BODY ARMOR

National Institute of Law Enforcement and Criminal Justice
Law Enforcement Assistance Administration
United States Department of Justice

Lightweight Body Armor for Law Enforcement Officers

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BODY ARMOR

LIGHTWEIGHT BODY ARMOR FOR LAW ENFORCEMENT OFFICERS

By

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FOREWORD

The personal safety of police officers has long been a concern of the National Institute. Since 1972, the Institute has sponsored research to develop a lightweight, inconspicuous body armor that could be worn routinely by officers, protecting them from attacks, particularly with handguns. According to the FBI, 129 Federal, state, and local law enforcement officers were killed in 1975, 93 by handguns.

Now being field tested in 15 cities, the body armor appears to be effective against bullets fired from many handguns. Three officers in the test cities have escaped serious injury -- perhaps death -- when they were shot while wearing the protective garments.

Research is continuing on certain aspects of the armor, particularly the problem of "blunt trauma," the crushing effect of the force of the bullet on human tissue. Also being evaluated in the field tests are the garment's comfort, adaptability to extremes of temperature, and durability over long periods. Equally important is the psychological effect of the armor on the officers who wear it -- whether they become more confident and relaxed in their encounters with the public, or whether the body armor might inspire them to take more chances with their lives and the lives of others.

Gerald M. Caplan,
Director
National Institute of Law Enforcement and Criminal Justice

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This task has been a 12-month project to develop inconspicuous, lightweight protective garments for use by public officials and law enforcement officers to defeat most handgun threats. A preliminary study on several promising protective materials indicated that Kevlar 29 material (PRD 49-IV) has superior ballistic protective properties and is suitable for tailoring purposes. This new material, while light, is also quite flexible.

This document defines the general tasks required on the part of the US Army (Biomedical Laboratory, Edgewood Arsenal, APG, MD and Natick Development Center, Natick, MA) to develop a fundamental understanding of the physical phenomena and related performance of Kevlar lightweight body armor as applied to law enforcement user needs.

We have found that it is within the state-of-the-art to produce a lightweight, inconspicuous, and wearable body armor that will give law enforcement personnel good protection from a surprise assault with common street handguns. Such an armor can be tailored; it does not have to look like an umpire's chest protector. It can be an undershirt or a sport coat; it can be the liner in a raincoat or tunic. This, we believe, has been the major result of our efforts in this ever-changing field - to show that it can be done and to determine the size of the total problem, the materials, testing, human engineering, blunt trauma effects, wearability, and maintenance.

Such a limited armor concept does not lessen the importance or applications of other body armors. On the contrary, it puts these armors in proper perspective and, hopefully, weeds out the inferior ones. Armors that protect against more powerful weapons play an important role in law enforcement.

This new lightweight armor development suggests even other applications for Kevlar. Wherever penetration or abrasion resistance is required, one can apply Kevlar. Potential law enforcement applications include: arm protectors for dog trainers, automobile seat covers, coveralls for rough country searches, emergency ropes, webbing for load-bearing straps, ladders and stretchers, embassy curtains, armored car door panels, and special protective panels to protect pilots from hijackers. The list is almost endless.

ABSTRACT

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PREFACE

The joint study described was originally tasked (January 1973) to the US Army Land Warfare Laboratory (LWL), Aberdeen Proving Ground, MD, by the National Institute of Law Enforcement and Criminal Justice (NILECJ), Law Enforcement Assistance Administration (LEAA), US Department of Justice. Shortly thereafter LWL was abolished and overall responsibility of the program was transferred to the Biophysics Division, Biomedical Laboratory, Edgewood Arsenal, APG, MD. The LWL Program Manager, Mr. Nicholas Montanarelli, provided overall coordination of the project and transferred with the program to Biomedical Laboratory. Mr. Clarence E. Hawkins is Project Officer of the Lightweight Body Armor Program for the Biophysics Division. Design, fabrication, and testing of different types of garments were provided under the direction of Mr. Edward R. Barron, Chief of Body Armor Section, Natick Development Center, Natick, MA. Materials for testing and specifications were furnished by Natick Development Center under the direction of Dr. Roy C. Laible, Chief of Fiber and Technology Branch.

The Aerospace Corporation, El Segundo, CA, assisted the Army laboratories by providing operational requirements, limited amounts of ballistic, environmental, and laboratory testing, as well as technical support in the area of material phenomena. Further prototype testing will be undertaken by Aerospace Corporation and directed by Mr. Louis G. King, Aerospace's Project Manager.

Aerospace Corporation has been programmed to furnish 4,000 protective soft body armor garments for full scale field testing through to FY 1976. Natick Development Center will assist in providing procurement specifications for material weaving and fabrication of the garments. Edgewood Arsenal shall provide a medical team to support the field testing of the garments.

In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals" as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council.

SUMMARY

Background. During the past decade numerous public figures and approximately 700 law enforcement officers have been shot and killed. Many of these deaths could have been prevented if adequate body armor had been available.

The objective of this program was to develop lightweight protective garments for use by public officials and law enforcement personnel. These garments must be relatively inconspicuous and inexpensive and adaptable to a number of clothing needs. Both inner and outer garments were investigated.

In the past, body armor has been generally developed by and for the military and then applied to civilian use. It has been conspicuous and heavy and oftentimes not worn unless an immediate danger was foreseen. The military armor has been of two general types: various hard-faced armor (steels or ceramics) for stopping high-velocity projectiles and soft-material armor (nylons) for stopping shrapnel.

The civilian application of these protective armors has concentrated on preventing projectile penetration, but little substantive effort has been undertaken to assess blunt trauma effects on the body even when non-penetration is assured. Furthermore, an assessment of available guns and weapon injuries to law enforcement personnel indicates a threat no worse than that presented by the .38 caliber police special occurs approximately 80% of the time.

This information on threat severity, coupled with development of new and stronger synthetic fibers by the textile industry, warrants the development of lightweight, inconspicuous, and relatively inexpensive garments that might satisfy the protective needs of public officials and law enforcement officers.

During 1973, LEAA sponsored a program at the US Army Land Warfare Laboratory (USALWL) to design and test a lightweight protective garment that could be worn by key public officials. The garment was designed to counter the threat of handguns, including the .38 caliber police special. The results of completed initial materials tests were encouraging in that the new materials are significantly better than any nylon type previously tested. The results thus permitted an extension of the lightweight body armor program to include protection of law enforcement officials.

Ballistic Evaluations. Confiscated weapons received from the various law enforcement agencies were tested for velocity measurements to determine if the velocities established by NBS for the .38 caliber and .22 caliber were realistic. The velocities used in laboratory evaluations were established as 800 fps for the .38 caliber and 1000 fps for the .22 caliber pistols. The data collected from the confiscated weapons show these velocities to be realistic and perhaps somewhat on the conservative side, i.e., slightly higher than those recorded with the confiscated weapons.

Ballistic tests were performed with .22 caliber bullets at 1000 fps to determine the number of layers of the candidate material that are needed to defeat the threat. It was concluded that seven layers of 400/2 denier Kevlar 29 material are necessary to prevent penetration.

Tests were initiated using biotargets to determine the damage incurred when using seven layers of the Kevlar material. This testing included blood gas analyses in addition to observations of tissue response. The data obtained from these tests were used to provide input to Respiratory Index Studies.

Human Thoracic Correlation. Additional computer data were received from the Maryland Institute for Emergency Medicine in connection with the effort to compare traumatized animals with traumatized humans. The use of the Respiratory Index for making human/animal correlations is a valid methodology.

Backface Signatures. A technique was developed for assessing the backface signature of material deformation when subjected to non-penetrating impacts. This technique utilizes high-speed photography and 20% gelatin as a tissue simulant. The loading parameters being determined through this technique are (1) volume of deformation; (2) depth of deformation; (3) time of deformation; and (4) velocity of deformation. Tests on 7-ply Kevlar 29 show this to be a readily duplicated, easily managed, testing technique which provides correlation of backface signature with blunt trauma data acquired through biotarget testing.

Material Test Matrix. The same technique and parameters used in the backface signature task of the program are also utilized for the material test matrix. 158 grain, .38 caliber projectiles were fired at 800 fps at 3, 5, 7, 9, 15, and 23 plies of Kevlar 29 to determine associated trauma and the potential to defeat higher threat levels.

Backface Signatures for Additional Threats (Knife Threat). A methodology similar to that used for determining backface signatures for ballistic threats was developed for testing the knife threat. For the developmental work, a 300 gm, M-16 bayonet; 4-inch switch blade; 10-inch butcher knife; and icepick were used. Tests indicated that the Kevlar 29 material (7-ply 400/2) would not defeat the icepick.

Blunt Trauma Data Correlation Task. In excess of 100 reports related to blunt trauma were reviewed. The inter-disciplinary review team was organized, a portion of the data categorized, and review of all documents completed by two to five reviewers each.

Empirical data of the type relevant to non-penetrating projectile and body armor effectiveness were scarce. However, the addition of data from several of the program subtasks and those which were available allowed for the development of provisional models to be used, predictive models applicable to generalized blunt trauma.

Environmental Testing. Using Natick Development Center's Load Profile Analyzer, several garments were tested to determine loads imposed on a test subject doing psycho-motor tasks. Results of this testing indicated little burden to the wearer and allowed design changes to correct any problem areas that would develop through continued use of the garments.

Climatic Testing. Through the use of Natick Development Center's "Copper Man," measurements of thermal insulating values and moisture permeability index studies were made on a cross section of different types of garments. Garments tested contained 7 plies of 400/2 denier Kevlar 29, and there was little evidence of burden to the user in a constant environment of 81°F, 50% relative humidity, and 60 fpm (0.3 mps) air movement.

ACKNOWLEDGMENTS

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BIOMEDICAL LABORATORY, EDGEWOOD ARSENAL, APG, MD: Victor R. Clare, Larry M. Sturdivan, William J. Sacco, Ph.D., and John W. Jameson for their work in blunt trauma data correlation and predictive modeling.

Michael A. Weinstein, M.D., Michael A. Goldfarb, M.D., and Carl A. Soderstrom, M.D., for their blunt trauma medical assessment.

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CHAPTER I. INTRODUCTION--LIGHTWEIGHT BODY ARMOR PROGRAM

The development of a new ballistic cloth, duPont Kevlar,* has offered exciting possibilities to those who are interested in designing lightweight, inconspicuous garments that will protect the wearer from injury by weapons.

Kevlar is the result of a search for a new tire cord material. Originally called duPont fiber PRD-26 and subsequently PRD 49-IV, it is now available in various deniers from duPont under the name Kevlar 29. The yarn can be readily woven into ballistic cloth in a variety of densities and patterns. The characteristic which makes Kevlar 29 so attractive, aside from its weavability, is its remarkably high strength-to-weight ratio.

This has led to a development program sponsored by the National Institute of Law Enforcement and Criminal Justice (NILECJ), Law Enforcement Assistance Administration (LEAA), US Department of Justice, and making use of the special expertise of the Biophysics Division, Biomedical Laboratory; the Law Enforcement Standards Laboratory (LESL), a part of the National Bureau of Standards; the US Army Natick Development Center; Aerospace Corporation; and others.

Although the project was originally intended to produce a garment to protect public officials, it was quickly recognized that law enforcement people in general had a real need that could be filled simultaneously. Therefore, the project was expanded to include the requirements of federal, state, and local law enforcement personnel.

The first step was to establish the criteria of the desired product--the purpose, function, and limitations of lightweight body armor. The purpose of armor is to protect the wearer from serious injury by weapons, but some of the questions that had to be resolved were:

1. What degree of threat (in terms of powerfulness of the weapon) should the armor be expected to protect against? At first, protection against what was known to constitute 80% of the everyday street handgun threat, the .38 caliber special, 158 grain, round-nose, lead bullet at 800 fps, was the goal. This was subsequently raised to include the 40 grain, lead bullet, .22 caliber LRHV at 1000 fps (handgun velocity). Others might want it raised still higher, perhaps to include the 9 mm's and possibly the .357 caliber magnum. Unfortunately, the higher the threat level, the further one departs from the concept of a lightweight, inconspicuous body armor that is comfortable enough to be worn for extended periods.

*A detailed description of Kevlar is contained in Appendix A.

2. What degree of injury is acceptable? This involves the compromises that must be made between ballistic protection, compactness, fit, and wearability. Consideration had to be given to such things as whether 48 hours in a hospital for observation and treatment, for instance, might be acceptable, or whether the wearer should be able to pursue his duties, returning fire if necessary after being shot. The criterion adopted by the Institute was that a man wearing the garment should be able to walk from the site of the shooting after being hit in the chest, back, or abdomen.

After these criteria were established, the ability to meet them had to be ascertained. This was done by testing the ballistic retardant properties of various plies of Kevlar.

Certain facts about the ballistic resistance of soft body armors have been established over the past few years, primarily as the result of research conducted by LEAA and the US Army. This work includes the effects of environmental conditions, maintenance, and wear on the comfort and protective abilities of the proposed garments.

Testing body armor for penetration might seem to be a straightforward process. However, much false information can result if all factors are not considered. For instance, if the armor is in contact with a steel plate or some other resistant backing which is not part of the armor, the garment will test better than it really is. The missile could bounce off the hard backing, falsely indicating no penetration; or it could bounce back into an intermediate layer of the fabric, again giving the false result of incomplete penetration.

Our study has included the preliminary evaluation of more realistic backing materials, approximating the body, that will also give us a picture of the extent of deformation resulting from the impact. Deformation is important in assessing whether the force of the impact of a missile that does not penetrate the armor would be sufficient to cause injury (blunt trauma). Blunt trauma is a real threat for lightweight, soft body armors because severe internal injury or death can still result.

In summary, the US Army approach has been to develop an armor which would provide police and others with an inconspicuous garment that could be worn through a complete working day, protecting the wearer from the majority of handgun threats expected in a surprise encounter. This limited armor concept was adopted because by far the largest percentage of assaults on police was found to occur during intervention in family disputes and in routine traffic "stops." Consequently, the LEAA lightweight armor is not an all-purpose, all-threat garment. It is reasonable to assume that in answering "man-with-a-gun" calls or when taking the offensive against an armed, barricaded suspect, a special purpose, high threat-level armor can be donned because there is forewarning.

CHAPTER II. THREAT DEFINITION AND BALLISTIC EVALUATION

A. ESTABLISHING WHICH WEAPONS THE LIGHTWEIGHT BODY ARMOR SHOULD PROTECT AGAINST.

In the past, body armor has generally been developed by the military for their use and then applied to civilian use. It is heavy, bulky, and conspicuous, and often not worn unless an immediate danger is foreseen. Military armor is of two general types: hard-faced armor (steel or ceramic plates) for stopping high-velocity missiles; and soft-material armor (usually nylons) for stopping fragments and low-velocity projectiles.

Since current technology has not advanced enough to develop a lightweight, inconspicuous, continuous wear garment that would protect against all threats, several independent approaches were made to determine the type of weapons used most against law enforcement personnel. The results are shown in figures 1 and 2. The weapons were separated into three groups(e.g., common handguns, high-energy handguns, and rifles/shotguns). The common handguns predominated the statistics for all four categories measured (confiscated, used in assaults, causing injury in assaults, and causing deaths). As indicated, the fatalities* from the high-energy handguns and shotguns/rifles represented a lower percentage of the total than did the common handgun. Therefore, the common handgun group was adopted as a major threat category.

From the data indicated in figure 2, the weapons confiscated by police officers were mostly the .38 caliber and the .22 caliber handguns. These two weapons were selected as the threats to be utilized in testing candidate materials. Of those weapons in the common handgun group, the caliber .38 Special and the caliber .22 LRHV present the highest penetration threat. The .38 Special is also the weapon carried by most policemen; and, as a maximum threat, it is by far the most likely to be encountered in a surprise assault on a police officer or public official today, as the data in figure 2 indicate.

Velocities for test rounds were then established. The Law Enforcement Standards Laboratory, NBS, recommended 800 fps for the .38 Special, round nose lead bullet and 1000 fps for the .22 LRHV lead bullet fired from a handgun. This recommendation was further corroborated by laboratory firings of selected confiscated weapons and the recommendation was accepted. Figures 3 and 4 show the selected weapons.

*Appendix B is a listing of the numbers of law enforcement officers killed by firearms from 1964-1973 broken down by type of weapon.

B. SELECTION OF ARMOR MATERIAL.

The US Army Textile Research Section, Fiber and Fabric R&D Branch, Natick Development Center, provided technical direction in the selection of ballistic materials to be used in the development of the protective garment. Additional information on protective vests and materials resulted from a survey of the following armor and material manufacturers: duPont de Nemours & Company; Burlington Industries; Union Carbide Corporation; 20th Century Body Armor; Armor of America, Inc.; Imperial Protective Equipment Transcon; Federal Laboratories, Inc.; Second Chance; Protective Materials, Inc.; Fabric Development, Inc.; American Safety; Goodyear Aerospace Corp.; Battelle Memorial Institute; institut de Medecine Legale (Dr. Jan Weinberger).

From this survey, the following materials were selected for testing: duPont's Hi-Tenacity Nylon, Nylon Felt, Hi-Tenacity Rayon, Kevlar 29, Kevlar 49; Union Carbide's Thornel Graphite Yarn; Stackpol Carbon Co.'s Panex, Graphite Yarn; Phillip 66's Marlex X-P; and Monsanto's X-55 Fiber and X-500 Felt.[1]

Selection or ranking of materials was based on consideration of the following factors:

1. Weight-to-strength ratio: lightweight but strong enough to prevent penetration of the bullet.

2. Flexible or nonrigid: fabric-type material that would allow wearer freedom of movement.

3. Inexpensive: adaptable in the future for law enforcement applications and procurement.

4. Good ballistic qualities: able to absorb bullet energy in defeating it.

5. Tailoring: able to be tailored to provide good fit and styling in order to reduce armor appearance.

The data compiled in figure 5 show Kevlar 29 to be the best of the materials considered.

C. BALLISTICS TESTING OF VARIOUS PLIES OF KEVLAR 29.

The ballistic evaluations were started with 3 plies of Kevlar, because previous tests had shown that 3 plies would defeat the .38 caliber bullet at 800 fps. Up to 7 plies backed with a gelatin block were tested against the .22 caliber, and the results are shown in table 1. As 7 plies appeared to protect against the missile, additional studies were done on this thickness.

Table 1. .22 Caliber Bullet vs Various Layers of Kevlar 29 (Gelatin Backed).

Number of Plies of 400/2 Denier Kevlar 29	Velocity (fps)	Results a/ b/
3	823	CP - Missile in gelatin block
	823	CP - Missile thru gelatin block
	840	CP - Thru sample & gelatin block
5	771	PP - Missile in 3rd ply
	794	PP - Missile in 2nd ply
	804	PP - Missile bounces off sample
	820	PP - Missile in 2nd ply
	837	PP - Missile bounces off sample
	853	PP - Missile hanging by threads in last ply
	853	PP - Missile in 3rd ply
	866	CP b/
	879	PP b/
	889	PP - Missile in sample
	896	CP - Missile in gelatin
	899	PP
	902	PP - Missile bounces off sample
	902	PP - Missile in 2nd ply
	912	PP - Missile in 2nd ply
	912	PP - Missile in sample
	915	CP - Missile in gelatin block
	919	PP - Missile in 3rd ply
	945	CP b/
6	906	PP b/
	922	PP - Missile in sample
	935	PP b/
	935	PP - Missile in sample
	938	PP b/
	948	PP - Large hole in gelatin block
	951	PP
	965	PP - Missile breaks thread on last ply
	968	PP - Large hole in gelatin block
7	922	PP - Missile in sample
	935	PP - Missile in sample
	935	PP - Missile in sample
	935	PP - Missile in sample
	1043	PP - Missile in sample
	1050	PP b/
	1063	PP b/
	1063	PP - Missile in sample
	1073	PP - Missile in sample
	1076	PP - Missile in sample

a/ CP - Complete Penetration. PP - Partial Penetration.
b/ Because tests were conducted by different investigators, the details of depth of penetration were not always recorded.

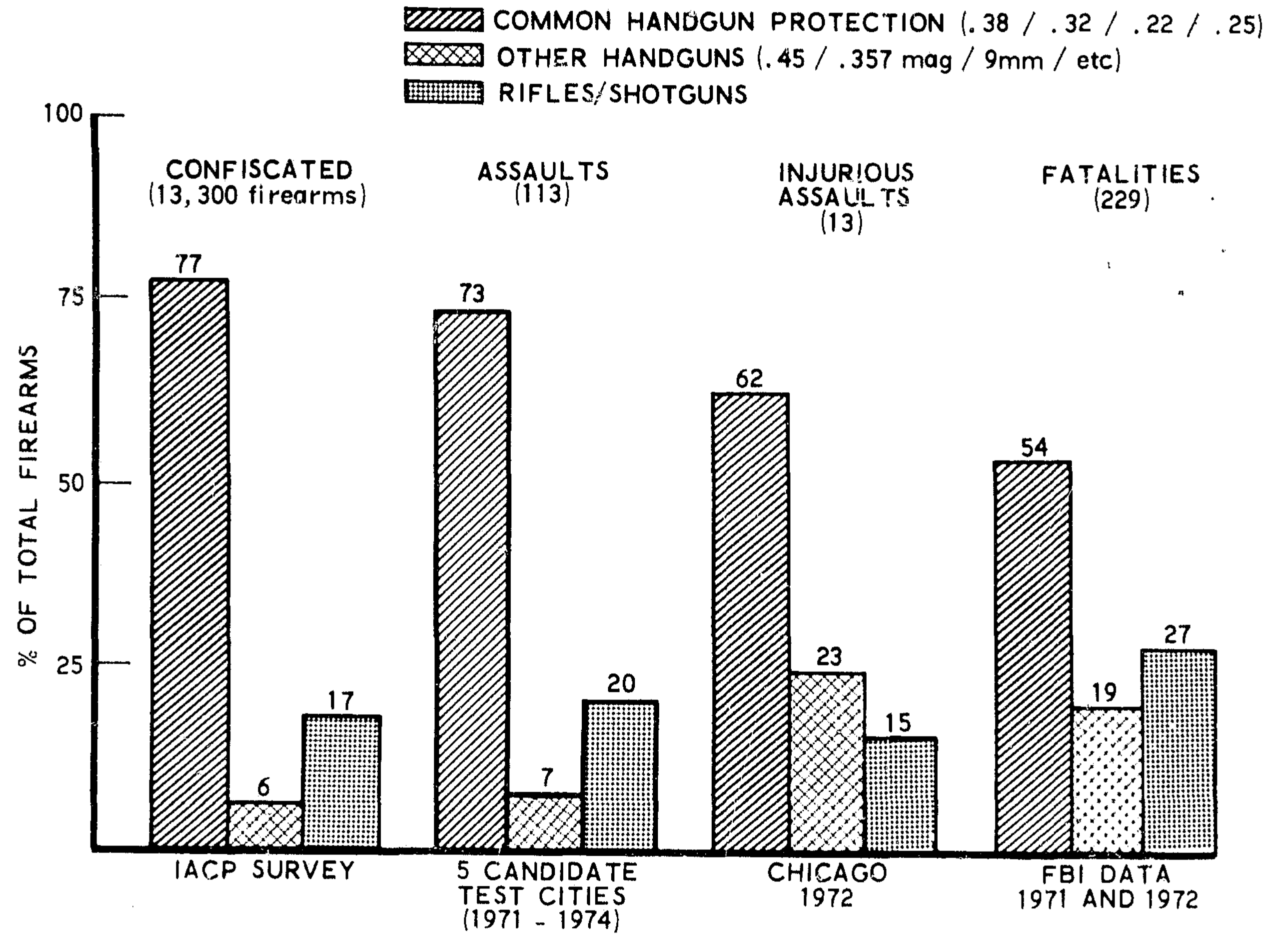


Figure 1. Summary of Firearm Threat Data.

1973 - 2,769 WEAPONS

● GROUP 1 - COMMON HANDGUNS

.22 Cal	528
.25 Cal	218
.32 Cal	317
.380 Cal Auto	31
7.63 mm	24
6.25 mm	9
.38 Cal Special	685
TOTAL	1,812

● GROUP 2 - OTHER HANDGUNS - HIGH POWERED

.22 Mag	43
.357 Mag	42
.45 Cal	50
9 mm	12
.44 Cal	7
.41 Cal	
TOTAL	154

● GROUP 3 - SHOTGUNS

All Gauges	455

● GROUP 4 - RIFLES

Low Power - .22 Cal	271
Highpower - 30.06	74

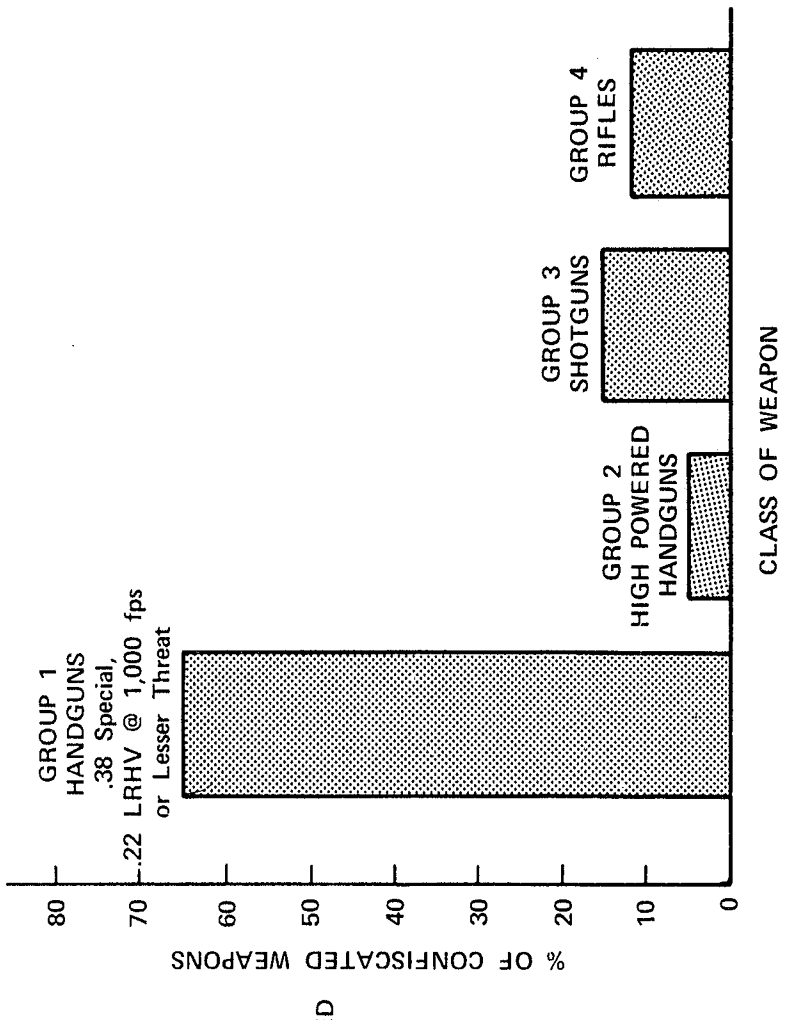


Figure 2. Breakdown of Confiscated Weapons.

Figure 3. Confiscated Weapons Used to Establish Ballistic Test Data.

#1. .22 Caliber, Star Automatic
#2. .22 Caliber, Erma Automatic
#3. .22 Caliber, Single Action Revolver
#4. .22 Caliber, Ruger Automatic
#5. .22 Caliber, Sentinel Revolver 3" Barrel
#6. .22 Caliber, Sentinel Revolver 2" Barrel
#7. .22 Caliber, Iver Hohnson Revolver
#8. .22 Caliber, Rohm M/RG-24 Revolver

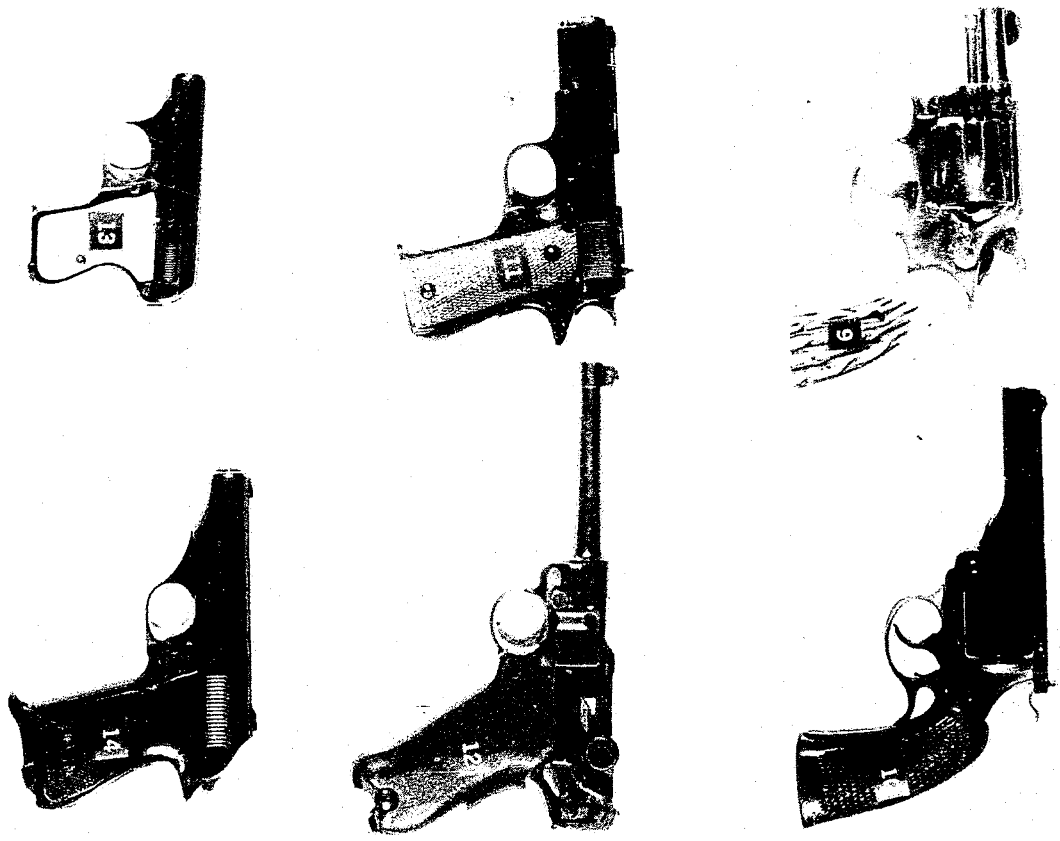


Figure 4. Confiscated Weapons Used to Establish Ballistic Test Data.

