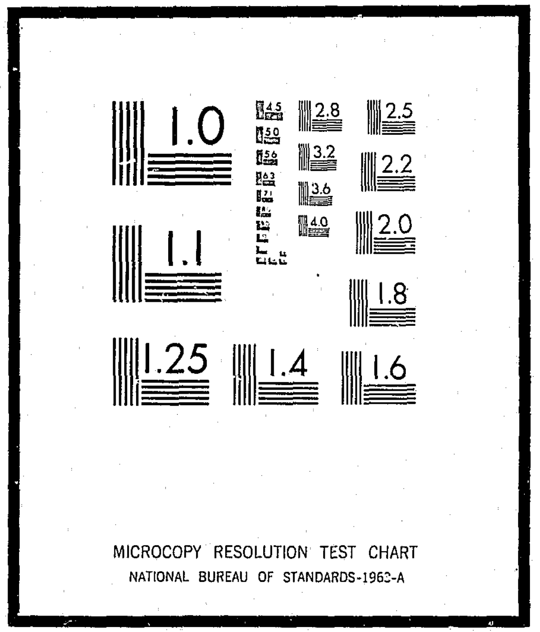

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RADIONUCLEAR FORENSIC INVESTIGATIONS

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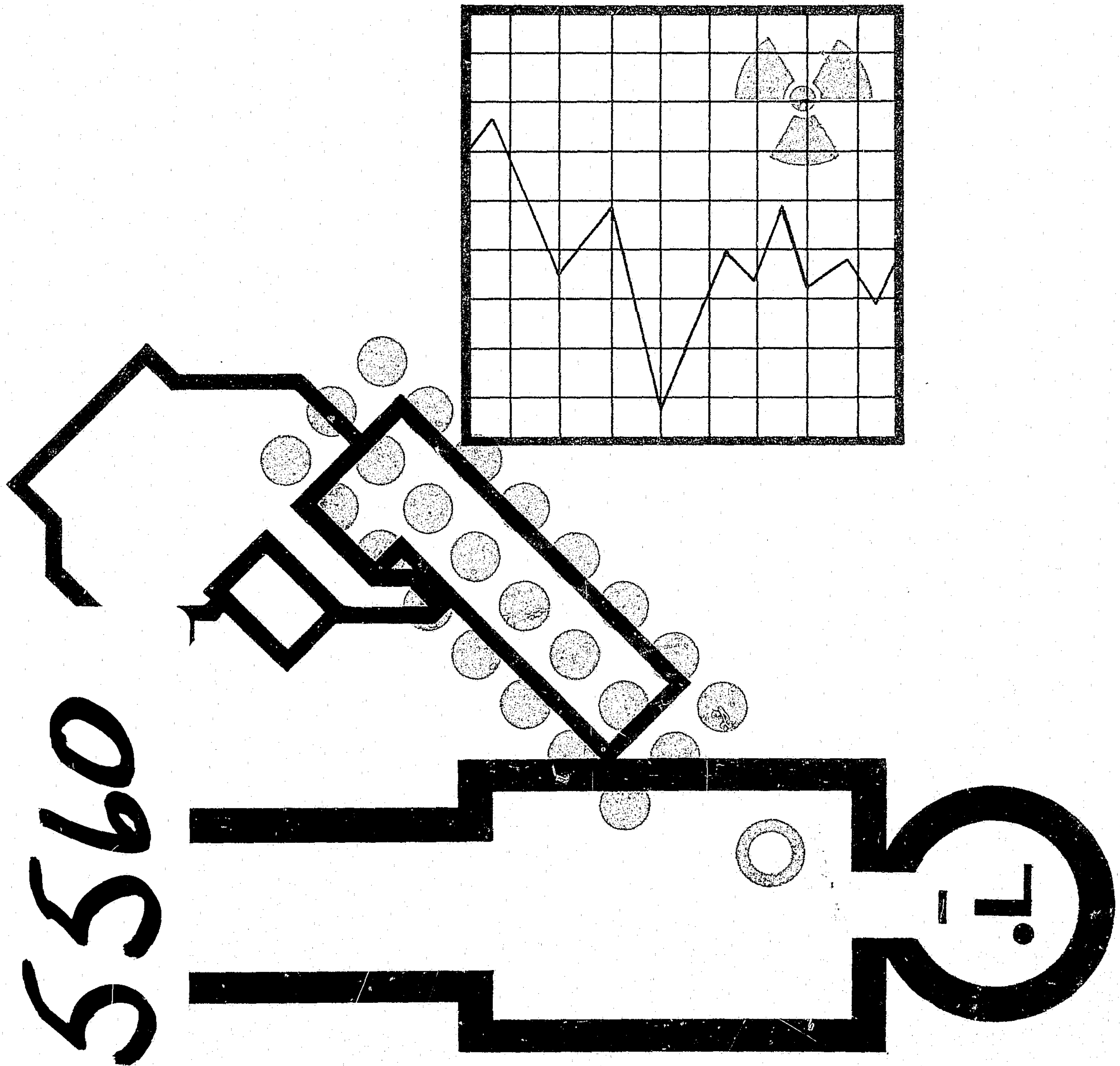

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RADIONUCLEAR FORENSIC INVESTIGATIONS

Final Project Report

by

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SUMMARY

This report briefly narrates the various tasks undertaken and the findings of a three year research and developmental program called Radionuclear Forensic Investigations conducted at the Nuclear Engineering Department of The Pennsylvania State University. The objectives of the program were to bring the applications of nuclear analytical techniques to forensic science investigations and to introduce some of these methods to the Pennsylvania State Police. This program has made modest achievements in both these areas and have been able to demonstrate the need to improve the methods of gathering evidence and to develop and apply advanced technological support resources if law enforcement is to respond adequately to the needs of the day.

One of the accomplishments of this investigation was the development of a simple but extremely efficient method for the collection of physical evidence during criminal investigations involving the use of firearms. This method - called Film-Lift Technique - has received acceptance by the field investigators using the material for evidence collection, from the analysts who perform the evidence analysis, and from the forensic scientists who are aware of the serious limitations of other evidence gathering techniques that are practiced today.

This investigation also undertook the development of radiochemical methods capable of analyzing several trace elements (Ba, Sb, Cu and Au) which are characteristic constituents of firearm discharge residues resulting from the use of almost all the ammunitions distributed in the United States. This method, while including all the best features of presently practiced analytical methods, has included the analyses of additional trace metals characteristic of gunshot residues. In addition, the proposed evidence collection and analysis method is capable of providing analytical results that lend themselves to better interpretation.

One of the observations made during the test firings conducted for gathering experimental data for the above mentioned investigations developed into a new research effort. This effort has demonstrated that when a firearm is discharged, the residues are carried in the vortex created behind the bullet and is distributed along the entire path of the bullet. These distribution patterns on the surfaces below the trajectory are characteristic of the firearm and ammunition used and it is also a function of the distance between the target and the gun. Systematic investigations conducted during the past three years have demonstrated that these findings could be readily adapted for evidence collection and could have significant value to forensic science investigations.

A physical evidence that is almost always found at the scene of violence is human hair. Hair is an important type of evidence because of its durability to environment compared to most other human tissues. In the past, neutron activation analyses have been successfully used to analyze several trace elements present in human hair and attempts have been made to use this technique to individualize human hair of a large population group. This investigation undertook a modified approach to hair analysis by isolating the trace element constituents of surface contaminants of hair from those of the hair matrix and analyzing both these samples independently using some of the best equipments and facilities that are available today. These efforts while allowing a reexamination of earlier work using modern instrumentation, attempted to explore the practical values of the isolation and analysis of hair and hair-wash samples to determine the common source of origin of two or more hair samples. Because of the numerous factors that can influence the trace element constituents of hair, the possibilities of individualizing human hair of a large population group seems extremely difficult. However, the isolation and analysis of trace constituents of hair and hair-wash samples can be of significant value to determining the common source of origin of hair samples, if the population group can be a limited one.

At the present time, most of the forensic analyses involving neutron activation is dependent on research reactor facilities that can provide thermal neutron fluxes of the order of 5 x 10^{10} to 3 x 10^{14} neutrons cm^{-2} sec^{-1}. However, a man-made radioisotope, now available in limited quantities, can act as a neutron source as it undergoes spontaneous fission giving neutrons in addition to other nuclear emissions. Because ^{252}Cf is an expensive material and its present availabilities are limited to 10^{-6} gm - 10^{-3} gm quantities, the neutron fluxes provided by these sources are inadequate for most types of activation analysis. There have been attempts made to enhance the neutron fluxes of ^{252}Cf sources using neutron multiplying devices. This program undertook to develop an optimum design of a subcritical assembly to provide maximum enhancement of ^{252}Cf neutron sources. This subcritical assembly was designed to provide optimum performance as determined by an extensive computer code analysis. These calculational methods have been experimentally verified as well. It was concluded that at the present price level (\$10.00 per 10^{-6} gm) of ^{252}Cf, the subcritical assembly is economically a better substitute for research reactors, if the neutron fluxes desired are in the range of 2×10^{7} to 1×10^{10} neutrons cm^{-2} sec^{-1}.

Some of the accomplishments of this investigation were introduced to a select group of officers of the Pennsylvania State Police. The evidence gathered by these officers are now being analyzed by a specially trained criminalist from the State Police Laboratory using the nuclear analytical techniques developed during this investigation. Other methods developed during this program await field testing and training of personnel before they can be introduced for routine use in criminal investigations.

I. INTRODUCTION

Some of the major functions of a criminalistics operation include, among others, investigation, discovery of evidence materials, analyses, interpretation, and testimony. All these functions require continuous involvement with education, training and research to maintain the quality of services. It is the recognition of these facts that prompted the Governor's Justice Commission of the Commonwealth of Pennsylvania to support a program - RADIONUCLEAR FORENSIC INVESTIGATIONS - of functional significance to criminalistics operation at The Pennsylvania State University through the Bureau of Research and Development of the Pennsylvania State Police. This program was further assisted by the contributions of the personnel of the Bureau of Technical Services of the Pennsylvania State Police. Over the past three years, the investigations at The Pennsylvania State University have made several achievements and have contributed to the better understanding of the problems of investigation, evidence collection, analyses and testimony, through extensive research efforts and associated programs of education and training.

The major objectives of the program were:

(1) To adapt the well-known principles of nuclear analytical techniques for practical applications in criminal investigations.

(2) To develop new and improved methods of neutron activation analysis applicable to the analyses of different evidence materials.

(3) To determine the potentials of the nuclear techniques in crime investigations and to train selected personnel of the Pennsylvania State Police in the proper methods of evidence collection and analyses.

This, the final project report, surveys the program since its inception and highlights major achievements resulting from this program. The details of the various research efforts, as well as the educational and training programs have been periodically reported in ten quarterly reports submitted during this period. The research efforts of this program have been the subject of five graduate theses submitted (or in preparation) in partial fulfillment of the requirements of graduate degree programs in Nuclear Engineering at The Pennsylvania State University. In-depth reports, as well as detailed topic discussions, are included in these five theses. This report, while pointing out the advantages of nuclear techniques, has also attempted an objective discussion of the limitations of these new methods.

To the uninitiated, the criminal investigation and the evidence analysis methods discussed here might sound expensive and unattainable by ordinary forensic laboratories. However, with little effort, it can be found that there are numerous nuclear facilities available throughout the U.S. for performing these analyses at nominal costs. For a legally constituted agency of the government, these nuclear facilities would be readily available if it can be demonstrated that there are qualified personnel available to utilize the facilities. With enlightened administrators in forensic science laboratories, the use of nuclear techniques in criminal investigation can become a common practice in many parts of the United States.

II. NEUTRON ACTIVATION ANALYSIS AS A TOOL FOR FORENSIC INVESTIGATIONS

Neutron activation analysis has been applied in many scientific fields and during the past decade its applications in forensic sciences have been steadily increasing. In addition, the past decade also saw a maturing in the understanding of the capabilities and limitations of this new analytical method by both the scientific and criminal justice communities. Some of the historical developments pertinent to the topics discussed in this report are reviewed in other sections. Because of the varying background of the audience to which this report is directed, a brief statement of the basic principles of neutron activation analysis is considered appropriate.

Neutron activation analysis is an analytical technique by which stable isotopes of an element are made radioactive through interactions with neutrons. The measurement of the characteristics of the induced radioactivity allows one to determine the amount of stable isotopes originally present. When a material is exposed to a neutron source such as a research reactor, one of the occurrences is the capture of neutrons by the nuclei of various atoms of elements present in the matrix. The probability that a nucleus will capture a neutron is measured by its cross section and is a characteristic property of the nucleus. In general, the larger the cross section for neutron capture, the lower the limit of detection of that element by neutron activation analysis.

The rate of formation of radioactive atoms when an element is exposed to a neutron flux is given by

$$A = n.\sigma.\phi \left(1-e^{-\lambda t_i}\right)$$

where A is the radioactivity of the sample, n is the number of atoms of the element exposed to a neutron flux ϕ, σ is the neutron capture cross section of the nucleus being transformed into a radioactive isotope, λ is $(=\ln 2/T_{1/2})$, the decay constant of the radioisotope produced, $T_{1/2}$ is the half-life of this new isotope, and t_i is the time of irradiation. In practice, the general expression for relating the quantity of an element and the observed radioactivity is

$$W = \frac{A.M.\ e^{\lambda t_d}}{N.f.\sigma.\phi \left(1-e^{-\lambda t_i}\right)}$$

where W is the weight of the element, M is the atomic weight of the element, f is the fractional isotope abundance of the particular nuclide undergoing nuclear transformation, N is Avogadro's number and t_d is the decay period following neutron irradiation.

Thus, in principle, it is possible to determine the amount of an element in a matrix provided the other quantities in the above relationship can be readily determined. However, in practice there are numerous variations to the analytical procedures that can be practiced depending on the sensitivity (see Table 1) of the particular element being analyzed, the facilities available for neutron irradiation, the kinds of equipments available for counting, the half-life of the radioactive isotope used in the measurement and the

Table 1

Sensitivities of Elements for Neutron Activation Analysis*

Sensitivity (gm)	Elements
10^{-13} to 10^{-12}	Dy, Eu
10^{-12} to 10^{-11}	Au, In, Mn
10^{-11} to 10^{-10}	Hf, Ho, Ir, La, Re, Rh, Sm, V
10^{-10} to 10^{-9}	Ar, Ag, Al, As, Ba, Br, Co, Cu, Er, Ga, Hg, I, Lu, Na, Pd, Pr, Sb, Sc, U, W, Yb
10^{-9} to 10^{-8}	Cd, Ce, Cl, Cs, Gd, Ge, Kr, Mo, Nd, Os, Pt, Ru, Sr, Ta, Tb, Th, Tm
10^{-8} to 10^{-7}	Bi, Ca, Cr, Mg, Ni, Rb, Se, Te, Ti, Tl, Xe, Zn, Zr
10^{-7} to 10^{-6}	S, Si, Pb
10^{-6} to 10^{-5}	Fe

The sensitivity is based on an irradiation period of 0.5 $T_{1/2}$ or ten hours whichever is less at a flux of 10^{13} neutrons cm^{-2} sec^{-1}. The activity is measured by NaI(Tl) gamma spectrometry.

*NOTE: The sensitivities for activation analysis are dependent on the thermal neutron fluxes at the irradiation facility, time of irradiation, and half lives of the radionuclides measured, among other factors. Hence, the numbers quoted here are only representative of the high sensitivities that can be obtained by neutron activation analysis.

precisions required in a particular set of analyses. While some of the analyses can be done by pure instrumental methods, very high sensitivities and analytical accuracies are attainable by appropriate combinations of radiochemical and instrumental methods. Discussions of the advantages and limitations of the various procedures employed during this investigation are included in other sections.

In general, the advantages of neutron activation analysis include the following:

(1) Neutron activation analysis is a highly sensitive analytical method that can be used for the analyses of nearly seventy naturally occurring elements.

(2) The matrix problems associated with neutron activation analysis of trace elements can in most cases be resolved by choosing proper instrumentation, by the adoption of multiple counting after different decay periods or by the choice of appropriate radiochemical separations.

(3) In many instances, the analysis can be nondestructive and extremely rapid.

(4) The costs of neutron activation analysis in most instances are compatible with the costs of other analytical methods of equal sensitivity.

Neutron activation analysis could be a valuable tool in many forensic science investigations, if the necessary facilities and equipment are available to laboratories that routinely perform evidence analyses. While the main application of neutron activation analysis is in the determination of elemental compositions, it could be readily adapted for numerous applications in toxicology, detection of firearm discharge residues, establishing common source of origin of materials such as hairs, fibers, fabrics, paints, inks, tool chips, glass, rubber, plastics, etc. that are often collected as evidence during criminal investigations. In the hands of qualified forensic scientists there are limitless possibilities for the application of neutron activation analysis to criminal investigations. Some of the areas of application discussed in this report can serve to illustrate the unique potentials of this analytical method. However, it should be recognized that neutron activation analysis is only an analytical tool and it can be advantageously employed for criminal investigations when properly trained investigators provide the necessary background information for the objective interpretation of the analytical results.

III. NEW METHODS FOR THE COLLECTION AND ANALYSIS OF FIREARM DISCHARGE RESIDUES

A. Background

Firearms play a major role in crime and violence in American society (1,2). The law enforcement agencies have been continually improving their capabilities for tracing individuals and guns involved in criminal acts through the application of improved scientific methods. The importance of firearm discharge residues in criminal investigations has long been recognized and there have been several major contributions leading to the development of nuclear techniques that are used in criminal investigations today (3-5). One of the chemical tests introduced in the early nineteen thirties was the "diphenylamine-sulfuric acid dermal nitrate test" on paraffin casts for the detection of nitrites and nitrates from gunpowder discharge residues (6). However, the limitations of this procedure was pointed out in 1935 and later in 1940 by the Federal Bureau of Investigations (7,8). In spite of the known limitations of this procedure, the use of diphenylamine tests to detect gunpowder residues continued because of the lack of other suitable test procedures to satisfy this need in criminal investigations. In 1959, Harrison and Gilroy (9) demonstrated the presence of barium, antimony and lead in the firearm discharge residues and devised qualitative chemical tests to identify the presence of these elements, thus offering a unique new method to detect gunshot residues. Because of the limitations in the sensitivity of the colorimetric reactions used to detect Ba, Sb and Pb, there was no widespread adoption of this method to replace the classical "diphenylamine test." The continued use of this test to identify gunshot residues is of great concern and this concern was eloquently expressed by practicing forensic chemists Cowan and Purdon (10). Because of the rapid increase in new products for consumers, numerous materials around a person's environment can develop a positive reaction to the diphenylamine tests. This fact is now generally recognized, although the use of the diphenylamine test has not been altogether abandoned.

The applications of activation analysis to forensic investigation began in earnest in the late nineteen fifties and several well known applications were reported (11,12) at that time. In an extensive investigation of the applications of neutron activation analysis to forensic investigations, scientists at General Atomics division of General Dynamics Corporation (now Gulf Radiation Technology of Gulf Oil Corporation) explored the possible uses of neutron activation analysis to the detection of gunshot residues through trace element analysis (13). The high sensitivity of neutron activation analysis to the detection of Ba, Sb and Cu and its poor sensitivity to the detection of Pb were the reasons for choosing Ba, Sb and Cu instead of Ba, Sb and Pb as originally suggested by Harrison and Gilroy (9). Since that time, the applications of neutron activation analysis for the detection of firearm discharge residues have been gaining acceptance both in the forensic laboratories and in the courts. A decade of efforts by General Atomic's group produced considerable volumes of information on the various aspects of the applications of neutron activation analysis for the detection of gunpowder residues

(14,15). In addition to this major contribution, there were contributions to this field by other laboratories during the nineteen sixties (16,17). Several new contributions to the neutron activation analysis of gunshot residues have been reported in recent years (18-21). Another promising development in recent years has been the application of atomic absorption methods to the analyses of trace elements characteristic of firearm discharge residues (21-25). The early works of Krishnan (22,23) and the recent contributions of Cone (24), Kinard and Lundy (25) are especially noteworthy. While there are recognized problems in the universal applications of atomic absorption techniques to the analyses of gunshot residues associated with various matrices, the general trend in methods improvement shows considerable promise.

The present investigations were directed at developing a new method to collect gunshot residues from human body surfaces for forensic neutron activation analysis and to explore the possibilities of using additional trace elements from gunshot residues to distinguish the presence of gunshot residues from environmental contaminations. A simple and unique sampling technique called, "film-lift" was developed and the analysis of copper and gold, in addition to barium and antimony, are suggested to assist in the interpretation of data from evidence analysis. A simple procedure is suggested to separate and quantitate copper and gold contents of film-lifts in addition to barium and antimony.

B. Review of Current Practices of Evidence Collection and Analysis

A variety of materials and procedures are currently employed for the collection of firearm discharge residues to be identified through the detection and quantitation of unique trace element constituents. Harrison and Gilroy (9) employed cotton cloth moistened with 0.1 N HCl to extract firearm discharge residues from human body surfaces. The General Atomics group (13) reported the use of filter papers soaked with 1% HNO_3 or paraffin oil to extract gunshot residues from the hands of persons during test firings, although the use of nitric acid was preferred over the use of paraffin oil. In later years, after having attempted numerous other collection techniques, the General Atomics groups preferred the use of high purity paraffin. The paraffin used in the collection of gunshot residues for neutron activation analysis has to be of exceptionally high purity and this is readily available in the U.S. and Canada through selective buying. However, in Australia where such high purity paraffin is not readily available, cotton balls soaked in a mixture of hydrochloric acid and acetone have been employed (26) to swab the hands of suspects or victims.

The search for new materials to extract gunshot residues has been rather extensive, primarily because of the cumbersome nature of the paraffin cast method and the necessity to take numerous precautions (27) to avoid contaminating the paraffin casts. One of the widely used procedures today is the use of dilute nitric acid-soaked cotton swabs (28). Another suggestion (22) for extracting gunshot residues for the analysis of lead and copper by atomic absorption and barium and antimony by neutron activation analysis involves the use of dilute nitric acid or hydrochloric acid contained in plastic bags to rinse the hands of persons suspected of having dischraged a firearm. Other alternates to paraffin casts and cellulose fibers soaked in acids include attempts to deposit film-forming materials on the surface of hands and removing the crust that is formed. Coleman (29) reported the use of collodion by Scott, et al. for extracting gunshot residues from human body surfaces for the development of autoradiographic patterns. Recently, Albu-Yaron and Amiel (30) suggested the use of a spray containing 4% cellulose acetate and the subsequent analysis of only antimony. The main drawback of these film-forming preparations has been their non-suitability for neutron activation analysis because of the impurities such as Ba, Pb, Sb, and Cu present in them. In addition, both collodion and cellulose acetate spray tend to block the pores on a person's skin and they seldom form films that are removable from all the surfaces of the hand covered by the coating and the experience of attempting to use the spray technique has been described as disappointing by Cornelis and Timperman (21). A spray technique also suffers from the disadvantage of blowing off the residues from the surface, as well as washing off the residues when an excess spray solution is applied inadvertently. Consdering all of the advantages and disadvantages, the paraffin cast method, despite all of its inconvenience in sample collection, is still one of the most satisfactory of all the methods mentioned above for the collection of gunshot residues for neutron activation analysis.

The analytical procedures used in the detection and quantitation of barium and antimony from gunshot residues collected involved neutron activation followed by chemical separation of barium and antimony. Because of the dissimilarity in the chemistry of barium and antimony, two stage separations of barium and antimony are generally employed. One of the analytical schemes, when followed carefully, provides extremely reliable results and was reported by Schlesinger, et al. (27). An alternate scheme combining the advantages of atomic absorption and neutron activation analysis was reported by Krishnan, et al. (22). More recently, Rudzitis, et al. (19) suggested the possible use of ^{133}Ba and ^{124}Sb as tracers to determine the chemical yield of antimony and barium separations using a mixture of sodium sulfate and thioacetamide in acid medium. The method proposed by Albu-Yaron and Amiel (30) to determine the presence of gunshot residues through the analysis of a single element, antimony, would be highly undesirable considering the mushrooming increase in consumer products such as hair-sprays, grease, and fabric finishes containing trace levels of antimony.

C. Film-Lift Techniques

While the method of collecting gunshot residues using high purity paraffin is generally considered as the most acceptable medium for neutron activation analysis, the desirability of employing an alternate procedure, simple enough to be used by field investigators, is accepted by most people familiar with present practices. The concept of extracting the residues on a crust or film that is readily removable from human body surfaces is again preferable to washing, swabbing, spraying or vacuuming. Because of the rigid requirements of neutron activation analysis, it is desirable to have a matrix composed of elements whose neutron absorption cross sections are poor and those that do not produce significant amounts of long lived radioisotopes. With these requirements, various natural and synthetic materials qualify as candidates. However, further requirements would include that the matrix be free from trace elements being examined to detect gunshot residues. This latter requirement eliminates most of the natural fibers and plant products and almost all of the synthetic polymers containing traces of antimony or barium. Although polymers seem ideal, there are a number of these polymers containing Sb as a catalyst residue and a considerable number of them contain excessive amounts of chlorine in the matrix which makes the irradiated materials highly radioactive. A further important requirement of the matrix to be used for collecting gunshot residues for neutron activation analysis is that it should form a removable film capable of efficiently collecting residues from human body surfaces without causing irritation or injury to the person.

In exploring the possible applications of commercially available preparations, we have examined numerous materials, both natural and synthetic. The materials that were examined as possible candidates include products bearing trade names such as "Spray Bandage," "Heddy Facial Mask," "Camag Laquer," "Quelspray," "Invisible Glove," "Krylon Acrylic Spray," "White Glue," "Casein Glue," and "Kleerkote," in addition to solutions of various commercially available polymers in volatile solvents. None of these preparations was found to be a satisfactory substitute to taking handcasts using molten paraffin.

D. Preparation of "Film-Lift"

"Film-lift" is the name given to a formulation developed by one of the authors which is found to be a highly desirable matrix to collect gunshot residues for neutron activation analysis.

The three basic constituents of this preparation are highly purified cellulose acetate, acetone and a plasticizer. Since most of the commercially available cellulose acetate contain varying amounts of Ba, Sb, Pb, Cu and Au, an initial screening of various batches of cellulose acetate is necessary. Most of the cellulose acetate containing very low levels of Sb, Pb, Cu and Au still show significant levels of barium. Therefore, the cellulose acetate is washed first with a dilute solution of acetic acid followed by deionized water. It is further washed with analytical grade ethanol followed by diethyl ether. The cellulose acetate is then air-dried and preserved in clean containers. This washing procedure is capable of removing almost all the barium and considerably diminishing levels of other trace elements such as Al, Pb, Cl, Sb, Br, Na, V, etc., normally found in cellulose acetate.

The principal solvent used in the preparation is high purity acetone. Ordinary acetone (reagent grade) contains undesirable levels of copper, zinc, gold, etc. and this can be considerably reduced by careful redistillation. However, spectrograde acetone available from some suppliers is quite satisfactory for direct use without purifications.

During this investigation, a number of plasticizers have been tested as a component of the "Film-lift" preparation. The acceptable qualities of a suitable plasticizer for this preparation are: (a) the plasticizer must have acceptable minimum of trace element composition to be part of the film-matrix; (b) the plasticizer should not cause any skin irritation and should not readily volatalize; and (c) the plasticizer should not coagulate or precipitate the components of "Film-lift" during preparation or extended periods of storage. Several plasticizers were found to have acceptable qualities and they include several vegetable oils and commercially available plasticizers such as dibutyl phthalate, di-2-ethyl hexyl phthalate, dimethyl phthalate, triethyl citrate and triacetin. Although most of these plasticizers and several others qualify to make readily removable film, few of them have been found to cause skin irritation on some people. One of the materials that was found to have no undesirable effects on any of the subjects tested during this study is specially purified coconut oil and the film-lift solution prepared using this plasticizer has all the other acceptable qualities as well. Most of the other plasticizers mentioned above have also been used after careful examination of their trace element constituents.

The purpose of adding a plasticizer to the solution of cellulose acetate in a volatile solvent is to make the film that is formed easily removable from the surface. However, the desired function of the "film-lift" is to extract and accumulate almost all the residues from the surface. Therefore, the amount of plasticizer added has to be carefully controlled to prevent sacrificing one property of the film for another. The preparations containing 10-15% cellulose acetate with 80-90% acetone and 1.5 to 3.0% plasticizer (by weight) have all the acceptable characteristics to make film-lift an ideal matrix to collect gunshot residues from human body surfaces for forensic neutron activation analysis. Although the preparation of "film-lift" requires careful examination of the properties of the components, this preparation can be made from materials obtained through selective buying without too many purification stages. Furthermore, large quantities of this preparation can be made at one time and proper blank determination can be made for batches of each preparation.

The application of film-lift material to collect residues from human body surfaces is simple and the film formed is readily removable. In addition, this matrix lends itself readily for further analysis of trace elements to detect firearm discharge residues. This preparation is a homogeneous solution with the viscosity of ordinary honey or molasses which lends itself for convenient application. "Film-lift" is spread on human body surfaces by squeezing out the solution from the nozzle of an all-polyethylene container and is smoothed out quickly by a glass rod or a polyethylene spatula to cover all the surface from which residue extraction is desired. This material dries to a hard film in three to four minutes and can be readily peeled off. Recently, a kit was assemlbed for use by the Pennsylvania State Police. The kit, its contents and the methods of application and removal of the film are illustrated in Figures 1 through 8.

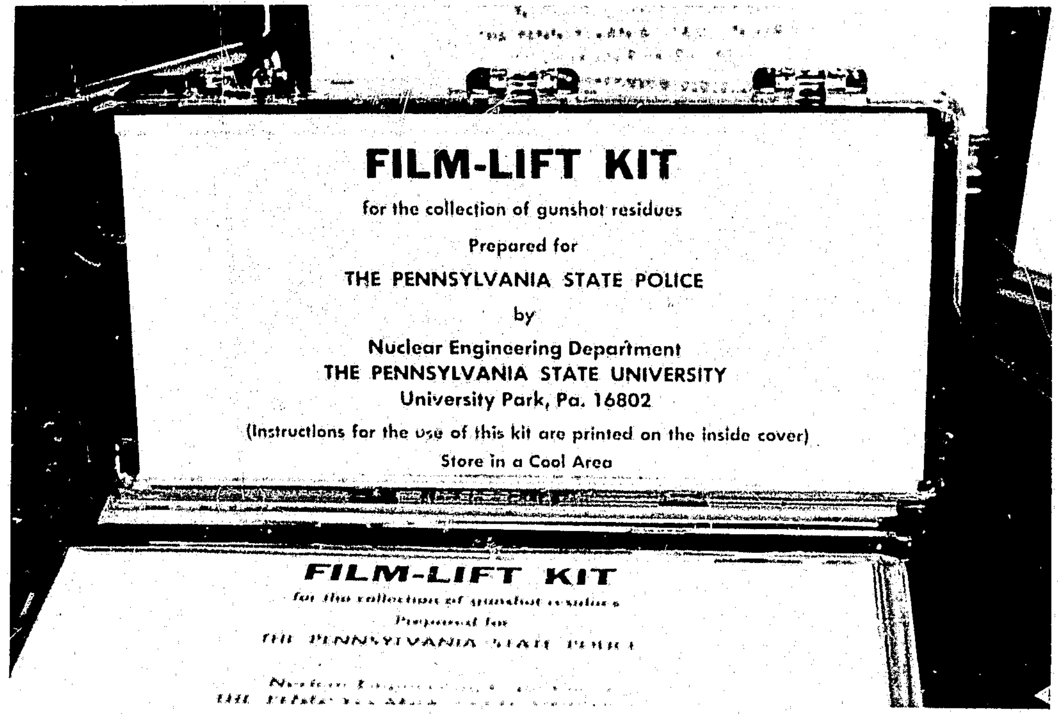

Figure 1. An External View of the Film-Lift Kit

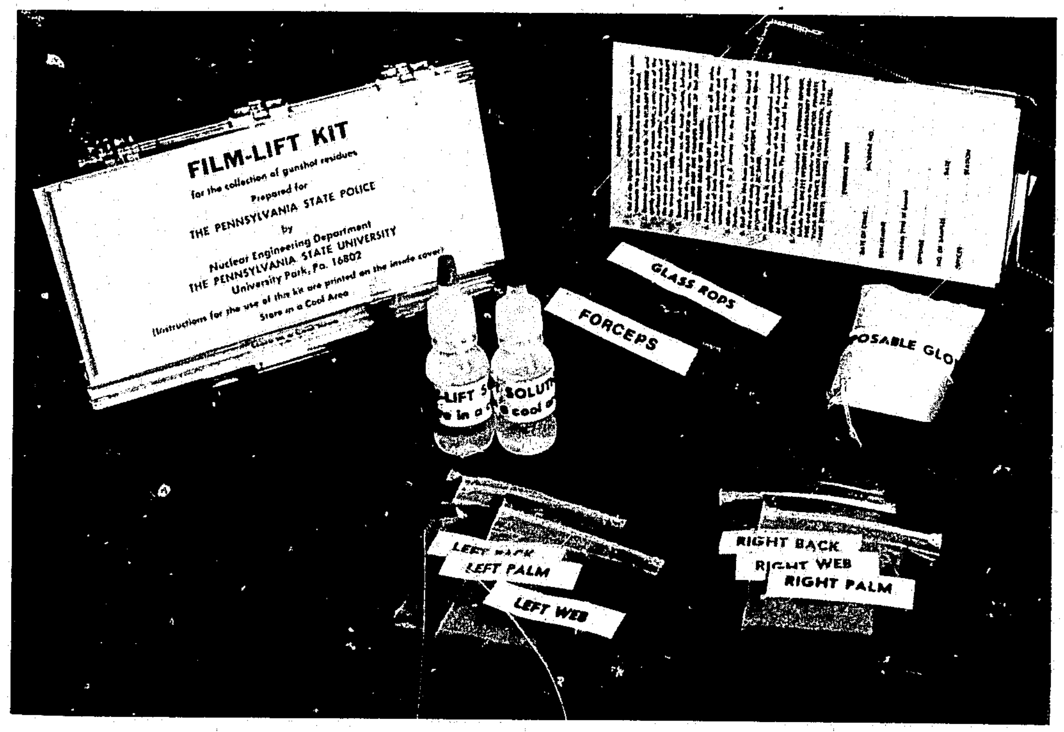

Figure 2. A Display of the Contents of the Film-Lift Kit

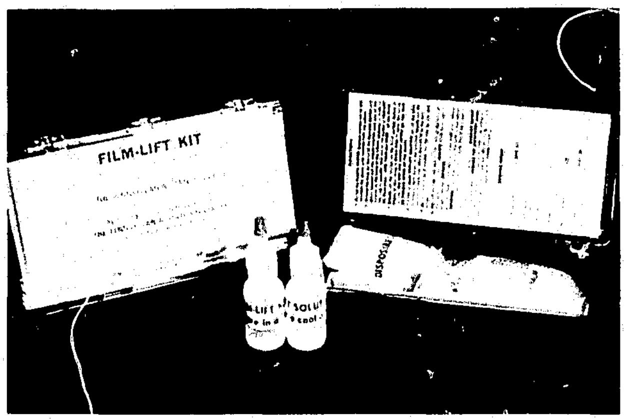

Figure 3. Instructions on the Proper Use of the Kit are Placed on the Inside of the Lid

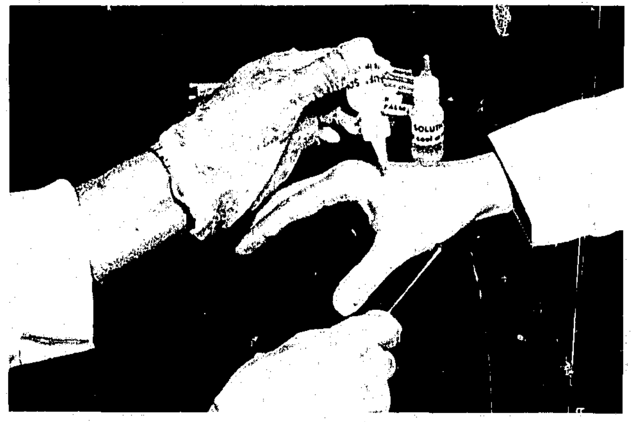

Figure 4. Application of Film-Lift Solution to the Web of Right Hand

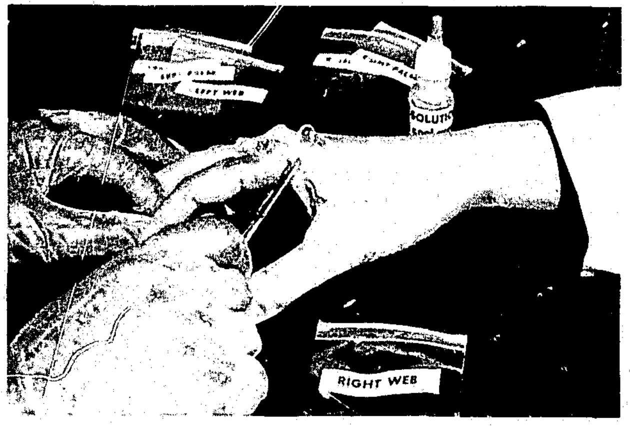

Figure 5. Removal of the Crusty Film that is Formed within 2 to 3 Minutes after the Application of the Solution

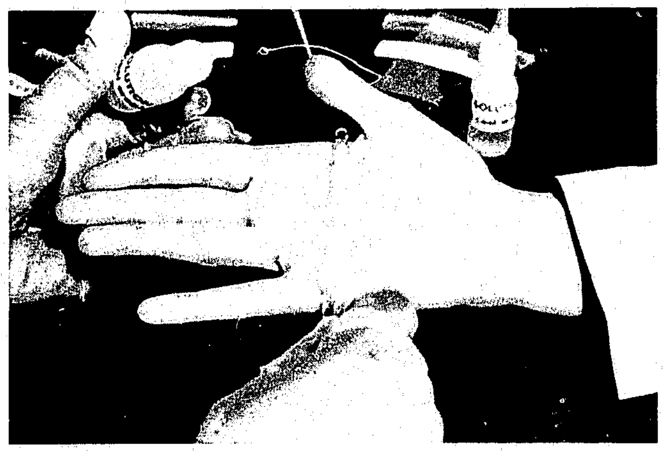

Figure 6. Applications of Film-Lift Solution on the Palm of a Hand

Figure 7. Film Removal from the Left Palm

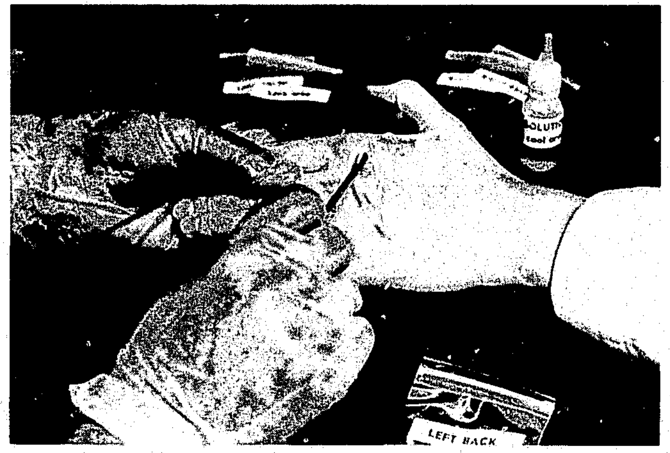

Figure 8. One of the Six Samples Collected from a Person is from the Back of the Left Hand

E. Neutron Activation Analysis of Firearm Discharge Residues

The high sensitivity of neutron activation analysis has been responsible for its becoming an accepted method to detect gunpowder residues through the analysis of traces of barium and antimony. Although the most desirable practice would be to perform non-destructive analysis, possibly using a high resolution detector system, this procedure cannot be recommended or practiced because of the interferences from various materials from human body surfaces that could be included during the process of collecting samples. Although the film lift matrix is relatively "clean" from the point of view of gamma ray spectrometric measurements of activated samples, non-destructive neutron activation analyses cannot be suggested for the analyses of all evidence samples because there are considerable amounts of other materials extracted from human body surfaces that cause significant interference problems.

The procedures suggested here for the isolation and analysis of barium, antimony, copper and gold are designed to isolate the radionuclides of these elements from other interfering activities to a level at which they can be readily identified and reliably quantitated. The films prepared from "film-lift" can be readily decomposed after neutron activation by a mixture of hydrochloric and nitric acids. In particular, samples exposed to reactor fluxes of high energy gamma radiations, neutrons and electrons are much easier to digest than raw films. This is because of the structural damage and preliminary degradations caused by the exposure to radiations.

The film samples suspected of containing the firearm discharge residues are weighed and encapsulated in clean polyethylene bags and labelled appropriately prior to neutron irradiation. The samples, along with analytical standards of the various elements to be quantitated (Ba, Sb, Cu and Au) are irradiated at a thermal neutron flux of 10^{13} neutrons cm^{-2} sec^{-1} for 15 to 30 minutes. These irradiated samples are processed to isolate elements Ba, Sb, Cu and Au from other materials after a decay period of about 30 minutes.

Several chemical separation schemes have been suggested in the literature for the isolation of barium and antimony (13,17,19,22). The procedures suggested here have adapted some of the best principles of the above separation schemes and include additional steps to work with samples taken with film-lifts and to quantitate the levels of copper and gold in addition to barium and antimony.

The neutron activated film samples are transferred to 50 ml. centrifuge tubes containing a mixture of non-radioactive carriers (10 mg Ba, 10 mg Sb, 5 mg Cu and 100 µg Au in 5 mls of solution). The carrier mixture is prepared to have an acid concentration of about 4 M HCl. After adding an additional ml of concentrated HNO_3 the mixture is warmed in a waterbath until the film samples degrade completely. Generally, a film sample weighing 300 to 500 mg decomposes readily within 10 minutes. If undecomposed residues of film remains, they may be removed by centrifuging or filtration using glass wool.

To the homogeneous digest of the film-lift sample, about 1.5 ml of 1:1 H_2SO_4 is added and the mixture diluted to about 10 mls with deionized water. After allowing the precipitates to coagulate, the $BaSO_4$ precipitated is separated by centrifugation. The barium sulfate precipitate is washed with a wash solution containing hold back carriers Na^+, Cl^- and PO_4^{-3} ions in a 2 M HCl solution. This precipitate is subsequently washed with deionized water followed by ethyl alcohol and collected on a tared filter paper (Gelman GA-3 47 m.m. diameter, 1.2 micron paper). These filter papers are folded when moist and placed in counting vials for gamma ray spectrometric measurements. After counting, the samples are dried in a 60°C oven, cooled and reweighed to determine the percent recovery of barium from each sample.

The acidity of the supernatant from the separation of barium is adjusted to 1-2 M by careful addition of enough NH_4OH to neutralize the excess acid. This solution is warmed and hydrogen sulfide gas is passed through the solution to precipitate Cu, Sb, Au, along with other sulfides. The H_2S treatment is repeated to complete the precipitation and coagulation of the sulfides. These sulfides separated by centrifuging are washed with warm dilute (1:20 by volume) hydrochloric acid. To each of the centrifuge tubes containing the sulfide precipitate is added two or three pellets (about 0.5 gms) of NaOH and 3 mls of deionized water. The contents are mixed well and heated to boiling with continuous agitation of the contents of the centrifuge tube. The mixture is diluted with 2-3 mls of water and allowed to stand in a waterbath at about 60°C. About 10 drops (0.5 mls) of 30% hydrogen peroxide are carefully added, avoiding violent bubbling, to assist the precipitation of gold from the sodium hydroxide solution and to separate copper as an insoluble oxide. The mixture is centrifuged and the supernatant containing antimony in solution is saved for the isolation of antimony. The treatment with NaOH and H_2O_2 may be repeated to extract residual amounts of antimony from copper. The precipitates containing copper and gold are washed with an excess of warm water followed by ethyl alcohol. These precipitates are also collected on filter membranes (GA-3 type) and mounted in counting vials for gamma ray spectrometry. After determining the ^{64}Cu and ^{198}Au radioactivities, these precipitates are left aside for a week to allow all the ^{64}Cu and most of the ^{198}Au radioactivities to decay out. These filter papers containing Cu and Au are reirradiated for about 10 minutes at a thermal neutron flux of 10^{11} neutrons cm^{-2} sec^{-1} to determine the recoveries of copper and gold from each sample.

The sodium hydroxide extract containing antimony is scavenged with a drop of copper nitrate solution containing about 0.5 mg of copper. If a distinctly visible black precipitate is not observed, the precipitation is assisted by the addition of a drop of dilute ammonium polysulfide. The mixture is warmed to coagulate the copper precipitate and is filtered using a coarse filter paper. The filtrate at room temperature is mixed with 1 ml of 30% H_2O_2 solution and the mixture is warmed in a waterbath to oxidize all the sulfide residues. The solution is then made distinctly acidic by adding about 6-8 mls of concentrated hydrochloric acid. This mixture is again warmed with a few additional drops of H_2O_2 to remove the final traces of H_2S, if any. After the effervescence has subsided completely, about 2 mls of chromous chloride solution (Fisher SO-C-169) is added to each of the centrifuge tubes containing the warm solution of antimony. This mixture is kept warm for 2 to 3 hours to allow the complete precipitation of antimony as elemental antimony. The antimony precipitated is separated by centrifuging and washing with warm deionized water followed by ethyl alcohol. The precipitates are collected on tared filter membranes for chemical yield determination using the procedures employed for barium sulfate. The samples containing antimony are used to measure the ^{122}Sb radioactivities by gamma ray spectrometry.

All the samples analyzed were counted using a large (10 cm x 10 cm) NaI(Tl) detector containing a 4.5 cm deep well. This detector, in association with a pulse height analyzer, was used to detect and quantitate the radioactivities efficiently. Because of the high radiochemical purity of the separated fractions, the use of a highly efficient detector system would be the ideal choice. In determining the recoveries of copper and gold by reirradiation, a high resolution Ge(Li) detector coupled to a 4096 channel pulse height analyzer was employed. This system could in principle be used to detect and measure the radiations from the various fractions isolated from gunshot residues, although in the processing of large numbers of samples, the long counting time required by Ge(Li) detector systems would be a disadvantage, especially when several samples of ^{139}Ba with 83 minute half-life have to be counted.

The radioactivities measured from barium (83.2 minute ^{139}Ba), antimony (2.8 day ^{122}Sb), copper (12.8 hour ^{64}Cu) and gold (2.693 day ^{198}Au) fractions of the gunpowder residues are compared with aliquots of the standards irradiated with the samples to quantitate the amounts of Ba, Sb, Cu and Au present in the various fractions. These results are further corrected for the chemical yields of Ba, Sb, Cu and Sb to calculate the actual amounts of these trace elements that were originally present in the film sample being analyzed.

F. Results

The chemical separation procedures described here are capable of isolating barium, antimony and copper from each other with extremely high radiochemical purity. The copper fraction, however, contains the gold separated. This, however, does not cause any problem in the determination of copper and gold using NaI(Tl) crystal detector system for gamma ray spectrometry. Generally, the chemical yields of barium separation are in the range of 85-95%, while the yields of antimony are about 50-70%. The isolation of copper and gold using the procedures described here yields about 70-90% of these elements, although there is no one-to-one correspondence between the copper and gold recoveries. These yield determinations have been confirmed by using ^{133}Ba, ^{125}Sb, ^{64}Cu and ^{198}Au tracers, confirming the reliability of the gravimetric methods for Ba and Sb and the reirradiation technique to determine recoveries of Cu and Au. Indeed, all the yield determinations can be made using this reirradiation technique, although the gravimetric procedures for Ba and Sb are relatively simple.

The other experimental results presented here include trace element composition data on a variety of materials used in the collection of gunshot residues for activation analysis, as well as data to compare the relative efficiency of residue collection by the film-lift technique. In addition, the results of the analyses of Ba, Sb, Cu and Au in the film-lifts collected after several test firings have been summarized. All the test firing samples were collected from the web, palm and back (three separate samples) of each of the firing hands and these samples were independently analyzed to determine the distribution of these trace elements in the various regions of the firing hand.

In examining the trace element levels of various materials useful for the collection of gunshot residues, emphasis was placed on examining the levels of Ba, Sb, Cu and Au. These elements were determined by neutron activation followed by the chemical isolation procedures described above. The results of these analyses are presented in Table 2. This data represents the average of at least six independent analyses of these various materials. Although there have been large variations between aliquots of few of the samples reported here, the average values in Table 2 are generally representative of most of the samples analyzed. In addition to determining these four elements, aliquots of some of these materials were irradiated and non-destructively analyzed to determine some of the short-lived radioisotopes produced. Using a gamma ray spectrometry system involving a 40 c.c. Ge(Li) detector and a 4096 channel pulse height analyzer, the various constituents reported in Table 3 were quantitatively measured. It is worth noting from the results presented in Tables 2 and 3 that the purification procedures employed to clean the cellulose acetate matrix result in considerable decrease in the levels of Ba, Sb, Cu and Au, in addition to several of the other trace elements. During the examination of several batches of cellulose acetate from various suppliers, a batch of cellulose acetate (E.K. batch A2X) received was found to be extremely pure from the standpoint of making film-lift preparations. Other batches of cellulose acetate received prior to or since this have not been of the same high quality.

