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EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

BODY ARMOR FIELD TEST AND EVALUATION FINAL REPORT

Volume II - Test and Evaluation

Law Enforcement and Telecommunications Division
September 1977

Prepared for

National Institute of Law Enforcement and Criminal Justice
LAW ENFORCEMENT ASSISTANCE ADMINISTRATION
U.S. DEPARTMENT OF JUSTICE

The Aerospace Corporation

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FINAL REPORT

BODY ARMOR FIELD TEST AND EVALUATION

VOLUME II - TEST AND EVALUATION

Approved:

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Law Enforcement and Telecommunications
Division

ABSTRACT

This report, in three volumes, examines the acceptability and performance of various designs of soft body armor utilizing Kevlar 29 as the principal ballistic material. The effects of fit, comfort, and heat containment on garment acceptance and wear are assessed. Those factors most important in the use and specification of armor are identified.

From statistics of confiscated weapons, FBI assault data, and wear histories of the garments tested, it is found that armor containing 7 to 12 5 plies of protective material is optimum in terms of the liklihood of preventing fatalities or injury. Changes in attitudes of the officers wearing armor was found to be negligible, and none of the armor designs tested interfered with officer activities. In no case were internal injuries experienced from assaults while wearing the armor.

Two areas meriting further investigation are the study of blunt trauma from higher-energy threats, in particular the .357-magnum and 9-mm handguns, and the determination of useful garment lifetime.

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PREFACE

The purpose of this final report is to present a comprehensive review of the field test and evaluation of the soft body armor developed and designed for the National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration (LEAA), as well as various commercial armor designs of identical ballistic material. Approximately 5000 garments were issued to patrol officers in 15 cities, and testing was conducted during CY 1976. The statistical analysis and evaluation of the test data, completed in August 1977, was supported by a subcontract to the Laboratory for Statistical and Policy Research of Boston College.

In addition to the field test and evaluation, various design modifications of the LEAA armor were implemented and tested, based upon the field test results. Studies to characterize the mechanical and ballistic properties of Kevlar 29 (the ballistic material common to all modern soft armor and that used in the field test) from a theoretical point of view were conducted. Finally, guidelines for the specification and procurement of armor were developed. A comprehensive review of these activities is given.

This report is presented in three volumes. Volume I, Executive Summary, presents an overview of the field test and evaluation activities, findings, and principal conclusions and recommendations. Volume II, Test and Evaluation, presents a comprehensive discussion of all tests, studies, analyses, and evaluations. In addition, details are given of the test design and analytical approach, as well as a summary of three medical-technical symposia held during the program, reports on all incidents or shootings involving armor, and the technology transfer activities carried out at the end of the program. Volume III, Appendices, includes the questionnaires used to generate the data, a Model Procurement Document, and data on later studies. The raw data used for statistical analyses are not included in

Volume III because of their sheer bulk. These data will be made available to interested parties.

These volumes represent a follow-on of previous reports covering the design and development and pilot test phases of the Body Armor Program.

CHAPTER I. INTRODUCTION

As part of its equipment systems improvement program, the National Institute of Law Enforcement and Criminal Justice (NILECJ) of the Law Enforcement Assistance Administration (LEAA) initiated a program in FY 1973 to determine the feasibility of developing lightweight, protective garments for use by law enforcement agencies. Existing armors which were available to the law enforcement community used ballistic nylon, metal inserts, ceramics, or laminated fiberglass. For the most part, these armors were used for special situations in which a known threat had been identified.

In the years preceding 1973, the substantial increase in law enforcement fatality rate plus assassination attempts on public officials, such as Senator Stennis and Governor Wallace, emphasized the need for protection against common handguns. There was an obvious need for armor that was lightweight and inconspicuous. Partly as a result of the recognition that recent developments in high strength, synthetic materials offered a potential for lightweight soft body armor, a continuous-wear capability for protective garments was mandated as part of the program.

The overall objectives established for the program were as follows:

- To develop comfortable, inconspicuous, lightweight protective garments capable of providing protection against common handguns
- To demonstrate adequate user protection and acceptance by pilot test and field test
- To disseminate the technology acquired to both users and industry

On the basis of these objectives, the program effort was structured into four phases: feasibility assessment, garment development and pilot test, field test, and technology transfer. This document reports the results obtained from the field test and technology transfer phase. Results of the first two phases are documented in the Edgewood Arsnel Special Report EB-SR-75001, "Lightweight Body Armor for Law Enforcement Officers" and The Aerospace Corporation report ATR-75(7906)-1, "Final Report: Protective Armor Development Program." Other reports on the first two phases are referenced in Section XII, Bibliography. In addition, a brief discussion of the garment development work is presented in the following as background and for ease of reference.

It was clearly recognized that the successful development of a new armor required the combined effort of many groups in order to provide knowledge and special equipment and facilities in many diverse technologies, such as physiology and blunt trauma, ballistics, material sciences, anthropometry and ergonomics, and law enforcement sciences, as well as the art of weaving with new materials and that of clothing design. As a result, under the management of the Advanced Technology Division of NILECJ, The Aerospace Corporation was made responsible for the integration of contributions by the following organizations:

- MITRE Corporation. Preliminary operational requirements and supporting operational analyses.
- National Bureau of Standards (NBS). Specifications, standards, test procedures, anthropomorphic data, and industry/user guidelines
- U.S. Army Laboratories (Edgewood Arsenal and Natick) - Detailed material, ballistic, and medical testing; garment development.
- Atomic Energy Commission (AEC) Lawrence Livermore Laboratories. Ballistic tests and backface signature analysis.
- Law Enforcement Agencies. Threat definition, test planning, test conductors, and garment review and critique.
- Industry. Material development, consultation, fabric weaves, and garment fabrication.

In addition to being assigned the program integration task, Aerospace carried out a number of tasks during both the development and field test phases of the program. The Aerospace Materials Science Laboratory provided mechanical tests, analyses, and preliminary ballistic tests for the selection of the yarn material and fabric weaves. Additionally, test plans for both the pilot test and field test were developed. Finally, technical direction was provided to the Lawrence Livermore Laboratories, which was subcontracted to conduct ballistic tests and studies of the backface signatures of nonpenetrating rounds.

Prior to the design and development of the garment, a feasibility assessment had established the operational requirements for soft body armor, in particular, the level of protection, and had identified the most promising ballistic material. An analysis of the location of fatal wounds compiled from the "FBI Unified Crime Reports" revealed that 51 percent were in the upper torso area, compared with 41 percent in the head and neck areas, and 9 percent below the waist. Thus, a garment to protect the upper torso was indicated. Statistics on assaults against law enforcement officers and on confiscated weapons directed the design to defeat the common handgun, i.e., one with energies equal to or less than a .38-caliber, 148-gr ball round at 900 fps. As shown in Figure 4-6 of Chapter IV, approximately 80 percent of all fatalities from handguns during the period 1964 through 1976 were due to weapons with energies less than the .38 caliber. Extensive materials testing, both mechanical and ballistic, resulted in the selection of Kevlar 29 as being clearly superior. Indeed, early in the development program, the armor industry switched over to the almost exclusive use of Kevlar as the protective constituent of garments. This partially achieved a major objective of the program, that of technology transfer to industry. It also permitted the subsequent field test to include for comparison a wide variety of garment designs tailored for various threat levels higher than that established by the threat assessment.

Early in the development phase, extensive research was conducted on the two roles armor must fulfill, that of defeating penetration and that of controlling blunt trauma to the tissue and vital organs of the wearer. Previous armor developments were directed toward defeating penetration and were based largely on experimental procedures. The objective of this development was to combine both analytical and experimental procedures and physical and medical research in order to better understand the processes involved in protecting the wearer. This required an examination of numerous other factors, in addition to the threat, such as shown in Figure 1-1. In particular, an assessment was made of the interaction among these factors in absorbing the kinetic energy and momentum of the bullet and preventing penetration and serious medical injury. Medical analysis and tests using animals and cadaver organs established the limits of permissible hydrodynamic shock in terms of depression factors or measurements of the cavity that is formed momentarily behind a nonpenetrating impact.

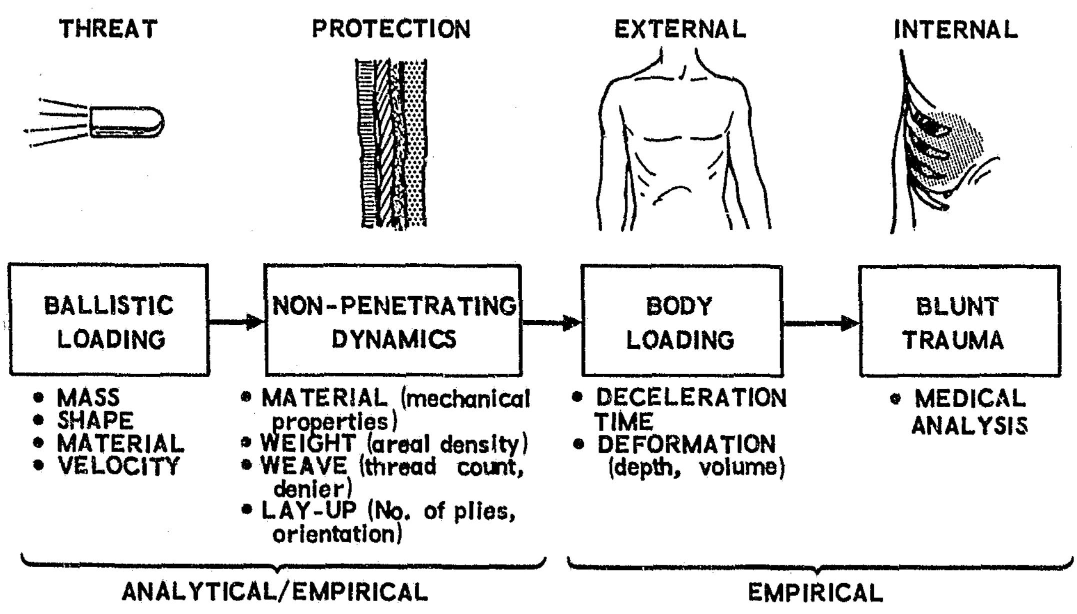

Figure 1-1. Factors Involved in Establishing Body Armor Effectiveness

This part of the development phase resulted in the specification of 7-ply Kevlar 29, 1000 denier, 31 threads/in. in both warp and fill for protection against the common handgun. Subsequent efforts were devoted to the human factors associated with garment design, e.g., form, fit, and comfort. The design required was such that the garments would meet the following operational requirements:

- Be inconspicuous
- Not hinder the wearer in the performance of his duties
- Be resistant to deterioration and environmental effects
- Not hinder self defense by the wearer

A total of 75 prototype garments designed to meet these requirements were fabricated for pilot testing in four cities over a period of six months, including the summer months. Several garment types, including undershirts, sport jackets, and elements of police uniforms, were provided for four law enforcement departments for user reaction and wearability assessment.

The purpose of this phase of the program was not only to assess user acceptance and to identify any design modifications that user performance might dictate, but also to uncover any fabrication problems that might occur with the material and designs selected for the garments. On the basis of these tests, two styles of undershirts or vests were selected. Although similar in construction, one provided complete side protection, while the other provided a contoured opening at the sides for added comfort in hot weather.

At this point, the procurement and field test of garment acceptance and performance was initiated, which is the subject of the remainder of this document.

CHAPTER II. TEST PROCEDURES

A. Planning

Planning for the Lightweight Body Armor Field Test Program was begun early in CY 1974. The initial effort was directed toward establishing the test objectives to be accomplished and sizing the test program to meet these objectives. Four broad goals were established toward which the program was directed:

- Evaluate acceptability of continuous-wear limited protection garments
- Evaluate impact of garments on law enforcement operations
- Evaluate garment performance
- Evaluate cost and ease of manufacture of quality garments

Associated with each of the four goals was a set of test objectives which, if met, would demonstrate the attainment of the program goals. Measurement questions were established which supported the test objectives. Questionnaires were then developed which would record the data required to answer the measurement questions.

In sizing the overall test program, FBI uniform crime reporting data on officers killed or wounded were used to estimate statistically the probability of an officer being wounded in the protected torso area by a common handgun (defined as having ballistic characteristics between the .22 caliber firing a 40-gr bullet at 1000 fps and the .38 caliber firing a 158-gr bullet at 800 fps). From the national statistics for 1971 and 1972, estimates were made of the probability of an officer being protected by the garment versus the total man years of garment wear (Figure 2-1).

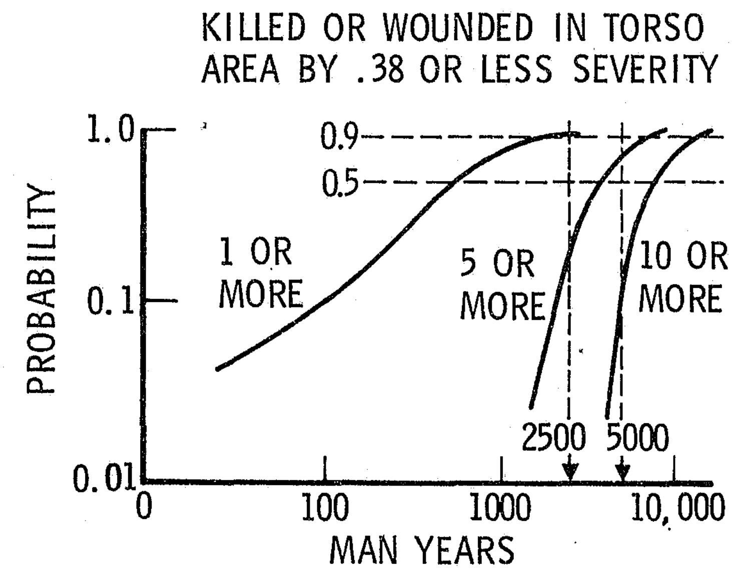

Figure 2-1. Probability of Torso Area Injuries as Function of Garment Wear

Figure 2-1 indicates that, with 5000 man years of garment wear, there is a 90 percent probability that four or more incidents of handgun injuries in the torso area will be less serious if the officers are protected. Since national average data were used in the analysis, the assault information is an average of that from all reporting agencies. By selecting cities with high assault rates and deploying the available garments in high-risk areas within these cities, the maximum protection advantage was provided.

It was found that the performance goal determined the scope of the program. The remaining goals and objectives could be met with fewer responses; hence, the loss of data as a result of officer aversion to paper work would not represent as serious a problem.

As in all test programs, there is a tradeoff between the optimum program and costs. In the data collection effort, consideration was given to on-site program representatives rather than test conductors provided by the departments. The on-site representatives may have yielded a more complete data set but would have represented a significant cost impact. It was felt that department test conductors would be more readily accepted by the participating officers and would provide a decided cost advantage. Since some loss of data was acceptable, this approach was selected and, for this particular program, was satisfactory.

With the selection of candidate cities and their agreement to participate in the program, detailed planning for the distribution of garments was undertaken. The requirement was to place a statistically significant number of garments in each of the police functional activities, to make the activity distribution representative of the risk as reflected in assault data, and to provide maximum benefit by providing garments to officers in the high-risk areas of the cities. In conjunction with the test conductors in each participating city, data on officer assaults were reviewed, and the distribution of garments was developed and negotiated. Tables 2-1 and 2-2 show the distribution of the garments.

A training program, including a training film, was planned for the participating officers to identify the capabilities and limitations of the garments and to provide instructions in the wear and maintenance of the garments. In addition, a disclosure statement was prepared which further defined the capabilities of the garments, which the officer was required to sign upon receipt of his or her garment.

As part of the implementation of the program, a test plan was prepared and provided to each of the departments.[1] This plan provided the guidelines for the conduct of the program, the data collection, and the data processing and evaluation efforts. A memorandum of understanding was executed between each participating department and The Aerospace Corporation which outlined the roles and responsibilities of each organization. These documents also established the requirement for a single point of contact within each of the two organizations.

Table 2-1. Basic Undergarment Distribution Summary

Participating Units and No. of Garments Distributed			
Albuquerque, N. Mex.		**Philadelphia, Pa.**	
Patrol (Sector 1)	60	Stakeout	100
Special Operations	30	Highway Patrol	80
Investigations	30	Narcotics	60
	120	Subway Detail	100
			340
Atlanta, Ga.		**Portland, Oreg.**	
Morning Watch - 5 Zones	127	East Precinct	147
Anti-Burglary	44	North Precinct	104
High Crime Foot Patrol	51		251
	222		
Birmingham, Ala.		**Richmond, Va.**	
Central Precinct (Patrol)	144	Office of the Chief	10
Vice Bureau	13	Operations	490
Major Felony	11		500
	168		
Detroit, Mich.		**St. Louis, Mo.**	
14th Precinct (Patrol)	220	Mobile Reserve	80
Tactical Mobile Unit	126	Traffic Safety	70
	346	Felony Squad	50
			200
Miami, Fla.		**St. Paul, Minn.**	
Patrol	200	Law Enforcement Aid Unit	113
Walking Detail	25	Platoons (2, 4, 7) Zone 2	40
Burglary	5	Detectives	7
Robbery	5	K-9	5
Narcotics and Vice	10		165
	245		
Newark, N.J.		**Seattle, Wash.**	
Patrol (North and East)	200	Central Precinct	288
Tactical Force	50	Special Enforcement	14
Tactical Anticrime	55	Motor Cycles	30
Detective	10	Tactical Operations	23
Traffic	50		355
	365	**Tampa, Fla.**	
		Division 1	150
		Division 2	150
			300
New Orleans, La.		**Tucson, Ariz.**	
District 6 Patrol	86	Precincts 1 and 2	110
Urban Squads	60	Narcotics	22
Special Investigations	12	Tactical Unit	8
Special Operations	40		140
Criminal Investigations	50		
Traffic	40		
	288		

Table 2-2. Other Garment Distribution Summary

City	Women's Garments	Integrated Garments	Commercial Garments
Albuquerque	4		110
Atlanta	10		
Birmingham	8		
Detroit	14	50	128
Miami	5		
Newark	-	50	77
New Orleans	5		132
Philadelphia	5		
Portland	7		
Richmond	7		100
St. Louis	6		
St. Paul	1	50	
Seattle	9	50	98
Tampa	8		96
Tucson	10	50	26

A medical plan was prepared in which local trauma specialists were identified in each participating city to act as consultants to the police departments and attending physician(s), if requested. Also, a team of medical experts was on 24-hour call at Edgewood Arsenal to respond on site in the event of an incident involving a participating officer. A medical protocol was also established and provided to the test conductors and the local trauma surgeons.

The test program was officially initiated during the "First Medical-Technical Symposium," which was held in Washington, D. C., on November 20, 1975. The test program was scheduled to be approximately one year in duration.

B. Questionnaires

Data gathering instruments were developed during the preliminary test planning effort which would meet the following three goals of the field evaluation:

- Evaluate the acceptability of continuous-wear limited protection garments
- Evaluate the impact of garments on law enforcement operations
- Evaluate garment performance

Five questionnaires were developed for this purpose and were identified as the Garment Wearer Pre-Test Interview Questionnaire (WPT), Non-Wearer Pre-Test Interview Questionnaire (NWPT), Garment Wearer Monthly Data Questionnaire (WMD), Garment Wearer Post-Test Interview Questionnaire (WAT), and Non-Wearer Post-Test Interview Questionnaire (NWAT). These questionnaires are reproduced in Appendix A, Volume III, of this report.

One method of determining what effect the garments had on the officers was to compare the responses of those who wore the garments with the responses of officers who experienced the same conditions but did not wear the garments. In this study, those who wore the garment are said to belong to the test group, and those who did not belong to the control group.

The WPT and NWPT questionnaires were submitted by the test and control groups, respectively, at the time the garments were issued. The purpose of these questionnaires was to provide a data base on the attitudinal and situational characteristics of these two groups. This was necessary so that differences between the two groups could be accounted for when evaluating the attitude changes which occurred over the test period and so that the correlation of attitude factors with garment acceptance could be determined.

The WMD questionnaire was administered on a monthly basis to the test group only. The purpose of these questionnaires were to assess the frequency by which the garments were worn, the problems the officers encountered with the garments, and the officers' attitudes toward them.

The WAT and NWAT questionnaires were administered to the test and control groups, respectively, at the completion of the 12-month field test. These questionnaires were designed to detect, by comparison with the WPT and NWPT questionnaire responses, attitudinal changes which occurred over the test period and to help assess the acceptability of the garments.

C. Analysis Philosophy

In the Body Armor Field Evaluation Program, the system being evaluated comprises the garment which is resistant to penetration by a ballistic projectile, the officer wearing the garment, the total environment within which the officer is operating, including numerous ancillary factors which affect the officer's attitude and acceptance of protective garments. Many of these factors can neither be controlled nor measured in an absolute sense; as a consequence, the test becomes quasi-experimental, and the data become more subjective in terms of experimental responses. This imposes more stringent requirements on the design of the data gathering instruments, increased judgment when reviewing the data for completeness and adequacy of responses, and a greater reliance on sophisticated statistical tools for data manipulation and analysis.

The distribution and collection of the questionnaires was accomplished through the assignment of a test conductor in each police department, who coordinated the questionnaire distribution and collection in his city. Each test conductor sent the questionnaires to The Aerospace Corporation, which then forwarded them to the Laboratory for Statistical and Policy Research (LSPR). The LSPR visually validated the questionnaire responses for correctness and completeness and then converted the questionnaire data into a machine-readable format so that the necessary analysis could be performed.

The two general procedures of statistical inference are the estimation of distributional parameters and the testing of null hypotheses. An example of parameter estimation is the calculation of the average time a specific style of garment is worn during the test period. This average would be a point estimate of the garment's wear potential. In addition to estimating the amount a specific garment type is worn, it is also important to determine if the value of that parameter for one garment type is actually different from the average for another type. Here, the individual estimates for the two types, when taken alone, do not answer the question. The two estimates may be different, but that difference could be caused by random chance instead of any real difference in the two parameter values. In this situation, it is appropriate to consider a test of the hypothesis that the parameter values are the same for both types. Appropriate statistical methods exist for testing this hypothesis, called the null hypothesis, in the sense that the method indicates that the hypothesis should either be accepted or rejected. If the null hypothesis is accepted, it is said that the two parameters are equal and that any observed differences are due to random choice. If the null hypothesis is rejected, it follows that the two parameters are significantly different.

The general procedure of analysis to be employed is determined from the goals and objectives of the test program. For example, if an objective was to determine if an officer's attitude had changed between the start and the end of the field evaluation, then a hypothesis testing procedure is called for.

Within these two general procedures, many specific methods of analysis are employed. The proper method is dictated by the nature of the data available for analysis and, in particular, the assumptions that can be made correctly about the distribution of the data. The number of questions that may be asked are unlimited; however, the types of questions that can be answered with statistical validity are limited to questions about certain parametric and nonparametric factors. These statistical methods must be used with care in order to preclude erroneous findings or conclusions. Wrong assumptions about the data characteristics (such as normality and independence of distribution of given measured attitudes) can lead to a worthless analysis. Most statistical methods are further limited by the sizes and types of samples available. Generally, questions that may be answered with statistical validity are related to parameters of the following types:

- Means (average)
- Variances (variation)
- Moments (higher order variations)
- Skewness (asymmetry)
- Covariances
- Correlation (linear relationship)
- Independence
- Same population (similarity)
- Trends (with time, location, etc.)
- Proportions
- Grouping
- Clustering
- Factor (intercorrelation)
- Ranks
- Differences

Before proceeding with the details of the statistical tests employed, it is useful to categorize statistical tests generally and to present some examples of their appropriate applications. The two general categories of tests are parametric and nonparametric.

A parametric test is one that makes use of a model based on an assumed distribution of the population being tested and one that most often also makes assumptions about the parameters of the population. A somewhat familiar example is the much used t-test, which is used to test whether two samples have the same mean. The assumptions made are that both samples are from normally distributed populations and that the two samples have the same variance (dispersion). If the assumptions fail, then the conclusions reached through the parametric test are invalid. In conducting tests in a relatively unknown environment, the conclusions based on parametric tests must be viewed with restraint until it can be demonstrated that the assumptions required for their use are satisfied.

In contrast are the nonparametric tests, which are also called distribution-free tests. These tests do not require assumptions regarding the population probability distributions and are, therefore, applicable in any situation where the sample values are independent, a fundamental requirement for statistical inference from sample data.

In situations where the parametric assumptions are known to hold exactly, the parametric tests are more powerful and more efficient (requiring less data) than the corresponding nonparametric tests because they take advantage of the distributional shape. However, if the assumptions are not satisfied, the question of comparative efficiency is irrelevant as only the nonparametric tests yield accurate estimates in that instance.

The following are examples of parametric tests:

- The chi-square test for variance, the Student's t-test for means
- The F-test for variance ratios
- The estimation of the Poisson and binomial parameters

The following are examples of nonparametric tests:

- Kendall's test for correlation
- The Mann-Kendall test for trend
- Tolerance intervals based on order statistics
- Rank correlation
- Median tests
- Distribution-free contingency tests.

Descriptions of the principal statistical methods employed in the analysis of the pretest, posttest, and monthly questionnaire data follow.

1. The Kolmogorov-Smirnov one-sample test. The Kolmogorov-Smirnov one-sample test is a test of goodness of fit. This test is useful when it is desired to check the agreement between the distribution of an empirical distribution and some specified theoretical distribution. For example, the most commonly used statistical tests, such as t-tests, Z-tests, and F-tests, assume normality, independent observations with equal variances. That is, the assumption is that the sample parameter values are from a population having values distributed according to

$$f(z) = p(z) = \frac{1}{2\pi} \exp(-Z^2/2) \qquad -\infty < z < \infty \qquad (2\text{-}1)$$

If such an assumption is wrong, conclusions based on the above tests and assumptions are at best questionable. The K-s test can be used to determine the reasonableness of assumptions about any underlying theoretical distribution.

The method involves the cumulative frequency distribution, which for the Gaussian (normal) density function f(z), is given by

$$F(z) = P(z > z_\alpha) = \int_{z\alpha} \frac{1}{\sqrt{2\pi}} \exp(-Z^2/2)\, dz \qquad (2\text{-}2)$$

For example, consider a test to determine if an observed cumulative frequency distribution $S_N(x)$ is normally distributed. $S_N(x)$ is obtained from a sample of N observations for which

$$S_N(x) = k/N \tag{2-3}$$

where x is any possible value and k is the number of observations equal to or less than x.

The null hypothesis H_0 is that the sample has been drawn from a population having the specified theoretical distribution $F_0(x)$. Therefore, it is expected that the difference between S(x) and $F_0(x)$ should be close for all values of x. Specifically, the difference should be within the limits of random errors if H_0 is true.

The Kolmolgorov-Smirnov test is a test on the largest difference between $F_0(x)$ and S(x) and is defined as

$$D_n = \sup_x |S_n(x) - F_0(x)| \tag{2-4}$$

D_n is completely distribution-free when H_0 holds. When $S_n(x)$ and $F_0(x)$ are plotted as ordinates against x as abscissa, D_n is simply the largest vertical difference between them. For example, if a sample distribution is tested for the Gaussian (normality) assumption and D_n is found to be 0.175, the probability is 0.94 that the sample came from a normal distribution.

2. The Kolmogorov-Smirnov two-sample test. The Kolmogorov-Smirnov two-sample test is similar to the one-sample test. It is a test to determine whether two "independent" samples are from the same population. Since all the participants are police officers, "independent" is used in the sense that a sample "group" (such as a department) is a separate entity. The two-tailed test is sensitive to most differences such as location (central tendency), dispersion, or skewness. The one-tailed test is used to determine

whether the values of the population from which one sample was drawn are stochastically larger (or smaller) than values from the other population. The general hypotheses are as follows:

H_0: The two groups are from populations with the same distribution.

H_1: The two groups are from different distributions (two-tailed)

H_1: Group 1 is from a distribution having values stochastically larger than Group 2. Another alternative is that the opposite is true.

When the sample sizes are larger than 40, tables may be used which do not require that the samples n_1 and n_2 be equal. The value of D_{max} may be computed from the sample sizes by

$$D_{max} = K\alpha \sqrt{\frac{n_1 + n_2}{n_1 n_2}} \qquad (2\text{-}5)$$

where $K\alpha$ is a constant, dependent upon the desired confidence level. If the observed value of D^* given by

$$D^* = \sup_x \left| S_{n_1}(X) - S_{n_2}(X) \right| \qquad (2\text{-}6)$$

equals or exceeds the value computed above using the sample sizes, H_0 is rejected at the corresponding level of confidence.

3. Chi-square test for two independent samples. Pearson's chi-square test is used to test independence between two variables. It does not measure the degree of association. The test is only an indicator of the probability that an observed distribution by chance alone is different from an independent sample statistically drawn from the true distribution. The test is generally used to test the relative frequency with which members of two

or more groups fall into various categories. The general hypotheses may be stated as follows:

H_0: There is no difference in the assault rate of officers in the age groups of 20 to 30 and 30 to 40

H_1: There is a difference.

To test the hypothesis, the number of cases in both categories are counted, tabulated using a table, and compared using the equation given by

$$\phi^2 = \sum_{i=1}^{r} \sum_{j=1}^{k} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{2-7}$$

where

O_{ij} = the observed number of cases in the i^{th} row and j^{th} column

E_{ij} = the expected number under H_0 that would be categorized in the i^{th} row and j^{th} column.

The values of ϕ^2 are distributed approximately as chi-square with degrees of freedom equal to $(r - 1)(k - 1)$. For a specified sample size having the computed degrees of freedom df for a given confidence level, if the computed value of ϕ^2 exceeds the x^2 value given in table, H_0 is rejected at that level.

The assumptions are as follows: (1) the samples are independent; (2) the expected frequencies are > 5*; and (3) the sample size is > 20.*

4. Nonparametric correlation analysis (Spearman's r_s and Kendall's tau). Both techniques produce standardized coefficients based on the amount of agreement between two sets of ordinal rankings. The methods may be used for different types of data composition. For example, Spearman's method is usually preferred when two sets of data include a

*Otherwise, Fisher's exact test must be used.

number of ties in ranking. Spearman's r_s method yields a closer approximation to product-moment correlation (Pearson's) coefficients when the data are more or less continuous. Kendall's coefficients are somewhat more meaningful when the data contain a large number of tied ranks. The details of Spearman's method, only, are described.

The equation for computing Spearman's correlation coefficient is given by

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^2}{N^3 - N} \tag{2-8}$$

where N is the number of observations and d_i is the difference between two sets of scores.

A correction for tied ranks may be made using the following equation:

$$r_s = \frac{T_x + T_y - \sum_{i=1}^{N} d_i^2}{2(T_x T_y)^{1/2}} \tag{2-9}$$

where T_x or T_y is defined by

$$\frac{N(N^2 - 1) - \Sigma R (R^2 - 1)}{12}$$

where R is the number of ties at a given rank for x or y, respectively. The significance of r_s can be determined by comparing the quantity $r_s [(N-2)/(1 - r_s^2)]^{1/2}$ with the Student's t-distribution with N-2 degrees of freedom.

5. Simple and multiple regression models. The correlation coefficient or normalized simple regression coefficient is a measure of the linear relationship between an independent variable and a dependent variable. Multiple regression is a method that provides a linear relationship between a set of independent variables and a number of dependent variables while also considering the interrelationships among the independent variables. This method provides a means to maximize the correlation, which subsequently may be used to predict the values of the dependent variables.

The "linear" model is linear in the parameters only. The "order" of the model is defined to be equal to the highest power of the independent variable. For example,

$$y = B_0 + B_1 x + B_2 x^2 + e \tag{2-10}$$

if of second order but linear in the B's. A simple model that may be used as an example for parameter estimates is

$$\hat{y} = b_0 + b_1 x \tag{2-11}$$

where y is the predicted value of y for a given x.

The sum of the square of deviations from a true line are given by

$$S = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} (y_i - B_0 - B_1 x_i)^2 \tag{2-12}$$

The estimates b_0 and b_1 can be determined by differentiating with respect to B_0 and then B_1 and setting the results equal to zero which gives

$$\frac{\partial S}{\partial B_0} = -2 \sum_{i=1}^{N} (y_i - B_0 - B_1 x_i) \tag{2-13}$$

and

$$\frac{\partial S}{\partial B_1} = -2 \sum_{i=1}^{N} x_i (y_i - B_0 - B_1 x_i) \tag{2-14}$$

from which the normal equations, with substitutions (b_0, b_1) for (B_0, B_1) are defined as

$$b_0 N + b_1 \sum_{i=1}^{N} X_i = \sum_{i=1}^{N} y_i \tag{2-15}$$

and

$$b_0 \sum_{i=1}^{N} X_i + b_1 \sum_{i=1}^{N} X_i^2 = \sum_{i=1}^{N} x_i y_i \tag{2-16}$$

Solving for b_1 and b_0 gives

$$b_1 = \frac{\Sigma (x_i - \overline{X})(y_i - \overline{y})}{\Sigma (x_i - \overline{X})^2} \tag{2-17}$$

and

$$b_0 = \overline{y} - b_1 \overline{X} \tag{2-18}$$

From which the approximate y_i values, given x_i, may be determined and plotted.

6. Kruskal-Wallis one-way analysis of variance. The Kruskal-Wallis test is an extension of the Mann-Whitney test and provides an alternative to the parametric F-test (one-way analysis of variance). The general hypotheses are based on medians as follows:

H_0: The medians of the K populations are equal.

H_1: At least one of the populations has a median different from the others.

The procedure is as follows: (1) Combine all scores for all K samples and rank in a single series; (2) replace scores by ranks of 1-to-N for lowest to highest score, respectively; (3) tabulate the ranks for each sample and sum; and (4) the H-statistic is calculated as

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} + (N+1) \qquad (2\text{-}19)$$

where

K = number of samples

n_j = number of cases in the j sample

N = Σn_k total number of cases for all samples

R_j = sum of ranks in jth sample

Under H_0, the H statistic is distributed as X^2 with K - 1 degrees of freedom if $n_j > 5$; otherwise, n_j's must be lumped to total > 5.

The assumptions are as follows: (1) All samples are random from their respective populations; (2) there is independence within samples and among individual examples; (3) all random variables are continuous; and (4) the measurement scale is at least ordinal.

In this study the unit of analysis to which these tests were applied was the city by garment type by shift by month. That is, the mean value of the responses to a particular variable for all officers in a particular city by garment type by shift by month was used as the unit of analysis. There were 15 cities, 14 garment types, 3 shifts (before 0800 hours, 0800 to 1600 hours, and 1601 to 2400 hours) and 12 chronological months yielding a maximum of 15 × 14 × 3 × 12 or 7650 units of analysis. All analyses were performed using the Statistical Package for the Social Sciences (SPSS) computer system of statistical subroutines, which includes among others those methods previously described.

D. Site Selection

For determination of the locations into which the test garments would be placed, the primary consideration was to provide maximum protection benefit to the law enforcement community. Additional requirements were representative geographical distribution, adequate trauma treatment facilities, and a recognized local trauma surgeon.

A review of the assault statistics on law enforcement personnel provided in the "Federal Bureau of Investigation Uniform Crime Report" indicated the highest officer assault rate occurred in the cities with populations of over 250,000 (these are identified by the FBI as Group I cities). A request was made to the Uniform Crime Reports Section to provide assaults with injuries data on law enforcement personnel for CY 1971 and 1972 for all Group I cities. The assault data were to reflect only officer injuries which resulted from the use of firearms and cutting weapons. The membership roster for the International Association for the Surgery of Trauma was obtained, and possible participating surgeons were identified. Table 2-3 shows the assault rate data and identifies whether local trauma surgeons were available in the highest assault rate cities. The 15 cities with the highest assault rate and registered trauma surgeons were selected and approached to participate in the program. Detroit was added as a result of a direct request from the Chief of Police to the LEAA.

Table 2-3. Police Assault Statistics – Assaults with Injury per 100 Officers

CITY	FIREARMS AND CUTTING WEAPONS 1971	FIREARMS AND CUTTING WEAPONS 1972	FIREARMS ONLY 1971	FIREARMS ONLY 1972	REGISTERED TRAUMA SURGEONS
MIAMI	3.92	2.73	3.22	1.09	✓
OAKLAND	2.34	-	1.52	-	✓
JACKSONVILLE	1.91	-	0.96	-	
AUSTIN	1.91	-	1.27	-	
WICHITA	0	1.88	0	1.17	
NEW ORLEANS	0.70	1.90	0.70	0.96	✓
ATLANTA	1.29	1.53	0.69	0.89	✓
ST LOUIS	1.39	0.49	0.94	0.49	✓
RICHMOND	1.13	1.24	0.57	0.18	✓
BIRMINGHAM	1.22	0	0.70	0	✓
PHILADELPHIA	1.10	0.34	0.12	0.07	✓
EL PASO	1.07	0	0.86	0	
ALBUQUERQUE	1.06	-	0.80	-	✓
TAMPA	1.06	0.18	0.18	0.18	✓
TUCSON	1.04	0.23	1.04	0	✓
NEWARK	1.03	0.61	0.27	0.55	✓
SEATTLE	0.50	1.02	0.42	0.60	✓
AKRON	0.38	0.99	0.19	0.99	
PORTLAND	0.14	0.97	0	0.41	✓
ST PAUL	0.20	0.86	0	0.17	✓
GROUP I AVG = 0.85					
DENVER	0.83	0.82	0.75	0.41	
BALTIMORE	0.47	0.77	0.26	0.31	
MEMPHIS	0.38	0.75	0.19	0.19	
MINNEAPOLIS	0.50	0.73	0	0.73	
CLEVELAND	0.52	0.52	0.35	0.43	
HOUSTON		0.63	-	0.43	
NATIONAL AVG = 0.47					

Each of the selected cities was contacted, and a briefing was presented outlining the proposed test program. At the conclusion of the briefing, each was asked to participate in the program and to provide additional detailed data. All the cities which were contacted agreed to participate and provide data, except Oakland, California, which declined on the basis that they were already planning to purchase armor for all their officers.

Figure 2-2 shows the geographic distribution of the candidate cities. This distribution provided good climatic variations representative of most of the continental United States.

E. Garment Selection

The development program demonstrated that 7-ply 1000-denier Kevlar would protect against the design threat of common handguns firing projectiles with ballistic characteristics between the .22-caliber, 40-gr round-nose lead bullet at 1000 fps or less and the .38-caliber, 158-gr round-nose lead

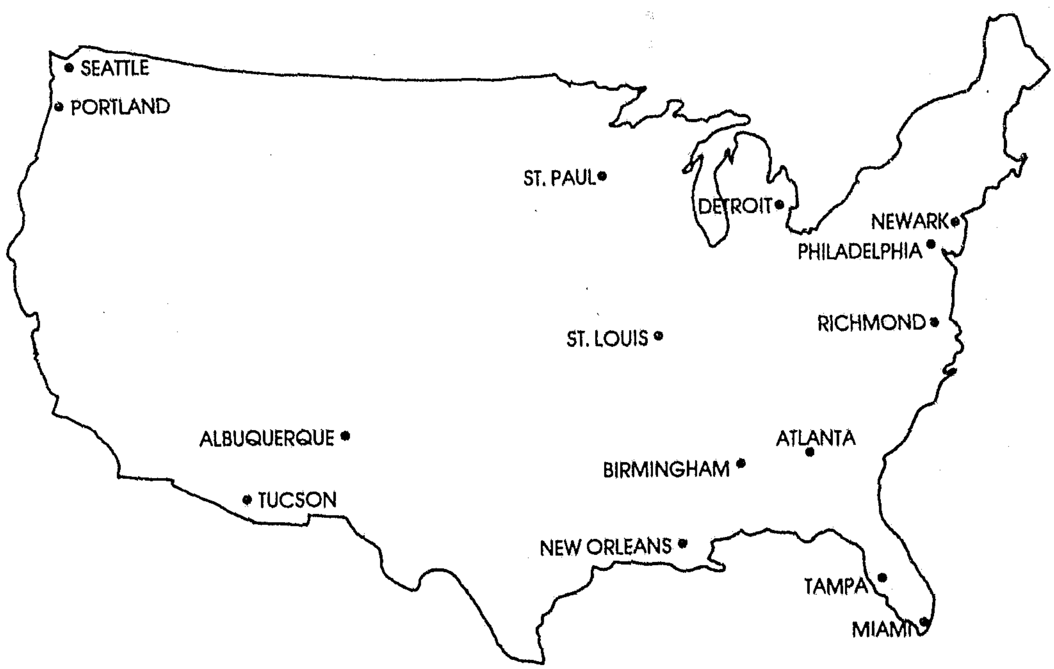

Figure 2-2. Geographical Distribution of Participating Cities

bullet at 800 fps or less. The baseline test garment, therefore, used 7-ply fabric armor as a minimum.

The development program, including the preliminary wearability test results, indicated the undergarment or undervest was the preferred configuration for a flexible continuous-wear apparel. The so-called integrated garments were limited in that they were generally seasonal-wear garments and for the most part front opening. Although they were well-received by the departments which reviewed them and by the officers who evaluated them, the wearing limitations and subsequent loss of protection during the nonwear months limited their utility to special purpose wear considerations, only.

The undergarment design underwent a number of changes as the development program progressed. The final preferred design provided full wraparound upper torso coverage. An alternate to this design provided for a slight gap at each side as a possible partial solution to the heat retention problem. The two styles selected were designated Style I and Style II, respectively, and are shown in Figure 2-3. Three thousand seven hundred of the two styles in 7-ply construction were provided in the program (1850 in each of the two styles). In addition, 300 Style II garments with 10-ply Kevlar were provided to assess the wearability difference associated with the added number of plies.

Two hundred fifty integrated uniform jackets were provided, primarily, to assess their wearability and to demonstrate fabrication methods. One hundred fifty garments were short cloth jackets; 50 were reefer-coat construction; and 50 were leather jackets. All integrated garments contained 7-ply 1000-denier Kevlar.

One hundred garments designed specifically to fit female officers were provided in the program. The garments for the woman officers were equally distributed between 7-ply and 10-ply construction. These garments incorporated seams with demonstrated ballistic integrity in the bust area to improve the fit.

Style I

Style II

Figure 2-3. Style I and Style II Garments

In addition to the garments specifically constructed for the program, commercially available garments were purchased and tested. These garments were used primarily for wearability comparison testing. Two hundred of each of four types of garments were purchased. The commercial garments represented the equivalent of approximately 12-, 14-, 18-, and 24-ply Kevlar and were designated Styles A, B, C, and D, respectively.

The 12-ply commercial garment (Style A) was full wraparound construction with separate carrier and front and rear ballistic inserts. The inserts were 12-ply scoured (not Zepel-D treated) 1000-denier Kevlar in a water-resistant cover. This garment provides protection against penetration of most of the high-velocity .38-caliber rounds and the .45-caliber automatic round.

The 14-ply commercial garment (Style B) consisted of front and rear panel protection. The construction was a carrier with removable inserts. Ballistic fabric layup consisted of both untreated Kevlar and impregnated Kevlar, contained in a waterproof cover. This garment was advertised to provide nonpenetration protection against most .357-magnum and 9-mm projectiles.

The 16-ply equivalent commercial garment (Style C) had front and rear panel protection. Two garment types were provided by the manufacturer. The first consisted of 8-ply Kevlar and 8-ply ballistic nylon. The outer ballistic nylon plies formed the cover. Advertised protection was for nonpenetration of most .357-magnum projectiles. The second version consisted of 16- to 18-ply Kevlar. No impregnated fabric was used, and penetration protection was advertised to include most 9-mm and most .357-magnum projectiles.

The final commercial garment (Style D) was 24-ply equivalent Kevlar. Construction details on this garment were proprietary. The garment was advertised to protect against ballistic impacts of most projectiles from the .44-magnum handgun.

Table 2-4 summarizes the various garments used in the test program.

F. Procurement

A relatively large number of procurement actions are required to support the lightweight body armor test programs. The majority of the procurements involved the purchase of Kevlar fabric and the fabrication of garments. The services of a data processing and evaluation contractor were also subcontracted.

The single most expensive procurement was for the weaving of the Kevlar fabric which was used in fabricating the test armor. The woven material, with Zepel-D treatment, was purchased in accordance with an Aerospace-developed specification.[2] The subcontract was let on the basis of an advertised competitive low-bid award. During quality control ballistic testing, it was noted that the fabric indicated a reduced penetration

Table 2-4. Test Garments

Designation	Description	Quantity	Approximate Equivalent Plies
LEAA Style I	Full wraparound	1850	7
LEAA Style II	Contoured wraparound	1850	7
LEAA Style II	Contoured wraparound	300	10
Women's	Full wraparound	50 50	7 10
Integrated 1	Seattle North Slope jacket	50	7
Integrated 2	St. Paul mackinaw	50	7
Integrated 3	Tucson jacket	50	7
Integrated 4	Detroit reefer coat	50	7
Integrated 5	Newark leather jacket	50	7
Style A	Commercial full wraparound	200	12
Style B	Commercial front and rear panels	200	14
Style C	Commercial front and rear panels	200	18
Style D	Commercial front and rear panels	200	24

resistance when compared to the fabric used in the development testing. An investigation revealed that the new fabric was being woven from a different merge of Kevlar yarn provided by DuPont. The new merge caused problems in the weaving operation, and the resultant fabric demonstrated reduced tensile strength and ballistic resistance. Investigations by DuPont, the weaver, and Aerospace resulted in changes to the manufacturing methods used by DuPont and improvements in the weaving operations which resulted in an acceptable fabric. The new fabric had improved ballistic resistance when compared to the development fabric although the tensile performance was still slightly degraded.

The original purchase order, as amended, was for 23,000 yards of material. As experience was gained in fabricating the garments, the purchase order was modified to reduce the total to 17,500 yards of fabric.

The LEAA Style I and Style II garments were also purchased on the basis of an advertised competitive low-bid award. Under this subcontract, 4000 garments were fabricated. The Aerospace Corporation was responsible for providing ballistic material woven to the approved specification. The subcontract was responsible for providing the goods and services to fabricate the two styles of garments in accordance with the garment specification[3] provided as part of the request for proposals. Patterns, size schedules, and serial numbering requirements were provided to the subcontractor.

The purchase of the commercial garments was accomplished by direct purchase order. In this case, the available commercial garments were reviewed in terms of construction and style to best fit the comparative wearability requirements. A recommended list of garments was submitted to the Government Program Manager for review and approval. Purchase orders were issued to the selected vendors. These garments were off-the-shelf items with the vendor supplying materials and design.

For the integrated uniform jackets and coats, the overriding requirement was that they be identical in external appearance to the department-issued garments. Five cities were selected to perform wearability testing on the integrated jackets, and the suppliers of the issue jackets were identified. Each supplier was contacted to determine his interest in constructing ballistic resistant models of the issue jacket by installing liners of 7-ply Kevlar in the standard jacket. Design flexibility was allowed each of the manufacturers to optimize the installation and to provide coverage in the front opening area. The first articles were required for Aerospace review and approval prior to fabrication of the 50 deliverable items. Bids were submitted by the manufacturers and purchase orders issued for garment fabrication. The Aerospace Corporation provided the specification ballistic fabric (Kevlar), and the subcontractor provided the goods and services to manufacture the items.

The women's protective undergarments were purchased by limited competitive procurement actions. Samples of commercial women's protective garments were reviewed for design, fabrication, and styling considerations. Two manufacturers had styles which were acceptable to the program requirements. Both vendors were requested to submit bids on 100 garments of which 50 were to be 10-ply and 50 were to be 7-ply Kevlar. The contract was awarded to the low bidder. The Aerospace Corporation provided the specification Kevlar material, and the subcontractor provided the goods and services to complete the fabrication.

The final major procurement was for the services of a data processing and evaluation subcontractor. The primary reason for the decision to subcontract this effort was the expected volume of the data to be received and the need for sociological and psychological interpretation of the data results. A statement of work was prepared which included the Aerospace test plan as a key technical exhibit. Proposals were received, and a subcontract was awarded to the low bidder. The contract performance period was approximately nine and one-half months.

CHAPTER III. STATISTICAL ANALYSIS

A. Garment Acceptability

The purpose of the results reported in this section is to determine the degree to which the garments are acceptable by the individual officer. The two principal objectives were to evaluate the officers' attitudes toward the garment and the extent to which the garment was used.

1. Officer attitudes. The three attitudinal questions which were asked concerning how individual officers felt toward the protective garments were:

- Do the garments afford an adequate level of protection?
- How does the officer feel while wearing the garment while interacting with the public?
- How does the officer feel toward his peers while wearing the vest?

a. Level of protection. The officers were asked to respond in terms of the level of protection they would find adequate for a continuous-wear garment, and they were asked to indicate this acceptable level of protection in terms of the pretest and posttest Question 31:

31. From the following list indicate what you feel is an acceptable level of protection for a continuous wear garment on your normal street duty assignment?

	Protection Level	Thickness (ins.)	Weight (lbs.)
1)___	None	-	-
2)___	.38 special	1/8	1.5
3)___	.45 auto	3/16	2.0
4)___	.357 mag	1/4	3.0
5)___	.9 mm auto	5/16	3.5
6)___	.41 mag	3/8	4.0
7)___	.44 mag	1/2	4.5

The distribution of responses to this item aggregated by the pretest, posttest, and participation groups is shown in Table 3-1. Figures 3-1 and 3-2 indicate, graphically, the proportion of officers with complete test data who responded in terms of the categories above.

Table 3-1. The Distribution of Acceptable Level of Protection for Continuous-Wear Garments Aggregated by Type of Instrument and Participant Group

	Within Group Percentage			
Instrument	Pretest		Posttest	
Participant Group	Test	Control	Test	Control
Number of Subjects	4037	533	2933	364
Response Category				
None	1.0	7.9	3.4	9.6
.38 Special	25.6	15.0	24.7	15.1
.45 Automatic	12.8	8.1	15.2	9.1
.357 Magnum	27.0	23.2	19.8	17.6
9 mm Automatic	18.1	14.3	21.4	18.4
.41 Magnum	1.1	2.6	1.5	2.5
.44 Magnum	9.4	20.7	9.0	19.8
Missing	5.1	8.3	4.9	8.0

Most of the officers would find a garment adequate if the garment was effective against a projectile equivalent to a .357 magnum or less. About 28 percent of the officers indicated that an adequate garment would protect them from the impact of a .38 special. Less than 10 percent of the officers felt that no protective apparel was necessary.

