in their multi-annual budgets for the investment cost of these high energy systems.

SELF-PROPELLED NON-INTRUSIVE X-RAY INSPECTION SYSTEM

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ABSTRACT

X-ray imaging is one of the most practical methods for contraband detection and manifest verification at ports of entry. However, most current systems are of the "car wash" type; i.e., they are permanently installed in a large structure and employ a special guided vehicle or other apparatus to tow the vehicle or container past one or more stationary X-ray sources and detectors. This approach is severely limited by the space required for the permanent facility, low throughput, and difficult logistics due to the requirement to transport containers to and from the facility. This paper describes a novel non-intrusive X-ray inspection system that is mobile and self contained (carries its own power source, etc.). This system does not require any dedicated space, can move to different locations within large operations, such as port facilities, and can perform inspections under its own power without touching or moving the container/vehicle. Furthermore, the elevation of the X-ray source and detector can be varied, permitting the inspection of containers on the ground or a chassis; and truck-borne cargo. The time required to inspect a 44-foot sea cargo container is estimated to be on the order of one minute.

1. INTRODUCTION

Currently, there are relatively few noninvasive cargo inspection systems in operation. However, many countries are actively considering deploying such systems at points of entry. In the U.S. and many other countries, the interdiction of drugs is the primary focus. However, many countries are also stimulated by economic interests, such as insuring the accuracy of manifests so that the proper duties can be collected and the detection of stolen articles, such as cars. Moreover, recent acts of terrorism are causing law enforcement agencies and defense organizations to consider various types of non-intrusive inspection systems for the detection of weapons and explosives.

X-ray imaging is considered to be one of the most practical approaches to contraband detection and manifest verification. In the U.S., a prototype system for inspecting sea cargo containers was evaluated at the Port of Tacoma and X-ray inspection systems are being deployed at several sites along the U.S.-Mexican border to search for contraband in cars and trucks. Several X-ray inspection systems have been installed in Europe and China and additional systems are on order.

These systems are generally similar in configuration, i.e., the X-ray sources and detectors are housed in a large shielded structure with the computer system in an adjacent area. Thus, the vehicles and containers to be inspected must be brought to the facility and mounted on some type of transport apparatus that moves the object past the stationary X-ray source(s) and detectors. Once the inspection has been completed, the transport apparatus must be unloaded and returned to the starting point to pick up another container or vehicle.

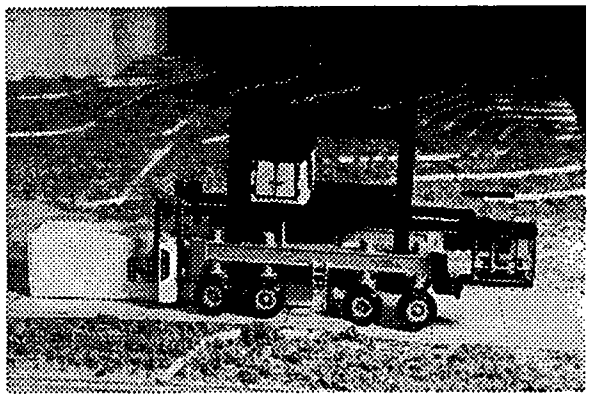
Although the "car wash" configuration has some advantages in achieving the necessary radiation safety, especially when 8-10 MV linear accelerator X-ray sources are employed, there are a number of drawbacks. A principal one being the relatively large amount of space that is required, a commodity that is at a premium at most seaports and border crossings. Cost is also an issue; the land plus the requirement for a shielded inspection bay, support buildings and infrastructure add considerable cost beyond that of the inspection system. Compounding the cost issue, is the relatively low throughput achieved by these inspection systems due to the requirement to mount the vehicle or container on a towing apparatus and, after inspection, to demount it. The reported inspection rates for the systems in operation are in the range of 6-to-12 vehicles/containers per hour. In addition to impacting the flow of commerce and limiting inspections to a small percentage of the "traffic," the high cost and low throughput result in a relatively high cost per container inspected.

Another drawback to these fixed-site systems is the lack of flexibility and "element of surprise." At a large seaport, the location of the inspection facility may mean that it is only practical to inspect containers from a few terminals. Thus, smugglers could direct their contraband to other terminals or even other seaports. Likewise, unless inspection facilities are implemented at all border crossings, smugglers will just move their operations to unprotected areas.

This paper discusses a novel self-propelled X-ray inspection system that provides much of the imaging capability of the fixed-site systems without many of their limitations. This system, designated the Eagle, can move under its own power within a large facility such as a seaport; carries its own power source and imaging equipment; does not require any dedicated space or structures; and can inspect a 44-foot sea cargo container or truck in less than a minute. All in all, the mobility, flexibility and economy provided by the Eagle provides a new range of options to Customs inspectors, law enforcement agencies and defense organizations.

2. THE EAGLE SYSTEM

The patented Eagle, shown as a model in Figure 1, represents an unique integration of field-proven equipment. The basic structure is a specially-designed straddle carrier; straddle carriers are used at most seaports in the world to move and stack sea cargo containers. It employs high-performance X-ray imaging hardware and software which have been evolved over the last 15 years and which is being employed for inspection applications more stringent than cargo inspection. For example, inspection systems such as employed in the Eagle are in daily use for such critical applications as the inspection of the nation's strategic rocket motors and



nuclear weapons, for detecting treaty-limited items in rail cars, as well as for industrial nondestructive inspection.

For inspections, the Eagle straddles the container or vehicle and moves past it at approximately a constant speed. During the movement, an X-ray source illuminates the object with a collimated beam of X rays; a linear array of detectors on the other side detects the transmitted X rays and sends electronic signals to the computer system for the production of an image of the contents. Any irregularity in motion is sensed by a motion encoder and the image is automatically corrected to eliminate blurring of the image.

The Eagle provides tremendous inspection flexibility; it can inspect any object that fits between its 11-foot wheel base. The straddle carrier design includes a capability for changing the elevation of the source and detectors so that inspection coverage can be obtained for vehicles and containers from just above ground level to a height of 19 feet. The flexibility to change the height of the imaging system enables the inspection of cargo containers on the ground, on chassis or trucks, and even in two-high stacks. In addition to sea cargo containers, the Eagle is capable of inspecting air cargo containers, automobiles, trucks, and rail cars.

Radiation safety is a primary consideration. In addition to insuring that the exposure to the Eagle's operator and analyst is within regulatory limits, the possibility of inadvertent exposure to others who happen to be in the vicinity must be prevented. There are several aspects of the system's design that promote radiation safety: the X-ray source is tightly collimated, and the detector package serves as a beam dump. Measurements of 6-MV X rays scattered from a variety of objects designed to simulate different types of cargo show that with the use of well designed shielding and appropriate procedures, radiation safety requirements can be met.

2.1 System Description

The principal components of the Eagle are a motorized structure that carries an X-ray source and a detector array. The structure consists of a customized straddle carrier: the "spreader" or "hoist" used to grip the container is not included, instead an equipment room is mounted on a platform to house the ancillary equipment. A source platform and a detector platform are provided on opposite sides of the structure, and shielded cabs for the driver and inspector are mounted to its legs.

For normal operation on a paved surface, the speed control included on the Eagle will result in images of satisfactory resolution for many applications. However, since changes in speed as the image is being formed will "fuzz" the image, the Eagle includes a motion encoder affixed to a wheel to measure the rotational velocity and transmit a signal to the imaging computer. If there is a change in speed, the computer automatically includes corresponding compensation in the timing of the X-ray signals for that location, effectively eliminating image distortion.

2.2 Imaging System

The selection of the Eagle's source involved a number of considerations. Sources that are higher in energy produce more X rays that are more penetrating; however, they are more costly and require more shielding. For systems operating in congested areas, safety considerations encourage the use of X-ray sources that are as low in energy as practical. The Eagle incorporates a linac that can be switched between 6-MV and 2-MV operation. The higher energy will be used for dense cargo and for high-resolution or high-throughput inspections. For low-density cargo, empty rail cars, tanker cars or for such applications as detecting stolen cars within sea cargo containers, operating at 2 MV should suffice.

The Eagle's linear-array detectors represent a highly-evolved design based on crystal-photodiode technology. The Eagle's electronics design takes full advantage of the operating range stability, linearity and detector-to-detector matching provided by photodiodes; an attenuation range greater than 50,000:1 can be accommodated. Automatic gain ranging is used to adjust to the wide range of attenuations encountered with densely-package cargo containers. The electronics provide a 16-bit depth of data over an operating range of greater than 10^6:1.

The detector array is designed to insure high performance and long life. The detector collimators are designed to limit the X-ray exposure to only active areas of the scintillators. The signal, in the form of X-ray-induced light, is conveyed through light pipes, which are at right angles to the X-ray beam, to the photodiode and associated electronics. Since the photodiodes and electronics are out of the direct x-ray beam and heavily shielded, they receive minimal radiation exposure. Provisions are included for interrogating each channel by self-diagnostic software which provides the absolute signal and noise level of each detector. If radiation damage occurs, it is manifested as a gradual decrease in signal strength due to radiation darkening of the X-ray converter crystals and/or an increase in electronic noise due to damage to the photodiodes.

During operation, the inspector will watch the image being displayed as the data are being gathered. The software provides powerful image analysis tools, such as edge enhancement, zoom (magnify), pan, contrast stretching, etc. An option will be provided to present a magnified image as it is being gathered. If a suspicious area is observed, the inspector can simply point and click a mouse to annotate the image and press a "No-Go" button or key. An annotated radiographic image will be printed along with identification of the cargo container. If there are no areas of concern, the inspector simply presses the "Go" button and the data are stored on a read/write optical disk and/or digital audio tape (DAT).

Although the manufacture of the prototype has not progressed to the stage where it can be used for inspecting cargo containers, the core imaging system has been used to inspect objects of a comparable size and with a greater attenuation than typically encountered in sea cargo containers. Shown in Figure 2 is an X-ray image of an inert Peacekeeper Stage 1 solid rocket motor. This motor is 8 feet in diameter and 29 feet in length, approximately the dimensions of some sea cargo containers. It is used as a test standard and has its internal structure comprised of concrete rather than propellant. The high performance of the imaging system is reflected in the sharpness of the image of the carbon-carbon nozzles and the resolution of the crack running up the bore.

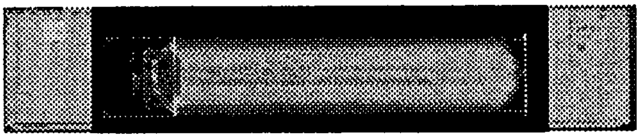


Figure 2. Radiograph of Peacekeeper Motor

3. INSPECTION OPTIONS

The Eagle is designed to be a stand-alone inspection system that does not require any designated buildings or infrastructure. The ability to vary the elevation of the source and detectors permits a wide range of inspection options. At seaports, it may be desired to inspect some containers on the pavement and others integrated with "roll-on roll-off" chassis; the Eagle can also inspect the top containers in single-row two-high stacks. Additionally, the Eagle could be employed at border crossings to inspect cars and trucks and at rail yards and sidings to inspect rail cars.

In previous tradeoff analyses, it was pointed out that if one port of entry had a perfect inspection system, it would soon be reduced to zero seizures. This is because smugglers are very adaptive and would move elsewhere. The Eagle was designed to provide the element of surprise. It can be transported fully assembled port-to-port and be in operation minutes after being off-loaded. Even for land sites, the system can be disassembled for transportation and reassembled at the destination in a few days.

Realizing that X rays provide an image resulting from the differential attenuation by materials of different atomic number and density, but do not specifically identify target materials, a scenario using two inspection methods could be considered. For example, several neutron-based inspection approaches are being evaluated. (thermal neutron analysis, pulsed fast neutron analysis, etc.). Although neutron inspection systems can specifically identify the presence of elements such as chlorine and nitrogen which are associated with many drugs and explosives, respectively, they are very expensive and slow. Thus, the Eagle, which can inspect a container in less than a minute, could be used to rapidly screen a large number of containers. Those deemed sufficiently suspicious could then be subjected to neutron interrogation.

4. SUMMARY

The Eagle system now under development provides inspection flexibility and throughput well beyond the capabilities of other methods. It is suitable for use at seaports, airports, border crossings and rail yards; and, since the system is self-contained and transportable, one system can be used at various sites thereby introducing an element of surprise. In addition, system attributes suggest that the Eagle could be a powerful complement to other inspection methods.

Adapting FAA Certified CT Technology to Detect Narcotics

Presentation at the ONDCP Symposium
by

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ABSTRACT:

The CTX 5000 SP Automated Explosives Detection System has surpassed other techniques in its ability to detect explosives by becoming the first and only explosives detection system to be Certified by the US FAA. The ability to tune the CTX to detect narcotics has been independently proven by InVision and other organizations to provide a significant level of narcotics detection without modifying the core technology. There are policy, technical and human factors issues that need to be evaluated and addressed to effectively adapt and implement the technology as a Narcotics Detection System (NDS). This paper draws from the experienced gained during the CTX 5000 SP's development and field deployment. It highlights the capabilities of CTX as an NDS, addresses the similarities and differences between Explosives and Narcotics detection applications and describes both technology and human factors issues. Finally it presents an approach for addressing these issues to provide another valuable tool and establish a new standard of detection for Narcotics interdiction officers.

Overview:

This paper presents an overview of CTX technology and how it can be adapted from its initial explosive detection application to detect concealed narcotics. It addresses the following areas:

1) Overview of the aviation security program that leads to its development and the parallels with the narcotic's detection application.
2) Basic description of the CTX including InVision's experiences in scanning narcotics and \ how CT properties can make them detectable.
3) Describes a plan for adapting CTX to automatically detect cocaine and heroin powders as well as a possible development path for detecting Marijuana.

1. Critical Success Factors For Explosive Detection System Development.

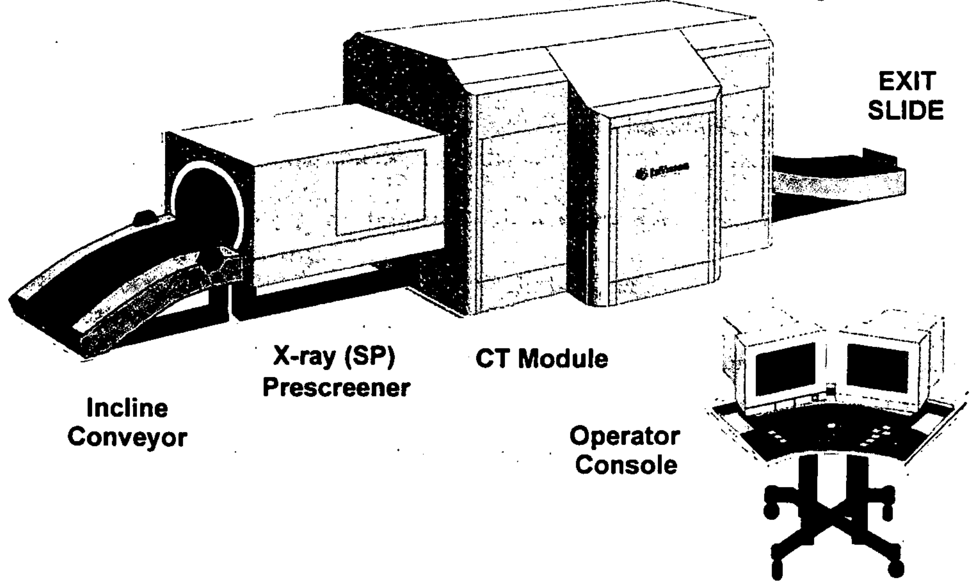
The FAA was committed throughout the process to develop and implement a technology solution. R&D funds drove the development effort and the Aviation Security Improvement Act created a potential market for successful developers. The FAA also developed clear performance standards in terms of different threat materials, minimum detectable quantities and all types of configurations that could pose a threat. These standards provided a clear goal for developers. Finally, the FAA worked closely with airports and airlines to assure that manufacturers spent time in the operational environment relatively early on in the development process. The data and experience gathered helped us develop the software algorithms and to gain valuable end-user feedback into the product design.

2. The CTX 5000 SP Product Description.

The CTX 5000 SP can be used either as a stand-alone or integrated into the baggage handling system. The primary system components are shown in Figure 1:

- The Incline conveyor, which is used to load the bag.
- The X-ray or SP prescreener, which is used to determine where to place the CT slices.
- The CT module, which collects the cross-sectional slices used to automatically find the target material.
- The exit slide, which removes the bags from the system.
- The operators' console, which provides control over the machine and displays images to the inspector

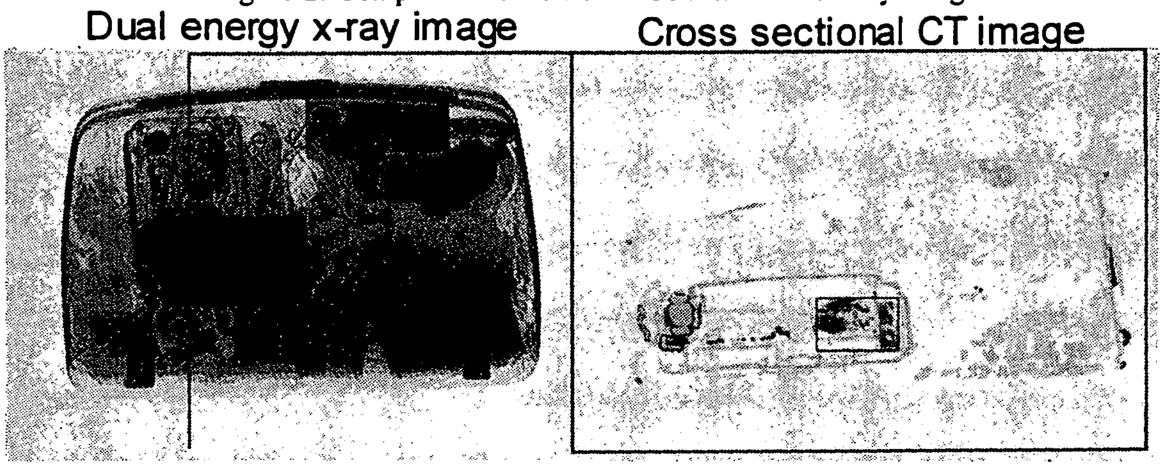
Figure 1: CTX 5000 SP Automatic Explosives Detection System



CT differs from conventional and backscatter X-rays in that the X-ray source and detector rotate around the stationary bag allowing the bag to be viewed from all angles. A cross-sectional CT image can be reconstructed from these views. Unlike the conventional or backscatter, CT images do not suffer from object superimposition. Each object in the container can be analyzed independently without being affected by any other item or any attempts at concealment. It is this unique capability that allows CTX to detect the broad ranges of explosives necessary for passing FAA Certification and can allow it to find drugs.

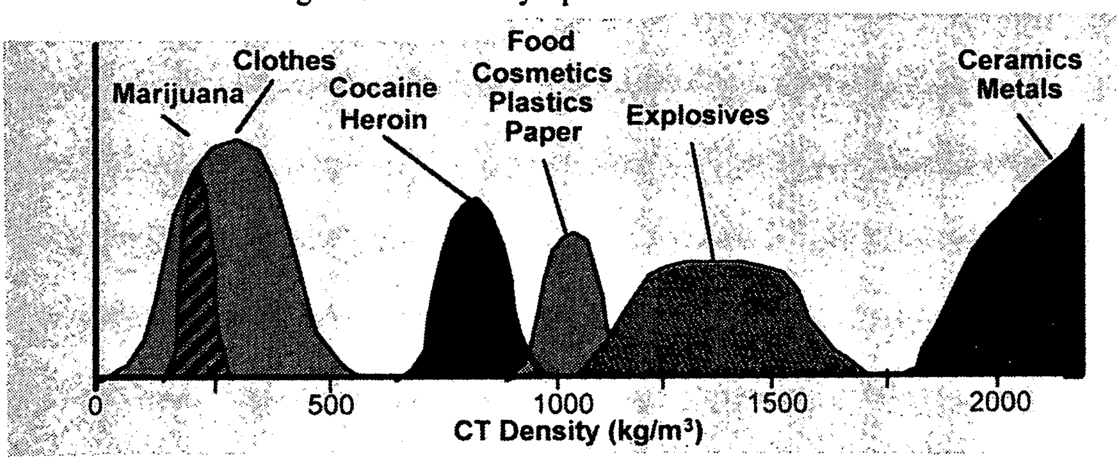
What this means in practice is that more information is available to both the machine and the human inspector. This allows the system to make better decisions. Figure 2 shows the difference between CT and conventional x-ray images. On the left is an X-ray image of a moderately cluttered suitcase. A bomb is located in a radio that is hidden behind another object, in this case a tin of candy. The clutter makes it extremely difficult for inspectors - and machines - to identify the contents. On the right is a CT image. The CT has sliced right through the radio, revealing the presence of concealed explosives. In addition to identifying and detecting the other bomb components, the image clearly shows the inspector how the device was concealed. The only other way to see such detail would be to disassemble the radio.

Figure 2: Comparison Of CT And Conventional X-Ray Images



Automatic detection of any material requires that the target material has unique properties compared to innocuous items that could also be present. Figure 3 shows the CT density spectrum (in measured kg/m3) of different materials in the range spanning both drugs and explosives.

Figure 3: CT Density Spectrum Of Different Materials



Innocuous objects tend to fall into 3 general ranges:

1. Low range 0 - 500 kg/m3 - Clothes
2. Mid range 800 - 1200 - Food, paper, cosmetics, wine, water, plastics
3. High range > 1600 - Ceramics, metals

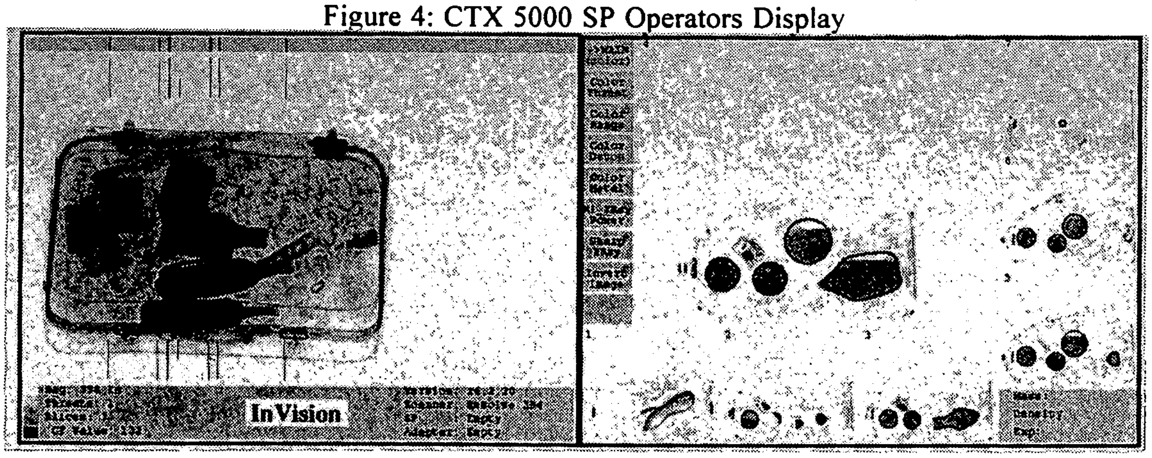
It is interesting and fortunate that explosives and narcotics (with the notable exception of Marijuana) fall between these ranges. Our limited experience scanning live narcotics indicate that compressed cocaine and heroin powders fall somewhere between 600 - 900 kg/m^3 with Marijuana falling in the middle of the clothing range at 240 kg/m^3. This makes them distinguishable from other materials and automatically detectable.

The CTX works as follows: first, a bag is scanned by the X-ray prescreener. The computer uses this image to determine where to place the CT slices. It does this by looking at the location of objects in the suitcase. The bag is then loaded into the CT module where the CT data is collected and analyzed for the presence of the threat. At the same time, the SP is scanning the second bag; screening 2 bags in parallel speeds up the total process. It is important to realize that the CT data, not the X-ray data, is used to detect the target material. If none is found, the bag is ejected. If something is located, additional slices are taken to determine the mass of the suspicious objects. If it is found to be above a mass threshold, the machine alarms, holds the bag and sends the images to the operator. This is the traditional way that the CTX works. It can be adapted to other ways of operating, for example, showing all images to an inspector regardless of whether a bag is rejected by the CTX. The current CTX data collection and inspection process has been optimized for explosives detection; it may need changes to be tuned for finding drugs.

The detection software uses the X-ray image to produce a mass profile of each bag. If objects exceed a mass threshold, the CTX will automatically place a slice inside them. The CTX will also put additional slices in other parts of the bag to find sheet materials, invisible to X-ray machines. The CT inspection algorithms determine the CT density of each significant object in the container. If the density is not in the range of interest, the algorithm moves on to the next object. If it finds something, additional slices will be taken to determine the length of the object. The mass is determined by measuring the density and cross-sectional area from the CT data and the length of the object by knowing the distance between all the slices that have alarmed. If the threat mass exceeds the threshold, then the machine alarms. It is then up to the inspector to make the final determination.

The operator's console presents the X-ray and CT images on two monitors (see figure 4): one for the X-ray and one for the CT. The X-ray image provides a bag overview; the CT images allow a detailed look inside. The features of the machine, while designed for explosives detection, may also have value (possibly with modifications) for Customs inspectors.

Figure 4: CTX 5000 SP Operators Display



3. Prior Experience Scanning Narcotics

InVision's experience with narcotics is limited, but goes back a number of years. After an initial trial at San Francisco in 1992, the San Francisco Police/DEA bought a seized cocaine brick to InVision for data collection and initial studies, though this was before any inspection software had been written. The results were encouraging enough that US Customs conducted a more extensive data-gathering exercise with different narcotics in various methods of concealment. [1]

During other trials in 1993 and 1994 around the world, there was opportunity to measure CT properties of various narcotics that had been seized at different locations. Most of our experience is with cocaine and heroin powders. Unfortunately, the largest trial that was conducted by Japanese Customs late last year was classified and the information and experience is not available. A non-classified test was conducted by Battelle using the CTX located at the FAA Technical Center. The results were reported at the 1996 SPIE Conference. [2] This independent test favorably positioned CT as an effective way of revealing contents of suitcases to inspectors. The success rate was 90% with incorrect decisions being made only 10% of the time. It is important to realize that this test was done with no automatic assistance at all. In fact, the machine was still set to detect explosives serving to confuse rather than help the inspector. It is important to note that existing airport operators have used CTX to reveal concealed narcotics in the real world. Two 1 kilogram bricks of cocaine were found in the false bottom of a suitcase by an alert operator in Europe. Machines installed in Europe have also revealed other contraband, including ivory tusks, in passenger luggage.

Figures 5 - 10 show images from some of the studies. These indicate how either simulants or real narcotics were concealed inside different objects, and how CT images are able to revealed the material and its concealment. Figure 5 shows powdered cocaine simulant concealed inside a frozen fish. The cocaine was colored green by selecting the appropriate CT range and coloring it. At this stage of development, this is a manual process requiring operators to view all images and color selected CT ranges. This is substantially less sophisticated than using automatic detection, which would eliminate the green pixels in the other objects and concentrate attention only on the target object. Furthermore, the machine would clear anywhere between 70 and 80% of bags automatically, without necessary inspector involvement. For those bags that were rejected, only the objects found to be suspicious would be colored. This significantly speeds up the inspection process and gives inspectors a greater degree of confidence in their decision and the ability to scan more bags. In Figure 6, a heroin simulant (a mixture of sugar, flour and salt) was concealed inside a can of clams. This can was packaged inside a box of similar, but unaltered cans. The heroin can easily be seen from the green coloration making it easy for an operator to see the threat. Figure 7, shows images of heroin simulant concealed inside frozen shrimp.

Figures 8 and 9 show images that were collected during a 1993 US Customs study of an early CTX prototype - long before certified automatic inspection software had been developed. The contrast between the X-ray and CT images clearly shows the potential and advantages of CT based detection. In these cases, real drugs (hashish and cocaine) were used.

Figure 10 shows an image of Marijuana inside a duffel bag. Marijuana poses a unique problem and also a potential solution. The problem is that the average CT density falls within the same CT range as clothing. Using today's CT algorithms would lead to a high false alarm rate as most suitcases contain sufficient clothes to cause an alarm. However, the stems of the Marijuana leaves - the dark gray dots in the image - give Marijuana a different textural appearance to clothing. It should be possible to develop software algorithms that key in on this difference to automatically distinguish Marijuana from clothing.

Figure 5: Cocaine Simulant Inside Frozen Fish

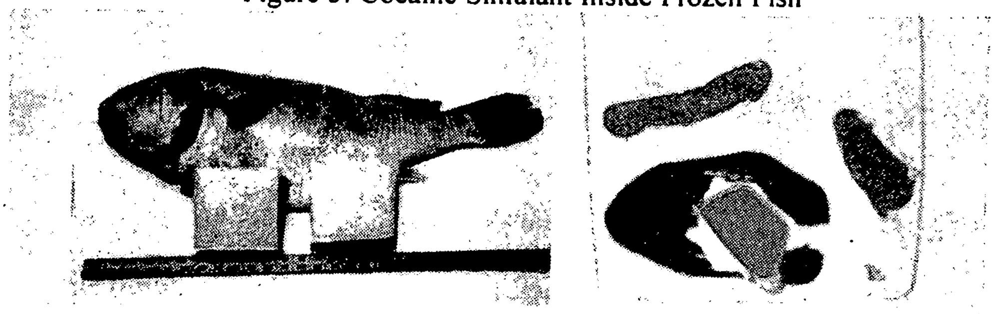


Figure 6: Cocaine Simulant Inside Frozen Fish

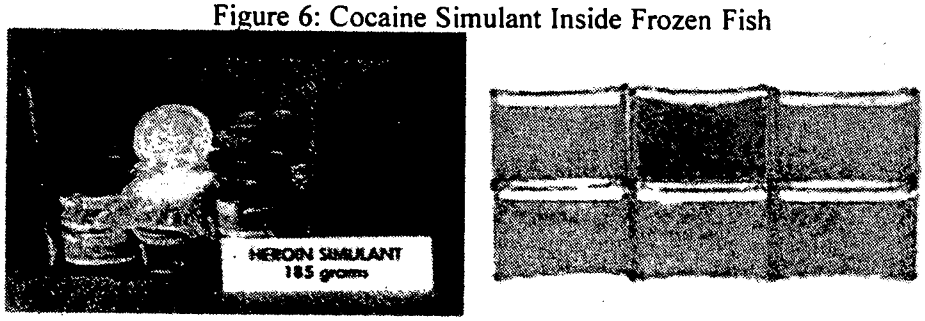


Figure 7: Heroin Simulant Inside Frozen Shrimp

Figure 8: X-Ray And CT Images Of Hashish In Rice Bin

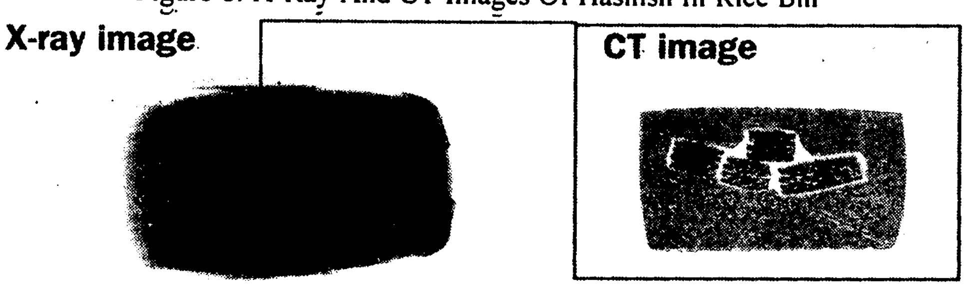


Figure 9: X-Ray And CT Images Of Cocaine Under Bowl

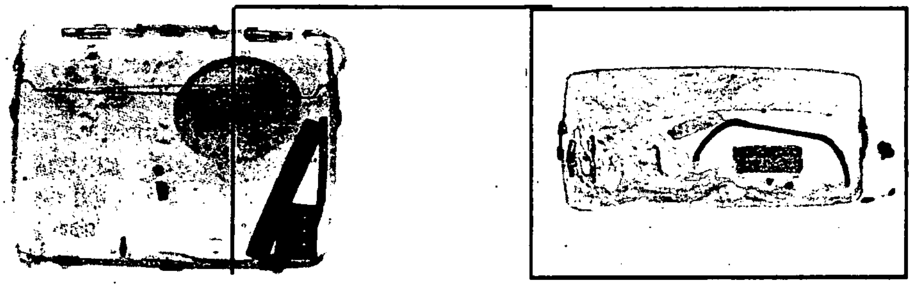
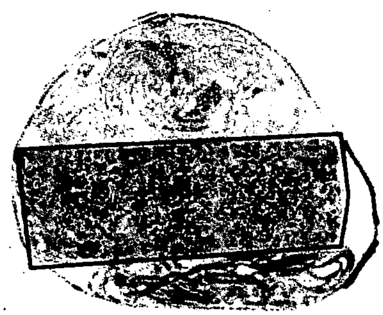


Figure 10: CT Images Of Marijuana In Duffel Bag With Clothes



4. Development Plan For Adapting CTX To Narcotics Detection.

The existing CTX 5000 SP can be modified with relatively little effort to detect narcotics. Adaptations of existing algorithms can made and be tested and will likely yield a high automatic detection probability for compressed Cocaine and Heroin hydrochloride powders. New algorithms could be developed to further reduce false alarms and to enable automatic detection of Marijuana. It is likely that the slice placement algorithms would need to be altered to more reliably look for the lower density narcotics, something that would be explored as part of an initial study. A development plan would also assess operational needs and provide information to enable the optimization of machine and inspector performance as well as provide valuable information that could serve as specifications for an improved machine.

To address the screening of larger container screening and assess the potential value of complementary detection technologies, a new CT engine design would likely be needed. While this would take additional effort, the existing scanner could be applied to screening at many ports of entry into the US and could be used to determine design specifications and better understand the operations at Customs inspection facilities.

To summarize, we believe that there is sufficient evidence that CT technology could become a valuable tool in the war against drugs. Much of this evidence comes from independent studies, such as those conducted by Battelle. Though InVision has had little experience with Customs' needs, we believe that there are strong parallels between narcotics and explosives detection. Based on where CTX technology is today, it would not take a substantial investment to develop and implement a plan that would adapt and demonstrate modifications to the existing technology.

Based on data obtained to date, heroin, cocaine, hashish and opium should be relatively easily detected with minor software modifications. Automatically finding Marijuana would need new algorithms but would still likely be detectable - in any case, the distinctive pattern of Marijuana leaves would provide inspectors with valuable information. Feedback from the Battelle Study indicated, from an independent source, that CT technology would make inspectors' jobs easier and faster, allowing more incoming items to be screened. Government interest, coupled with initial deployments would prompt development of better and more economical systems that would expand the screening capabilities to larger containers.

In conclusion, we believe that CT technology could help the drug interdiction efforts even in the relatively short term, without substantial development costs and effort.

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A MOBILE X-RAY SYSTEM FOR NONINTRUSIVE INSPECTION OF VEHICLES

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ABSTRACT

A mobile, rapid-deployment, 450kV X-ray system has been developed for the nonintrusive inspection of vehicles and cargo containers. The system provides simultaneous transmission and backscatter digital images for enhanced contraband detection. Backscatter imaging is particularly sensitive to organic materials such as drugs and explosives. The MobileSearch™ system, truck-mounted and fully self-contained, requires a crew of three for efficient setup and operation. Upon arrival at the inspection site, it can be deployed for operation in about 10 minutes. A slow-speed drive moves the system past the stationary inspected vehicle at a speed of 6.5 inches per second. The field of view is high enough to scan vehicles with heights up to about 6 feet in a single pass for each side. For taller vehicles the field of view can be tilted upward to complete the coverage with additional scans. An X-ray source with a much larger field of view is under development. MobileSearch is configured and certified as a "cabinet" X-ray system according to FDA standards. The system configuration, measured radiation levels, and protoype images are presented.

1. Introduction

As part of the program to interdict drugs entering the United States across the border with Mexico, a fixed-site system [1] capable of rapidly inspecting trucks up to 70 feet long was designed and installed at Otay Mesa, California. Operations at this site have been extremely effective, and a second system is now in operation at Calexico. Eight others are in various stages of planning or construction. All of these systems utilize two 450kV X-ray sources and provide both backscatter as well as conventional transmission images.

As a complement to these fixed sites, the first truck-mounted mobile system (MobileSearch™) [2] was developed and is now in service on our southern border. This single-source system utilizes only backscatter imaging, justified at the time by early experience with the first fixed-site system. Subsequent experience has shown that adding transmission imaging will sufficiently increase the inspection efficiency to justify the additional complexity and expense of the large transmission detector and its ancillary systems. The new MobileSearch unit includes not only transmission imaging but also improvements suggested both internally and by operators in the field. A noteworthy feature is the system's ability to accommodate, with modest changes, an X-ray source with a much larger field of view which is currently under development.

2. Single-Source Backscatter and Transmission Imaging

The two major X-ray technologies currently in use for nonintrusive inspections are transmission imaging, offered in a variety of manifestations by all X-ray system suppliers, and backscatter imaging, offered for packages and cargo only by AS&E[3]. Transmission imaging has several limitations. In particular, it provides absolutely no information if the object is too dense to penetrate. It emphasizes the strongly absorbing high-Z materials and suppresses the low-Z materials such as organics. It suffers from the confusing clutter of overlayed objects. It is insensitive to relatively thin objects.

Backscatter imaging is a major development which addresses these four limitations. Backscatter images highlight the near-surface regions, independent of the penetrability of the entire package or cargo. As a consequence, the images have little clutter. The low-Z materials are very pronounced, making the identification of drugs and other organic contraband straightforward. More subjectively, operators find backscatter images easier to interpret not only because they are less cluttered but also because they appear similar to what they would see with ordinary light (but with transparency). Transmission images, on the other hand, are essentially density maps which are generally difficult to interpret.

Most AS&E systems employ both transmission and backscatter digital imaging. The dual presentation provides extremely valuable insights for interpreting the transmission images. In all of these systems a conventional X-ray source is collimated to produce a fan beam which in turn illuminates the inner surface of a rapidly rotating hollow-spoked wheel. The pencil beam emerging from the hollow spokes sweeps through the inspected object in adjacent slices as the object moves past the rotating wheel. Double use is made of the beam in that it simultaneously generates both backscatter as well as transmission images. Very sensitive large area detectors are used, providing maximum information at minimum dose.

The fixed-site CargoSearch™ systems employ two X-ray sources, enabling the inspection of the bottom and both sides of the vehicle, as well as the interior, in a single pass. For practical reasons PalletSearch™[4] and MobileSearch employ a single source. Therefore, at least two passes are needed for a complete inspection; more than two passes are necessary for objects taller than the X-ray fan beam field of view.

3. System Description and Operation

MobileSearch [Figures 1and 2] is a completely self-contained, mobile system, able to be moved over ordinary roadways to its intended operating site and be set up easily by a crew of three in approximately 10 minutes.

The 450kV X-ray tube produces a cone beam with an opening angle of approximately 45°. The resulting field of view is large enough to cover objects up to about 6 feet tall. In order to fully inspect taller loads it is necessary to rotate the field of view upward and scan past the object again. The tilt angle can be remotely adjusted by the operator in about one second.

In order to obtain a cross-sectional view through the front wall, for example, of a truck being scanned, the X-ray beam plane is angled from the perpendicular relative to the scan motion [see Figure 1]. This is similar to the geometry used in the fixed-site CargoSearch systems, where it has proven extremely effective in detecting contraband concealed in nominally perpendicular sections such as rear doors, baffles, etc.

The backscatter detectors are mounted just inside the MobileSearch truck wall on both sides of the chopper wheel and detect backscattered X-rays from the entire field-of-view of the source [see Figure 2].

Adding transmission imaging to MobileSearch was motivated primarily by the proven advantages in interpretation provided by the dual presentation of both backscatter and transmission images. The transmission detector consists of a 10 foot long horizontal section and a vertical section 15 feet long. All parts of the inspected object above the straight line connecting the center of the X-ray source to the lower end of the transmission detector will be imaged [see Figure 2]. This is the region likely to contain the densest part of the cargo. Computer simulations indicate that 1kg of cocaine behind slightly less than 4" of steel and 10 kg of cocaine behind slightly more than 4" of steel can be detected. These results assume only a moderate ability to distinquish contrast given a reasonable signal-to-noise ratio, negligible clutter, and no other visual clues that the packages might be suspicious [5].

An electric drive mechanism and a precision tachometer are directly coupled to one of the rear tires. This drive provides the slow speed of motion necessary for the scanning process in both the forward and reverse directions. Thus vehicles, or other objects, are scanned without requiring them to be moved or disturbed in any way. Two scan speeds are provided. While the 3.25 inches per second speed provides somewhat better signal-to-noise in the image, and hence somewhat better penetration, the 6.5 inches per second speed is expected to result in decision-quality images in most cases and will be the speed of choice of the operator. Consequently, the system operating parameters presented in Table I are based on the higher scan speed.

Table I. MobileSearch Characteristics

Max. height over the road:	11' 10"
Tunnel opening:	12'W x 14'H
X-ray source:	450kV 10mA
Fan beam opening angle:	43°
Range of tilt for fan beam:	-20° ; + 25°
Pixels per vertical scan line for both transmission and backscatter images:	1024
Scan speeds:	
Normal:	6.50in/S
Slow:	3.25in/S
Max. vehicle length (image completely in memory):	~70ft.
Exposure at scanned surface:	65μR/scan

Objects ranging in size from a small car up to a full-size tractor-trailer rig can be scanned and the resulting images presented to the operator for further enhancement, archival storage, or hard copies. At 6.5 inches per second scan speed there is enough space in memory for a 74 foot scan. Because the X-ray beam is angled and because one should allow for a couple of feet uncertainty in locating the beginning of the scan, the practical maximum vehicle length is 65' - 70'. There is an option which permits a continuous scan of a longer vehicle or a long row of vehicles. In this mode only the most recent 74 feet of scan are retained in memory.

Before leaving an inspection site, the transmission detector must be securely stowed for normal driving. The vertical section is raised to a horizontal position just beneath the horizontal section, and the boom is rotated to place the folded assembly squarely above the truck body then locked in place as shown in Figure 1.

4. Prototype Images

Representative transmission and backscatter images taken in the laboratory with a prototype 450kV system in a scan geometry similar to MobileSearch are shown in Figures 3-6. The prototype transmission detectors had much larger afterglow than those used in the final product. As a consequence, the actual transmission images will have intrinsically even better contrast than shown in these figures.

5. Radiation Safety

MobileSearch was designed to meet FDA cabinet certification requirements [6]. While these requirements are most commonly applied to baggage inspection systems at airports, they can also be applied to much larger systems. If the requirements are met, minimal operator training is required, there are minimal regulations and restrictions on the user, and dosimetry and record keeping are not required.

The wings on the vertical transmission detector [Figure 1] were added in order to satisfy two of the requirements. They establish a crucial part of the "cabinet surface" outside of which the radiation exposure must be less than 0.5mR/hr. They are also the barrier which prevents inadvertently putting any part of the human body in the direct X-ray beam [7]. All of the other requirements were more easily satisfied.

In actual practice, during any inspection period the X-rays are on at most half of the time. Assuming this worst-case macro duty factor of 50%, a stationary observer at the cabinet surface will receive much less than the 0.5mR/hr limit. This upper limit is based on actual measurements with the first MobileSearch unit, whose X-ray source, filtering, shielding, and AS&E MICRO-DOSE®

technology features are identical to those of the new MobileSearch, which incorporates transmission imaging.

6. Future Developments

It is planned to incorporate an X-ray tube with a larger field-of-view as soon as the tube and funding become available. This will require a new local collimator and chopper wheel as well as several software modifications. The larger field of view will cover any vehicle which can pass under the extended boom with only minimal corner cutoff. Thus only one scan will be needed to inspect a single side of a tall vehicle. Any cutoff corner will be imaged when the opposite side of the vehicle is scanned.

7. Conclusions

MobileSearch provides thorough nonintrusive inspection of vehicles and other large objects by utilizing both backscatter and transmission X-ray imaging in a single system. High efficiency detectors and the use of the same X-ray beam for both sets of images insures minimum dose to the cargo as well as to the environment.

8. Acknowledgements

American Science and Engineering, Inc. wishes to acknowledge the support received by the Department of Defense Counter Drug Technology Development Program Office.

9. References

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Lindquist, R. P., "Application of X-ray for the Examination of Commercial Vehicles in a U. S. Customs Service Environment", in *Proc. Conterdrug Law Enforce-* Figure *ment: Applied Technology for Improved Effectiveness International Technology Symposium ,Part I* (sponsored by ONDCP Counterdrug Technology Assessment Center), Nashua, NH, pp. 6-53 - 6-57, October, 1995

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[3] Annis, M. and Bjorkholm, P. J., "X-Ray Imaging Particularly Adapted for Low Z Materials", *United States Patent 5,313,511*, May, 1994.

[4] Smith, G. J., "X-Ray Inspection of Palletized Cargo for Security and Drug Interdiction", *Proc. 13th Annual Security Technology Symposium & Exhibition* (sponsored by ADPA/NSIA Sercurity Division), Virginia Beach, VA, June, 1997 (to be published).

[5] The measured performance characteristics are law-enforcement-sensitive. Anyone with a legitimate need to know should contact
US Customs Service
Applied Technology Division
(202) 927-1900

[6] Code of Federal Regulations 1020.40: Cabinet x-ray systems

[7] With such large ports it is clearly possible for anyone to enter the cabinet, ignoring the required warning signs and lights. The exterior operator who watches these ports can turn off the X-rays. In any case the dose would be very small, less than 0.1mR per scan, unless the person walks so as to stay well aligned with the beam during the scanning operation.

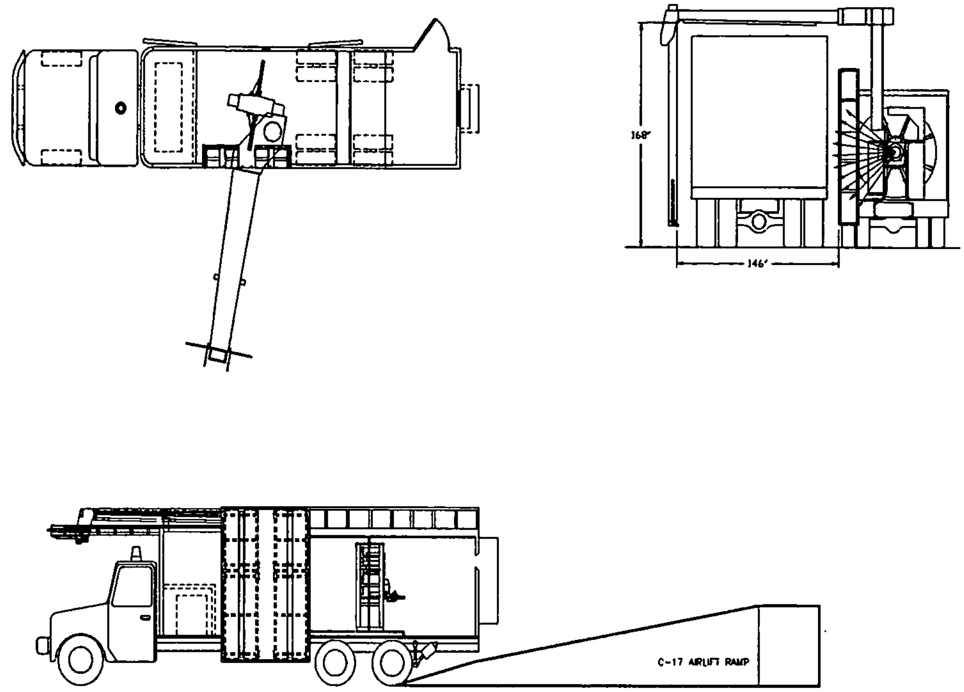

Figure 1. Plan, side, and end views of MobileSearch. The transmission detector boom is shown deployed in the plan and end views. It is shown stowed in the side view. The defined cabinet ports extend from the barrier at the end of the boom to the corners of the truck body. Five centimeters outside of these ports the radiation exposure must be less than 0.5mR in any hour.

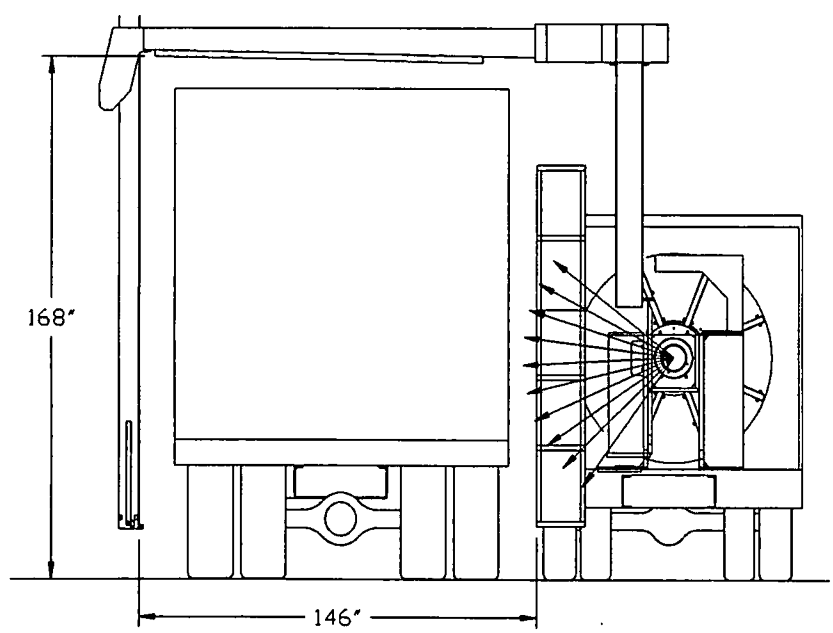

Figure 2. End view detail. For the tall truck shown in the figure two scans on each side of the truck are required for a complete inspection. (A small corner cutoff, which will be imaged when the opposite side is scanned, would be eliminated by a third scan.) The portion of the truck above the line connecting the lower end of the boom to the X-ray source will be imaged in the transmission mode as well as the backscatter mode.

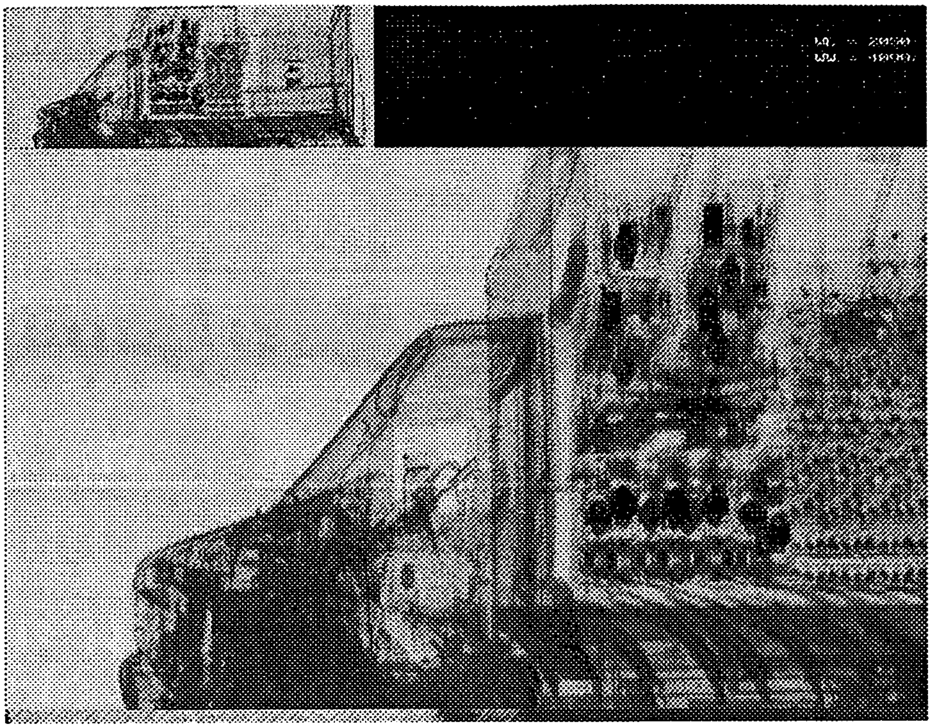

Figure 3 Transmission image of the front end of a small truck. The complete image is shown in reduced form at the upper left. Cargo is boxed electronic components. Image obtained with prototype system in the laboratory.

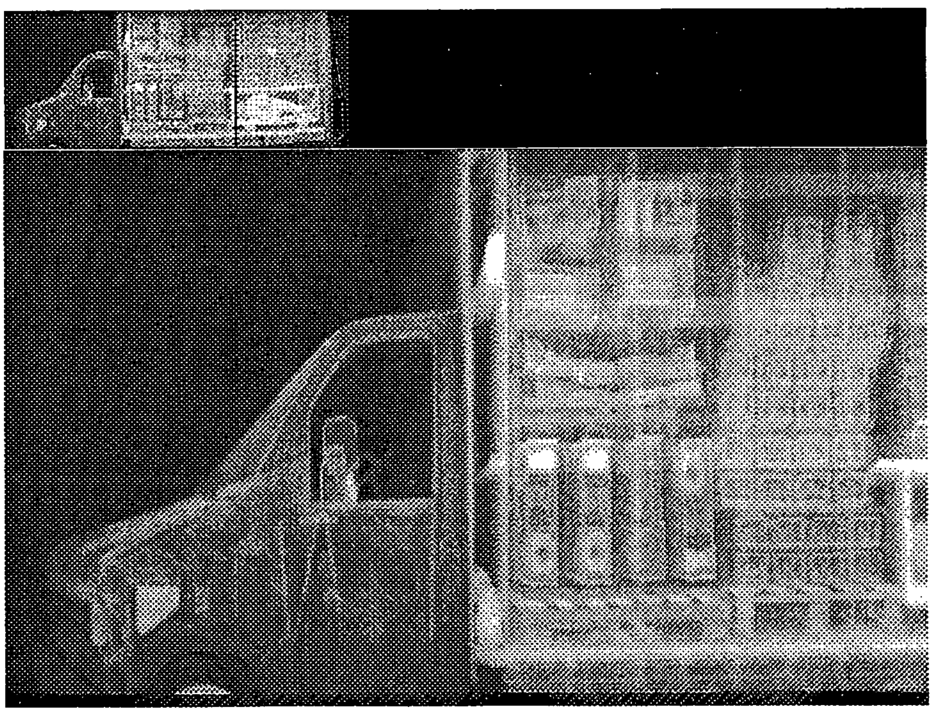

Figure 4 Backscatter image of the truck in Figure 3. Note the liquid in the window washer container behind the headlight, the false front wall with contraband simulant at the bottom, a case of guns, and the sense of perspective of the boxes which helps the interpretation of the image.

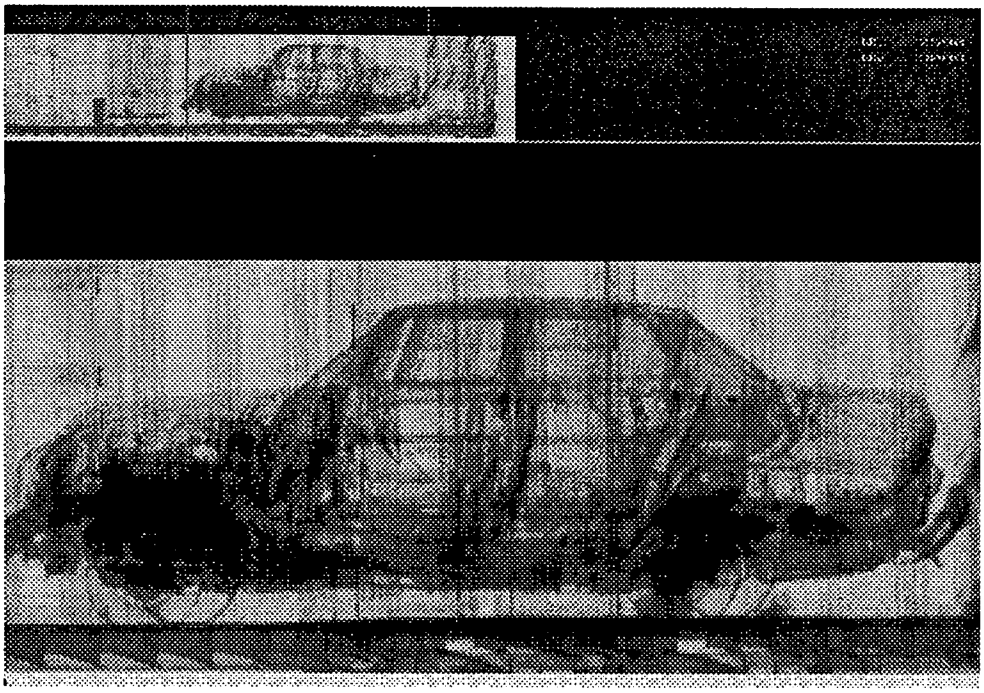

Figure 5 Transmission image of the rear end of a truck trailer, obtained with a prototype system in the laboratory.

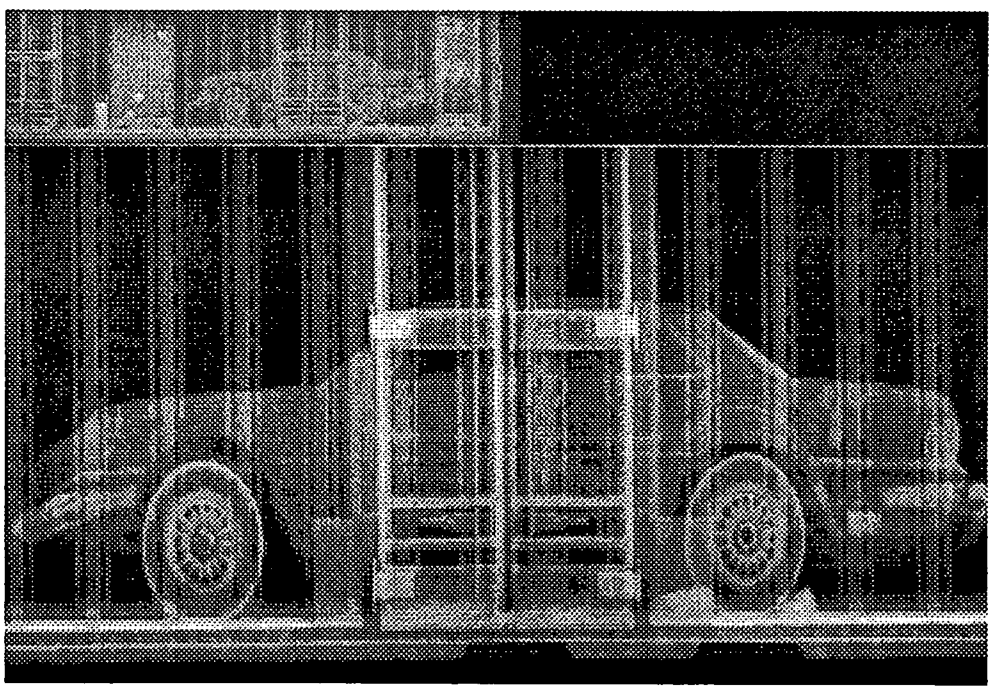

Figure 6 Backscatter image of the same trailer as in Figure 5. Note the wood bracing for the car and the 2 kg contraband simulant in its trunk.

THE DESIGN, CONSTRUCTION AND OPERATION OF A 9 MeV VEHICLE CARGO X-RAY SYSTEM

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ABSTRACT

In 1994 British Aerospace completed a 9 MeV Falcon Vehicle Cargo X-ray System for the Customs Authority of the People's Republic of China. The technology used for this system was recently acquired by EG&G Astrophysics.

The system, which can process in excess of 25 vehicles per hour, has been in operation for over 3 years on a routine basis. During this time many thousands of vehicles have been inspected and a large number of detections of contraband have been made.

This paper discusses the design of the system, including the reasons for the choice of energy, and describes some of the operating experience. Examples of a number of contraband detections are illustrated.

1 Introduction

In 1994 British Aerospace completed a Vehicle Cargo X-ray system for the Customs Authority of the People's Republic of China. The system is located in Shenzhen, on the border with Hong Kong. Following completion of the system the British Aerospace X-ray technology was transferred to J S Chinn, and has recently been transferred again, to EG&G Astrophysics. EG&G are now responsible for the maintenance of the system.

The system has been operated on a routine basis by the Chinese Customs for over 3 years. During this time many thousands of vehicles have been processed and a large number of detections of contraband made. The main purpose of the system is to detect goods which are being smuggled into China in order to avoid the payment of duty, although drugs, arms, explosives and other types of contraband are, of course, of interest.

This paper describes the system and its operation, discusses the choice of energy and describes a number of typical contraband detections.

2 Outline description of the system

The principle of X-ray imaging is illustrated in figure 1. The beam from the X-ray source is restricted to form a narrow fan-shaped beam. This beam passes through the object to be examined and falls on a linear detector-array. This array consists of a large number of individual detectors arranged in a line in the plane of the beam. The object to be examined is moved through the beam at a constant speed. The signals from the detectors are read out and stored many times

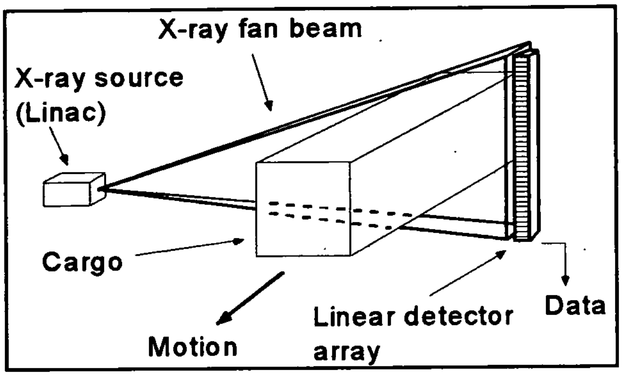

Figure 1; Principle of X-ray imaging

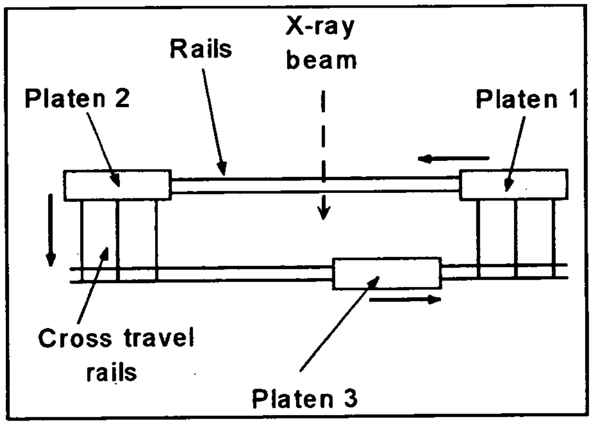

Figure 2; Principle of the conveyor

per second, so that an image of the complete object is made up from a large number of vertical strips.

In the system in Shenzhen the X-ray source is a 9 MeV industrial linear-accelerator. The detector array consists of 1344 individual detectors and the spacing between each detector is approximately 4 mm. The signals from the array are read out once for approximately every 4 mm of movement of the vehicle.

There are four display-stations for examining the images. Each station consists of two screens, one for the X-ray image and the other for the cargo manifest. The result of the inspection can be entered into the data processing system, which contains information such as the vehicle registration number, weight and manifest. If required, images can be archived for permanent storage.

3 The conveyor system

Vehicles are carried through the system on automatically controlled platforms, or platens, which run on rails. The principle of these platens is illustrated in figure 2. Platen 1 is at the loading position. The vehicle to be loaded drives up a ramp and onto the platen. The driver leaves the vehicle and the platen then moves through the X-ray beam and stops at the unloading position, occupied by platen 2 in the diagram. The driver then rejoins his vehicle and drives off the platen. The platen then moves sideways on the cross-travel rails to the return rails. It then returns to the entry end of the building. Finally, when the loading position is free, it moves back across to this position.

Each platen can carry one vehicle weighing up to 60 tonnes and up to 17.5 m long, or two smaller vehicles.

There are three platens in the system in order to maintain the throughput. Whilst one platen is in the building being X-rayed, one of the others is at the loading position receiving the next vehicle, and the other is either at the unloading position or on the return journey. In this way a regular throughput in excess of 25 full-sized vehicles per hour can be achieved.

The system can be operated with one, two or three platens. Any one of the platens can be removed from the system and taken to the maintenance shed or the siding for maintenance (see figure 3), and processing can continue with the remaining platens.

4 Layout and operation of the system

The layout of the system is shown in figure 3, overleaf.

A vehicle to be processed drives up the entry ramp and on to the weighbridge, where it is weighed. The driver hands his manifest documents into the entry kiosk, where they are entered into the computer system using a flat-bed scanner. The vehicle then moves forward onto the waiting platen. The driver gets out and follows the driver's walkway to the exit end to await his vehicle. When the operator has completed a safety

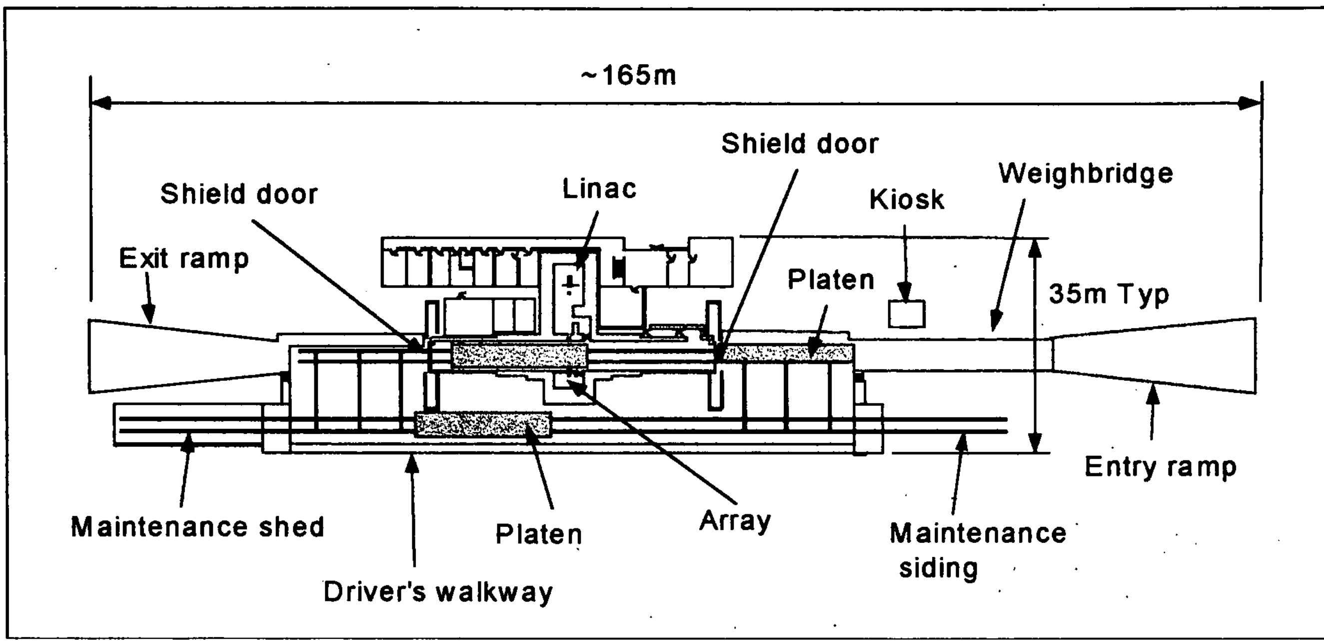

Figure 3; System layout

check, he/she initiates the scan sequence. From this point on the whole sequence is fully automatic.