Table 2

Analyses of Various Materials used as Matrices for Collecting Firearm Discharge Residues

	Materials Analyzed	Concentrations of Elements (in 10^{-9} gms/gm of matrix)			
		Barium	Antimony	Copper	Gold
1.	Paraffin (Fisher P-28)	180	140	4800	80
2.	Paraffin (A. H. Thomas C-568-W51)	30	10	2100	42
3.	Whatmann No. 1 filter paper	70	5	1220	18
4.	Whatmann No. 541 filter paper	30	10	190	20
5.	Cotton balls (J & J #6105BB)	130	5	270	180
6.	Cotton gauze (J & J #8515)	190	60	1130	230
7.	Cellulose acetate (MCB Batch #20)	210	3	5300	190
8.	Cellulose acetate (MCB Batch #25)	270	10	3090	112
9.	Cellulose acetate (MCB #25 purified as described)	10	7	120	N.D.*
10.	Cellulose acetate (E.K. Batch A-2X)	54	4	58	N.D.
11.	"Film-Lift" blank when dry	50	20	320	N.D.
12.	Collodion (J.T.B9202 - Lot 41.001)	820	180	3500	220
13.	Cotton from swabs (SIRCHIE KIT-A)	120	250	260	N.D.
14.	Cotton from swabs (SIRCHIE KIT-B)	320	100	570	28

*Not Detectable

Table 3

Trace Element Composition of some of the Materials used for Collecting Firearm Discharge Residues

Materials	Micrograms (10^{-6} gm) of Element/gm of Matrix						
	Na	Cl	Br	Mn	Ca	Al	V
Cotton balls (J & J)	116	140	0.78	0.42	20	22	0.05
Cotton gauze (J & J)	162	75	0.45	0.28	19	16	0.03
Cotton swab (SIRCHIE)	131	78	1.02	0.24	12	15	0.33
Cellulose acetate (MCB #25)	6	142	6.11	0.23	63	2	N.D.*
Cellulose acetate (MCB #25 purified as described)	2	75	2.61	N.D.	3	N.D.	N.D.
"Film-Lift" blank	2	64	1.91	N.D.	3	N.D.	N.D.

*Not Detectable

The efficiency of film-lift techniques for collecting gunpowder residues from human body surfaces are compared with paraffin cast techniques by contrasting the amounts of barium and antimony contents of gunshot residues collected using these two different techniques. The results of these analyses are presented in Table 4. These results show that the film-lift techniques are generally as efficient as paraffin cast techniques for collecting firearm discharge residues. In addition, in a few instances after removing the film-lifts, paraffin casts were taken from the same areas of the hand. These paraffin casts did not show any detectable levels of Ba or Sb.

During the past two years, while developing the film-lift technique and these chemical separation procedures, several test firings were conducted to evaluate the potentials of these procedures. Since establishing the merits of these techniques, a number of test-firings were performed using a variety of firearms and ammunitions. These results are summarized in Table 5. All these tests were conducted in in-door test facilities and, therefore, represent more or less ideal conditions. A close examination of the data shows that there are recognizable differences in the levels of these four trace elements on various regions of the firing hand that were monitored. However, in examining the values of barium, antimony, copper or gold independently, it reveals that a significant proportion of the data does not follow a normal distribution and that there is considerable variation in the ratios of any two of the four elements that are being examined. In making these qualitative observations, it should be emphasized that this data is very limited for comparison with any extensive statistical analyses reported by other investigators (17,27).

Table 4

Comparison of the Ba and Sb Contents of Paraffin Casts and Film Lifts taken from Firing Hands after Single Firing using a Revolver*

			Barium Content (10^{-9} gm)			Antimony Content (10^{-9} gm)		
Sampling Technique	No. of Samples	Areas of Firing Hand	Range	Average	Median	Range	Average	Median
Paraffin cast	21	web	120 - 610	260	170	10 - 130	50	50
Paraffin cast	21	palm	40 - 620	240	110	10 - 140	60	40
Paraffin cast	21	back	20 - 450	170	80	10 - 30	20	20
Film-Lift	30	web	70 - 520	270	260	20 - 70	40	50
Film-Lift	30	palm	60 - 410	240	180	10 - 40	30	30
Film-Lift	30	back	60 - 210	130	170	10 - 70	20	30

*Revolver, caliber 0.22, H & R Model 900
Ammunition, Canadian-Imperial Ltd. (Long Rifle, Western T22LR)

Table 5

Summary of the Analysis of Ba, Sb, Cu and Au from Single Test Firings (in 10^{-9} gms)

Firearm Type and Ammunition	# of Test Firings	Elements Analyzed	Concentrations of Elements in the Film-Lifts taken from Various Regions of the Firing Hand								
			WEB			PALM			BACK		
			Range	Average	Median	Range	Average	Median	Range	Average	Median
Revolver, cal, 0.22,		Ba	70-870	365	300	40-1440	252	170	30-3520	288	140
H & R Model 900	29	Sb	10-600	93	60	10-580	77	40	10-200	26	20
Ammunition: Long Rifle,		Cu	920-2680	2070	2120	480-2340	2080	1550	600-1540	850	630
Western T22LR		Au	12-156	56	90	8-97	40	68	24-190	80	75
Revolver, cal, 0.38,		Ba	240-1260	587	490	180-1030	362	300	140-590	248	230
Colt Officer's Model	14	Sb	110-690	310	250	50-520	186	160	70-170	125	120
Ammunition: 0.38 Special,		Cu	260-2360	1336	1050	320-3480	1430	1020	310-1130	790	670
Remington Arms		Au	16-90	42	30	24-160	89	60	10-90	20	24
Pistol, cal. 0.22,		Ba	200-910	540	550	20-960	352	200	30-480	233	200
S & W Model 41	12	Sb	50-360	228	200	30-430	288	270	10-310	163	120
Ammunition: Long Rifle,		Cu	1260-3930	2780	2080	1510-3250	2530	2430	650-2300	1300	1230
Remington-Peters		Au	54-320	170	190	72-410	107	140	16-490	140	90
Pistol, cal. 0.45, Remington-Rand Model	12	Ba	1550-5560	3900	4240	520-1200	778	540	530-2000	1330	1470
1911-A		Sb	510-1580	913	630	350-570	467	460	260-650	405	290
Ammunition: 0.45 auto,		Cu	1050-2560	1700	1330	1070-3940	2040	1320	710-990	870	850
Remington Arms		Au	25-164	82	98	30-160	67	85	10-120	32	48
Pistol, cal. 0.32,		Ba	600-2030	1487	1560	380-1980	1263	1430	270-1430	610	360
Savage Arms Co.	9	Sb	370-1040	780	930	210-1070	826	590	200-540	333	260
Model 1917, Ammunition:		Cu	1210-2990	2840	2690	930-1480	1465	1450	1070-1777	1620	1470
0.32 Auto, Winchester-Western		Au	16-90	45	48	25-180	80	75	10-48	22	25

CONTINUED

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importance of the methods of evidence collection, the preservation of samples and the procedures employed in the analysis. It is also well recognized that in the analysis of forensic evidence, the interpretation of the results is at least as important as the analysis itself. The desirabilities and advantages of proper sampling and analyses may be further illustrated by considering an ideal case involving a victim believed to have committed suicide discharging a firearm, while the circumstances surrounding the incident are open to suspicion involving possible homicide. If film-lifts are taken from both hands of the victim, it would help to identify the firing hand or the complete absence of gunpowder residues under ideal conditions. However, ideal conditions rarely exist in actual cases involving criminal acts. Therefore, if film-lifts are separately taken from various regions of both hands of the victim (web, palm and back) and these, along with the analysis of proper blanks, could enable the analyst to interpret his findings in a meaningful manner, although this suggestion would involve the analysis of at least seven samples instead of two. The experience gained during this investigation support the desirability of multiple sampling of various regions of each hand instead of taking one sample from each of the hands. In cases involving rifles and other large firearms, it would be desirable to collect a sample from the cheek of the person suspected of having discharged the rifle, in addition to six samples from two hands. The best approach to collecting suitable samples would be educating the field investigators of the principles and limitations of the analysis and to use their best judgment to collect necessary samples from which a useful evidence could result.

The neutron activation analysis procedures presently practiced are primarily directed at determining the barium and antimony contents of samples collected and through careful analysis of blanks to determine the possible presence of gunshot residues. However, small caliber ammunition is sold in the market that do not contain barium or antimony in the primer. The emissions from discharging these ammunitions would not contain barium, although there will be traces of antimony from the volatalization of the lead bullet (18). Not only in these limited cases, in all analyses involving the use of unique trace elements to detect gunshot residues, the job of interpretation becomes less burdensome if more elements characteristic of the gunshot residues are identified. While elements lead and copper are more abundant in our environment in comparison with Ba, Sb, and Au, it would be desirable to determine as many of these elements as possible from film lifts and through careful comparison of samples from various regions of the hand, one might be able to arrive at a better interpretation of the facts surrounding the incident. Many investigators are nowadays looking for the presence of lead as one of the additional elements to identify gunshot residues using x-ray fluoresence or atomic absorption technique (22,31), although the environmental concentrations of lead in the U.S. are extremely high resulting from the discharge of more than 400 tons of lead to the atmosphere per day through gasoline consumption alone (32).

The choice of copper and gold as additional elements to be analyzed to determine the presence of gunshot residues is primarily due to the ease of analysis of these elements by neutron activation and their universal presence in all varieties of firearm discharge residues. Although copper is found in abundance in our surroundings, the environmental levels of copper as a constituent of particulate matter is much less than that of lead in the urban environment (33). Gold, on the other hand, is a rare element and this could readily qualify as an additional element in the neutron activation analysis of gunshot residues. In all the test firings reported here, there have been recognizable differences in the levels of Ba, Sb, Cu and Au from various regions of the firing hand and much sharper differences between the hand blanks and the film-lifts taken from the firing hands of persons who have recently discharged a gun.

The processes involved in the emission of barium, antimony, copper and gold during the discharge of a firearm and its deposition on human body surfaces are controlled by numerous factors. These involve the pyrolytic volatalization of these elements from the various regions of an ammunition, namely the primer, the bullet, the primer cup, the bullet casing and the coatings on the ammunition. Other major factors that influence the emission and deposition of gunshot residues include those dependent upon the firearm, the person discharging the firearm, and various environmental conditions. While it is possible to list numerous factors under these subtitles, it would be adequate for the present discussion to recognize that there exists an extremely large number of possible variations in the trace element concentrations in the firearm discharge residues deposited in human body surfaces and extracted for neutron activation analysis. These variations are fewer for the depositions on the firing hand and further restrictions can be imposed if the firearm and the ammunition employed are identified.

The elements Ba, Sb, Cu and Au are found in trace levels in the film-lifts taken from human body surfaces exposed to various environments. Therefore, the identification of firearm discharge residues through the analysis of trace elements has to be examined in the light of known levels of Ba, Sb, Cu and Au found on hand blanks. Extensive investigations conducted by the General Atomic group (27) on the hand blank levels of Ba and Sb on various occupational groups have demonstrated that several occupational exposures can result in hand blank values that could make the interpretation of data rather difficult. Again, the changing patterns of consumer goods and the addition of newer products for human consumption make the environmental exposure factors very significant. This necessitates the periodic reexamination of hand blank values collected on various occupational groups. However, from the practical point, a forensic analyst must design his sample collection in such a way that he will have representative hand blanks to compare for each of the evidence sample he analyzes. The most useful sampling, therefore, would be samples from various regions of both the firing and non-firing hands of the suspects or the victims.

The findings of this investigation clearly demonstrate the usefulness of "Film-lift" as a medium to collect gunshot residues for neutron activation analysis. The method of employing multielement analysis combined with sampling of various regions of both the hands of a person suspected of having discharged a firearm would be of great assistance in the least ambiguous interpretation of the data. The suggestion made here of sampling at least six regions of the hands and the analyses of four elements are directed toward this goal. The use of film-lift procedures in sample collection should considerably reduce the task of the field investigator and the forensic analyst, while the additional sampling and analyses suggested here would be of great value in developing the data into a useful forensic evidence.

H. Analysis of Film-lifts using Atomic Absorption Techniques

Recent applications of atomic absorption techniques to determine the trace metals characteristic of firearm discharge residues (21-25) have prompted us to examine the possible use of samples collected using film-lift techniques for analysis by atomic absorption methods. Through the courtesy of the Department of Chemistry at Penn State, the Perkin Elmer Corporation and the Forensic Laboratory of the Alcohol, Tobacco and Firearms Division of the U.S. Treasury Department, we have examined the possible applications of three different instruments that are widely used for flameless atomic absorption measurements. A varian Model AA-5 atomic absorption spectrometer equipped with the varian Model 63 carbon rod atomizer available at Penn State was used in most of the experiments in this series.

The analytical samples for atomic absorption were prepared by dissolving the film-lifts in warm nitric acid with the addition of a few drops of 30% hydrogen peroxide. The homogeneous solution thus prepared was diluted to a known volume and 5 μl aliquots of this solution were employed for atomic absorption measurements. The experiments included the analyses of blank film-lifts, film-lifts spiked with known amounts of Ba, Sb, Cu and Pb and film-lifts taken from test firings. It was possible to determine Pb, Sb and Cu reliably using the carbon rod atomizer while the determinations of barium required the use of a tantalum sleeve inserted into the graphite sample holder to prevent the formation of nonvolatile carbides. Because of nonavailability of an atomic absorption unit for this program, the exploration of the potentials of atomic absorption for the analyses of film-lifts were limited to these preliminary experiments. The results of these experiments clearly demonstrated that film-lift is an excellent medium for the collection of evidence samples to be analyzed by atomic absorption methods as well.

IV. DISTRIBUTION PATTERNS OF GUNSHOT RESIDUES

A. Background

The importance of firearm discharge residues in criminal investigations has long been recognized. At the present time, neutron activation analysis, atomic absorption and x-ray fluorescence are being successfully employed for the detection of gunshot residues via the analysis of trace metals - Pb, Zn, Cu, Ba, Sb, Cr, Au, etc. - which are characteristic of gunshot residues. A majority of the published works on gunshot residues deals with evidence materials collected from human body surfaces (34) and the residue depositions on the garments of victims (35,36). Earlier investigations conducted at The Pennsylvania State University have demonstrated the possibilities of detecting airborne gunshot residues several hours after discharging a gun (18). Recently, Smith (37) reported the use of geographic coordinates in preparing a detailed description of a discharging firearm. The present investigation has revealed yet unrecognized features of firearm discharge residues that may be properly adapted for criminal investigations.

Almost all the textbooks on scientific methods of criminal investigations point out the importance of proper collection and analyses of powder residues as a useful forensic science evidence. However, there is little or no recognition of the gunshot residues beyond a few feet from the firearm (38,39). When a firearm is discharged, minute quantities of the constituents of the ammunition undergo pyrolytic volatilization. These combustion products are distributed between the gun and the target, most of it centered around the trajectory of the bullet. A systematic examination of the distribution patterns of some of these elements that are constituents of the primer and the bullet of the ammunitions used in handguns indicates that these patterns are highly reproducible for a firearm with similar ammunitions and, therefore, could have valuable applications in criminal investigations.

B. Experimental Procedures

The test firings conducted during this investigation were limited to hand guns and utilized two different in-door firing ranges. One of these firing ranges had a gun to target distance of 2.5 meters while the second facility had a 12 meter separation between the gun and the target. The smaller test facility allowed the use of only a 0.22 caliber revolver, while the larger test facility allowed the use of other handguns although there was restriction to the use of steel-jacketed ammunitions. There was excellent control over the climatic conditions in the small test range, whereas the larger test facility had no such provisions. Both the facilities utilized soft penetrating materials as targets.

Initial experiments conducted using both the test facilities demonstrated that there is an adequate amount of residues deposited per unit area of the floor surface during the single discharge of a 0.22 caliber gun to enable us to collect and analyze it quantitatively. Again, through the analyses of samples collected from various points around the gun and the target, it was determined that the most desirable region to monitor was an approximately one meter-wide area around the hypothetical line parallel to the trajectory of the bullet. Relatively large concentrations of residues were found on this tract compared to other areas farther from the trajectory.

The collection of residues from floor surfaces was attempted using various sampling techniques. These included the use of cotton balls, cotton gauze or filter papers moistened with dilute nitric acid and the use of a vacuum pump to gather residues from the floor surface onto a filter membrane. The use of moistened filter paper (Whatmann #541) was preferred over other methods, although the use of the portable vacuum pump shows considerable promise. The use of cotton balls and gauzes was avoided because of the undesirable levels of barium found in these matrices. After establishing the possibilities of sample collection using acid-moist filter paper strips, the test firings were repeated with moist filter paper squares placed on predetermined areas before the firing. The analyses of these samples gave good agreement with the results obtained from samples collected after test firings. It was also established that the amount of residues deposited on the floor surfaces of the test facilities between the gun and the target was directly proportional to the number of firings. The various firearms and ammunitions used during these tests are summarized in Table 6.

In order to simplify the sample collection and analysis procedures, the following experimental protocol was used for most of the nearly forty sets of test firings mentioned here.

Table 6

Handguns and Ammunitions used in Test Firings

Type	Model	Caliber	Ammunition
Revolver*	Harrington & Richardson Model 900	0.22	Long Rifle, Western T22LR
Semiautomatic Pistol	Smith & Wesson Model 41	0.22	Long Rifle, Remington-Peters High Velocity
Semiautomatic Pistol	Colt	0.25	Remington-Peters 50 Grain, Full Metal Jacket
Semiautomatic	Savage Arms Model 1917	0.32	Winchester-Western, Full Metal Jacket
Semiautomatic Revolver	Colt, Officer's Model	0.38 Special	Remington Arms, 0.38 SPL, Full Metal Jacket
Semiautomatic Pistol	Remington-Rand Model 1911-A	0.45	Remington Arms, Full Metal Jacket
Revolver	Smith & Wesson	0.455	Remington Peters Caliber 0.45, 185 Grain Wadcutter (used with clips)

*The only firearm used in the 2.5 meter long test range.

1. The floor surfaces of the test facility was cleaned and a fresh clean surface between the target and the firing position was prepared using large sheets of brown paper laid down on the floor. The sample collection areas are carefully marked on this sheet of paper and it is then affixed on the floor using adhesive tapes.
2. Just a few minutes before the test firing, a large transparent, clean polyethylene sheet (about 2 meters wide) is placed on top of the paper surface. Filter paper strips (15 x 15 cm squares) were then placed on the sampling points marked on the paper and visible through the polyethylene sheets. A fine mist of deionized water is then sprayed on these filter paper sheets. The sampling positions used during these test firings are illustrated in Figures 9 and 10 for the two test ranges.
3. Immediately after placing the sample collection paper strips, test firings were conducted observing the range regulations. Multiple firings (up to 6) were used to increase the concentration levels of the residues on the floor.
4. The filter papers containing the firearm discharge residues were then recovered. Each of these strips were folded and rolled in cylinders (ca. 5 cm long) and placed in clean two dram polyvials marked appropriately to identify the location from which the sample was collected.

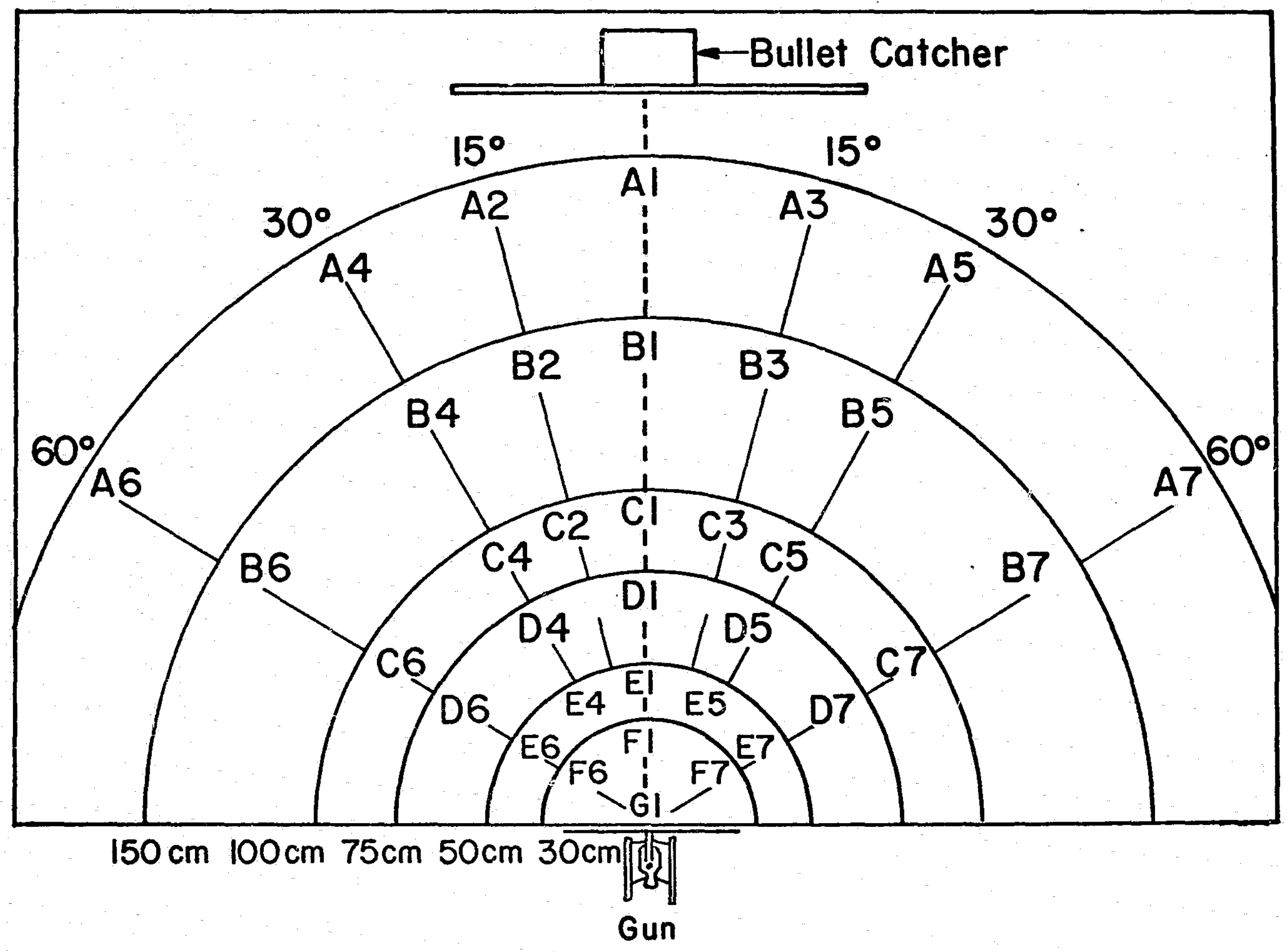


Figure 9. Sampling Positions used in the 2.5 Meter Long Firing Range

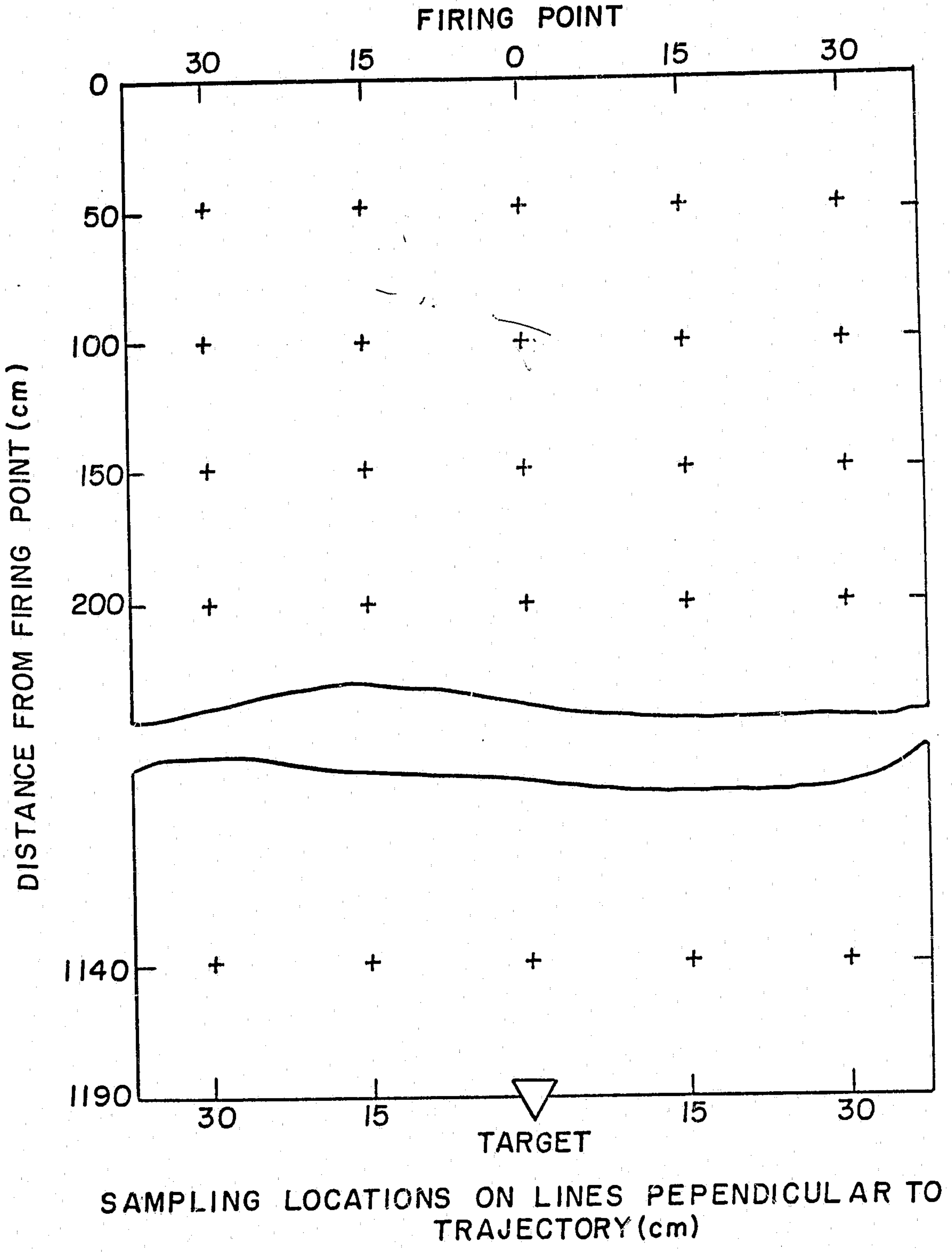


Figure 10. Grid Patterns used in the Collection of Gunshot Residues from the 12 Meter Long Firing Range

The above mentioned four steps were repeated for each series of test firing, thus ensuring that there was no cross contamination between each series of firing. A systematic examination of the influence of airborne particulates slowly settling on the surfaces of the test facility was done using the smaller of the two test ranges. Here, there were adequate provisions to periodically exhaust the test room. Samples collected after 5 minutes, 30 minutes, 4 hours and 24 hours after the test firing showed that the distinguishable distribution patterns observed was formed within a few seconds after the firing. Delays in sample collections up to 24 hours did not show any major changes in this pattern, although there was a small observable increase in the general background level of residues due to the settling of fine particulates suspended in the air.

The filter paper squares containing the powder residues were dried at 50°C to remove moisture prior to reactor irradiation. Barium and antimony standards were also prepared to match the geometry of the test samples and were irradiated under identical conditions.

The dry filter paper samples contained in polyethylene vials were irradiated for 2 to 5 minutes at a thermal neutron flux of 10^{13} neutrons/cm^2/sec using the pneumatic transfer system at the Penn State TRIGA Reactor. The samples from 0.22 caliber ammunitions were usually irradiated for 5 minutes, while those from higher caliber ammunitions required only a 2 minute reactor irradiation. The irradiated samples were transferred to clean counting vials and counted with a 2 minute decay period. The short-lived isotopes of interest were ^{139}Ba (83.2 minutes), ^{122m}Sb (4.2 minutes) and ^{66}Cu (5.1 minutes). All the samples were counted using a 40 c.c. lithium drifted germanium detector as part of a high resolution gamma ray spectrometer. The multichannel analyzer used was a 4096 channel, soft-ware oriented and programmable pulse-height analyzer. The data from the gamma-ray spectrometric measurements were recorded on computer compatible magnetic tapes and processed using an IBM 360-370 computer system. Although it was possible to nondestructively determine the levels of Ba, Sb and Cu from these samples using the procedures described here, only barium and antimony were quantitatively determined from all the samples analyzed during this investigation.

C. Results

Some of the results typical of the various experiments conducted during this investigation are presented here. Several two dimensional illustrations of distribution patterns and a few tabulations of analytical data are utilized to convey the findings of this investigation. Table 7 is a summary of the results of six test firings conducted at the 2.5 meter long test range. Here, a comparison is also made of the two different sampling techniques described earlier. The averages and standard deviations of the barium levels in the samples collected during six separate test firings are tabulated. These involved single firings for each of the six tests. During three of these tests, the residues from the floor were gathered using filter paper strips moistened with dilute nitric acid while the other three tests were conducted by placing the moist filter paper squares (15 cm x 15 cm) on predetermined areas prior to discharging the firearm. The sample numbers used in the tabulation are based on the

Table 7

Distribution Patterns of Barium from Gunshot Residues
0.22 Revolver (H & R Model 900)
Long Rifle, Western T22LR Ammunition
2.5 Meter Long Test Range

(All Concentrations are in 10^{-9} gm of Ba/Cm^2/Firing)

Sample Position	Nitric Acid Moist Paper Collection After Firing	Moist Filter Papers Placed before Firing
A1	4.1 ± 1.3	5.3 ± 1.1
A2	2.8 ± 1.3	3.4 ± 1.3
A3	0.6 ± 0.08	0.6 ± 0.05
A4	1.2 ± 0.7	0.7 ± 0.5
A5	0.7 ± 0.7	N.D.*
B1	8.1 ± 5.3	12.5 ± 4.0
B2	6.0 ± 6.0	10.1 ± 4.5
B3	0.8 ± 0.4	0.9 ± 0.6
B4	2.2 ± 1.4	1.6 ± 0.7
B5	0.5 ± 0.5	0.3 ± 0.4
B6	0.5 ± 0.6	0.9 ± 0.6
C1	33.1 ± 26.2	40.4 ± 21.3
C2	8.1 ± 2.0	4.6 ± 4.5
C3	2.8 ± 1.5	3.0 ± 0.8
C4	1.9 ± 1.7	1.4 ± 0.5
C5	0.8 ± 0.7	1.2 ± 0.7
C6	0.5 ± 0.4	1.1 ± 0.05
D1	20.5 ± 10.4	18.2 ± 9.2
D4	2.5 ± 1.8	2.6 ± 1.2
D5	1.3 ± 0.9	1.1 ± 0.5
D6	0.8 ± 0.5	1.3 ± 0.2
E1	7.1 ± 0.7	5.8 ± 2.8
E4	2.9 ± 1.6	2.1 ± 0.9
E5	0.6 ± 0.3	1.1 ± 0.8
F1	3.9 ± 0.9	4.1 ± 1.2
F6	1.4 ± 0.7	1.5 ± 0.4
F7	0.6 ± 0.2	0.4 ± 0.05

*N.D. - Not detectable by the analytical methods used.

(See page 48 for details of data presentation.)

notations employed in Figure 9. While there are observable variations in the absolute values of the trace elements, the overall pattern produced is almost identical from one test firing to another. These results also illustrate that the sample collection technique of using filter paper strips moistened with dilute nitric acid is a satisfactory method for collecting most of the trace metallic residues from the combustion products of a discharged handgun.

The results of antimony analyses for these same samples show similar agreement between the two kinds of sample collection, as well as the reproducibility of patterns evident in the case of barium. Figures 11 and 12 illustrate the distribution patterns of barium and antimony produced on the floor of the test facility (2.5 meters long) when a 0.22 caliber revolver was discharged.

The 12 meter long indoor test range was used for more than thirty sets of test firings during this investigation. Six different types of handguns were used for these test firings and the repetition of the tests was generally done on a different day using a different person to discharge the same firearm with similar ammunitions. Two sets of analytical results for a 0.25 caliber semiautomatic pistol and a 0.38 special pistol are summarized in Tables 8 and 9, respectively. Other representative results of several test firings conducted during this investigation are included as Appendix A of this report. Both the barium and antimony levels of paper strips collected from the regions marked in Figure 10 are presented.

The analyses of samples from different test firings using the same firearm and similar ammunitions show excellent reproducibility of the distribution patterns for both barium and antimony. Figures 13 and

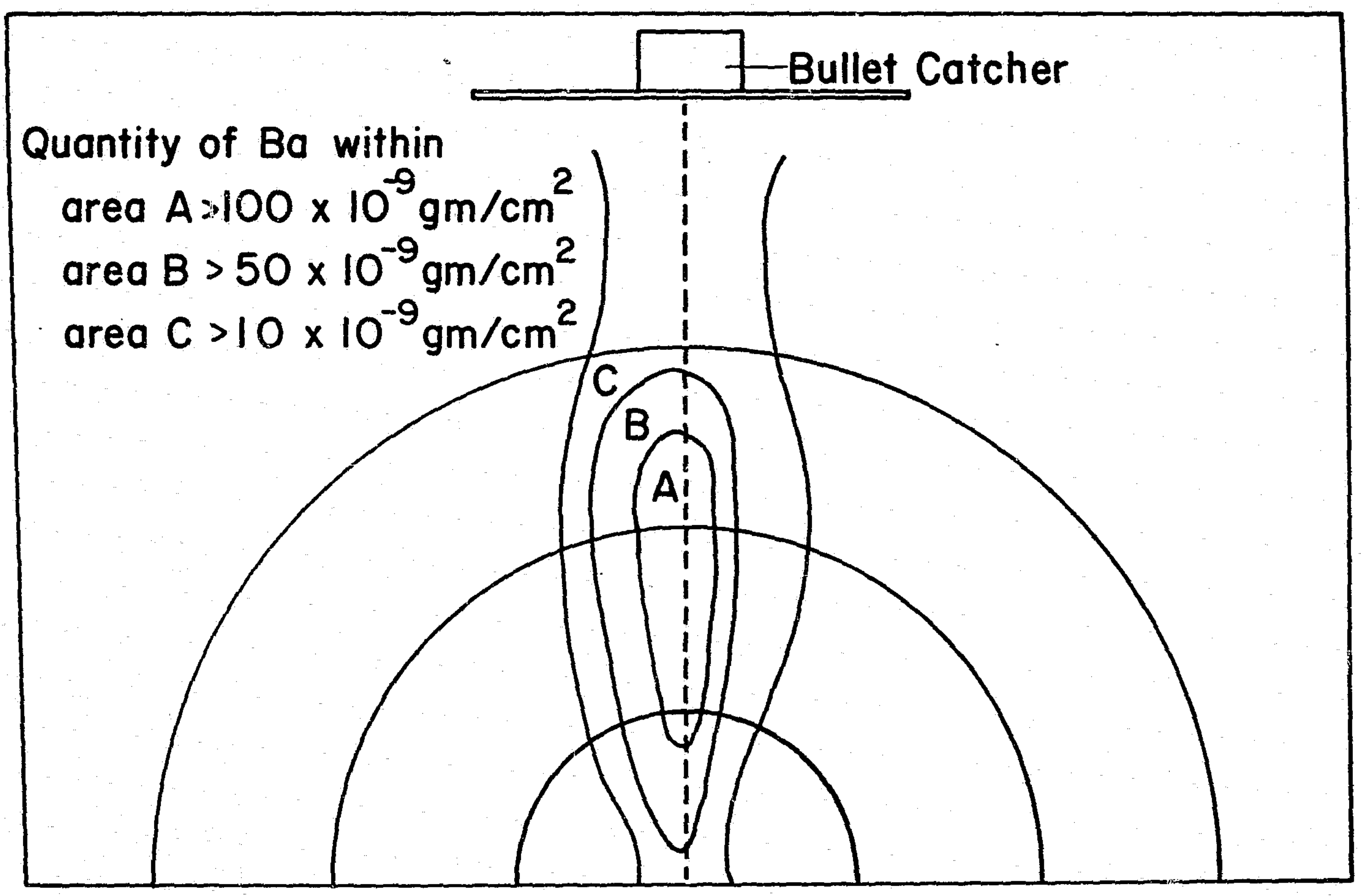


Figure 11. Distribution Pattern of Barium from the Discharge of a 0.22 Caliber Revolver

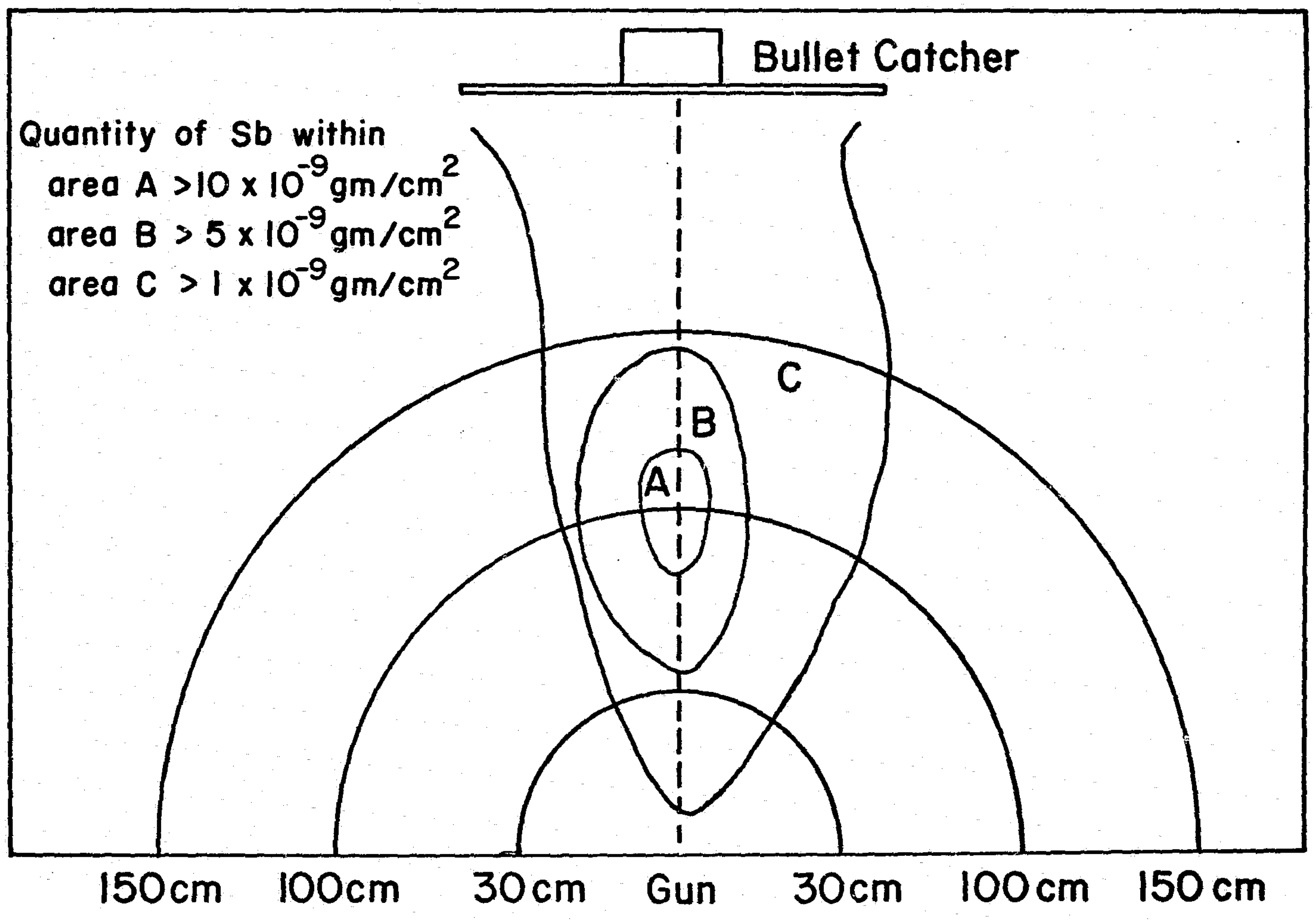


Figure 12. Distribution Pattern of Antimony from the Discharge of a 0.22 Caliber Revolver

Table 8

Distribution of Barium and Antimony
from Gunshot Residues from a 0.25 Caliber Pistol
[All the Results are in 10^{-9} gms of Element/cm^2/Firing]

BARIUM

Distance from Firing Point along Bullet Trajectory (cm)	Distance of Sampling Points from Bullet Trajectory [perpendicular to trajectory] (cm)				
	30	15	0	15	30
0	1.38	3.91	25.04	33.11	11.70
50	3.14	5.63	23.79	38.30	15.01
100	3.58	8.04	28.43	32.63	15.78
150	2.20	8.16	12.71	10.21	11.52
200	2.12	2.67	5.19	2.50	3.01
500	N.D.*	N.D.	0.67	N.D.	N.D.
1000	N.D.	N.D.	N.D.	N.D.	N.D.
1140	N.D.	N.D.	N.D.	N.D.	N.D.
1190	N.D.	0.86	3.81	0.62	9.45

ANTIMONY

Distance from Firing Point along Bullet Trajectory (cm)	Distance of Sampling Points from Bullet Trajectory perpendicular to trajectory (cm)				
	30	15	0	15	30
0	1.10	2.02	26.57	36.48	10.69
50	1.53	5.25	22.26	29.83	9.75
100	6.60	8.85	16.31	30.43	14.05
150	1.67	7.08	17.46	23.57	8.66
200	7.71	1.93	4.85	7.08	4.95
500	N.D.	N.D.	N.D.	N.D.	N.D.
1000	N.D.	N.D.	N.D.	N.D.	N.D.
1140	0.52	0.47	0.41	N.D.	0.40
1190	1.73	0.54	2.63	0.99	1.65

*N.D. - Not detectable by the analytical methods used.

Table 9

Distribution of Barium and Antimony
from Gunshot Residues from a 0.38 Special Revolver
[All the Results are in 10^{-9} gms of Element/cm^2/Firing]

BARIUM

Distance from Firing Point along Bullet Trajectory (cm)	Distance of Sampling Points from Bullet Trajectory perpendicular to trajectory (cm)				
	30	15	0	15	30
0	7.21	24.94	43.34	57.47	19.68
50	9.77	20.62	31.82	35.34	25.01
100	6.37	8.23	11.81	12.24	9.16
150	1.84	11.65	5.62	3.71	2.83
200	1.10	0.62	2.27	3.69	1.44
500	0.88	N.D.*	0.75	N.D.	N.D.
1000	2.81	1.74	56.94	1.10	2.28
1140	133.16	21.01	15.19	127.61	16.96
1190	46.16	11.26	1.03	N.D.	N.D.

ANTIMONY

Distance from Firing Point along Bullet Trajectory (cm)	Distance of Sampling Points from Bullet Trajectory perpendicular to trajectory (cm)				
	30	15	0	15	30
0	1.00	1.09	2.00	3.30	1.63
50	1.02	1.34	2.43	2.09	2.25
100	0.91	2.75	2.27	1.92	1.46
150	0.47	1.05	1.00	0.85	0.52
200	0.28	0.53	0.59	0.54	0.30
500	N.D.	N.D.	N.D.	N.D.	0.32
1000	1.74	1.12	0.70	0.48	21.56
1140	1.01	2.59	101.32	N.D.	1.03
1190	0.72	N.D.	0.55	N.D.	N.D.

*N.D. - Not detectable by the analytical methods used.

14 illustrate the average distribution patterns of barium and antimony from three sets of test firings of a 0.22 caliber semiautomatic pistol. Similar illustrations of barium and antimony distributions between the firearm and the target are illustrated for 0.32, 0.45 caliber pistols and a 0.455 caliber revolver in Figures 15 through 20.

A comparison of the distribution patterns of antimony from two separate test firings at one grid line, which is 100 cms down range, is made in Figure 21. Similar comparisons of the distribution patterns at the 100 cm grid line for four different kinds of firearms are illustrated in the composite Figure 22. Close examination of the experimental results brings out differences like these at other grid lines, although at some of these lines, the differences are not so spectacular. There are, however, distinguishable differences in the overall distribution patterns of discharge residues from different handguns. In particular, there are very pronounced differences in the distribution patterns from rimfire ammunitions when compared with similar patterns produced by centerfire ammunitions. These differences in the barium and antimony distributions are readily observable in Figures 13 and 14 (rimfire) when compared with Figures 15 through 20 for centerfire ammunitions.