The pretest data set contained the responses of 4570 officers (4037 test group and 533 control group). Of these, only 2722 officers had responded to this question on both the pretest and the posttest. A comparison was then made of the responses of officers who submitted only pretest

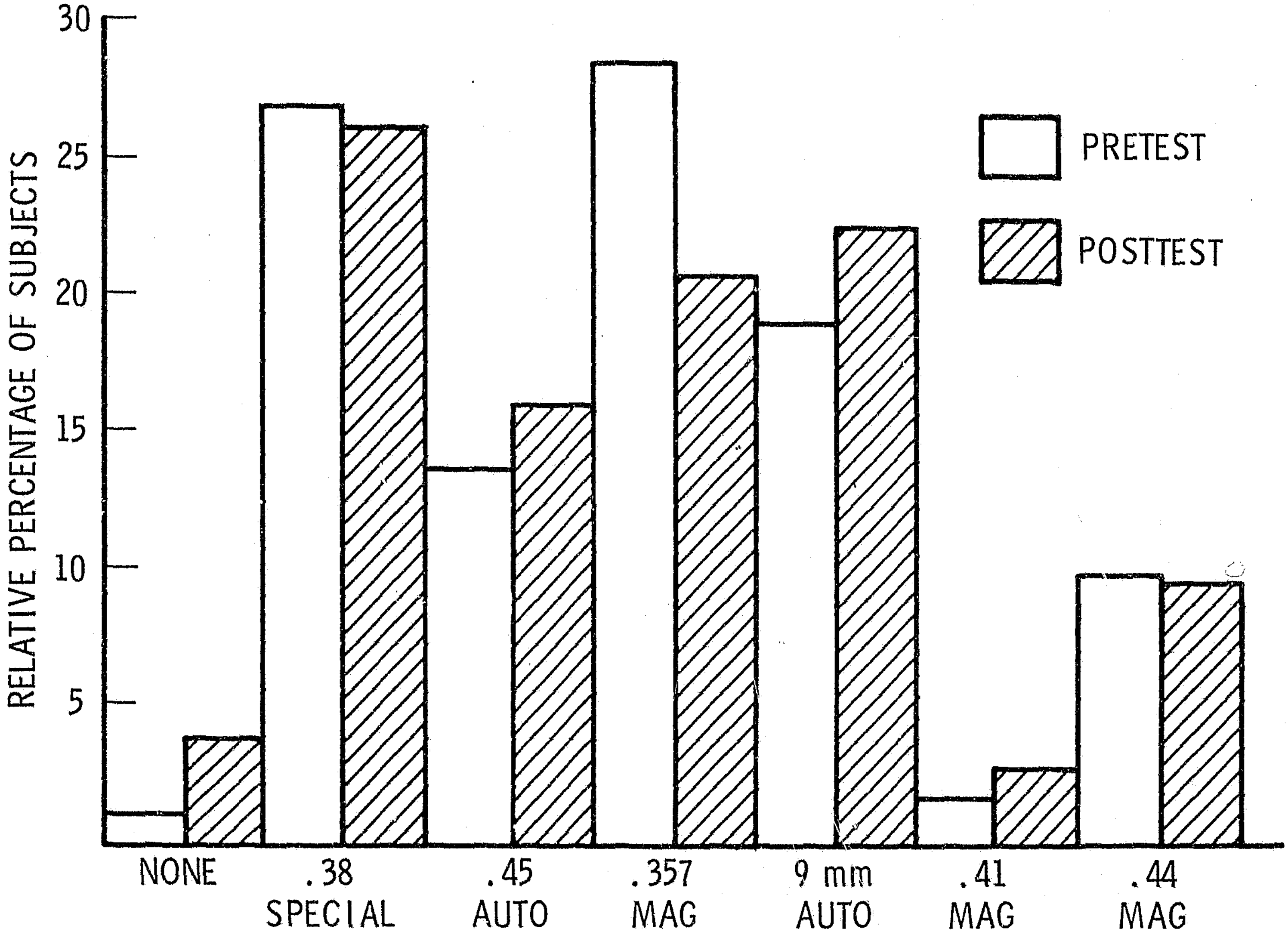

Figure 3-1. Acceptable Level of Protection — Test Group

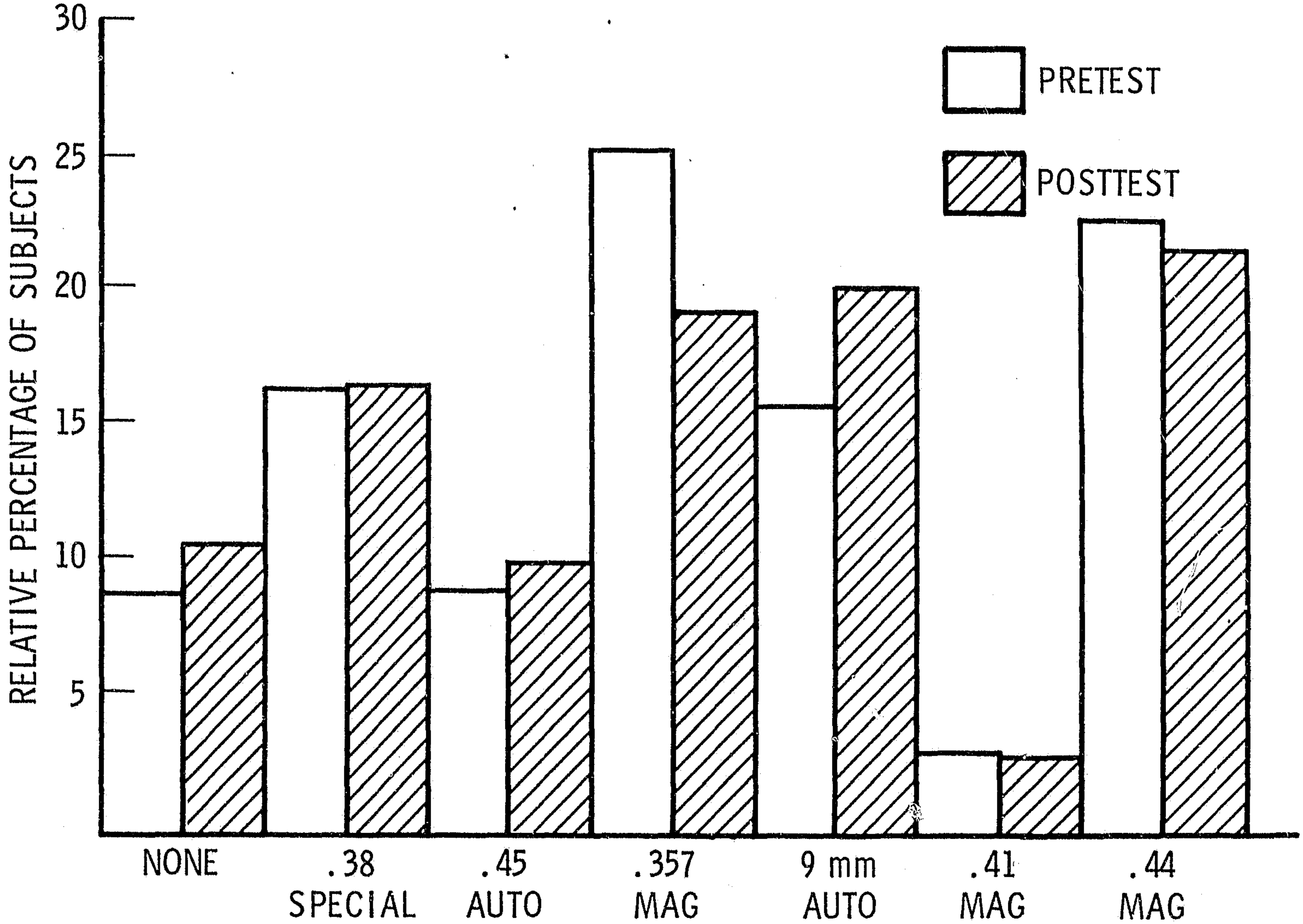

Figure 3-2. Acceptable Level of Protection — Control Group

information with officers who submitted complete information. The responses of the officers to this item as contained on the pretest data are shown in Table 3-2. The observed differences between the proportion of subjects in each response group to each type of response was found not to be significant using a chi-square test of proportions. Therefore, the group for which complete data were obtained (pretest and posttest) was considered to be representative of the entire group of officers.

Table 3-2. Pretest Within Group Proportion of Subjects That Indicated Particular Garment Acceptability Categories Aggregated by Whether or Not Complete Pretest and Posttest Data Were Obtained

Type of Data	Within Group Percentages	
	Complete Data	Pretest Data Only
Response Category		
None	1.7	2.4
.38 Special	27.2	23.2
.45 Automatic	13.3	12.3
.357 Magnum	28.8	26.9
9 mm Automatic	18.0	19.6
.41 Magnum	1.1	1.8
.44 Magnum	10.0	13.8

The Friedman analysis of variance procedure was applied to these data to determine if a significant change occurred over a period of time. The Kruskal-Wallis analysis of variance procedure was applied to determine if the participation groups differed systematically or differentially. The results of the application of these procedures are shown in Table 3-3.

No significant difference was observed between the pretest and the posttest relative to the adequate level of protection (chi-square = 0.111, df = 1, $p > 0.739$). The groups were also not found to behave

Table 3-3. Results of the Analysis of the Possible Significance of Observed Differences of the Officers' Concept of an Adequate Level of Protection

Source of Variation	Test Statistic	df	Significance[a]
Pretest Post Test Contrast	0.111[b]	1	>0.739
Between Groups Contrast	10.358[c]	1	<0.001
Interaction Contrast	0.111[c]	1	>0.999

[a]Probability of the observed value of the test statistic occurring by chance.

[b]Friedman Test Statistic

[c]Kruskal-Wallis Test Statistic

differentially over a period of time (chi-square = 0.000, df = 1, $p > 0.999$). Both groups did not change their desired level of protection, and no group submitted a pattern of variation over a period of time which was significantly different than any other group.

The test group was found to differ significantly from the control group in terms of the level of adequacy (chi-square = 10.358, df = 1, $p > 0.001$). On the average across questionnaires, the test group felt that a level of protection less than a .357 magnum and greater than a .45 automatic was necessary. Again, on the average and across questionnaires, the control group felt that a level of protection somewhat greater than a .357 magnum and less than a 9-mm automatic was required. The observed between group difference was found to exist across time. The test group was not found to behave differently after the garment was issued.

b. Psychological aspects. Question 34 on the pretest and posttest questionnaires for both groups was designed to assess the effect of the garment upon the officers' interaction with the public in terms of six dimensions: relaxation, effectiveness, safety consciousness, public hostility, security, and self confidence. The exact question asked was:

34. In your contact with the public while on duty do you feel:

Relaxed:
1)___ Very relaxed
2)___ Somewhat relaxed
3)___ Neutral
4)___ Somewhat tense
5)___ Very tense

Safety Conscious:
1)___ Very safety conscious
2)___ Somewhat safety conscious
3)___ Neutral
4)___ Somewhat less safety conscious
5)___ Much less safety conscious

Secure:
1)___ Very secure
2)___ Somewhat secure
3)___ Neutral
4)___ Somewhat insecure
5)___ Very insecure

Effective in interacting with citizens:
1)___ Very effective
2)___ Somewhat effective
3)___ Neutral
4)___ Somewhat frustrated
5)___ Very [illegible]strated

Feeling of Public Hostility:
1)___ Is very hostile toward the police
2)___ Is somewhat hostile
3)___ Neutral
4) Is somewhat friendly
5)___ Is very friendly toward the police

Self-Confident:
1)___ Very self-confident
2)___ Somewhat self-confident
3)___ Neutral
4)___ Somewhat apprehensive
5)___ Very apprehensive

Using a scale of 1 for a very positive response to 5 for a very negative response, the average pretest and posttest responses to the questions and their variances are given in Table 3-4 for the test and control groups. The mean responses are plotted for the six dimensions in Figure 3-3 through Figure 3-8. The pretest differences between the test and control group responses were tested using the Kolmogorov-Smirnov two-sample test. The

Table 3-4. Responses to Public Interaction Dimensions

Interaction	Group	Pretest		Posttest	
		Mean	Standard Deviation	Mean	Standard Deviation
Relaxation	Test	2.67	0.85	2.67	0.81
	Control	2.58	0.90	2.44	0.81
Effectiveness	Test	1.95	0.78	2.44	0.76
	Control	1.96	0.80	1.83	0.80
Safety Consciousness	Test	1.65	0.77	2.15	0.80
	Control	1.67	0.76	1.67	0.75
Public Hostility	Test	2.33	0.80	2.66	0.87
	Control	2.49	0.92	2.68	0.94
Security	Test	2.39	0.84	2.42	0.68
	Control	2.22	0.84	2.15	0.75
Self Confidence	Test	1.70	0.74	2.17	0.79
	Control	1.67	0.70	1.74	0.73

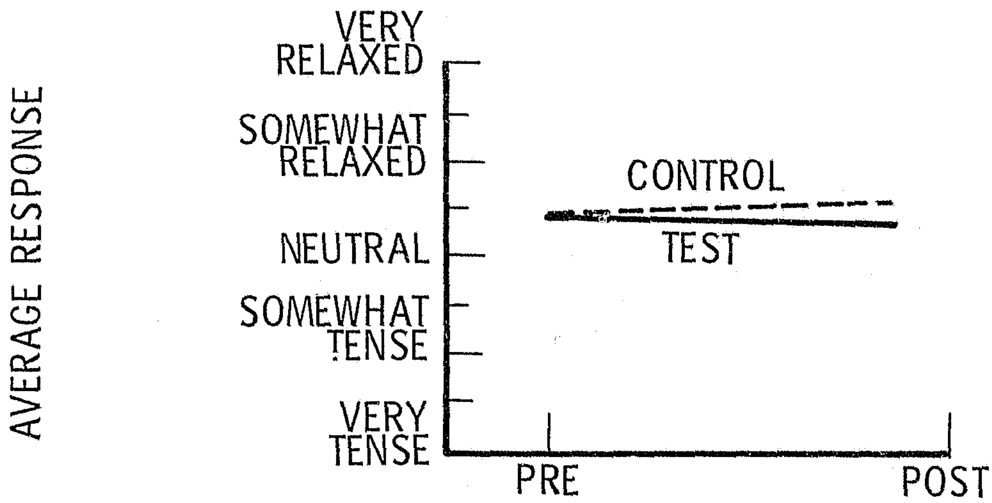

Figure 3-3. Relaxation

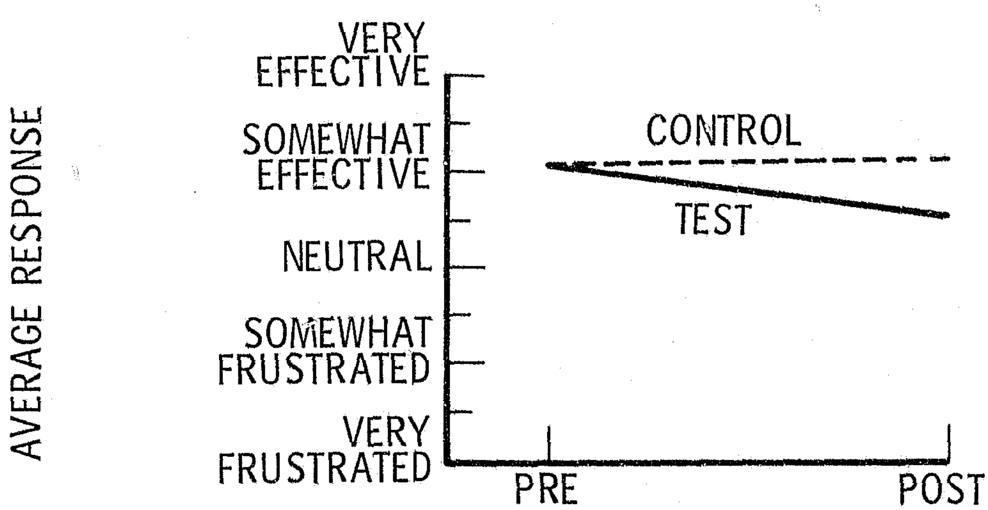

Figure 3-4. Effectiveness

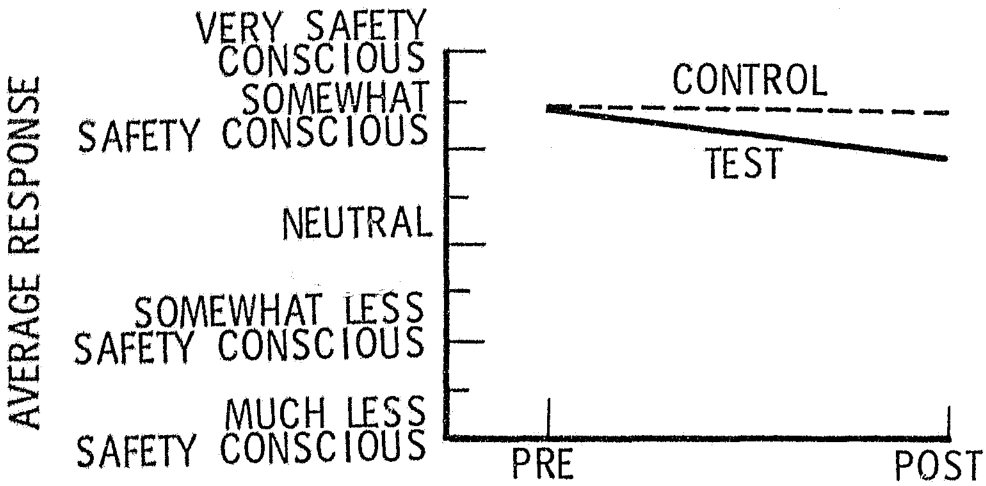

Figure 3-5. Safety Consciousness

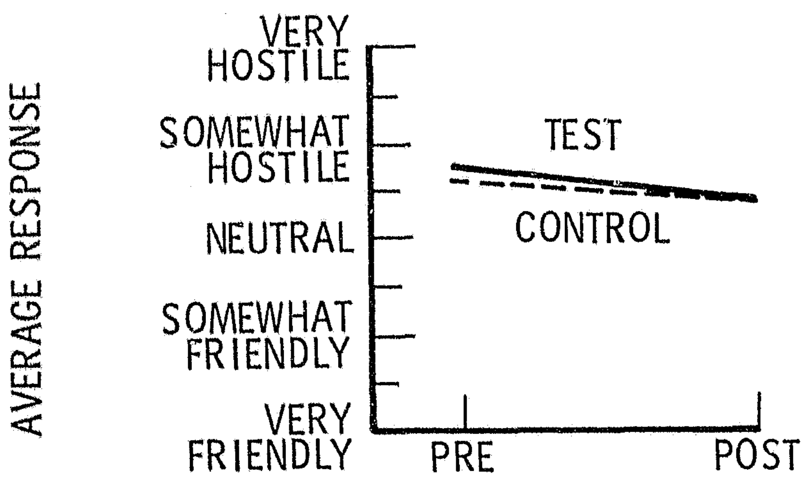

Figure 3-6. Public Hostility

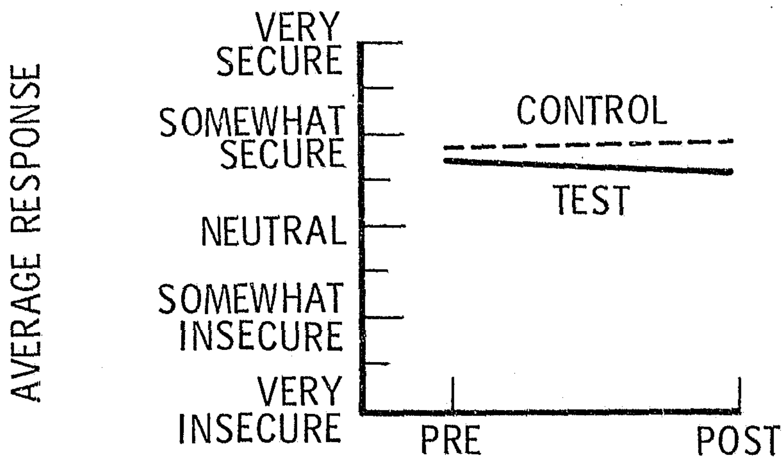

Figure 3-7. Security

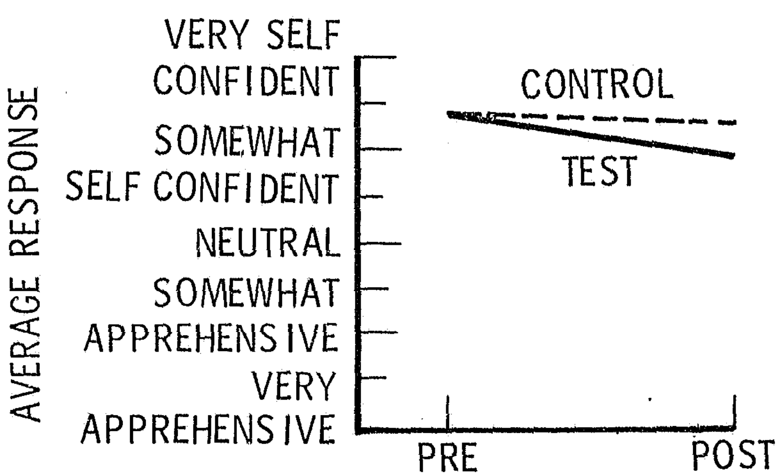

Figure 3-8. Self Confidence

only statistically significant difference was the response to the public hostility dimension. Checking Table 3-4, one can see that this difference is only 0.16, which is less than 25 percent of the standard deviation of the responses. Hence, it appears that the significance may be due to the large sample sizes involved, and, in reality, there may be no substantive difference between the two groups with respect to their pretest responses.

Again, using the Kolmogorov-Smirnov two-sample test, the responses of the two groups on the posttest questionnaires were examined. In this case, there were five dimensions which were statistically significantly different. These are relaxation, effectiveness, safety consciousness, security, and self confidence. In the case of relaxation and security, the observed differences of 0.23 and 0.27 are less than 40 percent of the corresponding response standard deviations and hence may not be true substantive differences. In the other three dimensions, the observed differences are greater than 50 percent of the corresponding standard deviations and hence may be real. If this is true, then the test group becomes slightly less effective, safety conscious, and self confident, with respect to the control group, after the test. Next the pretest and posttest responses were compared within the control group and within the test group. For the control group, there are three statistically significant pretest-posttest differences: relaxation, effectiveness, and public hostility. These differences are 0.14, 0.13, and 0.19, respectively, which are less than 20 percent of the corresponding standard deviations and hence do not appear to be real differences.

Of the six pretest-posttest differences within the test group, five are significantly different statistically: effectiveness, safety consciousness, public hostility, security, and self confidence. For public hostility and security, the differences are 0.33 and 0.03, respectively, which are less than 40 percent of the corresponding standard deviations and hence are probably not real. The differences for effectiveness, safety consciousness, and self confidence are all greater than 60 percent of their corresponding standard deviations and thus may be substantive.

In summary, the responses to this question suggest that at the start of the test, both groups felt that while interacting with the public they were:

- Neutral in their relaxed feelings
- Somewhat effective interacting with citizens
- Somewhat safety conscious
- The public was somewhat hostile
- They were somewhat secure
- They were somewhat self confident.

During the field test, the control group did not alter its feelings, while the test group changed over the test period in that they felt:

- Slightly less effective in interacting with citizens
- Slightly less safety conscious
- Slightly less self confident with respect to how they felt at the start of the test and with respect to how the control group felt at the end of the test.

Question 35 on the pretest and posttest questionnaires for both groups was designed to measure the "fatalism" feeling of the officers. The question was:

35. To what extent to you agree or disagree with the following statements?
"When your time is up, it's up, and there is nothing you can do to prevent it".
1)___ Strongly agree
2)___ Agree
3)___ Neutral
4)___ Disagree
5)___ Strongly disagree
"A good police officer doesn't need to wear a protective vest to adequately protect himself in any situation".
1)___ Strongly agree
2)___ Agree
3)___ Neutral
4)___ Disagree
5)___ Strongly disagree

The means and standard deviations of the pretest and posttest responses for the test and control groups are given in Tables 3-5 and 3-6, and the mean responses are shown in Figures 3-9 and 3-10.

Table 3-5. "When Your Time Is Up..." Wear Response

Group	Pretest		Posttest	
	Mean	Standard Deviation	Mean	Standard Deviation
Test	3.23	1.26	3.22	1.25
Control	3.22	1.27	3.22	1.29

Table 3-6. No Need for Vest

Group	Pretest		Posttest	
	Mean	Standard Deviation	Mean	Standard Deviation
Test	4.20	0.78	4.13	0.78
Control	3.89	0.90	3.84	0.94

The responses to Question 35 were analyzed using the Kolmogorov-Smirnov two-sample test. For the "When your time is up..." part of this question, there were no differences between the test and control groups on either the pretest or the posttest questionnaires and no pretest-posttest differences within the test or control groups. The responses remain constant within the neutral range.

With regard to the "No need for a protective vest" part of the question, statistically significant differences existed between the two groups in both the pretest and the posttest scores. These differences, 0.31 and 0.29, respectively, are less than 40 percent of the corresponding standard deviations and hence, again, the differences may not be substantive.

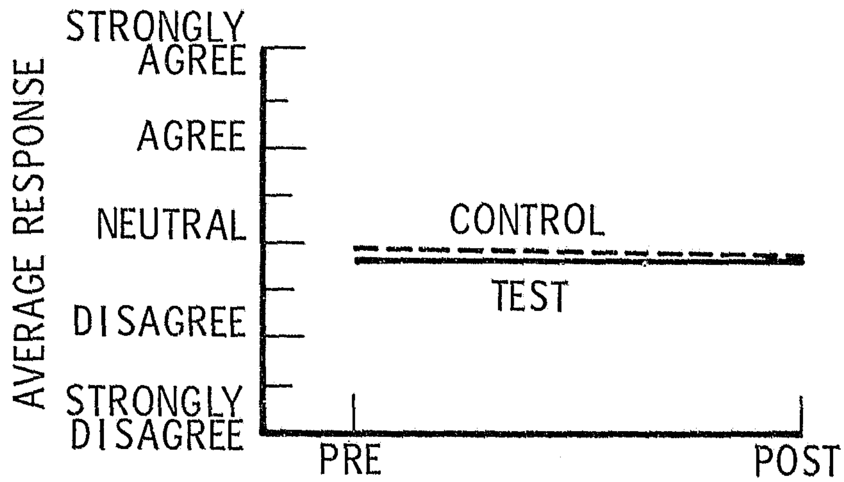

Figure 3-9. "When Your Time Is Up..." Wear Response

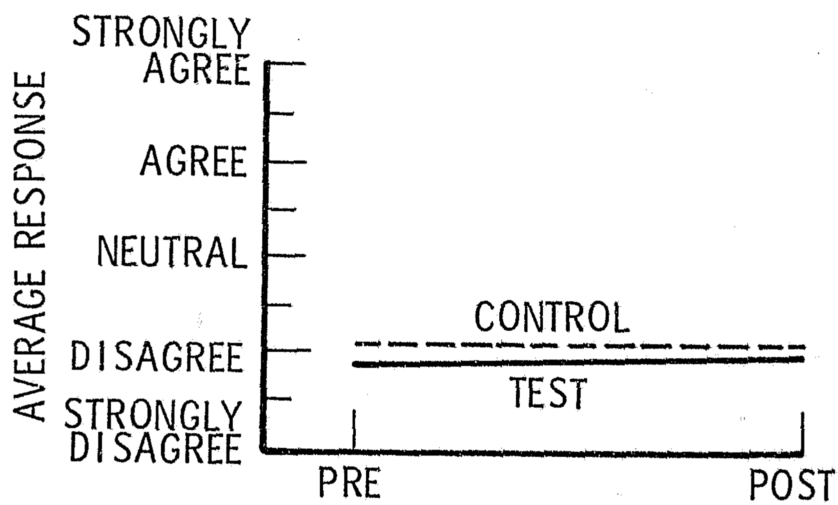

Figure 3-10. No Need for Vest

There was no pretest-posttest difference in the responses for the control group, but the difference (0.07) for the test group was just statistically significant. This difference is only 2 percent of the corresponding standard deviation and hence is probably not real. Thus, it appears that both groups responded in the same way to this question over the test and that they disagree with the statement that a good police officer does not need a protective vest.

A set of 20 optional questions, which are a version of Rokeach's Dogmatism Scale, was included on the pretest and posttest questionnaires for both the test and control groups. The dogmatism scale was designed as a means of determining the degree to which individuals manifest a particular personality construct called dogmatism. The highly dogmatic personality exhibits three basic characteristics: (1) the dogmatic personality type is opinionated in the sense that there exist sharp distinctions between beliefs and disbeliefs; (2) a person exhibiting a high degree of dogmatism is pessimistic and has a fear of power or other powerful people; (3) the dogmatic person believes strongly in the absolute nature of authority and is highly aggravated by other people who do not share this belief in authority and authority figures. The dogmatic personality relies greatly upon authority and categorically rejects opinions not concordant with his or her established values.

The question to be answered in this phase of the study is: Is the degree to which an officer reflects dogmatic characteristics affected by the wearing of body armor? The average dogmatism scores and their standard deviations for the two groups are given in Table 3-7, and the mean scores are plotted in Figure 3-11. The score which a person can receive ranges from 20 to 120; the higher the score, the more dogmatic a person is.

The data obtained from these questions were analyzed by means of the Kolmogorov-Smirnov two-sample test, and it was found that there were no differences between the test and control groups on either the pretest or the posttest and that there were no pretest-posttest differences with the test group or the control group.

Table 3-7. Dogmatism Scores

Group	Pretest		Posttest	
	Mean	Standard Deviation	Mean	Standard Deviation
Test	81.6	11.3	82.3	11.6
Control	81.8	12.4	80.8	14.3

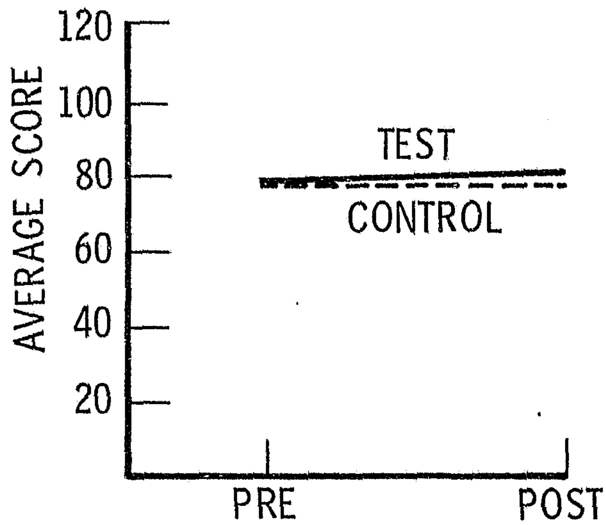

Figure 3-11. Dogmatism Scores

c. Peer group. Each member of the test group was asked to respond to pretest and posttest Question 38 in terms of the opinion of other officers to the garment:

38. (31) How do you think your fellow officers feel about your wearing a protective garment?

1) _____ Highly complimentary
2) _____ Complimentary
3) _____ Indifferent
4) _____ Critical
5) _____ Highly critical

The distribution of responses for the entire pretest and posttest, test group sample is shown in Table 3-8. The pretest and posttest responses of officers who responded are shown in Figure 3-12.

To assess the extent of missing data, the pretest responses to the item by officers who completed both questionnaires were compared with the responses of the officers who submitted only pretest information. The distribution of responses is shown in Table 3-9. The value of the raw chi-square for the cell frequencies corresponding to the entries in Table 3-9 was found to be 1.071 with four degrees of freedom. The probability of obtaining a value of chi-square at least as large due to chance is greater than 0.899. Therefore, there is no significant difference in the pretest response patterns of officers who submitted either only pretest data, or both pretest and posttest data. The officers for which both pretest and posttest data were available were considered representative of the entire sample of officers with respect to this item.

Table 3-8. The Distribution of Test Group Response to the Attitude of Other Officers to the Protective Garment Aggregated by Pretest and Posttest Samples

Instrument	Within Group Percentages	
	Pretest	Posttest
Number of Officers	4037	2933
Response Category		
Highly Complimentary	11.0	6.0
Complimentary	39.2	36.7
Indifferent	45.6	50.7
Critical	1.8	2.4
Highly Critical	0.2	0.2
Missing	2.1	4.0

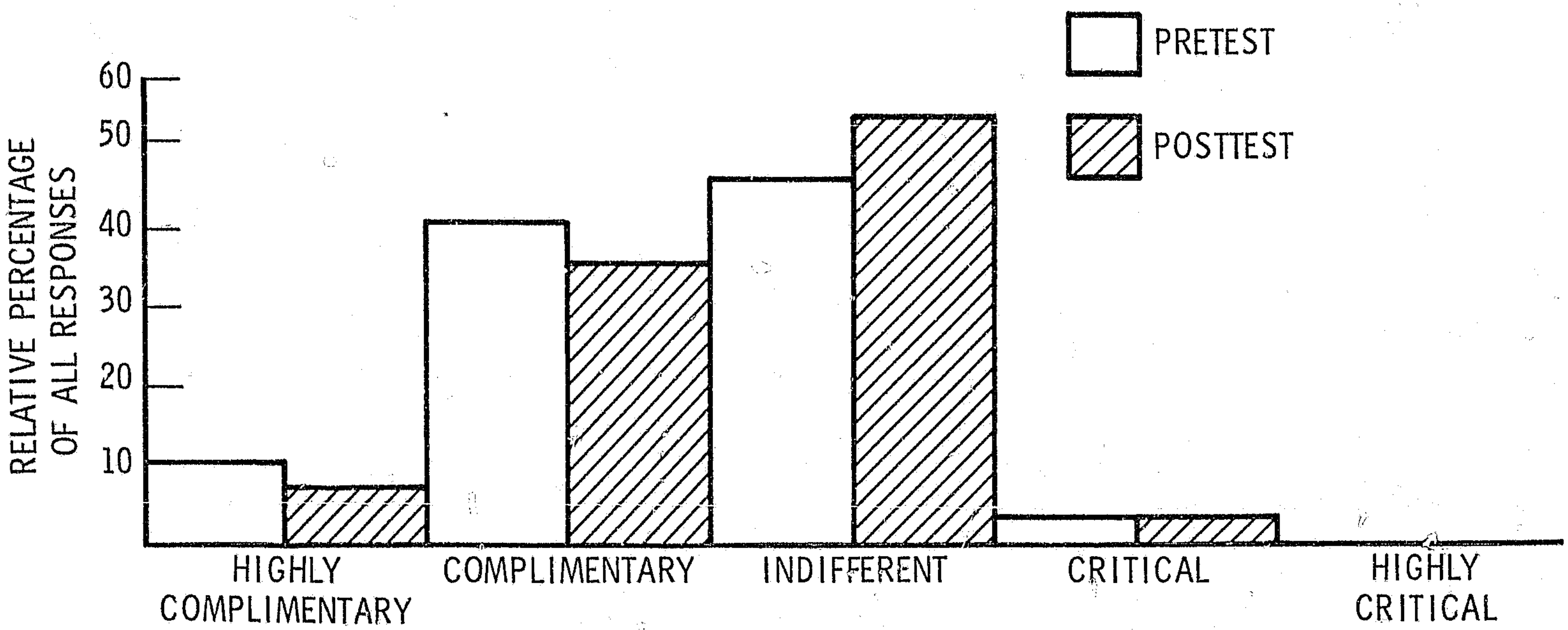

Figure 3-12. The Opinion of Test Group Officers of the Attitude of Other Officers to Protective Garments Aggregated by Pretest and Posttest

Table 3-9. The Distribution of the Test Group Pretest Responses to the Attitudes of Fellow Officers Toward Protective Garments Aggregated by Whether or Not Pretest and Posttest or only Pretest Data Were Available

Type of Data	Within Group Percentages	
	Complete Data	Pretest Only
Number of Officers	2586	1404
Response Category		
Highly Complimentary	11.2	11.5
Complimentary	40.5	39.4
Neutral	46.4	46.9
Critical	1.7	2.0
Highly Critical	0.2	0.3

The Friedman procedure was applied to the pretest and posttest data. The average pretest response was 2.976 with a standard deviation of 1.877. The average posttest response was 2.797 with a standard deviation of 1.424. The value of the Friedman test statistic with 2877 matched cases and one degree of freedom was 1.693. With a sample this size, the Friedman test statistic is distributed approximately as chi-square with one degree of freedom. The probability of obtaining a value of chi-square at least as large as 1.693 due to chance is greater than 0.193. Therefore, there is no apparent difference between pretest and posttest responses to this item. Most of the test groups felt that the attitude of other officers was one of indifference.

2. Garment utilization. The purpose of this phase of the study was to determine the amount of time the various garments were worn and to try and identify those factors which affected the wear frequency.

a. Wear history. Each test officer was asked to respond on the monthly questionnaire in terms of the garment wear frequency. The exact question and the associated response categories were:

7. What amount of the time did you wear the garment during the month?
1) ___ All the time
2) ___ All but a few hours
3) ___ About half the time
4) ___ A few hours
5) ___ Did not wear at all

For each garment type, the responses were converted for ease of interpretation into a single quantity called the "percent time worn." The formula use in this conversation was

Percent time worn = (Percent who wore all the time) +
0.75 × (Percent who wore all but a few hours) +
0.50 × (Percent who wore about half the time) +
0.25 × (Percent who wore a few hours).

In addition to the three LEAA garments, four examples of commercially available garments were selected. The characteristics of the commercial garments are as follows:

Garment Source	Equivalent No. of Plies	Coverage
A	12	Full wraparound upper torso
B	14	Front and rear panels only
C	18	Front and rear panels only
D	24	Front and rear panels only

For these seven garment types, a plot of the percent of time the garment was worn versus calendar month is presented in Figure 3-13. This figure shows an initial high acceptance and wear of the garments at the beginning of the program. As the novelty wore off and the weather became warmer, the garments were worn less and less. The upward trend from August to December

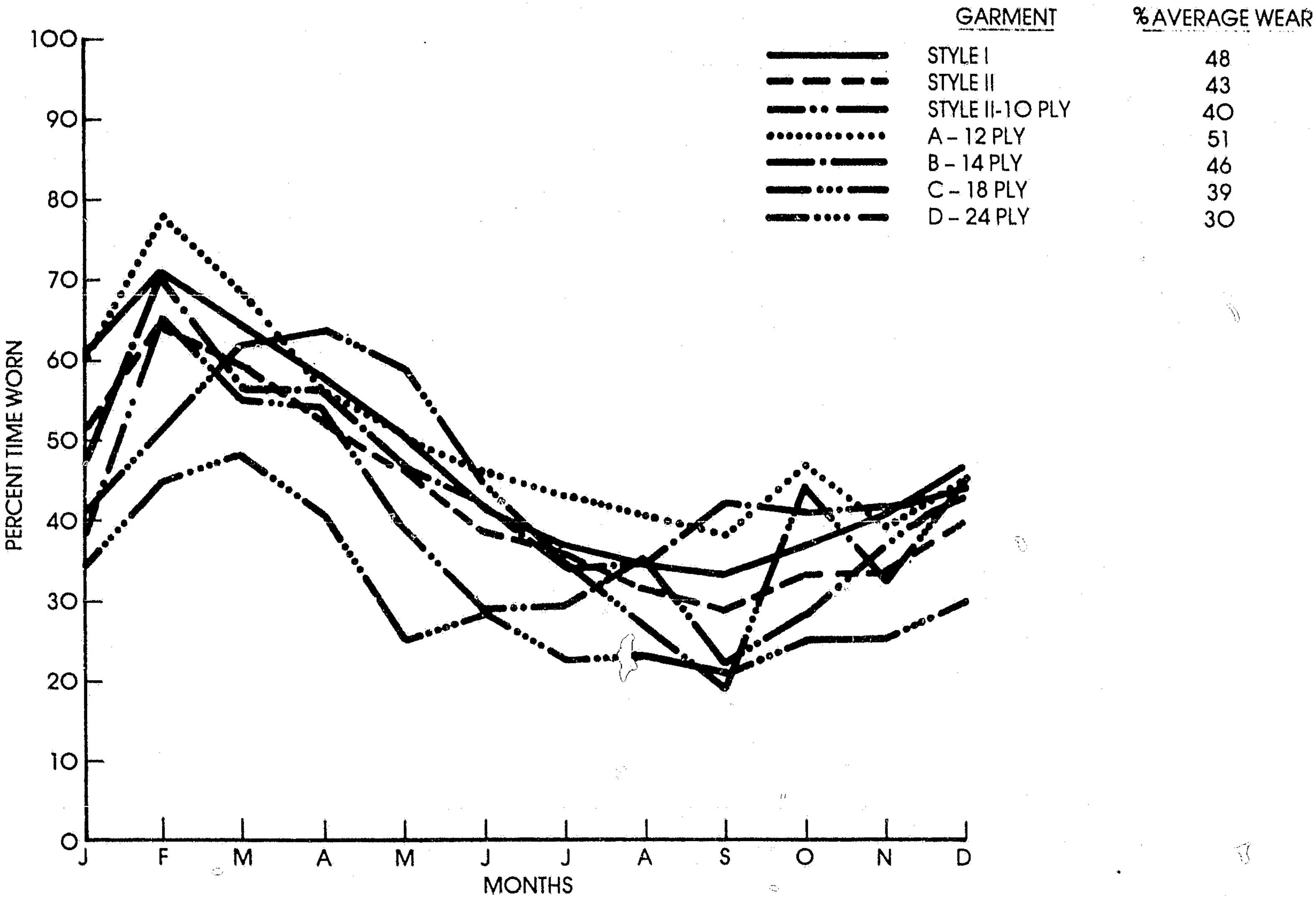

Figure 3-13. Garment Wear Versus Month

indicates the officers were willing to resume wearing the garments as the weather became cooler. A rough grouping of the garments shows the two garments with full wraparound protection were worn the most. The very heavy 24-ply garment was worn consistently less than any of the other garments. The remainder of the garments were distributed between these two.

In order to evaluate the effect that temperature and humidity had upon the frequency with which a garment was worn, National Oceanic and Atmospheric Administration (NOAA) weather data were obtained for the 15 test cities. From these data, the Temperature Humidity Index (THI) was computed for three shifts: 0001 to 0800, 0801 to 1600, and 1601 to 2400. These shifts were chosen to correspond to the three times of the day where there are the greatest temperature shifts. If an officer's work shift did not correspond with these time periods, the THI for the time period during which his work shift started was used.

The THI is calculated using the equation:

$$THI = 0.4 \times (T + TW) + 15$$

where

T = dry bulb temperature in degrees Fahrenheit

and

TW = wet bulb temperature in degrees Fahrenheit

The THI is used by the U.S. Weather Bureau as a measure of the degree of environmental discomfort one experiences. At indices below 70, few people experience discomfort. Values between 70 and 80 represent a transition period in which the sensation of discomfort increases with the index. At values above 80, discomfort becomes acute.

Figure 3-14 shows the percent of time a garment type was worn versus the THI, and one can see a rapid rate of decrease in the time a garment was worn for indices between 70 and 80. Again, the very heavy 24-ply garment was worn consistently less than any of the other garments.

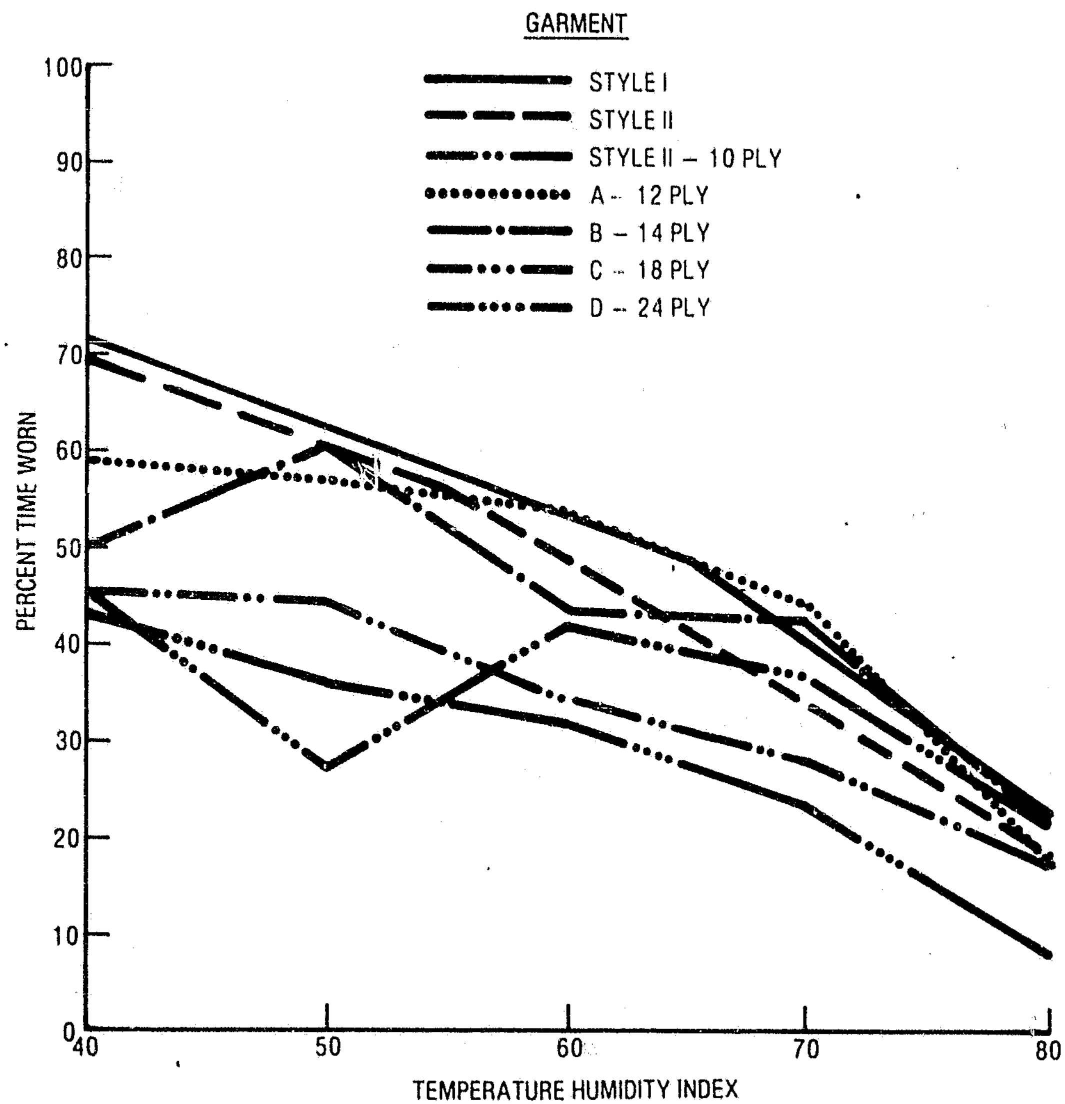

Figure 3-14. Wear History Versus Temperature Humidity Index

A factor correlation with the percent of time a garment was worn was performed. The most significant factor was the THI which had a negative correlation coefficient of -0.75 with wear. A summary of the correlation coefficients of wear with other measured factors is given in Figure 3-15. The coefficients falling within the range of ±0.1 are considered to be of marginal significance. Other than THI, it can be seen that the most significant factors involve garment comfort and freedom, officer age and weight, and characteristics of the officer's work area.

In addition to the monthly wear data, the test participants were asked to respond on the pre and posttest questionnaires as to how much they expected to wear and actually wore the garments during the summer (warm) months and winter (cold) months.

The distribution of pretest and posttest responses to the wear during the warm months is shown in Table 3-10. Table 3-11 shows the frequency of wear indicated on the pretest aggregated by whether or not the officer submitted pretest and/or posttest information. The largest difference in within group percentage was 1.8 percent. This did not produce a significant chi-square value, and thus the officers who submitted both pretest and posttest information are considered to be proportionately equivalent to the entire group of officers who submitted pretest questionnaires with regard to this item.

The average anticipated frequency of wear during the warm months as determined from the pretest data was 65.2 percent with a standard deviation of 18 percent. The same officers indicated a mean frequency of wear during the warm months on the posttest questionnaire of 38.6 percent with a standard deviation of 33 percent. The Friedman analysis of variance procedure was applied to these data to determine if the pretest-posttest contrast was statistically significant. The value of the Friedman test statistic was 1106.232. With a sample of 2877 matched cases, this value of the Friedman test statistic is distributed approximately as chi-square with one degree of freedom. The probability of obtaining a value of chi-square at least as large as 1106.232 with one degree of freedom is less than 0.011.