The platen moves forward into the building and the shield doors close behind it. The X-ray source is switched on and allowed to stabilise. The platen and the vehicle then move passed the X-ray beam at a constant speed, and the image is collected. When the entire vehicle has been X-rayed, the exit doors open and the platen moves out of the building. At the same time as this platen is moving out, the next one can be moving in.

When the platen is completely out of the building, the exit doors close so that processing of the next vehicle can begin. The driver re-joins his vehicle and drives off down the exit ramp to a waiting area, to await the result of the inspection.

When the vehicle has driven off the platen, the platen moves sideways and returns to the entry end. At the same time as one vehicle is being X-rayed, the next is being loaded onto the platen at the loading area.

When the image has been examined, the result is entered into the computer system and is transmitted to an office at the waiting area. The vehicle is then either released or sent for manual inspection. If manual inspection is required, a hard copy of the image can be produced to assist the manual inspection team.

5 Choice energy

The question: "Why is it necessary to use such a high energy?" is often asked. This can be answered by referring to figure 4, where the relative intensity of the X-rays reaching the detector is plotted against total width of the cargo for various energies. The cargo selected is a typical high-density cargo, of average density 1 g/cc, such as canned drinks for example.

The range of relative intensities used is 1 to 10,000 as this matches the usable dynamic range, for practical purposes, of the best detector systems available. In other words, if the maximum signal which can be detected is 10,000 then the minimum signal which can detected is 1.

Looking at the curve for 1 MeV, it can be seen that it is possible to penetrate just over 1 metre of cargo at this energy. In order to penetrate a full container or vehicle width of 2.5 metres it is necessary to choose an energy of 8 MeV or higher. Greater energies would,

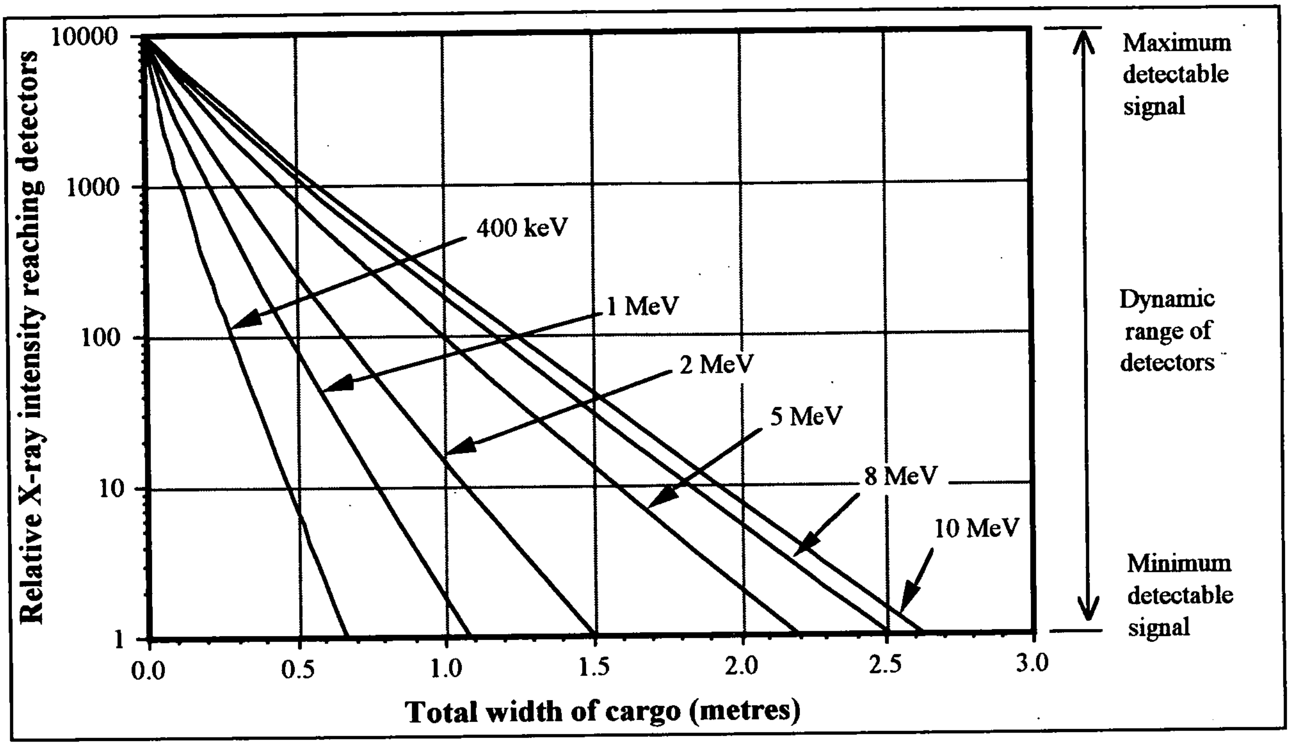

Figure 4; Choice of energy

of course, provide even greater penetration, depending on the material within the container. However, at energies greater than 10 MeV the possibility of neutrons being created becomes significant and so there is a risk of induced radioactivity. For this reason the World Health Organisation recommends an energy of not more than 10 MeV for the inspection of foodstuffs, and this forms a practical limit for most purposes.

6 Operating experience

The system has now been operating successfully for just over 3 years. During that time many thousands of vehicles have been examined and a large number of attempts at smuggling detected. For example, during the first six months of this year goods to the value of over $US 1.5 million were seized. In addition to this, additional revenue will have been collected due to the deterrent effect of the system, as some would-be smugglers will have chosen to pay the duty rather than risk being caught.

During the time that the system has been in operation, the total value of goods seized and disposed of exceed the capital cost of the equipment, so the system has already more than paid for itself.

Generally, the system is operated one shift per day, although the timing of this shift varies from day to day and sometimes a split shift is worked. When the system first came into operation, a single, standard, daytime shift was worked. It quickly became apparent, however, that smugglers had realised this and so were crossing the border when the system was not operating.

Reliability of the system has been excellent. The climate in the area is very hot and very wet at certain times of the year, but in spite of this the system availability is consistently in excess of 95%.

7 Examples of smuggling

The range of smuggling scenarios encountered is very broad: consumer goods, electronic equipment, cars, and industrial and medical products are smuggled in virtually all types of cargo which enter the country. Some cases of smuggling which have been encountered are given below:

False compartments

A number of false compartments built into the structure of the vehicle have been discovered. An example of one such false compartment, built into the front of the load space, is shown in figure 5.

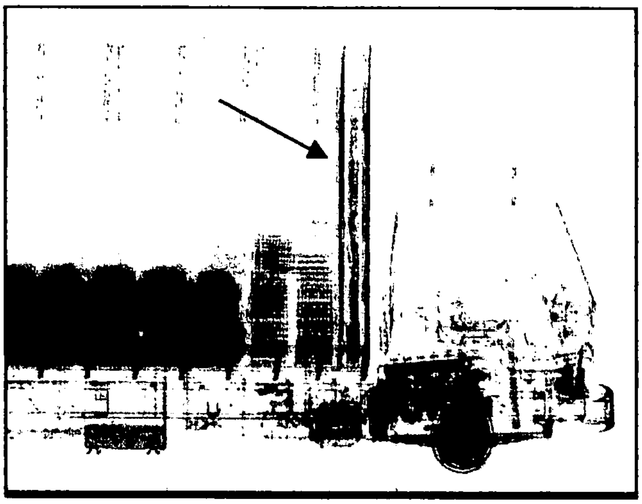

Figure 5; Example of a false compartment

When a manual search was carried out this was found to contain radio pagers. The compartment itself was very narrow, and the only way it would have been found by manual means would have been to make very careful measurements of both the outside and the inside of the vehicle.

Fuel tank

Figure 6 shows a zoomed image of a fuel tank. Compare this to the fuel tank on the vehicle shown in figure 5. Clearly, it contains more than just fuel.

Investigation revealed that false compartments had been built into the inside of the tank in such a way that anyone checking the tank through the normal filler would find the full depth of the tank. The contraband consisted of mobile telephones and computer hard disks.

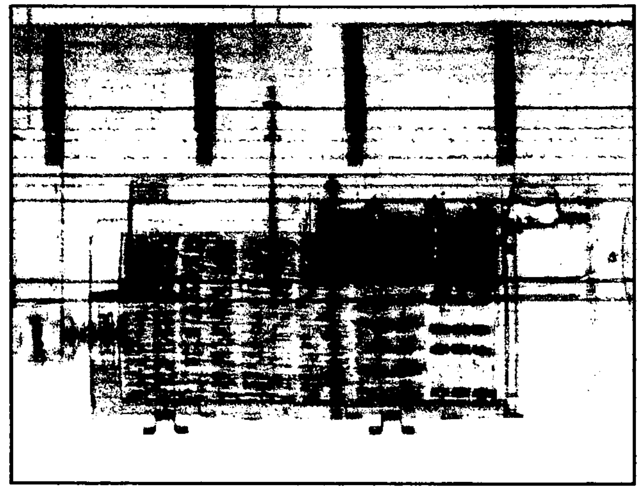

Figure 6; Contraband hidden in a fuel tank

Contraband in dense cargo

A common way of smuggling goods is to simply hide them in a very dense cargo or a cargo which is difficult to unload for manual inspection. Figure 7 show an unprocessed image of a cargo consisting of sacks plastic granules, which are extremely dense.

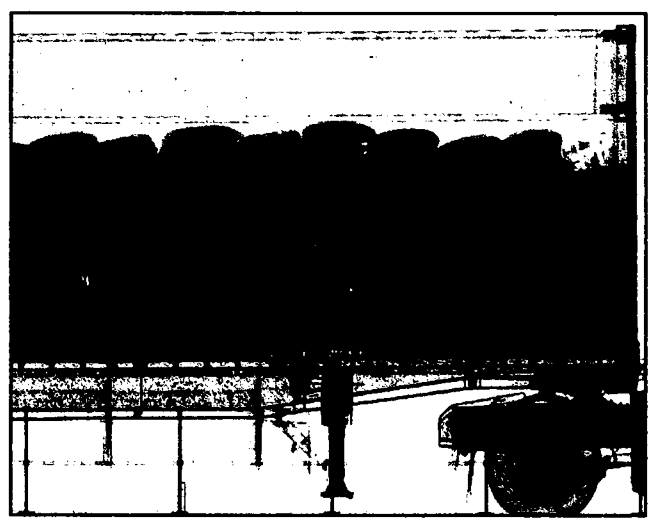

Figure 7; Unprocessed image of a dense cargo

Little can be seen in the image. However, when image processing is applied, as in figure 8, two motorcycles are revealed.

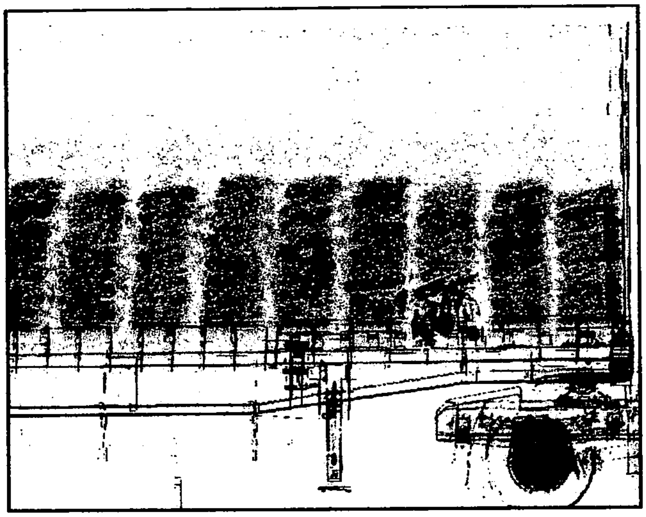

Figure 8; Image processing reveals contraband

This illustrates the importance of using high energy X-rays for the inspection of fully laden vehicles and containers.

Figure 9 shows another example of contraband hidden in dense cargo.

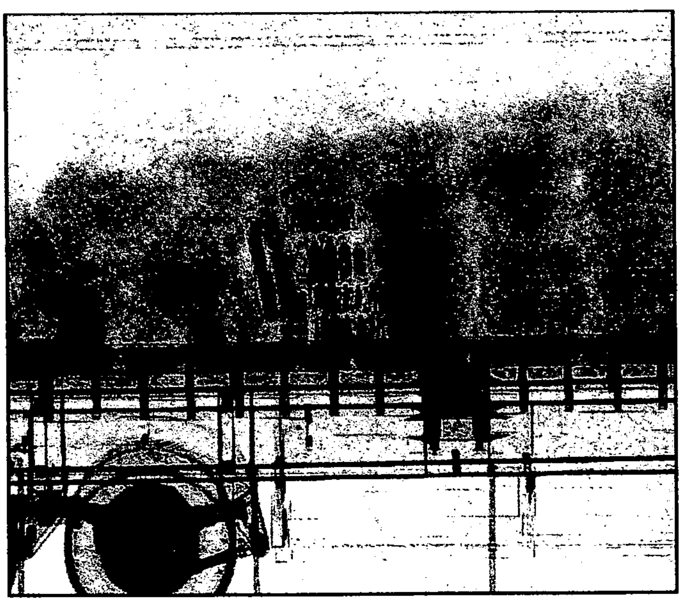

Figure 9; Bottles and electrical goods in dense cargo

A number of bottles can clearly be seen even though they are in the middle of the load. They are surrounded by domestic electrical goods. Again, this shows the importance of using high-energy X-rays for dense cargo.

Although all of the examples given above show contraband which was being smuggled in order to avoid the payment of duty, other types of contraband, such drugs, would have been detected just as easily.

8 Conclusion

A Vehicle Cargo X-ray system, using a 9 MeV X-rays, has been operating successfully for the last 3 years in China, at Shenzhen, on the border with Hong Kong.

The system uses automatically controlled platens to carry the vehicles through the X-ray beam, and has a throughput in excess of 25 full-sized vehicles per hour.

In order to achieve the penetration required to successfully inspect the full width of typical cargoes, the system uses an energy of 9 MeV.

Since the system came into operation, many thousands of vehicles have been inspected and large number of detections made. The total value of the goods seized and disposed of exceed the capital cost of the system, so that the system has more than paid for itself.

Contraband has been found in many situations including false compartments, fuel tanks and hidden in dense cargo.

The large number of cases of contraband being hidden in dense cargoes emphasises the importance of using high-energy X-rays for the inspection of fully loaded trucks and freight containers.

Performance Assessment of the Mobile Truck X-ray (MTXR) System

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ABSTRACT

The Naval Surface Warfare Center Dahlgren Division serves as the Executive Agent for the Department of Defense Counterdrug Technology Development Program. The DoD Counterdrug Technology Development Program Executive evaluated the Mobile Truck X-ray (MTXR) system. The system was developed by American Sciences and Engineering, Inc. (AS&E) under contract to the US Army.

The MTXR was evaluated extensively. The evaluation included controlled field and actual stream-of-commerce assessments. These two assessments alone covered approximately 10 weeks during the period 4 March through 27 August 1996. System acceptance and safety verification will also be covered in this report.

The primary objective of the assessment was to determine the ability of the MTXR to detect operationally significant quantities of contraband in empty trucks. This assessment reports the MTXR's ability to spot a variety of contraband and to confirm that an empty vehicle was indeed empty. The secondary objective was to determine the ability of the MTXR to detect contraband in similar trucks within the cargoes aboard.

Results from all phases of testing are presented in the body of the main report. The controlled field performance evaluation and the stream-of-commerce assessment phases are the portions of the experiment that address the evaluation objectives.

1. Introduction

The Naval Surface Warfare Center Dahlgren Division serves as the Executive Agent for the Department of Defense Counterdrug Technology Development Program. The DoD Counterdrug Technology Development Program Executive evaluated the Mobile Truck X-ray (MTXR) system.

The MTXR was evaluated extensively. The evaluation included controlled field and actual stream-of-commerce assessments. These two assessments alone covered approximately 10 weeks during the period 4 March through 27 August 1996.

The MTXR assessment was conducted in five phases: 1) an acceptance test conducted and witnessed by a TMEC independent evaluator to verify that the system was operational as defined in the proposal; 2) safety verification (radiation levels and safety features assessed); 3) specification verification (X-ray capabilities assessed); 4) system operations training (National Guard personnel trained in the operation of the MTXR); and 5) a controlled field performance assessment. In addition to the controlled field assessment the MTXR also underwent a stream-of-commerce assessment phase at a USCS port of entry. During this phase the MTXR actually inspected stream-of-commerce vehicles.

The primary objective of the assessment was to determine the ability of the MTXR to detect operationally significant quantities of contraband in empty trucks. This assessment reports the MTXR's ability to spot a variety of contraband and to confirm that an empty vehicle was indeed empty.

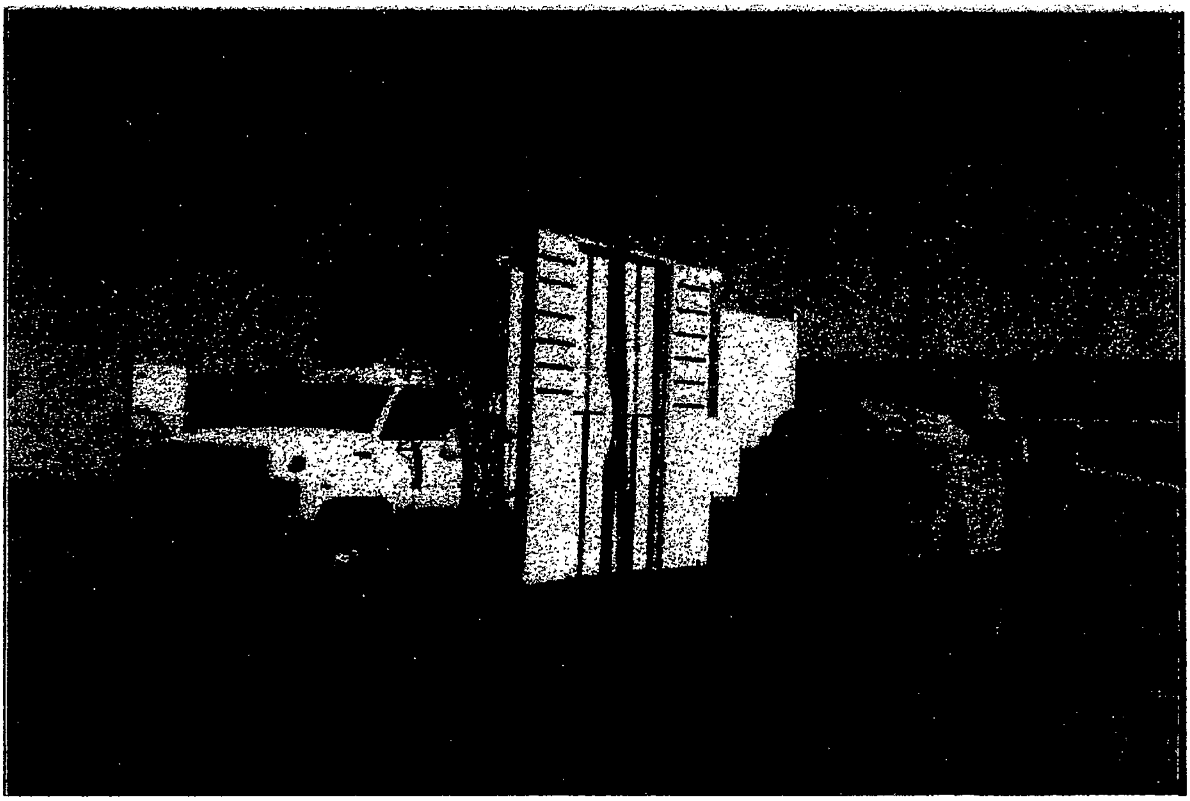

Figure 1 MTXR in Operation

The secondary objective was to determine the ability of the MTXR to detect contraband in similar trucks within the cargoes aboard.

The controlled field performance evaluation and the stream-of-commerce assessment phases are the portions of the experiment that address the evaluation objectives. A summary of the procedures and results of these 2 phases follows.

2. Controlled Field Performance Procedures and Results

The MTXR controlled field performance assessment used controlled test conditions including contraband location, contraband quantity, and cargo density. These items were the core of the evaluation matrix. The test design utilized three groups. Red and Blue Teams consisted of individuals whose job responsibilities were to simulate real world smugglers and law enforcement personnel, respectively. The Silver Team represented the interests of the government in an unbiased manner, to control the test, to archive data (X-ray images, Red and Blue Team forms), and to score the results of the test.

The Red Team used a random draw process to determine the vehicle to be used, the location(s) on the vehicles, and the quantity and amount of contraband to be used for each trial. The Red Team also created and utilized false compartments, or altered the cargoes in order to conceal the contraband or simulant. The Blue Team inspected vehicles using the MTXR system. X-ray images from the MTXR were analyzed.

In order to insure meaningful performance results, the goal during the MTXR assessment was to obtain 30 observations per variable [i.e. a given location, contraband amount and cargo density]. Up to seven zones per truck were used for test purposes. This permitted an efficient test design which simulated up to seven trucks with one truck. This was done to minimize the number of trials needed to accomplish the assessment task.

Various operationally significant quantities of contraband were used in the MTXR assessment. The contraband quantities were grouped into the following categories: None, Low, Medium , and High.

During the 50 days that controlled performance trials were conducted, the MTXR inspected a total of 552 vehicles. The inspection of a vehicle included the scanning of the top and bottom halves of both sides of the vehicle. This was considered a complete scan of the vehicle and is how all scoring was conducted. The average time to inspect a vehicle was 20.6 minutes. The median time was 18 minutes. The skew in the data was because of the slow times achieved during the early portions of the evaluation and the data include long inspection periods due to equipment problems. The results indicate that a trained crew would achieve a complete inspection rate of 3 to 4 vehicles per hour. This rate could be increased by only inspecting one side of the vehicle or finding a scan position which inspects a large portion of the vehicle.

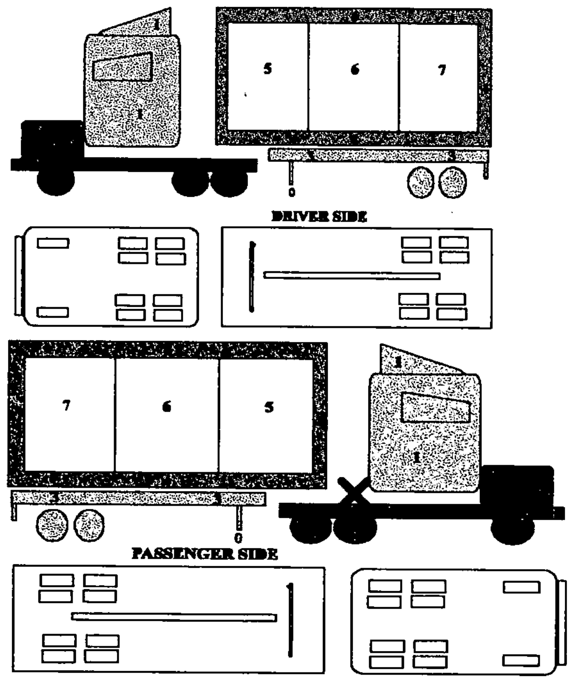

Figure 2 An excerpt from the Red Team form for the documentation of contraband loading on a given vehicle. The Red X illustrates the way that concealment locations

The 552 vehicles were inspected in a thorough, efficient manner. Figure 3 shows the effects of the major variables on the percent of correct inspections achieved over the entire testing period. The data also allows one to investigate the effects that system experience of the observer may have on performance results. The system operators were primarily Arizona National Guard who are part of the Thunder Mountain Evaluation Center [TMEC]. These personnel have had experience conducting contraband inspections of cargo using a small mobile X-ray van. Therefore they had significant experience with X-ray systems and X-ray backscatter images. However, there was not an experience base of using a system for the viewing of whole trucks and their contents. A period of 2 weeks for system familiarization was provided to the operators to give them a chance to adapt to the differences in the images. After this time data collection commenced. Figure 4 below shows that the correct inspection performance changed during the first 10 to 15 days of testing. This indicates that there needs to be a training program for operators to operate complex X-ray equipment such as the MTXR.

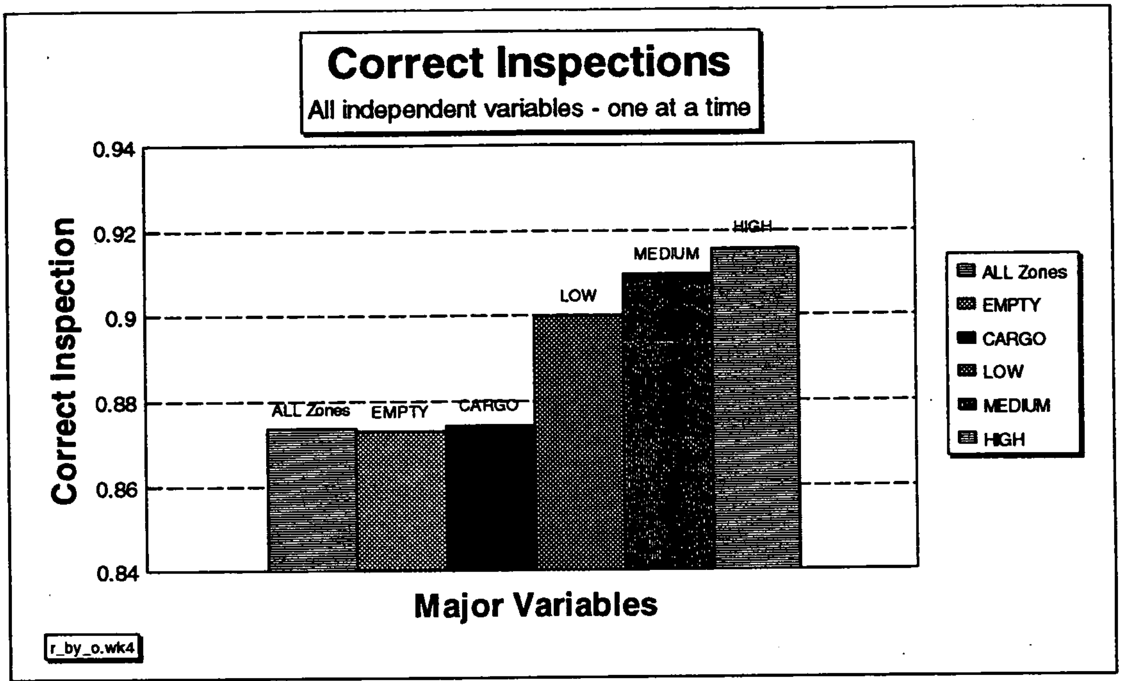

Figure 3 Correct inspections as a function of the major experimental variables

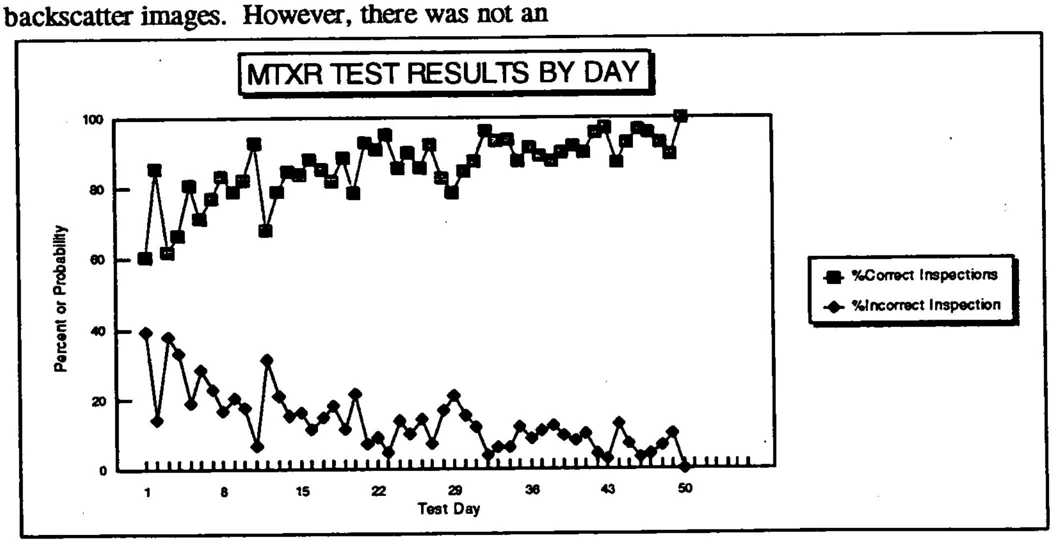

Figure 4 Correct Inspections and Incorrect Inspections as it progressed for each day of the test

3. Stream-of-Commerce Procedures and Results

Eight members of the Thunder Mountain Evaluation Center's (TMEC) Arizona National Guard, and one CSC employee, deployed with the MTXR on 31 May 1996 to the various United States Customs Service (USCS) Ports of Entry (POE) in and around El Paso, Texas. The primary purpose of the deployment was to conduct a limited operational test of the MTXR on a stream-of-commerce under actual field conditions at the POEs. A secondary purpose was to test the road worthiness of the MTXR itself. Although there was an unofficial schedule for each day, the MTXR was also available for special missions at all times; thus, another aspect of the field test was the responsiveness of the equipment and crew to special non-intrusive inspection requests.

Two deployments to the ports of entries in the El Paso, Texas area were made to support stream-of-commerce evaluations of the MTXR at an operational port. These evaluations were done at the invitation of the US Customs Service and were supported by the Red and Blue Team members from TMEC and the Arizona National Guard.

The Arizona National Guard operators were able to drive the vehicle at highway speeds of 60 to 65 MPH without difficulty.

Trucks of various sizes, shapes, and conditions were selected from the stream of trucks entering the Port by the Customs Inspectors assigned to the Team. The MTXR's boom is hydraulically and mechanically operated and is designed so that trucks not exceeding the "normal" maximum height of 13 feet, 6 inches will pass under the boom without hitting it. A few trucks barely exceeding this height caused minor delays in the procedure because they could not be inspected as per the protocol.

The quality of the X-rays obtained from the MTXR was excellent. The operators could easily and readily identify most items commonly found in both the cars and the trucks inspected. When an object was encountered which was not readily identified, either the customs inspectors or the X-ray operator, or both, would look to determine what the object was. This provided instant feedback to the X-ray operator.

Several field expedient measures were developed by the test Team that have been included into future designs. Design improvement suggestions that have come from the evaluations are being used in future prototypes being pursued by the Department of Defense Counterdrug Technology Development Program

4. Summary

The evaluation measured the capabilities of the MTXR to perform X-ray inspections of vehicles in a controlled environment test and in a real Port of Entry. The results indicate performance adequate for use at Ports of Entry by US Customs. It is noted that the effect of operator experience with this system is also an important factor in the use of the system.

The MTXR system was developed as a first prototype system to determine the feasibility of using such a design in an X-ray inspection role. Design upgrades have been proposed for the second prototype now under development. Initial investigations into the integration of an MTXR system was started under the Stream-of-commerce activities.

5. Acknowledgments

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Abstract

The Federal Aviation Administration has been working on methods to screen the contents of bottles for dangerous substances. Numerous bottles containing fluids such as wine, liquor, soap, shampoos, etc., pass through airports each day. Technologies are being developed that enable an operator to test the contents of bottles without the need to either open the bottle or destroy the contents. These devices are relatively small and could be located at the security checkpoint and could thus complement the baggage screening system.

(Paper Not Available at Time of Publication)

15

Communications, Surveillance, and Tracking Methodologies (Session 3B-2)

THE EGMONT SECURE WEB SYSTEM

Leveraging the Internet Infrastructure to Provide Secure International Communication to the Egmont Group

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ABSTRACT

On June 9, 1995, representatives of twenty-four nations and eight international organizations came together at the historic Egmont-Arenberg Palace in Brussels, Belgium, to discuss the specialized anti-money laundering organizations known as "disclosures receiving agencies" or "financial intelligence units (FIUs)." These organizations have been established or are in the process of being created by a number of countries as part of their anti-money laundering efforts----over a dozen such organizations were present at the meeting. Although different in size, structure, and individual responsibilities, all of these organizations----like the Financial Crimes Enforcement Network (FinCEN)----share a common goal of striving to keep criminals from using the legitimate financial system and other economic sectors to profit from their illegal activities- many of which are drug related.

Since this first meeting of FIUs was held at the Egmont-Arenberg Palace in Brussels, it was decided that the gathering should be known as the "Egmont Group." Ultimately, we anticipate that the organizations represented in the Egmont Group will work together to become the first nodes in an expanding international communication network for sharing information on money laundering and financial crime. This Secure Web System will facilitate in the timely exchange of this type of information.

By providing centralized access to information and easier secure communications, the Web Server empowers the Egmont Group to support and coordinate national anti-money laundering efforts on an international level. Furthermore, it is intended to support the long-term efforts of the Egmont Group in establishing and strengthening a global network of Financial Intelligence Units.

This system is accessible only by authorized FIUs and their users and provides top business quality information presented in high performance and easy to use graphic user interface (Web Browser) in multiple languages.

The FinCEN/SAIC team was instrumental in implementing state-of-the-art technology in computer and networking security as well as Web development techniques. New concepts such as digital certificate authentication and dynamic encryption were integrated with one of the best firewall systems in the US market place. Java and database programs were developed in a few days to enhance the systems capabilities. The performance period started in October 1996 and the system was successfully completed, online, and operational on February 19, 1997.

SECTION ONE - Introduction

1.0 General

This document provides the design requirements, design concepts and design specifications for the Egmont Secure Web Server. The design contained in this document is based on the *Egmont Secure Web Operational Requirements Document* and the *Egmont Secure Web Concept Document* delivered under separate covers.

1.1 Scope

This Design Document defines the design for each element of the Egmont Secure Web Server. It contains a mapping of the requirements established in the *Egmont Secure Web Operational Requirements Document* to each functional hardware or software element and then provides the design concept and the design specification to meet the functional requirement. The Egmont Secure Web Server will be delivered to this Design Document.

1.2 Document Structure

The document provides an overview of the Egmont Secure Web Server based on the *Egmont Secure Web Operational Requirements Document* followed by an individual section that defines the design for each functional Web Server element. These sections are:

1.2.1 Section Two - Overview

Section Two provides a summary of the Egmont Secure Web Server operational concept and the specifics for each element of the server architecture. Following the operational concept is a short description of the design for each of the web architecture elements.

1.2.2 Section Three - Web Browser

Section Three covers the Web Browser concepts. No actual design is implemented in the Web Browser except for the addition of SecuRemote client capabilities. It is expected that all Web Browser software will be commercial off-the-shelf.

1.2.3 Section Four - Router

Section Four covers the router which will provide the interface between Internet communications and FinCEN internal communications.

1.2.4 Section Five - Firewall

Section Five covers the firewall. All communications with the Egmont Secure Web Server will be through a firewall. The firewall will be implemented separate from the Web Server, both in hardware and software.

1.2.5 Section Six - Web Server

Section Six covers the various elements implemented within the Web Server. The Egmont Secure Web Server will be built on a commercial, integrated, World-Wide Web software suite. The suite will have e-mail, news and data base access capabilities in addition to the standard web server functions.

1.3 References

1. Science Applications International Corporation, *Orientation Briefing for FinCEN Secure Internet Server Development*, 8 October 1996.
2. *FinCEN Secure Web Operational Requirements Analysis*, 13 November 1996.
3. *Egmont Secure Web System Concept Document, Final*, 6 December 1996.
4. *Egmont Secure Web System Concept Document, As-Built Version 1.0*, 7 March 1997

1.4 TBR/TBD Table

All TBDs and TBRs have been resolved.

SECTION TWO - Concept of Operations

2.0 General

This paragraph covers the general concept of operations for the Egmont Secure Web Server. Greater detail can be found in the *Egmont Secure Web Concept Document* dated 6 December 1996.

2.1 Architecture Overview

The Egmont Secure Web architecture will support Internet access to the server by approved personnel in countries that are members of the Egmont Group. Users will be able to use both the Netscape Navigator and the Microsoft Internet Explorer to access information on the web server. The Egmont Web Server will have features that require users to have Version 3.0 of these web browsers to take full advantage of all its capabilities. The basic architecture for the system is shown in Figure 1.

Users in Egmont member countries will be able to use their personal computers or workstations to connect to the Egmont Web Server through the Internet. It is the responsibility of each user to obtain Internet access from within their country. At FinCEN Headquarters the requested connection will be passed through a standard Internet Protocol (IP) router which will be configured to pass communications only to the firewall. A second router will be used to connect internal FinCEN users through the firewall to the Egmont Server. This will provide the first level of security for the internal FinCEN network. The firewall will receive the connection request, validate the user and pass the request to the Web Server. The firewall will be configured to pass only authorized protocols to only the Web Server. This will provide another level of security for the internal FinCEN network.

2.2 User Access Procedures

The detailed user access procedures are shown in Figure 2. The user will require two items to access the Egmont Secure Web Server. The first is a web browser installed on his/her personal computer or workstation. Although the architecture is being designed and tested using Windows95 and any use of UNIX workstations will require additional testing to insure full support for SecuRemote client software and certificates.

See Figure 2: User Access Procedure

The second item the user will require is the SecuRemote client software and certificates provided by FinCEN. The software and certificate will be required to authenticate the user to the SecuRemote Server that is running on the firewall. Only those requests for access that pass the authentication requests of the SecuRemote Server will be forwarded to the Egmont Web Server.

2.3 Web Page Tree Structure

The first item the user sees will be the Egmont Home Page. The page will form the basic index for server access with the most utilized areas contained in a vertical frame that is always visible to the user and the specific information topics contained in the main, central frame. The basic tree structure for web pages is shown in Figure 3.

The pages presented to the user will have text and graphic information, will allow the user to access reports and other documents and will provide access to data base information. The data base access function will be provided as an integral part of the web server software suite.

2.4 Secure E-Mail

E-mail will be provided for the Egmont Group members through the functionality inherent in the web server software suite. Accounts will be established for authorized personnel and they will be provided standard e-mail addresses on the server. The individual Post Office Protocol (POP) accounts will only be accessible through the web browser after user authentication. The goal of the program is to use SSL to insure security for sending and reading mail. Both Netscape and Microsoft are rapidly moving to provide the capability in their next server releases. However, the Netscape capability may not be available in time for the Initial Operational

Capability. This will require an interim, alternate design which will be coordinated with FinCEN.

See Figure 4: Mail Flow

2.5 News Group Access

A news server will be established as part of the suite of capabilities provided by the Egmont Secure Web Server. The news groups will be for internal Egmont Group support only, and no outside news feeds from Internet groups will be provided.

See Figure 5: News Service

The situation with SSL support for news is the same as that for support for e-mail. SSL is designed to support encryption for all protocols passed through the sockets layer, however Netscape has not implemented this in the news server at this time. Initial access to news groups will be protected using the SecuRemote encryption capabilities.

2.6 Security Overview

Figure 6 provides a view of the overall goal for the security functions that will be provided as part of the infrastructure. Robust security is provided through the use of SecuRemote and SSL encryption for Web page access and SecuRemote encryption for e-mail and news group access..

See Figure 6: Security Functions

2.7 Following Sections

The following sections provide the design solutions to meet the operational concept presented in this section. Each section begins with a list of the operational requirements allocated to the particular architecture element, followed by the design requirements that flow from the operational requirements and the design concept to meet the requirements.

A paragraph is provided in each section for the Design Specification. The individual design specifications will be developed following FinCEN approval of the design concepts.

SECTION THREE - Web Browser Design

3.1 Operational Requirements Allocated to Web Browser

The following requirements allocations are extracted from the *Egmont Secure Web Concept Document.*

3.1.1 Organizational User Requirements

The following Organizational User Requirements are allocated to the Web Browser.

1. The Web Server shall be established and administered by FinCEN

3.1.2 Internet Service Requirements

The following Internet Service Requirements are allocated to the Web Browser.

1. Secure Socket Layer support shall be provided on the Web Server
2. Internet electronic mail capabilities shall be provided on the Web Server
3. News group capabilities shall be provided on the Web Server
4. The Web Server shall provide an FTP capability

3.1.3 Server Information Content Requirements

The following Server Information Content Requirements are allocated to the Web Browser.

1. The capability shall be provided to directly access and display HTML and text information
2. The capability shall be provided to directly access and display fielded POC data base information
3. The capability shall be provided to create displayable files from graphic information
4. The capability shall be provided for users to download documents of any format
5. The capability shall be provided to notify users of long download times
6. The capability shall be provided to notify users of unique viewing program requirements for specific file types

3.1.4 Presentation Requirements

The following Presentation Requirements are allocated to the Web Browser.

1. The capability will be provided to display web pages in different languages based on user selection
2. A "user friendly" index of server information shall be provided and shall be selectable from any web page
3. Web pages shall be supportable by both Netscape and Microsoft Internet Explorer
4. Graphics on web pages shall be provided as thumb nails with the option to download the full image
5. The capability shall be provided to integrate a text search tool with the web server

3.1.5 Security Requirements

The following Security Requirements are allocated to the Web Browser.

1. The capability shall be provided to validate users based on a combination of user and organization authorization before access is allowed to the server
2. The capability shall be provided to encrypt and decrypt transmitted data

3.2 Design Requirements

The design requirements contained in this paragraph have been derived from the operational requirements of Paragraph 3.1. These requirements form the basis for selecting the Web Browsers. Currently both the Netscape Navigator Version 3.0 and the Microsoft Internet Explorer Version 3.0 meet these requirements. However, these requirements will provide the evaluation criteria should a Egmont Secure Web user want to employ a third browser to access the server.

The design requirements are defined below. As is shown in the Requirements Trace Matrix in Appendix A, a single design requirement will often satisfy multiple operational requirements.

1. The Web Browser shall be capable of running under the Windows 95 and the Windows NT operating systems.
2. The Web Browser shall support the following protocols: HTTP, NNTP, SMTP and FTP.
3. The Web Browser shall provide a client for access to news groups.

4. The Web Browser shall provide a client for access to an e-mail server through SMTP and POP3.
5. The Web Browser shall support HTML Version 3.0 with Netscape extensions.
6. The Web Browser shall be Java enabled.
7. The Web Browser shall support language font sets for English and French.
8. The Web Browser shall support Secure Sockets Layer Version 3.0.
9. The Web Browser shall support user authentication through SecuRemote and Certificate technology.

3.3 Design Concept

The design requirements specified above are to guide the selection of appropriate web browsers. Currently both the Netscape Navigator Version 3.0 and the Microsoft Internet Explorer Version 3.0 meet the requirements set. There are other browsers that may meet the requirements, to include the Oracle browser and versions of Mosaic. However, the design concept has been developed to insure that all web pages and other applications (Java, VRML, etc.) are compatible with both Netscape and Microsoft.

3.4 Design Specification

The FinCEN Secure Web user workstation architecture is configured as follows:

1. Windows 95 or Windows NT on an Intel-based personal computer
2. Microsoft Internet Explorer Version 3.01 or above
3. Netscape Version 3.01 or above (except where country encryption laws have disabled the capability to download certificates - initially France)
4. SecuRemote client software provided by FinCEN
5. VeriSign Certificate provided by VeriSign and downloaded from the VeriSign Certificate Server. The VeriSign certificate is then mapped to the Egmont Secure Web Server and the user account is established to insure secure access.

SECTION FOUR - Router Design

4.1 Operational Requirements Allocated to Router

The following requirements allocations are extracted from the *Egmont Secure Web Concept Document.*

4.1.1 Organizational User Requirements

The following Organizational User Requirements are allocated to the Router.

1. The Web Server shall be established and administered by FinCEN
2. The Web Server shall be available for access by members of the Egmont Group.

4.1.2 Security Requirements

The following Security Requirements are allocated to the Router.

1. The capability shall be provided to protect information on the web server from unauthorized access.
2. The capability shall be provided to protect information on the web server from unauthorized modification.
3. The capability shall be provided to control access to the server based on IP address domains.

4.2 Design Requirements

The design requirements contained in this paragraph have been derived from the operational requirements of Paragraph 4.1. These requirements form the basis for selecting the IP Router. The requirements defined below would allow selection of a router from any reputable vendor.

The design requirements are defined below. The tracking of operational requirements to design requirements is contained in the Requirements Trace Matrix in Appendix A.

1. The router shall have the capability to be configured to accept IP packets from only a predefined set of IP address domains.
2. The router shall have the capability to be configured to pass IP packets to only the IP address of the Egmont firewall.
3. The router shall be capable of remote configuration.

4.3 Design Concept

The design concept is to use a standard Cicso 2501 router to provide the communications connectivity between the Internet and the FinCEN Egmont Firewall. The specific router configuration design is discussed below. The design concept below must be analyzed in conjunction with FinCEN since two approaches are feasible. The first is to use the router as the first line of defense and have it drop all packets that can be identified as unwanted. However, this approach reduces the audit capability of the system and makes it more difficult to identify attacks. The second approach is to have the router forward all packets to the firewall where full logging and auditing capabilities exist. The design discussed below assumes that the logging and auditing functions will be available at the router in the near future, so until these are available all packets should be forwarded to the firewall.

The router will be configured to drop connection requests coming from the Internet to its own management ports, including SNMP, TFTP, and proprietary management ports. These requests must be considered hostile penetration attempts aimed at taking control of the router. The knowledge about the occurrence of such attacks will be lost. However, without logging and alerting, there would be no way of knowing when such an attack was taking place.

Phase Two of the Router Design Concept involves the introduction of new IP security filters on the router. These may include:

- Dropping packets from unauthorized source addresses
- Dropping requests for unauthorized services, such as RPC and NFS.

The benefits from adding this type of filtering to the router are two-fold:

- Adds an effective first layer of security ahead of the firewall
- Offloads some of the work of evaluating and rejecting packets from the firewall.

The firewall can then devote more of its resources to more complex tasks such as session encryption. There are two prerequisites for implementing Phase Two:

- Full logging capability for packets rejected by the router
- Integration of the logging and other router security features into the total security system.

It is important for the integration to be in place to provide for the same level of security analysis and intrusion alerting as supplied by the firewall. Firewall-1, the recommended solution for the Egmont Firewall, already supports the editing and uploading of filters and other router configuration information to Cisco and Bay Networks routers. Therefore it is reasonable to expect that future router logging output will also be integrated into the firewall technology.

4.4 Design Specification

To be supplied following FinCEN approval of the design requirements and design concept.

4.4.1 Hardware

One each CISCO 2501 IP Router w/ Optional 8 Mbytes of DRAM Memory
One each CISCO 2541 IP Rotuer

4.4.2 Software

CISCO 2500 Series IOS IP Only Feature Set

4.4.3 Configuration

CISCO 2501 is configured between the Internet CSU/DSU and the Firewall. The CISCO 2514 is configured between the FinCEN internal network and the Firewall. The CISCO 2501 passes packets from the CSU/DSU to the Firewall, only. The CISCO 2514 passes packets from the internal FinCEN network to the Firewall, only. Both routers are configured to route IP only.

SECTION FIVE - Firewall Design

5.1 Operational Requirements Allocated to Firewall

The following requirements allocations are extracted from the *Egmont Secure Web Concept Document.*

5.1.1 Organizational User Requirements

The following Organizational User Requirements are allocated to the Firewall.

1. The Web Server shall be established and administered by FinCEN
2. The Web Server shall be available for access by members of the Egmont Group.

5.1.2 Internet Service Requirements

The following Internet Service Requirements are allocated to the Firewall.

1. Only SSL, HTTPS support shall be provided on the Web Server.
2. Secure Socket Layer support shall be provided on the Web Server

5.1.3 Security Requirements

The following Security Requirements are allocated to the Firewall.

1. The capability shall be provided to protect information on the web server from unauthorized access
2. The capability shall be provided to protect information on the web server from unauthorized modification
3. The capability shall be provided to control access to information on the server based on a combination of user and organization authorization
4. The capability shall be provided to restrict users to specific information domains based on a combination of user and organization authorization
5. The capability shall be provided to control a users ability to read and write data on the server based on a combination of user and organization authorization
6. The capability shall be provided to validate users based on a combination of user and organization authorization before access is allowed to the server
7. The capability shall be provided to control access to the server based on IP address domains
8. The capability shall be provided to monitor and audit web pages and provide detailed audit trails

5.2 Design Requirements

The design requirements contained in this paragraph have been derived from the operational requirements of Paragraph 5.1. These requirements form the basis for selecting the Internet Firewall hardware and software.

The design requirements are defined below. As is shown in the Requirements Trace Matrix in Appendix A, a single design requirement will often satisfy multiple operational requirements.

1. The firewall shall be able to accept connection requests from only a predefined set of IP domains and reject all others.
2. The firewall shall be able to direct protocol packets to the Egmont Web Server IP address only.
3. The firewall shall be able to accept only requests for HTTPS, NNTP, SMTP and POP3 protocol based services and reject all others.
4. The firewall shall be able to host the SecuRemote Access Control Module (ACM) software and accept only requests that are authorized by the ACM.
5. The firewall shall be able to protect against IP spoofing attacks.
6. The firewall shall be able to monitor and log all network traffic based on administrator input. This capability shall include monitoring source and destination addresses, data and time of access attempts, protocol used and action carried out by the firewall.
7. The firewall shall be able to make routing decisions based on applications layer information contained in the data packets.
8. The firewall shall be capable of installation on a SUN SPARC workstation under the Solaris 2.5 operating system.
9. The firewall shall be capable of supporting a minimum of thirty (30) simultaneous access requests.

10. The firewall shall have the capability of being upgraded to support encrypted virtual private networks.

5.3 Design Concept

The firewall is the primary location for the establishment and enforcement of network security policy on the Egmont Secure Web. Secondary locations are on the Web server and the router. In order to meet the security requirements outlined above, and to protect the security of the Egmont Web in general, we make the following design recommendations:

- No devices should reside on the link between the firewall and the router
- All traffic to and from the Web server should pass through the firewall
- Any network connection to FinCEN should be made at the firewall, not the router
- The Internet connection must be monitored for signs of an attack

The reason for not placing any devices outside the firewall is that they are unprotected. Such devices are subject to being compromised and used as network sniffing devices for the benefit of intruders. Since they are situated to intercept all traffic going in or out of the system, they make very good sniffers. Even network hubs with RMON capability are candidates for misuse in this situation. The network should be configured straight through from the router to the firewall. That connection on the firewall is considered the firewall's "outside interface" with respect to the Internet. The Web server side is the "inside interface."

In order to maintain the security policy and audit trail, all traffic involving the Web server should pass through the firewall security mechanism. The firewall both enforces the security policy and keeps log files of network activity. For the same reason, no network connections to FinCEN should be made to additional interfaces on the Egmont Web Server. This would bypass the primary security layer and audit mechanism.

In the event an internal network connection to FinCEN is desired for administration purposes, it should be made at the firewall only. The firewall can then be configured to also protect FinCEN in the event the Egmont server is compromised. Similarly, an internal connection to FinCEN at the router would weaken the router's security and expose FinCEN to a new Internet entry point. It would also require opening holes in the firewall's outside interface security to allow administrative entry to the Egmont equipment.

In order to protect the integrity of the Egmont Web system, we believe it is necessary to actively log and monitor unauthorized access attempts. It is no longer considered adequate security to simply bar the front door. One must know if an intruder is outside the door and what tools he is using to attempt entry. Routers can make excellent front doors because they are simple and dependable. However, most current router operating systems to not allow for any logging information regarding filtered packets.

For these reasons, the router will initially be configured for minimal IP packet filtering to allow the intrusion detection features of the firewall to operate effectively. The router filters used are mainly to protect the router itself and are described in the router design concept.

The firewall will be configured according to the following design guidelines:

- Reject IP spoofing. Packets arriving at the outside interface with source addresses belonging to the inside network are illegitimate and should be dropped. These are often from intruders hoping to gain unauthorized privileges by claiming to be from the inside, or trusted network. In any case, the firewall will not grant privileges to the outside based solely on IP address.
- Allow only authorized IP services to and from the Web Server. These include HTTP(S), SMTP, NNTP, and outbound DNS.
- Hide the real IP address of the Web Server. This may be done either by address translation or by application proxy. The real IP address of the Web Server may be a private network (RFC 1918) address, and not an InterNIC registered address.
- Intercept incoming requests for authorized services and demand user authentication before passing the request to the Web Server.

- Run a server process on the firewall for the SecuRemote Access Control Module (ACM) to enable one-time passwords for user authentication.
- Provide capability to encrypt all authorized remote application sessions with SecurRemote for virtual private networking and SSL for application level encryption.
- Log all rejected packets according to the severity level defined by the security policy. Make the log files available to the system administrator and the security officer in readable format.
- Alert required system personnel via console messages and E-mail about pre-defined security events. Use a flexible configuration to allow different types of alerts to go to different personnel.

The design goal of the firewall is to provide the required level of security in the most transparent way possible. Wherever possible, user interaction with the firewall will be limited to providing a User ID and a SecuRemote password. The user may also be involved in choosing the type and level of encryption, depending on the sensitivity of the transaction the user wants to perform.

5.4 Design Specification

The Firewall specification consists of both the hardware and software configured as the FinCEN Secure Web Firewall.

5.4.1 Firewall Hardware

The firewall hardware consists of the following items:

The Sun Sparc 5 is fitted with 96 Megabytes of RAM, a standard internal 2 Gigabyte hard drive, one 10/100BaseT autosensing Ethernet S-bus card (hme0), and one 10BaseT Ethernet S-bus card (le2). There are additional hardware specifications, but these are most relevant to the operation of the firewall.

5.4.2 Firewall Software

The firewall software consists of the following items:

5.4.2.1 Operating System

The Sun Sparc 5 is loaded with the Solaris 2.5.1 operating system. All of the Sun recommended patches for 2.5.1 are loaded. The additional security patches not included in the recommended patch list were reviewed and determined to be not relevant to this installation. Two subsequent CERT Advisories pertaining to Solaris 2.5.1 were followed up with their recommended workarounds and patches.

The Common Desktop Environment (CDE) is NOT loaded. This is for 2 reasons: 1) The Firewall-1 software is written for Open Windows (Open Look), not CDE (Motif), and 2) The CDE uses a lot of additional system resources, which increases not only the system load but the number of unknown security weaknesses as well. In any case, the firewall is not a user environment and so does not benefit from CDE.

5.4.2.2 File System

The internal 2 Gigabyte hard disk is divided into three partitions:

/	1299 MB
/var	500 MB
/swap	128 MB

This allows maximum flexibility for loading software while keeping one finite partition (/var) for logging and spool files to keep them from using all available space. This is necessary to prevent certain denial of service attacks. For the applications running and with 96 MB of memory available, 128 MB of swap space is more than enough, and 2xRAM is not needed.

5.4.2.3 User Accounts

The hostname of the Sparc 5 is "XX." There are two user accounts on the system, root and "XXXX." It is common practice NOT to create any more user accounts on a firewall or Bastion host. This limits the number of entry points for an intruder. In theory, the XXXX account is for network administrators to log into to check machine status, log files, etc.

In practice, engineers have been sitting directly at the console and logging in as root. This makes it easier to use the GUI application controls. The discipline is to engage the password protected screen lock whenever leaving the machine. This allows the log viewer to stay active behind the screen lock. Currently, the root password and the XXXX password are the same.

There are other system accounts present; these do not include login shells.

5.4.2.4 Network Services

The following network services have been modified or turned off for the purposes of firewall security on *io*.

1. *Sendmail* does not run in daemon mode. This means it can process outgoing mail like security alerts to designated FinCEN personnel, but will not receive incoming mail. Authorized incoming mail is passed directly to the Egmont Secure Web Server.
2. *Telnet* and *ftp* daemons are replaced with Firewall-1 authenticating daemons.
3. All non-essential services in /etc/inet/inetd.conf are turned off. This includes all of the Berkeley UNIX services.

5.4.2.5 Network Interfaces

All network interfaces on io are configured with a netmask of 255.255.255.XXX. The Internet address assignment to egmont.org consists of 64 host addresses, or ¼ of a Class C address. Hence the non-standard netmask. According to Sun, Solaris 2.5 does not support the use of different netmasks on different interfaces. Therefore we use .XXX on all. Support for variable length subnet masks is targeted for Solaris 2.6.

5.4.3 Configuration

The configuration of the Firewall is as follows:

5.4.3.1 Application Software

Three separate items from the Solstice Firewall-1 version 2.1 inventory were purchased and loaded on io.

1. Light Security Center (smallest version, max. 50 users)
2. Authenticating Inspection Module (proxy services)
3. VPN Encryption Module (for SecuRemote clients)

The 50 user restriction refers to internal users. That means any IP node connected through the DMZ or Internal interfaces defined below. Since the internal network from the perspective of Firewall-1 now includes all of FinCEN's network, care must be taken not to allow more than 49 FinCEN nodes to reach XX. The server www.xxxx.xxx counts as the first internal node. The Light Security Center is supposed to merely cap its list of authorized users at the first 50 IP addresses it sees on internal interfaces. Only one external interface is allowed. In practice, the behavior of the license scheme can be unpredictable when 50 users are exceeded.

5.4.3.2 Network Interfaces

The available Ethernet interfaces have been assigned in the following way:

1. Internal 10BaseT (le0) = External network (UUnet, Internet)
2. S-bus 10/100BaseT (hme0) = DMZ network (www.egmont.org)
3. S-bus 10BaseT (le2) = Internal network (xxxx.xxx)

5.4.3.3 Network Objects Defined

1. Gateways (firewalled hosts)
   - xx

   The definition for io includes *ioEncryptDomain* and interfaces le0 and hme0, but NOT le2. Nevertheless, the rules are enforced on le2. When le2 is added, all traffic through le2 is blocked.
2. Groups
   - xxEncryptDomain

   The set of hosts for which the gateway will perform encryption. Contains only io. The IP addresses in this list are given out to anyone with the SecuRemote client who contacts egmont.org. Thus we do not reveal our internal (private) IP addresses even to SecuRemote. The default is to reveal them.
   - clientnets

   Contains all network objects representing IP networks where authorized Egmont users have source addresses.
   - EgmontUsers

   Includes objects for each authorized Egmont user.
   - transnet

Encompasses the translating networks around the firewall. Includes the external (xxxx.xxx) network and the private (DMZ) non-routable network which must be translated to egmont.org IP addresses. This group is mainly used for the IP spoof checks.

3. Networks, Routers, Hosts, Domains

There are many more objects defined in these categories that are self-explanatory. The above objects are key to the configuration.

5.4.3.4 SNMP Configuration

Firewall-1 opens two SNMP daemons by default. One on port 161 (standard) and another on port 260 (FW-1). The server on port 161 handles all normal SNMP requests, such as system status. The server on port 260 runs the Firewall-1 MIB which is not supported by standard SNMP. This MIB includes the status of the Firewall-1 application. Thus, a network management system with hooks written for the FW-1 MIB could be used to monitor the health of the firewall.

The default community strings (public and private) have been changed to protect the SNMP information as follows (case sensitive):

Read Only = xxxxx

Read/Write = xxxxxxx

These may be changed at any time in the file /etc/fw/conf/snmp.C.

5.4.3.5 Address Translation

The Egmont.org system uses network address translation (NAT) primarily for security to hide the actual system address of the Egmont Web Server. Further, this real address is an RFC 1918 private address which is not routable on the Internet. This helps to ensure that all communication with the Egmont Web Server must pass through the firewall application software. Even the firewall Sparc 5, without the firewall software (including NAT) running, cannot complete the connection from the advertised address to the real address.

The resulting address configuration has three subnets (CIDR notation):

1. xxx.xxx.xxx.xx/xx Internet subnet issued by UUnet
2. xxx.xxx.x.x/xx DMZ subnet from RFC 1918 Class C range
3. xxx.xxx.x.x/xx FinCEN subnet from RFC 1918

The /26 in CIDR notation refers to a 26 contiguous bit netmask which results in 64 addresses beginning with the listed address. The FinCEN subnet serves only as a link to a FinCEN router and has no hosts on it.

Egmont members on the Internet use the public address xxx.xxx.xxx.xx to reach the Egmont Secure Web. The firewall on xx responds to this address and translates it to xxx.xxx.x.x which is the real (private) address of the Web server. FinCEN personnel reaching the Egmont Web server from the FinCEN network also use the public address. However, because intervening firewalls at FinCEN and Treasury will not pass specialized security protocols necessary for the Egmont system, the FinCEN router must have a static route configured to take the traffic directly to the Egmont system. This static route directs traffic for xxx.xxx.xxx.xx to xxx.xxx.x.x on xx. The route must be static because the io firewall does not run RIP or OSPF for security reasons.

The address translation table for this service looks somewhat like this:

From Original To Original Method
First Translated
Address Address
Address
xxx.xxx.x.x xxx.xxx.x.x
FWXT_SRC_STATIC xxx.xxx.xxx.xx
xxx.xxx.xxx.xx xxx.xxx.xxx.xx
FWXT_DST_STATIC xxx.xxx.x.x

The first two columns define the range of addresses to translate. In this case there is only one. This table can be viewed and changed by running the program */etc/fw/bin/xxxxxxx.*

In order for the NAT to work, special entries are required in the io firewall routing and ARP tables:

route add xxx.xxx.xxx.xx
xxx.xxx.x.x x
arp -s xxx.xxx.xxx.xx x::xx:xx:xx:
pub

The route command tells the firewall that packets arriving for the public address of the Web server should be sent to the next hop at the private address of the Web server. The address is not translated until it is picked up by the Firewall-1 NAT utility. Thus if the Firewall-1 were down but the Sparc station was still working, packets might go straight through. However, the Web server does not know that packets sent to xxx.xxx.xxx.xx are meant for it, so it ignores them.

The arp command tells the upstream router on the xxx.xxx.xxx.xx subnet (the UUnet router) to send packets addressed to xxx.xxx.xxx.xx to the MAC address of io. This is actually the first step of starting the whole NAT process.

One more similar command is needed to allow io to reply correctly to FinCEN users and not send the replies out to the Internet where they get lost or blocked:

route add xxx.xxx.x.x
xxx.xxx.x.xx x

This tells io that the FinCEN Class B network is via the FinCEN router on the le2 private address subnet. The above commands are contained in the system startup script */etc/init.d/xxxxxx* which is included in this report in item III.B.

5.4.3.6 Encryption

Configuring the encryption on io is actually one of the simpler parts of the installation. Once the VPN module has been installed, (see section II.A) all that is required is to:

1. Add the group *ioEncryptDomain* to the Properties window for Object io under Encryption Domain
2. Define an object for each authorized user and choose a (secure) password
3. Add a rule to the rule base to require *Client Encryption* for Egmont users

The first step prepares Firewall-1 to perform encryption. A stated limitation with SecuRemote in version 2.1, documented in the Solstice Firewall-1 Administrator's Guide on page 141, is that by default, private internal addresses are revealed to anyone with SecuRemote software. This software is freely available on the Internet. We overcame this undesirable characteristic by limiting the Encryption Domain to io only. The only side effect is that users must first navigate to io.egmont.org to establish their encryption session. After that it is transparent.

In step three, Client Encryption is synonymous with SecuRemote. Only an authorized user with SecuRemote can pass a Client Encryption rule.

5.4.3.7 Egmont User Passwords

The original design for the Egmont Secure Web called for Security Dynamics SecurID "one-time" passwords. During the process of evaluating the SecuRemote client, it was discovered that the client application did not support the use of SecurID passwords. A call directly to the manufacturer CheckPoint (Sun resells Firewall-1) revealed no plans to include SecurID in upcoming releases of the SecuRemote client. It was then determined that the combination of SecuRemote, digital certificates from VeriSign, SSL for Web traffic, and static passwords offered a better overall security package than SecurID and SSL alone. Without SecuRemote the present system also could not offer encryption for E-mail, an important feature.

5.4.3.8 Security Policy and Rules

The security policy and rule base installed on io is subject to change as needed as new users and services are added. Thus our discussion here is limited to general terms, and the exact rulebase(s) are not reprinted. We do include for reference a copy of the FW-1 Inspect language script for one of the current rulebases in section III.C.

Currently, one set of rules is used for normal operation and another during the enrollment of new users. The latter allows FW-1 administrative protocols and pings from the user's site to aid in establishing their first connection to xxxx.xxx

In general terms, the Control Properties/Security Policy window includes:

1. No FTP
2. No Real-Audio
3. No VDOLive
4. No RIP
5. No RPC
6. No FW-1 Control Connections
7. No Domain UDP or TCP

Item six is not needed with only one FW-1 machine. Item seven is handled by the rule base with specific rules. Since the Internet DNS for

egmont.org is maintained at UUnet, there is no need for io to accept any DNS queries from the Internet.
In general terms, the current rule base includes the following:

(Omitted)

The rules are always read in order from top to bottom. Thus, the last rule is a catch-all any rejects any unapproved incoming traffic (so long as the Security Policy window above does not allow it).

SECTION SIX - Web Server Design

6.1 Operational Requirements Allocated to Web Server

The following requirements allocations are extracted from the *Egmont Secure Web Concept Document.*

6.1.1 Organizational User Requirements

The following Organizational User Requirements are allocated to the Web Server.

1. The Web Server shall be established and administered by FinCEN
2. The Web Server shall be available for access by members of the Egmont Group.
3. Each Egmont Group member will be responsible for selecting the individuals who have access to the Web Server from that nation.

6.1.2 Internet Service Requirements

The following Internet Service Requirements are allocated to the Web Server.

1. Secure Socket Layer support shall be provided on the Web Server
2. Internet electronic mail capabilities shall be provided on the Web Server
3. News group capabilities shall be provided on the Web Server
4. Direct POC data base access shall be provided on the Web Server
5. The capability to upload web pages from external locations shall be provided with prescreening and permission
6. The Web Server shall provide an FTP capability

6.1.3 Server Information Content Requirements

The following Server Information Content Requirements are allocated to the Web Server.

1. The capability shall be provided to create HTML pages through a graphic user interface.
2. The capability shall be provided to convert text and Microsoft Word documents to HTML.
3. The capability shall be provided to directly access and display HTML and text information
4. The capability shall be provided to directly access and display fielded POC data base information
5. The capability shall be provided to create displayable files from graphic information
6. The capability shall be provided for users to download documents of any format
7. The capability shall be provided to notify users of long download times
8. The capability shall be provided to notify users of unique viewing program requirements for specific file types

6.1.4 Presentation Requirements

The following Presentation Requirements are allocated to the Web Server.

1. The capability will be provided to display web pages in different languages based on user selection
2. A "user friendly" index of server information shall be provided and shall be selectable from any web page
3. Web pages shall be supportable by both Netscape and Microsoft Internet Explorer
4. Graphics on web pages shall be provided as thumb nails with the option to download the full image
5. The capability shall be provided to integrate a text search tool with the web server

6.1.5 Security Requirements

The following Security Requirements are allocated to the Web Server.