D. Discussion

The results of various test firings conducted during this investigation show that a unique distribution pattern of firearm discharge residues is deposited on surfaces immediately below the trajectory of the bullet. When a firearm is discharged, a cloud of combustion products is emitted through the barrel of the weapon. This

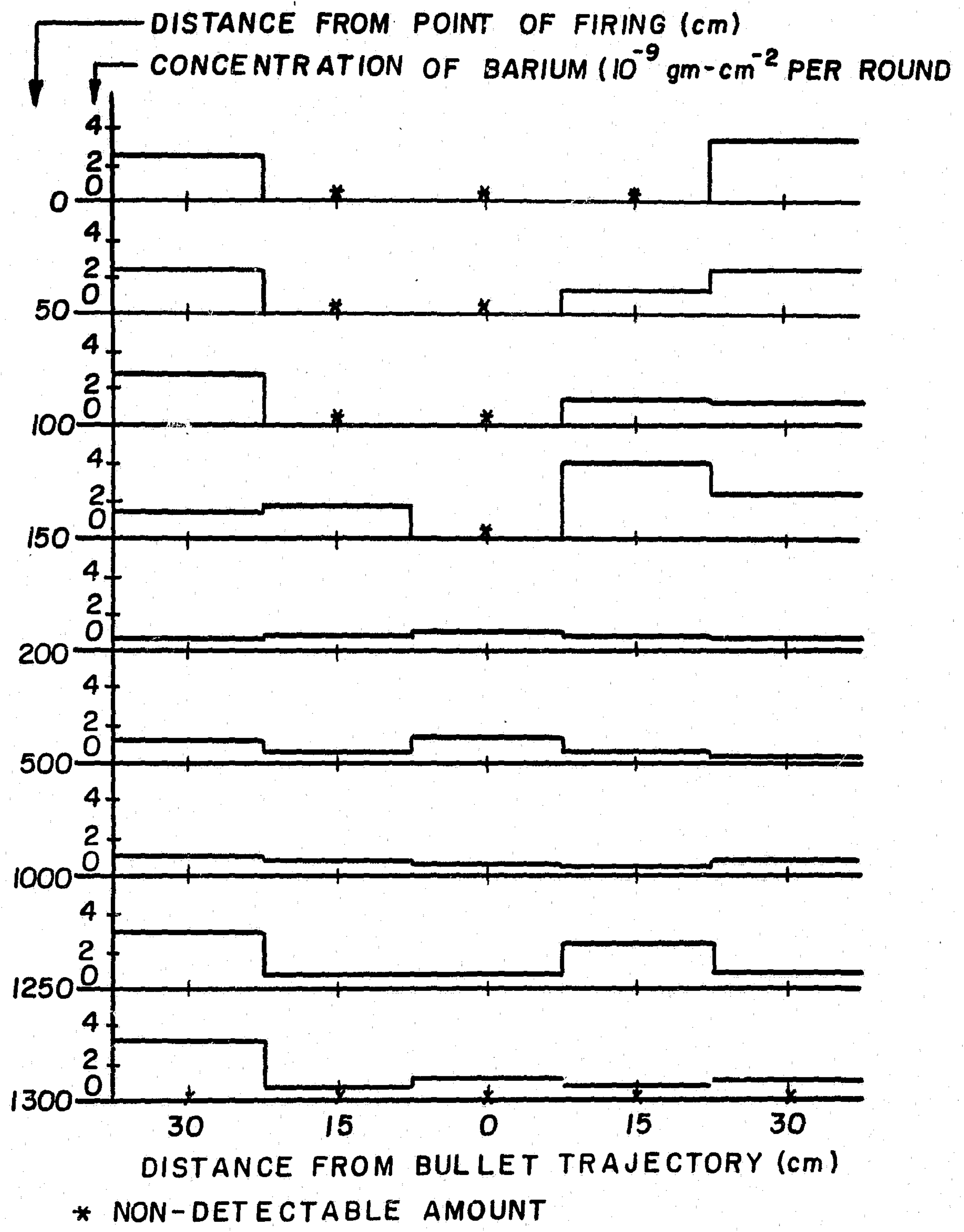


Figure 13. Distribution Pattern of Barium at Various Grid Lines of the Large Test Facility when a 0.22 Caliber Semiautomatic Pistol was Discharged

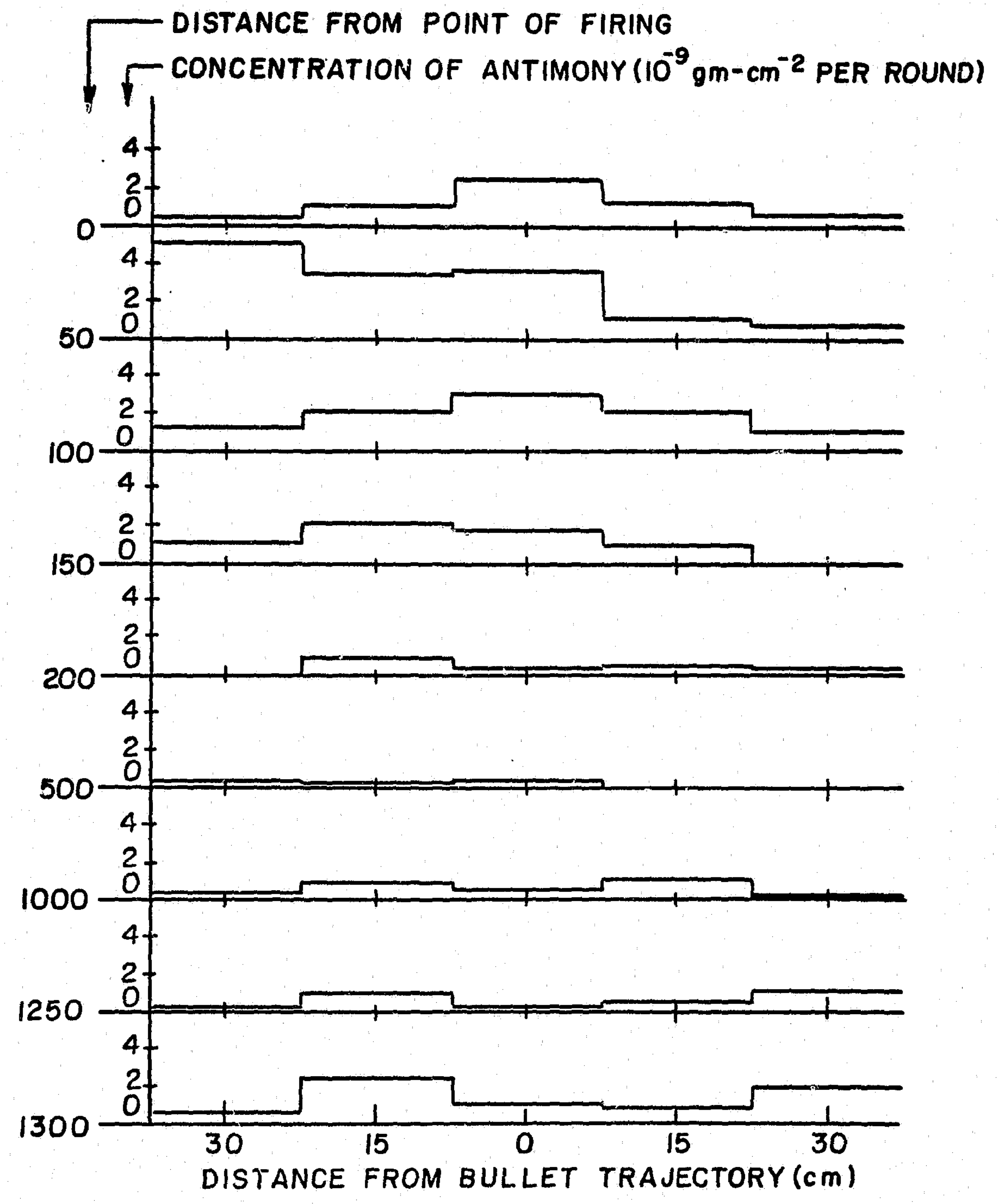


Figure 14. Distribution Pattern of Antimony at Various Grid Lines of the Large Test Facility when a 0.22 Caliber Semiautomatic Pistol was Discharged

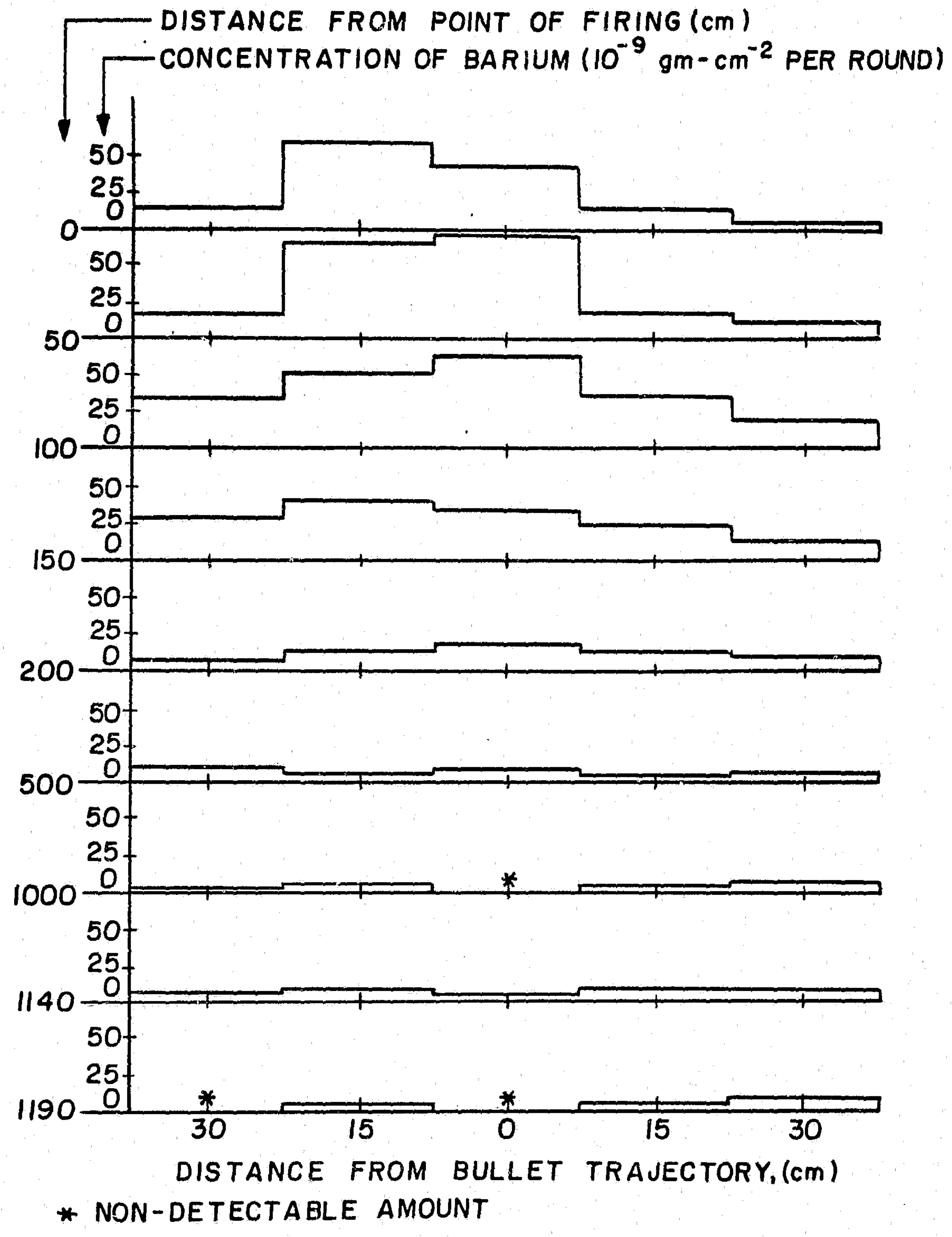


Figure 15. Distribution Pattern of Barium in the Firearm Discharge Residues from a 0.32 Caliber Semiautomatic Pistol

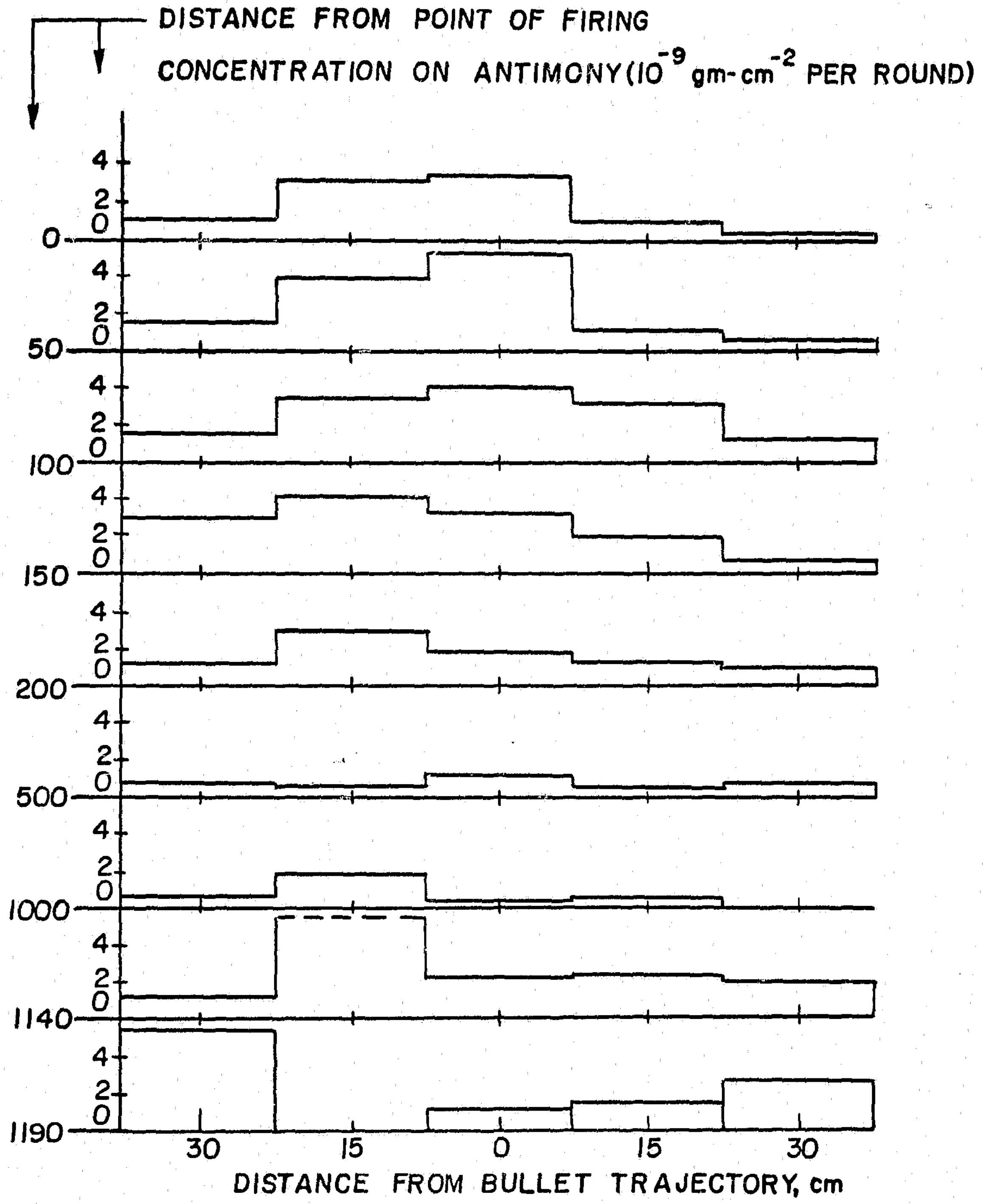


Figure 16. Distribution Pattern of Antimony in the Firearm Discharge Residues from a 0.32 Caliber Semiautomatic Pistol

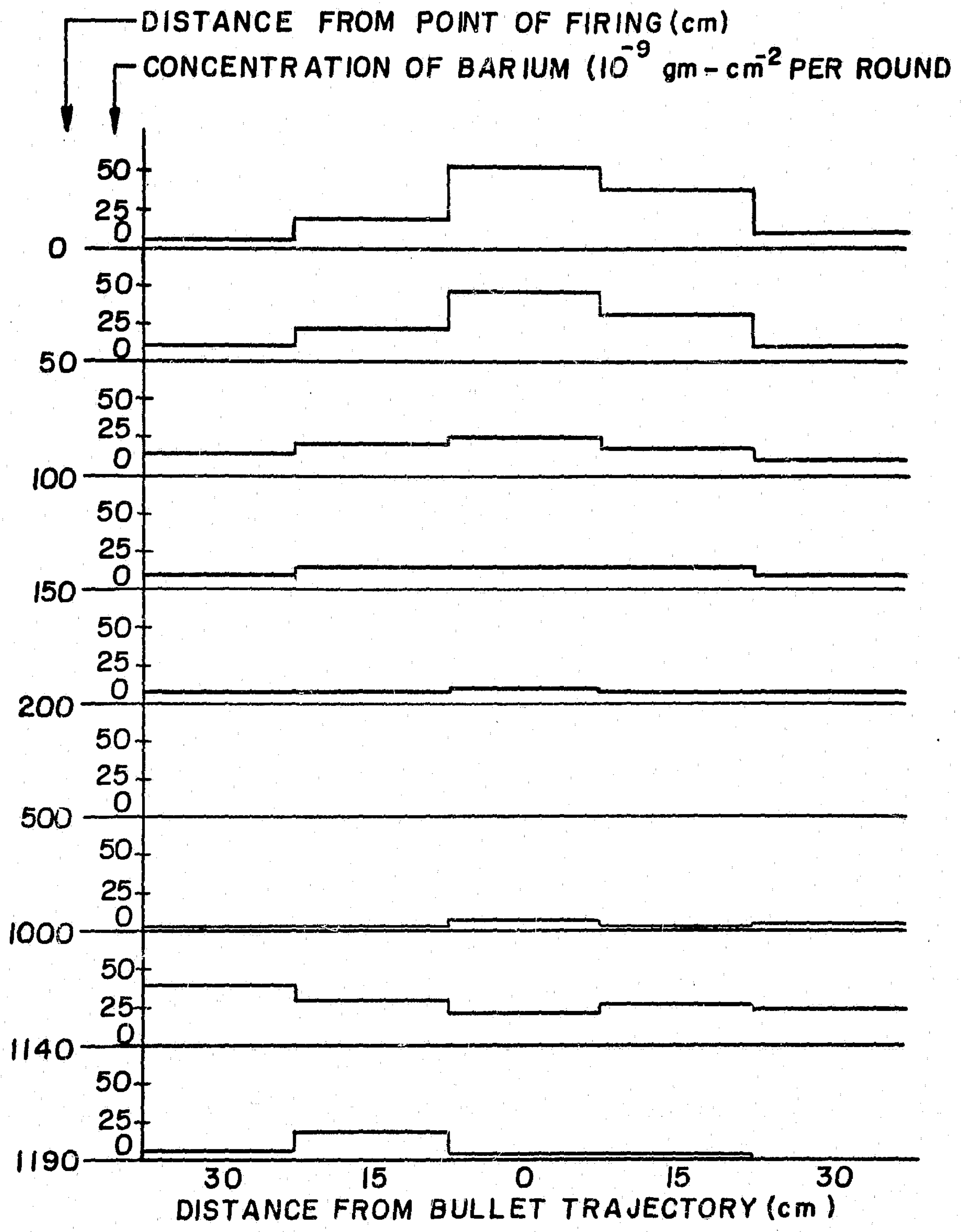


Figure 17. Distribution Pattern of Barium in the Discharge Residues from a 0.45 Caliber Semiautomatic Pistol

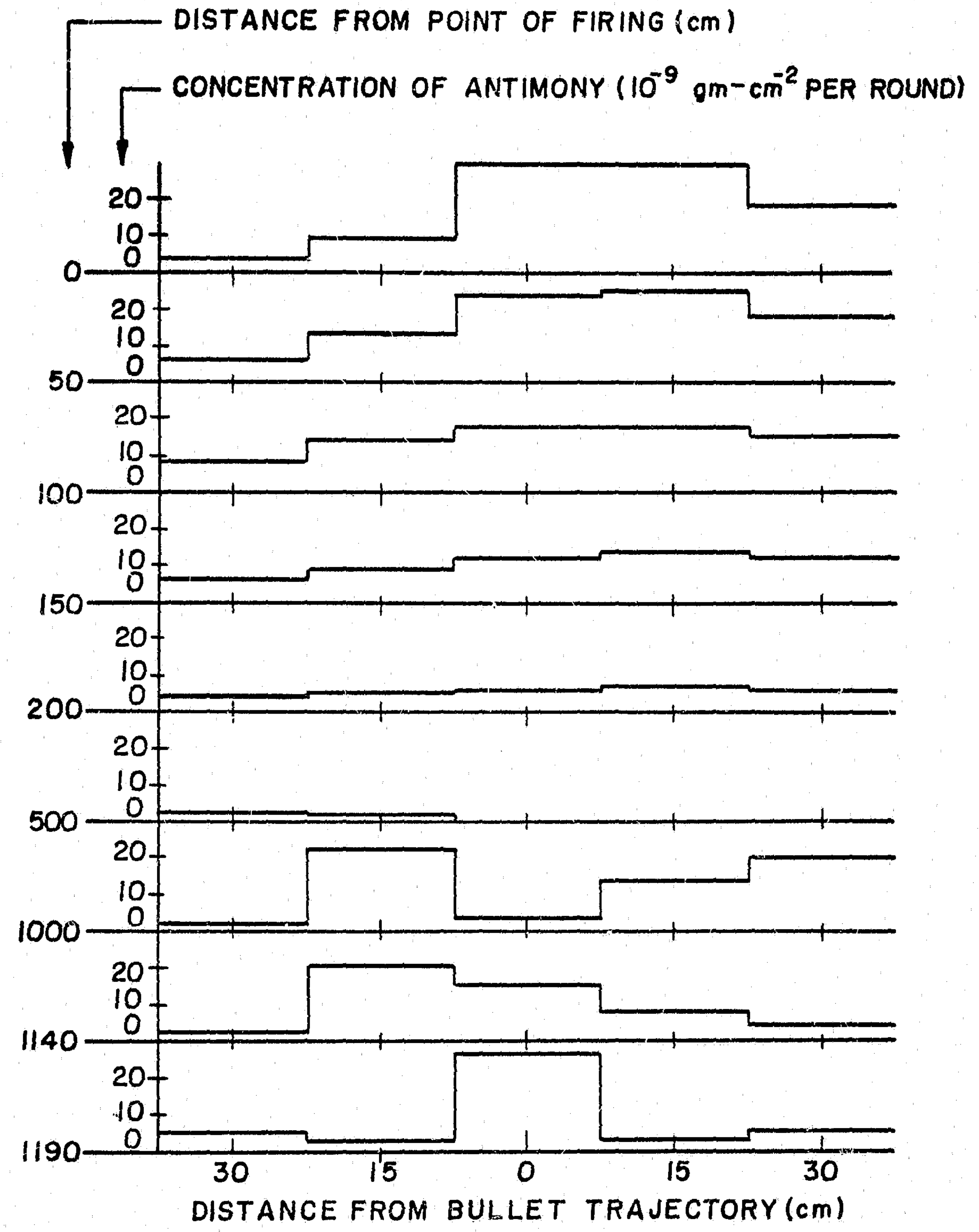
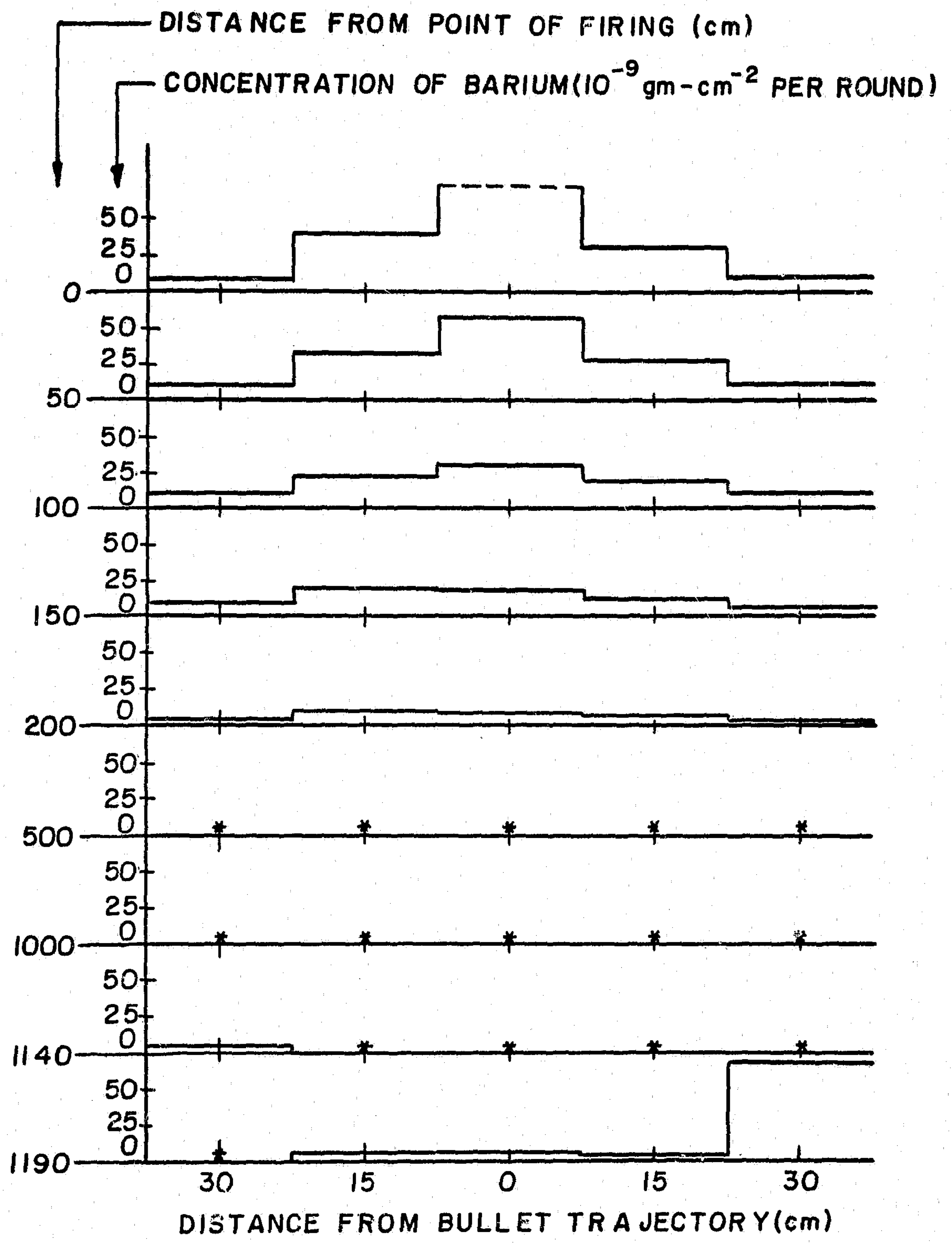


Figure 18. Distribution Pattern of Antimony in the Discharge Residues from a 0.45 Caliber Semiautomatic Pistol



*Non-Detectable

Figure 19. Distribution Pattern of Barium during the Discharge of a 0.455 Caliber Revolver

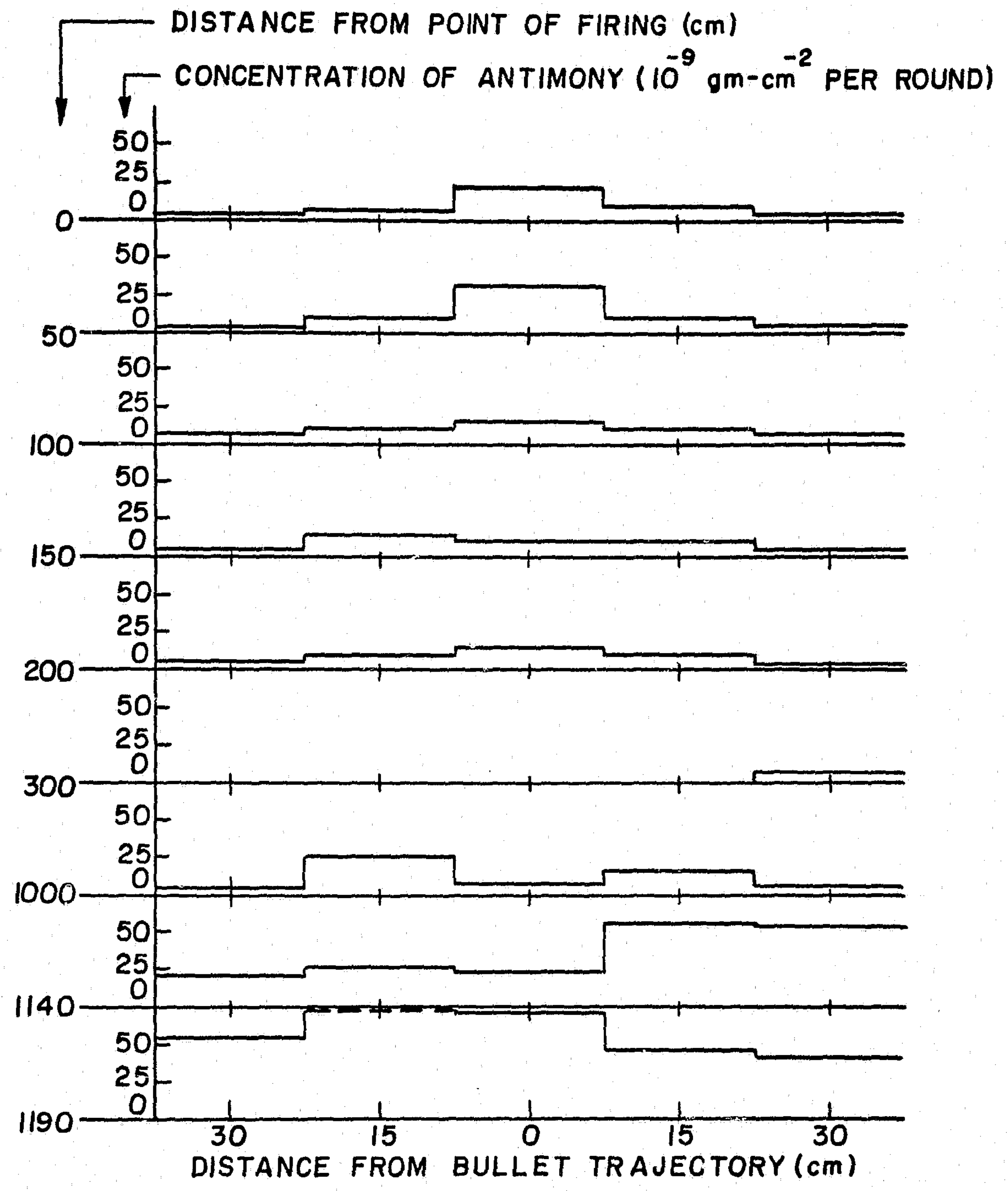


Figure 20. Distribution Pattern of Antimony during the Discharge of a 0.455 Caliber Revolver

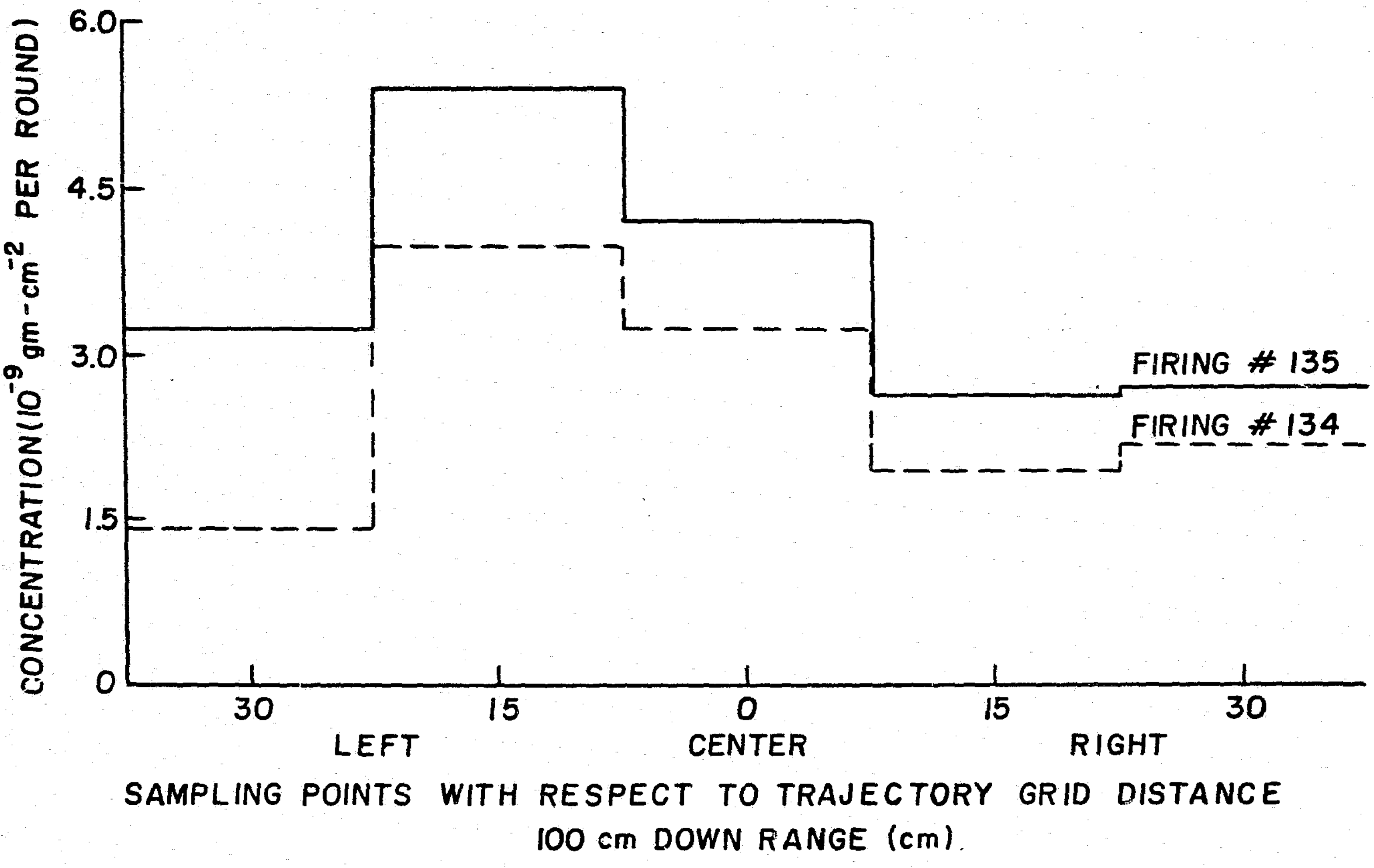


Figure 21. Comparison of the Distribution Patterns of Antimony from Two Separate Test Firings (at the 100 cm Grid Line) using a 0.455 Caliber Revolver

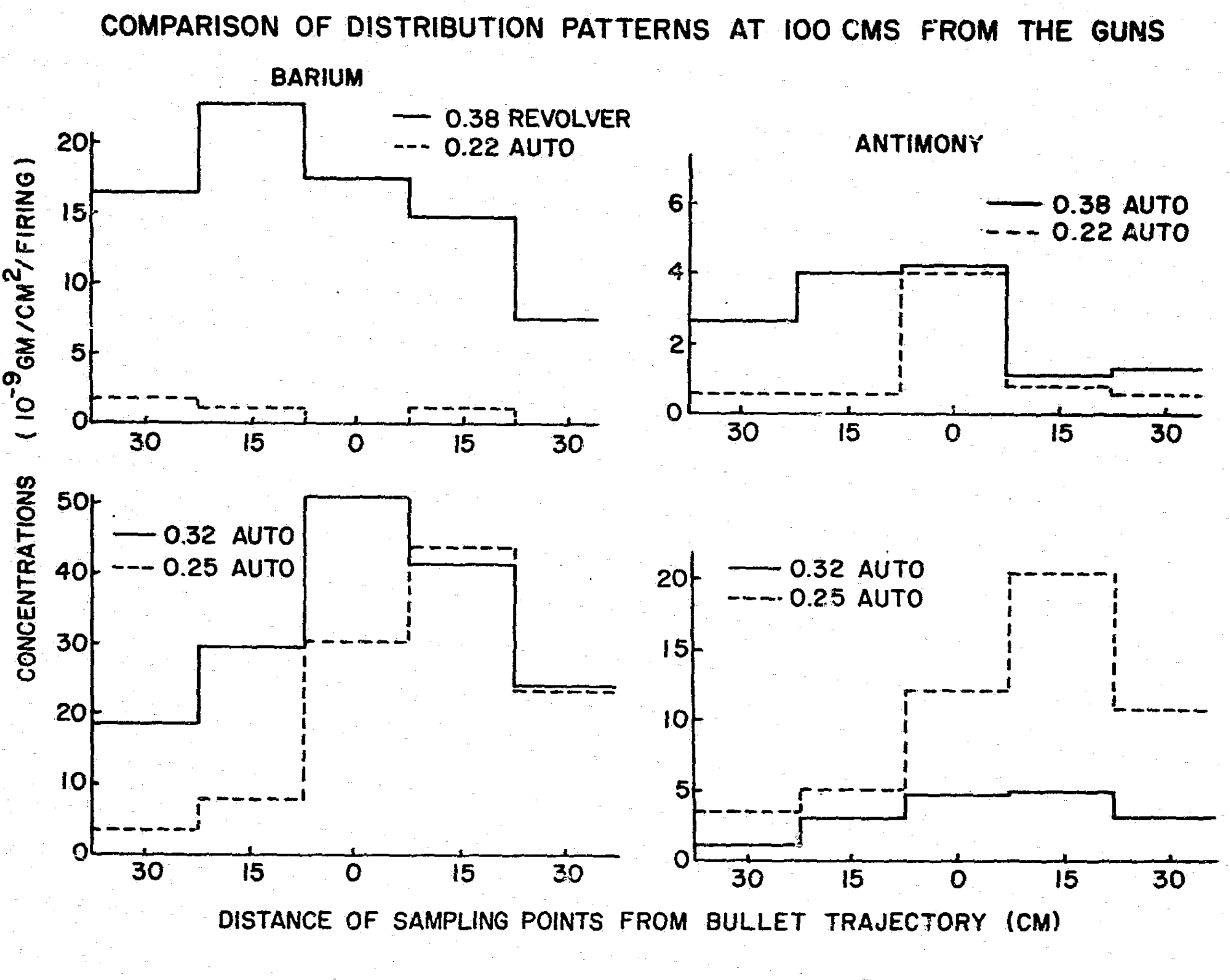


Figure 22. A Composite of the Comparisons of Barium and Antimony at the 100 cm Grid Line from Four Different Handguns

emission sequence has been recorded using high speed photography (40). While there are no known prior reports about the distribution patterns of residues along the trajectory of a bullet, from the observations made during this investigation, the following mechanism may be proposed. When a projectile leaves the barrel of the gun at a high velocity, it sets up a wave front which extends out from the nose of the bullet. This condition creates an area of lower pressure immediately in its wake. In addition, due to the rifling action in the barrel of the gun, the projectile is discharged with a tangential velocity component. The combination of these two conditions creates a vortex in the wake of the bullet which carries with it some of the combustion products. Further, the continuous spinning of the bullet during its forward motion allows the spewing out of small amounts of combustion products within its wake. When the bullet hits the target, the wave front collapses, depositing all the remaining residues around the target. While this seems to be the mechanism by which the residues are carried farther from the gun, the major contributions to the residue patterns generated in the immediate vicinity of the firearm are the emissions from the barrel of the gun.

On the basis of the above mentioned mechanism, a number of variables characteristic of a firearm (barrel length, twist of the rifling grooves, location of the emission ports, etc.) can influence the amount and nature of the distribution of combustion products. In addition, the size of the projectile, its shape and velocity can influence the amount of residue carried within the wake of the bullet and its distribution along the trajectory. The experimental observations made during this study generally substantiate the dependence of gunshot residue patterns on the above mentioned characteristics of the weapon and the bullet.

A closer examination of the results of test firings conducted using the two test facilities suggests that a combination of firearm and ammunition creates unique patterns near the gun and the target. The features of the distribution patterns observed from the 2.5 meter long test facility is the result of the overlapping of these two regions, while the two regions are distinguishable from the test results obtained from the large firing range.

E. Conclusion

Nondestructive neutron activation can be used for the detection and measurement of barium, antimony and copper from residue samples collected from the floor surfaces of the firing range after the single firing of a handgun. These analytical results can be utilized to construct unique distribution patterns of firearm discharge residues on surfaces immediately below the trajectory of the bullet. While the findings of this study offer new avenues for further exploration, they establish the possibility of using this technique to determine the flight path of a bullet. The existence of two distinct regions in the distribution patterns observed offers the possibility of estimating the proximity of the handgun with respect to the target if a distribution pattern can be developed. These findings also show the prospects for classifying the ammunition used as a rimfire or centerfire type from the distribution patterns of barium and antimony. The development of this information, particularly in the absence of a firearm, a bullet or an eyewitness, would be of considerable value to criminal investigations.

V. EXAMINATION OF HUMAN HAIR AS FORENSIC EVIDENCE USING NEUTRON ACTIVATION ANALYSIS

A. Background

In most criminal investigations involving crimes of violence, hair may be found as evidence at the scene of the crime, on the criminal, on the victim and on the weapons and tools used in criminal activities. Investigators and evidence technicians are normally trained to gather hair samples, if any, during their investigations at the scene of the crime. However, the results of hair examinations provided by the forensic laboratories, in most instances, do not justify the work involved in the search and collection of this material as evidence. When hair is found at the scene of a crime, various questions are raised: 1) Is the material hair? 2) Does it come from furs or from animals? 3) Does the hair come from a human? 4) What part of the body does the hair come from? 5) Does it come from a particular person? The answers to some of the above questions can be developed through morphological examinations and the most important question - does the hair come from a particular person? - cannot be answered by any of the routine practices of forensic laboratories today, although certain physical examination procedures employed are capable of answering the other four questions with a certain degree of reliability (41).

During the nineteen sixties, there was a sudden upsurge of interest in the possible trace element analysis of human hair in criminal investigations (12,42-48). In recent years, there have been further examinations of the findings of these earlier studies through the application of both new and improved analytical techniques (49-54). A very large number of the above mentioned investigations utilized neutron activation analysis techniques while other analytical methods such as spark source mass spectrometry (45), x-ray fluorescence (46) and atomic absorption (49,50) have also been employed. Because of the recognition that various factors can influence the trace element composition of hair, several investigations were undertaken to examine these phenomena (48,49,52-54). These include, a) the examination of the effects of washing hair samples prior to the analysis to remove the surface contaminants (48,52), b) investigation of the variation of trace elements along the length of a hair strand from an individual (52), c) the study of the hair samples collected from different parts of a person's head (51,52), d) the examination of the variations of trace elements in human hair with time (53), and e) the differences in the levels of trace element constituents in hair samples from male and female subjects (49,54).

The potentials of trace element analysis of human hair as forensic evidence received overly optimistic evaluations in the press and in numerous trade journals. However, the evaluations of investigators as published in refereed scientific journals varied from cautious optimism as expressed by Perkons and Jervis (43) to concerned pessimism as opined by Cornelis (53). In addition, there have been responsible and justifiable applications of trace element analysis of hair as forensic science evidence by Erickson (55), Schlesinger, et al., and by Pillay, et al. (57), among others (58). There are, however, reasons for genuine concern and need for more extensive investigation of the trace element composition of human hair and its possible applications in criminal investigations. Recent advances in analytical techniques and the improvements in instrumentation available for nondestructive neutron activation analysis has prompted this investigation to further evaluate the potentials and limitations of neutron activation analysis for the examination of human hair as forensic science evidence. This investigation also undertook the development of analytical procedures to independently examine surface contaminants of human hair along with the examination of trace elements in the matrix of the hair.

B. Modifications in Hair Analysis Methods

The trace elements found in hair samples generally consist of trace elements accumulated in a person's hair through biological processes and those adhering to or adsorbed on the hair from environmental contaminants. The latter category also includes trace elements from cosmetic preparations and grooming aids as well as from the environment to which a person is exposed to during his/her normal activities. It was attempted to isolate the trace elements from these two sources and independently analyze the hair and surface contaminants of hair. The procedure finally adopted was an extraction process using freshly distilled diethyl ether in a soxhlet extractor. This procedure, when compared with the use of water, acetone, detergent, or dilute acids for washing hair, was found to have the least effect in leaching out trace elements from hair matrix. The ether extract was carefully evaporated, quantitatively extracted and analyzed to determine the trace elements from the hair wash. While these procedures are time consuming, this modified approach to hair analysis seems to have practical values in comparing hair samples collected during a criminal investigation.

C. Hair Samples from Volunteers

The primary group of volunteers selected for the study was the students entering the University Park campus of The Pennsylvania State University during the Summer and Fall terms of 1972. The volunteers were then requested to submit the names of the members of their family who would be willing to participate in the Hair Analysis Program. Of the nearly 3000 persons contacted, about six hundred persons expressed their willingness to participate in the program by donating a sample of their hair once every six months. While the study group did include people of all ages, nearly half the group were in the age group of 17 and 18 year olds.

Once every six months, all the volunteers were contacted through the mail and a sample of hair was requested. In addition to the letter requesting the sample, a questionnaire was sent for each person along with specially fabricated plastic containers for the collection of hair. The methods of hair collection required were explained everytime and a postage-paid envelope was also included to return the samples and questionnaire to our laboratory. The method for the collection of hair most preferred for our analysis was the hair collected during normal grooming using a comb or a brush. It was felt that this would most likely represent the hair samples that would fall during physical disturbances. Most of the volunteers collected the hair samples using the procedures we have suggested and the questionnaires were returned with relevent answers. The samples and questionnaires that did not satisfy our selection criteria were not analyzed during this investigation.

The utilization of volunteers to participate in this hair analysis program by periodically donating a sample of their hair was considered "human experimentation" according to the local interpretation of the general guidelines of the U. S. Department of Health, Education, and Welfare. Therefore, the plans for the investigations were examined by the Human Experimentation Committee of The Pennsylvania State University. The sample collection plans and the utilization of the samples and data were approved by the committee through a lengthy process of justifying the value of this research effort to the participants, as well as, to the society at large.

The hair samples received from the participants were preserved in sealed polyethylene containers and stored until ready for analysis. Physical examination of the samples revealed that there were little or no root structures of hair seen among the samples collected using the procedures suggested. This may be because most of the hair samples accumulated on brushes and combs may be those that were removed by breaking the hair above the root structure. During this investigation, there was no attempt made to examine all the hair samples microscopically to confirm the absence of root structures in the samples. Another general observation that may be made about the hair samples received is that most of the samples were long hair strands which were easy to handle and manipulate during the analysis. This seems to be because the sample collection period (1972-1974) happened to be during the hair-length-revolution period on this continent.

D. Preparation of Samples for Analysis

Small quantities (10 mg each) of the hair samples were placed in clean polyethylene bags. They were then twisted and rolled into a bundle using a pair of forceps. These hair samples were then placed in single thickness cellulose extraction thimbles (Whatmann 10 x 50 mm), previously leached in high purity diethyl ether. The cellulose extraction thimble containing the hair sample is then placed in a soxhlet extractor (Figure 23) and the hair samples are separately washed using freshly distilled diethyl ether. The ether extraction is generally contained for a period of 30 minutes for each of the samples. The washed hair is dried and weighed.

The ether wash in the boiling flask of the soxhlet extractor is transferred to a specially shaped round bottomed flask of a concentrator (Kimax-K-283500). The apparatus shown in Figure 24 is set up to evaporate the ether and concentrate the hair-wash. During the concentration process, the dissolved residues in the ether wash concentrates and finally accumulates in the small bulb at the bottom of the boiling flask. After allowing almost all the ether to evaporate, the residues are extracted with about one ml of warm dilute nitric acid. This extract constitutes the analytical "hair-wash" sample for the particular hair that was washed.

E. Neutron Activation Analysis

The multielemental analyses of hair and hair-wash samples were done using multiple neutron irradiation and high resolution gamma ray spectrometry. All the neutron irradiations were performed at the Penn State TRIGA Reactor at a thermal neutron flux of approximately

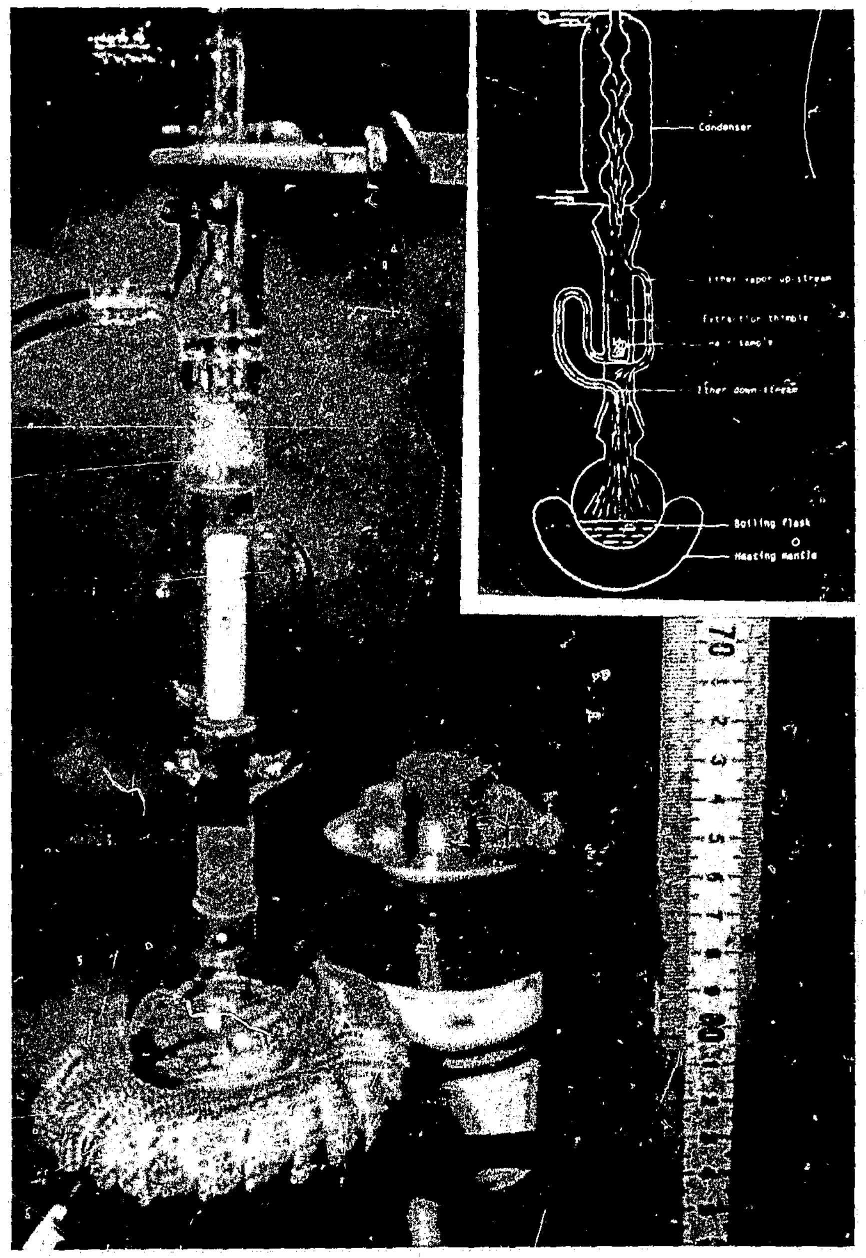


Figure 23. A Soxhlet Extractor used for the Washing of Hair Samples

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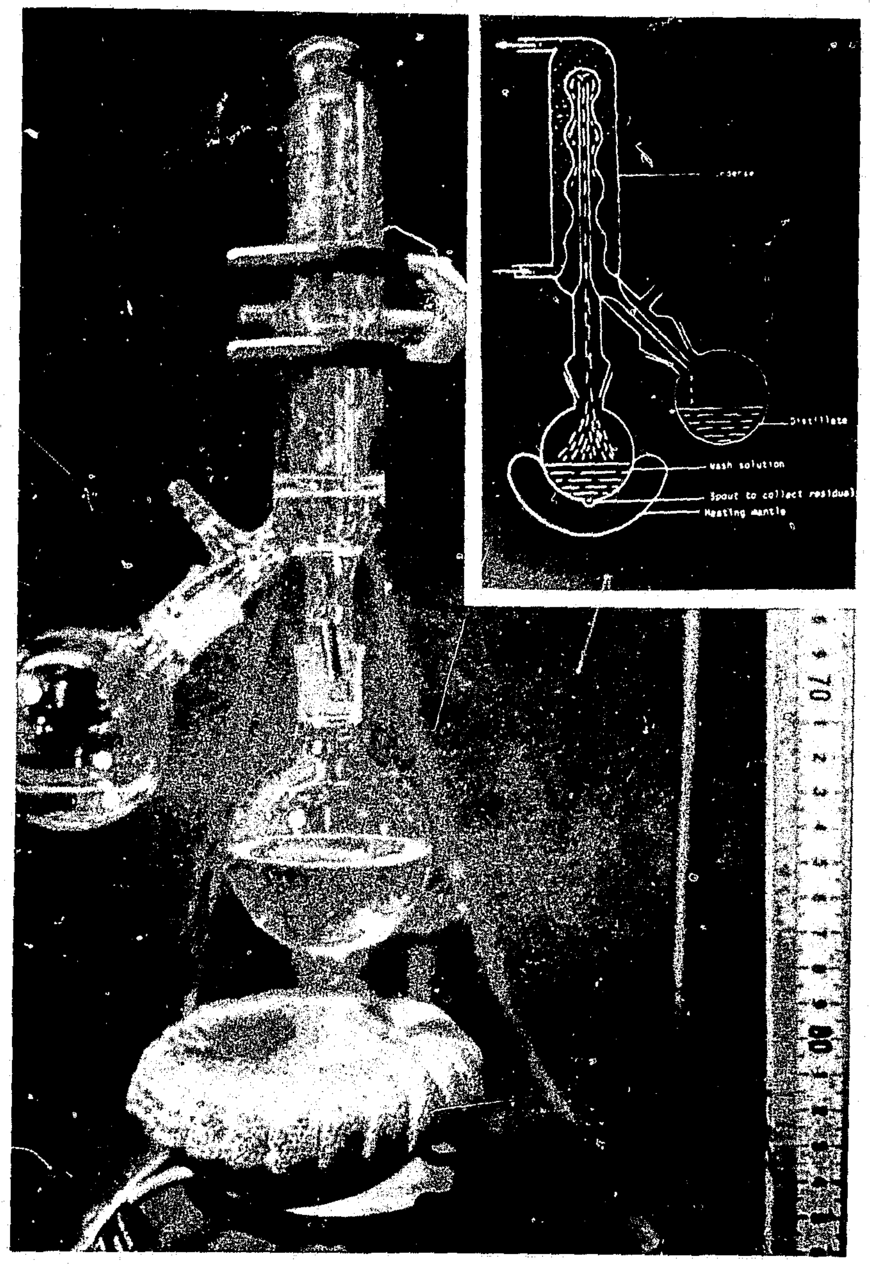

Figure 24. Apparatus used to Evaporate the Hair-Wash Solution to Prepare Analytical Samples for Neutron Activation Analysis

10^{13} n. cm^{-2} sec^{-1}. The gamma ray spectrometric measurements utilized a 40 c.c. high resolution Ge(Li) detector with a resolution of 2.1 Kev at 1.33 MeV range. This detector, in association with a soft-ware oriented programmable multichannel analyzer (ND-4410) with a 12 K core size, was used for gamma ray spectrometric measurements. The data were recorded on computer compatible magnetic tape using a PERTEC tape drive. The data analysis - the determination of the γ-ray energies and the count rates due to each of these γ-rays - was done using a Penn State version of the Lawrence Radiation Laboratory program called "ENERGY". All the data processing were done using the IBM 360/370 computer facilities at The Pennsylvania State University.

The irradiation and counting schedule used for neutron activation analysis of both the hair and "hair-wash" samples is summarized in Table 10(a).