#9. .38 Caliber, S&W Special Revolver
#10. .38 Caliber, Harrington Richardson Revolver
#11. .32 Caliber, Llama Automatic
#12. 9mm Luger Automatic
#13. .25 Caliber, Galesi Automatic
#14. 7.65 Bernadellia Automatic

MATERIAL	MANUFACTURER	SELECTION CRITERIA: WEIGHT TO STRENGTH PENETRATION CHARACTERISTICS	FLEXIBILITY (non rigid)	COST	BLUNT TRAUMA	TAILORING
NYLON	DUPONT	P	G	G	G	G
RAYON	DUPONT	P	G	G	P	G
DACRON	DUPONT	P	G	G	P	G
KEVLAR 29	DUPONT	G	G	F	G	G
KEVLAR 49	DUPONT	F	G	G	F	G
THORNEL GRAPHITE YARN	UNION CARBIDE	P	P	P	P	P
PANEX GRAPHITE YARN	UNION CARBIDE STACKPOLE INC	P	P	P	P	P
MARLEX X-P	PHILLIP 66	G	P	P	G	P
X-55 FIBER	MONSANTO	P	F	F	P	F
NYLON FELT	DUPONT	P	P	P	P	P
X-500 FELT	MONSANTO	P	P	P	P	P

G = GOOD F = FAIR P = POOR

Figure 5. Protective Material Evaluations.

Tables 2 and 3 show the results when the 158-grain, .38 caliber bullet and the 40-grain, .22 caliber bullet were fired at 7 plies of 400/2 denier Kevlar 29 with a gelatin block backing. There were no complete penetrations by the .38 caliber bullet; there were some complete penetrations by the .22 caliber bullet at velocities higher than 1107 fps, but there were also only partial penetrations at a velocity of 1194. These results show that 7-ply 400/2 denier Kevlar 29 defeats both threats beyond the guideline velocities (1000 fps for .22 caliber and 800 fps for .38 caliber). Some additional ballistic testing was performed with other caliber handguns. Table 4 gives results of this limited ballistic testing together with the number of layers of 400/2 denier Kevlar needed to prevent penetration.

D. PRELIMINARY DEFORMATION STUDIES.

An assessment of the blunt trauma threat can be made by observing the maximum deformation of the armor on impact.

Preliminary results of deformation studies, using Plastilina No. 1 clay blocks as the backing deformation block, are shown in Table 5. Only three parameters of measurement were determined from these studies: depth of penetration, diameter of the deformation, and volume of the deformation. These experiments were conducted in an attempt to provide data for the backface signature studies using gelatin blocks and high-speed photography which will be discussed later.

Although there are differences in the results for different backing materials (i.e., gelatin vs clay), some correlation has been found in the measurements of volume and depth of deformation.

Table 2. 158-Grain .38 Caliber Bullet vs 7-Ply 400/2 Denier Kevlar 29 (Gèlatin Backed).

Velocity (fps)	Results
837	PP - Missile bounces off sample
840	PP - Missile bounces off sample
843	PP - Missile bounces off sample
843	PP - Missile bounces off sample
846	PP - Missile bounces off sample
850	PP - Missile bounces off sample
853	PP - Missile bounces off sample
860	PP - Missile bounces off sample
883	PP - Missile bounces off sample
981	PP - Missile bounces off sample
1001	PP - Missile bounces off sample
1043	PP - Missile bounces off sample
1047	PP - Missile bounces off sample
1050	PP - Missile bounces off sample
1063	PP - Missile bounces off sample
1079	PP - Missile in sample

PP - Partial Penetration.

Table 3. 40-Grain .22 Caliber Bullet vs 7-Ply 400/2 Denier Kevlar 29 (Gelatin Backed)

Velocity (fps)	Results
1037	PP - Missile in 1st ply
1060	PP - Missile in 1st ply
1070	PP - Missile in 3rd ply
1075	PP - Missile in 2nd ply
1075	PP - Missile in 6th ply
1076	PP - Missile in 3rd ply
1076	PP - Missile in 3rd ply
1079	PP - Missile in 5th ply
1085	PP - Missile in 4th ply
1099	PP - Missile in 4th ply
1107	PP - Missile in 3rd ply
1112	PP - Missile in 3rd ply
1112	CP - Missile in gelatin block
1119	PP - Missile in 4th ply
1128	PP - Missile in 5th ply
1133	CP - Missile in gelatin block
1135	PP - Missile in 5th ply
1135	PP - Missile in 3rd ply
1148	CP - Missile in gelatin block
1148	PP - Missile in 3rd ply
1148	PP - Missile in 3rd ply
1148	PP - Missile in 3rd ply
1181	CP - Missile in gelatin block
1184	CP - Missile in gelatin block
1194	PP - Missile in 5th ply

CP - Complete Penetration.
PP - Partial Penetration.

Table 4. Recommended Layers of Protection Afforded by 400/2 Denier Kevlar 29 Against Various Threats

Caliber	Grain	Type of Bullet	Barrel Length (inch)	Muzzle Velocity (fps)	Muzzle Energy (ft-lb)	Recommended Layers
.22 LR	40	Lead	4	1000	90	7
.22 mag	40	Lead HP	6-1/2	1550	213	15
.22 mag	40	Lead	7-1/2	1570	213	22
.25 auto	50	FMJ	2-1/2	810	73	7
.32 auto	71	FMJ	3-1/2	950	145	7
.32 revol	98	Lead	4	680	100	7
*.38 spec	158	Lead	6	855	255	7
.38 Hi-Vel	110	JHP	6	1350	450	15
.38 Hi-Vel	115	FMJ	6	1000	300	15
.357 mag	110	JHP/SP	6	1650	685	15
.357 mag	158	FMJ	6	1250	475	15
.45 auto	240	FMJ	5	850	369	15
9 mm auto	100	Lead/JSP	5	1180	310	15
9 mm auto	115	JHP	5	1201	380	15
9 mm auto	124	FMJ	5	1175	375	23
9 mm auto	90	JHP	5	1400	400	15
44 mag	240	Lead	6-1/2	1450	1150	23

*Medical assessment of blunt trauma behind the armor material was not performed on threats above to .38 Special 158 grain lead bullet. Additional layers of material can be added to prevent penetration of higher threat levels, however, no medical data is available to indicate resulting damage from the higher threats.

Table 5. Deformation Studies of Various Bullets vs Clay-Backed Kevlar.

Bullet and No. of Plies of 400/2 Denier Kevlar 29	Velocity (fps)	Clay Deformation			Result
		Depth (cm)	Diameter (cm)	Volume (cc)	
.38 Caliber 7-ply	813	3.9	6.6 x 6.8	50	PP - Missile bounced off
.38 Caliber 7-ply	1008	4.3	5.6 x 6.2	55	PP - Bullet in 1st ply
.38 Caliber 10-ply	990	3.8	6.5 x 6.4	70	PP - Bullet in 1st ply
.38 Caliber 7-ply	837	4.2	6.2 x 6.8	85	PP - Bullet in 3rd ply
.22 Caliber 7-ply	1022	2.2	4.5 x 4.3	16	PP - Bullet in 3rd ply
.45 Caliber 7-ply	791	5.2	6.8 x 6.3	85	PP - Bullet in 2nd ply
.357 magnum 14-ply	1145	4.6	6.5 x 5.5	65	PP - Bullet in 2nd ply

PP - Partial Penetration

CHAPTER III. BLUNT TRAUMA DATA CORRELATION

A. PURPOSE.

The purpose of this task was to assemble and correlate already existing blunt trauma data with primary emphasis on the relevancy of the data to the Lightweight Body Armor Program. The applicability of these data to generalizations about projectile-induced blunt trauma was also considered.

B. SCOPE.

This correlation effort was centered around, but not limited to, data on projectile-induced blunt trauma generated by the following organizations, which were thought to be the most likely sources of relevant information: Calspan; Edgewood Arsenal; Land Warfare Laboratory; Lovelace Foundation; MB Associates; and the United Kingdom.

C. METHODOLOGY.

The task was carried out in two related phases. The first was a review phase during which the data were organized as to type (research, test, empirical, theoretical, etc.) and were evaluated by a mixed-discipline team to establish the validity of each data set and its applicability to the objectives of this task. This phase resulted in interim conclusions and recommendations within a 2-month period.

The second phase involved the analysis of those data sets identified as most relevant during the review phase and resulted in provisional multiplicative models. The correlation analysis involved an objective function of the fewest misclassifications and/or the smallest zone of mixed results for positive (lethality) and negative (nonlethality) responses in biotargets struck in the thorax by nonpenetrating projectiles. The starting point for the analysis was with two parameters (minimum logical parameters) and proceeded through successive combinations of "physical" parameters to a level of five (maximum available). Three "physiological" parameters were also correlated with response. The models were validated using available, independently obtained data for similar and dissimilar projectiles as well as for different biotarget species. Extension of the four-parameter model to abdominal impacts was attempted and validation within the limits of available data accomplished.

D. RESULTS AND CONCLUSIONS.

Mathematical models capable of predicting and/or evaluating projectile-induced blunt trauma and blunt trauma behind soft body armor resulted from this study. One such model, Figure 6, is generally representative of those formulated and specifically representative of the

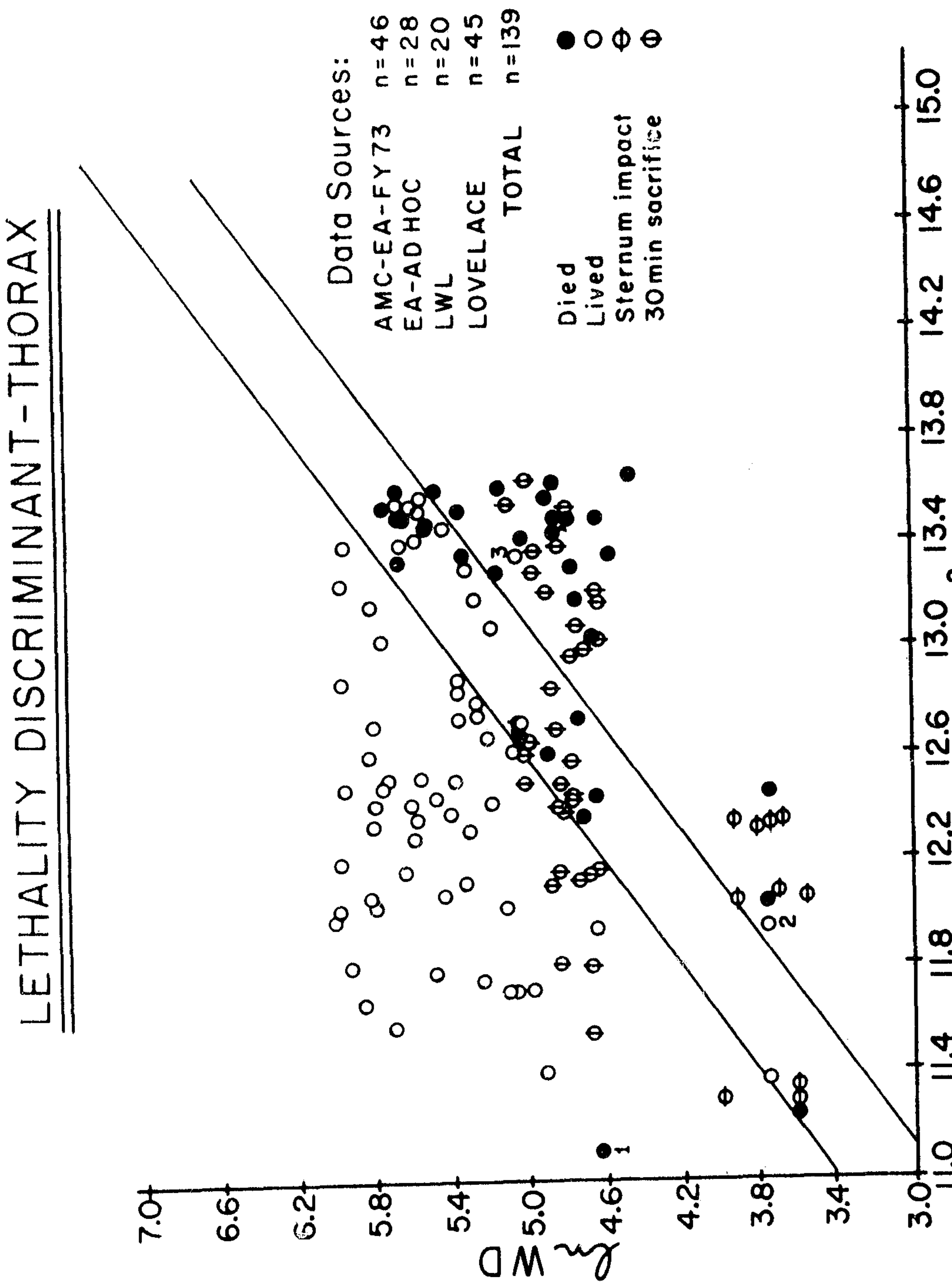


Figure 6. Four-Parameter Model. Thoracic Impacts.

maximum number of parameters (4) common to the data reviewed. These data include three biotarget species and 12 projectile variations. This specific model has suggested application for generalized projectile-induced blunt trauma to the thorax and is predictive to the extent that all of the parameters which may be measured experimentally can also be assumed. The model is of the form:

$$P(R) = f\frac{MV^2}{WD}$$

where the parameters are:

- P(R) = probability of a response (liver fracture, lethality)
- M = mass of the projectile in gm
- V = impact velocity of the projectile in mps
- W = body mass of the biotarget in kg
- D = effective diameter of the projectile in cm

Because of the volume of the data analyzed, the complexity of the correlation procedures, and the potentially multiple functions of the models, no attempt will be made here to describe these results in detail. Instead the reader is referred to the separate detailed report covering this area.[2] However, these models coupled with data derived through methodology developed in the Backface Signature Task of this program (described later is this report) provide a behind-the-armor predictive (pre-experimental) live/die capability for biotargets based on the "physical" parameters, and a more sensitive discriminant capability given post-experimental "physiological" measures.

Generalized conclusions resulting from this effort were:

1. There is a general scarcity of empirical data of the type relevant to nonpenetrating projectile and body armor effectiveness evaluations.

2. Of those data sets which are available, none offers a complete consideration of all of the parameters thought to be important in blunt trauma assessment.

3. In those instances where separate sources of data were uncovered for similar nonpenetrating projectiles, inconsistence in and between the test methodology and data collection techniques preclude broad and absolute data correlation between the studies.

4. While a sufficient data base from which to form absolute generalizations (criteria) for blunt trauma produced by high velocity/low mass projectiles does not appear to exist, predictive and experimental models applicable to generalized blunt trauma and blunt trauma behind soft armor have been modified or developed during this effort and are presented in the body of the specific report of this portion of the study.[2]

However, because of the aforementioned insufficient and inconsistent data base, model formulation and validation were restricted both in sample size and range of input parameters evaluated. For this reason, pending availability of additional data for further validation, the models presented by Clare et al.[2] should be considered as provisional.

5. Data reviewed during this effort show that serious injury and death can occur from nonpenetrating projectile impacts in animals unprotected by armor. Data from the Backface Signature and Medical Assessment Tasks of the Soft Armor Program (described later in this report) indicate that serious injury and death can also occur from nonpenetrating projectile impacts in animals protected by armor. Therefore, any thorough evaluation of the effectiveness of soft armor should include, in addition to the obvious ability to prevent projectile penetration, the ability of the armor to prevent or significantly reduce the occurrence of blunt trauma sufficient to cause serious injury and death.

6. In view of the above, the ongoing Lightweight Body Armor Program appears to represent a reasonable effort within state-of-the-art limits and major alterations in that program are not indicated.

CHAPTER IV. DEFINITION OF GARMENT PROTECTION AND ORGAN VULNERABILITY*

A. PURPOSE.

The purpose of this project was to evaluate 7 plies of 400/2 denier Kevlar 29 in a protective garment with regard to the consequences of an impact of a .38 caliber, 158 grain bullet at 800 fps, and a .22 caliber bullet at 1000 fps (Figure 7). Data on other higher and lower threats will also be discussed throughout this report; however, the medical evaluation of these additional threats is limited.

As agreed, a protective garment should have the following associated capabilities with regard to this project's goals:

1. It should prevent penetration by the bullet into the chest, abdomen, or back.

2. Any blunt trauma effects requiring surgical repair should have a mortality risk of 10% or less.

3. A man wearing the garment should be able to walk from the site of a shooting after being hit in the chest or abdomen by a bullet of specified caliber or weight and velocity.

It is assumed that the patient will receive medical attention at a hospital within one hour.

Suppose that a jacket is meant to cover and protect the thorax, abdomen, and back, as in the accompanying four diagrams (Figures 7-10). The areas that are outlined represent the organs that will register damage that would probably require surgery or result in intensive care monitoring if covered by a new 7-ply Kevlar jacket and impacted with a .38 caliber bullet. Vulnerability then, with regard to body armor, should perhaps refer to that area of the body that will require surgery or intensive care even if the overlying body armor prevents penetration of the particular missile fired. The frontal view (Figure 7a) indicates that the liver and spleen are vulnerable. The area of the heart is also probably vulnerable, and this will be tested further in the biotarget. The right lateral view (Figure 9) illustrates the large area occupied by the liver and the small area occupied by the right kidney. It should be noted here that the location of goat kidneys is variable, and they are small targets. Renal contusions, however, are usually managed conservatively and rarely is surgery necessary. Since a patient with a renal contusion would have hematuria, he would be hospitalized and followed closely for signs of blood loss. The left lateral view (Figure 8) demonstrates the vulnerable kidneys, spleen, and heart.

*A detailed report of this study has been published by Goldfarb et al.[3]

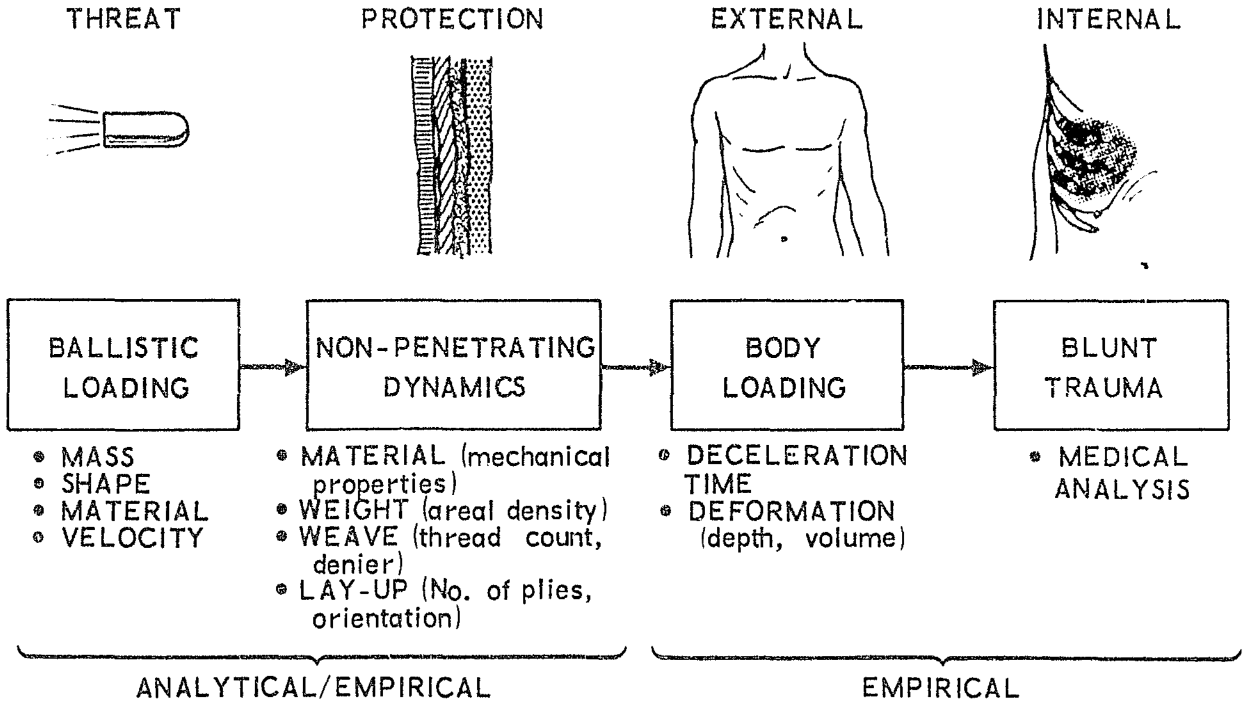


Figure 7. Threat Definition.

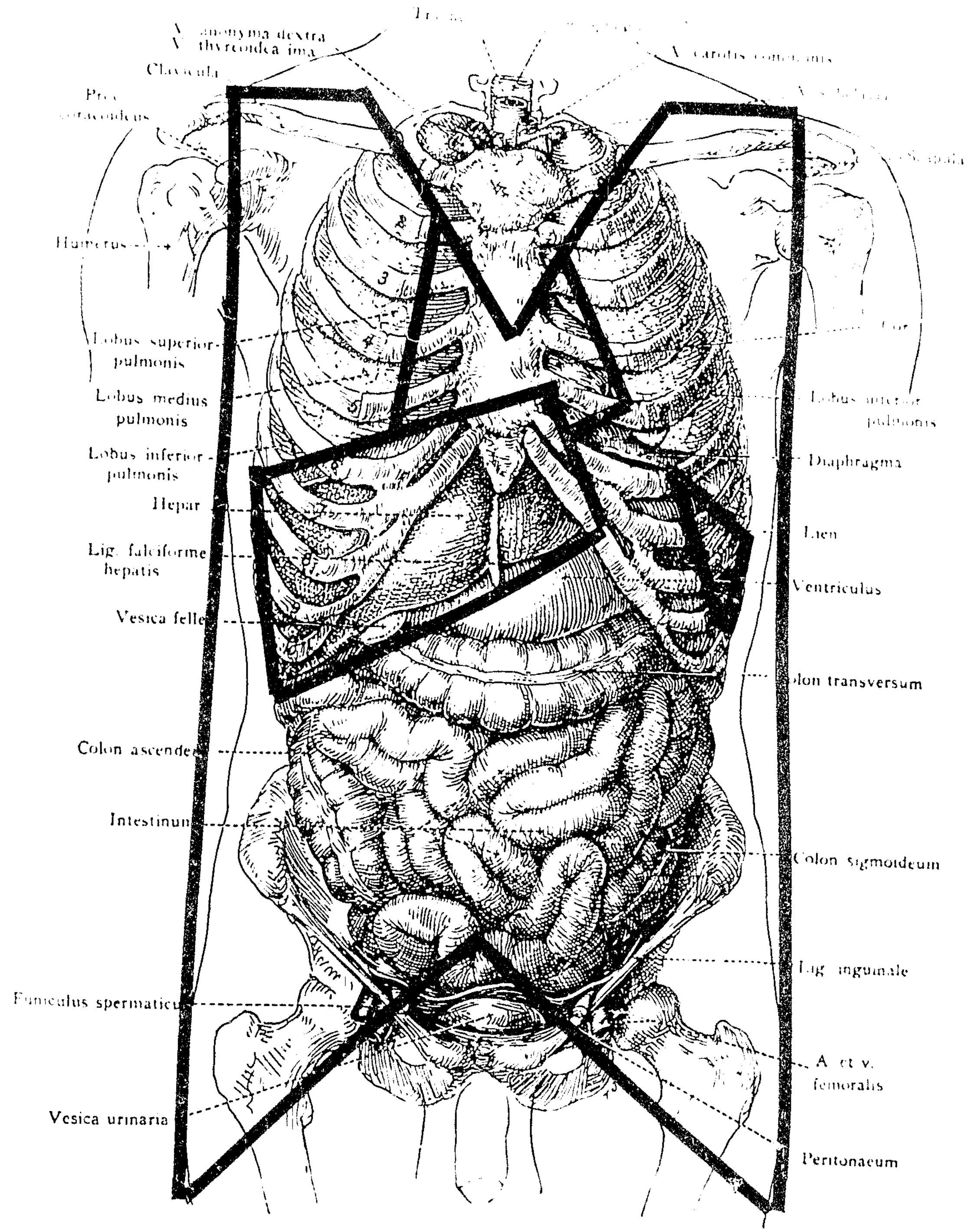


Figure 7a. Frontal View with Jacket, Indicating Vulnerable Areas.

[The liver (11.9%), heart (5.1%), and spleen (0.8%) account for 17.8% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

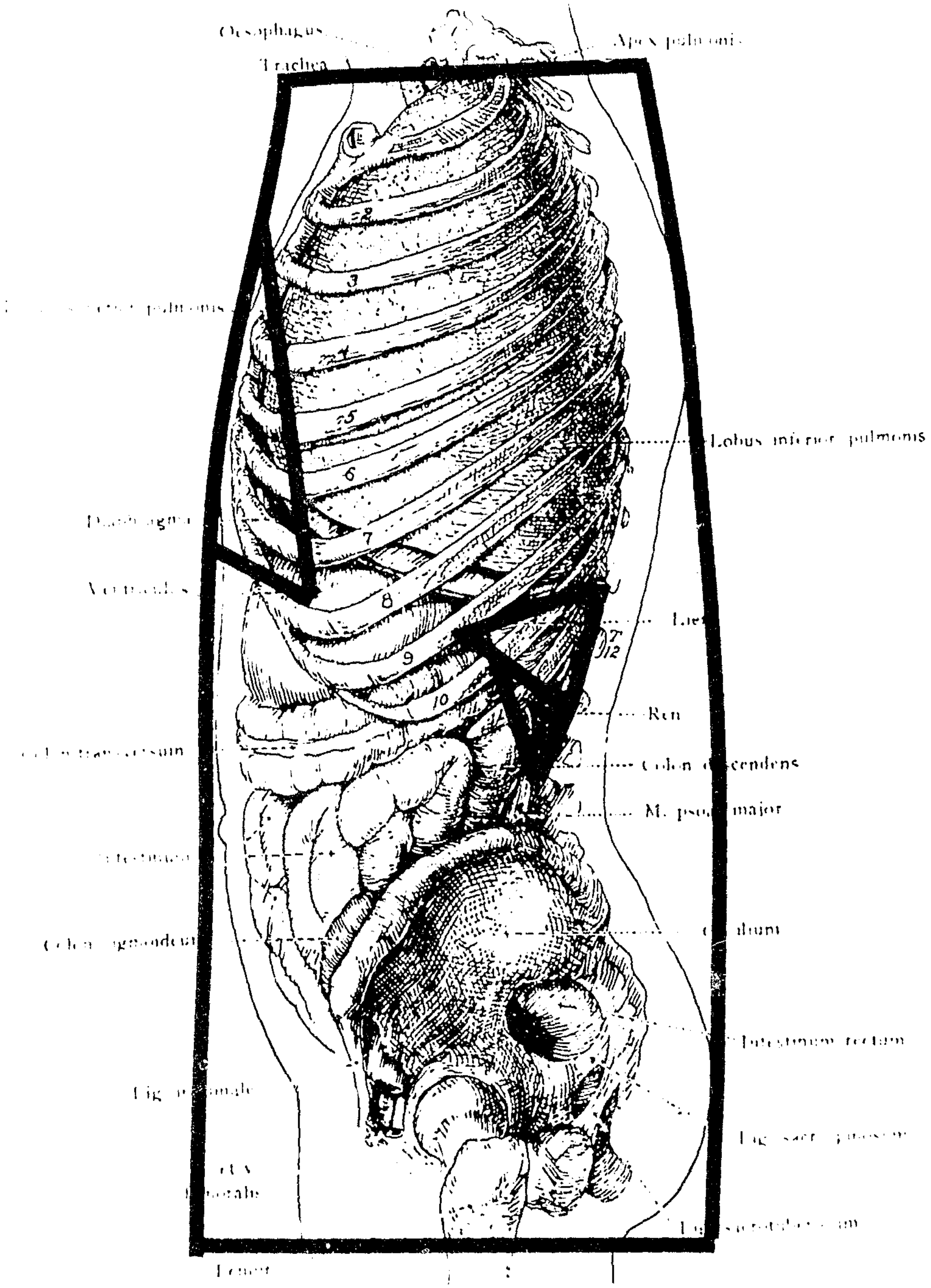


Figure 8. Left Flank View with Jacket, Indicating Vulnerable Areas.