1. The capability shall be provided to protect information on the web server from unauthorized access
2. The capability shall be provided to protect information on the web server from unauthorized modification
3. The capability shall be provided to control access to information on the server based on a combination of user and organization authorization
4. The capability shall be provided to restrict users to specific information domains based on a combination of user and organization authorization

5. The capability shall be provided to control a users ability to read and write data on the server based on a combination of user and organization authorization
6. The capability shall be provided to monitor and audit web pages and provide detailed audit trails

6.2 Design Requirements

The design requirements contained in this paragraph have been derived from the operational requirements of Paragraph 6.1. These requirements form the basis for selecting the Web Server software suite and hardware.

The design requirements are defined below. As is shown in the Requirements Trace Matrix in Appendix A, a single design requirement will often satisfy multiple operational requirements.

1. The Web Server shall be configurable on a SUN Microsystems Ultra SPARC series hardware platform running Solaris 2.5 or above.
2. The Web Server shall be capable of full administration through a graphic user interface (GUI).
3. The Web Server shall be configured with an integrated software suite that provides standard Web access services, e-mail services, news services and data base access, as a minimum.
4. The Web Server shall support SSL Version 3.0.
5. The Web Server shall support HTTP, NNTP, SMTP and FTP as a minimum.
6. The Web Server shall support Java, Java Script and CGI programming.
7. The Web Server shall provide a GUI for the generation of HTML pages.
8. The Web Server shall provide a GUI based support for the conversion of graphic file formats to formats that can be directly displayed in HTML pages.
9. The Web Server shall provide GUI support for automatic display of HTML page structures and linkages.
10. The Web Server shall provide a separate download area for remote users to submit HTML pages and other information for inclusion as Web accessible information.
11. The Web Server shall provide a user friendly access method for HTML page access that implements a straight forward page-to-page flow with direct access to important information areas directly from any HTML page.
12. The Web Server shall provide HTML pages that can be displayed in both Netscape Navigator Version 3.0 and Microsoft Internet Explorer Version 3.0.
13. The Web Server shall provide the capability to restrict the ability to modify any information on the server to the system administrator.
14. The Web Server shall provide the capability to restrict the ability to access any information on the server to those users that have been authenticated by the Firewall.
15. The Web Server shall provide the capability to isolate data in all databases so access can only be by server initiated calls.
16. The Web Server shall provide the capability to control access to e-mail mailboxes and news groups based on separate User Password and User ID verification.
17. The Web Server shall provide the ability to conduct a text based search of all information on the server.
18. The Web Server shall provide a logging capability to identify all information access on the server. This accesses to be logged will be configurable by the system administrator.
19. The Web Server shall provide access to document archives and storage areas directly from HTML pages.
20. The Web Server shall provide access to field data in data bases directly from HTML pages.
21. The Web Server shall provide a method for communications from users to the Egmont System Administrator directly from HTML pages.
22. The Web Server shall provide fonts for English and French.

6.3 Design Concept

The main focus of the design concept is to use an integrated commercial off-the-shelf software suite to provide the full set of required functionality. This includes the functionality for the basic Web Server, and additional functionality for the E-Mail Server and the News Server. The two main options that meet the requirements are the Microsoft Internet Information Server and the Netscape SuiteSpot Server software. SAIC's preliminary analysis of the requirements, and discussions with FinCEN concerning their preferred hardware/software platforms, let to the decision to base the design concept on Netscape SuiteSpot applications.

6.3.1 Server Functionality

To meet expected growth requirements Netscape SuiteSpot will be hosted on a SUN Microsystems Ultra SPARC 2 server with 256 Mbytes of memory. A hard disk array will be provided that is capable of growth to at least 96 Gbytes of on line storage.

The Netscape SuiteSpot components consist of the following:

1. Netscape Enterprise Serverproviding a secure web server for creating, managing and distributing information and running live, online applications.
2. Netscape Mail Serverto support client-server messaging through combined intranet and Internet mail without gateways.
3. Netscape News Serverto provide secure public and private discussion groups for access within a local area network or across the Internet.
4. Netscape Catalog Serverfor creating, maintaining, and searching an up-to-date catalog for Internet and intranet resources such as documents, email addresses, and file archives.
5. Netscape Directory Services Serverfor providing DNS functionality.
6. Netscape LiveWire Proproviding a visual development environment with built-in database connectivity for building live, online applications. It includes the Informix online workgroup database and provides interfaces to Oracle, Sybase, and Illustra and ODBC support for most other data bases.

Although not all applications are required for the initial operational capability, they provide an effective growth path as FinCEN gains experience with the server architecture and new requirements are generated. In addition, Netscape is on the leading edge in providing enhanced security solutions for the SuiteSpot product.

LiveWire Pro provides a number of operations and management functions that will make administration of the Egmont server substantially easier. These functions include visual site management to view the organization of the entire web site; image conversion support for BMP, WMF, TIFF, PICT and PCX files; document conversion support for Microsoft Word, WordPerfect, FrameMaker and rich text formatted documents; automatic link reorganizations to manage links to documents and files that are moved within the site; and a JavaScript compiler to support Java programming within HTML pages.

The Egmont Web Server will be configured with a number of separate information areas. These separate areas will allow FinCEN to implement separate security controls for each area and will provide improved efficiency in system administration applications. The separate areas will include:

1. The HTML page area where all HTML pages will be maintained. As new pages are created and existing pages modified the administration of these page swill be simplified by using a single directory. This directory will be set as read only by the web access applications and read/write for the System Administrator.
2. The data base area where the POC fielded data will be maintained. Access through this data will be read only from HTML pages and read/write for the System Administrator.
3. A document archive area where documents available for download to the Egmont members will be maintained. This area will be read only for Egmont members and read/write by the System Administrator.

An Egmont Mail Server will be established with mailboxes for Egmont members who are nominated by their respective countries and approved by FinCEN. Each member will have a separate UserID/Password combination for access to his/her mailbox.

An Egmont News Server will be established with Egmont-only news groups. The news server will have the capability of controlling access to news groups by UserID and Password, if required.

The standard Netscape text search tool provided in SuiteSpot will be used for searching the Egmont information directories. Search capabilities will be provided directly from a text search HTML page.

6.3.2 Server Security Functionality

In the proposed design concept for the initial implementation of the Egmont Secure Web, the Web Server contains the secondary security mechanisms for the system. The firewall is the primary security vehicle. The router initially performs only a minor role in providing security. As the secondary security system, the Web Server will perform the following vital functions:

- Maintain individual user accounts and storage space for POP E-mail.
- Protect itself from network-based attacks on all well-known services.
- Log all access, access attempts, file uploads, and system modifications.
- Maintain a security database of certificates for all access.
- Scan itself periodically and report any changes or additions to critical file list.

The Server will be configured in the manner of an Internet Bastion Host to resist network based attacks. This means that default network services such as NFS and NIS, if not used will be turned off.

6.4 Design Specification

The FinCEN Secure Web Server design specifications defines of the hardware and software installed and configured as the FinCEN Secure Web Server.

6.4.1 Web Server Hardware

The Web Server hardware consists of the following items:

1. Sun Microsystems Ultra 2 Server
2. Memory upgrade to 256 MBytes
3. CD-ROM Drive
4. RAID hard disk controller cage
5. 12 GBytes of disk storage (initially provided as 6 each 2 Gbyte Syquest drives)

6.4.2 Web Server Software

The Web Server software consists of the following items:

1. Sun Microsystems Solaris 2.5.1 operating system
2. Netscape Suite Spot Server Version 2.0 consisting of:
   - Netscape Enterprise Server
   - Netscape Mail Server
   - Netscape News Server
   - Netscape Catalog Server
   - Netscape Directory Services Server
   - Netscape LiveWire Pro

APPENDIX A - Requirements Verification and Trace Matrix

Table A-1: Web Browser Requirements Trace Matrix

Design Operations	3.2-1	3.2-1	3.2-3	3.2-4	3.2-5	3.2-6	3.2-7	3.2-8	3.2-9
3.1.1-1	x								
3.1.2-1					x			x	
3.1.2-2		x		x					
3.1.2-3		x	x						
3.1.2-4		x							
3.1.3-1					x				
3.1.3-2					x	x			
3.1.3-3					x	x			
3.1.3-4					x	x	x		
3.1.3-5					x	x			
3.1.3-6					x	x			
3.1.4-1					x		x		
3.1.4-2					x				
3.1.4-3	x				x	x	x		
3.1.4-4	x				x	x			
3.1.4-5					x				
3.1.5-1					x	x			x
3.1.5-2					x			x	

Table A-2: Router Requirements Trace Matrix

Design Operations	4.2-1	4.2-1	4.2-3
4.1.1-1			x
4.1.1-2	x		
4.1.2-1	x	x	
4.1.2-2	x	x	
4.1.2-3	x		

Table A-3: Firewall Requirements Trace Matrix

Design / Operations	5.2-1	5.2-2	5.2-3	5.2-4	5.2-5	5.2-6	5.2-7	5.2-8	5.2-9	5.2-10	5.2-11
5.1.1-1									x	x	
5.1.1-2	x			x							x
5.1.2-1			x					x			
5.1.2-2			x					x			
5.1.3-1	x	x		x	x	x					x
5.1.3-2	x	x		x	x	x					x
5.1.3-3	x	x		x			x				x
5.1.3-4	x	x		x			x				x
5.1.3-5	x	x		x			x				x
5.1.3-6	x	x		x							x
5.1.3-7	x	x		x							x
5.1.3-8						x					

Table A-4: Web Server Requirements Trace Matrix

Design Operations	6.2-1	6.2-2	6.2-3	6.2-4	6.2-5	6.2-6	6.2-7	6.2-8	6.2-9	6.2-10	6.2-11
6.1.1-1	x	x									
6.1.1-2	x	x									
6.1.1-3											
6.1.2-1			x		x						
6.1.2-2				x							
6.1.2-3			x		x						
6.1.2-4			x		x						
6.1.2-5						x					
6.1.2-6					x					x	
6.1.2-7		x			x						
6.1.3-1							x		x		
6.1.3-2								x			
6.1.3-3											
6.1.3-4							x				
6.1.3-5								x			
6.1.3-6										x	
6.1.3-7											
6.1.3-8											
6.1.4-1											
6.1.4-2											x
6.1.4-3											
6.1.4-4								x			
6.1.4-5											
6.1.5-1				x							
6.1.5-2				x							
6.1.5-3				x							
6.1.5-4											
6.1.5-5											
6.1.5-6											

Table A-4: Web Server Requirements Trace Matrix (Cont)

Design Operations	6.2-12	6.2-13	6.2-14	6.2-15	6.2-16	6.2-17	6.2-18	6.2-19	6.2-20	6.2-21	6.2-22
6.1.1-1											
6.1.1-2										x	
6.1.1-3										x	
6.1.2-1											
6.1.2-2											
6.1.2-3					x						
6.1.2-4					x						
6.1.2-5									x		
6.1.2-6											
6.1.2-7											
6.1.3-1								x			
6.1.3-2											
6.1.3-3	x							x			
6.1.3-4	x										
6.1.3-5											
6.1.3-6											
6.1.3-7	x										
6.1.3-8	x										
6.1.4-1											x
6.1.4-2	x										
6.1.4-3	x										
6.1.4-4	x										
6.1.4-5						x					
6.1.5-1		x		x							
6.1.5-2		x		x							
6.1.5-3		x	x								
6.1.5-4			x								
6.1.5-5		x	x								
6.1.5-6							x				

Figure 1: Egmont Web Server Architecture

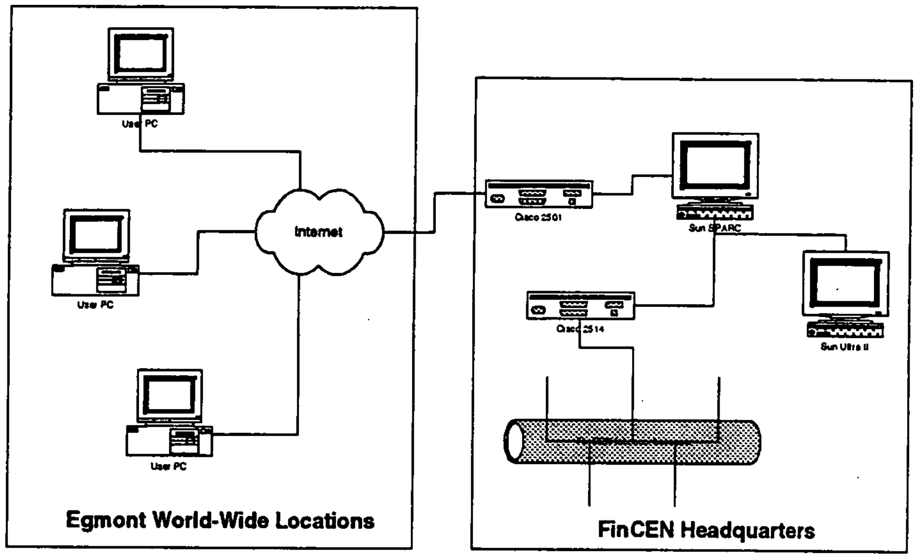


Figure 2: User Access Procedure

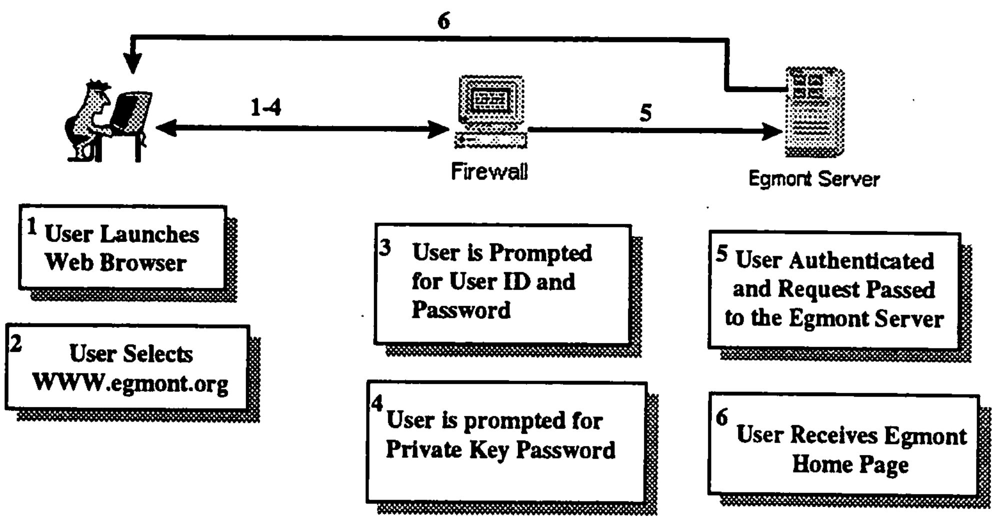


Figure 3: Web Page Structure

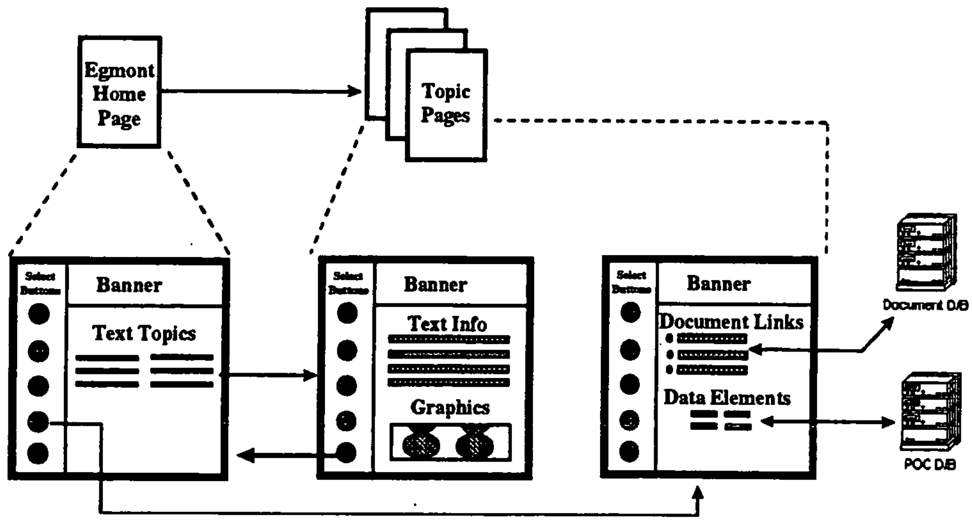


Figure 4: Mail Flow

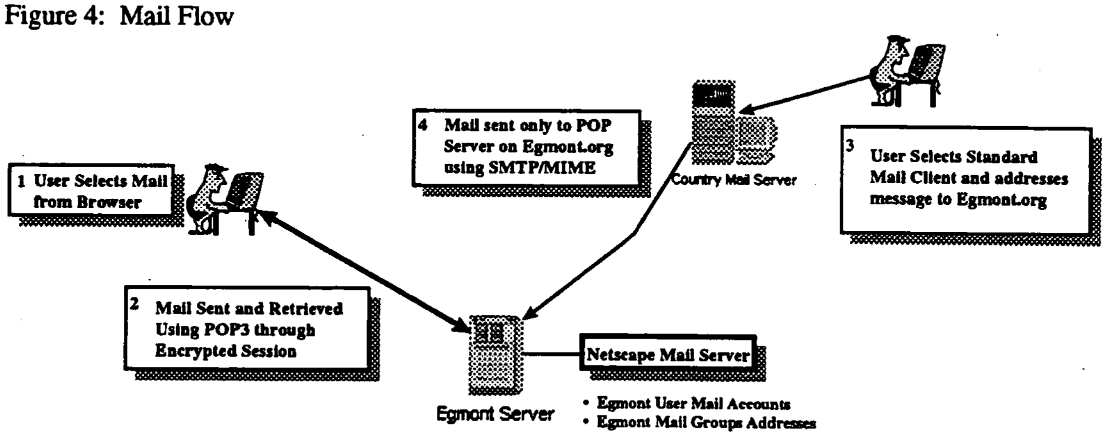


Figure 5: News Service

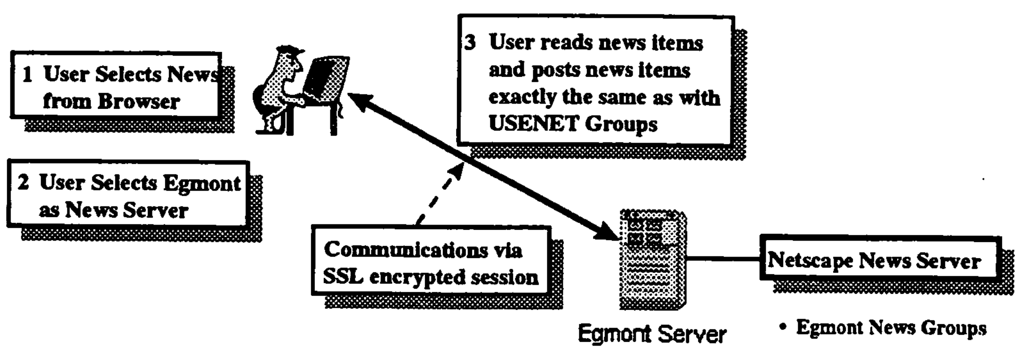
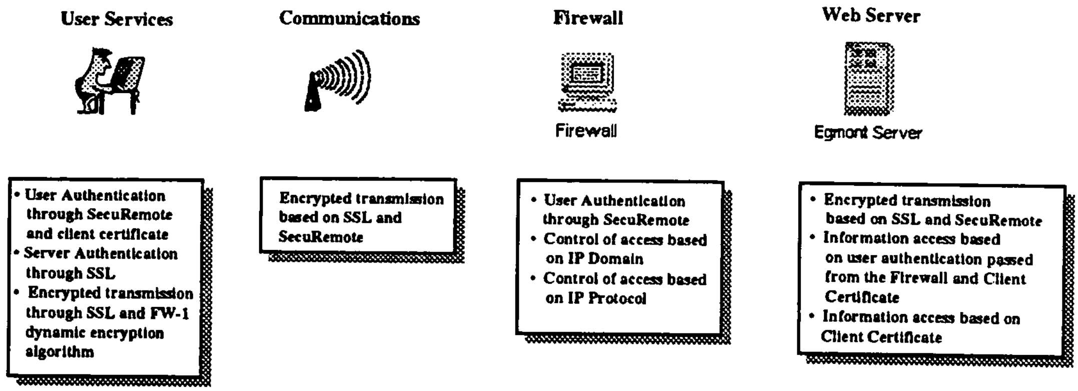


Figure 6: Security Functions



GLADYS

Information Technology for Communications Traffic Analysis

Fred J. Rayano, John R. Schmid, A. E. Lancaster, Jr.

Presented at 1997 ONDCP International Symposium
Chicago IL, 21 Aug 97

GLADYS: Background

- In Summer, 1993, the OCTF/NYS requested ONDCP/CTAC technological assistance

- Illicit drug distribution rings were making extensive - and effective - use of public communications systems
  - Cloned cellular telephones calling wireline numbers and pagers are a common means to communicate
  - Reading the reports of cloned telephones, OCTF overwhelmed with the frequency and quantity of the data available

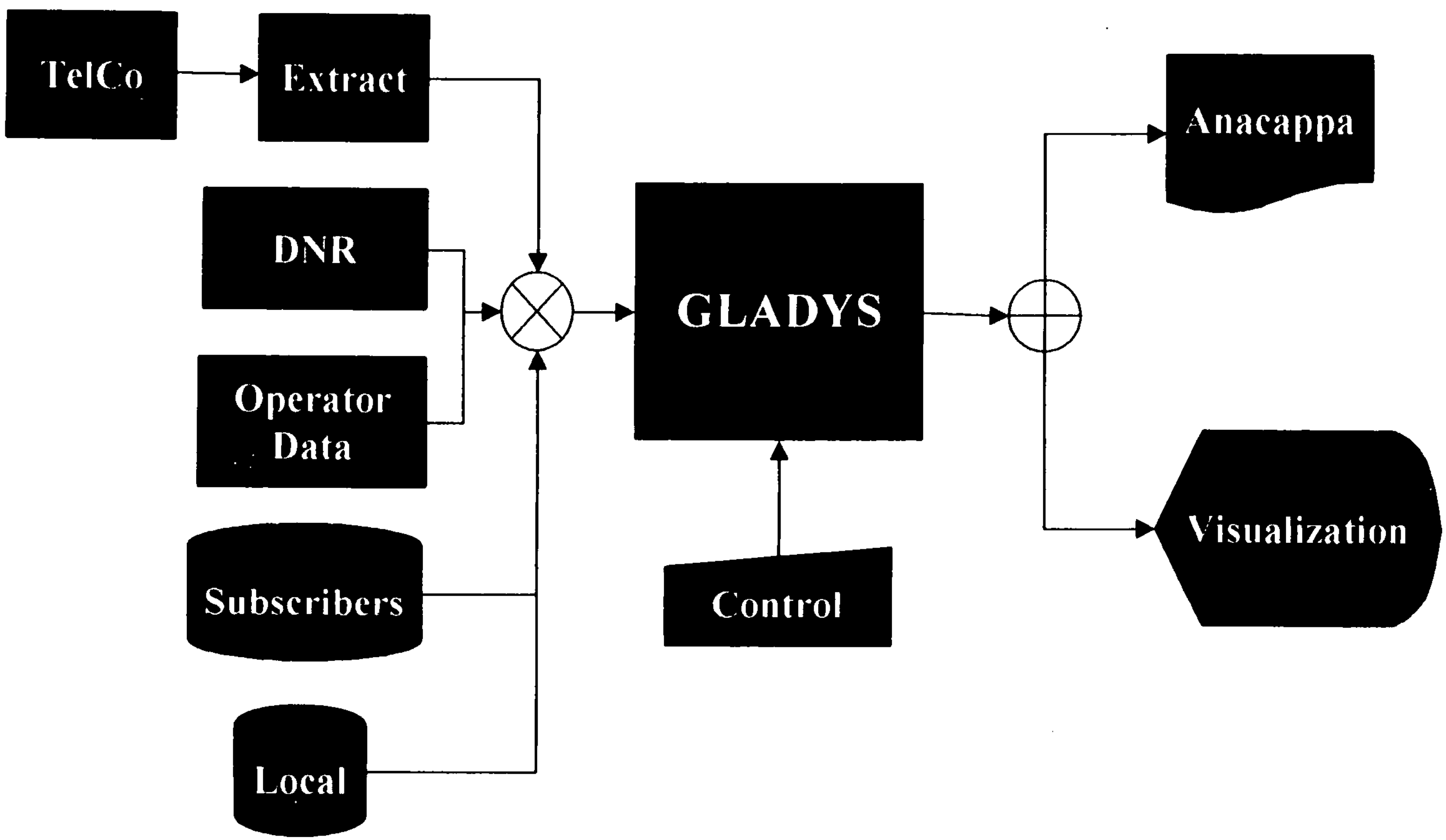
GLADYS: Approach

- OCTF had the skills to employ advanced automation
  - Few resources to apply to emerging requirements
  - No experience in system development
- Form a joint OCTF/CTAC development team to prototype and test 60 days after project start
- OCTF resources: Win 3.1 on 286 Intel machines, 40 MB HDD
- Cellular phone company producing 300 KB files per day per calling area
  - Various formats, depending upon telco needs
  - Bigger files when produced less often

GLADYS: Solution Development

- Reengineer the data acquisition process
  - Source data automation: automate once, use many times
  - Customized processing for police intelligence production
- Accommodate more data sources:
  - More telcos and DNR-generated data
  - Operator-supplied data and ad hoc local data bases
- Add new resources:
  - Pentium class machines with 1+ GB HDD
  - Contemporary Relational Database Management System
    - Define, create, and redefine a database
    - Application programming language and/or interface
  - High-speed modems (14.4, 28.8 K bps)

GLADYS: Operation



GLADYS: Employment

- Means to deal with quantities of data produced
  - No matches will be overlooked
  - Archived data will build up quickly
- Part of a comprehensive communications surveillance program
  - Some reason to do this
  - Some means to take advantage of the data produced
- Basic operation requires access to large data files
  - Defined cellular telephone activity: roaming mobile phones making a large number of calls in telco's area
  - Subscriber files for listed numbers
  - Means to obtain unlisted numbers

GLADYS: Legal Implications

- Cloning cellular phone ESNs is illegal, but easy to do
  - Lists of cloned numbers sold
  - Telco wants to shut it off: lost revenue and inconvenience to their customer
- LEA wants it to continue
  - LEA reimburses telco for use of the cloned number
  - TelCo issues new number to the customer
- PURPOSE: Develop probable cause to intercept or eavesdrop on any future calls

GLADYS: Future Possibilities

- Recognizing pager, fax, and computer dial-up calls
- Analyzing for temporal patterns: how intelligence data bases form over time
- Use of the Internet by criminal organizations offers new challenges and opportunities for LEAs
  - Access through dial-up accounts remain the popular means
  - Working with the Internet Service Provider vice TelCo
- Encryption makes traffic analysis more important
- Planning a future full-scale employment test
  - Multiple telcos will be involved
  - Determine maximum performance capacities

GLADYS: References

- "An Interactive System for Telephone Traffic Analysis: the GLADYS Call Processing System," John R. Schmid, DynCorp I&ET, October 1994, Proceedings of the 1994 ONDCP/CTAC Counterdrug Technology Symposium, Nashua NH. Detailed description of GLADYS' processing.

- "Telecommunication Methods of Colombian Cocaine Syndicates: The Challenge to Law Enforcement," Fred Rayano and Terrence M. Kelly, July 1995, Police Executive Research Forum, 1120 Connecticut Avenue, N.W., Suite 930, Washington DC 20036. Detailed description of how cartels use public communications systems and the legal implications of monitoring them.

Antennas for Tactical Tracking and Radiolocation

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Abstract

Antennas are an important part of any communications chain. Unfortunately, they are frequently the weakest link in the chain due to lack of understanding, or the need to make an antenna do what it was not designed to do. It is important to understand just enough about the "black art" of antennas to apply them properly. A review of antenna fundamentals will lead off the discussion.

Miniaturization and concealment issues are best addressed in the design phase of the antenna. Antennas designed specifically for covert beacons and covert trackers will be examined. Antennas do not have to be poor radiators just because they are physically small. The requirements for efficient radiation from small antennas will be presented. The criterion for trading off performance for increased ruggedness and reliability will be discussed. "Slap-and-dash" vehicular beacons and their antenna problems are discussed, and solutions offered.

The smallest practical beacons offer a formidable challenge for the engineer due to limited battery life, and lack of volume for a "traditional" antenna. DTC has minimized this problem by designing special antennas around the available covert packages.

The use of circular polarization in cellular tracking will be explained. The problems of using the GPS system in covert tracking is briefly mentioned.

Finally, the simple rules for successful antenna deployment will be taught. These rules will allow any user of tracking and radiolocation equipment to maximize their probability of mission success.

What is an antenna supposed to do?

All conductors radiate electromagnetic waves when carrying alternating current. The wire from our toaster to the wall outlet is carrying alternating current changing direction 60 times per second. The wire from our tactical repeater to the antenna is carrying current changing direction at 170 million times per second. They both radiate electromagnetic waves, but neither do it as efficiently as an antenna. Why?

A wavelength is the distance a radio wave travels in one cycle. Radio waves travel the speed of light, about 186,000 miles per second (300 million meters per second). A wavelength at 170 MHz is approximately six feet. The most commonly used vehicle antenna, the "quarter-wave whip" is about 1.5 feet long, or about 18 inches. [1]

Rule #1 of radiation is that wires that are *electrically* one quarter-wavelength or longer tend to be efficient radiators. Below a quarter-wavelength, the radiation efficiency declines linearly. This is why small wire antennas which are much shorter than they should be work poorly. A good example of this is the 3 or 4 inch wire found on garage door opener receivers. These are intentionally short to limit range.

Note that there is a difference between electrical length and physical length. *Physical* length will be the same as electrical length unless some special *loading* techniques are used. An example of loading is a loading coil at the center of a whip antenna.

Rule #2 of radiation is that nearby objects will reduce the efficiency of a radiator designed to operate in the clear. Objects further away have less effect. As an experiment, take a handheld radio or a beacon transmitting a signal, and place it on the hood of a car (a large metal plate). With the antenna vertical measure the signal strength at a distant receiver. Then, lay down the transmitter so the antenna is laying on the hood. Measure the signal again, and it will be weaker. The proximity of the hood reduces the efficiency of the antenna because the antenna was not designed to operate in its presence. It is in fact possible to design the antenna to operate in the presence of nearby objects.

Rule #3 of radiation is that an impedance-matched radiator will work better than one that is mismatched. This means that if the system impedance is 50 ohms, which is almost always the case, the antenna input should be designed to present a 50 ohm impedance. Random lengths of wire used as radiators rarely meet this criteria, and while they may seem to work sometimes, there is a performance penalty to offset the ease of implementation.

What limits antennas from doing their job?

Unfortunately, tactical antenna deployments are often far from optimum for the antennas used. The key is to use antennas that were designed for the application, and to place them properly. Sometimes antenna measurements can help the process of optimizing performance in specific deployment situations.

Common antennas and their relative merits

Dipole

The dipole is the most fundamental, practical antenna. It consists of a one-half-wavelength wire, center fed. It is a balanced antenna, meaning that it is symmetrical. It is therefore properly fed with a balanced transmission line. The peak gain of a dipole is 2.15dBi [2,3], which occurs perpendicular to the wire. The dipole is often used as a reference antenna for gain measurements. This is because it is easily reproducible, as opposed to the theoretical isotropic radiator (as in dBi) which is impossible to physically realize. Antenna gains that are referenced to a dipole are given units of dBd. The impedance of a dipole in free space is 73 ohms [2], which would result in a standing-wave ratio (SWR) in a 50-ohm system of about 1.5:1.

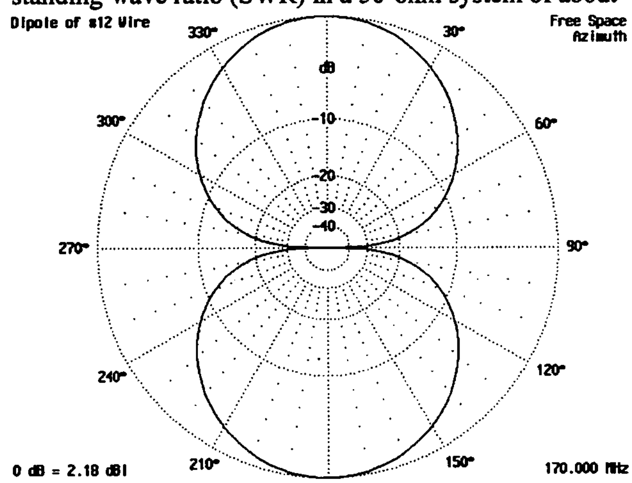


Fig. 1 Dipole antenna pattern

Quarter-wave

The quarter-wave radiator is a special case of the dipole antenna. Usually, it is realized as a quarter-wave over a ground-plane, such as a car roof. When the ground plane is very large (greater than ten wavelengths), the pattern of the antenna is identical to a vertical dipole. The quarter-wave monopole is one half of the dipole, the other half being realized in the ground plane reflection, or "image".

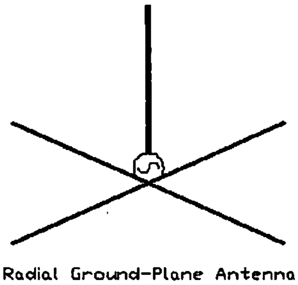


Fig. 2 Quarter-wave Radial Groundplane antenna

Since it is usually not possible to mount the antenna on a large ground-plane, an array of quarter-wave radials can be used to simulate it. When the quarter wave radiator is above a ground-plane of quarter-wave radials, the gain is reduced. This antenna has a gain of about -1.5 dBi. See Fig. 3. [3]

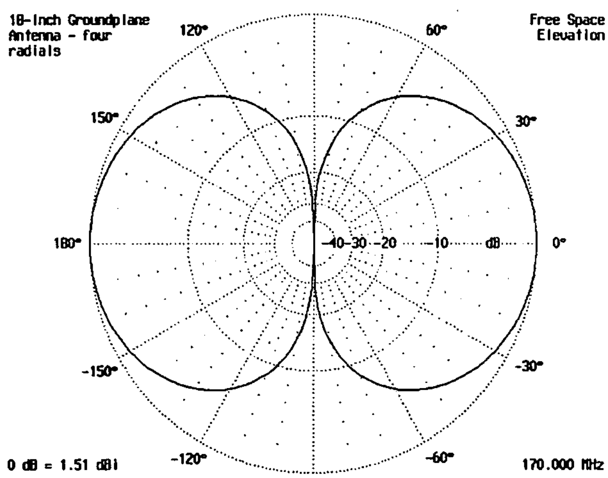


Fig. 3 Quarter-wave radial GP antenna pattern

In the special case of the quarter-wave radiator over an undersized ground-plane, the question of gain becomes more complicated. When the ground plane becomes greater than a quarter-wave, but less than ten wavelengths, the angle of the peak radiation elevates significantly above the horizon. In the case of VHF frequencies and car roofs, this will be 30-40 degrees of elevation [4]. This significantly reduces the gain on the horizon.

The quarter wave radiator is the most prolific antenna in vehicular applications, despite its shortcomings. The impedance of an ideal quarter-wave radiator is one half that of a dipole, or 37 ohms for an SWR of about 1.4:1

5/8-wave

The 5/8 wave antenna was originally developed for use in the AM broadcast industry [5]. When operated over a ground plane, it behaves as two collinear dipoles, giving a gain near 5 dBi or 3 dBd[1]. It is often sold as a "gain" antenna for vehicular VHF applications. Due to the ground-plane limitations explained above, it realizes a gain of about 2 dBi or 0 dBd on a car roof, with its radiation angle very close to the horizon. It is an ideal antenna for general-purpose vehicular applications. The 5/8-wave antenna requires a loading coil at its base, and the resulting impedance is very close to 50 ohms, or a 1:1 SWR.

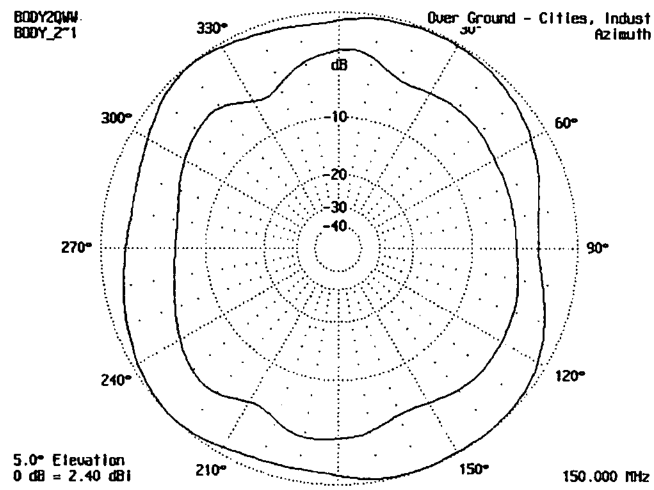


Fig. 4 5/8-wave vs. 1/4-wave vehicle roof simulation

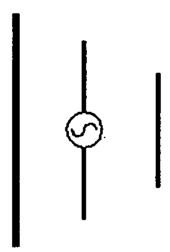
Figure 4 shows the results of a computer simulation comparing the relative gains of a quarter-wave and a 5/8-wave radiator on a vehicle. The vehicle was simulated with a grid of steel wires in the shape of a Buick Park Avenue. The outer curve is the gain of the 5/8-wave antenna, which is about 2.4dBi. The inner curve is the gain of the quarter-wave antenna, which is about 4 dB below the 5/8-wave antenna, or about -1.6dBi. The graph also shows the variation of the gain due to the shape of the vehicle. The ground under the vehicle was assumed to be similar to that of an industrial area. The measurements were taken at an elevation angle of 5 degrees.

Yagi

The yagi antenna has application in radiolocation because it is a directional antenna. By definition a Yagi antenna (more properly called a Yagi-Uda array [6]) consists of

[1] This neglects "image" gain, which simplifies the discussion.

one element connected to the feedline (the driven element), usually a dipole or a variant, and multiple parasitic elements as directors and reflectors. There is usually only one or two reflector elements; there can be many director elements. The reflectors are electrically longer than a half-wave, and the directors are shorter. A three-element yagi, one director and one reflector, has a gain of about 7 dBi or 5dBd. More relevant in radiolocation applications, it can have a front to back ratio of 20 dB or more in a narrow frequency band, perhaps 10%. The yagi is sensitive to its surroundings, and may easily be detuned by metal objects closer than a half-wavelength. The LPDA is a better choice in most hand-held direction-finding applications. The feedpoint impedance of a yagi is highly dependent on the parasitic elements. Usually, a matching network is incorporated into the driven element, allowing a 50-ohm feed.

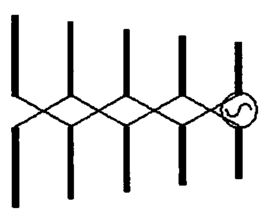


Yagi-Uda Array

Fig. 5

LPDA

The Log-periodic Dipole Array is a directional, wideband design. It is similar in appearance to the yagi, except that all elements are driven. The gain of the LPDA is dependent upon design and size, but it is often about the same as a three-element yagi, or about 7 dBi or 5 dBd.



Log-Periodic Dipole Array

Fig. 6

The characteristics of the LPDA remain the same over a wide range of frequencies, often over a 3-to-1 range. This characteristic also tends to make the antenna insensitive to metal objects in its vicinity, making it a reliable direction-finding antenna in the field. The LPDA is somewhat more complicated mechanically, due to the fact that each element is driven. The input impedance of an LPDA is highly dependent upon its design, but a common value is about 70 ohms.

Understanding antenna specifications

Gain and other lies

The gain of an antenna is one of the most abused performance measurements. Gain is a comparative measurement, and to give the gain of an antenna in dB without indicating what reference is being used is to say nothing. There are two proper references used in the measurement of antenna gain. They are the isotropic radiator and the dipole.

An isotropic radiator is a theoretical point source of radiation. If we were to enclose an isotropic radiator in a sphere, it would illuminate the sphere uniformly. The closest real-world example is a bare lightbulb hanging in a room. Even in this case, the bulb is not truly isotropic, as the ceiling just above the bulb is usually shadowed. Gain measured with reference to an isotropic radiator is in units of dBi, read as "decibels with respect to isotropic". The isotropic radiator is still a useful concept because it measures directivity of an antenna. An isotropic radiator has a gain of 0dBi and has zero directivity.

A dipole antenna is a useful reference because we can build one with near-theoretical performance. That makes a gain measurement a matter of measuring the radiation pattern from a dipole antenna, then substituting the antenna under test, and reporting the ratio of the two as dBd, or "decibels with respect to a dipole". The dipole has an antenna pattern which has the shape of a doughnut (some would prefer a bagel). The radiation off the end of the dipole is zero (this would be the bagel hole) and broad side to the antenna is maximum. The peak gain of the dipole is 2.15 dBi. The intensity broadside to the antenna is increased as a result of the lower energy off the ends.

A third reference antenna which crops up in antenna gain specifications is the quarter-wave radial ground plane antenna. Since the gain of the radial ground plane antenna is about -3 dBd, it makes gain figures look high on a data sheet. Beware, when the gain is expressed in dB, with no reference given, it is frequently the radial ground plane being used as a reference.

A measurement in decibels (dB) is a ratio, and the question that must always be asked in antenna gain figures is "dB with respect to what?" Reject any gain measurement which does not give a reference.

Radiation resistance and efficiency

Power fed to an antenna is dissipated in two ways: radiation and loss. When power is dissipated by radiation, the desired mode of dissipation, we can think of the power being dissipated in a resistance called the "radiation resistor". Of course, a real resistor would dissipate the energy as heat, not radiation, but this is a convenient way of modeling the system. An ideal dipole antenna, for example, has a radiation resistance of 73 ohms. The power radiated by the antenna can be modeled as if the power were dissipated in a 73-ohm "radiation resistor".

If the loss in the wire that makes up a real-world dipole is 0.5 ohm, then there is now power being dissipated in the loss resistance as well. This power is turned into heat, and is wasted as far as radiation is concerned. Since the loss resistance and the radiation resistance are in series, they share the same current and the power dissipated in each is proportional to the resistances. Efficiency is defined as the ratio of the radiation resistance to the sum of the radiation resistance and the loss resistance. In the case of the given example, the efficiency would be 99.3% or -0.03 dB.

As a second example of efficiency, we'll look at a very small resonant loop antenna. Such an antenna is typical of that integrated into a tactical transmitter. If the loop is on the order of one-tenth of a wavelength in diameter (1.8 inches at 170 MHz), then the radiation resistance of the loop is only about 0.1 ohm. If the loss resistance remained at 0.5 ohms as before, then the efficiency of this antenna system is 17% or -7.8 dB at best. In reality, losses can be held to much lower than 0.5 ohms in small antennas, but materials and components used are critical.

Having an antenna efficiency of -7.8 dB may not be a show-stopper, however; the system needs to be evaluated as a whole. It may prove to be an acceptable loss, if it is technically acceptable and the small size lowers the risk of discovery.

SWR and input impedance

The easiest, most popular antenna measurement is standing-wave-ratio or SWR. SWR is a measure of the matching between the feedline impedance and the antenna impedance. Low antenna SWR is the holy grail of many system designers. A better return on investment will be had by putting more time into radiation measurements and *in situ* testing prior to system deployment, rather than optimizing antenna SWR.

Generally high SWR is a bigger problem for transmitters than for receivers. In receivers, the tradeoff for high SWR at the antenna port is reduced sensitivity or noise figure. However, typical low-noise VHF receiver front-ends would require an SWR of more than 4:1 for a 1 dB degradation of receiver sensitivity. Transmitters, on the other hand, have an SWR-stability-efficiency tradeoff. Stability can be sacrificed at SWRs of 5:1 or even lower. Transmitters can be designed for higher stability margins at the expense of power efficiency, the ultimate example being commonly available unconditionally-stable power amplifier modules. Tactical transmitters, however, are frequently designed for very efficient battery operation, often considerably reducing the stability margin.

Antennas designed for tactical deployment, especially those for beacons, should be designed for a good match in the operating condition that is typical. Further, it should be tolerant of changes in the environment so that a reasonable match is obtained with various deployments. If a typically deployed vehicular beacon can have an antenna SWR of 2-to-1, for example, this would be an acceptable match, and no further time should be spent making it lower.

Designing an antenna for wide-band operation is a good philosophy, because it usually means that the design will be relatively insensitive to its surroundings, particularly when operated at its center frequency.

Radiation from small antennas

The physical and electrical length of antennas need not be the same. We routinely use "rubber duck" antennas at VHF that are electrically a quarter-wave (about 18 inches), but are physically about 5 inches. This is due to antenna loading. We can load antennas with the intention of making them physically shorter for ease of use. This is particularly important in tactical deployments, especially when the antenna is meant to be covert.

Physically small antennas can be good radiators

When antennas are made smaller by loading, the designer must take steps to keep the antenna efficient and maintain a reasonable impedance match. Theoretically, antennas made of perfect conductors and surrounded by loss-less dielectrics can be made microscopically small, and have the same radiation pattern as their full-size counterparts. The key words here are "perfect conductors" and "loss-less dielectrics". Most materials used in antenna fabrication have losses which are big enough to prevent making the microscopic antennas field agents would love to have, and only really work in the movies.

Low loss conductors

The table below shows the most common materials that antennas are made from. Copper is considered to be the material with the lowest practical resistance. Mechanical properties can dominate the material selection if the antenna will be exposed to the elements. Stainless steel has excellent corrosion properties, for example, but has 52 times the resistance of copper. Aluminum can be a good alternative, but special care must be taken when making electrical connections to prevent galvanic corrosion.

Material	Resistivity (ohm-cm x 10e-6)	Relative resistivity
Copper	1.72	1.0
Aluminum	2.62	1.5
Brass	3.9	2.3
Steel	13-22	7.6-12.7
Stainless Steel	90	52.3
Tin	11.4	6.6
Lead	21.9	12.7

Table 1

Low loss dielectrics (insulators)

The insulators used in making small antennas must also be considered. They, too, can induce significant losses. Fortunately, low-loss dielectrics are commonly available. Below is a table of common insulating materials and their relative dielectric losses.

Material	Dissipation factor
Vacuum	0.0
Teflon	<0.0002
PVC	0.008
Styrofoam	<0.0001
Epoxy	0.03
Nylon	0.02
Water (distilled)	0.005

Table 2

Note that some PVC pipes have additives for strength which significantly increase the high frequency losses.

Dielectric losses are easily tested using common laboratory equipment: the microwave oven. Put a mug of water in one corner of the oven (This is to protect the oven from operation while "empty"). In the other corner place samples of the plastics to be tested for loss. Microwave on high for one minute. Plastics which get warm (or hot) are dissipating RF energy. The warmer the plastic, the higher the dissipation factor. The frequency of the microwave oven is about 20 times higher than typical VHF frequencies, but the relative measurement is valid. A piece of Teflon can be used as a standard for low loss. While simplistic, this test can offer surprising results when testing plastics of unknown dissipation factor.

Another factor which limits the shrinking of antennas is the *radiation bandwidth.* This is the frequency bandwidth over which the antenna radiation is within 3 dB of peak radiated field strength.

As antennas are physically made smaller, this bandwidth narrows. Ultimately, the bandwidth may shrink to be narrower than the modulation used in the transmitted signal! Long before that happens the deployment margin will be lost, and the antenna will not be a practical tactical solution.

To paraphrase Einstein: "Tactical antennas should be made as small as possible, but not smaller."

In some special situations, the antenna must be placed in a physical space smaller than the antenna designer would like to have. In this case, some loss of antenna efficiency is accepted, and steps may be needed to improve the SWR bandwidth in order to keep the transmitter stable. One solution is to introduce just enough loss in the antenna to improve the matching, but not so much as to lose all the transmitter power to heating the losses. One way to accomplish this is with a resistive load in the antenna structure; a bulk resistor can be used or the antenna materials can be changed to a lossier material such as steel instead of copper.

An important consideration in the design and application of small antennas is the proximity to the transmitter. If the transmitter is insufficiently shielded and of a design prone to RF feedback, it is possible for there to be problems if the antenna is very close. The primary solution to this problem will be the proper shielding of the transmitter, including bypassing of the power supply lines. Certain transmitter designs, those that do not have high gain stages at the transmitter output frequency, are far less prone to this type of problem. However, if one does not have the luxury of redesigning the transmitter, then separating the transmitter and antenna, or shielding the transmitter is the solution.

Pitfalls of integrating small radiators

Integrating antennas into the same package as a covert transmitter has some risks that must be addressed in the design phase of the project.

Feedback into the transmitter

Since the antenna will be in close proximity to the transmitter circuit there will be coupling between them. Whether or not this is a problem is a function of the shielding of the transmitter and its architecture.

The simplest form of shielding is a ground plane under the transmitter circuit. This effectively makes all the printed circuit traces microstrip transmission lines, which tend to contain their electric fields, and are resistant to coupling from external fields. An even better method would be to use two ground planes and put the transmitter circuitry between them. This type of construction is called stripline, and the shielding properities is far superior to microstrip. Both of these methods are not complete shielding solutions, however.

Complete shielding of the transmitter would be the best protection, although this solution may result in a larger transmitter, and one that weighs more.

Change of antenna impedance due to nearby objects

When integrating the antenna with the transmitter, the proximity of the transmitter will affect the antenna impedance. It will also impact antenna pattern, but it is assumed that the antenna is small, and the pattern is not a major consideration.

The antenna design will need to be optimized in the presence of the transmitter. If the transmitter is not yet available, an appropriate model may be used. The model must have the same dimensions as the final transmitter design, and use the same materials. It is likely that this technique will allow a reasonably accurate model for impedance matching of the antenna, there will probably be a need to tune each individual unit to resonance.

Tuning integrated antennas

When designing covert transmitters with integrated antennas, some means should be provided for tuning the antenna in the environment that it will be used.

In the case of the DTC Model T-75-TWC "Tango" transmitter, a procedure is followed that allows the antenna tuning to be the last step in the production process. The trimmer capacitor which tunes the antenna to resonance is adjusted while measuring field strength. The pager host device is in the exact configuration that will be used in operation when the measurements are taken.

Miniaturization and Concealment

Designing antennas around hosts

One of the most challenging aspects of antenna design is to marry available space with desired performance. Often, especially in the area of covert transmitters, the space available is much smaller that would be ideal. It is frequently an operational requirement that the host device, be it a cellular phone or a pager, operate normally despite the addition of a covert transmitter. This is when *in situ* measurements and design techniques become critical.

In the T-75-TWC "Tango" transmitter, we were faced with the challenge of incorporating a covert transmitter and antenna into a pager housing, while keeping the apparent functionality of the pager and its external appearance intact. This also required that the transmitter operate from the same AAA battery that powered the pager. By replacing the RF portion of the pager with the DTC T75 electronics, and the "reply" antenna of this two-way pager with a proprietary DTC design, we met the objective. The antenna had to be surgically transplanted. A special jig was designed to carefully cut open the pager housing to facilitate the operation. The new antenna had to fill the volume of the old, so that there were no cosmetic changes.

The tuning and matching of the new antenna had to be done after the completed assembly. The result is a covert transmitter with a highly efficient antenna, giving radiated field strengths approaching that of body-worn transmitters with transmitter power output levels more than 10dB higher.

Covert tracking antennas

The usual antennas for Doppler direction finding of covert transmitters are far from unobtrusive. The four antenna array is distinctly visible from long distances, and are often seen on police cars using the Lo-Jack system. This is not the ideal situation for tracking covert beacon transmitters.

The DTC AA-3 covert antenna array was designed with several objectives in mind. The first goal was to lower the visual profile of the antenna array without compromising performance. The second goal was to disguise the low-profile antenna sufficiently so that it would be interpreted as something non-threatening. The third goal was to provide a rapid deployment system which could be used on a variety of vehicles.

The four antenna array requires that each antenna lie on a circle of approximately one quarter-wavelength in diameter. Each antenna element is a quarter-wave whip. The tracking system electronically switches between each antenna in sequence, simulating a mechanical rotation. This rotation produces a Doppler shift in the signal, which is processed by the system to resolve direction information.

In order to lower the visual profile of the array, the first thing we did was to shorten each element using a technique called spiral top-loading. Each element is only three inches high physically, but acts as a quarter wave (about 18 inches at 170 MHz) electrically. The antenna also has a special matching section on the element which is adjustable. In production, both the tuning and the matching of each of the four elements is optimized for the specified center frequency.

The second goal, disguising the array, was accomplished by its housing. The housing is a plastic material, identical to that used in equipment cases. When on the vehicle, it resembles a part of a luggage rack, or a case strapped to the top of the car. At a height of about three inches, it almost disappears, or looks like an open sun roof in the rear view mirror.

The third goal, rapid deployment, was accomplished using a unique arrangement of four magnets on compliant gimbals. The magnets can change their angle as well as their height, thus conforming to a wide variety of vehicle roofs. Deployment on a roof takes only seconds, and is actually much faster than the standard four-whip array.

Measured tracking performance shows that the covert array behaves identically to the standard array when operated at the frequency for which it is tuned. One feature of the covert array is that it is inherently narrow-banded. This may limit flexibility somewhat, but it also serves to attenuate out-of-band signals.

Can the array be made even smaller and more covert? Yes, but at a price. Making the elements smaller would lower the bandwidth even further. The SWR 2:1 bandwidth of the 3-inch high element is about 1%. The match bandwidth can be improved at the expense of signal loss, but this would not be a wise tradeoff in a weak-signal receiver system. The element spacing can be made smaller, but the signal-to-noise ratio of the direction-of-arrival measurement would begin to rise rapidly. The current configuration has proved successful and well accepted in the field.

If the low visual profile was no longer a consideration, and weak-signal performance was the top priority, quarter-wave whip antennas should not be used. In automotive applications, where the car roof is the attachment surface and electrical ground plane, quarter-wave whips have a radiation angle of between 30 and 40 degrees above the horizon.

A better choice would be a 5/8-wave whip antenna, as previously discussed. The 5/8-wave antenna elevates the antenna current maximum, so that the antenna effectively operates as a vertical dipole above the car. This results in a peak radiation angle nearly on the horizon, and a resultant signal strength increase.

It should be noted that at 800 MHz and above, the car roof begins to act as a reasonable ground-plane, and antennas begin to achieve their theoretical gains if mounted near the roof center.

Covert beacons

Covert beacons have the worst of all worlds. The beacons and their antennas should be extremely small, and will be stuck in the worst possible places in terms of radiating a signal. For this reason, antenna patterns, peak radiation angles, and antenna gain have no almost no bearing on their design. The antenna for a covert beacon has but one rule: radiate the signal!

Almost universally, the covert beacon antenna will be smaller than a half-wavelength, especially at VHF. This means that efficiency and impedance matching are the important design considerations.

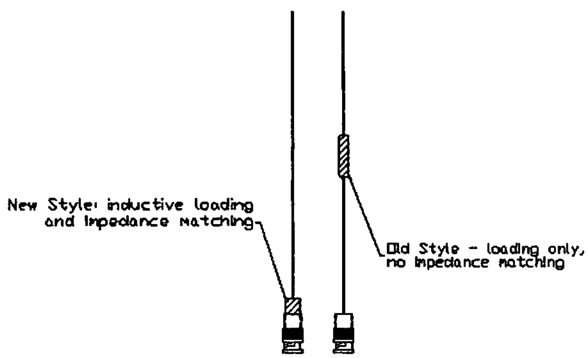


Fig. 7

A good example of this is the antenna on the DTC vehicular beacon model VB-1 (See Fig. 7). In the past, antennas for this application have been center loaded, quarter-wave whips. The loading allowed VHF operation with whips of 8 inches length rather than 18 inches. Unfortunately, the best case SWR of this type of antenna is 4-to-1. Most high-quality transmitters will remain stable into such a load, but when an actual deployment is made, the SWR may approach 8-to-1 or worse. This will lead to lower radiated power at best, and spurious transmitter operation at worst.

The DTC model VB-1 antenna uses special impedance matching to assure a low SWR match in a typical deployment. This insures that the match begins near 1-to-1 and may degrade from there. This is called *deployment margin*, and is an important consideration in any tactical antenna.

Flexible Wire antennas

Wire antennas find their biggest application in package beacons and body wires. (The antennas used in vehicular beacons are not considered "flexible" for the purposes of this paper). The biggest problem with flexible wire antennas in tactical deployment is when the wire is not stretched out to its full length. If it is necessary to fit a beacon and antenna into a space which too small to stretch the antenna out completely, the preferred method is to zigzag the antenna, keeping it away from itself as much as possible. This will lead to the highest radiation resistance, and the maximum signal radiated. If a flexible wire antenna is folded back upon itself, it acts as a transmission line where near-equal current is flowing in opposite directions, effectively canceling radiation from that part of the antenna.

The design of wire antennas follows the doctrine of maximum deployment margin. The antenna is designed to be stretched out, perhaps taped along the inside of a cardboard box. Then, deviation from this type of deployment will tend to degrade performance slightly. This is, however, a better procedure than optimizing the antenna for free-space operation, which will surely never be seen in the field. It is prudent to contact the antenna supplier, should a it be desired to optimize the antenna for a specific mission. In the lab, the conditions would be simulated and the antenna optimized.

It should be obvious that wire antennas should never be shortened or lengthened in the field. The chances of it improving performance are slim, and without making a proper measurement, the performance could not be verified.

Integrated antennas for "slap-and-dash" applications

Integrating the antenna into a vehicular beacon is a two edged sword. On the one hand, it eliminates the pervasive problem of antenna breakage due to the typical environment and handling these devices see. On the other hand, integrated antennas require specific training in proper deployment, because it is not obvious where the antenna is, and how to keep it as far away from metal objects as possible.

Special Topic: Cellular Tracking

The issue of tracking cellular phone transmissions has been of increasing importance lately. The financial losses suffered as a result of cellular fraud are driving the need for improved cellular tracking capability. As far as antennas are concerned, the technology used to track a cellular transmitter to the "city-block" or building level are very similar to that used in beacon tracking: Doppler direction finding. In order to achieve the close-in radiolocation performance necessary to pinpoint the transmitter location to within a room, new technology was developed at DTC.

The DTC Bullseye system uses a circularly-polarized patch antenna, a proprietary receiver, and a wireless earpiece to allow an agent to walk right up to the target cellular phone. The earpiece presents the receiver audio and tones indicating relative signal strength. The signal strength indication is automatically compensated for changes in the cellular phone power level, which occur normally in cellular operation. The agent carries the equipment in a shoulder bag, such as a gym bag or other disguise, and can walk into a building with no sign that he is tracking a signal.

Directionality

Close-in direction finding requires two things: an unambiguous indication of signal arrival bearing, and a small, covert antenna. The DTC Bullseye antenna achieves this with a proprietary device called the Hybrid Patch Antenna [7]. Essentially an air-dielectric circularly polarized patch antenna, it has an antenna pattern with an essentially hemispherical response. The front-to-back ratio is on the order of 20 dB.

At first, the major response lobe will be the primary direction-finding tool. As the receiver gets closer to the transmitter, however, the null off the back of the antenna becomes more effective in discerning the signal bearing. After a little operator training, this simple antenna has proven itself extremely effective in finding transmitters in a busy office building.

Circular polarization

In this application it is very important to use circular polarization. The cellular system uses linear polarization normally, but due to reflections and unpredictable antenna orientation of handheld cell phones, the polarization angle of the signal arriving at the receiver is unpredictable. Use of a linearly polarized antenna in this application would cause confusion as the signal may fade due to cross polarization, and not proximity. [8]

When a linearly polarized signal is received by linear antenna which is rotated ninety degrees to the incoming signal, fades of 30 dB or more are possible (ideally it is infinite). When a randomly oriented linear signal is received by a circularly polarized antenna, there is a uniform 3 dB penalty regardless of polarization angle. This is the ideal situation for close-in tracking, and it improves the relevance of signal strength changes.

Concealment

The Hybrid-Patch antenna is only 10 inches on a side and one inch thick. The receiver is sized to match it, and together they fit nicely into a nylon shoulder bag. Due to the very wideband design of the Hybrid-Patch Antenna, the presence of the nylon bag in front of the antenna has very little effect on its performance. Any metal, such as zippers, should obviously be avoided.

Special Topic: GPS problems

With the advent of the Global Positioning system, precise positioning is possible anywhere on the globe to within 300 feet or better. This is an attractive capability for vehicular tracking, despite the technical challenges of using GPS in a covert installation.

The sky-view problem

Proper processing of the GPS signal requires reception of at least three and preferably more satellites. This means that a large sector of unobstructed sky be visible to the GPS antenna. Further, the signal is fairly weak, so reasonable care must be taken with the design of any antenna used. In a covert application, hiding the antenna and giving it a good sky view are competing requirements, especially in a slap-and-dash application.

The signal from the GPS satellites is right-hand circularly polarized (RHCP). All commercially available GPS antennas are, therefore, RHCP as well.

Circular polarization vs. size tradeoff

One of the first tradeoffs that can be made in the design of a GPS antenna for covert applications is sacrificing the RHCP nature of the receive antenna. A simpler linear polarization antenna can be used for a gain penalty of 3 dB. Practical experience with high-quality GPS receiver indicates that this penalty is well tolerated provided a good sky view is available.

The major advantage to a linear antenna is that it can be made smaller, at least in one dimension, than its RHCP counterpart. This improves the probability that the antenna can be concealed in a covert vehicle installation. In going to a dipole type antenna from a patch antenna, another 4 dB or so penalty must be paid, but the size advantage is tremendous.

Under development at DTC is a sleeve-decoupled dipole antenna, with a diameter under 0.1 inch, and a length of 2.5 inches. A possible application of this antenna is inserting it through a small hole in a taillight, mirror, or speaker grille. An integral preamplifier would allow the use of very small coax feeding the antenna.

Simple rules for antenna deployment

1. Air is good, metal is bad

Surround an antenna with as much air as possible. This will help prevent detuning of the antenna, and losing power to eddy currents in nearby metal surfaces rather than radiation.

2. Altitude is good, buried is bad

Higher is better. Placing a transmitter in a speaker grille on the back deck of a vehicle is far superior to placing the same transmitter under the bumper. Using a hide-in-plain-sight antenna, such as a cellular disguise on the roof, is even better.

3. Bigger is better

Physically larger antennas will tend to perform better, all other things being equal. The 5/8-wave antenna is the best VHF antenna for vehicular applications.

4. Hide in plain sight when possible

The cellular antenna is ubiquitous. It acts like a quarter-wave radiator resonant at 179MHz. With proper matching techniques, it can be used throughout the VHF range. These days, it is nearly invisible. Hiding in plain sight means that covert antennas can be up in the clear, where they can radiate effectively.

5. If in doubt, try it

Make a field strength measurement using the actual transmitter, receiver, and antennas prior to deployment. Such a test will speak volumes more than any calculation or simulation.

Conclusion

Antennas should be a high priority

Antennas are probably the most often broken link in the communications chain. Because they appear to be simple pieces of wire, they are often afforded far less attention than the transmitter or receiver attached to them. This is a costly mistake, since an antenna system failure will have exactly the same mission impact as a receiver or transmitter failure.

Allocate at least 10% of budget to the antenna

Ten percent of the cost of a transmitter or receiver should be allocated to the antenna system. If it seems too difficult to spend that much because the antennas aren't that expensive, buy a spare. An old TV commercial for motorcycle helmets said, "If you have a ten-dollar head, buy a ten-dollar helmet."

Train personnel in deployment

Training the field personnel in proper deployment of antennas is vital. Antennas are far more frequently misunderstood than receivers and transmitters, yet the mission is equally dependent upon them.

At DTC we received a complaint about a tactical repeater that was not working properly; the transmitted signal was very weak. After some investigating, we learned that the repeater and its associated antenna were locked in the trunk of a car so they would not be detected.

A little education goes a long way.

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AN IMPROVED PIN-HOLE VIDEO CAMERA FOR COVERT SURVEILLANCE

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ABSTRACT

We have constructed an improved pin-hole video camera which operates through a 100 micron hole. Proprietary optics allow the unit to have a 180 degree field of view (circular fish-eye image), so everything in a room can be seen. The camera operates at very low light levels, and also operates in the near infrared. The image can be rectified and zoomed using available computer technology. The pin-hole has the advantage over glass lenses in that it can be pressurized and is then self-cleaning. The unit is simple, compact, rugged, and battery-powered. Additional design work in progress allows the unit to have full color capability at extremely low light levels. In addition, a new technology increases the resolution of the image as it is enlarged during zooming. The loss of resolution on zooming closer (loss of Pixels) was a major criticism for the zooming system used earlier.

1. Introduction

The availability of covert, comprehensive, reliable surveillance systems is of prime importance to the law enforcement community. The optical system we have designed both fits the above objectives, and supports another project we have undertaken at our laboratory (presented at this conference[1]). This second project involves storing, scanning zooming and rectifying the images.

2. Text

The first object of this project was to design the smallest practical viewport for our covert surveillance system. The limitation in a pinhole is that if it is too large, the image blurs because of the hole size. If the pinhole is too small, the image also blurs because of a property of light called diffraction. The optimum pinhole size-not too large and not too small, is about 100 microns. This is in practical terms about one tenth the diameter of a pencil point. Normally, if the surface containing the pinhole is placed on a desk in front of an observer, he cannot find it! One advantage of the pinhole over a glass lens is that it can be made self-cleaning. If air at low pressure is introduced behind the pinhole, rain, snow, or dust will be blown away.