F. Handling of Samples Before and After Neutron Irradiation

1. Hair

The hair samples were sealed in small, clean polyethylene bags immediately after ether washing and weighing. These samples were placed in a two-dram polyvial, along with a separately sealed flux monitor. The sample contained in the polyvial is inserted into a polyethylene rabbit with the use of appropriate spacers as shown in Figure 25. The placing of the hair sample and the flux monitor in the vial and the insertion of the vial in the rabbit were reproducible. After reactor irradiation, the hair sample was removed from the sealed polybag and placed in a clean counting vial. The flux monitor is placed in a separate counting vial and counted with a fixed 5 minute

Table 10(a)

Neutron Activation Analysis Schedule Employed for the Determination of Trace Elements in Human Hair

Irradiation Period	Irradiation Facility	Decay Period	Counting Period	Elements Determined
5 minutes	Pneumatic transfer system and polyethylene rabbits	2 minutes	50-100 seconds	Ti, I, Br, Mn, Cu, V, Cl, Na, Ca
25 hours	Merry-Go-Round facilities	2-3 days	400-4000 seconds	Au, As, Br, La
	Quartz encapsulated samples in aluminum tubes	10-25 days	10,000 to 40,000 seconds	Se, Hg, Cr, Sb, Ag, Sc, Zn, Co, Fe

NOTE: The thermal neutron fluxes at the irradiation facilities were about 10^{13} neutrons cm^{-2} sec^{-1}.

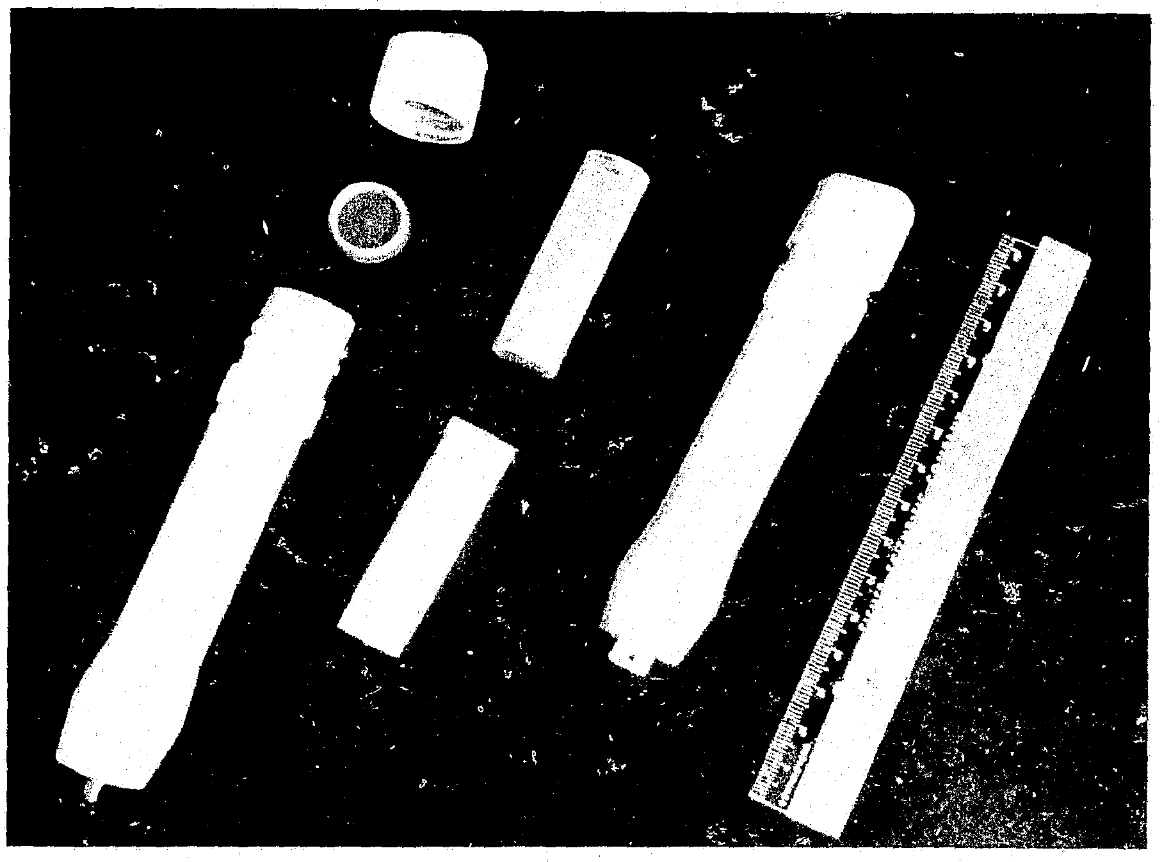

Figure 25. A Display of the All-Polyethylene Container ("Rabbit") used for the Short-Term Irradiation of Hair Samples

decay period. The geometry and the positioning of the hair samples were reproduced by inserting freshly punched out clean pieces of polyurathane sponge into the counting vial before closing the snap-cap lid. During each batch of sample irradiations, at least two sets of the analytical standards of all the elements being analyzed are irradiated and counted. The flux foils of pure copper were prepared by weighing out accurately known amounts of copper foil (50-100 μgm) and sandwiching it between two thin sheets of pure polyethylene. Circular pieces of these polyethylene sheets are punched out keeping the copper foil at the center of the circle. The diameter of these circular discs is chosen to place these discs in a reproducible geometry for irradiation and counting.

The hair samples are allowed to decay for a week or more before they are repackaged for long irradiation. The hair samples are placed in a properly shaped aluminum foil tube and the ends of this tube are crimped. This aluminum tube containing the hair sample is inserted into a quartz tube container (5 m.m. I.D. and 10 cm long). A small plug of (1-2 cm long) quartz wool is inserted after the aluminum foil container and the quartz tube is sealed to contain the sample. The reflective properties of the aluminum foil and the insulation provided by the quartz wool prevent the hair from burning during heat sealing of the quartz tubes.

A facility that could be used to irradiate several samples for extended periods at a uniform neutron flux was built during this investigation. The primary design of the facility was based on the original design of the merry-go-round facilities of the PULSTAR reactor at the State University of New York at Buffalo. This device

(Figure 26) was fabricated from reactor grade aluminum tubes and plates. Twenty-four of the sealed quartz tubes containing hair samples can be placed in the merry-go-round for simultaneous irradiation. The usual loading of a merry-go-round for irradiation contains 18 hair samples, two flux monitors of high purity iron wire sealed in quartz and four quartz vials containing specially constituted mixtures containing the various elements being quantitatively analyzed. The merry-go-round containing the samples to be irradiated is attached to the end of a long (23 ft.) aluminum pole and positioned near the core of the reactor. This device is then rotated at a speed of about 3 rpm using an electric motor mounted on top of the reactor bridge. Through a series of experiments, it was determined that all the samples in the merry-go-round get exposed to the same flux during extended periods of irradiation. However, two flux monitors (one in each row of the sample assembly in the merry-go-round) are included with each irradiation to monitor the total flux the samples in each row were exposed to during the irradiation period.

After reactor irradiation for about 25 hours and decay for two days, the merry-go-round is dismantled and the quartz tubes containing hair samples are separated. The hair samples at this point are extremely fragile and electrostatically charged to a highly undesirable level for handling. The handling of the hair without any loss at this point offered considerable problems and a satisfactory solution to this problem was developed during this investigation. The principle used in collecting the electrostatically charged hair samples quantitatively involved the use of a suction device and mounting the samples simultaneously at a reproducible geometry for counting purposes.

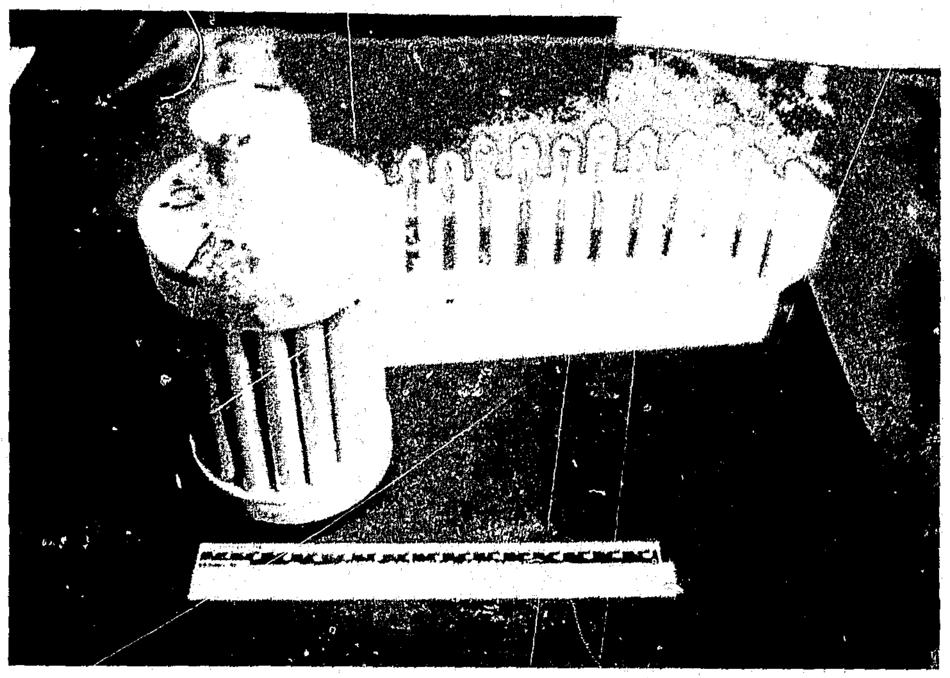

Figure 26(a). A View of Sealed Quartz Capsules and the Aluminum Container called "Merry-Go-Round"

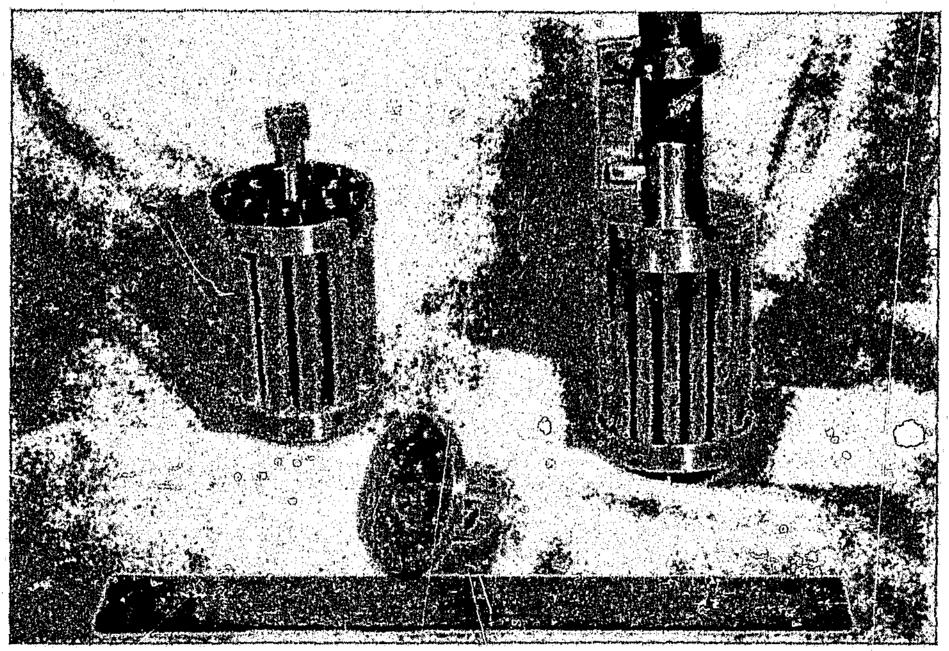

Figure 26(b). An Opened Merry-Go-Round Showing Sample Positions and an Illustration of Handling the Assembly for Reactor Irradiation

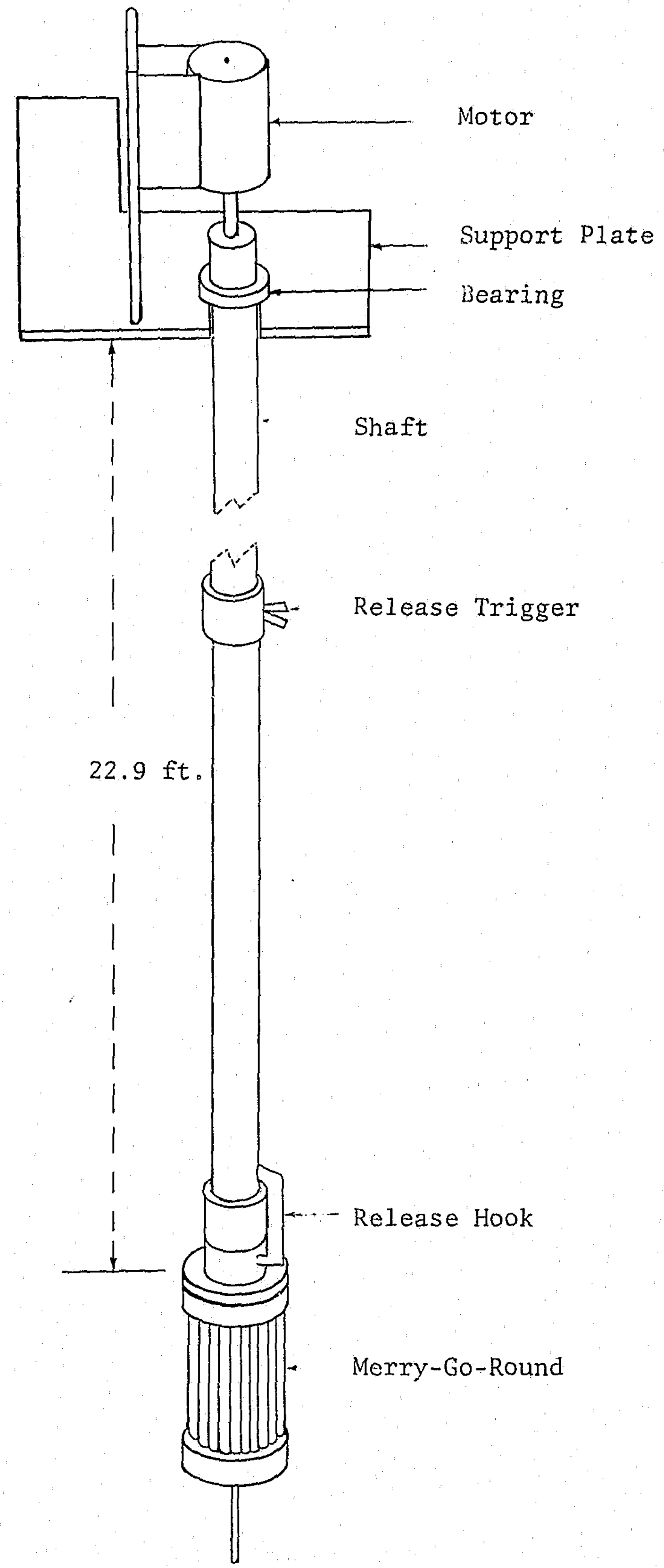

Figure 26(c). A Schematic Diagram Showing the Merry-Go-Round Facilities at the Penn State TRIGA Reactor

The counting vial used for collecting the hair samples is prepared by punching a small hole at the bottom of a two dram vial. A one centimeter long cylindrical plug of polyurathane foam is placed at the bottom of each vial. This tight fitting plug prevents the loss of fine particles of hair collected on its surface by applying suction at the bottom of the vial. Several such counting vials are prepared in advance and preserved for sample collection. An air pump using a 0.1 H.P. electric motor was used as a suction device. The irradiated hair sample contained in the aluminum foil is carefully separated after breaking open the quartz container. The crimped ends of the aluminum foil wrap are scissored out and the aluminum foil is opened. The specially prepared counting vial attached to the suction device containing the polyurathane plug is carefully placed over the hair sample. By carefully tilting the vial or by having small indentations made at the open end of the vial, an airflow is allowed through the counting vial. This method collects and retains the irradiated hair samples quantitatively on the surface of the sponge. While the suction pump is still working, the counting vial is inverted and sufficient quantities of additional polyurathane foam inserts are placed to retain the hair samples at a flat reproducible geometry. This procedure for the collection and mounting of the hair samples has been found to be extremely satisfactory. A schematic illustration of this sample collection procedure is included as an insert in Figure 27.

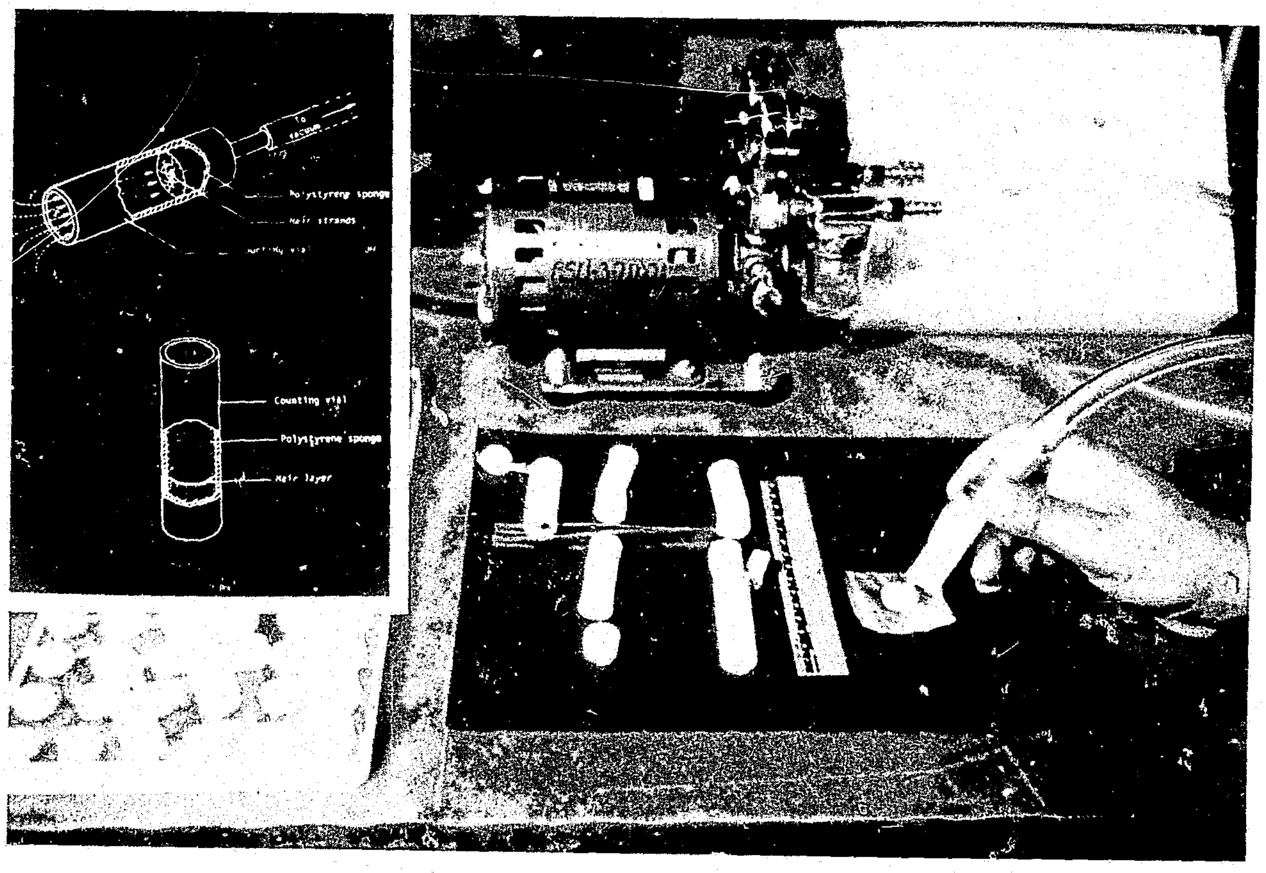

Figure 27. Equipment used and Illustration of the Method for the Collection and Mounting of Electrostatically Charged Hair Samples

2. Hair-Wash

The hair-wash samples prepared by dilute nitric acid extraction of the residues in the ether wash concentrator are placed in clean half-dram polyvials with snap caps. The vials are heat-sealed and irradiated in polyethylene rabbits observing the detailed procedures described for hair samples. When the samples return to the rabbit terminus after irradiation, the lid is quickly opened using a heated scalpel blade. The hair wash sample is then quantitatively transferred into a clean counting vial using several small rinses with deionized water. The quantities of water added to each sample is maintained almost the same using calibrated pipettes. The nitric acid used in sample preparation is periodically analyzed for blank determinations.

The hair-wash samples, after a decay period of a week or more, are transferred to specially fabricated quartz tube containers (10 mm I.D., 10 cm long). The hair-wash solutions are freeze dried in the quartz tubes and they are heat-sealed for merry-go-round irradiations. The irradiation of freeze-dried hair-wash samples is done in the same manner as described for hair samples. Freeze-drying of these samples almost eliminates the problems associated with the pressure build-up due to radiation decomposition of water. The quartz vials, after 25 hour irradiation and at least two days' decay, are opened by scratching the fabricated constriction of the container with a glass cutting file. The residues of hair-wash in the quartz vials are extracted using a carrier solution containing the trace elements being analyzed. The extract is placed on a one cm thick sponge placed at the bottom of a 2 dram polyvial. The quartz tubes are carefully rinsed out with warm dilute acid and this is also added to the counting vial. The entire extraction and rinsing is achieved by using a total volume of less than 1 ml of liquids. The hair wash samples now contained in the counting vials are centrifuged to bring all the liquid drops to the bottom of the vial and on to the sponge insert. This procedure allows for a counting geometry that could be reproduced for all hair-wash samples. All the analytical standards used in these long irradiations are similarly extracted using corresponding carrier mixtures and counted along with the samples.

G. Results

The data from gamma ray spectrometric measurements detailed in Table 10(a) are first processed using a computer program "ENERGY" to identify the γ-ray peaks and the contributions of these γ-rays in each spectrum. This data, along with similar data from analytical standards and flux monitors, is used to calculate the concentrations of various elements per unit weight of the hair sample. In expressing the analytical results of hair-wash samples, the weight of hair from which the hair-wash originated was used to calculate the results in terms of unit weight of hair.

The trace element compositions of 22 elements - Ti, I, Br, Mn, Cu, V, Cl, Al, Na, Ca, Se, Hg, Cr, Au, As, Sb, Ag, Sc, Zn, Co, Fe, and La - were calculated using certain unique gamma ray emissions of the (n,γ) products of these elements. The isotopes and the γ-rays employed in the quantitative determination of the above mentioned trace elements are listed in Table 10(b). In addition, it was recognized that in a

Table 10(b)

(n,γ) Products and the γ-Radiations used in the Quantitative Analyses of Trace Elements in Hair

Radioisotope	Half-Life	Specific γ-Radiation Used (Kev)	Other γ-Rays (Kev)
^{51}Ti	5.8 m	320.0	608.4, 928.5
^{128}I	25.0 m	442.7	526.3, 743.5, 968.9
^{80}Br	18.0 m	617.0	640.0, 665.7, etc.
^{56}Mn	2.58 h	846.8	1811.0, 2113.2
^{66}Cu	5.1 m	1039.0	833.6
^{52}V	3.8 m	1434.4	-
^{38}Cl	37.3 m	1642.0	2166.8
^{28}Al	2.3 m	1778.9	-
^{24}Na	15.0 h	1368.5	2754.1
^{49}Ca	8.5 m	3083.0	4071.0, 4680.0
^{75}Se	120.4 d	264.6	121.1, 279.5, 400.6, etc.
^{203}Hg	46.57 d	279.2	-
^{51}Cr	27.8 d	320.1	-
^{198}Au	64.63 h	411.8	657.9, 1087.7
^{76}As	26.5 h	559.1	657.0, 1216.3, etc.
^{124}Sb	60.3 d	1691.0	602.7, 722.7, 2091.1, etc.
^{110m}Ag	253.0 d	884.5	657.6, 937.3, 1384.3, etc.
^{46}Sc	84.0 d	889.3	1120.5
^{65}Zn	243.8 d	1115.5	β^+, -
^{60}Co	5.25 y	1173.2	1332.5
^{59}Fe	45.0 d	1099.7	1291.6
^{140}La	40.2 h	1596.2	328.7, 487.0, 815.8, etc.

composite spectrum, there are possibilities of contribution by γ-rays from other isotopes or from single or double escape peaks from high energy γ-radiations to the observed photopeak due to some of the isotopes. These problems were recognized as possible in the combinations of ^{75}Se-^{203}Hg, ^{110m}Ag-^{46}Sc, ^{65}Zn-^{46}Sc and ^{140}La-^{51}Cr. Whenever these interferences were recognized as significant, other γ-ray emissions from one of the isotopes were utilized to appropriately account for the level of interferences. In incorporating these corrections, the γ-ray spectra of the analytical standards irradiated along with the samples were used.

The results of all the analyses completed so far are included as Appendix B of this report. This list is incomplete because additional analyses of some of the samples were still in progress at the time of preparing this report. The efforts now underway are designed to complete the analyses of additional samples, to perform multiple analysis of hair samples from several individuals, to complete the work now underway to determine the levels of trace elements in 18 different shampoos and hair rinses used by the volunteers of this program, as well as to undertake a detailed statistical analysis of all the data. These efforts are being carried out as a thesis topic in partial fulfillment of the requirements of a master's program in Nuclear Engineering by one of our graduate students. Copies of this master's thesis, when completed, will be made available to the sponsors of this investigation.

The results presented in Appendix B are of hair samples from different groups of people, most of the samples being from students at the University Park campus of The Pennsylvania State University. The samples identified by numbers 1 through 400 are of freshmen students who entered Penn State during the Summer and Fall of 1972. The numbers 401 through 700 and 901 through 999 are of hair samples from the relatives (parents and siblings) of these student participants. Numbers 701 through 800 are for hair samples from other Pennsylvania residents. The hair samples analyzed and reported in Appendix B include samples collected at six month intervals from the same donors. The first collection has no alphabet as suffixes to the number. The second and the third collections have suffixes "x" and "y", respectively. Other suffixes (A, B and R) have been employed to identify more than one sample received from the same donor, the suffix "R" denotes pubic hairs.

A major portion of the results presented in Appendix B has been used to study the distribution patterns of trace elements in both hair and hair-wash samples. Histograms representing some of these results are illustrated in Figures 28 through 42. In comparing these distribution patterns with the work of other investigators (43,44,49, 52,54) certain similarities are evident, although the mode and median of these distributions vary significantly among the results of different investigators. These variations could be true variations due to differences in population groups or they could be variations due to systematic errors in the procedures employed during different studies. It is worth mentioning that some of these elements such as zinc, calcium, manganese, cobalt, etc., the analyses of which are probably the most reliable among the22 elements analyzed during this survey, show a near normal distribution pattern, whereas the results of the analysis of the other elements show highly skewed distribution patterns.

Figures 28 through 34 are representative distribution patterns of seven of the elements - Mn, Ca, Na, Cl, Cu, Co, and Zn - quantitatively determined during this study. Included in these illustrations are the differences in the distribution patterns of these elements between male and female volunteers of this group. There are observable differences in the concentration levels of calcium and manganese between hair samples from male and female subjects. These differences are, however, not observable in elements such as Cu, Co, etc. The randomness evident in the chlorine results is possibly due to the numerous sources of chlorine exposures through air, water, shampoos, hair rinses, coloring aids and other cosmetic preparations.

The results of the analyses of hair-wash samples are distinguished primarily by their nonconformity with any of the patterns for hair. This nonconformity can be an asset to making the analyses of hair-wash samples a valuable forensic science evidence. Some of the typical distribution patterns of trace elements found in hair-wash samples are presented in Figures 35 to 42, along with corresponding patterns of the same elements in hair samples. The hair-wash samples representing the surface contaminants of hair is characteristic of the environmental exposures of an individual, including personal habits of hair care and grooming. In order to examine the potentials of these new approaches to hair analysis as a forensic science evidence, some selected samples of hair received as evidence by the Pennsylvania State Police Crime Laboratory were analyzed. Numerous similarities between the analyses of two sets of

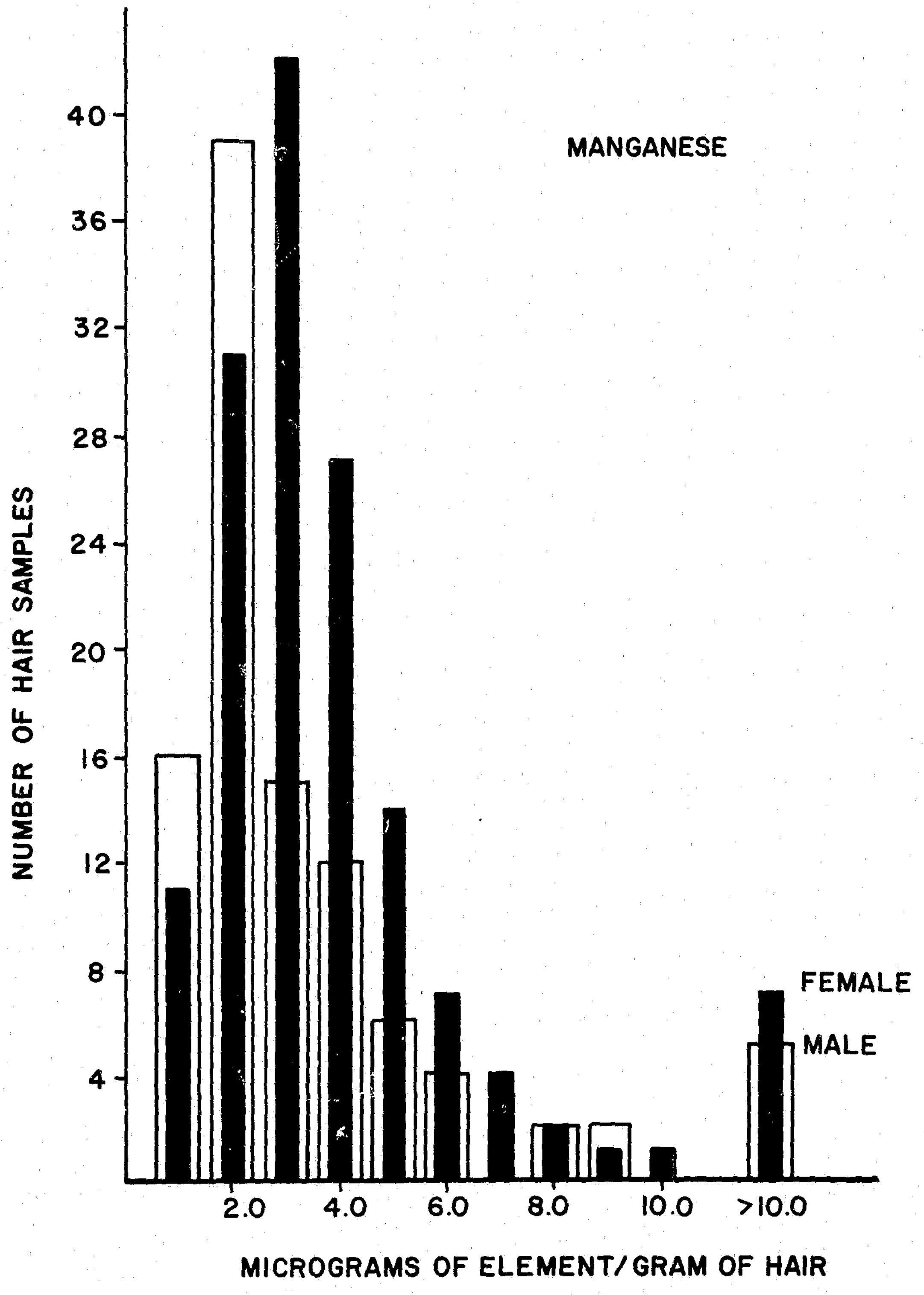

Figure 28. A Histogram Showing the Distribution Patterns of Manganese in Human Hair (Shaded Area Represents Female Volunteers)