[The heart (3.2%), spleen (1.5%), and kidney (0.4%) account for 5.1% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

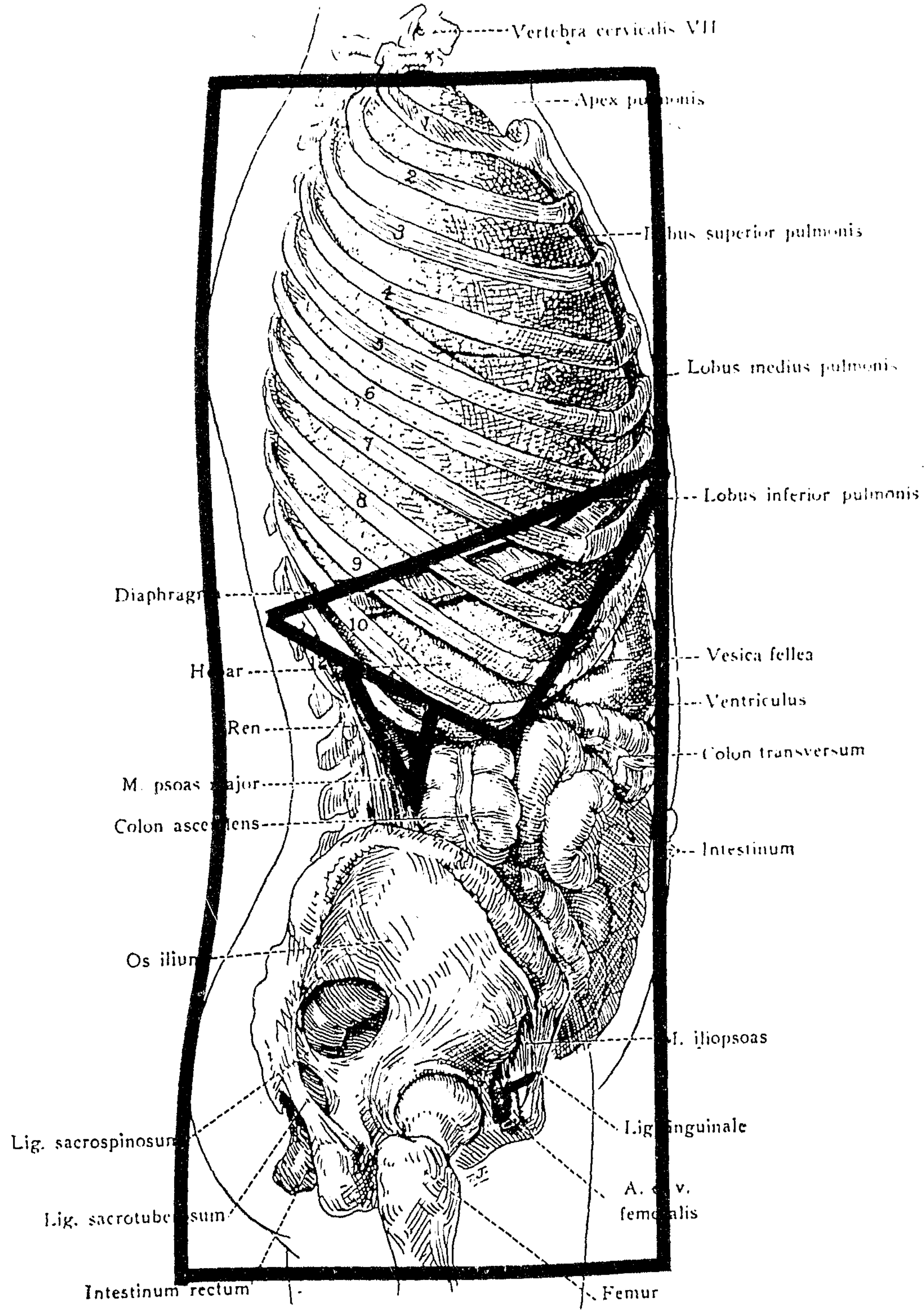


Figure 9. Right Flank View with Jacket, Indicating Vulnerable Areas.

[The liver (8.7%) and kidney (0.7%) account for 9.4% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

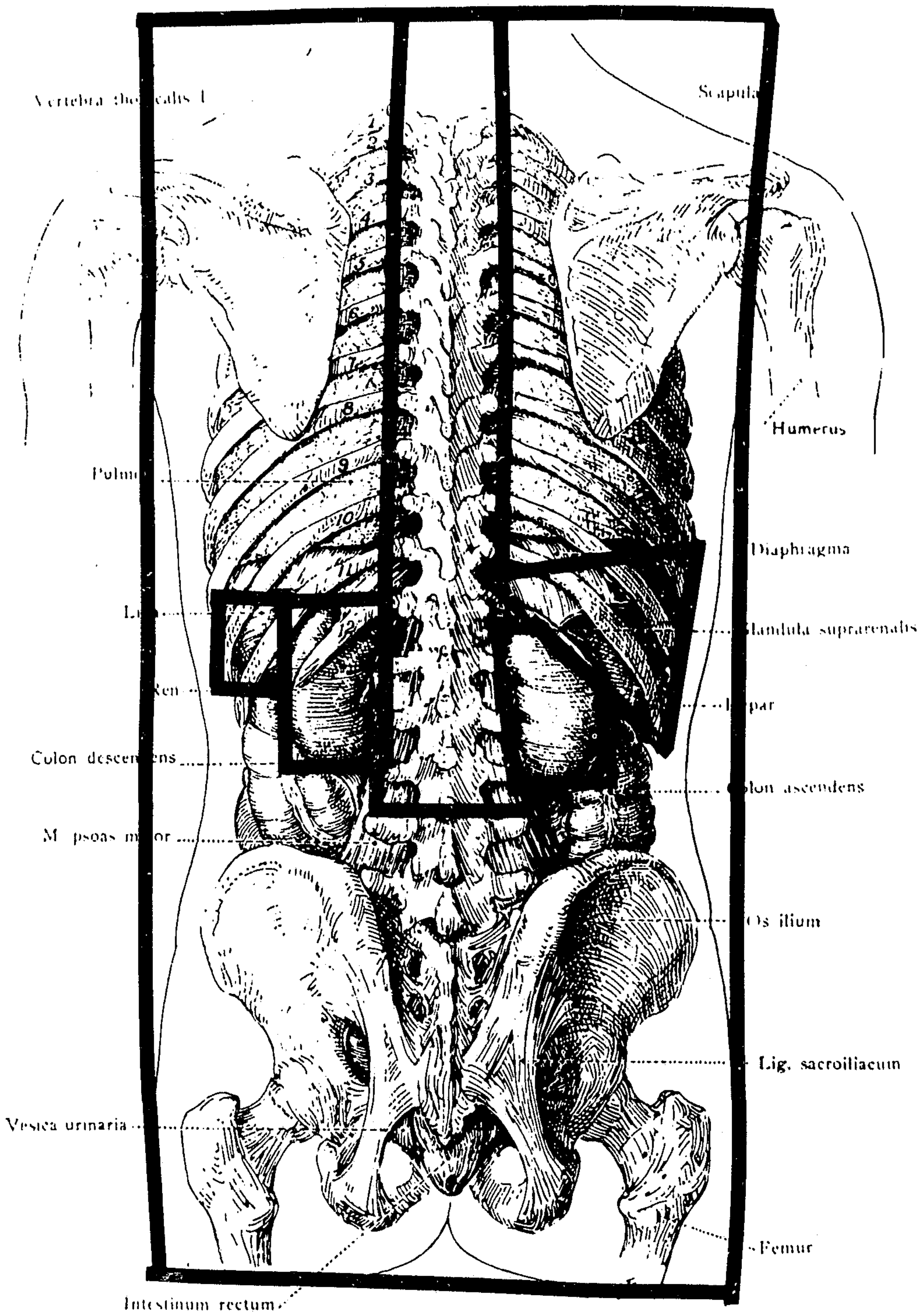


Figure 10. Back View with Jacket, Indicating Vulnerable Areas.

[The spleen (1.1%), kidney (4.7%), spine (13.5%), and liver (3.2%) account for 22.5% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

The percentage of vulnerable area will vary according to the design of the protective garment. Based on earlier testing, the number of layers of flexible Kevlar necessary to convert most of the vulnerable areas into totally invulnerable areas would probably be too heavy to incorporate into a garment that would be comfortable enough for routine use.

B. METHOD TO DETERMINE MORTALITY WITH AND WITHOUT BODY ARMOR.

In order to answer the problem as to the mortality probability after being shot with a .38 caliber bullet with and without the protective garment, the following method was used:

1. The area of each of the vulnerable organs was determined for the human target. Thus, for example, on a frontal view the heart accounts for 5.1%, the liver 11.9%, and the spleen 0.8% (Table 6). The remaining organs occupy 82.2%. The organs considered to be vulnerable are those organs that revealed damage when the garment was used to protect the goat. The damage would necessitate either observation in an intensive care unit or surgery. The lung, therefore, is not considered vulnerable since there was minimal damage in the 14 goat thoracic impacts.

2. Two mortality rates were then assigned to each area, assuming a garment not worn. One rate may be considered an optimistic evaluation (O), and the other, a pessimistic evaluation (P). These figures are based on data ranges in various surgical series. The "truth" is probably somewhere between these two ranges. With regard to the frontal view, a random liver wound would be associated with a 15% to 60% mortality.

3. The total probability of mortality was calculated by multiplying the mortality times the area fraction of each organ and adding all these probabilities. Thus, in a frontal random shot with a .38 caliber bullet the pessimistic probability of mortality is 0.051 + 0.071 + 0.002 + 0.164 = 0.289 or 28.9%; the optimistic probability is 10.1%.

4. The projected areas of each view are approximately equal. The probabilities for each of the four views were then added and divided by four to derive a mean probability which ranges from 6.9% to 25.4% (Table 7). In this step one assumes that each view is hit with equal frequency without armor. From preliminary field data another hit distribution has been suggested. If we assume that a man is hit 60% of the time in the front, 15% in each side, and 10% in the back, how are our final probabilities altered? Calculations reveal an overall change of 2% lower mortality. Regardless of the hit distribution, the mortality is between 7% to 25%.

5. The mortality rates associated with the lesions as a result of blunt trauma beneath the vest were then assigned to the various areas. According to the experimental data, the lungs and non-dilated GI tract are not vulnerable and, therefore, have an associated mortality of zero if impacted while the garment is worn. The liver and spleen injury should carry a mortality of less than 5%. A 10% mortality rate was assigned to the heart.[4] It is possible that this is too high, so further testing is necessary. The spinal injury assessment has been managed by assuming that in one case (optimistic evaluation), no spinal impact would result in death. In the other case, every spinal hit would result in death. Again we believe the "truth" is somewhere between the two estimates. The kidney impact may produce a small hematoma requiring hospital observation, but it is associated with a negligible mortality.

6. Analysis using the mortality rates when armor is worn reveal a range between 1% to 5% (Table 8). This represents the mortality associated with a .38 caliber bullet impacting the 7-ply Kevlar.

C. METHOD TO DETERMINE PROBABILITY OF SURGERY WITH AND WITHOUT BODY ARMOR.

In this study we have again considered two alternatives. In the pessimistic case every .38 caliber bullet striking an unarmored human would result in surgery. A more optimistic case is where a penetration to any lung area is associated with a 0.2 probability of surgery (instead of 1.0). The remaining areas would still be associated with surgery on every occasion. In this optimistic case the probability of surgery would be 81.4% (Table 9).

The probability of surgery if a human is protected by Kevlar is much less. Surgery would be required if the liver or spleen were impacted under the garment. The only other area that might require surgery is the spine. If we consider that surgery is always necessary if the spine is hit (pessimistic case), the total probability for surgery given a random hit anywhere on the garment is 10%. If, however, surgery is not considered when the spine is hit (optimistic case), the total probability for surgery is 7% (Table 10).

In summary, *without the garment the mortality after a random hit with a .38 caliber bullet is between 6.9% to 25.4%. If the garment is worn, the mortality is decreased to 1% to 5%. The chance of surgery without armor is 81.5% to 100% and with armor it is 7% to 10%.*

D. CONCLUSION.

As a final note, we would like to again emphasize the exact scope of our investigation to date. That is, we have had success with the unaged 7-ply Kevlar vest against the threat of the .22 caliber bullet traveling at a velocity of 1000 fps and the .38 caliber traveling at 800 fps. No inference can or should be drawn from these tested threats to other partially or totally untested threats such as the .45 caliber bullet, 9-mm bullet, shotgun, or higher velocity weapons.[10] Thus, from the blunt trauma aspect of our investigations, only the damage produced by the .38 caliber and the .22 caliber bullets beneath the 7-ply, unaged Kevlar vest has been evaluated.

Table 6. Probabilities of Mortality from a .38 Caliber Bullet without Body Armor for Frontal, Side, and Back Views.

(Note that next to each organ "P" represents the pessimistic case and "O", the optimistic case.)

No armor	Mortality rate	X	Area fraction of organ	Probability
		I. FRONTAL VIEW		
Heart - P	1.0		0.051	0.051
O	0.9		0.051	0.046
Liver - P	0.60		0.119	0.071
O	0.15		0.119	0.019
Spleen - P	0.30		0.008	0.002
O	0.15		0.008	0.001
Other - P	0.20		0.822	0.164
O	0.05		0.822	0.041
Total - P				0.289
O				0.101
		II. LEFT SIDE		
Heart - P	1.0		0.033	0.033
O	0.9		0.033	0.029
Spleen - P	0.3		0.015	0.005
O	0.15		0.015	0.002
Kidney - P	0.10		0.004	0.000
O	0.05		0.004	0.000
Other - P	0.2		0.948	0.189
O	0.05		0.948	0.041
Total - P				0.227
O				0.072
		III. RIGHT SIDE		
Liver - P	0.60		0.087	0.052
O	0.15		0.087	0.013
Kidney - P	0.10		0.007	0.001
O	0.05		0.007	0.000
Other - P	0.20		0.906	0.181
O	0.05		0.906	0.045
Total - P				0.234
O				0.058
		IV. BACK VIEW		
Spleen - P	0.3		0.011	0.003
O	0.15		0.011	0.002
Kidney - P	0.10		0.047	0.005
O	0.05		0.047	0.002
Spine - P	1.0		0.135	0.135
O	0		0.135	0.000
Liver - P	0.6		0.032	0.019
O	0.15		0.032	0.005
Other - P	0.2		0.775	0.154
O	0.005		0.775	0.039
Total - P				0.316
O				0.048

Table 7. Probability of Mortality if Hit with a .38 Caliber Bullet and not Wearing Body Armor.

View	Probability of mortality optimistic case	Probability of mortality pessimistic case
Frontal	0.101	0.289
Left	0.072	0.227
Right	0.058	0.234
Back	0.048	0.316
Mean probability	0.069	0.254

Table 8. Comparison Between Probabilities of Mortality with and without 7-Ply Kevlar if Hit with a .38 Caliber Bullet.

View	7-Ply Kevlar	No armor
Front	0.02	0.101 - 0.289
Left	0.01	0.72 - 0.227
Right	0.01	0.058 - 0.234
Back	0.01 - 0.15	0.048 - 0.316
Mean	0.01 - 0.05	0.069 - 0.254

Table 9. Probability of Surgery without Body Armor in Optimistic Case is 81.5% and in Pessimistic Case 100%.

View	No armor	Area fraction of organ	Probability of surgery	P
Front	Lung	0.163	0.2	0.033
	Other	0.837	1.0	0.837
	Total			0.870
Left	Lung	0.28	0.2	0.056
	Other	0.72	1	0.72
	Total			0.776
Right	Lung	0.28	0.2	0.056
	Other	0.72	1	0.720
	Total			0.776
Back	Lung	0.194	0.2	0.039
	Other	0.806	1	0.806
	Total			0.835
Average				81.4%

Table 10. Probabilities of Surgery with and without Body Armor (Optimistic Case)

View	7-Ply Kevlar	No armor
Front	0.127	0.870
Left	0.015	0.776
Right	0.086	0.776
Back	0.043-0.178	0.835
Mean	0.068-0.101	0.814

CHAPTER V. MATERIAL TEST MATRIX AND BACKFACE SIGNATURE

A. PURPOSE.

The objectives of these subtasks were as follows:

1. To develop a technique for the assessment of the behind-the-armor deformation parameters (backface signature).

2. To apply this technique and define the backface signatures of a) candidate lightweight armor materials when subjected to non-penetrating impacts by the .38 caliber Special and the .22 caliber LRHV; and b) a predefined matrix of materials, plies, and ballistics to ascertain any data trends in the backface signature parameters as functions of the incident ballistic parameters and material characteristics.

3. To characterize the backface signature in such a manner that it could be applied to predictive models similar to those developed under the Blunt Trauma Data Correlation subtask (Chapter III).

By using this predictive capability and determining the degree of decreasing non-lethal injury potential with decreasing dose, an analysis of the backface signature alone could provide an initial estimate of a candidate armor material's effectiveness, thereby reducing the need for other extensive and costly experimental designs.

B. THREATS AND MATERIALS TESTED.

The principal threats specified for use under these subtasks were: .38 caliber, 158 grain projectile, 800 fps; .22 caliber, 40 grain projectile, 1000 fps; 9-mm, 124 grain FMJ projectile, 1175 fps; .45 caliber, 240 grain projectile, 800 fps; and the knife (4-inch switch-blade, 10-inch butcher knife, M-16 bayonet).

Some of the materials tested under this subtask were 400/2 denier Kevlar 29, 200 denier Kevlar 29, and Standard Ballistic Nylon.

C. BACKFACE SIGNATURE.

The initial objective of this subtask was to develop a technique which would allow visualization and measurement of the armor deformation with the degree of speed necessary to capture the energy distribution. Several approaches were examined for feasibility and cost effectiveness. The one described below was selected.

The armor under test was fastened in front of the gelatin block, impacted by the missile, and the event recorded on high-speed film.

The test setup is shown in Figure 11 and consists of the following:

1. The weapon: a 7-inch, .38 caliber Mann barrel with remote firing capability; or a 7-inch, .22 caliber Mann barrel.

2. A 1/2 meter baseline utilizing silver grid screens which activate an electronic chronograph (ECI Model 4600) to measure missile velocity.

3. A Redlake Hycam camera focused on the gelatin-armor interface.

4. A large bank of quartz lights necessary to completely backlight the gelatin block.

5. A steel frame for supporting the armor material.

6. The armor material.

During the actual test operation the camera was activated and when the proper framing rate was achieved, a signal was sent to the firing mechanism to activate the weapon. The various deformation parameters were then "read" from the film and processed through a computer program which provided depth of penetration, velocity of deformation, a maximum deformation surface, and a maximum deformation volume.

Using these deformation parameters, the initial impacting missile parameters, and the principle of the conservation of linear momentum, the backface signature for a particular armor was characterized by a mass, a velocity, and the time and diameter of deformation which would define a tissue impactor. Figure 12 is an example of a record of the deformation time history used in developing the backface signature. Figure 13 is an illustration of the .38 caliber deformation envelope. Average backface signature data for the various missiles and armor samples tested listed in Table 11 were then applied to the four-parameter model proposed under Blunt Trauma Data Correlation subtask described in Chapter III and are illustrated in Figure 6.

Due to the complexity of applying backface signature data to the other models developed, the reader is referred to the reports of Clare _et al._[2] on blunt trauma data correlation and Metker _et al._[5] on determining backface signatures.

D. TEST MATRIX.

The test matrix, as defined by the sponsoring agency (LEAA/NILECJ), consisted of the following eight tests:

1. Test 1. Fire the .38 caliber, 158 grain-lead projectile at a nominal velocity of 800 fps against 3, 5, 7, 9, 15, and 23 plies of 400/2 denier Kevlar 29. This test was designed to determine the effect of the number of plies of Kevlar 29 on the backface signature.

2. Test 2. Fire the .38 caliber, 158 grain lead projectile at a nominal velocity of 800 fps against 7 plies of 400/2 denier Kevlar 29 with material standoffs at 0.5 and 1.0 inch; repeat using 15 plies of 400/2 denier Kevlar 29 at a standoff of 1 inch. This test was designed to examine the effect on backface signature of material standoff in conjunction with the number of plies.

3. Test 3. This test was designed to examine the effects of material denier on backface signature. The .38 caliber, 158 grain projectile, launched at a nominal velocity of 800 fps, was tested against different deniers of Kevlar material having the same areal density (weight/sq ft) of 7 plies of the 400/2 denier Kevlar 29, approximately 0.44 lb/sq ft. The three materials tested were 400/3 denier (PRD 105-27A), 400/2 denier (Kevlar 29 - Candidate Material), and 1500 denier (PRD 105-628).

4. Test 4. The .38 caliber, 158 grain projectile was fired at nominal velocities of 600, 700, 900, and 1000 fps against 7 plies of 400/2 denier Kevlar 29. This test was designed to examine the effect of velocity (varying striking kinetic energy, constant mass on material performance.

5. Test 5. The .22 caliber, 40 grain projectile was fired at a nominal velocity of 1000 fps against 7 and 15 plies of 400/2 denier Kevlar 29. This test, similar to Test 1, was designed to examine the effect of the number of plies on the backface signature produced by the .22 caliber missile as well as the effect of a missile of smaller caliber, reduced striking kinetic energy, and higher velocity on the material performance characteristics.

6. Test 6. The 9-mm, 124 grain jacketed bullet, launched at a nominal velocity of 1150 fps, was fired against 15 and 23 plies of the 400/2 denier Kevlar 29 material. This test was similar to Tests 1 and 5.

7. Test 7. Projectiles with diameters of .22 caliber, .32 caliber, and .38 caliber were fired against Kevlar at velocities which yield a striking kinetic energy of 305 joules (225 ft-lb). The missile masses and corresponding test velocities were: .22 caliber, 40 grain projectile at 1600 fps; .32 caliber, 101 grain projectile at 1000 fps; and .38 caliber, 158 grain projectile at 800 fps. This test was designed to examine the combined effect of missile diameter, mass, and striking velocity on material performance while maintaining a constant striking kinetic energy.

8. Test 8. .38 caliber projectiles, launched at velocities of 800, 1000, and 1200 fps, were fired against 7 plies of Kevlar 29. The missile mass was adjusted so that a striking kinetic energy of 305 joules (225 ft-lb) was maintained. The missile masses and corresponding velocities were: .38 caliber, 70 grain projectile at 1200 fps; .38

Table 11. Average Backface Signature Parameters.

Missile caliber	Missile weight	Material	Ply	Striking Velocity (mps)	Maximum Depth (cm)	Maximum Volume (cc)	Deformation Time (sec)
.22	40	Kevlar 29, 400/2 denier	5	240.1	2.38	24.99	.0010
			7	309.2	2.78	41.70	.0009
			15*	310.8	2.02	29.02	.0016
		Kevlar 29, 200 denier	7	310.1	2.60	33.70	.0008
.38	158	Kevlar 29, 400/2 denier	3*	247.5	6.78	203.43	.0020
			5	246.3	4.89	140.33	.0015
			7	250.7	4.74	145.89	.0017
			9*	241.9	4.53	166.90	.0019
			15*	247.9	4.08	176.78	.0020
			23*	248.5	3.38	113.07	.0025
		Kevlar 29, 200 denier	7	257.3	5.46	178.86	.0017
		Ballistic nylon Kevlar 29, 400/2 denier (aged)	12	245.7	3.10	115.89	.0014
.45	234	Kevlar 29, 400/2 denier	7	242.1	5.32	210.3	.0017
9 mm	124	Kevlar 29, 400/2 denier with 13.2 oz/ft x P	7*	370.1	3.72	189.5	.0017
		Kevlar 29, 400/2 denier	23*	322.8	3.66	93.95	.0017

*One Round.
(Note. x P is an experimental armor material currently under study against higher threats.)

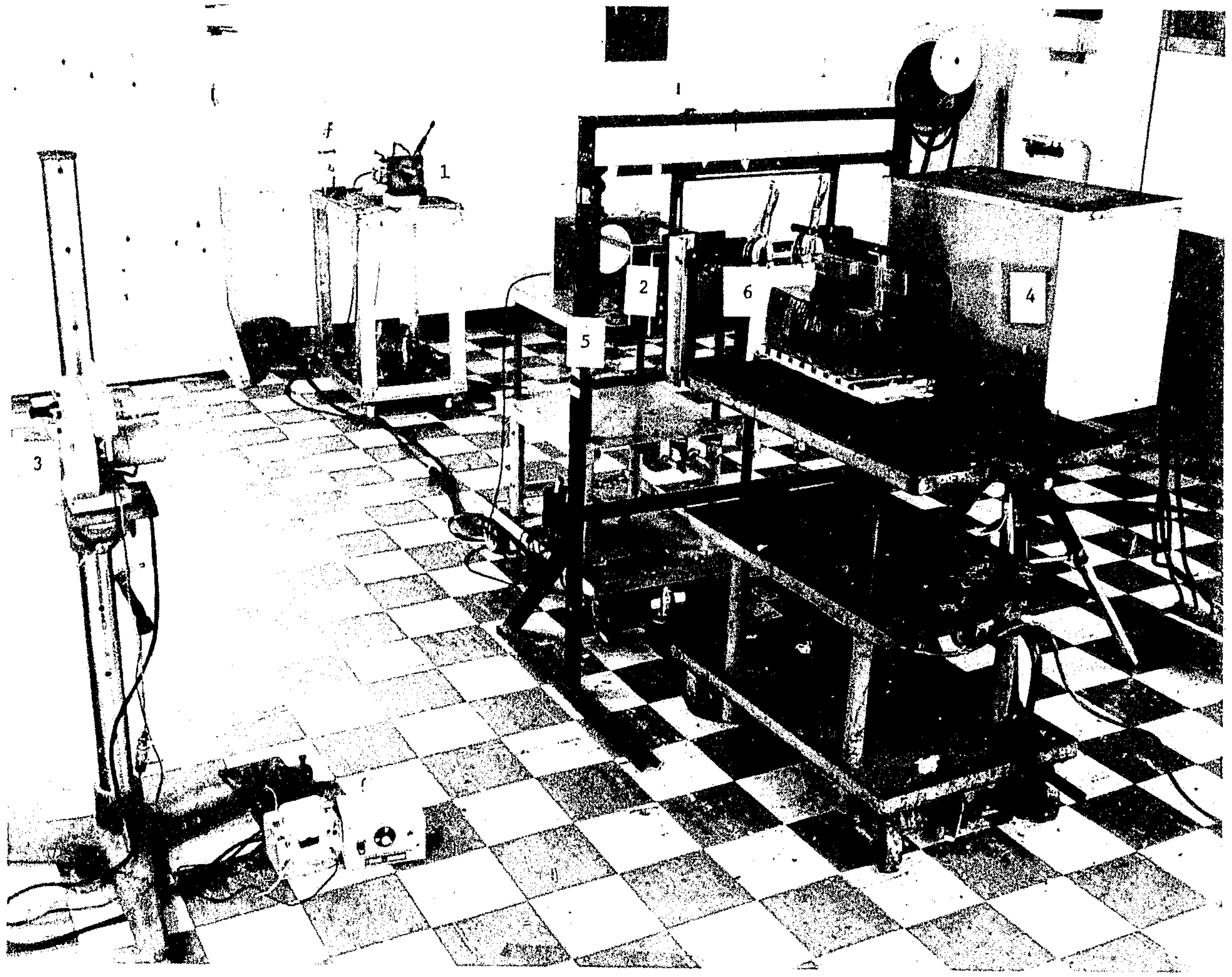


Figure 11. Experimental Setup.

1. 7-inch .38 caliber or .22 caliber Mann barrel with remote firing capability.
2. A 1/2 meter baseline utilizing silver grid screens which activate an electronic chronograph (ECI Model 4600) to measure missile velocity.
3. A Redlake Hycam camera focused on the gelatin-armor interface.
4. A large bank of quartz lights necessary to completely backlight the gelatin block.
5. A steel frame for supporting the armor material.
6. The armor material.

Figure 12. Deformation-time History.

Left, .38 Caliber; Right, .22 Caliber, both vs. 7 plies of Kevlar 29 Material.