The second object of this project was to make the surveillance system have a 180 degree field of view. In other words. if the pinhole is placed in a wall, the whole room is in view, up to the surface of the wall containing the pinhole. There is no way to enter the room without being observed. By connecting the pinhole camera to a motion detector- a computer program that compares sequential images- the system can warn the operator when someone enters the room. The 180 degree system is simply a massive block of glass or plastic that bends the 180 degree image into a smaller cone of light. It reproduces what a fish sees when looking at the surface of a pond from below, and so is called a "fish-eye image". Unfortunately, this image is not normally observed, because on leaving the block, the light is

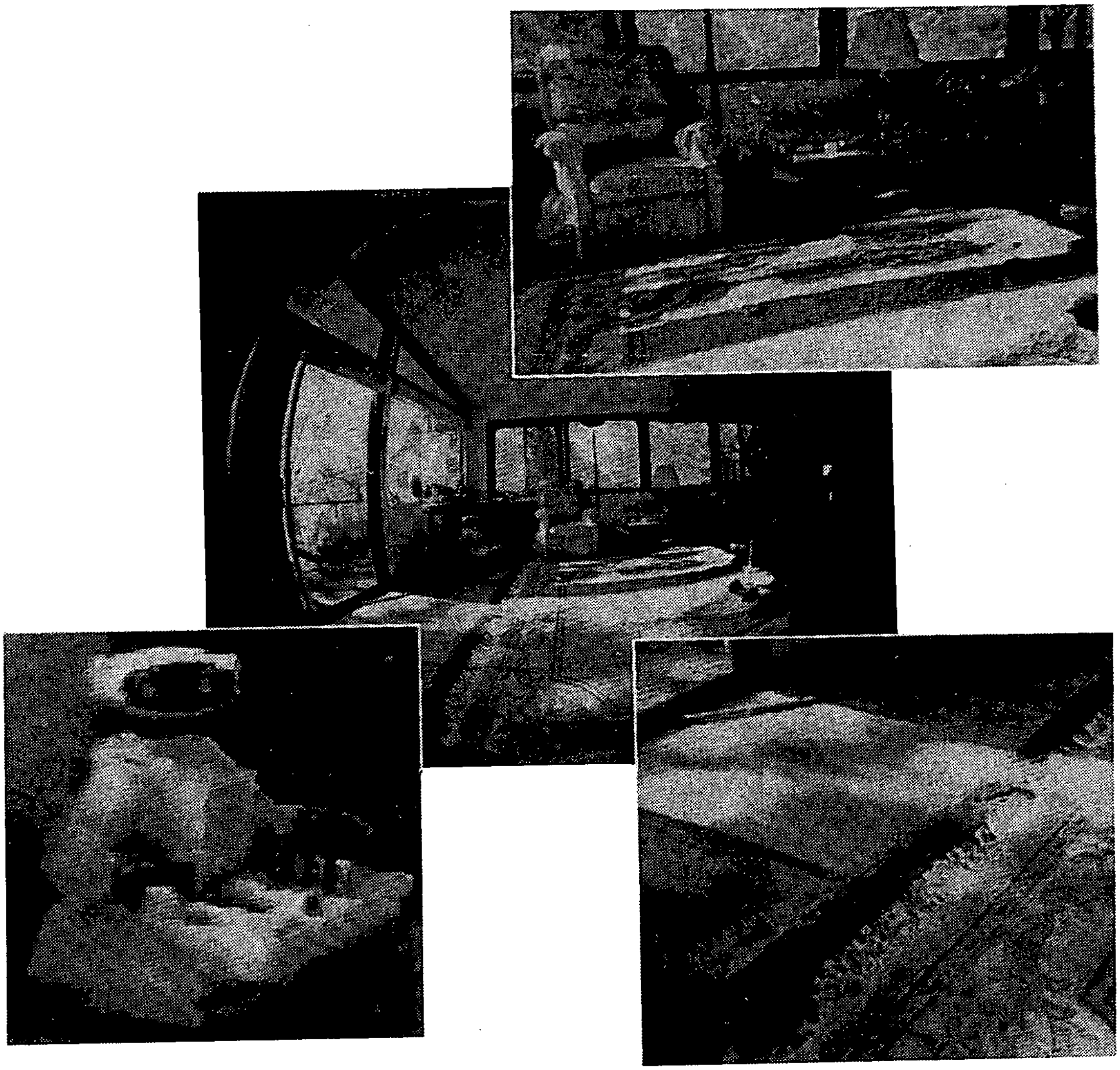

Figure 1 Fish Eye Lens at High Resolution

again bent into a 180 degree spread. However, we have corrected this problem, as is discussed in the next section.

The third object of this project was to make the image visible. Pin hole cameras suffer from lack of light- the pinhole is just too small. We have solved this problem by using a state- of- the- art image intensifier to enhance the image. We found that the new intensifiers actually work so well that the surveillance system works at extremely low light levels- levels at which human vision becomes impaired. In addition, the intensifiers we have worked with are sensitive to the near- infra- red. Human eyes cannot see in this wavelength, so an interior room could be illuminated with infra- red radiation to allow the camera to operate in a room that appears to be totally dark. An additional advantage of using the image intensifier is that it can be optically coupled to the optical block of glass or plastic with glue, grease, or just contact pressure. In this way, the fish-eye image never really leaves the block, but is transmitted to the image intensifier without loss.

A forth object of this project is to recover the color content of the image. Image intensifiers transmit the image by electrons, and so lose color content. The intensified image is generally displayed as a green monochrome. We have corrected this problem by placing an electrically tuned color filter behind the pinhole (Coupled to the glass or plastic block, of course.). Thus each green intensifier image is transmitted to the recording computer with the information that it really is a red, yellow, or blue image, and the computer reconstructs the image in natural color. A simplified system using two sets of color filters allows the observer to view the image in natural color without the need for an attached computer.

A fifth object of this project is to preserve the resolution of the image as you zoom in on a subject. The former technique used in electrical zooming simply used the computer to expand a part of the image. This expansion is simply spreading the obtained information over a larger area, and the image just gets fuzzy. This loss of resolution was considered to be major defect of the old system. We have corrected the zooming loss of resolution in two ways. First, we have designed a system that electrically (not mechanically!) expands the image on a given image chip. Thus, the amount of information transmitted is constant, and the zoomed image remains sharp. A disadvantage of this system is that the zooming occurs in steps. Second, we are electrically (not mechanically!) jittering the image on the image chip to utilize the spaces between the detector elements where image information is normally lost. Thus you get more information, and the loss of information on zooming is not as severe.

3. Additional Advances After Abstract Submission

We have eliminated the image intensifier and loss of color information, and have improved the resolution of the image at the cost of expanding the pinhole by a factor of 20. We still maintain the 180 degree field of view. The pin- hole is now about the size of a thick pencil lead. With the larger pinhole, we use specially designed lenses behind the pinhole to focus the light and greatly reduce the loss of resolution by diffraction. The proprietary lenses are not color corrected at present, so the image when viewed by the eye, shows color fringing. This fringing is corrected easily with the computer.

We have developed a large-format 180 degree fisheye camera for obtaining very high resolution images for recording crime scenes. This camera produces images on 4" x 5" film, yielding a circular image with 16 times the area and resolution than that obtained by a 35 mm camera. Two photos taken with this camera 180 degrees apart record everything in the room with very high resolution. It is not a covert camera, however.

4. Conclusions

We have developed several versions of covert fish-eye cameras that view an entire room through a very small pin-hole. They operate with high resolution and at low light levels. In addition, we have produced a very high resolution fish-eye camera for recording evidence. These cameras are compact and robust, and should be very useful to the law enforcement community.

5. References

1. Client/Server Design for Very Large Image Exploration, Dr. Peter Hansen and Professor J. D. Birdwell, (This Conference).

VISION TECHNOLOGIES FOR MANNED AND UNMANNED SURVEILLANCE

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ABSTRACT

This paper describes the applicability of computer vision and image processing technologies to many problems that arise in surveillance. A key enabling technology is image stabilization, which eliminates vibration-induced image jitter and also forms the basis for various video enhancements, such as "super-resolution" for increasing camera acuity, and multisensor image fusion. Motion in the scene can also be highlighted, enabling increased operator alertness. Sarnoff has constructed and deployed field-proven algorithms and hardware systems for stabilization, multisensor image fusion, and moving-target indication.

Sarnoff is building on these algorithms to develop robust systems for unmanned surveillance that can monitor locations and gather data without a human operator. Autonomous surveillance systems can detect moving targets and record imagery only when there are specific behavior events present within in the scene, thereby dramatically reducing the amount of video that must be transmitted back to a remote observer. The key problem in building such autonomous surveillance systems is to make them robust to false detections from image changes caused by wind, shadows, and varying illumination. Sarnoff is actively pursuing approaches to obtain this robustness, as is evident in fielded commercial systems for detecting moving targets and characterizing their motion for traffic monitoring and airport security.

1. Introduction

The application of video processing technology to manned and unmanned surveillance operations is an emerging influence in the enforcement of drug control policies. Digital video processing techniques, formerly only available to defense-related applications and high-end commercial operation, are now beginning to be applied to law enforcement due to the improving price and performance of these technologies, and the continued emphasis of the enforcement of drug control policies and drug interdiction activities.

Manned surveillance, either from airborne or ground locations, uses video both for monitoring and for evidence gathering. Prolonged surveillance is typically plagued with problems of observer fatigue and an inability to discern activity and detailed information from the scene being monitored. These problems result from camera instabilities, including the effects of vehicle vibration and the motion typical of hand-held cameras. These motions are exacerbated by high-magnification lenses frequently used with surveillance.

Electronic video stabilization, performed through analyzing video information from the sensor, can be used to measure and compensate for unwanted image motion electronically. The residual frame-to-frame change after stabilization can be used to detect motion in the scene, providing indications of activity within the scene automatically. Image fusion techniques can also be used to combine the video information from multiple sensors, providing the operator with a single image that contains salient information from both images. Unwanted image motion and a lack of co-registration between the sensors can both be eliminated through merging the fusion process with image stabilization.

Video processing is also capable of providing advanced techniques for unmanned surveillance. Remote cameras, placed with video processing equipment, are capable of monitoring scenes and providing important information about scene activity and scene content without requiring continuous manned operation. Events such as the arrival and departure of automobiles or individuals within an area can be automatically detected with video processing techniques and stored for later analysis. Suspicious activity, such as loitering about an area, can also be detected, resulting in video being stored that illustrates the suspicious activity using short video clips or through synopsis representations. Advances in motion detection and target behavior allow the robust extraction of such information in outdoor environments without excessive amounts of false alarms and undesired detections.

The remainder of this paper describes some of these video technologies and their application to the enforcement of drug control policy. The techniques of electronic video stabilization, multisensor image fusion, and autonomous scene analysis are explained along with scenarios illustrating how these techniques can be applied.

2. Electronic Video Stabilization

Electronic video stabilization measures the motion between successive images in a video sequence and compensates for that motion, providing a stable display that does not contain effects of vibration and movement that is present in the original video.

Video stabilization is not new within the surveillance community. Mechanical camera stabilization, using passive systems or actively controlled stabilization units, are used on many types of aircraft and ground-based vehicles, and can remove vibration and de-rotate the camera using electromechanical compensation. Electronic video stabilization, currently available with some hand-held video recorders [1], are capable of measuring and smoothing translational motion to remove unwanted instabilities with hand-held cameras.

The type of electronic stabilization proposed here improves significantly on the aforementioned techniques [2]. This stabilization uses local correlation estimates to compute the motion between frames of small patches in the scene, which yields a representation of motion referred to as optical flow [3]. This optical flow is then analyzed using a regression process to determine the global motion within an image scene, thus registering the two image frames. Using this technique, image motion can be measured to sub-pixel precision, even in the presence of camera translation, zoom, rotation, or perspective effects [4]. A warping step after the image registration yields an image that is registered to the prior images, and thus provides a display where the scene is stable.

Computing optical flow and image registration at rates suitable for processing live video continues to be a challenge. One effective strategy for reducing the computational cost of the motion estimation process is through the use of the image pyramid [5]. Pyramids are an efficient representation of images generated through recursive steps of image filtering and resampling, which result in representations of the original image at reduced spatial resolutions with reduced size. Through measuring motion initially at lower spatial resolutions, large displacements can be measured with relatively low computational cost. These initial measurements are then refined through an iterative process where the images are warped into approximate alignment with another, then residual motion is measured and compensated for at successively higher resolutions. This process is called coarse-to-fine processing, and enables visual motion to be quickly measured to the desired sub-pixel accuracy [6].

Sarnoff has developed hardware technology to perform image operations such as image warping and pyramid filtering at real-time video rates using specialized hardware architectures and ASICs [7]. These systems are now capable of implementing electronic video stabilization, pyramid generation, and a host of higher-level image operations at rates suitable for providing processed imagery based on live video.

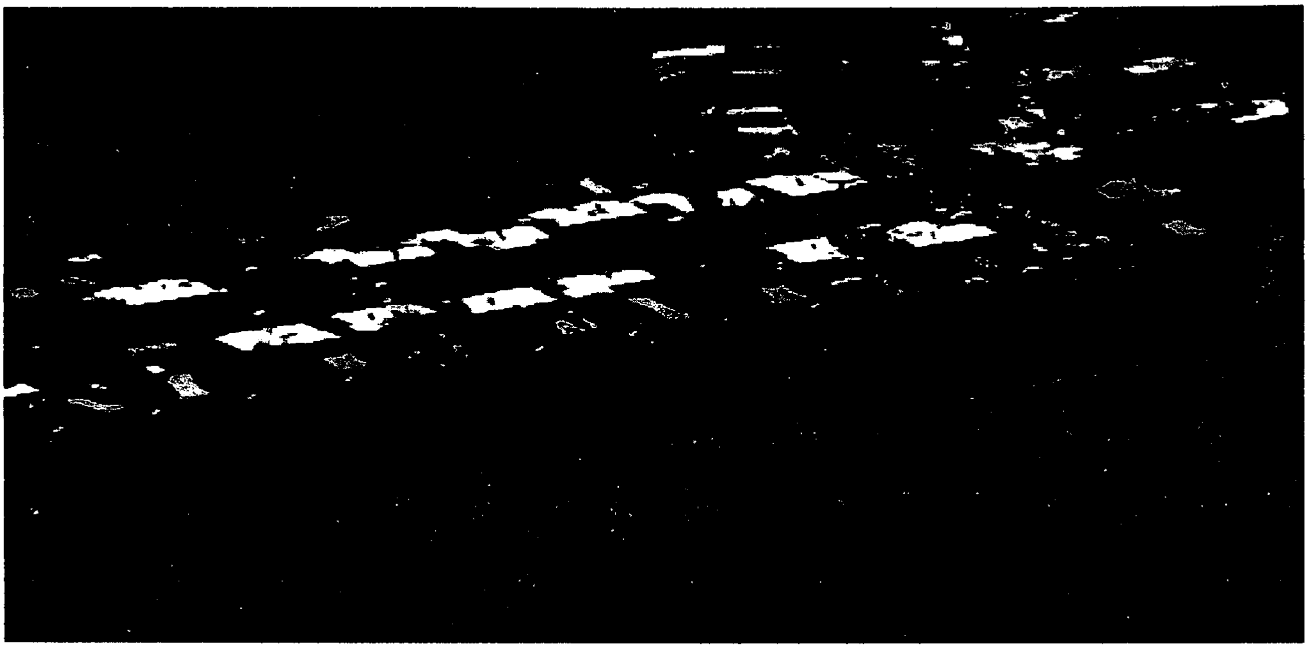

Figure 1. Aerial mosaic of an urban sequence with a car. This synopsis mosaic indicates the position of the car over time, thus summarizing the vehicle's activity while being observed. Actual mosaic constructed from approximately 30 seconds of video.

2.1. Stabilized Displays

Presenting a stabilized display for the operator using this method of image registration provides a number of important features. Unwanted motion, particularly vibration, can be removed from the video sequence prior to viewing, resulting in greatly enhanced visual acuity for the operator and less operator fatigue. Because this stabilization method is image-based, there are no limitations or degradations in stabilization performance with high magnification lenses, unlike mechanical systems which degrade in performance with the use of high zoom. The precision of this stabilization is also much higher than that available with hand-held stabilization systems, thus greatly enhancing the quality of the video output.

The precision of the stabilization also provides a method for performing additional processing on the video sequence. For example, residual motion in the scene after stabilization can be indicated to the observer, thus automatically indicating areas of change. Also, images can be filtered over time to increase the resolution of imagery [8] and to increase the signal-to-noise of the video signal.

2.2. Mosaic Displays

The typical surveillance scenario requires the operator to view the scene at the highest available magnification in order to discern objects within the scene. such as the identity of suspects under surveillance. Performing surveillance under these conditions often causes the operator to lose their context within the larger scene that is being viewed, since very high magnification does not have along with it a broad view of the scene.

Electronic stabilization can be coupled with a process that accumulates scene information over time. This process, referred to as mosaic construction, paints a panorama of the scene much larger than the sensor's field of view. This panorama generation is performed automatically along with the image registration and stabilization, thus not requiring any operator intervention. Viewing a mosaic of a scene, rather than single fields of view of the same scene, results in the operator understanding the context of the scene and the location of the current field of view within the scene.

Figure 2. Example of visible and IR image fusion. The visible image (top left) has been fused with the IR image (top right) to yield a single display (bottom) containing salient information from both source images.

The process of mosaic construction has already been applied with great success to aerial surveillance. In these surveillance situations, it is important to retrieve a high-resolution representation of a large area using video taken of the area. This video can then be annotated, stored, and printed in large format for later analysis and dissemination.

An example of this technique is shown in Figure 1. This mosaic was constructed from a video sequence taken from an airborne platform, where an observer was following the motion of a car. The mosaic itself is a static representation; however, through showing the position of the car at different instances in time, the overall motion and speed of the car is discernible, even from this static representation. This type of mosaic is also called a synopsis mosaic.

Sarnoff developed a system that automatically constructs similar mosaics in real-time from video taken from Unmanned Aerial Vehicles (UAVs), such as the Predator aircraft. Using mosaics in conjunction with the Predator, defense analysts have been able to determine the numbers, positions, and movements of refugees during the conflicts in Zaire, and also have performed reconnaissance in other areas of conflict such as Bosnia.

3. Multisensor Image Fusion

It is becoming more commonplace within the surveillance community to have multiple sensors available for observation. These sensors include both visible sensors, which are used for daytime observations, and infra-red (IR or FLIR) sensors, which are most often used during night operations.

Both visible and IR sensors frequently contain important scene information. However, the observer has to select one of the two sensors to use for surveillance operations, since a dual display containing both types of information is usually not available. An image processing operation called multisensor image fusion can combine the salient image information from both sensors, and presents them to the operator in a single display [9].

Multisensor image fusion is performed through analyzing the two images from the two sensors at multiple resolutions. Significant image features at each image resolution, representing features of different physical sizes, are combined together and then reconstructed into a single image. This selection and recombination operation is performed using an image pyramid.

This technique for image fusion provides a display that retains important image features from both sensors, without the associated problems of loss of contrast and gain and canceling of image features due to the inversion of the pixel intensity of important features. An example of this fusion technique, shown in Figure 2, highlights how visible features (such as the aircraft tail number) can be fused with an IR image that indicates the heat of the aircraft engine and tires. Traditional methods of image fusion, such as simply averaging two sensor images together, suffer from problems of loss of image sharpness and contrast, and will allow the cancellation of image features that have inverse intensities in the two images, as can happen with black-hot vs. white-hot IR images.

Sarnoff has already fielded systems that are capable of performing the multisensor image fusion operation at full rates on live video.

4. Unmanned Surveillance

The previous sections discussed how vision processing can be used to enhance a human observer's visual acuity or reduce their perceptual effort. Another goal is to eliminate the need for continuous manned surveillance by developing vision systems capable of autonomous surveillance. Such unmanned systems would allow data logging for later retrieval and analysis, or allow a single operator to control multiple surveillance systems. In this section, we describe the difficult issues that must be overcome to enable unmanned operation and survey applications (both actually fielded and envisioned) of such unmanned systems.

Typically, an unmanned surveillance system must be able to detect "interesting" events over a wide range of illumination and weather conditions, and log in memory or transmit to a human operator data and imagery related to these interesting events. Here we shall concentrate on the first of these two problems, event detection.

There are two key problems in constructing detection systems. The first is ensuring that the system's probability of detecting the event is always acceptable. In outdoor domains (and indoor domains where windows are present), this is made difficult by the fact that the ambient illumination conditions change between day and night for outdoor domains. This can cause changes in the camera's sensitivity and ability to detect low-contrast features. (As an example, consider the difference between the daytime and nighttime traffic scenes shown in Figures 3 and 4.) Further, in the event that the ambient conditions do not permit reliable detection (e.g., in fog), the system should be able to detect this and enter some failsafe mode or alert a human controller.

The second problem in designing detection systems is to ensure that the rate at which they produce false positive detections is within acceptable bounds. In detection systems based on the detection of motion (i.e. frame-to-frame image changes), false positives often arise due to apparent motion in the scene that can be incorrectly interpreted as an event of significance. In the visible and near IR wavelengths, typical causes of such apparent motion are moving shadows or headlight reflections cast by passing street traffic. Figure 3, for example, shows a traffic image where vehicles in one lane cast shadows into adjacent lanes that should not be detected as vehicles. Other sources of apparent motion present in all wavelengths can be rustling leaves, swaying branches, moving clouds, and blowing curtains.

Figure 3. Daytime traffic scene .

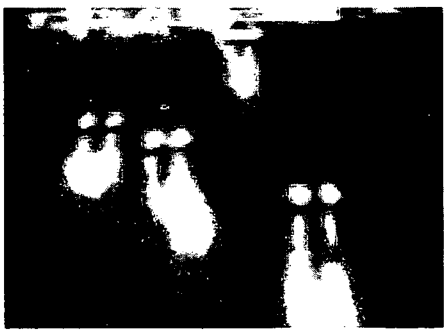

Figure 4. Nighttime traffic scene. Vehicle bodies are hard to distinguish, and headlight reflections are present.

To date, Sarnoff has developed and deployed unmanned surveillance systems for two commercial applications that have confronted the above issues. The first of these is a video-based vehicular traffic monitoring system that is used to measure traffic data (e.g., volume and average speed) and detect vehicle presence at traffic lights. To do so, it uses cameras mounted above or adjacent to roadways. Figures 3 and 4 show typical views from these cameras. The system, developed under contract to a leader in the traffic control industry, operates by detecting differences between the current image and an automatically-updated "reference" representation that characterizes the scene as it would appear if no vehicles were present. These differences are grouped into symbolic "fragments", which are classified based on their appearance and texture as either "vehicle", "shadow", or "headlight reflection". The classification method used depends on which of three operating modes (day, day with shadows, and night) the system automatically determines is appropriate [10]. The "vehicle" fragments are then clustered and symbolically matched between successive frames using a predictive model, enabling vehicle counting and speed and proximity logging. In addition to reducing false positive counts due to vehicle shadows or headlight reflections, the system is also capable of selectively filtering the logged traffic data so as to count only those vehicles that are moving in a certain direction, thereby avoiding detection of vehicles that may only be crossing perpendicular to a traffic lane rather than moving along it. The software runs on a cost-effective Vision Processor Module (VPM) consisting of three 3U VME boards that was completely developed at Sarnoff. The VPM is capable of monitoring up to 4 cameras at 7.5 Hz per camera, and can simultaneously compress and transmit to a remote workstation imagery using a Laplacian pyramid representation [5]. Further details are presented in [10].

The symbolic fragment-matching approach to tracking that is used in the traffic monitoring system is appropriate when objects of interest are well-spaced and appear against a background with limited texture (e.g. a highway). For applications involving tracking individuals or looking for certain events within a large field of movement (e.g. within a crowd) the use of optical flow data is necessary. Our second commercial unmanned surveillance system can be applied to such domains and has been developed for monitoring foot traffic at the exits of airport terminals to ensure that no intruder can enter the terminal through the hallway that is used by exiting passengers. In most airports today, a guard stands at the hallway to fulfill this purpose. (In a much-publicized incident last year, a reporter infiltrated a New York City airport terminal through such a hallway while the guard was distracted.) The Sarnoff system uses optical flow (computed as in [6] to identify motion in the "illegal" direction as distinct from motion in the allowed direction and sounds an alarm upon such a detection. It runs on the same Sarnoff VPM hardware as the traffic monitoring system described above.

5. Future Capabilities

Sarnoff is continuing to improve upon the above unmanned surveillance systems and is developing new algorithms to further decrease false positive detections while at the same time increasing the probability of detecting true events. Chief among these improvements is the use of stereo pairs of cameras for detection. By using a pair of stereo images, the shape of 3D surfaces in the scene can be recovered. This can be a powerful cue for discriminating true objects from illumination artifacts such as shadows and headlight reflections, and Sarnoff has developed several cost-effective vision systems capable of performing this form of stereo at real-time video rates. A second improvement is the ability to detect moving targets from a moving platform such as an overhead helicopter [11]. Additional capabilities are also under development that will further increase system autonomy, such as automatic camera aiming and zooming to keep a moving target in the field of view.

We conclude by describing a hypothetical unmanned video surveillance system that could be implemented within the next few years. Consider the problem of monitoring activity at a remote landing strip. Rather than dispatching an agent to watch the airstrip, an covert unmanned surveillance system could be installed. The system would periodically pan the camera across the airstrip, 24 hours a day, until it detected significant salient motion such as a plane landing or ground vehicles arriving. It could then track the activity, constructing a synopsis mosaic such as the one shown in Figure 1, and log additional data as required. This data could then be downloaded via radio modem to a control center where it could be analyzed, and any appropriate operations taken as a result of the analysis.

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ImageBase™

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ABSTRACT

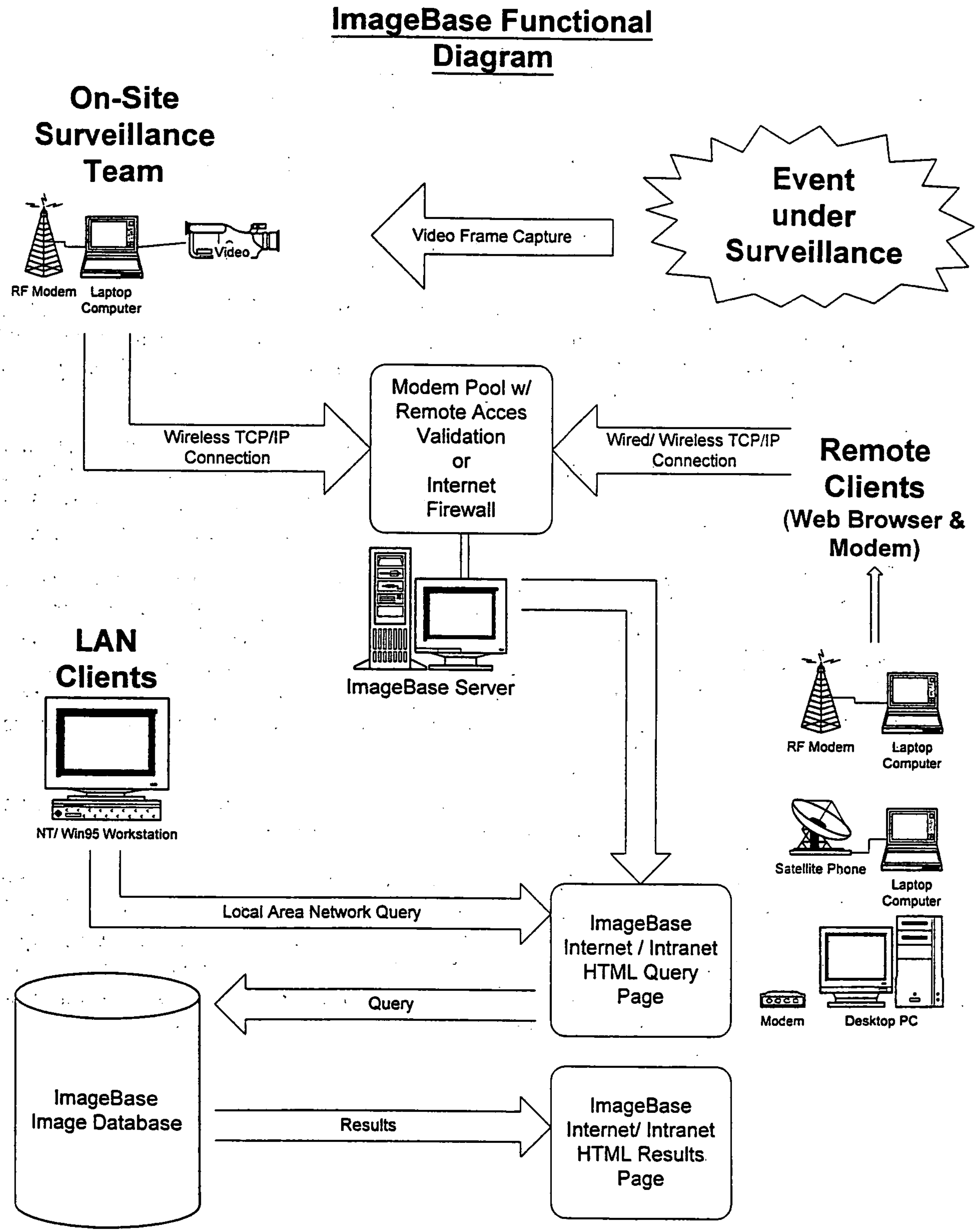
ImageBase **™** is a Server / Client Application that utilizes Windows NT and Windows '95 operating system. It transmits ***frame video images*** from field to base and out to field, utilizing standard NTSC, PAL, SVHS video, over ***wireless*** networks. It is a dynamic internet / intranet browser base query / retrieval system.

The purpose of ***ImageBase*™** is to provide **wireless** real time data from an event to related remote agents thereby allowing near real time wireless consultation via a WAN to multiple parties in a simultaneous fashion. This system is designed to work in conjunction with one's existing mode of communication whether it be radio or phone.

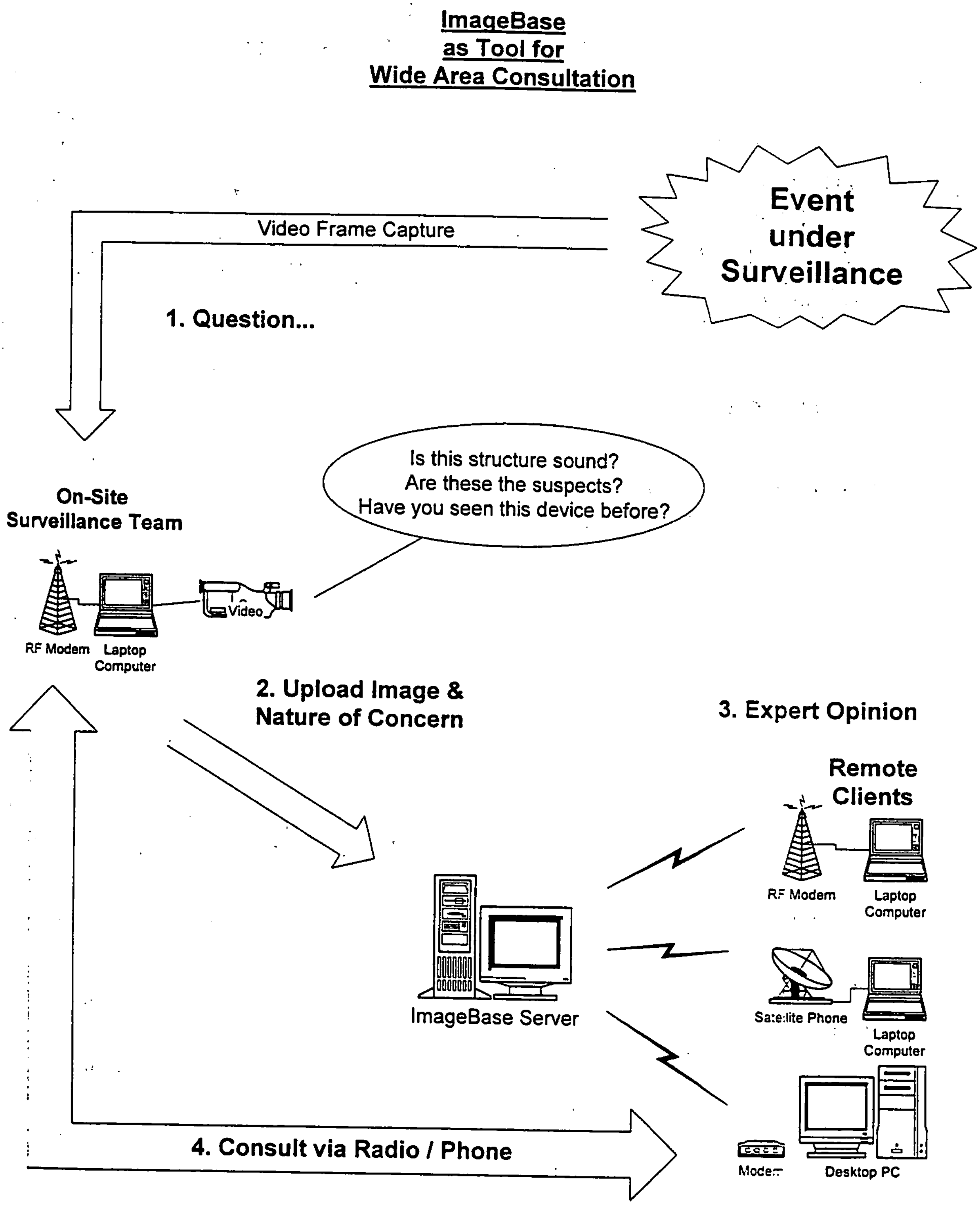
The evolution of ***ImageBase*™** began in 1992 with the secure wireless transmission of ECGs (electrocardiograms) to physicians via a pager and a palmtop computer. This technology evolved through a partnership with *CTAC* and ***Data Critical Corporation*** which began in 1994 where ImageAPB™ was initially developed. ImageAPB™ allowed **FBI** test-bed agents equipped with pagers and small palmtop computers to *wirelessly transmit encrypted* images (mugshots) to their field agents. Today in a test bed with **DEA** we have evolved ImageAPB™ to ***ImageBase*™**.

Key issues with **ImageBase™** are coverage, cost, availability, bandwidth, transmission speed and security of the wireless network as well as the server network.

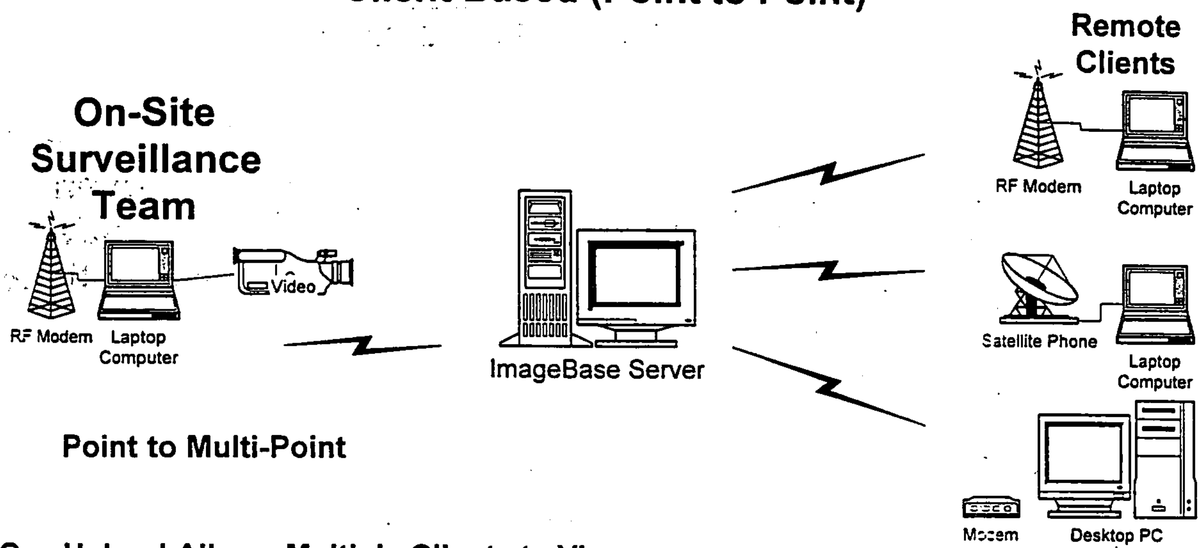
The initial application in the ***Drug Enforcement Agency*** **(DEA)** test bed was to enhance a surveillance setting by capturing an event(s) on a standard video camera and efficiently transmitting it over secure wireless network(s). This gives remote agents the ability to dynamically review new data and to comment back and forth to other team members relative to the most current operational information. ***ImageBase*™** allows the team leader to continuously on-the-spot make operational and time critical decisions.



ImageBase Functional Diagram
On-Site Surveillance Team
Video
RF Modem
Laptop Computer
Video Frame Capture
Event under Surveillance
Modem Pool w/ Remote Acces Validation or Internet Firewall
Wireless TCP/IP Connection
Wired/ Wireless TCP/IP Connection
Remote Clients (Web Browser & Modem)
ImageBase Server
LAN Clients
NT/ Win95 Workstation
RF Modem
Laptop Computer
Satellite Phone
Laptop Computer
Modem
Desktop PC
Local Area Network Query
ImageBase Internet / Intranet HTML Query Page
Query
ImageBase Image Database
Results
ImageBase Internet/ Intranet HTML Results Page


ImageBase
as Tool for
Wide Area Consultation
Event
under
Surveillance
Video Frame Capture
1. Question...
Is this structure sound?
Are these the suspects?
Have you seen this device before?
On-Site
Surveillance Team
Video
RF Modem
Laptop
Computer
2. Upload Image &
Nature of Concern
3. Expert Opinion
Remote
Clients
RF Modem
Laptop
Computer
ImageBase Server
Satellite Phone
Laptop
Computer
Modem
Desktop PC
4. Consult via Radio / Phone

ImageBase is Server Based (Point to Multi-point)
vs.
Client Based (Point to Point)

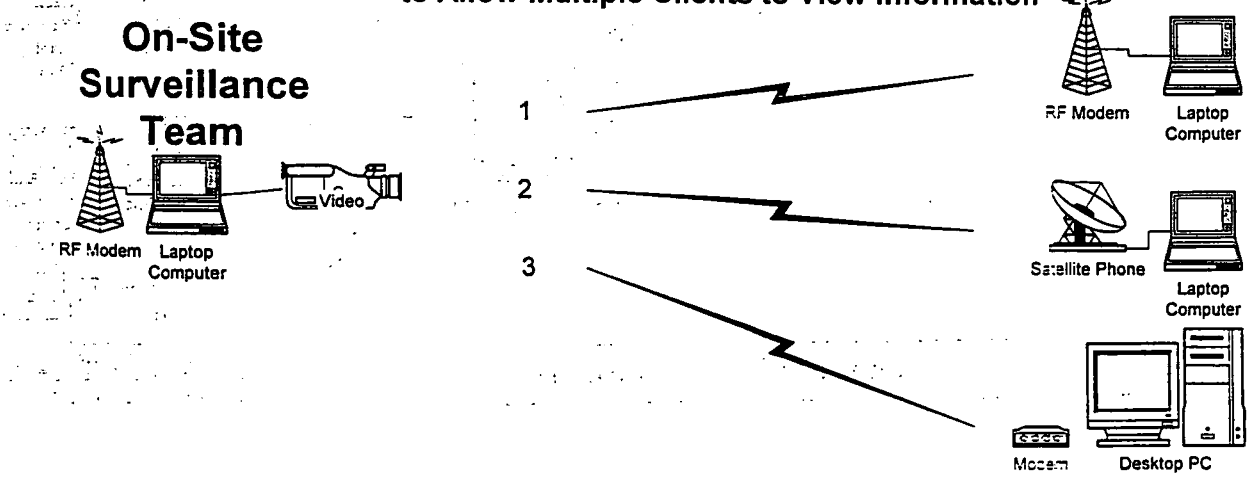


Point to Multi-Point

One Upload Allows Multiple Clients to View Information

Point to Point

Multiple Uploads must be completed to Allow Multiple Clients to View Information



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6

Information Systems Methodologies (Session 3B-3)

SIMS: INTEGRATING HETEROGENEOUS, DISTRIBUTED INFORMATION SOURCES

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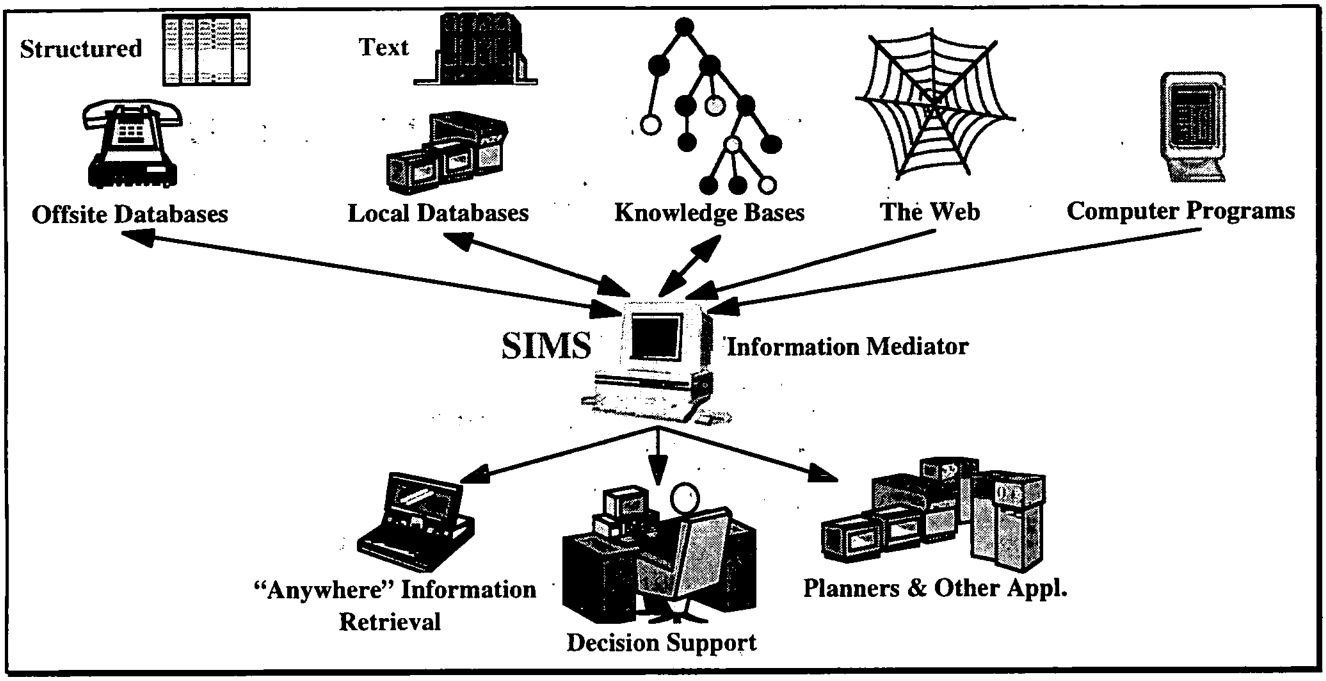
ABSTRACT

Even when databases can easily be accessed electronically, their heterogeneity with respect to contents, query language, semantics, organization, etc., still presents serious obstacles to convenient querying. The querying user (or system) must break down a retrieval task into a sequence of specific queries to sources, must formulate the queries in the appropriate languages, and must handle the temporary storing and possible transformation of intermediate results – all this while satisfying constraints on reliability of the retrieval process and its cost.

The SIMS (Single Interface to Multiple Sources) system addresses this global integration problem. It does so by defining a single language for describing the domain about which information is stored in the databases and using this language as the query language. Each information source is modeled using this language. The model describes a source's contents, organization, and other relevant features. SIMS uses these models, together with a planning system drawing on techniques from Artificial Intelligence, to decompose a user's high-level query into a series of queries against the sources, and other data manipulation steps. The retrieval plan is constructed so as to minimize data movement over the network and maximize parallelism to increase execution speed. SIMS can recover from network failures during plan execution by obtaining data from alternate sources, when possible.

SIMS currently supports access to relational databases, some network and text databases, and information in Web pages. The research is funded by DARPA and has been demonstrated in the domains of logistics and medical informatics with new prototypes currently being developed for the field of battlefield awareness.



1. Introduction

Much productivity is lost today due to the inability of people in business, the military, industry, and academia to identify and access some of the varied stores of information that exist and may be of use in the performance of their tasks. Even when needed information sources *are* found, the effort – and hence cost – that must go into dealing with the different organizations, access and query languages, and different data formats can be enormous. For example, an intelligence analyst may need information about a plane suspected of being involved in drug transport. Information about plane ownership can be found in one database, controlled and maintained by one agency; information about pilot identity and flight plans filed may be found elsewhere; and information about airports and landing strips in areas of interest are located elsewhere yet. Furthermore, the data in different sources may require the use of different keys for identification of the same people or objects and may use different encoding standards. Collecting all the necessary information will require a large amount of effort that would simply be taken away from more productive analysis tasks. Often, the difficulties involved will mean that potentially helpful information will just not be found.

The problem is that locating, retrieving and combining information is an arduous task. Even if one knows where all information that may be relevant to one's task is stored – and that is *not* typically the case – different information sources organize their data differently, require different access and query languages, and use different formats for what is stored in them. Various government and other initiatives making greater amounts of information available over electronic networks make the matter worse. The problem of providing access to heterogeneous, distributed information sources must be solved to take advantage of new data sources – or even just to make full use of the numerous databases that already exist within even moderately large organizations. Today, people build specialized applications to handle their specific tasks because general tools for integrating and processing information do not exist. Such specialized, custom applications suffer from inflexibility: they are difficult and expensive to modify and are not portable to other application domains.

2. The SIMS* Project at USC/ISI

The SIMS Group at the Information Sciences Institute of the University of Southern California has been engaged in research and development efforts on the problem described above and related issues for more than six years. The core SIMS system presents an elegant solution to the problem: the

* Single Interface to Multiple Sources.

creation of a knowledge server – an information mediator. In the SIMS system the query is presented to the mediator in a language that is independent of the distribution of information over available sources, of the various query languages, the location of data- and knowledge- bases, etc. To obtain the data, SIMS goes through several steps: analyzing the high-level user query to identify potential sources of useful data, breaking down the user's query into a series of queries to be made to sources of relevant data (the *query plan*), optimizing the query plan for enhanced efficiency, and finally executing the optimized query plan. *Wrappers* around the different information sources take care of any translation and reformatting needed between SIMS' internal data and query formats and those of the wrapped source.

To perform its task SIMS utilizes techniques from Artificial Intelligence, including *knowledge representation,* to create models of the application domain and the available information sources, and *planning,* to create the query plan. *Learning* and *data mining* are used to support semi-automated modeling and system setup.

In SIMS,

- The user requests information using **domain terms**, referring to entities and actions that make sense to people who engage in the targeted application – and who are not expected to know exactly where and how the data they need is stored.
- A plan is devised for obtaining the information from multiple sources, while insulating the user from the need to make any reference to:

  –information distribution, source structure, languages;

  –dependencies among needed data;

  –data formats, intermediate data storage and manipulation;

  –efficiency.
- The SIMS system monitors execution of its query-plans to ensure robustness. It currently supports:

  –Recovery from execution-time failures;

  and the SIMS group is in the process of developing mechanisms for:

  –sensitivity to bandwidth and load;

  –addressing data reliability and inconsistency considerations;

  –automatic full/partial source replication.
- The knowledge of the SIMS system about each information source is modular and independent of its knowledge of other sources, supporting:

  –simple incorporation of new information sources;

  –simple maintenance of existing information sources;

  –semi-automated support for system setup and administration.

It should be noted that by declaratively modeling structure, content, and other characteristics of information sources, the SIMS approach provides a solution to the problem of incorporating legacy databases into a more modern and powerful information retrieval system. The old systems are not changed or rewritten. Instead, SIMS uses their descriptions (i.e., models) to reason about how to access their data, which it can then process further or join with data from other systems, as needed.

Existing SIMS prototypes obtain information from multiple structured databases, knowledge bases, text databases and/or Web pages in several application domains. Many of the sources are on remote machines, some across the continent. SIMS accepts queries from both humans and other computer systems. Numerous papers describing aspects of SIMS have been published, some of those are listed below. Specifically, papers have provided details on the following topics:

- Query processing [2, 3, 9, 10, 11]
- Semantic query optimization [8]
- Knowledge discovery and learning [4, 5, 6, 7]
- Information caching [1]
- Information agents [12, 13]

Additional information can be obtained from the authors and from the SIMS project Web page, http://www.isi.edu/sims.

3. Acknowledgment

The SIMS system and prototypes are based on contributions from all members of the SIMS Group at USC/ISI. In addition to the author of this paper, who head the SIMS project, past and present group members include: Chin Chee, Craig Knoblock, Steve Minton, Jay Modi, Maria Muslea, Andrew Philpot, Wei-Min Shen, Wayne Zhang, José-Luis Ambite,

Naveen Ashish, Ion Muslea, Sheila Tejada and short term student contributors.

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Joint Interoperability and Database Compatibility for the Counterdrug Intelligence Community

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ABSTRACT

An effective defense against organized criminal drug enterprises, usually international in scope and essentially stateless, requires cooperation and effectiveness between the intelligence and law enforcement communities. The required cooperation and effectiveness, not previously practiced or envisioned, must be instituted in a manner that fully complies with all laws and regulations and protects the rights of all citizens. This paper describes a technical concept to provide information sharing among the federal law enforcement, intelligence, and defense counterdrug communities, and introduces the United States Department of Justice National Drug Intelligence Center and the Technical Advisory Board. Information sharing requires compatible communication, database sharing, and protection of information which may be provided from systems that are disparate and comprised of considerable legacy information. Our technical approach examines the use of the Antidrug Network (ADNET) to provide low cost, secure, private, and compatible communication for the counterdrug community. The technical approach also examines the use of virtual database technology introduced to us by the National Security Agency OpenRoad project and by the Mitre Corporation. Data sharing within the counterdrug community depends on mutual confidence about data protection of both classified and law enforcement sensitive information. Our technical concept includes the application of Standard Generalized Markup Language (SGML) technology for data tagging. Data tagging provides protection, audit, and the additional benefit of expedient analysis.

The National Drug Intelligence Center (NDIC) was created by Congress to fill a need in the counterdrug community—to provide more and better strategic intelligence necessary for fighting the threat posed by drug trafficking organizations. It has been long recognized that providing counterdrug agencies with timely multi-source assessments and analyses about drug trafficking organizations is beyond the capabilities of operational or policy-charged agencies. NDIC is a strategic intelligence center, however, and as such, fills this intelligence requirement as an independent component of the United States Department of Justice.

What is NDIC?

- Established by Congress
- Component agency of DoJ
- Counterdrug strategic intelligence center
- Produces strategic assessments and analyses
- Richard Cañas is the current Director
- Approximately 250 personnel at the NDIC

NDIC is unique within the counterdrug community for its scope, objectivity, and commitment to support integrated strategic planning and national policy. NDIC produces requested assessments and analyses on drug trafficking organizations with enough specificity to assist the tasking enforcement agencies with their investigative initiatives, yet general enough to provide strategic value to the overall community. NDIC explores open-source material and keeps up with the activities of the counterdrug community in search of emerging trends and patterns.

Background

- **1990:** National Drug Control Strategy calls for a strategic intelligence center
- **1991:** DoD Budget includes $10M for NDIC
- **1992:** DoD Budget includes $40M for NDIC
- **1994:** Director of Investigative Policies (DIAP) issues resolution identifying NDIC as the primary DoJ center for Strategic Organizational Drug Intelligence
- **1996:** NDIC included in Community Management Staff budget
- **1996:** Attorney General's Executive Order implements NDIC's current mission and charter

NDIC is a neutral broker without investigation or operational charter. It's primary interest is to obtain information from multiple sources, correlate and fuse the information for added value and return that information as counterdrug intelligence for use by the community. While NDIC's mission is specific to the counterdrug effort and not as broad as other agencies in the department, that focus permits and encourages quick success on a limited scale that can later be expanded in scope.

How NDIC fits

- Is a neutral broker–no operations
- Produces intelligence to dismantle drug trafficking organizations
- Collects, automates, correlates, fuses, and analyzes information from multiple sources
- Promotes and protects information sharing
- Promotes compatible procedures and technology

NDIC's mission is to coordinate and consolidate strategic organizational drug intelligence from national security and law enforcement agencies in order to produce requested assessments and analyses regarding the structure, membership, finances, communication, transportation, logistics, and other activities of worldwide drug trafficking organizations. To carry out this mission NDIC needs information from multiple sources.

NDIC Mission

To coordinate and consolidate strategic organizational drug intelligence from law enforcement and national security agencies in order to produce requested assessments and analyses regarding the structure, membership, finances, communication, transportation, logistics and other activities of drug trafficking organizations.

From 1979 until the present, Congress and the GAO [1] assessed electronic system connection, interoperability, and information sharing within the counterdrug community to be a failure. This assessment was derived when examining the problem from many perspectives. GAO criticism and Congressional direction to fix the problem is largely on target. For the most part, information handling systems used within the counterdrug community in the past could not connect with one another or exchange information in a manner that allowed rapid correlation and fusion of strategic or tactical counterdrug information. At NDIC, connection to the sources is no longer a major problem. NDIC personnel routinely connect to more than 30 counterdrug community sources and can select from thousands of open sources.

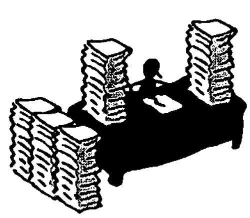
Connection

- Connecting to sources is not a technology problem
- NDIC connects to about 30 counterdrug community sources and can select from thousands of open sources

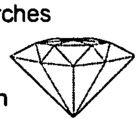
The larger problems are finding and integrating usable information from not only counterdrug community sources, but also open sources. Open sources, especially, can be overwhelming. The challenge is to glean the critical and pertinent information, about 5 percent on average, from the other 95 percent of relevant information.

Finding Information

The volume of Open Source information can be overwhelming



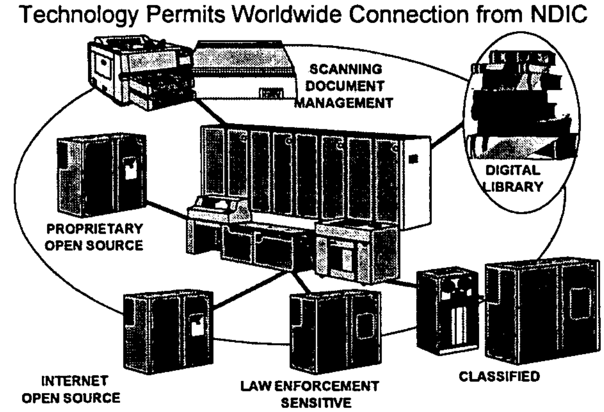
Good searches yield 5 % usable information



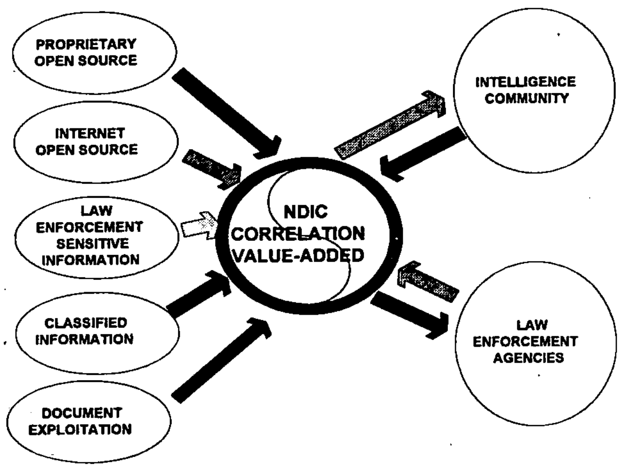
The remaining 95 percent is

There are over 30 federal information systems that contain primary counterdrug information. Three examples of these federal information systems are the DEA's NADDIS (Narcotics and Dangerous Drug Information System), the FBI's NCIC (National Criminal Information Center), and Treasury's TECS (Treasury Enforcement Communication System). There are also thousands of federal, state, local, and open source information systems that contain valuable complementary counterdrug information. This information, however, is in hundreds of different formats and from many different kinds of communication and computing systems.

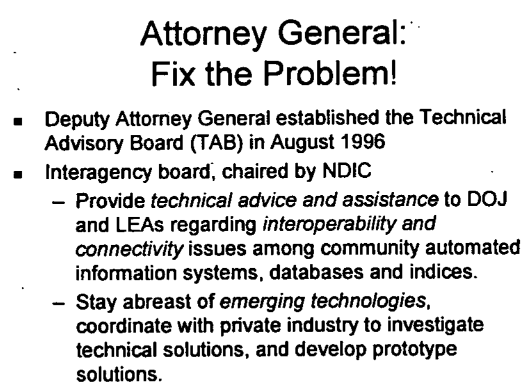
Technology Permits Worldwide Connection from NDIC



Previously, if this information was correlated and fused, it was done so by "cutting and pasting"—a process too complex and laborious to be cost effective. Missing is a common connection and mutual operability. Surely technology provides methods to integrate this information without requiring a community of users to comply with archaic and lock-step communication, computer, and software standards. Users should be able to access any complementary computer system using a method common to all systems and, at the same time, assure the contributor that the information and source will be completely protected.



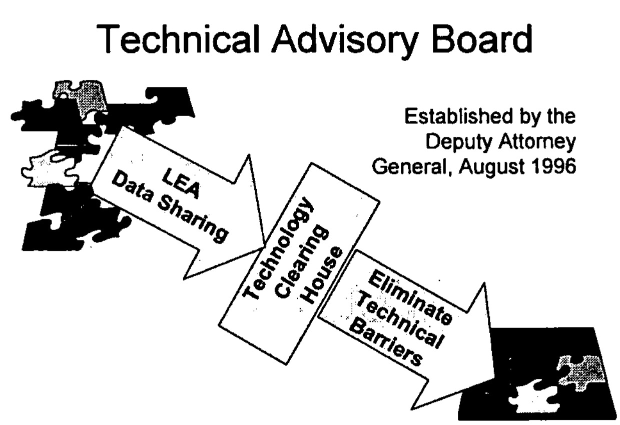
The United States Attorney General said, "fix the problem." In response, the United States Deputy Attorney General established in August 1996 the Department of Justice Technical Advisory Board (TAB) as an interagency board chaired by the NDIC.



TAB membership is composed of representatives from

- National Drug Intelligence Center (NDIC)
- Bureau of Alcohol, Tobacco, and Firearms (ATF)
- Federal Bureau of Investigation (FBI)
- Drug Enforcement Administration (DEA)
- Intelligence Systems Secretariat
- Office of National Drug Control Policy (ONDCP)
- U.S. Coast Guard
- U.S. Customs Service
- U.S. Department of Justice (DOJ); and
- U.S. Department of the Treasury's FinCEN.

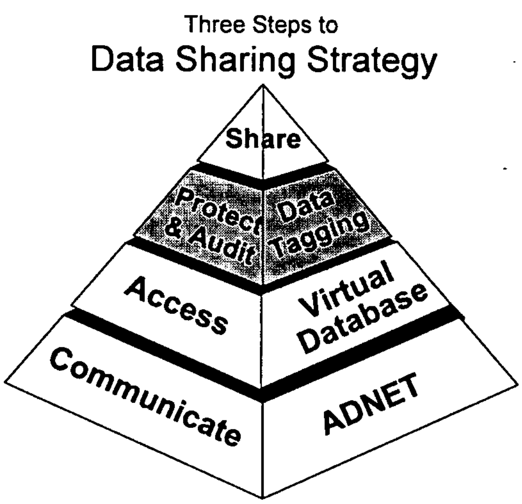
The Technical Advisory Board members were directed to examine and define database connectivity and interoperability problems with the goal of eliminating technical barriers to cross-agency data sharing. The TAB provides technical advice and assistance to the Department of Justice and law enforcement agencies regarding interoperability and connectivity issues among community automated information systems, databases, and indices. The TAB is responsible for staying abreast of emerging technologies, coordinating with private industry to investigate technical solutions, and developing prototype solutions using both commercial- and government-off-the-shelf products. By direction of the TAB Charter, the TAB Chairman reports the results of the TAB actions to the Director of the NDIC and to the Deputy Attorney General's NDIC Executive Advisory Board. In this formula, the NDIC operates as a technology clearing house with the objective of eliminating technical barriers that might constrain the National Drug Control Strategy and Policy which mandates data sharing.



There are five core issues related to the mandated implementation of data sharing:

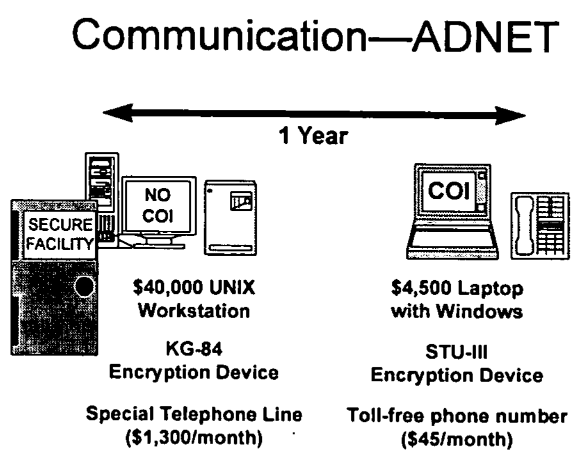
- Connection among different kinds of counterdrug information systems.
- Correlation of data from one system with similar data from other systems and sharing of results.
- Implementation of a common user interface to access all systems.
- Protection of special information shared between systems.
- Exploitation of the added value.

To address the core issues above, the TAB has established a 3-step strategy to implement data or information sharing, as illustrated by the pyramid below. For the goal of effective information sharing to be reached, the 3 steps of the foundation must first be in place.



First, agencies must be able to connect and communicate data and do so simply, securely, and at low cost. Second, after receiving data it must be possible to integrate and use it. Third, data providers must be assured that their data is protected and audited during every step of the sharing process. These three foundation steps must be built before the apex, data sharing, can take place. The following slides outline what the TAB is doing now and where we intend to be in the next six months. This paper refers principally to the federal counterdrug community, not because state and local members of that community are not integral, but because our focus is to build the federal level first.

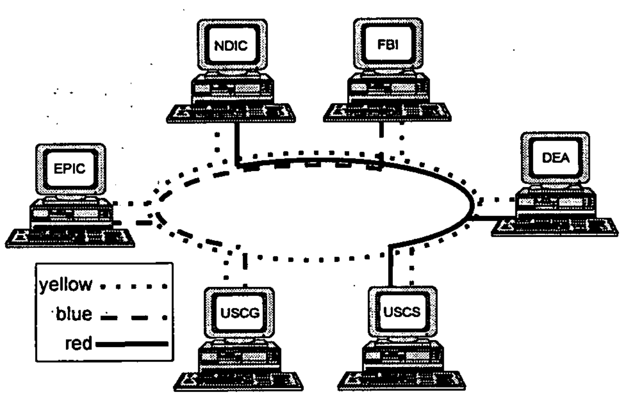
Our first foundation step—communication—is in place. The Department of Defense Information Systems Agency (DISA), provides a secure AntiDrug Network (ADNET) with access to Intelink for members of the federal counterdrug law community. ADNET is a DoD provided Internet-like, secure, communication system linking all the major federal law enforcement and Department of Defense counterdrug-associated organizations. The Deputy Attorney General and Director Central Intelligence instructed the TAB to evaluate the community's use of ADNET. During our 1996 review, the TAB found that ADNET was not being used to its full potential. The TAB identified several technical and equipment problems that limited wider use.



In 1996, ADNET sites required an expensive secure facility, a $40,000 Unix workstation, an expensive KG-84 encryption device, and a special $1,300 per month telephone line. One year later, ADNET is now accessible using only a $4,500 laptop, a STU-III encryption device, a toll-free telephone number, and a $45.00 per month telephone connection. The ADNET program office reduced the cost by a factor of ten and eliminated many of the onerous security impositions while increasing overall security. Today ADNET can be used virtually anywhere by any authorized counterdrug officer. ADNET is secure and protected, from the unclassified level to the Top Secret level with compartmented access. ADNET will soon provide a community of interest (COI) privacy feature needed by law enforcement agencies and task forces to protect sensitive law enforcement information to a strict need-to-know. In addition, ADNET will provide a family of collaborative data sharing tools—hyper news, multicast audio and video, and whiteboard tools—to enhance data sharing and joint analysis.

Information about sensitive sources and information required for indictment and prosecution require strict need-to-know protection and special handling; case privacy is an absolute requirement. Consequently, ADNET users will be able to have full ADNET connection, while also being able to participate in private community of interest links called COI.

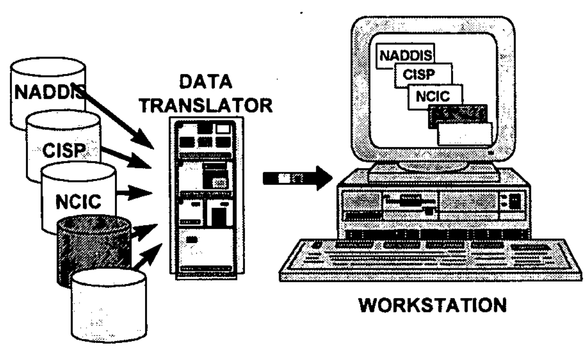
Communities of Interest



The Communities of Interest diagram above shows all ADNET users with the yellow (dotted) line. The red (solid) line shows an example COI comprised of NDIC, DEA and USCS. The blue (dashed) line shows another example COI comprised of USCG, EPIC and FBI. The red and blue COI users are invisible to one another. As a direct result of the TAB's work in this area, ADNET has gone from very limited use by participants to being recommended by the FBI and DEA as the communication and analytical tool for the newly created collaborative major criminal organization Joint Task Force.

The second foundation step to data sharing is access. After sending and receiving information over ADNET, users must be able to easily access that information. All agencies have their own data and information systems. Each system is unique, serves proprietary requirements peculiar to each agency, and is not designed to communicate with other systems. Three examples of those systems are the DEA's NADDIS (Narcotics and Dangerous Drug Information System), the FBI's CISP (Criminal Intelligence Support Program) and the FBI's NCIC (National Criminal Information Center). Currently a separate terminal is required to access each system. A translation device we generically refer to as a "data translator" is needed to provide a standard user interface and access point to the many counterdrug information and data systems.

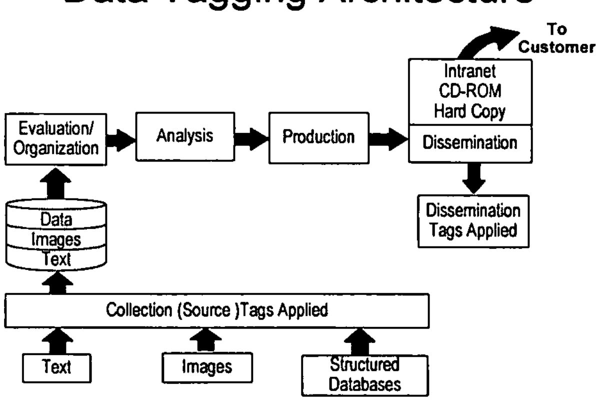
Data Access—Virtual DB



Off-the-shelf technology will within a year provide the capability to exchange information among a wide variety of structured relational databases used by the federal law enforcement, intelligence, and defense communities. This will be done by automatically interpreting and converting data from multiple sources, including legacy data, to a common user front-end. The ability to also share information from multiple free text sources and a wide variety of formats is only slightly behind. The TAB is sponsoring demonstrations by potential candidates using law enforcement type information. Pointer systems like the National Drug Pointer Index (NDPIX) system point users in the right direction faster than before, but the ability to share large amounts of data requires a "virtual database." Prototypes are currently being tested by the intelligence community and DoD. The TAB is evaluating several prototype COTS "data translators" applied in both the intelligence community and industry. Results to date have been very encouraging.

The third foundation step to data sharing requires data protection and audit of information released by one agency for use by others. Contributing agencies must be assured that their information will be protected and audited during every step of the intelligence production and distribution cycle. The TAB solution to this requirement is called data tagging. Data tagging "paints" pieces of information with permanent and transparent markers or tags conveying ownership, protection, use, restrictions, and other controls.