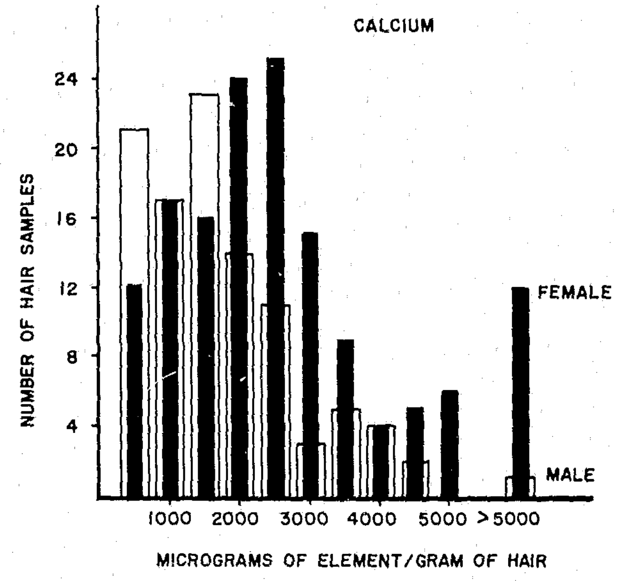

Figure 29. Distribution Patterns of Calcium in Human Hair

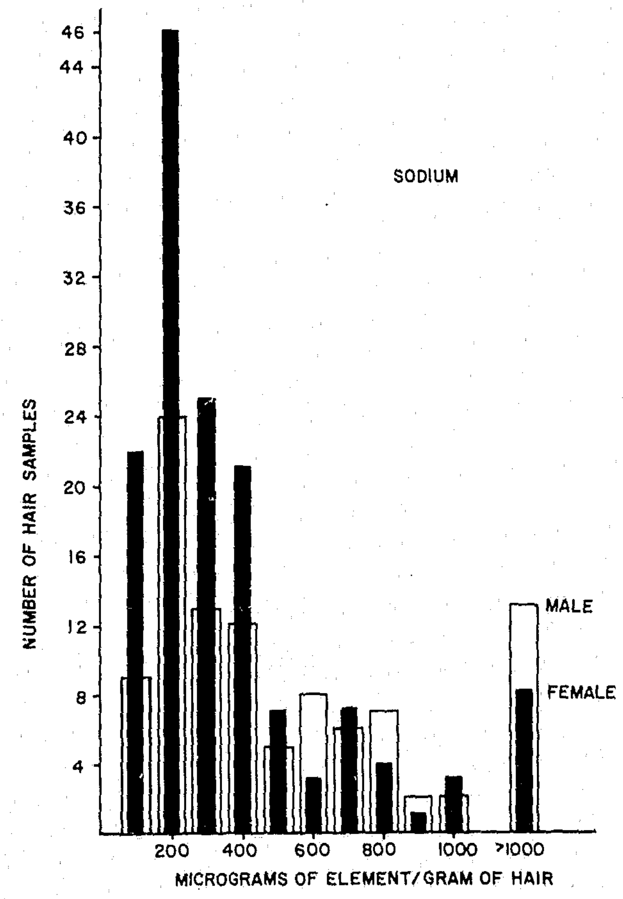

Figure 30. Distribution Patterns of Sodium in Human Hair

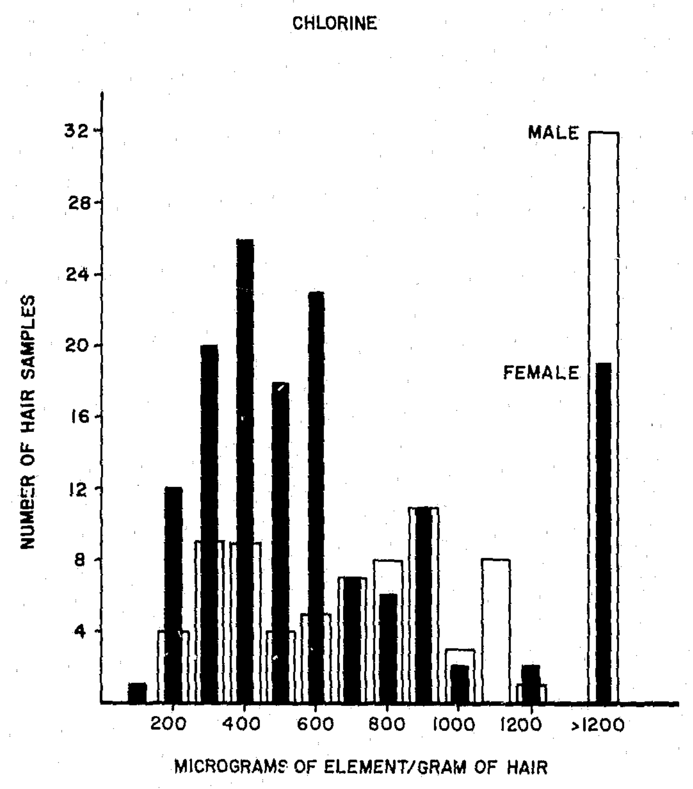

Figure 31. Distribution Patterns of Chlorine in Human Hair

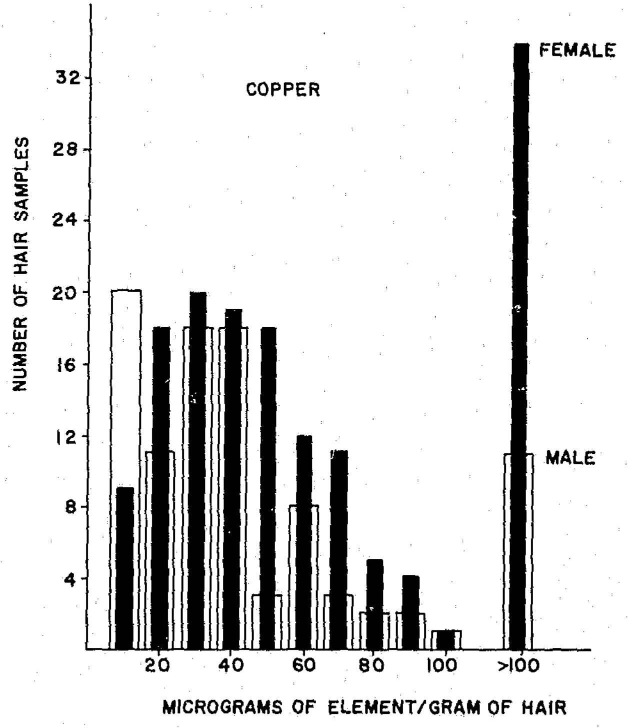

Figure 32. Distribution Patterns of Copper in Human Hair

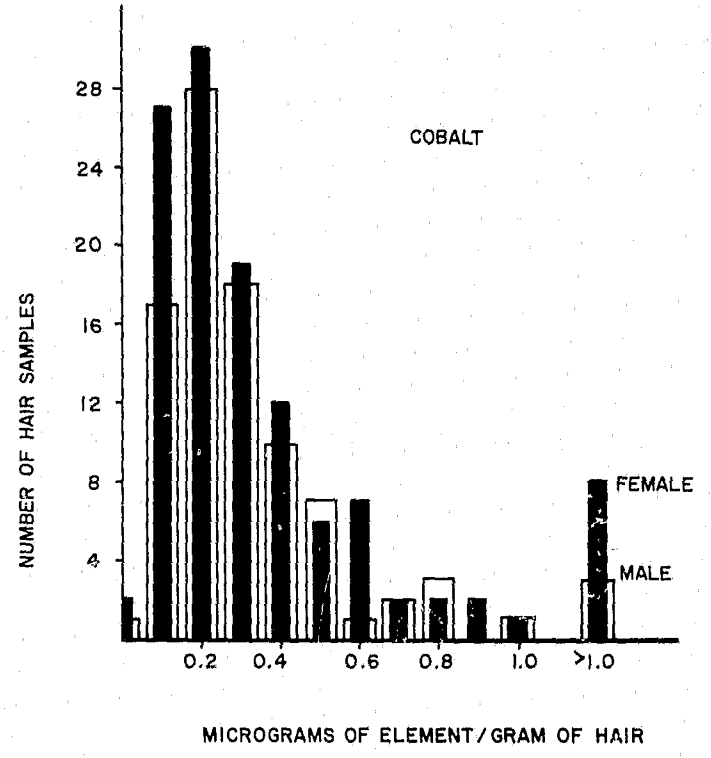

Figure 33. Distribution Patterns of Cobalt in Human Hair

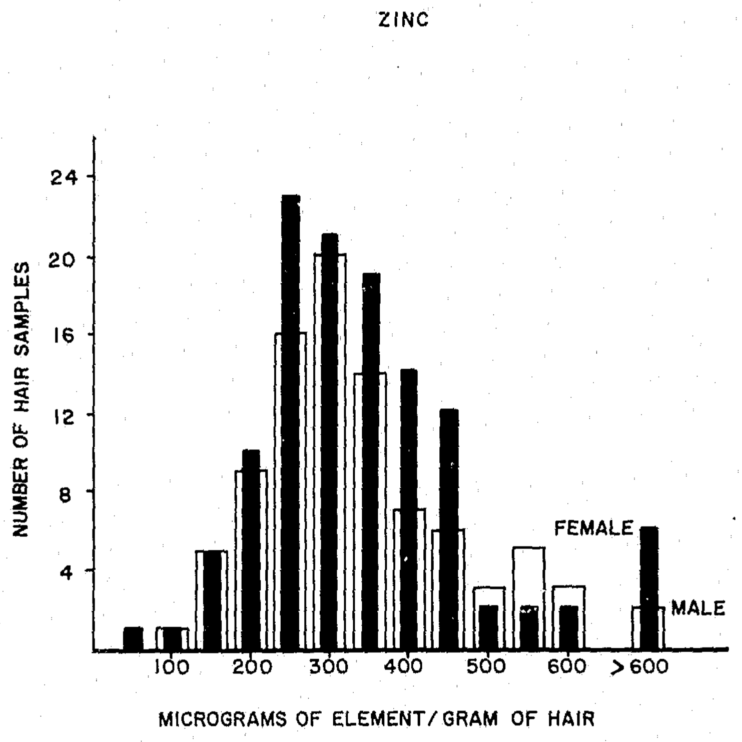

Figure 34. Distribution Patterns of Zinc in Human Hair

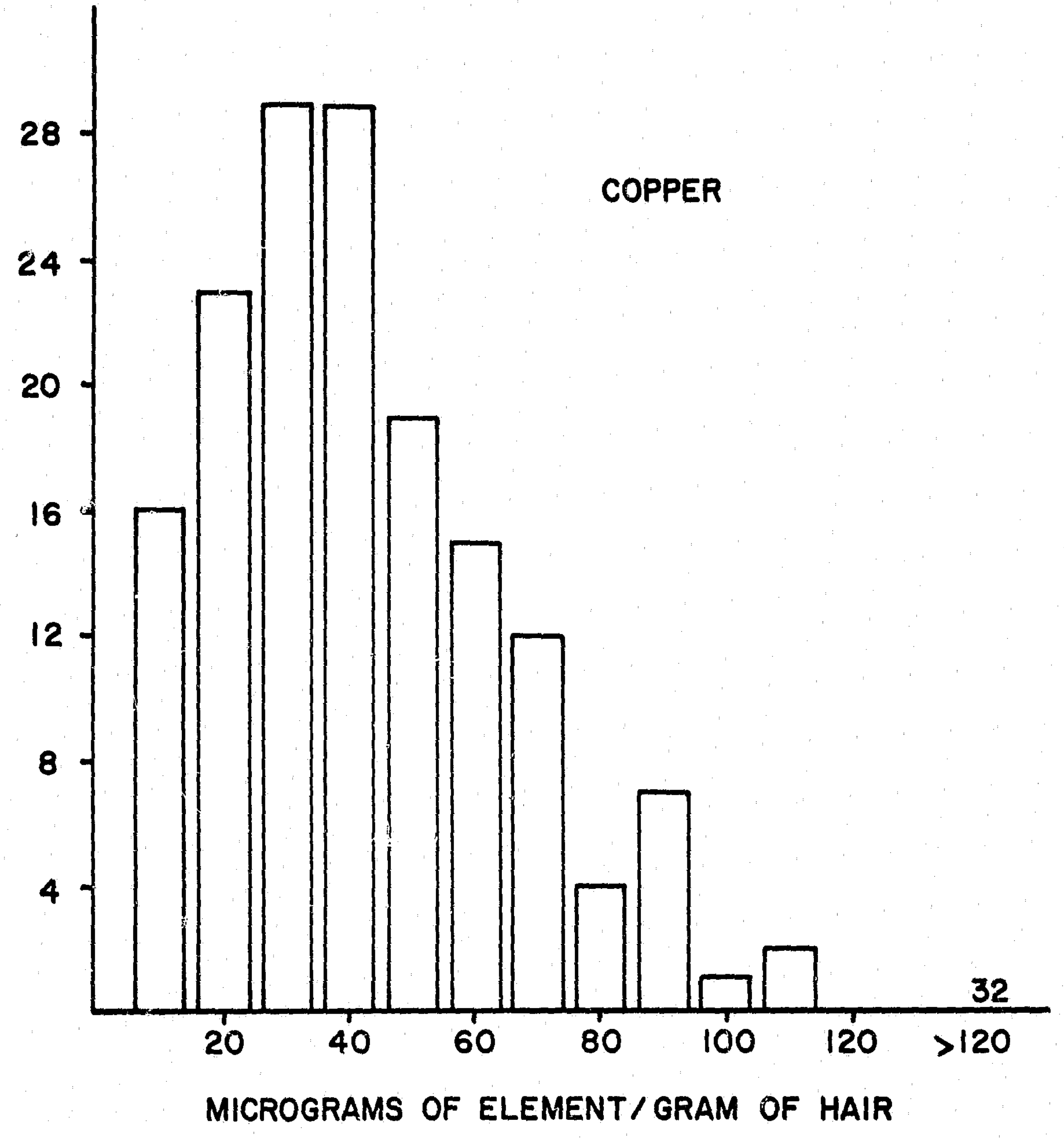

Figure 35. Distribution Pattern of Copper in Hair

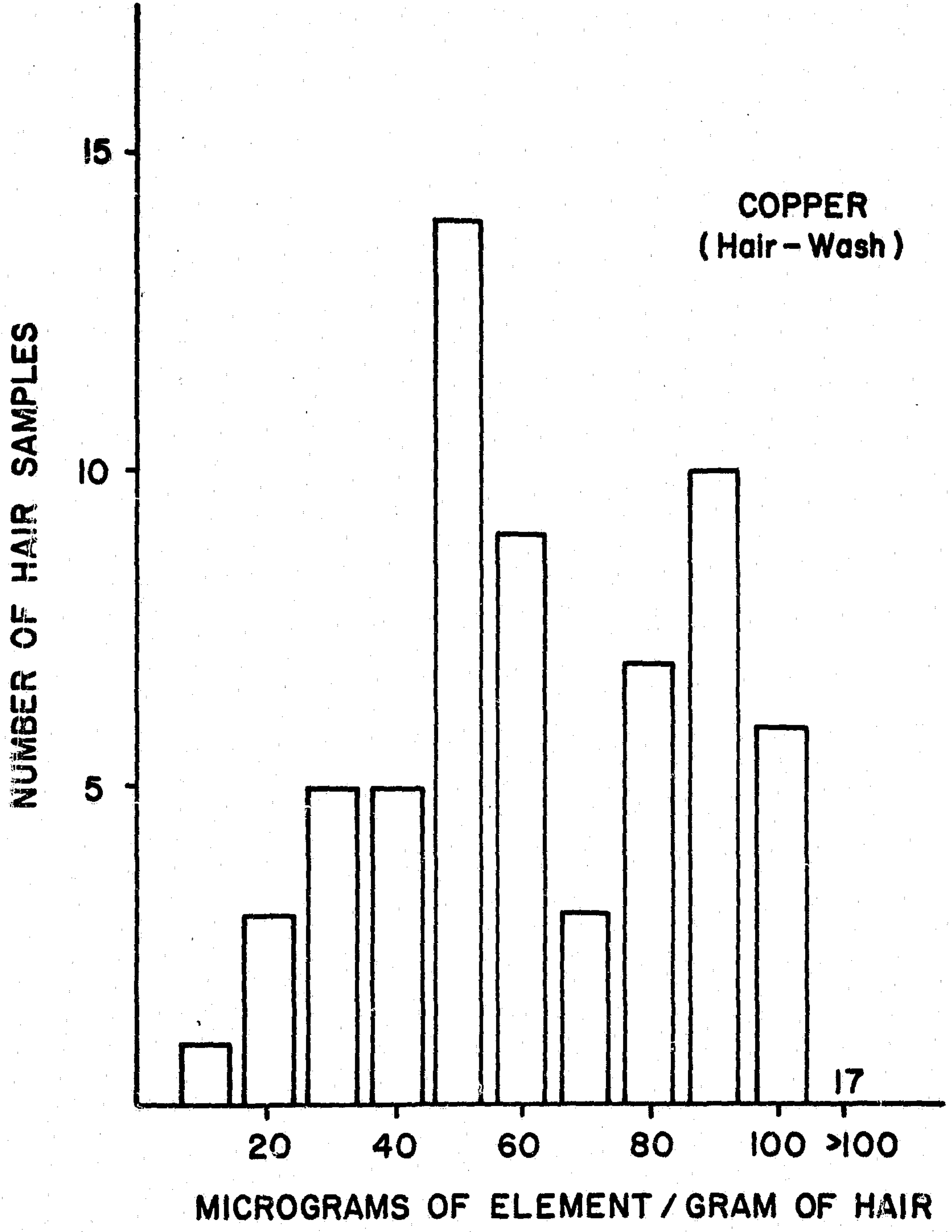

Figure 36. Distribution Pattern of Copper in Hair-Wash

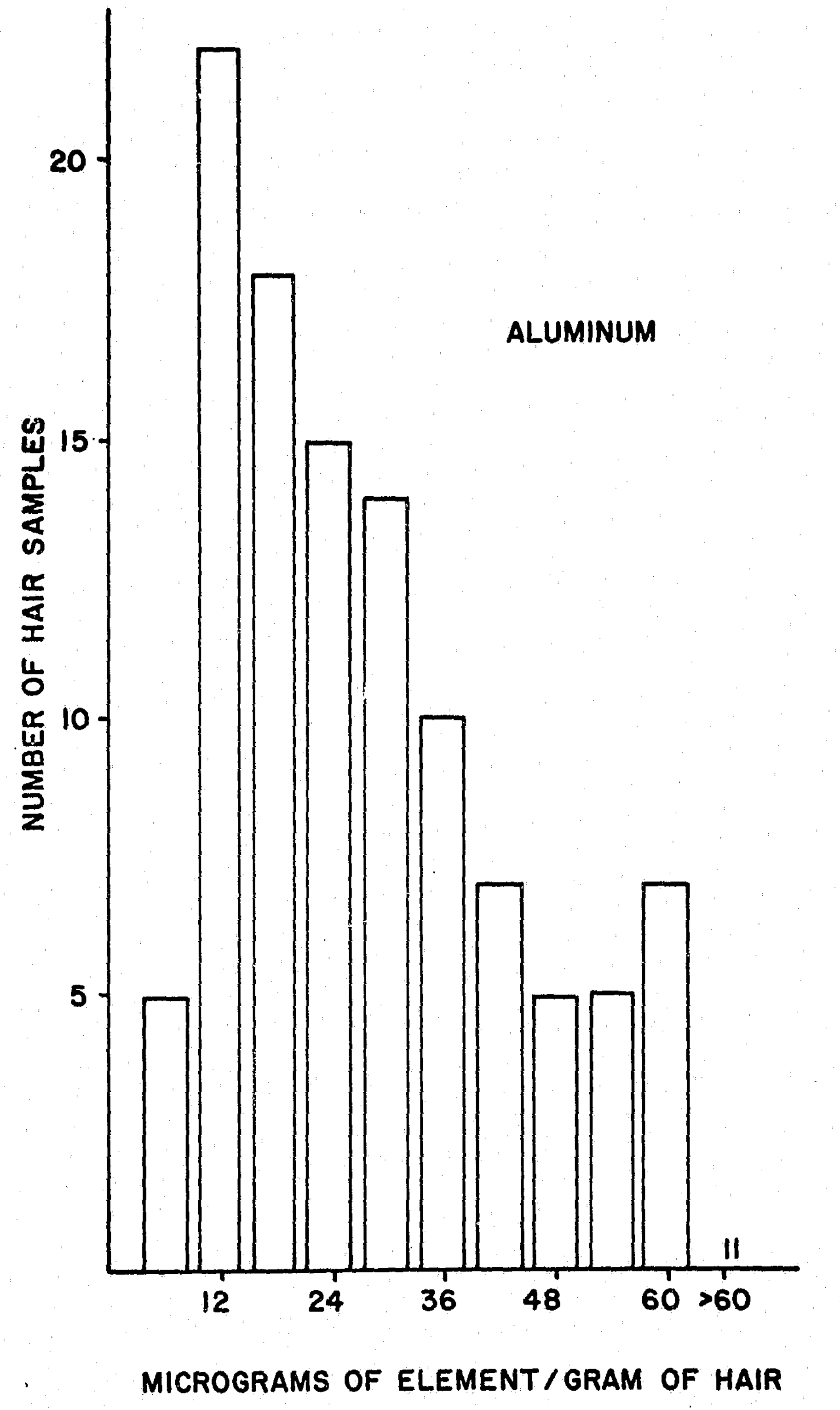

Figure 37. Distribution Pattern of Aluminum in Hair

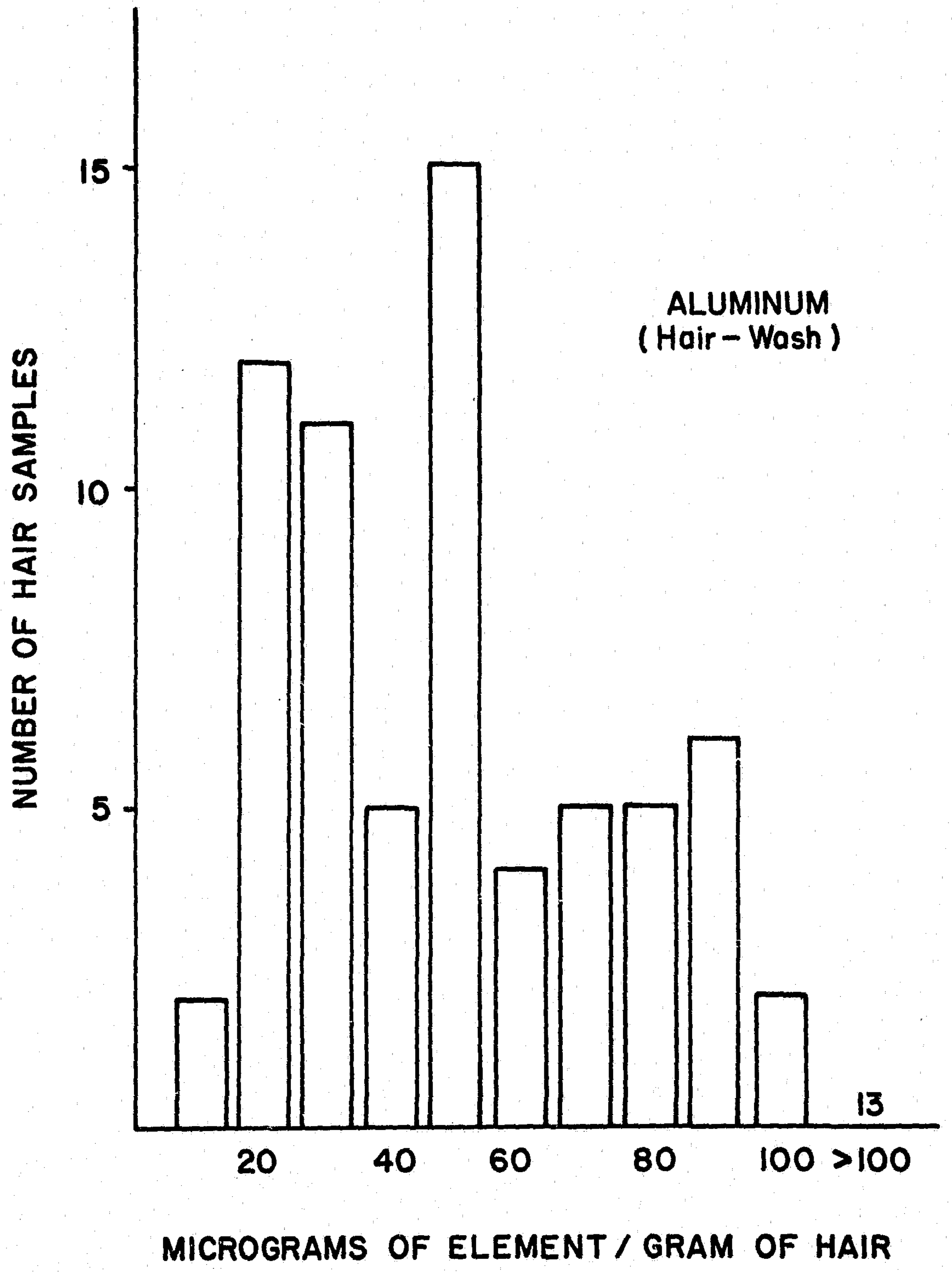

Figure 38. Distribution Pattern of Aluminum in Hair-Wash

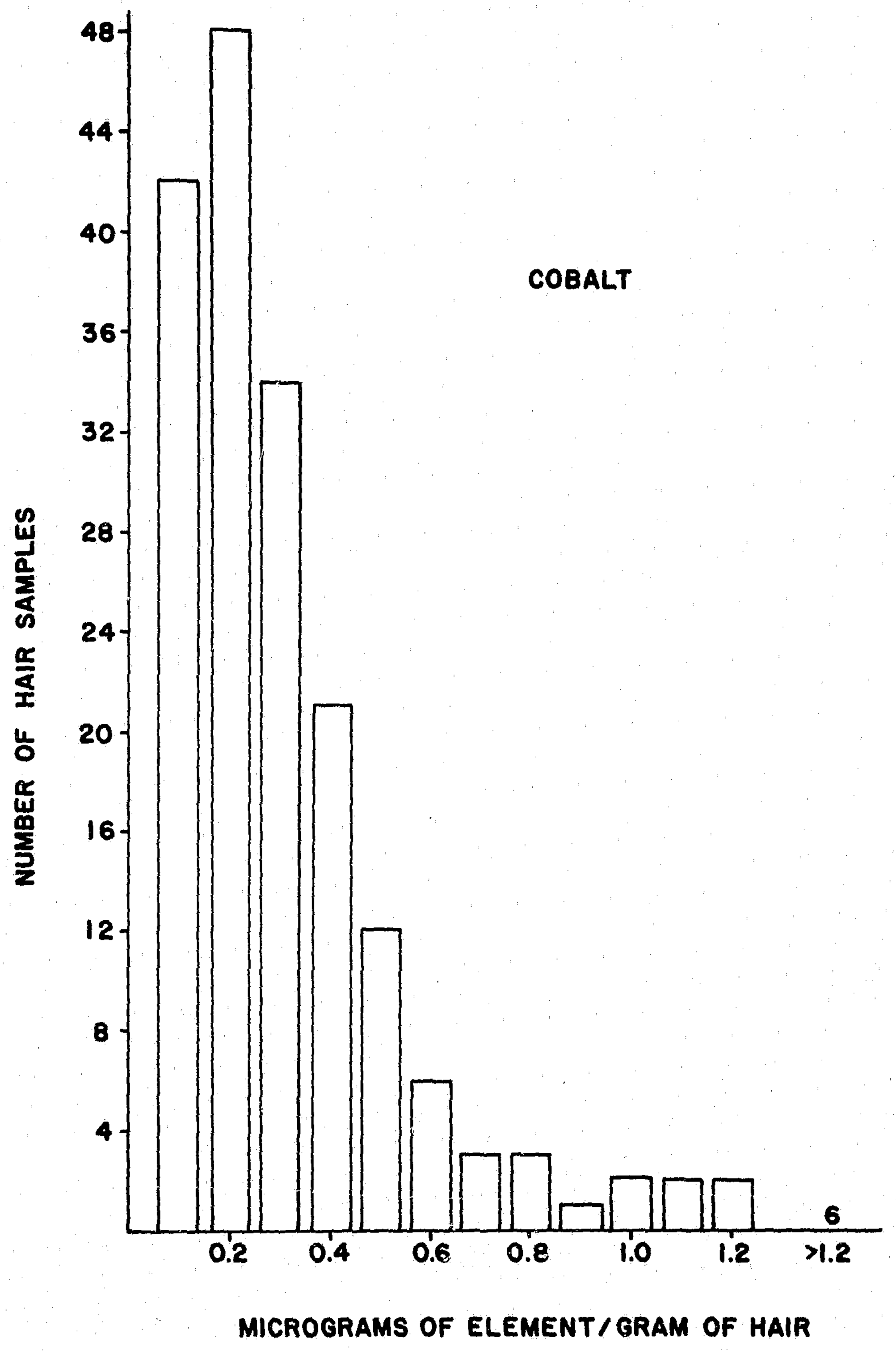

Figure 39. Distribution Pattern of Cobalt in Hair

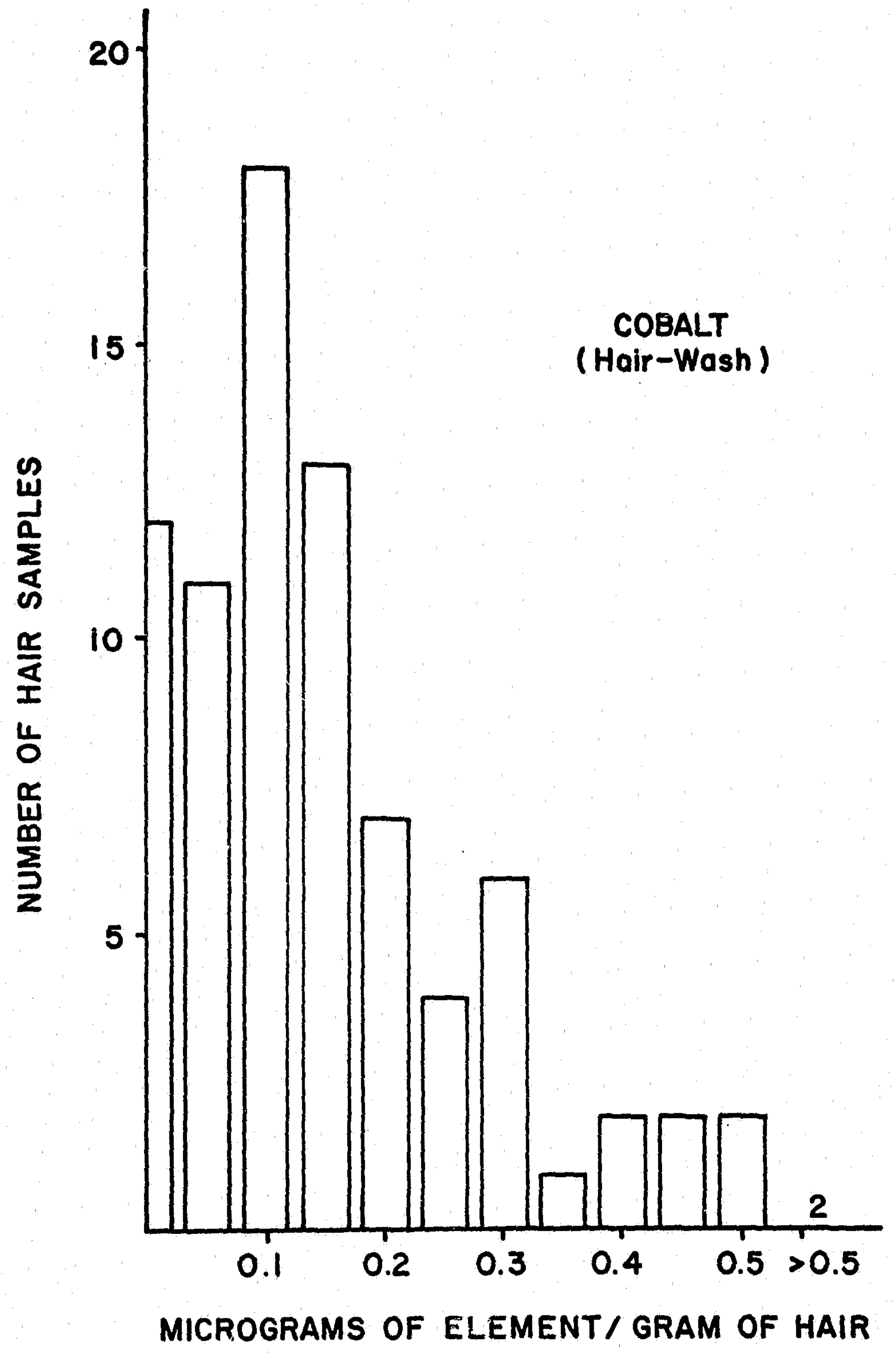

Figure 40. Distribution Pattern of Cobalt in Hair-Wash

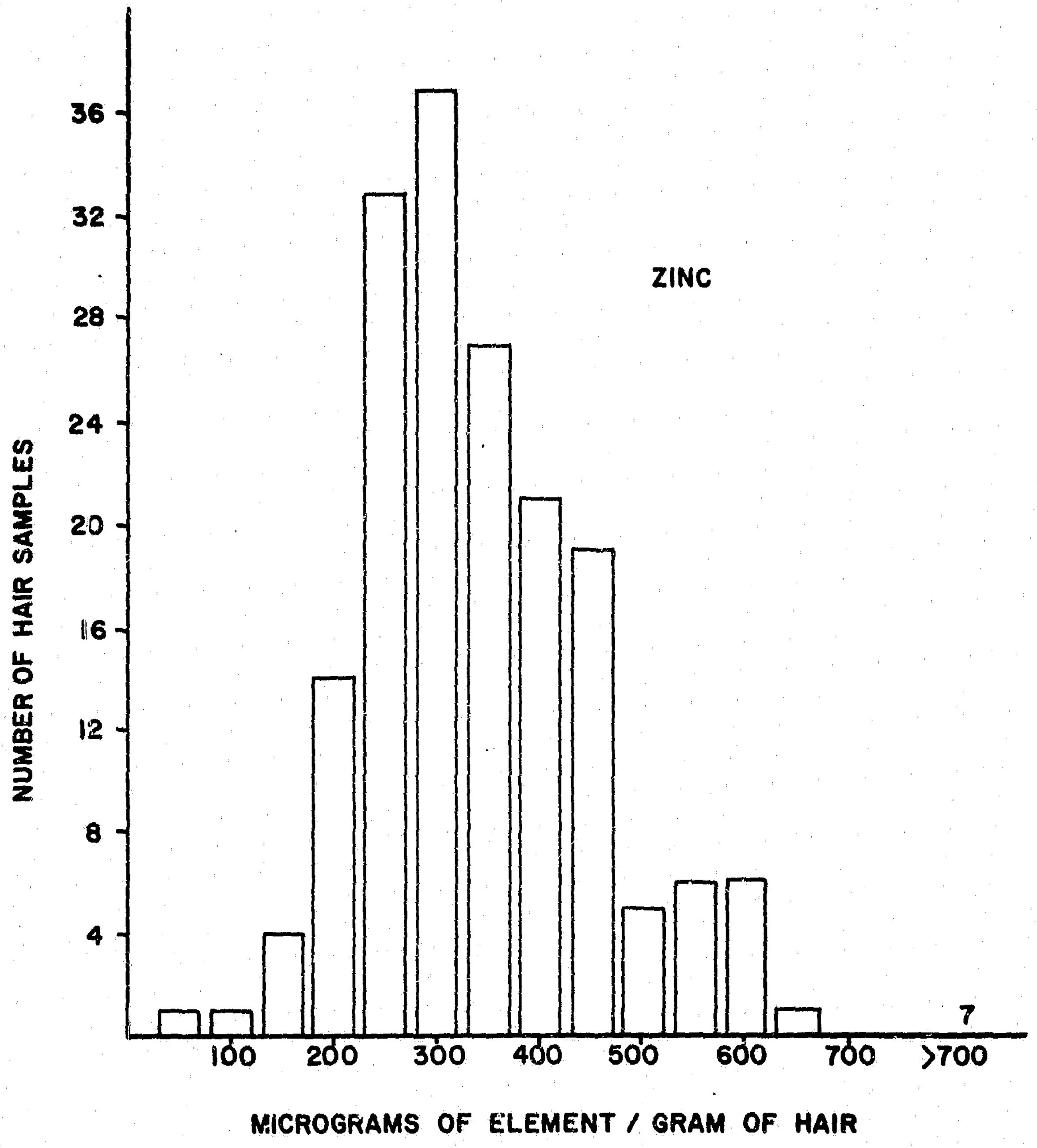

Figure 41. Distribution Pattern of Zinc in Hair

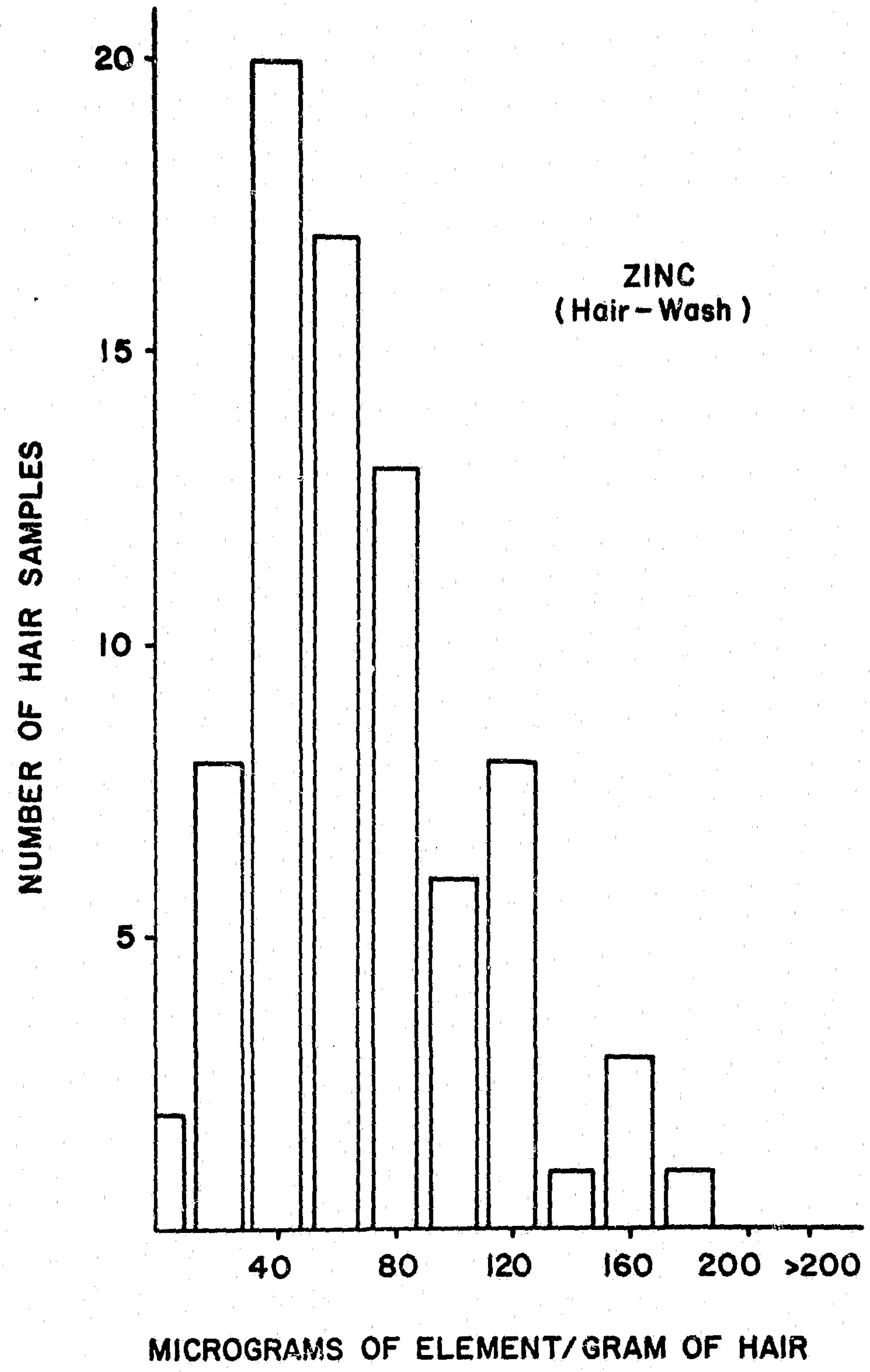

Figure 42. Distribution Pattern of Zinc in Hair-Wash

hairs and corresponding hair-wash samples showed a very high degree of probability for the common source of origin of these evidence materials. It should be added here that these evidences were not presented in court because of the lack of detailed information about the methods of collection and preservation of this evidence material.

In order to compare the observed variations of analytical results of trace elements, the coefficients of variance of these distributions are calculated and presented in Tables 11 through 20. The quotient, σ/μ, known as the coefficient of variance, is the standard deviation with the mean expressed as unity. The various tabulations considered here are the following:

a. A summary of all the results tabulated in Appendix B constitutes all the samples analyzed so far. This also represents people of different age groups, people originating from rural and urban areas and an almost equal number of male and female volunteers (Table 11).

b. Tables 12 and 13 are the results of hair and hair-wash analyses compared to examine differences, if any, due to sex.

c. A second comparison is made between rural and urban populations (as the volunteers described themselves) of this group. These results of hair and hair-wash analyses are presented in Tables 14 and 15, respectively.

d. A third, rather broad, classification considered is the division of the volunteers as freshmen students who entered The Pennsylvania State University and their

Table 11

Summary of the Analyses of Hair and Hair-Wash Samples

	HAIR			HAIR-WASH		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	10.6	19.3	1.82	4.2	12.3	2.93
I	0.6	1.2	2.00	0.01	0.10	10.00
Br	8.0	4.8	0.60	1.1	2.7	2.45
Mn	2.6	1.8	0.69	1.4	1.8	1.29
Cu	34	23	0.68	52	27	0.47
V	0.05	0.11	2.20	0.03	0.09	3.00
Cl	492	236	0.48	105	133	1.27
Al	23.8	13.6	0.57	30.5	14.4	0.47
Na	289	221	0.76	283	221	0.78
Ca	1854	1322	0.71	315	846	2.69
Se	1.3	1.1	0.85	0.2	0.5	2.50
Hg	6.3	6.4	1.02	0.4	0.6	1.50
Cr	1.6	4.7	2.94	1.5	2.5	1.67
Au	0.15	0.13	0.87	0.01	0.03	3.00
As	1.9	4.6	2.42	1.6	3.1	1.94
Sb	0.7	0.7	1.00	0.6	0.6	1.00
Ag	0.41	0.53	1.29	0.16	0.32	2.00
Sc	0.07	0.07	1.00	0.01	0.03	3.00
Zn	290	109	0.38	67	65	0.97
Co	0.30	0.21	0.70	0.19	0.19	1.00
Fe	30	28	0.93	26	28	1.08
La	0.06	0.25	4.17	0.42	1.05	2.50

Total number of samples of hair - 249

Total number of hair-wash samples - 187

Table 12

Comparison of the Trace Element Constituents of Human Hair
From Male and Female Volunteers

	MALE			FEMALE		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	6.9	17.7	2.57	13.2	19.9	1.51
I	0.52	1.16	2.23	0.64	1.28	2.00
Br	9.3	4.8	0.52	7.1	4.5	0.63
Mn	2.3	1.8	0.78	2.9	1.8	0.62
Cu	29	22	0.76	38	23	0.61
V	0.05	0.11	2.20	0.06	0.10	1.67
Cl	552	247	0.45	462	225	0.49
Al	21.6	12.9	0.60	25.3	13.9	0.55
Na	331	242	0.73	261	203	0.78
Ca	1429	1108	0.78	2160	1382	0.64
Se	1.2	1.1	0.92	1.3	1.1	0.85
Hg	4.9	5.2	1.06	7.2	6.9	0.96
Cr	2.3	6.3	2.74	1.1	3.1	2.82
Au	0.11	0.12	0.92	0.18	0.13	0.72
As	2.0	4.8	2.40	1.8	4.4	2.44
Sb	0.7	0.7	1.00	0.8	0.6	0.75
Ag	0.38	0.55	1.45	0.41	0.51	1.24
Sc	0.07	0.07	1.00	0.07	0.07	1.00
Zn	298	114	0.38	285	105	0.37
Co	0.29	0.19	0.66	0.31	0.21	0.68
Fe	27	29	1.07	32	27	0.84
La	0.06	0.24	4.00	0.07	0.25	3.57

Total number of male subjects - 102

Total number of female subjects - 147

Table 13

Comparison of the Trace Element Constituents of Hair-Wash Samples

From Male and Female Volunteers

	MALE			FEMALE		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	3.5	10.7	3.06	4.8	13.4	2.79
I	0.03	0.16	5.33	0.01	0.02	2.00
Br	1.3	3.5	2.69	0.9	1.9	2.11
Mn	1.1	1.7	1.55	1.6	1.9	1.19
Cu	51	28	0.52	53	26	0.49
V	0.02	0.06	3.00	0.04	0.11	2.75
Cl	80	111	1.39	123	145	1.18
Al	29.0	14.3	0.49	32.0	14.5	0.45
Na	252	220	0.87	307	221	0.72
Ca	233	614	2.64	376	980	2.61
Se	0.2	0.5	2.50	0.2	0.5	2.50
Hg	0.4	0.7	1.75	0.4	0.6	1.50
Cr	1.7	2.1	1.24	1.4	2.7	1.92
Au	0.01	0.03	3.00	0.01	0.03	3.00
As	1.9	4.3	2.26	1.4	2.1	1.50
Sb	0.6	0.6	1.00	0.6	0.6	1.00
Ag	0.19	0.42	2.21	0.15	0.26	1.73
Sc	0.01	0.03	3.00	0.01	0.04	4.00
Zn	78	57	0.73	60	68	1.13
Co	0.19	0.18	0.95	0.19	0.20	1.05
Fe	20	26	1.30	29	29	1.00
La	0.49	1.15	2.35	0.39	0.99	2.54

Total number of male subjects - 77

Total number of female subjects - 110

Table 14

Comparison of the Trace Element Constituents of Human Hair From Rural and Urban Populations

	RURAL			URBAN		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	11.3	19.3	1.71	9.9	19.4	1.96
I	0.60	1.35	2.25	0.59	1.09	1.85
Br	8.0	5.0	0.63	7.9	4.5	0.57
Mn	2.8	1.9	0.68	2.4	1.7	0.71
Cu	39	25	0.64	29	20	0.69
V	0.05	0.10	2.00	0.05	0.11	2.20
Cl	498	237	0.48	486	236	0.49
Al	25.1	13.4	0.53	22.3	13.8	0.62
Na	286	217	0.76	291	226	0.78
Ca	2008	1450	0.72	1685	1148	0.68
Se	1.3	1.0	0.77	1.3	1.1	0.85
Hg	6.1	6.0	0.98	6.4	6.8	1.06
Cr	1.5	4.3	2.87	1.8	5.2	2.89
Au	0.14	0.12	0.86	0.16	0.14	0.88
As	2.4	5.4	2.25	1.2	3.3	2.75
Sb	0.7	0.6	0.86	0.7	0.7	1.00
Ag	0.4	0.5	1.25	0.40	0.53	1.33
Sc	0.07	0.06	0.86	0.07	0.07	1.00
Zn	301	109	0.36	279	108	0.39
Co	0.30	0.20	0.67	0.30	0.19	0.63
Fe	31	27	0.87	29	29	1.00
La	0.07	0.26	3.71	0.06	0.24	4.00

Total number of participants identified as "Rural" population - 130

Total number of participants identified as "Urban" population - 119

Table 15

Comparison of the Trace Element Constituents of Hair-Wash Samples

From Rural and Urban Populations

Elements Analyzed	RURAL μ (Mean)	 σ Standard (Deviation)	 σ/μ	URBAN μ (Mean)	 σ Standard (Deviation)	 σ/μ
Ti	5.0	14.0	2.80	3.3	10.0	3.03
I	0.02	0.12	6.00	0.01	0.07	7.00
Br	0.8	2.3	3.83	1.3	3.1	2.38
Mn	1.4	2.0	1.43	1.4	1.6	1.23
Cu	51	27	0.53	53	27	0.51
V	0.04	0.09	2.25	0.03	0.10	3.33
Cl	95	113	1.19	118	155	1.31
Al	28.1	14.7	0.52	33.5	13.6	0.41
Na	276	231	0.84	274	209	0.76
Ca	322	938	2.91	308	734	2.38
Se	0.19	0.58	3.05	0.17	0.47	2.76
Hg	0.4	0.7	1.75	0.4	0.6	1.50
Cr	1.6	3.0	1.88	1.4	1.9	1.36
Au	0.01	0.01	1.00	0.01	0.04	4.00
As	1.0	1.7	1.70	2.2	4.1	1.86
Sb	0.5	0.6	1.20	0.6	0.6	1.00
Ag	0.16	0.37	2.31	0.16	0.27	1.69
Sc	0.01	0.03	3.00	0.01	0.04	4.00
Zn	61	51	0.84	73	76	1.04
Co	0.19	0.19	1.00	0.19	0.20	1.05
Fe	22	26	1.18	30	30	1.00
La	0.36	0.94	2.61	0.49	1.15	2.35

Total number of persons identified as "Rural" population - 101

Total number of persons identified as "Urban" population - 86 parents. The student population fell within a very narrow age group of 17 to 19 years, while the age of the parents ranged from 35 to 60 years. The classification of the analyses of hair and hair-wash samples are presented in Tables 16 and 17.

e. Table 18 is the summary of the analyses of several hair samples from two subjects. Eighteen separate samples were collected from these two subjects during a two week period using the collection procedures described earlier. These samples were analyzed separately and these analyses show the overall distribution of the analytical results among the hair samples from the same individuals collected within a short period of time and analyzed using the procedures described here.

f. Another comparison made in Tables 19 and 20 is the variations of trace element constituents within human hair and in the hair-wash samples of the students who entered the University Park campus of The Pennsylvania State University during the Summer and Fall of 1972. The two time periods involved are 1) before the arrival of students to the campus and 2) six months after they have remained on the campus respectively. Two of the known major changes that took place immediately after the first sample collection were: a) the change in the dietary

Table 16

Differences in the Trace Element Concentrations of Hair Constituents among Two Different Age Groups

	PSU STUDENTS (17-19 YEARS)			PARENTS OF STUDENTS (35-65 YEARS)		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	11.0	19.1	1.74	8.9	20.2	2.27
I	0.63	1.29	2.05	0.40	0.89	2.23
Br	7.7	4.6	0.60	9.5	5.5	0.58
Mn	2.6	1.7	0.65	3.0	2.2	0.73
Cu	35	22	0.63	27	25	0.93
V	0.05	0.10	2.00	0.06	0.12	2.00
Cl	480	230	0.48	580	264	0.46
Al	24.0	13.8	0.58	22.6	12.6	0.56
Na	265	205	0.77	438	260	0.59
Ca	1910	1300	0.68	1580	1420	0.90
Se	1.3	1.0	0.77	1.1	1.2	1.09
Hg	6.6	6.5	0.98	4.1	5.1	1.24
Cr	1.5	4.3	2.87	2.4	7.0	2.91
Au	0.15	0.13	0.87	0.16	0.14	0.88
As	2.0	4.7	2.35	1.1	3.8	3.45
Sb	0.8	0.6	0.75	0.6	0.7	1.17
Ag	0.40	0.54	1.35	0.36	0.44	1.22
Sc	0.07	0.07	1.00	0.07	0.05	0.71
Zn	302	109	0.36	225	82	0.37
Co	0.29	0.19	0.66	0.35	0.22	0.63
Fe	30	27	0.90	32	31	0.97
La	0.06	0.23	3.83	0.06	0.35	5.83

Total number of PSU students - 206
Total number of parents - 43

Table 17

Differences in the Trace Element Contents of Hair-Wash Samples among Two Different Age Groups

	PSU STUDENTS (17-19 YEARS)			PARENTS OF STUDENTS (35-65 YEARS)		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	4.4	12.4	2.82	3.1	12.1	3.90
I	0.02	0.11	5.50	0.01	0.18	18.00
Br	1.0	2.4	2.40	1.4	4.4	3.14
Mn	1.3	1.8	1.38	2.0	2.2	1.10
Cu	52	26	0.50	55	37	0.67
V	0.03	0.07	2.33	0.07	0.17	2.43
Cl	108	135	1.25	81	117	1.44
Al	30.5	14.7	0.48	31.2	7.2	0.23
Na	285	223	0.78	275	219	0.80
Ca	336	890	2.65	180	447	2.48
Se	0.2	0.6	3.00	0.01	0.06	6.00
Hg	0.4	0.7	1.75	0.2	0.4	2.00
Cr	1.5	2.6	1.73	1.0	2.0	2.00
Au	0.01	0.02	2.00	0.02	0.05	2.50
As	1.5	2.8	1.87	2.4	5.1	2.13
Sb	0.6	0.6	1.00	0.3	0.5	1.67
Ag	0.16	0.32	2.00	0.17	0.35	2.06
Sc	0.01	0.04	4.00	0.01	0.02	2.00
Zn	69	66	0.96	51	56	1.10
Co	0.20	0.20	1.00	0.14	0.11	0.79
Fe	25	27	1.08	32	33	1.03
La	0.46	1.10	2.39	0.16	0.40	2.50

Total number of PSU students - 163

Total number of parents - 24

Table 18

Multiple Analyses of Human Hair

Elements Analyzed	SUBJECT 1 Mean	Standard Deviation	Coeff. of Variance	SUBJECT 2 Mean	Standard Deviation	Coeff. of Variance
Ti	N.D.*	N.D.	N.D.	N.D.	N.D.	N.D.
I	2.6	1.6	0.62	0.08	0.34	4.25
Br	4.0	1.8	0.45	15.5	2.6	0.17
Mn	2.0	1.2	0.60	1.1	0.3	0.27
Cu	26.9	16.9	0.63	27.5	12.7	0.46
V	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Cl	103	55	0.53	807	130	0.16
Al	9.5	5.6	0.59	15.8	3.4	0.22
Na	83	42	0.51	243	37	0.15
Ca	4224	2595	0.61	910	223	0.25
Se	0.8	0.6	0.75	0.5	0.3	0.60
Hg	1.0	1.7	1.70	N.D.	N.D.	N.D.
Cr	2.6	3.1	1.19	0.4	0.5	1.25
Au	0.40	0.18	0.45	0.35	0.99	2.82
As	0.6	0.5	0.83	9.9	2.0	0.20
Sb	0.9	0.5	0.56	0.7	0.5	0.71
Ag	0.36	0.30	0.83	0.3	0.2	0.67
Sc	0.06	0.02	0.33	0.04	0.02	0.50
Zn	236	42	0.18	169	33	0.20
Co	0.12	0.03	0.25	0.11	0.03	0.27
Fe	103	45	0.44	34	17	0.50
La	0.09	0.3	3.33	N.D.	N.D.	N.D.

*N.D. - Not detectable by the analytical procedures employed

Total number of samples from each subject - 18

Table 19

Comparison of the Variations of Trace Element Concentrations within Human Hair During a Six Month Interval

	1ST SAMPLING			2ND SAMPLING		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	11.1	20.1	1.81	13.2	21.2	1.61
I	0.43	1.05	2.44	0.52	0.79	1.52
Br	7.9	4.6	0.58	7.6	4.4	0.58
Mn	2.8	1.9	0.68	2.2	1.2	0.55
Cu	32	22	0.69	41	22	0.54
V	0.06	0.12	2.00	0.04	0.07	1.75
Cl	508	235	0.46	442	223	0.50
Al	26.2	14.9	0.57	20.7	12.0	0.58
Na	287	220	0.77	234	178	0.76
Ca	1758	1275	0.73	2194	1247	0.57
Se	1.6	1.0	0.63	1.0	0.9	0.90
Hg	8.3	6.9	0.83	4.4	5.2	1.18
Cr	1.6	5.3	3.31	2.2	5.1	2.32
Au	0.16	0.14	0.88	0.15	0.12	0.80
As	1.9	4.5	2.37	2.5	5.2	2.08
Sb	0.8	0.7	0.88	0.8	0.7	0.88
Ag	0.44	0.55	1.25	0.39	0.52	1.33
Sc	0.07	0.07	1.00	0.07	0.07	1.00
Zn	334	104	0.31	282	103	0.37
Co	0.34	0.21	0.62	0.23	0.16	0.70
Fe	30	27	0.90	31	27	0.87
La	0.11	0.36	3.27	0.03	0.07	2.33

Total number of samples from 1st collection - 119

Total number of samples from 2nd collection - 58

Table 20

Comparison of the Variations of Trace Element
Compositions of Hair-Wash Samples from Human Hair
Collected at Six Month Interval

	1ST SAMPLING			2ND SAMPLING		
Elements Analyzed	μ (Mean)	σ Standard (Deviation)	σ/μ	μ (Mean)	σ Standard (Deviation)	σ/μ
Ti	4.5	11.3	2.51	4.8	14.7	3.06
I	0.01	0.08	8.00	0.03	0.15	5.00
Br	0.5	1.0	2.00	2.3	4.3	1.87
Mn	0.8	1.2	1.50	2.2	2.2	1.00
Cu	51	26	0.51	54	26	0.48
V	0.02	0.05	2.50	0.05	0.09	1.80
Cl	75	79	1.05	172	184	1.07
Al	28.4	13.9	0.49	36	15	0.42
Na	222	181	0.82	383	255	0.67
Ca	238	843	3.54	553	1000	1.81
Se	0.2	0.7	3.50	0.2	0.4	2.00
Hg	0.5	0.7	1.40	0.4	0.6	1.50
Cr	1.3	1.9	1.46	2.2	3.4	1.55
Au	0.01	0.01	1.00	0.01	0.04	4.00
As	0.7	1.0	1.43	3.0	4.7	1.57
Sb	0.5	0.5	1.00	0.8	0.7	0.88
Ag	0.11	0.36	3.27	0.26	0.32	1.23
Sc	0.01	0.03	3.00	0.02	0.04	2.00
Zn	61	52	0.85	85	82	0.96
Co	0.14	0.15	1.07	0.27	0.23	0.85
Fe	19	26	1.37	34	25	0.74
La	0.33	1.22	3.70	0.68	1.02	1.50

Total number of samples from 1st collection - 95

Total number of samples from 2nd collection - 42 habits - all the freshmen changed from dietary habits at their respective homes to consuming institutional diets at the dormitories; and b) the change in their environment to a common nonindustrialized community around the University campus.

The coefficients of variance from the multiple analyses of hair samples presented in Table 18 when compared with similar values calculated for the general population of this study (Table 11) show the magnitudes of variations that could be expected within a person and within a population group. These comparisons also reveal possibilities and limitations of neutron activation analysis of human hair as a forensic science evidence. It should be admitted that this investigation has not been extensive enough to answer all the questions regarding human hair analyses, although we feel that the methods of isolating and analyzing both the hair constituents and its surface contaminants have practical value in comparing limited numbers of hair samples to determine their common source of origin.

As mentioned earlier, an extensive discussion of these results will be considered separately. There are several interesting observations to be made from the tabulations presented here. The comparisons made in these tables (11 through 20) not only have value to forensic science analysis, they seem to have more significance to the further understanding of the role of trace elements in human health.

about 10 mg of hair and the irradiation conditions used in this investigation, only about twenty of them can be reliably analyzed.

4. Of the nearly twenty elements that are analyzable by nondestructive neutron activation analysis, only about ten of them - Ca, Zn, Na, Cu, Cl, Al, Mn, Co, Fe, and Se - can be determined with good precision and accuracy at the levels that are normally found in human hair.
5. It can be argued that the isolation and analysis of hair-wash residues have potentials of becoming useful forensic evidence in determining the common source of origin of different hair samples, provided adequate care was taken in the collection and preservation of evidence samples.
6. There are measurable differences in the trace element compositions of hair samples collected from the same volunteers at six month intervals.
7. Some of the hair preparations and grooming aids contribute to certain uniquely high levels of specific trace elements in hair and/or hair-wash samples. Such information could have valuable forensic significance.
8. There are recognizable differences in some of the trace element levels in hair of people of different age groups.
9. The analysis of the trace element constituents of hair and hair-wash samples by neutron activation is both time consuming and expensive. Its possible

application in criminal investigation has to be determined by competent authorities with the benefit of the field investigator's findings.

10. Although neutron activation analysis of hair cannot fulfill all the high expectations of individualization of human hair, it still has a vital role to play in forensic science investigations. If characterization of the trace element profile of hair and/or hair-wash could identify the common source of the origin of hair, there is no analytical method known today which is as versatile and as sensitive as neutron activation analysis.

Since hair is a common physical evidence at crime scenes involving physical violence and hair is resistant to degradation than most other human tissue, there is considerable interest in developing better use of these evidence materials. The limitations of morphological examinations have led to the search for other methods of examining hair samples as a forensic science evidence. These new methods include trace elemental analysis and the examination of genetically determined variants in the structural proteins of human hair. Continuous investigations of the trace element constituents and compositions of human hair over the past decade have developed several useful applications of this method, while pointing out its limitations. There are very sound scientific reasons behind the methods of comparing physical evidences to determine their common source of origin through the analysis of their trace element composition. The accumulated knowledge regarding the nature of trace elements in human hair makes the possibilities of individualizing human hair of a large population group rather difficult. However, if the hair samples collected during a criminal investigation is done with the knowledge of this limitation and if it is desired that the hair found at the scene of a crime be compared with those of a limited number of suspects, there are extremely useful comparisons that can be made from the analyses of the trace element compositions of hair and hair-wash samples using the procedures described here.

VI. ^{252}Cf NEUTRON SOURCE DEVELOPMENT

A. Background

Neutron activation analysis is a powerful analytical technique which requires the availability of moderately intense neutron fields. The primary source of such neutron fields today is research reactors which are primarily funded at certain government laboratories and some of the large universities. There are relatively few of these throughout the country, and because of the high construction and operation cost, the prospects of increasing this number is dim. The Pennsylvania State University Breazeale Nuclear Reactor is the only research reactor facility in Pennsylvania.

Because of the increasing demands of radionuclear applications in various fields, there is considerable interest in the development and use of nonreactor neutron sources such as accelerators and radioactive isotopes. The standard small accelerator has a usable thermal flux of 1×10^5 to 1×10^8 n/cm^2-sec (59). Short target life and maintenance have been a factor in making the accelerator unattractive for a neutron source. Another nonreactor neutron source is the isotopic neutron source which is free from maintenance and is simple to utilize. The (γ,n) sources like ^{124}Sb - ^{9}Be produce a neutron flux of the order of 6×10^8 n/cm^2-sec (60-62). Since ^{124}Sb has a half-life of only 60 days, the source must be reactivated two or three times a year. One of the other less attractive features of this neutron source is the rather high gamma flux associated with the thermal neutron flux. Although a neutron flux of 10^8 n/cm^2-sec are satisfactory for many applications, including neutron radiography, thermal fluxes of 10^{10} n/cm^2-sec or greater are usually needed for radioisotope production and neutron activation analysis of forensic or biological samples.

In the past few years, a new isotopic source, californium-252 (^{252}Cf), has become available. It holds great promise for producing a less costly neutron source having reasonable neutron intensities. One milligram of ^{252}Cf emits by spontaneous fission 2.34 x 10^9 n/sec and this isotope is now available in microgram and milligram quantities (63). The present cost of ^{252}Cf is $10 per microgram so that the large quantities required to produce adequate neutron fields makes such a source currently too expensive for these purposes. However, it is possible to multiply a neutron source with a subcritical reactor by more than an order of magnitude and thereby improve the current cost picture. Since a subcritical assembly can be operated without the costly A.E.C. licensing requirements and can be constructed at considerably lower cost than a research reactor, its use with a ^{252}Cf source appears to be very attractive. Hence, careful design of a neutron source multiplier can enhance the neutron source intensity sufficiently to allow substantial improvements in existing applications of ^{252}Cf. An optimization program was investigated to design a subcritical assembly using ^{252}Cf neutron sources as a neutron irradiator. This neutron irradiator should provide a sufficiently intense thermal neutron flux without having to use extremely large quantities of the expensive ^{252}Cf sources. An upper limit on the safe value of the multiplication factor, k_{eff}, of such multipliers should be confined so that criticality cannot be inadvertently obtained. However, the maximum attainable k_{eff} of the multiplier will depend on its design and applications. One of the most important aspects in the development of a subcritical multiplier for laboratory applications is the cost comparison of such a system to other systems. It is clear that at \$10 a microgram (\$10,000,000/gram) or even less, neutron multipliers are essential if neutron fluxes of the order of 10^{10} n/cm^2-sec are to be obtained economically. Thus, the development of practical subcritical multipliers, optimized to enhance the thermal neutron flux in a safe and economical manner, will provide for a greater number of ^{252}Cf neutron source applications, and fulfill many of the current needs for radionuclear applications.

1. ^{252}Cf Neutron Sources in Non-Multiplying Media

^{252}Cf is a relatively new neutron source produced by successive neutron captures in ^{238}U in nuclear reactors interspersed with beta decays. Unlike most conventional isotopic neutron sources, this material decays both by α-particle emission (96.9%) and by spontaneous fission (3.1%) with an effective half-life of 2.65 years (64). The small physical volume of the source includes only the radionuclide and no target material as required in (γ,n) and (α,n) neutron sources. Since encapsulation problems are minimal, small size sources can be fabricated with obvious advantages in source applications. Only 11 curies of ^{252}Cf are needed for a neutron emission rate of 5 x 10^{10} n/sec compared to five thousand curies of ^{124}Sb required to produce the same neutron intensity. The smaller gamma dose rate from ^{252}Cf makes it most attractive as a practical neutron source. Conventional isotopic neutron sources that emit more than 10^9 n/sec are rarely used because of their cost, half-life, volume, gamma emission, or heat emission. On the other hand, the nuclear properties of ^{252}Cf are ideal for a neutron source with all the advantages and none of the drawbacks of the conventional isotopic sources.

The neutrons produced during the spontaneous fission of ^{252}Cf have very high velocities and these have to be slowed down to make these neutrons useful for activation analysis. Therefore, the neutron source must be surrounded by a moderator such as water or other hydrogeneous matrix to thermalize the available fast neutrons. The neutron flux peaks at the immediate vicinity of the source and drops off rapidly with distance, resulting in a rather large flux gradient.

The thermal flux as a function of distance from a ^{252}Cf source can be measured in a moderator by irradiating both bare and cadmium-covered gold foils separately. McKenzie (65) performed this measurement in a water system with aluminum as structure material and source holder. Figure 43 shows the measured thermal neutron fluxes around the ^{252}Cf source as repeated by McKenzie.

A subcritical assembly, sometimes called a subcritical reactor, is an assembly of fuel, moderator, and other assorted materials placed in subcritical array. It, therefore, cannot sustain a chain reaction. A constant neutron flux level can be maintained with an artificial source in the system. This assembly amplifies the source strength, and the neutron multiplication is roughly given by $1/(1-k_{eff})$, where k_{eff} is the effective multiplication factor of the system (65).