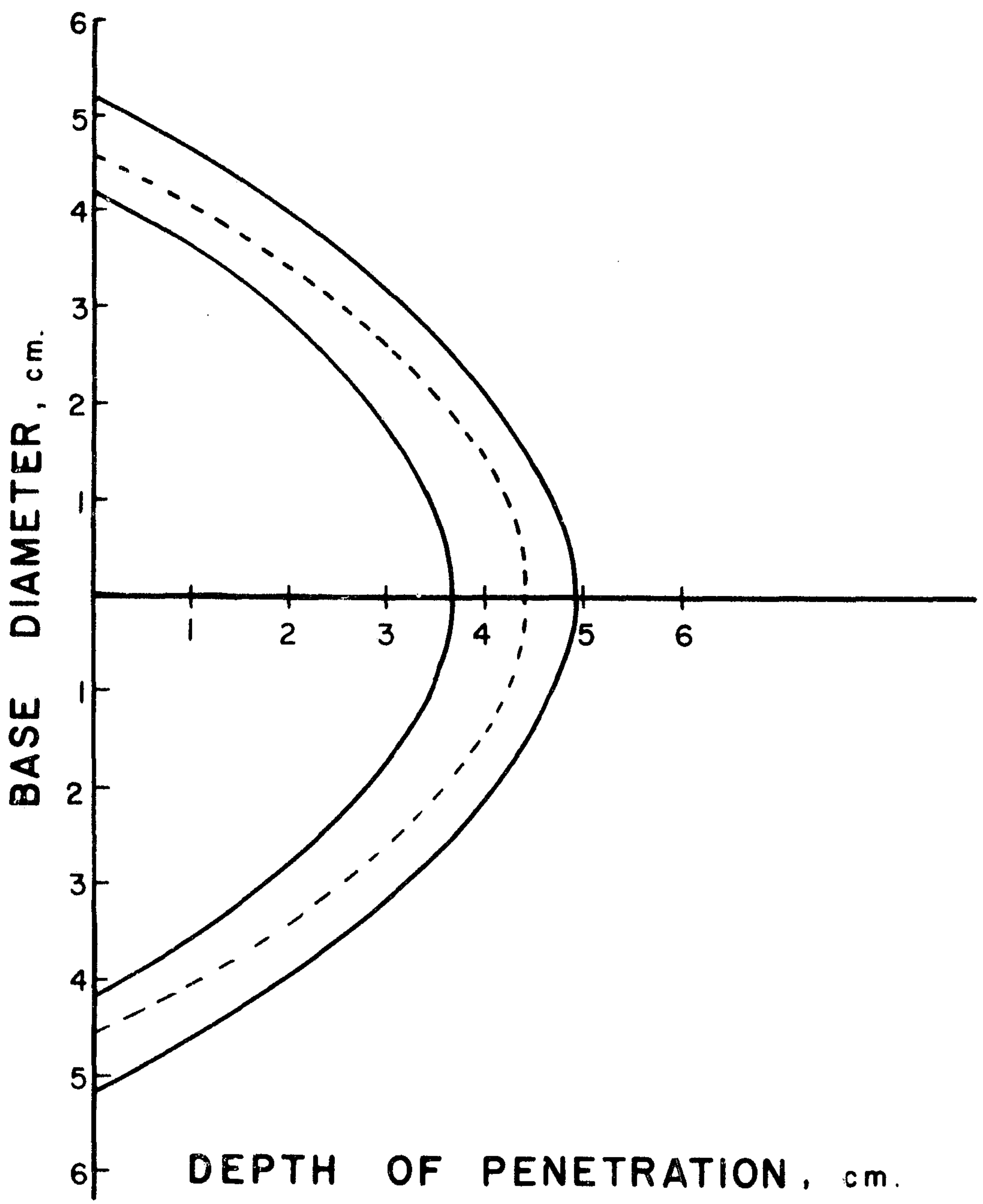


Figure 13. .38 Caliber Deformation Envelope.

caliber, 101 grain projectile at 1000 fps; and .38 caliber, 158 grain projectile at 800 fps. This test was designed to examine the effect of a change in momentum at constant striking kinetic energy.

The following conclusions were drawn from the matrix data:

1. Test 1. An increase in the number of material plies (increase in material mass) produced an expected decrease in the depth of penetration and volume of deformation, Figures 14 and 15.

2. Test 2. Standoff produced no significant effect.

3. Test 3. 400/2 denier Kevlar 29 was more effective in reducing the depth of penetration than either the 400/3 or 1500 denier material.

4. Test 4. Increasing the striking velocity of the .38 caliber, 158 grain projectile increased the backface signature, Figures 16 and 17.

5. Tests 5 and 6. These two tests ranked the severity of the more common threats. As one would expect, the backface signature ranked the threats as: 9-mm, 124 grain projectile; .38 caliber, 158 grain projectile; and .22 caliber, 40 grain projectile. To defeat the particular 9-mm projectile tested requires the use of more than 15 but less than 23 plies of 400/2 denier Kevlar 29 material. The .22 caliber projectile, when defeated, produces a significantly lower backface signature than the other two threats.

6. Test 7. An increase in the missile diameter, along with a corresponding increase in missile mass and a decrease in striking velocity in order to maintain a constant striking kinetic energy, produced little, if any, change in the backface signature parameters.

7. Test 8. Maintaining a constant missile diameter and striking kinetic energy by increasing the missile mass and decreasing the velocity appears to have little effect on the backface signature. Except in the case of small-caliber projectiles, which tend to slip through the weave and defeat the armor, the material backface signature appears to be dependent upon changes in striking kinetic energy, material mass, and material denier. However, the sample size for this test is too small to allow any definite conclusions to be drawn.

A detailed report of the study on the ballistic test matrix has been written by Prather and Metker.[6]

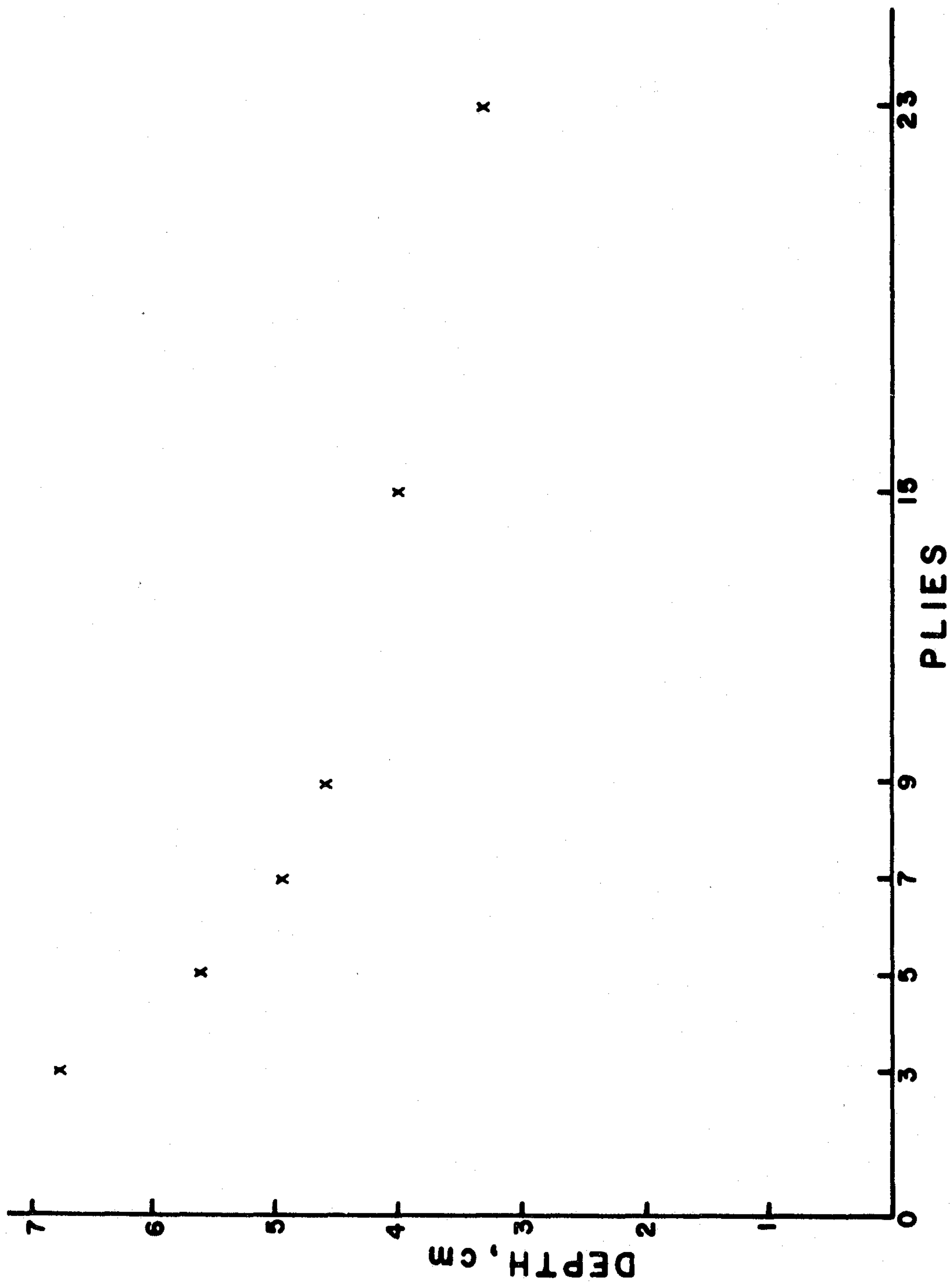


Figure 14. Increase in Number of Plies of Material and Decrease in Depth of Penetration.

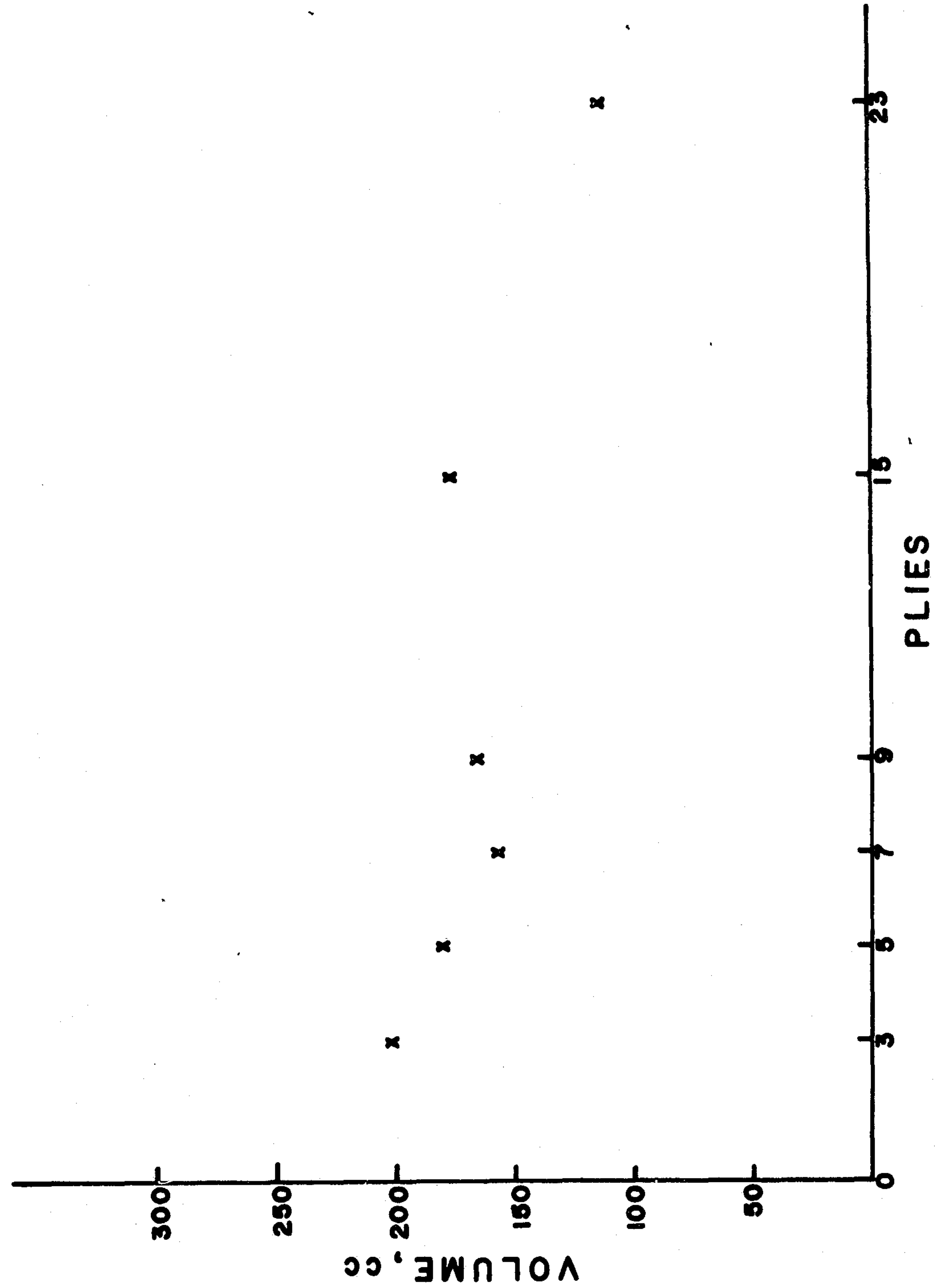


Figure 15. Increase in Number of Plies of Material and Decrease in Volume of Deformation.

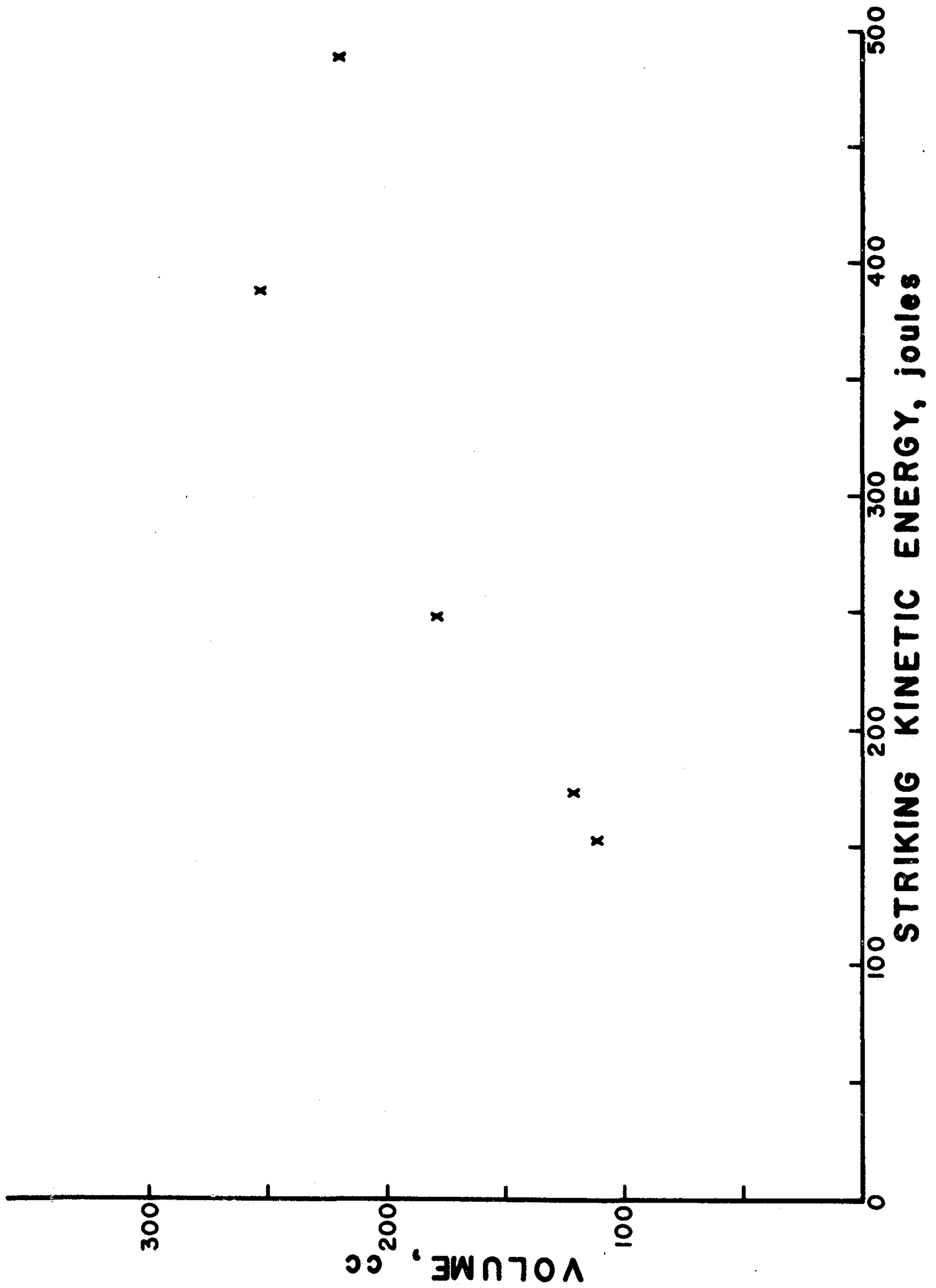


Figure 16. Projectile Energy as it Relates to Volume of Deformation.

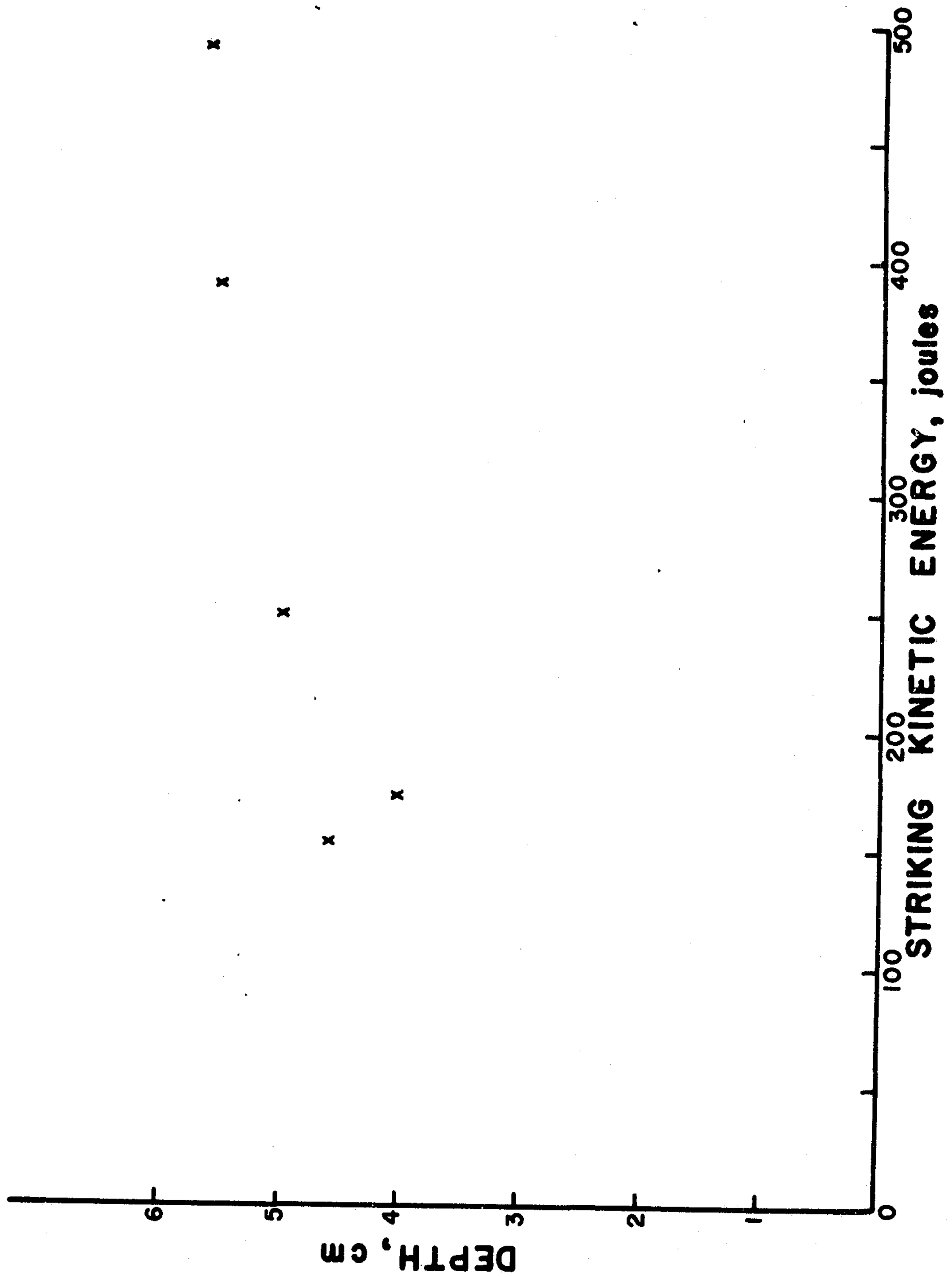


Figure 17. Projectile Energy as it Relates to Depth of Penetration (1 Joule = 0.73756 ft-lb).

CHAPTER VI. ENVIRONMENTAL TEST OF VARIOUS PROTECTIVE MATERIALS TO DETERMINE DEGRADATION EFFECTS ON THE MATERIALS.

A. PURPOSE.

This portion of the study was to examine physical changes in protective materials which have been subjected to simulated environmental changes. These environmental changes could affect the ballistic capabilities of the materials under investigation.

Basically the tests simulated various conditions to which a protective material or garment could be subjected. Some of the obvious conditions which would effect substantial changes would be the following:

1. Extremely cold temperatures
2. Extremely hot temperatures and humidity
3. Immersion in water
4. Cleaning solvents
5. Salt spray (perspiration)
6. Sunlight
7. Long-term wear

Note: All ballistic tests reported in this chapter were conducted with the .38 caliber bullet at 800 fps and the .22 caliber bullet at 1000 fps.

B. ACCELERATED AGING.

The following procedures constitute the standard Army method for accelerated aging tests of ballistic materials. Each material is to be oven-heated (apparatus in accordance with test method 5850 of Federal Standards #191) for 116 hours at 71°C (160°F) and 65±5% RH. This is followed by weighing the material to the nearest ounce and recording the weight. The material is then totally immersed in water at a temperature of 70° ± 10°F for one hour. The material should not be folded to permit free entry of water to all surfaces. The saturated material should be re-weighed to the nearest ounce immediately after removal from the water and the weight recorded. While the material is still saturated with water it is frozen in a cold chamber (apparatus in accordance with test method 5874 of Federal Standards #191) for 50 hours at -32°C (-26°F). Then the material is allowed to defrost overnight under standard atmospheric conditions (ref: Section 4, Federal Standards #191). Ballistic tests are then conducted on the material.

Some modifications to this procedure were made because of the nature of the protective garment program. The materials were ballistically evaluated after each phase of exposure. That is, after heat and humidity exposure, test ballistically. The same for water immersion and freezing. In this way ballistic data were collected for each type of exposure. The ballistic evaluations performed after each exposure were compared with data collected from materials "as received." There was no significant difference in the strength of the material after accelerated aging tests and this was verified by ballistic testing.

C. SIMULATED PERSPIRATION.

A 7-ply Kevlar panel (8 oz/sq yd prepared from 400/2 ply yarn) was immersed for 2 hours at room temperature in a 3% salt solution. The panel was removed from the solution, wrung out by passage through squeeze rolls, placed in a sealed polyethylene bag, exposed to 100°F for 48 hours, and then air-dried. The ballistic retardant properties of the panel were tested, and no loss was noted.

D. EXPOSURE TO ULTRAVIOLET (SIMULATED SUNLIGHT) AND ACTUAL SUNLIGHT.

Single layers of 5 oz/sq yd 8 Harness Satin Kevlar 29 fabric weave were exposed to accelerated weathering using the carbon arc as a simulant. A two-layer piece of fabric was left outdoors for 3 months with one side facing up. Warp yarns were extracted from the fabrics and tested for tensile strength with the following results:

Type Exposure	Exposure	Yarn Strength *(lb pull to break)*	Strength Loss *(%)*
	0	14.2	0
Carbon Arc	17 hr	10.6	25
Carbon Arc	34 hr	4.5	67
Carbon Arc	68 hr	3.8	73
Carbon Arc	200 hr	0.9	95
Outdoor	3 mo	0.6	98

The results show that single layers of Kevlar fabric suffer serious strength losses when subjected to UV. However, the second layer of the panel exposed outdoors for three months retained 83% of its strength as contrasted with the 2% retained by the first layer.

The ballistic retardant properties of a panel of 32 layers of Kevlar 29 measured with the 1.7 grain fragment simulator showed no diminution even after 3 months of outdoor exposure.

Two 7-ply panels of the 8 oz/sq yd Kevlar 29 used for the law enforcement work were exposed in the carbon arc for 72 hours. One panel was also exposed to ozone in a chamber for 72 hours. There was no loss in the ballistic resistance of these panels to the .38 caliber and .22 caliber threats when compared to a control panel.

The results on ballistics tests do not alter the conclusion that, when possible, single ply Kevlar fabric should be protected from direct exposure to UV light because of mechanical strength losses.

E. LAUNDERING.

The 5 oz/sq yd 8 Harness Satin Kevlar 29 fabric available at Natick Development Center was overedge stitched and single plies were subjected to standard Army launderings. High phosphorus Dash, hot water (140°F maximum temperature), and 28-minute wash cycles were used. This was followed by a three-hour air-dry cycle (120°F).

The results obtained on yarn tensile tests are shown below.

	Strength		Strength Loss	
Cycles	Warp	Filling	Warp	Filling
	(lbs pull to break)			
0	12.4	15.3	0	0
1	13.6	15.5	+10%	0
5	12.4	14.7	0	-4%

These results show little or no damage. As expected, laundering of the same fabric in the same manner but adding 0.4% Chlorox resulted in a 28% loss in yarn tensile strength, and rose to 40% when the Chlorox concentration was raised to 0.8%. It was concluded that Chlorox or other bleaches degrade Kevlar material.

F. DRY CLEANING SOLVENTS.

To determine the effects of cleaning solvents on the material, it was immersed in the solvent for a specified time, allowed to dry, and evaluated ballistically. In addition, the material was examined to determine if the solvent had affected the weave or yarns (degradation). It was found that perchloraethylene was the only solvent that did not degrade the material or affect its ballistic retardant properties.

G. WET TESTING.

1. Complete immersion of test item. A 7-ply 400/2 denier Kevlar 29 vest was ballistically tested before being wet. Then the vest was weighed to the nearest ounce, totally immersed in 11 inches of water at a temperature of 70° ± 10°F for a specified time (2, 5 or 10 minutes), reweighed to the nearest ounce immediately after removal from water, and then ballistically tested.

2. Spray method. Materials tested were (a) a single layer of Kevlar, (b) multiple layers of Kevlar, or (c) a combination of two different materials, as a garment plus lining. The standard testing procedure using multiple layers with outer binding stitch was the spray method. Three specimens were tested from each sample of material received from the manufacturer.

A horizontal water spray from a nozzle that had 13 holes (0.0390 inch in diameter) was directed against the material which was placed at a right angle to the spray 24 inches from the nozzle. The material was ballistically evaluated immediately after spraying and was resprayed every 15 minutes during tests.

3. Water Repellent materials. Various materials with a water repellent finish were considered. However, for this specific time frame only two kinds of Kevlar were tested: 400/2 denier and 1000/1 time denier. They were treated as follows:

a. Scotch Guard type coating

b. Natick Finished (Phobotex coating)

c. DuPont Finish (Zepel D)

e. 2.5% Polymer coated

f. 5.3% Polymer coated

All of these materials were subjected to both water immersion and spray. In addition, the materials were stitched in some cases so only outer layers became wet and unstitched to provide wetting of all layers. Where time permitted clay blocks studies of deformation were conducted to compare with standard materials not subjected to water or water repellents.

4. Results of Ballistic tests. Results indicated that, water immersion affected the ballistic retardant effectiveness of the materials more than any other condition tested. As an example of how water affects the penetration characteristics of a bullet (.22 caliber) and a specific material (7-ply Kevlar 29, 400/2 denier), note Tables 12, 13, and 14. There were no complete penetrations of 400/2 denier Kevlar 29 at a velocity lower than 1047 fps, which is well above the guideline velocity of 1000 fps. When the same material was tested after water immersion, complete penetration occurred at a velocity as low as 850 fps, well below the guideline velocity of 1000 fps. When the same material was treated with duPont Zepel D water repellent and immersed in water, complete penetration did not occur under a velocity of 1076 fps, which is comparable to the results with the dry, unrepellent treated material.

H. CONCLUSIONS.

Table 15 is a summary of the tests conducted, the results, and the recommendations.

Table 12. .22 Caliber Bullet vs 7-Ply 400/2 Denier Kevlar 29, Tested Dry Condition (Gelatin Backed).

Velocity (fps)	Results
1148	CP - Missile in Gelatin Block
1050	CP - Missile in Gelatin Block
1027	PP - Missile in Last Ply
1010	PP - Missile in 3rd Ply
1004	PP - Missile in Last Ply
1033	PP - Missile in 1st Ply
1053	PP - Missile in Last Ply
1031	PP - Missile in Last Ply
1050	CP - Missile in Gelatin Block
1047	CP - Missile in Gelatin Block
978	PP - Missile in 2nd Ply
1047	CP - Missile in Gelatin Block
1017	PP - Missile in 2nd Ply

Table 13. .22 Caliber Bullet vs 7-Ply 400/2 Denier Kevlar 29, Immersed 10 Minutes, Drained 5 Minutes (Gelatin Backed).

Velocity (fps)	Time of Shot (hour)	Results
906	1011	PP - Missile in 1st Ply
969	1015	CP - Missile in Gelatin Block
876	1023	CP - Missile in Gelatin Block
853	1027	PP - Missile in 7th Ply
863	1032	CP - Missile in Gelatin Block
840	1036	PP - Missile in 2nd Ply
873	1040	PP - Missile in 7th Ply
909	1045	CP - Missile in Gelatin Block
902	1050	CP - Missile in Gelatin Block
850	1055	CP - Missile in Gelatin Block
863	1100	PP - Missile in 3rd Ply
866	1105	PP - Missile in 2nd Ply
945	1109	PP - Missile in 2nd Ply
948	1113	PP - Missile in Last Ply

Table 14. .22 Caliber Bullet, 40 Grain vs 400/2 Denier Kevlar 29, Zepel D Treated Only; Immersed in Water 5 Minutes; Time 1002-1104.