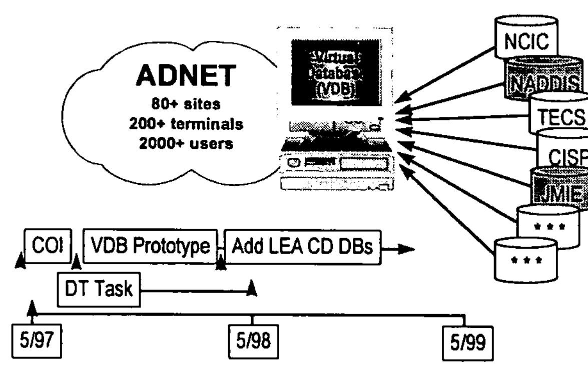
Data Tagging Architecture



The controls remain with the data when cut and pasted elsewhere. As data from multiple sources is processed, the source, organization, analysis, and distribution tags are attached to the data elements. This allows faster data processing and also apprises the "owners" of the data where and how their data was used and protected during the production of intelligence products at NDIC. Data tagging will provide both protection and expedient handling of data sharing between law enforcement and intelligence agencies. A core technology applied for data tagging is Standard Generalized Markup Language (SGML). A contract to implement this capability within NDIC is imminent.

Once the three foundation steps are in place, effective and secure data sharing will be possible. The TAB goal is to combine the three foundation steps into one seamless system that results in the data sharing apex. This will enable all members of the federal counterdrug community to access, when authorized, each other's data using ADNET terminals and assure that the use of the data is protected and audited.

Data Sharing Concept



We see a partnership created among the federal law enforcement community, the Department of Defense, and industry that will remove all technology barriers to real and secure data sharing for the counterdrug effort.

[1] Drug Control: Actions Needed to Improve Automated Information Sharing (GAO/NSIAD-94-2, October 1993).

CLIENT/SERVER DESIGN FOR VERY LARGE IMAGE EXPLORATION

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ABSTRACT

Spherical imaging is a new technology with a wide range of potential applications in counter-narcotics. Applications range from conducting virtual tours of crack houses as an aid to planning drug raids, to providing comprehensive documentation of crime scenes. A spherical image enables users to interactively explore a 360-degree panoramic view of any environment in any direction and with a wide range of magnification. This technology is being successfully used in commercial advertising applications. Several improvements to the current state of this technology must be made before it can become a useful tool for law enforcement, the most serious of which is limited resolution. The Laboratory for Information Technology (LIT) is developing methods that enable very high-resolution spherical images to be interactively navigated within a secure networked environment. The paper provides an overview of spherical imaging, and describes the implementation currently being developed by LIT.

1. Introduction

Drug enforcement agents often enter life-threatening situations in their battle against illegal drug trafficking. Crack house raids are a particularly dangerous example: Drug dealers are generally well armed, and lookouts often are positioned to provide an advance warning of an impending raid. Since events take place rapidly during a raid, a high degree of preparation and mission planning is required to minimize the risk to law enforcement personnel. Furthermore, experience indicates that drug trafficking is frequently re-established in the same location, requiring follow up raids. The safety of this team could be improved if the agents could take a computer generated "virtual tour" of the crack house while planning the operation. This virtual tour would enable agents to examine every room in any direction and navigate from room to room, enabling them to form a mental picture of the structure's layout

A virtual tour can be generated by linking together a sequence of "spherical Images." A spherical image represents a complete 360 degree panorama of an environment from a given vantage point. The simplest approach to creating a spherical image is to record two 180-degree field-of-view fisheye images on photographic film. These images can then be scanned and digitally recorded. Another processing operation allows the images to be joined at the seam, and saved as a compressed bitmap. A portion of the spherical image can then be displayed on a computer monitor without distortion and in any direction. Details of the spherical image can be examined by increasing the level of magnification. Since the amount of information displayed in a fixed size window on a computer monitor is constant, increased magnification also reduces the field-of-view. By reducing the magnification, the field-of-view is increased, giving a broader perspective of the environment.

A virtual tour of a crack house is only one application of spherical imaging which may be applied to counter-drug operations. Comprehensive documentation of crime scene evidence is another example that is relevant to all branches of law enforcement, including counter-narcotics. High-resolution spherical imaging is ideal for documenting crime scenes since it:

- *Provides an accurate archive of a crime scene in all directions.* High-resolution spherical images reduce the risk of inadvertently failing to photograph regions of a crime scene that might contain relevant information. Nothing visible from a selected vantage point can be inadvertently excluded.
- *Preserves spatial relationships.* A spherical image provides incontrovertible proof of the relative location, size and orientation of items of evidence before they are handled for forensic examination. This cannot be done with traditional photography since it is generally not possible to include widely separated items in the same photograph.
- *Assists witnesses' ability to recall details of a crime.* A witness can navigate and explore a crime scene as if it were one continuous panorama. Details of a crime are easier to recall if witnesses can "immersively" view the crime scene within a well-defined context.
- *Enables additional information to be extracted.* A spherical image can be viewed in any direction with varying levels of magnification. In addition, any orientation of the viewing plane can be specified, enhancing the investigator's ability to extract useful information. For example, a handwritten note on a table surface can be made easier to read by properly adjusting the viewing parameters.
- *Provides a basis for planing law enforcement operations.* Investigators at different locations on a secure network can analyze spherical images and add annotations that can be shared with other investigators in their work group. Compared to conventional white boards, ambiguity is eliminated since annotations can be made within a well-defined context. For example, an agent may circle the entrance to a crack house, which is then shared with other agents working the case. There is no confusion since the entire environment around the crack house can be observed giving context to the annotation. Spherical imaging enables collaboration to be done effectively in a distributed environment.

The spherical imaging technology was initially developed by Interactive Pictures Corporation (IPIX), of Knoxville, TN, and is already in commercial use for advertising applications. A spherical image is called a PhotoBubble by IPIX. The technology, as implemented by IPIX, has several significant limitations that must be resolved before it can become a useful tool for law enforcement. The most serious limitation is the low resolution that results from projecting the large amount of information contained in a fisheye image onto the relatively small exposure area of a 35mm negative. A second limitation is the excessive time and effort required to stitch together, or seam, multiple fisheye images to generate a full 360-degree spherical image.

Methods to resolve these limitations have been developed by LIT. The remainder of this paper provides an overview of spherical imaging as well as improvements to this technology made by LIT.

2. Spherical Imaging

A spherical image can be created from two hemispherical images taken in opposite directions. The first image is taken with the camera facing in the "forward" direction. The front coordinate frame, C_f, is embedded in the camera as illustrated in Figure 1. The back image is taken with the camera in the C_b coordinate frame, which is found by rotating the camera 180 degrees relative to the Y axis of the C_f frame. Figure 2 shows the circular images that would be obtained from the camera in both orientations. Pixels in the front image are referenced relative to the front image frame, I_f, and pixels in the back image frame are referenced relative to I_b. The relationships with the camera frames are also shown in figure 2.

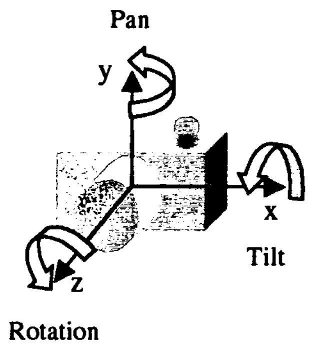

Figure 1: The front camera frame. C_f

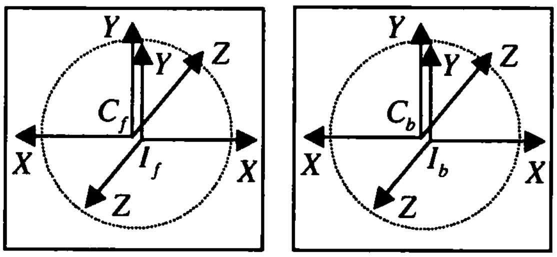

Figure 2: The front and back image frames, I_f and I_b.

Conceptually, the image frames I_f and I_b can be thought of as being attached to opposite sides of an "image" plane as illustrated in Figure 3. The fisheye lens maps light rays directed towards the center of the lens to pixels in the front and back image planes. To obtain an undistorted view of the image, pixels in the image planes must be re-mapped back to the display plane, D, with the inverse of the mapping process used by the fisheye lens. The display plane may be a computer monitor used to view the image. The location of the image plane on a sphere of radius mR is determined by the pan (θ_{pan}) and tilt (θ_{tilt}) angles. The radius of the image is R, and the current level of magnification is given by m. The rotation angle (ϕ), and the horizontal (ϕ_h) and vertical (ϕ_v) tilt angles determine the orientation of the display plane.

Since the display plane can be positioned with six degrees of freedom ($\theta_{\text{pan}}, \theta_{\text{tilt}}, m, \phi, \phi_h, \phi_v$), it can be placed in any location in the three dimensional space, and with *any* orientation. The orientation can be manipulated to uncover evidence that might otherwise be difficult to interpret. For example, a handwritten note can be made easier to read by making the orientation of the display plane parallel with the note. The IPIX software does not enable the orientation of the display plane to be specified. Admissibility as evidence in a court of law should not be an issue since the transformations do not change the actual content of the source pixels. Regardless, extracting additional information from crime scene documentation is a valuable asset during any forensic investigation.

An undistorted view of a segment of the spherical image is found by mapping each pixel in the display (D) to pixels (x, y) in the front (I_f) or back image (I_b) frame. The relationship between pixels in frame D and frame I_f (or I_b) is defined by the coordinate transformation:

$$T_{I_f}^{D} = \text{Rot}(Y, \ -\theta_{\text{pan}}) \cdot \text{Rot}(X, \ \theta_{\text{tilt}}) \cdot \text{Rot}(Z, \ -\phi) \cdot \text{Trans}(z, \ mR) \cdot \text{Rot}(X, \ \phi_h) \cdot \text{Rot}(Y, \ \phi_v),$$

where Rot() and Trans() are rotation and translation coordinate transformations. The location of a pixel $p^D = (u, v)$ in the display relative to the front image frame I_f is:

$$p^{I_f} = T_D^{I_f} p^D,$$

where $T_D^{I_f}$ is the inverse of $T_{I_f}^{D}$. A simple trigonometric relationship determines the included angle α between the Z axis of the I_f frame and p^{I_f}. A property of a 180-degree fisheye lens is that light directed towards the center of the lens at an angle α from its axis is refracted to a distance ρ

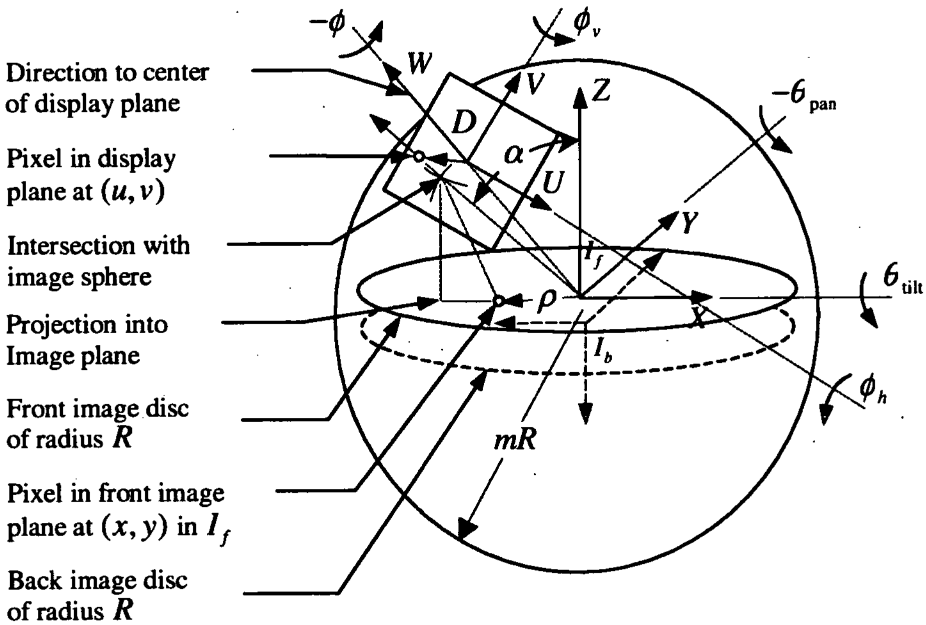

Figure 3: Coordinate frames used to map image pixels to the display.

from the center of the frame I_f:

$$\rho = \frac{2R}{\pi}\alpha.$$

The location of the pixel (x, y) corresponding to (u, v) is found by projecting p^{I_f} into I_f and normalizing its length to a distance ρ from the origin of frame I_f. The sign of the Z component of p^{I_f} determines if the source pixel originates from the front or back image frame.

An equivalent expression for ρ can be found by substituting in a trigonometric relationship for α:

$$\rho = \frac{2R}{\pi}\tan^{-1}\sqrt{\frac{p_x^2 + p_y^2}{p_z^2}},$$

where $p^{I_f} = (p_x, p_y, p_z)$. A look-up table (LUT) enables this expression to be calculated for each pixel in the display in real time:

$$\mathrm{LUT}(\xi) = \frac{2\mathrm{R}}{\pi}\tan^{-1}\sqrt{\xi}; \quad 0 \le \xi \le 1.$$

With the look-up-table, the distance ρ is:

$$\rho = \begin{cases} \mathrm{LUT}(\xi); \quad \xi = \dfrac{p_x^2 + p_y^2}{p_z^2} & \text{if } p_x^2 + p_y^2 \le p_z^2 \\ R - \mathrm{LUT}(\xi); \quad \xi = \dfrac{p_z^2}{p_x^2 + p_y^2} & \text{if } p_z^2 < p_x^2 + p_y^2 \end{cases}.$$

3. Client/Server Design

Spherical images provide a useful method for documenting evidence at a crime. All evidence visible from the vantage point of the camera is included in a single spherical image. The relative size, location and orientation of all items of evidence are preserved enabling investigators and witnesses to view the crime scene as it was *before* evidence was handled for analysis. Spherical imagery is convenient since little time and effort is required to record two fisheye images. With adequate resolution, spherical imaging is a useful tool for documenting crime scene evidence.

Standard 35mm film does not provide the surface area needed to produce a high-resolution spherical image. A low cost prototype camera and fisheye lens has been developed by LIT. This camera can be built from commercially available components with minor modifications. The lens provides a field of view slightly greater than 180 degrees, which greatly simplifies the process of creating a single spherical image. More important, the camera acquires an approximately 80mm diameter image on a 4"x5" negative. Compared to standard 35mm film, this increases the resolution by a factor of 16. In reasonable quantities, the expected manufacturing cost of the camera, lens, and tripod will be approximately $750.

The bitmaps obtained from these high-resolution spherical images are huge. Each fisheye image scanned at the optical limit of high quality film contains approximately $5x10^7$ pixels. Without compression, this translates into roughly 300Mbytes of storage for each spherical image. Due to the large size of these images, it is not practical to transmit the entire content of a spherical image to a client computer used to view it, even with compression. A better approach is to transmit the minimum amount of information necessary to enable *client* viewers to navigate within the spherical image while maintaining a high degree of responsiveness. An image *server* provides blocks of source image data to the client as needed. The same approach can be used to interactively explore *any* large high-resolution image such as more traditional flat panoramas, and is not limited to spherical images.

The user must be able to navigate high-resolution images in *three* dimensions. The first two dimensions determine the region of the image being explored. For example, this is pan and tilt in a spherical image, and *XY* coordinates in a flat image. The third dimension is the magnification, which controls the amount of detail displayed by the client. The image server must provide the client with data from different locations within the image and at multiple levels of resolution. The client application requests segments of source image data at specific levels of resolution. Conceptually, the client assumes data is stored in a multi-resolution segmented format as illustrated in Figure 4. Each segment contains a block of source image data at a level of resolution on a power of two boundary. A lower table of segments L_j contains twice as much detail information in each dimension as the next higher table L_{j+1}. The server does not actually store images like this, since it is wasteful of storage space. Instead, more detailed segments are formed by combining the lowest resolution segment with detailed corrections. With wavelet compression, this provides an efficient method for storing image data at multiple levels of resolution.

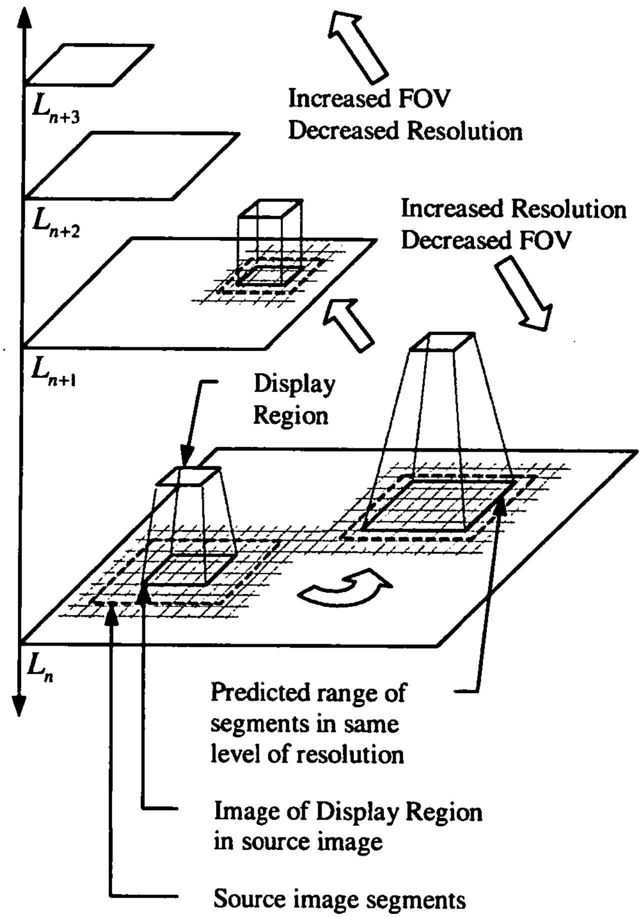

Figure 4: Conceptual model for storing a multi-resolution segmented flat image on the server.

As the user navigates in the image, the client requests segments of image data needed for the current view. When the segments are available, a transformation maps pixels in the source image to the display. This transformation removes the distortion from a spherical image. In the case of a flat image, the transformation is trivial.

Concurrently as the user navigates in the image, the client predicts the next viewing direction, orientation, and level of magnification based on a recent history of the user input. As the viewing direction changes, a *lateral* prediction is done at the current level of resolution. A transition to a higher or lower level of resolution, L_j, is made when the amount of detail that can be displayed increases or decreases to the next power of two. Since the amount of information displayed by the client is constant for a fixed size display window, more detail decreases the field-of-view. Navigation continues at the new level of resolution until a change in magnification causes a transition to a different level. The prediction algorithm mitigates the latency inherent in the network and drastically improves the responsiveness of the client application.

The number of segments of image data stored by the client is bounded to limit the demand on the client computer's resources. If this is not done, the entire image would eventually be loaded by the client application, possibly exhausting virtual memory. An algorithm replaces old segments of image data with segments required for the current view, or close to the current prediction. The limit on segments can be increased for computers with extra memory or disk capacity to improve performance. In the limiting case, the entire image will be loaded on the client computer eliminating all network delay.

4. Prototype Software

A prototype software application was developed to demonstrate the feasibility of the technology. The computer screen display in Figure 4 shows the client viewer and server application which communicate through a TCP/IP connection.

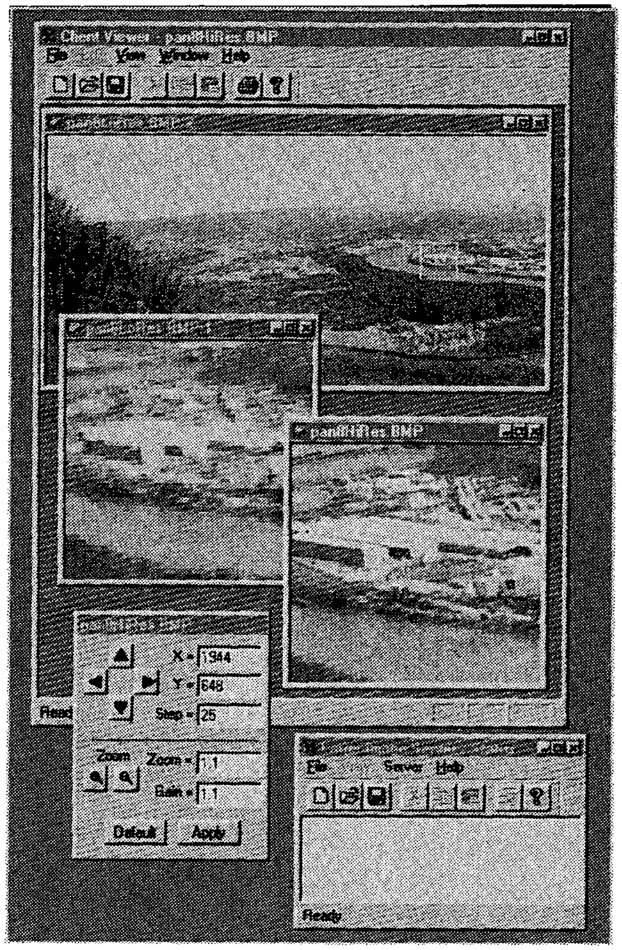

Figure 5: Prototype client/server software to view large images at multiple resolutions.

The viewer is displaying three images. The top image is a low- resolution panorama of a section of the Tennessee River winding around Chattanooga, Tennessee. A magnified view of the inset region is shown in the second image. The third image shows the same region of a second panorama with a 16-fold improvement in resolution. This is the same increase in resolution of the LIT camera compared with the 35mm camera. The software enables the user to quickly navigate anywhere within the panorama. At the same time, the demands on the personal computer running the viewer are minimal, since only very small segments of the overall image need to be downloaded from the server. The server application in the bottom right corner will typically run in the background on a machine configured to provide optimal performance as an image server. The main window of the server will show status information describing activity on the server.

5. Operational Setting

The objective of LIT is to place this software in an operational setting for evaluation after the next phase of the development effort has been completed. Initially, the primary use of this software will be for documenting evidence at crime scenes and performing virtual tours of hazardous environments, such as crack houses. Figure 6 illustrates how the spherical imaging system will fit within a networked environment.

One or more central locations will contain large image servers and high-resolution scanners. After the images are scanned, they will be seamed into spherical images by a separate workstation working in conjunction with the server. The seaming algorithm finds the set of parameters that give the best alignment of the fisheye images across the seam boundary. Since these images overlap slightly, this problem can be fully automated by solving a nonlinear optimization problem. This should not be a legal issue since this process does not change the content of pixels in the source images. The seaming program and server will need relatively little expertise or intervention from law enforcement personnel.

With the current state of technology, high-resolution spherical images must be captured with photographic equipment. An alternative is to use lower resolution digital cameras as illustrated in Figure 6. These cameras can be used for surveillance applications. In fact, a surveillance camera with a "pin-hole" lens has been developed by LIT. Due to its low profile, this camera is ideal for covert surveillance applications. Video may be transmitted to a mobile data acquisition unit with a high speed wireless encrypted modem. Since the camera acquires a 180-degree field-of-view image, there is no need for any sort of mechanical pointing system which would compromise the covert nature of the camera.

6. Summary

A spherical image is a new photographic technology that enables 360-degree panoramas to be easily recorded on film. Applications that will be beneficial to law enforcement include comprehensive crime scene documentation and virtual tours of hazardous environments, such as crack houses. Certain aspects of this technology need improvement before it can be fully used to its full potential. The LIT is developing a spherical imaging system that enables very high-resolution spherical images to be interactively explored within a networked environment. This system includes a new lost cost camera with fisheye lens and software applications. The client/server software developed by LIT incorporates prediction algorithms to reduce the effective latency in the network, enabling these images to be navigated with a high degree of responsiveness. Seaming algorithms to stitch together fisheye images are also under development.

7. Acknowledgements

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Public/Private/Wireless Information Security
A blue print for safeguarding sensitive information

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ABSTRACT

Rapid access to investigative information stored on computer systems by narcotics and other law enforcement agencies is essential to the success of many investigations. Public, private, and wireless networks can provide connectivity among participants in an investigation and substantially enhance productivity. The unwary agency, however, can provide information about ongoing investigations to unauthorized persons, or expose the underlying information database to attack. A typical problem is the interconnection of narcotics units with agency networks with a minimal firewall or router between the narcotics unit and other organizations. This configuration allows sensitive data to exist on portions of the network where it is easy to program a personal computer to "snoop" the network and obtain user password and other text-based information.

This paper describes a way to create an affordable firewall that can be used both to compartmentalize networks (intranets) and to protect their resources from public Internet threats. The firewall uses the Linux operating system on a Pentium PC and the Trusted Information Systems (TIS) firewall toolkit (fwtk). A transparent encryption layer can be added to the firewall to protect sensitive data exchanged with external or internal cooperating agencies across insecure networks such as the Internet. The encryption layer also provides a basis for secure wireless access to network resources by investigators in the field.

By using inexpensive internal firewalls with strong encryption, investigative agencies can segment their internal networks to allow for supervised access control and encryption across sensitive segments. Network activity can be monitored without compromising security to aid the detection and prosecution of unauthorized users either inside or external to the agency.

1. Introduction

This document describes a firewall methodology which can be used to create affordable firewalls at institutions requiring information security for their internal networks or Intranets and the Internet at large. This type of firewall can be produced using the Linux operating system on a fast Pentium PC with either the Trusted Information Systems (TIS) toolkit or several of the publicly available TCP wrappers. All of these wrappers, proxies, and authentication schemes have individual advantages and disadvantages over the other publicly available toolkits. The choice of toolkit and methodology comes down to two questions. How secure do I need my system, and how much outside access my users really need?

A firewall is described which both acts as a portal to a secure network and as a 10base-T to 100base-TX bridge. The secure network topology is a class C network with 2 subnets. One of these subnets is a 100base-TX leg connected directly to the secure side of the firewall. The second subnet is a 10BaseT segment connected to the secure network through a gateway machine. The firewall machine is secured with the philosophy of no access for all machines and no remote firewall access.

These firewalls can be used both as gateways to the Internet and as segmentation points to separate secure or sensitive data nets from the rest of an organization's network. The records stored on this firewall can be used to log accesses across the firewall and are essential in tracking and prosecuting hackers. A properly configured firewall can also be used to encrypt network traffic from the secure subnet to other secure subnets. This is a useful technique in preventing electronic eavesdropping of file and password information.

2. Philosophy of Firewalling and Security

The design and implementation of an Internet security system first begins at the site policy level. The basic security policies put in place by the site's administrators will determine the effectiveness of the firewall and the degree to which services will be limited to the desktop user. To put an effectively firewall security system in place, a site policy must be adopted which allows the firewall administrator to secure the Intranet/Internet interface and stop security violators. We advocate a philosophy of no access except those which are unless expressly permitted.

Physical as well as network security must be addressed in the design of a your firewall system. It is, in the author's opinion, better to have the firewall physically accessible to a select group of trusted users that to one person as penetration signs, such as excessive drive usage, will often be noticed by users and reported. The philosophy of our system will be to forbid login to the firewall system from other nodes of the network, or to limit network login to a select number of machines using a one time challenge-response system and/or packet level encryption.

Basic System Configuration

The system configuration is a low to mid performance IBM compatible PC with hardware modifications to enhance the system's performance for firewalling. The operating system is Linux with the 1.2.13 kernel, and the TIS toolkit. A minimal hard drive is used; however, the amount of logging information is generated by network traffic may require additional space. Two network cards are required. The first is a 3com 509 Combo card and will function as the interface to the outside network. The second is a 3Com 595 Vortec 10/100 baseTX Card and will function on the secure side of the network.

Dual Purpose Bastion Machines

Our firewall serves two purposes. Its primary function is that of a firewall and security monitor for our secure subnet. This allows us to monitor all incoming and outgoing traffic. Neither side of the firewall has any direct connection to the other except through the firewall host. This meets the definition of a Bastion Host.

The second purpose is to act as a bridge between the outside 10baseT network and the internal 100baseTX network. Selecting different network speeds and connection types offers several physical security advantages. One of the easiest ways to defeat a firewall security system is to create a physical connection from the secure network to the unsecured network with a simple patch cable. If the two networks are incompatible, except through the firewall bridge machine, security to your site is increased. Other external network adapters can be supported, including T-1 interfaces for point-topoint links.

System Selection

Selection of the hardware and software components of the firewall are critical to the success of the unit and minimization of network user frustration. A limited capacity machine will lead to network congestion and eventual collapse of the firewall due to overloading.

Hardware Selection

One of the major factors in selecting the hardware for the firewall is the network speed and usage of the Inter-intranet getaway. As a rule of thumb, bigger is better and, too much capacity will not be noticed but too little will bring about user problems and slow down network operations. In particular, if 100Base-TX network connections are being used Pentium™ machines with chip speeds of greater than 100MHz are indicated. Memory can be a limiting factor of many of the off the shelf machine configurations. Practical experience has shown that while not memory intensive as a single process, multiple proxy connections can consume extraordinary amounts of memory particularly when the firewall machine may be acting as primary router and as a gateway between Ethernet segments of unequal speed. A CD-ROM drive is essential to setting up this system.

For our own internal network a Gateway 2000 P5-100 was selected with 48 Megabytes of RAM and a 1-Gigabyte hard drive. The machine was originally configured with 16 Mbytes of RAM, but this proved to be a major impediment to the firewall performance. The TIS firewall code has also been tested on P5-75 machines with satisfactory performance. A third firewall machine with a 486-50 processor was also constructed. This proved to be an unsatisfactory arrangement, as the Linux kernel and firewall code required 10-12 hours to compile.

As Linux was designed to be a poor mans version of UNIX, it has been found through experience that the less expensive and more common the hardware selected the greater the odds of success. Most of the drivers are written for the common denominator hardware components, so use of more exotic components many result in a loss of time while the proper drivers are acquired.

Software Selection

The operating system chosen for the firewall was Red Hat "Official" Linux. This package was chosen for a variety of reasons. These reasons include:

1. Ease of installation.
2. Stability of the Kernel
3. Utilities included with the distribution.
4. Final installation configuration.

Several versions of Linux were tested for ease of installation and the final configuration of the system drives. Significant problems were found with the selection of the proper boot disk images to install the software. This process has been automated with the 3.03 "Picasso" Release of Red Hat so that a CD-ROM is required. This version of Linux can also be installed over the Internet from the site ftp.redhat.com with the instructions provided there.

There are at least two publicly available firewall codes available over the Internet. The first is the Trusted Information Systems "TIS" firewall toolkit available from ftp.tis.com under the directory /pub/firewalls/toolkit; another option is the TAMU Tiger toolkit available from net.tamu.edu under the directory /pub/security/TAMU. The second site also includes some intrusion detection tools as well as a proxy firewall code.

Red Hat Linux also comes with a proto-firewall code in the form of TCPD for allowing and denying access to the machine login prompt. This is insufficient for true firewall purposes, as the code strategy is "what is not denied is permitted". This means that a table denying access to all machines except your own systems must be setup. Any flaws in the denial logic will permit access by unwanted machines into your system. Also, this access logic does not discriminate between services; if access is allowed for one service it is allowed for all supplied services.

Other sites offering useful software include BELLCORE with the S/Key software package at **thumper.bellcore.core** under the directory /pub/nmh/skey, Stanford with the SWATCH Logfile at **sierra.stanford.edu** under the directory /pub/sources, and Cert with the COPS package at __________.

3. Setting up the System

Once the system has been selected and purchased, it must be prepared for use as a firewall by making numerous changes both to the system software and the hardware attached to the computer system. These changes include removal of most or all of the Microsoft operating system components, addition of the network cards, and installation of the Linux operating system with all necessary system patches to ensure that the network cards and system hardware operates we suggest leaving the case off of the system during installation. This allows ready access to information about the system while the software is being installed.

Software Installation

The first step in installing the Linux OS is to repartition the hard drive into two parts using the `fips` software tool provided with most versions of Linux. This step creates two logical disk drivers on a single physical device. The first partition is a DOS/Windows partition and is useful for some system maintenance task such as configuring network cards and other pieces of hardware. The second partition houses the Linux operating system. This partition will yet be subdivided into swap space and additional Linux partitions as required. In order to do this successfully a de-fragmentation utility must be run in order to compress all of the DOS/Windows software into the lower segments of the drive; otherwise, this software may be lost in the partitioning process.

The next installation step is to run the program called **RedHat.exe** located on the distribution CD-ROM. This starts the installation procedure and will ask several questions about system configuration and the installed hardware. The installer can usually easily answer these questions. In our case with the two 3Com network cards, we will select the driver for 509 3Com card. As there are no included drivers for the 595 Ethernet card, in the initial installation the 509 card will become eth0.

The Red Hat installation program will now boot the system into Linux to continue installation. In this portion of the installation process, the hard drive can be subdivided into additional partitions using the Linux analog of FDISK. A swap partition of at least 50MB should be defined, and we recommend that the remaining portion of the hard drive be split into two other partitions. This provides a total of 4 primary partitions: One for DOS, one for swap, and two for Linux. The reason for this extra partition is to allow the administrator to put dangerous applications into this area and dismount the partition during normal firewall operation. It is also recommended that all of the applications be installed. The Ethernet device for the insecure IP address is also configured during this step, as you access to several sites on the Internet is needed for later steps in the installation procedure.

Hardware Configuration

Configuring the hardware for the Linux operating system is fairly straight forward but is easier to do under the dos/windows environment. This requires the setup disks supplied by the manufacture of the various components. Very few of the components require any hardware setting modifications except for the two network interface cards for use on the secure and insecure side of the firewall. These two cards require some change to the IRQ and I/O address settings to function properly.

In particular, the high-speed interface card requires the transmission speed setting to be locked to the high-speed setting. Under the Linux 1.2.13 Kernel the driver available under Linux does not support the automatic mode sensing. The second card should require no modifications to the hardware settings, but knowledge of the settings is in order for the Linux loader (LILO) configuration to allow for the use of both network cards. For proper setup, both the IRQ and the I/O address are needed.

Required Patches

Most of the major security breaches in the UNIX operating system come from not installing required supplemental security patches. This leaves known security holes in the operating system. Known breaches can aid a potential intruder, once it is determined what operating system is being used by the secure system. RedHat Inc. maintains a series of security patches and alerts on their web site at **www.redhat.com.**

A second patch is required to provide Linux support for the fast network interface installed in the firewall machine. This patch is available at **http://cesdis.gsfc.nasa.gov/linux/drivers/vortex.html** and works for the Picasso edition of RedHat. This patch is required for our system. It is not required if two supported cards are used. Newer versions of the RedHat Linux support all of these cards, and not require the patches.

Configuring LILO

In order to use the second network interface card, the system must be made aware of the card and its associated IRQ and I/O address. This can be done manually at boot up but can be done automatically with changes to LILO or the Linux Loader (LILO). Automation of the network card configuration is easily accomplished using the LILO method.

Automatic network configuration is added by editing the file lilo.conf under the /etc directory. The file listing below is typical of the machines with two Ethernet adapters:

```
boot=/dev/hda
map=/boot/map
install=/boot/boot.b
prompt
timeout=50
```

```
image=/vmlinuz
        label=linux
        append = "ether=3,0x280,0,1,eth1"
        root=/dev/hda3
        read-only
#       append = ""
other=/dev/hda1
        label=dosc
        table=/dev/hda
```

The line = "ether=3,0x280,0,1,eth1" must be added to this file to allow the slow speed card to be recognized. In this command line the first parameter is the IRQ setting of the 10baseT card. The second option is the memory I/O address of the 10baseT-network card. The next two parameters are constant for all network cards and the final parameter indicates the network card id. For other systems these parameters will change. One of the features of the network driver is that the high speed Ethernet device must be eth0.

After this file has been saved, the command "lilo" is run to reconfigure the master boot record (MBR) of the computer. This will add the command line to the boot up system. Otherwise the command ether=3,0x280,0,1,eth1 must be typed at boot-up each time.

Configuring System Software for Gateway Transport and Compiling the Kernal for 100baseTX operation

The final step in the initial configuration is to recompile the Kernel. This is accomplished by going to the directory /usr/src/linux and running the command make config. This will run the Kernel configuration routine. Most of the default options will be sufficient, but changes must be made to 3 of the default options. The changes are:

1. Answer "Yes" to Do you want to see Alpha Drivers.
2. Answer "Yes" to Enable IP forwarding and gatewaying
3. Answer "Yes" when offered the 595 driver.

This will enable the machine to act as a router for first testing of the network. It will next be necessary to run the command string make dep; make clean; make zlilo. This will rebuild the kernel and load it for use. The final step in this rebuild is to reboot the machine.

The final stage of the preparation process is to configure the IP address and network of each card. This is easily done as root under X-Windows, and is done from the Red Hat Package Manager control panel under network configuration. The 10baseT card will be eth1 with the 100baseTX card being eth0. Rebooting may be necessary after this step. It would be advisable to test the network configuration at this point and ensure that, not only does the firewall machine see both sides of the network, but also the computers inside see external systems.

4. Firewall Construction

The construction of the actual firewall consists of 3 steps. These steps include:

1. Recompiling the Kernel to break the network connection between the two network segments.
2. Obtaining compiling and installing the TIS tool kit.
3. Removal of Extra Services not needed by or dangerous to the firewall machine.

These steps are extremely time consuming and unless proper care is taken the firewall will have significant security holes in it.

Breaking the Gateway Connections

The first step in firewall construction is to eliminate the network connection formed during the Linux installation. Recompiling the Kernel as described above with the following options changed from their default does this:

1. Answer "No" to enable IP forwarding and gatewaying.
2. Answer "Yes" to enable IP firewalling.
3. Answer "Yes" to enable IP logging.

and recompile the Kernel.

This will disable the network forwarding and enable the native firewall protection under Linux. At this point, after rebooting the system both the Inter and Intranets will be physically and electronically separate.

TIS Toolkit

The next step in the process is to obtain, compile and install the TIS tool kit. The tool kit can be obtained from Trusted Information Systems using ftp at

www.tis.com under the directory /pub/firewalls. TIS has instituted an e-mail policy that in order to obtain the tool kit, an e-mail must be sent to their server and the exact location of the took kit will be disclosed. Details can be obtained under /pub/firewalls. In addition, the e-mail logs of frequently asked questions and reports of problems can be obtained at this address.

In addition to the TIS tool kits there are several independent patches developed for the tool kit and are available at the site **ftp://ftp.optimation.co.nz/pub/fwtk/fwtk-2.0alpha-Optimation1.tar.gz**. These files replace several of the tool kit files to remove several bugs. Namely they make changes to HTTP-GW to allow it to function properly under Linux.

Next it will be necessary to uncompress both the TIS tool kit and the Optimization patches, in that order, to a specific sub directory in the root home area. . For simplicity sake, the directory created will be called fwtk2alpha. The decompression of the tool kit creates a directory called fwtk in this sub directory, and the patches will have to be uncompressed into the fwtk directory. It will next be necessary to edit the file ***Makefile.config***, and change the following lines.

```
#FWTKSRCDIR = /u/b/mbr/firewalls/fwtk
FWTKSRCDIR = /usr/local/src/fwtk
```

to reflect the absolute path of the kit. In our case it will be

```
FWTKSRCDIR = /root/fwtk2alpha/fwtk
#FWTKSRCDIR = /usr/local/src/fwtk
```

changes are also necessary for auto install of the Manuel pages but are not required for the installation. Next run the command fix/make to create a customized make file for your system. Then as root run the command make. This will create the tool kit binaries. To install these binaries in the directory /usr/local/etc run the command make install. This installation directory can be configured in the file Makefile.config. This will complete the installation of the actual toolkit. The final two steps are required to configure the Linux OS to use the tool kit for IP proxy services.

Removal of Extra Services

To activate the tool kit proxy services it will be necessary to edit two files. They are /etc/services and /etc/inetd.conf. These will be configured to use the IP tool kit as opposed to the telnet.d and other services normally offered under Linux. It will also be necessary to remove extra services such as httpd and sendmail from the rc3.d and rc2.d directory to prevent their use. Sendmail in particular is known as being the largest security breech in the UNIX operating system. The listing, shown below, is typical of the services in a firewall stripped machine:

```
USER PID %CPU %MEM SIZE RSS TTY
STAT START TIME COMMAND
bin      79 0.0 0.7  68 372 ? S   Aug 14
0:01 rpc.portmap
root      1 0.0 0.7  39 368 ? S   Aug 14
0:06 init [3]
root     48 0.2 0.8  73 424 ? S   Aug 14
66:35 syslogd
root     57 0.0 0.7  52 360 ? S   Aug 14
0:00 klogd
root     68 0.0 0.9  62 432 ? S   Aug 14
0:00 crond
root     88 0.0 0.8  58 416 ? S   Aug 14
0:48 inetd
root     99 0.0 0.7  84 368 ? S   Aug 14
0:01 lpd
root    103 0.0 0.7  76 380 v02 S Aug 14
0:00 /sbin/getty tty2 VC lin
root    104 0.0 0.7  76 380 v03 S Aug 14
0:00 /sbin/getty tty3 VC lin
root    105 0.0 0.7  76 380 v04 S Aug 14
0:00 /sbin/getty tty4 VC lin
root    106 0.0 0.7  76 380 v05 S Aug 14
0:00 /sbin/getty tty5 VC lin
root    107 0.0 0.7  76 380 v06 S Aug 14
0:00 /sbin/getty tty6 VC lin
root    108 0.0 0.6  35 296 ? S   Aug 14
0:00 bdflush (daemon)
root    109 0.0 0.6  35 304 ? S   Aug 14
0:01 update (bdflush)
```

It can be noted that there is very little background process active on this machine to give an active security hole for a hacker to exploit.

The listing below shows typical services file prepared for firewall use:

```
tcpmux          1/tcp
        # rfc-1078
systat          11/tcp          users
qotd            17/tcp          quote
chargen         19/tcp          ttytst
source
chargen         19/udp          ttytst
source
```

```
ftp-data 20/tcp
ftp-gw          21/tcp
telnet          23/tcp
rlp             39/udp          resource #
resource location
name            42/udp
        nameserver
domain          53/tcp
domain          53/udp
mtp         57/tcp              # deprecated
gopher          70/tcp
        # gopher server
rje             77/tcp
httpd           80/tcp
ssl-gw          81/tcp
link            87/tcp          ttylink
auth            113/tcp
        authentication
sftp            115/tcp
# End of services.
```

This listing is incomplete but it can be noted that several services such as pop-2 and pop-3 have been eliminated. Services that have still been provided are now shifted to use by the kit. The next listing is most important as it redirects the original functions to the FWTK. This is the innetd.conf file and is show below:

```
# Wrappers
        /usr/sbin/in.ftpd
ftp-gw          stream  tcp     nowait
        root    /usr/local/etc/ftp-gw
        ftpd-gw
telnet          stream  tcp     nowait
        root    /usr/local/etc/tn-gw
login           stream  tcp     nowait
        root    /usr/local/etc/rlogin-gw
httpd           stream  tcp     nowait
        root    /usr/local/etc/http-gw
        httpd-gw
ssl-gw          stream  tcp     nowait
root    /usr/local/etc/http-gw  http-gw
#
# Authentication Server
#
auth            stream  tcp     nowait
        root    /usr/local/etc/authsrv
        authsrv
```

It can be noted that all of the services offered under inetd.conf are now redirected to the FWTK. These steps activate the firewall tool kit after rebooting the system or locating the inetd process and running the command kill -HUP # where # is the number of the inetd process. This is usually less than 100, and in the case of the example given above it is 88. At this point your machine is now a firewall with one major flaw. At this point neither side is allowed access to the firewall services, not even the host machine. The final step is to configure the firewall access privileges.

Firewall Access Control

The final step in configuring the firewall is to edit the netperm-table in the directory /usr/local/etc. This table gives the firewall its character and defines down to the user level, if need be, who can access network services. The listing given below is a typical netperm-table:

```
# Example netacl rules:
# ---------------------
# if the next 2 lines are uncommented, people
can get a login prompt
# on the firewall machine through the telnet
proxy
#netacl-in.telnetd: permit-hosts 127.0.0.1 -
exec /usr/sbin/in.telnetd
#netacl-in.telnetd: permit-hosts
xxx.xxx.xxx.xxx -exec /usr/sbin/in.telnetd
#netacl-in.telnetd: permit-hosts
xxx.xxx.xxx.xxx -exec /usr/sbin/in.telnetd
#
# if the next line is uncommented, the telnet
proxy is available
#netacl-in.telnetd: permit-hosts * -exec
/usr/local/etc/tn-gw
#
# if the next 2 lines are uncommented, people
can get a login prompt
# on the firewall machine through the rlogin
proxy
#netacl-in.rlogind: permit-hosts 127.0.0.1 -
exec /usr/sbin/in.rlogind -a
#netacl-in.rlogind: permit-hosts xxx.xxx.xxx.*
-exec /usr/sbin/in.rlogind -a
#
# if the next line is uncommented, the rlogin
proxy is available
#netacl-in.rlogind: permit-hosts * -exec
/usr/local/etc/rlogin-gw
#netcal-in.ftpd: permit-hosts 127.0.0.1 -exec
/usr/sbin/in.ftpd
#netcal-in.ftpd: permit-hosts xxx.xxx.xxx.*-
exec /usr/sbin/in.ftpd
#netcal-in.ftpd: permit-hosts * -exec
/usr/local/etc/ftp-gw
#
```

to enable finger service uncomment these 2 lines
#netacl-fingerd: permit-hosts xxx.xxx.xxx.*-exec /usr/libexec/fingerd
#netacl-fingerd: permit-hosts * -exec /bin/cat /usr/local/etc/finger.txt

Example smap rules:

#smap, smapd: userid 6
#smap, smapd: directory /var/spool/smap
#smapd: executable /usr/local/etc/smapd
#smapd: sendmail /usr/sbin/sendmail
#smap: timeout 3600
Example ftp gateway rules:
ftp-gw: denial-msg /usr/local/etc/ftp-deny.txt
#ftp-gw: welcome-msg /usr/local/etc/ftp-welcome.txt
#ftp-gw: help-msg /usr/local/etc/ftp-help.txt
ftp-gw: timeout 3600
uncomment the following line if you want internal users to be
ftp-gw: permit-hosts xxx.xxx.xxx.*
Example telnet gateway rules:
----
tn-gw: denial-msg /usr/local/etc/telnet-deny.txt
#tn-gw: welcome-msg /usr/local/etc/tn-welcome.txt
#tn-gw: help-msg /usr/local/etc/tn-help.txt
#tn-gw: timeout 3600
tn-gw: permit-hosts xxx.xxx.xxx.* -passok -xok
Example rlogin gateway rules:
----
rlogin-gw: denial-msg /usr/local/etc/rlogin-deny.txt
#rlogin-gw: welcome-msg /usr/local/etc/rlogin-welcome.txt
#rlogin-gw: help-msg /usr/local/etc/rlogin-help.txt
#rlogin-gw: timeout 3600
rlogin-gw: permit-hosts xxx.xxx.xxx.* -passok -xok
Netscape Proxy Services
http-gw: timeout 3600
http-gw: denial-msg /usr/local/etc/httpd-deny.txt
http-gw: permit-hosts xxx.xxx.xxx.*
plug-gw: permit-hosts xxx.xxx.xxx.*

Example auth server and client rules
----
authsrv: hosts xxx.xxx.xxx.1
authsrv: database /usr/local/etc/fw-authdb
authsrv: badsleep 1200
authsrv: nobogus true

clients using the auth server
*: authserver xxx.xxx.xxx.1 7777

X-forwarder rules
#tn-gw, rlogin-gw: xforwarder /usr/local/etc/x-gw

This netperm table, disables all but console login to the firewall machine and only allows the secure subnet to pass outward. DNS, SNMP and other dangerous services are denied the use of the firewall. In particular x services are disabled. One point of interest is that the TIS kit looks for the first instance. This can create an accidental security hole in your firewall. This can be accomplished by reversing the order of the commands. A typical example is

ftp-gw permit-host 111.111.111.*
ftp-gw deny-host 111.111.111.123

where the network to be protected is 111.111.111.* and the host to be denied access is 123. This will not work as the deny is after the global permit. The order on these two commands needs to be reversed in order for this to work.

5. Results of Satan Tests

In order to test the firewall effectiveness SATAN was used against the system at full user load to check for security leaks. SATAN was used in unfriendly mode and there was a noticeable effect on firewall performance. SATAN was unable to find any security holes in the system to exploit and often gave the user false information. A typical example is on the machine type. In most instances SATAN returned the wrong machine type to the operator.

6. Conclusions

We have successfully installed and demonstrated the practicality of building a Linux based firewall based upon the TIS tool kit. In addition, it has been demonstrated that the firewall is an effective deterrent to both the casual and serious hacker through the use of SATAN.

DEFINITIVE USER ACCESS ON A SECURE WEB SERVER

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ABSTRACT

The WHOSINIT application controls internal access to files, programs and applications on a Web Server based on user name/password login. This allows access for each User to the resources on the server to be controlled on a file, Case and directory basis. WHOSINIT, when used in conjunction with a secure web server, allows the administrator to give access to specific Users through a secure graphical point-and-click interface, thus giving easy to use, exhaustive management of access to documents within or beyond the agency. WHOSINIT was developed to be a stand alone management interface that could be adapted to legacy systems. From the initial development, emphasis was placed on generic, flexible structures that could be adapted to a wide variety of data. The objectives of the development effort were:

1. Provide stable and easy to use software,
2. Allow other hierarchical structures to be imported,
3. Implement as a stand-alone program,
4. Provide a point-and-click graphical interface (using a secure web server), and
5. Allow information to be added for individual users. (e.g., e-mail and phone),

By using WHOSINIT in conjunction with a Secure Web Server, and only allowing access to the sensitive information by programs that check access through the WHOSINIT controlled database, it is possible to allow definitive management of user access with versatility and ease of use.

1. Introduction

Using secure Internet technologies for a law enforcement "Intranet" provides a way for law enforcement officers to share information with each other and outside agencies. Existing encryption technologies ensure that information being transmitted will not be compromised by unauthorized users "listening" to the transmissions. A second security consideration must be addressed when dealing with sensitive counternarcotics information: Prevention of legitimate users from accessing unauthorized information belonging to another user. Agents, particularly those dealing with counternarcotics investigations, will not be comfortable sharing information unless they can be exactly sure who will be accessing that information.

In these environments, even in a mid-sized sheriff's office, there are hundreds of thousands of cases and possibly thousands of users. In order to insure that each user can only access the information he or she is authorized to see, a robust and definitive user access scheme is needed. In response to this need the Laboratory for Information Technologies developed WHOSINIT, the Web Hierarchical Operational Security: INternal InTerface.

2. Definition of User Authorization Needs

WHOSINIT is a security management interface for an encrypted web server that can be adapted to legacy systems. Emphasis is placed on generic, flexible structures that can be adapted to wide variety of data.

The primary objectives of WHOSINIT are control of:

1. Access to individual Cases by an individual User,
2. Access to individual Cases by Groups of Users,
3. Access to individual Cases by Groups of Groups, and
4. Access to individual Cases by any combination of 1, 2 or 3

Further design criteria are:

1. Access is granted by directory name and by filename based on the case name.
2. Provide stable, easy to use software.
3. Versatility, allowing data and hierarchical security structures to be imported.
4. Stand alone program (requires Perl 5)
5. Point-and-click graphical user interface
6. Give the administrator an intuitive grasp of the existing security structure.
7. Allow information to be added for individual users (email etc.).
8. Create a case directory structure to be used by other programs.
9. Allow three levels of Access:
   - Access Granted,
   - No access, anonymous contact available, and
   - No access, existence not visible.
10. Show Group hierarchies with Users.
11. Allow text descriptions for Cases and Groups.
12. Allow Users to update their own Personal Information.
13. Allow all Users, Groups and Cases to be edited in "Realtime".
14. Secure administration of the server is to be allowed remotely.
15. Robust enough to handle hundreds of thousands of cases, and thousands of users.
16. Speed: able to respond to multiple queries with no server performance degradation.

3. WHOSINIT Solution

The solution was to create server side applications (cgi scripts) that create and manage all aspects of case maintenance, without relying on the local web server's own internal file access methods. WHOSINIT creates its own case structure and file locations. No case information (picture or text) is accessible except by programs that use the WHOSINIT for an authorization check.

Each application uses WHOSINIT to check case information before passing any case information back to the user. If an application determines that a user has access, other programs (such as the Image Archive and the Data Miner) will pass the information back via the secure web server. These programs will check user access rights and notify the adminstrator if improper use is attempted (Figure 1).

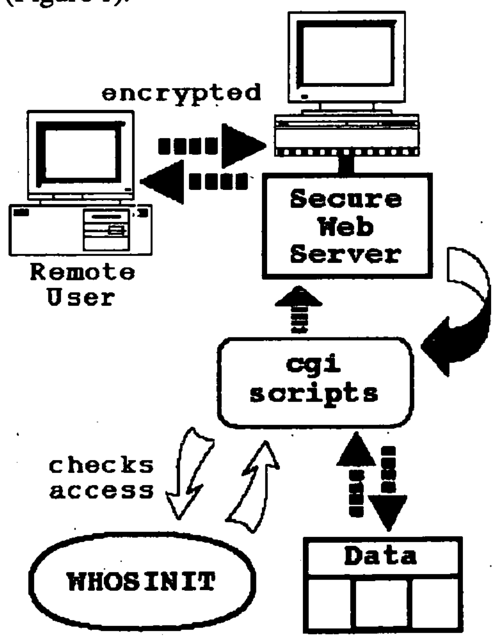

Figure 1 WHOSINIT Access Control

All information stored under control of WHOSINIT is associated with a Case. When a Case is created, a Case directory and path created within the ~server/files directory. Each Case will have its own directory that can only be accessed through WHOSINIT and related programs.

When adding a Case to WHOSINIT, several things will take place. Not only is the Case added to the WHOSINIT database, but a directory for that Case is created under the ~server/files directory. When entering the "Case Number" and "Path", a "Path/Case" directory is created. If path=PRIMARY and Case=BLUE the directory ~server/PRIMARY/BLUE would be created for the Case "BLUE". Anyone given access to "BLUE" would have access to everything within that directory. Users with access to BLUE will also be given access to all files of the form BLUE*, where * is a non-alpha-numeric character followed by an arbitrary string of zero or more characters. As other Cases are created they can share paths (Figure 2), but each Case name must be unique.

If a User or Group has access to that Case they will have access to all files and directories contained within the Case directory. It is also possible to access data from other directory structures on the same server. Any legacy directories, called case file directories (Figure 3), that have the same name as a Case will be treated as belonging to that Case. In other words, if there is a Case called "BLUE", and a directory (besides the one created for the Case itself as was shown in Figure 2) called "BLUE" is also accessable outside the ~server/files area, any User who has access to the Case "BLUE" also has access to the directory "~case/files/BLUE" and all things contained therein. In this case, there are Case directories belonging to GREEN and PURPLE that any person having access to BLUE would also be able to have access. Anyone with access to GREEN would be able to see the directory GREEN, but no other directories unless they had alternative access.

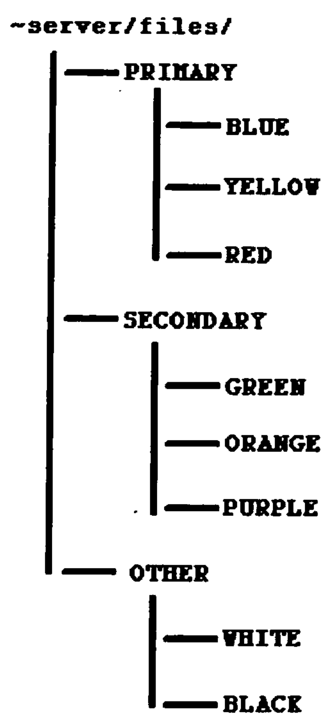

Figure 2 Case Structure

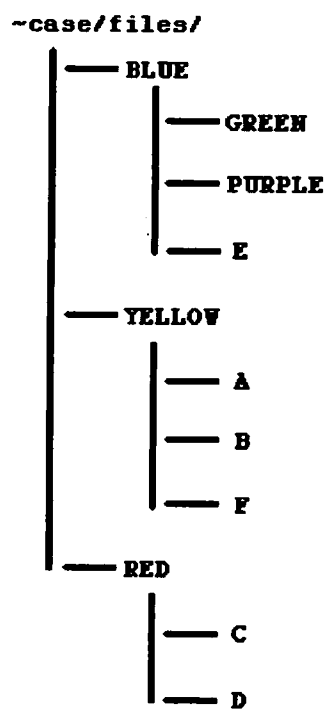

Figure 3 File Structure

Besides directories with Case Names being available, individual file access is also available. If a file name begins with the Case Name or number and then a non-alpha-numeric character followed by more alpha-numeric characters, and if a User has access to that Case he or she will have access to that file. This was done in order to comply with the ACISS method of storing files. For example, if User has access to Case "BLUE" and the file BLUE*DOG (Note: This is case sensitive.) exists within the file area accessible by WHOSINIT then that User will be able to read that file even if is is not within the specified Case "BLUE" directory.

All files in the htdocs area are not protected by WHOSINIT; the server controlleshas access to these areas. For documents to be secure through the HTTPD interface, they must be in an area not accessible through the web server. Specific programs have been developed in order to serve these documents (./cgi-bin/results and ./cgi-bin/showpic). If either of these programs or anything within the WHOSINIT application is modified, or if new applications are added to the cgi-bin directory that do not use WHOSINIT to check access, security could be compromised.

The WHOSINIT application controls access to files, programs and applications on a web server based on the username/password login. This allows access for each User to the resources on the server to be controlled by file, Case and/or directory basis. WHOSINIT, when used in conjunction with a secure web server, allows the administrator to give access to specific Users through a secure graphical point-and-click interface, thus giving easy to use, exhaustive management of access to documents within or beyond the agency.

4. Interface and Access

WHOSINIT is a CGI script that runs through a web server to a web browser (designed for Netscape 3.x or greater). When a user is given access to the adm-bin directory through the web server configuration file, he/she has complete control of WHOSINIT and all relevant documents that are available through it. Only the people responsible for adminstration of the secure site should have these access rights. To set up this cgi area for Stronghold (or another Apache-related Secure Server) the following could be used in the httpsd.conf file:

```
<Directory /usr/local/apache/adm-bin>
   Options Indexes FollowSymLinks
   AllowOverride Limit AuthConfig
   AuthUserFile /usr/local/apache/conf/.htpasswd
   AuthGroupFile /usr/local/apache/conf/.htgroup
   AuthName By Password Only!
   AuthType Basic
   <Limit GET POST>
      require group admin
   </Limit>
</Directory>
```

Once the httpsd.conf file has been configured, the application files and structure must be copied onto the server. The basic WHOSINIT file layout is as follows:

Perm	Owner	Group	path and filename
dr-xr-x---	root	www	~server/adm-bin
-r-xr-x---	root	www	~server/adm-bin/whosinit*
-r-xr-x---	root	www	~server/lib
-r--r-----	root	www	~server/lib/access.pl
-r--r-----	root	www	~server/lib/dbmanage.pl
-r--r-----	root	www	~server/lib/formgen.pl
-r-xr-----	root	www	~server/lib/perfmarc.pl*
-rwxr-x--	root	www	~server/support/htpasswd2*
dr-xr-x---	root	www	~server/valid
-r--r-----	root	www	~server/valid/global.pl
drwxr-x--	www	www	~server/valid/cases/
-rw-r-----	www	www	~server/valid/cases/casepdb.dir
-rw-r-----	www	www	~server/valid/cases/casepdb.pag
drwxr-x--	www	www	~server/valid/groups/
drwxr-x--	www	www	~server/valid/users/
-rwxr-x--	www	www	~server/files
-rwxr-x--	www	www	~server/cgi-bin/showpic

If the httpsd.conf configuration example shown above is used and the WHOSINIT files are copied into the areas specified, the URL:

https://server-name/adm-bin/WHOSINIT

will start the WHOSINIT application, showing the initial page in FIG 4.

This interface is extremely simple to use and highly intuitive for the user. After using WHOSINIT for only a short time, the administrator should have no problems understanding and using all of its functions.

By selecting links (blue underlined areas) the administrator may make a selection from this page to take him/her to different areas within WHOSINIT. These links can be thought of as a menu; by clicking on one the administrator has made and executed a selection. Most of the Menus will terminate in a form (a page where text can be entered or edited, boxes of selections chosen, or selections from pull down menus made).

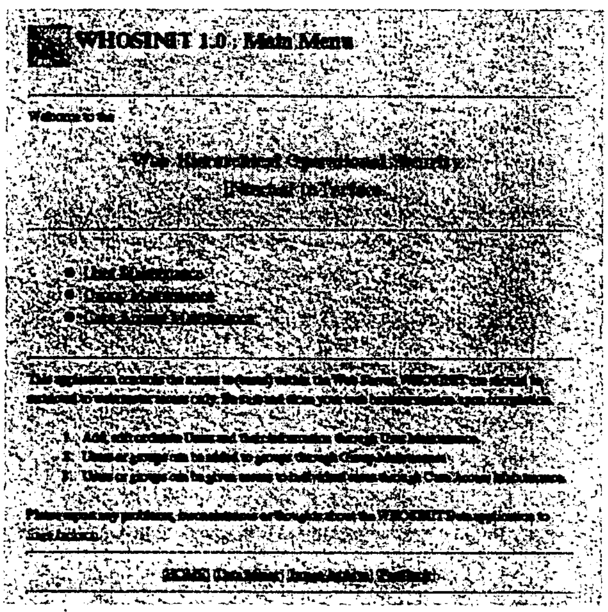

Figure 4 WHOSINIT first page

The WHOSINIT program will not be cached on the browser; it forces the browser to update its pages. This prevents old data from appearing in forms or pages and being accidentally incorporated into new data.

The Show Hierarchy function, showin in FIG 5, from the Group Maintenance Menu is a very useful diagnostic tool. It allows you to see the Hierarchies of all the Groups on the Server. For each Group that is a root of a Hierarchy (belongs to no other Group), Show Hierarchy will display all subsets of that Group. It will show not only all the Users and sub-Groups that belong directly to the Group, but all the Users and Groups of the sub-Groups *ad infinitum.*

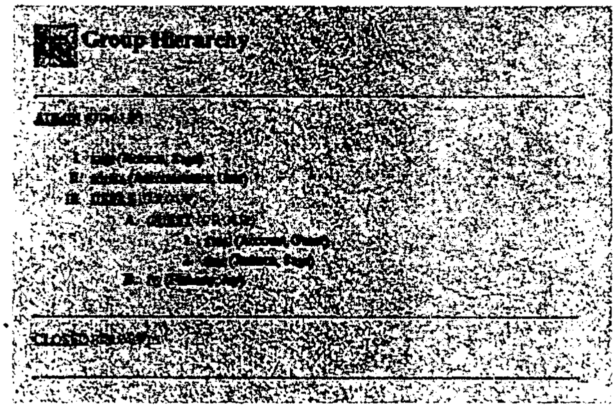

Figure 5 Group Hierarchy

This allows the administrator to see at a glance the Group's infrastructure, giving an intuitive grasp of who has access by Groups (NOTE: This does not show individual Users that have access, unless they belong to a Group). Anyone who has access at a level will have access to all Groups below that level.

To add a New Case to the WHOSINIT Database use the form shown in Fig 6. Enter the unique name of the Case you wish to add and the path you want it to have. (The agencies we were dealing with wished to have a year/month/day format, but other formats can be used.)

"Contact" is an email address of the person who is to be contacted for any questions concerning this Case. For access purposes, if this field has any value and access is attempted, access will not be given but a blind e-mail request form will be available to request access from the Contact. If this field is blank, the user will never know that this Case exists. "Description" is the textual description of the Case. When a user is using an application, the Case will be described using this description.

The table "Group Access" allows the administrator to give access to all Users within that Group

(AND TO ANY GROUP WHICH CONTAINS THAT GROUP AS A SUB-GROUP). The table "Individual User Access" will give access to any User checked regardless of any Group identities. If only one person is to have access to a Case, no Groups are given access, and only that User ID is selected.

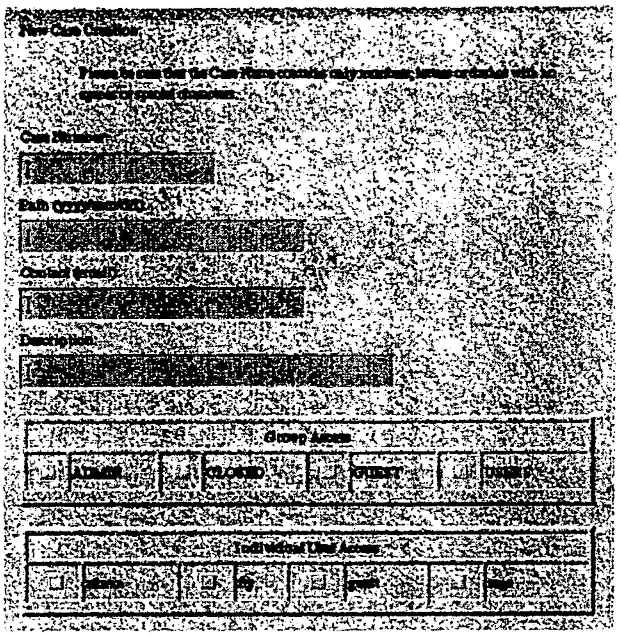

Figure 6 New Case Add Form

5. Performance

WHOSINIT was developed on a Sun Ultra 1 and tested on several UNIX platforms. As speed was a primary design criteria, WHOSINIT was benchmarked at 2,000 random User verifications per second. This performance was on a Ultra 1 with a WHOSINIT database of 400,000 Cases and 1,000 Users. This User and Case database is actual data from Pinellas County, Florida, where WHOSINIT is being used as part of the West Florida Counterdrug Investigative Network (WFCIN) test bed.

6. Summary

WHOSINIT provides definitive user access management. Used in conjunction with a secure web server and other server-side applications developed by LIT, WHOSINIT allows the widespread dissemination and distribution of new and legacy information databases to be securely managed. By using WHOSINIT, an administrator can easily allocate user authorization on a case-by-case basis with fine control.

7. Acknowledgements

WHOSINIT was developed for use by the law enforcement agencies who are participating in the WFCIN test bed project. Most of these agencies use the ACISS investigative support system. WHOSINIT was designed to work beyond these boundaries. It is capable of managing thousands of Users and hundreds of thousands of Cases.

The original purpose of WHOSINIT was to regulate access to individual Cases from a WAIS search engine using the Data Miner Image Archive tools (see other papers in this proceedings). WHOSINIT can also be used for menu generation.

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Chemical Tagging/Trace Detection Technologies
(Session 3B-4)

FAA Trace Explosives Detector Acceptance Testing Program

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ABSTRACT

During the last two years, the FAA has been actively engaged in the development of explosive detection standards for trace detection equipment. To some measure, the whole area of development and deployment of trace detection equipment has been spurred by recent developments in testing standards by which detector performance and sampling efficiency can be effectively determined and improved. This paper describes the process used by the FAA in the development of current performance standards for explosive trace detection equipment that is currently being deployed to screen luggage and carry-on items in airports.