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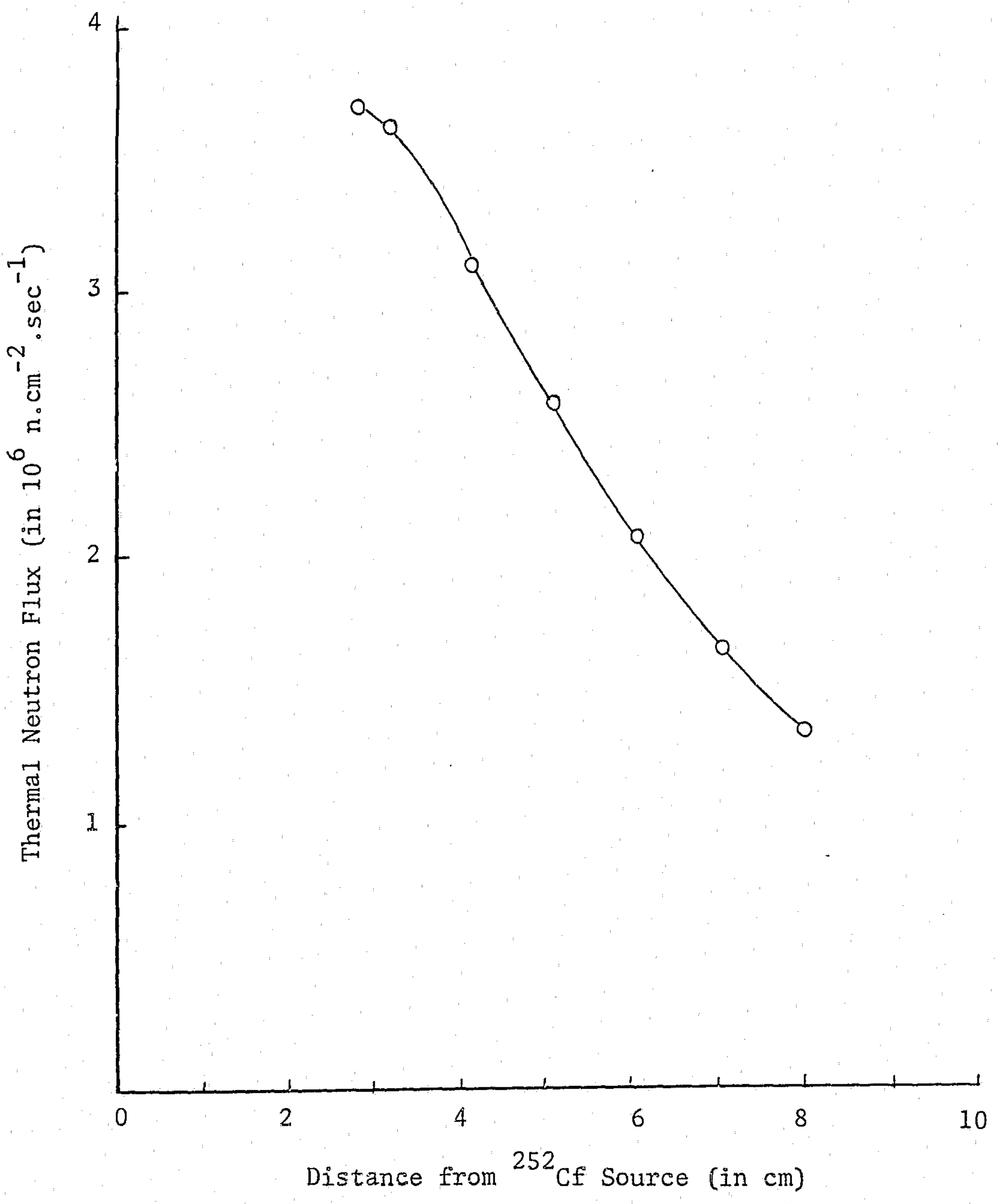


Figure 43. Neutron Flux Measured by Gold Foil Irradiation in a Non-Multiplying Medium from a 235 μg ^{252}Cf Source

The subcritical assembly is extremely versatile and the user is not encumbered by an extensive control system since it is incapable of supporting a diverging chain reaction.

2. Subcritical Assemblies as Neutron Amplifiers

The feasibility of using a small subcritical assembly with an isotopic neutron source for performing neutron radiography or neutron activation analysis has been explored. Preliminary experiments with a 1 mg ^{252}Cf source were conducted in a subcritical assembly, the Nuclear Test Gauge (NTG), in an attempt to amplify the source. The results showed that radiography exposure time was reduced from 18 hours with the water-moderated system to only 30 minutes when the same source was amplified with the NTG at $k_{eff} = 0.988$ (67). Extensive studies, including demonstration of subcritical multiplication with a 3 mg ^{252}Cf source, have been conducted by Miller, Watanabe, and Kunze (68). Intelcom Rad Tech, San Diego, California, has designed a neutron multiplier operating at $k_{eff} = 0.990$. Using 1 mg ^{252}Cf source, this multiplier would produce a thermal flux of around 3×10^8 to 4×10^8 n/cm^2-sec. They believe that a properly engineered system can be licensed to operate without AEC licensed operators (69). This type of neutron multiplier primarily utilizes a flux trap of high-density polyethylene surrounded on all sides by a region of aluminum clad fuel plates. The neutron beam was extracted from the core with a divergent collimator and served as a neutron radiography facility. Hansen et al., conducted experiments with subcritical multiplying assembly for activating samples to demonstrate that the predicted flux enhancements can be actually achieved (70). This assembly consisted of a PuO_2

polyethylene mixture surrounding a ^{252}Cf source as core, reflected by plexiglas. The position for irradiation of samples is next to the core where the thermal flux peaks. As the authors indicated, this design was by no means optimum, but was chosen because the material was available and could easily be assembled for a feasibility demonstration.

3. General Characteristics of the Subcritical Assembly

The design selected as the appropriate one for the subcritical assembly with ^{252}Cf sources is an annular core having its neutron irradiation hole in the center of the core. A cross-sectional picture of this annular core with an arrangement of ^{252}Cf neutron sources around the irradiation hole is shown in Figure 44. The annular core is positioned near the bottom of a large pool of water and makes use of ordinary water as a reflector. Both ordinary water and polyethylene were chosen as possible moderators for the core and the irradiation hole. The use of a central flux trap substantially enhances the central thermal neutron flux for the subcritical assembly and provides a maximum thermal flux for neutron irradiation. The materials of the fuel lattice consist of aluminum clad uranium fuel. Aluminum is also used as the construction material. Both enrichment of the uranium fuel and the fuel loading can be varied to determine their values for maximum enhancement. The advantages of this type of construction are low cost, safety, flexibility and accessibility.

A pneumatic transfer system is required so that the subcritical assembly can provide a rapid and convenient means of transferring

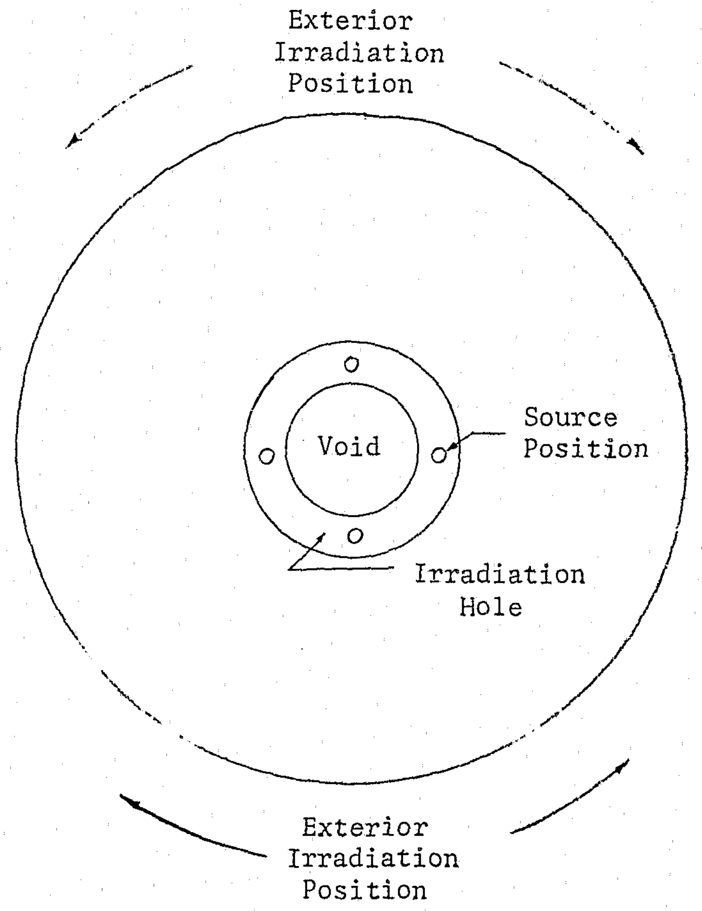


Figure 44. A Cross-Sectional Picture of the Annular Core

irradiated samples from the subcritical assembly to laboratories in the facility. The center of the core provides the greatest flux intensity; consequently, the pneumatic transfer system is installed in the center of the core.

It was expedient to design the system based on calculational methods using the computer codes such as LEOPARD (71), FOG (72), CITATION (73), and EXTERMINATOR II (74). The design parameters for effecting a subcritical assembly to multiply a ^{252}Cf source in the optimum manner were determined. Subcritical experiments were performed with The Pennsylvania State University Breazeale Reactor to verify the calculational techniques. Absolute thermal neutron fluxes and hence thermal flux enhancement were measured in several TRIGA subcritical assemblies containing a calibrated ^{252}Cf neutron source. Based on these studies, a final design of the optimum subcritical assembly has been established and is presented in the following section. The detailed theoretical investigation and experimental methods are included in a Ph.D. thesis (75). Also included in the Ph.D. thesis is a novel way of enhancing the neutron source using depleted uranium. By surrounding the ^{252}Cf source with ^{238}U material, the neutron source intensity can be increased by approximately 10%. In the actual experimental set-up whereby the source was enclosed in a cylinder of ^{238}U, a Monte Carlo calculation predicted a fast flux increase of approximately 8.5% whereas the experiment measured an increase of 7.4 ± 0.2%. Although some potential exists in utilizing this technique to increase the enhancement of ^{252}Cf neutron sources in subcritical assemblies, such increase in enhancement is not obtained using existing assembly design because of the high thermal absorption property of ^{238}U. Future studies could possibly find an effective way to incorporate this technique into a multiplying assembly.

B. Design of the Subcritical Assembly

1. Mechanical Design

The subcritical assembly has been designed to meet the optimum enhancement performance. The mechanical design of the system includes the core fuel elements, control rods, core support structure, control rod drive and their support structure, and the irradiation facility.

The subcritical irradiator was designed similar to the pool-type reactor which has a high degree of accessibility. Experience with this type of reactor has demonstrated that it can be simple and safe to operate. Engineering type drawings of the major components are given in Figures 45 through 49.

2. Fuel Elements

A square plate type fuel element design similar to the MTR fuel element shown in Figure 45 was chosen for this subcritical assembly. This design is simple and economical to fabricate and will meet all of the requirements on structural strength, stability, etc., needed to meet the desired design characteristics. Only the two end plates will be welded to the aluminum frame to provide structure stability (see Reference 76). The remaining fuel plates will be removable to provide flexibility in attaining the correct core k_{eff}. The plates are of uranium-aluminum fuel alloy clad in 15 mil aluminum.

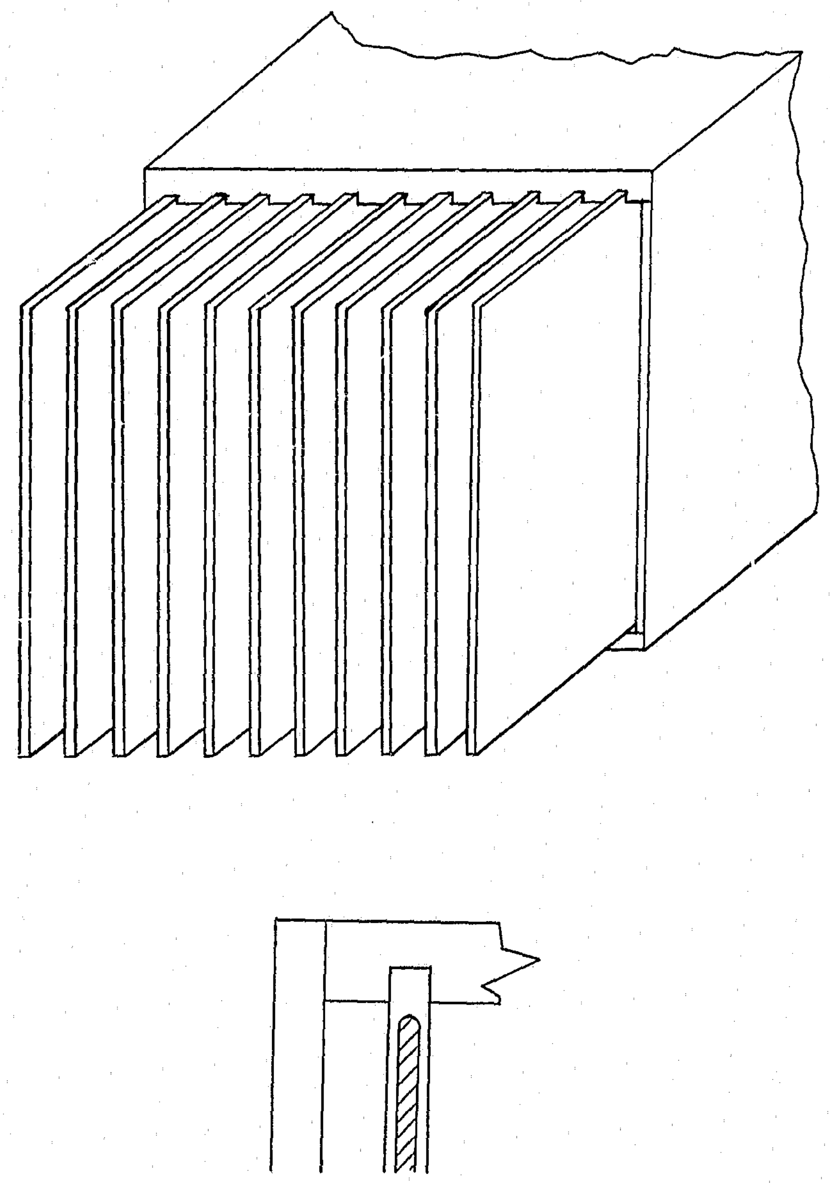
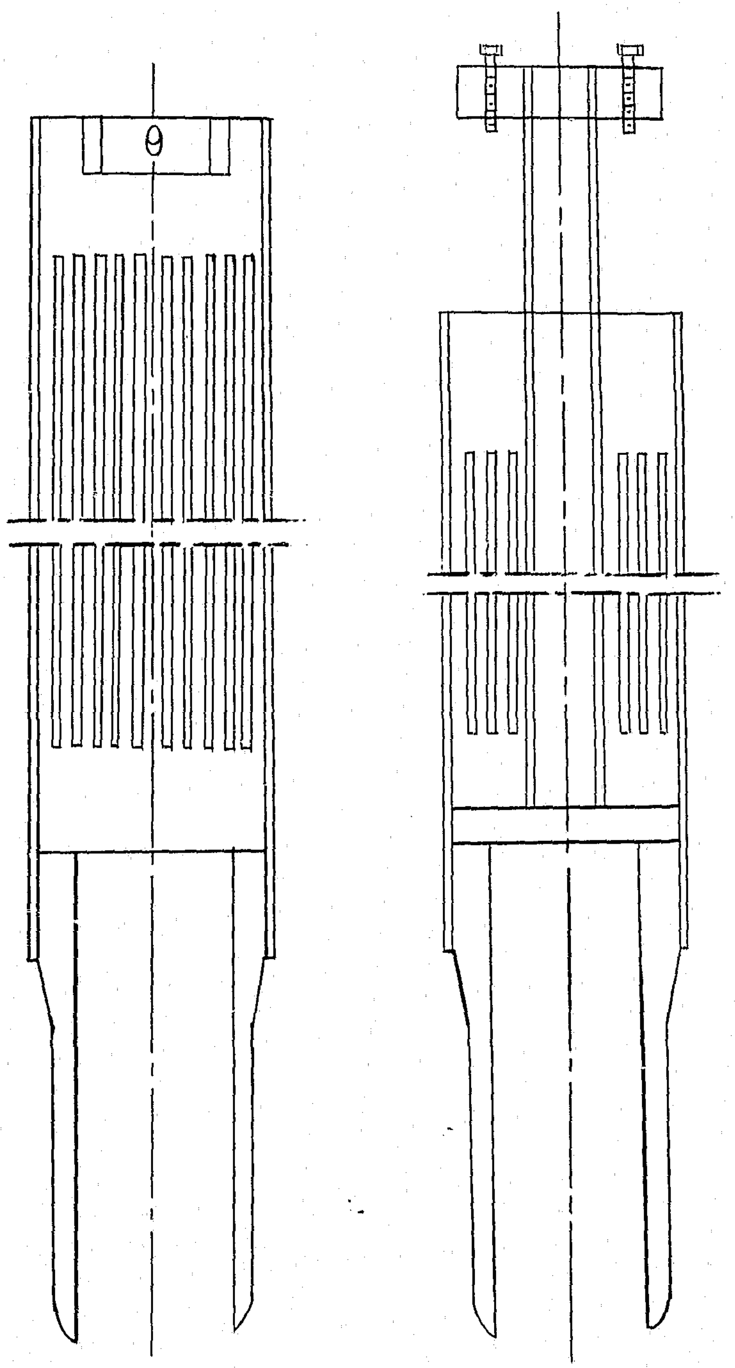


Figure 45. A Sectional View of the Plate Type MTR Fuel Elements



MTR-Type Fuel Element

Special Fuel Element

Figure 46. MTR-Type Fuel Elements

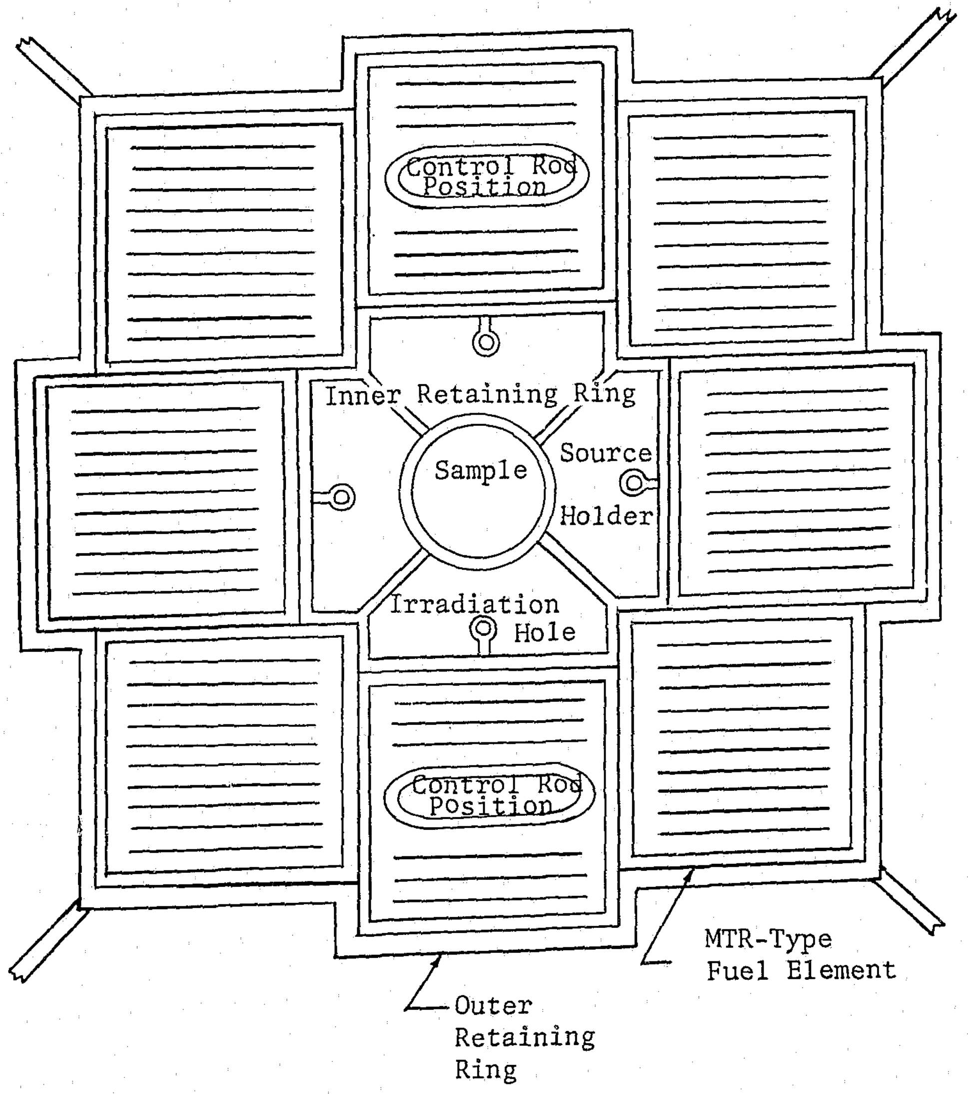


Figure 47. Schematic Drawing of the Top Section Subcritical Assembly

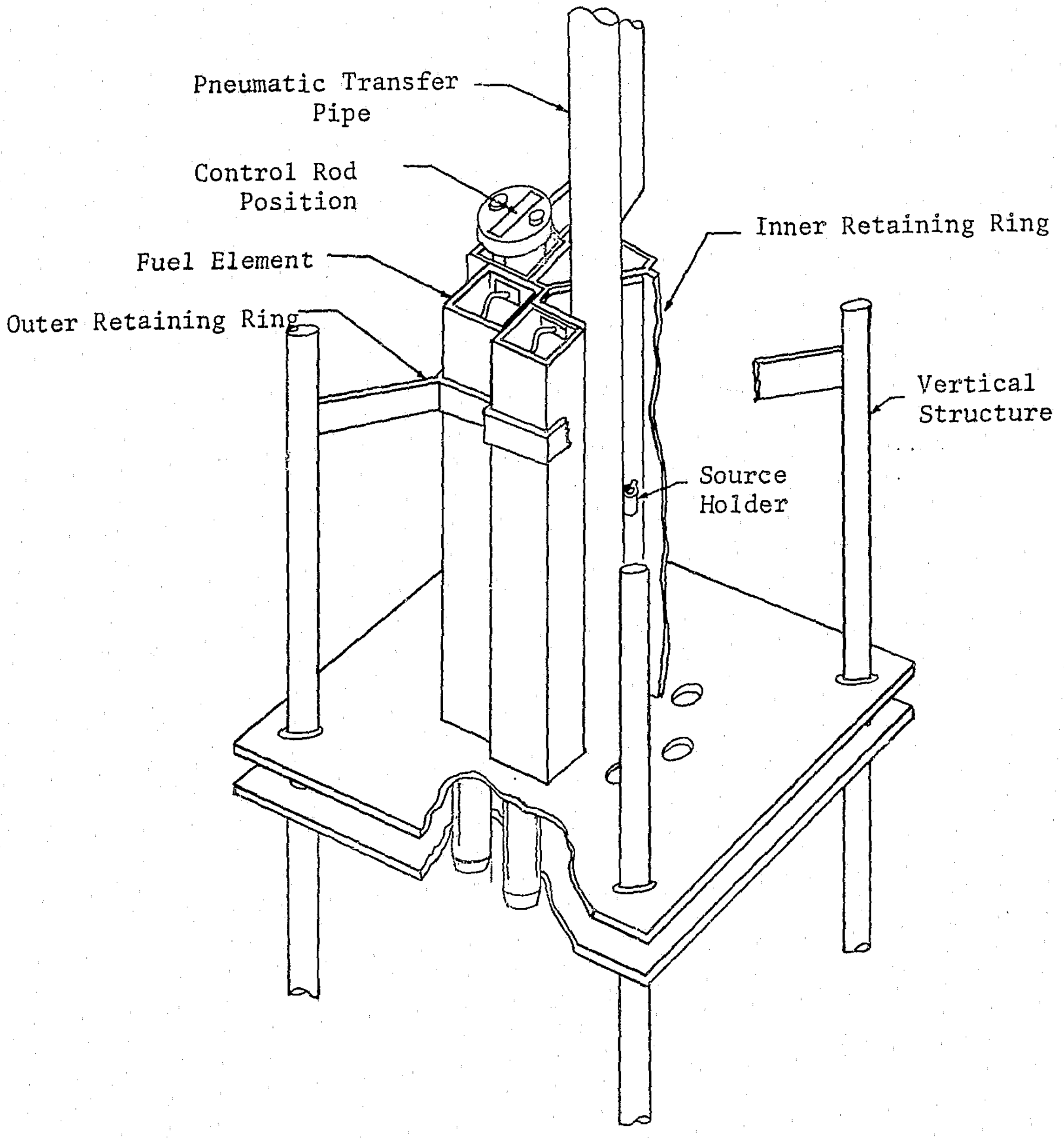


Figure 48. Fuel Elements and Supporting Structures of the Subcritical Assembly

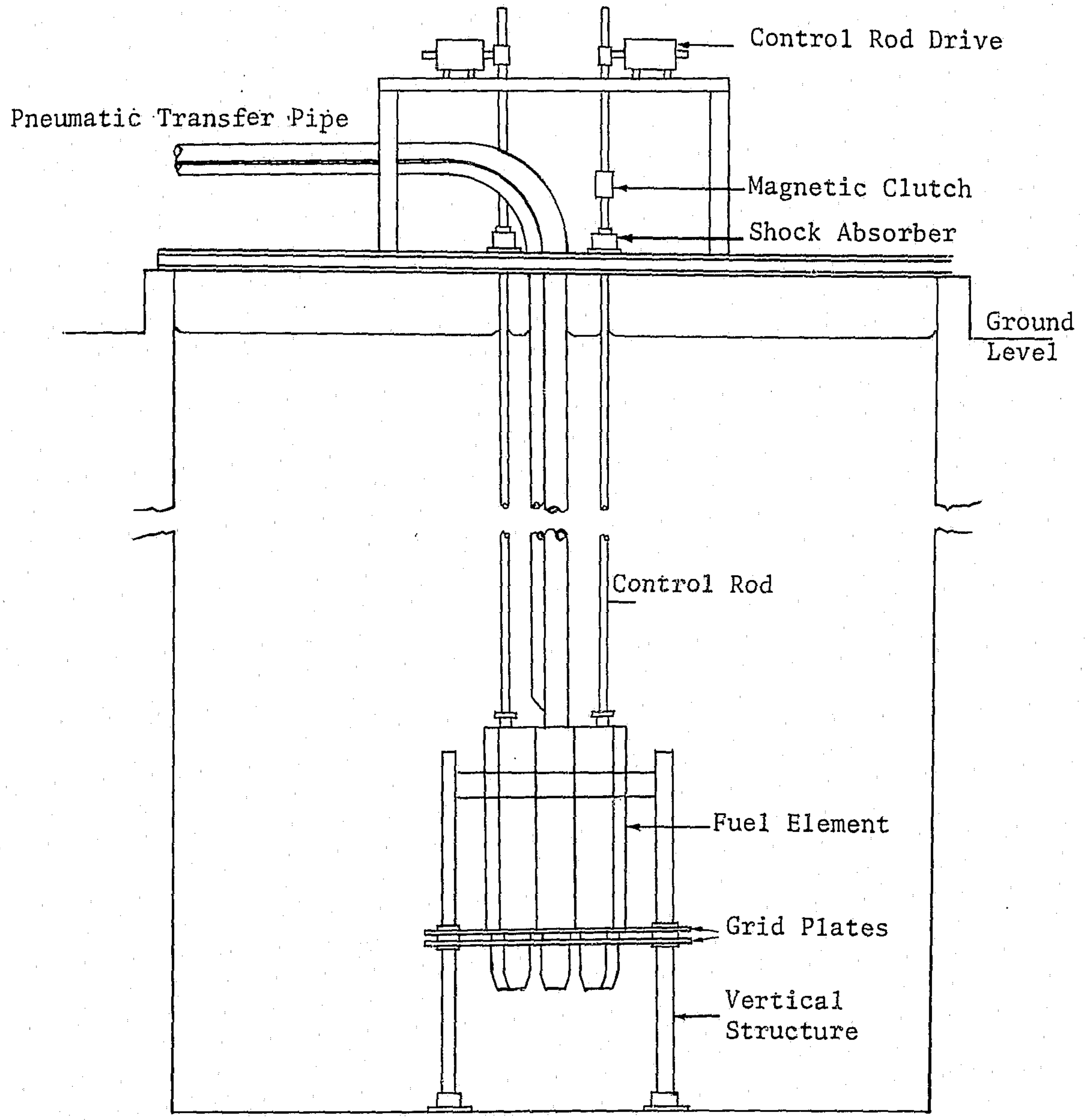


Figure 49. Side View of Neutron Irradiator in Pool Container

The fuel material is designed to have a thickness, d, such that $\Sigma_a \cdot d$ is less than 0.08 to ensure negligible flux depression in the fuel assembly. Σ_a is the neutron absorption cross section of the fuel material. In addition, the overall size and fuel content is made to conform to the optimum design for water moderated and polyethylene moderated fuel assemblies. The polyethylene will be secured as slabs between fuel plates. The design parameters which provide optimum H/^{235}U, W/M, fuel loading, etc., are presented in the section on summary characteristics of the assembly.

3. Control Rods

The subcritical assembly is provided with two boron safety rods consisting of a mixture of steel and boron carbide enclosed in a steel can. These rods travel inside special fuel elements which have longitudinal holes. The rods fall by gravity when scrammed and the fall is dampened by shock absorbers. The magnets (and hence the safety rods) are raised and lowered by a rod and pinion motor-driven device on the reactor bridge.

4. Framework and Support

The subcritical assembly core consists of a stack of 8 MTR-type fuel elements mounted on aluminum grid plates as shown in Figure 48. Two of the fuel elements are designed for guiding and containing the safety rods. In addition, the inner and outer retaining structures, welded to the grid plate and the other support structures, secure the fuel elements in the vertical position. Four ^{252}Cf source holders are welded at the mid-plane of the supporting plate to provide the greatest effectiveness for source enhancement. An aluminum pipe of the pneumatic transfer system passes through the center of the core and is used for transferring samples.

The subcritical irradiator is designed to have all control rods out during operation and all rods in for shut-down. Figure 49 shows a side view of the subcritical assembly which consists of a subcritical assembly supported from the bottom of an underground steel or aluminum tank filled with water.

5. Support Equipment

Support equipment for the irradiation facility includes a control console, safety and radiation monitoring equipment, and a water handling system. The water handling system consists of equipment to transfer water to and from the assembly water tank as well as a water treatment system to maintain the water very low in impurity content, i.e., conductivity of the water below approximately 5 mhos/cm. The console is designed to be near the irradiator.

6. Summary Characteristics of the Optimum Design

The fuel elements were designed to meet the optimum conditions as determined by the computer analyses. Polyethylene is a superior moderator for a multiplying assembly when the maximum thermal fluxes required are below 10^{10} n/cm^2-sec. For fluxes greater than 10^{10} n/cm^2-sec, it may be necessary to replace the polyethylene with water, since polyethylene becomes very brittle with time at high integrated flux, i.e., from 10^{17} n/cm^2 to 10^{18} n/cm^2.

A summary of the optimum design parameters for both water-moderated and polyethylene-moderated fuel elements are presented in Table 21. The assemblies were designed for a $k_{eff} = 0.99$, and the characteristics of the assemblies are also given in Table 21. The thermal flux enhancement of water and polyethylene moderated assemblies are 0.138 cm^{-2} and 0.200 cm^{-2}, respectively.

C. Safety Analysis

Safety is a paramount feature of the subcritical assembly and it is assured by the following conditions:

1) The assembly remains unconditionally subcritical for all aspects of operation with all safety rods out of the core.
2) The core is designed to be inherently safe.
3) Safety devices are used to monitor the subcriticality of the core and provide a high safety shutdown margin (insertion of safety rods) should the flux exceed some established value.

A safeguard analysis has been performed to ensure that the above safety conditions can be met and that the core itself is inherently safe. Conditions or events which are important to the safe performance of the subcritical assembly have been investigated and the results are given in Table 22. As an example, consider the temperature coefficient which is negative. This means that if somehow the core should go critical, the heat produced would quickly cause it to go subcritical again. In addition, an accidental flooding of the central

Table 21

Design Parameters for Fuel Elements and the Assembly

Parameters	Polyethylene Moderator	Water Moderator
^{235}U enrichment	93%	93%
$H/^{235}U$	300	300
Water to metal or polyethylene to metal ratio	3	3
Fuel Material	U alloyed with Al	U alloyed with Al
Fuel Material Dimension	0.04 x 3.0 x 9.5 in.	0.04 x 3.0 x 13 in.
Plate Dimensions	0.07 x 3.15 x 10 in.	0.07 x 3.15 x 15 in.
^{235}U per plate	13.5 gm	12.5 gm
No. of plates per element	10	10
Dimension of fuel element	3.20 x 3.20 x 18 in.	3.37 x 3.20 x 24 in.
Core loading for $k_{eff} = 0.99$	1.08 kg	1.50 kg
No. of fuel elements	8	12
Diameter of void	2 in.	2 in.

Table 22

Effect on k_{eff} of Changes in the Subcritical Assemblies

	Polyethylene Moderator	Water Moderator
Flooding of void region, $\delta k/k^*$	-0.0146	-0.0117
Temperature coefficient, $\delta k/k$	-5.3×10^{-5}	-6.9×10^{-5}
Fuel elements move inward 1 cm, $\delta k/k$	0.027	0.018
Fuel elements move outward 1 cm, $\delta k/k$	-0.033	-0.024
Aluminum worth in the center of void region, $\delta k/k$	-3.9×10^{-5}	-2.8×10^{-5}
^{235}U worth in the center of void region, $\delta k/k$	0.0017	0.0014

$^*\delta k/k = \frac{k'-k}{k}$ is ratio of the change in multiplication factor to the initial multiplication factor.

void tube will also have a negative reactivity effect. Inward motion of the fuel elements will cause an increase in the reactivity of the core. However, the inner retaining structure is designed (see Figure 47) to make this type of accident impossible. Outward motion of the fuel elements produces a negative reactivity effect and is not a safety problem. However, the core is prevented from such motion by appropriate supporting structure. The only possible way to change reactivity during operation is by inserting materials for irradiation. Non-fissile materials such as aluminum will produce a slightly negative change in reactivity, while insertion of fissile materials will produce a positive change in reactivity. Any accidental addition of a gram equivalent of ^{235}U will increase the reactivity by less than 0.002 $\delta k/k$ so that it would take more than five grams of ^{235}U to make this assembly critical. Even so, the scram rods would return the assembly to a subcritical condition.

D. Economic Analysis

An important criterion for selecting a neutron multiplier is the cost of such an assembly relative to that of another device having the same radiation capability. Thus, an economic evaluation was made to compare the cost of producing the equivalent thermal flux by a ^{252}Cf source or sources without a multiplier and with a multiplier. It should be understood that this underestimates the relative usefulness of the neutron multiplier since it can produce such fluxes over a large volume allowing for the irradiation of larger samples or groups of samples. Thus, the specific objectives of these analyses were:

a) To estimate the cost of the subcritical facility having the optimum design, and b) to compare the cost of the subcritical multiplier to that of a ^{252}Cf source in a non-multiplying medium and to a research reactor.

Previous analysis has shown that a polyethylene moderated assembly provides the greatest source enhancement over any other moderator, including water. However, polyethylene is subject to radiation damage and thus, polyethylene may not be desirable when fluxes equal to or above 10^{10} n/cm^2-sec are required. Further investigation of the radiation strength of polyethylene will have to be performed if fluxes close to 10^{10} n/cm^2-sec are actually designed into the source-assembly system. For the purpose of this study, 10^{10} n/cm^2-sec was chosen as the dividing line between the choice of the two assemblies.

The items of the mechanical design required for the subcritical irradiator, including the assembly, control and safety system, and auxiliary facilities, are listed in Table 23. Also included in Table 23 are the costs of each item. The cost information was collected from either company catalogues or private communications. A fuel element consisted of 10 fuel plates, and the cost of fuel elements were based on \$100 per fuel plate. Additional construction cost resulted in \$1,500 per fuel element. Although polyethylene moderated assemblies needed fewer fuel elements, the cost of polyethylene and replacement for polyethylene increases the cost of the assembly. These additional costs are not included in this analysis because the former is negligible relative to the uncertainty in the total costs. The latter cost is neglected because a much more detailed cost analysis must be performed if an assembly is to be procured to produce a flux

Table 23

Estimated Costs of the Subcritical Assembly

Cost Item	Number	Cost/Per ($)	Total Cost ($)
1. Reactor Assembly			
a. Fuel elements	12	1,500	18,000
b. Grid plates	1	620	620
c. Inner core retaining structure and source holders	1	360	360
d. Outer core retaining structure	1	200	200
e. Vertical support structure	1	200	200
2. Control and Safety System			
a. Control rod	2	300	600
b. Control rod mechanism	2	1,000	2,000
c. Control circuits and console	1	3,500	3,500
d. Radiation detectors	2	500	1,000
e. Area radiation survey and monitoring equipment	3	300	900
3. Pool and Water Supply			
a. Reactor bridge	1	500	500
b. Water treatment unit	1	2,000	2,000
4. Reactor building crane	1	2,000	2,000
5. Pneumatic transfer system	1	3,500	3,500
Contingency			4,620
TOTAL			$40,000

of the order of 10^{10} n/cm^2-sec in order to determine the precise comparative advantages of water and polyethylene moderated assemblies. The control rod circuit used for this irradiator was basically the same design as that reported by McKenzie (65). The cost of the subcritical irradiator was estimated at $40,000, using the present price of materials. This cost does not include the costs of the ^{252}Cf source and the water tank and building housing the assembly. The water tank cost is estimated at approximately $25,000.

The total cost of any irradiation facility does not initially include the cost of the building for obvious reasons. In addition, these cost analyses will not include the cost of the water tank, since all such facilities will require one. In this cost analyses all other costs are examined, including maintenance and operation. For a system containing only a ^{252}Cf source immersed in a moderator, only the cost of the source is included. These costs are shown in Figures 50 and 51. The current price of ^{252}Cf is $10 per microgram. However, the AEC is conducting a market evaluation program and estimating the future production and price trends. The AEC estimates the price of ^{252}Cf will be $2-3/μg in the late 1970's and $0.5-1.5/μg in the early 1980's (77). Thus, the source cost based on $3/μg and $1/μg were also analyzed and presented in Table 24 and Figures 50 and 51. Thermal flux enhancements used in these analyses were 0.138 cm^{-2} and 0.200 cm^{-2} for water and polyethylene moderated assemblies, respectively, and a 1 mg ^{252}Cf source is calculated to produce 2.1 x 10^7 n/cm^2-sec in the non-multiply medium.

Table 24

Cost of Thermal Flux as a Function of ^{252}Cf Unit Price

Thermal Flux	Total Cost in a Non-Multiplying Medium			Total Cost in a Multiplying Medium					
				Water Moderator			Polyethylene Moderator		
n/cm^{2}-sec	\$10	\$3	\$1	\$10	\$3	\$1	\$10	\$3	\$1
$1x10^{7}$	$4.80x10^{3}$	$1.4x10^{3}$	$4.8x10^{2}$	$4.03x10^{4}$	$4.01x10^{4}$	$4.00x10^{4}$	$4.02x10^{4}$	$4.01x10^{4}$	$4.00x10^{4}$
$2x10^{7}$	$9.50x10^{3}$	$2.90x10^{3}$	$9.50x10^{2}$	$4.06x10^{4}$	$4.02x10^{4}$	$4.01x10^{4}$	$4.04x10^{4}$	$4.01x10^{4}$	$4.00x10^{4}$
$5x10^{7}$	$2.38x10^{4}$	$7.14x10^{3}$	$2.38x10^{3}$	$4.16x10^{4}$	$4.05x10^{4}$	$4.02x10^{4}$	$4.11x10^{4}$	$4.03x10^{4}$	$4.01x10^{4}$
$1x10^{8}$	$4.76x10^{4}$	$1.43x10^{4}$	$4.76x10^{3}$	$4.31x10^{4}$	$4.09x10^{4}$	$4.03x10^{4}$	$4.21x10^{4}$	$4.06x10^{4}$	$4.02x10^{4}$
$2x10^{8}$	$9.52x10^{4}$	$2.86x10^{4}$	$9.52x10^{3}$	$4.62x10^{4}$	$4.19x10^{4}$	$4.06x10^{4}$	$4.43x10^{4}$	$4.13x10^{4}$	$4.04x10^{4}$
$5x10^{8}$	$2.38x10^{5}$	$7.14x10^{4}$	$2.38x10^{4}$	$5.55x10^{4}$	$4.47x10^{4}$	$4.16x10^{4}$	$5.07x10^{4}$	$4.32x10^{4}$	$4.11x10^{4}$
$1x10^{9}$	$4.76x10^{5}$	$1.43x10^{5}$	$4.76x10^{4}$	$7.13x10^{4}$	$4.93x10^{4}$	$4.31x10^{4}$	$6.13x10^{4}$	$4.64x10^{4}$	$4.21x10^{4}$
$2x10^{9}$	$9.52x10^{5}$	$2.86x10^{5}$	$9.52x10^{4}$	$1.03x10^{5}$	$5.86x10^{4}$	$4.62x10^{4}$	$8.26x10^{4}$	$5.28x10^{4}$	$4.43x10^{4}$
$5x10^{9}$	$2.38x10^{6}$	$7.14x10^{5}$	$2.38x10^{5}$	$1.97x10^{5}$	$8.65x10^{4}$	$5.55x10^{4}$	$1.47x10^{5}$	$7.20x10^{4}$	$5.07x10^{4}$
$1x10^{10}$	$4.76x10^{6}$	$1.43x10^{6}$	$4.76x10^{5}$	$3.53x10^{5}$	$1.33x10^{5}$	$7.13x10^{4}$	$2.53x10^{5}$	$1.04x10^{5}$	$6.13x10^{4}$
$2x10^{10}$	$9.52x10^{6}$	$2.86x10^{6}$	$9.52x10^{5}$	$6.60x10^{5}$	$2.26x10^{5}$	$1.03x10^{5}$			
$5x10^{10}$	$2.38x10^{7}$	$7.14x10^{6}$	$2.38x10^{6}$	$1.59x10^{6}$	$5.05x10^{5}$	$1.97x10^{5}$			
$1x10^{11}$	$4.76x10^{7}$	$1.43x10^{7}$	$4.76x10^{6}$	$3.14x10^{6}$	$9.70x10^{5}$	$3.53x10^{5}$			

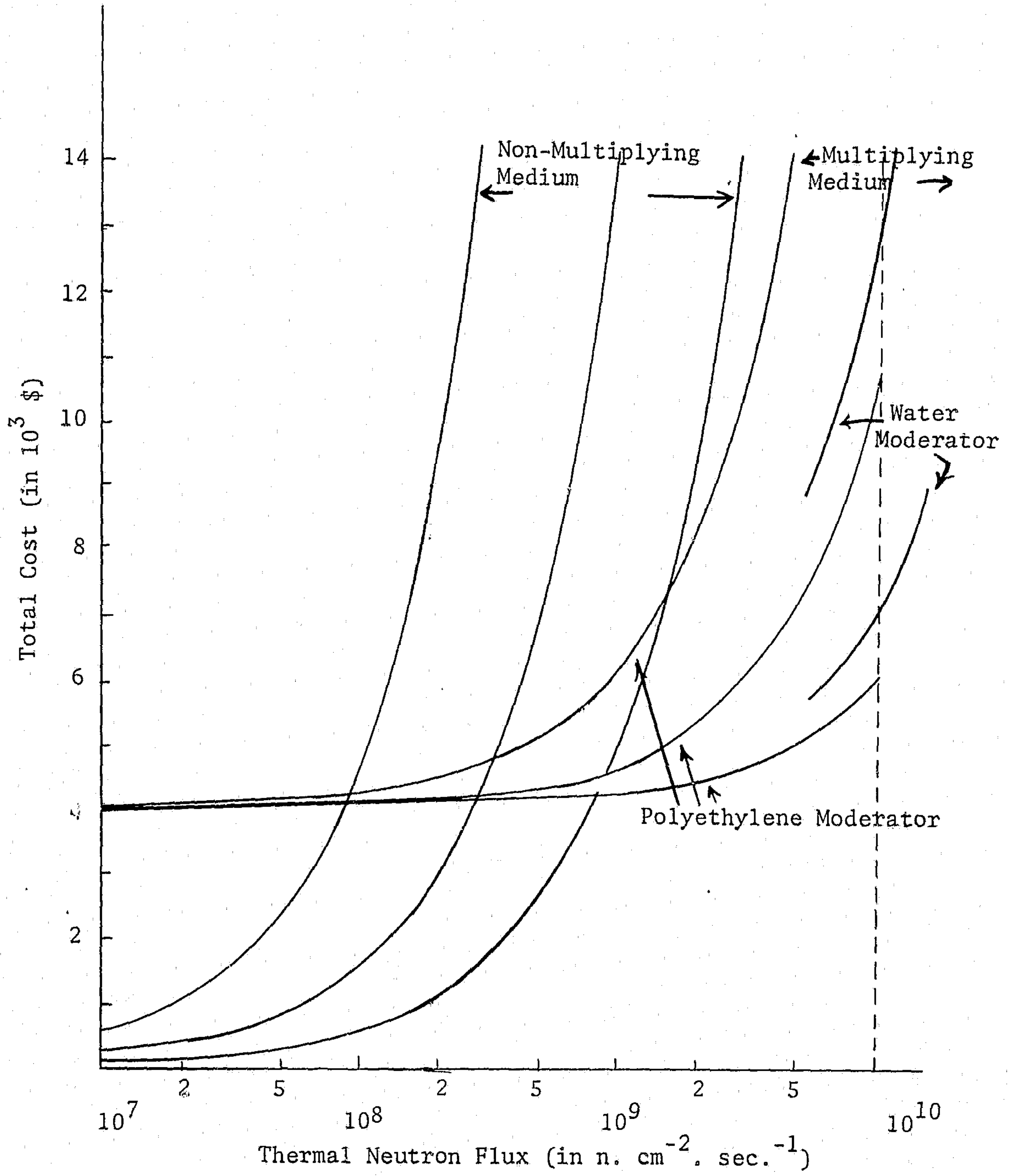


Figure 50. Total Cost of Neutron Irradiation Facility as a Function of Thermal Flux (A)

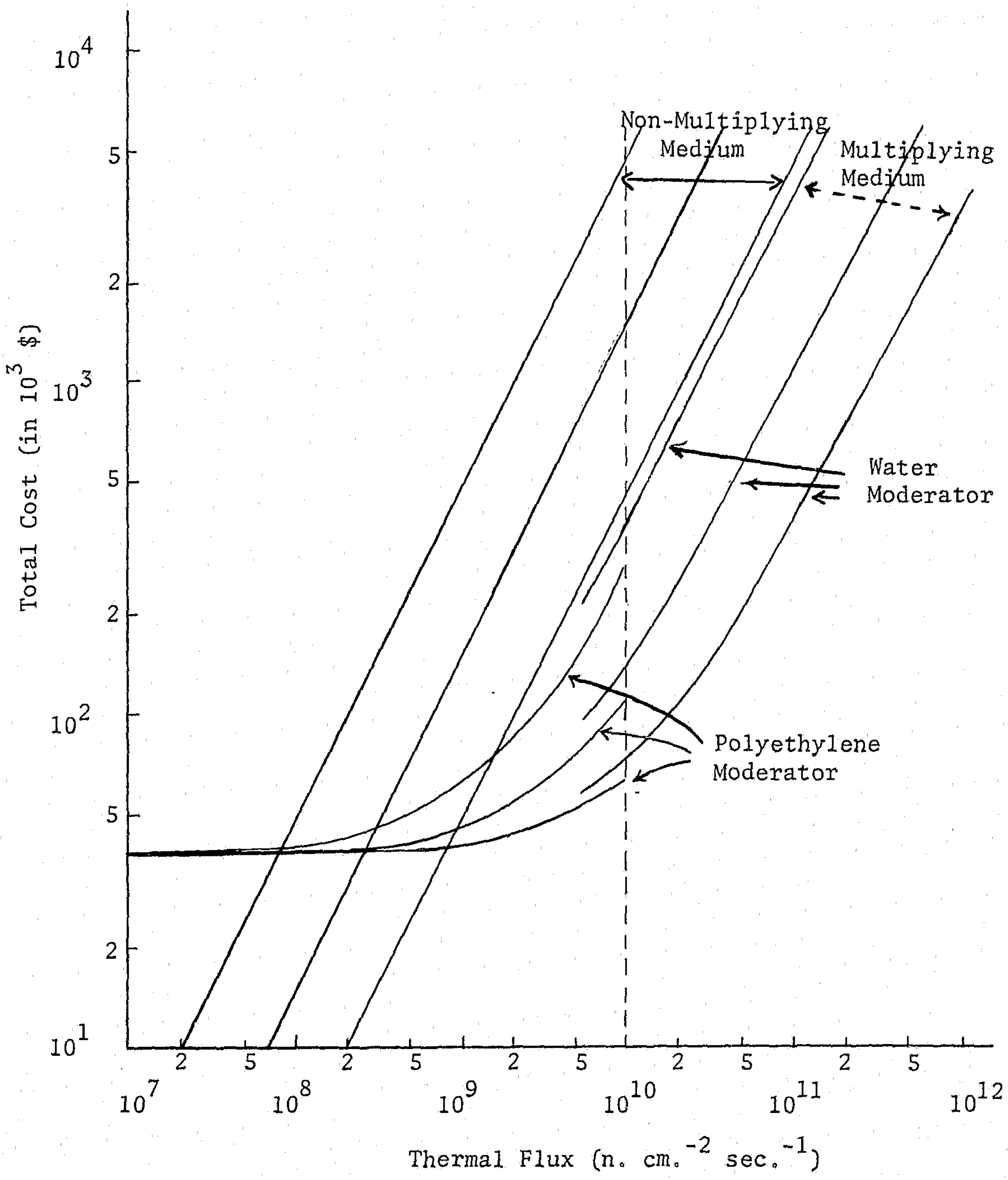


Figure 51. Total Cost as a Function of Flux (B)

Figures 50 and 51 illustrate the total costs of source-irradiators as a function of the thermal flux based on the data presented in Table 24. Figure 50 focuses on the thermal flux region 10^7 to 10^{10} n/cm^2-sec while Figure 51 covers a larger range. Note that large cost savings are realized by the multiplying system over the non-multiplying medium when the thermal flux is above 10^8 n/cm^2-sec for ^{252}Cf at $10 per microgram. As the costs of the source material drops, the non-multiplying assembly can be more economical for fluxes as high as 5 x 10^8 n/cm^2-sec. As the fluxes produced by the irradiator approach 10^{10} n/cm^2-sec, the costs of the system are dominated by the source cost, which is directly proportional to the high thermal flux. Thus, the thermal flux of 10^8 and 10^{10} n/cm^2-sec can be treated as a lower and upper limit within which the cost of the multiplying irradiator is most beneficial. With predicted lower prices for ^{252}Cf, the range of optimum thermal flux will shift to higher thermal fluxes.