Velocity (fps)	Results
1179	CP - Missile in Gelatin Block
1128	CP - Missile in Gelatin Block
1106	CP - Missile in Gelatin Block
1076	CP - Missile in Gelatin Block
1031	PP - Missile in 2nd Ply
1056	PP - Missile in 3rd Ply
1067	PP - Missile in 3rd Ply
1079*	PP - Missile in 5th Ply
1086	CP - Missile in Gelatin Block
1091	CP - Missile in Gelatin Block
1076	PP - Missile in 4th Ply
1083*	PP - Missile in 5th Ply
1087*	PP - Missile in 5th Ply
1064*	PP - Missile in 5th Ply
1122	CP - Missile in Gelatin Block
1105	PP - Missile in 5th Ply
1133	CP - Missile in Gelatin Block
1152	PP - Missile in 6th Ply

*Missile stops in various plies, but the yarns are broken on the last ply.

Table 15. Kevlar Environmental Results.

ENVIRONMENT	EXPOSURE	TEST METHOD*	RESULTS/RECOMMENDATIONS
• CLEANING-WASHING AND DRYING	WASHING AND DRYING UNDER NORMAL CONDITIONS	MECHANICAL/BALLISTIC	DETERGENTS AND BLEACH DEGRADE FABRIC SEVERELY
			USE COLD WATER WOOLITE AND AIR DRY CYCLE
• CLEANING-DRY CLEANING	COMMERCIAL CLEANING PROCEDURE	MECHANICAL/BALLISTIC	ONLY PERCHLOROETHYLENE SOLVENT DID NOT DEGRADE FABRIC (double knits)
• SALT SPRAY	3% SALT SOLUTION 48 HOURS (simulate perspiration)	MECHANICAL/BALLISTIC	NO DEGRADATION TO FABRIC
•			
• OZONE AND ULTRAVIOLET	72 HOURS AT EXTREME CONDITIONS	MECHANICAL/BALLISTIC	NO DEGRADATION TO FABRIC
• HUMIDITY	100% RELATIVE HUMIDITY AT ROOM TEMP. FOR 48 HOURS	BALLISTIC	MINOR CAVITY DEGRADATION
• WATER IMMERSION	TOTAL IMMERSION ~10 MINUTES	BALLISTIC	SIGNIFICANT DEGRADATION, WATERPROOFING MAY BE REQUIRED

*MECHANICAL TEST: INSTRON TENSILE, CHARPY IMPACT

BALLISTIC TEST: .38 CAL. BULLET, .22 CAL. BULLET

CHAPTER VII. THE COPPER MAN STUDY

A. PURPOSE.

The purpose of this test is to determine how the uniform (protective) or undergarment will affect the wearer.

B. METHODOLOGY.

The copper manikin, developed by the US Army and used by the US Army Research Institute of Environmental Medicine, was constructed to the size of an average US Army infantryman; as such he wears standard (medium, regular) uniforms. The manikin is hollow; inside his "skin" are three electrical components (Figure 18):

1. Heating wires: to deliver heat to his copper skin.

2. Thermocouples: to measure the temperature at 19 representative sites on his skin.

3. A thermostat: to control the power delivered to the heaters.

In use, the desired skin temperature is maintained by delivering electrical power to the heating wires. If the number of watts of heat required to maintain a constant skin temperature is measured, this amount of heat must exactly equal the heat lost from the skin, or skin temperature would change. This heat loss is a direct measure of the insulation provided by clothing or equipment worn by the manikin. This technique is used to measure the insulation ("clo" index) of sleeping bags and cold weather or other uniforms in which the soldier does not usually sweat. If a cotton "skin" is used to cover the manikin and wetted, the extent to which a uniform interferes with evaporative cooling ("sweating") can be measured (impermeability index - i_m).

These two parameters, clo and i_m, which are measured on the manikin, completely describe how uniforms and equipment will affect the wearer, although adjustments are needed to allow for the cooling effects of wind and/or motion such as in walking.

Thus, the military clothing and equipment designers can be told how good or bad a new sleeping bag, uniform, or body armor is with regard to its effects on the body temperatures of the wearer. The clo and i_m values are also used to predict the tolerance time for troops during military operations in severe hot and cold environments.

C. SCOPE OF WORK PERFORMED.

The test procedure consists of using the Copper Man, with a cotton skin layer over the total area of the man. This skin layer is wetted down, the test garment is then placed over the man, and he is placed in a

Figure 18. Copper Man.

controlled environment, 81°F/50% RH, for approximately one-half hour to reach equilibrium. Nineteen sensor points in the Copper Man monitor the amount of electrical energy required to maintain a nominal skin temperature of 90°F.

The standard Army combat fatigue uniform has been used as the control for comparison testing of all protective garments.

The clo factor is the basic unit of measure. A normal business suit provides one clo unit. The other more important factor is the evaporative cooling permeability of the material or item.

D. UNIFORM AND ITEM DESCRIPTIONS.

1. Short sleeve uniform.

a. Shirt, Police, short sleeve, Miami P.D., collar open

b. Trousers, Police, polyester, summer weight

c. Cap, Police, open-weave

d. Police belt with holster (containing 1.5 kg weight), whistle, pen and pencil holder, double cartridge case, handcuffs

e. In trouser pockets: 12-inch billy, leather notebook, and flashlight with wand.

f. Cushion sole socks and combat boots (US Army items)

2. Long sleeve uniform. (Same as item 1 above, except components a, b, and c were as follows)

a. Shirt, Police, long sleeve, New York City P.D., collar buttoned, with tie.

b. Trousers, Police, polyester.

c. Cap, Police, closed weave.

3. S/N 012 undershirt vest. Natick Development Center design, 7 plies Kevlar 29, front opening, Velcro seal.

4. U-0024 undershirt vest. Aerospace Corporation design, side opening, 7 plies Kevlar 29.

5. Ballistic undershirt, over-the-head, side closure and adjustment, 7 plies Kevlar 29, 8 oz 400 denier 2 ply cloth; cotton outer cover, weight 1 lb 14 oz. (Similar in appearance to item 4 above, but slightly longer.)

6. Police Reefer Coat (Blauer) with integrated ballistic lining of 7 plies Kevlar 29, 8 oz 400 denier 2 ply cloth, weight 6 lb 6 oz.

7. Control item for 6 above, no ballistic lining.

8. Ballistic vest, front zipper closure, police blue nylon inner and outer coverings, ballistic lining of 7 plies Kevlar 29, 8 oz 400 denier 2 ply cloth, S/N 031, weight 2 lb 8 oz (LEAA Protective Vest).

9. Raincoat (London Fog), black with removable lining of 7 plies Kevlar 29, 8 oz 400 denier 2 ply cloth, weight 5 lb 7 oz.

10. Liner, insulating, nonballistic for item 9 above. Weight of raincoat plus liner 3 lb 3 oz.

11. Sportswear Ensemble, ballistic:

a. Shirt, Police, long sleeve, New York City P.D., collar buttoned, with tie.

b. Trousers, Police, polyester.

c. Sport coat (Screnci), blue with integrated ballistic lining of 7 plies Kevlar 29, 8 oz 400 denier 2 ply cloth, weight 3 lb 15 oz.

d. Cushion sole socks and combat boots (US Army items).

12. Same as 11 above, except sport coat had no ballistic lining.

E. <u>RESULTS OF TESTS</u>.

A summary of results and description of the ensembles studied are given in Table 16. Numbers in parentheses after the ensemble or item are keyed to the uniform and item description (Section D above).

1. The increases in insulation (clo) value with the Kevlar 29 layers were approximately the same as with other armor of similar thickness, i.e., the usual felt or nylon vest without ceramic plates. However, in general, the effects on the permeability index (i_m) of the Kevlar 29 ballistic layers were smaller than expected, based on the results with the various types of conventional body armor studied in the past. Furthermore, the reductions in i_m/clo ratio, which determine the maximal evaporative heat

loss and hence the tolerance time with heavy activity in a warm environment, are also much smaller than with other types of armor. Percentage changes in clo, i_m, and i_m/clo caused by Kevlar 29 layers in each ensemble studied are compared in Table 16 with those caused by adding body armor over the US utility fatigue uniform (including helmet liner).

2. No exact estimate of the effect of the ballistic raincoat is possible since the raincoat without liner was not measured. However, the i_m value with ballistic liner was no lower than when the insulating liner, which had an open, highly vapor permeable construction, was substituted. From this comparison, it is evident that the ballistic liner did not greatly hinder evaporative heat loss.

3. For comparing the police ensembles with more familiar military wear, the short-sleeve police uniform has the same clo and i_m values as a lightweight cotton coverall without headgear; it has slightly lower insulating value than utility fatigues without headgear (1.33 clo), but about the same i_m value. Adding an undershirt vest has less effect than including a helmet liner in the utility fatigue ensemble (1.45 clo, 0.42 i_m). The long-sleeve police uniform has clo and i_m values like utility fatigues without headgear (1.33 clo, 0.45 i_m) and an undershirt vest has about the same effect as adding a helmet liner (1.45 clo, 0.42 i_m). Adding the reefer coat provides a clo value slightly higher than winter underwear, heavy wool shirt and trousers and head protection, and an i_m value about 0.02 lower (1.82 clo, 0.35 i_m).

4. The importance of the increases in heat stress on an individual wearing LEAA ballistic protection of the type measured can be inferred from the manikin results by calculating the reductions in maximal heat dissipation which the armor would cause in typical environments. Such values will be only approximations since clo and i_m are altered by body movement; i.e., should be adjusted in accordance with the "pumping coefficient" for each ensemble. These coefficients can at present be obtained only through physiological measurements on active subjects. However, the coefficients and percentage changes in clo and i_m should be similar with and without the ballistic protection used in the present ensembles and the calculated <u>changes</u> in maximal heat dissipation with Kevlar 29 protection should be similar to the actual changes for an active man. These calculations reveal the following for three of the systems studied:

a. For the short-sleeve police uniform in a 90°F, 75% relative humidity environment, adding the U-0024 undershirt vest reduces maximal heat dissipation by about 30 watts out of a total of about 200 watts. This reduction would create no problem unless the wearer were continuously engaged in heavier than moderate activity, since he would otherwise not require maximal heat dissipation and could compensate for a 30-watt reduction by wetting 10% more of his skin area.

b. With the long-sleeve police uniform in an appropriate environment of 70°F, 50% RH adding the U-0024 vest reduces maximal dissipation by about 50 watts. However, the maximal dissipation with or without the vest totals above 350 watts, and this is much greater than required for very strenuous police duty. Of course, if this uniform were worn in a hotter, more humid environment, maximal dissipation would be reduced but the effect of the armor would also decrease proportionately. In this situation, the comments made regarding the short sleeve uniform would apply since the percentage changes in clo and i_m/clo produced by the U-0024 vest are about the same for either uniform (see Table 17).

c. With the long-sleeve uniform and reefer coat in a 50°F environment, the ballistic protection reduces maximal dissipation by only 16 watts out of a total of about 300 watts. This protection would not create any serious heat stress problem unless the wearer were exercising heavily or wearing the reefer coat in a much warmer environment.

5. Information is furnished that undershirt vest U-0024 under the police long-sleeve uniform blotted up (or condensed) 240 gm (8-1/2 oz) of water during a 6-hour period with the "skin" of the manikin maintained completely wet and at normal human skin temperature. This water uptake was about 25% of the dry vest weight.

Table 16. Study Results.

Ensemble	clo	i_m	i_m/clo
Short-sleeve uniform (1)	1.28	.46	.36
with 012 undershirt vest (3)	1.39	.43	.31
with U-0024 undershirt vest (4)	1.42	.43	.30
Long-sleeve uniform (2)	1.32	.44	.33
with U-0024 undershirt vest (4)	1.46	.41	.28
with Natick undershirt vest (5)	1.50	.44	.29
with reefer coat, ballistic (6)	2.02	.30	.15
with reefer coat, non-ballistic (7)	2.00	.33	.165
with ballistic vest (8) plus reefer coat, non-ballistic (7)	2.13	.30	.14
with raincoat, ballistic liner (9)	1.98	.41	.21
with raincoat, non-ballistic insulating liner (10)	2.04	.41	.20
Sportwear Ensemble			
with ballistic coat liner (11)	1.70	.42	.25
non-ballistic coat liner (12)	1.66	.43	.26

Table 17. Changes Resulting from Addition of Ballistic Protection (percentage of values for ensembles without ballistic protection).

Ballistic Item	clo	i_m	i_m/clo
SYSTEMS WITH KEVLAR 29 PROTECTION			
.012 undershirt vest	+8.6%	-6.5	-13.9
U-0024 undershirt vest			
with short-sleeve uniform	+10.9	-6.5	-15.7
with long-sleeve uniform	+10.6	-6.8	-15.7
Natick undershirt vest	+13.6	0	-12.0
Ballistic reefer lining	+1.0	-9.1	-10.0
Ballistic vest (under reefer coat)	+6.5	-9.1	-14.6
Ballistic raincoat liner	NA	NA	NA
Ballistic sport coat lining	+2.4	-2.3	-4.6
*PREVIOUSLY MEASURED BODY ARMOR (OVER FATIGUES)**			
Nylon felt vest, lightweight	+5.5	-16.7	-24.1
12-ply nylon vest	+6.9	-23.8	-27.6
Marine Corps armor, M-1955	+9.0	-11.9	-20.7
Felt vest, variable type without plates	+15.2	-11.9	-24.1

*From Tables of Best Available Values, USARIEM.

CHAPTER VIII. LOAD PROFILE ANALYSIS

A. PURPOSE.

The purpose of the analysis using the Load Profile Analyzer* was to obtain objective baseline data which can be used to improve design, fit, and acceptability of inconspicuous ballistic protective garments. The data are obtained from the loads imposed on a test subject doing simulated psychomotor tasks.

With this objective in mind, the Natick Body Armor group approached the problem applying their years of experience in the design of military fragment and small arms protective body armor. The skills of this group include pattern makers, clothing designers, cutting, stitching, selection of materials, human factors, and utilization of the Load Profile Magnitude Analyzer. Their combined experience and background was applied to the problem. The Army has in the past and is presently engaged in the development of a new family of body armor to protect against fragments using different weaves and weights of Kevlar 29. The methods of cutting, stitching, and fabrication were applied to the development of inconspicuous, lightweight, law enforcement body armor (see Appendix C).

The knowledge of anthropometrics, changes in body dimensions associated with body movement, articulation of materials, parameters of neck openings, arm hole (scye), torso front and back lengths, chest and waist circumferences, and soft seam technology were also applied.

B. DESCRIPTIONS OF BALLISTIC CLOTHING.

1. Ballistic Undergarment, Aerospace/Natick Development Center Over-the-Head Model.

This is an over-the-head style undergarment, which is a finalized version of the Aerospace/Natick model tested in July 1974. The item contains 7 plies of 2-ply/400 denier 8 oz/sq yd, Kevlar 29 ballistic cloth. It has split overlapping sides and two 1-inch wide Velcro adjustment tapes at each side, which can be loosened for donning and tightened and fastened to the front panel for adjustment after donning. The Velcro tapes are passed through metal loops which are fastened to the sides by means of 1-inch wide elastic web shapes. The undergarment has an outer cover of white woven fabric and front and back tails of knit T-shirt material for tucking into the trousers. All edges are bound with a white lightweight binding tape. Weight is approximately 1 lb 14 oz (Figure 19).

2. Class II - Ballistic Protective Outer Vest (Natick Development Center).

This vest was designed at Natick Development Center and is patterned after a commercial thermal insulator vest which is normally worn over the shirt and under the coat. The vest has a zipper front closure,

*The anatomical load distribution analyzer has been described by Barron et al.[7]

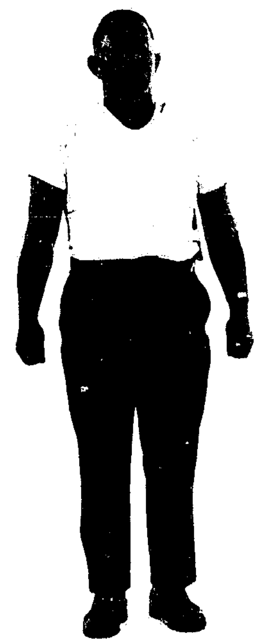


Figure 19. Ballistic Undergarment, Aerospace/Natick.

has no adjustment at the sides, and is longer in the back than the front. A lightweight nylon cloth covers the 7 plies of 2-ply/400 denier, 8 oz/sq yd Kevlar 29 ballistic cloth. The vest is police blue and weighs 2 lb 8 oz in the size large regular (Figure 20).

3. Raincoat (Natick Devlopment Center).

a. Raincoat with thermal liner. This is a commercial (LF) raincoat with a zip-in thermal liner. The raincoat is size 42 regular and weighs 3 lb 2 oz. The raincoat is of the water repellent, dress type.

b. Raincoat with ballistic liner. This is the same raincoat as in a above. The thermal liner was removed and replaced by a zip-in ballistic liner of 7 plies of Kevlar 29 2-ply/400 denier, 8 oz/sq yd cloth. The ballistic liner was designed to fit closer to the body to minimize "belling" of the coat. Weight of the ballistic raincoat is 5 lb 6 oz (Figure 21).

4. Ballistic undergarment, commercial model #NLPACE. This is a "sandwich board" type item with two panels, one front and one back, suspended at the shoulders by a 2-inch wide webbing and fastened together at the waist by 2-inch wide elastic webbing (two elastic straps per side). All straps are stitched into the back panel and fastened to the front panel with 2 x 3-inch Velcro tabs. The panels, each 12.5 inches wide and 14 inches long, consist of 18 plies of 14 oz ballistic nylon cloth. There is no means of adjusting any of the straps. Weight of this is 4 lb 6 oz (Figure 22).

5. Ballistic undergarment, commercial model #NLPABU. This is a "sandwich board" type item (over-the-head) consisting of two ballistic panels, one front and one back, inserted into a light blue cotton cloth carrier with "tails." The panels are made of 18 plies of 14 oz ballistic nylon and measure 14 x 16 inches each. There are two 1-1/2 inch wide elastic webs stitched into the back panel which fasten to the front by means of Velcro strips. There is little adjustment in the straps. Each weighs 4 lb 6 oz (Figure 23).

6. Ballistic undergarment, commercial model #NLPACA. This is an "over-the-head" undergarment consisting of two panels of 7 plies of Kevlar 29, 8 oz/sq yd cloth which fit into a white removable carrier. The carrier has 3 straps of 1-inch wide elastic webbing on each side. The straps are sewn to the back and attach to the front by means of two snap fasteners on each strap. The snaps provide an adjustment of about 1 inch on each side. No size is indicated on the garment. The carrier also has "tails" for tucking into the trousers. Weight is 2 lb 3 oz (Figure 24).

Figure 20. Ballistic Protective Outer Vest.

Figure 21. Raincoat with Ballistic or Thermal Liner.

Figure 22. Ballistic Undergarment NLPACE.

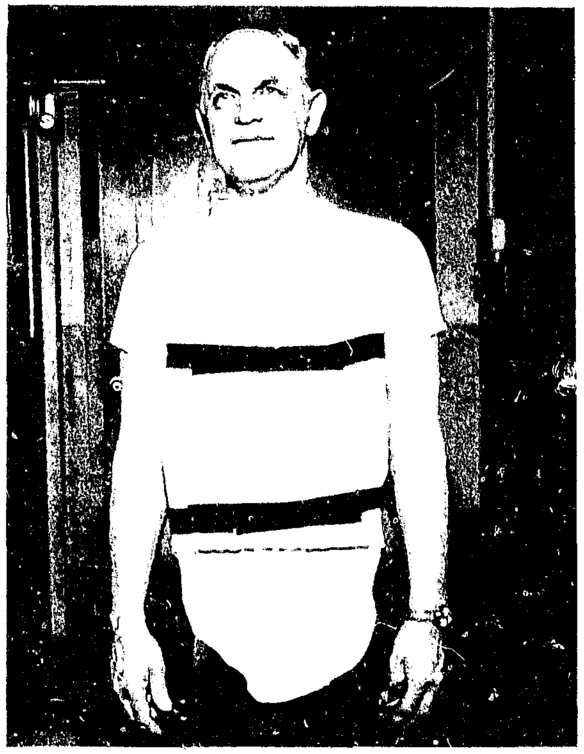


Figure 23. Ballistic Undergarment NLPABU.

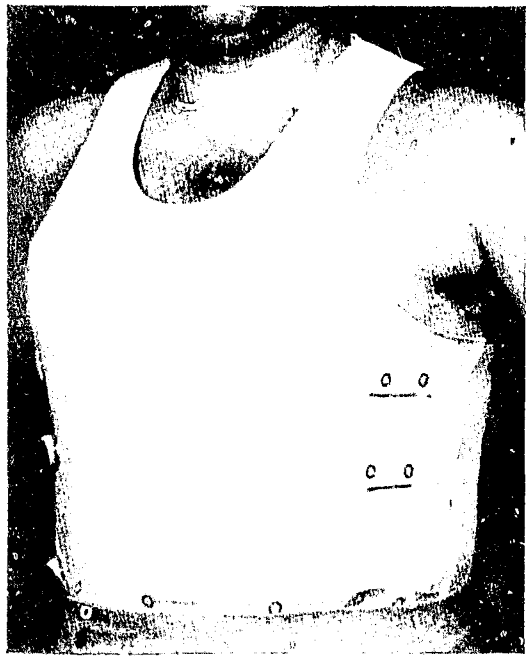


Figure 24. Ballistic Undergarment NLPACA.

7. Sport Jacket (Natick).

a. Commercial sport jacket. This is a commercial sport jacket (SC style 506) size 42 regular made by a custom clothing manufacturer. The cloth in the coat is 55% Dacron 45% Wool. Weight of the coat is 2 lb (Figure 25).

b. Ballistic sport jacket (Natick). This is the same jacket as in a above, except that a ballistic filler of 7 plies of Kevlar 29, 2-ply/400 denier 8 oz/sq yd cloth has been incorporated into it. This jacket also has a ballistic flap which, when pulled out into place, covers the chest area between the lapels. Weight of the ballistic jacket is 4 lb 2 oz for size regular (Figure 26).

8. Police Reefer Coat.

a. Commercial reefer coat (Police). This is a commercial police reefer coat with a built-in thermal lining (BL). Weight of the reefer is 3 lb 13 oz size 42 regular.

b. Ballistic reefer coat for Police (Natick). This is the same reefer coat as in a above, except that the thermal liner has been removed and a ballistic liner has been incorporated into it. The ballistic liner is made of 7 plies of 400 denier/2 ply, 8 oz/sq yd Kevlar 29 cloth. Weight of the ballistic reefer coat is 6 lb 1 oz (Figure 27).

9. Police Winter Jacket (Natick).

This garment, as with the reefer coat, had its thermal lining replaced with 7 plies of 400/2 denier Kevlar 29 material (Figure 28).

C. ANATOMICAL LOAD PROFILE ANALYSIS.

Anatomical load profile analysis was conducted on most of the protective garments developed for this program. Comparisons were also made of outer garments of similar types but without ballistic Kevlar liners to obtain control measurements. Figure 29 gives an outline of the way the Anatomical Load Distribution Analyzer operates. Each of the bar graphs in Figures 30-35 gives characteristic load profiles of compared garments in various zones of the body covered by the ballistic Kevlar material.

D. CONCLUSION.

Based on the load analysis studies, the Army is now able to provide specifications and patterns for field evaluation. In order to support the LEAA/Aerospace procurement of a large quantity of ballistic undershirts (or undergarments) Natick graded patterns for an 8-size system: size small (34-38 inch chest); medium (38-42 inch); large (42-46 inch); and extra

large (46-48 inch), in regular and long. These will be furnished to the selected contractors. Limited Purchase, Purchase Descriptions for the undershirts, which describe all materials, fabrication methods, and quality control were also prepared by Natick Development Center. These patterns and purchase descriptions will be available to industry and all Law Enforcement Agencies through LEAA's Technology Transfer Program at a later date. See Appendix C for the Natick Preamble on garment design and fabrication. Appendix D gives the purchase description.

The prototype protective garments (undershirts, zipper front vests, police-type reefer coats, raincoats, sport jackets, and golf jackets) designed and developed to date by Natick, in conjunction with the overall ballistic/trauma data developed by Edgewood Arsenal, demonstrate the technical feasibility and LEAA objectives that inconspicuous, lightweight, ballistic protective garments can be manufactured and will be acceptable for use by Law Enforcement Agencies, thereby reducing casualty rates of law enforcement personnel.

As a result of this overall effort and "exposure" of this significant development, many Federal government and local law enforcement agencies have indicated strong interest in the use of these types of garments in their activities. Several have already obtained from the US Army specific types of garments for their field evaluations. As the demand increases for larger quantities of particular garments, prototypes, patterns, and purchase descriptions can be prepared by Natick Development Center.

Figure 25. Sport Coat.

Figure 26. Ballistic Sport Coat with Ballistic Flap in Place.

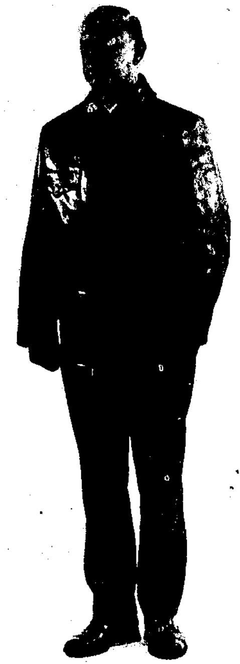


Figure 27. Police Reefer Coat with Ballistic Liner.

Figure 28. Police Winter Jacket with Ballistic Liner.

- **ARMY NATICK LABORATORIES CAPABILITY (equipment has patent pending)**
- **INSTRUMENT TO EVALUATE AND IMPROVE THE DESIGN OF PROTECTIVE GARMENTS**
- **CAPABLE OF MEASURING AND DISPLAYING**
  - **PRESSURE**
  - **PRESSURE CHANGES**
  - **LOAD MAGNITUDE**
  - **DISTRIBUTION OF FORCES TRANSMITTED TO THE TORSO BY THE GARMENT**
- **CONSISTS OF:**
  - **248 MINIATURE LOAD SENSORS**
  - **"3D" UNIT TO VISUALLY DISPLAY LOADS**

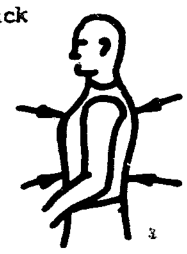
Figure 29. Anatomical Load Distribution Analyzer.

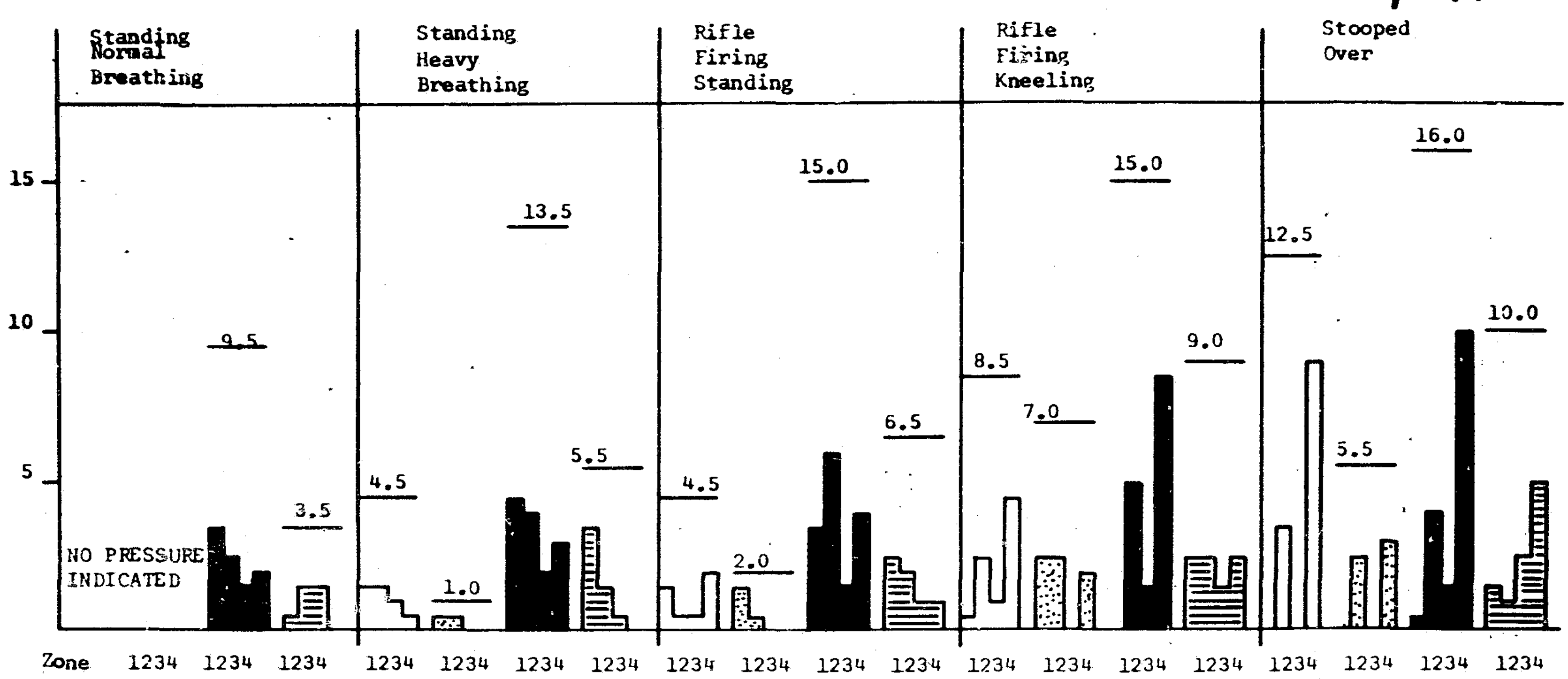
U. S. Army Natick Laboratories, Natick, Massachusetts November, 1974

LOAD PROFILE ANALYSIS - COMMERCIAL BALLISTIC PROTECTIVE UNDERSHIRTS AND AEROSPACE/NLABS BALLISTIC UNDERSHIRTS.