1.0 Introduction

The Federal Aviation Administration (FAA) Aviation Security Research and Development Program has been conducting independent technology assessments of explosives detection devices for a number of years. In December 1993, this program resulted in the FAA's certification of the first Explosives Detection System (EDS), the InVision CTX-5000. Although a program has recently been established for the development of standards for acceptance of explosive trace detection equipment capable of screening electronic devices, a formalized program like that for EDS involves a lengthy rulemaking process that could take as long as several years. This process would not meet the FAA's immediate needs.

In the wake of the TWA Flight 800 tragedy, the White House Commission on Aviation Safety and Security, headed by Vice President Al Gore, was created to erect immediate, greater safeguards against terrorism. On the strength of the Commission's recommendations, Congress appropriated $144 million for the FAA to purchase and deploy advanced technology security equipment. As a part of its continuing commitment to implement these White House and Congressional mandates, the FAA allocated $12.2 million to purchase trace detection security equipment for the nation's largest and busiest airports. The purpose of this equipment was to be used primarily in conjunction with X-ray machines to detect explosives in electronic equipment, articles in carry-on or checked baggage, and other suspect items found in or around airports.

Faced with the need to develop a deployment plan for trace detection equipment, the Aviation R&D Program was tasked with developing a technical evaluation plan that could be used as the basis to accept trace explosives detection equipment for use in airports. Moreover, an extremely tight time line was established leaving no more than two months for both the development of the test plan, and the testing and evaluation of the candidate equipment for deployment. This precluded the formalized certification process. This time line was established such that the original deployment schedule of equipment could be accommodated. Because the intended use of the equipment was beyond the original scope of the emerging electronics screening certification protocol, this mandated the development of a new expanded testing paradigm, one that would call out performance standard characteristics for more explosives than originally defined in the electronics protocol and on a wider variety of surfaces characteristic of suitcases or small carry-on bags. Due to the limited amount of time available for the decision making process, it was decided to conduct a laboratory evaluation of the performance characteristics of the equipment, with the understanding that initial deployments would offer the opportunity for the evaluation of the operational aspects of the equipment. This paper describes the development of the laboratory test protocol that was used as the acceptance test for explosives trace detection equipment that is being purchased and deployed at major US airports by the Security Equipment Integrated Product Team for screening applications for carry-on and checked articles.

2.0 Contamination Transfer Study

Arguably the most important part of the process is developing a test matrix that is physically representative of what the threat is. A vendor will attempt to modify an explosive detection device to pass any given test protocol, so the protocol must mirror the reality of the threat presentation. A simplistic approach to this is to prepare a number of Improvised Explosive Devices (IED's) placed into a wide variety of bags or other articles, and determine if the explosive detector can detect explosive residues on the outside of the bag or article. However, this approach is not feasible for a variety of reasons. Firstly, the preparation of an IED results in extreme variations in the amount of residue found on the surface of the IED. The variance of the contamination level is much great than the variance of machine to machine performance, so that such a test would not be diagnostic of machine performance. Secondly, even if a bomb maker was capable of leaving a standard residue on a surface, the act of sampling a threat article depletes the amount of explosive residue available for the next sample, so that a single test article could not fairly be used to evaluate a more than one machine. The solution to this dilemma is to produce test articles utilizing a process that yields a highly reproducible level of contamination in a physical form characteristic of those found on IED's. To first approximation, with some explosives this physical form is a residue left behind as fingerprints. However, the nature of other explosives indicates that the handling of them produces a fine dust that permeates all surfaces, while others offer a vapor presentation. In the case of dynamite, IED's contain the more volatile EGDN or NG as the explosive charge.

The first part of the development of the test matrix is determining what the range of concentrations of explosive residues might be expected on surfaces characteristic of luggage resulting from a bomb building activity. This involved building a number of IED's and implanting them into suitcases, and measuring the contamination level resulting from this bomb building activity. Levels of contamination were mapped. In particular, vapor emissions from suitcases containing nitrodynamite bombs were monitored for NG emissions for 4 hours. At the end of four hours, surfaces of the suitcase were carefully monitored for external contamination using trace detection equipment. Residue was collected from the following areas on each suitcase: Handles, latches, zippers, top of suitcase, bottom of suitcase, and three locations inside of the suitcase.

2.1. Explosives Type

There are a number of explosives and incendiaries that can be utilized in the preparation of IED's. Because of the need to develop a test procedure rapidly, only five explosives were utilized in this protocol. The explosives that were tested were: Composition 4 (C-4), Detasheet, Semtex H, trinitrotoluene (TNT), and nitroglycerin (NG). The challenge levels and controlled contamination procedures for the C-4, Semtex and Detasheet were used from data collected to support the emerging certification protocol for trace detection equipment for screening electronic items.(1,2) Data on contamination levels resulting from bomb building activities using NG based dynamite or TNT are described in this study.

2.2. Threat Articles

Although there are a wide variety of luggage types, for this test, two broad categories of luggage were used, hardsided and softsided. Softsided suitcases were either canvas or vinyl. All had plastic handles. Hardsided suitcases appeared to be vinyl material. Three suitcases of each type were used to contained IED's made with either TNT or nitrodynamite as the explosive charge. The IED's were implanted into suitcases, and typical suitcase fillers (clothing and other articles) were planted in the suitcase around the IED.

2. 3 Equipment Used

The following was used in this phase of the study: Kraft paper (used to establish clean working areas), a thermocouple (used to validate that explosive charges had reached ambient temperature, a video recorder, used to record all bomb building activities such that contamination observed could be correlated to activities of bomb technicians, latex surgeon gloves, used by bomb technicians during IED fabrication process, and sufficient supplies necessary to build six IED's. They included mock batteries, switching devices, inert detonators, suitcases, wiring, suitcase filler matrix (clothing, etc.,). Sticky tape, plastic wrap, and scissors were also available to bomb technicians for their IED fabrication activities. All activities were timed. For the analysis of residual explosives contamination, the following equipment was used: An EGIS 3000 chemiluminescence detector, manufactured by Thermedics, a Barringer Ionscan 400, manufactured by Barringer instruments, and an Itemiser, manufactured by Ion Track Instruments. Sufficient wipes and air samples were used, as specified by the manufacturer. All analyses were performed in a room removed from the bomb building activity by technicians who where not allowed in the area of the bomb building activity. All operators, areas, and equipment were frequently certified as being uncontaminated during the analysis activities.

2.4 Fabrication of IED's

Prior to building a device, all working surfaces were covered with Kraft paper. Prior to any activities, the work area was certified as being contamination free by taking wipes and analyzing the working surface. The suitcases were also certified to be free of explosive residue. The Dynamite bombs were built and monitored during one trial, and the TNT bombs were prepared during a separate trial, a few days later. The trace detection equipment used to monitor contamination was calibrated prior to use.

Bomb technicians were instructed to prepare bombs, with minimal manipulation of the explosive material; additionally they were instructed to use gloves during the process of manipulating the explosive materials. Bomb builders were aware that bombs were being prepared for trace analysis. Although no other instructions were provided, one bomb technician was observed repeatedly washing his hands throughout the entire process. Prior to handling explosive charge materials, bomb technicians prepared circuitry for the IED devices. All devices nominally contained a battery, a timing or other triggering device, and an inert blasting cap. All subcomponents were wired together ahead of time, such that fabrication of the IED could be facilitated by the single process of implanting the inert blasting cap into the explosive charge. The ramification of this procedure is that the IED was prepared without contamination, since no explosive charge was in the area. Manipulation with the actual explosive was minimal, occurring only when the blasting cap was placed into the charge. Procedurally, the IED detonation device was implanted into the explosive charge within the suitcase. The IED was then surrounded by clothing or other suitcase articles, and the suitcase was latched shut. This activity was done without gloves.

Bomb technicians used latex surgeon gloves during the manipulation of the explosives. For the dynamite bombs, Austin Powder 40 Ex Gel, stock # SE95J1 dynamite was used. This dynamite is NG based. The dynamite was stored wrapped in saran wrap. The dynamite was allowed to warm to room temperature, and the surface temperature was monitored with a thermocouple. After a 2.5 hours warming time, bomb technicians rewrapped the explosive in the saran wrap taco style in six threat quantities, to be utilized for the preparation of IED's. Operators then removed the gloves and washed their hands 2 or 3 times. During the TNT experiment, the TNT explosive charges was allowed to equilibrate to room temperature, and pieces were taped together into strips, and then wrapped into saran. The charge and the rest of the device were put together essentially inside the suitcase by piercing the saran with the inert blasting cap, into the cavity of the charge.

2.5 Measurement of contamination on the outside and inside of suitcases.

Contamination in both the vapor phase, and solid phase (residue on surfaces) were measured during this test series for dynamite and TNT IED's. The process was such that immediately after the bomb was built, vapor samples were collected around the seam areas of all six of the test suitcases. The EGIS and Itemiser systems were used for this process, since their samplers were known to accommodate the collection of vapor phase material. After this initial analysis, vapor samples were also collected at intervals of 1, 2, and 4 hours. At the end of four hours, the suitcases were also "burped", that is compressed to force entrapped air out of them.

Particle contamination was measured only once at the end of four hours. The suitcase was divided into areas that were discretely sampled to determine the areas of highest probability of contamination. The areas were: handle, latches and zipper, top of suitcase, and bottom of suitcase. The procedure was to use three sequential wipes for each area. The recommended sampling wipe for each instrument was used as prescribed by the instrument manufacturer. The EGIS wipe was performed first, followed by the Barringer wipe, followed by the Itemizer wipe. It was recognized that sample collection depletes the presence of sample, and no inferences were made from this experiment about instrumental capabilities. The EGIS was always used as the first interrogation device since the standard response curve of this instrument is known to be linear over at least six orders of magnitude, making this machine the most suited for quantitative analysis. The Ionscan and Itemiser are known to be quantitative in a fairly narrow range of concentrations, however, arguably, most samples collected appeared to be in the range of linear response to explosive quantities. Nevertheless, the results obtained from the other devices were used more as confirmatory evidence of findings quantitated by the EGIS 3000. After contamination levels were established for the outside of the suitcase, three locations on the inside of the suitcase were swiped to determine contamination levels.

2.6 Results

Results of vapor testing are shown below. As might be expected, NG dynamite provided a more consistent vapor presentation of contamination from the suitcases. The level seemed to deplete as a function of time.

Table 1: Vapor contamination measured on the outside of suitcases

Vapor Collection time	TNT Hard sided suitcase	TNT Soft sided suitcase	NG Hard sided suitcase	NG Soft sided suitcase
0 hr	+,-,-	+,-,-	+,+,+	+,+,-
1 hr	-,+,-	+,-,-	+,+,+	+,+,+
2 hr	-,-,-	-,-,-	+,+,+	+,+,+
4 hr	-,-,-	-,-,-	-,-,-	-,-,-
4 hr, suitcase burped	-,-,-	-,-,-	+,+,-	-,-,+

Results of surface residue analysis are shown below. It should be noted that similar values were obtained using the Barringer Ionscan 400, but are not discussed here. However, these values were also used to calculate target quantities of explosive used in the acceptance test.

These results suggest two important findings. Firstly, it would appear that hard bags, and non-fabric hard surfaces offer the best surfaces to find explosive residues. This is particularly noticeable on the dynamite bombs. Clearly, hardsided suitcases offer a better substrate to either deposit, collect, (or deposit and collect) explosive residue. Of all suitcases areas, the most consistent place to find explosive residue is on the latch/zipper and handle area, where the suitcase was touched by bomb maker.

Table 2: EGIS wipe test response of bags with TNT bombs enclosed.

Bag type	Latch zipper	Handle	Top	Bottom	Surface of bomb	Inside suitcase
hard	743294	31998	378820	1041844	1041844	54660
hard	26535	0	440108	0	65906	168373
hard	63436	13210	739394	403520	87117	1045217
soft	18149	1041651	618905	168838	1042278	1042350
soft	20362	83608	33665	87353	164955	174833
soft	192787	259820	1043688	18847	1045055	4674

The results also suggest that TNT leaves greater residue than many other explosives, and because contamination was uniformly found in high amounts in all locations of the suitcase, it could be inferred that the contamination migration occurred as a fine particulate dust resulting from the handling process. This hypothesis was also supported by the finding that people who observed the bomb building process, but did not participate in any way, were almost as contaminated as the suitcases containing the IED's.

2.7 Correction for sampling efficiencies

Since this data represents the amount of explosive residue collected from surfaces, and not necessarily the amount of residue deposited on surfaces, a correction was made for sampling efficiencies, utilizing the collection method and surfaces used in the exercise. Briefly, this was determined by generating a standard response curve bracketing the range of contamination noted in the test. Known quantities of explosives standards used to generate the standard curve were then placed onto the luggage areas. The ratio of the response represented the sampling efficiency of the system. Similar studies were also conducted to evaluate the sampling efficiency of the Barringer Ionscan 400.

Table 3: Sampling Efficiency using EGIS sampling procedure (N=3 for each concentration)

Amount of Explosive Applied (ng)	% Wipe Efficiency for NG	% Wipe Efficiency for TNT
25	29%	31%
50	39%	27%
75	69%	20%
100	42%	14%

In-house testing revealed that the nitroglycerin solutions are readily volatile and disappear from surfaces in a very short time. Although the physical presentation of NG in dynamite may be different than solution deposition, the decision was made to increase the deposition value of NG solution by 50% above average values obtained as surface contamination in this experiment, and perform all NG tests within an hour of deposition.

Average target threat quantities were determined by the following equation

Amount of residue on (Handle + zipper/latch)/collection efficiency X correction factor (NG only)

3. Development of vendor testing protocol

Having determined appropriate threat contamination levels, sufficient information existed to develop a test matrix. The primary objective was to prepare a series of test articles with a high level of quality control such that the standard deposition onto the surface provided a highly repeatable, stable standard material available for detector challenge.

3.1 Test surfaces

Three surfaces were selected as substrates for testing. The materials used as substrates include 3 1/2 inch floppy disks, vinyl luggage handles, and zippers with metal pulls. The floppy disks were selected because they are a convenient well characterized surface similar to that of a hard sided suitcase, laptop computers, cellular phones, etc. and were used in the development for electronic standards.

3.2 Explosive Types

The explosives that were tested were: Composition C-4 (C-4), Detasheet, Semtex H, trinitrotoluene (TNT), and nitroglycerin (NG). The amount of explosive used was varied to simulate a practical challenge to the instrument based on data collected on contamination activities, as determined using procedures described and elsewhere (1). The challenge levels and controlled contamination procedures for the C-4, Semtex and Detasheet were used from data collected to support the emerging certification protocol for trace detection equipment suitable for use in screening electronic items, and have been described elsewhere. (1,2)

3.3 Number of sample replicates

A sample set (Table 4) consisting of 240 computer disks, 120 zippers and 120 luggage handles was used to determine the false alarm rate and throughput rate verification. Detection verification test were performed using individual sample sets consisting of ten substrate spikes (substrate on which an explosive had been added), thirty blank substrate samples (substrates on which no explosive had been added during false alarm rate test) and five quality control samples The detection verification test consisted of two sample sets for each of the plastic explosives (C-4, Detasheet and Semtex), per sample substrate, per explosive amount: two concentrations were used. The second concentration was sufficiently lower than the first to provide a significant challenge to instruments. The artificial deposition procedure previously developed at the aviation security R&D laboratory was used to contamination substrates (2). In addition, NG and TNT were tested only at one concentration on 3 1/2 inch floppy disks. Because of the time constraints in developing this test, extensive morphological characterization of contamination on surfaces was not done for the NG and TNT test. The contamination for these species was prepared as a methanolic solution, and was placed as a small drop directly onto the substrate surface. The solutions prepared of plastic explosive were certified as being within +/- 20% using HPLC analysis. The solutions prepared for NG and TNT were obtained from Accustandard, and were used without further characterization.

Table 4: Substrate Test Matrix as Performed by Laboratory 2. Explosives used were Semtex, C-4, Detasheet, NG, and TNT.

Activity	Substrate	Sample Sets	Contaminant	Substrate Replicates
False Alarm rate and Throughput Verification	3 1/2" Floppy Disks	120 blanks	None	2 sets per instrument
False Alarm rate and Throughput Verification	zippers	120 blanks	None	1 set per instrument
False Alarm rate and Throughput Verification	luggage handles	120 blanks	None	1 set per instrument
Detection Verification	3 1/2" Floppy Disks	3 blanks, 2QC spikes followed by 10 substrate spikes with 3 blanks between each substrate spike	low concentration of explosive	2 sets per explosive per instrument
Detection Verification	zippers	3 blanks, 2QC spikes followed by 10 substrate spikes with 3 blanks between each substrate spike	high concentration of explosive	2 sets per explosive per instrument
Detection Verification	luggage handles	3 blanks, 2QC spikes followed by 10 substrate spikes with 3 blanks between each substrate spike	explosive	2 sets per explosive per instrument

Note: Actual threat quantities of explosive material are sensitive information

3.4 Explosive Test Standard Testing Measures

The instruments were evaluated against completeness, accuracy, precision, and comparability. Completeness is a measure of whether the instrument was able to be used for the analysis of each explosive and each sample substrate. Accuracy of an instrument was determined by monitoring: 1) the alarm rate for non-explosive contaminated samples 2) the alarm rate of explosive contaminated samples, and 3) identification of the appropriate explosive for explosive contaminated samples. The accuracy was monitored by evaluating the level of response for all explosive samples, each sample substrate, and each explosive type and amount.

3.5 Determination of False Alarm Rates and Throughput Rate Verification.

One of the two labs performing this test was directed to determine the false alarm rate, and the throughput rate. The sample set consisted of 120 new computer disks. The disks were sampled using the vendor recommended method. The sampling media was the analyzed by the instrument per vendor specifications. If the instrument did not alarm, the next substrate blank was sampled and analyzed. If the substrate did alarm, the vendor specified clear-down procedure were followed. Once the system was verified as clear-down, the substrate was resampled. If no alarm occurred, this first alarm was counted as a false alarm. If the substrate realarmed, it was retained for further evaluation with respect to contamination.

3.6 Quality Assurance Requirements Applied to Performance of the Vendor Testing Project

Because of the significant need to produce extremely high quality data, after the test plan had been developed, the decision was made to perform parallel test and evaluation at two independent laboratories. The laboratories chosen were the contractor supported FAA lab at the William J. Hughes Technical Center in Atlantic City, NJ (DCS) and the Lockheed Martin Idaho Technologies Company (LMITCO) personnel for the Idaho National Engineering Laboratory (INEL) facilities at the Idaho Research Center (IRC) and the North Holmes Laboratory (NHL). Each laboratory was directed to develop a quality control plan that would address quality control samples, contamination control practices, and standard preparation procedures. Key elements of the quality control plans used by each laboratory are listed below.

* Program Description
* Organization and Responsibility
* Quality Assurance Objectives
* Sampling Procedures
* Sampling Custody
* Calibration Procedures and Frequency
* Analytical Procedures
* Data Reduction, Validation and Reporting
* Internal Quality Control Checks
* Performance and System Audits
* Preventative Maintenance

* Specific Routine Procedures to Assess Data Quality Objectives
* Corrective Action
* QA Reports to Management

Each laboratory was provided with the same stocks of explosive standard material, and of substrate materials. All sampling and analysis operations for each EDS were performed within the specific protocols and training provided by each instrument vendor to the personnel would be conducting the test and evaluation.

4.0 Results of Test and Evaluation

As a result of this activity, 6 trace detection systems have been evaluated to date. Two vendors displayed high levels of performance on this test and were immediately accepted as eligible vendors for equipment purchase. One vendor was initially considered unacceptable for using a sampling system that was awkward, and not field tested, nor operationally acceptable. The procedure was modified and the vendor re-tested where necessary. The final result was that the updated results were acceptable. Another vendor was required to modify alarm algorithms, and otherwise perform additional R&D before the detector could pass the test. As a courtesy to the vendors, individual test results were shared.

Each vendor was allowed to service and optimize the machine prior to the start of testing. If a determination was made that the system was not performing to specifications the decision to continue was made on an individual basis. The vendor was given ample chance to assure that the machine was operating at an acceptable performance level, as determined by the manufacturer. In some cases tests were halted and the machine was sent back.

Interlaboratory results were remarkably similar. The only discrepancy in results centered around results generated using the vinyl luggage handle as the substrate. One noticeable difference between the two laboratories was that the Atlantic City lab made up all contaminated substrates weeks prior to the testing activity. However, all instruments were evaluated on the same day. The Idaho lab made up contaminated substrates immediately prior to testing. It appears that the vinyl handle degrades the amount of explosive available on the surface of substrate. (The lead hypothesis is that the plasticizer solubilizes the plastic explosives.) As a result of this, if was found that the Idaho lab reported higher alarm rates for vinyl handle substrates for all vendors than did the Atlantic City lab. However, because the Atlantic City lab had evaluated all machines in the same day, results could be used comparatively from machine to machine.

Acknowledgments: We would like to thank Mr. William Morgan and Mr. Ray Schillinger for preparing threat articles. We would like to thank Mr. Steve Sisk and his staff at DCS for performing test and evaluation on both the contamination determination studies, and in the execution of the vendor test plan. We would like to thank Dr. Steve Hartenstein and his staff at the INEL in the execution of the vendor test plan, and many excellent technical suggestions he made that strengthen the test plan. We express our appreciation to all in planning and executing this test plan within an eight week period.

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Application of Solid Phase Microextraction (SPME) in the Headspace Sampling of Contraband Drugs

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ABSTRACT

The potential of using solid phase microextraction in sampling of contraband drug vapors was recently demonstrated. It was found that SPME can be used conveniently in combination with ion mobility spectrometry (IMS), gas chromatography (GC), and GC-mass spectrometry (GC-MS) in the detection, identification and analysis of cocaine, heroin, and their decomposition products. The present paper gives additional detail on analytical methods development using SPME headspace sampling of cocaine freebase and cocaine hydrochloride in combination with GC. A dynamic range between 25 ng and 2 μg was demonstrated for both compounds. The use of SPME-GC with cocaine was illustrated in a study of cocaine freebase and cocaine hydrochloride decomposition on surfaces. Of the variety of materials examined, an organophilic zeolite and quartz fibers gave high cocaine decomposition. Cocaine freebase showed greater reactivity than did cocaine hydrochloride. The major decomposition product was found to be anhydroecgonine methyl ester (AEME) (methyl ecgonidine).

1. Introduction

Solid phase microextraction (SPME) has emerged as a rapid alternative technique to conventional sample extraction techniques. SPME can be used in solids, liquids, and sample headspace. Compounds are sorbed by a stationary phase coated on a fused silica fiber. The compounds are desorbed, and analyzed using gas chromatography (GC), and high performance liquid chromatography (HPLC). We have found that SPME can also be used conveniently with ion mobility spectrometry (IMS) [1-3]. We are using SPME-IMS, and SPME-GC systems for vapor detection of cocaine and heroin and their decomposition products. The present paper gives specific details on SPME headspace sampling of cocaine freebase and cocaine hydrochloride in combination with GC. A method was developed which allows these compounds to be studied at nanogram to microgram levels.

Solid Phase Microextraction (SPME).

SPME was invented and applied in conjunction with GC [4]. SPME is a solventless extraction technique. The idea is based on sorption of analytes on a fused silica fiber coated with an organic polymer. The analytes are thermally desorbed from the fiber, for instance, in an injection port of a gas chromatograph. Commercialization of SPME has been led by Supelco. Descriptive information on SPME can be found in Supelco's Reporter and SPME Highlights [e.g., 3 and 5]. A typical SPME device consists of a holder with a stainless steel plunger and a stainless steel shield (needle) for the fiber. The fiber, 1 cm length fused silica coated on its outer surface with a polymer (stationary phase), is connected to the plunger. The shield is used to pierce septa of sampling vials or an injection port of a GC. The height of the stainless steel shield is adjustable. By pushing in or pulling out the plunger, the fiber can be exposed or withdrawn into the shield. Diffusion of an analyte from a sample matrix into the fiber coating, and its subsequent desorption from the coating depends on thickness and polarity of the coating [6, 7]. SPME has been adapted into a configuration that can also be used in scenarios outside of the laboratory [8].

2. Experimental

Reagents and Materials

All drugs used in the present work were obtained as standard solutions. Cocaine freebase (1 mg/mL in acetonitrile) and anhydroecgonine methyl ester (AEME) (1 mg/mL in acetonitrile) were purchased from Radian International; cocaine hydrochloride (1 mg/mL in methanol) was purchased from Sigma Chemical Co.; and ecgonine methyl ester (EME) (1 mg/mL in methanol) was purchased from Restek. The zeolite powders used in this study were purchased from Aldrich Chemical Co., except for Sigma-zeolite which was obtained from Sigma Chemical Co. We examined the following zeolites: organophilic zeolite (OPZ), molecular sieves 3A, 4A, 5A, and 13X, NH_4Y zeolite, NaY zeolite, montmorillonite KF10, montmorillonite KSF, Ag exchanged zeolite, and Sigma-zeolite. Organophilic zeolite-Teflon™ membranes were fabricated by FluoroTechniques. QMA quartz fiber filters were obtained from Whatman.

SPME devices, polyacrylate fibers (85 µm), Ekonical™ vials with crimped aluminum caps with viton septa, and a heating block, were purchased from Supelco.

Sampling with SPME

Sampling experiments were performed with a SPME device for manual injection. A weighed amount of powder, was placed into an Ekonical™ vial. A 10 µL volume of cocaine freebase or cocaine hydrochloride solution was deposited into the vial. The solvent was evaporated using a one minute purge with ultrapure nitrogen gas. The gas was swept approximately 1 cm above the mouth of the vial at a pressure of 10 psi. (With membranes and filters, a weighed piece was placed into the vial. The cocaine solution was deposited onto the sample. The solvent was allowed to evaporate as described above.) The vial was then immediately sealed with a viton septum crimp-cap using a hand crimper. The vial was placed into a heating block and allowed to incubate at 140°C for 2.5 minutes. An 85 µm polyacrylate fiber, set to a needle depth of 1 cm, was inserted after the 2.5 minutes of sample incubation and then allowed to extract the vapors for one minute. The heating was continued during the sampling. The fiber was withdrawn into the needle at the end of the sampling period, and the needle was removed from the vial. The fiber was set to a needle depth of 3 cm. Analyses with GC were performed immediately after the sampling.

Analyses with GC

A gas chromatograph (Hewlett Packard model HP-6890), coupled with a flame ionization detector (FID) and a capillary column HP-INNOWax (15 m, 0.25 mm I.D., 0.25 µm film thickness), were used in the SPME-GC experiments. The fiber from the sampling process was introduced to the split/splitless injection port of the GC. The analytes from the fiber were thermally desorbed in the GC injection port. The GC parameters follow: the temperature of the injection port was 250°C, the temperature of the oven was programmed: 50°C held for 1 min, then ramped with 3 steps: 50°C/min to 200°C held 2min, 20°C/min to 230°C held 2 min, 20°C/min to 250°C held 2 min. Helium was used as a carrier gas; a pulsed split: 30 psi for 0.5 min was used to minimize solvent tailing, and then a constant pressure of 14 psi was kept for the rest of the chromatographic process. A purge time to vent was set for 4 min to allow a complete desorption of analytes from the fiber and their transfer to the head of the column. (After 4 min the purge valve was opened.) The exposed fiber remained in the injection port 1 min after the purge valve was opened. This allowed removal of excess solvent from the fiber.

3. Results and Discussion

Sampling Technique Development

Application of SPME for our purpose required development of sampling procedures and optimization of parameters. The first priority was to select a vessel that would allow cocaine reactions to be studied in nanogram to microgram levels. The choice of Supelco Ekonical™ vials with vitôn septa resulted from many tests using different sample vial designs. Some of our previous data were collected with typical 2 ml GC vials equipped with glass conical inserts and plastic supports. However, at higher temperature (up to 140°C) the plastic support melted and the conical insert dropped to the bottom of the vial. Vapors formed in the conical inserts (0.1 mL), and migrated to the much larger volume of the vial; sampling yields decreased markedly and varied from run to run. The use of higher temperatures allowed us to decrease sampling time, and to examine the contraband drug conversion chemistry in more detail. Samples were heated using a heating block. Temperatures obtained with the heating block were very stable, e.g., at 140°C it varied ± 0.2°C. The temperature was checked by placing a thermocouple inside the conical shape of the vial. We chose a reaction temperature of 140°C to demonstrate the use of SPME in studying the chemistry of contraband drugs. Details on selection of a SPME fiber coating, the solvent evaporation technique, optimum incubation period, and optimum sampling period will be given elsewhere.

Quantitative Analyses

Cocaine freebase and cocaine hydrochloride studies can be performed at nanogram to microgram levels using the SPME-GC method described in this paper. Calibration curves were produced using both direct injection and SPME techniques and are compared in Figures 1-4.

The SPME method gave a dynamic range between 25 ng and 2 µg with a correlation coefficient of 0.999 for cocaine freebase headspace analysis as shown in Figure 2. At lower amounts in the range of 0-200 ng, the cocaine freebase curve gave a correlation coefficient of 0.946 with a slightly higher slope (Figure 2).

The SPME-GC calibration curve for cocaine hydrochloride also exhibited a dynamic range between 25 ng and 2 µg (Figure 3); the correlation coefficient was 0.994. The precision of the SPME-GC technique was found to be 0.999 for the freebase. Also, the sensitivity is somewhat better; the slope was 7.5 in comparison to 5.2 for the hydrochloride. This is not surprising since the hydrochloride needs to dissociate for the cocaine to be sampled in the vapor state. It was interesting to find that the correlation coefficients for SPME-GC compared very well to those obtained with direct injection techniques.

Calibration curves were also obtained using direct injection of cocaine solutions (Figures 1-4). As one would expect, the slopes are higher (about five times) than those using SPME. SPME-GC signals were on the average 50% of those from direct injection. The correlation coefficients are excellent. The lower sensitivity of SPME-GC in comparison to direct injection is undoubtedly related to the sampling process. Usually, the longer sampling time, the more analyte is sorbed on the SPME fiber until equilibrium is reached. Under the conditions chosen in our experiments (temperature 140°C), longer sampling times resulted in sampling losses. That might by caused by the vials unsealing due to the temperature. We noted a significant drop in cocaine peak intensity for sampling times longer than 5 minutes. The choice of 2.5 minutes incubation and 1 minute sampling at 140°C, was made in an attempt to minimize sampling time, and to obtain reasonable GC response from cocaine and its decomposition products. The slope difference between direct injection of cocaine samples and SPME procedures, reflects a tradeoff of sampling parameters.

Cocaine Surface-Chemistry

The SPME-GC method was used to study the surface chemistry of cocaine freebase and cocaine hydrochloride with a variety of materials. Approximately 1-2 mg of the test materials were weighed into Ekonical™ vials prior to deposition of cocaine. Examples are given with Whatman QMA quartz fiber filters, Aldrich organophilic zeolite (OPZ), organophilic zeolite - Teflon membrane (OPZ 1A) fabricated by FluoroTechniques, and Aldrich 4A molecular sieve (Figures 5 and 6). Both AEME and residual cocaine were found in all chromatograms. This indicates that elimination of benzoic acid is the major mechanism under the conditions of the experiments. In the case of QMA, a peak for benzoic acid and several other peals were also observed. The other peaks are due to impurities in the QMA. Benzoic acid peaks did not appear in the chromatograms for the other test materials shown. Our experience is that OPZ, many zeolites and other materials, including QMA, tend to strongly sorb benzoic acid.

The percent reaction of cocaine freebase and cocaine hydrochloride was estimated from the residual cocaine appearing in the chromatograms by using the SPME calibration curves. The estimates are given in Tables 1 and 2. Use of OPZ gave high conversion of both the freebase and the hydrochloride. QMA quartz fibers were much more reactive with cocaine freebase than with the hydrochloride. Molecular sieve 4A appears to be the least reactive of the four materials shown.

Conclusions

SPME is a very convenient sampling technique. One attraction for sample collection relates to variety of analytes including cocaine freebase and cocaine hydrochloride that can be sampled from different matrices by using the same fiber. Also, SPME is a solventless extraction method. It is clear that SPME-GC can be used to conveniently sample and analyze cocaine and its decomposition products. A dynamic range between 25 ng and 2 μg was demonstrated for both cocaine freebase and cocaine hydrochloride. The methodology is applicable to a variety of conditions and scenarios.

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Table 1. Cocaine Freebase Chemistry on Several Surfaces

Surface	Conversion Product(s)	Cocaine Conversion
QMA	AEME Benzoic acid	90%
OPZ	AEME	86%
OPZ 1A	AEME	77%
Sieve 4A	AEME	72%

Table 2. Cocaine Hydrochloride Chemistry on Several Surfaces

Surface	Conversion Product(s)	Cocaine Conversion
QMA	AEME Benzoic acid	66%
OPZ	AEME	90%
OPZ 1A	AEME	70%
Sieve 4A	AEME	60%

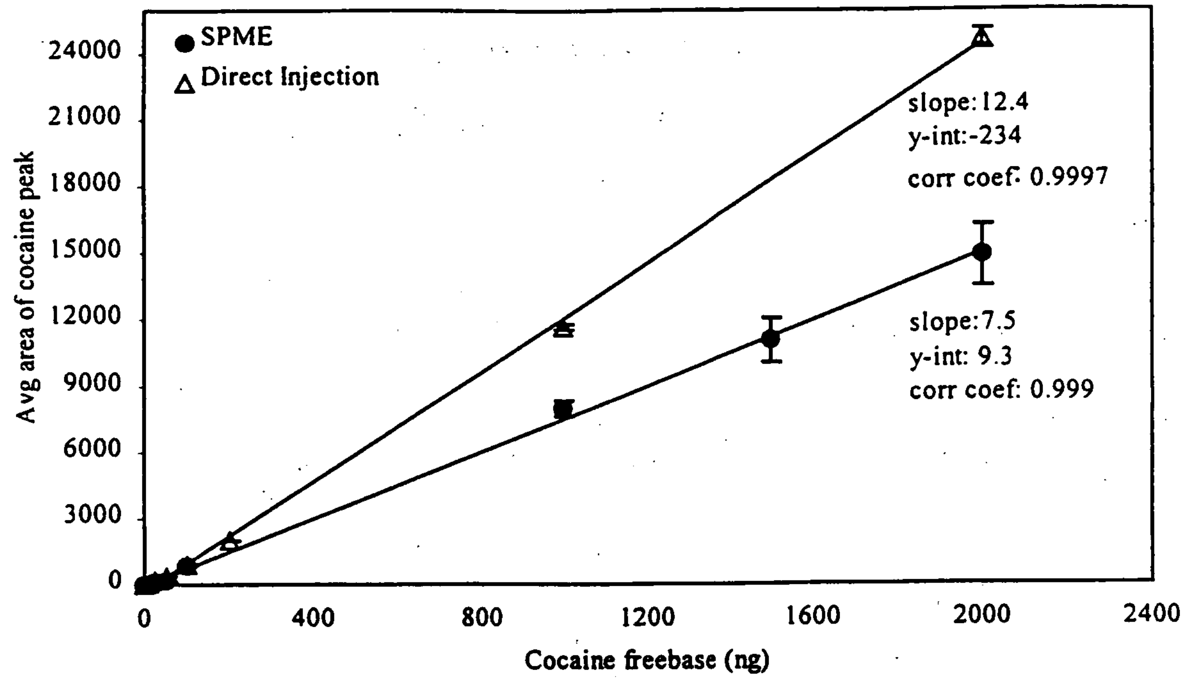

Figure 1. Comparison of GC calibration curves for cocaine freebase using direct injection and SPME techniques for the concentration range of 0 - 2000 ng.

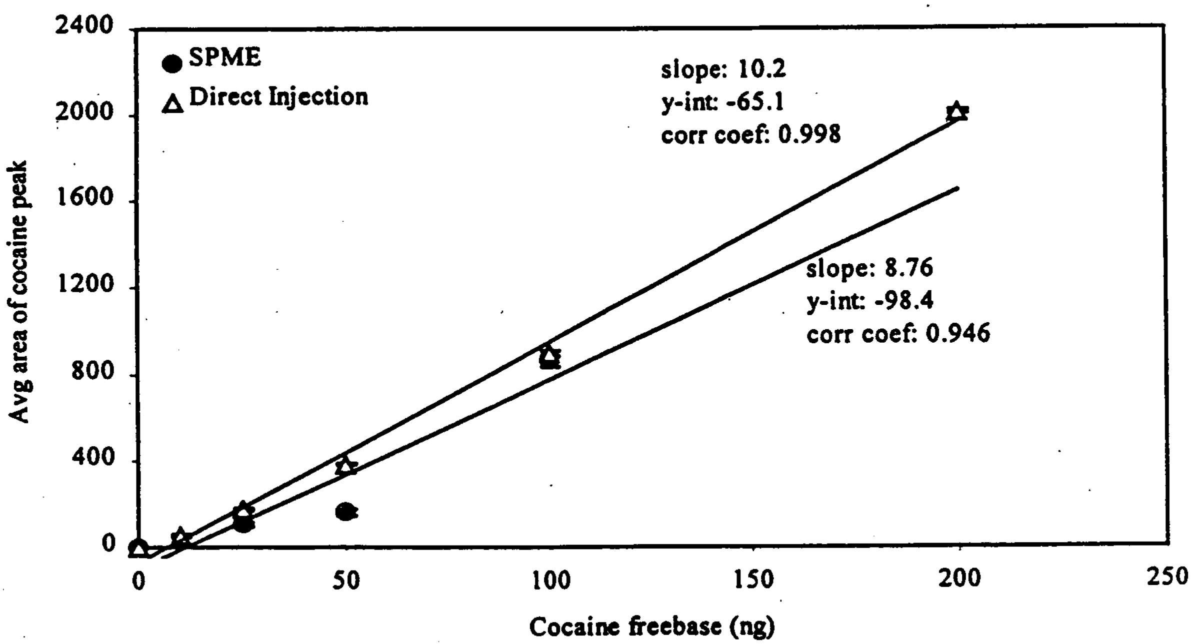

Figure 2. Comparison of GC calibration curves for cocaine freebase using direct injection and SPME techniques for the concentration range of 0 - 200 ng.

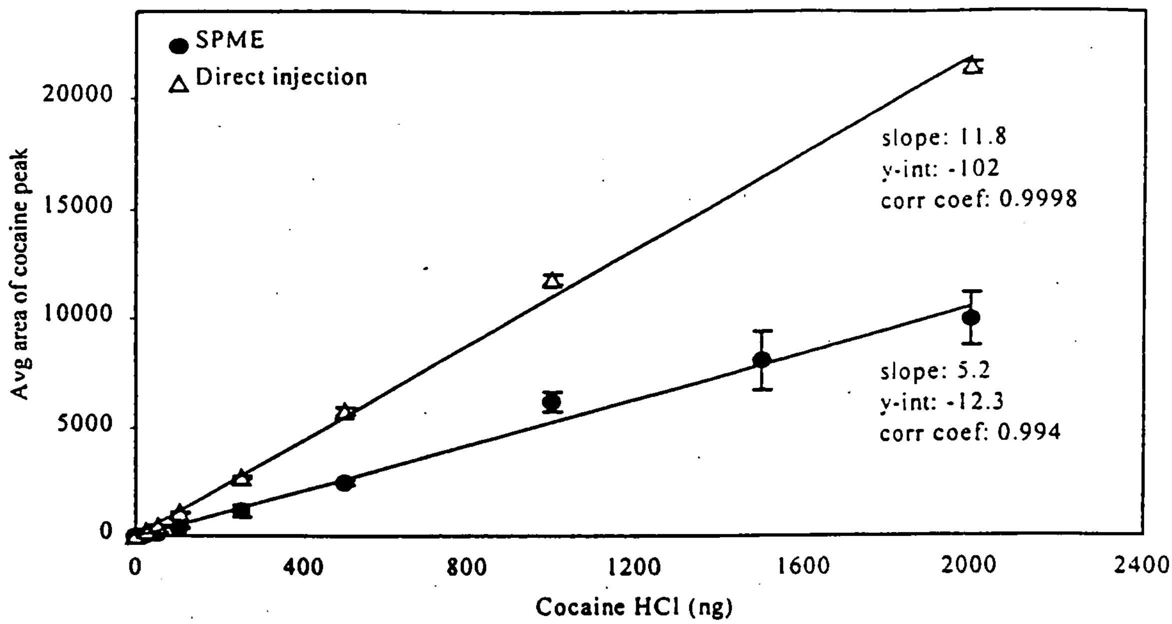

Figure 3. Comparison of GC calibration curves for cocaine hydrochloride using direct injection and SPME techniques for the concentration range of 0 - 2000 ng.

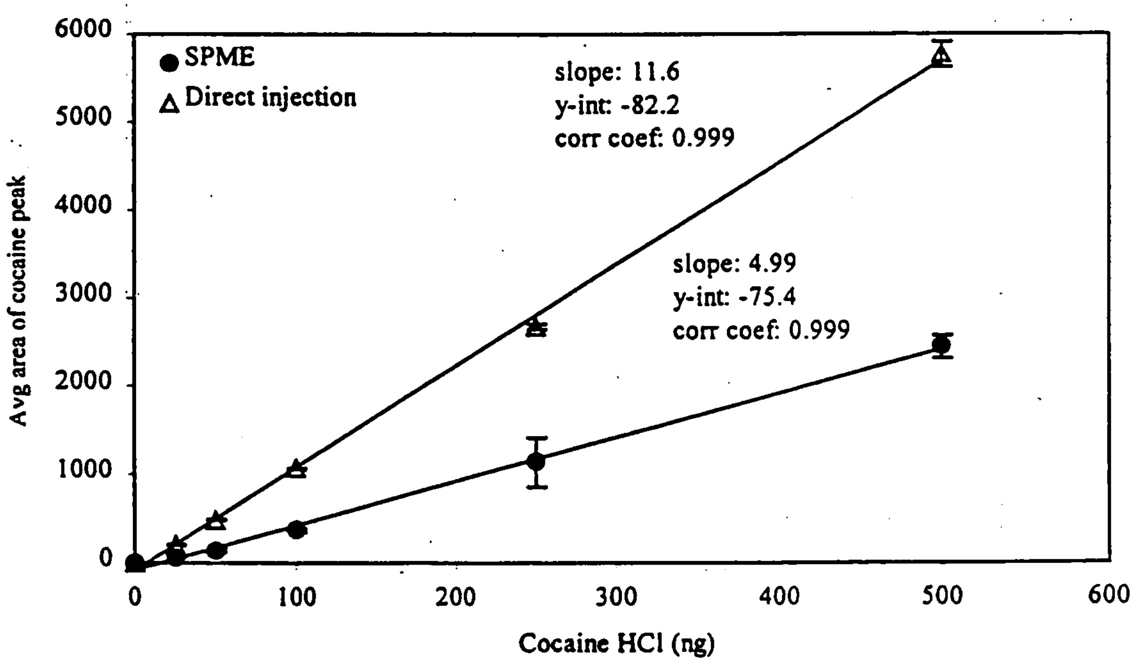

Figure 4. Comparison of GC calibration curves for cocaine hydrochloride using direct injection and SPME techniques for the concentration range of 0 - 500 ng.

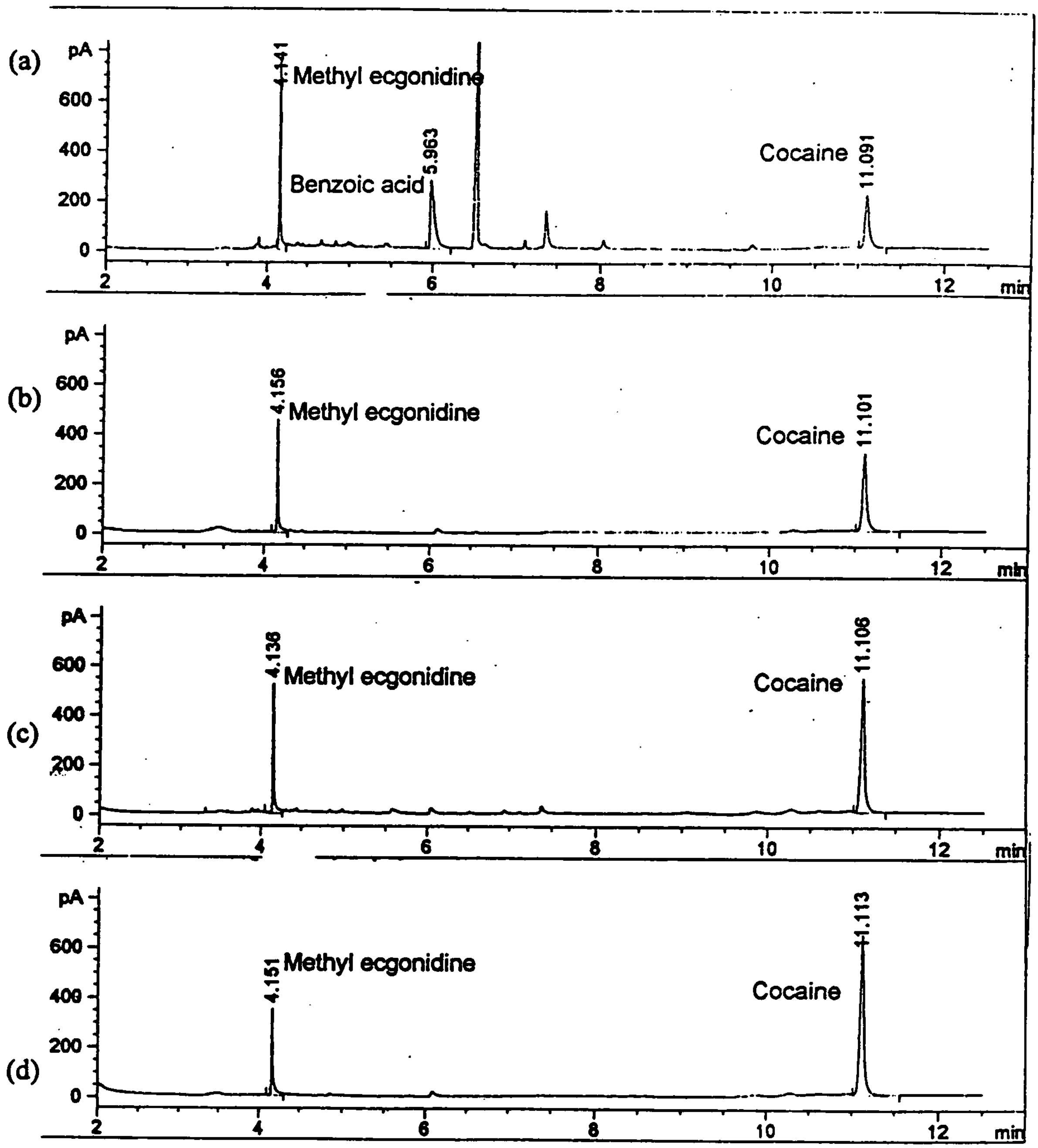

Figure 5. SPME-GC chromatograms from reaction of cocaine freebase with (a) QMA, (b) organophilic zeolite, (c) OPZ 1A, and (d) molecular sieve 4A.

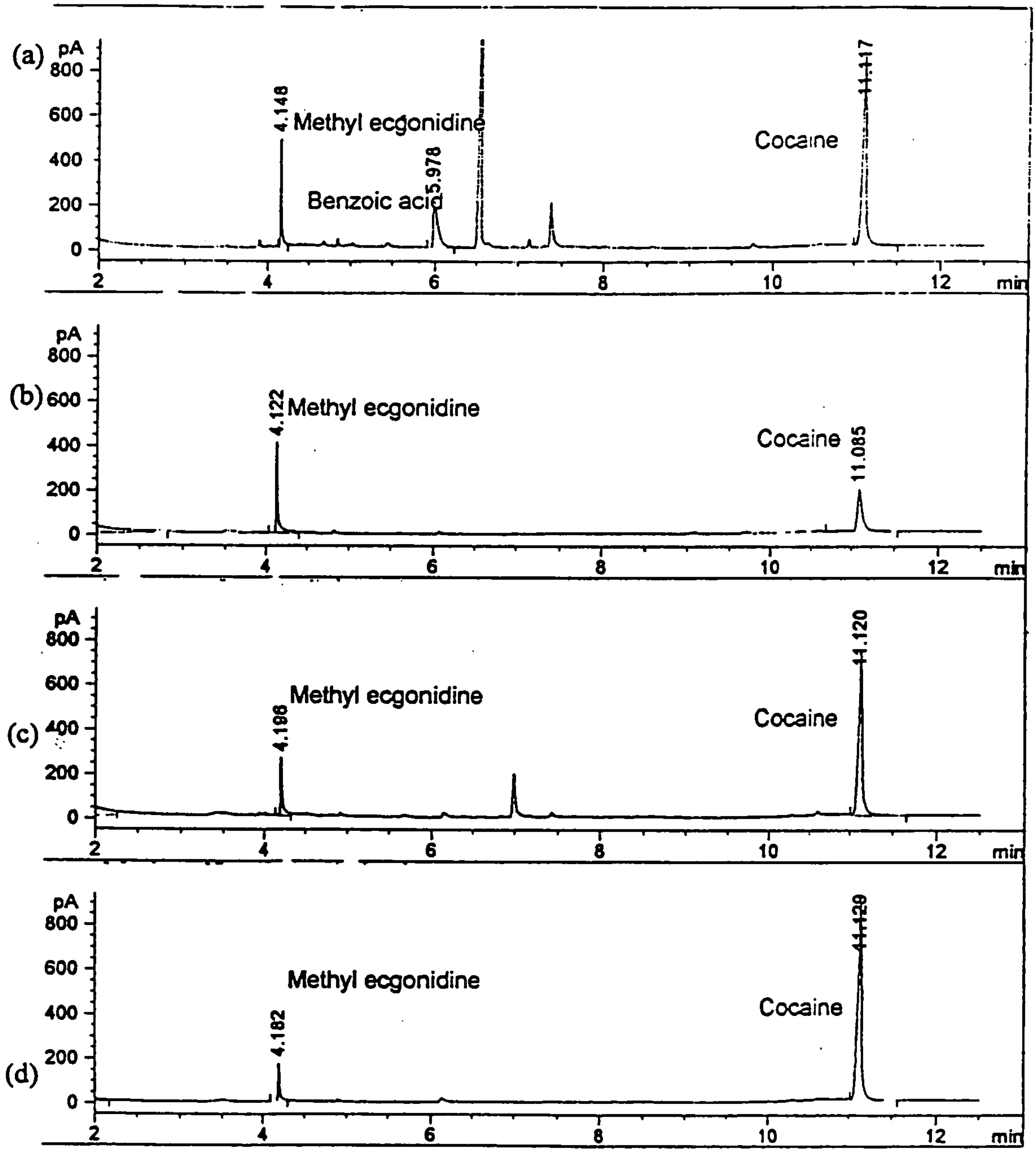

Figure 6. SPME-GC chromatograms from reaction of cocaine hydrochloride with (a) QMA, (b) organophilic zeolite, (c) OPZ 1A, and (d) molecular sieve 4A.

The Graseby NARCOTEC™ narcotics detector: a non-radioactive version

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ABSTRACT

This paper discusses the operation of a Graseby NARCOTEC™ narcotics trace detector equipped with a non-radioactive ionization source. This ionization source is a pulsed corona discharge ionizer which has been engineered to fit into a standard NARCOTEC unit. Traditionally, analytical instrumentation using ion mobility spectrometry (IMS) relies on the use of a ^{63}Ni radioactive source for sample ionization. Obstacles to the deployment of such portable IMS detectors associated with the licensing requirements for radioactive sources are eliminated by use of the corona discharge source.

The spectral response of the system to quantified samples of cocaine, heroin, MDMA, methamphetamine and amphetamine are shown. The ion chemistry generated by the corona source is shown to be identical to that of a NARCOTEC fitted with a ^{63}Ni source by comparison of the corresponding spectral responses.

Introduction.

Since the inception of ion mobility spectrometry as an analytical detection method in the early 1970's (1), ^{63}Ni radioactive foils have been used extensively as the source of ionisation. The advantages of such a source are obvious, these include no power requirement, provides a source of both positive and negative ions and they are small in size. However, in regard to IMS development for the commercial market where the systems are often required to be portable, the use of the ^{63}Ni radiation source in some countries presents the user with significant paperwork to satisfy current legislation governing the carriage of such sources. For applications where portability is vital, a system equipped with a non-radioactive ionisation source is beneficial in that the aforementioned problems is avoided.

Several groups have looked at alternative ionisation methods for IMS, often prompted by particular detection requirements; these include UV photoionisation (2,3), photoemissive ionisation (4), resonance enhanced laser ionisation (5-7), laser desorption/ionisation (8-10), electrospray ionisation (11,12) for liquid sample interfacing and corona discharge ionisation (13). However, most of these studies have been confined to the research laboratory and have not found much use in field instruments.

With a view to developing a rugged source of ionisation which would avoid the above radiation legislation problems and the inherent health and safety risks associated with radioactive sources, we have studied the use of pulsed corona discharge ionisation as an alternative IMS ion source. The development of this novel pulsed ion source for IMS was first described by Taylor (14).

This patented corona discharge source (15,16) has now been developed for use in high temperature IMS environments, specifically the Graseby PLASTEC™ explosives detector and the Graseby NARCOTEC™ (see Figure 1) drugs detector. In this paper, the use of the source in NARCOTEC only is discussed.

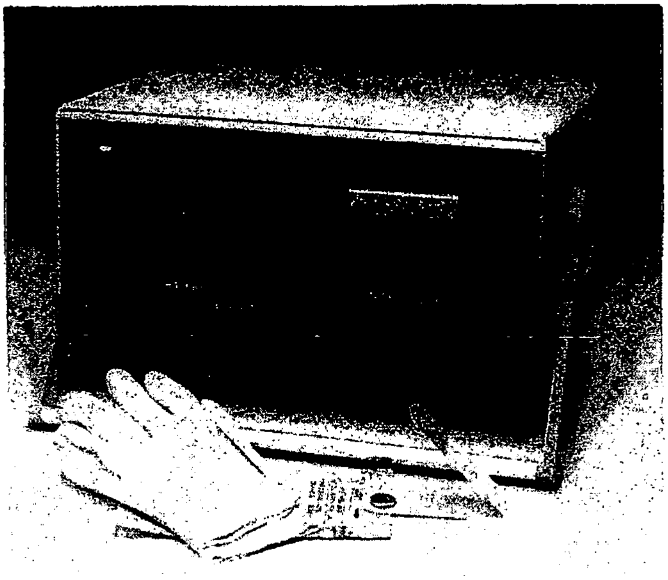

Figure 1: NARCOTEC™ narcotics trace detector

Ion mobility spectrometry-general principles

The technique of ion mobility spectrometry was first demonstrated in 1970 by Karasek (1) and since then the technique has been the subject of a number of useful reviews (17-19).

The fundamental process involves the separation of ions in the gas phase, normally at atmospheric pressure, under the influence of an electric field in accordance with their ionic mobilities in a neutral drift gas. A schematic diagram of a typical IMS system is shown in Figure 2. The primary components of the system are a sample inlet, an ionisation source, a reaction region, an ion gate, an ion drift region and finally a collector electrode as shown.

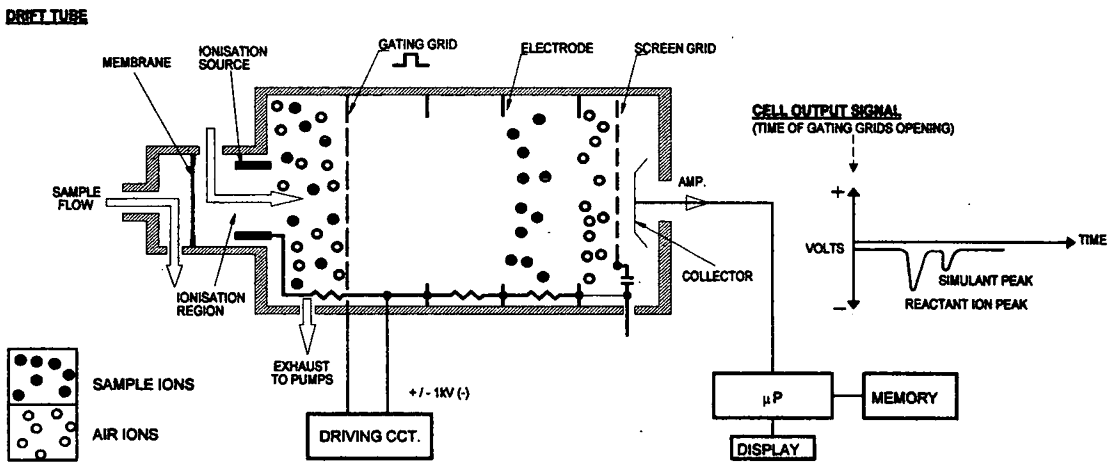

Figure 2: Schematic diagram of typical IMS system.

The ionisation source generates a supply of stable ion species in the reaction region; these ions are termed reactant ions and the collector current associated with these ions is called the Reactant Ion Peak (RIP). In a system using air as the carrier gas the reactant ions have been shown to be of the form $H^+ (H_2O)_n$ (n=1,2,3,..) for positive ions and $O_2^- (H_2O)_m$ (m=1,2,3,..) for negative ions. The degree of water clustering associated with these ions (i.e. the value of n,m) is dependent upon cell parameters such as temperature and humidity.

Analyte material is introduced into the reaction region of the instrument in a carrier gas flow. The ionisation of an analyte molecule is dependent upon whether a reaction between the analyte molecule and a reactant ion can take place. If this is the case, charge is exchanged between reactant ions and analyte molecules generating a population of analyte ions. An ion gate or shutter which forms the boundary between the reaction region and the ion drift region is electronically opened (usually for ~200μs) which allows a packet of ions to pass from the reaction region into the drift space. These ions drift under the influence of a weak electric field (typically 200V/cm) against a countercurrent gas flow towards the collector electrode. During this transit to the collector electrode, separation of ion species in terms of their ionic mobilities in the drift gas used takes place. Measurement of the ion current at the collector electrode following gating of ions into the drift space gives rise to an IMS spectrum. The formation of product ion peaks (PIP) which are characteristic of the sample under study allows specific detection of materials by monitoring for these ion species. The use of microprocessor based systems to monitor for ions of particular mobility can give rise to simple display outputs which can alert the user to the presence of target materials.

Narcotec-background of operation

The IMS detector at the heart of Narcotec is a high temperature cell of ceramic construction which can be operated at temperatures up to 250°C. A pneumatic diagram of the system is shown in Figure 3. A single pump is used to generate both a cell drift flow and a desorption nozzle flow and in recirculatory mode both flows are returned to the pump through an exit port in the sample door as shown. The system includes an Ammonium Carbamate permeation source which chemically dopes both gas flows of the system. The presence of this material modifies the ion chemistry in the source of the instrument such that the reactant ion species are water clusters of ammonia.

The sampling system used in Narcotec is a high temperature thermal desorption source which releases solid material collected on paper sample wipes into the gas phase. Vapourised material is entrained in the desorption flow and transported to the ionisation source of the system.

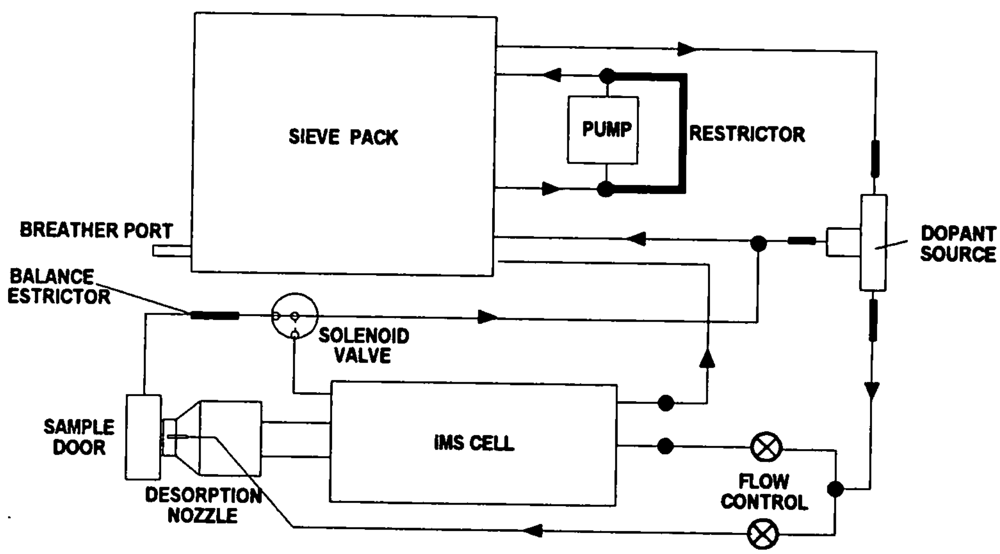

Figure 3: Diagram showing pneumatic system in NARCOTEC

In a standard Narcotec, sample material is ionised via ion molecule reactions with reactant ion species formed in the ^{63}Ni radioactive source. Product ion species so formed are periodically injected into the clean drift region of the spectrometer by briefly opening an ion gate for typically 180μs. An on-board microprocessor is programmed to monitor for ions of defined mobility (narcotic product ion species) and displays both the intensity and the identity of any narcotic species present. The detection windows are positioned in relation to a calibrant material which the system requests on a regular basis. The processor measures the drift time of the calibrant ion species and sets the detection windows for the narcotic target species at well defined multipliers of the calibrant position. Constant monitoring of the RIP position and appropriate adjustments based on any movement of the RIP maintains system calibration and ensures the target windows are positioned correctly. All spectra shown have been averaged over 32 individual spectra.

Before the experimental data are discussed a brief description of the corona discharge system is given.

Corona discharge operation

A schematic diagram of the corona discharge ionisation source is shown in Fig. 4. The source consists of two fine platinum wires of 10μm diameter and approximately 1.5mm in length, which are located in the grounded (0V) front flange of the instrument. The platinum wires are spot welded onto corona discharge electrodes which take the form of a ceramic tube of 3.9 mm diameter into which is brazed a copper wire of 0.7mm diameter. A locating disk brazed on the outside of the ceramic tube (not shown in the diagram) bears against a flat in the front flange of the cell and ensures that the corona point positions are well defined and reproducible in the source region of the instrument.

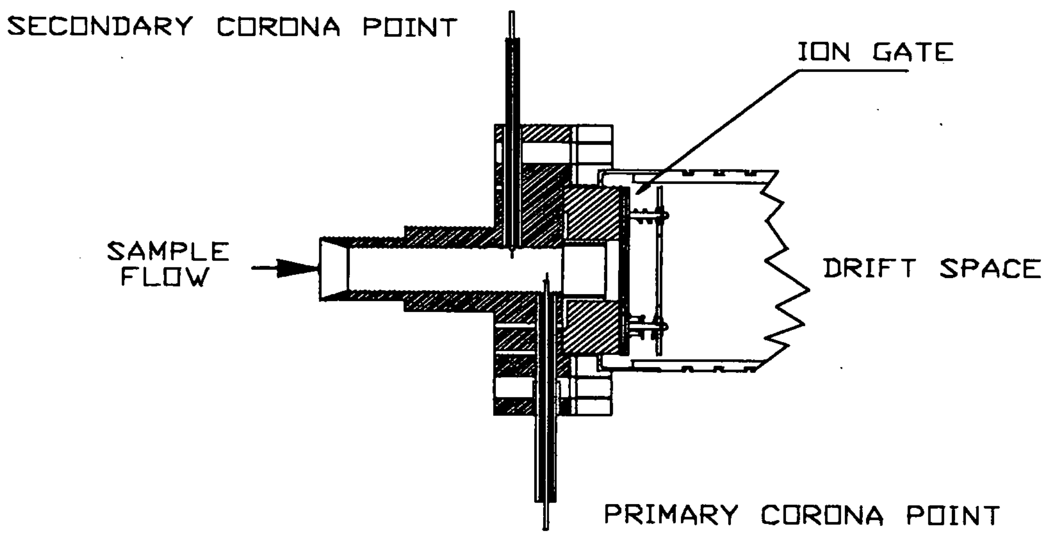

Figure 4: Schematic diagram showing both corona points and the ion gate of the IMS cell.

In NARCOTEC, the primary ionisation point (the one which is pulsed to produce a discharge) is operated with +400V d.c. and high voltage pulses applied to the point. At the operating temperature of the unit (200°C) this d.c. voltage is below the threshold voltage required for self-sustaining d.c. corona discharge. In order to produce a pulsed corona discharge, a 5μs pulse of amplitude 2kV is periodically applied to the primary point. When the pulse is applied the corona discharge threshold for the point is exceeded which results in a pulsed electron avalanche in the source region. Stable reactant ion species result from this pulsed discharge and provide a supply of charge for ionisation of analyte vapour. As shown on the diagram in Figure 4 a second corona electrode is employed; this point is operated at a d.c potential of opposite polarity to that of the ions one wants to generate. For Narcotec operation, the secondary corona point is held at -900V (just below its corona threshold for self-sustaining discharge) and this serves to stabilise the pulsed discharge at the primary point.

The primary point is positioned approximately 10mm from the ion gate structure and due to the pulsed nature of the discharge, time synchronism between the corona pulse and the opening of the ion gate is required. It is worth mentioning at this point that the same point geometry has been integrated successfully in PLASTEC, albeit with slightly different voltages.

Experimental Data.

Data was recorded for narcotic samples deposited on clean PTFE sample disks. The sample disk was cleaned with methanol and heating to approximately 300°C to ensure cleanliness and was allowed to cool before any samples were deposited. A spectrum of the cleaned PTFE disk was taken and no product ion peaks were present in the targetting regions of the instrument.

Due to the pulsed nature of the corona source, it was necessary to study the dependence of ion transmission into the drift space as a function of the delay between the corona pulse and the ion gate opening. The graph shown in Figure 5 shows the measured variation in the RIP intensity as the delay between the corona pulse and the ion gate trigger is changed, where it can be seen that the maximum RIP intensity occurs at approximately 800μs. At small delays (less than 500μs) the RIP intensity is observed to fall off rapidly until at around 300μs no reactant ions are injected into the drift space.

As the graph shown is effectively a measurement of the temporal width of the ion pulse arriving at the ion gate it is evident that the ion density arising from the 5μs corona discharge is subject to significant broadening (possibly space charge repulsion) since it persists in the source region of the instrument for greater than 4 ms. A simple calculation assuming low field ion drift in the volume between the corona point and the ion gate and uniform extraction field, defined by the potential of the ion gate and the earthed flange, predicts that reactant ions would reach the ion gate in around 7 ms, which is clearly much greater than the maximum measured in Figure 5. This is further indication that some other mechanism, such as space charge repulsion, significantly affects the ion transit time to the ion gate.