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1 OF 4

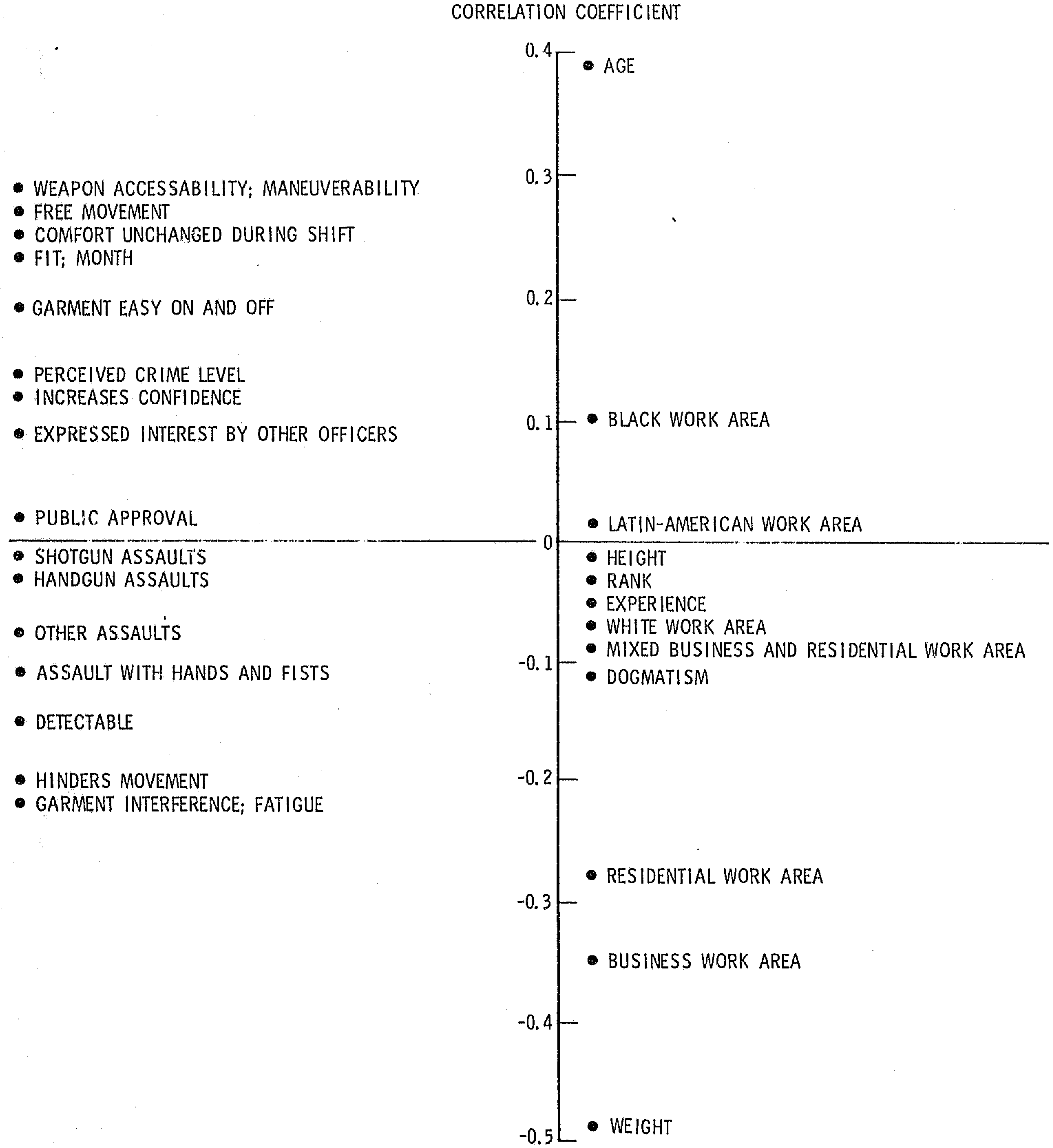


Figure 3-15. Correlation of Wear with Measured Factors

Table 3-10. The Distribution of Frequency of Wear During Warm Months Responses for Pretest and Posttest Respondents

Instrument	Within Group Percentage	
	Pretest	Posttest
Number of Officers	4037	2933
Response Category, %		
100	47.2	12.9
75	22.3	11.8
50	17.7	16.0
25	7.9	32.2
0	1.7	23.4
Missing	3.2	3.7

Table 3-11. The Distribution of the Pretest Garment Wear Frequency in the Warm Months Aggregated by Whether or Not the Officer Submitted Both Pretest and Posttest Information or Exclusively Pretest Data

Type of Data	Within Group Percentages	
	Complete	Pretest Only
Number of Officers	2554	1393
Response Category, %		
100	49.1	48.2
75	23.1	23.0
50	18.1	18.2
25	8.5	7.6
0	1.1	2.9

The general inference is that as officers wear the garment, they tend to be selective as to when they wear the garment; about 40 percent of the time during the warm months after one year of exposure.

The distributions of responses to the items regarding wear during the cold months for the entire pretest and posttest samples are shown in Table 3-12. Table 3-13 describes the distribution of responses to this item for the officers who submitted pretest information only. The maximum deviation of within cell proportions was less than three percent. This did not produce a significant chi-square value, and thus the officers that submitted both pretest and posttest information were considered equivalent to the original group of officers who submitted pretest questionnaires with respect to this question.

The responses of the officers who submitted both pretest and posttest questionnaires were analyzed using the Friedman procedure. This was performed to determine if the observed variation from pretest to posttest was statistically significant. The mean anticipated frequency of wear for cold months was 73.38 percent with a standard deviation of 54.28 percent. The mean reported posttest frequency of wear was 55.5 percent with a standard deviation of 59.00 percent. The value of the Friedman test statistic with 2877 matched cases was 1233.73. Given a sample of this size, the distribution of the Friedman test statistic is asymptotic to a chi-square distribution with one degree of freedom. The probability of obtaining a value of chi-square at least as large as 1233.73 with one degree of freedom due to chance is less than 0.001. Therefore, the observed decrease in frequency of wear during the cold months from 73.38 percent from the pretest to 55.5 percent on the posttest is statistically significant.

These data show that the officers wore the garments a lower percentage of the time than they anticipated at the start of the program. In actuality, the garments were worn approximately 55 percent of the time in the winter months and 40 percent of the time in the summer months.

Table 3-12. The Frequency of Wear During Winter or Cold Months Aggregated by Pretest and Posttest Samples for Test Group Subjects

Instrument	Within Cell Proportions	
	Pretest	Posttest
Number of Subjects	4037	2933
Response Category, %		
100	72.6	25.2
75	16.3	20.6
50	5.8	14.5
25	2.7	22.6
0	0.6	13.6
Missing	2.0	3.5

Table 3-13. The Pretest Frequency of Garment Wear During Cold Months for Officers Who Submitted Pretest and Post-test Questionnaires and Officers Who Submitted Only Pretest Questionnaires

Instrument	Within Cell Percentages	
	Complete Information	Pretest Only
Number of Officers	2587	1408
Response Category, %		
100	74.7	72.9
75	15.9	18.0
50	6.3	5.3
25	2.8	2.6
0	0.3	1.1

In addition to the approximately 5000 men's undergarments which were distributed, there were 50 women's LEAA 7-ply garments, 50 women's LEAA 10-ply garments, and 200 LEAA integrated uniform jackets distributed.

The questionnaire response from the test group wearing the LEAA women's 10- ply garments was not sufficient to allow any valid interpretation of the data. For the LEAA women's 7-ply garments, the percent of time worn versus month is shown in Figure 3-16 and the percent of time worn versus THI in Figure 3-17. The wear history for the women's 7-ply garments is similar to that of the LEAA men's 7-ply garments except that the women show a greater sensitivity to THI with a marked decrease in the percent of time they wear their garments for THIs over 70 as opposed to the men wearing 7-ply garments.

The integrated uniform jackets were designed for wear during the cold months, and therefore data were collected only for the months of November through March. The percent of time these garments were worn for these months is shown in Figure 3-18. This figure shows that the garments were worn a rather constant amount of time over this period and were well accepted with an average percent of time worn of 62 percent.

b. Reasons for not wearing. Each month the officers were asked the major reason for not wearing the garment. The exact question asked was:

8. What was the major reason for not wearing the garment?

1) __ Chafes
2) __ Binds
3) __ Rides up
4) __ Too hot
5) __ Too heavy
6) __ Too cumbersome
7) __ Inside duty
8) __ Did not want to
9) __ Not dangerous situation

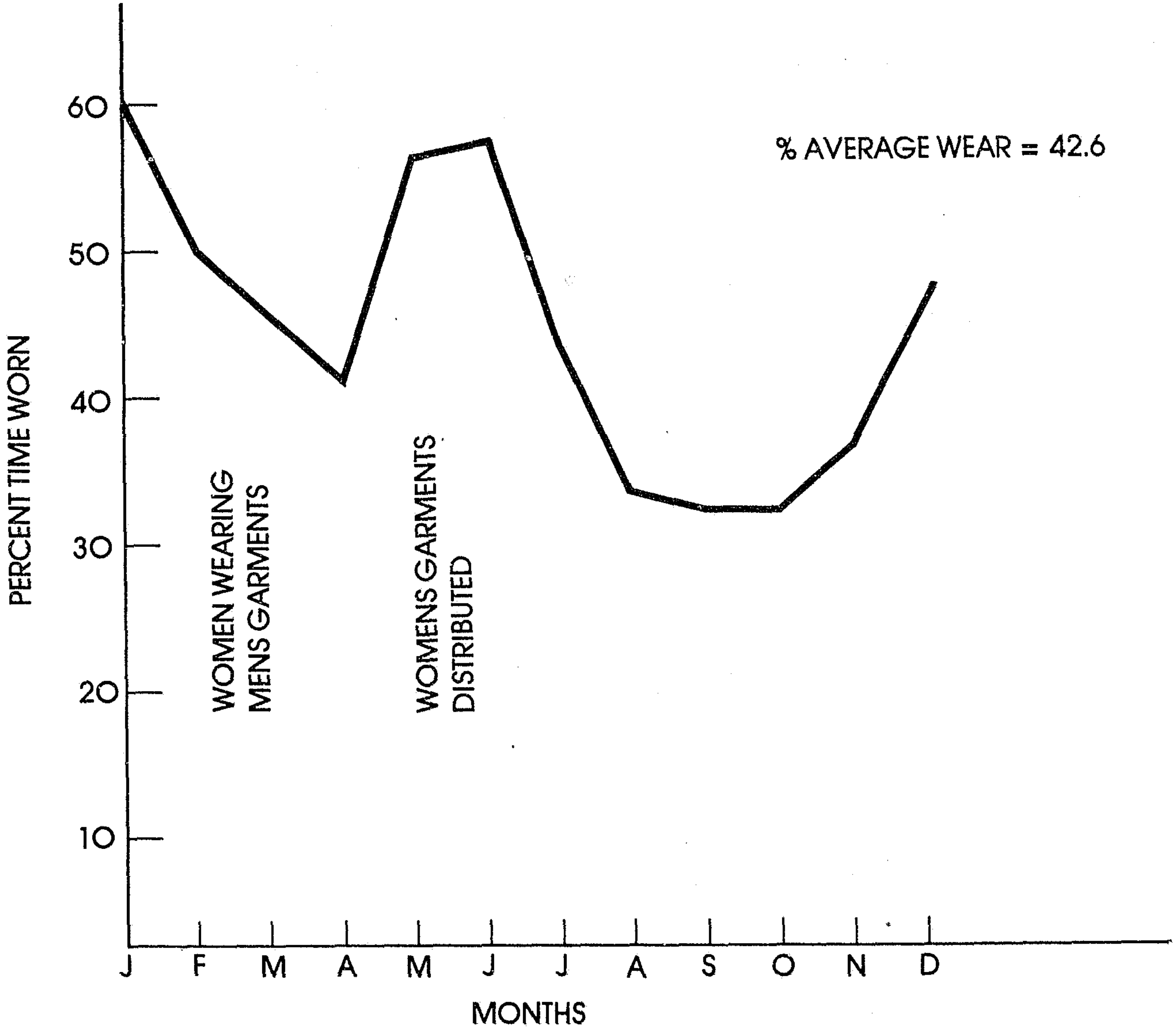


Figure 3-16. Wear History Versus Month – LEAA Women's 7-Ply Garment

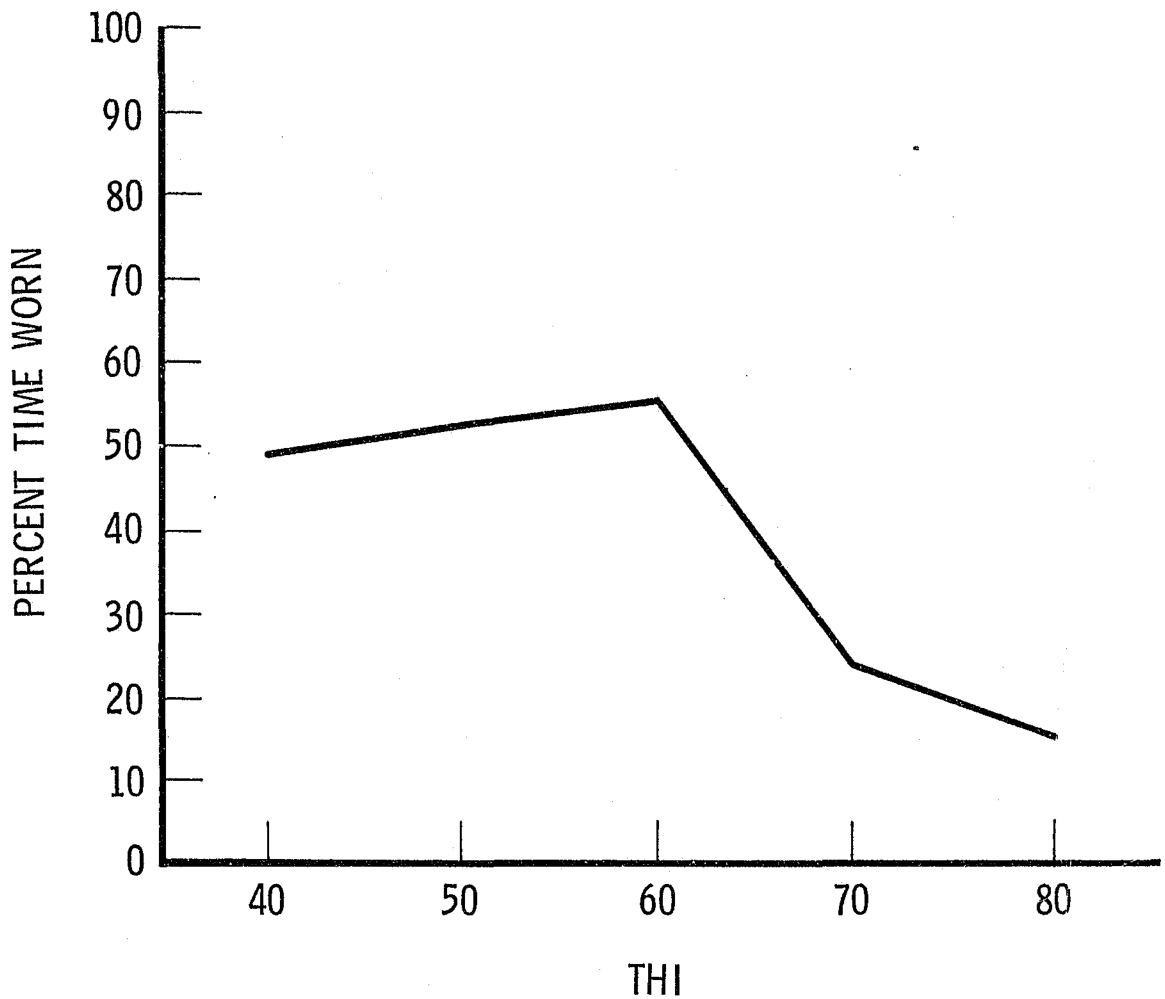


Figure 3-17. Wear History Versus THI — LEAA Women's 7-Ply Garment

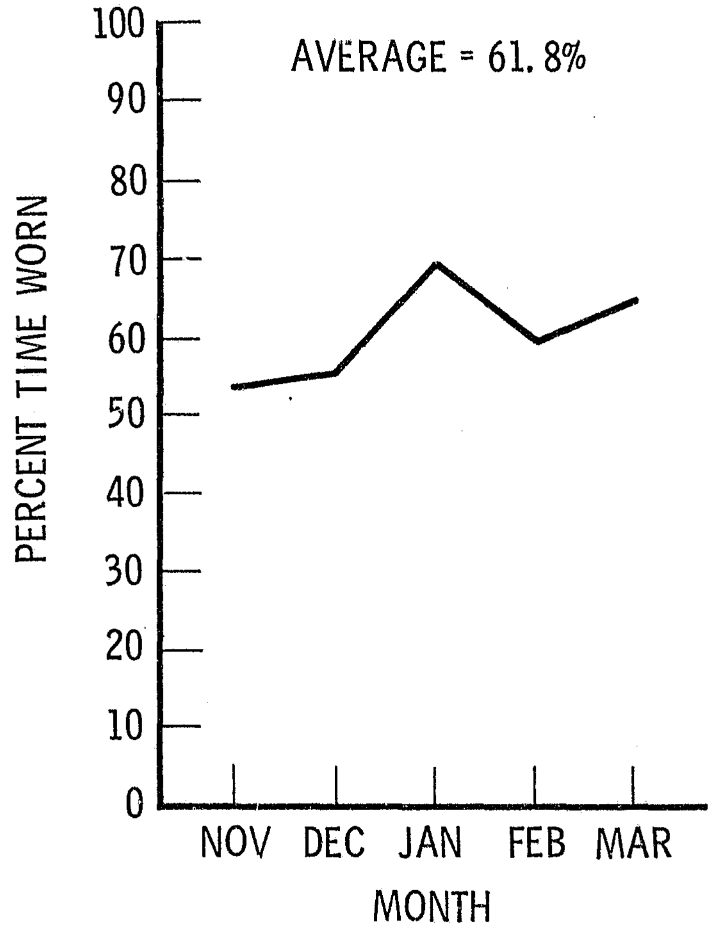


Figure 3-18. Wear History – November Through March, LEAA Integrated Uniform Jacket

The proportion of those officers who responded to one or more of the items above is shown in Table 3-14. The expected proportions were calculated using the marginal totals. The value of the chi-square statistic between observed and expected frequencies was 1317.6 with 40 degrees of freedom. The probability of obtaining such a value of chi-square due to chance was less than 0.001. The garment types differed most between each other in the responses in the columns designated "Too Heavy" and "Too Cumbersome." The LEAA Style I and II garments were represented by a lower proportion of the subjects who indicated that their reason for not wearing the garment was that it was too heavy. In addition, the Commercial Type A (12-ply) and D (24-ply) garments were not worn because they were too heavy a disproportionately longer amount of time than expected. The Commercial D (24-ply) garments were also too cumbersome more frequently than expected from the marginal probabilities. By contrast, the LEAA Style I garments were reported as too cumbersome less often than had been expected.

However, the most frequently reported reason for not wearing the garment cited that the garments were too hot. Containment of heat appeared to be the most commonly reported negative factor across garment types.

The riding up of garments was the second most frequent reason stated for not wearing the garments. The propensity of the garment to chafe, bind, or become too cumbersome ranks equally with the frequency with which they are reported. The responses indicated that garment weight was the least frequently chosen reason for not wearing some garment types. Yet, a disproportionately greater number of officers indicated that garment weight was, in fact, a major reason for not wearing Commercial Garments A (12 ply) and D (24 ply). Again, a disproportionately fewer number of officers than anticipated on the basis of the marginal proportions indicated that weight was a major factor in the infrequent wear of LEAA Styles I and II (7-ply) garments.

Table 3-14. Proportion of Officers Who Indicated That the Garment Chafed, Bound, Rode Up, or Was Too Hot, Too Heavy, or Too Cumbersome Aggregated by Garment Type

Garment Type	Chafes	Binds	Rides Up	Too Hot	Too Heavy	Too Cumbersome	Marginal Proportion
LEAA-I (7 ply)	8.4	9.9	25.8	34.2	1.8	8.6	0.457
LEAA-II (7 ply)	8.8	10.4	29.6	35.7	2.2	9.2	0.334
LEAA-II (10 ply)	8.5	8.1	30.2	31.0	1.9	9.1	0.039
Commercial							
A (12 ply)	7.1	9.0	16.2	36.7	6.6	10.4	0.052
B (14 ply)	6.0	5.9	19.2	35.1	3.5	10.3	0.040
C (18 ply)	3.2	4.0	12.2	37.8	2.7	7.4	0.019
D (24 ply)	11.3	11.8	16.5	36.0	14.8	19.1	0.034
Marginal Proportion	0.091	0.106	0.283	0.380	0.033	0.106	

c. Garment discomfort. On the Wearer Monthly Data Questionnaire, each officer was asked to respond in terms of the degree of discomfort experienced when wearing a protection garment. The particular question and response categories were:

31. If you were to characterize any discomfort experienced in wearing the garment it would be:

Very serious – cannot wear (1)	Serious – prevents wear for more than 2 hours (2)	Moderate – prevents wear for full shift (3)	Slight – noticeable (4)	Irritating only (5)	
___	___	___	___	___	Rides up
___	___	___	___	___	Chafes
___	___	___	___	___	Contains heat
___	___	___	___	___	Binds
___	___	___	___	___	Heavy
___	___	___	___	___	Cumbersome

The average and standard deviation of the responses to the items above are shown in Table 3-15.

Many officers felt that the garment was somewhat irritating in each of the areas listed. Many officers also believed that the garments were uncomfortable enough that they could not be worn for an entire shift.

Each of the garment types were rank-ordered from most comfortable (1) to least comfortable (7) for each category. The rank-orderings are shown in Table 3-16.

The subpopulation means are based upon relatively large samples. The difference between the mean ratings of garments with adjacent ranks was less than 0.10 in most cases. A mean difference of less than 0.10 scale units is also less than 0.10 standard deviation units. The difference between the largest and smallest garment type mean is less than 0.55 scale units and more often less than 0.30 scale units. Given samples of this size, a difference between a cell mean and the grand mean of 0.015 will result in

Table 3-15. The Mean and Standard Deviations of the Responses of All Officers to the Degree of Discomfort Experienced[a, b]

	Major Areas of Discomfort					
Garment Type	Rides Up	Chafes	Contains Heat	Binds	Heavy	Cumbersome
LEAA-I (7 ply) N = 9984	3.63 (1.137)	4.03 (1.055)	3.37 (1.214)	3.91 (1.04)	4.26 (0.88)	4.08 (1.02)
LEAA-II (7 ply) N = 7373	3.51 (1.189)	3.98 (1.077)	3.35 (1.230)	3.83 (1.09)	4.16 (0.93)	3.98 (1.09)
LEAA-II (10 ply) N = 884	3.61 (1.201)	4.01 (1.062)	3.33 (1.240)	3.81 (1.06)	4.17 (0.85)	3.99 (1.02)
Commercial						
A (12 ply) N = 1011	3.79 (1.041)	4.02 (1.034)	3.37 (1.228)	3.91 (1.06)	3.98 (1.08)	3.98 (1.08)
B (14 ply) N = 844	3.67 (1.162)	4.12 (0.963)	3.36 (1.204)	3.90 (1.05)	4.11 (0.98)	3.99 (1.06)
C (18 ply) N = 392	3.85 (1.066)	4.21 (0.908)	3.30 (1.245)	4.05 (1.03)	4.14 (0.88)	4.04 (0.97)
D (24 ply) N = 670	3.57 (1.075)	3.75 (1.163)	3.07 (1.286)	3.62 (1.18)	3.59 (1.25)	3.55 (1.22)

[a]Standard Deviation in parenthesis.

[b]The lower the number, the more irritating the source of discomfort.

Table 3-16. Rank Ordering of Garment Types in Terms of Category of Discomfort[a]

Garment Type	Rides Up	Chafes	Contains Heat	Binds	Heavy	Cumbersome
LEAA-I (7 ply)	4.0	3.0	1.5	2.5	1.0	1.0
LEAA-II (7 ply)	7.0	6.0	4.0	5.0	3.0	5.5
LEAA-II (10 ply)	5.0	5.0	5.0	6.0	2.0	3.5
Commercial						
A (12 ply)	2.0	4.0	1.5	2.5	6.0	5.5
B (14 ply)	3.0	2.0	3.0	4.0	5.0	3.5
C (18 ply)	1.0	1.0	6.0	1.0	4.0	2.0
D (24 ply)	6.0	7.0	7.0	7.0	7.0	7.0

[a]7 = Least comfortable,
1 = Most comfortable

statistical significance at the 0.05 level. As is the case of any large sample, the substantive significance of a statistically significant result is a matter of scientific opinion. It appears that the officers found the garments to be, in general, sufficiently uncomfortable so as not to be worn for an entire shift, while differences between garment types were not substantively meaningful, as opposed to the differences among garment types indicated in the earlier discussion of the reasons for not wearing the garments.

B. Garment Performance

In this section, evaluation is made of how well the garments fulfilled the physical requirements of ballistic protection, undetectability, fit, and structural integrity.

1. Performance.

a. Shooting incident performance.

(1) Introduction. This section discusses garment performance in terms of the dual requirements of (1) ballistic penetration resistance and (2) acceptable blunt trauma absorption, which is the capability of the protective garment to minimize the blunt trauma injury potential associated with nonpenetrating ballistic impact phenomena. For discussion purposes, a tabular synopsis of the overall LEAA Body Armor Incident Data Base is presented which includes data on three categories of incidents involving impact to armor while being worn by law enforcement officers: Program Participant Assaults (Table 3-17), Nonprogram Assaults (Table 3-18), and Nonweapon Incidents (Table 3-19). Primary emphasis was given to the performance of the basic LEAA 7-ply Kevlar garment in terms of defeat of the common handgun ballistic threat and the minimization of blunt trauma injury, as observed in incidents occurring during the nominal 1-yr field test experiment. However, all incidents involving law enforcement personnel receiving armor under the LEAA program or possessing soft body armor via other means for which information is available are displayed in the summary tables. The inclusion of data on nonprogram assaults and incidents offers the opportunity for interesting comparisons.

Table 3-17. Program Participant Assaults

Location	Date of Assault	Vest	Weapon	Range	Medical Data	Code
Seattle, WA	23 Dec 75	7-Ply Kevlar	.38 Cal Revolver with 2-in. Barrel	Point Blank	Cardiac monitoring revealed no irregularities. Serial EKGs, chest X-rays, and arterial blood gases were all within normal limits.	a
Richmond, VA	5 Jan 76	7-Ply Kevlar	.22 Cal Revolver with 4-in. Barrel	7 ft	Cardiac monitoring revealed no irregularities. Serial EKGs, chest X-rays, and cardiac enzymes were within normal limits.	a
Portland, OR	7 Jan 76	24-Ply Kevlar and Plastic (Commercial vest supplied by program)	.38 Cal Revolver with 2-in. Barrel. (also bird shot and solid bullet)	10-12 ft	52 pellets in left arm and head; superficial wound on right side from solid slug. No impact on vest.	d
New Orleans, LA	12 Jan 76	7-Ply Kevlar (not being worn)	.38 Cal Police Revolver	7-10 ft	Officer was shot in upper leg. No impact on vest area.	d
Philadelphia, PA	25 Feb 76	7-Ply Kevlar	.22 Cal Rifle	Over 100 yd	Officer was hit over left eye; pronounced dead on 28 Feb 76. No impact on vest area.	d
Albuquerque, NM	26 Aug 76	7-Ply Kevlar (not being worn)	.38 Cal Revolver with 3-in. Barrel	4-8 ft	Officer was struck four times and seriously wounded. Vest would have prevented two of the penetrating wounds and reduced the seriousness of the injury.	d

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

Table 3-17. Program Participant Assaults (Continued)

Location	Date of Assault	Vest	Weapon	Range	Medical Data	Code
Atlanta, GA	14 Jan 77	7-Ply Kevlar (not being worn)	.32 Cal Revolver with 4-in. Barrel	20 ft	Officer was struck in upper abdomen 2 in. right of center about 4 in. above belt. Bullet hit liver, gall bladder, and an aorta artery; near fatal. Officer recovering.	d
Miami, FL	24 Jan 77	7-Ply Kevlar	Metal Tipped Walking Cane	Not Applicable	Officer was struck repeatedly on left rear rib cage. Multiple bruises but no fractures.	a
Portland, OR	29 Nov 76	7-Ply Kevlar	.22 Cal Carbine with 18-in. Barrel	150 yd	Cardiac monitoring, serial EKGs, chest X-rays, cardiac enzymes, and radio-isotope scans revealed no internal damage.	
Philadelphia, PA	13 Jan 77	7-Ply Kevlar	Knife	Not Applicable	Undercover "Granny" officer struck in left rear by knife. Slight soreness; no penetration.	a
Newark, NJ	22 Mar 77	7-Ply Kevlar	.25 Cal Semi Automatic	10 ft	Bullet lodged in note book in officer's pocket. No impact on vest.	a
Philadelphia, PA	4 May 77	7-Ply Kevlar	Knife	Not Applicable	Undercover "Old Man" officer struck on rear by knife. Slight soreness; no penetration.	d

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

Table 3-18. Nonprogram Assaults

Location	Date of Assault	Vest	Weapon	Range	Medical Data	Code
Prince Georges, MD	30 Sep 75	Second Chance (18-ply ballistic nylon)	.38 Cal Revolver with 2-in. Barrel	6 in. to 1 ft	2-in. contusion under point of impact. No incapacitation.	c
Colorado Springs, CO	3 Feb 76	Safariland M-2 (11-ply Kevlar and plastic)	Unknown. Thought to be .22 Cal Rifle	15-30 ft	No external or internal damage behind point of impact.	b
Kansas City, MO	4 Feb 76	Armor of America (14-ply Kevlar)	.38 Cal Smith and Wesson with 4-in. Barrel	Point Blank	2-in. contusion under point of impact. No incapacitation.	b
New Orleans, LA	27 Feb 76	Second Chance (18-ply ballistic nylon)	Dinner Fork	Not Applicable	Officer was struck on the vest. Some soreness behind point of impact; no bruise or redness observed.	c
Detroit, MI	3 Mar 76	Unknown	.22 Cal Rifle	Approx 10 ft	Officer was shot near right eye while attempting to rescue Police Chaplain William Paris. Officer lost his right eye.	d
Colorado Springs, CO	14 Mar 76	Second Chance (8-ply ballistic nylon, 8-ply Kevlar thin nylon)	Knife	Not Applicable	Cut on left forehead, right hand, and right side. Vest deflected knife.	b
Chicago, IL	30 Jun 76	Second Chance Model Y (14-ply Kevlar, 4-ply ballistic nylon)	Probably .22 Cal Revolver	Point Blank and 12 in.	Officer was struck twice on vest in upper abdomen area. Two weeping contusions with bruises; no apparent internal damage.	b

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

Table 3-18. Nonprogram Assaults (Continued)

Location	Date of Assault	Vest	Weapon	Range	Medical Data	Code
Jacksonville, FL	30 Aug 76	Second Chance (14-ply Kevlar, 4-ply ballistic nylon)	.38 Cal Revolver	7-10 ft	Officer was struck in lower chest and upper abdomen on vest. Two weeping contusions with bruises. No apparent internal damage.	b
San Jose, CA	4 Oct 76	Safariland M-3	.22 Cal Rifle	15-20 ft	3 impacts on back of vest. Reported soreness on back at impact points.	b
Gainsville, FL	30 Aug 76	Second Chance (14-ply Kevlar, 4-ply ballistic nylon)	12 ga Sawed-Off Shotgun Magnum Load 12-00 Buck Pellets	Point Blank	Bruise behind point of impact. Held 24 hrs in hospital then released. External damage similar to .38 cal wound.	b
Omaha, NE	24 Aug 76	Federal Labs	12 ga Shotgun with 00 Buck Pellets	0-6 in.	No penetration. Possible bruises to heart and lung.	
Omaha, NE	1 Dec 76	Federal Labs	.36 Cal Cap and Ball Revolver	6 ft	Bruise and contusion to right chest.	
Sausalito, CA	17 Jan 77	Second Chance (8-ply Kevlar, 8-ply ballistic nylon)	.38 Cal Revolver	15 ft	Officer struck in upper abdomen. Surface contusion. No internal injury.	b
Inglewood, CA	7 Mar 77	Safariland M-3	.30 Cal Carbine	50 ft	Deep contusion of right chest with possible lung damage. Officer recovered.	b
San Francisco, CA	15 Mar 77	Safariland M-2	9 mm Auto	15 ft	Bullet passed through door prior to striking officer in chest; slight bruise.	b

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

Table 3-18. Nonprogram Assaults (Continued)

Location	Date of Assault	Vest	Weapon	Range	Medical Data	Code
Los Angeles, CA	9 Apr 77	Safariland M-3	.38 Cal Revolver	12 ft	Bruise and swelling in left chest area with no internal injuries.	b
Lynwood, CA	20 May 77	Safariland M-3	.22 Cal Rifle	100 yd	Slight bruise and laceration to chest. X-rays revealed no internal damage.	b
Houston, TX	26 Apr 77	Armor of America (Siege vest, 28-ply Kevlar)	.357 Magnum Handgun	10-12 ft	No penetration of Kevlar plies. Officer sustained minor bruise of left side. Officer treated and released from hospital with negligible lost time due to assault.	b

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

Table 3-19. Nonweapon Incidents

Location	Date of Incident	Vest	Scenario	Medical Data	Code
Seattle, WA	6 May 76	LEAA 7-Ply Undergarment	Motorcycle flipped at 55 mph on freeway.	No apparent damage under vest.	a
Marion County, MD	26 May 76	Safariland M-2A	Collision on emergency run; officer caught steering column in chest.	Vest prevented rib damage.	b
Indianapolis, IN	1 Jun 76	Safariland M-2A	Officer struck on chest by mirror on passing van.	Vest prevented rib damage.	b
Los Angeles County, CA	6 Dec 76	Safariland M-3	Officer charged by bull; struck on chest and left arm.	Vest prevented chest and rib damage.	b

CODE: a — Vest Impact (7-Ply Kevlar)
b — Vest Impact (Composite, Multi-Ply Kevlar and Other Materials)
c — Vest Impact (Non-Kevlar Armor)
d — No Vest Impact

(2) Definition of garment protection. Before discussion of the observed "shooting performance" of the LEAA 7-ply and other protective armors, the definition of garment protection for the LEAA 7-ply armor is restated as a means of providing a clearer perspective of garment performance requirements.

As part of the overall program to evaluate the protection afforded by soft body armor, it may be recalled that medical personnel at the Edgewood Biomedical Laboratory performed a goat-human correlation analysis in conjunction with the extensive animal ballistic test experiment conducted prior to the Body Armor Field Test. The stated definition of garment protection (for the LEAA 7-ply Kevlar garment) for the field experiment was:

- It should prevent penetration by the specified ballistic threat into the upper torso.
- Any blunt trauma effects should have a mortality risk of 10 percent or less.
- An adult male wearing the garment should be able to walk from the site of a shooting after being hit in the chest or abdomen by the specified ballistic threat.

The specified ballistic threats were:

- A .22 caliber projectile weighing 40 gr and traveling at 1000 fps.
- A .38 caliber projectile weighing 158 gr and traveling at 800 fps.

(3) Incident performance (7-ply LEAA undergarment). Reference to Table 3-17 reveals that six incidents involved garment impact while the basic 7-ply Kevlar undergarment was being worn (Code a incidents). Only three of these involved assaults by firearms. The latter will be discussed in terms of garment performance, followed by comments on the nonfirearm incidents.

(a) Seattle, Wash., 23 December 1975. Program participant assaulted with a .38-caliber handgun at near pointblank range with two missiles impacting the 7-ply garment frontally.

1 Medical assessment. The victim officer, a 33-yr-old male, was admitted to a local hospital in approximately 30 min after assault. At no time during or before the hospital stay was there a loss of consciousness. Examination of the head, chest, heart, and abdomen revealed no abnormalities. The admission chest x-ray revealed clear lung fields without evidence of hemo- or pneumothorax damage or fractured ribs. Similarly, the EKG was within normal limits. Two lesions of the anterior chest wall were noted behind the Kevlar armor with an area of contusion and abrasion with focal superficial laceration in the upper right anterior chest. The patient was admitted to General Surgery service, under regional anesthesia, for treatment of an injury to the left hand sustained during the assault. Post surgery EKGs, chest x-rays, and monitoring of arterial blood gases again revealed no abnormalities or irregularities. The victim was discharged from the hospital on 26 December 1976. Based on the medical assessment, the resulting blunt trauma injury was adjudged to be minimal. Figure 3-19 displays the two healing chest wounds (contusions) at four days post injury.

2 Results of garment examination. The protective garment worn by the officer was a 7-ply, 1000-denier, Style II Kevlar vest. Examination of the vest (which had not been laundered prior to the assault) revealed the following:

- No penetration or separation of the Kevlar material
- Powder marks and a tear in the cotton cover (covering the ballistic material at the point of impact) to the left and below center of the vest
- Small tear in cotton cover also noted in right shoulder area with no powder marks and no damage to the underlying Kevlar material.

Figure 3-19. Healing Chest Wounds After 4 Days

Thus, with no penetration of the Kevlar plies, the .38-caliber ballistic threat fired at close range was clearly repulsed. Further inspection revealed that the 158-gr (soft-lead, round-nose) bullet travelled through the officer's outer jacket, police shirt, and undershirt before impacting the vest. In the opinion of the State Crime Laboratory specialists, the missiles did not strike badges, buttons, or other hard objects.

3 Incapacitation effect. Following the two impacts in the chest area, the assaulted officer fought with the assailant, and both fell to the floor, whereupon two more shots were fired with one impacting the officer in the left hand. After struggling free, the victim officer went up and down a staircase before dialing the 911 police emergency system to report the incident and await transport to the local hospital. Thus, though the hand wound was severe, the officer was not incapacitated as a result of the vest impacts. Figure 3-20 shows respectively:

- Frontal view of the vest, including two areas of missile impact and associated powder burns, which indicate the proximity of the assault.
- Inner surface of vest front panel showing a blood stain (arrow) over the area of injury (contusion) (Note that no disruption of the Kevlar material occurred.)
- Recovered .38-caliber round-nose lead missile which struck the central area of the vest; asymmetric deformity indicates a slightly angled impact to the armor.

(b) Richmond, Va., 5 January 1976. Program participant assaulted with a .22-caliber handgun (hollow-point lead slug) from approximately 7 ft with one missile impacting the 7-ply garment frontally.

1 Medical assessment. The victim officer, a 28-yr-old male, was admitted to a local hospital in approximately 30 min after the assault. On initial examination, the patient was noted to be alert and in no distress with normal pulse, respiration, and blood pressure measurements. A single chest wound, located 1 in. left of the left nipple, consisted of a slightly elliptical abrasion with a centered superficial laceration and

Figure 3-20. The Views at the Top Show Two Areas of Impact and Powder Burns at the Left and the Blood Stained Inner Panel at Right with No Disruption of Kevlar. Below Is the .38-Caliber Missile Which Struck the Central Area

generalized swelling in the breast area. The patient complained of some tenderness to palpation in the region of the wound. Admission chest x-rays showed no rib fractures or discernible injury to underlying structure, and an EKG was normal. The patient was then placed in an intensive care unit for cardiac monitoring and antibiotic treatment. Following 24-hr observation, the patient was transferred to General Surgery. Again, serial EKGs, chest x-rays, and cardiac enzymes did not show evidence of pathology. Following 48 hr hospital observation, the assaulted officer was discharged to the care of his private physician.

Based on the medical assessment, the resulting blunt trauma injury, a moderately severe contusion with abrasion and superficial laceration of the injured area, was judged to be minimal, since there was no discernible injury to the underlying rib cage or viscera. Figure 3-21 depicts the location of the wound on the pathological body diagrams used by local trauma surgeons participating in the Body Armor Field Test experiment.

<u>2</u> <u>Results of garment examination</u>. The protective garment worn by the officer was a 7-ply, 1000-denier, Style II Kevlar vest. Examination of the vest, which (as in the previous assault incident) had not been laundered prior to assault, revealed the following:

- No penetration or separation of the Kevlar material
- A 10-mm slit with slight gray staining of the white cotton outer layer in the anterior left panel of the vest. (The heat of the impacting missile appeared to have fused the underlying first layer of ballistic material, but no penetration occurred.)

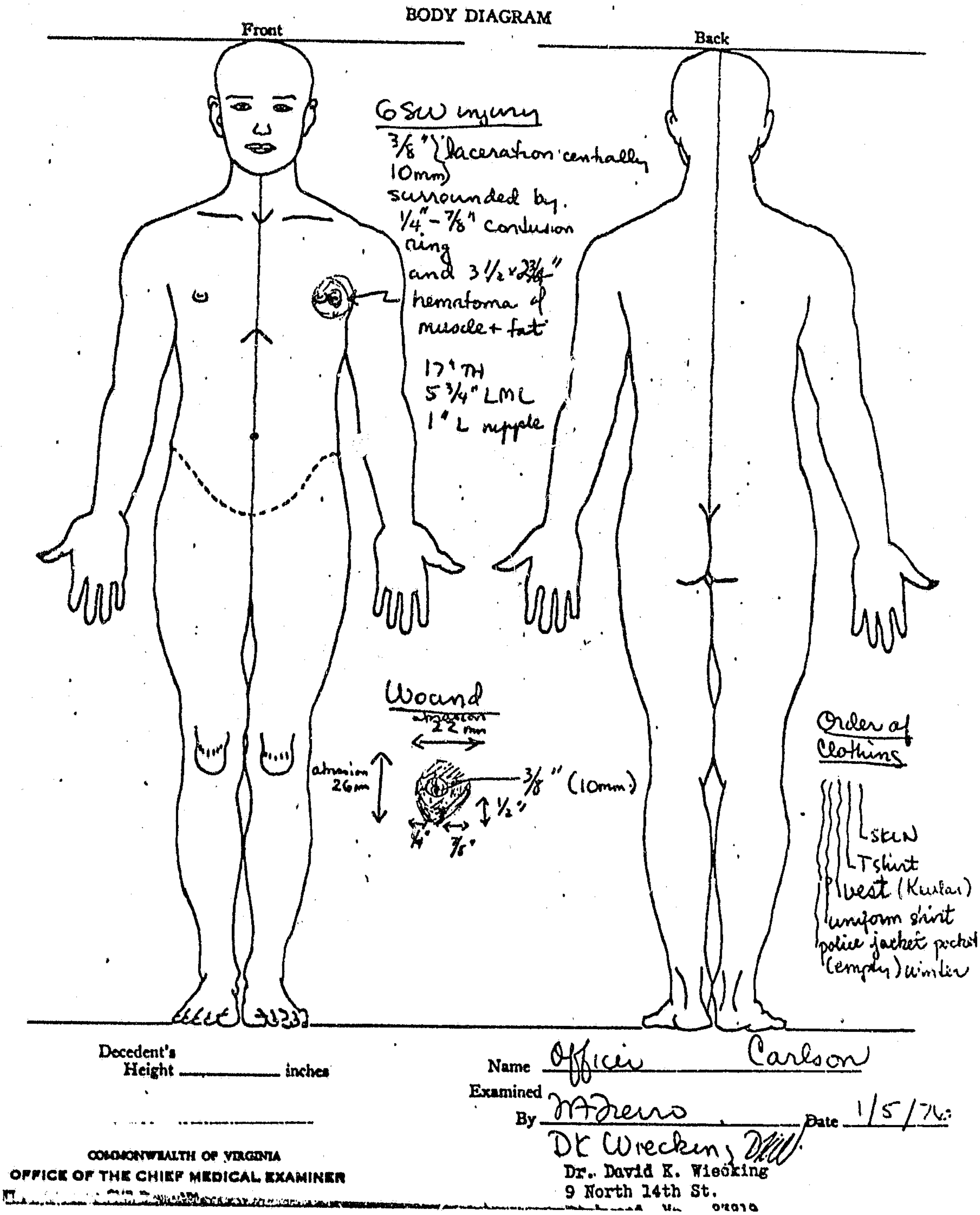


Figure 3-21. Wound Location on Pathological Body Diagram

Thus, with no penetration of the Kevlar plies, the .22-caliber ballistic threat delivered from 6 to 8 ft with probable angling from left to right was clearly defeated. Further inspection of assault evidence data revealed that the impacting missile entered through the officer's brown winter blouse (breast pocket), tan uniform shirt, and undershirt before impacting the Kevlar vest. In the opinion of the State Crime Laboratory specialists, the missile did not strike badges, buttons, or other hard objects before impacting the vest.

3 Incapacitation effect. Following his response to a suspected "burglary in process" call, the victim officer had entered the assault location and apprehended two of three suspects, when he was suddenly assaulted by the third suspect as he turned to face the suspect approaching from his rear. As related by the victim officer, "the weapon was essentially horizontal and aimed straight toward my chest." The officer related that there was no immediate sensation of impact although a "slight dull pain" became noticeable in 30 to 45 sec after the weapon was fired. The assaulted officer was able to pursue the suspect, resulting in apprehension of the suspect outside the house. Thus, as in the previous case, there was no incapacitation following impact of the 7-ply garment by the common handgun. Figure 3-22 shows the following:

- Frontal view of the impacted 7-ply garment with laceration of the outer cover in the left nipple area
- Closeup print of the impacting missile, a 40-gr lead hollow-point, .22 caliber (Note scoring of missile caused by contact with Kevlar material.)
- Sturm Ruger Bearcat .22-caliber revolver with a 4-in. barrel, the weapon used in the assault.

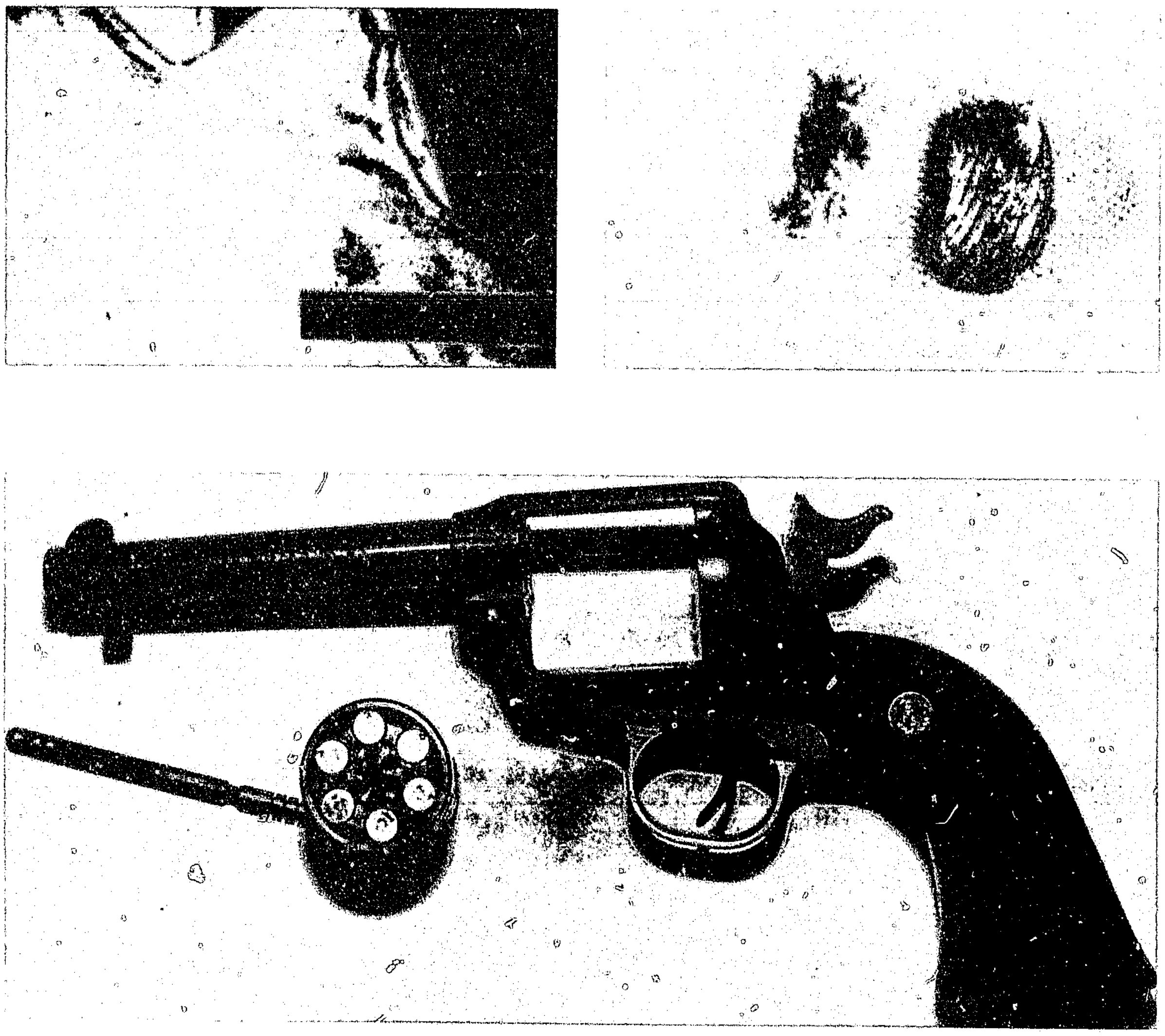


Figure 3-22. Top Left Shows the Laceration of the Outer Vest, and the .22-Caliber Missile Is at the Right (Note Scoring from the Kevlar Material). The Weapon Is Shown Below

(c) Portland, Ore., 29 November 1976. Program participant assaulted with a .22-caliber semiautomatic rifle (long-rifle bullet, 40-gr solid, round nose, lead) from approximately 150 yd with one missile impacting the vest frontally.

1 Medical assessment. The victim officer, a 29-yr-old male, was admitted to a local hospital in approximately 30 min following the assault. After initial examination, emergency treatment, and chest x-rays, the officer was placed in the coronary unit for extensive cardiac monitoring. The impact point was between the fifth and sixth rib adjacent to the left side of the sternum. The resulting abrasion of the chest was approximately 1 in. in diameter with some seeping of serous fluid. Swelling of the surrounding area was approximately 4 in. in diameter. The victim officer stated that the impact was felt simultaneously with hearing the rifle report. Witnesses to the assault commented that the officer recoiled from the impact and fell face down. During the post treatment interview, the officer was uncertain as to whether he lost consciousness; however, there was a short period in which there was evidence of "loss of awareness." Following the normal 24-hr observation period in intensive care, serial EKGs, chest x-rays, monitored cardiac enzymes, and a radioisotope scan revealed no irregularities nor internal damage. The assaulted officer was discharged from the hospital 48 hr after admittance. As in the previously described firearm assaults, the blunt trauma injury was adjudged to be minimal despite the impact recoil effect and "loss of awareness," since no discernible internal injury was observed beneath the point of impact. Figure 3-23 depicts the abrasion and swelling resulting from impact.

2 Results of garment examination. The protective garment worn by the officer was a 7-ply, 1000-denier, Style II Kevlar vest. Examination of the vest (which had been laundered prior to assault) revealed the following:

- The projectile was stopped in the first ply of the ballistic material (Figure 3-23).