AEROSPACE/NLABS
NLPACA
NLPACE
NLPABU

Zone 1 - Upper Front
Zone 2 - Lower Front
Zone 3 - Upper Back
Zone 4 - Lower Back





(Note: In Figures 30-35 the underlined numbers are the totals of the pressure points (lb/sq in) on the four zones.)

U. S. Army Natick Laboratories, Natick, Massachusetts November, 1974

LOAD PROFILE ANALYSIS - COMMERCIAL BALLISTIC PROTECTIVE UNDERSHIRTS AND AEROSPACE/NLABS BALLISTIC UNDERSHIRTS

AEROSPACE/NLABS

NLPACA

NLPACE

NLPABU

Zone 1 - Upper Front
Zone 2 - Lower Front

Zone 3 - Upper Back
Zone 4 - Lower Back

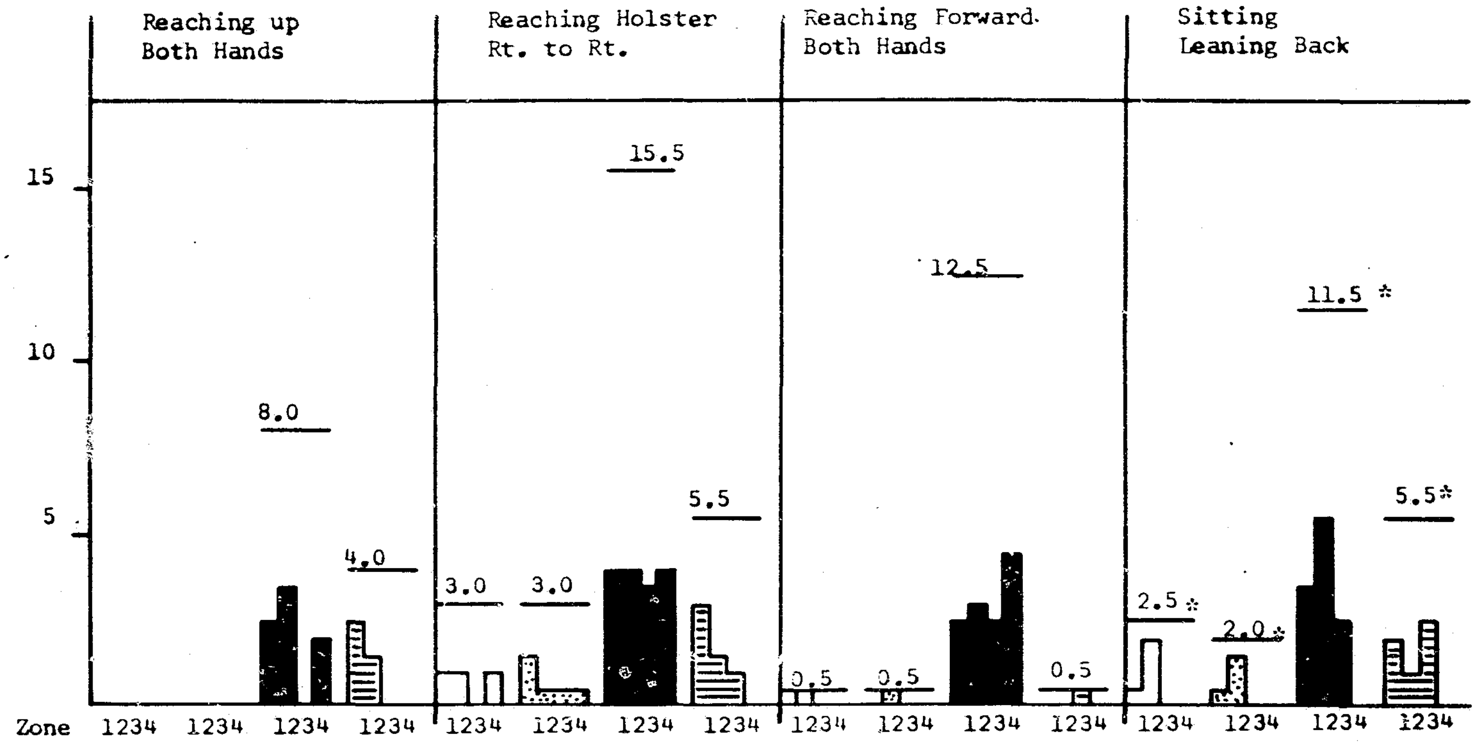


Figure 31

* Zone 4 (Lower Back) not included

U. S. Army Natick Laboratories, Natick, Massachusetts November, 1974

LOAD PROFILE ANALYSIS - EXPERIMENTAL BALLISTIC UNDERSHIRT FOR LAW ENFORCEMENT PERSONNEL - KEVLAR-29, 400 D. 2 PLY, 8 OZ./SQ. YD. CLOTH, 7 LAYERS.

UNDERSHIRT, OVER-THE-HEAD, MODIFIED, ORIGINAL MODEL FURNISHED BY AEROSPACE CORPORATION

UNDERSHIRT, OVER-THE-HEAD, SIDE ADJUSTMENT, AEROSPACE/NLABS FINAL MODEL.

Zone 1 - Upper Front
Zone 2 - Lower Front

Zone 3 - Upper Back
Zone 4 - Lower Back

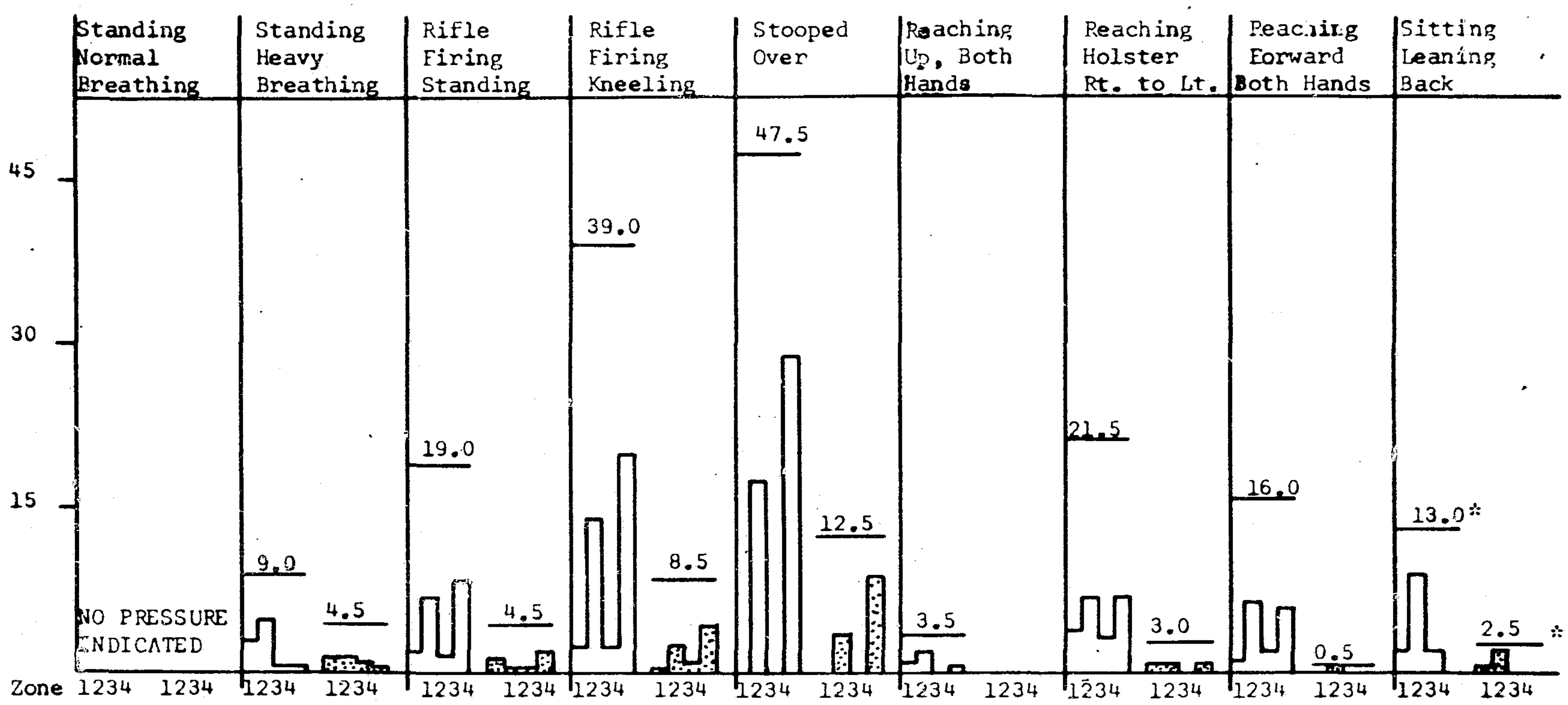


Figure 32

*Zone 4 (Lower Back) not included.

U. S. Army Natick Laboratories, Natick Massachusetts — November, 1974

LOAD PROFILE ANALYSIS - EXPERIMENTAL BALLISTIC POLICE REEFER COAT

BLAUER REEFER COAT w/INTEGRATED THERMAL LINING (CONTROL) - Wt. 3 lbs. 13. oz.

BLAUER REEFER COAT w/INTEGRATED NLABS BALLISTIC LINER - Wt. 6 lbs. 1 oz.
LINER IS OF KEVLAR-29, 400 D. 2 ply, 8 oz./sq. yd cloth - 7 layers.

Zone 1 - Upper Front
Zone 2 - Lower Front
Zone 3 - Upper Back
Zone 4 - Lower Back

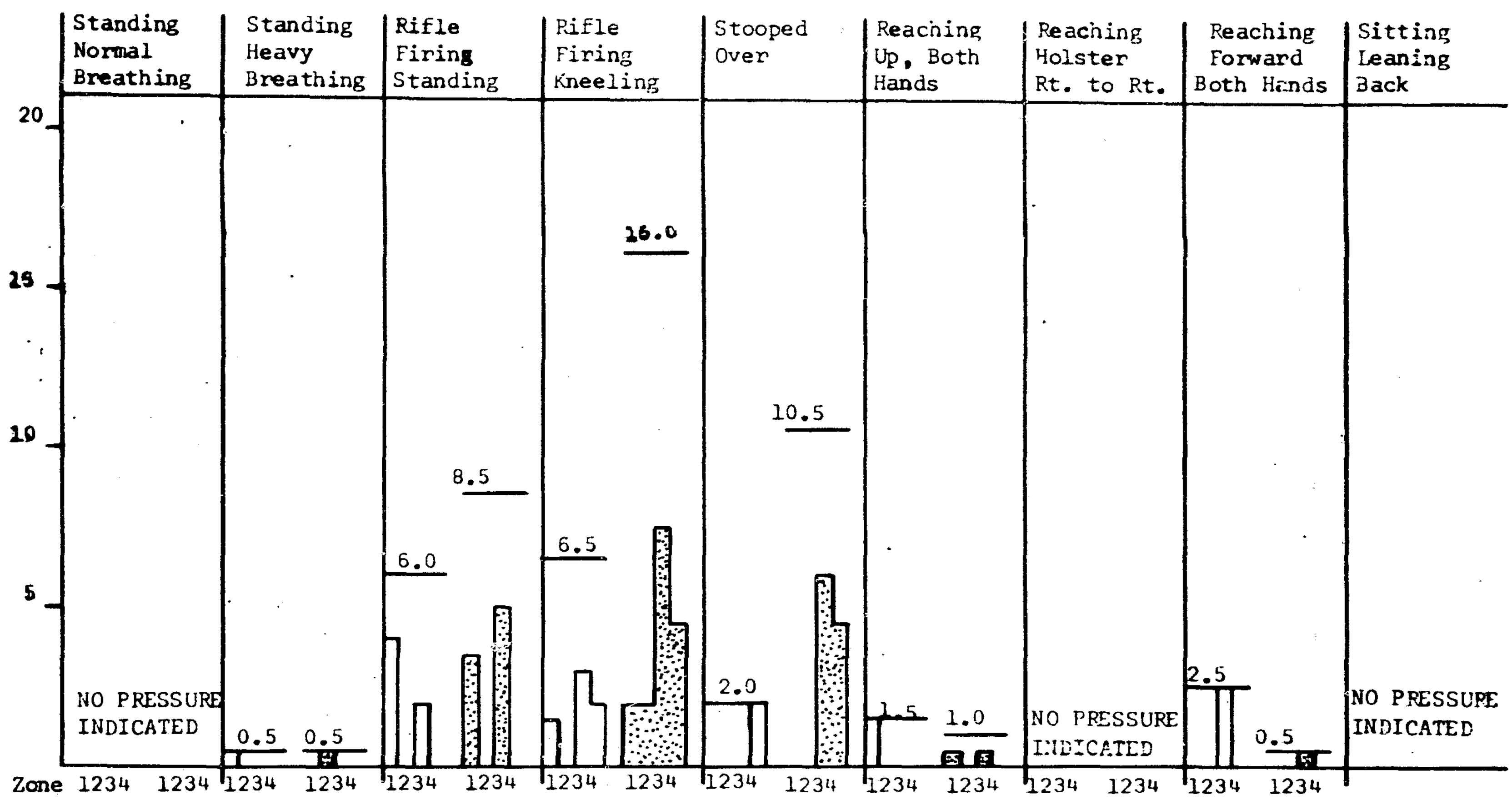


Figure 33

U. S. Army Natick Laboratories, Natick, Massachusetts — November, 1974

LOAD PROFILE ANALYSIS - EXPERIMENTAL BALLISTIC DRESS SPORT COAT FOR LAW ENFORCEMENT PERSONNEL

SCRENCI SPORT COAT - 55% DACRON - 45% WOOL (CONTROL) - Wt. 2 lbs.

SCRENCI SPORT COAT w/INTEGRATED NLABS BALLISTIC LINER AND BIB - Wt.4 lbs. 2 oz.
LINER IS OF KEVLAR-29, 400 D. 2 ply, 8 oz./ sq. yd. cloth - 7 layers.

Zone 1 - Upper Front
Zone 2 - Lower Front
Zone 3 - Upper Back
Zone 4 - Lower Back

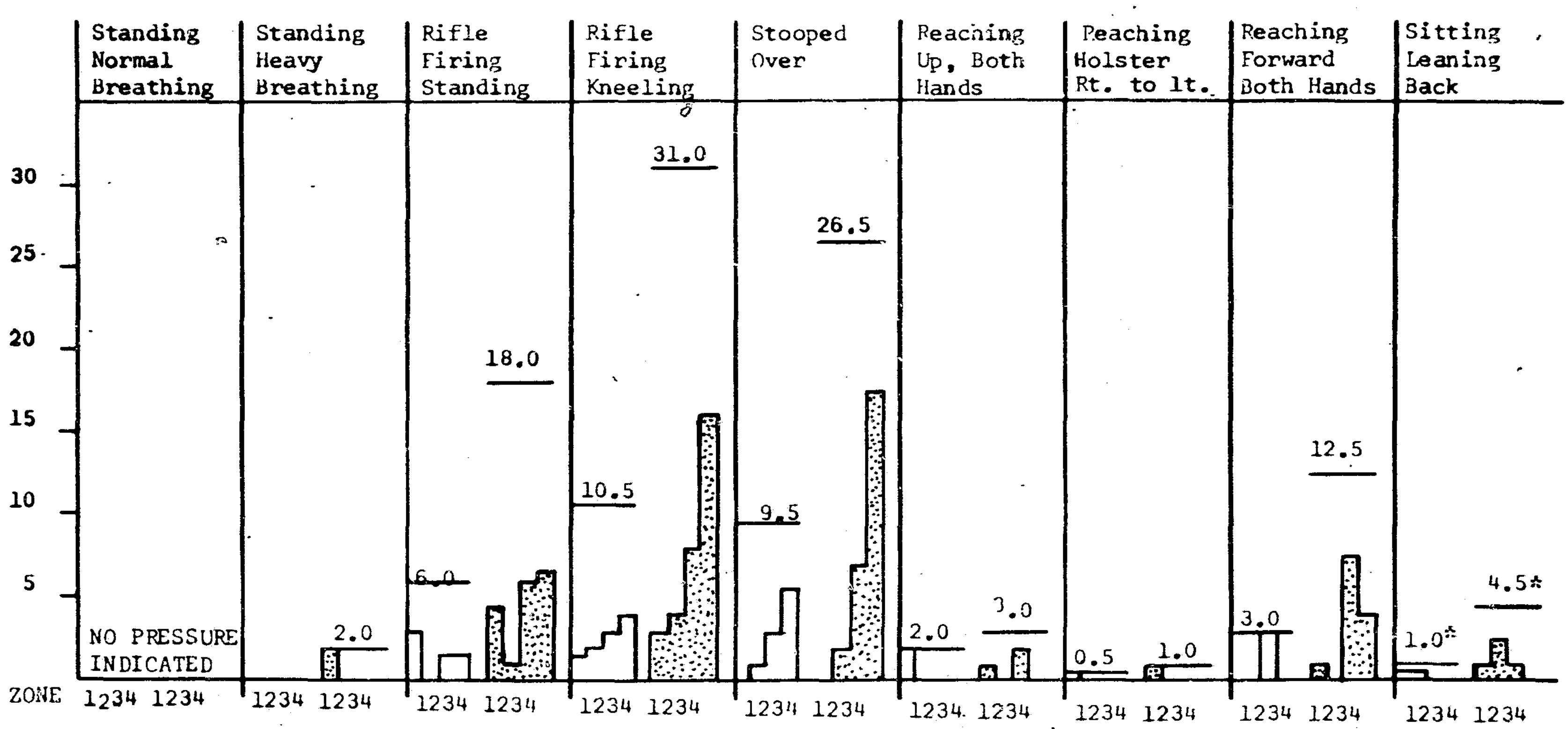


Figure 34

*Zone 4 (Lower Back) not included

U. S. Army Natick Laboratories, Natick, Massachusetts November, 1974

LOAD PROFILE ANALYSIS - EXPERIMENTAL BALLISTIC RAINCOAT FOR LAW ENFORCEMENT PERSONNEL

BALLISTIC ZIP-OUT LINER - KEVLAR-29, 400 D. 2 ply, 8 oz./sq. yd. cloth - 7 layers.

☐ LONDON FOG "DANTON" RAINCOAT w/THERMAL LINER (CONTROL) - Wt. 3 lbs. 2 oz. - Size 42 P.

☐ LONDON FOG "DANTON" RAINCOAT w/ZIP-OUT NLABS BALLISTIC LINER - Wt. 5 lbs. 6 oz. - Size 42 R.

Zone 1 - Upper Front Zone 3 - Upper Back

Zone 2 - Lower Front Zone 4 - Lower Back

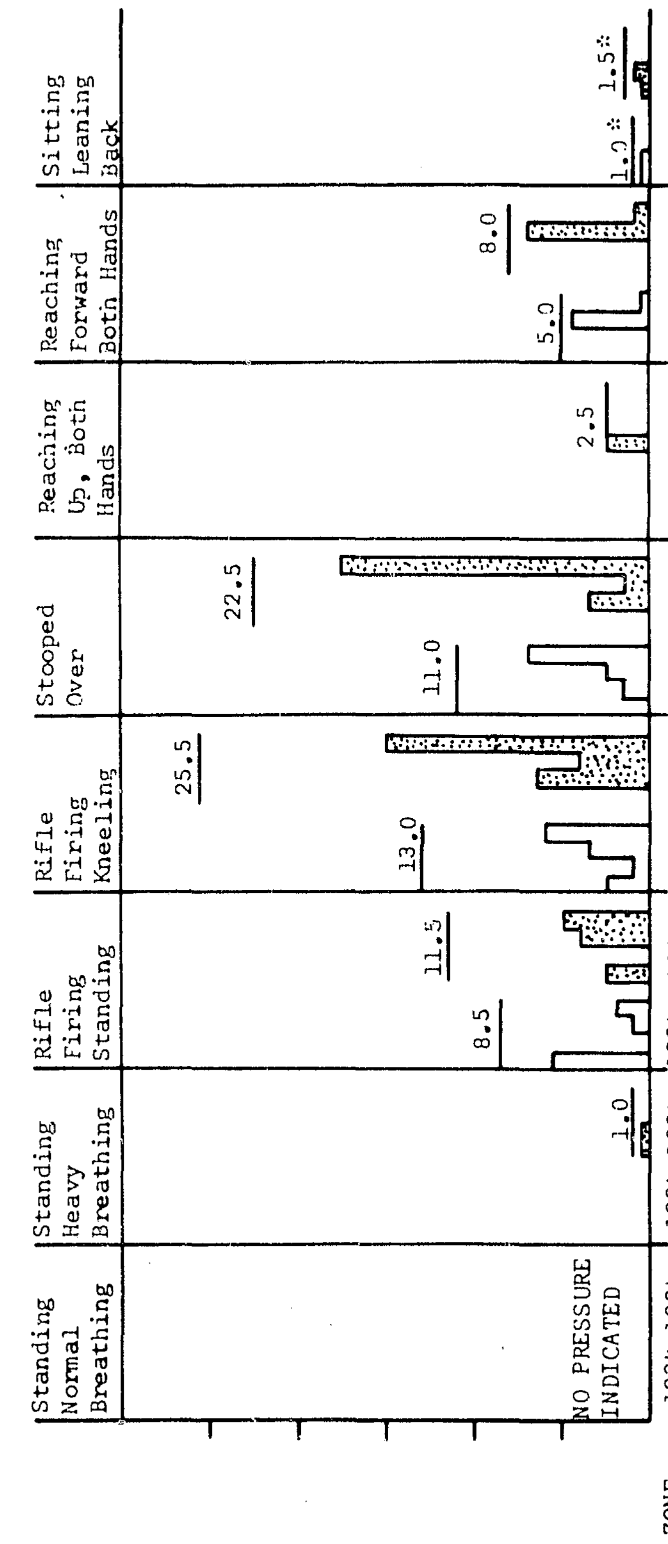


Figure 35

*Zone 4 (Lower Back) not included

CHAPTER IX. KNIFE THREAT*

A. PURPOSE.

During the course of the program test design, a subtask was included to determine the protective capabilities of the garment against a knife. Two specific objectives of this subtask were to determine the pressure (energy) of a knife assault and to experimentally deliver the load to the candidate armor material.

B. METHODOLOGY.

At the start of the Soft Body Armor Program little information was available on the physical parameters which could be used to characterize a knife assault; in particular, determinations had to be made of the type of weapon most frequently encountered and the mass-velocity relationship for the attack. Furthermore, a standard launch system had to be designed which would deliver the designated threat at a precisely determined velocity and angle of attack.

1. Weapon system. By using the criteria of frequency of occurrence, availability, and threat severity, the following three types of knives were defined by the National Bureau of Standards: 4-inch switchblade; 10-inch butcher knife; and icepick. Preliminary tests on Kevlar material had indicated that the icepick would not be defeated by the garment as designed (7-ply 400/2 denier Kevlar 29). In the tests conducted to develop a suitable launch system, data had been collected with the M-16, 300-gram bayonet, which is a double-edged cutting mechanism. This weapon was substituted for the icepick (Figure 36).

2. Method of Delivery. A number of methods for launching the knife with the desired precision and stability were investigated, e.g., a spring-loaded arm, ballistic propulsion, etc. It was decided that a drop test would be the simplest and most inexpensive way to propel the weapon with controlled velocity and stability at impact. While a drop test fails to simulate the angular aspect of a knife thrust, the design angle of attack of 0° obliquity allowed use of the drop test as a somewhat conservative estimate for the candidate armor materials' resistance to a knife assault.

The drop system consisted of a 2-3/4 inch diameter, 19-foot long pipe erected in an indoor vertical range. The weapon used for the particular assault was mounted in a 2-5/8 inch diameter, 12-inch long polyethylene cylinder (Figure 37) which was hollowed out to permit variation in striking mass by the addition or subtraction of lead weights. The polyethylene cylinder also acted as a guide to keep the weapon stable and minimize the friction while traveling down the drop tube.

*A detailed report of this study is being prepared by Prather et al.[8]

CONTINUED

1 OF 2

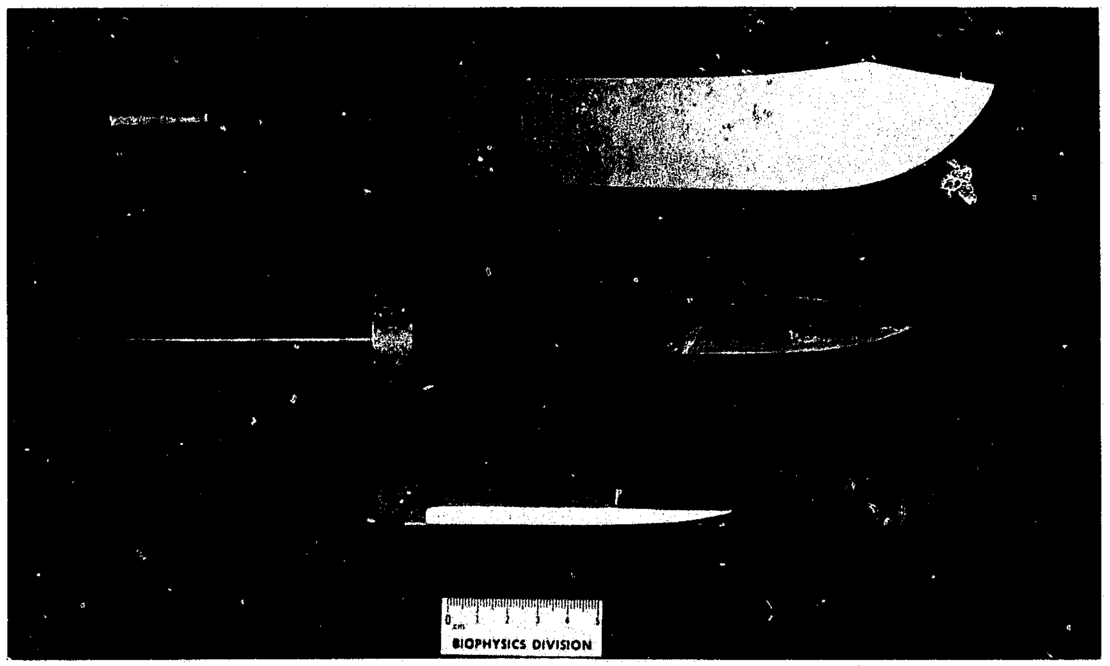


Figure 36. 10-Inch Butcher Knife, Bayonet, 4-Inch Switchblade.

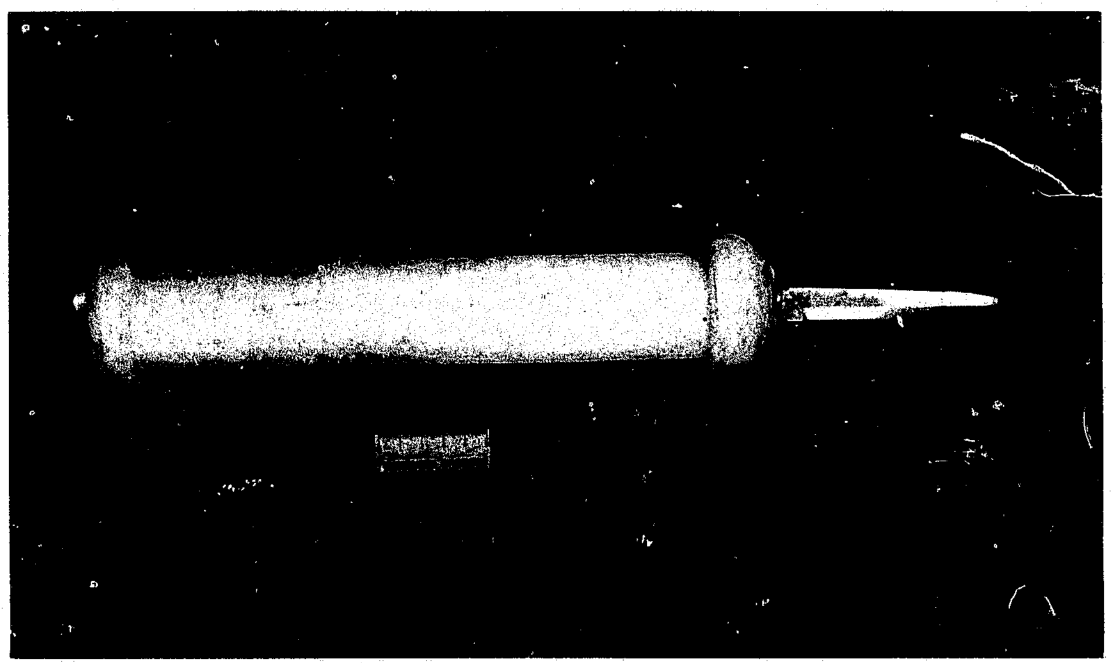


Figure 37. Polyethylene Mount.

3. Physical Characteristics of Knife Assaults. In order to define the mass-velocity relationship expected in a knife assault so that controlled tests could be conducted in a laboratory environment, the following procedures were used:

A number of volunteers selected from among laboratory personnel thrust the M-16, 300-gm bayonet into blocks of gelatin either underhand or overhand. From high-speed photographs of this exercise, thrust velocities and depths of penetration into the gelatin were determined. For underhand thrusts, a penetration of 14.3 cm and a velocity of 6.11 mps were found. For overhand thrusts, the values were 17 cm and 14.2 mps, respectively.