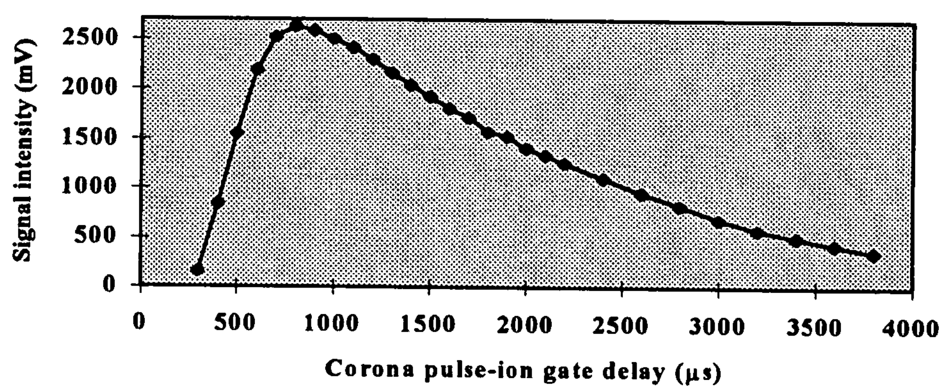

Figure 5: Measured RIP intensity plotted as a function of delay between corona discharge and ion gate operation

An investigation into the optimum delay for maximising the transmission of narcotic product ion species was made and results for cocaine and methamphetamine are shown in Figure 6. The data presented show that the profiles for both cocaine and methamphetamine are maximised at around 2.5 - 3ms, although the graph shows some relative displacement of the curves. A comparison of both curves shows that at delays less than 2.5ms, the intensity of the cocaine peak falls off more rapidly than that of methamphetamine, but that for delays greater than 3 ms, the cocaine peak is relatively more intense. The maxima of both curves occur around 2.5-3 ms, but the experimental accuracy of the measurements made to produce this graph prevent an accurate measurement of the optimum delays. It would appear however that the maximum for cocaine occurs after that of methamphetamine. Consideration of mobility effects in the region between the corona point and the ion gate would predict that the maximum in the graph for cocaine would occur later than that of methamphetamine due to its lower ionic mobility.

The curves show that for a delay of around 3 ms, the product ions associated with both samples are transmitted into the drift space of the cell giving rise to significant product ion intensity. Consequently, all spectral data reported in this paper were recorded for a delay of 3 ms. Similar measurements were made for the other narcotic compounds of interest and all show significant intensity for a delay setting of 3ms.

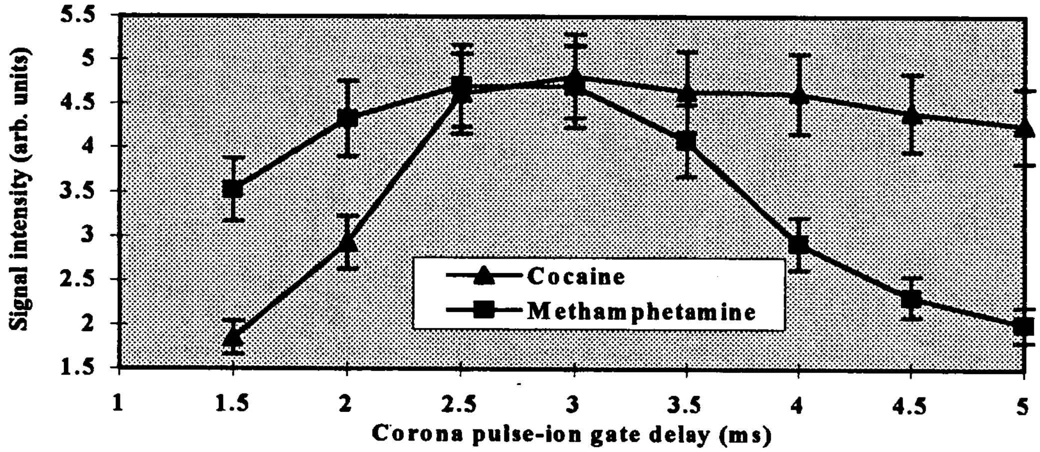

Figure 6: Product ion intensity plotted as a function of delay between corona discharge pulse and ion gate opening for Cocaine and Methamphetamine.

Quantified samples of the above narcotic materials were deposited onto PTFE disks in methanol solution for analysis. It was observed that the surface temperature of the PTFE disk onto which samples were deposited affected the desorption profile of the sample under test, the profile being much sharper for higher surface temperatures. Care was taken therefore to ensure that all PTFE wipes used were at room temperature before an analysis was made. An additional problem pertaining to the relative positioning of the sample deposit and the hot desorption air flow introduced further uncertainty in the maximum signal observed in any analysis. To minimise this effect PTFE disks which self-located on the desorption nozzle were used. This ensured that the centre of the disk was in the same position relative to the nozzle thus removing any uncertainty associated with the relative positioning of the sample and the desorption nozzle.

It was an original concern during the development of the corona source that the ion chemistry generated by the source may be different to that of the ^{63}Ni source. The spectra shown in Figure 7a) and 7b) show the reactant ion peaks generated in the ^{63}Ni NARCOTEC unit and the corona discharge NARCOTEC unit respectively. Clearly, the RIP drift times are very similar suggesting that the same reactant ion species are being generated in each source.

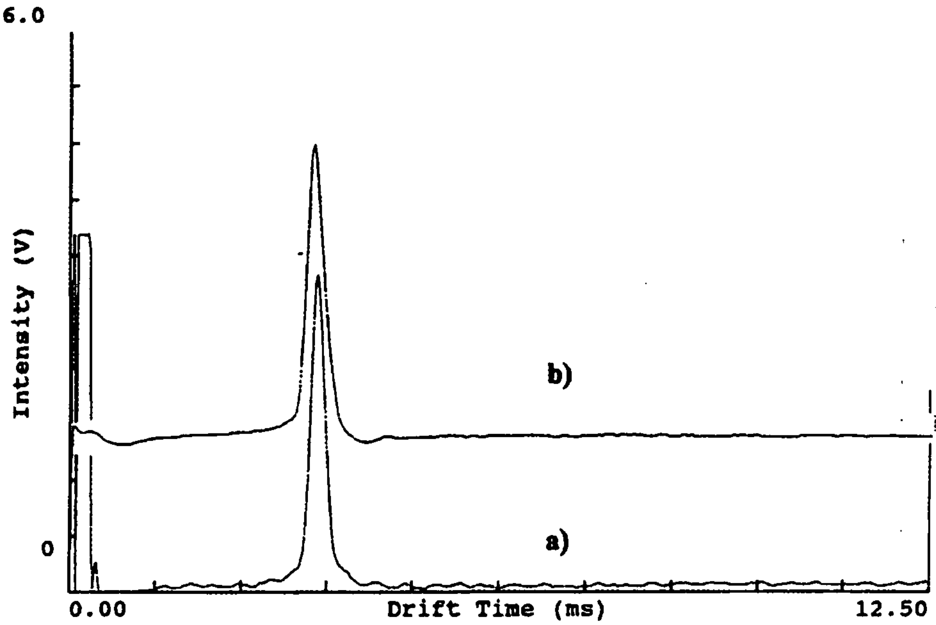

Figure 7: Reactant ion spectra for a) ^{63}Ni NARCOTEC, and b) Corona NARCOTEC

A comparison of the response of both a ^{63}Ni Narcotec and a Corona Discharge Narcotec to quantified samples of Cocaine, Heroin Hydrochloride, Methamphetamine, Amphetamine Sulphate and 3,4-Methylenedioxymethylamphetamine (MDMA) was made. Quantified amounts of the above samples were deposited onto cleaned PTFE disks by depositing the required amount of methanol solution on the wipe and allowing the solvent to evaporate. The wipe was then placed in the sample door of the system and analysed.

Figure 8a) shows the typical response of the corona Narcotec to 500pg of cocaine, the corresponding response of a ^{63}Ni Narcotec being shown in Figure 8b). To facilitate a simple comparison of signal-to-noise ratios between the two systems the gain of the corona NARCOTEC unit was increased until the single shot noise levels i.e. the noise level on a single unaveraged spectrum, of both systems were the same. This was required since the signal-to-noise ratios of the signals generated in the corona source are generally much higher than that of the ^{63}Ni source.

In a similar fashion, Figures 9 a,b), 10 a,b), 11a,b) and 12 a,b) show the corresponding response to 2ng of Amphetamine Sulphate, 2ng of Methamphetamine, 2ng of MDMA and 4ng of Heroin Hydrochloride. In all cases, identical product ion species are observed for both systems showing that the ion chemistry generated in the source region of the corona discharge system replicates that of the ^{63}Ni radioactive source. In the spectra shown in Figs. 9-12, there is evidence of slight cocaine contamination. The only significant difference is observed in the spectra shown for Heroin Hydrochloride, where is noted in that the peak appearing at around 9.5ms is relatively more intense in the corona discharge unit. The detection sensitivity of both instruments look to be similar on comparing the product ion intensities although the product ion peaks are slightly wider in the corona discharge unit. This is believed to be due to space charge broadening, primarily in the region of the ion gate, where the product ion population and the reactant ion population are not separated.

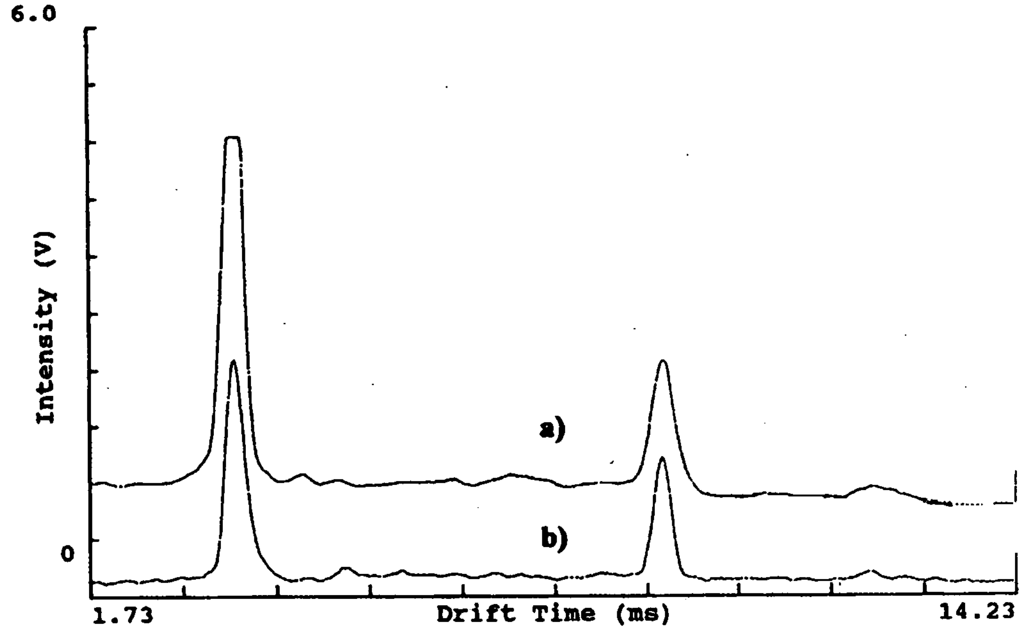

Figure 8: IMS spectra showing the response to 500pg of Cocaine using a) Corona NARCOTEC, and b) ^{63}Ni NARCOTEC.

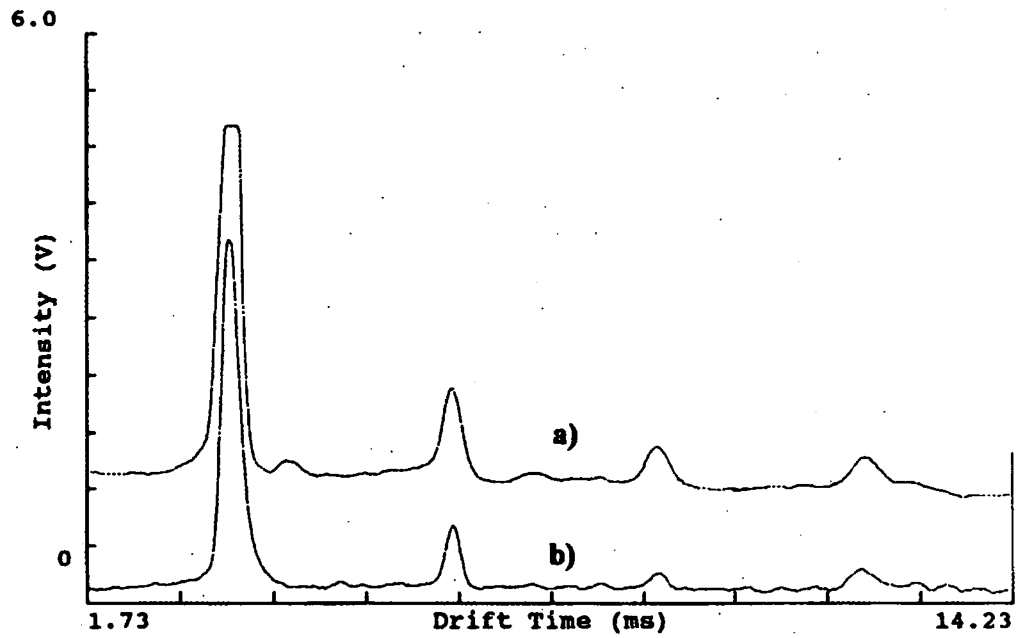

Figure 9: IMS spectra showing the response to 2ng of Amphetamine Sulphate using a) Corona NARCOTEC, and b) ^{63}Ni NARCOTEC.

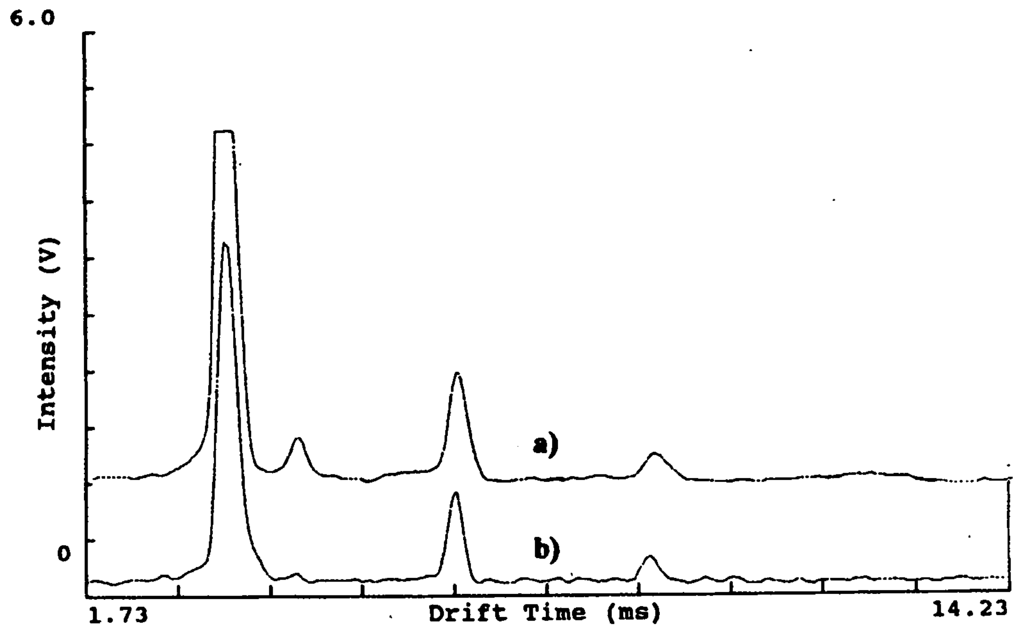

Figure 10: IMS spectra showing the response to 2ng of Methamphetamine using a) Corona NARCOTEC, and b) ^{63}Ni NARCOTEC.

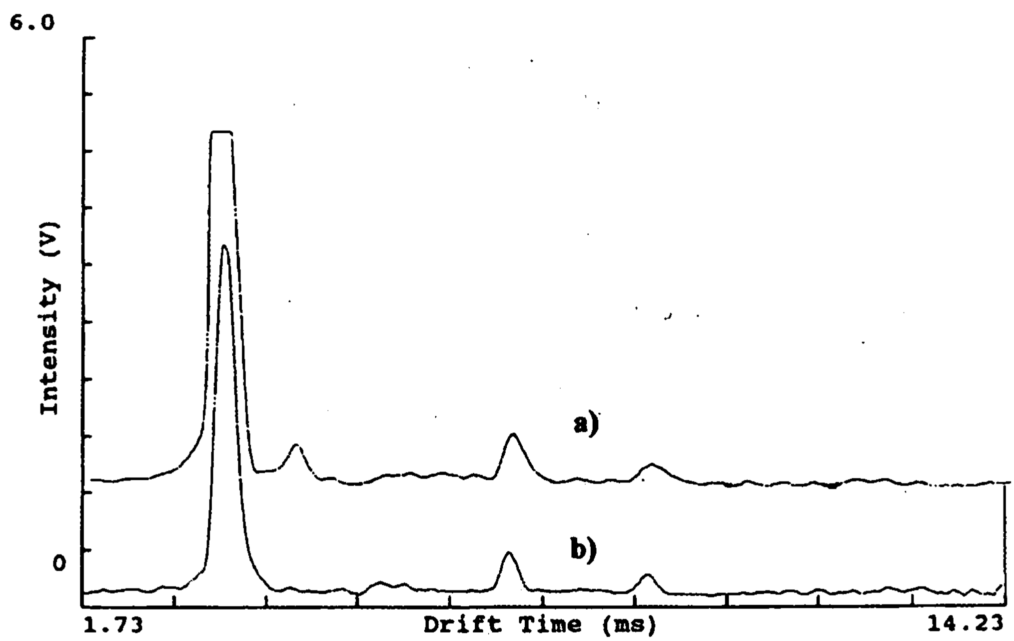

Figure 11: IMS spectra showing the response to 2ng of MDMA using a) Corona NARCOTEC, and b) ^{63}Ni NARCOTEC.

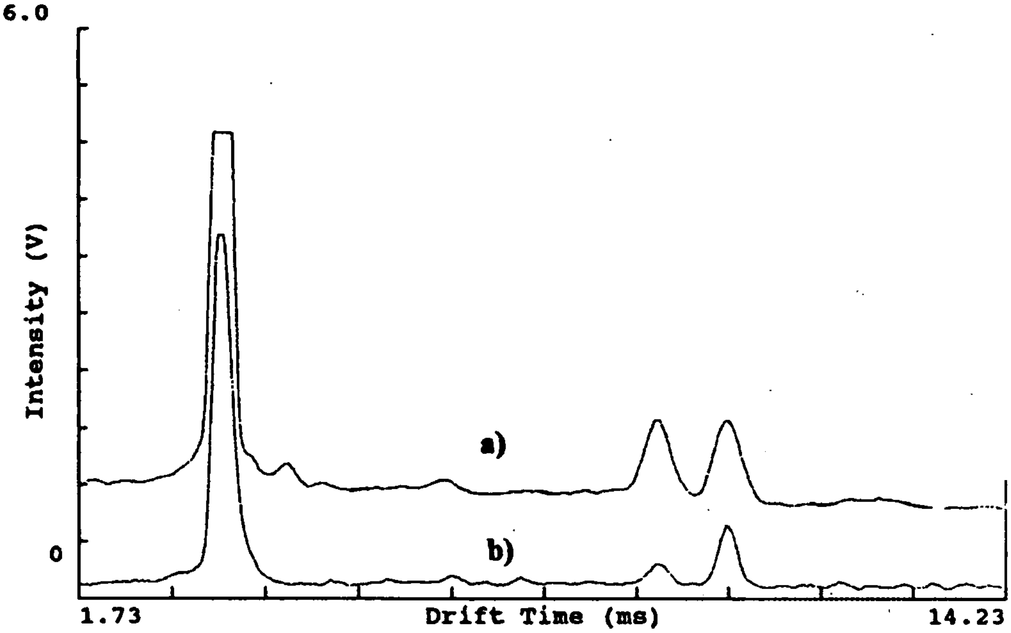

Figure 12: IMS spectra showing the response to 4ng of Heroin Hydrochloride using a) Corona NARCOTEC, and b) ^{63}Ni NARCOTEC.

Discussion.

The data presented is a clear indication that the pulsed corona discharge source is a suitable replacement for the traditionally used ^{63}Ni source. The ion chemistry generated in the ion source of the corona discharge system is shown to be identical to that of the ^{63}Ni source by comparison of the ion mobility spectra. Further, the sensitivity of the corona unit looks to be as good as the ^{63}Ni system.

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Monitoring and Deterring Drug Use

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Abstract

An effective drug deterrent program often includes a random testing element. Urine has been the favored testing medium for detecting and deterring drug use. However, the short window of detection for many drugs in urine coupled with the personal inconvenience in collection has led to the search for alternative matrices for analysis. Testing for drugs of abuse can be accomplished in a number of other matrices, such as hair, saliva, and sweat, which have advantages over urine in ease of collection, longer window of detection, and higher resistance to adulteration. This paper discusses the advantages and limitations of sweat testing (obtained by wiping the forehead). Cocaine levels >15 ng/wipe appear to be indicative of cocaine use rather than exposure. A ratio of benzoylecgonine to cocaine of greater than 0.1 also appears to support use rather than exposure.

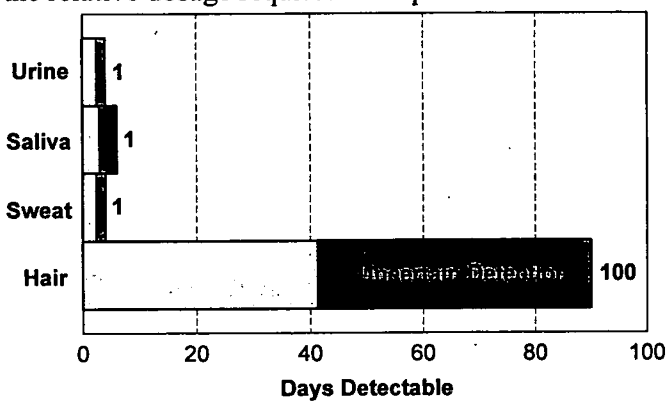
Introduction

For over a decade, the Department of Defense (DoD) has placed emphasis on detection and deterrence of drug use. The employment of testing and education are key components of this deterrence program.[1] The Navy has been a strong proponent of urinalysis and as such is one of the world's largest drug screening organizations. As the use of urinalysis increased and military personnel became more aware of the disciplinary measures, the self-reported use rate (past 30 days) in the Navy dropped from 33 percent in 1980 to under 4 percent in 1994.[2] Likewise in the civilian sector, as drug testing has expanded, the rate of drug use has declined.[3]

The deterrent effect of urinalysis is suggested by the observation that for a random sample of Navy personnel, 48% believe that urinalysis testing has contributed to reduced drug abuse in the military.[2] It is often assumed that the perception of detection influences the deterrence effect of testing, although there is no hard proof of that assumption. The likelihood of catching a drug user depends on the window of detection and the frequency of detection. The short half-life of many drugs of abuse in urine makes detection of infrequent drug use an unlikely event. Figure 1 shows the approximate window of detection for low cocaine use. Urine, sweat, and saliva have relatively short detection widows compared to hair. Even with a once a month testing program, a 1-2 time/month user would not be discovered for years, given the short half-life of most drugs in urine. To maximize the probability of a drug free population, testing must be as frequent as the window of detection. In some parolee populations, testing is done on random basis as frequently as twice a week.

The often ascribed attractions of hair analysis is the greater positive rate of the technique over urinalysis.[4],[5],[6],[7] However, most of these studies have concentrated on relatively high drug use individuals such as addicts in treatment or individuals in the criminal justice system. A given matrix may not be applicable to all testing scenarios or populations. Besides the window of detection, Figure 1 also indicates the relative amount of cocaine necessary to produce a positive result. Although hair analysis has advantages in the length of time a positive is detectable (thereby reducing the testing necessary), the amount of drug required to produce a positive hair test is much greater than the other matrices. In an infrequent, low use population ("recreational use"), hair testing may miss a substantial number of users notwithstanding a greater window of detection. Likewise, for assessing the fitness for employment or operating a motor vehicle, short term monitors such as blood, saliva, or sweat may be more appropriate as they more likely reflect intoxication rather than past use.

Figure 1 - Detection of cocaine in various matrices. The italized numbers to the right of each bar indicates the relative dosage required for a positive test.



Although it has long been known that drugs are excreted in sweat, sweat† has had less use as a drug detection media.[8],[9],[10],[11],[12] Early, controlled dose studies have suggested that cocaine appears in sweat one hour after administration and may be present in sweat for up to 48 hours.[13] Follow-on studies by other authors have suggested up to a seven day window of detection for cocaine when the sweat collection device remains on the individual.[14] Besides devices which passively collect sweat,[15],[16] sweat can be collected by devices that accelerate the process[17] or more simply by wiping the skin with a pad wetted with a solvent.[18] Other authors have also detected drugs on the clothing of suspected drug users.[19],[20],[21]

Although sweat testing is thought to measure both use and exposure, it still could provide important information in certain scenarios. One application of sweat testing by skin wipes is in answering questions surrounding driving a motor vehicle while intoxicated. A positive sweat wipe, coupled with subjective observations of driving behavior and personnel demeanor, would provide powerful evidence to arrest a driver, impound the car, and conduct more extensive testing back at the station. Technology is commercially available that could be applied to field sweat testing and provide a quick answer to: "Has this individual likely to have taken drugs?". A roadside sobriety program, with sweat testing as a component, would reduce Driving Under the Influence of Drugs (DUID) - a major cause of traffic fatalities in this country. For the use of skin wipes in DUID investigations, information on the concentrations of cocaine on the skin of the general population must be available so that levels substantially above those concentrations would indicate recent use/exposure. Because a definitive result is not necessary for road-side testing, either a portable immunoassay[22],[23],[24],[25] or instrumental test[26],[27] could be used.

Another possible application of sweat wipe testing could be in validating survey data on drug use. Surveys are frequently used to allocate government resources and make policy decisions, but they are often considered as under reporting drug use.[28] A skin wipe test may provide a rapid way to gather supplemental data about drug use/exposure without the concern for cosmetic damage often expressed by individuals asked to provide hair samples or the embarrassment felt when obtaining urine samples.

†Because the exact fluid analyzed is not known, the term sweat refers to both the aqueous secretions (true sweat) as well as sebum. Depending upon their lipophilic properties, some drugs may be preferentially excreted and reside in one secretion or the other.

Sweat from individuals in a drug treatment program, collected by a simple forehead wipe, can detect cocaine use/exposure at twice the rate as hair analysis and at a substantially higher rate than can be obtained from urinalysis.[29] Likewise, in a randomly selected population, sweat testing showed twice the detection rate for cocaine use/exposure than did hair analysis.[30] This paper discusses some of the advantages and disadvantages of sweat as a testing matrix. The issues concerning hair testing will be briefly reviewed and contrasted to sweat testing because of its longer window of detection.

Results and Discussion - Sweat Testing

Compared to urinalysis, the analysis of sweat is challenging because of the limited amount of sample that can be collected and the concentration of drugs present. For most studies, sweat has been collected either by exercise induced stimulation, perspiration stains on clothing, plastic body gloves,[31] or with bandages. Although exercise can greatly increase sweating rates, resting individuals still excrete 1-2 L/day of sweat,[32] and insensible (resting) can be analyzed for drugs.[33] Recently, a sweat patch (Sudormed, Inc.) has become available that can be worn for extended periods of time to collect insensible sweat. These are large bandage-like devices that consist essentially of a 3x5 cm portion of blotter paper covered by a plastic barrier.[34] The sweat patch has a special adhesive to allow long term skin contact without irritation. A removal scheme is also present to indicate if the individual has removed the device. The manufacturer claims that an inactive person would sweat approximately 2.5 mL into the pad over a one week period making this device capable of long term drug monitoring. Preliminary studies have shown that 5-10 mg of cocaine administered interveneously could produce measurable levels of the drug in the patch. Excreting in these low dose studies could be observed 24-48 hrs. after administration.[13]

In contrast to devices that require continuous wearing, we have concentrated on simple wiping of the skin to remove both sweat and external contamination resulting from drug use. Sweat-wipes are fast and convenient.

The removal of drugs from human skin was tested on laboratory volunteers to determine the best solvent for their removal. Alcohols containing mild acids (tartaric or citric) were the most favorable for removing cocaine from human skin. However, they were not used in field studies due to safety concerns. Isopropanol (90%) was employed instead because the general population would have more experience with this solvent. Isopropanol appeared to remove 55% of the cocaine and 60% of the benzoylecgonine (BE) applied to skin.[30] Moderate amounts of cocaine and BE (<20 ng/8 cm^2 of skin) are slowly lost when placed on the skin, possibly due to absorption. After 7 hours only 14% of the cocaine and 28% of the BE can be recovered.[30] This indicates that swabbing skin may not detect recent, very low exposure such as might occur on a non-drug user from being in the presence of cocaine. In order to examine the persistence of drugs on skin, cocaine and BE (10 μg each) were applied to approximately 8 cm^2 of the skin of laboratory personnel. Their loss was studied as a function of removal by normal hygiene and absorption by the body. Sweat wipes were taken at varying times, 1-3 days after application. Cocaine (3 ng) and BE (6 ng) can still be observed 65 hrs. later after at least three hygienic washings. The persistence of cocaine on the skin may account for some of the predose positive results observed in controlled dose studies[13],[14] because out of necessity, controlled dose studies employ cocaine using individuals as the subjects.

To measure the use of cocaine in a light to non-using population (such as might be found in a DUID stop), samples of hair and sweat were obtained from a random selection of university students and personnel.[30] Where both matrices agreed in detecting cocaine use, it was assumed that the individual was a drug user. Disagreement in the two matrices did occur. This may be due to the inability of hair to detect low use rates or false positives in the sweat wipes due to passive exposure. Both possibilities are discussed below.

The distribution of cocaine positives in the hair of the university population is summarized in Figure 2 and for the sweat in Figure 3. Of the sweat samples for the university population, 19/158 or 12% were positive for cocaine and of the matched hair samples 10/158 or 6% were positive. All the hair positive specimens, except one low value, were also positive by sweat analysis. From the persistence data for cocaine on human skin, the sweat positive individuals must have come into contact with the drug within the past three days before sampling. The timing of this contact is surprising because the samples were collected on Thursday mornings. Mid-week use or contact to cocaine would be unexpected compared to occasional cocaine use on weekends.

Figure 2 - Distribution of cocaine hair positives in a random population of university personnel. The numbers over the bars represent the number of individuals in each range. The ranges are not uniform.

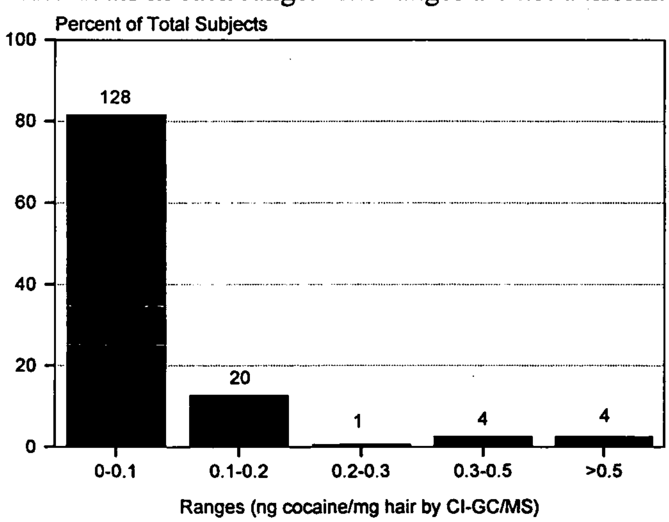
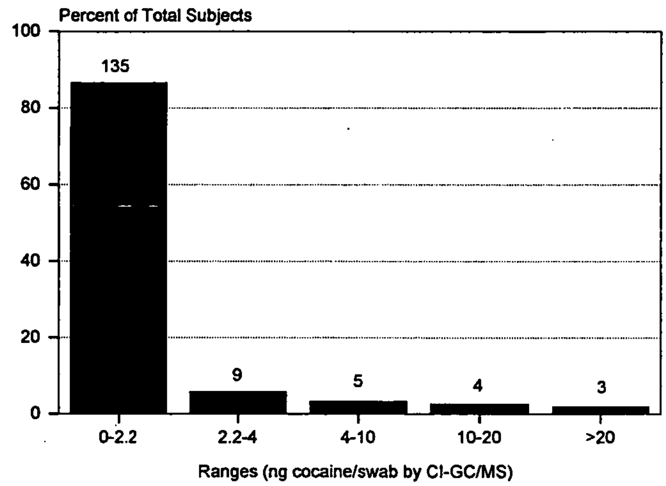


Figure 3 - Distribution of cocaine sweat-wipe positives in a random population of university personnel. The numbers over the bars represent the number of individuals in each range. The ranges are not uniform.



In controlled dosage studies, cocaine levels of up to 69 ng/patch were observed with only a 42 mg dose of cocaine administered by smoking[13] and the dose remained detectable for 2-4 days. A major difference between the protocols in the controlled dose studies and the work reported here is that the controlled dose studies employed patches that protected the skin from external contamination by cocaine.[13] In contrast, sweat wipes could measure both cocaine excreted on the skin (from internal ingestion) and cocaine present from contact with the external environment.

The data summarized in Figures 2 and 3 imply that either exposure of the general population to cocaine is significant and/or use of cocaine in this population is greatly under reported. For the general population, statistical data is available. Two major surveys have been conducted on a periodic basis in the U.S. to monitor trends in drug use. The 1994 National Household Survey on Drug Abuse is the fourteenth survey in a series first commissioned in 1971.[35] The Monitoring the Future study has annually measured drug use trends in individuals from high school to age 32 since 1975.[36] Both studies would predict approximately a 2% positive use rate (past 30 days). This is a much lower percentage than is observed by either hair or sweat analysis. However, the observed rates could be lowered by applying arbitrary cut-off levels. If cut-off levels of 1 ng/mg are applied to the hair results, as some authors have proposed,[37] a 1.3% positive rate would be observed. If cut-off levels of 0.5 ng/mg of hair are applied, as other authors have proposed,[4] then a 2.6% positive rate would be observed. Because of the small numbers of individuals tested, either rate would be consistent with the predicted rate based upon survey data. Likewise, a much higher cut-off value of 15 ng/wipe for sweat could also generate a 2.6% positive rate and identify the same individuals by both sweat and hair. The minimum cut-off level to produce a concordance of hair and sweat data may be more useful than the actual number of individuals identified as positive.

It is unknown if the sweat positives are due to passive exposure or use; likely some of both is occurring. One measure of use/exposure could be the BE:cocaine ratio. Examining this ratio from the controlled dosage study an average BE:cocaine ratio of 0.3 can be calculated.[38] However, this study was confined to three subjects, and BE was only detected three out of 17 times when cocaine was present. The ratio of BE to cocaine in these three cases was broad (0.11 to 0.6) so that the average of 0.3 has limited value. If it is assumed that the four highest individuals in the university population are true users, an average BE:cocaine ratio of 0.09 could be calculated. Because the LOD for BE was 1, the cocaine concentration must be greater than 11 ng/wipe for the BE to be detectable.

The study of random populations has limitations because the number of positives is small. Therefore, hair and sweat wipes from individuals in a diversionary program[7] were also studied to better define the detection ability of sweat vs. hair and the diagnostic ratio of BE:cocaine in cocaine users. The distribution of hair positives for cocaine are shown in Figure 4 and the distribution of sweat positives are shown in Figure 5. In comparing Figure 2 with Figure 4 a similar pattern is evident. In contrast, the individuals in drug treatment had much larger percentages of cocaine sweat positives than did the general population (compare Figures 3 with 5). As in the general population, sweat detected twice the use/exposure rate than did hair analysis in this drug rehabilitation group.

Figure 4 - Distribution of cocaine hair positives from a population in drug treatment. The numbers over the bars represent the number of individuals in each range. The ranges are not uniform.

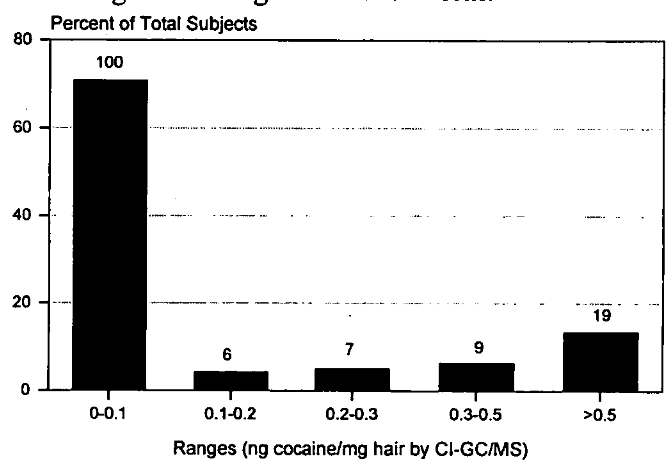
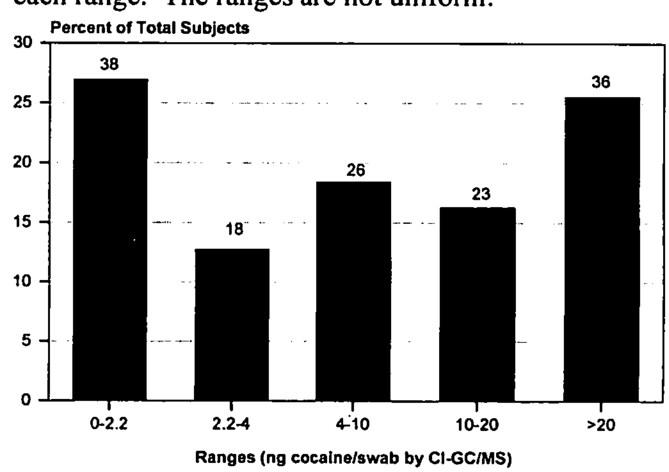
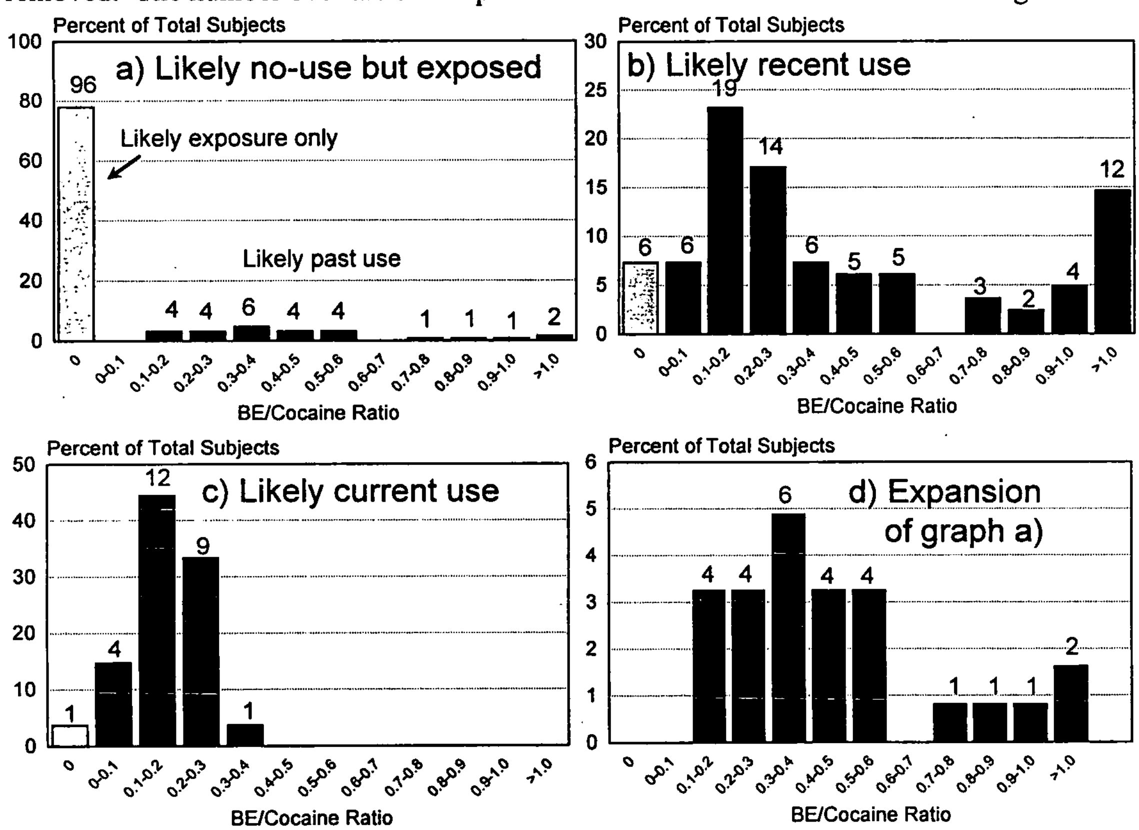


Figure 5 - Distribution of cocaine hair positives from a population in drug treatment. The numbers over the bars represent the number of individuals in each range. The ranges are not uniform.



The presence of cocaine in sweat wipes is not necessarily characteristic of cocaine use because of passive exposure. Also, a fixed BE:cocaine ratio need not be arbitrarily applied for all amounts of cocaine. In fact, the BE:cocaine ratios should be examined for differing amounts of cocaine because the timing of use is unknown and this timing affects the ratio. The usage patterns of cocaine may be broken into four categories: (1) no cocaine present: no use or exposure. (2) no-use but recent exposure: A non-using individual is likely to be exposed to low levels of only cocaine from the environment and have little or no BE present; (3) recent use and exposure: An individual who used cocaine a few days ago is likely to have larger levels of cocaine on the skin than a non-using individual because their contact during use was high. However, some hygienic washing has occurred. Also, BE would be present because of metabolism and non-specific hydrolysis; or (4) current use and exposure: An individual who is currently using cocaine would likely be contaminated with high amounts of cocaine. BE would be present but it may be overshadowed by the cocaine contamination occurring during use.

Figure 6 - Benzoylecgonine:cocaine ratios for individuals in a drug treatment program. (a) Cocaine concentrations <15 ng/wipe. (b) Cocaine concentrations >15 ng/wipe but <100 ng/wipe. (c) Cocaine concentrations >100 ng/wipe. (d) Same data as (a) with the zeros removed. The number over the bars represent the number of individuals in each range.



The cocaine sweat wipe positives were divided into three categories based on the amount of cocaine present. The ranges and distributions are shown in Figure 6a-c. Because no cocaine was intentionally administered to these individuals, their drug use status was unknown. The no-use (but exposed) individuals would likely correspond to Figure 6a. Based on the presence of BE, some of the individuals with cocaine levels <15 ng/wipe are likely past cocaine users. The case of recent use and exposure would correspond to values <100 ng/wipe but >15 ng/wipe as shown in Figure 6b. Because recent contact with cocaine can contaminate the wipes, the BE:cocaine ratios vary over the entire plotted range. The case of current use plus current exposure would likely correspond to Figure 6c. As expected, for high cocaine values corresponding to recent use, the BE:cocaine ratios are lower (compare Figure 6b with c) because the recent contact with cocaine swamps-out some of the BE. Nevertheless, it should be pointed out that most of the individuals in Figure 6c had an absolute amount of BE greater than the other two groups.

Surprisingly, if the individuals with BE levels of zero (less than the detection limit) are excluded from Figure 6a, the distribution of ratios for the remaining individuals are similar to the recent use case (compare Figure 6d with b). This implies that some (or all) of the individuals with BE present are likely cocaine users. Therefore, the presence of BE (>0.1 in reference to cocaine) may be a good discriminator of cocaine use over cocaine exposure.

Even in the moderate and high cocaine concentrations some individuals had no detectable levels of BE. One possibility is the identification of individuals who sell cocaine or live with cocaine users but are non-users. Individuals in frequent contact with cocaine would likely have large amounts of cocaine present but little BE.

Issues with Hair Analysis

Although hair testing is assumed to have a wider window of detection, there are several disadvantages to its widespread use: (1) the potential for passive exposure confusing use with the mere contact with drugs; (2) the inability to detect low dosages of drugs; (3) the detection of marijuana and LSD use is difficult with hair; and (4) the detection probability differs with hair type and tends to be biased against Black hair types. All these issues have been throughly reviewed.[39],[40]

Bias in a low-use population may be seen by comparing Figure 2 with Figure 3. This comparison shows that sweat detects drug use/exposure about two times more frequently than does hair analysis. A similar higher detection rate was observed with the individuals in drug treatment. Three interpretations of the higher frequency of cocaine detection by sweat vs. hair are possible. (1) Detection of a single dose of cocaine by hair analysis may be difficult.[31] Individuals with cocaine positive sweat yet negative hair may use cocaine but at low levels on a infrequent basis. (2) Some hair types appear to incorporate more drugs than do other hair types.[31],[41],[42] The individuals negative by hair analysis may have hair types more resistant to incorporation/retention of cocaine. (3) Hair is relatively resistant to external exposure compared to sweat. The individuals with cocaine positive sweat yet cocaine negative hair had only recent contact with cocaine but are not users.

With any of these explanations, a difficulty with hair analysis is evident. Certainly use of cocaine implies exposure but exposure does not imply use. When the racial distribution of the individuals positive by sweat is compared, 12/19 (63%) are Black and 7/19 (37%) are Caucasian and other races. Assume that sweat would define the exposure and use group and hair analysis would define only the use group. In the hair positive group, 9/10 (90%) of the hair samples are from Black individuals and only 1/10 (10%) is from one Caucasian individual. The percentage difference of the races in the sweat group vs. the hair group has only a 3% chance of occurring randomly. Therefore, unless some reason could be found for Caucasian individuals to be more exposed to cocaine (but not users) than Black individuals, a selection bias is likely to exist for hair analysis in random populations.

Bias is the increased likelihood of detecting one group of individuals over another when both are given similar use/exposures. Bias is not surprising because racial differences in uptake and retention of cocaine have been found before for hair analysis.[31],[41],[42],[43] However, this subject is controversial[44] and has never been studied in a random population not suspected of using drugs. In heavy-using populations, bias is difficult to detect because most individuals are greatly above the instrumental detection limits so that use is readily determined. In contrast, bias is more evident in low dose populations because of the limitations imposed by the instrumental cut-offs. Thus hair analysis is likely bias in the occasional drug using population.

Conclusions

Sweat wipes contained detectable quantities of cocaine more frequently than did hair samples in both suspected drug users and the random population. Sweat wipes have the following advantages over hair: rapid analysis time without extensive wash and extraction procedures necessary, adaptable for field use, less concern for cosmetic disfigurement, and much higher drug concentrations (making analysis easier). Sweat wipes appear promising for epidemiological surveys and roadside cocaine testing. From both the study of individuals in drug treatment and random individuals, cut-off levels for cocaine greater than 15 ng/wipe in sweat are unlikely to occur in the general population. Therefore, this value could be applied for decision making in DUID cases where recent cocaine use is suspected and provide good confidence that use is being measured. A BE to cocaine ratio >0.1 appears to distinguish use from exposure.

Acknowledgments

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DRUGWIPE -

A TRACE DETECTOR FOR COUNTERDRUG OPERATIONS OF LAW ENFORCEMENT

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ABSTRACT

DRUGWIPE is a pen size, test strip based immunochemical device for detecting narcotic contamination on surfaces. Main characteristics are its high sensitivity combined with ease-of-use and short examination times. By the determination of the presence of traces of drugs on surfaces it is possible to identify drug smugglers and dealers as well as consumers. Seized material can be identified rapidly and reliably.

After extensive field testing, the German Customs Service has introduced *DRUGWIPE* into its routine operations at the beginning of 1996. In September 1996 *DRUGWIPE* was evaluated by the United States Customs Service (USCS) Applied Technology Division (ATD) at the Houston Advanced Research Center (HARC). Since that, *DRUGWIPE* was involved in several field trials in Canada and the United States.

This paper focuses on the description of operational scenarios where immediate trace detection is useful to confirm or contradict a suspicion of the presence of drugs. To fulfill their mission customs services, traffic and drug enforcement police and armed forces as well as correctional institutions already make use of trace detection technologies. The usage of *DRUGWIPE* by corporate and private entities is under discussion. In the following several example counterdrug cases from one year of routine operational usage of *DRUGWIPE* by the German Customs Service are presented. Technical, operational and legal issues related with the application of this kind of trace detectors are discussed.

1 Introduction

Between 1993 and 1995 the German Ministry for Education, Science and Research funded a research project aimed at the development of a handheld drug detector. In representation for the different potential endusers the German Customs Service participated in this project and contributed its needs on such a handheld device. In the beginning of 1995 a first series of prototypes was manufactured and delivered to selected customers to perform an initial evaluation campaign. Comments and feedback were provided in the first half of 1995 and were directly used to design the final *DRUGWIPE* product [1].

The Customs Service in Germany introduced *DRUGWIPE* into its routine operations at the beginning of 1996 and by the end of that year some 160 different units were equipped with a total quantity of 35000 *DRUGWIPEs*. Now after more than one year of operational field experiences a first resume can be drawn. The principle decisive criteria leading to the introduction of this type of drug detector were mobility and broad applicability in combination with high reliability.

Mobility is given by size and weight of each test kit. Reliability is determined by the biotechnological detection principle. The broad application range is given by the capability of the test to detect trace amounts of drugs on a wide variety of solid surfaces, to identify unknown materials or to detect narcotics in liquids and other materials.

2 Fundamentals

2.1 Trace Detection - State of the Art

Different types of trace detectors are described and commercially available. Hoglund et al. [2] are describing in total 27 existing vapor/particle detection devices and are distinguishing between commercially available instruments, devices on a prototype level and detection systems under development. 17 of these drug detection instruments are derived from laboratory based analytical instruments and are Ion Mobility Spectrometers or/and Gas Chromatographs. 5 of them are classified as biosensors or biological detectors.

Figure 1 describes the general analytical course of trace detection. A sample is taken from a suspicious surface, either by wiping or by vacuuming. The sample is then transferred into the analytical device which determines the presence of one or more illegal narcotics. Complex samples are analysed by combining chromatographic separation methods with high-specific electronical detectors. Signal outputs are given as chromatograms and, in an integrated form, as peak areas or amounts of drugs present in the sample.

DRUGWIPE is an integrated biochemical device and has simplified the sampling and measurement steps as well as the interpretation process for the user. *DRUGWIPE* consists of two major parts. The wiping part is responsible for the collection of drug particles from a suspicious surface. If necessary it can be combined with different types of additional samplers, e.g. vacuum samplers, wiping pads, etc. The detection element contains an immunologic test strip and is in charge of the separation, the recognition, the signal transduction and the signal output steps. The output signal is generated by the coloration of a read-out window. Only yes or no decisions are possible. The total analytical course only requires two to three minutes.

The area for sampling is selected by the user with respect to his experience and the general knowledge about probable locations for drug contamination. Laboratory based instruments have to be calibrated at reasonable time intervals. They need suitable environmental conditions and power supply. Provided that instrument parameters are set correct, measurement is performed automatically. One or several analytes can be determined in one measurement run. After the measurement the user has to interpret the signal output before further actions can follow.

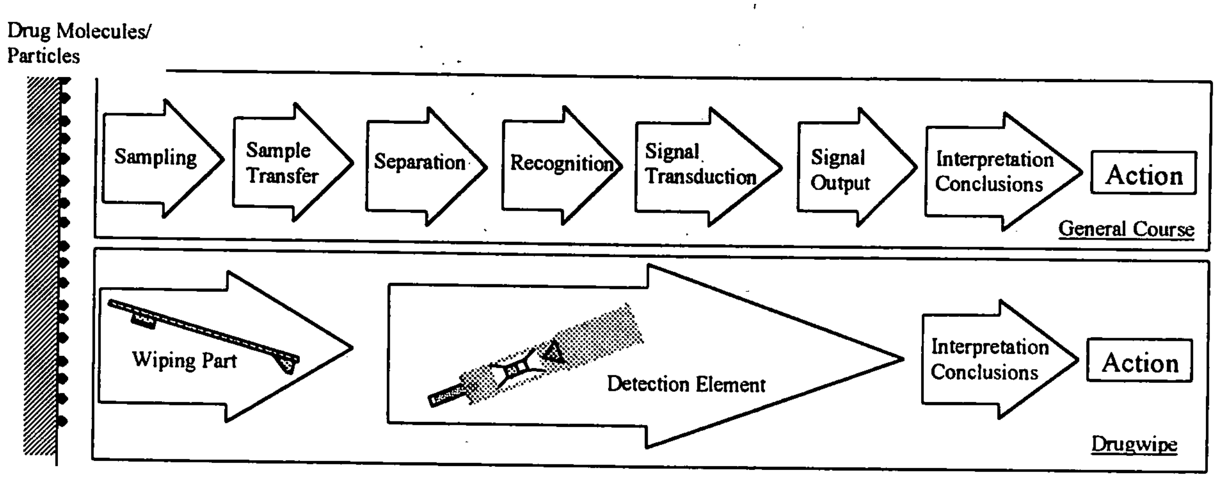

Figure 1: *Schematic drawing demonstrating the analytical course of trace detection*

To take appropriate measures the user has to interpret the result of his trace detector with respect to the conduction course of the test and with consideration of his reponsibilities and the legal possibilities dependent upon his subsequent actions. *DRUGWIPE* is not only an aid for gaining or confirming a suspicion. In the field *DRUGWIPE* can supply the officer with a minimum of time needed with a rapid advice on how to proceed. It saves personnel recourses for other important tasks and prohibits unnecessary and expensive follow up actions, e.g. detailed investigations, X-ray examinations etc..

2.2 Description of the *DRUGWIPE* Technology

Figure 2 shows the general construction principle of *DRUGWIPE*. The wiping part enables the user to sample drug particles from any kind of surface. Samples are then transferred onto the detection element by simply re-attaching the wiping part to the detection element as shown in figure 2.

The main part of the detection element is an immuno-chromatographic test strip, which is based on the Frontline® urine test strip from Boehringer Mannheim GmbH [3]. It consists of four functionally different elements mounted on a carrier foil.

As shown in figure 3, the conjugate field is loaded with antibody-gold-conjugates specifically designed to recognize the different groups of illegal narcotics. Depending on the type of *DRUGWIPE*, these conjugates can specifically bind to Cocaine, Opiates, Cannabinoids or Amphetamines[1]. The capture matrix consists of a porous carrier material and is coated with drug analoga. Its function is to retain antibody-gold-conjugates not saturated in the conjugate field by their complementary drug molecules (immunochromatographic separation step). Antibody-gold-conjugates that bind to drug molecules are able to pass through the capture matrix and to diffuse into the read-out window. The water container is important for a defined immersion of the absorbant pad in tap water.

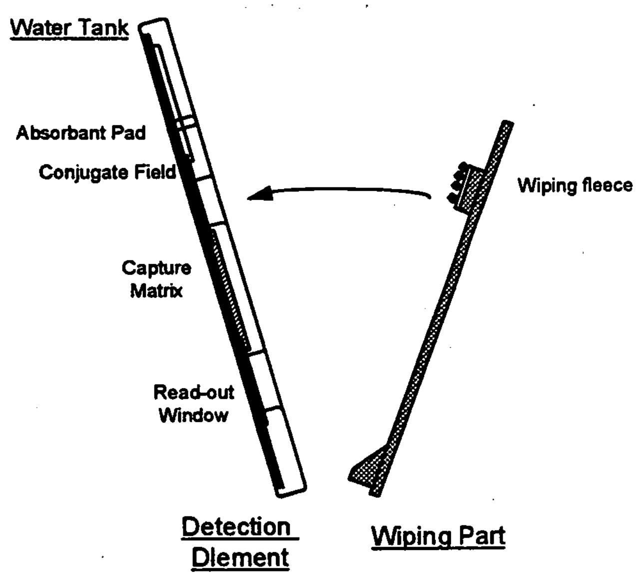

Figure 2: *Cross-sectional view of the DRUGWIPE test kit showing the immunochromatographic detection principle*

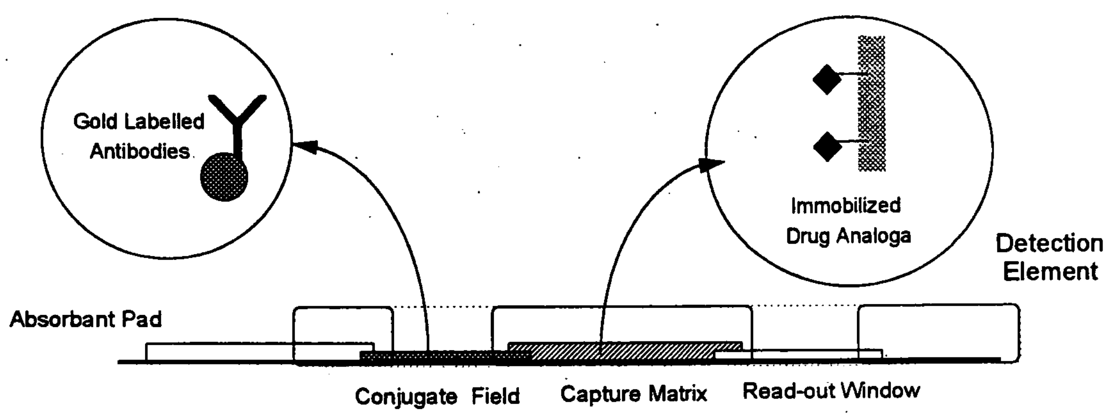

Figure 3: *Descriptive drawing of the different functional elements of the DRUGWIPE test strip.*

[1] *DRUGWIPE* "Amphetamine" recognizes Amphetamines (MDA, MDE) as well as the most important Methamphetamines like MDMA (Ecstasy).

The immunochromatographic reaction is initiated by dipping the absorbant pad into tap water. Provided that drug molecules, their particles or metabolites were present on the investigated surface and were picked up by the wiping fleece the detection field will change its coloration from white to light pink or red in dependence of the amount of drugs collected. If no drug molecules, particles or metabolites were present, the read-out window remains white. [1]

2.3 Handling instruction for *DRUGWIPE*

The following steps are performed to apply *DRUGWIPE* for the determination of traces of narcotics on solid surfaces: [4]

1. Wipe a suspicious surface several times under light pressure by means of the wiping part as shown in figure 4. [2]
2. Re-attach the wiping element to the detection element.
3. Remove water tank and fill up to mark with potable tap water.
4. Immerse the absorbent pad for 10 seconds.
5. Hold detection section horizontal for 1 to 2 minutes.
6. Read result in the read-out window.

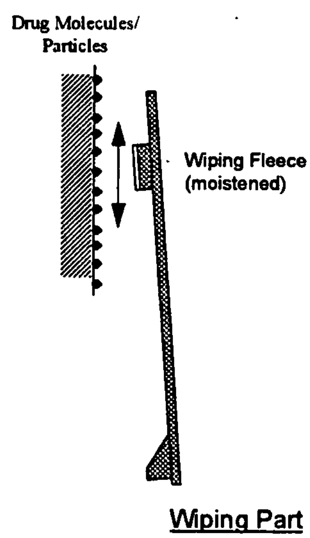

Figure 4: Wiping a suspicious surface with the wiping part of DRUGWIPE

[2] It is important to moisten the wiping fleece prior to sampling. This can be done by applying a drop of water onto the sample fleece and shaking off the excess water.

2.4 Main Characteristics of *DRUGWIPE*

Table 1 summarizes the sensitivities of the individual *DRUGWIPE* types. It is usually necessary to distinguish between surface sensitivity and volume sensitivity. Surface sensitivity is important for all applications where traces of illegal drugs on surfaces are to be determined. Here *DRUGWIPE* is able to detect amounts down to 10 nanograms. These amounts are approximately 1'000 times less than the resolving power of the human eye, thus *DRUGWIPE* allows the detection of particles invisible to the naked eye.

Volume sensitivity is important for the examination of liquids or substances dissolved in liquids. The sensitivities described in table 1 apply directly for urine testing. Due to the fact that the detection element contains a urine test strip, it is possible to determine the presence of illegal drugs in urine by simply dipping the absorbant pad into a urine sample. Other liquids can only be tested for illegal narcotics after a dilution step. Dilution can be done by mixing one small drop of the suspicious liquid with a volume of tap water sufficient to fill up the water tank.

Table 1: The lower detection limits for surface and volume applications and the substances used to determine these detection limits for the individual DRUGWIPE test kits.

DRUGWIPE Type	Surface Sensitivity [ng]	Volume Sensitivity [ng/ml]	measured with
"Cocaine"	10	100	Cocaine-HCl
"Opiates"	25	300	Heroin-HCl
"Cannabis"	50	1000	Δ9-THC
"Amphetamines"	50	300	Amphetamine-Sulfate
	10	250	MDMA-HCl
	10	300	Methamphetamine-HCl

3 Operational Aspects of Trace Detection Devices

3.1 Duties and Authority of a Customs Officer in Germany

Success in applying this new kind of trace detector depends not only in the knowledge of how this test device works but also on how to use it to the most advantage. Success is mostly determined by the correct implementation into the operational processes of a law enforcement agency. The operational conditions of the German Customs Service are described to make obvious where Customs and other drug enforcement officers can profit from the application of *DRUGWIPE* (figure 5). As this is only for illustration of the value of a trace detector like *DRUGWIPE*, the following description is simplified to the necessary extent.

Based upon the EU/German Customs Code, officers of the German Customs Service have to control the transport of goods and people carrying goods across the border. On the one hand a Customs Officer is responsible for clearance of persons with goods and the levying of taxes and duties. On the other hand Customs officers have to prosecute infringements of the Customs Code and other German laws (e.g. law against the abuse of drugs).

Citizens crossing the border have to supply all necessary information which are needed by Customs to fulfill their tasks. In the case of a suspicion of an infringement of laws or regulations, the officers authority is determined by the criminal law and the particular law on infringement of regulations. In such a case a suspicious person has no obligation to collaborate or to supply any information to the officer.

In the case of a suspicion on an infringement against a law or regulation the Customs officer can immediately introduce a preliminary inquiry. He acts then as a representative of the public prosecutor and has to take all necessary measures to elucidate or to prevent a criminal offence. This especially includes the confiscation of all forms of evidence and the provisional arrest of a suspect. In the case of danger of suppression of evidence, measures can be taken which are a major intrusion into one's personal rights. This includes the order for examination by a doctor or the search of a suspect's apartment to look for further evidence.

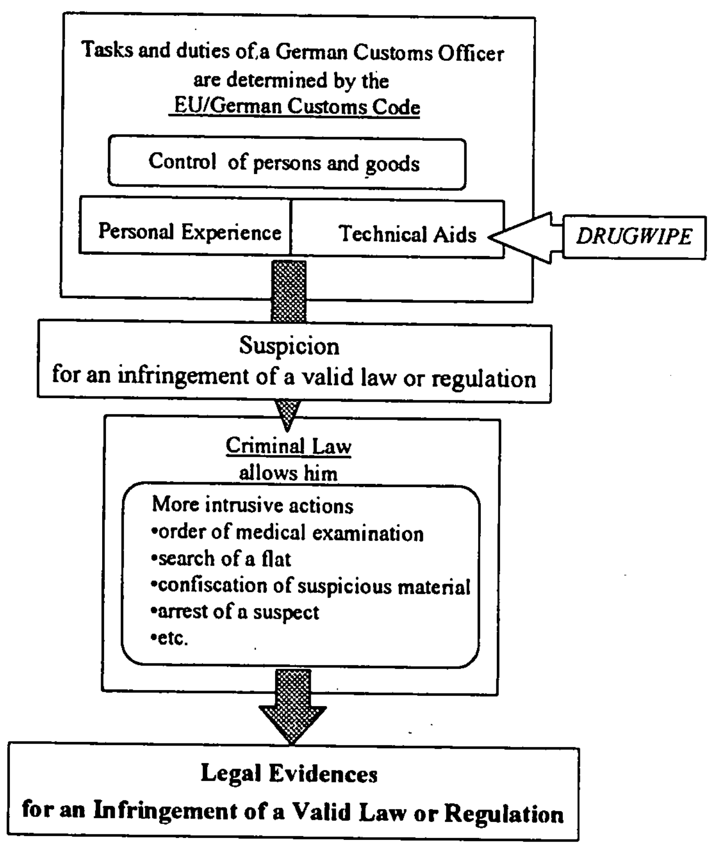

Figure 5: Schematic description of the tasks and duties of a Customs Officer in Germany

3.2 Application Scenario for *DRUGWIPE*

Due to the fact that the decision to start a preliminary inquiry has massive consequences for the person under suspicion, the process whereby such a "suspicion" is verified is of great importance. A main factor in this process is the personal experience of the individual Customs officer and the specific counter-drug strategies of the responsible Customs Service. To support the Customs officer in his operations, a set of technical aids are available. Well known examples are the dogs used in the search for hidden narcotics. Equipment such as trace detectors that can confirm the presence of minute amounts of drugs on the hands or the personal items of a subject are more prevalent, thus indicating an offence of the law against the abuse of drugs (figure 5). Chemical tests, that allow the identification of unknown substances in cases, where the officer has doubts about the identity of a material are readily available. In fact personal experience, strategic approaches and the application of technical tools are current practice in the normal course of Customs operations.

DRUGWIPE supports the officer in all of the above areas but especially in the phase of confirming a suspicion (figure 5). An officer can confirm, that someone had contact with an illegal narcotic by determining traces of the narcotic on his fingers, his passport or other personal items. The test is also useful for the detection of illegal drugs in liquids, in polymeric materials or in textiles. Identification of unknown substances is very easily done and extended areas can be sampled with additional tools for collecting drug particles from "large" surfaces.[3]

In the course of the following investigatory work the officer has to gain the necessary evidence to prove before court the suspected infringement of a valid law or regulation. The confiscation of an illegal drug and an expert's report on the identity of the seized material based on analytical reference methods can supply such evidence. The German legal system also allows prosecution purely on the suspects confession.

4 Field Operational Examples

4.1 Introductory Remark

The following examples were recorded by the German Customs Service during the first 12 months after the official introduction of *DRUGWIPE* and the details have kindly been put at our disposal.

4.2 Identification of Body Packing (Case I)

The application of *DRUGWIPE* for the identification of body packers was evaluated by the German Customs Service during their initial test campaign with *DRUGWIPE* prototypes in 1995 [4]. In 1996 several cases were recorded, where *DRUGWIPE* indicated the smuggling of internally concealed drugs. In one case even the urine analysis had indicated a negative result.

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[3] SECURETEC is offering under the brand name "Drugdec I" a vacuum sampler for large surfaces especially developed for the combination with *DRUGWIPE*.

In one case, three people from South America arrived by plane at a German Airport. The Customs officers became suspicious because of the circumstances of the trip and performed a routine questioning, which strengthened the initial suspicion. *DRUGWIPE* was applied to confirm this initial suspicion for all three persons before they were brought to the hospital for further examination and treatment.

In total 1174 grams of cocaine were confiscated.

4.3 Confirmation of Ownership (Case II)

After the removal of the boarder controls between Germany and the other countries of the European Community, the German Customs Service has established mobile control groups which are operating behind the boarder and are allowed to control cars and trucks on the roadside. In one case such a mobile group checked a car on a highway and found concealed under the drivers seat a parcel containing 1,1 kilograms of heroin. The driver denied any knowledge of the heroin but *DRUGWIPE* proved by testing his hands, that he had indeed contact with the illegal narcotic.

In the following court trial, the result of *DRUGWIPE* was accepted by the public prosecutor because the suspect had denied any contact with heroin beforehand.

4.4 Confirmation of Ownership (Case III)

German officers controlled routinely a train compartment and asked the travelers to identify their luggage. A rucksack remained unrelated. Therefore the officers examined the rucksack in more detail and found 400 g of heroin and 50 amphetamine pills. By means of personal items in the rucksack and the application of *DRUGWIPE* the Customs officers were able to identify the smugglers (2 travelers from the investigated train compartment) of the illegal narcotics definitely.