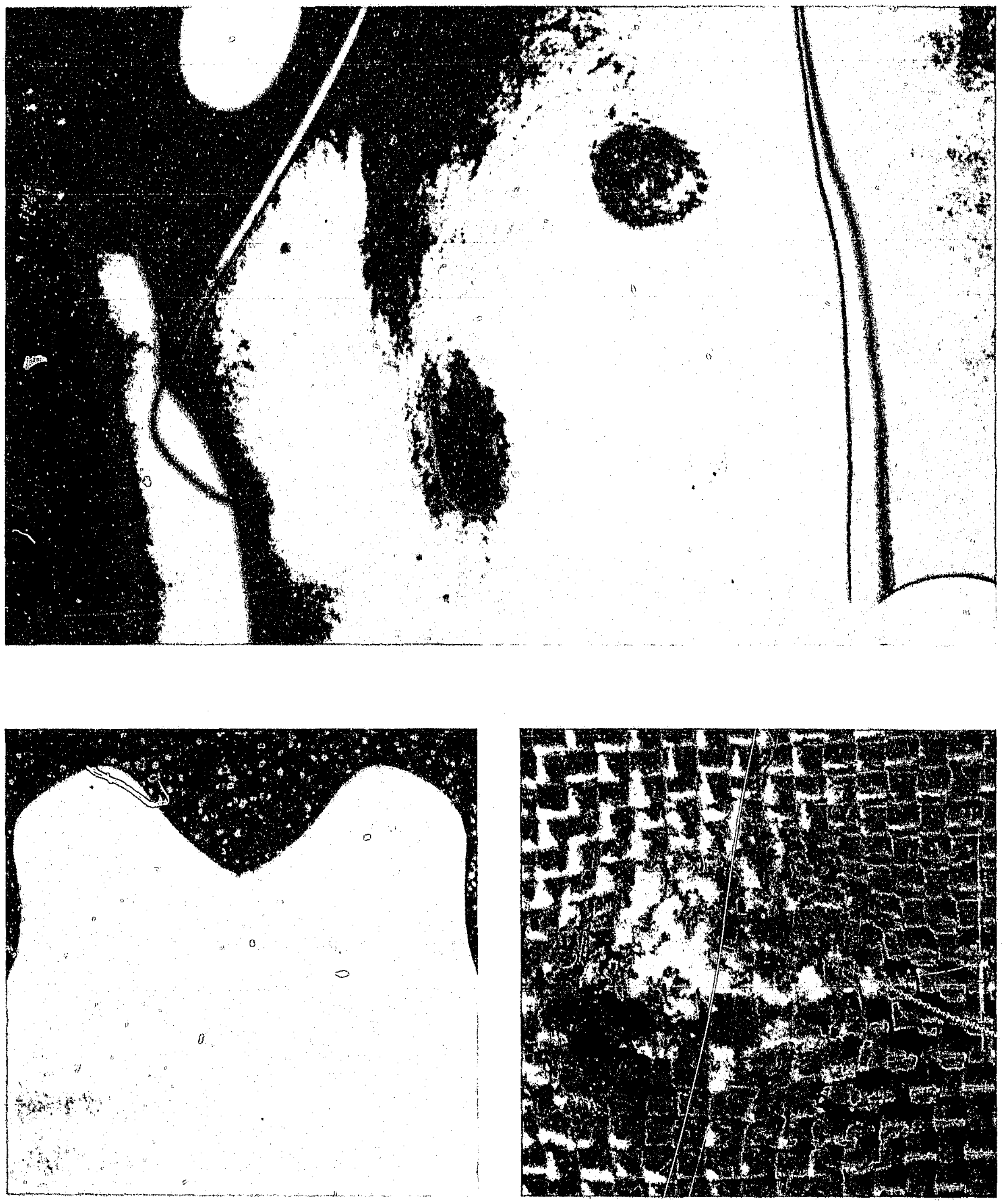


Figure 3-23. Impact Abrasion and Swelling Are Shown at Top. Below Is the Damaged Vest at Left and an Enlargement of the Fabric Damage at Right.

- There was visible evidence of fabric stretching at the point of impact, but no significant damage to the yarns. Slight stretching of yarns beneath the point of impact was also observed in the second ply of ballistic material.
- The impacting missile passed through the officer's outer jacket, wool uniform shirt, and outer cover of the vest, and filaments of these materials were observed in the missile cavity or depression made in the first ply. The victim officer stated that he could sense the bullet trapped in the plies of his vest following impact. Later, following the entry of the vest as criminal evidence, the deformed missile was recovered along the bottom seam of the vest between the outer cover and the first ply of ballistic material.

Thus, with penetration limited to the first ply of the 7-ply garment, the threat was clearly defeated, despite the fact that the threat potential exceeded the design capability of the protective garment. The rated muzzle velocity of the .22-caliber, semiautomatic rifle (with an 18-in. barrel) used in this assault was 1260 fps. The velocity of the weapon was subsequently measured using a chronograph and a test range of 6 ft. The average velocity obtained with this method for four test firings was 1247 fps. Since the range in the incident was approximately 150 yd, it was theorized by ballistic specialists that the impacting velocity was significantly less than rated muzzle velocity and probably closer to 1000 fps. Hence, it is highly probable that the ballistic impact equated reasonably with that of a .22 caliber handgun.

3 Incapacitation effect. As previously stated, in the postassault interview, the officer was uncertain as to whether he lost consciousness as a result of the impact. It was reported, however, that he did recoil from the impact and was also observed to experience a short period of "loss of awareness." Despite this, the officer was able to communicate by radio with police headquarters to report the incident and request medical aid. He then moved to an area of cover while awaiting the arrival of an ambulance. By comparison with the previous incidents, the immediate incapacitation effect in this case was noticeably more severe; however, the officer was still able to walk away from the point of assault under his own power.

b. Nonshooting incident performance. As referred to earlier in Tables 3-17 and 3-19, four nonfirearm incidents involved the 7-ply Kevlar vest: three assault cases and one motorcycle accident. Two of the incidents did not occur during the formal test period, but they are included here simply to attest to the nonfirearm protective features of the 7-ply protective garment.

The comments in Table 3-17 are sufficient to assess garment performance in the nonfirearm incidents, since there was only one case in which the resulting injury required hospitalization. The four incidents are labeled with Code a in the table, and one occurred in Miami, two in Philadelphia, and one in Seattle. The Philadelphia incidents were both knife assaults involving undercover agents in disguise. In both cases, the officers were assaulted from the rear with no penetration of the Kevlar material. As noted in the column "Medical Data," postassault injury was limited to a feeling of "slight soreness" as stated by the assaulted officers.

In the Miami incident, a metal-tipped walking cane was used as the assault weapon. As noted under the column "Medical Data," the officer sustained multiple bruises as a result of repeated blows to the rib cage, but he did not require hospitalization when it was ascertained that no fractures occurred. The officer returned to duty the following day.

The final incident falls in the category of a nonweapon incident, and, as noted in Table 3-19, involved an officer somersaulting from a motorcycle while traveling at a speed of 55 mph. This incident, of course, required hospitalization; however, the injury to the upper torso area protected by the LEAA 7-ply undergarment was limited to soreness resulting from impact with the pavement and ground, and x-rays of the rib cage revealed no broken or fractured ribs and no external damage (contusions, abrasions) to the protected area occurred. The officer's helmet, uniform jacket, shirt, pants, boots, gun, holster, and handcuffs were completely destroyed as he slid approximately 200 ft down a freeway. The officer was treated for bruises and contusions on all parts of his body except the area covered by the Kevlar vest. In the opinion of the attending physician, both external and internal damage would have occurred if the garment had not been worn.

c. <u>Performance summary</u>. In summarizing the performance of the 7-ply LEAA undergarment in incidents involving program participants, it can be stated that two and possibly three fatal assaults were prevented by wearing the armor, and, that in four other cases not involving firearms, severe external and internal injury was avoided in the opinion of attending medical personnel. As is noted in Table 3-17, there were also two unfortunate program incidents involving impact to the torso area when the garment was not being worn. The medical assessments in both cases were that substantial damage and surgery would have been prevented if the garment had been worn. Fortunately, neither incident was fatal, although each officer required a long recovery period.

The remaining entries in Tables 3-17, 3-18, and 3-19 cover program incidents involving no impact to the armor and other categories that do not involve the basic 7-ply LEAA undergarment. Sufficient data are included for the reader to make several interesting comparisons. In addition, significant comparisons can be made by reference to Figure 3-24, which portrays typical posttreatment incident wounds for wearers protected by the basic LEAA 7-ply vest, protected by commercial vests, or not protected. The

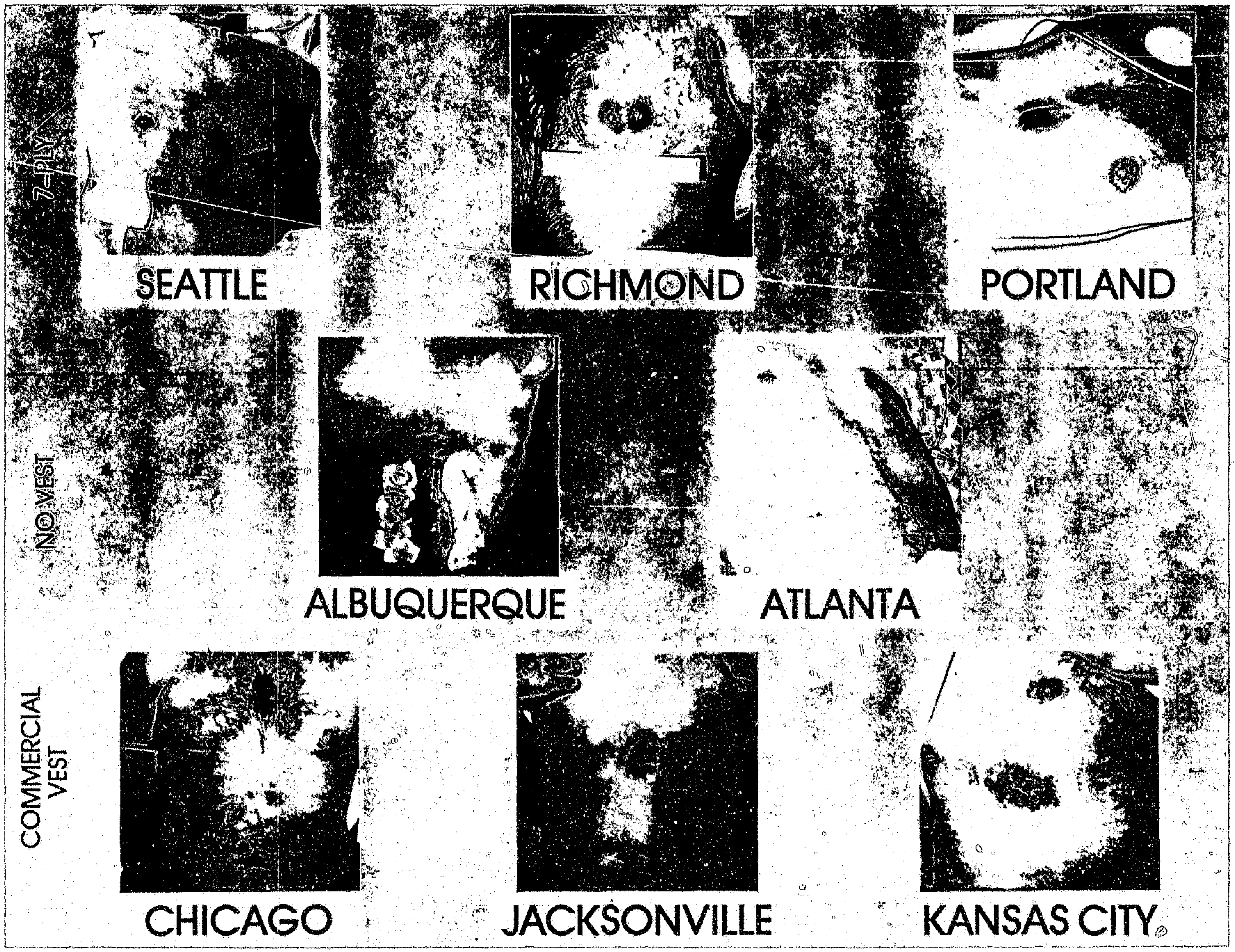


Figure 3-24. Typical Incident Wounds

efficacy of the vest versus no vest by comparison of the external wound and the apparent similarity of wounds behind soft armor for common handgun weapons (although one .22-caliber long-rifle incident is included), when the ply count is different is readily apparent.

The three top photographs show from left to right the Seattle incident in which the officer was struck twice in the chest by a .38 special, the officer in Richmond who was hit with a .22 revolver, and the officer in Portland who was struck by a sniper with a .22 carbine. All were wearing LEAA garments and received no internal damage. The incidents in Seattle and Portland would probably have been fatal were armor not worn.

In the next two photographs, the officers were not wearing armor. The officer in Albuquerque was struck three times in the upper torso area by .38-caliber projectiles, and the officer in Atlanta received a .32-caliber gunshot wound. The opening caused by an exploratory operation is shown. Both officers were in very critical condition. In both instances, the 7-ply vest would have prevented penetration.

The last three pictures show the condition of the officers' torsos who were shot with .38 handguns while wearing commercial garments. The Chicago and Jacksonville incidents involved an 18-ply composite of Kevlar and ballistic nylon designed to stop the .357 magnum. The Kansas City incident involved a 14-ply Kevlar vest, and the officer was shot with his own weapon.

It is interesting to compare these results with the predictions of the protective capabilities of the LEAA armor design. These predictions were made during the development phase of the program by means of the so-called "lethality model" developed by medical researchers and ballistics experts of the Edgewood Arsenal Biomedical Laboratory of the U.S. Army. The assumptions used in the development of this model included:

- A random distribution of hits to the upper torso by a .38-caliber special, 158-gr lead, round-nose bullet at 800 fps
- Upper torso coverage with 7-plies of Kevlar 400

- Hospital attention within 1 hr
- Standard cross sectional areas of vital organs (i.e. liver, spleen, heart, and kidney)
- Standard vulnerability likelihoods for each vital organ based on friability tests.

The friability tests were made using a water lavage on the vital organs of both the test animals (goats) and cadavers. These tests permitted an assessment of the degree of tissue damage suffered from hydrodynamic shock, which is similar to the blunt trauma damage observed in animal tests. By convoluting these probabilities of damage with the organ cross sectional areas, mortality and surgery probability rates were then calculated for each area for the two cases of with and without armor.

The mortality probability after a random hit without armor was found to be between 7 and 25 percent; the probability of surgery was 82 to 100 percent. If the armor is worn, the mortality rate is reduced to between 1 and 5 percent, and surgery rate to 7 to 10 percent. Based upon the fact that none of the incidents involving armor resulted in a fatality or in the need for surgery, it is evident that the garment performance exceeded predictions or that the lethality model was too conservative in regard to blunt trauma from armor impacts.

2. Detectability. On the wearer monthly data questionnaire, the test group was asked the following question:

	Agree strongly (1)	Agree (2)	Neither (3)	Disagree (4)	Disagree strongly (5)	
25.	____	____	____	____	____	Frequent comments by the public indicate that the garment is easily detected

Figure 3-25 shows the average response of the officers over time, and Figure 3-26 shows the average response of the officers with respect to garment type. Applying a scale of 1 to agree strongly and 5 to disagree strongly, the greatest monthly shift in Figure 3-25 is less than 0.3, which is less than one standard deviation in the monthly responses. Thus, there is no substantive seasonal variation in the detectability of the garment, and the officers indicated a neutral attitude towards the public's ability to detect the garment.

In Figure 3-26, again using a scale of 1 to 5 for the responses, the greatest differences between responses is 0.52, which is less than the standard deviation of 0.8 among the responses. Hence, there is no substantive difference among the garments in their detectability by the public, and all of the average garment responses are in the neutral range.

In addition, the test participants were asked on the Wearer Post Test Questionnaire the degree to which they found the LEAA Style I and Style II garments inconspicuous. The exact question asked was:

42. From your observation of other officers wearing the LEAA garments, which is the most inconspicuous?
1) _____ Style 1 (full side protection)
2) _____ Style 2 (front and rear shaped panels)
3) _____ Both about the same

The distribution of responses to this question is shown in Table 3-20.

Table 3-20. The Garment Inconspicuousness Distribution

Most Inconspicuous Garment	Absolute Frequency	Relative Percent
LEAA Style I	508	17.3
LEAA Style II	706	24.1
Both the same	1520	51.8
Missing	199	6.7

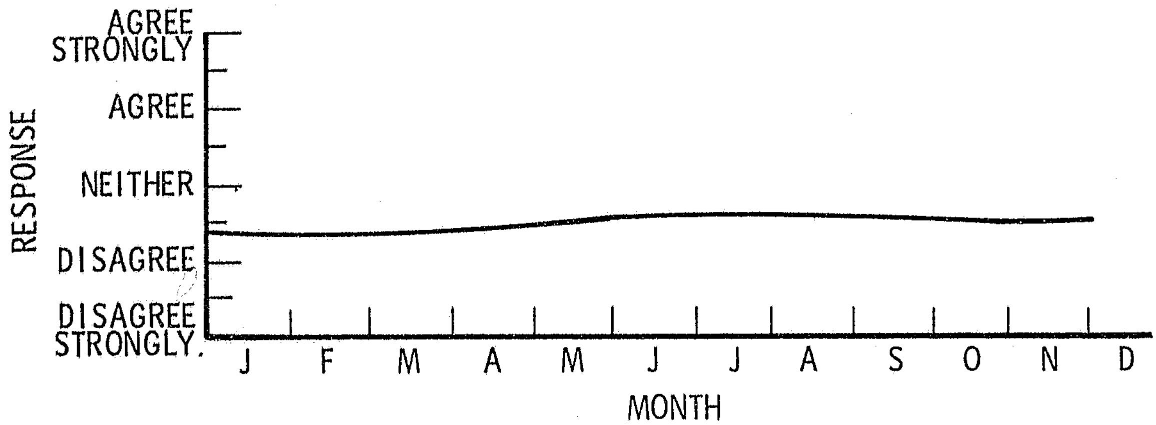


Figure 3-25. Garment Detectability Versus Month

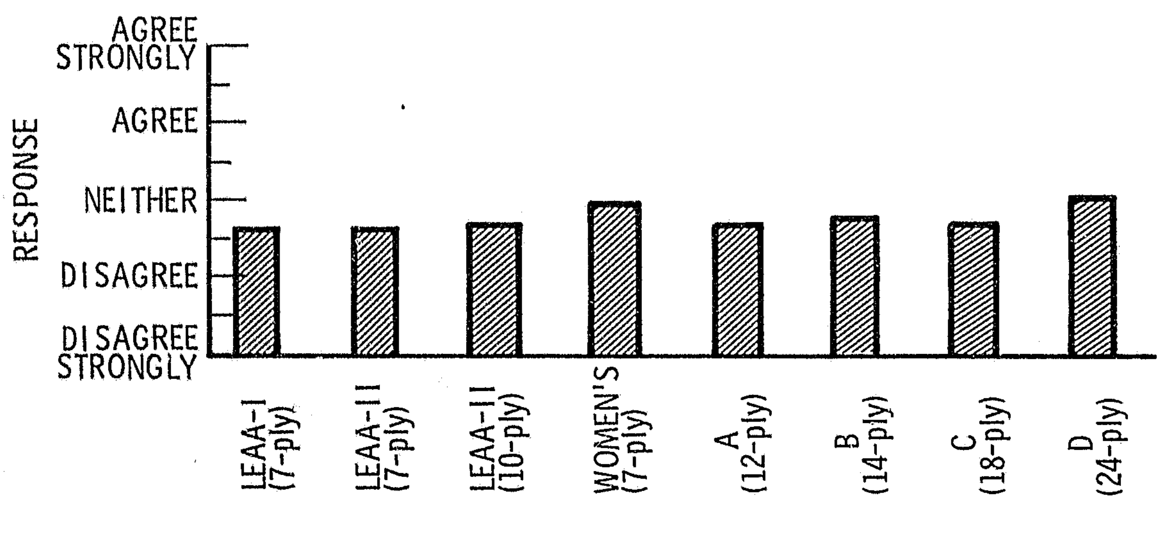


Figure 3-26. Garment Detectability Versus Type

The number of subjects who contend that one garment is less conspicuous than another (1214) is statistically different from the number of officers (1520) who feel that both types of garments are equally inconspicuous (chi-square = 77.13, df = 1, p = 0.001). Therefore, most officers feel that the two garments (LEAA Style I and Style II) do not differ in the degree of conspicuousness. However, the number of officers (508) who feel that LEAA Style I type garments are more inconspicuous than LEAA Style 2 garments is significantly smaller than the number of officers (706) who feel the opposite (chi-square = 77.17, df = 1, p = 0.001).

3. Comfort. On the Wearer Monthly Data Questionnaire, the test group was asked to respond to the following six questions relating to garment comfort.

	Agree strongly (1)	Agree (2)	Neither (3)	Disagree (4)	Disagree strongly (5)	
15.	______	______	______	______	______	The garment is easy to put on and take off
16.	______	______	______	______	______	The garment fits well
17.	______	______	______	______	______	The garment allows free movement
18.	______	______	______	______	______	The garment allows easy access to my weapon
19.	______	______	______	______	______	The garment allows normal maneuverability
24.	______	______	______	______	______	The garment comfort remains the same throughout the shift

Figure 3-27 through Figure 3-32 show, as a function of time, the percentage of officers who answered these questions with the agree response. From these figures, it can be seen that there is little monthly variation in the officers' attitudes towards the garments' comfort.

Table 3-21 shows the average category response to these questions over the test period.

From this table, one can see that generally the officers exhibit positive attitudes toward all these questions except that the garment comfort

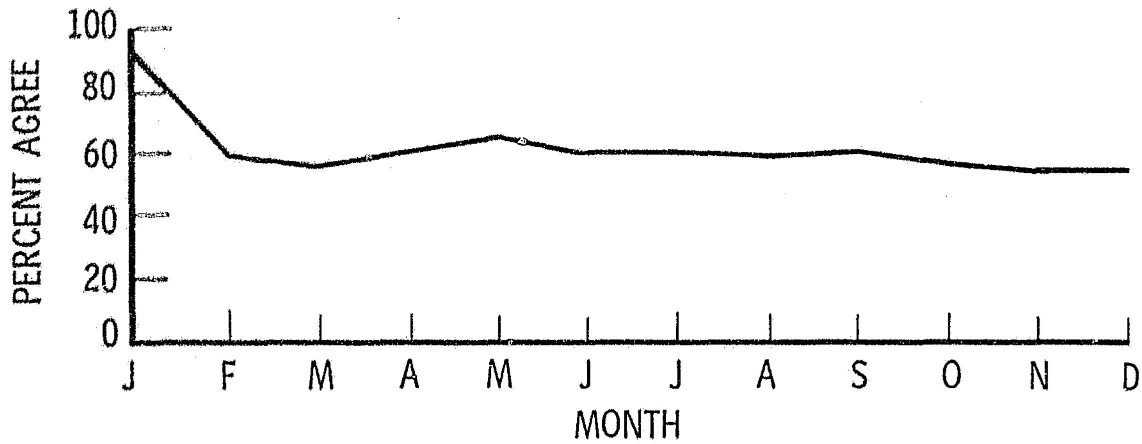


Figure 3-27. Easy On and Off

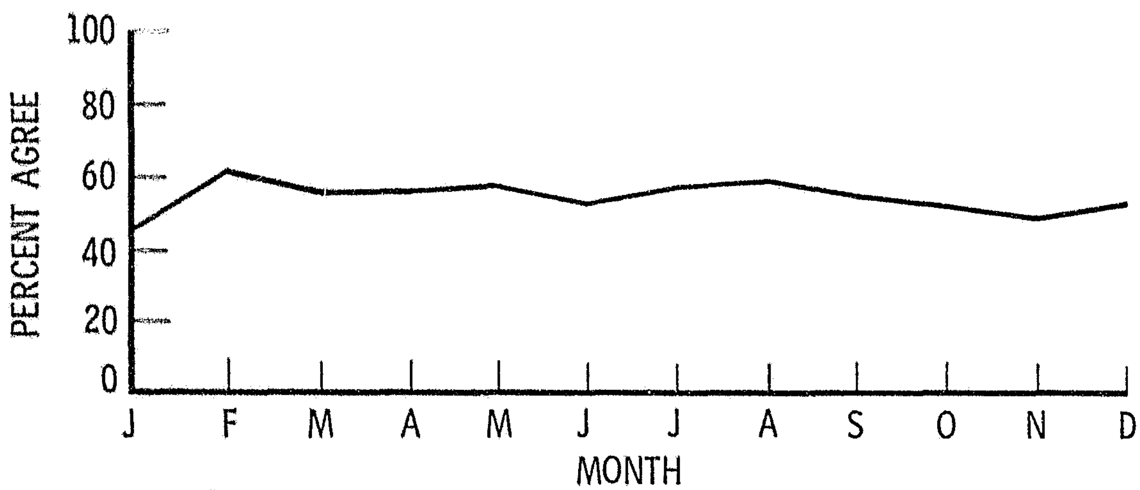


Figure 3-28. Fits Well

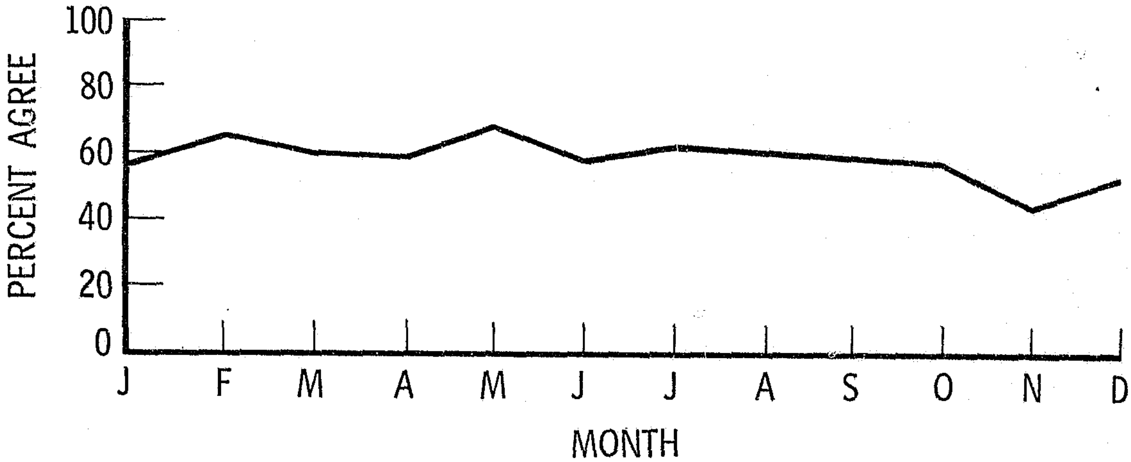


Figure 3-29. Allows Free Movement

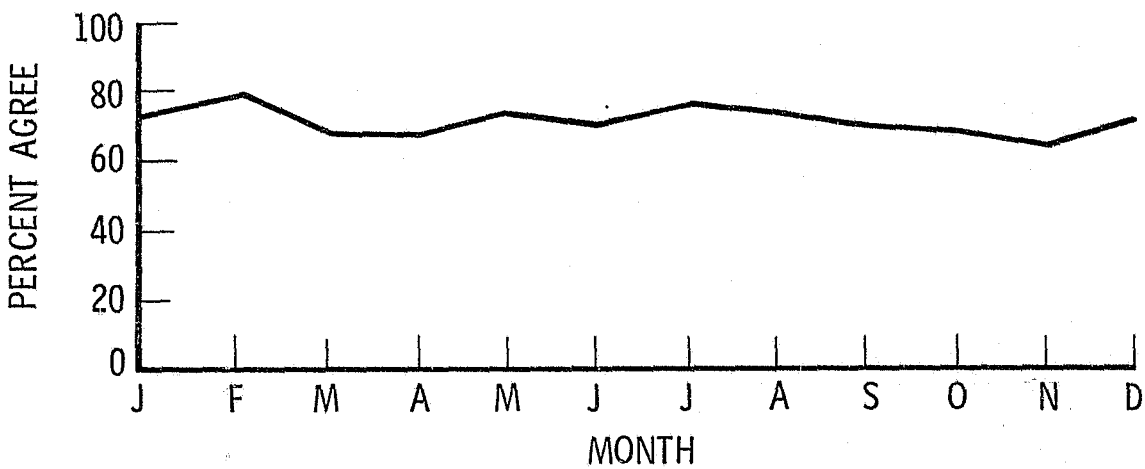


Figure 3-30. Easy Weapon Access

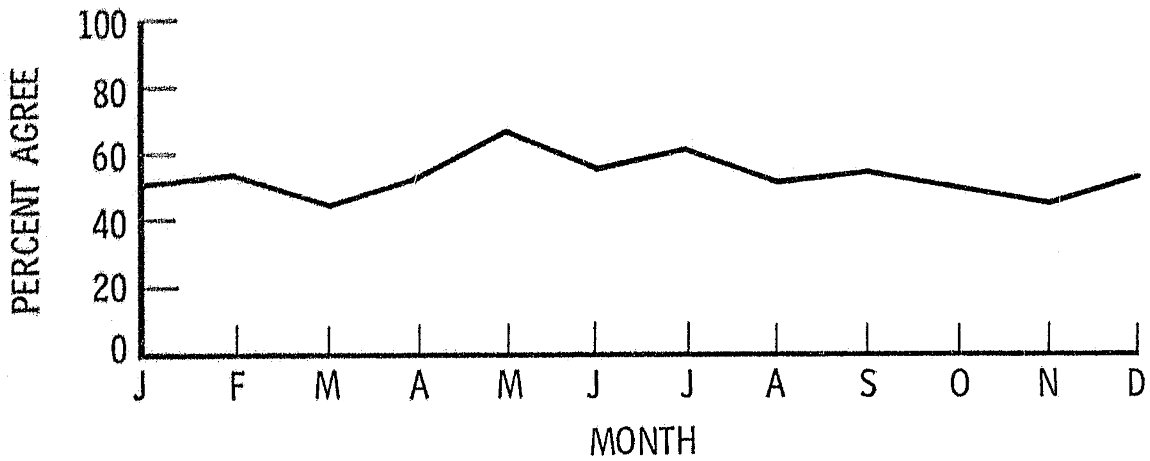


Figure 3-31. Allows Maneuverability

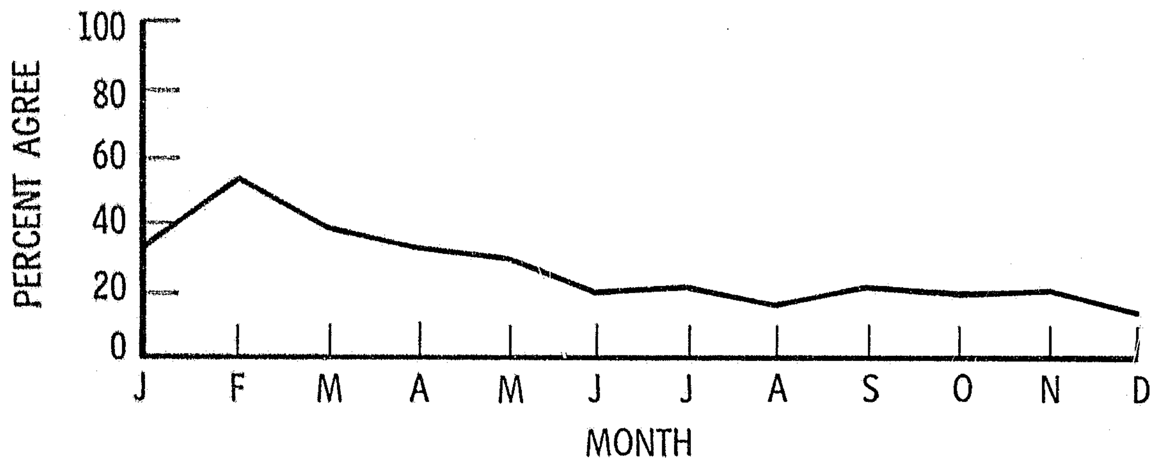


Figure 3-32. Constant Comfort

Table 3-21. Average Comfort Responses

Questions	Average Response				
	Agree Strongly	Agree	Neutral	Disagree	Disagree Strongly
Easy on and off	15.1	70.7	9.0	4.6	0.6
Fits well	5.2	55.4	15.8	20.1	3.6
Free movement	4.6	56.5	18.0	18.7	2.2
Access to weapon	8.5	74.8	10.4	5.6	0.7
Normal maneuverability	4.6	54.6	19.6	19.7	1.5
Constant comfort	1.4	26.6	15.7	47.2	9.1

does not remain the same throughout the shift. This correlates well with the results presented in the earlier discussions, and it appears that heat containment is the primary reason that the garment does not remain comfortable.

The general comfort and fit of the garments was ascertained from a pretest and posttest question directly addressing the issue for test group officers:

41. From your experience in wearing the garment would you say the general comfort level was:

1) ____ Very comfortable
2) ____ Comfortable
3) ____ No change
4) ____ Slightly uncomfortable
5) ____ Very uncomfortable

A similar pretest question indicated the degree of anticipated comfort. The distribution of responses for the entire pretest and posttest samples is shown in Table 3-22.

Table 3-22. Pretest and Posttest Questionnaires — Garment Comfort

Instrument	Within Group Proportion	
	Pretest	Posttest
Number of Officers	4037	2933
Response Category		
Very Comfortable	3.0	1.2
Comfortable	28.2	19.1
No Change	6.6	5.6
Slightly Uncomfortable	6.8	55.6
Very Uncomfortable	2.3	13.9
Missing	3.1	4.5

The responses to the pretest question for subjects who submitted both pretest and posttest information were compared to the responses of the subjects who submitted posttest information only. Table 3-23 contains the observed within cell percentages. The within cell percentages were not observed to vary more than three percent for any one category between the group of officers who submitted both questionnaires and the group who submitted only pretest information. The group of officers for which both pretest and posttest information was submitted was considered to be equivalent to the group of officers who submitted only pretest questionnaires.

In general, the officers initially felt that the garment would either be somewhat comfortable or not change its general comfort level. At the end of the test period, the officers felt that the garments were slightly uncomfortable. The Friedman analysis of variance procedure was employed to determine if this change in comfort was statistically significant.

The value of the Friedman test statistic that was obtained using 2877 pretest and posttest responses was 1106.23. With a sample of this size, the Friedman test statistic is distributed approximately as a chi-square with one degree of freedom. The probability of obtaining a value of chi-square at

Table 3-23. Distribution of Garment Comfort Responses Aggregated by Whether or Not the Officer Completed Both Pretest and Posttest Questionnaires

Instrument	Within Cell Proportions	
	Both	Pretest Only
Number of Officers	2552	1396
Response Category		
Very Comfortable	3.0	3.4
Comfortable	30.1	27.1
No Change	6.8	6.9
Slightly Uncomfortable	58.2	59.5
Very Uncomfortable	2.0	3.0

least this large due to chance is less than 0.001. Therefore, the observed decrease in garment comfort between the pretest and posttest was statistically significant.

4. Deterioration. The purpose of this phase of the study is to address two major questions. The first examines the degree to which the various garments retain their structural integrity, and the second is concerned over whether or not the ballistic material bunches. In order to answer these questions, officers were asked to respond on the monthly questionnaires to questions regarding the structural integrity of the garment and the amount of ballistic material bunching they experienced. The officers responses were solicited from Question 14.

14. The garment showed wear as follows:

- ___ seams opening
- ___ fasteners working loose
- ___ buttons falling off
- ___ ballistic material bunching up
- ___ wear at crease location
- ___ wear at material edges
- ___ velcro does not hold well
- ___ appearance deteriorating
- ___ other ___________
- ___ none

The proportion of officers wearing each type of garment and responding to one or more of the questions above is shown in Table 3-24, and the average monthly responses over time for all garments are shown in Figure 3-33.

The data show that less than 2 percent of the officers indicated they experienced bunching of the ballistic material, regardless of the type of garment worn. Therefore, this table supports the conclusion that bunching of the ballistic material is not considered a major problem by the officers.

The officers' responses to the garment integrity questions were not as conclusive as the responses to the ballistic material item. Approximately 5 percent of the officers indicated that the garment fasteners had a tendency to work loose. The occurrence was most often cited by officers who wore the LEAA Style II, 10-ply garment.

Again about 5 percent of the officers indicated a problem with fabric wear at the garment's seams. Officers wearing Commercial Styles A (12 ply) and B (14 ply) reported the highest percentage of problems with garment wear at the crease. The results were 9.3 percent and 12.8 percent, respectively. Significantly, less than 3 percent of the officers wearing Commercial Styles B (14-ply), C (18-ply), and D (24-ply) garment types experienced this problem.

Approximately 6 percent of the officers indicated they found problems with the Velcro. The incidence of Velcro-related problems was generally consistent for all garment types, except Commercial Style C (18 ply). Only 1.4 percent of the officers testing Commercial Style C (18 ply) garment noted a Velcro problem.

Relative to concern about garment appearance, about one percent of all officers reported that the garment appearance was deteriorating. The highest percentages of this deficiency, 3 percent, were reported by those wearing Commercial Styles A (12-ply), B (14-ply), and D (24-ply) garments.

In general, it can be said that the garments retained much of their structural integrity.

Table 3-24. Proportion of Officers Wearing Each Type of Garment Who Indicated That They Experienced One or More Forms of Garment Degradation

Garment Type	Seams Opening	Fasteners Loose	Buttons	Bunching	Crease	Edges	Velcro	Deteriorate
LEAA-I (7 ply)	0.037	0.058	0.130	0.006	0.042	0.041	0.071	0.012
LEAA-II (7 ply)	0.053	0.068	0.050	0.009	0.062	0.047	0.064	0.017
LEAA-II (10 ply)	0.095	0.112	0.020	0.008	0.054	0.050	0.059	0.009
Commercial								
A (12 ply)	0.051	0.044	0.044	0.000	0.093	0.041	0.066	0.028
B (14 ply)	0.072	0.043	0.037	0.017	0.128	0.028	0.064	0.029
C (18 ply)	0.061	0.025	0.019	0.000	0.033	0.005	0.014	0.008
D (24 ply)	0.065	0.021	0.022	0.011	0.020	0.019	0.046	0.034

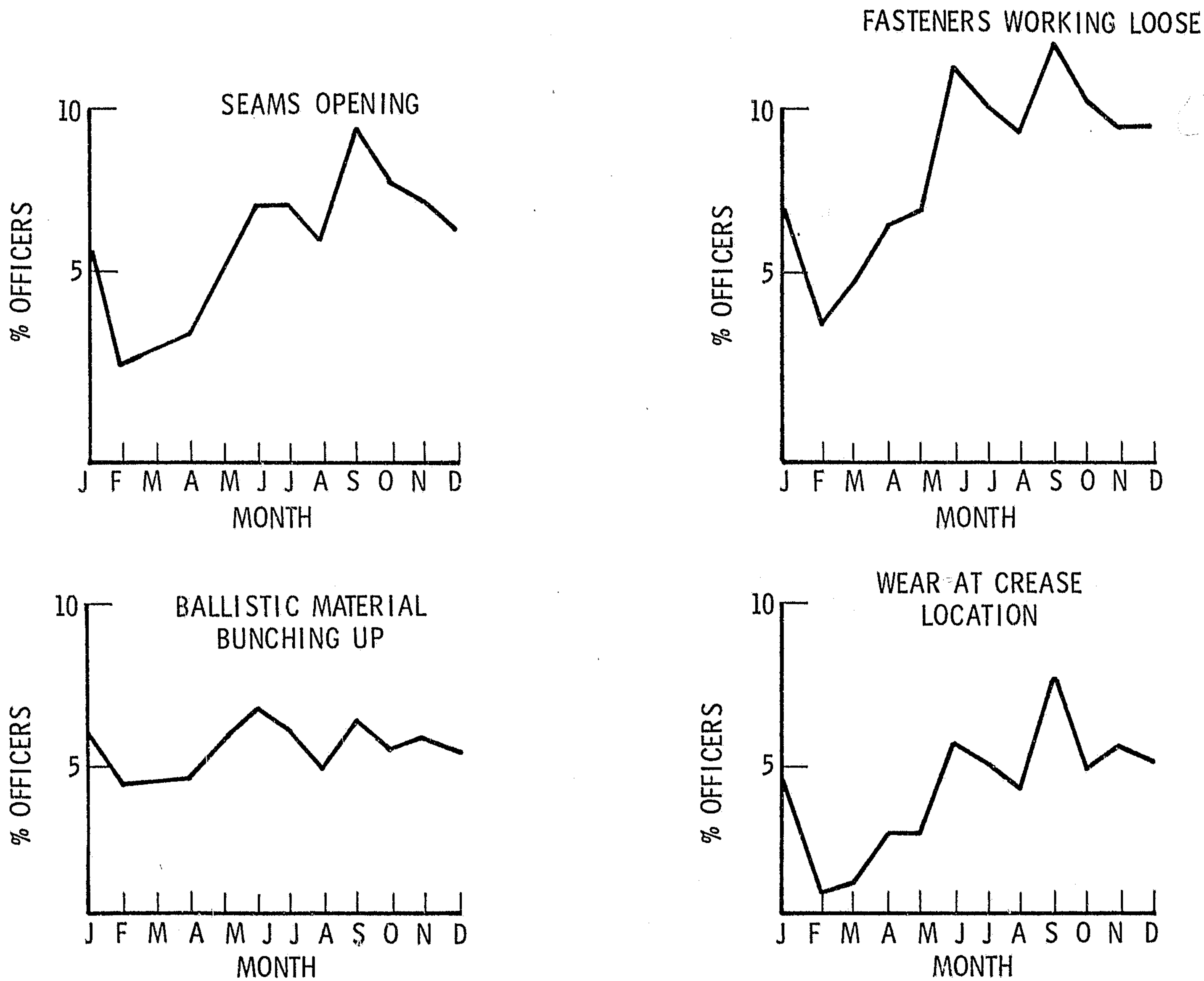


Figure 3-33. Garment Deterioration

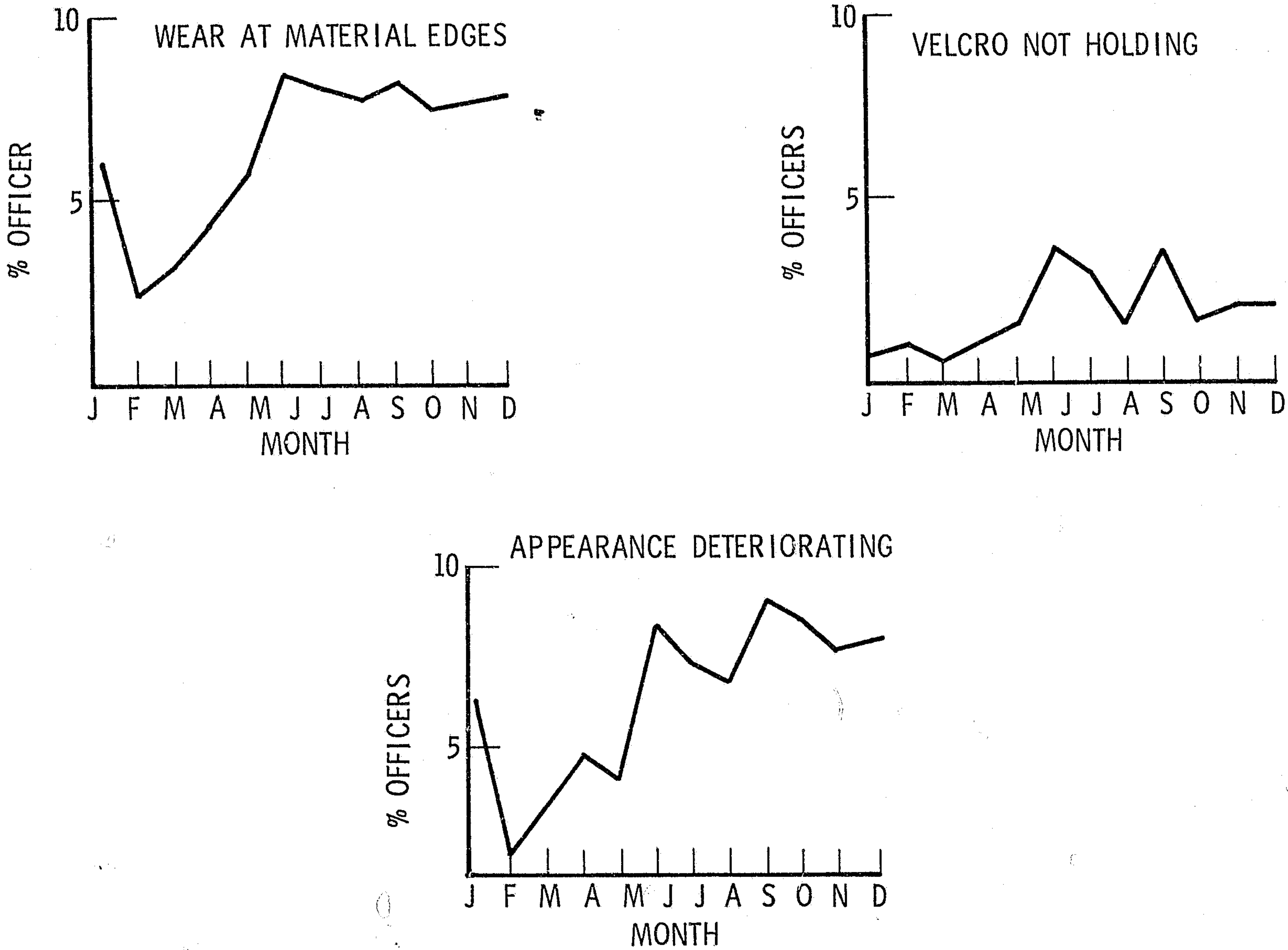


Figure 3-33. Garment Deterioration (Continued)

C. Impact on Law Enforcement Operations

An investigation was also conducted of the possible overt and covert changes in officer attitudes or performance which may have resulted from wearing the garments, and thus impact law enforcement operations. These changes were defined in terms of four measurement questions, each associated with one or more pretest and posttest items. The items associated with each measurement question and results of the response analyses are discussed below.

1. Aggressiveness. A major issue surrounding protective apparel is whether or not the garment tends to make the officer more aggressive toward the public. This issue was addressed in Question 30.

30. Do you think wearing soft body armor would make you more or less aggressive an officer?
1) ___ Much less
2) ___ Less
3) ___ No different
4) ___ More
5) ___ Much more

The responses to this question aggregated by participation group are shown in Table 3-25. Most of the officers (89 percent) felt that wearing a protective garment would have, or has had, no effect on the level of aggression they experienced while interacting with the public.

Complete pretest and posttest information was available for 2848 subjects. There remained 1754 subjects who submitted pretests but did not submit posttests. In order to address the missing data issue, the pretest responses of the officers who submitted complete data were compared with the pretest responses of the officers who submitted pretest data only. The resulting cross tabulation is shown in Table 3-26. The raw value of the chi-square statistic was 1.818 with 4 degrees of freedom. The probability of obtaining a value of chi-square at least that large due to chance is greater

Table 3-25. Levels of Aggression Experienced by Officers While Interacting with the Public Aggregated by Participant Group

Instrument	Within Group Percentage Responding to Each Category: Pretest		Posttest	
Subpopulation	Test	Control	Test	Control
Number of Officers	3995	581	2933	364
Response Category				
Much Less	0.2	0.5	0.2	0.8
Less	0.9	1.4	0.7	2.5
No Different	89.3	89.5	85.9	83.5
More	8.1	6.5	9.2	7.1
Much More	0.5	0.3	0.4	0.5
Missing	1.0	1.7	3.5	5.5

Table 3-26. Level of Pretest Aggressiveness in Interacting with the Public Aggregated by Whether or Not Complete Data Were Available.

Response Group	Within Group Percentages: Complete Data	Pretest Data Only
Response Category		
Much Less	0.2	0.3
Less	1.0	0.9
No Different	90.4	90.4
More	8.4	7.8
Much More	0.4	0.6

than 0.769. It is concluded that the responses to this item by the officers who submitted complete data did not differ from the responses of the officers who submitted only pretest information. The officers who submitted complete information were considered equivalent to the general population of officers.

The Friedman analysis of variance procedure was used to detect change between pretest and posttest responses. The Kruskal-Wallis analysis of variance procedure was used to determine the significance of the difference between test and control groups and interaction contrasts. The results of these procedures appear in Table 3-27. The values of the interaction contrast (chi-square = 0.000, df = 1, p = 0.294) were found to be not significantly different from zero. Therefore, a conclusion might be that the aggressive behavior of police officers is not dependent upon the wearing of protective apparel. Caution should be exercised in the interpretation of these results. It has been shown that the responses to this item seem to cluster about a neutral position, which is highly suspicious. The item itself may cause a particularly sensitive reaction by police officers. Certain items are "social desirability" factors if they elicit similar responses from most people. Deviation from such specific responses indicates a departure from a strong social belief structure. It is possible that the responses for this item contain a high social desirability component. The result of no significant differences may be true; however, the responses to this item may not clearly demonstrate that fact.

The next measurement item used to define officer aggression is composed of four subitems. The collection of four subitems attempts to determine the number of times the officer experiences a violent confrontation while in the line of duty. The appropriate pretest question is reproduced below for convenience.

Table 3-27. Results of the Analysis of the Significance of Observed Differences in Aggression

Source of Variation	Test Statistic	df	Significance[a]
Pretest Posttest Contrast	1.100[b]	1	0.294
Between Groups Contrast	0.000[c]	1	0.999
Interaction Contrast	0.564[c]	1	0.453

[a]Probability of the observed value of the test statistic occurring by chance

[b]Friedman Test Statistic

[c]Kruskal-Wallis Test Statistic

20. Approximately how many times have you been assaulted in the line of duty since January 1972? (violence or threat of violence)

Never (1)	One time (2)	Two times (3)	Three times (4)	More than three times (5)	
____	____	____	____	____	Handguns
____	____	____	____	____	Shotguns and rifles
____	____	____	____	____	Other dangerous weapons
____	____	____	____	____	Hands, arms, fists, etc.

The corresponding posttest question is reproduced below for comparison.

20. Approximately how many times have you been assaulted in the line of duty during the test period (violence or threat of violence).

Never (1)	One time (2)	Two times (3)	Three times (4)	More than three times (5)	
____	____	____	____	____	Handguns
____	____	____	____	____	Shotguns and rifles
____	____	____	____	____	Other dangerous weapons
____	____	____	____	____	Hands, arms, fists, etc.

It should be clear from the examination of the questions that the pretest and posttest refer to two different periods of time. Since the reference period is not the same for the pretest as it is for the posttest, any pretest-posttest contrast would not be meaningful, and any between participation group contrasts would not be substantively meaningful to this study since this contrast would be indicative of differences which existed over time and therefore not attributable in any manner to the garment. What is meaningful to this study is if the two participation groups behaved differently. The only contrast which would indicate a possible garment effect would be a significant interaction contrast. Only the pretest-posttest interaction contrast will be examined for each type of assault.

The distributions of assaults for pretest, posttest, test, and control groups are shown in Tables 3-28 through 3-31. The responses to each of the pretest questionnaires were compared to the responses for the same items from subjects who submitted pretests only. The results of these comparisons are shown in Tables 3-32 through 3-35. The response patterns did not exhibit significant variation between groups. Therefore, the subjects who submitted both pretest and posttest questionnaires can be considered equivalent to the entire pretest sample.