Using the drop system, the bayonet, under a fixed mass of 1.18 kg, was launched into gelatin over a range of heights to establish the energy-depth of penetration relationships. Approximate impact velocities, V, were calculated according to the formula

$$V^2 = 2\ gh$$

where

g is the gravitation constant
h is the height

Precise impact velocities were determined by analyzing high-speed photographs taken of the missile just prior to impact. Figures 38 and 39 show the relationships established for the underhand and overhand thrusts.*

By applying the data on depth of penetration and velocity obtained in the volunteer studies to the curves (Figures 38 and 39) obtained from the drop tests with a fixed mass, the masses required to achieve the striking energy levels a human would be capable of were calculated. They were 1.48 kg for underhand assaults and 1.09 kg for overhand assaults. These masses times the velocities obtained in the volunteer studies would result in the following striking energies: underhand, 27 joules; overhand, 110 joules.

The tube used in the drop tests was not long enough to achieve a velocity of 14.2 mps (overhand thrusts). However, increasing the test mass to 2.02 kg and reducing the velocity to 10.4 mps (the maximum achievable in the tube) would produce the same striking energy level (110 joules).

The weapons, supplemented with various weights, were then launched over a range of velocities to determine the energy required to penetrate 7 plies of 400/2 denier Kevlar 29. In some tests the material was clamped over the gelatin test block; in others it was laid loosely over the block.

*Twenty percent gel was used to establish the underhand thrust relationship; however, 40% gel was used for the overhand tests because the studies with humans had shown that not enough resistance was afforded by the 20% gel to keep the bayonet from completely penetrating the block when they made overhand thrusts.

C. RESULTS.

To date, only the bayonet has been tested against Kevlar for underhand assaults. The weapon plus weights to bring it up to the 1.48 kg mass established as described began to penetrate the unclamped material at a velocity of 8.9 mps (59 joules). Clamping the material lowered the velocity necessary for penetration to 7.8 mps (45 joules).

The bayonet, switchblade, and butcher knife have been tested for overhand assaults against unclamped Kevlar. Using the 2.02 kg test mass, the butcher knife bent at impact but did not penetrate the material at a striking energy of 91 joules. The bayonet began to penetrate at an energy level of 61 joules (7.8 mps). The switchblade penetrated the armor at an energy level of 22.2 joules (4.7 mps).

D. COMMENT.

This study is not yet complete and no conclusions can be drawn. It does appear that 7 plies of 400/2 denier Kevlar 29 will not protect against overhand assaults, but may protect against underhand assaults with the weapons tested.

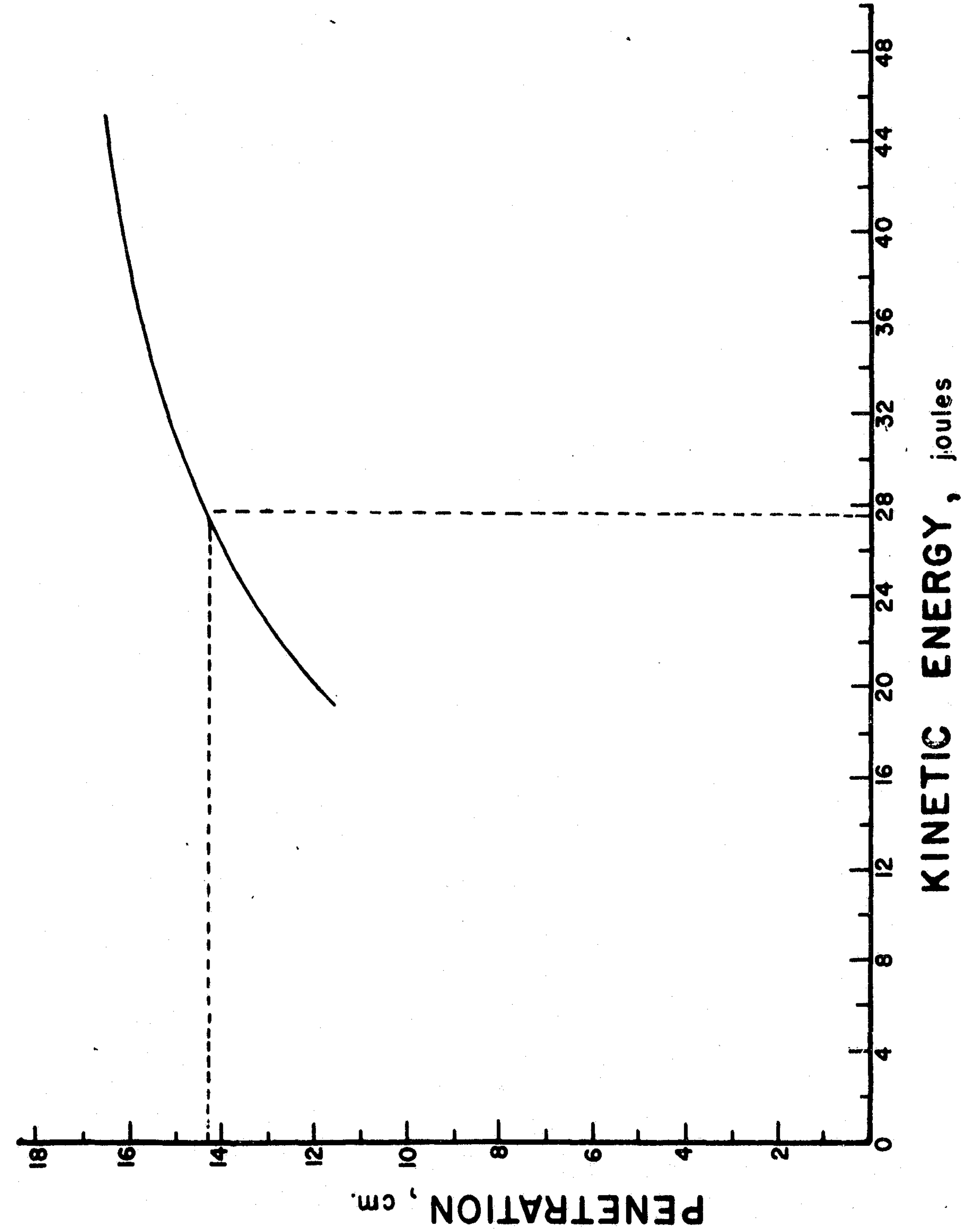


Figure 38. Underhand Thrust Relationship. 20% Gel.

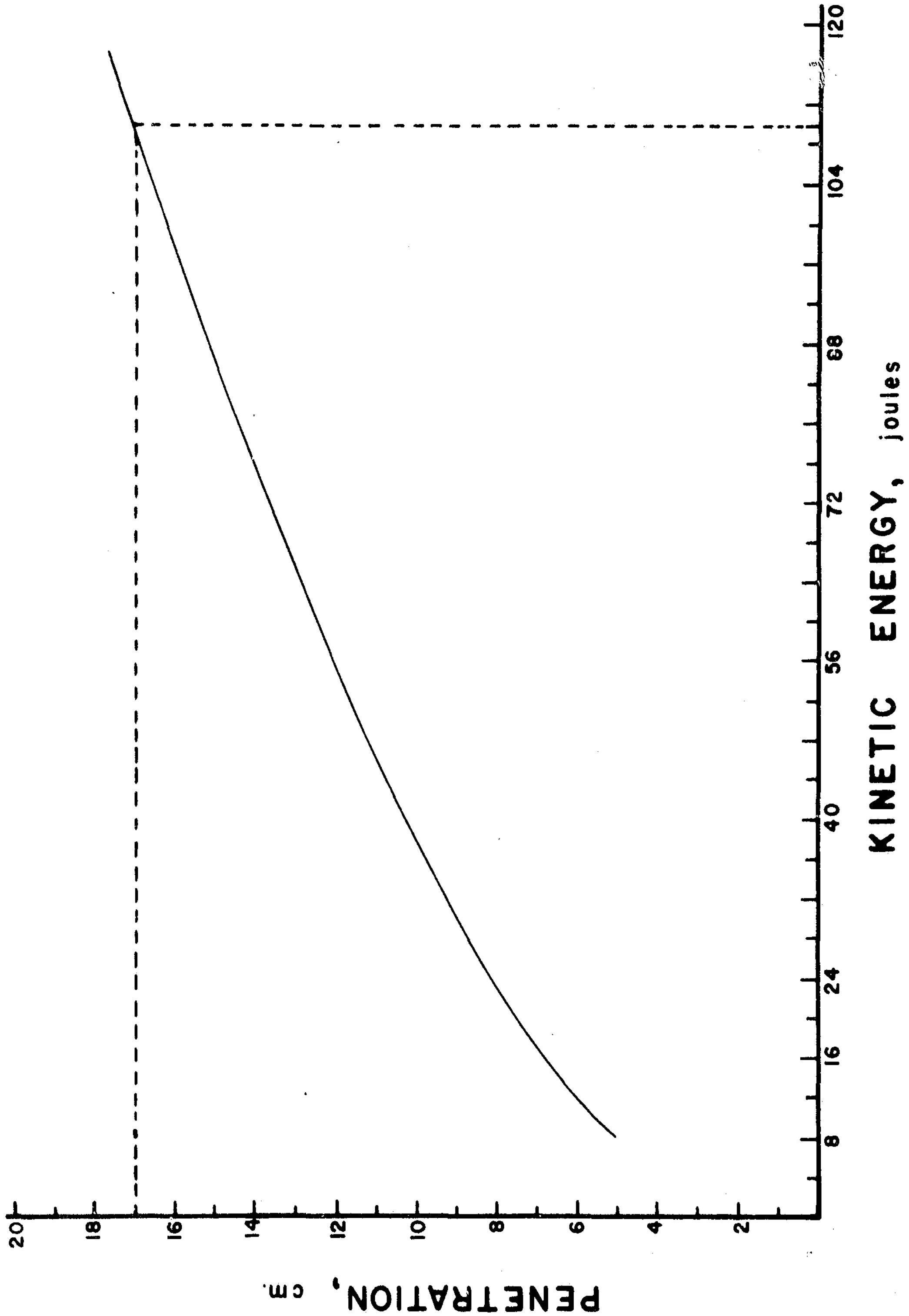


Figure 39. Overhand Thrust Relationship. 40% Gel.

CHAPTER X. RECOMMENDATIONS

Data from the FBI "Uniform Crime Reports" 1964-73 indicate an increase in the caliber of handguns used against law enforcement officers. It is recommended that the present investigation of inconspicuous, soft body armor be extended to develop a garment that will defeat the .45 caliber and .357 magnum threats (Appendix B).

It is recommended that the .44 magnum not be considered a threat at the present time because of the following:

1. FBI data do not indicate a substantial threat to law enforcement officers from the .44 magnum.

2. The .44 magnum FMJ bullet energy would still cause lethal damage if the bullet were stopped by the soft body armor. At least 20 layers of 400/2 denier Kevlar 29 would be required to protect against the .44 magnum and this would make the garment conspicuous.

3. The .44 magnum is a large weapon and not easily concealed.

4. Cost and availability of the .44 magnum make it less sought after by criminals.

5. Aiming the second shot from the .44 magnum is difficult because of the reaction time needed for a quick and accurately placed shot after the first round has been fired.

The backface signature parameters cannot be used to evaluate the effectiveness of protective armor until these physical measures are related to the probability that a particular combination would result in a serious or lethal injury. A predictive model relating the physical measures of the backface signature to the physiological effects, particularly in the nonlethal area, would greatly reduce the cost of armor evaluations. At this time, only a limited data base is available, and it is insufficient for developing an overall vulnerability model.

Backface signature work has also indicated that different combinations of soft armor materials may exhibit different dose-response relationships. Various armor materials which are commercially available should be evaluated.

By increasing the data base from which to draw conclusions, the goal of an overall vulnerability model for predicting the effectiveness of soft armor materials could be reached.

It is recommended that, at the successful completion of the field test and evaluation of the soft body armor, patterns for the garments be provided to industry for civil law enforcement use and to the General Services Administration for federal agency procurement.

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APPENDIX A

KEVLAR 29 - PHYSICAL PROPERTIES, MATERIALS TESTING, AND SPECIFICATIONS

A. PURPOSE.

Because of recent release of Kevlar 29 material to the commercial market, this appendix is intended to familiarize potential users of this material with its basic physical properties and the specifications that were used to order 400/2 denier Kevlar 29 ballistic material.

B. PHYSICAL PROPERTIES OF KEVLAR 29 YARN AND MATERIAL.

1. Warp. 400 denier, 267 filaments, 2-ply, 4-twist/inch, Z direction for both longitudinal and filling.

2. Weave. Plain

3. Ends/inch. 38 ± 2

4. Picks/inch. 38 ± 2

5. Weight in ounces/square yard. 7.45 ± 0.25 ounces

6. Method. After fabric is woven, it is scoured, rinsed, and dried.

7. Width. 38.25 or 48.0 inches

8. Thickness. Approximately .015 inch

9. Current Cost. Approximately $10-15/pound for 400 denier

C. PHYSICAL PROPERTIES OF KEVLAR 29 YARN.

1. Density. 1.45 g/cc. 40% lower than glass and boron and slightly lower than graphite.

2. Tensile Strength. 400,000 psi. Substantially above conventional organic fibers and equivalent to most high performance reinforcing fibers.

3. Specific Tensile. 8×10^6 inch. Highest of any commerically available reinforcing fiber.

4. Modulus. 19×10^6 psi. Twice that of glass fibers.

5. Specific Modulus. 3.5×10^8 inch. Between that of the high modulus graphites and boron and that of glass fibers.

6. Chemical Resistance. Good. Highly resistant to organic solvents, fuels, and lubricants.

7. Textile Processibility. Excellent. Can be readily woven on conventional fabric looms. Yarns retain 90% of their tensile strength after weaving. Can be easily handled on conventional filament winding equipment.

8. Flammability Characteristics. Excellent. Inherently flame resistant. Self-extinguishing when flame source is removed. Does not melt.

9. Temperature Resistance. Excellent. No degradation of yarn properties in short-term exposures up to temperatures of 500°F.

D. QUESTIONS AND ANSWERS ABOUT KEVLAR 29.

1. What is Kevlar 29? Kevlar 29 is a new organic fiber from duPont and has been classified as an "Aramid" (Aeromatic Polyamides).

2. How i Kevlar 29 sold? Available in yarns, rovings, or woven fabrics.

3. What are the key characteristics of Kevlar 29? High strength, high modulus, low elongation, lightweight, and ease of processibility.

4. What are the main uses? Tire cord, lightweight body armor, tension cables, reinforcement for plastic composites, and other specialty industrial uses.

5. What is the price? Currently the price of Kevlar 29 ranges from $7 to $20 per pound dependent on denier and quantity.

6. Is Kevlar 29 material available in commercial quantity? Large deniers such as 1000 and 1500 are available off the shelf; however, 400/2 denier material required at least four weeks advance notice before delivery of the yarn.

7. What is the current production of Kevlar? A plant that produces 6 million pounds per year is presently operating. However, a plant that will produce 50 million pounds per year is now under construction.

E. YARN PROPERTIES AND COMPARSION WITH OTHER MATERIALS (FIGURES A-I, A-II, AND A-III).

	Kevlar	T-68 Dacron	T-728 Nylon	Rayon	Wire	Glass
Specific gravity	1.45	1.38	1.14	1.52	8.0	2.5
Denier	1500/ 1000/400	1300/1000	1260/840	-	-	-
Tenacity, GPD	20-22	9.2	9.8	4.1	3.9	9.6
Elongation @ break, %	3.6	15	19	17	1.1	3.1
Initial modulus, GPD	480	115	50	110	200	250
Loop tenacity, GPD	12	6.3	6.8	-	-	-
Loop elongation @ break, %	2	9	12	-	-	-
Shrinkage	0	11.0	7.2	0	0	0
Melt Point, °F	>800*	482	482	-	-	-
(*Charrs)						

F. KEVLAR PROPERTIES AT ARCTIC TEMPERATURES.

	Dipped Cord (6.5 TM) 75°F	-50°F
Tenacity, GPD	19.1	19.8
Elongation, %	4.1	3.9
Modulus, GPD	425	521
Loop tenacity, GPD	8.3	7.7
Loop elongation, %	2.0	1.8

G. DISCUSSION OF KEVLAR MATERIAL.

Four Kevlar material yarns as noted below were investigated by US Army laboratories:

1. 200 denier, 134 filament, R-80 untwisted, type 964 Kevlar 29 yarn.

2. 400 denier, 267 filament, R-80 untwisted, type 964 Kevlar 29 yarn.

EFFECT OF TEMPERATURE ON TENACITY

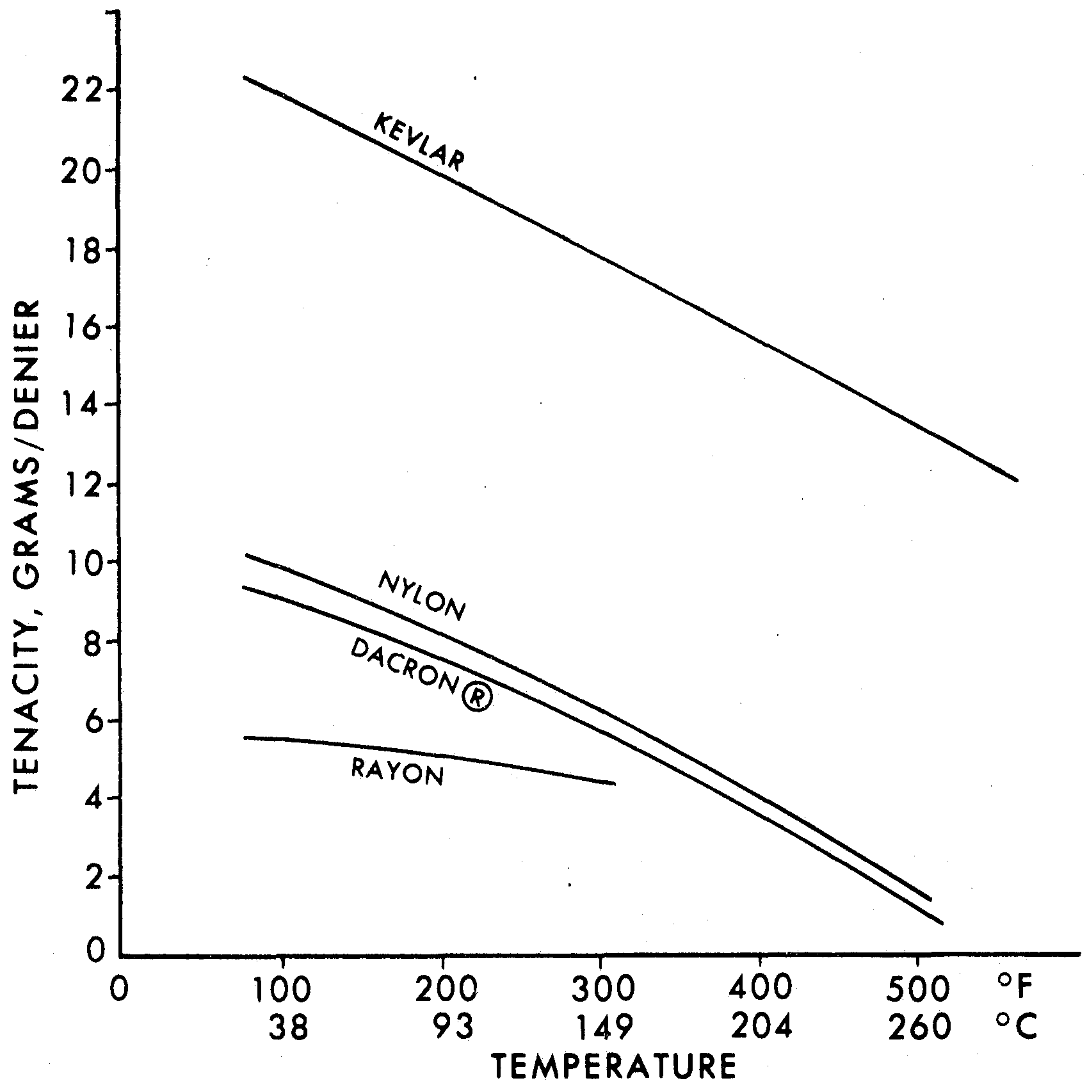


Figure A-I. Effect of Temperature on Tenacity.

EFFECT OF TEMPERATURE ON MODULUS

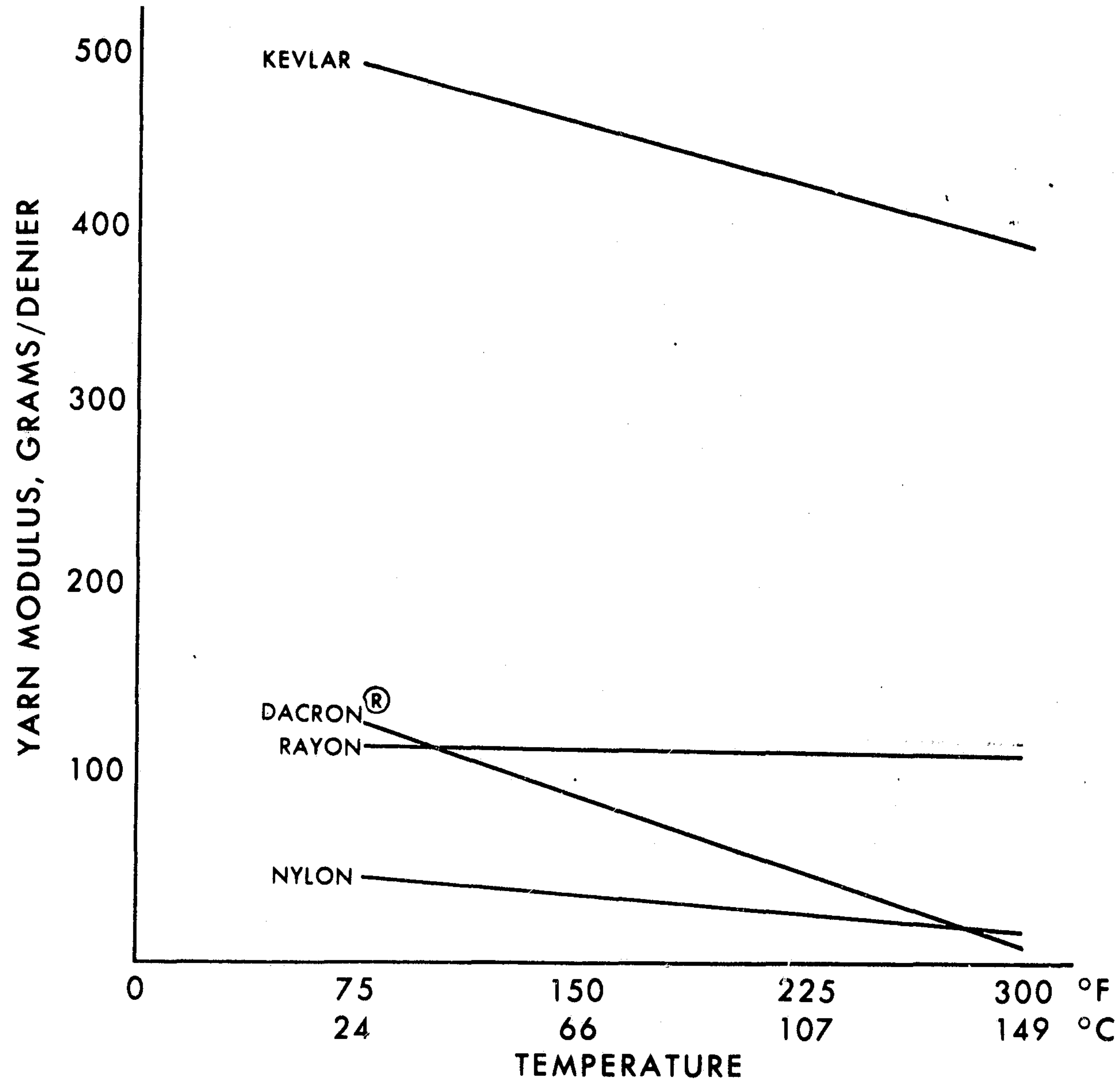


Figure A-II. Effect of Temperature on Modulus.

YARN STRESS-STRAIN CURVES

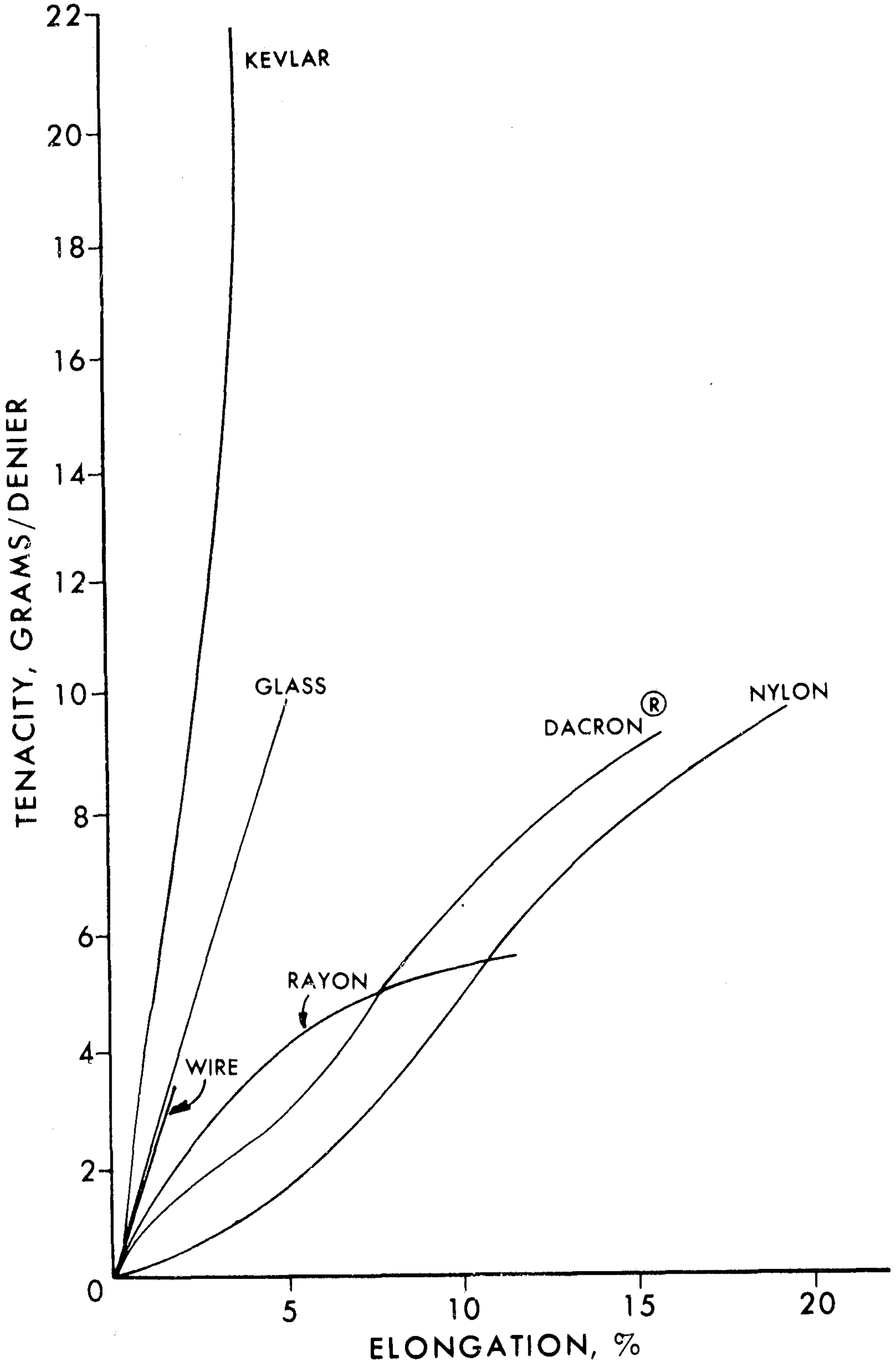


Figure A-III. Yarn Stress-Strain Curves.

3. 1000 denier, "est. 400 filament," R-80 untwisted, type 964 Kevlar 29 yarn.

4. 1500 denier, 100 filament, R-80 untwisted, type 964 Kevlar 29 yarn.

H. TWISTING OF KEVLAR YARN BEFORE WEAVING.

Most synthetic yarns are twisted before being woven into fabric to avoid production delays due to broken filaments and to strengthen the fabric. All of the 400/2 denier yarn used to date on this program has had three twists per inch before woven into fabric for the protective garments. DuPont has established limits on various deniers of Kevlar material which, when exceeded, reduce tensil strength. For 200 denier, maximum twist is five turns per inch. For 400 denier, maximum twist is three turns per inch; and for 1500 denier, 1.1 twist per inch. Recent test results from Natick Development Center indicate that there is very little reduction in the Kevlar material's ballistic strength when no twist is applied to the yarn prior to weaving the fabric.

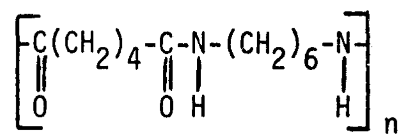
I. ENERGY SHORTAGE.

A duPont sales representative stated that the shortage of petroleum products has in no way reduced the production of Kevlar yarn.