To date, the research reactor is the major source of neutrons. Most reactors operating at moderate power levels have a readily available thermal flux with sufficient intensity to activate samples. However, the cost of acquiring and maintaining a critical facility is high. A 100 kw small research reactor with a thermal flux of 10^{12} n/cm^2-sec and a one megawatt research reactor with a thermal flux of 10^{13} n/cm^2-sec can be purchased at $300,000 and $1,000,000, respectively. This does not include the cost of building and the water tank. In addition, at least two licensed operators are required for the operation. This will add another $50,000 per year to the total cost based on \$25,000 per man per year. Furthermore, a larger maintenance cost of \$10,000 per year is required for the reactors because they utilize more sophisticated instrumentations than subcritical assemblies. An overall comparison between the subcritical assembly and the research reactor must include the cost of maintenance and operation. The research reactor will cost \$60,000 per year more for maintenance and operation of the facilities, not including the cost of any neutron sources. The subcritical assembly will require additional annual costs to replenish the ^{252}Cf. These costs can be substantial. The annual cost is equal to

$$\frac{\text{Half cost of initial source}}{2.65 \text{ year (half-life of } ^{252}\text{Cf)}}$$

Thus, when these costs are included, the subcritical assembly is most economical when:

1) The cost of ^{252}Cf is \$10/µg and the flux is below 10^{10} n/cm^2-sec.
2) The cost of ^{252}Cf is \$3/µg and the flux is below 2×10^{10} n/cm^2-sec, and
3) The cost of ^{252}Cf is \$1/µg and the flux is below 10^{11} n/cm^2-sec.

Consequently, at the current cost of \$10 per microgram, a subcritical assembly should only be considered if the flux is below 10^{10} n/cm^2-sec; for fluxes above 10^{11} n/cm^2-sec, a research reactor will be the most economical device to procure. Table 25 summarizes the results of these analyses.

Table 25

Preferred System for Various Thermal Flux Range

Preferred System	Thermal Flux Range, n/cm^2-sec \$10/μg	 \$3/μg	 \$1/μg
Source in non-multiplication	below 7×10^7	below 2×10^8	below 7×10^8
Subcritical assembly	7×10^7 to 10^{10}	2×10^8 to 5×10^{10}	7×10^8 to 10^{11}
Research reactor	above 10^{10}	above 2×10^{10}	above 10^{11}

E. Conclusions

An optimized subcritical irradiator using ^{252}Cf as a neutron source has been designed primarily for neutron activation analysis. The design incorporates MTR-type fuel elements which is composed of a subcritical assembly and is immersed in a tank of water. Polyethylene moderator is used as an option which is recommended if the operational neutron flux is less than 10^{10} n/cm^2-sec. Engineering drawings for the construction of a subcritical assembly have also been completed. These plans provide a complete design of an optimum subcritical irradiator using ^{252}Cf sources.

The theoretical interpretation of source enhancement for designing a subcritical multiplier have been formulated starting from the two-group diffusion theory with a source term. The design parameters for effecting the multiplying capability of a subcritical assembly have been studied using the neutronic digital computer codes LEOPARD, FOG, CITATION, and EXTERMINATOR II. Based on computer analyses, the optimum design parameters were determined.

The multiplication method appears to offer a very safe and practical means of inexpensively enhancing the output of a ^{252}Cf source if fluxes below a certain maximum value are desirable. The assembly has strong negative temperature coefficient, and the multiplier would be rendered more subcritical by a flooding of the central void tube. Furthermore, for neutron activation analysis, the pneumatic transfer system provides a convenient means for transferring activated samples and gives large volumes with high thermal flux. Utilizing the subcritical multiplier designed with thermal flux enhancement

$0.138\ cm^{-2}$ at $k_{eff} = 0.99$, a 31 mg ^{252}Cf source would provide $10^{10}\ n/cm^2$-sec thermal flux.

The cost of such a subcritical assembly was estimated at $40,000. The cost does not include the costs of the ^{252}Cf source, the water tank, and the building housing the assembly. Of particular importance to the desirability of procuring a subcritical system is the comparative costs of these systems. Table 25 provides a summary of the fluxes to be obtained with a non-multiplying assembly, a multiplying assembly, and a research reactor under the most economical conditions when all costs, i.e., system and maintenance and operation are included. At the present cost of $10 per microgram, the subcritical assembly could be procured for producing thermal fluxes between 7×10^7 and $10^{10}\ n/cm^2$-sec. At $1 per microgram the optimum values are between 7×10^8 and $10^{11}\ n/cm^2$-sec. A research reactor will be the best choice when fluxes above $10^{11}\ n/cm^2$-sec are desired.

Before a choice of moderator is made between water and polyethylene for a subcritical assembly to produce thermal neutron fluxes in the range of $10^{10}\ n/cm^2$-sec, it is recommended that further studies be conducted regarding the cost of the polyethylene moderated system at these flux levels. Polyethylene will be damaged by the radiation, so that the material will have to be periodically changed. The additional cost and frequency of making these changes should be studied in great detail.

VII. TRAINING OF STATE POLICE PERSONNEL IN THE APPLICATIONS OF NUCLEAR TECHNIQUES

A. Background

In order to solve many crimes, the field investigators must be able to identify, collect and preserve evidence from the scene of a crime. In addition, the law enforcement agencies have the responsibility to analyze the physical evidence and correlate it with the investigation data to produce useful criminal evidence. In recent years, court decisions and more effective criminal defense have placed a stronger burden on police agencies to prove their cases. While there have been several advances in the field of forensic sciences, few police agencies have taken full advantage of the developments in this field. Recognizing this fact, the National Advisory Commission on Criminal Justice Standards and Goals has recommended (78,79) that "every police agency provide all incoming police personnel with formalized basic training in forensic science and evidence gathering techniques and that every police agency also develop and deploy specially trained personnel to gather physical evidence 24 hours a day."

An efficient and productive criminal investigations laboratory capable of application and adaptation of new developments in science and technology can be an invaluable asset to the police investigation process. It is the recognition of these facts that has prompted the Bureau of Technical Services of the Pennsylvania State Police to initiate a formal training program for a select group of laboratory personnel and Troop Identification Officers in the applications of nuclear techniques to criminal investigations.

B. Personnel Participation

Some of the research efforts of the Radionuclear Forensic Investigations at Penn State have been developed to a stage where they could be readily applied for the routine work of law enforcement agencies. The training programs conducted by the Pennsylvania State Police varied from informal visits and a tour of the research reactor facility at Penn State to formal classroom and laboratory instruction for extended periods. The administrative staff of the Bureau of Technical Services have visited the research laboratories at Penn State on several occasions during this program and have offered their suggestions and constructive criticisms. Two of the personnel of the chemistry section of the State Police Laboratory, Mr. Harold Freed and Mr. Harry A. Fox III, attended formal class sessions introducing nuclear applications. In addition, Mr. Harry A. Fox III spent nearly four months in full-time training under the direction of Dr. K. K. S. Pillay in the performance of radiochemical procedures developed for the detection of firearm discharge residues through the applications of film-lift techniques and neutron activation analysis. The details of this training program are included in the following section. Mr. Fox has been working full time on evidence analysis since March 1974.

C. Training in Radiochemical Techniques

A formal program was designed to train personnel of the State Police Laboratory to undertake all aspects of the analyses of gunshot residues using the film-lift method and neutron activation analysis.

The person selected for the first training program had a bachelor's degree in science (chemistry) with a few years work experience in an industrial chemistry laboratory. The formal part of the training program at Penn State included the introduction of the trainee to the theory and practice of nuclear analytical techniques with special emphasis on neutron activation analysis. The program included extensive laboratory work designed to train a qualified individual to carry out the preparation of evidence collection kits and the analysis and interpretation of evidence materials suspected of containing gunshot residues. Some of the topics discussed during the fifteen week training period included the following:

1. Fundamentals of radioactivity
2. Principles and practices of nuclear techniques of elemental analysis
3. Theory of neutron activation analysis
4. Applications of neutron activation analysis on the detection of gunshot residues
5. Counting techniques and gamma ray spectrometry
6. Statistical nature of radioactive disintegration and the significance of counting data
7. Chemistry of the isolation procedures involved in gunshot residue analyses
8. Safety practices in handling radioactive materials
9. Radiochemical separations and carrier techniques
10. Data processing and interpretation
11. Preparation of "Film-Lift" and its quality control analyses

12. Various gunshot residue collection techniques
13. Collection and analyses of gunshot residues as possible criminal evidence material
14. Multielement analyses using high resolution gamma ray spectrometry
15. Radioactive tracer techniques in the evaluation of analytical procedures
16. Comparison of analytical techniques presently employed by other laboratories for gunshot residue analysis
17. Significance of the analysis of copper and gold traces in gunshot residues in addition to barium and antimony
18. Discussion of the limitations of forensic neutron activation analyses

The educational aspects of the training program also included twelve weeks of extensive laboratory work to familiarize the trainee with the art of neutron activation analysis to detect and quantitate trace elements characteristic of gunshot residues. The sound background of the trainee in conventional chemical techniques and his willingness to undergo a busy training schedule did contribute significantly to the success of the training program. This trained criminalist from the State Police Laboratory has been continuously improving his abilities to perform these radiochemical analyses for more than fifteen months, and he is now capable of undertaking and performing these analyses with ease.

D. Training of Troop Identification Officers

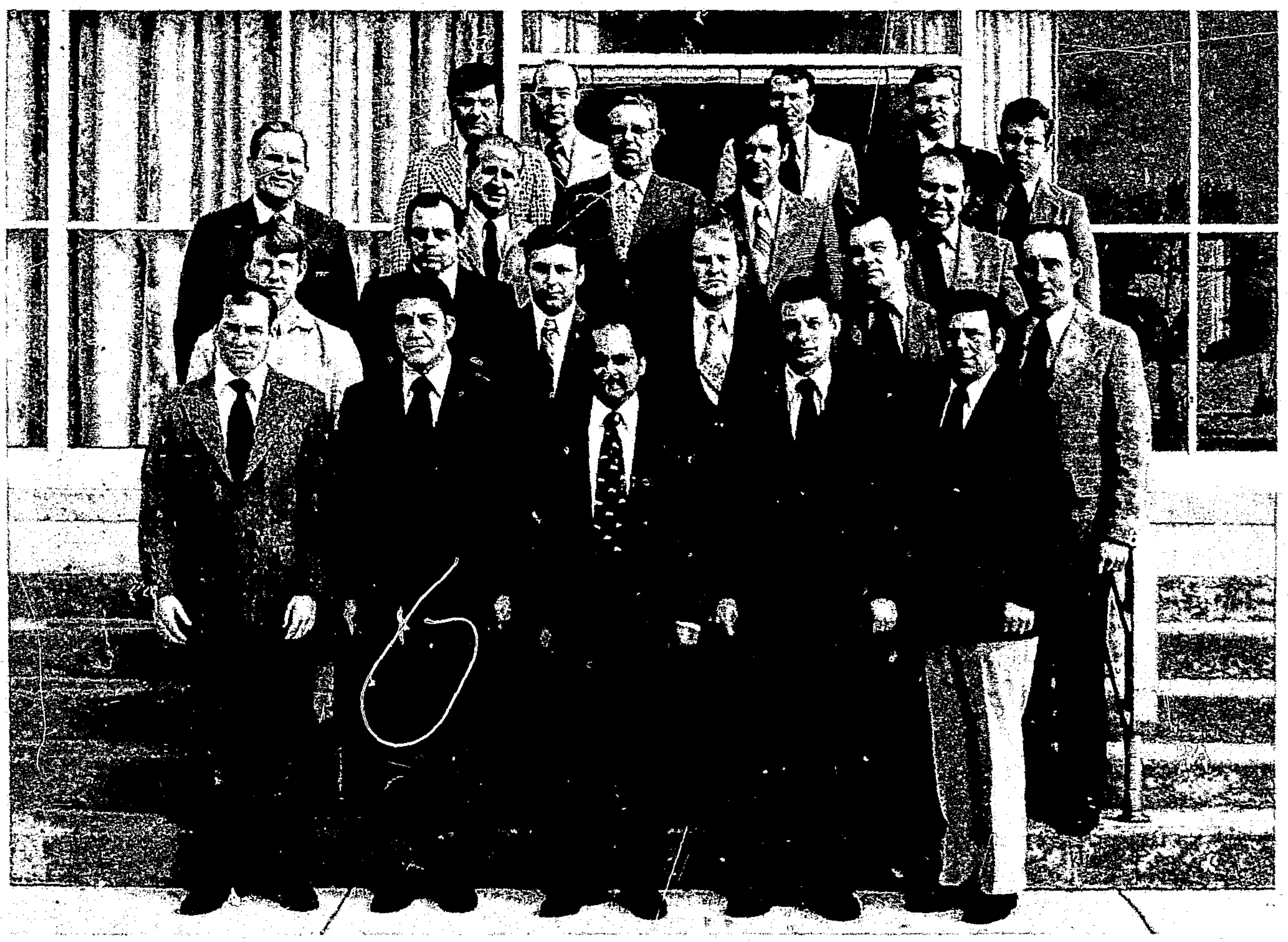
The first group of Troop Identification Officers of the Pennsylvania State Police were offered a two-day course at the State Police Academy at Hershey, Pennsylvania. The training session conducted during March 1974 was attended by representatives of almost all the regional centers of the Pennsylvania State Police. A list of participants and a group photograph taken during this first formal training session are included here. During the two-day session, the officers were introduced to the basic principles of gunshot residue collection using film-lift techniques and evidence analysis using neutron activation. They were also informed about both the advantages and limitations of the new procedures being introduced for crime investigation. During the two days, several demonstrations of the use of film-lift kits were offered to the participants and this was followed by allowing them to practice the use of the kits in evidence collection. The formal presentations included discussion of descriptive materials on film-lift techniques, a slide-show presentation, as well as the showing of a 16 m.m. movie (educational film) produced at The Pennsylvania State University. The 22 minute length movie is titled, "Neutron Activation Analysis," and it emphasizes the practical applications of neutron activation analysis in forensic science investigations. Several copies of this movie and television video tapes are available for the use of the Pennsylvania State Police.

List of Participants in the First Training Session to Introduce Film-Lift Techniques

1. BALDO, Richard D., (PSP), Butler, Pa.
2. BALSHY, John C., (PSP), Records & Identification Div., Harrisburg, Pa.
3. BEAVER, Elmer D., (PSP), Harrisburg, Pa.
4. BEYNON, Charles H., (PSP), Bethlehem, Pa.
5. BIVENS, Paul R., (PSP), Washington, Pa.
6. BROWN, Charles H., (PSP), Lancaster, Pa.
7. BROWN, Richard D., (PSP), Punxsutawney, Pa.
8. CAVRICH, John V., (PSP), Hollidaysburg, Pa.
9. CENTI, Eugene J., (PSP), Wyoming, Pa.
10. COLYER, Ronald F., (PSP), H.Q., Harrisburg, Pa.

*11. DUFFLEY, James, (PSP), Ballistics Section (LAB)
*12. FOX III, Harry A., (PSP), Chemistry Section (LAB)
13. GARNON, David L., (PSP), Erie, Pa.
†14. KWIATEK, Albert F., (PSP), Director, Bureau of Technical Services
15. McCOMMONS, Paul T., (PSP), Greensburg, Pa.
16. MEREVICH, Andrew, (PSP), Dunmore, Pa.
*17. PILLAY, K. K. S., (PSU), Department of Nuclear Engineering
18. SACHS, Richard W., (PSP), Hazleton, Pa.
*19. SAGANS, James, (PSP), Director, Laboratory Division
20. SMITH, John R., (PSP), Philadelphia, Pa.
21. SUTHERLAND, Ronald L., (Pa. Game Commission), Palmyra, Pa.
22. TROUT, Larry K., (PSP), Montoursville, Pa.
23. ZALEGOWSKI, Chester, (PSP), Reading, Pa.

*Instructors
†Director



A group photograph of the participants of the first training session held at the State Police Academy at Hershey, Pennsylvania to introduce Film-Lift Techniques to the Pennsylvania State Police (March 1974)

E. Evidence Collection and Analysis

The introduction of film-lift techniques for evidence collection was well received by the Pennsylvania State Police. Because of a restriction that only a trained person should collect the evidence using the new method, these procedures are applied only by a limited number of Troop Identification Officers in different parts of the state. However, during the three month period from April to June, 1974, there were 59 evidence collections made and submitted to the State Police Laboratory for analysis. Of these, 39 cases involved suspected suicides, while there were 20 cases involving murders using firearms. These evidence samples have been analyzed by the trained criminalist from the State Police Laboratory. The rate of submission of evidence samples have increased and new ways of providing manpower to undertake these analyses are being considered.

The experience gained through the analyses of numerous evidence samples indicate that there are considerable variations in the levels of trace elements found in the film-lifts taken from different regions of the hands. In most cases of suspected suicides, the levels of Ba, Sb, Cu and Au are high and the distribution patterns of these trace elements on both the hands allows objective interpretation. In suspected homicides, the evidence collected after several hours of the incident from a suspect shows extremely low levels of these trace metals characteristic of gunshot residues. The general suggestions made by Kilty (80) are followed in the collection of film-lift samples from suspects in a homicide case. These instructions issued to the Troop Identification Officers have helped minimize the collection and analyses of evidence samples that cannot produce any useful information. The experience of the criminalist who performs these analysis is that his discussions with the officers who collected and submitted the evidence samples assists him in the interpretation of his data and the development of useful forensic science evidence using these procedures.

The officers of the Pennsylvania State Police who are presently using film lift techniques to collect evidence samples have often made excellent suggestions to improve the evidence collection methods and it is hoped that the Pennsylvania State Police will continue to draw on the experiences of their field investigators and laboratory personnel to continuously improve the applications of these new methods of evidence collection and analysis.

VIII. LIST OF PUBLICATIONS

The following is a list of publications that have resulted so far from the investigations summarized in this report.

1. K. K. S. Pillay, W. A. Jester, and H. A. Fox III, "New Methods in the Collection and Analysis of Gunshot Residues as a Forensic Evidence," paper no. 23 (Nuclear Chemistry & Technology Division), presented at the 166th National Meeting of the American Chemical Society, Chicago, Illinois, (August 1973).
2. K. K. S. Pillay, D. C. Driscoll, B. W. Lee and W. A. Jester, "Distribution of Firearm Discharge Residues," Transactions of the American Nuclear Society 18, (1974), pp. 61-62.
3. K. K. S. Pillay, S. H. Moss, M. A. Bricklemyer and W. A. Jester, "A Modified Approach to Forensic Activation Analysis of Hair," Transactions of the American Nuclear Society, 18 (1974), p. 62.
4. K. K. S. Pillay, W. A. Jester, and H. A. Fox III, "New Methods for the Collection and Analysis of Gunshot Residues as Forensic Evidence," *Journal of Forensic Sciences* 19, 1974, pp. 768-783.
5. K. K. S. Pillay and Lieut. James Sagans, "Gunshot Residue Collection using Film-Lift Techniques for Neutron Activation Analysis," AFTE Journal of the Association of Firearm and Tool Mark Examiners, 6, No. 3, (1974), pp. 4-12.
6. K. K. S. Pillay, W. A. Jester and H. A. Fox III, "Gunshot Residue Collection using Film-Lift Techniques," *Forensic Science*, 4, (1974), pp. 1-9.
7. B. W. Lee, S. H. Levine and W. A. Jester, "The Optimum Design of a Subcritical Neutron Irradiation using ^{252}Cf Neutron Source," paper to be presented at the National Meeting of American Nuclear Society, Washington, D.C. (Oct. 1974).

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APPENDIX A

DISTRIBUTION PATTERNS OF GUNSHOT RESIDUES

Typical Examples of Test Results using Different Handguns

Tables A-1 through A-4

Table A-1

Distribution of Barium and Antimony from Gunshot Residues Collected from Test Facility at Harrisburg

0.45 Caliber Automatic

FIRING #123

(All the data presented are as 10^{-9} gm/cm^2/firing)

BARIUM

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	20.60	38.96	65.46	13.83	2.68
50	18.80	40.65	47.18	15.61	5.74
100	22.68	32.97	31.40	14.58	5.56
150	15.18	21.48	14.36	14.43	10.60
200	18.21	14.93	13.18	12.13	10.39
500	3.76	1.63	1.73	2.16	2.14
1000	6.80	3.61	15.23	1.86	1.65
1140	23.50	39.54	23.59	58.52	42.74
1190	11.44	91.62	1.92	N.D.*	1.22

ANTIMONY

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	8.52	18.39	32.77	5.57	1.37
50	9.17	18.73	18.81	7.77	2.26
100	12.77	23.14	14.81	7.59	2.86
150	6.70	9.55	6.30	6.82	3.06
200	5.09	4.76	3.66	4.80	3.26
500	1.13	0.65	0.47	0.62	0.36
1000	0.75	0.65	1.41	2.31	0.73
1140	1.17	78.16	5.35	3.35	2.47
1190	10.07	2.33	94.69	3.43	6.06

*Not Detected

Table A-2

Distribution of Barium and Antimony from Gunshot Residues Collected from Test Facility at Harrisburg

0.455 Revolver

FIRING #134

(All the data presented are as 10^{-9} gm/cm^2/firing)

BARIUM

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	2.21	15.90	111.28	32.03	12.68
50	2.77	26.74	45.49	35.35	17.52
100	7.96	20.70	18.24	13.62	9.51
150	14.18	13.92	11.35	9.63	3.53
200	5.25	5.19	4.49	3.72	2.87
500	0.82	1.12	1.44	0.66	1.18
1000	N.D.*	1.40	0.91	1.47	1.17
1140	0.74	0.78	0.70	1.51	1.03
1190	N.D.	1.56	N.D.	1.70	1.24

ANTIMONY

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	0.46	1.62	15.49	3.53	1.25
50	0.57	2.20	5.06	4.59	1.84
100	1.41	3.96	3.21	1.94	2.16
150	1.26	2.93	2.00	1.45	0.58
200	0.87	1.76	N.D.	0.65	0.57
500	N.D.	N.D.	0.51	N.D.	N.D.
1000	0.20	0.35	N.D.	N.D.	0.18
1140	3.75	0.87	1.00	4.73	0.49
1190	15.27	2.06	2.61	4.71	1.51

CONTINUED

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Table A-3

Distribution of Barium and Antimony from Gunshot Residues Collected from Test Facility at Harrisburg

0.32 Caliber Semiautomatic

FIRING #127

(All the data presented are as 10^{-9} gm/cm^2/firing)

BARIUM

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	14.06	66.84	44.23	15.20	4.09
50	17.84	66.45	72.47	23.90	9.78
100	35.15	52.45	65.44	37.21	21.33
150	27.08	40.78	32.69	22.35	11.61
200	7.59	11.87	15.50	10.82	8.10
500	7.34	4.68	6.03	2.78	3.14
1000	1.34	1.91	N.D.*	1.07	1.75
1140	4.62	3.02	1.72	1.99	2.00
1190	N.D.	1.33	N.D.	1.25	1.96

ANTIMONY

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	0.97	3.20	3.26	1.02	0.24
50	1.47	3.96	5.39	1.11	0.61
100	1.57	3.38	4.03	3.24	1.14
150	2.92	4.01	3.20	1.98	0.64
200	1.20	2.77	1.69	1.15	0.90
500	0.69	0.64	1.03	0.42	0.53
1000	0.45	1.95	0.31	0.41	N.D.*
1140	1.31	23.67	2.25	2.26	2.10
1190	6.90	N.D.	0.94	1.14	4.47

*Not Detected

Table A-4

Distribution of Barium and Antimony from Gunshot Residues Collected from Test Facility at Harrisburg

0.22 Caliber Revolver

FIRING #114

(All the data presented are as 10^{-9} gm/cm^2/firing)

BARIUM

Distance from Firing Point along Bullet Trajectory	Distnace of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	2.59	N.D.*	N.D.	N.D.	3.17
50	2.35	N.D.	N.D.	1.37	2.33
100	2.72	N.D.	N.D.	1.32	1.24
150	1.37	1.41	N.D.	3.95	2.34
200	0.55	0.83	0.95	0.70	0.67
500	1.15	0.65	1.42	0.52	0.35
1000	0.95	0.74	0.64	0.54	0.86
1250	2.97	0.50	0.45	2.25	0.71
1300	3.26	0.51	1.08	0.56	0.70

ANTIMONY

Distance from Firing Point along Bullet Trajectory	Distance of Sampling Points from Bullet Trajectory (perpendicular to trajectory) (cm)				
	30	15	0	15	30
0 cm.	0.51	0.91	2.50	1.45	0.70
50	5.34	3.64	3.71	1.04	0.67
100	1.46	1.99	3.05	2.08	1.11
150	0.95	2.03	1.72	1.03	N.D.
200	N.D.	0.80	0.21	0.36	0.35
500	0.25	0.17	0.37	0.19	0.16
1000	0.17	0.74	0.47	0.99	0.18
1250	0.29	0.91	0.29	0.57	1.18
1300	0.61	2.44	1.10	0.94	1.94

*Not Detected

APPENDIX B

RESULTS OF HAIR AND HAIR-WASH ANALYSES USING MULTIPLE NEUTRON ACTIVATION AND HIGH RESOLUTION γ-RAY SPECTROMETRY

Explanation of Terms and Abbreviations used in the Tables

Hair - Hair samples from participant identified by the number that follows

H.W. - Hair-Wash sample corresponding to the hair with similar identification

N.D. - Not detectable by the analytical procedures used

****** - Denotes analyses still incomplete

Suffix X - Denotes sample collected from a participant at a six month interval

Suffix Y - Denotes sample obtained after 12 month interval after the first donation

Suffixes A, B, etc. - Denotes several hair samples submitted by the same individual

Suffix R - Pubic hair

Numbers 1-400 - Penn State students

Numbers 400-700 and 901-999 - Parents and siblings of PSU students

Numbers 701-800 - Other Pennsylvania residents

Table B-1

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 1	ND	ND	22.6	4.9	17	ND	341	21	265	2022	1.7	5.0	ND	ND	4.2	0.9	ND	ND	327	0.1	ND	ND
HAIR 2	ND	3.0	24.1	2.3	ND	0.5	2440	60	1414	1052	1.0	6.5	7.4	0.2	7.2	4.0	0.7	0.1	301	0.3	95	ND
HAIR 3	42.9	1.8	5.9	2.3	72	0.2	379	27	166	1604	1.2	9.8	3.8	0.4	2.6	1.2	0.7	ND	306	0.3	68	ND
HAIR 4	ND	3.2	6.1	1.3	142	ND	550	67	188	2640	3.9	63.0	ND	9.7	ND	0.6	2.9	ND	414	0.4	ND	ND
HAIR 5	ND	ND	6.7	2.1	30	ND	684	52	212	700	1.7	5.1	2.9	0.1	ND	0.6	ND	ND	490	0.4	61	ND
HAIR 6	ND	2.4	5.9	3.3	30	ND	645	21	239	2171	0.7	1.1	ND	ND	1.7	0.4	ND	ND	162	0.2	ND	ND
HAIR 7	ND	ND	8.2	18.5	46	ND	180	11	107	1545	1.3	23.6	ND	0.2	ND	0.3	ND	ND	491	0.6	ND	ND
HAIR 8	ND	1.8	5.1	2.1	28	ND	197	18	139	2219	2.0	10.2	ND	0.2	ND	0.4	0.8	ND	232	0.1	32	ND
HAIR 8A	17.5	ND	3.5	3.2	15	0.1	303	16	135	898	1.6	8.4	ND	ND	10.0	4.6	0.5	ND	365	0.3	26	ND
HAIR 10A	ND	2.1	8.1	4.1	84	ND	524	50	337	787	8.0	9.2	ND	1.5	ND	0.8	1.5	ND	219	0.5	35	ND
HAIR 11	ND	1.9	12.7	3.6	107	0.2	275	26	150	1814	2.4	18.5	ND	0.6	2.5	0.5	0.5	0.2	829	0.5	31	0.3
HAIR 12	37.4	ND	10.3	4.1	38	0.2	574	55	331	3423	0.8	3.6	1.8	0.2	2.0	1.1	0.5	ND	287	0.2	67	0.4
HAIR 13	ND	1.9	6.3	2.0	16	ND	848	17	175	2416	1.0	8.1	ND	0.1	ND	0.2	ND	ND	504	0.3	13	ND
HAIR 13A	ND	ND	11.5	2.1	17	0.2	683	29	245	2585	1.1	13.7	ND	0.1	2.4	1.2	ND	0.2	925	0.2	37	ND
HAIR 15	ND	ND	17.6	316.0	246	ND	1350	43	746	ND	ND	5.5	2.8	0.1	ND	2.3	1.0	ND	389	0.5	ND	ND
HAIR 16	ND	ND	6.4	1.3	15	ND	339	11	207	2183	ND	5.2	ND	0.3	ND	0.6	ND	ND	331	0.6	63	ND
HAIR 17	ND	ND	36.1	2.8	ND	ND	3747	37	1071	ND	ND	2.0	ND	ND	ND	0.6	1.1	ND	284	0.4	70	ND
HAIR 18	47.8	ND	6.3	6.0	91	ND	807	59	497	6294	2.5	13.0	4.6	3.9	ND	1.4	1.0	0.2	438	2.1	68	ND
HAIR 19	ND	ND	285.4	1.3	53	ND	3544	29	820	292	479.6	129.0	ND	0.9	ND	4.0	0.9	0.1	268	0.2	ND	ND
HAIR 20	ND	ND	91.8	1.0	34	ND	795	27	326	ND	2.6	3.7	ND	ND	ND	2.5	ND	ND	291	0.3	ND	0.7
HAIR 21	23.9	1.0	3.7	12.2	54	0.2	322	40	174	2710	1.2	5.7	2.5	1.3	ND	0.8	0.6	0.1	315	1.7	474	ND
HAIR 22	67.4	ND	5.1	0.8	136	ND	808	70	196	2242	ND	1.9	ND	ND	ND	ND	0.1	ND	208	0.5	62	ND
HAIR 23	60.3	ND	ND	3.1	147	ND	461	36	587	951	ND	6.3	ND	0.5	2.7	ND	1.8	ND	400	1.0	161	ND
HAIR 24	32.7	ND	16.7	2.8	340	ND	359	73	146	254	ND	3.0	2.4	3.2	ND	ND	ND	ND	137	0.3	157	ND
HAIR 25	ND	ND	7.1	8.2	19	ND	1109	13	372	1200	2.8	4.7	ND	ND	1.4	0.4	ND	ND	1012	1.6	ND	ND
HAIR 26	48.0	ND	3.4	1.5	25	0.2	516	31	78	1089	2.3	21.1	ND	0.2	2.1	1.1	0.5	0.1	433	0.6	39	ND
HAIR 27	ND	ND	4.9	1.1	33	ND	705	13	233	902	2.0	14.6	ND	0.1	5.2	2.5	ND	0.1	511	0.5	ND	ND
HAIR 27A	ND	ND	5.0	0.9	60	ND	817	16	223	1211	2.0	14.9	6.0	0.1	ND	ND	ND	0.1	562	0.3	ND	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 28	ND	ND	ND	ND	6320	0.3	594	53	931	724	2.5	12.9	ND	0.1	ND	ND	ND	ND	550	1.1	65	ND
HAIR 29	ND	7.6	3.8	3.2	44	0.3	348	27	52	2302	2.6	14.7	ND	0.1	1.8	1.0	0.4	0.1	414	0.2	ND	ND
HAIR 30	40.0	ND	36.7	10.0	30	ND	875	79	784	6055	2.7	38.4	ND	0.3	ND	ND	ND	ND	224	2.6	83	ND
HAIR 31	ND	1.7	10.1	1.6	34	0.2	331	71	174	1266	1.8	19.6	ND	0.5	ND	0.6	ND	ND	248	0.4	ND	ND
HAIR 32	ND	ND	13.3	33.0	389	ND	601	23	355	599	1.4	5.6	ND	1.0	1.9	ND	1.6	ND	352	0.6	39	ND
HAIR 33	ND	2.8	15.4	2.4	30	ND	1944	46	727	463	1.6	9.7	ND	0.1	20.6	9.9	0.8	ND	333	0.1	39	ND
HAIR 34	ND	ND	22.4	8.2	32	ND	1509	76	1162	3807	1.3	3.4	ND	0.1	ND	1.7	0.6	0.1	450	1.0	ND	ND
HAIR 35	ND	ND	22.2	1.8	31	ND	774	40	454	1541	7.8	28.5	ND	0.1	ND	1.8	ND	ND	300	0.3	42	ND
HAIR 36	29.7	2.7	3.7	1.8	27	ND	396	29	121	1687	1.1	6.3	ND	0.4	ND	0.8	0.7	ND	246	0.1	ND	ND
HAIR 37	ND	ND	51.5	2.5	20	ND	649	20	353	580	1.3	5.9	ND	ND	ND	2.1	0.3	0.1	265	0.2	15	ND
HAIR 38	17.8	0.9	4.2	5.1	23	ND	450	33	104	2702	0.7	2.6	1.7	0.4	9.7	5.0	ND	0.1	309	0.4	36	1.9
HAIR 39	ND	ND	10.5	2.4	34	ND	1220	131	183	ND	3.5	38.4	ND	0.1	ND	2.6	0.6	0.1	264	0.2	60	ND
HAIR 40	ND	ND	8.5	3.9	17	ND	1480	23	313	1098	1.5	4.1	ND	0.1	ND	1.0	ND	ND	322	0.2	62	ND
HAIR 41	17.6	ND	7.5	2.9	62	ND	825	32	253	3494	1.1	3.7	ND	0.1	ND	0.4	0.4	0.1	334	0.2	46	ND
HAIR 42	ND	1.1	6.4	0.8	44	ND	454	11	231	1260	1.5	5.2	ND	0.1	ND	0.5	0.3	0.1	290	0.1	ND	ND
HAIR 43	903.2	ND	8.8	ND	6612	ND	1538	33	616	1183	1.0	1.1	ND	0.1	ND	ND	ND	0.1	277	0.7	ND	ND
HAIR 44	ND	ND	62.7	10.1	ND	ND	3127	128	727	550	ND	2.4	3.4	0.3	ND	3.3	0.9	0.1	245	0.4	91	ND
HAIR 45	ND	ND	3.4	1.6	32	ND	435	18	100	2113	1.3	2.8	ND	0.1	2.4	2.0	0.7	0.1	298	0.2	ND	ND
HAIR 46	ND	ND	10.4	4.2	63	ND	1013	30	179	5149	ND	2.9	ND	0.1	1.7	0.8	1.7	0.1	332	0.2	ND	ND
HAIR 47	ND	ND	199.2	3.3	32	ND	1036	12	596	3046	1.8	7.6	ND	ND	ND	0.5	1.3	0.1	310	0.3	ND	ND
HAIR 48	ND	ND	3.7	3.9	61	ND	700	58	345	5808	2.5	21.8	ND	0.1	ND	1.0	0.9	0.1	329	0.9	42	1.4
HAIR 48A	ND	ND	11.1	5.2	31	ND	1530	68	405	811	1.1	2.3	ND	0.2	ND	0.7	0.5	0.1	585	0.3	55	ND
HAIR 49	38.5	1.9	36.7	1.4	48	ND	827	14	212	977	2.2	9.7	ND	ND	ND	0.9	0.4	ND	315	0.2	ND	ND
HAIR 50	ND	ND	6.6	1.7	75	ND	459	24	173	1933	1.2	5.0	ND	0.2	ND	1.1	ND	0.1	385	0.2	73	ND
HAIR 51	83.3	ND	14.9	3.2	61	ND	1250	40	552	3177	2.1	4.3	ND	0.5	ND	3.1	1.2	0.1	520	0.3	ND	ND
HAIR 53	ND	ND	11.4	2.0	18	0.2	1097	34	191	657	1.8	ND	ND	ND	ND	0.7	0.5	0.1	430	0.2	56	0.4
HAIR 53A	16.8	ND	7.1	2.2	20	ND	464	7	377	1676	1.7	ND	ND	ND	ND	0.6	ND	0.1	478	0.3	ND	ND
HAIR 54	34.6	ND	21.9	5.8	406	0.2	712	45	218	4535	1.8	17.6	23.1	1.0	1.5	3.9	8.1	ND	1802	0.5	43	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CD	FE	LA
HAIR 55	81.4	ND	133.0	2.2	41	0.2	825	14	76	1789	1.5	8.7	ND	0.2	ND	1.8	0.4	0.1	358	0.2	20	ND
HAIR 56	ND	ND	4.7	3.3	31	ND	256	59	67	2601	4.3	24.6	12.3	0.3	ND	1.2	0.9	0.1	493	0.4	46	ND
HAIR 57	ND	ND	8.2	7.7	43	ND	751	13	644	3621	2.4	18.5	ND	0.2	ND	1.1	0.7	0.1	427	0.8	33	ND
HAIR 58	ND	ND	15.9	3.9	35	ND	1077	16	715	1183	ND	119.0	ND	3.6	ND	ND	ND	ND	563	0.5	ND	ND
HAIR 59	ND	ND	4.9	1.8	17	ND	206	7	106	1835	1.6	5.8	ND	ND	3.2	2.2	2.4	ND	425	0.4	ND	ND
HAIR 60	ND	ND	16.0	3.2	ND	ND	2918	11	1015	503	2.7	4.6	ND	0.1	ND	1.0	ND	0.1	509	0.4	46	ND
HAIR 61	25.2	ND	71.1	ND	502	ND	295	25	172	1005	7.3	60.4	ND	2.0	ND	0.7	3.4	ND	552	0.4	39	ND
HAIR 62	ND	ND	3.1	1.7	22	ND	522	20	147	1775	2.0	11.0	1.8	0.3	1.3	1.1	ND	ND	363	0.4	ND	0.6
HAIR 63	ND	ND	ND	1.7	ND	ND	529	19	409	764	4.8	17.7	ND	ND	ND	ND	ND	ND	479	0.2	ND	ND
HAIR 64	37.4	ND	ND	5.2	25	0.3	637	94	430	1310	ND	6.7	ND	0.2	1.1	2.4	ND	0.2	521	0.7	106	ND
HAIR 65	ND	1.1	2.5	2.4	40	ND	531	6	ND	1897	5.3	20.9	ND	1.0	ND	ND	ND	0.1	431	0.6	ND	ND
HAIR 66	ND	0.9	2.6	0.5	11	ND	183	11	139	334	1323.4	593.1	ND	0.2	ND	ND	ND	ND	244	0.2	ND	ND
HAIR 67	50.3	ND	62.7	3.1	70	ND	335	18	ND	4230	3.6	14.2	ND	0.4	ND	1.1	ND	0.1	421	0.3	ND	ND
HAIR 68	ND	ND	10.4	7.5	35	ND	515	37	1362	854	2.3	5.0	ND	0.2	ND	0.4	ND	0.1	319	0.5	44	ND
HAIR 69	ND	ND	13.9	1.8	172	ND	1935	14	698	ND	1.5	5.5	ND	ND	ND	0.3	0.8	0.1	362	0.3	ND	ND
HAIR 70	ND	ND	9.2	3.8	36	ND	897	34	174	1299	3.1	28.5	ND	0.1	ND	0.7	0.9	ND	268	0.6	49	ND
HAIR 71	ND	ND	17.7	2.6	ND	ND	705	26	368	2796	2.5	11.9	ND	ND	ND	1.0	ND	ND	262	0.2	ND	ND
HAIR 72	ND	ND	25.1	4.4	ND	ND	4687	60	1919	693	2.5	13.9	2.6	0.1	ND	1.9	1.0	0.1	292	0.3	92	ND
HAIR 72A	28.5	ND	ND	5.3	67	ND	524	106	317	4752	ND	108.5	4.7	0.8	3.6	6.0	0.8	ND	412	4.4	64	ND
HAIR 73B	ND	ND	15.6	1.6	35	ND	395	6	78	1624	1.5	4.3	ND	0.1	ND	1.0	ND	0.1	287	0.3	ND	ND
HAIR 74	176.3	ND	16.9	4.6	111	ND	1453	32	1168	1075	145.0	34.7	39.9	0.4	12.1	9.1	ND	0.1	237	0.8	94	2.0
HAIR 75	ND	ND	22.0	1.4	194	ND	930	18	316	908	1.6	12.0	2.0	0.1	ND	1.7	1.0	0.2	759	0.3	34	ND
HAIR 76	ND	ND	5.3	2.5	78	ND	184	23	110	3112	1.4	10.9	ND	0.1	ND	0.5	0.5	0.5	355	2.2	48	ND
HAIR 77A	ND	ND	3.5	2.5	47	ND	319	14	256	2033	1.0	ND	ND	0.1	ND	0.4	ND	ND	276	0.3	43	ND
HAIR 77B	ND	ND	6.3	2.7	64	ND	286	13	250	1595	0.8	1.5	ND	0.3	ND	0.7	0.5	0.1	383	0.3	ND	ND
HAIR 78	38.3	ND	6.3	ND	796	0.5	335	15	154	3298	0.8	ND	ND	0.1	ND	0.4	3.9	ND	579	0.5	31	0.2
HAIR 79	ND	ND	8.6	1.2	30	ND	2116	9	359	1046	1.4	8.1	ND	ND	ND	1.0	ND	ND	223	0.3	27	ND
HAIR 80	ND	ND	12.7	3.6	27	ND	256	16	96	2340	1.3	1.8	ND	0.1	ND	0.2	ND	0.1	435	0.2	47	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 101	34.2	ND	6.4	3.1	85	0.1	498	23	282	2056	1.7	11.7	ND	0.6	ND	0.4	0.4	0.1	325	0.3	31	ND
HAIR 102	ND	ND	4.5	1.2	123	ND	255	7	61	1075	1.4	2.7	1.5	0.1	ND	0.3	ND	0.2	393	0.2	15	ND
HAIR 103	ND	2.1	2.6	2.5	42	0.1	142	8	393	802	1.7	11.5	ND	0.1	ND	0.2	ND	0.1	270	0.2	ND	ND
HAIR 104	ND	ND	8.9	3.3	31	0.5	227	12	301	3197	0.9	ND	ND	ND	ND	0.5	0.6	0.1	326	0.5	19	ND
HAIR 106	ND	ND	11.6	30.4	57	ND	600	52	183	1541	0.8	8.2	17.7	0.1	ND	0.3	0.6	0.1	269	1.2	56	ND
HAIR 107	10.1	ND	0.9	2.2	13	ND	92	6	96	1797	1.4	3.3	ND	0.1	0.7	0.6	0.3	0.1	306	0.4	24	ND
HAIR 107A	9.9	ND	3.9	2.1	21	0.2	572	25	283	991	1.2	1.7	0.9	0.2	1.9	1.0	0.8	0.1	295	0.1	44	ND
HAIR 108	ND	ND	14.3	5.3	250	ND	337	16	85	585	2.2	15.6	ND	0.2	ND	0.5	0.7	0.1	282	0.1	13	ND
HAIR 109	ND	1.0	4.2	2.8	36	0.1	844	55	293	1576	0.7	ND	19.3	0.1	ND	1.0	0.4	0.1	394	0.2	23	ND
HAIR 110	61.8	ND	9.4	ND	1238	0.2	886	38	555	2186	1.1	3.1	ND	0.8	ND	0.7	2.4	0.1	405	0.4	41	1.0
HAIR 111	ND	ND	8.1	5.3	28	0.2	342	42	109	1301	4.9	6.0	ND	0.4	ND	0.5	0.3	0.1	278	0.3	84	0.1
HAIR 117	ND	ND	29.0	2.9	62	ND	4741	34	2524	2941	1.4	8.8	1.5	0.2	13.8	0.4	ND	ND	158	0.2	42	ND
HAIR 121	ND	ND	35.3	1.6	10	0.1	320	32	61	766	0.9	ND	2.0	ND	25.8	ND	ND	ND	228	0.1	24	0.2
HAIR 132	ND	ND	10.5	1.3	19	0.2	832	16	223	2176	0.9	2.1	ND	0.4	10.1	0.4	ND	0.2	275	0.1	42	ND
HAIR 133	44.3	ND	9.8	ND	ND	ND	1866	19	384	409	488.7	66.0	ND	0.1	8.2	0.2	ND	0.1	182	0.2	ND	ND
HAIR 134	ND	ND	8.1	0.7	ND	ND	825	11	46	167	ND	3.3	ND	0.1	15.4	0.5	ND	ND	175	0.2	ND	ND
HAIR 135	ND	0.7	4.5	1.1	16	0.1	334	21	95	1439	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 136	ND	ND	24.3	0.8	ND	ND	3613	10	956	260	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 136A	ND	ND	18.1	0.9	ND	ND	3462	15	575	538	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 137	ND	ND	23.2	3.8	53	ND	239	19	124	4507	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 139	ND	ND	5.0	1.3	10	ND	426	8	208	1991	1.4	5.5	ND	0.4	5.9	0.3	ND	0.1	406	0.1	14	ND
HAIR 140	24.1	ND	14.1	4.0	53	ND	683	59	374	5583	1.6	12.4	ND	0.7	17.3	2.1	ND	0.3	1083	0.3	70	ND
HAIR 140A	12.1	ND	14.2	2.4	42	ND	441	22	213	5541	1.6	16.7	ND	0.2	18.7	1.2	ND	0.1	835	0.2	34	ND
HAIR 141	22.6	ND	4.7	1.8	34	ND	948	18	71	1468	1.0	3.4	ND	0.1	4.1	0.6	ND	0.1	351	0.1	26	ND
HAIR 149	ND	ND	41.7	3.5	226	ND	530	21	55	1245	6.3	27.7	ND	0.2	2.7	4.3	0.4	ND	317	0.3	25	ND
HAIR 153	ND	ND	6.2	4.9	433	0.1	427	43	672	2546	0.7	1.9	ND	0.8	2.2	1.9	1.2	0.1	316	1.1	38	ND
HAIR 169	ND	ND	14.1	3.5	36	ND	1740	20	276	697	1.0	1.3	ND	0.1	ND	0.5	0.4	0.1	310	0.1	29	ND
HAIR 179	ND	2.3	28.9	4.2	277	0.2	1012	28	499	4092	0.7	5.2	ND	ND	ND	0.5	ND	0.1	248	0.4	32	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 186	1.3	ND	0.1	ND	0	0.1	0	574	0	23	ND	ND	0.9	3.8	2.1	51.0	0.1218.0		22473.0		954	1.2
HAIR 199	ND	ND	8.2	2.4	50	0.1	548	10	293	3350	1.4	9.0	ND	0.5	ND	0.6	0.3	0.1	212	1.1	47	ND
HAIR 205	ND	ND	15.7	12.8	395	0.4	1741	77	372	3612	1.3	9.4	ND	1.1	ND	ND	1.9	ND	259	0.2	22	0.1
HAIR 213	14.4	ND	14.2	4.3	12	ND	277	19	337	1080	1.5	13.2	ND	0.1	ND	0.6	0.3	0.1	225	0.1	36	ND
HAIR 221	20.2	ND	29.5	6.0	19	ND	561	21	242	1534	2.9	4.6	ND	0.2	2.2	3.3	ND	ND	206	0.3	33	0.3
HAIR 232	44.5	1.2	5.4	2.3	143	0.2	684	20	151	2432	1.8	6.3	4.6	0.1	ND	0.6	1.0	0.2	408	0.2	31	ND
HAIR 245	37.0	1.1	9.7	2.0	247	ND	1047	27	113	423	1.4	6.4	ND	0.2	ND	4.7	0.2	0.1	311	0.3	50	ND
HAIR 245A	ND	ND	11.9	2.0	20	ND	2076	21	195	278	2.2	0.8	ND	0.3	ND	0.8	2.0	0.1	137	0.1	37	ND
HAIR 401	ND	ND	26.3	2.8	22	ND	141	35	204	4942	1.1	ND	ND	0.1	ND	ND	ND	ND	102	0.2	ND	ND
HAIR 402	ND	2.5	ND	22.5	398	ND	341	77	87	689	1.1	6.5	1.0	0.1	ND	0.6	0.6	ND	161	0.9	100	0.2
HAIR 405	ND	ND	13.9	ND	279	ND	758	11	ND	1082	2.3	4.3	9.6	ND	ND	1.5	ND	0.1	200	0.2	63	ND
HAIR 406	49.7	ND	60.3	9.9	27	0.2	865	158	593	6186	4.9	3.9	1.0	0.5	ND	0.7	ND	ND	134	0.6	87	ND
HAIR 407	ND	ND	418.8	3.9	65	ND	687	56	1523	2431	ND	2.8	ND	0.3	ND	1.6	ND	ND	215	0.3	ND	ND
HAIR 410	ND	1.7	ND	2.2	39	0.1	307	15	69	1045	3.7	21.8	ND	0.1	0.3	0.5	ND	ND	144	0.2	24	ND
HAIR 411	ND	2.3	30.1	0.8	24	ND	3307	17	859	ND	2.1	2.6	ND	ND	ND	0.8	ND	ND	208	0.2	ND	ND
HAIR 412	15.6	4.7	12.8	1.3	219	0.2	755	14	138	580	1.6	3.2	ND	ND	ND	0.2	ND	0.1	213	0.1	17	ND
HAIR 413	38.3	ND	9.7	1.2	ND	0.3	2150	35	692	484	3.0	10.5	ND	0.1	ND	1.3	ND	0.1	275	0.2	21	ND
HAIR 416	17.8	ND	5.4	0.5	11	ND	858	24	246	801	1.3	6.1	ND	0.1	ND	0.2	ND	ND	183	0.1	15	ND
HAIR 417	ND	ND	4.5	2.5	22	0.3	782	20	304	1268	2.8	7.2	1.6	0.1	ND	2.1	ND	0.1	231	0.3	38	ND
HAIR 419	ND	6.0	18.2	1.1	23	ND	1245	25	282	377	2.0	3.3	ND	0.2	ND	1.1	ND	0.1	166	0.2	43	ND
HAIR 421	ND	ND	11.9	2.9	26	ND	793	25	2253	2044	ND	69.8	ND	ND	ND	1.5	ND	0.1	153	0.2	32	ND
HAIR 422	ND	ND	5.3	2.2	60	ND	635	7	854	941	ND	85.6	ND	ND	ND	0.3	ND	ND	191	0.2	29	ND
HAIR 423	29.6	6.7	5.8	1.5	74	ND	538	30	246	660	1.3	7.2	ND	0.3	1.1	1.2	ND	ND	150	0.1	34	ND
HAIR 426	ND	1.1	17.1	1.3	20	0.2	990	31	232	447	1.4	0.8	ND	ND	ND	0.5	ND	ND	142	0.1	33	ND
HAIR 428	ND	ND	34.8	2.3	ND	ND	12570	24	3629	ND	2.0	11.1	3.3	0.1	2.4	4.0	ND	ND	67	0.2	ND	ND
HAIR 429	ND	ND	ND	4.3	300	0.5	2519	56	311	6527	6.6	60.1	ND	ND	12.3	11.5	ND	0.1	312	0.3	138	0.3
HAIR 430	ND	ND	29.6	3.8	186	0.3	395	42	151	2193	1.7	6.6	ND	0.4	ND	0.5	ND	0.1	202	0.3	109	ND
HAIR 433	34.6	2.3	2.5	7.1	29	0.2	294	98	376	5761	*	*	*	*	*	*	*	*	*	*	*	*