The values of the Kruskal-Wallis and Friedman test statistics for each category of assault are shown in Table 3-36. It should be easily seen from the table that all pretest-posttest contrasts were, as expected, significant. Also, all between group contrasts were not significant. As previously stated, however, since the questions spanned varying time periods, the only meaningful contrast is the interaction contrasts. The values of the interaction contrasts for two types of assaults were found not to be significant. These two categories of assaults were "Shotguns and Rifles" and "Other Dangerous Weapons." Therefore, it seems that whether or not an officer is wearing a protective garment does not have an effect on the rate of assaults which occur with either shotguns, rifles, or other dangerous weapons.

Table 3-28. Distribution of the Number of Assaults Using Handguns for the Entire Pretest and Posttest Data Sets

Instrument	Within Cell Percentage			
	Pretest		Posttest	
Participation Group	Test	Control	Test	Control
Number of Officers	4037	581	2933	364
Response Category				
Never	58.1	69.1	87.5	79.3
Once	17.6	14.2	7.1	9.1
Twice	10.2	8.2	3.0	4.7
Thrice	4.1	1.8	0.9	2.0
More Than Three	9.9	6.6	1.5	4.7
Missing	(9.6)	(14.1)	(13.4)	(19.0)

Table 3-29. Distribution of the Number of Assaults Using Shotguns and Rifles for the Entire Pretest and Posttest Data Sets

Instrument	Within Cell Percentage			
	Pretest		Posttest	
Participation Group	Test	Control	Test	Control
Number of Officers	4037	581	2933	364
Response Category				
Never	75.0	77.0	93.9	86.0
Once	15.0	14.5	3.8	9.3
Twice	4.9	5.0	1.4	1.8
Thrice	1.7	1.0	0.4	1.4
More Than Three	3.4	2.4	0.4	1.4
Missing	(10.8)	(14.6)	(16.4)	(23.4)

Table 3-30. Distribution of the Number of Assaults Using Other Dangerous Weapons for the Entire Pretest and Posttest Data Sets

	Within Cell Percentage			
Instrument	Pretest		Posttest	
Participation Group	Test	Control	Test	Control
Number of Officers	4037	581	2933	364
Response Category				
Never	55.6	67.9	84.9	77.1
Once	14.7	10.5	7.5	10.4
Twice	10.9	8.5	4.0	4.3
Thrice	5.1	3.2	1.4	2.5
More Than Three	13.7	9.9	2.3	5.7
Missing	(10.8)	(14.6)	(14.7)	(23.1)

Table 3-31. Distribution of the Number of Assaults Using Hands, Arms, Fists, Etc. for the Entire Pretest and Posttest Data Sets

	Within Cell Percentage			
Instrument	Pretest		Posttest	
Participation Group	Test	Control	Test	Control
Number of Officers	4037	581	2933	364
Response Category				
Never	21.0	30.3	55.2	41.6
Once	8.5	7.7	10.9	13.9
Twice	13.0	11.5	11.3	13.9
Thrice	10.2	12.9	7.7	11.7
More Than Three	47.3	37.6	14.9	18.9
Missing	(9.3)	(13.1)	(5.2)	(12.9)

Table 3-32. Distribution of the Number of Pretest Assaults Using Handguns Aggregated by Whether or Not the Officer Submitted Pretest and Posttest or Only Pretest Questionnaires

Instrument	Within Cell Percentage	
	Both	Pretest Only
Number of Officers	2591	1590
Response Category		
None	59.8	59.1
One	16.8	17.9
Two	10.0	9.7
Three	4.2	3.3
More Than Three	9.1	10.0

Table 3-33. Distribution of the Number of Pretest Assaults Using Shotguns and Rifles Aggregated by Whether or Not the Officer Submitted Pretest and Posttest or Only Pretest Questionnaires

Instrument	Within Cell Percentages	
	Both	Pretest Only
Number of Officers	2557	1575
Response Category		
None	75.1	75.2
One	15.0	15.1
Two	5.2	4.6
Three	1.4	1.9
More Than Three	3.3	3.2

Table 3-34. Distribution of the Number of Pretest Assaults Using Other Dangerous Weapons Aggregated by Whether or Not the Officer Submitted Pretest and Posttest or Only Pretest Questionnaires

Instrument	Within Cell Percentage	
	Both	Pretest Only
Number of Officers	2556	1575
Response Category		
None	56.3	58.3
One	14.7	13.5
Two	10.6	10.5
Three	5.1	4.5
More Than Three	13.2	13.3

Table 3-35. Distribution of the Number of Pretest Assaults with Hands, Fists, Etc. Aggregated by Whether or Not the Officer Submitted Pretest and Posttest or Only Pretest Questionnaires

Instrument	Within Cell Percentage	
	Both	Pretest Only
Number of Officers	2604	1594
Response Category		
None	22.3	21.8
One	8.4	8.4
Two	13.2	12.2
Three	11.0	9.8
More Than Three	45.0	47.8

Table 3-36. Values of Test Statistics for Each of Three Contrasts and Four Types of Assaults

Assault Category	Comparison Contrast		
	Pretest/Posttest[a]	Between Groups[b]	Interaction[b]
Handguns	175.174[c]	0.634[d]	5.180[c]
Shotguns and Rifles	64.636[c]	1.132[d]	3.593[d]
Other Dangerous Weapons	192.995[c]	0.461[d]	3.680[d]
Hands, Fists, Etc.	584.861[c]	2.100[d]	16.392[c]

[a]Friedman Test Statistic, df = 1.
[b]Kruskal-Wallis Test Statistic, df = 1.
[c] $p < 0.05$
[d] $p > 0.05$

The value of the interaction contrast was found to be statistically significant for two types of assaults: Handguns and Hands, Fists, Etc. The average number of assaults within these categories aggregated by type of questionnaire and participation group is shown in Table 3-37. On the surface, it would appear from the table that the officers who were issued garments experienced a greater decrease in the number of assaults involving weapons included in the handguns, hands, and fists category than officers who were not issued protective garments. Blind reliance upon the statistical procedure would lead to the conclusion that protective garments may contribute to a decrease in the number of certain types of assaults experienced by police officers. However, a close examination of the entries in Table 3-37 seems to indicate that this conclusion lacks substantive validity. With regard to assaults with handguns, the pretest difference between test and control groups was 0.1 (standard deviation = 1.28), and the posttest difference between the same groups was -0.27 (standard deviation = 0.8 approximately). The pretest difference between test and control mean assaults with "hands, fists, etc." was 0.21 (standard deviation = 1.6), and the posttest difference for the same groups was -0.42 (standard deviation = 1.54 approximately). Considering the relatively large size of this sample, and that the number of officers in each

Table 3-37. Mean and Standard Deviation of the Number of Times an Officer Was Assaulted with Handguns or Hands and Fists[a]

Assault Category	Pretest		Posttest	
	Test	Control	Test	Control
Handguns	0.869(1.29)	0.769(1.27)	0.22(0.69)	0.49(1.06)
Hands, Fists, Etc.	2.500(1.63)	2.290(1.65)	1.14(1.51)	1.56(1.59)

[a]Standard deviation in parenthesis.

cell of the design are not proportional, the differential effect sizes are not impressive. In light of these details, it seems that a conservative inference is in order. It can be said that there exists evidence which indicates that the wearing of a protective garment does not have an impact upon the number of assaults experienced by a police officer. There exists a very small amount of evidence which seems to indicate that protective garments may reduce the number of assaults experienced by the officer in certain categories (handguns, hands, fists, etc.) by an extremely small and, perhaps, nonmeaningful amount.

2. Performance of duties. On the wearer monthly data questionnaire, the test group was asked the following three questions relating to the degree that the garments interfere with their performance of their duties.

	Agree Strongly (1)	Agree (2)	[illegible] (3)	Disagree (4)	Disagree Strongly (5)	
21.						The garment hinders my movements while pursuing a suspect
22.						The garment hinders my efforts to subdue an adversary
23.						The garment interferes with my efforts during a rescue operation

The percent of officers who agreed with these statements, with respect to time, are presented in Figures 3-34 through 3-36. The total average responses to the questions for each category are presented in Table 3-38. These data show that less than 25 percent of the test group responded that the garment hindered their performance and that these responses were stable over time.

3. Fatigue. Each month, the test group was asked if the garment increased their fatigue while on duty. The exact question asked was:

Agree strongly	Agree	Neither	Disagree	Disagree strongly	
(1)	(2)	(3)	(4)	(5)	
20. ____	____	____	____	____	Wearing this garment increases my fatigue on duty

Figure 3-37 shows the responses with respect to time of the percent of officers who agree with the statement, while Table 3-39 gives the total percent response to each category. These data show that approximately 25 percent of the test group felt that the garment did increase, to some extent, their fatigue on duty. There is no significant trend in the data with respect to time, but there appears to be a slight increase during the summer months in the number of officers who feel that the garments increase fatigue.

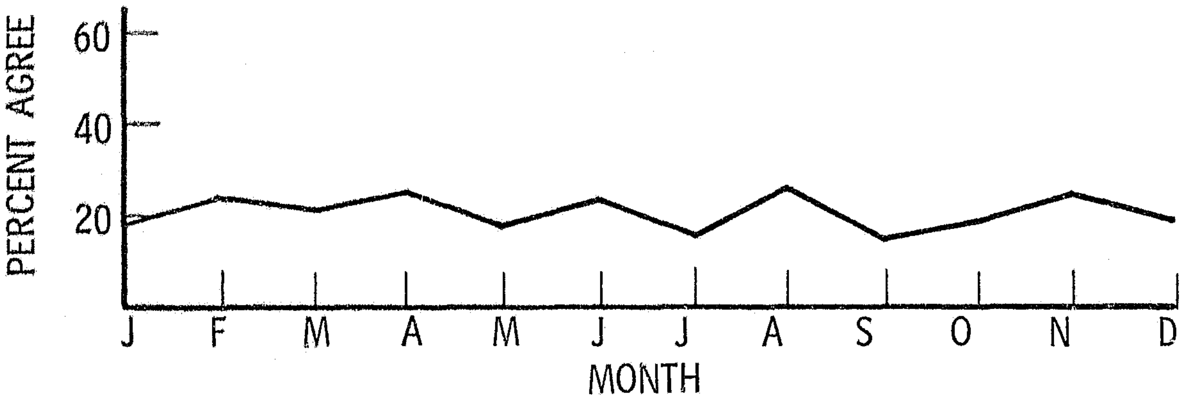


Figure 3-34. Hinders Movements

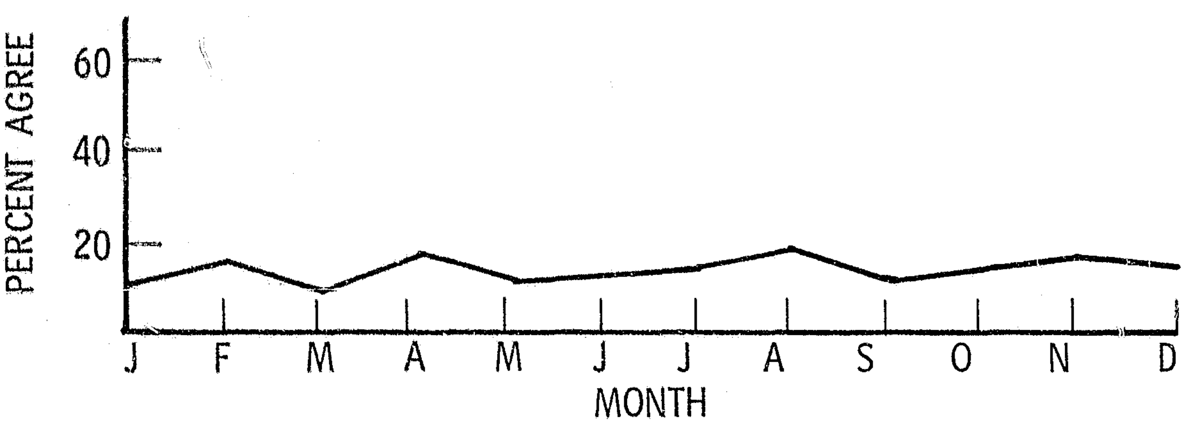


Figure 3-35. Hinders Efforts To Subdue

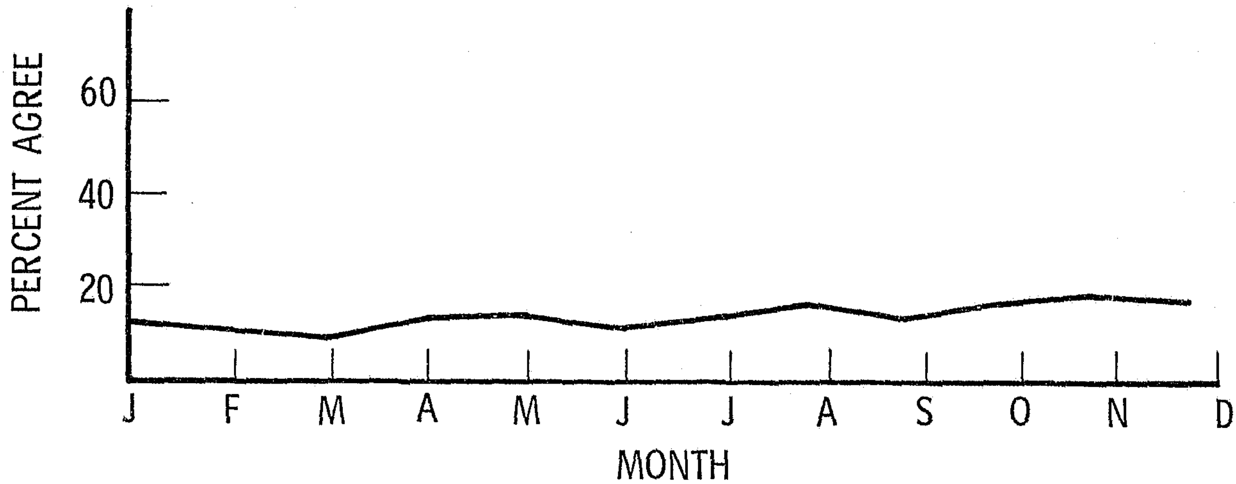


Figure 3-36. Hinders Efforts To Rescue

Table 3-38. Average Hindrance Responses

Question	Average Response				
	Agree Strongly	Agree	Neither	Disagree	Disagree Strongly
Hinders Movements	1.5	21.1	34.7	39.6	3.1
Hinders Subdue Efforts	0.9	14.8	35.9	45.0	3.3
Hinders Rescue Efforts	0.8	13.7	43.5	39.3	2.7

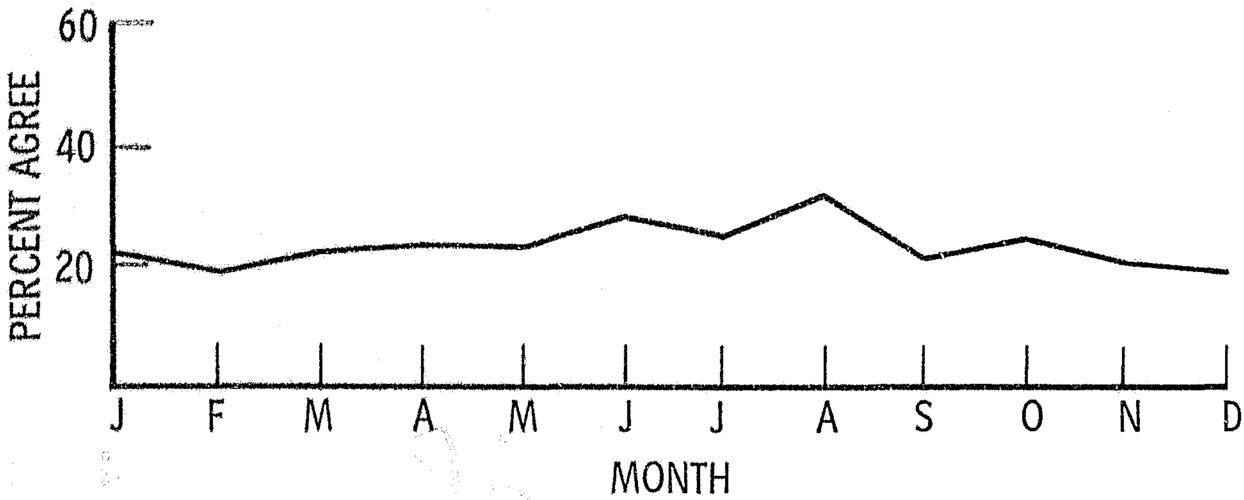


Figure 3-37. Increased Fatigue

Table 3-39. Average Fatigue Responses

Question	Percent Response				
	Agree Strongly	Agree	Neither	Disagree	Disagree Strongly
Garment Increases Fatigue on Duty	2.5	24.1	31.7	37.9	3.9

CHAPTER IV. SUPPLEMENTAL TEST AND ANALYSES

A. Recall Garments

The test plan required the periodic recall of garments from the field to monitor their performance for degradation. The garments to be recalled were identified on the basis of frequency of laundering and amount of times worn. When the garments to be recalled were identified, replacements with new garments in the same size and style were delivered to the test conductors. The new garments were then exchanged for the worn garments to eliminate nonavailability to the officers.

The test program was established to determine changes in penetration resistance to the .22-caliber projectile, changes in the clay cavity from the .38-caliber projectile, changes in the tensile strength in the warp and fill directions, mechanical damage to the fabric fibers, and degradation in the Zepel-D water-repellant treatment.

The recalled garments were tested in the following manner. The rear panel was used for ballistic testing. Three .38-caliber impacts were made on each panel to obtain average clay cavity measurements. The rear panel was then impacted with 10 well-separated .22-caliber impacts to determine penetration velocities. The front panel was used to obtain tensile specimens of 10 by 2 in. in both the warp and fill direction. Four samples were taken from each ply in each direction. Scrap sections from the panel were used for microscopic examination and water-break testing.

1. Tensile tests. The tensile tests were performed on the Instron test equipment equipped with 1 by 2-in. pneumatic jaws operating at 3000-psi pneumatic pressure. The jaws were 2-in. long in the pull direction. These 10 by 2-in. test samples were prepared by glueing (contact cement) 2-in. square cardboard tabs to each side of both ends of the specimen. This gave a 6-in. pull specimen. The jaws were aligned with the specimen in such a way that the same threads or yarns were engaged by both the upper and lower

jaws. The tensile load was therefore applied to the center 1 in. of fabric in the 2-in. width (approximately 31 threads). The samples were then loaded to failure.

Table 4-1 contains the results of the tensile tests on the recalled garments. The average values in the warp and fill direction are presented for each garment tested. The results shown in the table are somewhat lower than the values measured during the acceptance testing of the production fabric. The acceptance testing showed fabric warp strengths between 1000 and 1300 lb. The warp strength of the samples in the table generally lay between 900 and 1200 lb. Only one garment, serial number B2235, was significantly outside these limits, but there did not appear to be a degradation in the ballistic performance. Similarly, the fabric acceptance testing showed fill breaking strengths between 1300 and 1500 lb. The test specimens from the recalled garments showed breaking strengths between 1100 and 1400 lb. Again only one garment, this time serial number A00614 was significantly outside these limits and, again, this garment performed well in ballistic tests.

These mechanical property degradations do not appear to be reflected in loss of ballistic resistance. In investigating mechanical properties on a layer by layer basis, it was found the innermost layer (the one exposed and toward the body) showed the largest amount of strength loss. This would tend to draw the average tensile strength down, but would contribute the least to ballistic penetration degradation.

Table 4-1, Recalled Garments — Tensile Test Results, presents the available data on the second set of recalled garments. These sets of tensile tests were made in June and July 1977 after approximately 15 to 18 months of wear. Again, there is no significant degradation in mechanical properties although the mean strength in both the warp and fill directions appear to be slightly degraded from the earlier test results.

2. Ballistic tests. The ballistic testing of the garments recalled from the field consisted in both .22-caliber and .38-caliber tests. The .22-caliber tests were performed to determine penetration resistance while the .38-caliber tests were performed to check the backface signature.

Table 4-1. Recalled Garments — Tensile Test Results

Vest	City	Warp $\bar{x}$ (lb)	Warp SD	Fill $\bar{x}$ (lb)	Fill SD
A00954	Newark	1075	78	1220	29
A00002	Newark	1175	70	1230	89
A00171	Newark	1030	20	1165	48
A00868	Newark	1160	14	1340	29
A00765	Newark	953	81	1318	60
A00585	Newark	1188	81	1255	52
B1965	Newark	1113	56	1400	42
B2705	Newark	873	38	1217	78
B3835	Newark	1088	21	1255	39
B1885	Newark	1108	57	1290	62
C4630	Newark	1120	134	1325	51
A00805	Seattle	1093	38	1310	46
A00285	Seattle	1140	0	1320	42
A00625	Seattle	1003	54	1260	42
A01335	Seattle	887	15	1112	13
A00845	Seattle	1003	73	1145	51
A00935	Seattle	1070	30	1187	35
B2735	Seattle	988	61	1485	7
B1955	Albuquerque	1088	69	1410	55
B3825	Albuquerque	1078	87	1270	82
B1895	Birmingham	1013	70	1388	21
B4065	Birmingham	1103	38	1208	70
B2245	Miami	1262	78	1248	46
B1855	Miami	1020	30	1243	95
A00255	St. Paul	1103	54	1197	90
B2235	St. Paul	823	42	1240	92
A00385	Detroit	1145	107	1207	67
A00705	Detroit	946	47	1265	71
A00975	Detroit	1143	67	1255	163
B3605	St. Louis	975	24	1263	94
B3415	St. Louis	988	90	1205	31
B3445	St. Louis	973	31	1128	86
A00155	Portland	1028	46	1323	35
A00825	Portland	1073	71	1113	50
A00655	Portland	1098	48	1183	62
B2477	Portland	1158	78	1210	70
B2715	Portland	1013	66	1328	75

Table 4-1. Recalled Garments — Tensile Test Results (Continued)

Vest	City	Warp $\bar{x}$ (lb)	Warp SD	Fill $\bar{x}$ (lb)	Fill SD
A00415	Philadelphia	915	94	1415	42
B3045	Philadelphia	1025	31	1190	55
B2598	Philadelphia	1070	92	1328	31
B2605	Philadelphia	1118	54	1120	42
B3407	Albuquerque	1040	75	1407	71
B3691	Albuquerque	1130	50	1025	76
B2343	Albuquerque	1160	119	1297	39
B3154	Albuquerque	1192	43	1288	119
B2805	Seattle	1223	74	1165	38
A01349	Seattle	1075	53	1273	59
A00606	Seattle	1018	101	1193	104
A00733	Seattle	1140	61	1243	90
A01356	Seattle	1103	71	1020	106
B2661	Seattle	1060	53	1263	86
B2667	Seattle	980	120	1283	156
B2740	Seattle	1053	70	1338	110
A01460	Seattle	1003	158	1250	71
B2659	Seattle	968	39	1305	34
B2819	Seattle	1100	54	1043	143
B2671	Seattle	1165	128	1160	64
A00983	Seattle	1160	39	1183	120
B2657	Seattle	945	163	1230	58
A00614	Seattle	935	34	877	80

Seven plies of new Kevlar fabric yield a nominal depth of cavity in Roma Plastallina Clay No. 1 of approximately 1.8 in. (4.6 cm) with the 158-gr round nose lead projectile of approximately 800 fps. Table 4-2 shows the cavity results for 41 garments recalled from the field. The mean penetration depth is 1.473 in. with a standard deviation of 0.185 in. In all the tests, the velocities were greater than 800 fps, with two exceptions. Vest number A00171 was impacted at 789 fps, while vest A00285 was impacted at 742 fps. There is apparently no significant increase in cavity depth for the garments tested.

Table 4-2. Recalled Garments — .38-Caliber Ballistic Test

Vest	City	Penetration Data				
		Velocity (fps)	Depth (in.)	Cross (in.)	Section (in.)	Volume (m)
A00954	Newark	847	1.775	2.325	2.330	42
A00002	Newark	890	1.550	2.275	2.135	48
A00171	Newark	789	1.535	2.510	2.400	58
A00868	Newark	888	1.545	2.340	2.400	37
A00765	Newark	915	1.475	2.175	2.550	38
A00585	Newark	820	1.475	2.025	2.025	28
B1965	Newark	860	1.725	2.225	2.175	45
B2705	Newark	930	1.450	2.300	2.300	40
B3835	Newark	---	1.550	2.450	2.250	42
B1885	Newark	929	1.925	2.275	2.125	44
C4630	Newark	884	1.200	2.400	2.170	41
A00805	Seattle	920	1.875	2.000	2.075	22
A00285	Seattle	742	1.250	1.800	1.800	16
A00625	Seattle	915	1.375	2.435	2.425	36
A01335	Seattle	951	1.300	2.200	2.475	32
A00845	Seattle	959	1.325	2.650	2.200	34
A00935	Seattle	933	1.400	2.275	2.725	36
B2735	Seattle	949	1.450	2.550	2.450	36
B1955	Albuquerque	871	1.450	2.325	2.325	28
B3825	Albuquerque	875	1.125	1.980	1.975	20
B1895	Birmingham	838	1.630	2.875	2.350	60
B45065	Birmingham	852	1.125	2.600	2.600	46
B2245	Miami	885	1.310	2.150	2.460	36
B1855	Miami	871	1.250	1.875	2.375	30
A00255	St. Paul	880	1.650	2.500	2.475	52
B2235	St. Paul	964	1.725	2.325	2.650	48
A00385	Detroit	856	1.350	2.275	2.450	42
A00705	Detroit	906	1.700	2.500	2.500	58
A00975	Detroit	925	1.400	3.050	2.250	42
B3605	St. Louis	923	1.600	2.550	2.200	52
B3415	St. Louis	879	1.350	2.225	2.015	32
B3445	St. Louis	975	1.525	2.600	2.950	56
A00155	Portland	927	1.425	2.575	2.575	46
A00825	Portland	869	1.550	2.575	2.350	42
A00655	Portland	913	1.375	2.375	2.725	46
B2477	Portland	885	1.575	2.575	2.550	50
B2715	Portland	895	1.600	2.275	2.250	36

Table 4-2. Recalled Garments — .38-Caliber Ballistic Test (Continued)

Vest	City	Penetration Data: Velocity (fps)	Depth (in.)	Cross Section (in.)		Volume (m)
A00415	Philadelphia	895	1.375	2.350	2.425	50
B3045	Philadelphia	935	1.400	2.550	2.800	40
B2598	Philadelphia	901	1.375	2.425	2.375	44
B2605	Philadelphia	915	1.350	2.575	2.575	46
B3407	Albuquerque	835	1.550	2.375	2.390	44
B3691	Albuquerque	843	1.660	3.025	2.375	44
B2343	Albuquerque	857	1.660	2.475	2.475	44
B3154	Albuquerque	843	1.675	2.460	2.460	46
B2805	Seattle	862	1.760	2.850	2.850	50
A01349	Seattle	875	1.580	2.290	2.450	44
A00606	Seattle	872	1.720	2.365	2.365	42
A00733	Seattle	846	1.675	2.175	2.615	50
A01356	Seattle	866	1.480	2.230	2.540	38
B2661	Seattle	868	1.680	2.280	2.825	56
B2667	Seattle	887	1.850	2.525	2.750	70
B2740	Seattle	867	1.855	2.745	2.745	50
A01406	Seattle	822	1.750	2.525	2.525	54
B2659	Seattle	864	1.765	2.695	2.695	58
B2819	Seattle	857	1.915	3.000	3.000	70
B2671	Seattle	845	1.775	2.570	2.570	56
A00983	Seattle	859	1.725	2.595	2.325	46
B2657	Seattle	830	1.800	2.600	2.675	64
A00614	Seattle	873	1.675	2.725	3.065	66
			$\overline{C}$ mean = 1.712		52.7 =	$\overline{V}$ mean = 5
			SD = 0.106		9.5 =	SD = 9

Table 4-2, Recalled Garments — .38-Caliber Ballistic Tests, indicates slightly larger and deeper cavities for the garments below the solid line which were tested later, than the first set of recalled garment tests. This could be due to either the garments becoming more flexible with use or the possibility that the Plastilina Clay No. 1 was somewhat softer for the second set of test results. Either way, the cavities are still reasonably consistent with those measured with new Kevlar panels.

The .22-caliber penetration characteristics of 7 plies of Kevlar is shown in Figure 4-1. This curve is typical of what is normally observed

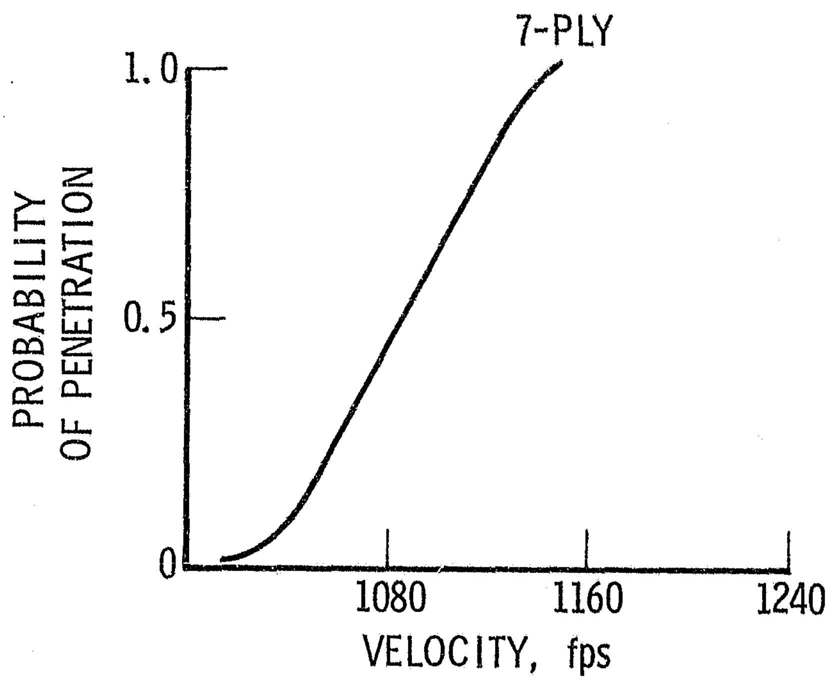


Figure 4-1. Typical .22-Caliber Penetration Probability— 7-Ply, 1000-Denier Kevlar

in ballistic testing. Because of fabric variations from weaver to weaver and within fabric from any one weaver, the actual location of the indicated curve will vary. The better fabrics will tend to shift the curve to the right or toward higher penetration velocities.

Table 4-3, Recalled Garments — .22-Caliber Ballistic Testing, contains the results of both the earlier and later recall programs. The mean penetration velocity for the first garment set was 1073 fps, and the second set

Table 4-3. Recalled Garments — .22-Caliber Ballistic Tests

Vest	City	Velocity $\bar{x}$ (fps)	Velocity SD	No. of Penetrations	Velocity of Penetration (fps)
A00954	Newark	1067	17	1	1078
A00002	Newark	1057	18	0	---
A00171	Newark	1045	23	0	---
A00868	Newark	1055	16	0	---
A00765	Newark	1062	16	0	---
A00585	Newark	1051	22	1	1047
B1965	Newark	1044	25	0	---
B2705	Newark	1045	14	0	---
B3835	Newark	1051	18	0	---
B1885	Newark	1055	15	0	---
C4630	Newark	1051	12	0	---
A00805	Seattle	1056	19	0	---
A00285	Seattle	1056	20	1	1072
A00625	Seattle	1064	18	0	---
A01335	Seattle	1051	22	0	---
A00845	Seattle	1060	20	1	1053
A00935	Seattle	1056	30	0	---
B2735	Seattle	1007	182	0	---
B1955	Albuquerque	1066	12	0	---
B3825	Albuquerque	1073	14	1	1070
B1895	Birmingham	1068	8	0	---
B4065	Birmingham	1067	18	1	1089
B2245	Miami	1035	13	0	---
B1855	Miami	1041	15	1	1032
A00255	St. Paul	1022	21	0	---
B2235	St. Paul	1068	11	2	1089, 1067
A00385	Detroit	1023	19	0	---
A00705	Detroit	1041	23	0	---
A00975	Detroit	1053	24	1	1111
B3605	St. Louis	1060	21	0	---
B3415	St. Louis	1043	22	0	---
B3445	St. Louis	1054	19	0	---
A00155	Portland	1061	21	1	1085
A00825	Portland	1072	19	1	1089
A00655	Portland	1068	18	1	1092
B2477	Portland	1056	21	0	---
B2715	Portland	1061	17	0	---
A00415	Philadelphia	1029	17	1	1043
B3045	Philadelphia	1033	22	0	---
B2598	Philadelphia	1025	26	0	---
B2605	Philadelphia	1040	20	0	---

Table 4-3. Recalled Garments — .22-Caliber Ballistic Tests (Continued)

Vest	City	Velocity $\overline{X}$ (fps)	Velocity SD	No. of Penetrations	Velocity of Penetration (fps)
B3407	Albuquerque	1042	40	2	1099, 1131
B3691	Albuquerque	1019	42	2	1075, 1101
B2343	Albuquerque	1046	46	1	1122
B3154	Albuquerque	1022	42	1	1086
B2805	Seattle	1053	32	2	1025, 1091
A01349	Seattle	1059	37	3	1130, 1114, 1120
A00606	Seattle	1055	38	2	1122, 1133
A00733	Seattle	1058	37	3	1094, 1101 1106
A01356	Seattle	1054	34	-	---
B2661	Seattle	1057	30	2	1112, 1089
B2667	Seattle	1042	30	1	1094
B2740	Seattle	1049	39	3	1109, 1112, 1126
A01406	Seattle	1045	41	1	1119
B2659	Seattle	1027	41	-	---
B2819	Seattle	1058	36	4	1096, 1097 1105, 1114
B2671	Seattle	1065	40	1	1034
A00983	Seattle	1052	35	6	1068, 1071 1069, 1097 1103, 1108
B2657	Seattle	1054	35	2	1049, 1099
A00614	Seattle	1070	38	1	1084

was 1097 fps. These values are consistent with what was measured on the new Zepel-D treated material as shown in Figure 4-1. Hence, the ballistic resistance of the Kevlar fabric does not appear to be seriously degraded with wear and age.

CONTINUED

2 OF 4

B. New Materials Testing

A review of the threat data, the availability of high velocity .22 caliber ammunition almost to the exclusion of the standard velocity rounds, and the Police Foundation Report findings that there is a general upgrading of handguns on the streets led to a reassessment of the .22-caliber projectile velocity. A review of available data along with the earlier experience in performing ballistic testing with .22-caliber revolvers indicated the design velocity for the common handgun threat regarding the .22-caliber projectile should probably be in the 1080-to-1100 fps region rather than the 1000 fps originally specified. In view of this, a test series was undertaken to obtain the probability of penetration versus velocity for both 8 and 9 plies of Kevlar fabric.

Samples of 1000-denier 31 × 31 plain weave Kevlar were purchased from five manufacturers of the woven fabric. The objective was to perform ballistic tests on all five sample fabrics to determine if major differences existed among the manufacturers and to determine the penetration probability curves of 8 and 9 plies of fabric versus .22-caliber projectile velocities. Table 4-4, New Materials Ballistic Testing, shows the results of the tests against the five samples of material. Only one sample, sample number 3, indicated poor performance in the 8-ply sample tests. The remaining samples were relatively close with some minor variations in performance.

Figures 4-2 and 4-3 show the ballistic test results for the 8-and 9-ply samples, respectively. These plots are the aggregate of all five samples of material.

Figure 4-4, Probability of Penetration versus Velocity, shows the penetration probability curves for 7-, 8-, and 9-ply samples. The curves are for the .22-caliber projectiles with the test samples backed with clay.

Table 4-4. New Materials Ballistic Testing

Sample 1

Plies – 8 | Cal 22 – 40-gr L. R.

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1077	PP	1080	PP	1014	PP	1150	CP
1102	PP	1093	PP	1103	CP	1119	CP
1059	PP	1076	PP	1144	CP	1180	CP
1101	PP	1090	PP	1181	CP	1138	CP
1097	PP	1049	PP	1142	CP	1123	CP
1097	PP	1068	PP	1091	PP	1112	PP
1087	PP	1089	PP	1102	CP	1151	CP
1080	PP	1085	PP	1100	CP	1108	CP
1095	PP	1116	CP	1100	CP	1155	CP
1073	PP	1054	PP	1190	CP	1141	CP
Plies – 9							
1144	PP	1163	CP	1128	PP		
1218	CP	1144	PP	1149	PP	1133	PP
1149	PP	1179	CP	1081	PP	1150	CP
1122	PP	1137	CP	1152	PP	1135	PP
1172	CP	1160	CP	1164	CP	1151	CP
1159	CP	1122	CP	1122	PP	1163	PP
1112	CP	1136	PP	1100	PP	1125	PP
1097	CP	1161	CP	1175	CP	1144	PP
1116	PP	1107	PP	1108	PP	1043	PP
1144	PP	1203	CP	1109	PP	1079	PP

Sample 2

Plies – 8 | Cal 22 – 40-gr L. R.

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1086	PP	1087	PP	1004	PP	1200	CP
1070	PP	1110	CP	1131	PP	1176	CP
1097	PP	1080	PP	1174	CP	1135	CP
1087	PP	1108	PP	1116	PP	1180	CP
1095	PP	1097	PP	1128	PP	1187	CP
1090	PP	1074	PP	1114	CP	1155	CP
1078	PP	1112	PP	1126	CP	[illegible]	CP
1116	PP	1096	PP	1114	CP	1091	PP
1084	PP	1107	PP	1133	CP	1135	PP
Plies – 9							
1168	PP	1103	PP	1109	PP	1166	PP
1207	CP	1136	PP	1193	PP	1204	CP
1155	PP	1122	PP	1108	PP	1142	PP
1129	PP	1128	PP	1223	CP	1191	CP
1134	PP	1171	PP	1163	PP	1175	CP
1122	PP	1210	CP	1157	PP	1153	PP
1164	PP	1103	PP	1119	PP	1204	CP
1052	PP	1105	PP	1170	PP	1157	PP
1181	CP	1203	PP	1184	PP	1181	PP
1117	PP	1117	PP	1173	PP	1167	PP
1132	PP	1125	PP	1119	PP	1176	PP

Table 4-4. New Materials Ballistic Testing (Continued)

Sample 3*

Plies – 8   Cal 22 – 40-gr L. R.

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1076	PP	1099	PP	1184	CP	1191	CP
1052	PP	1083	PP	1184	CP	1106	PP
1094	PP	1094	PP	1153	CP	1194	CP
1077	PP	1090	PP	1189	CP	1163	CP
1109	PP	1096	PP	1133	PP	1153	CP
1084	PP	1101	PP	1219	CP	1241	CP
1095	PP	1078	PP	1263	CP	1161	CP
1081	PP	1054	PP	1192	CP	1181	CP
1088	PP	1075	PP	1118	PP	1149	CP
1082	PP	1089	PP	1207	CP	1212	CP

Plies – 9

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1219	CP	1127	PP	1197	CP	1175	PP
1146	PP	1165	CP	1148	CP	1110	PP
1177	CP	1166	PP	1205	CP	1167	CP
1195	PP	1158	PP	1137	PP	1192	PP
1153	PP	1157	CP	1153	PP	1153	PP
1127	PP	1184	PP	1160	PP	1202	CP
1149	PP	1157	PP	1117	PP	1162	CP
1171	PP	1192	CP	1144	PP	1138	PP
1146	PP	1181	PP	1149	PP	1149	PP
1132	PP	1114	PP	1157	PP	1144	PP

*Fabric contained creases and folds – poor quality

Sample 4

Plies – 8   Cal 22 – 40-gr L. R.

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1091	PP	1118	CP	1073	PP	1081	PP
1081	PP	1118	CP	1087	PP	1052	PP
1050	PP	1080	PP	1074	PP	1036	PP
1123	CP	1045	PP	1107	CP	1116	CP
1082	PP	1089	CP	1117	CP	1083	CP
1071	PP	1117	CP	1059	PP	1076	PP
1080	PP	1081	PP	1103	CP	1096	CP
1083	PP	1092	CP	1090	CP	1103	CP
1070	PP	1083	PP	1101	PP	1067	PP
1060	PP	1066	PP	1059	PP	1110	PP

Plies – 9

Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1199	CP	1148	CP	1204	CP	1153	CP
1152	CP	1176	CP	1156	CP	1248	CP
1232	CP	1196	CP	1167	PP	1171	PP
1117	PP	1103	PP	1184	CP	1202	CP
1187	CP	1201	PP	1091	PP	1146	CP
1209	CP	1143	PP	1168	PP	1182	CP
1148	CP	1158	PP	1188	CP	1116	PP
1234	CP	1189	CP	1177	PP	1170	CP
1189	PP	1204	CP	1218	CP	1168	CP
1125	CP	1124	PP	1184	CP	1167	PP

Table 4-4. New Materials Ballistic Testing (Continued)

Sample 5							
Plies – 8						Cal 22 – 40-gr L.R.	
Velocity	Penetration	Velocity	Penetration	Velocity	Penetration	Velocity	Penetration
1067	PP	1093	PP	1153	CP	1162	CP
1124	PP	1087	PP	1168	PP	1157	CP
1100	PP	1068	PP	1177	CP	1220	CP
1070	PP	1071	PP	1188	CP	1205	CP
1142	PP	1079	PP	1165	CP	1163	CP
1062	PP	1061	PP	1167	CP	1156	PP
1070	PP	1088	PP	1191	CP	1168	CP
1086	PP	1100	PP	1151	CP	1209	CP
1083	PP	1099	PP	1171	PP	1208	CP
1082	PP	1091	PP	1189	CP	1182	CP
Plies – 9							
1195	CP	1189	CP	1177	PP	1194	CP
1224	CP	1184	CP	1225	CP	1182	PP
1187	PP	1207	CP	1232	CP	1185	PP
1183	CP	1169	PP	1174	PP	1155	CP
1211	CP	1188	PP	1222	CP	1190	CP
1189	PP	1208	PP	1196	PP	1187	CP
1223	CP	1190	PP	1198	CP	1143	PP
1188	PP	1158	CP	1197	CP	1208	CP
1153	CP	1191	CP	1205	CP	1158	PP
1184	PP	1184	PP	1213	CP	1230	CP

C. High Energy Threat Considerations

There has been concern expressed by most of the law enforcement community that there are more and more 9-mm and .357-magnum weapons appearing on the streets and used as threats against law enforcement personnel. In addition, a number of municipal police departments have been specifying the .44 magnum as one of the threats required to be defeated by lightweight continuous wear armor. In an attempt to quantify the high energy handgun threat, two short studies were undertaken. One was to obtain data on confiscated weapons, or weapons which had passed through police property rooms. This was accomplished by requesting data from the

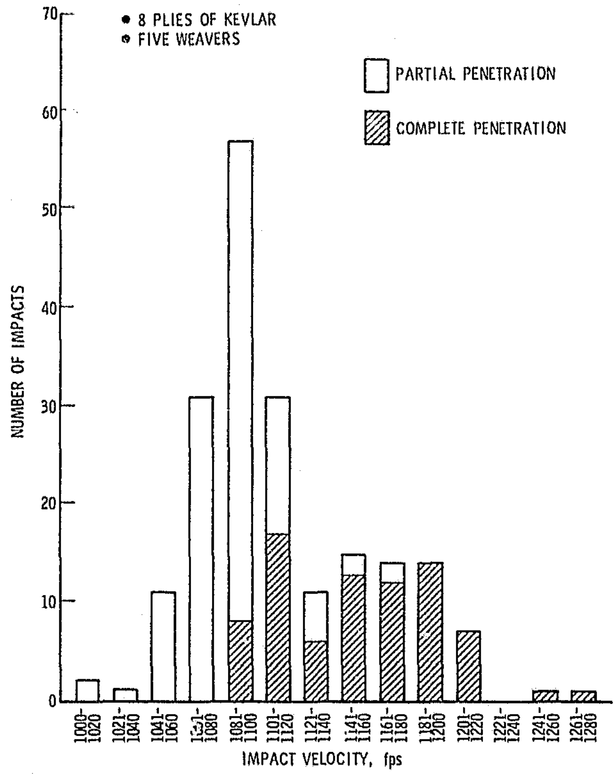


Figure 4-2. Ballistic Test Results — 8-Ply Kevlar

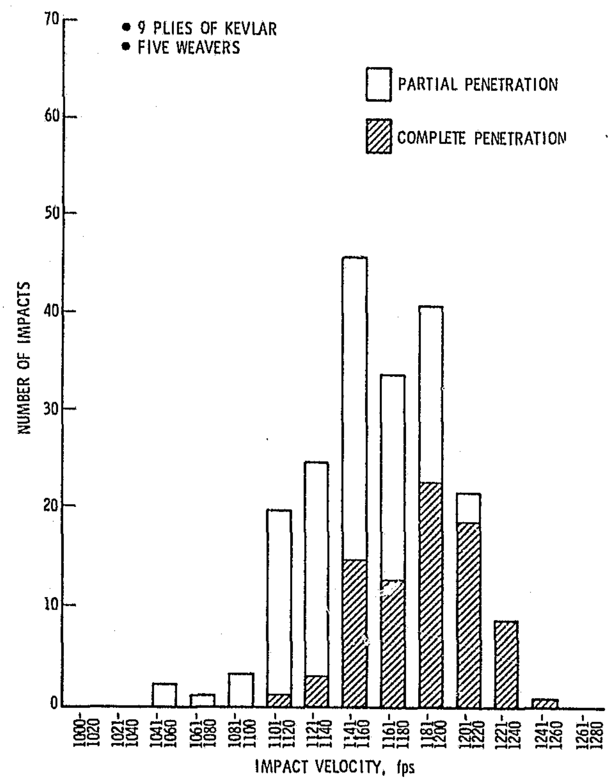


Figure 4-3. Ballistic Test Results — 9-Ply Kevlar

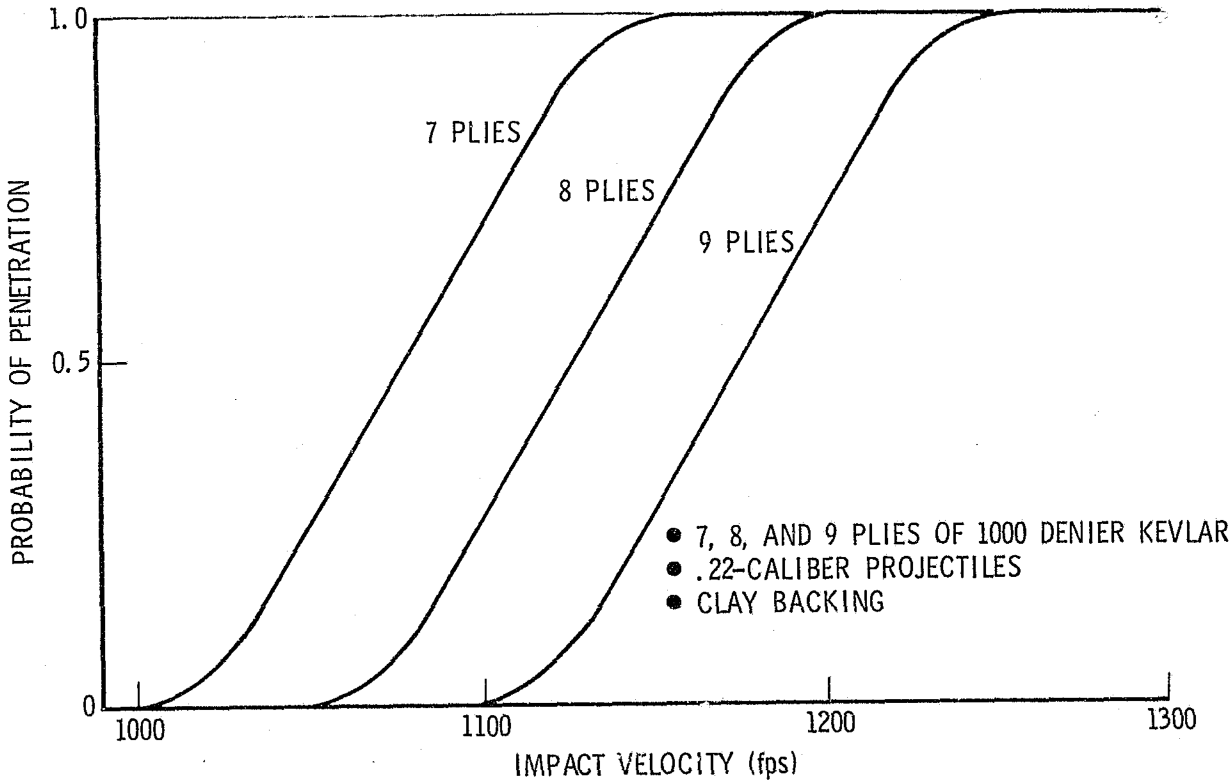


Figure 4-4. Probability of Penetration Versus Velocity

police departments which were participating in the program for the years 1975 and 1976. The second investigation was to review the law enforcement officer fatalities summary data from 1964 through 1976. These two short studies are contained in Volume III, Appendix G, of this report.

The confiscated handgun data were reviewed to determine if there was a measurable increase in the high energy handguns between the 1971-1972 International Association of Chiefs of Police study and the 1975-1976 participating department supplied data. Figure 4-5 shows the comparison between the two sets of data. As will be noted, the high energy handguns comprise almost 10 percent of the 1975-1976 data as opposed to 5 percent in 1971 and 1972. The greatest increase was in the .357-magnum weapons. Of the 18,500 handguns surveyed, only about 0.8 percent were .41-magnum and .44-magnum weapons. These weapons are not considered a significant portion of the firearms threat.