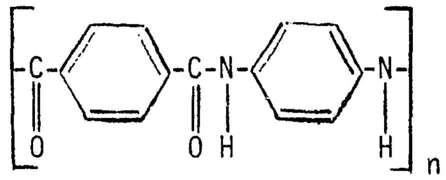
J. MATERIAL STRUCTURE.

The nylon tire cord used as a 12-ply Army standard fragmentation vest was the fabric material used most frequently for police armor prior to the initiation of this present work. At that time the military was already evaluating and considering a new material developed by duPont. This material, a polyamide like its predecessor nylon, was chemically based upon the condensation product of P-phenylene diamine and terephthalic acid. This polymer was then similar to nylon in its functional chemical groupings (amide groups), but far different because of the aromatic groups in the backbone. The comparative formulas for the two polymers are shown below:

1. Nylon 66.



2. Kevlar 29.



The presence of the aromatic group results in a large increase in strength (2-3X), modulus (10-15X) and heat resistance (no weight loss at 600°C versus melting for nylon at 255°C).

The fracture pattern of the Kevlar 29 upon impact can be contrasted with the melting characteristic of nylon when ballistically impacted (Figures A-IV and A-V).

This information was all available from prior Army work which concentrated on fragment protection. The evidence was sufficient to suggest the evaluation of Kevlar 29 for protection against handguns, such as the .38 caliber, .22 caliber, and conceivably the 9-mm threats. Other evidence from US Army evaluations for fragmentation protection favored the use of the lighter yarns, such as 400 denier or 1000 denier as contrasted with the cheaper but heavier (1500 denier) tire cord. Ballistic evaluations conducted by Edgewood Arsenal conclusively proved that the Kevlar fabric was superior to nylon and in fact would stop the .38 caliber ball at 830 fps with only 3-4 oz/sq ft. Medical tests which have been described elsewhere indicated that 6 oz/sq ft of Kevlar 29 fabric (7 plies of 8 oz/sq yd material) would be needed to mitigate the dangerous effects of blunt trauma.

Kevlar 29 in loose form and in laminate form was then supplied to Edgewood Arsenal by Natick Development Center to determine the amount of material necessary to defeat faster threats, such as the .22 caliber and the 9-mm threats. For the 9-mm threat, a laminate of Kevlar 29 in which 24% resin (phenolic modified polyvinyl) was the binder required 25 oz/sq ft to defeat this threat. The back surface of the fired panels showed little permanent deformation or delamination (Figure A-VI) and qualitatively one would expect little blunt trauma.

Comparison firings on laminated glass woven roving showed the glass to be inferior, giving one complete penetration even at 34 oz/sq ft and considerable permanent deformation and delamination (Figure A-VII).*

*Laible, Roy C., Figucia, Frank, and Kirkwood, Barbara. Natick Development Center Technical Report 73-58-CE. Scanning Electron Microscopy as Related to the Study of High-Speed Fiber Impact. October 1973.

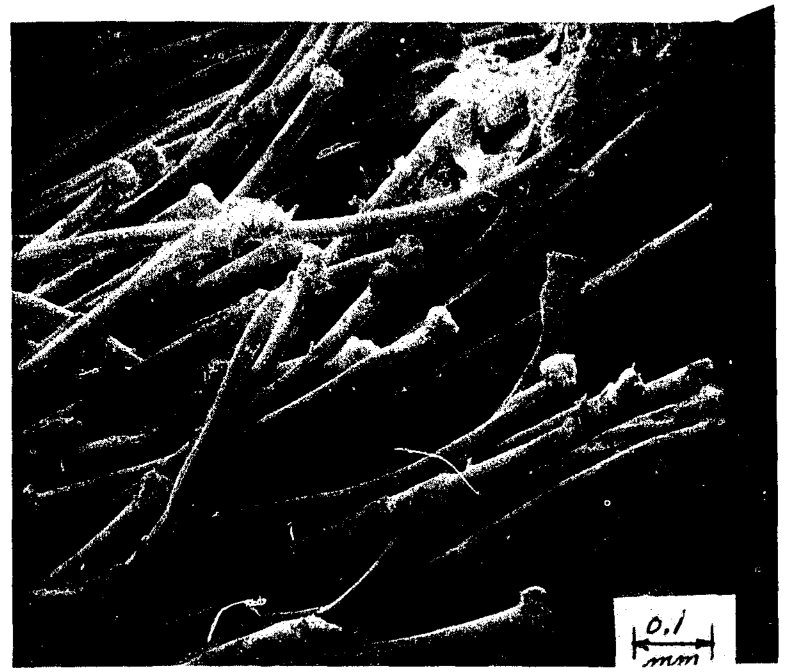


Figure A-IV. Nylon Fibers after Ballistic Impact (440X).

Figure A-V. Kevlar Fibers after Ballistic Impact (500X).

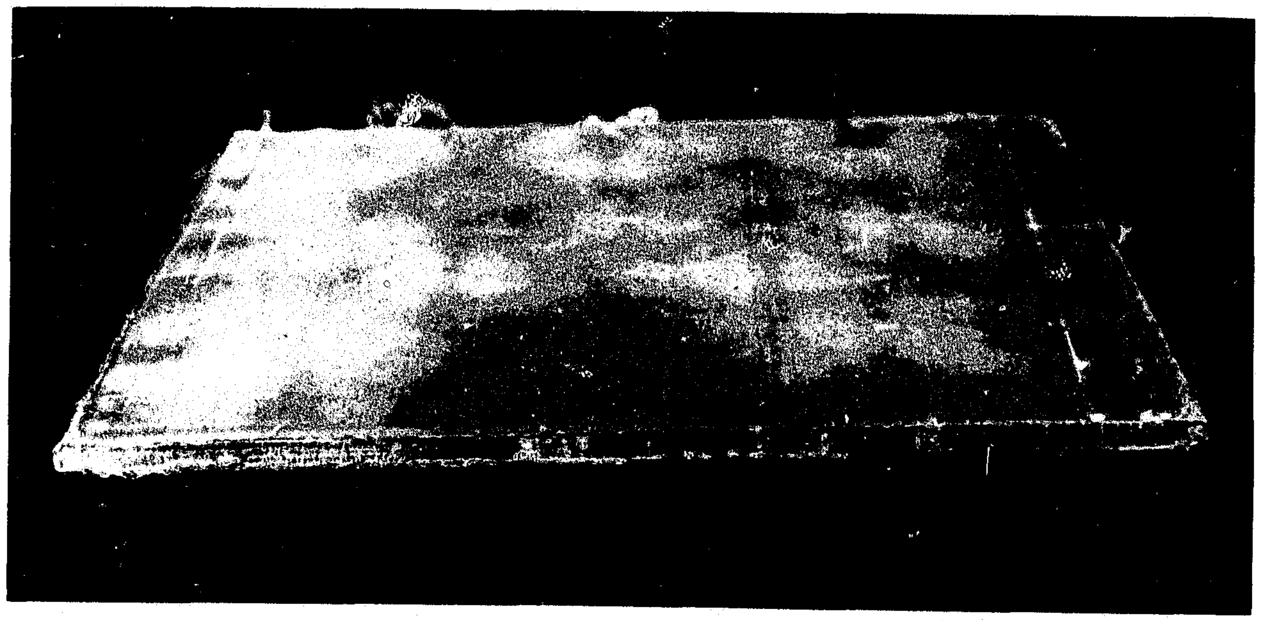


Figure A-VI. Back Surface of Kevlar Laminate after 7 Impacts with 9-mm Bullets.

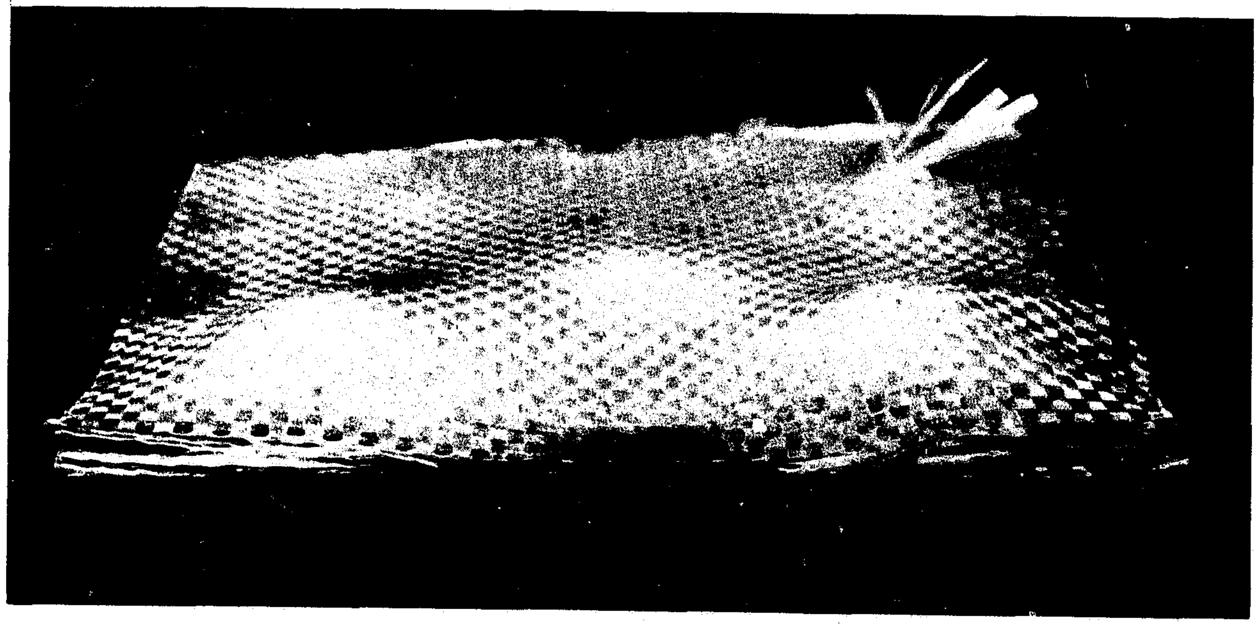


Figure A-VII. Back Surface of Glass Laminate after 5 Impacts with 9-mm Bullets.

APPENDIX B

LAW ENFORCEMENT OFFICERS KILLED BY FIREARMS

Handguns	1973	1972	1971	1970	1969
.22 caliber	8	10	14	6	9
Officer's own weapon			(1)		
.25 caliber	4	2	9	3	4
6.35 mm	1				
.30 caliber				1	
7.65 mm	2	1		1	
.32 caliber	8	5	14	5	4
.32-20 caliber					
Officer's own weapon					
.38 caliber	42	36	38	30	23
Officer's own weapon	(9)	(11)	(11)	(3)	
.357 magnum	19	13	3	3	2
Officer's own weapon	(12)	(6)	(2)		
9 mm	5	1	2		2
.380 caliber		1	3		
.41 magnum				1	2
Officer's own weapon				(1)	(1)
.44 magnum		1	1		1
.445 (.455)					
.45	1	1	5	4	9
Officer's own weapon			(1)		
Caliber not reported	-	4	8	19	11
TOTAL	90	75	97	73	67

APPENDIX B (cont'd)

LAW ENFORCEMENT OFFICERS KILLED BY FIREARMS

Handguns	1968	1967	1966	1965	1964
.22 caliber	9	5	6	6	9
Officer's own weapon				(1)	
.25 caliber	4	4	1	1	
6.35 mm					
.30 caliber					
7.65 mm	1		2		2
.32 caliber	5	6	2	5	5
.32-20 caliber		1			
Officer's own weapon		(1)			
.38 caliber	20	24	20	13	21
Officer's own weapon	(7)	(4)	(4)	(2)	(11)
.357 magnum		1	3	4	2
Officer's own weapon			(2)	(2)	
9 mm		2	1		
.380 caliber					
.41 magnum					
Officer's own weapon					
.44 magnum					
.445 (.455)					
.45	2	3	3		3
Officer's own weapon			(1)		
Caliber not reported	5	8	3	3	4
TOTAL	46	54	41	32	46

APPENDIX C

NATICK DEVELOPMENT CENTER PREAMBLE ON GARMENT DESIGN AND FABRICATION

The overall Natick Development Center objectives are to design, develop, and fabricate two classes of inconspicuous ballistic protective garments. Class I garments are to be worn between the individual's underwear and his shirt. Class II garments are a family of police environmental outer wear and dress clothing, in which the ballistic materials are incorporated into the garment as an integral part or as a zip-in component.

The Class I items were designed to have the following characteristics:

1. Minimum amount of bulk and weight.

2. Inconspicuous.

3. Easily donned and doffed.

4. Size adjustment capability while maintaining ballistic integrity at the sides.

5. Provide upper torso area coverage, shaped and sized, so as to prevent any deleterious effect on the performance of the individual's duties.

6. Stable and comfortable during long periods of inactive and active wear.

7. Compatible with all other clothing and ancillary equipment.

8. Capable of being laundered without seriously affecting the size.

9. Durable.

10. Capable of being mass produced with uniform quality at minimum cost.

The Class II items were designed to have the following characteristics:

1. Inconspicuous. The ballistic garment should not appear different from the same non-ballistic garment.

2. Minimum bulk and weight.

3. Should not be more difficult to don or doff.

4. Incorporation of the ballistic material should not affect the sizing of the garment.

5. Provide upper torso area coverage, shaped and sized to prevent any deleterious effect upon the performance of the individual's duties.

6. Stable and comfortable during long periods of wear.

7. Compatible with all other clothing and ancillary equipment.

8. Will not seriously reduce the warmth intended to be provided by the original outer garments nor increase the heat stress to the individual.

9. Capable of being mass produced with uniform quality at minimum cost.

10. Demonstrate the feasibility that Kevlar ballistic materials could be integrated into police and dress clothing and encourage manufacturers to develop their own lines of ballistic garments.

In order to provide an acceptable, wearable garment of this type, which provides ballistic protection and other characteristics as specified above, and still be comfortable, the following construction and design features are considered essential:

1. Keep the stitching and seams to a minimum. Every stitch contributes to stiffness. Whenever possible, stitching should not pass through all layers of ballistic material.

2. Any stitching required to hold the components or plies together prior to final stitching should be removed.

3. Edges of the ballistic filler (plies) which exert pressure on sensitive areas (shoulder and arm) should be feathered (stepped off) to provide minimum bulk and a softer edge.

4. Particular attention should be given to the trade-offs in area coverage versus freedom of movement. The most important are:

a. Shoulder should not be too wide.

b. Armhole should not be too small.

c. Width across the chest should not be too wide.

d. Front length should not be too long.

e. Neck opening should not be too high.

f. Undergarment appears to require a tuck in bottom.

g. For loose fitting garments (reefers, raincoats, golf jackets, etc.), the ballistic filler should taper towards the body to the extent that it minimizes the "barrel" effect and maintains comfort.

h. Seam construction should take into account the requirement for maximum flexibility and maintain ballistic integrity.

DESCRIPTION OF CLASS I ITEMS

1. Ballistic Undergarment, Aerospace/Natick Over-the-Head Model.

This is an over-the-head style undergarment, which finalized is a version of the Aerospace/Natick model tested in July 1974. The item contains 7 plies of 2 ply/400 denier 8 oz/sq yd Kevlar 29 ballistic cloth. It has split overlapping sides and two 1-inch wide velcro adjustment tapes at each side, which can be loosened for donning and tightened and fastened to the front panel for adjustment after donning. The velcro tapes are passed through metal loops which are fastened to the sides by means of 1-inch wide elastic web shapes. The undergarment has an outer cover of white woven fabric and front and back tails of knit T-shirt material for tucking into the trousers. All edges are bound with a white lightweight binding tape. Weight is approximately 1 lb 14 oz.

2. Ballistic Undergarment, Natick Development Center Front Closure Model.

This is a ballistic undergarment of the front closure type which was designed at Natick. The item contains 7 plies of 2 ply/400 denier 8 oz/sq yd Kevlar 29 ballistic cloth. It has split overlapping sides and two 1-inch wide velcro adjustment straps at each side. Unlike the Aerospace/Natick over-the-head model, the adjustment straps fasten to the back of the undergarment. The wearer is required to adjust and fasten the straps only once, the first time he wears the undergarment. The undergarment has an outer cover of white woven fabric and the front closure is effected by means of four velcro 3/4-inch diameter tabs. All edges of the undergarment are bound with a lightweight, white cloth binding tape. Weight of the size medium undergarment is approximately 1 lb 14 oz.

DESCRIPTION OF CLASS II ITEMS

1. Ballistic Protective Sport Jacket (Natick Development Center).

This is a commercial sport jacket (style SC 506) from a custom clothing manufacturer in which 7 plies of 2 ply/400 denier, 8 oz/sq yd Kevlar 29 ballistic cloth have been incorporated. The ballistic layers were shaped to fit the contours of the jacket to reduce lumps and increase comfort. The jacket was made slightly oversized so that the finished ballistic garment would properly fit the intended size. The cloth of the outer jacket is 55% Dacron and 45% wool. The inner lining is of a lightweight nylon satin cloth.

This jacket has a ballistic flap which lays inside the jacket under the lapel. When pulled out and fastened into place, the flap protects the chest area between the lapels.

The weight of this ballistic sport jacket, size 42 regular, is 4 lb 2 oz. The weight of the jacket without the ballistic material is 2 lb.

2. Ballistic Protective Man's Raincoat (Natick Development Center).

This is a commercial water-repellent dress type raincoat (style LF 2775) in which the zip-out thermal liner has been removed and replaced by a ballistic liner of 7 plies of 2 ply/400 denier, 8 oz/sq yd Kevlar 29 cloth. The ballistic liner covers the upper torso from the waist up and has a flap on each side at the front. When the raincoat is buttoned, the flaps extend over each other to provide positive overlap in front. The ballistic liner was designed to fit closer to the body to minimize the "belling" effect caused by the stiffness of the liner. The raincoat remains intact and either the thermal liner or the ballistic liner may be zipped in. The back portion of the ballistic liner is covered with black lightweight cloth to somewhat simulate the thermal liner and the flaps are covered with the same material as the outer coat. If desired, a greater area of protection may be obtained by extending the ballistic liner to the same length of the thermal liner. However, this makes the coat stiffer, therefore, more conspicuous. The weight of this raincoat in the size 42 regular is 5 lb 6 oz. The weight of the raincoat with the thermal liner is 3 lb 2 oz.

3. Ballistic Protective Golf Jacket (Natick Development Center).

This is a commercial, 2-pocket, waist length, raglan sleeve, front zippered golf jacket (style LF 720) in which a non-removable ballistic lining of 7 plies of 2 ply/400 denier, 8 oz/sq yd Kevlar 29 cloth have been incorporated. The body of the jacket is of a water repellent treated fabric. The sleeves are of the same material which has been rubberized. The collar and cuffs each have two buttons for closure. The jacket is "full" at the back and fits snug at the waist. The ballistic liner covers the upper torso from just above the waist and has a flap on each side at the front. When the jacket is zipped, the flaps extend over each other to provide positive overlap in the front. Because of the "fullness" of the jacket in the back, the ballistic lining is designed to fit close to the body. In order to maximize freedom of

movement, the back of the ballistic lining is attached to the jacket by a button and tab at the neck and at the armholes. The front of the lining is stitched to each side of the jacket near the zipper. All visible areas of the liner are covered with matching jacket material. The ballistic golf jacket in a size 42 regular weighs 3 lb 2 oz.

4. Ballistic Protective Police Reefer Coat (Natick Development Center).

This is a commercial police reefer coat (style BL 375) in which the built-in thermal lining has been removed and replaced by 7 plies of 2 ply/400 denier, 8 oz/sq yd Kevlar 29 ballistic cloth. The ballistic lining covers the upper torso from the waist up and has thermal lining material attached to its lower edge so that the overall dimensions of the complete lining are the same as those of the non-ballistic reefer coat. The entire lining is covered with the same lining materials as the original coat. The ballistic lining extends to the buttons and to the button holes, thus providing positive overlap in the front. The weight of this ballistic reefer coat size 42 regular is 6 lb 1 oz compared to 3 lb 13 oz for the non-ballistic item.

5. Ballistic Protective Outer Vest (Natick Development Center).

This vest was designed at Natick and is patterned after a commercial thermal insulator vest which is normally worn over the shirt and under the coat. The vest has a zipper front closure, has no adjustment at the sides, and is longer in the back than the front. A lightweight nylon cloth covers the 7 plies of 2 ply/400 denier, 8 oz/sq yd Kevlar 29 ballistic cloth. The vest is police blue and weighs 2 lb 8 oz in the size large-regular.

APPENDIX D

NATICK DEVELOPMENT CENTER PURCHASE DESCRIPTION		NUMBER	DATE
stock number	name of item		unit
	CLOTH, BALLISTIC, PLAIN WEAVE, ARAMID		YARD

1. SCOPE

1.1. This purchase description covers ballistic cloth made from an aramid fiber (see 6.3).

2. APPLICABLE DOCUMENTS

2.1. The following documents of the issue in effect of date of invitation for bids or request for proposal, form a part of this purchase description to the extent specified herein:

SPECIFICATIONS

FEDERAL

PPP-P-1133 - Packaging and Packing of Synthetic Fiber Fabrics

STANDARDS

FEDERAL

Fed. Std. No. 191 - Textile Test Methods

MILITARY

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.

(Copies of specifications, standards, drawings and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

PUBLICATION

Rules and Regulations under the Textile Fiber Products Ident. Act.

(Copies may be obtained without charge from the Federal Trade Commission, Washington, DC 20580.)

3. REQUIREMENTS

3.1. First article - This purchase description contains provisions for first article inspection and approval (see 4.2, 6.2 and 6.4).

3.2. Material.

3.2.1. Fiber - The fiber shall be non-melting, high strength, aromatic polyamide (aramid) and shall not char at a temperature less than 800°F, when tested as specified in 4.5 (see 6.3).

3.2.2. Yarn - The yarn for the warp and filling shall be continuous filament, 400 denier (nominal) and twisted into a 2-ply yarn. The final ply shall have 4 to 5 turns per inch when tested as specified in 4.5.

3.2.3. Reeding - The warp yarn shall be reeded with not more than 2 ends per dent.

3.3. Color - The color of the finished fabric shall be natural as produced from the fiber provided by the manufacturer. The supplier shall certify that the yarn and the fabric have not been subjected to any bleaching process.

3.4. Physical Requirements - The physical requirements of the finished cloth shall be as specified in Table I when tested as specified in 4.5.

TABLE I - Physical Requirements

Characteristics	Requirements	
	(min)	(max)
Weight per sq yd (ounces)	7.90	8.25
Yarns per inch (minimum)		
Warp	34	
Filling	36	
Yarn Breaking strength (lbs)(min)		
Warp	35	
Filling	35	
Air Permeability, cu ft/min/sq ft (max)	20	

3.4.1. Weave - The weave shall be plain.

3.4.2. Width - The width shall be 48 ± 1/2 inches inclusive of selvages.

3.4.3. Finish - The cloth shall be scoured.

3.5. Length and put-up - Unless otherwise specified (see 6.2), the cloth shall be furnished in continuous lengths each not less than 40 yards Each length shall be put-up in full width rolls as specified in PPP-P-1133

3.6. Fiber identification - Each roll of cloth shall be labeled, ticketed or invoiced for fiber content in accordance with the Rules and Regulations under the Textile Fiber Products Identification Act.

3.7. Workmanship - The finished cloth shall conform to the quality and grade of product established by this purchase description. The occurrence of defects shall not exceed the applicable acceptable quality levels.

4. QUALITY ASSURANCE PROVISIONS

4.1. Responsibility for inspection - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the purchase description where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1. Certificate of compliance - Where certificates of compliance are submitted, the Government reserves the right to check test such items to determine the validity of the certification.

4.2. First article inspection - The preproduction sample submitted in accordance with 3.1 shall be visually inspected and tested in accordance w/4.5.

4.3. Inspection - Sampling for inspection shall be performed in accordance with MIL-STD-105, except where otherwise indicated hereinafter.

4.3.1. Component and material inspection - In accordance with 4.1 above, components and materials shall be tested in accordance with all the requirements of referenced specifications, drawings and standards unless otherwise excluded, amended, modified or qualified in this purchase description or applicable purchase documents.

4.3.2. Examination of the end item - Examination of the end item shall be in accordance with 4.3.2.1 thru 4.3.2.3.2.

4.3.2.1. 100 percent inspection - The entire yardage of each roll of cloth shall be inspected. All defects found shall be counted except where two or more defects appear within 1/2 linear yard of the cloth, in which case only one defect shall be counted. A continuous defect shall be counted as one defect for each warpwise yard or fraction thereof in which it occurs. Each defect shall be marked with a red string, 1 inch to 1-1/2 inches long, sewn into the selvage opposite the defect. A deduction of 1/4 yard for each strung defect shall be subtracted from the gross length of the roll to determine the net yards to be entered on the roll ticket. Acceptance shall be on a net yardage basis. The cloth shall be examined at a viewing distance of approx. 3 feet for the presence of the following defects, and the criterion for classification as a defect is being visible and definable at 3 feet. The roll shall be rejected if it contains more than 15 strung defects per 100 yards.

Crease
Cut, hole or tear
Broken or missing yarn
Smash
Float, mispick, harness skip, or other misweave
Hitchback, stripback
Open or thin place, crack (warp or filling)
Loose, slack, or tight yarns
Fine yarn
Mixed yarn
Reed mark
Spot, or stain

4.3.2.2. Overall examination - The cloth shall be examined for extensive, general, or overall defects. Any roll containing any of the following defects shall be rejected:

Width not within established tolerances.
Net length less than indicated on the ticket.
Incorrect deduction for defects strung by the supplier, as indicated on piece ticket.
Fiber identification missing.

4.3.2.3. Government verification - Verification examination shall be on a sampling basis.

4.3.2.3.1. Yard-by-yard examination - The inspection level shall be level III of MIL-STD-105 and the acceptable quality level (AQL) shall be 1.0 unstrung defects per 100 linear yards. The sample unit shall be one linear yard and the lot size shall be expressed in units of one yard each. The required yardage shall be examined, and any defects listed in 4.3.2.1 and not strung, which are visible at a viewing distance of 3 feet and not within 1/2 linear yard of a strung defect shall be scored. If the number of unstrung defects in the sample equals or exceeds the reject number for the sample size and foregoing AQL, the entire lot shall be returned to the supplier for screening and stringing of all unstrung defects.

4.3.2.3.2. Overall examination - The sample size for overall examination shall be the number of rolls selected for the yard-by-yard examination (see 4.3.2.3.1). The lot shall be unacceptable if one or more rolls contain any of the defects listed in 4.3.2.2.

4.4. Examination of preparation for delivery requirements - An examination shall be made in accordance with the provisions of PPP-P-1133, to determine that packaging, packing and marking complies with the section 5 requirements of this purchase description.

4.5. Testing of the end item - The methods of testing specified in FED-STD-191, wherever applicable, as listed in table II shall be followed. The physical and chemical values specified in section 3, except where otherwise specified, apply to the results of the determinations made on a sample unit for test purposes as specified in the applicable test method. The sample unit shall be 2 continuous yards, full width, of the finished cloth. All test reports shall contain the individual values utilized in expressing the final result. The lot shall be unacceptable if one or more units fail to meet any requirement specified. The lot size shall be expressed in units of 1 yard. The sample size (number of sample units) shall be as follows:

Lot size (yards)	Sample size
800 or less	2
801 up to and including 22,000	3
22,001 and over	5

TABLE II - Test methods

Characteristic	Requirement paragraph	Test method
Fiber		
Fiber Identification (aromatic polyamide)	3.2.1	1/
Charring temperature	3.2.1	1/
Yarn		
Denier	3.2.2	4021 1/
Ply	3.2.2	Visual
Twist (turns per inch)	3.2.2	4054
Reeding	3.2.3	1/
No Bleaching	3.3	2/
Yarn Breaking Strength		
Warp	3.4	4100 3/
Filling	3.4	4100 3/
Weight	3.4	5041
Yarns per inch		
Warp	3.4	5050
Filling	3.4	5050
Air Permeability	3.4	5450
Weave	3.4.1	Visual
Scoured	3.4.3	1/

1/ Unless otherwise specified, a certificate of compliance shall be submitted and will be acceptable for the stated requirement.

2/ The supplier shall certify that the yarn and the fabric have not been subjected to a bleaching process.

3/ The yarn shall be removed from the finished fabric.

5. PREPARATION FOR DELIVERY

5.1. Put up and packaging - Put up and packaging shall be level A or C as specified (see 6.2).

5.1.1. Levels A and C - The cloth shall be put up and packaged in accordance with the applicable requirements of PPP-P-1133.

5.2. Packing - Packing shall be level A, B or C as specified (see 6.2).

5.2.1. Levels A, B, and C - The cloth shall be packed in accordance with the applicable requirements of PPP-P-1133.

5.3. Marking - In addition to any special marking required by the contract or order, shipments shall be marked in accordance with the requirements of PPP-P-1133.

6. NOTES

6.1. Intended use - The cloth covered by this purchase description is intended for use in ballistic garments.

6.2. Ordering data - Procurement documents should specify the following:

(a) Title, number and date of this purchase description.

(b) First article - (see 3.1, 4.2 and 6.4).

(c) Minimum length if other than specified (see 3.5).

(d) Selection of applicable levels of packaging and packing (see 5.1 and 5.2).

6.3. The cloth described in this purchase description was produced from Dupont's "Kevlar 29" fiber.

6.4. First article - When a first article is required, it shall be inspected and approved under the appropriate provisions of ASPR 7-104.55. The first article should be a preproduction sample. The first article should consist of 5 yards of the finished cloth. The contracting officer should include specific instructions in all procurement instruments regarding arrangements for inspection and approval of the first article.

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