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 435	ND	4.9	23.5	ND	53	ND	3243	17	1535	ND	ND	ND	ND	3.9	0.6	0.3	0.7	ND	246	0.3	82	ND
HAIR 436	ND	ND	163.8	5.5	39	ND	1020	40	908	1894	ND	ND	ND	0.1	ND	ND	ND	ND	306	1.7	ND	ND
HAIR 437	ND	2.1	9.0	4.3	19	ND	1328	34	542	2424	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 438	ND	ND	8.1	7.5	52	ND	1636	38	648	1873	ND	ND	1.6	0.1	ND	4.1	ND	0.1	111	0.4	ND	ND
HAIR 441	ND	ND	ND	5.4	121	0.3	968	13	376	2484	ND	2.3	ND	0.2	ND	0.3	1.2	0.1	222	0.4	70	ND
HAIR 442	ND	ND	5.7	2.6	106	ND	698	21	318	ND	2.9	32.7	ND	0.1	ND	0.1	0.8	0.1	136	0.3	77	ND
HAIR 443	ND	ND	17.1	1.4	ND	ND	1530	25	284	ND	1.5	1.5	4.5	ND	0.1	ND	0.5	0.1	286	0.2	52	ND
HAIR 444	ND	ND	140.5	3.1	ND	ND	779	21	684	1617	ND	2.5	ND	0.1	ND	1.1	ND	0.1	172	0.3	ND	ND
HAIR 448	ND	ND	14.2	1.6	23	ND	329	5	ND	2458	1.3	4.7	ND	0.1	ND	ND	0.9	0.1	256	0.4	ND	ND
HAIR 449	ND	ND	52.4	ND	61	ND	3005	18	2076	1646	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 450	ND	ND	37.9	4.5	ND	ND	4064	38	1470	ND	ND	11.5	0.1	0.2	ND	0.3	1.0	0.1	43	0.4	9	ND
HAIR 451	ND	ND	46.1	2.8	ND	ND	5150	17	1470	ND	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 453	32.6	3.0	3.8	3.3	ND	ND	408	18	288	2962	1.9	ND	ND	0.4	ND	2.2	3.0	0.1	233	0.9	131	ND
HAIR 454	ND	5.6	4.6	8.7	191	ND	229	35	240	5519	ND	1.0	ND	0.6	ND	0.7	0.9	0.1	316	0.3	ND	0.3
HAIR 458	ND	ND	17.2	3.3	166	ND	2034	70	751	817	ND	ND	1.6	0.5	1.6	0.6	0.8	0.1	318	0.7	ND	ND
HAIR 461R	ND	ND	40.0	2.4	ND	ND	1142	40	476	1283	1.0	ND	ND	0.1	ND	0.2	ND	0.1	142	0.1	ND	ND
HAIR 461	21.9	ND	8.7	2.6	16	ND	597	28	247	2117	20.1	10.6	ND	0.2	ND	ND	2.4	0.1	206	0.3	69	ND
HAIR 463	ND	ND	9.6	0.7	ND	0.5	701	6	126	1308	0.8	1.5	ND	0.1	0.8	0.4	0.8	0.1	176	0.2	49	ND
HAIR 464	ND	ND	13.4	10.4	133	ND	1996	22	14200	1770	ND	2.0	ND	ND	ND	0.3	ND	0.1	149	0.6	51	ND
HAIR 465	ND	ND	128.7	3.3	53	ND	2926	37	2014	1892	1.8	ND	2.0	0.2	ND	0.9	1.1	0.1	428	0.5	164	ND
HAIR 466	ND	ND	25.9	3.6	ND	ND	6175	21	2216	ND	0.8	4.9	1.5	ND	ND	0.4	1.3	0.1	173	0.3	76	ND
HAIR 467	ND	ND	9.9	2.5	ND	ND	1397	12	1326	1333	ND	1.3	1.6	0.1	ND	ND	0.6	ND	246	0.1	53	ND
HAIR 468	ND	ND	38.9	2.8	ND	ND	5371	17	1963	ND	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 470	ND	2.4	ND	4.2	37	0.2	406	9	738	2140	0.8	3.2	ND	0.1	ND	0.8	ND	0.1	366	0.2	47	ND
HAIR 473	ND	ND	58.9	1.2	27	ND	207	12	634	1634	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 475	ND	ND	24.6	14.3	41	ND	378	37	180	2386	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 476	ND	ND	9.2	ND	100	ND	1202	19	258	402	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 477	21.7	ND	5.1	1.8	40	ND	357	10	81	2425	*	*	*	*	*	*	*	*	*	*	*	*

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 478	ND	ND	17.1	4.3	80	0.2	551	27	375	4157	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 479	ND	ND	15.9	1.8	27	ND	2193	21	664	355	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 607	ND	6.1	33.2	ND	ND	ND	1836	12	545	ND	1.0	ND	ND	0.1	ND	0.2	ND	ND	210	0.3	ND	ND
HAIR 608	ND	1.0	2.4	1.0	16	ND	344	3	272	1439	0.9	4.6	ND	0.1	ND	0.3	0.3	0.1	237	0.7	25	0.1
HAIR 609	*	*	*	*	*	*	*	*	*	*	0.8	4.5	1.4	0.2	0.4	0.5	0.4	ND	289	0.4	34	ND
HAIR 612	ND	ND	8.2	0.5	13	0.1	833	10	323	579	ND	3.9	ND	ND	ND	0.2	0.4	0.1	214	0.2	21	ND
HAIR 612R	ND	ND	3.9	1.2	11	ND	592	9	322	348	3.1	25.5	ND	0.2	0.2	0.2	ND	ND	183	0.2	14	ND
HAIR 801	54.4	2.9	9.6	6.8	42	ND	544	47	920	2595	ND	73.2	ND	0.3	ND	ND	0.5	0.1	326	0.8	ND	ND
HAIR 802	ND	ND	13.6	3.9	31	ND	870	35	699	4616	ND	2.4	3.7	0.2	ND	ND	ND	0.1	233	0.3	ND	ND
HAIR 808	20.2	2.0	16.5	5.0	33	ND	106	23	146	6080	ND	2.7	2.7	0.2	18.6	6.4	ND	0.1	287	0.2	ND	ND
HAIR 4X	ND	ND	4.8	2.9	153	ND	235	49	137	4215	ND	1.1	ND	0.2	ND	ND	ND	ND	14	ND	1	ND
HAIR 6X	ND	ND	9.6	1.2	13	ND	207	5	96	1483	ND	3.1	1.0	0.1	ND	0.6	ND	ND	247	0.5	ND	1.0
HAIR 9X	ND	ND	11.5	14.1	57	ND	1077	15	598	2112	ND	4.1	ND	ND	ND	1.0	1.1	0.3	518	1.2	34	ND
HAIR 12X	25.5	ND	13.2	3.2	62	0.3	1168	33	620	3467	ND	7.3	8.9	0.2	ND	1.6	3.5	0.3	401	0.3	76	ND
HAIR 13X	ND	ND	335.6	2.1	60	0.1	380	27	84	2582	ND	0.5	1.3	0.1	ND	ND	ND	ND	64	ND	11	ND
HAIR 14X	16.2	2.1	6.2	1.2	16	ND	415	13	240	1006	0.7	ND	1.7	0.9	2.1	2.5	ND	0.1	177	0.2	31	0.2
HAIR 22X	ND	ND	8.9	0.8	37	ND	533	6	133	1503	3.2	22.7	ND	0.1	0.3	0.7	0.4	ND	239	0.7	ND	0.2
HAIR 33X	ND	2.6	6.6	0.8	24	ND	926	8	179	424	0.6	3.4	0.9	ND	ND	0.7	0.5	ND	189	0.4	ND	ND
HAIR 46X	ND	ND	4.0	3.0	71	ND	481	21	193	3938	ND	5.2	1.4	0.1	ND	0.9	2.3	0.2	258	0.1	57	ND
HAIR 53X	ND	ND	2.4	1.9	26	0.1	167	4	71	2437	ND	ND	ND	0.1	ND	ND	ND	0.1	414	0.2	ND	ND
HAIR 56X	41.3	ND	165.9	2.5	35	ND	993	13	358	1455	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 57X	*	*	*	*	*	*	*	*	*	*	ND	38.3	21.2	0.2	9.4	7.6	ND	0.1	245	0.3	ND	ND
HAIR 60X	ND	1.2	17.0	2.7	ND	ND	899	10	347	1194	ND	56.3	22.9	0.1	ND	10.9	0.4	0.2	338	0.2	100	ND
HAIR 61X	32.4	ND	8.2	4.0	296	ND	270	19	128	1410	ND	2.0	ND	0.6	29.4	1.2	ND	0.1	386	0.1	22	ND
HAIR 62X	ND	ND	3.4	2.2	51	0.1	274	7	112	3138	ND	38.3	2.3	0.1	ND	29.2	1.1	0.1	374	0.5	ND	ND
HAIR 64X	22.3	1.4	5.5	1.7	40	ND	753	38	190	1226	1.1	2.6	1.1	0.1	0.7	1.0	0.8	0.1	269	0.4	36	ND
HAIR 66X	ND	ND	4.0	1.0	31	ND	776	30	347	2008	295.3	45.9	ND	0.5	ND	0.4	0.3	0.1	189	0.3	31	0.2
HAIR 74X	95.6	ND	5.0	4.0	29	0.2	1386	47	557	1637	ND	8.1	3.2	0.3	ND	2.4	0.9	0.2	388	0.3	68	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 77X	ND	1.3	4.4	0.9	49	ND	224	9	106	1701	ND	2.0	ND	0.3	ND	0.3	ND	0.3	434	0.1	32	ND
HAIR 80X	ND	ND	62.6	1.7	60	ND	263	11	86	1931	ND	ND	ND	0.1	ND	ND	ND	ND	220	0.2	ND	0.2
HAIR 111X	14.0	1.1	8.9	2.0	33	0.1	266	13	173	2098	23.8	8.0	25.5	0.3	1.2	1.9	0.4	0.1	284	0.3	135	ND
HAIR 117X	ND	0.8	5.3	2.7	132	0.1	222	17	95	7449	0.4	2.4	ND	0.1	1.9	ND	ND	0.1	189	0.1	30	ND
HAIR 121X	ND	ND	5.6	1.4	29	ND	148	8	37	1624	0.6	ND	ND	ND	13.1	0.1	ND	0.1	254	0.1	23	ND
HAIR 132X	ND	ND	19.9	1.5	30	ND	440	13	420	1279	3.7	3.3	ND	0.9	19.3	2.7	ND	0.1	276	0.2	ND	ND
HAIR 133X	ND	2.0	5.5	1.3	25	ND	462	12	188	2755	1443.9	210.7	ND	0.2	3.4	ND	ND	0.1	229	0.2	ND	ND
HAIR 134X	ND	2.6	12.6	1.4	67	ND	628	17	162	1395	2.8	2.6	1.6	0.3	9.0	ND	ND	ND	279	0.3	51	ND
HAIR 135X	ND	ND	3.6	1.1	28	ND	298	11	78	1405	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 136X	ND	1.6	4.6	0.9	15	ND	713	4	76	982	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 137X	22.4	ND	6.0	1.6	46	ND	122	15	75	2886	*	*	*	*	*	*	*	*	*	*	*	*
HAIR 139X	15.4	1.2	12.1	1.4	32	ND	460	11	155	1698	3.0	2.1	ND	0.2	14.6	0.2	ND	0.1	322	0.1	11	ND
HAIR 140X	26.7	ND	8.5	2.2	30	ND	581	26	272	3665	1.5	6.4	19.7	1.0	9.0	2.1	ND	0.1	397	0.2	38	ND
HAIR 141X	41.1	ND	8.8	2.0	63	ND	501	26	130	3268	1.8	9.6	1.7	0.8	8.8	2.0	ND	0.1	357	0.1	ND	0.3
HAIR 149X	ND	ND	4.8	1.4	186	ND	223	26	63	2058	ND	13.4	ND	0.4	2.1	2.3	0.3	0.1	286	0.1	27	ND
HAIR 153X	24.4	ND	5.1	3.9	215	0.1	360	37	135	3839	0.5	3.5	3.6	1.5	0.6	0.6	1.0	0.1	335	0.6	38	ND
HAIR 154X	19.9	2.5	6.5	3.3	83	ND	371	39	169	5918	ND	ND	3.0	0.8	4.3	5.6	0.9	ND	172	0.4	ND	ND
HAIR 159X	ND	0.8	1.8	3.3	13	ND	266	15	125	2497	0.6	ND	ND	0.1	0.2	0.2	ND	ND	207	0.2	ND	ND
HAIR 169X	17.7	1.1	8.8	1.6	39	ND	1467	23	164	2101	ND	ND	2.1	0.1	89.9	79.3	ND	ND	283	ND	ND	ND
HAIR 177X	ND	1.0	4.4	4.1	26	ND	418	15	183	4185	355.5	45.9	2.5	0.1	1.2	1.3	ND	ND	149	0.2	ND	ND
HAIR 179X	44.5	ND	39.3	3.5	85	ND	865	42	568	4144	0.6	4.7	2.7	0.1	ND	0.7	ND	0.1	181	0.2	36	ND
HAIR 186X	ND	ND	3.7	1.6	45	0.1	231	18	193	1811	1.7	ND	ND	0.2	0.6	ND	ND	ND	625	0.1	25	ND
HAIR 192X	ND	ND	7.1	1.5	56	ND	1366	23	633	1612	529.3	77.6	ND	ND	ND	ND	ND	ND	246	0.2	58	ND
HAIR 199X	46.8	ND	9.3	2.7	106	ND	479	21	111	3706	ND	1.5	8.3	2.5	65.0	65.5	0.3	ND	240	0.8	55	ND
HAIR 200X	25.8	2.4	10.1	3.2	54	ND	371	45	137	2239	1.0	1.8	ND	0.3	ND	1.0	0.7	ND	241	0.4	ND	ND
HAIR 205X	ND	0.7	3.5	1.8	46	ND	133	12	53	2355	1.4	2.4	ND	0.3	1.1	1.0	0.8	ND	215	0.1	26	ND
HAIR 210X	ND	1.8	2.9	1.8	22	0.1	174	5	114	1572	0.7	ND	ND	ND	ND	0.3	ND	ND	341	0.4	ND	ND
HAIR 213X	ND	0.7	9.6	3.9	47	0.1	125	20	42	2697	1.9	11.6	ND	0.1	ND	0.3	0.2	ND	238	0.1	37	ND

Table B-1 (continued)

Trace Element Composition of Human Hair (in 10^{-6} gm per gm of Hair)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
HAIR 218X	58.0	ND	18.8	1.7	212	ND	2547	74	637	364	1.4	2.5	ND	0.3	4.2	4.7	2.2	ND	190	0.2	56	ND
HAIR 219X	39.5	ND	44.3	2.0	35	0.2	688	24	270	3720	4.0	ND	0.8	0.3	4.7	6.3	ND	0.1	222	0.2	52	0.3
HAIR 224X	92.6	ND	32.7	2.3	63	0.2	469	121	186	1828	451.2	67.1	1.4	0.4	ND	3.0	0.6	0.1	231	0.6	97	0.1
HAIR 225X	ND	ND	67.4	1.7	40	ND	827	20	353	2025	17.6	1.9	ND	ND	ND	1.6	0.3	ND	250	0.2	ND	ND
HAIR 229X	60.9	1.1	8.8	3.2	41	ND	229	20	115	4907	2.8	ND	ND	0.5	ND	0.8	0.4	ND	219	0.4	ND	ND
HAIR 230X	ND	0.8	7.4	1.2	27	ND	578	10	170	1223	0.9	ND	ND	ND	ND	0.2	ND	ND	265	0.1	29	ND
HAIR 232X	50.6	1.1	4.4	2.8	121	0.2	450	39	229	3239	2.1	5.5	1.5	0.1	2.1	2.2	0.9	0.1	387	0.1	49	0.2
HAIR 236X	ND	ND	6.1	1.6	27	ND	865	35	411	2347	1.9	9.8	11.3	ND	ND	0.4	0.3	ND	251	0.1	55	0.2
HAIR 239X	ND	2.7	35.7	1.3	ND	ND	5351	22	2182	ND	1.3	ND	ND	0.1	ND	0.8	0.3	0.1	141	0.1	20	ND
HAIR 241X	ND	ND	5.1	1.1	25	ND	357	18	162	2541	1.5	10.9	ND	0.1	ND	0.3	ND	ND	210	0.1	ND	ND
HAIR 245X	38.0	0.7	3.6	3.8	188	0.1	216	47	77	3283	1.3	7.3	ND	0.3	3.1	3.5	0.2	0.2	440	0.2	81	ND
HAIR 251X	ND	ND	34.6	1.7	53	ND	303	8	98	1589	0.9	ND	ND	ND	ND	0.2	ND	0.1	304	0.1	ND	ND
HAIR 254X	ND	1.0	10.3	1.6	57	ND	627	11	178	2608	1.0	2.5	1.1	0.1	0.5	0.6	0.4	ND	326	0.1	68	ND
HAIR 4Y	43.6	1.4	6.6	2.5	88	ND	482	125	231	3480	ND	ND	1.1	3.6	ND	0.3	1.5	0.1	302	0.2	106	0.2
HAIR 13Y	ND	0.9	4.0	2.4	38	ND	558	29	87	2682	0.5	ND	ND	0.1	ND	0.3	ND	0.1	296	0.1	67	ND
HAIR 22Y	ND	ND	11.5	1.2	82	ND	848	48	259	1821	213.4	55.1	3.1	0.2	1.4	1.3	0.6	0.1	268	0.5	63	ND
HAIR 53Y	ND	ND	4.3	1.1	86	0.1	288	11	104	1287	81.8	21.3	1.2	ND	ND	0.5	0.2	ND	103	0.2	24	ND
HAIR 64Y	ND	1.5	17.7	5.7	48	0.2	1699	131	966	1506	0.8	ND	1.2	0.1	2.7	3.4	0.8	0.1	267	0.4	81	ND
HAIR 117Y	ND	ND	3.7	1.2	185	0.1	253	8	115	4439	0.8	7.2	ND	ND	ND	0.3	0.3	ND	232	0.2	61	ND
HAIR 121Y	52.0	ND	13.4	0.7	ND	ND	2678	32	707	517	1.1	5.8	ND	0.1	ND	0.4	ND	0.1	298	0.1	25	ND
HAIR 133Y	ND	ND	8.7	0.8	23	ND	1774	17	352	848	1362.3	170.8	0.7	0.2	ND	0.3	0.2	ND	180	0.1	25	ND
HAIR 141Y	22.0	0.6	4.6	1.0	49	ND	343	25	143	2265	1.0	6.8	1.1	0.1	1.1	1.3	0.8	0.1	337	0.1	43	ND
HAIR 205Y	ND	ND	44.6	1.3	50	ND	318	16	60	1371	1.0	4.8	ND	0.2	ND	1.4	ND	0.1	263	0.1	22	ND
HAIR 213Y	24.9	ND	3.8	4.0	58	ND	151	23	145	2810	1.0	2.7	ND	0.1	ND	0.2	0.5	0.1	274	0.1	32	ND
HAIR 245Y	ND	ND	120.9	6.4	212	ND	356	112	216	777	1.5	6.2	ND	0.2	ND	2.7	0.6	0.1	360	0.3	86	ND

Table B-2

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 1	ND	ND	ND	2.2	ND	ND	ND	518	308	229	ND	ND	ND	ND	1.3	1.4	ND	ND	60	0.3	196	ND
H.W. 2	ND	ND	4.2	1.9	97	ND	129	232	292	ND	ND	ND	6.0	ND	2.0	1.4	ND	ND	110	0.2	206	ND
H.W. 4	ND	ND	ND	1.6	165	ND	64	79	404	697	ND	ND	ND	ND	ND	ND	ND	ND	157	0.2	159	ND
H.W. 5	ND	ND	ND	1.5	90	ND	68	170	204	205	ND	ND	7.6	ND	ND	1.3	ND	ND	128	ND	ND	7.0
H.W. 6	ND	ND	2.0	1.2	58	ND	69	77	168	359	ND	ND	1.8	ND	1.6	0.8	ND	ND	72	0.2	126	ND
H.W. 7	ND	ND	ND	0.9	83	ND	73	64	287	ND	ND	ND	2.0	ND	ND	0.5	ND	ND	103	0.2	ND	ND
H.W. 8	ND	ND	ND	0.8	41	ND	52	36	155	ND	ND	ND	1.4	ND	1.6	0.6	ND	ND	82	0.1	ND	ND
H.W. 9	ND	ND	ND	0.4	12	ND	19	41	47	ND	ND	ND	1.6	ND	1.2	0.6	ND	ND	168	0.1	ND	1.5
H.W. 10A	ND	ND	2.1	0.5	42	ND	91	48	88	73	ND	0.7	0.6	ND	0.5	0.2	ND	ND	104	0.1	46	0.1
H.W. 13	ND	ND	ND	0.2	24	ND	24	30	60	ND	ND	0.4	1.0	ND	1.1	0.7	0.1	ND	44	0.1	19	ND
H.W. 20	ND	ND	ND	0.3	48	ND	41	22	126	ND	ND	ND	2.0	ND	ND	0.7	ND	ND	154	0.5	ND	ND
H.W. 21	25.1	ND	ND	0.3	87	ND	54	19	123	ND	ND	ND	0.5	ND	ND	0.2	0.2	ND	29	0.1	ND	ND
H.W. 25	11.8	0.7	1.1	0.3	38	ND	20	21	84	ND	ND	ND	0.2	ND	ND	0.3	ND	ND	61	0.1	15	ND
H.W. 26	14.0	ND	ND	0.2	21	ND	27	17	120	ND	ND	ND	3.2	ND	ND	ND	ND	ND	6	ND	ND	ND
H.W. 27A	ND	ND	ND	0.2	59	ND	50	29	175	ND	ND	ND	0.4	ND	0.7	0.4	ND	ND	27	0.1	31	ND
H.W. 28	13.9	ND	ND	0.3	46	ND	ND	26	152	ND	ND	ND	ND	ND	ND	1.4	ND	ND	148	0.3	53	ND
H.W. 29	ND	ND	ND	0.3	56	ND	65	69	188	ND	ND	ND	ND	ND	ND	ND	ND	ND	8	ND	ND	ND
H.W. 30	ND	ND	1.7	0.6	85	ND	125	95	334	ND	0.4	ND	1.9	ND	ND	1.2	ND	ND	67	0.1	21	ND
H.W. 31	ND	ND	ND	0.5	61	ND	188	87	379	ND	ND	2.2	ND	ND	1.9	1.6	ND	ND	65	ND	93	ND
H.W. 32	ND	ND	ND	0.4	28	ND	27	38	134	ND	ND	ND	ND	ND	ND	ND	ND	ND	28	0.1	ND	ND
H.W. [illegible]	21.3	ND	ND	0.4	42	ND	ND	46	158	ND	ND	0.8	ND	ND	ND	ND	ND	ND	27	ND	ND	ND
H.W. 34	ND	ND	2.4	0.7	66	ND	72	87	218	ND	ND	1.1	ND	ND	ND	ND	ND	ND	95	ND	ND	ND
H.W. 35	52.1	ND	ND	0.6	108	ND	78	59	293	ND	ND	1.7	ND	ND	4.7	2.5	ND	ND	65	ND	ND	ND
H.W. 36	ND	ND	ND	0.3	16	ND	22	16	52	ND	ND	0.6	ND	ND	0.4	0.3	ND	ND	13	ND	ND	ND
H.W. 37	4.2	ND	ND	0.2	41	ND	15	16	49	ND	ND	0.2	ND	ND	0.3	0.1	ND	ND	26	ND	ND	ND
H.W. 38	25.7	ND	ND	ND	43	ND	46	47	172	ND	ND	ND	2.3	ND	1.0	0.4	ND	ND	31	0.1	ND	ND
H.W. 39	12.6	ND	ND	ND	35	ND	ND	62	110	ND	ND	ND	ND	ND	ND	0.4	ND	ND	10	ND	ND	ND
H.W. 40	ND	ND	ND	0.3	39	ND	49	27	165	ND	ND	ND	ND	ND	ND	ND	ND	ND	37	0.2	ND	ND

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 41	ND	ND	ND	ND	29	ND	12	13	31	ND	ND	ND	0.5	ND	0.3	0.1	ND	ND	12	ND	ND	ND
H.W. 42	ND	0.2	0.9	0.2	40	ND	23	15	83	ND	ND	0.4	ND	ND	0.5	0.2	ND	ND	22	ND	ND	ND
H.W. 43	ND	ND	ND	0.5	85	ND	82	73	205	ND	ND	2.3	ND	ND	1.3	0.6	ND	ND	48	0.1	64	ND
H.W. 44	ND	ND	3.0	0.8	80	ND	198	86	218	ND	ND	1.4	1.4	ND	1.2	0.6	ND	ND	47	0.1	ND	ND
H.W. 45	27.9	ND	ND	0.3	44	ND	45	35	53	ND	ND	0.4	1.1	ND	ND	0.2	ND	ND	28	ND	32	ND
H.W. 46	62.3	ND	ND	ND	74	ND	47	47	106	ND	ND	2.5	ND	ND	1.5	0.3	ND	ND	49	ND	ND	ND
H.W. 47	ND	ND	ND	ND	52	ND	ND	28	136	ND	ND	ND	2.1	ND	ND	0.5	ND	ND	52	0.1	ND	ND
H.W. 48	ND	ND	ND	0.4	55	ND	29	20	183	ND	ND	ND	ND	ND	1.6	0.7	ND	ND	41	ND	ND	5.1
H.W. 48A	ND	ND	ND	0.2	19	ND	10	15	81	ND	ND	ND	ND	ND	0.4	0.3	ND	ND	15	ND	45	ND
H.W. 49	ND	ND	ND	0.3	40	ND	29	19	199	ND	ND	0.5	ND	ND	ND	0.3	ND	ND	29	0.1	32	ND
H.W. 50	31.8	ND	ND	0.4	82	ND	56	45	179	ND	ND	1.1	ND	ND	ND	0.2	ND	ND	60	0.1	25	0.3
H.W. 51	ND	ND	ND	ND	6	ND	ND	3	13	ND	ND	ND	ND	ND	ND	ND	0.3	ND	20	0.1	ND	ND
H.W. 52	26.7	ND	ND	0.4	93	ND	57	27	135	ND	ND	ND	2.0	ND	ND	0.9	ND	ND	109	0.4	ND	ND
H.W. 53	ND	ND	ND	0.3	95	ND	81	44	139	ND	ND	ND	0.1	ND	ND	0.1	0.1	ND	15	ND	ND	ND
H.W. 53A	ND	0.6	ND	0.4	72	ND	ND	51	57	ND	ND	0.1	0.2	ND	ND	0.1	ND	ND	22	0.1	10	ND
H.W. 54	ND	ND	2.4	1.1	104	ND	80	23	174	1854	ND	0.2	0.2	ND	ND	0.4	ND	ND	72	0.3	12	ND
H.W. 55	ND	ND	ND	0.5	100	ND	ND	41	114	ND	ND	0.1	0.2	ND	ND	0.1	ND	ND	13	ND	ND	ND
H.W. 57	ND	ND	1.6	0.2	82	ND	35	27	74	ND	1.7	1.2	ND	ND	1.5	0.6	ND	ND	108	ND	28	0.2
H.W. 61	ND	ND	1.8	0.6	71	ND	55	41	154	ND	4.2	2.5	1.9	ND	ND	0.2	ND	ND	34	0.1	153	ND
H.W. 63	ND	ND	ND	0.7	52	ND	70	25	98	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 64	ND	ND	ND	0.5	87	ND	35	51	161	86	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 65	ND	ND	ND	0.3	48	ND	121	24	94	ND	1.8	1.1	1.4	ND	0.5	ND	ND	ND	20	ND	12	ND
H.W. 66	13.8	ND	ND	0.7	66	ND	38	30	112	274	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 67	ND	ND	1.8	0.5	42	ND	144	53	181	87	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 68	ND	ND	ND	1.6	165	ND	71	90	367	ND	7.4	2.8	2.8	ND	ND	0.6	ND	0.1	119	0.3	131	ND
H.W. 69	ND	ND	ND	0.8	135	ND	96	47	208	147	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 70	ND	ND	ND	1.0	48	ND	ND	34	162	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 71	ND	ND	ND	1.0	78	0.1	75	33	196	407	ND	0.9	0.8	ND	ND	ND	ND	ND	58	0.1	80	ND

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 72	ND	ND	3.5	0.8	72	0.1	106	41	327	ND	ND	1.0	1.9	0.1	ND	0.3	ND	ND	65	0.1	64	ND
H.W. 72A	ND	ND	ND	0.3	45	ND	14	13	79	ND	ND	0.4	2.1	ND	ND	0.1	ND	ND	21	0.1	32	ND
H.W. 74	ND	ND	1.0	ND	62	ND	36	27	169	ND	ND	ND	0.6	ND	0.6	0.3	ND	ND	25	0.1	40	ND
H.W. 75	ND	ND	0.7	0.4	55	ND	23	8	121	ND	ND	ND	0.8	ND	ND	0.1	0.3	ND	23	0.1	ND	ND
H.W. 76	ND	ND	0.3	0.4	13	ND	34	3	53	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 77A	ND	ND	10.1	6.2	302	ND	735	143	1260	552	ND	2.4	5.0	0.2	ND	0.6	0.5	ND	92	0.3	643	4.3
H.W. 77B	ND	ND	ND	1.2	170	ND	81	79	538	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 78	ND	ND	ND	0.2	38	ND	14	13	90	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 79	ND	ND	0.9	0.5	70	ND	18	28	79	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 80	ND	ND	0.8	0.3	28	ND	121	14	117	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 101	ND	ND	ND	0.2	15	ND	68	9	85	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 102	ND	ND	ND	0.6	85	ND	17	30	108	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 103	ND	ND	ND	0.7	57	ND	535	29	285	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 104	ND	ND	ND	0.4	59	ND	ND	20	113	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 111	ND	ND	ND	0.2	37	ND	133	16	151	ND	ND	0.2	0.5	ND	0.2	0.1	ND	ND	26	ND	25	0.2
H.W. 117	ND	ND	0.9	0.4	39	ND	195	23	202	158	ND	0.2	1.2	ND	0.3	0.4	0.1	ND	27	0.1	13	ND
H.W. 121	4.8	ND	0.3	0.1	12	ND	79	11	63	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 132	ND	ND	0.2	0.1	7	ND	28	4	54	23	ND	0.1	0.1	ND	0.1	0.1	ND	ND	16	ND	6	0.1
H.W. 133	ND	ND	ND	0.4	21	ND	39	28	98	ND	2.0	0.4	2.8	ND	0.7	0.7	ND	ND	76	0.1	38	ND
H.W. 134	ND	ND	ND	0.2	17	ND	ND	9	61	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 135	ND	ND	ND	0.4	37	ND	ND	26	146	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 136	ND	ND	ND	1.7	90	ND	199	112	538	309	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 136A	ND	ND	ND	1.2	65	ND	46	46	300	167	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 137	ND	ND	2.5	0.9	34	ND	1319	41	409	ND	0.2	0.8	1.6	ND	0.7	ND	ND	ND	29	0.1	17	0.4
H.W. 139	ND	ND	ND	1.0	98	0.2	170	98	700	158	ND	ND	9.4	ND	2.6	ND	0.4	ND	74	0.6	56	1.0
H.W. 140	14.9	ND	2.2	0.9	31	0.1	98	25	491	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 140A	ND	ND	ND	0.7	73	0.1	78	76	453	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 141	ND	ND	ND	0.5	38	ND	57	52	552	ND	ND	0.2	4.0	ND	0.8	ND	ND	ND	31	0.3	16	ND

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 149	ND	ND	ND	1.8	35	ND	140	63	325	5390	ND	ND	0.6	ND	ND	0.9	0.2	ND	62	0.2	78	ND
H.W. 153	ND	ND	ND	2.4	43	ND	123	75	496	9050	ND	0.3	0.5	ND	1.3	0.8	0.2	ND	58	0.3	83	ND
H.W. 169	ND	ND	ND	21.0	209	ND	194	285	945	51863	ND	ND	4.9	ND	3.3	ND	ND	0.1	190	0.3	ND	ND
H.W. 179	ND	ND	ND	17.8	119	ND	ND	491	978	14776	ND	ND	5.2	ND	ND	2.8	2.3	0.1	228	2.1	ND	0.7
H.W. 186	ND	ND	ND	9.7	44	0.2	ND	234	377	5135	ND	ND	ND	ND	ND	0.8	1.8	0.1	78	0.3	ND	ND
H.W. 199	ND	ND	3.1	1.6	192	ND	197	99	372	1224	ND	ND	3.3	ND	1.2	1.2	ND	ND	121	1.1	281	17.8
H.W. 205	ND	ND	ND	3.1	569	0.2	236	147	373	1270	ND	ND	ND	ND	2.6	1.4	ND	0.1	212	0.8	132	ND
H.W. 213	ND	ND	ND	2.3	180	0.3	195	156	489	868	1.1	0.4	2.3	ND	1.0	0.8	0.3	ND	5	0.2	51	5.1
H.W. 221	ND	ND	ND	1.0	112	0.1	134	57	217	179	1.3	0.8	0.5	ND	1.5	0.8	0.3	ND	5	0.2	45	ND
H.W. 232	ND	ND	2.6	1.7	218	0.1	212	101	428	613	1.0	0.6	1.0	ND	2.6	1.3	0.3	ND	10	0.2	53	0.6
H.W. 245	31.2	ND	ND	0.5	36	ND	103	35	179	66	0.5	0.2	0.6	ND	1.1	0.9	0.2	ND	21	0.3	180	ND
H.W. 245A	ND	ND	ND	1.9	84	ND	375	138	645	407	0.9	0.6	0.8	ND	1.7	1.3	0.3	ND	6	0.1	35	ND
H.W. 402	*	*	*	*	*	*	*	*	*	*	ND	ND	0.5	ND	0.7	ND	0.1	ND	26	0.2	15	ND
H.W. 405	*	*	*	*	*	*	*	*	*	*	ND	ND	1.4	ND	1.3	ND	ND	ND	81	0.5	85	ND
H.W. 406	*	*	*	*	*	*	*	*	*	*	0.1	ND	0.2	0.1	0.5	ND	0.1	ND	13	0.1	21	ND
H.W. 407	*	*	*	*	*	*	*	*	*	*	0.2	0.1	0.5	ND	0.6	ND	0.1	ND	15	0.2	17	ND
H.W. 408	*	*	*	*	*	*	*	*	*	*	ND	ND	0.5	ND	0.5	ND	0.1	ND	20	0.2	23	ND
H.W. 410	*	*	*	*	*	*	*	*	*	*	ND	0.3	1.0	ND	ND	ND	0.3	ND	38	0.7	91	ND
H.W. 411	ND	ND	ND	1.2	103	ND	ND	288	98	ND	ND	0.3	0.4	ND	ND	ND	ND	ND	33	ND	16	0.4
H.W. 412	ND	ND	ND	1.3	100	ND	ND	226	210	ND	ND	ND	0.3	ND	ND	0.3	ND	ND	16	ND	9	ND
H.W. 413	ND	ND	ND	3.7	269	0.7	ND	619	731	ND	ND	1.0	1.2	ND	0.9	0.7	ND	0.1	108	0.2	99	ND
H.W. 416	ND	ND	ND	1.0	91	ND	61	230	360	ND	ND	ND	0.2	ND	0.1	0.1	ND	ND	ND	ND	5	0.2
H.W. 419	ND	ND	4.0	1.6	55	0.3	151	181	464	ND	0.2	ND	0.5	ND	ND	0.3	ND	ND	63	0.2	ND	ND
H.W. 421	ND	ND	1.5	0.6	19	ND	52	42	162	ND	0.2	ND	0.6	ND	ND	0.6	ND	ND	34	0.1	37	0.5
H.W. 422	ND	ND	ND	0.6	12	ND	43	29	54	ND	0.1	ND	0.4	ND	0.6	0.4	ND	ND	16	0.2	ND	0.4
H.W. 423	ND	ND	ND	0.7	18	0.1	54	11	118	ND	ND	ND	0.3	ND	0.4	0.3	ND	ND	14	ND	ND	ND
H.W. 426	10.8	ND	ND	0.8	21	ND	23	27	128	ND	ND	ND	0.2	ND	ND	ND	ND	ND	20	ND	ND	ND
H.W. 428	ND	ND	ND	26.2	188	0.4	167	368	648	ND	ND	0.3	0.6	ND	0.7	0.8	ND	ND	84	0.2	ND	ND

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 429	ND	ND	ND	25.0	106	ND	ND	313	610	ND	ND	ND	0.3	ND	0.8	0.3	ND	ND	11	ND	37	ND
H.W. 430	ND	ND	ND	24.9	464	ND	ND	329	647	ND	ND	ND	1.0	ND	2.0	0.5	ND	0.1	230	0.3	ND	ND
H.W. 433	ND	ND	ND	19.0	266	0.2	ND	251	265	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 435	ND	ND	ND	6.0	326	ND	459	336	1063	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 436	ND	ND	ND	22.6	228	ND	107	295	398	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 437	ND	ND	ND	11.3	276	ND	85	132	239	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 438	ND	ND	ND	19.3	382	ND	1033	859	2384	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 441	ND	ND	ND	9.0	376	ND	1141	703	2513	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 442	ND	ND	ND	3.4	193	ND	472	205	666	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 443	ND	ND	3.6	2.7	208	ND	246	228	530	1848	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 444	ND	ND	2.7	1.4	96	ND	103	158	ND	295	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 607	ND	ND	ND	5.5	210	ND	ND	1300	267	480	ND	2.1	ND	ND	1.2	ND	0.6	0.1	98	0.2	67	0.7
H.W. 608	ND	ND	ND	1.6	113	ND	ND	558	159	209	ND	0.7	ND	ND	0.4	ND	0.3	ND	35	0.1	14	0.1
H.W. 609	ND	ND	ND	0.2	18	0.1	54	29	143	51	ND	0.2	0.2	ND	0.5	ND	0.1	ND	18	0.1	17	0.1
H.W. 612	ND	ND	ND	2.8	153	ND	ND	570	205	193	ND	0.9	ND	ND	0.4	ND	0.4	ND	38	0.1	13	0.1
H.W. 612A	ND	ND	ND	2.4	166	ND	ND	410	166	146	ND	0.8	ND	ND	0.4	ND	0.5	ND	38	0.1	18	0.1
H.W. 612R	ND	ND	ND	2.0	136	ND	ND	744	244	502	ND	ND	ND	ND	0.6	ND	0.2	0.1	64	0.3	151	0.2
H.W. 801	ND	ND	ND	1.0	210	ND	83	138	156	ND	ND	ND	ND	ND	5.5	3.0	ND	ND	62	0.1	63	ND
H.W. 802	ND	ND	ND	0.3	87	ND	32	44	142	ND	ND	ND	ND	ND	2.2	1.5	ND	ND	25	0.1	28	ND
H.W. 808	54.7	ND	2.1	0.6	121	ND	56	86	183	ND	ND	ND	2.4	ND	4.7	2.7	ND	ND	50	0.1	85	1.6
H.W. 4X	ND	ND	4.5	15.4	53	ND	423	59	276	130	ND	0.2	1.4	ND	1.5	0.2	0.1	ND	49	0.2	48	ND
H.W. 6X	ND	ND	1.8	0.9	60	0.1	72	53	431	103	ND	ND	ND	ND	0.4	1.3	18.6	1.2	ND	3.4	ND	ND
H.W. 9X	ND	ND	4.9	19.7	95	ND	1222	77	544	187	ND	ND	2.0	ND	2.6	0.5	ND	ND	63	0.4	73	0.6
H.W. 12X	ND	ND	ND	21.5	131	ND	1201	128	998	487	ND	0.2	1.1	ND	6.9	1.3	0.2	ND	74	0.2	60	ND
H.W. 13X	ND	ND	3.9	15.2	84	0.1	419	77	394	252	ND	ND	ND	3.7	ND	ND	ND	ND	ND	ND	ND	ND
H.W. 14X	ND	ND	ND	1.0	42	0.1	1406	12	22	43	ND	1.8	ND	ND	0.9	ND	0.2	0.1	76	0.2	34	ND
H.W. 22X	ND	ND	1.9	0.6	45	0.2	76	49	259	93	ND	0.6	ND	ND	0.9	ND	0.2	ND	56	0.1	47	ND
H.W. 33X	ND	ND	1.7	0.6	23	ND	158	46	292	104	ND	1.4	ND	ND	1.2	ND	ND	ND	59	0.4	173	ND

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CO	FE	LA
H.W. 46X	ND	ND	7.2	13.0	155	ND	1823	125	754	336	ND	0.6	2.2	ND	6.0	1.1	0.2	ND	98	0.1	65	0.5
H.W. 53X	ND	ND	3.1	8.8	47	ND	592	42	365	184	ND	ND	1.2	ND	5.4	1.0	0.3	ND	49	0.4	31	4.0
H.W. 57X	ND	ND	ND	ND	21	ND	647	19	151	137	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 60X	ND	ND	9.6	37.6	122	ND	1246	91	867	662	ND	0.7	2.8	0.1	10.5	2.2	ND	ND	113	0.5	62	0.8
H.W. 61X	73.4	ND	ND	17.5	95	0.2	1636	633	7000	1900	ND	0.2	1.7	ND	10.4	1.7	ND	ND	82	0.3	37	0.7
H.W. 62X	ND	ND	8.1	20.8	82	ND	1872	45	558	ND	ND	ND	2.0	ND	10.7	1.9	0.1	ND	65	0.1	24	0.5
H.W. 64X	ND	ND	1.6	0.4	41	0.1	89	40	352	122	ND	0.5	ND	ND	0.8	ND	0.5	ND	48	0.1	25	ND
H.W. 66X	30.2	ND	2.0	0.9	53	0.1	112	86	459	200	ND	0.9	ND	ND	1.0	ND	0.5	ND	58	0.2	37	ND
H.W. 74X	ND	ND	20.0	96.4	215	ND	3193	221	2371	1029	ND	ND	8.5	0.2	21.2	4.0	1.4	ND	236	1.9	188	20.9
H.W. 77X	ND	ND	7.8	18.4	195	ND	1247	67	727	302	ND	ND	1.3	ND	9.1	1.5	ND	0.1	119	0.2	29	0.9
H.W. 80X	ND	1.0	ND	0.4	22	ND	114	17	127	46	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 111X	ND	ND	2.4	1.9	99	0.2	ND	291	369	333	0.3	0.4	0.9	0.1	ND	0.5	0.4	ND	64	0.2	64	2.2
H.W. 117X	ND	ND	ND	0.9	50	ND	89	138	192	127	ND	ND	0.7	ND	0.8	1.0	0.3	ND	51	0.8	187	0.7
H.W. 121X	ND	ND	1.1	0.4	19	ND	32	53	105	46	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 132X	ND	ND	ND	2.3	134	ND	77	353	409	512	0.3	ND	2.1	ND	0.6	0.7	0.5	ND	84	0.2	35	ND
H.W. 133X	ND	ND	ND	3.9	154	ND	ND	648	1278	738	2.0	ND	4.8	ND	ND	ND	1.0	0.1	204	0.7	225	1.4
H.W. 134X	ND	ND	19.4	11.4	800	ND	ND	1965	2015	2370	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 135X	ND	ND	ND	1.9	86	ND	165	154	776	274	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 136X	43.1	ND	ND	3.1	151	0.2	228	239	1114	279	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 137X	31.4	ND	ND	2.6	133	ND	173	223	883	289	ND	2.7	2.6	ND	2.4	ND	0.8	0.1	107	0.5	209	2.2
H.W. 139X	ND	ND	ND	1.7	105	ND	152	164	564	271	ND	0.4	2.6	ND	3.3	ND	0.4	ND	88	0.3	75	ND
H.W. 140X	ND	ND	5.7	4.5	238	0.5	ND	451	1368	759	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 141X	ND	ND	ND	2.8	87	ND	ND	254	802	478	ND	ND	4.0	ND	2.8	ND	0.4	ND	88	0.3	80	ND
H.W. 149X	ND	ND	ND	1.4	12	0.1	91	34	206	1366	ND	ND	0.7	ND	1.2	0.8	0.9	ND	55	0.2	43	ND
H.W. 153X	ND	ND	ND	15.2	60	ND	200	286	528	6626	ND	ND	3.8	ND	3.3	2.2	ND	ND	115	0.7	ND	0.7
H.W. 154X	ND	ND	ND	1.0	74	ND	110	62	191	ND	*	*	*	*	*	*	*	*	*	*	*	*
H.W. 169X	ND	ND	ND	8.8	106	0.1	130	188	306	11690	ND	ND	5.6	ND	1.4	0.9	1.0	ND	108	0.2	ND	0.3
H.W. 179X	ND	ND	ND	10.1	121	ND	184	261	493	8204	ND	ND	5.1	ND	ND	1.0	ND	0.1	168	0.7	164	1.2

Table B-2 (continued)

Trace Element Composition of Ether-Wash of Human Hair (in 10^{-6} gm per gm of Hair Washed)

SAMPLE	TI	I	BR	MN	CU	V	CL	AL	NA	CA	SE	HG	CR	AU	AS	SB	AG	SC	ZN	CD	FE	LA
H.W. 186X	56.2	ND	ND	6.1	481	0.3	407	220	621	9270	ND	ND	22.6	ND	1.2	1.5	ND	ND	58	ND	ND	ND
H.W. 199X	ND	ND	ND	3.6	436	ND	251	150	459	1631	ND	ND	ND	ND	1.9	1.4	ND	ND	132	0.4	ND	1.4
H.W. 205X	ND	ND	ND	2.3	157	ND	81	63	206	6804	ND	ND	ND	ND	0.7	0.9	ND	ND	74	ND	ND	ND
H.W. 213X	ND	ND	ND	0.6	78	ND	112	48	153	177	0.4	0.2	0.4	ND	0.9	0.6	0.1	ND	3	0.1	26	ND
H.W. 221X	ND	ND	ND	1.6	180	ND	174	83	305	534	1.1	0.7	ND	ND	0.9	0.9	0.3	ND	10	0.2	58	ND
H.W. 232X	ND	ND	ND	7.5	143	ND	675	183	863	ND	0.4	ND	0.2	ND	ND	0.2	0.1	ND	3	ND	22	0.5
H.W. 245X	11.5	ND	2.9	2.1	185	ND	142	14	92	287	ND	ND	0.6	ND	0.7	0.6	ND	ND	22	ND	205	0.3
H.W. 4Y	*	*	*	*	*	*	*	*	*	*	ND	ND	5.2	0.1	4.8	2.4	0.6	0.2	534	0.9	438	2.4
H.W. 13Y	*	*	*	*	*	*	*	*	*	*	ND	ND	1.0	ND	2.1	0.6	0.6	ND	147	0.2	260	0.5
H.W. 22Y	*	*	*	*	*	*	*	*	*	*	1.3	0.9	2.5	ND	5.0	2.0	0.4	0.1	156	0.4	1578	ND
H.W. 53Y	*	*	*	*	*	*	*	*	*	*	1.2	0.7	2.5	ND	21.6	2.9	0.4	ND	77	0.4	360	1.0
H.W. 64Y	*	*	*	*	*	*	*	*	*	*	0.3	0.2	3.1	ND	8.6	1.7	0.2	ND	64	0.3	301	0.5
H.W. 117Y	*	*	*	*	*	*	*	*	*	*	ND	ND	1.0	ND	1.2	1.1	ND	ND	121	0.8	251	2.7
H.W. 121Y	ND	ND	2.8	3.4	35	0.2	174	92	369	3665	0.4	ND	1.9	ND	ND	1.8	0.4	0.1	115	0.4	110	0.9
H.W. 133Y	ND	ND	ND	1.2	13	ND	97	31	177	2693	1.5	0.5	2.6	ND	2.1	1.5	ND	ND	164	1.8	271	1.8
H.W. 141Y	31.9	ND	ND	1.1	30	ND	76	27	126	5539	0.1	ND	ND	ND	1.1	0.4	0.2	ND	40	0.1	81	ND
H.W. 205Y	ND	ND	ND	1.5	266	ND	230	116	444	758	ND	1.3	ND	ND	ND	0.8	ND	ND	99	0.3	ND	ND
H.W. 213Y	ND	ND	3.4	1.3	115	ND	99	82	247	248	0.3	ND	1.6	ND	0.6	0.4	0.2	ND	3	ND	40	ND
H.W. 245Y	ND	ND	1.3	1.7	31	0.1	165	38	149	128	0.7	0.5	6.3	ND	ND	0.8	0.3	ND	16	0.2	137	2.1

END