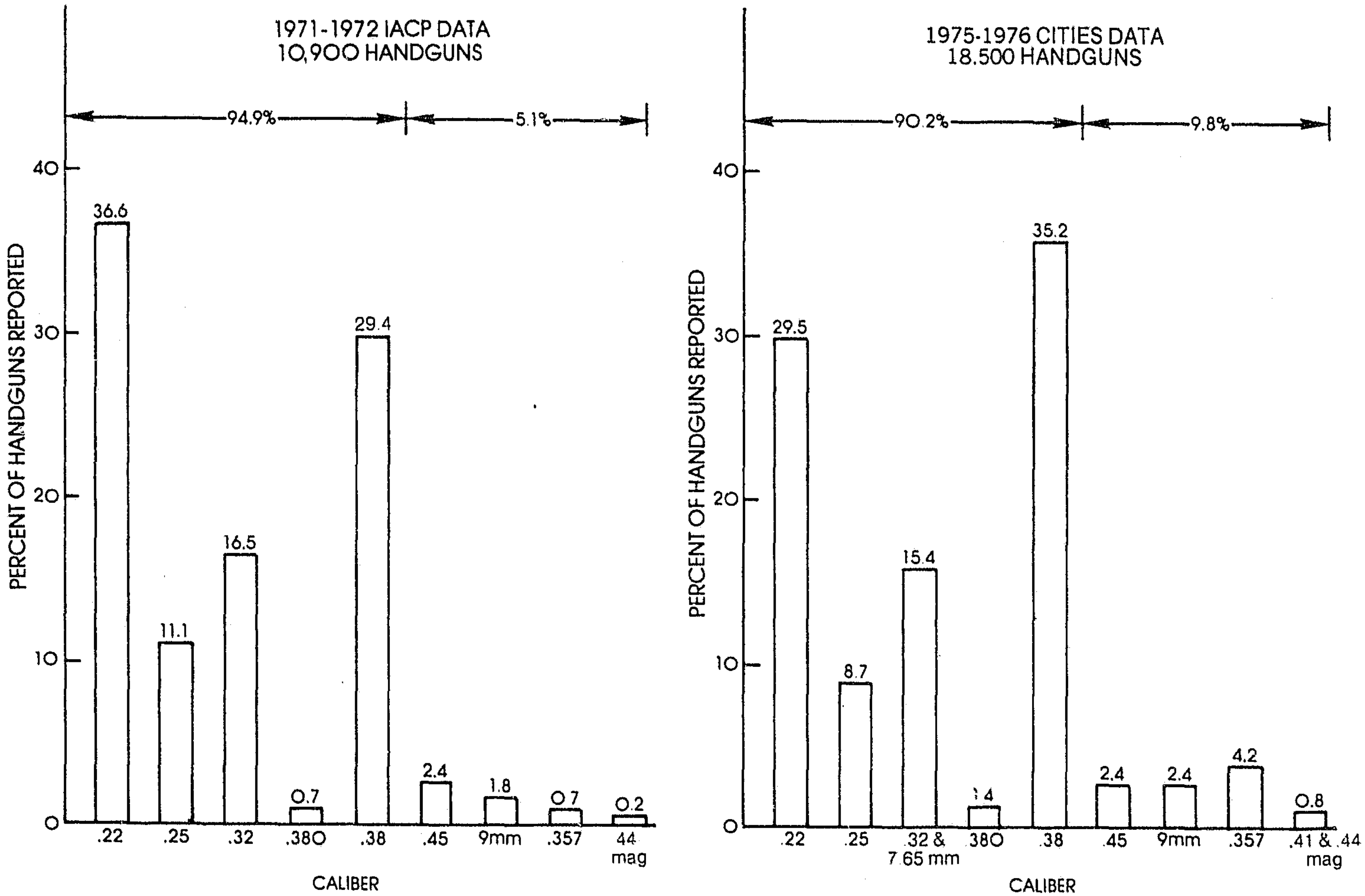


Figure 4-5. Confiscated Handguns Comparison–
1971/1972 and 1975/1976

Figure 4-6 shows the history of law enforcement officer fatalities inflicted by felonious assaults using handguns. Since 1964, there has been a steadily increasing trend in the percentage of fatalities from the higher energy weapons. In 1976, almost 30 percent of the fatalities were from these firearms. A detailed review of the data indicates that of the total of 874 handgun fatalities, only 6 involved the use of .41-magnum or .44-magnum weapons. Three of these were inflicted by the use of the officers' own weapons. Again, this represents less than 1 percent of the fatalities. This would further substantiate the position that these weapons are not a significant portion of the handgun threat.

D. Miscellaneous Testing

To address specific questions, a number of investigative test programs were undertaken on a limited scale. These are discussed below.

1. Test duplication of Inglewood incident. An attempt was made to duplicate the ballistic conditions on the Inglewood motorcycle officer incident. The incident involved the nonpenetration shooting of the officer wearing a commercial vest with a .30-caliber carbine.

The test was set up with double chronographs, one on either side of the sheet of 1/8-in. lexan, and a similar vest to the one the officer was wearing.

In the first attempt, military surplus full metal jacketed ball ammunition was used. The first test round penetrated the lexan with approximately 40-fps velocity loss and then completely penetrated the vest.

When these data were made available to the police, an investigation was made of the vest and it was determined that the projectile was not jacketed but was all lead.

With this information, commercial ammunition with round nose lead bullets was obtained and the test repeated. The results were the same; in other words, the projectile penetrated the lexan and the vest. Subsequent to these tests, it was determined by questioning the suspect that the ammunition used in the assault had been hand-loaded. Since there was no convenient way to duplicate these loads, the testing was discontinued.

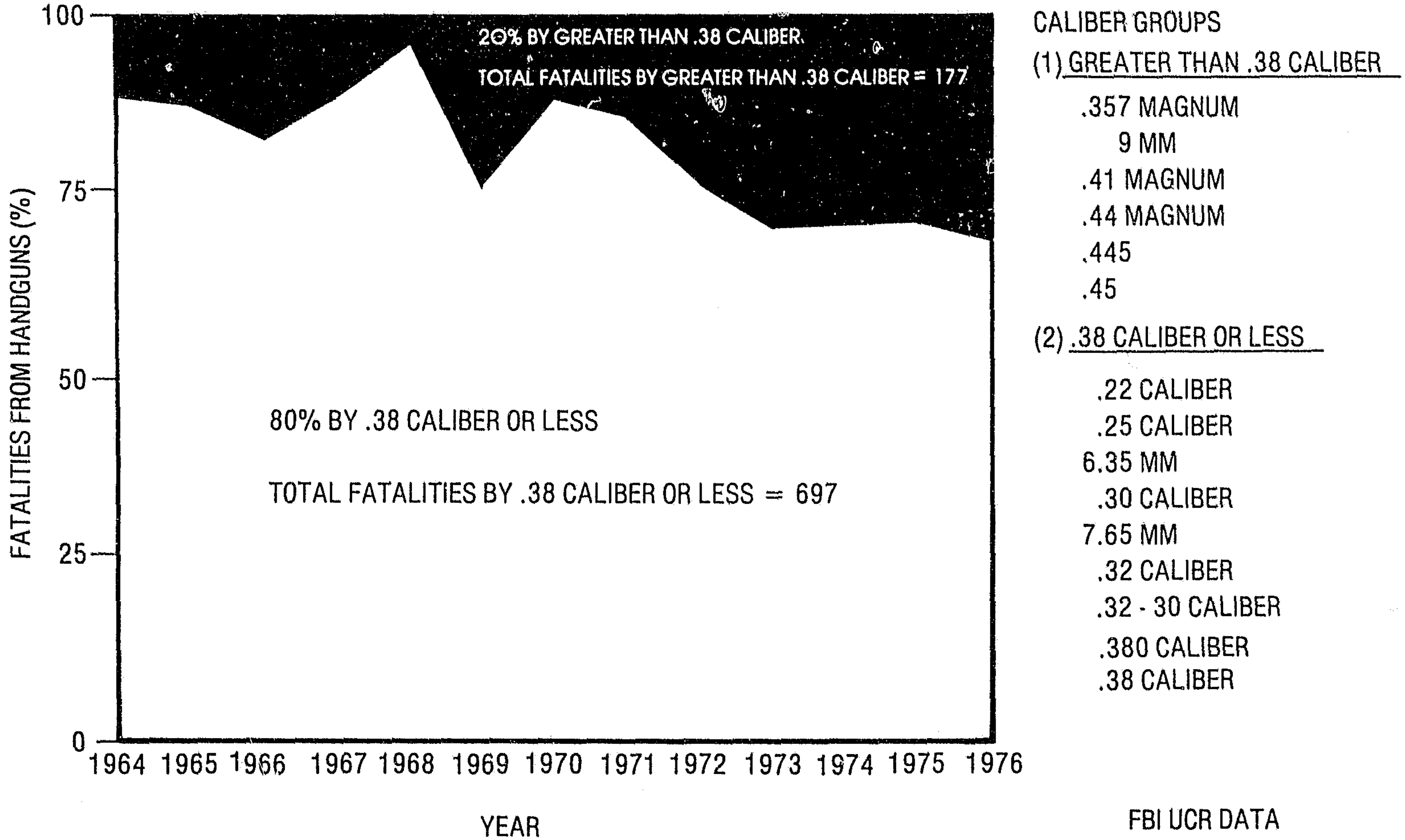


Figure 4-6. Officer Fatalities by Caliber of Handgun — 1964-1976

2. Wood backing evaluation. In the certification test program defined by the State of California, one of the penetration test series required wood backing. In an attempt to assess the impact of this requirement, a limited test series was run with duplicate Kevlar test samples with both clay and wood backing against the program threat projectiles of .38 caliber and .22 caliber. The objective was to determine if such a backing change would significantly affect the penetration of 7 plies of Kevlar at the design threat. Although the number of shots into each backing material was limited to two for the .38 caliber and three for the .22 caliber, there was no significant difference. No tests were performed at the higher threat levels.

3. Support to Los Angeles Police Department. At the request of the LAPD, the Aerospace ballistic range was made available to chronograph a number of high energy handguns against their vests. Aerospace provided the range, operated the chronograph, and monitored the tests and LAPD provided the weapons, ammunition, vests, and test matrix.

4. Other fabric tests. A limited number of tests were made on other fabrics woven from 1500-denier yarn and from Kevlar 49 yarn. These were small sample tests directed at a quick evaluation for significant improvements potential over the baseline material. At the design threat of the .38-caliber, 158-gr round nose lead bullet at 800 fps and the .22-caliber 40-gr round nose lead bullet at 1000 fps, there was no significant improvement over the baseline material of Kevlar 29, 1000 denier in a 31 × 31 weave. From a performance point of view, the very limited higher energy tests were inconclusive when tests were performed on equal areal density samples. There may be some cost performance improvement available for some combinations of threat versus material. These were not investigated.

CHAPTER V. KEVLAR CHARACTERIZATION STUDY

The two most important characteristics of the soft body armor are (1) the ability to defeat the projectile, and (2) the ability of the armor to spread the momentum of the projectile over a large enough region such that lethal trauma is not transmitted to the body. A considerable amount of experimental work has been directed toward measuring the penetration and trauma characteristics of the Kevlar 29 fabric. In particular, the 400/2 (34 × 34) Kevlar 29 fabric was thoroughly tested by Edgewood Arsenal, Lawrence Livermore Laboratory, and The Aerospace Corporation and is reported in Aerospace Report No. ATR-75(7506)-1. In addition, ballistic tests of the 1000 (31 × 31) Kevlar 29 material were conducted to verify its equal resistance to the .38- and .22-caliber handgun threats. Yet, little experimental information has been gathered to account for, or characterize, the ballistic performance of these fabrics versus areal density, or ply count. This chapter reports on two sets of empirical experiments conducted at Aerospace that were designed to supply this baseline information.

The completion of the lethality model by Edgewood Arsenal motivated additional measurements of the momentum transfer properties of the Kevlar fabric. Edgewood Arsenal's lethality model correlates the probability of lethal trauma in man with the cavity formation in the Roma Plastilina No. 1 clay. Thus, a model that relates cavity formation to projectile momentum gives both the garment manufacturer and user a tremendous tool for assessing the goodness of a particular armor, and the practicality of attempting to defeat a given threat. These clay cavity measurements were carried out specifically to yield the information necessary for utilizing the lethality model in this manner.

Similarly, penetration tests were conducted under simplified conditions to provide a baseline for predicting penetration.

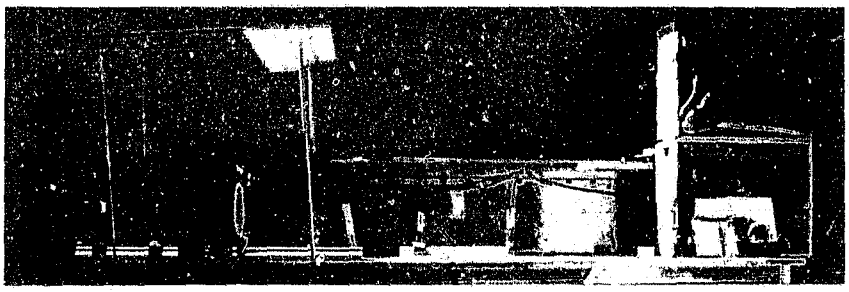
A. Clay Cavity Measurements

The fabric tested was Kevlar 29, 1000-denier (31×31) simple weave treated with DuPont's Zepel-D. The 12 by 12 in. Kevlar specimens were completely taped around the periphery and mounted on the 3 by 9 by 9 in. clay blocks using elastic bands. The clay blocks were constrained around the periphery by an aluminum frame, which also facilitated reworking of the clay between each test. During the test, the clay, with frame, was mounted on the front of the steel trap shown in Figure 5-1. A 6-in.-diameter hole in the front of the trap allowed the clay to be unsupported on the back side during impact. A total of four clay blocks was used in the testing to ensure that the block being tested had returned to 70° $\pm$2° after reworking of the clay.

Bullet hardness is not critical for the clay cavity measurements, since complete penetration does not occur. However, since penetration tests were also carried out, the 37-gr .22-caliber and the 248-gr .44-caliber bullets were cast in the laboratory to ensure equal hardness with the 158-gr .38-caliber bullets purchased from Speer. An alloy of 3-percent antimony and 97-percent lead yielded a bullet of hardness equal to those purchased from Speer when measured on the Rockwell hardness tester. These projectiles, together with the 100-gr, 9-mm, full metal jacket projectile used in the penetration study, are displayed in Figure 5-2.

The test matrix reported in Table 5-1 was carried out on the ballistic range shown diagrammatically in Figure 5-1. The range utilizes a Thompson-Center Contender pistol having interchangeable barrels. Velocity is doubly measured by the two Hewlett-Packard counters in conjunction with the paper grid system.

The ballistic impact on the Kevlar fabric typically forms a conical depression in the clay, where a cross section of the cone is, in essence, an ellipse. The mean of the major and minor axes and the depth of the clay cavity were used to calculate the increase in surface area ΔS and the



1 2 3 4 5

1. Steel catch tank
2. Paper grid system II
3. Cloth support frame
4. Paper grid system I
5. Plywood box w/Thompson-Center Contender firearm

Figure 5-1. Ballistic Range

(1) (2) (3) (4)

(1) Cast lead (0.97 Pb/0.03 Sb) .44 caliber, 248gr r/n;
(2) Speer cast lead .357 caliber 158gr r/n;
(3) Hornady 9 mm 100gr FMJ;
(4) Cast lead (0.97 Pb/0.03 Sb) .22 caliber, 37gr r/n.

Figure 5-2. Bullets Used in Test Series

Table 5-1. Clay Cavity Matrix

No. Plies	Velocity (fps)			
	500	800	1200	1400
4	.22 .38 .44	.22 .38 .44		
7			.22 .38 .44	
10 13 16	.44 .44 .44	.44 .44 .44	.44 .44 .44	.22 .22 .22

volume V, assuming the cavity to be a right circular cone. These data were then plotted in various ways to determine the functional relation between the properties of the projectile, armor, and clay cavity. Figures 5-3 and 5-4 both display a good linear relationship in the log-log plot.

In Figure 5-3, the product of the increase in surface area $(S_f - S_i)$, where the initial surface area S_i is simply the area of the base of the cone in square inches, and $\sqrt{1+n}$, where n is the number of plies, is plotted against the momentum of the projectile in slug-fps. The slope of the line through the data is 1.35. Thus, we may write

$$\Delta S = \frac{\Delta S_o \sqrt{1+n_o}}{\sqrt{1+n}} \left(\frac{mv}{m_o v_o}\right)^{1.35} \qquad (5\text{-}1)$$

$$\Delta S = \frac{1}{\sqrt{1+n}} (8.62\ mv)^{1.35} \qquad (5\text{-}2)$$

where $\Delta S_o \sqrt{1+n_o}$ is chosen as unity, which yields $m_o v_o = 0.116$. Thus Eq. 5-2 may be used to calculate the increase in surface area in the clay behind a Kevlar 1000-denier (31 × 31) garment of any ply thickness for a projectile of given mass and velocity.

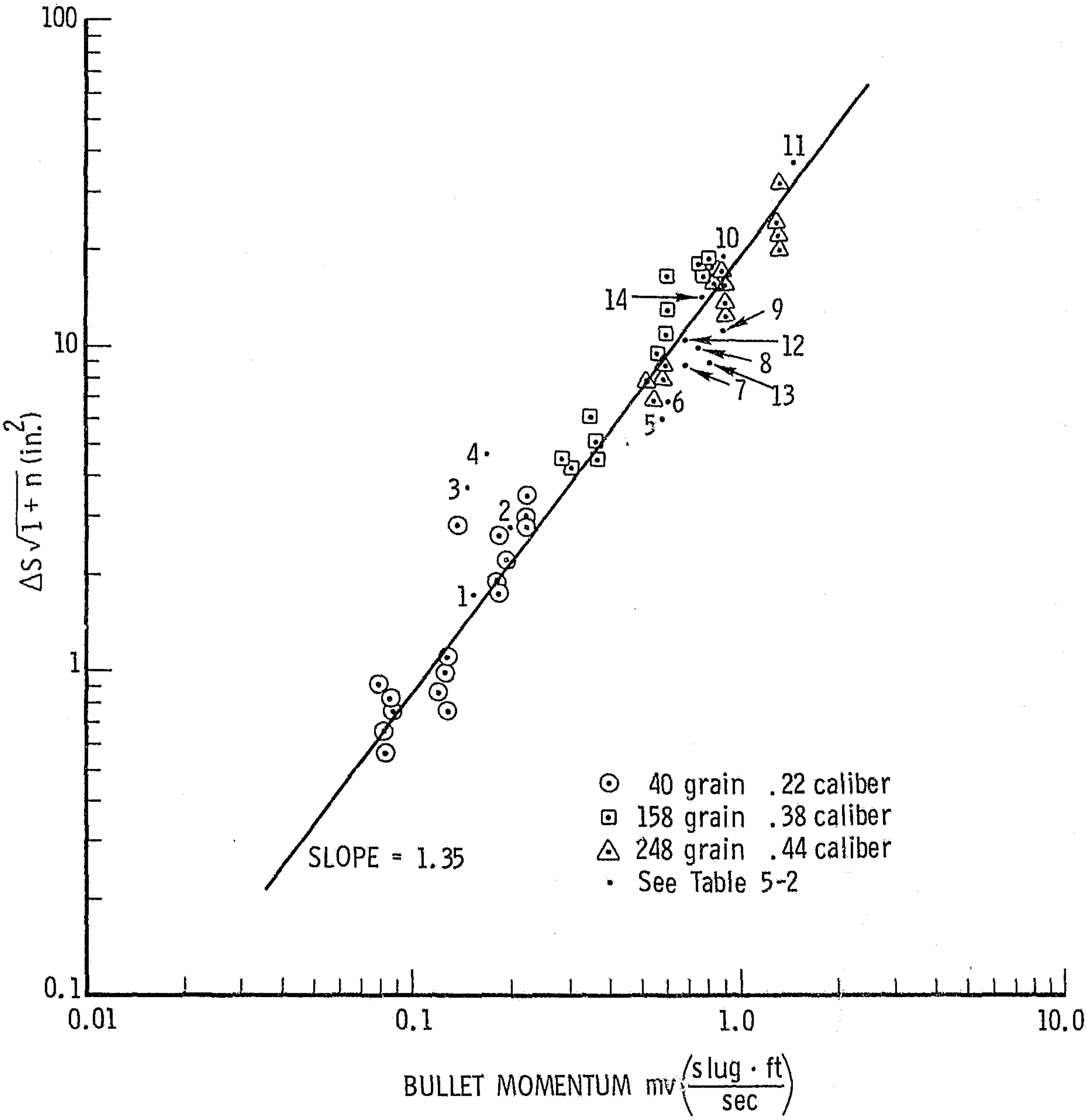


Figure 5-3. Cavities in Plastilina No. 1 Clay Behind Kevlar 29, 1000-Denier (31 × 31)

Note, in Figure 5-3, that the $\sqrt{1+n}$ is used to normalize the data rather than n. Apparently the cavity size or momentum transfer to the clay is scaled by the square root of the areal density, and not the first power. Secondly, the cavity formed in the clay is related to the total momentum of the projectile, and not the momentum density, or momentum per cross sectional area of the projectile. Later, the results of the penetration study indicate that penetration is better scaled by the kinetic energy and momentum densities of the projectile. Thus, penetration tends to be more of a local phenomenon, whereas the cavity formation depends on the total momentum of the projectile.

In Figure 5-4, $dV\sqrt{1+n}$ is plotted against the momentum of the projectile, where d and V are, respectively, the depth in inches and the volume in cubic inches of the clay cavity. Again, a very good straight line is obtained; in this case, having a slope of 2.14. Thus, we may write

$$dV = \frac{d_o V_o \sqrt{1+n_o}}{\sqrt{1+n}} \left(\frac{mv}{m_o v_o}\right)^{2.14} \qquad (5\text{-}3)$$

or

$$dV = \frac{1}{\sqrt{1+n}} (5.0\ mv)^{2.14} \qquad (5\text{-}4)$$

where $d_o V_o \sqrt{1+n_o}$ is chosen as unity, which yields $m_o v_o = 0.2$. A similar plot was made of $V\sqrt{1+n}$ versus mv, but considerable scatter in the data resulted. The dV product reduces the scatter considerably and is reminiscent of the conical depression factor (CDF), with the variable time left out, used by Lawrence Livermore Laboratory

$$CDF = \frac{r^2 h^2}{t} \qquad (5\text{-}5)$$

where r and h are, respectively, the base radius and height of the cone at time t.

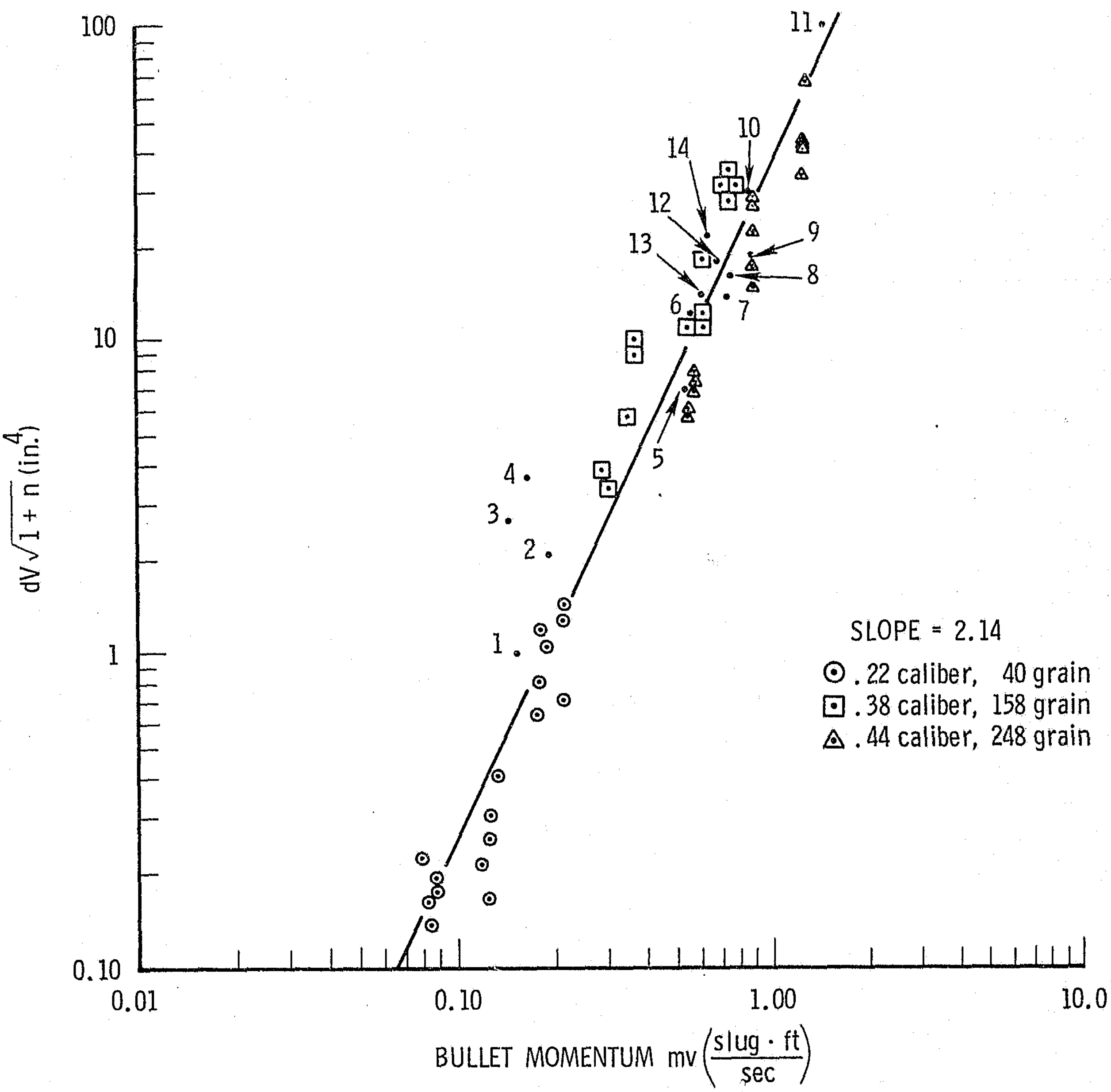


Figure 5-4. Cavities in Plastilina No. 1 Clay Behind Kevlar 29, 1000-Denier (31 × 31)

Also plotted in Figures 5-3 and 5-4 and listed in Table 5-2 are data reported in Edgewood Arsenal's "Backface Signatures Study." Except for points 3 and 4, the agreement is excellent. Points 3 and 4 are .22-caliber impacts, which typically have very small cavities in the clay and result in the largest error in measurement. Points 2, 6, 12, 13, and 14 are also worth noting. Points 2 and 6 represent shots into the 1140-denier (27 × 27) Kevlar 49 fabric. This result was somewhat surprising since the Kevlar 49

Table 5-2. Data From Army Report: "Backface Signatures Studies"

Data Point	Caliber	V (fps)	Ply	Identification	r (in.)	h (in.)	$\Delta S\sqrt{1+n}$ (in.^{2})	mv (slug-fps)
1	.22	950	12	1000 Kevlar 29	0.876	0.591	1.79	0.156
2	.22	1186	7	1140 Kevlar 49	0.965	0.866	2.84	0.195
3	.22	836	7	1000 Kevlar 29	0.925	1.020	3.71	0.145
4	.22	1011	7	1000 Kevlar 29	0.935	1.180	4.74	0.166
5	.38	833	7	1000 Kevlar 29	1.152	1.333	6.24	0.584
6	.38	831	7	1140 Kevlar 49	1.348	1.378	6.94	0.583
7	.38	1041	15	1000 Kevlar 29	1.378	1.299	8.93	0.730
8	.38	1061	12	1000 Kevlar 29	1.457	1.417	9.50	0.744
9	.38	1247	20	1000 Kevlar 29	1.378	1.378	11.32	0.874
10	.38	1246	23	1000 Kevlar 29	1.329	1.772	18.12	0.873
11	.44	1406	23	1000 Kevlar 29	1.772	2.559	36.56	1.497
12	9 mm	1236	23	1000 Kevlar 29	1.476	1.260	10.56	0.680
13	9 mm	1099	12	1000 Kevlar 29	1.191	1.575	10.57	0.605
14	9 mm	1204	16	400/2 Kevlar 29	1.225	1.772	14.72	0.622

fabric exhibits twice the Young's modulus as the Kevlar 29 yarn; this result is perhaps fortuitous and deserves additional testing. Points 12, 13, and 14 are 9-mm impacts, which fall nicely within the other data. Additionally, point 14 represents the original 400/2 (34 × 34) Kevlar 29 fabric. Note that the three fabric styles plotted here all have nearly the same areal densities per ply. Thus, the factor $\sqrt{1+n}$ reduces the data quite well. If the higher areal density fabrics such as the 1500 denier were included, it would be necessary to replace n by a thickness or areal density factor.

Lastly, the various armors employing elastomeric coatings should not be expected to be described by Eqs. 5-2 or 5-4, since the momentum transfer characteristics of the coated fabric are significantly altered.

Reported in Figures 5-5 and 5-6 are the same data plotted against the kinetic energy of the bullets. In both figures, the cavities formed upon impact with the .22-caliber bullet cluster about a different line than those formed on impact with the .38- and .44-caliber bullets; however, the slopes are equivalent. Although the physical explanation of this result is not presently known, this result does indicate that the projectile momentum is the better parameter for scaling the cavity formation in clay.

To determine the sensitivity of the response of the Plastilina No. 1 clay to temperature, tests were conducted in accord with NILECJ Standard 0101.01 at 32°, 79°, and 92°F. Briefly, a 1-kg, 1.75-in.-diameter steel cylinder having a hemispherical end was dropped into an 18 by 18 by 4 in. clay block. The depth of the cavities formed was used to calculate the volume and surface areas (V and S) presented in Figure 5-7. The results indicate that cavity formation is extremely sensitive to the temperature of the clay. Thus, it is important to maintain constant clay temperature in making clay cavity measurements. The 4°F tolerance used in this test matrix seems fairly satisfactory since the overall scatter was acceptable and good agreement was obtained with Edgewood Arsenal, which also maintains its laboratory at 70°F.

B. Penetration Study

The penetration study was carried out to establish the baseline penetration characteristics of the 1000-denier (31 × 31), Zepel-D-treated Kevlar 29 fabric. This investigation utilized air-backed specimens for several reasons. First, excluding the backing material greatly simplifies

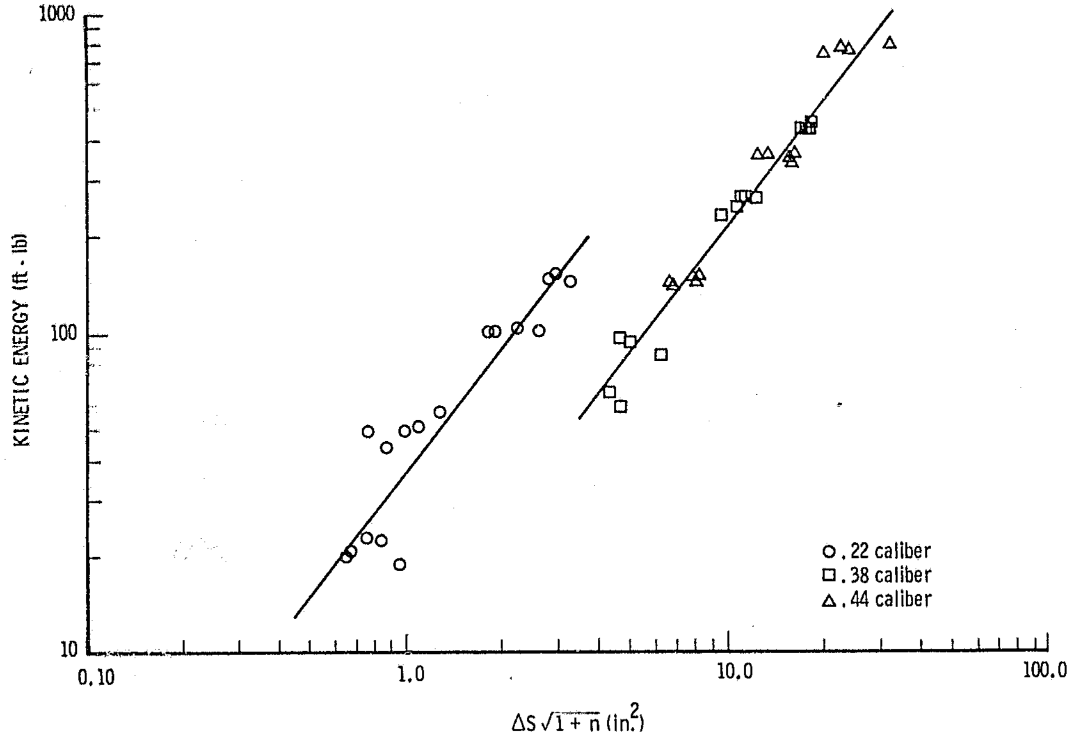


Figure 5-5. Cavities in Plastilina No. 1 Clay Behind Kevlar 29, 1000-Denier (31 × 31)

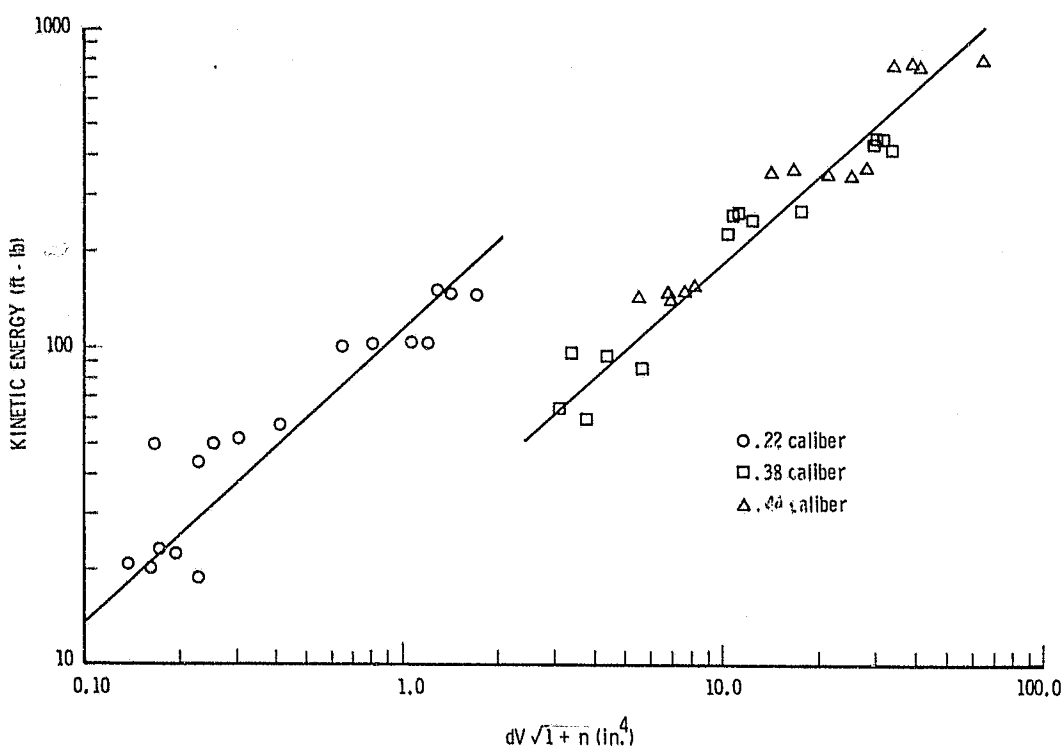


Figure 5-6. Cavities in Plastilina No. 1 Clay Behind Kevlar 29, 1000-Denier (31 × 31)

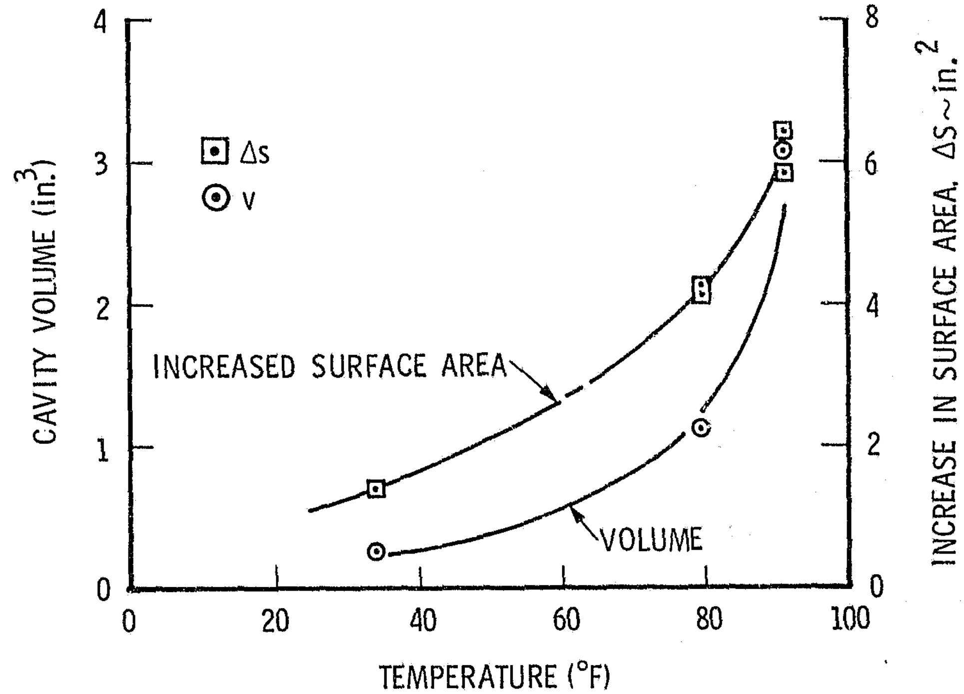


Figure 5-7. Increase in Surface Area and Volume of Cavities Formed from Steel Cylinder Drop Test

the interaction; not only is the overall experimental scatter reduced, but the test results may be directly related to projectile-fabric interaction. Secondly, exit velocities of the projectiles were desired; although use of clay or gelatin backing does not preclude the measurement of exit velocities, it introduces additional unknown variables, in addition to the influence of the backing material on the armor. Lastly, high speed photography becomes much simpler without a backing material.

Figure 5-8 shows a 248-gr .44-caliber projectile exiting three plies of Kevlar fabric at 1240 fps. The picture clearly shows that penetration occurs prior to the transverse shear wave reaching either the clamped or free edge of the specimen. Thus, the boundaries of the Kevlar specimen do not influence the test results. This picture also displays the result that penetration of the Kevlar fabric generally occurs with little or no

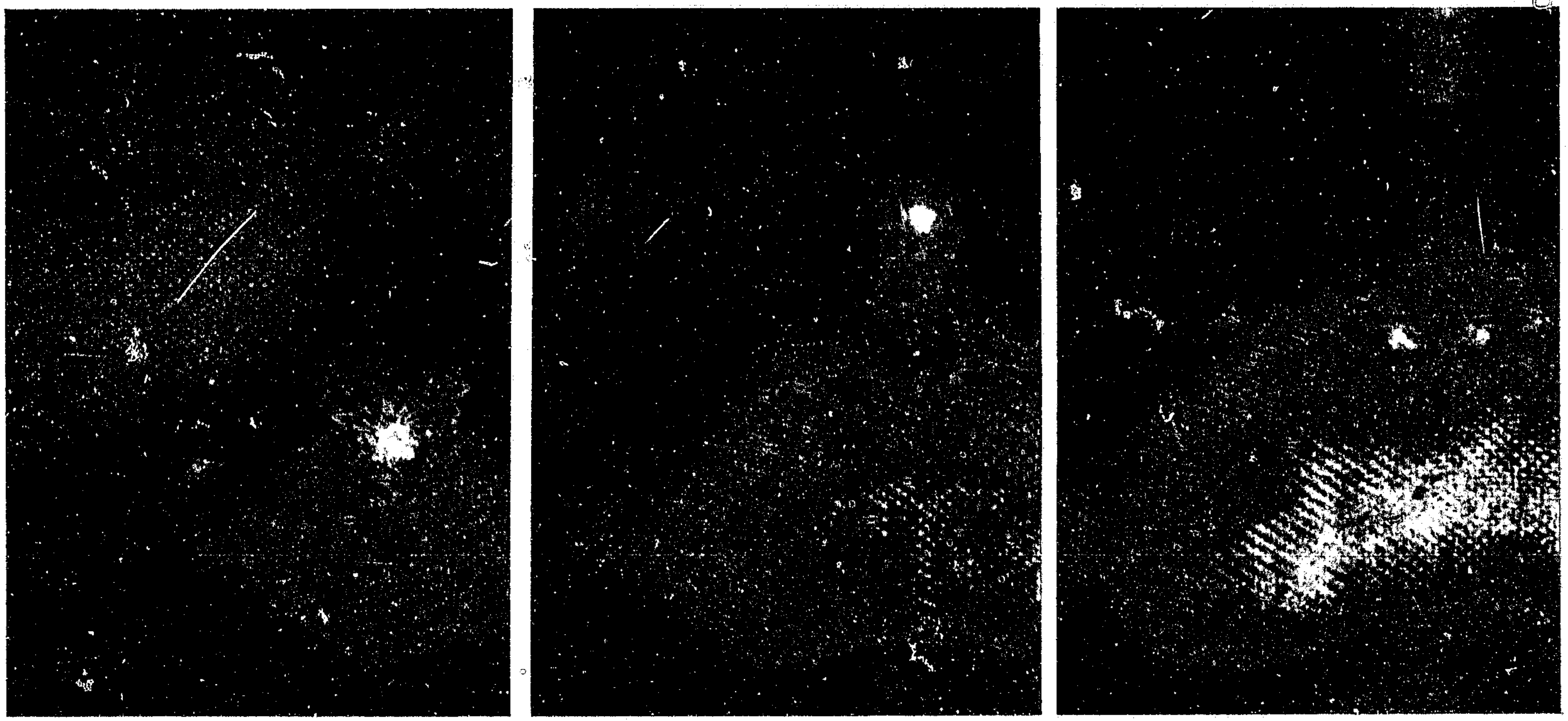


Figure 5-8. Penetration of Three Plies of Kevlar 29 by .248-gr, .44-Caliber Bullet at 1240 fps

deformation of the projectile. This result is not generally true for impact velocities very close to the critical penetration velocity of the armor, i.e., the velocity at which penetration initially occurs.

Displayed in Figure 5-9 is the typical data reduction scheme used by the Ballistic Research Lab (BRL) of the U.S. Army for determining penetration

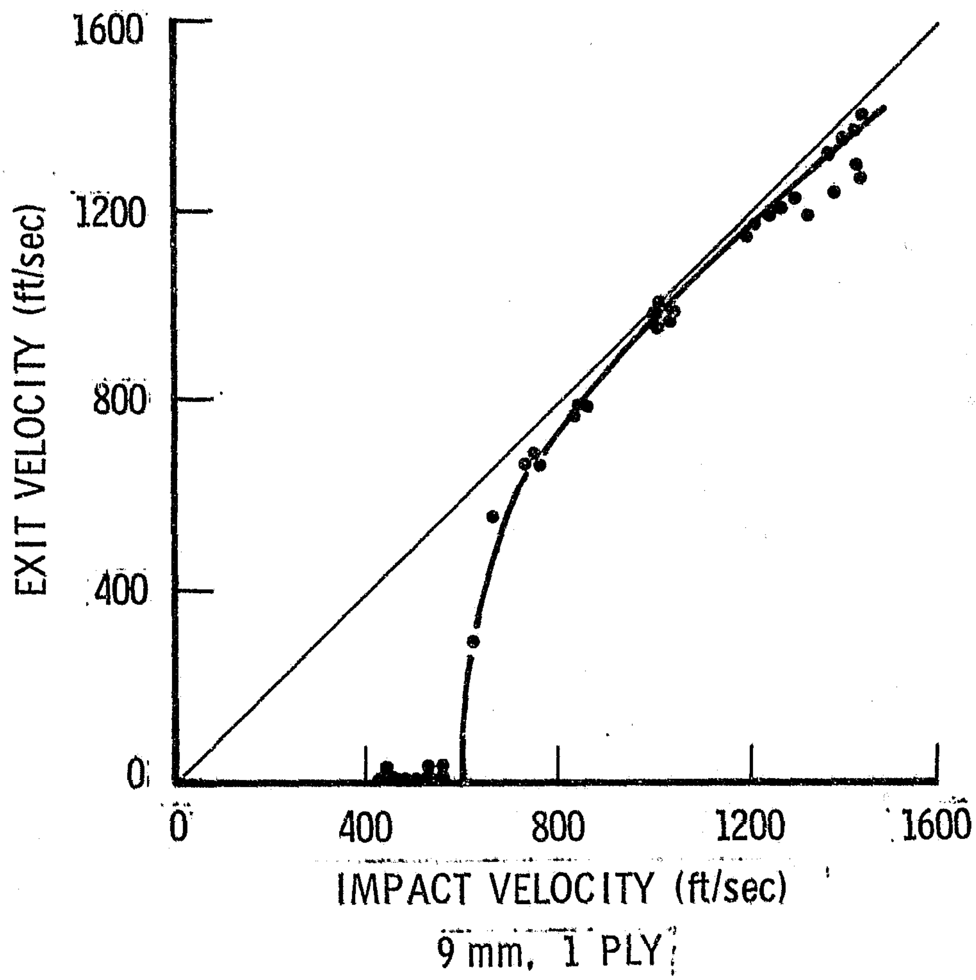


Figure 5-9. Data for Determining Penetration Velocity of Armor

velocities of armor. The exit or residual velocities are plotted against the impact velocities for each ply configuration. The best curve is then put through the points and extrapolated to zero exit velocity. The impact velocity obtained in this manner is called the limit velocity for that particular armor configuration. The data points plotted along the ordinate represent tests in which complete penetration did not occur.

The limit velocities for all the armor configurations tested are plotted in Figure 5-10. The scatter in the data is typical of this type of testing and demonstrates why a great number of tests must be carried out in order to determine accurately the ballistic limit of these materials. Figure 5-11 shows the same data reduced in terms of kinetic energy per cross sectional area of the projectile, or kinetic energy density. These data are nearly linearized in this plot, except for the single-ply data in the case of the .22- and .44-caliber bullets.

The implications of Figure 5-11 are puzzling. The .22-, .38-, and 44-caliber projectiles are nearly equal in hardness, aspect ratio (length/diameter), and shape (see Figure 5-2); they essentially differ in cross sectional area relative to weave geometry. Thus, we might expect these three projectiles to yield three lines of equal slopes, but having different intercepts, or vice versa. Conversely, 9-mm projectiles differ both in aspect ratio and hardness (due to the full copper jacket), but have the same diameter as the .38. No reasonable explanation is offered at this time for interpreting these results. Additionally, if the linear relations of Figure 5-11 are extrapolated to higher ply numbers, it appears that the .44-caliber bullet will become the most penetrating around 17 plies. It is difficult to imagine the .44-caliber soft lead projectile becoming more highly penetrating than a 9-mm copper jacketed projectile of equal kinetic energy density. Unfortunately, time did not permit carrying this matrix out to greater ply numbers; this matrix should be extended in the future.