400 g heroin and 50 amphetamine pills were seized.

4.5 Indication of Smuggling/Dealing (Case VI)

During the control of a person entering Germany, *DRUGWIPE* was applied to examine his fingers. The officer got a positive result, but subsequently did not find any drugs. The strength of the officers suspicion was such that the flat of the person was searched.

319 Ecstasy pills and 75 grams of cocaine were confiscated.

4.6 Examination of Liquids (Case V)

Several bottles in a suitcase contained suspicious liquids. *DRUGWIPE* was applied to test the liquid in the bottles as well as clothes contaminated with the liquid. In each case *DRUGWIPE* provided a positive result. Subsequent analytical examination procedures have proven that cocaine was dissolved in the liquid.

1000 g of cocaine were seized.

4.7 Examination of Personal Items (Case VII)

Customs officers can check by determining traces of drugs on the surface of an item whether a personal item contains a narcotic. In the first 12 months of routine usage of *DRUGWIPE* within the German Customs Service several smugglers were convicted carrying drugs hidden in personal items like books, shoes or bags.

1000 g of cocaine were seized, which were hidden in the soles of shoes.
500 g cocaine were confiscated concealed in two photo albums.
Another smuggler concealed 570 g of cocaine in his bag.

5 Discussion

Smuggling in small quantities is increasing and ways of smuggling are becoming more and more sophisticated. Detection of traces of illegal narcotics on the hands of a person crossing the boarder is indicating contact with a drug of abuse. This can either provide the reason for an initial suspicion or confirm or contradict an initial suspicion originating from other sources. In most cases, trace detectors are still used to validate a suspicion before entering into measures foreseen in the criminal law or other valid regulations. This is seen as necessary because such measures have massive consequences for a person under suspicion.

In the first year of application *DRUGWIPE* has proven its reliability and value in the real world of Customs daily operations. The most important performance data (reliability, sensitivity, measurement time) of *DRUGWIPE* are comparable to the characteristics of laboratory derived instruments. Its big advantage however is, that a decentralized organization like the German Customs Service is able to equip all counterdrug units with a sufficient number of test devices within a reasonable investment budget.

This offers new chances in the fight against the flood of illegal narcotics. It also requires new ways of thinking within the responsible authorities. Strategies to combat drug smuggling have to be changed to gain optimal success. Application policies have to be developed. And last but not least the officers fighting at the front have to be trained and introduced into the great potential of this novel counterdrug device.

6 Outlook

Since the beginning of 1996 *DRUGWIPE* is implemented by the German Customs Service in its routine operations. More than 160 different units are equipped with the *DRUGWIPE* trace detectors for cannabis, opiates and cocaine. After more than one year of field experiences a first positive resume can be drawn. Next step will be the introduction of the *DRUGWIPE* test for the detection of amphetamine traces. An introductory campaign is scheduled for September 1997, immediately after the official market introduction of this test.

In September 1996 *DRUGWIPE* was evaluated by the United States Customs Service (USCS) Applied Technology Division (ATD) at the Houston Advanced Research Center (HARC). Since that, *DRUGWIPE* is also involved in field trials in Canada and the United States. First positive cases are documented and it seems that *DRUGWIPE* can also be successfully implemented in the different Drug Enforcement Authorities in the United States and Canada.

Besides this *DRUGWIPE* is currently evaluated by the German Traffic Police for the applicability to detect impaired drivers. In cooperation with different Institutes for Legal Medicine it was found that *DRUGWIPE* is able to detect drug molecules or their metabolites in sweat or saliva. Preliminary results obtained in the evaluation campaign of *DRUGWIPE* for sweat testing have been published on different conferences [5, 6]. A first official report from the German Traffic Police and the Institute for Legal Medicine in Munich will be available in autumn 1997.

7 Acknowledgment

SECURETEC would like to thank the German Customs Service and the Zollkriminalamt (ZKA), Cologne, for its excellent cooperation during development and introduction of *DRUGWIPE*. Field operational examples have kindly been provided by the ZKA. Development of *DRUGWIPE* was financially supported by the German Ministry for Education, Science, Research and Technology (BMBF).

SECURETEC also thanks the Traffic Police of the Landespolizeidirektion Stuttgart I (Verkehrsdienst Waiblingen) for conducting the *DRUGWIPE* field trial and Dr. Hans Sachs, Institute for Legal Medicine of the University of Munich, who is responsible for the scientific evaluation of *DRUGWIPE* for sweat applications. Dr. Johanser, Institute for Legal Medicine, Munich, is engaged in the examination of suspicious drivers. The traffic control project is financially supported by the Bund gegen Alkohol im Straßenverkehr e.V.

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VAPOR CONSTITUENTS OF ILLICIT COCAINE HCl AS DELIVERED THROUGH AN OLFACTOMETER

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ABSTRACT

The performance of the dog as an effective general-purpose detection device has challenged current analytical methods. To better understand the role of vapor constituents emitted from illicit cocaine HCl during olfactory detection by trained dogs, we utilized two types of vapor delivery systems, Single Source Olfactometer (SSO) and Multi-Source Olfactometer (MSO). The SSO serially dilutes a single odorant through multiple dilution stages thus allowing the operator to choose a particular concentration level to be delivered. The MSO is a unique testing procedure where by the canine is allowed to choose which odorants or mixtures of odorants smell similar to the compound of interest. As a result, threshold concentrations and a vapor signature of illicit cocaine HCl sample based upon canine recognition may be proposed. Since both designs utilized the same illicit cocaine HCl sample and vapor generation cell, it was determined that protocol for this experiment would not have to be duplicated for each design. The focus of this study is to identify and quantify major vapor constituents of illicit cocaine HCl sample by utilizing the vapor generation cell of the olfactometer and GC/MS techniques. A summary of the data from an illicit cocaine HCl sample will be presented.

INTRODUCTION

Quantitative vapor delivery systems, termed olfactometers, have been developed to study canine olfaction at the Institute for Biological Detection Systems-IBDS (1,2). In order to evaluate canine sensitivity and vapor signature for illicit cocaine HCl sample it is essential that both olfactometer designs (SSO & MSO) be utilized. Since both designs utilized the same illicit cocaine HCl sample and vapor generation cell, it was determined that protocol for this experiment would not have to be duplicated for each design. The vapor generation cell of the olfactometer is unique in that it allows airflow through the sample to create a concentrated vapor source. By controlling the conditions to which the sample is subjected and not requiring equilibration to be present in order to evaluate the vapor headspace, unique analyses of compounds of interest can be evaluated. Additionally, evaluation of the importance of constituents' vapors during "weathering" of a sample can be determined in a controlled manner. To simulate realistic environmental conditions, effects of humidity and temperature also can be evaluated. Earlier studies have indicated that the production of methyl benzoate, a major vapor constituent of cocaine, is directly linked to humidity (3). The objective of this study was to determine what effects, if any, would humidity play in the detection of other vapor constituents of this sample of illicit cocaine HCl and what changes would occur in the vapor signature over time. Data are presented summarizing: (1) the output of the vapor generation cell in terms of the components delivered from an illicit cocaine HCl sample and (2) the sample's profile as a function of time.

METHODS

Vapor Generation. The odorant source was kept in a water bath at 30 C. The water bath was made of 0.125 in. stainless steel (153/8 in. x 153/8in. x 7 in.) and fitted with a hinged lid. The walls were 1.5 in. thick and filled with foam insulation to provide thermal stability. The odorant sample vessel (Figure 1) was made of borosilicate glass (ca. 100 mL). The top of the vessel was fitted with a 65-40 ball joint sealed with a Viton O-ring and a fritted glass disc was fused 0.5 in. from the bottom. Inlet and outlets ports (0.25 in., OD) were fitted to the top and bottom of the vessel. Inlet air was purified by pressure swing adsorption (PG-030, Peak Scientific, Chicago, IL) and maintained 70 to 80% relative humidity. The input flow rate was maintained at 850 ml/min by a mass flow controller (Teledyne-Hastings Instruments).

Vapor Collection. The odorant source used for this study was seized sample of illicit cocaine HCl that had been in the possession of IBDS for 4 years. The exact age of the sample was unknown. For each experiment, approximately 10 g of cocaine was place in the vapor generation cell. An adsorbent bed consisting of 65 mg Tenax TA (35-60 mesh, Tekmar-Dohrmann, Cincinnati, OH) was packed within a quartz inlet liner (Tekmar-Dohrmann, Cincinnati, OH). Vapor from the vapor generation cell was passed through the adsorbent trap at a rate of 20 mL/min for duration of 30 minutes. Triplicate samples were collected directly from the output port of the vapor generation cell under each experiment.

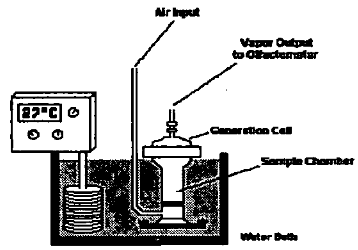

Figure 1 Design schematic of the vapor generation cell

Vapor Analyses. Analyses were performed by gas chromatography/ mass spectrometry (GC/MS) on a GCD-1800A system (Hewlett-Packard, Palo Alto, CA). The GC was fitted with 0.25 mm x 30 m column with a film thickness of 0.25 um 5% phenyl substituted methylpolysiloxane (DB-5, Restek, Bellefonte, PA). Joined to the analytical column was 0.53 mm guard column with phenyl-methyl deactivated material (Restek, Bellefonte, PA). Quadrupole mass spectrometry was obtained via an electron impact ionization source and the scan range selected was *m/z* 29 to 425. Adsorbent packed inlet liners previously described were placed in a temperature programmable injection port (Optic, Tekmar-Dohrmann, Cincinnati, OH) and thermally desorbed onto the guard column. The guard column was utilized for the on-column cryogenics (Scientific Instruments Services, Ringoes, NJ). The cryo unit was set at –60°C during desorption then ramping to 150°C after desorption completion. The carrier gas (He) flow rate was 1 mL/min. The injection port temperature was programmed to desorb the Tenax® from 40°C to 280°C (hold) at 1 ° C/s and the detector temperature was 250°C. The column temperature was programmed from 40° C to 300° C (1 min) at 25°C/min. Observed analytes were identified by mass spectral fragmentation patterns and statistical comparison with NIST/EPA/NIH library mass spectra.

RESULTS AND DISCUSSION

Vapor samples were collected directly from the output port of a vapor generation cell. Representative chromatograms of the "Fresh" sample under low humidity conditions and "Fresh" sample under high humidity are presented in Figures 2 and 3 respectively. The "Fresh" sample was considered to be a sample not exposed previously in the cell. Triplicate experiments were conducted under each condition and, within each experiment, triplicate vapor samples were analyzed. Peaks labeled as GC artifacts were determined to be either from the GC column (i.e., sioloxanes) or from the adsorbent trap as evidence by backgrounds controls. In analyzing "Fresh" sample under low humidity (<2%) conditions, the major vapor constituents identified were 2,5,6-trimethyloctane, benzoic acid, substituted phenol, and cocaine, however, cocaine was not detected consistently from sample to sample. We proposed that the detection of cocaine was due to the airflow disturbing the sample, therefore allowing cocaine particulates into the odorant air stream. The detection of methyl benzoate was identified in the low humidity samples, but it was not consistent in each sample nor was it considered to be the most abundant constituent.

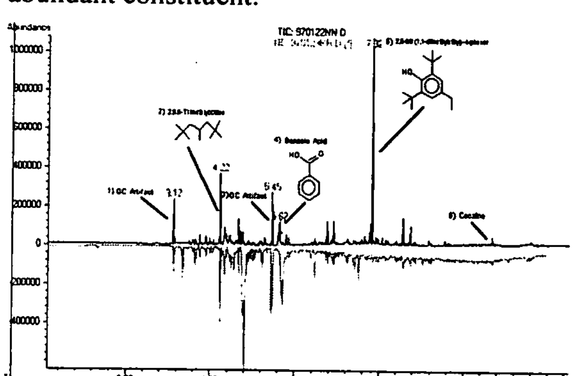

Figure 2: Representative chromatogram of an "Fresh" sample under low humidity conditions.

With increased humidity (70% to 80%), we found an increased abundance of previously identified analytes as well as additional analytes that were not present under low humidity conditions (Figure 3). The major vapor constituents were acetic acid, propylene glycol, 2-ethyl-1-hexanol, benzyl methyl ketone, benzoic acid, and diethyl phthalate. In 4 of the 9 experiments conducted, there was a decrease in detection of benzyl methyl ketone with a concurrent increase in abundance for benzoic acid and methyl benzoate. The mechanism for this phenomenon is undetermined.

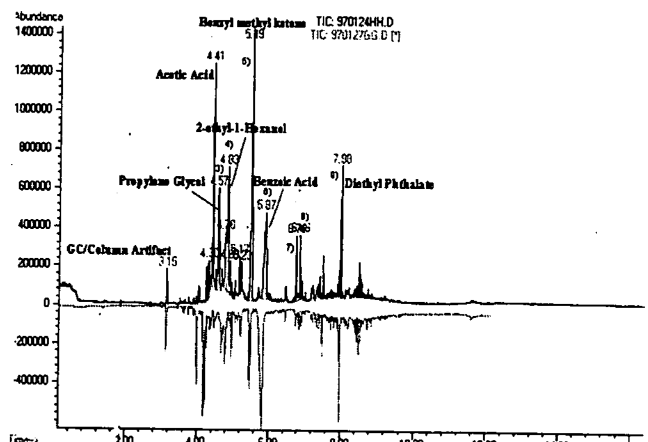

Figure 3: Representative chromatogram of an "Fresh" sample under high humidity conditions

Because "fresh" samples were only exposed for a limited amount of time, we analyzed a sample that had been exposed for a longer duration to the high humidity air in order to evaluate the effects of "weathering". Chromatographic analyses of triplicate vapor samples from a "30 Day" old sample, which had been exposed to high humidity air for approximately one month (Figure 4), were performed for this study. Ten additional analyses were performed with "two week old" samples to confirm the findings of the "30 day old" sample. We found that extensive exposure to humidified air would produce a steady state release of vapor constituents. Major vapor constituents identified were acetic acid, substituted hydrocarbon, methyl benzoate, and diethyl phthalate. In all "weathered" samples, benzoic acid and benzyl methyl ketone were not detected.

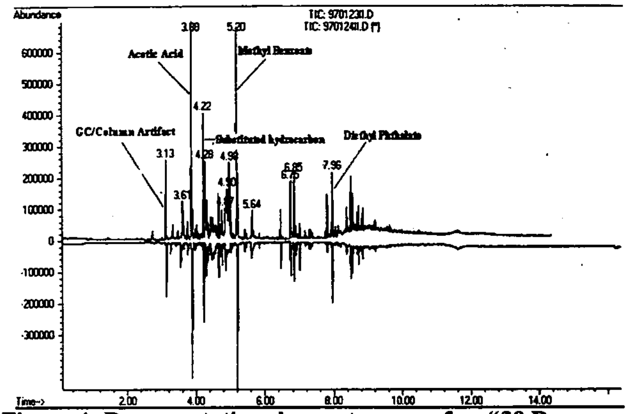

Figure 4: Representative chromatogram of an "30 Day Old" sample under humidity conditions.

CONCLUSIONS

Our data indicated that, due to the complexity of a compound such as illicit cocaine HCl, a clear vapor signature could not be determined in evaluating analyses from different experiments. However, in analyzing samples that were exposed to high humidity conditions for an extended period, a clearer signature was noted. The data also indicated that with an increase in humidity, multiple vapor constituents are affected. To evaluate the dogs vapor signature for our illicit cocaine HCl sample, we decided to use higher humidity conditions because of: (1) the increase in the abundance of vapor constituents; (2) the consistent detection in the vapor output; (3) the higher humidity conditions are more reflective of natural searching conditions.

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The Development of A Unique Chemical Tracing System for the Non-Invasive Detection of Drugs, Crops, Chemical Compounds, Currency and Contraband.

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ABSTRACT

Tracer Detection Technology Corp. is a New York State corporation pioneering in the field of chemical tracing and detection systems for a range of governmental and corporate applications. It is engaged in an aggressive licensing program at Oak Ridge National Laboratory to identify and acquire state of the art sensor technologies to detect Perfluorocarbon tracers and for the detection of explosives without a chemical tracer being added. Additionally, Tracer holds the rights to "A Method for the Tracing and Detection of Drugs, Crops, Chemical Compounds and Currency with Perfluorocarbon Tracers" and has filed additional patents for the Laser-based Perfluorocarbon Detection the Surveillance and Control of Contraband and Sensitive Documents. Tracer has also formed a close strategic alliance Oak Ridge National Laboratory (ORNL) to conduct R&D in the area of Chemical Tracing and its applications in law enforcement, national security and corporate security applications.

We expect to develop a Chemical Tracing and Detection System using the use of theencapsulated Perfluorocarbon tracer family of compounds to trace and detect drugs, crops, chemical compounds and currency,; and subsequently, tracking the movement and location of vehicles and boats, or individuals involved in inthese illegal activities or the transport of contraband. This PFT tracer technology and its relatively high vapor pressure provides the unique ability to permeate closed doors, windows, containers and luggage, and is impervious to electronic interference and other problems inherent with electronic tracing technologies. Once a location reaches steady state, the actively emitting tracer marked item will provide vapor traces that are detectable in the vicinity (even temporarily following removal of the tracer marked item). By extending the detectable life of the PFT tracer materials, Tracer will provide a unique tool for law enforcement in numerous applications including non-invasive inspection of locations and cargo under surveillance. The ability to mix several compositions of PFTs and then selectively detect such mixed compositions will allow several intelligence scenarios to be conducted concurrently without cross operational interference or contamination (an important evidentiary consideration). It is possible to envisage applications for future encapsulated PFTs, where tracer release is intelligently triggered either by the presence of the contraband itself, or when an item has been tampered with.

<u>General Discussion of Related Research</u>: PFT tracers are safe, non-reactive, and environmentally benign and volatile gaseous compounds. The ambient background levels of the five routinely used PFTs are in the range of parts per 10^{15} of air. Tracer presented a paper (11/93) on this subject after which a number of Law Enforcement Agencies expressed interest in applications related to the Tracer's patent to tracer currency and contraband. On 9/19/95, Tracer, successfully demonstrated its method of detecting the location of a bag containing 9 previously tracer marked bills in a test conducted at

the F.B.I. Training Facility at Quantico, Va. On 10/31/96, Tracer demonstrated its ability to detect a black powder explosive device containing a small amount of encapsulated PFT tracer. Field

analysis confirmed the presence of a signal from the chemical tracer being emitted from the bomb; subsequently, analysis of the soil from around the "blast site" and from the canvas bag also confirmed the presence of the tracer. Both demonstrations employed gas chromatographs (GC) as the detection method, and conclusively established PFTs as a useful tool, and that a slow-release products must be developed for the technique to practical in the field.

Technical

Tracer's team proposes to research and deliver a turn-key system deployable upon contract conclusion. We will seek field tested solutions that are manufacturable under reliable specifications, and defensible under the judicial system. We will develop a plan that designs an analytical method which will be employed to characterize the prototype encapsulated PFTs. The company and its partners have extensive experience in delayed release mechanisms for commercial applications. We begin by screening "off-the shelf" or modifiable encapsulation technologies for preparation of a wide range of encapsulated PFTs. These efforts will be followed by evaluation of the prototype encapsulated PFTs for performance and manufacturability. Finally we will research several approaches to intelligent tracers that release PFTs under certain preprogrammed conditions. Concurrently, our subcontractorsORNL will develop the applicable laser and a printer (applicator forsolid state sensor system; Tracer's staff of chemists and electronic engineers will develop applicators associated with the selected encapsulation approach and usage scenario.

PHASE ONE: Development of the analytical methods
which will be employed to characterize the prototype encapsulated PFTs; The test method will employ a head-space gas chromatography technique using an electron capture detector (ECD). ECD is the detector of choice since it is highly sensitive to halogenated hydrocarbons, such as PFTs. The primary objective during phase 1 will be to determine the optimal head-space sampling and instrumentation parameters for maximum sensitivity and selectivity for each PFT. We propose to explore other characterization techniques to determine the structure of encapsulated PFTs. The literature suggests that the ideal encapsulated PFT would follow Fick's First Law of Diffusion which states that the flux of a core component across a membrane is independent of time, or follows zero order kinetics. Other mechanisms afford release profiles which are time dependent.

PHASE TWO: The screening of "off-the shelf" encapsulation technologies for preparation of a wide range of encapsulated PFTs; Since it is impossible to predict the release profile of a core - encapsulation combination(s), they must be determined experimentally. In phase two, a range of off-the-shelf encapsulation technologies will be screened for their usefulness in developing PFT microcapsules with the desired properties. Each technology is scaleable and can be used in the manufacture of encapsulated PFT systems. Among the materials for evaluation at this time are cyclodextrins, liposomes, and synthetic polymer systems in the development of encapsulated PFTs. As a group, these technologies provide a menu of tracer devices which can be tailored to meet a specific need.

PHASE THREE: The evaluation of the prototype encapsulated PFTs; They will be ranked according to their performance characteristics and ease of process scale-up. The ideal systems will be identified as those which exhibit prolonged release of the tracer from the encapsulated PFT, and the method of preparation is amenable to scale-up. The encapsulated PFTs will be pilot manufactured and linked to the microcantilever detectors discussed below.

PHASE FOUR: Under a development agreement with Oak Ridge National Laboratories, Dwe will develop and integrate microcantilever sensor chemical specific coatings for tracer applications. To accomplish this end, several steps must be performed:
(1) binding affinities of several chemical compounds to PFT and develop a map of potential interferences. (2) resolve the specifics of attachment chemistry of the PFT sensitive chemical compounds to materials typically used for microfabricated cantilevers: silicon, silicon nitride, silicon oxide/silicon, etc. (3) develop the specific coating techniques for the micorfabricated cantilevers using the combination of chemical reagents determined in (2). The potential exists for an array of microcantilevers with distinct coatings to discriminate between interferences as well as enhancing the sensitivity to the target species.

Tracer anticipates the completion of R&D to deliver the following within an 18 month effort:

- a family of delayed release PFTs which modulate the release of the tracer(s) to produce a constant and long-lasting signal for detection by a lasethe Microcantilever sensor. Initially, the encapsulated PFT tracers will have maintainable lives of one to six months and will show highly reproducible tracer release profiles from batch-to-batch.

- a custom designed tracer (tracers and printers) and detection systemss and applicators) and cantilever-based detection systems. The tracers, based on the Perfluorocarbon family of compounds and, will be amenable to manufacturing processes that produce a high yield of microcapsules, show highly reproducible tracer release profiles, are free of agglomeration, and possess a high efficiency of encapsulation of PFT.

- prototypes of a Microcantilever chip-based sensor (or sensor array) capable of sensing PFT vapors remotely and stably in the field at parts per billion. As part of this development, included will be a PFT specific coating for use on the cantilever device itself, yielding a detection system of ultimate specificity and precision.

OTHER

Business Relationship and Format

Tracer Detection Technology Corp. is intends to enter into a Multi-Task Cooperative Research & Development Agreement (CRADA) underwhich Tracer and Oak Ridge will simultaneously develop of a number of tasks related to the objective of supporting Chemical Tracing activities in Law Enforcement, national security and corporate security. The work relates to the use of chemical tracers in general, and the Perfluorocarbon tracer family of materials specifically. The tasks contemplated include (but are not limited to):

- Adaptation of MicroCantilever sensor technology to detect Perfluorocarbon chemical vapors in the areas of law enforcement and national security as well as a unique coating material for the MicroCantilever armature to which the PFT vapor tracer will have an affinity.

- R&D on the encapsulation and delayed release of PFTs and for subsequent, other new tracer materials.

Strategic Alliance with the National Security Program Office at Oak Ridge (NSPO)

The partnership of Tracer Detection Technology Corp. with the National Security Program Office at Oak Ridge will facilitate the development and then use of an extremely sensitive new tool for the tracing, tracking and detection of drugs, crops, chemical compounds and currency, as well as the people, places and conveyances used in the illegal transactions. Additionally, this effort will enable the "filtering" of high-technology law enforcement capabilities to local and state law enforcement agencies through the development of these unique tools for the federal and corporate security sectors.

Extremely sophisticated, often one-of-a-kind, equipment and very-capable scientific expertise are resident at U.S. federal government laboratories and, until recently, have not been applied often to law enforcement problems, particularly at the state and local level. While there have been a number of research and development programs at national laboratories sponsored by agencies such as the National Institute of Justice, most of these have been focused on long-term objectives to meet broad national needs. In discussions with local law enforcement personnel, it is apparent that there are much more immediate technology needs, which are not being addressed by nationwide programs, in fundamental areas including video and audio surveillance, trace and physical evidence sampling, and forensic laboratory analysis. In a pilot program, Oak Ridge National Laboratory (ORNL), a significant component of the nation's science and technology resources located in Tennessee, recently made a commitment to support law enforcement where possible with advanced technology. The National Security Program Office created the FASTec program as the conduit through which Oak Ridge and other resources are brought to bear on applications as they arise.

The FASTec program was formally established in early 1997 to provide program management structure to a number of individual rapid response technology applications carried out within the Oak Ridge complex for national security, law enforcement, emergency response customers, and corporate security. FASTec is headquartered within the Oak Ridge Centers for Manufacturing Technology (ORCMT), which maintains an infrastructure that can support all of the rapid design, engineering, manufacturing, deployment, and technical support functions needed to serve FASTec customers. FASTec maintains around-the-clock, integrated, on-call capabilities for its customers. It draws upon the $10 billion public investment in Oak Ridge scientific, engineering, manufacturing, and testing facilities operated by over 13,000 scientists, engineers, and craftspeople at the Oak Ridge National Laboratory & the Y-12 Facility.

Examples of customers presently supported by FASTec (or expected to become customers in the near future) include:

- A U.S. Government agency requiring execution of quick response and near term, ad hoc tasks in support of national level needs.
- A U.S. military command responsible for the rapid application of technologies to the needs of U.S. forces world wide.
- A U.S. government agency requiring emergency manufacturing in response to national disasters and emergencies.
- A Fortune 200 professional organization requiring unique and specialized technologies and technical support applicable to corporate security.
- A U.S. Department of Energy office requiring quick response security technology and rapid performance testing.
- A U.S. Department of Energy office requiring rapid forensic science applications to the needs of law enforcement and the "Special Activities" community.
- A Department of Defense agency requiring rapid applications of electronics, detector, and instrumentation technologies.
- The police chiefs association for a southern state requiring forensic science and other technology support to the ad hoc needs of police departments across the state.

A component of FASTec is the Center for Applied Science and Technology for Law Enforcement (CASTLE), a partnership of scientific, university, private sector, and law enforcement personnel. The goal of the CASTLE program is to apply technology at the grassroots working level to both solve crimes and make the officer's job safer and more efficient.

Oak Ridge National Laboratory is a multi-program, multi-disciplinary national laboratory within the U.S. Department of Energy with broad-ranging capabilities in basic and applied science and engineering. Pioneering work has been performed in Oak Ridge in areas such as transgenic mice, ion trap mass spectrometry, scanning tunneling microscopy, advanced materials, environmental analysis, microelectronics, geographic information systems, etc. Instrumentation includes state-of-the-art mass spectrometers, one-of-a-kind scanning electron microscopes, prototype parallel-based supercomputers, and other advanced equipment. These resources have not been made available routinely to law enforcement organizations in the past. By working closely with personnel in police, sheriffs, and other law enforcement organizations throughout the Southeastern U.S. region, technology needs are identified and sent to CASTLE for assistance. These needs may be met with existing technology, require some short-term applied development, or may necessitate revolutionary advances in technology. Where it can be ascertained that the need cannot be met either in the private sector or by organizations such as the Tennessee Board of Investigation (TBI) or Federal Bureau of Investigation (FBI) and where ORNL has a specialized or unique expertise, CASTLE endeavors to provide a technological solution. Using unique Oak Ridge expertise, technology applications for law enforcement may include operational or tactical support, evidence analysis, technical advice, equipment modifications, or addressing broad, generic problems. If a short-term solution cannot be provided, funding from national-level organizations to address broad problems under a research and development effort is sought.
CASTLE activities have included:

- Numerous armed robberies, several homicides and other crimes were solved through advanced video enhancement

- An improved scheduling system for the Atlanta police was deployed for the 1996 Olympic Games

- Studies into the disappearance of children's fingerprints have revealed dramatic differences in chemical composition from adults and possible identification of physical characteristics

- Computer and intelligent systems technologies can provide significant improvements in quality, costs, and production time for cranio-facial reconstruction (joint effort with University of Tennessee)

- Forensic analyses of materials have provided significant evidence for homicide investigations.

The key to the success of CASTLE has been the linkage with and support of law enforcement personnel at the local, state, and federal level. With the success of the pilot effort, the vision is to extend the CASTLE concept to other geographic regions of the country by using other federal laboratories as the focal points.

POTENTIAL CUSTOMERS

Tracer Detection Technology Corp. has developed a lengthy list of potential federal agency end-users. While at this time there is no guarantee that contracts to deliver finished products will develop from any of these, the following agencies and entities have met with or defined certain operational scenarios and end-uses for chemical tracing systems that they wish to see deployed.

- Federal Bureau of Investigation

- U.S. Intelligence community

- U.S. Customs

- National Institute of Justice

- State and local law enforcement

- Federal, state and local drug enforcement agencies- High Density Drug Trafficking Area programs (HIDTA)

- Alcohol Tobacco and Firearms (ATF)

- Corporate Security applications within FORTUNE 200 Corporations

Licensing Agreement(s)

Tracer Detection Technology Corp. holds patent rights to a "Method of Tracing and Detection of Drugs, Crops, Chemical Compounds and Currency with Perfluorocarbon Tracers." The Company now has other disclosures and applications pending with the United States Patent and Trade Mark Office including protection for concepts relating to new detection methods. In 1997, Tracer entered a licensing agreement to complete the development of the Microcantilever sensor technology developed at Oak Ridge. Specifically, Tracer obtained the Commercial Rights via licensing agreement with Lockheed Martin for the detection of Perfluorocarbons as a tracer in law enforcement and security related applications. Additionally, Tracer has acquired preliminary rights to the use of the Microcantilever sensor for the detection of ambient vapors of various explosives (without the addition of a chemical tracer). The Company is also exploring the use of other new sensor technologies from Oak Ridge that promise to offer the precision of chemical analysis detectors like gas chromatographs with electron capture detectors in a compact, portable, real-time detector. Tracer has also filed a U.S. Patent Application covering the Laser-based Perfluorocarbon Detection for the Surveillance and Control of Contraband and Sensitive Documents. At this time, the Company believes that this patent will provide broad protection in the optical detection of chemical tracers.

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Appendix B
List of Abstracts Submitted

B

A Handheld Prototype Instrument for Cocaine Freebase and Cocaine Hydrochloride Using Surface Acoustic Wave Sensors
Edward J. Poziomek, Hank Wohltjen, Brent Busey, Julie Patrick
Old Dominion University

A Mobile X-ray System for Nonintrusive Inspection of Vehicles
W. Wade Sapp, Gerald J. Smith, Roderick D. Swift
American Science and Engineering

A New Sensor Technology for Rapid Drug Detection and Identification
Nile F. Hartman, Daniel P. Campbell, Robert E. Schwerzel
Georgia Tech Research Institute

A Non-Fluidic Optical Immunosensor
Davis B. Silcott, Greg A. Tilley, Edward N. Silcott
Biosterics, Inc.

A Pulsed Fast-Thermal Neutron Probe for Contraband Detection
P. C. Womble, M. Belbot, L. Dep, J. Paschal, G. M. Spichiger, G. Vourvopoulos
Department of Physics and Astronomy, Western Kentucky University

A Radiographic Test and Simulation (RTAS) System
Tom Cassidy, Robert Shiner, Forest Scott
Sensor Concepts & Applications, Inc.

A Study on the Temperature Profile of Ecgonidine Methyl Ester Using a Finnigan GCQ
Lindy E. Dejarme, Neal D. McCall, Lisa H. Clay, Laurence E. Slivon
Battelle

Adapting CT Based Explosives Detection Technology to Detect Narcotics in Passenger Luggage
Stephen Wolff
InVision Technologies

Airborne System for Tracking and Surveillance Coordination
Trooper Mark Dunaski, Yuki Novick
Minnesota State Patrol

An Improved Pin-Hole Video Camera for Covert Surveillance
Igor Alexeff, J. Douglas Birdwell
University of Tennessee

Analysis of Photon-Based Non-Intrusive Inspection Systems
B. J. Micklich, C. L. Fink, L. Sagalovsky
Argonne National Laboratory

Anomalies in the Detection of Contraband Drugs Using Ion Mobility Spectrometry
Grazyna E. Orzechowska, Edward J. Poziomek, Henri K. Parson, Denise E. Lucas
Old Dominion University

Antennas for Tactical Tracking and Radiolocation
Spencer L. Webb
DTC Communications

Applicability of Counterdrug Non-Intrusive Inspection System to Alternative Applications
Michael Spradling, John Pennella, James Petrousky
Battelle

Application of Probability-of-Detection Concepts to Performance Characterization of Contraband Detection Systems at Border Crossings
Roger Hyatt, Michael Spradling, John Pennella
Battelle

Application of Solid Phase Microextraction in the Headspace Sampling of Contraband Drugs
Grazyna E. Orzechowska, Edward J. Poziomek, Vangielynn C. Tersol
Old Dominion University

Applied Counterdrug Law Enforcement Technology
J. M. Johnston, J. M. Jackson, L. Paul Waggoner, M. Williams, M. Jones, T. Boussom, J. A. Petrousky
Auburn University

Automation of "Pouring" in DoD Drug Testing Laboratories
Neal Owens
Battelle

Automation of Temporal Pattern Detection in Financial Crime Analysis
Christopher R. Westphal, Teresa A. Blaxton, David J. O'Connor
United Information Systems, Inc.

Bottle Screening Systems for Aviation Security
William Curby, Ken Novakoff, B. Michael Smith
Federal Aviation Administration

Cargo Screening: The Effect of Using Different Energies
Paul J. Bjorkholm
EG&G Astrophysics Research Corp.

Client/Server Design for Very Large Image Exploration
Peter Hansen, Igor Alexeff, J. Douglas Birdwell
University of Tennessee

Cocaine Decomposition on Silica Surfaces
Grazyna E. Orzechowska, Edward J. Poziomek, Vangielynn C. Tersol
Old Dominion University

Cocaine Metamorphosis Study
Chih-Wu Su, Kim Babcock, Steve Rigdon, Gary Reas, Tim Noble
United States Coast Guard

Cocaine Pyrolysis Degradation Study
Chih-Wu Su, Kim Babcock, Steve Rigdon
United States Coast Guard

Container Inspection System Operation
Pierre Harris, Fred Hemp
Heimann Systems Gmbh., Europ Scan S.A.

Contraband Detection Using K-40 Gamma Ray Emissions: Field Tests
Nina V. Arendtsz, Bruce Rosenquist, Andre Cote
R Tech

Counterdrug Mapping, Tracking and Databases Position Data Gathering (PDG) System
Lt. Josh Landers, Yukie Novick
Yonkers Police Department

Data Collection During Operational Deployment of Explosive Detection Equipment for the White Commission on Aviation Safety and Security
James Connelly, Tom Guarini
Federal Aviation Administration

Definitive User Access on a Secure Web Server
Sage Jackson, J. Douglas Birdwell
University of Tennessee

Detection of Cocaine Residue on Currency
Special Agent Tom Loper
Financial Crimes Division, Office of the Attorney General, Texas

Developments in Contraband Detection Using X-ray Technology
N. C. Murray, R. J. Lacey, P. H. Mason, J. G. Rushbrooke
Police Scientific Development Br.

Drugbuster
B. Castle Maglich, C. Powell, D. W. Scott, K. Kani
HiEnergy Microdevices, Inc.

Drugwipe **- a Trace Detector for Counterdrug Operations of Law Enforcement**
Franz Aberl (Chris McLean - Manager, North America)
Securetec, Inc.

Eagle Eye Mobile Messaging PLuS Personal Locating Service via Satellite
Matthew Schor
Eagle Eye Technologies, Inc.

Effectiveness Indicators for Drug Interdiction Technology
Hal Crane, Raymond Mintz
Consultant - U.S. Customs Service

Electronic Surveillance of Patterns of Entity Relationships (E.S.P.E.R.)
Robert D. Hogan
Texas Attorney General's Office

Evaluation of NII Imaging Equipment for USCS Applications
Roy P. Lindquist, M. Annis,
U.S. Customs Service

Evaluation of Three Prototype Cocaine Vapor Detectors Under Controlled Operational Conditions
Rachel Gooding, A.W. Richardson, M. L. Spradling, J. J. Pennella
Battelle

FAA Trace Explosive Detector Acceptance Testing Program
Susan F. Hallowell, Paul Z. Jankowski
Federal Aviation Administration

Georgia Courts Automation Program
Lisa Sills
Georgia Tech Research Institute

GLADYS: Information Technology for Communications Surveillance
F. J. Rayano, J. R. Schmid, A. E. Lancaster, Jr.
Dyncorp I&ET/Consulting Services Division

High Energy Material Discrimination (HEMID) in the X-ray Imaging of Cargo Containers at Linac Energies
J. G. Rushbrooke, W. W. Neal, R. E. Ansorge, C. E. Hooper
Cambridge Imaging Limited

HISAR: An Advanced Multi-Applications Surveillance and Reconnaissance System
C. Y. Chang
Hughes Aircraft Company Sensors and Communications Systems

How Organized Crime Is Helping Mexico Become Another Columbia
Julie Salzano
Pace University

Imagebase
Richard Sallee, Dale Gillham
Data Critical Corp.

Immunochemical Detection of Drug Vapors
H. R. Lukens, A. Wu, E. Duff
Diametrix Detectors, Inc.

Improved Methods for Estimating Yields of Narcotic Crops
Mary C. Acock, Basil Acock
USDA:ARS:BA:NRI Remote Sensing and Modeling Laboratory

Improved Over-the-Horizon-Radar Detection for Counterdrug Mission in the Presence of Range-Folded Spread Doppler Clutter
Michael P. Hartnett
Decision-Science Applications, Inc.

Improved ROTHR Detection and Tracking Using MLANS Algorithm
Leonid I. Perlovsky, Capt. Christopher A. Hansen
Nichols Research Corp.

Inexpensive Linux Firewalls for Inter-Intra Network Security
Mark Rader, J. Douglas Birdwell
University of Tennessee

Intrusion Detection Using Signal Processing and Neural Nets
Linda B. Lankewicz, Radhakrishnan Srikanth, Roy George
University of the South

Joint Interoperability and Database Compatibility for the Counterdrug Intelligence Community
T. A. Campen
National Drug Intelligence Center

Law Enforcement Applications of Time-Modulated Ultra-Wideband RF Technology
Paul Withington, II
Vice President, Time Domain Systems, Inc.

Learning to Extract and Classify Names from Text
Ralph Weischedel, Richard Schwartz, Daniel Bikel
BBN Systems and Technologies

Link Discovery Tool
Roger Horn, J. Douglas Birdwell, Lenny Leedy
University of Tennessee

Magnetic Loop Based LORAN Receiver for Urban Canyon Applications
Capt. Benjamin B. Peterson, Yukie Novick, Kenneth U. Dykstra, Lance Miller
U.S. Coast Guard Academy

Methamphetamine Versus Nicotine Detection on the Barringer Ion Mobility Spectrometer
Angela DeTulleo Smith
Drug Enforcement Administration

Millivision Camera for the Detection of Narcotics, Metallic and Non-Metallic Weapons, Explosives, and Other Contraband and For Through-Wall Imaging
G. Richard Huguenin
Millimetrix, Llc

Mini-Lidar for Non-Contact Chemical Identification
Carl L. Chen, Arthur J. Sedlacek
Brookhaven National Laboratory

Model 66Z Interactive Training
Robert Fleck
American Science & Engineering

Monitoring and Deterring Drug Use
David A. Kidwell, Janel C. Holland, Marsha A. Blanco
Naval Research Laboratory

Multi-Agency Interoperable Communications (Magic)
Louis Cegala, Michael R. Martins, Kevin D. Callahan
U.S. Customs Service

Multi-Use Technologies to Support U.S. Customs Multiple Missions
Douglas E. Smith,
U.S. Customs Service

Narcotic Detection Technology Assessment Program (NDTAP) Status Update
David Hoglund, Patrick Shier (Kentco, Inc.)
U.S. Customs Service

Narcotics Detection Using Piezo-Electric Resonance - Results and Future Direction
Roy P. Lindquist, B. Bartell, E. Magnuson, T. Rayner,
U.S. Customs Service

Netscape Plug-In for Secure Distributed Data Mining
Roger D. Horn, J. Douglas Birdwell
University of Tennessee

New UAV Technology, Combined with a Unique Satellite Communications Package, Promises to Establish a New Trend in Counter Drug Law Enforcement
Morris Messinger
Omega Technologies

NII Test Procedures vs. Drug Interdiction
Roy P. Lindquist
U.S. Customs Service

Non-Intrusive Detection of Contraband Drugs Using Neutron Transmission
T. G. Miller, P. Van Staagen, B. C. Gibson, J. L. Orthel
Tensor Technology, Inc.

Operation Breakthrough: Coca Cultivation & Cocaine Base Production in Peru
Daniel L. Augenstene
DEA Investigative Technology Section

Operational Evaluation of Trace Explosives Detection Equipment
Paul Jankowski
FAA

PC-Based Real-Time Face Recognition for Access Control
Malay Kindu, Eugene Gusyatin, Alex Pentland
Facia Reco Associates

Peformance Assessment of the Mobile Truck X-ray (MTXR) System
Tom Cassidy, John Pennella
Sensor Concepts & Applications, Inc.

Performance and Applications of a New Portable Detection System for Drugs and Explosives
William J. McGann, Paul Becotte-Haigh
Ion Track Instruments

Performance Assessment of Prototype Gamma-ray Imager for Illicit Drugs
Michael L. Spradling, Roger W. Hyatt, Sirai M. Khan
Battelle

Performance Assessments of Cabinet X-ray Systems for Narcotics Detection
B. J. Micklich, C. L. Fink, L. Sagalovsky
Argonne National Laboratory

Personnel Screening Systems for Aviation Security
Marti Snyderwine, Ken Novakoff
Federal Aviation Administration

Practical Applications of Linkage Analysis Technology in International Counterdrug Law Enforcement Arena
Ryan J. Wagener
American Management Systems, Inc.

Public/Private/Wireless Information Security
Mark Rader, J. Douglas Birdwell
University of Tennessee

Real-Time Positional Accuracy Improvment for ROTHR Drug Interdiction Using Beacon Assisted Coordinate Registration
Ellen Ferraro, Doug Cameron
Raytheon Company

Recent Advances in Counterdrug OTH Radar Ship Surveillance
James R, Barnum, Julia A. Olkin, John W. Ciboci
Sri International

Remote Sensing of Suspect Drug Laboratories by Dial Techniques
James C. Sentell, H. Irvin Brock
Coleman Research Corporation

Research and Application of Speech Processing Technology
Sharon M. Walter, Roy J. Ratley, Maria Amodio
Rome Laboratory

Self-Propelled Non-Intrusive X-ray Inspection System
R. A. Armistead
Aracor

Sharing Is Vital
Capt. Kurt F. Schmid
Illinois State Police

Signature Profiling of Trace Components in Illicit Cocaine Samples for Tactical and Strategic Law Enforcement Purposes
John F. Casale, David R. Morello, James M. Moore
DEA Special Testing & Research Lab

Sims: Integrating Heterogeneous, Distributed Information Sources
Yigal Arens
USC/ISI

Southern California Integrated Communications Network (SCICN)
Jim Cole
Electronic Proving Ground

Strategic Problem Solving in the Customs Service
William S. Heffelfinger, Leo A. Morris
U.S. Customs Service

Strategies for Biological Control of Narcotic Plant
Bryan A. Bailey, Karol S. Elias, Javier Gracia-Garza, Prakash Hebbar, Amy J. Nelson, Robert D. Lumsden
Biocontrol of Plant Diseases Laboratory, ARS, USDA

The Body Search System: X-ray Imaging of Contraband Concealed on the Body
David S. deMoulpied
American Science and Engineering

The Design, Construction and Operation of a 9 MeV Vehicle Cargo X-ray System
Gordon Bennett
EG&G Astrophysics, Cargo X-ray Division

The Detection and Identification of Drugs at Crime Scenes
Lucille Harries, Peter Hulmston
Nottinghamshire Constabulary, Scenes of Crime Dept.

The Development of a Unique Chemical Tracing System for the Non-Invasive Detection of Drugs, Crops, Chemical Compounds, Currency and Contraband
Jay Fraser, Norman Kaish
Tracer Detection Technology Corp.

The DoD Counterdrug Technology Development Program
John J. Pennella, Jo R. Gann
Naval Surface Warfare Center - Dahlgren Division

The Egmont Secure Web System
Emile Beshai
Financial Crimes Network (FinCEN)

The Face Recognition Technology (FERET) Program
P. Jonathon Phillips, Patrick Rauss
U.S. Army Research Laboratory

The Graseby Narcotec Narcotics Detector: a Non-Radioactive Version
Alastair Clark, Paul Arnold, Alan H. Brittain, Roderick C. Wilson
Graseby

The Search for Clandestine Drug Tunnels along the Southwest Border
Maureen K. Corcoran, Robert F. Ballard, Jr., Joseph B. Dunbar
U.S. Army Corps of Engineers Waterways Experimental Station

The Use of Radar Techniques for Remote Heartbeat, Respiration, and Human Presence Detection Through Walls
E.f. Greneker
Georgia Tech Research Institute

The West Florida Counterdrug Investigative Network Experience Implications for Managing Technology Transfer
Gregory Larsen, Capt. Dan Wiggins, J. Douglas Birdwell
Tennessee Valley Authority

Thunder Mountain Evaluation Center - the Organization and the Support
Stacy Wright
Thunder Mountain Evaluation Center

Time Line Analysis Tools for Law Enforcement
John Mucks
Rome Laboratory

Tunnel Detection and Site Characterization
Robert F. Ballard, Jr., Dan Keiswetter, I. J. Won
U.S. Army Corps of Engineers

U.S. Customs Strategy for Deploying High Technology NII Equipment at Land Border and Sea Ports
Robert S. Armstrong
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Uses of High Resolution Folpen Sar in Counterdrug Surveys
Roger S. Vickers
Sri International

VACIS, a Versatile Gamma-Ray Vehicle and Cargo Inspection System
Victor V. Verbinski
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Value Assessment of Chemical Markers for Cocaine Hydrochloride
Lindy E. Dejarme, Vincent G. Puglielli
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Vapor Constituents of Illicit Cocaine HCI as Delivered Through an Olfactometer
Cindy C. Edge, Karen Kajiya-Mills
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Vision Technologies for Manned and Autonomous Surveillance
Michael W. Hansen, Lambert Wixson
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Web-Based Secure Telephone Electronic Registry (WEBSTER)
Jay Flaherty, J. Douglas Birdwell
University of Tennessee

Wide Area Information Services in Secure Environments
J. Douglas Birdwell, D. Wiggins, L. Leedy, D. Icove, G. Larsen
University of Tennessee

X-ray Inspection of Pallet and Sea-Cargo Containers Using 1 MeV and 2 MeV X-ray Sources
Richard J. Adler, Martin Annis
North Star Research Corp c/o Annis Tech, Inc.

Appendix C
Index of Authors

Appendix D
Symposium Program

D

1997 ONDCP INTERNATIONAL TECHNOLOGY SYMPOSIUM

Harnessing Technology to Support the National Drug Control Strategy

PROGRAM

Sponsored by:

Executive Office of the President
Office of National Drug Control Policy
General Barry McCaffrey, Director
The Counterdrug Technology Assessment Center

and the

Department of Defense National Institute of Justice
Drug Enforcement Administration
Immigration and Naturalization Service
Federal Bureau of Investigation
Federal Aviation Administration
U.S. Customs Service U.S. Coast Guard
United Kingdom Home Office Revenue Canada

August 18–21, 1997
Hotel Inter-Continental
Chicago, Illinois

Detailed Program

Hotel Inter-Continental **Chicago, Illinois**

<u>**Monday, August 18, 1997**</u>

5:30-7:30 p.m. Spanish Court Toledo & Cordova Renaissance	**Early Registration** **Technology Demonstrations** **Welcoming Reception**

<u>**Tuesday, August 19, 1997**</u>

7:00 a.m.–8:00 p.m. Spanish Court Toledo & Cordova	**Registration and Information Desk** **Technology Demonstrations**
	Morning
8:00–8:30a.m. Grand Ballroom	**Session 1A: Welcome and Administrative Instructions:** Dr. Albert E. Brandenstein, Office of National Drug Control Policy/Counterdrug Technology Assessment Center (ONDCP/CTAC). **Welcome to Chicago:** Superintendent Matt Rodriguez, Chicago Police
8:30–9:00 a.m. Grand Ballroom	**Session 1B: Harnessing Technology to Support the National Drug Control Strategy** **Goal 1:** *Motivating America's Youth* Dr. Lloyd Johnston, Institute for Social Research
9:00–9:45 a.m. Grand Ballroom	**Keynote Address:** General Barry McCaffrey, Director, ONDCP
9:45–10:15 a.m.	**Break** **Director's Press Conference**
10:15–11:15 a.m. Grand Ballroom	**Session 1B: Harnessing Technology to Support the National Drug Control Strategy** ***(Continued)*** **Goal 2:** *Reducing Crime and Violence* Speaker: Ms. Claire McCaskill, Prosecutor, Jackson County Missouri **Goal 3:** *Reducing Health and Welfare Costs* Dr. Donald Vereen, National Institute on Drug Abuse
11:15 a.m.–12:00 p.m.	**Break**
12:00–1:15 p.m. Grand Ballroom	**Luncheon** **Speaker:** The Honorable Thomas Constantine, Administrator, Drug Enforcement Administration
1:15–1:45 p.m.	**Break**
1:45–3:10 p.m. Grand Ballroom	
3:10–3:30 p.m.	**Break**

3:30–5:30 p.m. Grand Ballroom	**Session 1C: Progress Reports on Key Medical and Treatment Projects** **Chair:** Dr. H. Kleber, National Center on Addiction and Substance Abuse	
	Cocaine Monoclonal Antibodies	Dr. Donald Landry
	Compounds Research	Dr. Michael Kuhar
	Drug Evaluation Network System	Dr. A. Thomas McLellan
	Youth Diversion	Dr. Jerome Platt
6:45–7:30 p.m. Renaissance	**Social Mixer**	
7:30–9:15 p.m. Grand Ballroom	**Banquet** **Speaker:** Ranking Government or Cabinet Official	

Wednesday, August 20, 1997

7:00 a.m.–7:00 p.m. Spanish Court Toledo & Cordova	**Registration and Information Desk** **Technology Demonstrations**	

Morning

7:00-7:45 a.m. Empire	**Daily Speakers' Meeting** **Technical Chair:** Dr. Arvid Larson	
8:00–9:45 a.m. Grand Ballroom	**Session 2A: Science and Technology Committee Reports:** *A 10-Year Technology Plan (Status)* **Chair:** Dr. Albert E. Brandenstein, ONDCP/CTAC	
	Nonintrusive Inspection	Mr. Ray Mintz
	Tactical Technologies	Mr. Anthony Bocchichio
	Wide Area Surveillance	Mr. John Pennella
	Medications Development, Treatment, and Prevention	Dr. Frank Vocci
9:45–10:15 a.m.	**Break**	
10:15 a.m.–12:15 p.m. Renaissance	**Session 2B: Presentation of Technical Papers (2 Tracks)** **2B-1: Technology Testbeds and Test Protocols** **Chair:** Mr. John Pennella, U.S. Department of Defense	

DOD Counterdrug Technology Development Program
Mr. John Pennella, Naval Surface Warfare Center, Dahlgren

Thunder Mountain Evaluation Center
Mr. Stacy G. Wright, Thunder Mountain Evaluation Center

Performance Measurements of Nonintrusive Inspection Systems
Mr. Roy P. Lindquist, U.S. Customs Service

Strategies for Biocontrol of Narcotics Plants
Dr. Bryan A. Bailey, U.S. Department of Agriculture

Research/Applications of Speech Processing Technology for Law Enforcement Technologies
Ms. Sharon M. Walter, U.S. Air Force Rome Laboratory

Tunnel Detection and Characterization
Mr. Robert E. Ballard, Jr., U.S. Army Corps of Engineers

Operation Breakthrough: Coca Cultivation and Cocaine Production in the Andean Ridge
Mr. Daniel L. Augenstene, U.S. Drug Enforcement Administration

King Arthur Court

2B-2: Nonintrusive Inspection Technologies
Chair: Mr. Ray Mintz, U.S. Customs Service

Detection Technology Assessment Update
Mr. David Hoglund, U.S. Customs Service

Effectiveness Indicators for Drug Interdiction Technology
Mr. Hal Crane, Diversified Technology Consultants

Multiple Missions, Multiuse Technologies for Customs
Mr. Douglas E. Smith, U.S. Customs Service

Performance Assessment of Cabinet X-Ray Systems for Narcotic Detection
Dr. Bradley J. Micklich, Argonne National Laboratory

Customs Strategy for Deploying High Technology NII Equipment at Land Border and Sea Ports
Mr. Robert S. Armstrong, U.S. Customs Service

Strategic Problem Solving in the Customs Service
Mr. Leo A. Morris, U.S. Customs Service

12:15–12:30 p.m. — **Break**

12:30–1:15 p.m. — **Session 2C: Presentation of Technical Papers (4 Tracks)**

Empire

2C-1: Nonintrusive Inspection Technologies
Chair: Dr. Peter Young, Police Scientific Development Branch

Developments in Contraband Detection Using X-Ray Techniques
Mr. N.C. Murray, Home Office, Police Scientific Development Branch

High-Energy Material Discrimination (HEMD) in the X-Ray Imaging of Cargo Containers at Linac Energies
Dr. John G. Rushbrooke, Cambridge Imaging Ltd.

King Arthur Court

2C-2: Communications, Surveillance, and Tracking Technologies
Chair: Mr. James L. Cole, Electronic Proving Ground

Multiple Agency Interoperable Communications (MAGIC)
Mr. Louis Cegalia, U.S. Customs Service

Southern California Integrated Communications Network (SCICN)
Mr. James L. Cole, Electronic Proving Ground

Exchange

2C-3: Information Systems Technologies
Chair: TBD

Wide Area Information Services in Secure Environments
Dr. J. Douglas Birdwell, University of Tennessee

The Face Recognition Technology (FERET) Program
Dr. Jonathon Phillips, U.S. Army Research Laboratory

Renaissance

2C-4: Chemical Sensing Technologies
Chair: Mr. Anthony Bocchichio, Drug Enforcement Administration

Methamphetamine Versus Nicotine Detection on the Barringer Ion Mobility Spectrometer
Ms. Angela M. DeTulleo Smith, Drug Enforcement Administration

A New Sensor Technology for Rapid Drug Detection and Identification
Mr. Nile F. Hartman, Georgia Tech Research Institute

1:30–2:45 p.m. — **Luncheon**
Grand Ballroom
Speaker: Senator Ben Nighthorse Campbell, R-CO

3:00–5:00 p.m. Empire	**Session 2C: Presentation of Technical Papers *(Continued)*** **2C-1: Nonintrusive Inspection Technologies *(Continued)*** **Chair:** Dr. Peter Young, Police Scientific Development Branch *A Pulsed Fast-Thermal Neutron Probe for Contraband Detection* Dr. Philip C. Womble, Western Kentucky University *Personnel Screening Systems for Aviation Security* Mr. William A. Curby, Federal Aviation Administration *The Body Search System: X-Ray Imaging of Contraband Concealed on the Body* Mr. David S. deMoulpied, American Science and Engineering, Inc. *Image Quality and Radiation Safety of Cargo Imaging at Various Energies* Dr. Paul J. Bjorkholm, EG&G Astrophysics
King Arthur Court	**2C-2: Communications, Surveillance, and Tracking Technologies *(Continued)*** **Chair:** Mr. James L. Cole, Electronic Proving Ground *Airborne System for Tracking and Surveillance Coordination* Trooper Mark Dunaski, Minnesota State Patrol *Eagle Eye Mobile Messaging PluS-Personal Locating Services via Satellite* Mr. Mathew Schor, Eagle Eye Technologies, Inc. *Law Enforcement Applications of Time-Modulated, Ultra-Wideband RF Technology* Mr. Paul Withington II, Time Domain Corporation *Magnetic Loop Based LORAN Receiver for Urban Canyon Applications* CAPT Benjamin B. Peterson, U.S. Coast Guard Academy
Exchange	**2C-3: Information Systems Technologies *(Continued)*** **Chair:** TBD *Anomaly Detection Using Signal Processing and Neural Nets* Dr. Linda B. Lankewicz, University of the South *Practical Applications of Linkage Analysis Technology in the International Counterdrug Law Enforcement Arena* Mr. Ryan J. Wagener, American Management Systems, Inc. *Link Discovery Tool* Dr. Roger D. Horn, University of Tennessee *Timeline Analysis Tools for Law Enforcement* Mr. John Mucks, U.S. Air Force Rome Laboratory
Renaissance	**2C-4: Chemical Sensing Technologies *(Continued)*** **Chair:** Mr. Anthony Bocchichio, Drug Enforcement Administration *Application of Short-Range Raman Lidar to the Detection of Chemicals* Dr. Carl L. Chen, Brookhaven National Laboratory *Immunochemical Detection of Drug Vapors* Mr. H. R. Lukens, Diametrix Detectors, Inc. *Evaluation of Three Prototype Cocaine Vapor Detectors Under Controlled Operational Conditions* Mr. Aaron Richardson, Battelle *Anomalies in the Detection of Contraband Drugs Using Ion Mobility Spectrometry* Ms. Grazyna E. Orzechowska, Old Dominion University *Cocaine Metamorphosis Study* Dr. Chih-Wu Su, U.S. Coast Guard Research and Development Center
5:00–5:15 p.m.	**Break**
5:15–6:00 p.m. Grand Ballroom	**Session 2D: Mini-Plenary** **Speaker:** Member, House of Representatives
6:00–7:00 p.m. Renaissance	**Speakers' Reception**

7:00 a.m.–6:00 p.m.
Spanish Court
Toledo & Cordova

Thursday, August 21, 1997

Registration and Information Desk
Technology Demonstrations

Morning

7:00–7:45 a.m.
Empire

Daily Speakers' Meeting
Technical Chair: Dr. Arvid Larson

8:00 a.m.–12:00 p.m.

Session 3A: Presentation of Technical Papers (4 Tracks)

Empire

3A-1: Nonintrusive Inspection Technologies
Chair: Dr. Lyle Malotky, Federal Aviation Administration

Contraband Detection Using K-40 Gamma Ray Emissions: Field Tests
Dr. Nina V. Arendtsz, Revenue Canada

VACIS, A Versatile Gamma Ray Vehicle
Dr. Victor V. Verbinski, Science Applications International Corp.

Performance Assessment of Prototype Gamma-Ray Imager for Illicit Drugs
Mr. Michael L. Spradling, Battelle

Nonintrusive Detection of Contraband Drugs Using Neutron Transmission
Mr. T. G. Miller, Tensor Technology, Inc.

Application of Probability-of-Detection Concepts to Performance Characterization of Contraband Detection Systems at Border Crossings
Mr. Roger W. Hyatt, Battelle

Applicability of Counterdrug Nonintrusive Inspection Systems to Alternative Applications
Mr. Michael L. Spradling, Battelle

Narcotics Detection Using Piezo-Electric Resonance Results and Future Direction
Mr. Roy P. Lindquist, U.S. Customs Service

King Arthur Court

3A-2: Communications, Surveillance, and Tracking Methodologies
Chair: Mr. Jack Maier, Drug Enforcement Administration

Improved ROTHR Detection and Tracking Using the MLANS Algorithm
Dr. Virgil H. Webb, Nichols Research Corporation

Recent Advances in Counterdrug OTH Radar Ship Surveillance
Dr. James R. Barnum, SRI International

Improved Over-the-Horizon-Radar Detection for the Counterdrug Mission in the Presence of Range-Folded, Spread-Doppler Clutter
Mr. Robert J. Denton, Jr., U.S. Air Force Rome Laboratory

The Use of Radar Techniques for Remote Heartbeat, Respiration, and Human Presence Detection Through Walls
Mr. Eugene F. Greneker, Georgia Tech Research Institute

HISAR: An Advanced Multi-Application Surveillance and Reconnaissance System
Dr. C. Y. Chang, Hughes Aircraft Company

Exchange

3A-3: Information Systems Methodologies
Chair: CPT Laura J. Shnider, Arizona Army National Guard, Joint Counter Narcotics Task Force

Learning to Extract and Classify Names from Text
Dr. Ralph Weischedel, BBN Corporation

Automation of Temporal Pattern Detection in Financial Crime Analysis
Mr. Christopher Westphal, United Information Systems, Inc.

E.S.P.E.R.: A Relational Database Analysis Tool
Mr. Robert D. Hogan, Office of the Texas Attorney General

Sharing is VITAL (Violent Crime Information Tracking and Linking)
CAPT Kurt F. Schmid, Illinois State Police

Counterdrug Mapping, Tracking, and Databases
Detective Joshua Landers, Yonkers Police Department

Data Collection During Operational Deployment of Explosive Detection Equipment for the White House Commission on Aviation Security and Safety
Dr. James M. Connelly, Federal Aviation Administration

Renaissance

3A-4: Chemical Sensing Methodologies
Chair: Dr. Andre Lawrence, Revenue Canada

Detection and Identification of Drugs at Crime Scenes
Ms. Lucille Harries, Nottinghamshire Constabulary

Detection of Cocaine on Currency
Special Agent Tom Loper, Office of the Texas Attorney General

Signature Profiling of Trace Components in Illicit Cocaine Samples for Tactical and Strategic Law Enforcement Purposes
Mr. John F. Casale, U.S. Drug Enforcement Administration

Cocaine Pyrolysis Degradation Study
Dr. Chih-Wu Su, U.S. Coast Guard Research and Development Center

Value Assessment of Chemical Markers for Cocaine Hydrochloride
Dr. Lindy E. Dejarme, Battelle

Performance and Applications of a New Portable Detection System for Drugs and Explosives
Dr. William J. McGann, Ion Track Instruments

Automation of Pouring in DOD Drug Testing Laboratories
Dr. Vincent Puglielli, Battelle

12:15–1:45 p.m.
Grand Ballroom

Luncheon
Speaker: Dr. Marino Costa Bauer, Minister of Health (Peru), and President, Contra Drogas

1:45–2:15 p.m.

Break

Afternoon

2:15–5:00 p.m.
Empire

Session 3B: Presentation of Technical Papers (4 Tracks)
3B-1: Nonintrusive Inspection Methodologies
Chair: Mr. Robert Armstrong, U.S. Customs Service

Container Inspection System
Mr. Pierre Harris, Europ Scan

Self-Propelled Nonintrusive X-Ray Inspection System
Dr. R. A. Armistead, Advance Research and Applications Corporation

Adapting CT Based Explosives Detection Technology to Detected Narcotics in Passenger Luggage
Mr. R. Stephen Wolff, InVision Technologies

A Mobile X-Ray System for Nonintrusive Inspection of Vehicles
Dr. W. Wade Sapp, American Science and Engineering, Inc.

The Design, Construction, and Operation of a 9 MeV Vehicle Cargo X-Ray System
Dr. Gordon Bennett, EG&G Astrophysics

Performance Assessment of the Mobile Truck X-Ray (MTXR) System
Mr. Tom Cassidy, Sensor Concepts and Applications, Inc.

Bottle Screening Systems for Aviation Security
Mr. William Curby, Federal Aviation Administration

King Arthur Court

3B-2: Communications, Surveillance, and Tracking Methodologies
Chair: TBD

Leveraging the Internet Infrastructure to Provide Secure International Communication to Egmont Group
Mr. Emile Beshai, FinCEN

GLADYS: Information Technology for Communications Surveillance
Mr. Fred Rayano, Rayano Communications Network, Inc.

Antennas for Tactical Tracking and Radiolocation
Mr. Spencer L. Webb, DTC Communications, Inc.

An Improved Pin-Hole Video Camera for Covert Surveillance
Dr. Igor Alexeff, University of Tennessee

Vision Technologies for Manned and Unmanned Surveillance
Mr. Michael Hansen, Sarnoff Corporation

Exchange

3B-3: Information Systems Methodologies
Chair: Marshal Ray Gagnon, U.S. Marshals Service

Integrating Heterogeneous Distributed Information
Dr. Yigal Arens, USC/ISI

Joint Interoperability and Database Compatibility for the Counterdrug Intelligence Community
Mr. Timothy A. Campen, National Drug Intelligence Center

Client/Server Design for Very Large Image Exploration
Dr. Peter Hansen, University of Tennessee

Public/Private Wireless Information Security
Dr. Mark Rader, University of Tennessee

Definitive User Access on a Secure Web Server
Mr. Sage Jackson, University of Tennessee

Renaissance

3B-4: Chemical Tagging/Trace Detection Technologies
Chair: TBD

Development of Performance Standards for Explosive Trace Detectors
Dr. Susan F. Hallowell, Federal Aviation Administration

Application of Solid Phase Microextraction in the Headspace Sampling of Contraband Drugs
Ms. Grazyna E. Orzechowska, Old Dominion University

The Graseby NARCOTEC Narcotics Detector: A Nonradioactive Version
Dr. Alastair Clark, Graseby Dynamics, Ltd.

Monitoring Drug Use
Dr. David A. Kidwell, Naval Research Laboratory

Drugwipe – A Trace Detector for Counterdrug Operations of Law Enforcement
Mr. Chris McLean, Securetec, Inc.

Vapor Constituents of Illicit Cocaine HCl as Delivered Through an Olfactometer
Ms. Cindy C. Edge, Auburn University

The Development of a Unique Chemical Tracing System for the Nonintrusive Detection of Drugs, Crops, Chemical Compounds, Currency, and Contraband
Mr. Jay Fraser, Tracer Detection Technology Corporation

5:00–5:30 p.m.
Grand Ballroom

Session 3C: Summary/Wrap-Up
Co-Chairs:
Dr. Hoover Adger, ONDCP
Dr. Albert E. Brandenstein, ONDCP/CTAC

5:30 p.m.

Adjourn

Key to Locations Within the Hotel Inter-Continental For Symposium Program

Meeting Space Name	Location
Grand Ballroom	7th Floor South
Toledo	5th Floor South
Cordova	5th Floor South
Empire	7th Floor South
King Arthur Court	3rd Floor South
Exchange	11th Floor South
Renaissance	5th Floor South

Support Functions	Name of Space	Location
Registration	Spanish Court	5th Floor South
Operations Office	Alhambra	5th Floor South
Press Office	Wisconsin	5th Floor South, Upper Level
Speaker Prep Room	Illinois	5th Floor South, Upper Level