Perhaps the most interesting result of the penetration study was the greater efficiency of the armor in the air-backed case. For instance,

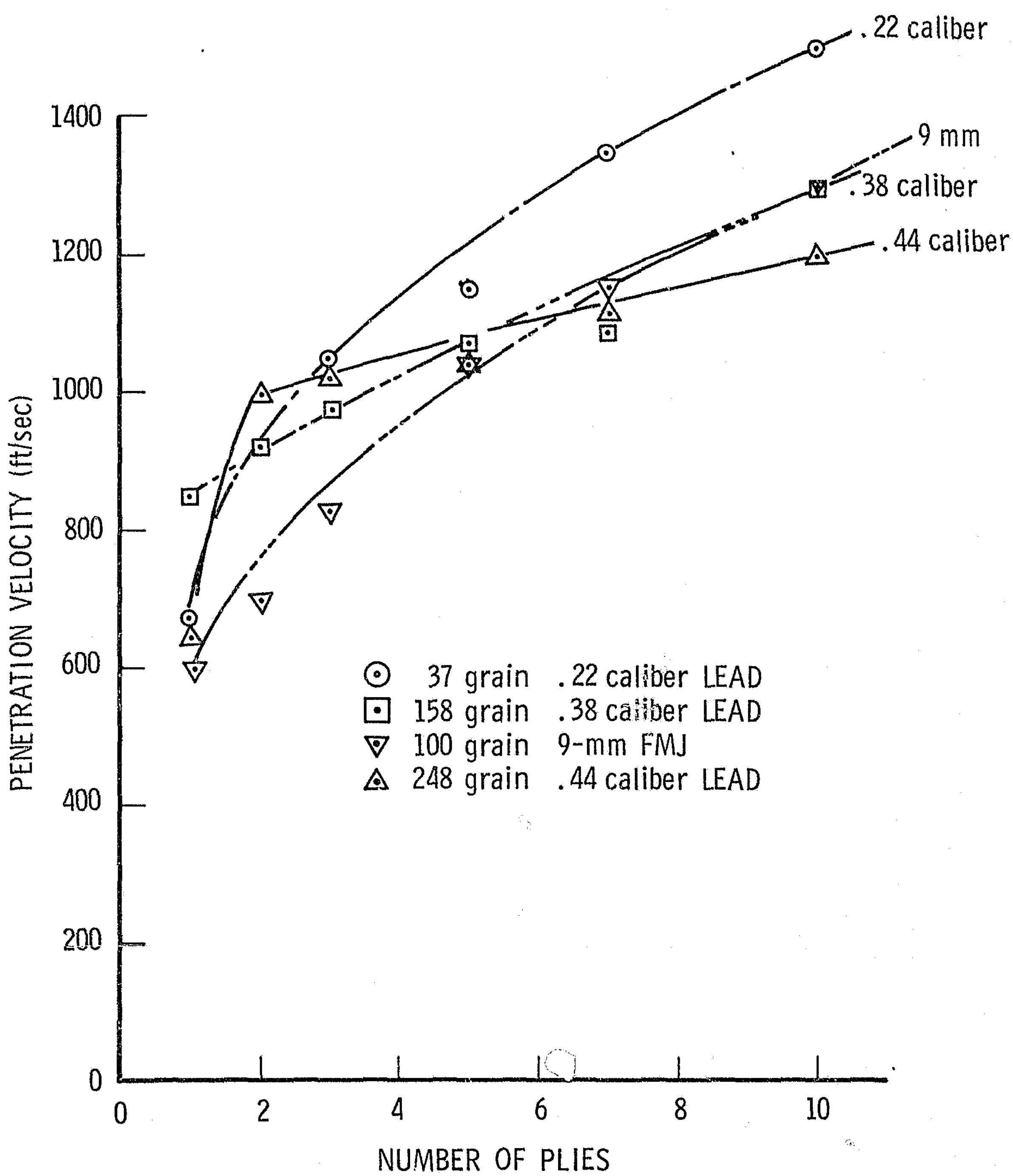


Figure 5-10. Penetration of 1000-Denier (31 × 31) Air-Backed Kevlar 29

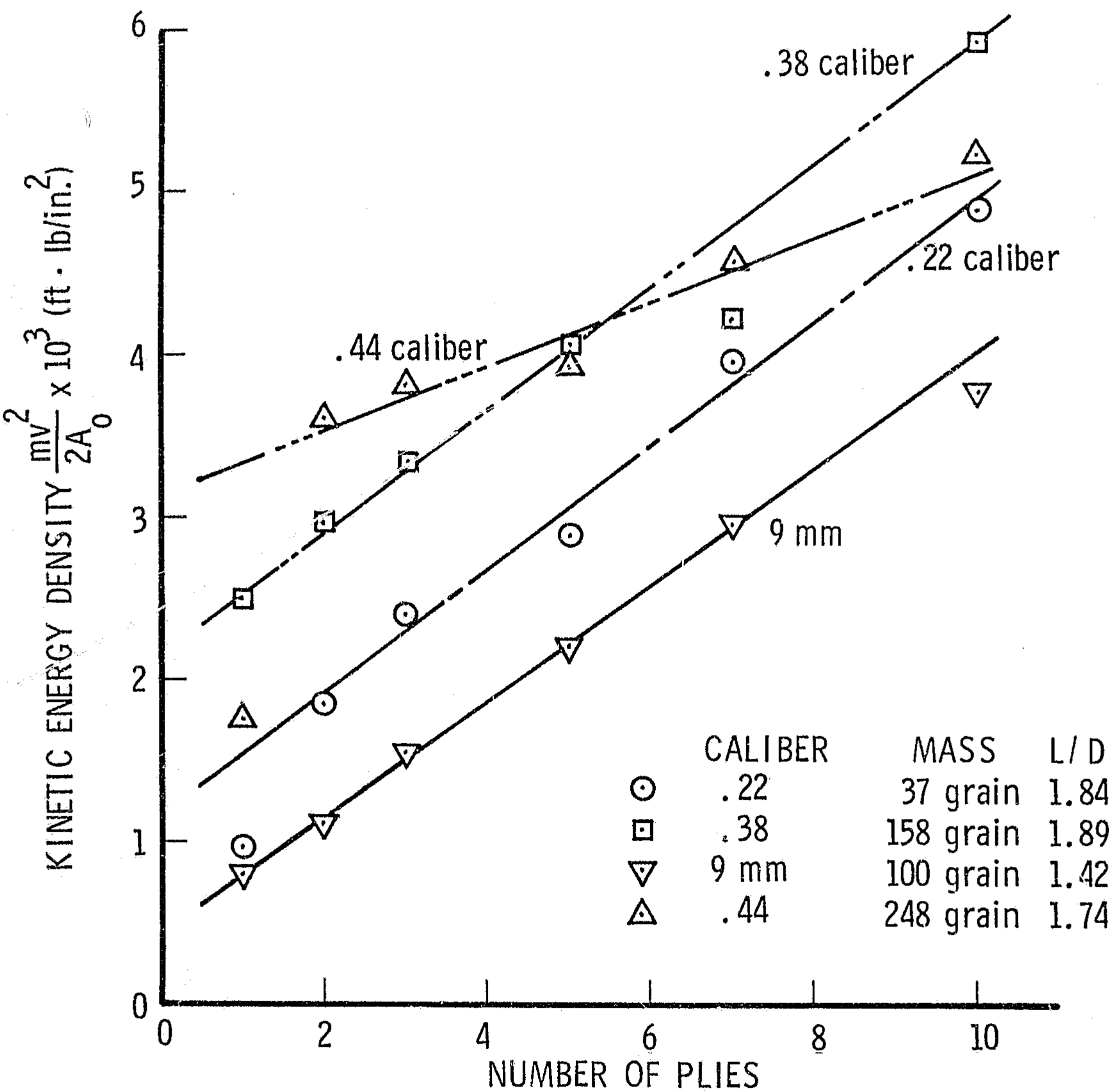


Figure 5-11. Kinetic Energy Density Required to Penetrate 1000-Denier (31 × 31) Kevlar 29

three plies of 1000-denier (31 × 31) Kevlar 29 fabric defeats the .22-caliber projectile at 1000 fps in the air-backed case, whereas seven plies of this same fabric are required to defeat this threat when backed with clay. Apparently the stresses resulting from bullet impact are better distributed when the rear surface of the fabric is not restrained. Obviously, either the clay or gelatin backing is a much more realistic backing when designing armor since they better simulate the human body. However, these results do imply that improved penetration might be obtained by providing some sort of slip plane between the armor and backing material to provide for more uniform loading of the armor.

In conclusion, the baseline behavior of the momentum transfer and penetration characteristics of the 1000-denier (31 × 31) Kevlar 29 fabric have been established. As such, the information may be used to measure the relative improvements of new armor systems that are thought or claimed to be superior. Additionally, these results suggest new areas of investigation. For instance, the greater stopping ability of the armor in the air-backed case certainly suggests an investigation directed toward determining the effects of friction reducing agents between armor and backing, and possibly between adjacent plies. The similarities in the penetration behavior of the .22- and .38-caliber and the 9-mm projectiles suggest an expanded study which would include the European 9-mm steel projectile in addition to a 9-mm lead and 9-mm FMJ projectile. Since the slopes of the kinetic energy density versus ply number is a measure of the ease with which penetration occurs, these three 9-mm projectiles would be expected to vary considerably. If not, the implication is that the intercept, or the onset of penetration, is related to projectile hardness.

CHAPTER VI. MEDICAL-TECHNICAL SYMPOSIA

A series of three medical-technical symposia were conducted during the LEAA Lightweight Body Armor Field Test Program. The purpose of the one-day symposia, which were held during the pretest, interim, and posttest periods of the operational field experiment, was to provide a forum for exchange of knowledge and experience regarding the blunt trauma injury phenomena occurring behind soft body armor following nonpenetrating ballistic impact. A secondary objective was to provide the opportunity for open discussion and informational exchange, relative to the scheduled field test, among the primary participants in the program — the local trauma surgeons and police department test conductors.

A. Pretest Symposium

Approximately 60 people, including 15 trauma surgeons and 15 law enforcement representatives from the agencies participating in the Body Armor Field Test, attended the inaugural Medical-Technical Symposium on Lightweight Body Armor held in the Washington, DC, area during November 1975. The pressing need to discuss the complex mechanism of blunt trauma injury with the nationally known and recognized medical trauma experts (who had consented to donate their time and expertise in support of the field test experiment) was the principal reason for convening the first symposium. Of equal importance was to explore how the phenomena would be dealt with in the event of its occurrence to a participant during the field test. The extensive animal ballistic testing performed by the U.S. Army's Edgewood Biomedical Laboratory during the development program that preceded the field experiment and the publication of the technical report entitled "A Method for Soft Body Armor Evaluation: Medical Assessment" provided the basis for the keynote briefing given by Dr. Carl Soderstrom, Major, U.S. Medical Corps (Edgewood, MD).

Dr. Soderstrom's briefing concentrated on what members of the audience, particularly the trauma surgeons, could expect to see (i.e., expected wound severity) in the event of handgun assault upon participants wearing the 7-ply protective garments during the field evaluation. A thorough discussion of the experimental protocol, justification for the choice of the animal type used in the biologic testing, and assumptions preceded the showing and discussion of slides portraying blunt trauma injury to animals following ballistic impact while wearing soft body armor. For each series of ballistic tests (one for each of the organs designated as vulnerable within the thoracic cavity) the presentation described the manner in which the results were correlated with expected human injury. Significant findings, in each case, were highlighted. For example, during the set of goat liver shots, first with the .38-caliber at 1000 fps using 7-ply, and subsequently, 10-ply, 1000-denier Kevlar, the experimental results tended to support the claim that the three additional layers of Kevlar fabric do not afford additional protection from blunt trauma, although the elevated .38-caliber velocity threat resulted in more extensive liver damage than did the nominal velocity of 800 fps under the same armor conditions.

As previously mentioned (and subsequently proven to be prophetic during the field experiment), the medical experts involved in the biologic testing at Edgewood, Md, postulated the type of wounds the trauma surgeons could expect to see in the event of common handgun assaults to the protective area of program participants during the field test. The presentation emphasized the need for immediate hospitalization, followed by 24 hours of observation during which cardiac arterial blood gas monitoring should be performed. This procedure is imperative, it was emphasized, even though the wounded officer may state he feels well or no external injury is noted by attendants. Dr. Soderstrom stated that the foregoing recommendation was based on experimental evidence observed during the biologic testing, which revealed that the external wound may not correlate well with the extent of injuries occurring behind it.

The medical assessment presentation was followed by a spirited discussion of the blunt trauma phenomenon by the attending surgeons. As a direct result of this discussion and in response to trauma surgeon inquiries concerning formal procedures to be followed in the event of assault incidents during the field test, a trauma surgeon's protocol was formulated by medical personnel from the Biomedical Laboratory, to be used as guidance by the local trauma surgeons during the field test. The recommended protocol is shown in Table 6-1.

In addition to the keynote briefing, Aerospace program personnel presented an overview of the Body Armor Development Program and the plan for conducting the Field Evaluation. In the latter briefing, it was stressed that although garment performance in terms of resistance to ballistic penetration and blunt trauma minimization are major issues to be addressed during the field evaluation, other issues of almost equal importance will be addressed, such as evaluating acceptability of protective armor by the individual officer, the overall impact of garment use on law enforcement operations, and the extent of degradation of garments and wear.

In summarizing the data processing analysis and evaluation effort, the Aerospace briefing emphasized the extent of the statistical assessment effort that would be undertaken to measure the "armor system" against the established program goals and objectives. In response to program participant inquiries about the conduct of the field test, it was decided that a periodic Body Armor Newsletter would be published, containing articles on items of general interest, events, guidance, and of assault incidents occurring during the test period.

In summary, agreement was unanimous that the Pretest Symposium was very beneficial, particularly, in terms of the feedback provided to program personnel for use during the field test period.

In addition to the primary program participants, representatives from LEAA, the U.S. Secret Service, the DuPont Company, U.S. Army's Natick Development Laboratories, the Armed Forces Institute of Pathology,

Table 6-1. Recommended Protocol in Treating an Officer Struck on the Protective Garment

Body Armor Field Evaluation Program	
1.	The assaulted officer should be taken to a hospital as soon as possible after being struck. This is imperative, even though the wounded officer feels well and minimal or no external injury is noted. This is based on the observation that the external wound does not correlate well with the extent of injuries occurring behind it.
2.	All officers struck on the body armor should be admitted to the hospital for at least 24 hours of observation.
3.	Patients struck on the body armor over the thoracic cavity should have an immediate chest x-ray and EKG. Those struck over the heart or the left chest should be placed on a cardiac monitor for at least 24 hours of observation. Cardiac enzymes should be monitored.
4.	Contrecoup injuries opposite the side of impact should be considered in evaluating the patient.
5.	In the case of abdominal strikes, careful serial examinations by a surgeon for peritoneal signs is the least required treatment. Abdominal paracentesis or exploration (depending on the institution) should be performed when intraabdominal injury is suspected. Shots occurring over the liver should be viewed with great suspicion of underlying hepatic injury.
6.	Skin contusions and lacerations should be cleansed and debrided as necessary.
7.	The appropriate body armor field evaluation medical report should be accomplished by the local trauma surgeon in consultation with the attending physician.

and the Aerospace body armor medical consultant attended the symposium. The symposium agenda is shown in Table 6-2.

B. Interim Symposium

The Second Medical-Technical Symposium was held in Miami Beach, Florida on 29 September 1976 in conjunction with the 83rd Annual Conference of the IACP. At this time, the field test had been under way for about nine months, and it offered an opportunity to present some of the preliminary results to the law enforcement community. Approximately 45 persons attended, including representatives of all agencies participating in the program, trauma surgeon consultants, industry, and law enforcement agencies.

The emphasis of the second symposium was placed on presenting preliminary test results, i.e., the 10-percent sample of garment wear data, and the incidents that had been investigated. In addition, progress reports on blunt trauma modeling efforts and higher energy threat studies by the U.S. Army were presented. The complete agenda is shown in Table 6-3.

Following the opening remarks by Chief Watkins of the Miami Police Department and Mr. Wormeli of LEAA, an overview of the program was presented as reference for those attendees unfamiliar with the program, and highlights of the test results obtained to date were summarized. The most significant findings at this time resulted in recommendations to replace the metal buckle fasteners of the Style I LEAA garment with wider Velcro straps and to add shirt tails to the Style II LEAA garment.

This was followed by a summary of the medical investigations of shooting incidents presented by Drs. Carroll and Soderstrom of the Edgewood Biomedical Laboratory, with Dr. Wachtel, a consultant from the School of Medicine of the University of Arizona, participating. The blunt trauma was characterized from the first two incidents involving test participants wearing LEAA garments (cf. Chapter III. B. 1). Five other nonprogram incidents involving commercial armor were reviewed with similar results, i.e., no internal injury, but with similar surface contusions. The devastating nature of the injuries suffered by one test participant not wearing the

Table 6-2. First Medical-Technical Symposium Lightweight Body Armor Program Agenda

9:00 am - 9:20 am	Introduction/Welcome (Joseph T. Kochanski, LEAA/NILECJ)
9:20 am - 9:50 am	Development Program Overview (R. A. Merkle, The Aerospace Corporation)
9:50 am - 10:25 am	Body Armor Training Films (Aerospace)
10:25 am - 10:50 am	Coffee Break
10:50 am - 11:30 am	Field Test and Evaluation Plan Overview (A. Kelleher, The Aerospace Corporation)
11:30 am - 12:00 noon	Discussion, Questions, and Answers (Field Evaluation) (All)
12:00 noon - 1:30 pm	Luncheon
1:30 pm - 2:30 pm	Medical Assessment - Blunt Trauma Injury in Animals Following Ballistic Impact Behind Soft Body Armor (Dr. Carl Soderstrom, Edgewood Arsenal Biomedical Laboratory - Major, U.S. Army Medical Corps)
2:30 pm to Adjournment	Discussion and Aerospace/NILECJ Closing Remarks

Table 6-3. Second Medical-Technical Symposium Lightweight Body Armor Program Agenda, 29 September 1976

Medical		
8:00- 9:00	Registration (Coffee & Rolls)	
9:00- 9:10	Welcome	Chief G. P. Watkins Miami P.D.
9:10- 9:30	Introduction/Overview	P. Wormeli/LEAA
9:30- 9:45	Body Armor Field Test Program Overview	Aerospace
9:45-10:30	Summary of Medical Investigation	Dr. Andrew Carroll U.S. Army Dr. Soderstrom Dr. Wachtel
10:30-11:00	Review of U.S. Army Modeling Efforts (Blunt Trauma Correlation)	L. Sturdivan U.S. Army
11:00-11:30	Summary of Data Processing Results	F. Maxwell Aerospace
11:30-12:00	Clear Hall/Luncheon Set-up	
Technical		
12:00- 1:00	Lunch (Invited Guests)	
1:00- 1:15	Summary of Ballistic Tests on New and Recalled Garments	J. Ward Aerospace
1:15- 1:30	Summary of New Laundry Tests	J. Ward Aerospace
1:30- 2:00	Review of Higher Energy Threat Study	C. E. Hawkins U.S. Army
2:00- 2:30	Aerospace In-House Fee Sponsored Research	R. Fillers Aerospace
2:30- 3:00	Break	
3:00- 3:30	Summary of Shark Program	R. Fillers Aerospace
3:30- 4:15	Importance of Proper Design Construction, and Fit of Law Enforcement Body Armor	E. Barron Natick Labs
4:15- 5:00	Discussion	

LEAA garment (cf. Chapter III B. 1) was clinically described. Interestingly, all but one of these incidents involved the most common of handguns, the .38 special.

Efforts to establish a predictive model of human lethality from animal data was reviewed by L. Sturdivan of the U.S. Army. An extension of previous discriminant models that only predicted survival or fatality was developed to delineate three regions of low and high probabilities of fatality, with a mixed region lying between. These regions were defined by critical values of a "dose measure" defined as:

$$\ln (mv^2/w^{1/3}\ TD)$$

where mv^2 is given in g $(m/s)^2$, T is the bodywall thickness at impact in cm, w is animal mass in kg, and D is the diameter of the missile in cm. When applying this to cases utilizing armor, it is necessary to obtain estimates of the effects of energy partition by the vest material. These were made from measurements of clay cavities obtained in ballistic tests. The diameter of the base of the cone was taken as the effective diameter of the missile (D). The mass of the circular piece of armor was added to the mass of the missile. By these methods the "dose" of blunt trauma was calculated for a 75-kg man with a lean, 3-cm body wall thickness when impacted under three vest-handgun combinations. The results are shown in Figure 6-1.

A concluding note of caution was emphasized. While the model is consistent with both experimental and field data (none of the officers shot while wearing the 7-ply Kevlar vest in field tests showed the respiratory distress exhibited by some of the much lighter test animals), it should not be taken as thoroughly tested. In addition, the lean body wall thicknesses assumed for the man lends a built-in conservatism, making the situation look a little worse than it might actually be. In any case, this information should not be taken to indicate that a bulky, perhaps conspicuous, vest is required for protection. One must trade off probability of lethality

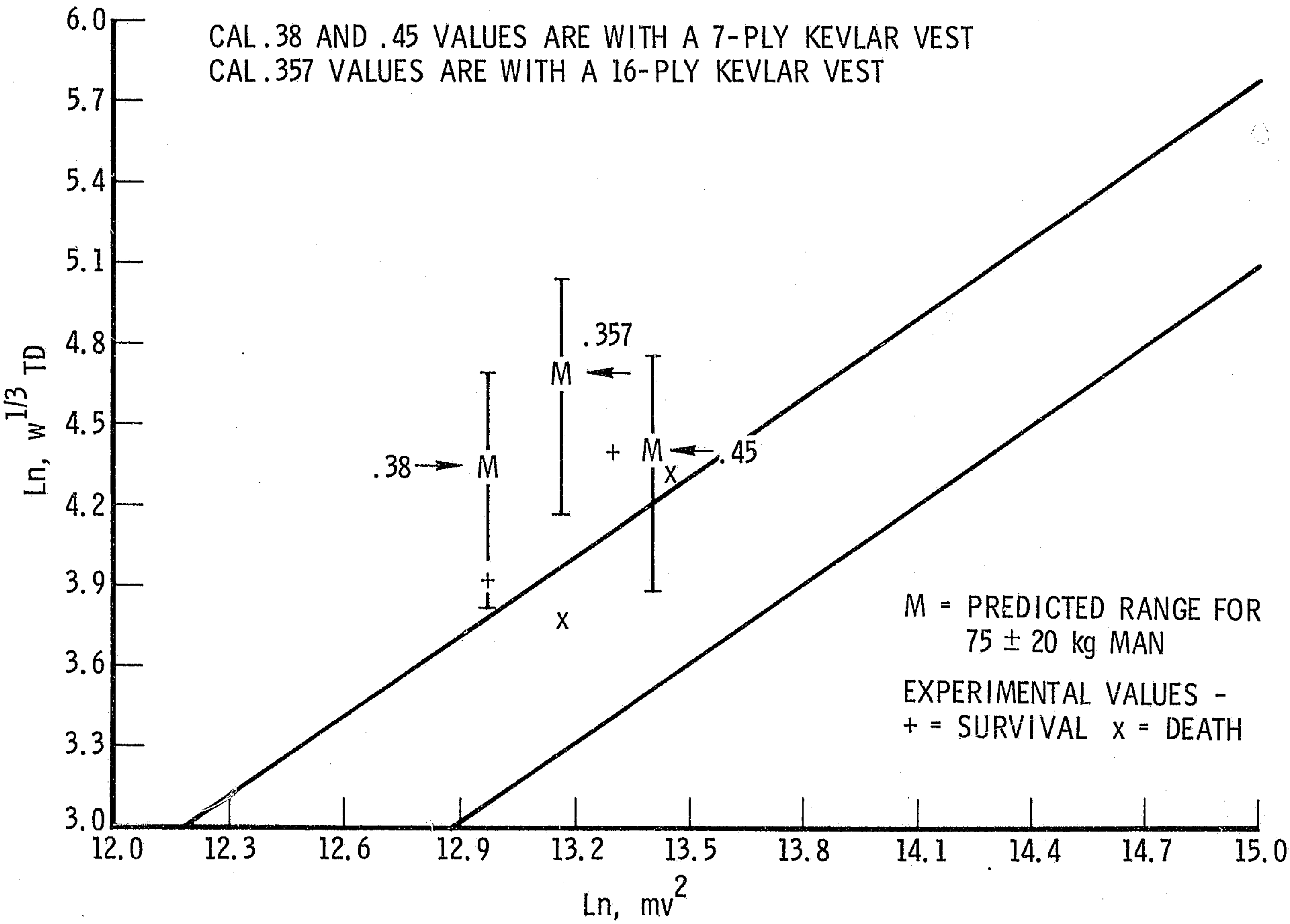


Figure 6-1. Lethality Prediction for the Man Wearing a Kevlar Vest (With Armored Animal Data)

against the probability that the armor will be worn. A vest that would decrease the probability of lethality by 5 percent over all threats and all users, but that simultaneously decreases the probability that it will be worn by 10 percent, increases the overall probability of lethality. Some study along this line is indicated so that the optimal protection may be achieved.

The lethality model was followed by a review of the preliminary test results on garment wear based on the 10-percent sample analysis of questionnaires received during the first six months of the test. The conclusions obtained at this juncture were in general agreement with those obtained from all data, and as reported on in detail in Chapter III.

The remaining agenda items, with the exception of the Shark Program, are also reported on elsewhere in this volume. The Shark Program was conducted for the U.S. Navy by Aerospace using corporate funds. Tests were made off San Diego using a dummy encased in a 1000-denier, 3-ply Kevlar suit. After an hour of shark attacks (attracted with chum) there was no penetration of the Kevlar material. The problem remaining is to increase flexibility, since the 3-ply proved too stiff for practical use by divers. Work will continue on different weaves to increase flexibility.

C. Posttest Symposium

It was agreed by all participants, at the conclusion of the Interim Medical-Technical Symposium, that a final symposium should be held as a culminating effort near the end of the LEAA Lightweight Body Armor Program. This final symposium, referred to as the Posttest Medical-Technical Symposium, was held in the Colorado Springs, Colorado area in mid-August 1977.

The symposium was timely in that the data processing, analysis, and evaluation task had proceeded to the point that a preview of the overall statistical assessment of garment wear profiles and acceptability as derived from participant questionnaires collected during the field experiment could be discussed.

A total of 38 people attended the Posttest Symposium, and, as before, the audience was comprised predominantly of the primary participants — the local trauma surgeons and the test conductors or their designees.

The agenda for the symposium is shown in Table 6-4. As noted, seven presentations were made. Other sections in this document provide a detailed report of the subjects of the morning briefings, and therefore, this section will limit discussion of the highlights to the first three presentations of the afternoon session.

1. Ballistic evaluation of high energy handgun threats. It is appropriate to begin the discussion of posttest symposium highlights with this subject because of the impact of the ballistic evaluation of high energy handgun threats on the subsequent, and related medical assessment of the blunt trauma injury phenomena. There was intense interest in this subject throughout the overall program (particularly during the preceding symposia), during subsequent briefings to law enforcement officials, and as evidenced by the responses to the field test questionnaires. A significant number of officers perceive a need for body armor capable of defeating the higher energy handgun threats, particularly the .357-magnum and the 9-mm. Recent surveys of the law enforcement community do in fact, support the need for armors capable of defeating these threats; however, in terms of the statistical assessment of the occurrence of fatal assault on law enforcement personnel by firearms, the common handgun continues to prevail by approximately a 4:1 ratio. Nonetheless, because of the interest expressed by the user community, LEAA authorized a continuation of ballistic evaluation by the Edgewood Biomedical Laboratory to include the performance of armors against these higher threats.

In presenting the results of the extended ballistic and biologic testing, Mr. Hawkins of the Edgewood Biomedical Laboratory explained that at this time, only limited data had been collected on animal tissue response to ballistic impacts from the higher energy handgun threats. As reported, some animal testing was performed using Kevlar 29, 1000-denier in a 16-ply configuration versus the 9-mm, 124-gr, full metal-jacketed projectile at velocities approaching 1200 fps and the .357-magnum handgun with 158-gr lead projectile at velocities approaching 1326 fps. The preliminary ballistic test results revealed, according to Mr. Hawkins, that these higher energy threats

Table 6-4. Third Medical-Technical Symposium Lightweight Body Armor Program Agenda, 18 August 1977

Time	Subject	Speaker
9:30	Welcome	Chief of Police John Tagert Colorado Springs Police Department
9:45	Introduction	Dr. Jay Merrill LEAA
10:00	Program Overview	Mr. Bob Merkle Aerospace
10:30	Test Data and Evaluation Results	Dr. Floyd Maxwell Aerospace
11:00	Incident Summaries and Medical Assessments	Dr. Drew Carroll Edgewood Arsenal
11:30	Recent Developments in Body Armor Design	Mr. Eddie Barron Natick Labs
12:15	LUNCH	
2:00	Medical Evaluation of High Energy Handgun Threats	Dr. Drew Carroll Edgewood Arsenal
2:45	Ballistic Evaluation of High Energy Handgun Threats	Mr. Eddie Hawkins Edgewood Arsenal
3:15	Ballistic Armor of Kevlar Including Recent Test Results	Mr. Lou Miner Du Pont
3:45	Trauma Surgeons Discussion	

could be defeated by soft armor of sufficient plies; however, he cautioned that no conclusive results were available relative to blunt trauma absorption capability. No test results were available involving biological testing with the .44-magnum.

In summarizing the limited higher energy ballistic threat evaluation, the Edgewood representative stated that more testing is required in order to generate sufficient data to enable a conclusive medical assessment to be made regarding the blunt trauma injury potential behind soft body armor, when the threat is greater than the common handgun.

2. Medical evaluation of high energy handgun threats. The presentation on the medical evaluation of high energy handgun threats was necessarily limited due to the sample size of the previous animal ballistic testing. In fact, the amount of data available did not lend itself to providing the basis for an in-depth medical analysis of the animal-human blunt trauma injury correlation. The Edgewood surgeon did show pictures of typical damage sustained behind Kevlar armor (16 plies as cited) following impact from the 9-mm and .357-magnum handguns. Even with the increased armor ply count, there appeared to be visible evidence of an increase in the severity of wounds sustained behind the armor in the higher energy case than in the case of projectiles from the common handgun with 7-ply protection. Figures 6-2 through 6-5 show in juxtaposition, skin lacerations and hepatic contusions resulting from the .38-caliber handgun and the higher energy .357-magnum.

In conclusion, the Edgewood medical specialist – prefacing his remarks with the statement on the availability of limited biological test data – inferred that comparison of blunt trauma injury in animals following impact behind soft body armor from common handgun projectiles and higher energy handgun projectiles reveals an increased damage potential in the case of the higher energy threat – even though the elevated ply count is sufficient to prevent ballistic penetration. Because of this, it was stated that the probability ranges for surgery and mortality given in EB-TR-74073 (Dept. of the

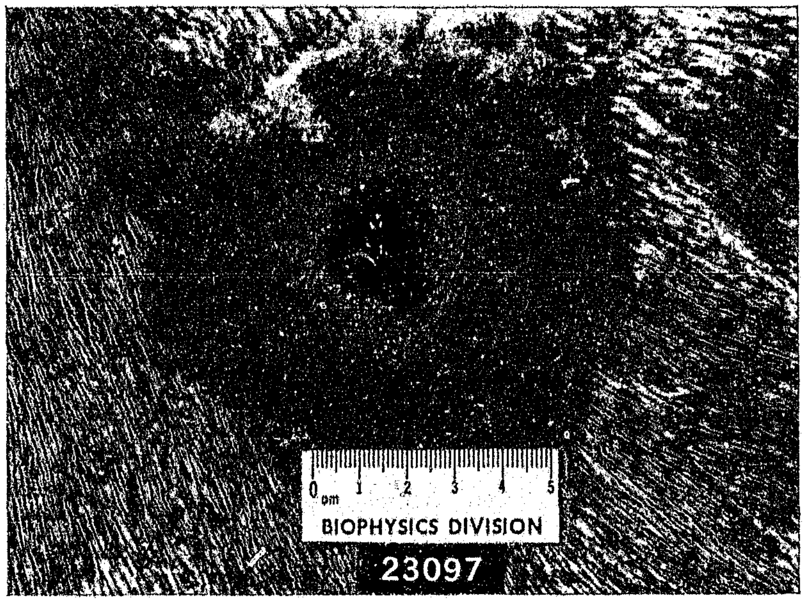


Figure 6-2. Skin Laceration - .38 Caliber at 800 fps; 7-Ply, 1000-Denier Kevlar

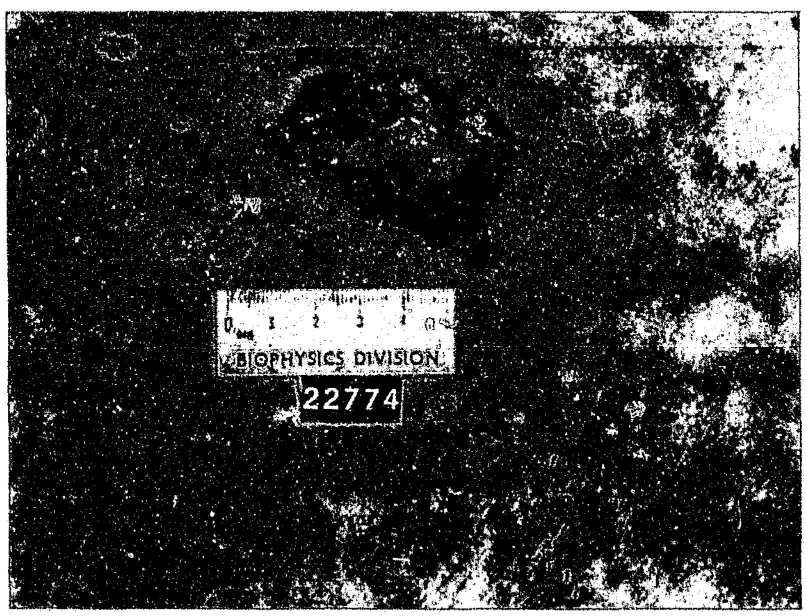


Figure 6-3. Skin Laceration - .357 Magnum at 1326 fps; 16-Ply, 1000-Denier Kevlar

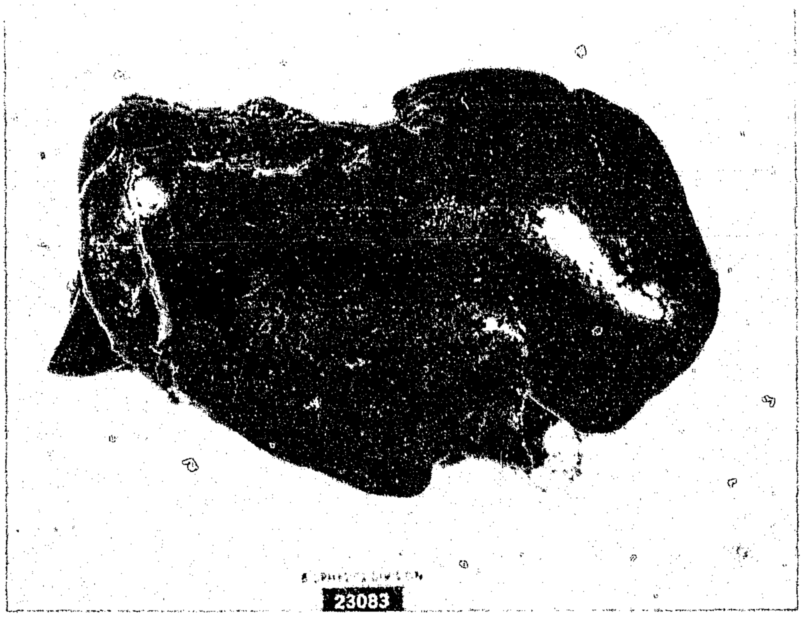


Figure 6-4. Hepatic Contusion – .38 Caliber at 800 fps; 7-Ply, 1000-Denier Kevlar

Figure 6-5. Hepatic Contusion – .357 Magnum at 1326 fps; 16-Ply, 1000-Denier Kevlar

Army Technical Report, dated January 1975) for the case of a human with and without armor, following impact from the .38-caliber (and below) handgun, would probably increase in the nonpenetrating case of impact from higher energy handguns such as the .357-magnum.

3. Ballistic armor of Kevlar aramid. Mr. Louis H. Miner, of the E. I. DuPont Company, Textile Fibers Division gave a presentation (the first and only briefing given by an industry representative during the series of three one-day symposia) focused on the basic 7-ply, 1000-denier, Kevlar 29 aramid fabric, with a weave construction of 31 × 31 pics per inch. He also provided some information and comparisons involving closely related aramid fabrics. Most of the data presented derived from recent tests on Kevlar aramid fabrics, including Kevlar 49, which was included in the preliminary ballistic screening activities conducted at the beginning of the LEAA Body Armor Program by The Aerospace Corporation, and the U.S. Army's Edgewood and Natick Laboratories. It should be recalled, that the results of those preliminary tests showed the Kevlar 29 aramid fabric to be slightly superior to the Kevlar 49 with respect to minimizing blunt trauma following nonpenetrating ballistic impact. Test results shown during this briefing still support the earlier program test results, as is seen in Table 6-5, in which the final column depicts the depression volume for .38-caliber impacts at a velocity of 800 fps. As is seen, the depression volume is less for the 7-ply Kevlar 29, 1000-denier fabric than it is for 7-ply Kevlar 49, 1140-denier fabric – even though the observed depth of penetration is less for the Kevlar 49 fabric.

Other test results provided in the briefing are shown in Tables 6-6 and 6-7. The effect of various laundering methods on the Level 1 ballistic resistance of the Kevlar 29, 1000-denier aramid fabric is shown in Table 6-6 (fabric is 7-ply). It is noted that these recent laundering tests still support the findings recommended by the LEAA Program; that is, hand washing in "Woolite brand" detergent is still a completely acceptable procedure, even though other methods are now shown to be equally effective in minimizing

Table 6-5. Effect of Material on Backface Signature ("Blunt Trauma") in Fabrics of Kevlar Aramid Plaster Mold in Clay .38 Caliber at 800 fps

Material	Indentation Geometry			
	No. of Plies	Depth (cm)	Diameter (cm)	Volume (cm^3)
Kevlar 29,1000-Denier (31 × 31)	7	3.2	7.0	58
		3.6	6.5	47
		4.0	7.2	67
Kevlar 49,1140-Denier (31 × 31)	7	2.5	8.9	80
		2.5	9.5	79
Kevlar 29,1000-Denier (31 × 31)	8	3.2	5.8	44
		3.2	6.2	36
		3.8	6.9	53
Kevlar 29,1000-Denier (31 × 31) Elastomer-Coated	8	1.3	6.0	33
		1.3	6.9	38

<u>Conclusions</u>: Means Available to Reduce Dynamic Deflection:

- Flexible Armor
- Increase number of Plies
- Kevlar 49 for Kevlar 29

Table 6-6. Effect of Laundering on Level 1 Ballistic Resistance

TEST CONDITIONS		
None:	•	Home Laundering (top 10 detergents) + Machine Dry up to 50 cycles
	•	Commercial Drycleaning 7 cycles
	•	Hand Wash ("Woolite") + Air-Dry 15 cycles
	•	Fabric Softener ("Downey") + Detergent ("Tide") + Machine Dry 15 cycles
	•	Presoak ("Wisk" or "Borateem") + Detergent ("Tide") + Machine Dry 5 cycles
	•	Stain Remover ("Shout") + Detergent ("Tide") + Machine Dry 5 cycles
	•	Machine Wash + Direct Sunlight Dry 35 hour UV exposure
Some:	•	Commercial Laundering 5 cycles
	•	Bleach ("Clorox") + Detergent ("Tide") + Machine Dry 5 cycles

Level 1 ≡ .38- and .22-Caliber Handgun
158- and 40-gr Round Nose Soft
Point Lead

Table 6-7. Preferred Fabric Styles

- Soft Armor
- Flexible Armor
- Hard Armor
- Combination Armor

Kevlar 29 Aramid, 1000-Denier, 31 × 31 (ends by picks) per in. Plain Weave - 8.3 oz/yd^2 Nominal or Kevlar 49 Aramid, 1140-Denier, 29 × 29 (ends by picks) per in. Plain Weave - 8.3 oz/yd^2 Nominal Best Value in Use
Kevlar 29 Aramid, 1500-Denier, 24 × 23 (ends by picks) per in. Plain Weave - 9.6 oz/yd^2 Nominal Less Expensive

- Lower Denier (200 and 400) Fabric Constructions are Superior Ballistically, but are expensive.
- All Other Kevlar Fabric Constructions are Inferior Ballistically by Our Tests.

minimizing the degradation of fabric ballistic resistance. Table 6-7 offers interesting conclusions relative to the preferred Kevlar aramid fabric weaves for use as ballistic armor. Again, it is noted that the fabric weave selected on the basis of the recently conducted industry tests is identical with the ballistic fabric recommended for use in soft body armor applications by this final report. (Copies of the industry presentation should be requested from the DuPont Company, Textile Fibers Division, Wilmington, Delaware 19898.)

CHAPTER VII. DESIGN MODIFICATIONS

A. Garment Modifications

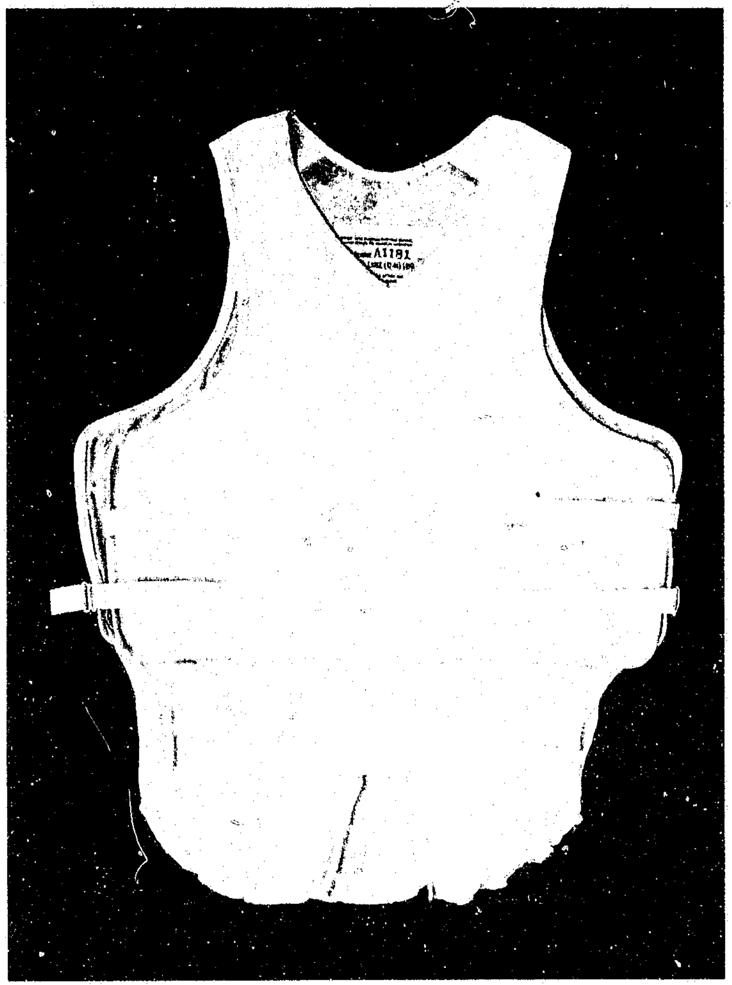
The baseline 7-ply garments were designed and constructed to have minimum weight and bulk. Testing in the development phase indicated minimum degradation of the ballistic fabric as a result of repeated wash cycles. The only serious limitation was that chlorine bleaches would degrade the mechanical and ballistic performance of the material. A second problem was also uncovered in that the ballistic resistance of the fabric was seriously reduced if the fabric became soaked with water. Experimentation with water-resistant treatments showed that the problem could be eliminated by treating the fabric with Zepel-D* or an equivalent. Repeated wash cycles did not seriously degrade the performance of the Zepel treatment.

With these and other considerations in mind, it was decided to integrate the ballistic fabric into the basic undergarment. The outer shell material, shoulder straps, adjustment straps, and finishing materials were sewn together to form a single integrated unit. Figure 7-1 shows the Style I garment outer and inner construction details. This approach yielded the lightest weight undergarment for the design protection level. Three vertical stitch lines were required through the 7 plies of material to minimize the blousing effect of the rear panel.

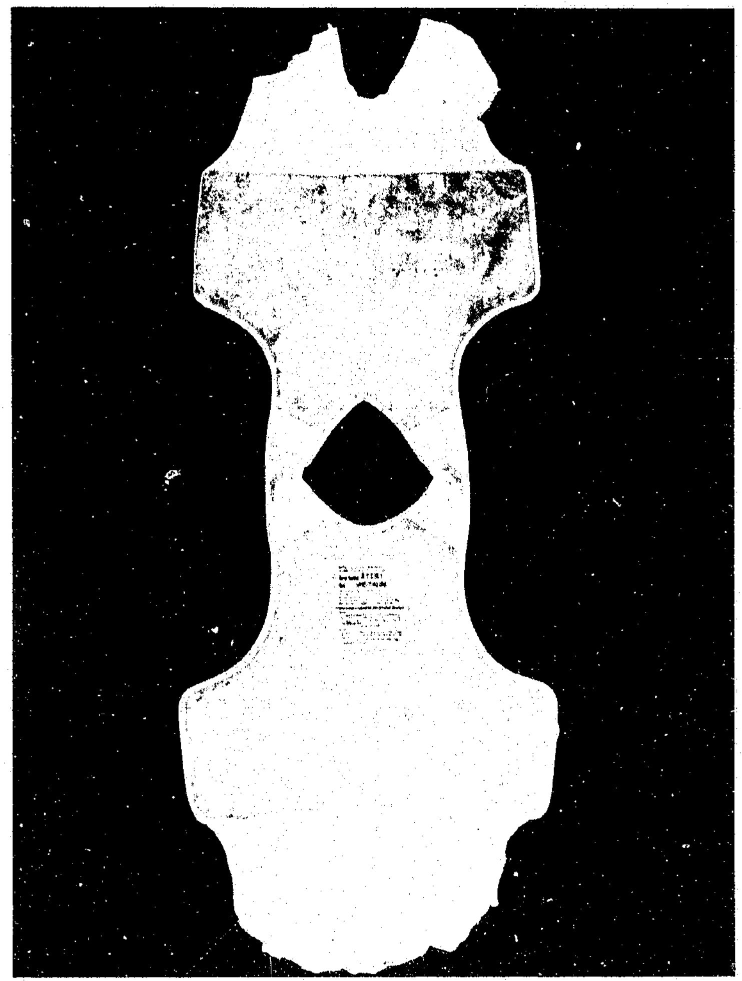
During the course of the program, a number of problems and deficiencies were uncovered which indicated a need for modifications on future garments.

In the baseline garments, the outer shell material and the ballistic material were edge-sewn with bias binding tape. In use, it was discovered that the coarse yarn ballistic fabric was pulling away from the binding tape by the fabric yarn being pulled from the material. This problem could be

*Registered trademark, E.I. Du Pont.



Style I -- Outside



Style I -- Inside

Figure 7-1. Style I Garment Configuration

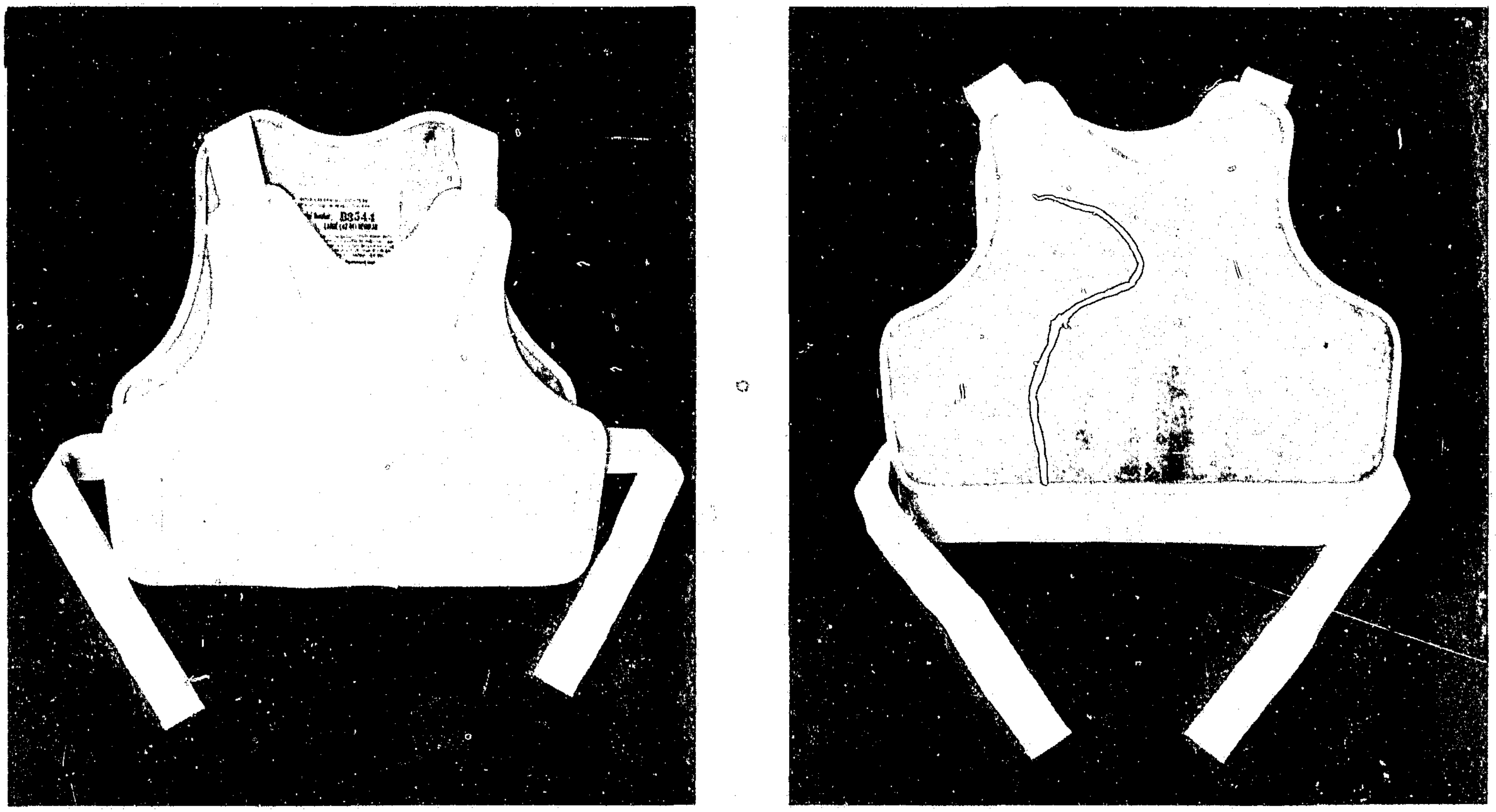
minimized or eliminated by exercising additional care in sewing the binding tape to the fabric and by using a wider tape to ensure engaging more yarns in critical areas. It is recommended that in future designs only the outer 2 plies be sewn with the bias binding tape. This will increase the apparent "softness" of the construction and reduce the probability of tearout of the fabric.

The adjustment straps on the Style I garments were equipped with buckles. The buckles were stamped and had relatively sharp edges. As the garments were worn, these buckles cut through their elastic retaining straps, resulting in failures. In addition, the buckles represent a potential source of secondary projectiles either by breaking themselves or by causing the ballistic projectile to fragment. Buckles should be eliminated in any future garment design.

As mentioned previously, the Style I garments had a short elastic strap as the buckle retainer. It was determined from use that the officers stretched this elastic to its limit when donning the garments. As a result, no elasticity remained and the garment could not adjust to changes in the torso under different conditions. Thus, the garment would bind and ride up. It is recommended that additional elastic be provided in the adjustment straps and that specific instructions be prepared for the wearers to only adjust the garments to a snug fit and ensure that additional stretch is remaining to allow the garments to expand and contract with the body movement.

The Style I garments were also equipped with 1-in. adjustment straps. Wider straps are recommended to allow the use of more elastic material and greater holding area in the Velcro fasteners.

In the Style II garments, shown in Figure 7-2, there were two main deficiencies. First, the Style II garments did not have tails to be tucked into the pants. Thus, they had a greater tendency to ride up. Second, the



Style II -- Outside

Style II -- Inside

Figure 7-2. Style II Garment Configuration

garments were equipped with a single adjustment strap without elastic inserts. Both the single strap and the lack of elastic contributed to the tendency of these garments to ride up.

Although the recalled garments test program did not show a significant reduction in either ballistic or mechanical properties of the garments after up to approximately 15 months of wear, there was some evidence of mechanical damage to the material which was apparently caused by agitation of the material during the laundry and drying cycles. Additional life cycle testing would be required to determine when or if this damage becomes critical. To ensure maximum ballistic fabric life, a design change was suggested which would reduce the number of required exposures to the wash and dry cycles.

Based on the reported data from the test program, discussions with participating police officers and test conductors, and additional work performed by Natick Laboratories and the industry manufacturers, extensive design modifications were recommended.

Figure 7-3 shows the basic characteristics of the recommended garment. Since weight did not appear to be a significant factor in the willingness of an officer to wear the garment, the decision was made to use the separate carrier and ballistic insert approach in the new design. This entails the fabrication of a carrier garment containing pockets for installation or removal of inserts which contain the ballistic fabric. The carrier provides the shoulder straps, the adjustment straps, and the garment tails. Two 2-in.-wide adjustment straps with Velcro fasteners are provided on each side of the garment. The adjustment straps are provided with a minimum of 3 in. of elastic to allow adequate give in the garment so that it can expand and contract with the wearer's body changes. The rear of the adjustment strap is attached to the garment in such a way that the front panel will overlap the rear when overlap is required for fit. Ideal fit would be for the front and rear panels to butt or have a slight gap when the wearer is standing and relaxed. Full wraparound upper torso protection is thus provided.

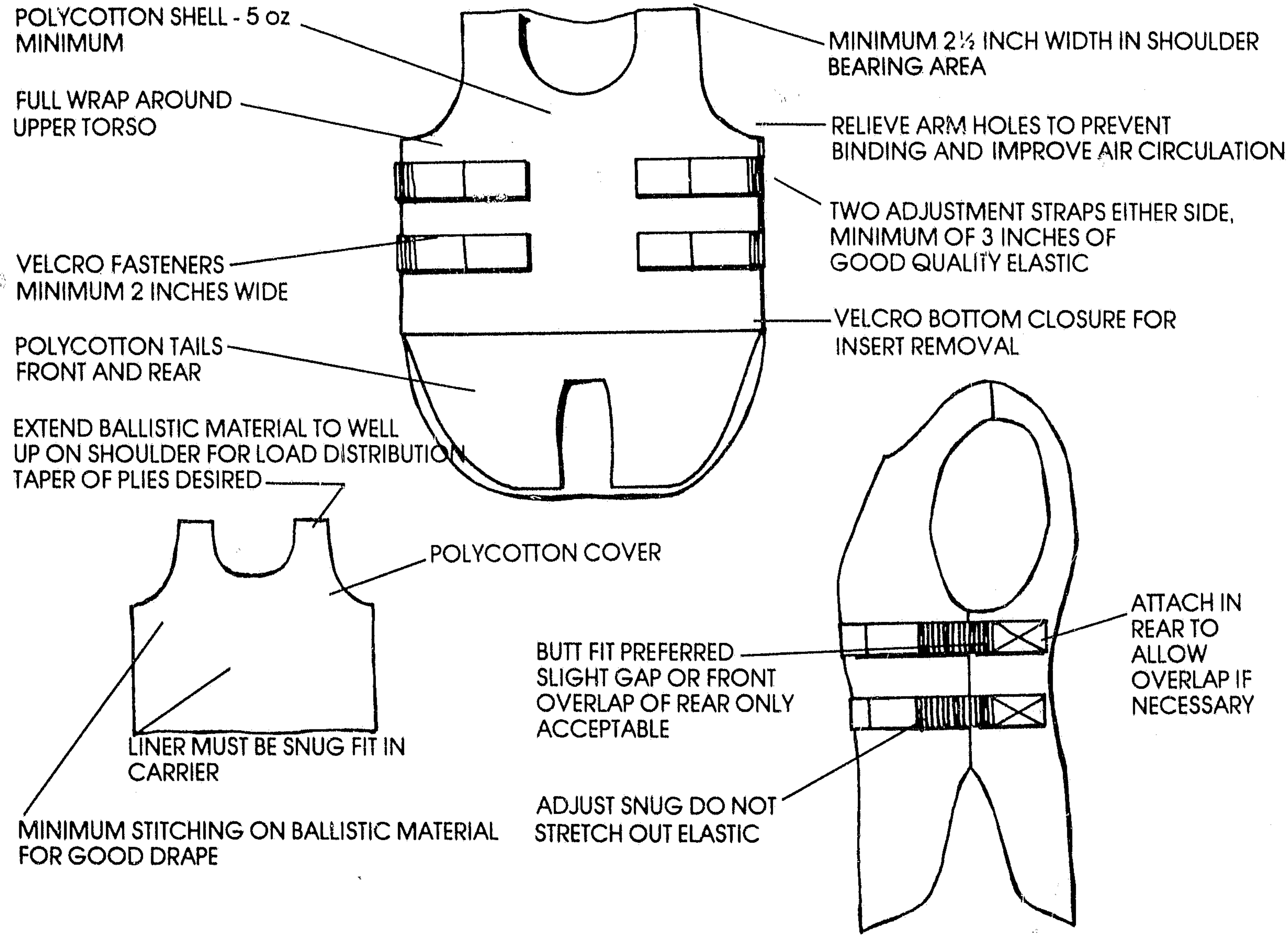


Figure 7-3. Recommended Garment Configuration

The recommended method of insert construction is to sew the shaped ballistic panels into a lightweight fabric cover. The recommended 8 plies of ballistic fabric should not be sewn together. Bar tacks only should be used in the top of the shoulder straps and at the four corners of the inserts. This will allow the fabric plies to slide over each other for a softer and more flexible garment, but will prevent material bunching when the inserts are washed.

One of the major advantages of the carrier-insert approach is that the carrier can be laundered frequently and the ballistic resistant inserts only occasionally. This will minimize the mechanical damage to the fabric due to the wash and dry cycles and should significantly extend the useful life of the expensive ballistic inserts. Also, if two carriers are purchased, then the inserts can be exchanged while one carrier is being laundered and the second is being worn.

A further advantage, which has not been addressed in detail, is the flexibility inherent in this design approach. The basic garment is recommended with 8 plies of 1000-denier fabric. By providing an additional set of inserts in either 8, 10, or 12 plies, higher level threat protection can be achieved. With two inserts front and rear, protection will be provided against penetration of most 0.357- and 9-mm projectiles. Variations in front and rear protection can then be selected by the wearer, depending on his perception of the risk and weather conditions. Minimum protection level would be the 8-ply insert in the front and no insert in the rear.

The recommendation was made to increase the number of plies from 7 in the test garments to 8 in the Model Procurement Document. The reasons for this are threefold. First, later data on the handgun velocity for the .22-caliber long rifle round indicates the design velocity should be closer to 1080 to 1100 fps, rather than the 1000 fps originally selected. Second, ballistic testing of Kevlar fabric has indicated a variation in ballistic resistance not only between fabric weavers, but also in fabric from the same weaver. Since rigid quality control and testing is an expensive operation, the additional ply of fabric will provide an added safety factor to the garment performance. Lastly, although there has been no evidence of a significant loss in ballistic resistance with wear or laundry cycles, the additional ply of material will safeguard against an undetected gradual degradation in ballistic performance in the high cost ballistic resistant inserts. This, combined with minimizing the wash cycles, will extend the useful life of the inserts.

B. Human Factors

The recommended design modifications which resulted from the evaluation of the test garments were substantial. As a result, it was decided to initiate a program with the support of the U.S. Army Natick Research and Development Command and the Research Institute of Environmental Medicine to obtain laboratory data comparisons between the field test garments and the recommended garment configuration. The recommended program was approved by the National Institute of Law Enforcement and Criminal Justice, which made funds available for the conduct of the test. The test plan for this series of tests is contained in Volume III, Appendix F.

The objective of the program was to obtain laboratory comparisons between the two configurations in terms of comfort and heat retention. The comfort factor was assessed using the load profile analyzer instrumentation system at the Natick Research and Development Command. The heat retention factor was analyzed by using the copper man in an environmental chamber at the Research Institute of Environmental Medicine. Both activities were monitored through the Natick Laboratories.

The second program which addressed the human factors aspects of the man and the armor was conducted at and by the Federal Bureau of Investigation Academy at Quantico, Virginia. It was determined in the development program that a wet garment lost a significant portion of its ballistic resistance and that Zepel-D treatment of the fabric prevented this loss in performance. The objective of the Quantico test was to determine if there was sufficient water uptake by the garment from human body perspiration to reduce the ballistic performance.

The results of these two programs are presented in the following sections.

1. Natick results. In the Natick test program, four garments were provided and were identified as follows:

- A-1. Style I LEAA test garment with Zepel-D treatment of Kevlar
- A-2. Modified garment (new design) with Zepel-D treatment of Kevlar
- A-3. Modified garment (new design) without Zepel-D treatment
- A-4. Style I LEAA test garment without Zepel-D treatment

The first set of tests was to investigate the relative comfort of the garments in terms of load distribution. An instrumentation system called the Anatomical Load Magnitude Analyzer was developed by personnel at Natick. The system is a reticulated series of 248 miniature, local sensors which covers the upper torso of an individual wearing the test garments. A "3D" display unit is provided to visually display loads and pressure points. The system is capable of displaying pressure, pressure changes, load magnitude, and distribution of forces transmitted to the torso by the garment as the test subject assumes a variety of positions.

In this evaluation, the 4 garments were to be tested while the test subject assumed 12 different positions. Figure 7-4 shows the basic elements of Anatomical Load Magnitude Analyzer. For the purpose of data recording and presentation, the pressure point readouts are summed over four areas or zones. The zones are as follows:

- Zone 1 — Upper front
- Zone 2 — Lower front
- Zone 3 — Upper rear
- Zone 4 — Lower rear

Table 7-1 contains the data results from the Anatomical Load Magnitude Analyzer comparison of the four garments tested. The data indicate that there is essentially no difference in load distribution among the

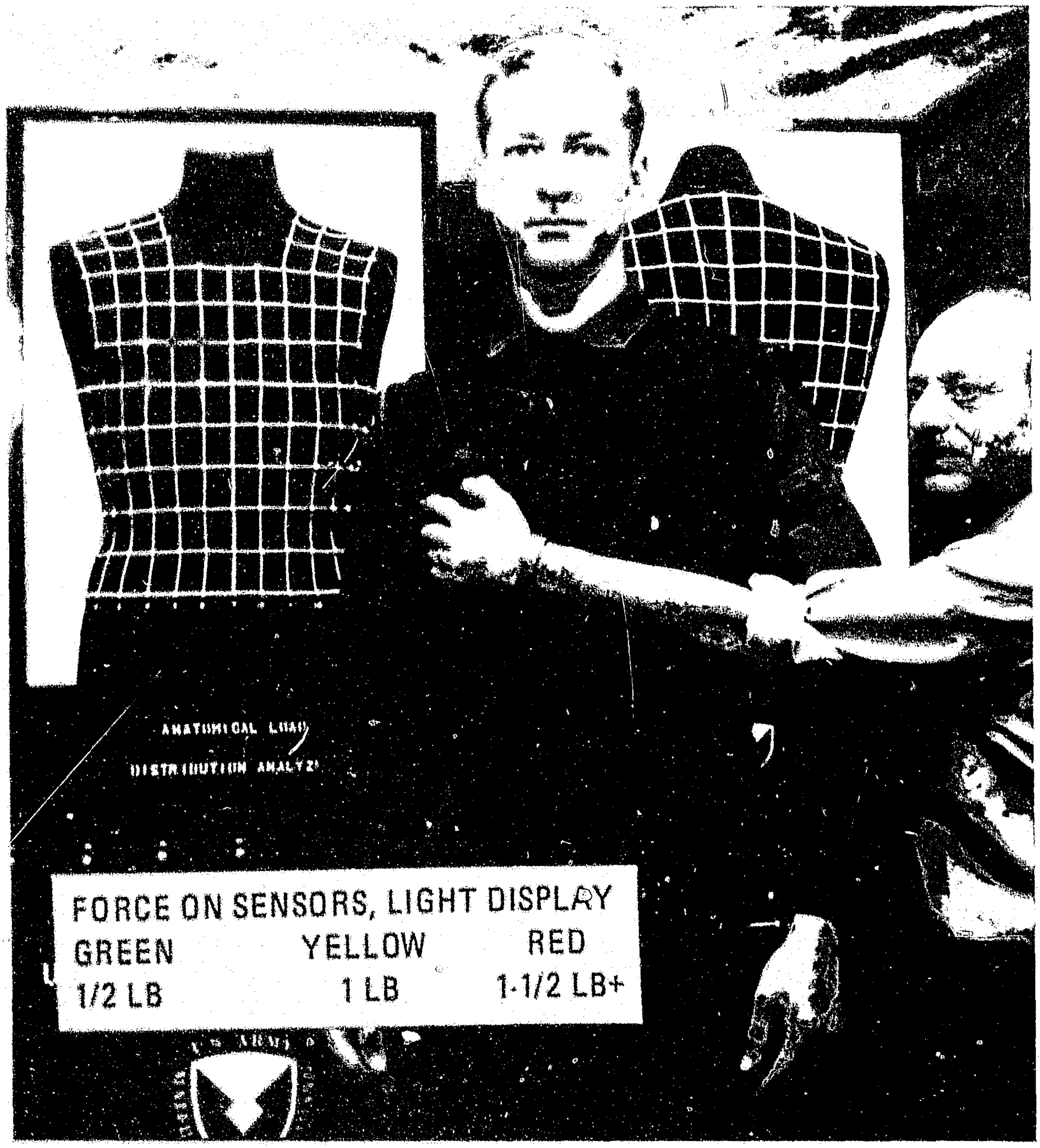


Figure 7-4. Anatomical Load Magnitude Analyzer

Table 7-1. Load Magnitude Analyzer — Garment Comparison Data[a]

Body Position	Item	Zone 1	Zone 2	Zone 3	Zone 4	Total
	Values Shown Are Averages of Two Tests in lb.					
1. Standing, Normal Breathing	A-1	0.50	0.25	0.00	0.00	0.75
	A-2	0.50	0.00	0.00	0.00	0.50
	A-3	0.25	0.00	0.25	0.00	0.50
	A-4	0.00	0.00	0.00	0.00	0.00
2. Standing, Heavy Breathing	A-1	1.50	1.25	0.00	3.50	6.25
	A-2	2.25	0.25	0.25	0.75	3.50
	A-3	2.50	0.00	0 00	0.50	3.00
	A-4	2.00	0.00	0.25	0.00	2.25
3. Reaching Up, Both Hands	A-1	1.00	0.00	0.00	0.00	1.00
	A-2	1.00	0.00	0.00	0.00	1.00
	A-3	0.75	0.00	0.00	0.00	0.75
	A-4	1.50	0.00	0.00	0.00	1.50
4. Reaching to Holster, Right Hand to Right Hip	A-1	0.00	0.00	1.00	0.25	1.25
	A-2	0.50	0.00	0.25	0.00	0.75
	A-3	0.00	0.00	0.25	0.00	0.25
	A-4	0.00	0.00	1.25	0.00	1.25
5. Rifle Firing, Standing	A-1	1.50	2.75	1.50	8.00	13.75
	A-2	1.50	0.00	1.50	7.00	10.00
	A-3	1.25	0.25	1.25	5.00	7.75
	A-4	1.00	1.00	1.25	5.75	9.00
6. Rifle Firing, Kneeling	A-1	0.25	4.00	0.00	13.25	17.50
	A-2	0.00	1.50	1.50	9.00	12.00
	A-3	0.25	3.75	0.25	8.75	13.00
	A-4	1.00	4.50	0.00	8.50	14.00
7. Pistol Firing Standing, Both Hands Forward	A-1	0.00	0.75	2.75	6.50	10.00
	A-2	0.75	0.25	3.50	5.50	10.00
	A-3	0.00	0.50	1.75	4.75	7.00
	A-4	0.75	0.75	2.50	4.50	8.50
8. Pistol Firing, Crouched, Both Hands Forward	A-1	0.75	7.50	0.00	13.50	21.75
	A-2	2.00	5.00	0.50	6.00	13.50
	A-3	1.75	6.25	1.00	6.75	15.75
	A-4	0.75	7.00	0.25	8.00	16.00
9. Stooped Over	A-1	0.00	0.25	0.00	11.00	11.25
	A-2	0.00	0.25	0.25	10.25	10.75
	A-3	0.25	1.25	0.00	10.25	11.75
	A-4	0.00	0.75	0.00	6.75	7.50
10. Pistol Firing, One Hand Forward	A-1	0.00	0.25	1.25	0.75	2.25
	A-2	0.00	0.00	0.25	0.50	0.75
	A-3	0.00	0.00	0.75	1.25	2.00
	A-4	0.00	0.00	0.25	0.00	0.25
11. Pistol Firing, One Hand at 45° Angle	A-1	0.00	0.00	0.00	0.00	0.00
	A-2	0.00	0.00	0.00	0.00	0.00
	A-3	0.00	0.00	0.00	0.00	0.00
	A-4	0.50	0.00	0.00	0.00	0.50
12. Pistol Firing, One Hand at 90° Angle	A-1	0.00	0.00	0.00	0.00	0.00
	A-2	1.00	0.00	0.00	0.00	1.00
	A-3	0.00	0.00	0.00	0.00	0.00
	A-4	0.00	0.00	0.00	0.00	0.00

[a]Items tested: A-1, Style I LEAA test garment with Zepel-D treatment of Kevlar, size medium regular; A-2, modified garment (new design) with Zepel-D treatment of Kevlar, size medium large; A-3, modified garment (new design) without Zepel-D treatment, size medium large; A-4, Style I LEAA test garment without Zepel-D treatment, size medium large.

four garments tested. The slightly higher readings noted for garment A-1 are attributed to the fact that this garment was a smaller size than the other three (medium regular rather than large regular). The test subject, with the instrumentation system in place, required a large regular size for proper fit. However, the results shown emphasize the need for proper fit to minimize the loads imposed on the body. The high readings in the heavy breathing, kneeling, and crouched positions indicate unnecessarily high loads imposed by a garment which is incorrectly fitted.

The conclusions from these data are that there is essentially no difference between the load distribution of the new design and the test garments.

The second phase of the human factors test program was performed by the U.S. Army Research Institute of Environmental Medicine. In this set of experiments, the Army-developed copper man in an environmental chamber was used. The copper manikin system comprises a hollow simulator constructed to the size of an average U.S. Army infantryman with thermocouples located at 21 representative sites on the skin. The copper skin is equipped with thermostatically controlled heating wires. Varying the thermostat setting to maintain skin temperature and measuring the power delivered to the heating wires enables determination of heat loss through the skin. By performing tests in a controlled external environment with the copper skin dry, the insulating effect of clothing placed on the manikin may be determined. This technique is used to measure the insulation index (clo) of various garments.

By placing a cotton skin over the manikin, wetting it, and adjusting the system to equilibrium conditions, the impermeability index (im) is determined.

The primary purpose of the copper manikin test series was to determine from laboratory measurements if the new garment designs would have a significantly different physiological impact on the wearers than those tested in the program. The tests were run in two series. First, the garments were placed on the copper manikin with dry skin, and the insulation index was determined. Next, the cotton skin was placed on the manikin, the protective garments were installed, the manikin was dressed the same as for the insulation index measurement, the cotton skin was wetted, and the impermeability index was measured. Figure 7-5 shows two photos of the copper man, one with the police uniform shirt installed and buttoned, and the other with the undergarment exposed under the open shirt. The ratio of the impermeability index (im) to insulation index (clo) is an indication of the comfort which should be experienced by the wearers. The three indices are interpreted as follows:

- Insulation index (clo). The higher this number, the warmer the garment should feel in cold weather, i.e., dry skin conditions.
- Impermeability index (im). The higher this number, the more evaporative cooling will take place, hence the cooler the body will feel with wet skin conditions.
- Comfort index (im/clo). This ratio is a measure of the combined effects of the garment and the actual sensed comfort. Adding a garment will make the subject warmer, but if the garment allows evaporative cooling, the discomfort will be reduced. The higher the ratio of the two numbers, the more comfortable the garment will feel.

In addition to the four protective undergarments provided, two peg-point configurations were also tested. The two configurations consisted of the dressed manikin without any protective garment and also with an early design, serial number U-0012, which was an integrated, full wraparound, non-Zepel-treated garment containing 7 plies of 400-2 Kevlar fabric. This was one of the test points in the original U.S. Army report. For all tests, the basic clothing used on the manikin comprised the following:

- Shirt, police, short sleeve, collar open
- Trousers, police, polyester, summer weight
- Cap, police, open weave
- Police belt with holster (containing 1.5-kg weight) whistle, pen and pencil holder, double cartridge case, handcuffs

Figure 7-5. Copper Manikin Instrumentation System

- In trouser pockets: 12-in. billy, leather notebook, and flashlight with wand
- Cushion sole socks and combat boots (U.S. Army items)

Table 7-2 contains the results of the copper manikin test program. In essence, the following conclusions can be drawn from this series of tests:

- The two new vests, which have separate carriers with and without the Zepel-D treatment to the Kevlar, have slightly higher insulation indices than the integrated garments.
- In terms of evaporative cooling, the use of carriers increases the evaporative cooling characteristics of the vests by increasing the water absorption and probably providing a medium to transport the water away from the skin.
- The integrated garment with Zepel-D treatment provided the least evaporative cooling and should exhibit the greatest hot weather discomfort.
- There is no significant discomfort difference between the two new designs and the untreated integrated vests. Water resistance treatment of the Kevlar fabric is required to maintain wet ballistic resistance.
- All garments show a decrease in evaporative cooling (comfort) by about 17 percent, except for the Style I test garment which indicated a 28-percent decrease.
- Both the load profile analysis and the physiological testing indicate the new design garments should be as comfortable as the Style I garments in the test program, and may show a slight improvement in terms of heat comfort.

2. Quantico results. The Quantico tests were undertaken to attempt to determine if there was sufficient water uptake from perspiration to degrade the ballistic performance of the Kevlar material.

During the development program and in subsequent testing, it was determined that when the untreated (not water-repellant-treated) Kevlar fabric is water soaked, the ballistic resistance is reduced. Submerging the

Table 7-2. Copper Manikin Test Results

Clothing Configuration	clo	im	im/clo	Vest, Dry Weight (g)	Vest, Final Weight (g)	% Water Absorbed	% Water Absorbed in Shirt
Basic — No Vest	1.32	0.48	0.36				
U0012 Vest	1.48	0.45	0.30	846	1125	33.0	23.5
A-1 (Test Vest)	1.46	0.38	0.26	963	1033	7.3	18.3
A-2 (New Design Zepel-D)	1.52	0.45	0.30	1087	1216	11.9	20.1
A-3 (New Design Not Zepel-D)	1.54	0.44	0.29	1069	1194	11.7	20.7
A-4 (Test Vest Not Zepel-D)	1.48	0.45	0.30	976	1232	26.2	19.7

fabric in water with and without agitation reduced ballistic resistance. Spraying the fabric with water yielded inconclusive results. Exposure to 100-percent-humidity environment did not indicate a significant degradation. The questions then remained of which procedure, submerging or spraying, was most representative of the actual water absorption possible from perspiration and whether sufficient water can be absorbed to reduce the ballistic penetration resistance.

The Federal Bureau of Investigation Academy at Quantico, Virginia, agreed to support a limited test program to obtain data on the subject. Instructors at the Academy agreed to participate in the test program by wearing water-repellant treated and untreated garments to determine the liquid takeup of each. Ballistic testing was performed on each garment at the conclusion of the wear period.

Six garments were provided for testing. All were the LEAA Style I configuration with 7 plies of Kevlar. Three garments contained Zepel-D treated material, and three contained Kevlar with a scoured finish and no water-repellant treatment. Two garments (one treated and one untreated) were control garments to be tested without being worn. The remaining four garments were to be worn by Academy instructors and then ballistically tested. The test procedure employed was to weigh each garment. The instructor would wear the garment for 5 to 6 hours of activity. The participant would then return to the range, where the garment would be removed and weighed to determine the amount of water absorbed. The garment was then placed against a block of Plastilina Clay No. 1 and ballistically tested with projectiles from .22- and .38-caliber handguns.

Two officers on auto patrol duty were each issued a vest, one of which was untreated and the other Zepel treated. Similarly, two instructors on the firing range were each issued a vest, one treated and one untreated. The two officers on patrol performed their regular duties without any outside activity. The two instructors played handball with the vests on for 2 hours in the morning, taught class after lunch, and played handball for 30 minutes just before their garments were tested in the afternoon.

The first test was on a new Zepel treated vest. Ten .22-caliber shots and three .38-caliber shots were made, and the cavities were measured. There were no penetrations. Next, a new untreated vest was tested with ten .22-caliber shots, and again there were no penetrations. This untreated vest was then soaked in water for 1 hour, drip dried for 3 minutes, and then tested with three .22-caliber shots. All three shots penetrated. Six .38-caliber shots were made, and there were no penetrations. After 1 hour of soaking, this vest contained 22.75 oz of water, an increase in weight of 66 percent. After 30 minutes of drip drying, this vest still contained 12.5 oz of water, an increase in weight of 36 percent.

The untreated vest worn by one of the instructors (subject 1) was tested next. This vest had absorbed 7.5 oz of moisture, an increase in weight of 22 percent. Ten .22-caliber shots were fired at the front of the vest, and there were nine penetrations. Five .22-caliber shots were fired at the back of the vest, and there were four penetrations.

Next, the Zepel treated vest worn by an instructor (subject 3) was tested. This vest absorbed 3.5 oz of moisture, an increase in weight of 12 percent. This vest was tested with ten .22-caliber shots, and there were no penetrations.

The final test was run on the untreated vest worn by the officer on patrol (subject 2). This vest had absorbed 1.625 oz of moisture, an increase in weight of 5 percent. This vest was shot ten times with a .22-caliber. There were no complete penetrations, but all were partial penetrations.

The treated vest worn by the officer on patrol (subject 4) absorbed 0.875 oz of moisture, an increase in weight of 3 percent. This vest was not tested ballistically, since the treated vest worn by an instructor had absorbed 3.5 oz of moisture and had already successfully passed ballistic testing.

From the data obtained by weighing the garments before and after the wear period, it appears that the water submergence test with approximately 1/2 hr of drip drying most closely approaches the water uptake from perspiration. These data also compare favorably with the water uptake measured on the copper man.

The ballistic test data sheets are contained in Tables 7-3 through 7-7. As indicated, five sets of ballistic tests were performed. During the ballistic testing, problems were encountered with the chronograph. As a result, the velocity measurements are suspect. However, since the same weapon (Smith and Wesson Model 45 with a 4-in. barrel) and ammunition (Remington) were used in all testing, and ten .22-caliber rounds were fired at each vest, some conclusions may be drawn. First, there were no .22-caliber projectile penetrations of the Zepel-D-treated garment. Prior testing indicated there was no significant difference in the penetration resistance of treated versus untreated fabric. Two of the untreated vests showed penetrations. The new vest which had been water soaked and the untreated vest which had the highest percentage by weight of water uptake during the wear testing were both penetrated by .22-caliber projectiles. Since the vest which was worn was penetrated by nine of the ten impacts and the probability of all nine being higher than nominal velocity is very small, it must be concluded that sufficient water can be absorbed from the body to reduce significantly the penetration resistance. Since none of the Zepel-D vests which were worn were penetrated, it can be concluded these vests were not degraded.

Table 7-3. Federal Bureau of Investigation Body Armor Test Data Sheet — Treated Zepel-D Pretest

Rounds 1 through 10 used a Smith and Wesson Model 45 with a 4-in. barrel and .22-caliber, 40-gr Remington Long Rifle LRN ammunition.

Rounds 11 through 13 used a Smith and Wesson Model 19 with a 4-in. barrel and .38-caliber, 158-gr Remington Long Rifle LRN ammunition.

Round No.	Test Results				
	Penetration	No Penetration	Trauma Depth (cm)	Trauma Width (cm)	Chronograph (fps)
1		X	2.0	3.5	989.1
2		X	1.5	3.0	984.2
3		X	1.3	3.0	970.8
4		X	2.0	5.0	980.3
5		X	1.7	4.5	973.7
6		X	1.7	3.0	961.5
7		X	2.6	4.5	980.3
8		X	2.5	3.5	999.9
9		X	2.4	4.5	963.7
10		X	2.3	4.0	961.5
11		X	2.7	5.0	692.0
12		X	3.0	5.5	724.6
13		X	3.4	5.5	731.1

Description of Body Armor: Treated Zepel-D Pretest, K29 1000/31 × 31, 2 lb, 1-3/4 oz, large regular

Table 7-4. Federal Bureau of Investigation Body Armor Test Data Sheet -- Untreated Pretest

Rounds 1 through 13 used a Smith and Wesson Model 45 with a 4-in. barrel and .22-caliber, 40-gr Remington Long Rifle LRN ammunition.

Round No.	Test Results				
	Penetration	No Penetration	Trauma Depth (cm)	Trauma Width (cm)	Chronograph (fps)
1		X	2.5	5.5	961.5
2		X	2.3	4.7	961.5
3		X	2.4	4.3	980.3
4		X	2.5	5.2	980.3
5		X	2.7	5.0	943.3
6		X	2.5	4.5	968.6
7		X	2.4	4.0	925.9
8		X	2.3	4.0	961.5
9		X	2.4	6.5	999.9
10		X	3.1	4.0	1211.4
11	X		-	-	961.5[a]
12	X		-	-	936.0
13	X		-	-	969.9

Description of Body Armor: Untreated Pretest, K29 1000/31 × 31, 2 lb, 1-3/4 oz, large regular

[a] Vest was immersed in cold water for 1 hr, drip drained for 1/2 hr. Weight before wetting -- 2 lb, 2-1/4 oz; weight after -- 3 lb, 9 oz. Weight after drip drain -- 2 lb, 14-3/4 oz. Six shots with .38-caliber; no penetration.

Table 7-5. Federal Bureau of Investigation Body Armor Test Data Sheet — Subject 1 Untreated

Rounds 1 through 10 used a Smith and Wesson Model 45 with a 4-in. barrel and .22-caliber, 40-gr Remington Long Rifle LRN ammunition.

Round No.	Test Results				
	Penetration	No Penetration	Trauma Depth (cm)	Trauma Width (cm)	Chronograph (fps)
1		X	-	-	1155.1
2	X		-	-	1183.2
3	X		-	-	1141.6
4	X		-	-	1180.3
5	X		-	-	1179.4
6	X		-	-	1200
7	X		-	-	1162.7
8	X		-	-	1190
9	X		-	-	1200
10	X		-	-	1205

Description of Body Armor: Subject 1 Untreated, K29 1000/31 × 31

Table 7-6. Federal Bureau of Investigation Body Armor Test Data Sheet — Subject 2 Untreated

Rounds 1 through 10 used a Smith and Wesson Model 45 with a 4-in. barrel and .22-caliber, 40-gr Remington Long Rifle LRN ammunition.

Round No.	Test Results				
	Penetration	No Penetration	Trauma Depth (cm)	Trauma Width (cm)	Chronograph (fps)
1		X			971
2		X			955
3		X			929
4		X			966
5		X			948
6		X			943
7		X			992
8		X			962
9		X			964
10		X			961

Description of Body Armor: Subject 2 Untreated, K29 1000/31 × 31

Table 7-7. Federal Bureau of Investigation Body Armor Test Data Sheet — Subject 3 Zepel-D Treated

Rounds 1 through 10 used a Smith and Wesson Model 45 with a 4-in. barrel and .22-caliber, 40-gr Remington Long Rifle LRN ammunition.

Round No.	Test Results				
	Penetration	No Penetration	Trauma Depth (cm)	Trauma Width (cm)	Chronograph (fps)
1		X	2.0	4.0	980
2		X	1.9	4.0	970
3		X	2.4	4.5	962
4		X	1.9	3.5	972
5		X	2.4	5.0	964
6		X	2.2	4.5	964
7		X	1.8	5.0	969
8		X	2.3	3.5	962
9		X	2.9	5.4	982
10		X	2.9	6.0	962

Description of Body Armor: Subject 3 Zepel-D Treated, K29 1000/31 × 31

CHAPTER VIII. TECHNOLOGY TRANSFER

The final phase of the Body Armor Program consisted of activities related to technology transfer. A major goal of the program was to disseminate the results of the design, development, and field evaluation among industry and the law enforcement community. As noted in the Introduction, the transfer of this technology to industry was initiated during the development phase, beginning in 1974 when the Institute released to the armor industry its findings on the superior mechanical and ballistic properties of Kevlar fabric. Since that time, the garment industry has switched almost exclusively to the use of Kevlar as the ballistic material in the manufacture of soft body armor.

The technology transfer to the law enforcement community utilized two methods. The first was the development of the "Model Procurement Document" as a guideline for the use and procurement of soft body armor. The second method consisted of a series of briefings to the major law enforcement agencies in the United States, at which the procurement guidelines were distributed, discussed, and clarified. In addition, an overview of the program was provided which stressed the findings of the analyses and tests that were the bases of the recommendations.

A. Procurement Guidelines

The procurement guidelines were based upon the results of the development and field test program and were coordinated with the IACP, as well as with the many organizations that participated in the program. These were published in the "Model Procurement Document," which is reproduced as Appendix D of Volume III of this report. As the Preface to Appendix D states, recommendations are given on the garment design in order to defeat a specified threat and to achieve maximum comfort and wearability. The recommendations are less restrictive than normal military specifications because of the limited resources of most police departments. Limited acceptance testing is proposed, with reliance placed on the vendor for certification of performance and design. The less restrictive requirements also allow flexibility and innovative approaches by industry, which continues to make design improvements.

The Preface to Appendix D also stresses that the guidelines only address the common handgun level of protection, which is normally characterized by the .38-caliber special with normal ammunition. This choice stems from the results of the program in which the greatest amount of blunt trauma data exist, yielding the highest confidence that adequate protection can be provided against these threats. Additional research on blunt trauma caused by higher energy impacts is needed to properly specify suitable ballistic performance for these threats. Similarly, the field test data on frequency of wear indicate that optimum protection is provided by garments with 8- to 12-ply ballistic material because of the tendency of officers to not wear the heavier garments.

The most important specification is that of ballistic performance. The guidelines recommend that the vendor certify ballistic performance by means of tests carried out in an approved laboratory using two threats as follows:

- Penetration - .22 caliber, 1000 to 1080 fps, 40-gr lead round nose
- Blunt Trauma - .38 caliber, 800 to 900 fps, 158-gr lead round nose

The vendor must certify that there is no penetration in five fair hits of each sample tested and that blunt trauma is controlled to the extent that the average clay cavity depth is not greater than 44 mm (no single cavity deeper than 48 mm) in five fair hits of each sample tested. The samples consist of 12 by 12 in., 8-ply panels selected at random from fabric woven from a single merge of yarn. The number is determined statistically to provide a quality assurance, or failure rate, of less than 0.25 percent (e.g., 5 panels for lots of up to 90, 8 panels for lots of from 91 to 150). Details of the test conditions are given in Appendix D, Volume III.

The guidelines on acceptance emphasize that each garment should be visually inspected for defects in construction or workmanship. In particular, since proper fit is important for wear and comfort, the size of each garment should be checked. The use of destructive ballistic testing as part of the acceptance procedure is considered optional because of the recommended test laboratory certification. If ballistic acceptance tests are conducted, it is important that the proper instrumentation and test procedures are used in order to obtain reproducible results. In particular, the chronograph used to measure bullet velocity must have sufficient precision and accuracy, and be properly calibrated, in order to discriminate the relatively narrow region (< 10 percent) that is the border between no penetration and complete penetration. Similarly, the clay must be handled properly to obtain uniform cavities. For these reasons, an acceptance policy that sends buyer representatives to witness laboratory certification tests conducted by the vendor has much to recommend it.

The remaining guidelines define the salient aspects of quality assurance, construction of the garment, and ballistic material. In general, the guidelines on construction follow that of the recommended design discussed in detail under Chapter VII. A. It is particularly important to maintain flexibility by not sewing the plies together.

B. Briefings

The briefings on the results of the Body Armor Program were presented to the major law enforcement agencies of the United States during July and August of 1977. In an attempt to maximize coverage, invitations were sent to all police departments with more than 1000 sworn officers. The letters of invitation urged that smaller, neighboring jurisdictions be invited to attend. In addition, briefings were presented to each of the test cities that participated in the field test and evaluation. State and county agencies, as well as city departments were included. Out of the 57 agencies invited, 45 accepted and 12 declined. The most common reasons given for not accepting were a lack of money for purchase or the fact that the department already had an ongoing armor program. A table listing the host agencies, the jurisdictions in attendance, and total attendance is given in Appendix E, Volume III. Including the smaller departments invited by the host agencies, 183 jurisdictions were represented.

Three types of briefings were prepared. The first was an executive summary to be presented to administrators, chiefs, and their staff. The second was a detailed briefing on the program background, test results, and procurement guidelines, to be presented to staff members concerned with the use or procurement of armor. The third was presented to the test cities and emphasized test results and procurement guidelines while minimizing background and development aspects already known by these departments. Data packages were prepared and distributed to attendees which covered all of the material presented. In addition, models of the recommended garment design were demonstrated.

On the basis of the comments received and the questions asked, these briefings proved to be an effective means for disseminating the technology developed by the Body Armor Program. In general, the interest appeared to center on the nature of the wounds (e.g., skin contusions) received by test participants from assaults while wearing armor, the garments integrity after wash and wear, and the compromise that must be made between comfort and level of protection. In regard to the latter, it appeared that the majority of those who wear garments are willing to accept increased weight and heat containment in order to achieve protection against a higher energy threat. A prime motivation for this attitude is the officer's concern of being assaulted with his own weapon since most police guns represent a higher threat level. For the same reason, the LEAA design concept of ballistic inserts was endorsed since it allows flexibility in selecting the degree of protection in accord with the perceived threat.

In summary, the response and interest in the program was excellent. It was also evident that most agencies believe research should continue on the potential for blunt trauma from higher energy weapons.

CHAPTER IX. CONCLUSIONS

As developed in the Body Armor Field Evaluation Test and Evaluation Plan of June 1975, the field test was structured around a set of four goals and related test objectives. Conclusions relative to the stated test objectives are reported in this section and can be summarized as follows.

A. Objective: Determine Attitude of Individual Officers to Protective Garments

The attitudes of individual officers were defined in terms of three items: the officer's conception of an adequate level of protection, his attitudes when interacting with the public, and his concept of his peer group feelings toward the garment.

The majority of the officers felt that an adequate level of protection could be obtained from a garment which would protect the officer from a projectile of an energy equivalent to a .357 magnum.

When interacting with the public, there was no change among the test participants in their feelings of relaxation, public hostility, security, fatalism, or dogmatism. The data did indicate that among the officers who wore protective garments there may have been a slight decrease in their feelings of effectiveness, safety consciousness, and self-confidence. The officers consistently felt that their peers were neutral (neither complimentary or critical) in their feelings toward someone wearing a protective garment.

B. Objective: Determine Acceptability of Protective Garments to Individual Officers

Garment acceptability apparently was divided among three general groups. The first group comprised those who tried the garments, accepted them completely, and wore them all the time. The second group were those who tried the garments and rejected them completely. The third and largest group were those who tried the garments, found them acceptable, but only wore them when their assessment of either comfort, assignment, or some other factor favored garment wear.

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The protective vests were worn between 30 and 50 percent of the time. The garments having the most plies were worn a lower percentage of the time than the more lightweight garments. The garments were worn an average of 55 percent of the time in the cold months and an average of 33 percent of the time in the warm months. This correlates well with the major reason that the garments were not worn, i.e., because they were too hot.

The discomfort due to heat was such that, on the average, the officers could not wear their garments for a full shift. The integrated uniform jackets seem to be appropriate for wear only during the winter months and during that period showed a high level of use, being worn on an average of 62 percent of the time.

Protection level may have contributed to the acceptability or unacceptability of the garments. There were two known instances where officers performed knife thrust tests against the garments which resulted in penetrations. Both officers rejected the garments as unacceptable. There were two actual street knife assaults on officers wearing garments in which there resulted no damage and no penetration. Adequate and controlled testing is important in demonstrating garments for acceptability to departments and individual officers.

For the most part, appearance seemed to have little or no effect on acceptability. In one department, the tailored shirts issued by the department would not allow the officers to wear the heavier garments.

C. <u>Objective: Determine Acceptability of Protective Garments by Department</u>

The participating police departments strongly supported the test program from the beginning. Only 1 of the 16 departments which were approached declined to participate, and that department did so on the basis that they had already decided to purchase garments for their whole department.

Subsequent to the start of the program, a significant number of municipal, county, state, and federal law enforcement agencies have purchased garments for their personnel.

At the end of the field test, the participating departments were offered the option of retaining the garments. All 15 departments accepted.

D. Objective: Obtain Data on Psychological Change of Officers While Wearing Protective Garments

There were no indications of any significant psychological change of the test group while wearing the protective garments. Concern was expressed by a number of law enforcement personnel that the wearing of the garments would induce a feeling of invincibility in the officers. The so called "superman" syndrome did not manifest itself either in the data or in the incidents which were investigated.

The officers' responses to questions of whether the wearing of protective garments would make him more or less aggressive indicated a neutral or no change response. There was some indication in the data that the officers wearing garments actually suffered proportionately fewer handgun assaults than the officers who were not issued garments.

A series of short-form dogmatism questions showed no change in dogmatic attitude before or after the test period, in either the test group wearing the test garments or in the control group that was not issued garments.

E. Objective: Obtain Data on Physiological Effect on Officers While Wearing Protective Garments

There were no indications that wearing the garments significantly degraded the ability of the officer to perform his assigned duties. Initially, there were reports of some irritation and rashes as a result of wear. In all but a few isolated cases, these disappeared with garment use and additional instruction. According to the data, about 25 percent of the responding officers indicated some increase in fatigue while on duty from wearing the garments.

In a few cases, participating officers experienced symptoms of hyperventilation while wearing the garments. This is the type of thing which is difficult to attribute to the situation and/or the garment. The possibility that wearing the garment could increase the probability of occurrence or aggravate an incipient situation should be part of the instructions to those officers intending to wear protective garments.

F. Objective: Obtain Data on Benefit of Protective Garments to Individuals and Departments

The benefit to the individual is, of course, that it may possibly save his life. An evaluation of all incidents involving body armor during 1976 upon which data could be obtained indicated that approximately 18 potential fatalities were avoided. Of these, 2 were contributed by officers wearing garments provided by the program, while the remaining 16 were associated with commercial armors.

Based on data obtained from a major police department on only the monetary losses associated with an officer fatally wounded, estimates were made of the cost benefit of the departments purchasing armor. For a city which has approximately 2000 sworn officers, it was determined that if one fatality is prevented in five years, then the city would break even. This assumes that the average cost of an undergarment is approximately 100 dollars. This does not take into account the cost savings associated with the injuries which would probably be avoided. Nor does it take into account the other factors such as impact on the survivors, impact on officer moral, or police-community relations.

One of the concerns early in the program was the possible impact on the community of the knowledge that the police were wearing armor. Some felt that the use of armor would create an additional barrier between the police and the community. It is interesting to note that in both Kansas City, Missouri, and Jacksonville, Florida, the local citizens and business community initiated a successful public subscription to purchase lightweight body armor for their police departments.

G. Objectives: Obtain Data on Inconspicuous Appearance of Garments

The majority of the data indicated that the garments were inconspicuous to the casual observer. As the garments become heavier and thicker, there is a tendency to add an appearance of bulk to the officers wearing the garments. There did not appear to be a significant difference in detectability between the Style I and Style II garments.

H. Objective: Obtain Data on Comfort of Garments

As mentioned previously, the factor which was most uncomfortable about the garments was their containment of heat. Other factors also contributed to the comfort or discomfort and general wearability of the garments.

Garment fit is one of the most important factors, particularly, with the lightweight armor garments. In the program, half the garments provided were regular length and half were long. One of the major complaints with the 7-ply Style I and Style II garments was that they tended to ride up. It is believed this is due to trying to fit long garments to officers who should have had regular sizes. Fitting the officer with the proper length garment is extremely important and should be a major consideration in any procurement action.

The Style I and Style II garments had no elastic in the adjustment straps. Sufficient elastic should be provided to allow the garments to give with normal changes in body dimensions. Also, the officers should be instructed to adjust the garments without taking all the stretch out of the elastic. The lack of elastic in the adjustment straps and lack of tails on the Style II garment were the major causes for their riding up.

The officers, in general, felt that the garments were easy to put on and off, fit well, allowed free movement and easy access to their weapons, and also allowed normal maneuverability. They did not feel that garment comfort remained the same throughout a shift.

Proper design for fit, load distribution, and clearance in the arm and neck area are the major considerations to assure maximum garment comfort.

I. Objective: Obtain Data on Wear Degradation of Garments

The ballistic material had a tendency to pull out from the bias binding tape which held the garments together. This could probably be eliminated or at least minimized by a design change (better shaping at the corners or wider tape) and by closer control of the sewing operation in the high-stress areas.

Buckles should not be used on any adjustment straps. On the Style I garments, the buckles cut through the elastic tape and caused failures. Also, the buckles could possible cause secondary missiles either by breaking up themselves or by impacting a projectile.

Bunching of the ballistic fabric was not a problem. Also, the Velcro fasteners held up well for the duration of the test.

A total of 60 LEAA garments were recalled during the field test to determine if there was any change in penetration resistance, clay cavity depth, or fabric tensile strength in either warp or fill direction. The selected garments were those that were worn the most and laundered the most frequently. The ballistic resistance of these garments was not degraded, nor was there any significant change in cavity depth or tensile strength.

J. Objective: Obtain Data on Predicted Protective Features of Garments

On the basis of the incidents which occurred involving the 7-ply garments, all operational requirements were met with the exception of the desired 80 percent wear. The wear history was somewhat lower than expected and will require a breakthrough in heat rejection to gain significant improvement. The recommended design changes should improve wear probability by increasing slightly the apparent comfort of the garments.

In the incidents which occurred involving the 7-ply program garments, there was no indication of any internal damage due to blunt trauma. The injuries which occurred were on the outer skin and comprised an abrasion-type contusion with some weeping of bloody fluid and a later developing bruise with discoloration. The contusion area was nominally 0.75 to 1 in. in diameter. The swelling and discoloration developed to 3 to 4 in. in diameter. On the basis of the limited data available, the U.S. Army predictions from the animal tests were too conservative.

K. Objective: Evaluate Cost and Manufacturability of Quality Garments

In fabricating both the undergarments and the integrated garments, once the design was established, there were no major problems in manufacturability. Good tailoring practices combined with commercial machines and qualified operators indicated no major difficulties in quantity production.

The best estimate average cost for the LEAA-designed garments was approximately $60. These were the first quantity (4000 garments) production, and improved fabrication techniques may have resulted in lower costs had these techniques been available at that time. Inflation in both labor and material since 1975 have probably offset these potential savings.

The new design garment which is recommended, including the 8-ply insert and carrier configuration, has been estimated at $80 to $90 in lots of 10 units and $65 to $75 in lots of around 1000. Inflation will cause these estimates to increase after the date of this report.

CHAPTER X. RECOMMENDATIONS

The Body Armor Program has accomplished two difficult tasks. First, it met all goals and objectives. Second, it achieved technology transfer to both industry and the user, which is rare indeed. One result of this success is a rather clear and specific set of recommendations that falls naturally into two categories; viz, additional research and guidance on the procurement and use of soft armor. Both groups of recommendations are based on the findings of the program.

A. Research and Development

The results of the work just completed point the way to additional work that is needed. Based on the discussions held with the nation's major law enforcement agencies during the body armor briefings, the users recognize this need and fully support what is recommended. Industry representatives also support it. The point should be made that this work does not involve a question of feasibility. The results to date clearly indicate that further improvements in soft body armor can and should be made.

- Almost all interested agencies asked for information on garment lifetime. The test program was limited to a one year period, during which time the garments remained relatively new. Since all of the test cities except one elected to retain the garments, an opportunity exists to obtain a better fix on wear characteristics and the lifetime of armor at relatively low cost. The program should be to continue recall and test of the garments which have been left with the participating cities. Emphasis should be placed on the penetration resistance to the .22 caliber threat.
- Research should be undertaken to define the protection level required to defeat the higher energy threat represented by .357 magnum and 9-mm handgun projectiles. The .41 and .44 magnum

should not be considered as design threats. The .357 magnum should be the 158-gr, semijacketed soft nose bullet at approximately 1400 fps. The 9-mm should be the 124-gr, full metal jacketed bullet at approximately 1200 fps. This effort should evaluate the ability of new weaves of various deniers of Kevlar, both with and without coatings, as well as existing commercial fabrics, to defeat penetration and to control blunt trauma from these threats. Additional medical research should be undertaken to determine the potential lethality of internal injuries sustained from nonpenetrating impacts of these projectiles.

- An evaluation program should be conducted on the characteristics of commercially available coated or impregnated Kevlar. Coatings are frequently applied to Kevlar fabric to reduce deformation caused by impact, particularly that from high energy weapons. The durability of these coatings, and their effect on wearability, should be tested. Emphasis should be placed on determining the useful life of coatings after calibrated exposure to various environmental agents (washing, dry cleaning, perspiration, etc.). Methods of garment construction and tailoring for maximum comfort should be explored.

B. Procurement and Use of Soft Body Armor

The following guidelines are the most important considerations to be kept in mind when buying or using soft body armor. They are not directed toward a single type of garment, though it is limited to the undervest. Otherwise, the guidelines are generally applicable.

- The ballistic certification of armor sold to law enforcement agencies should be provided by the vendor or by an independent agency. The certification should be based on tests conducted at a laboratory with proven and traceable standards for the chronograph, and with specified test procedures, particularly in the handling of clay for cavity measurement. The number of samples should follow the schedule of MIL Standard 105 for a quality assurance level of 0.25 percent.

- The acceptance tests of the buyer should include a visual examination of each garment for defects in material or workmanship. Since proper fit is paramount, the size of each garment should be checked. User ballistic acceptance tests are optional. If the vendor certifies the ballistic performance, witnessing these tests is more cost effective in most cases.
- The ballistic material should consist of Kevlar 29 woven from scoured yarn of a single merge. The fabric should be treated with Zepel-D, or equivalent, water repellant to avoid ballistic degradation from perspiration or other sources of water. If alternative water repellants are used, ballistic tests should be conducted to ensure that the fabric maintains its ballistic resistance.
- Since laundering of the test garments appears to cause mechanical damage due to the agitation in the washer and dryer, it is recommended that the basic garment design be changed to a carrier with a removable set of inserts.
- The outer carrier of the garment should incorporate shirt tails front and rear to prevent riding up of the inserts. Relief at the arm holes should be adequate to prevent binding and to improve air circulation. No metal (e.g., buckles) should be used in construction since this is a potential source of shrapnel. Velcro straps, two on each side, with a minimum of 3 in. of good quality elastic is recommended to ensure that additional stretch remains after donning the garment such that it flexes with body movement, particularly breathing. The plies of ballistic inserts should not be stitched together, but only minimally tacked to maintain flexibility.

- Fit is very important to wearability. Instructions should be given to each officer on the proper way to don the garment. The user should exercise care in specifying sizes to be procured to ensure a proper size garment for each officer. The fabricator must exercise care in tailoring to ensure proper fit and comfort.

CHAPTER XI. NOTES

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2. "Weaving Specification for Kevlar-29 Fabric for Lightweight Body Armor," LEDG 7906-1, El Segundo, California, The Aerospace Corporation.

3. "Fabrication Specification for Ballistic Protective Undergarment," LEDG 7906-2, El Segundo, California, The Aerospace Corporation.

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