TECHNICAL REPORT
67-40-CM

RESEARCH DESIGN STUDY OF VARIABLE ARMOR CONCEPTS

by

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IIT Research Institute
Technology Center
Chicago, Illinois

and

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U. S. Army Natick Laboratories

Contract No. DA19-129-AMC-555(N)

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UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic Materials Division
TS-148

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FOREWORD

This is the final report for the "Research Design Study of Variable Armor Concepts." The research and development in the preliminary investigative phase of this program has been directed toward the design of armor with variable levels of protective capability to accommodate varying combat hazards. Considerable progress has been achieved in this program to demonstrate the feasibility of a unique concept in protective armor for the infantryman.

The IIT Research Institute has prepared this report under Contract No. DA19-129-AMC-555(N). Mr. Richard Rodzen, Mr. Frank Scribano and Mr. Marvin Burns are responsible for the generation of this document. The models fabricated for the concepts were tailored in a large part by Mr. Rodzen and Mr. Scribano. These prototypes employed ballistic elements representative of the final armor with respect to weight, rigidity, and thickness of material.

The contract was administered by Mr. Edward Barron, Project Officer, Clothing and Organic Materials Division, U. S. Army Natick Laboratories. Mr. Barron's contributions to the program were invaluable. His guidance and suggestions channeled IITRI's efforts in the development of an entirely new approach to the protection of infantrymen.

Anthropometric data necessary to the contract were supplied by Technical Report EP-150, Anthropometry of Army Aviators by Robert M. White, Physical Anthropologist for the U. S. Army Natick Laboratories. Important supplementary data were derived from the Aircrew Armor Program DA-19-129-AMC-641(N) and Technical Report TS-130, Design and Development of an Articulated Armor Garment.

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ABSTRACT

This program was directed toward investigating the feasibility of "Variable Armor Concepts" which would provide selective and variable levels of protection to the infantryman. Three concepts of variable armor comprising differential protection were originated. Variations of approaches to utilizing rigid and flexible ballistic materials of varying areal densities were represented through the fabrication of eight models.

The models suggest guidelines for improved future families of infantry protective garments. They are not intended to suggest an optimum design but to portray the results of our preliminary investigation. These results enable the investigator to conduct a trade-off study which will form the basis for an optimum approach in a finalized system.

The theme of variability of protective coverage is carried throughout the development of all concepts. Variability of ballistic protection is accomplished through several approaches.

A. Rigid elements of varying areal densities are inserted into pockets of a basic ballistic garment. The basic garment provides protection against low level fragmentation for the posterior and anterior thoracic-abdominal torso and peripheral areas.

B. Rigid or flexible elements of varying areal densities are inserted into a basic carrier resulting in differential protection. Flexible elements for low-level fragmentation protection are provided in the peripheral areas; rigid elements for the anterior and posterior torso are employed to protect the vital organs from small arms fire.

C. A basic flexible garment for maximum coverage and low-level fragmentation protection is combined with overlay rigid elements of varying areal densities and area coverage, in a separate carrier.

The work accomplished thus far indicates the feasibility of providing significantly greater protection for the infantryman than has been achievable previously.

RESEARCH DESIGN STUDY

OF VARIABLE ARMOR CONCEPTS

Introduction

Past efforts to provide infantrymen with protection against small-arms fire have shown limited results because of excessive weight, discomfort and degradation of combat efficiency. With recent technological advances in ballistic materials, it has become possible to produce elements that can defeat both fragments and small-arms projectiles and still be light enough to be worn comfortably by military personnel. The degree of ballistic protection afforded is a direct function of the material employed. Similarly, the total garment weight is directly related to the area coverage and areal density (Figure 1).

Since the modern soldier may be exposed to a broad range of ballistic hazards (fragmentation hazards and small-arms fire, including caliber .30 AP projectiles), a variable armor system is most desirable.

Under Contract DA19-129-AMC-555(N), IITRI has developed several unique and distinct approaches to provide variable ballistic protection for the infantrymen. Three concepts were generated from which eight models were fabricated for evaluation. The theme of "variability" was followed in all approaches. The variable armor systems can be adapted to a particular tactical need by allowing the infantrymen to select the level of protection required for a particular combat situation. Variability of protection is achieved by adding appropriate ballistic elements or modules in the anatomical regions of the vital organs (specifically, the thoracic-abdominal cavity).

The concepts developed are capable of providing maximum protection to the vital body organs with decreasing protection to the peripheral areas or non-vital organs. Both rigid and flexible materials encompassing a broad range of areal densities are employed to accomplish variability.

Three models for Concepts 1 and 2 and two models for Concept 3 were fabricated. The eight models developed have been evaluated on a laboratory basis with respect to area coverage, weight, degree of variability, method of donning and doffing, and other significant design parameters.

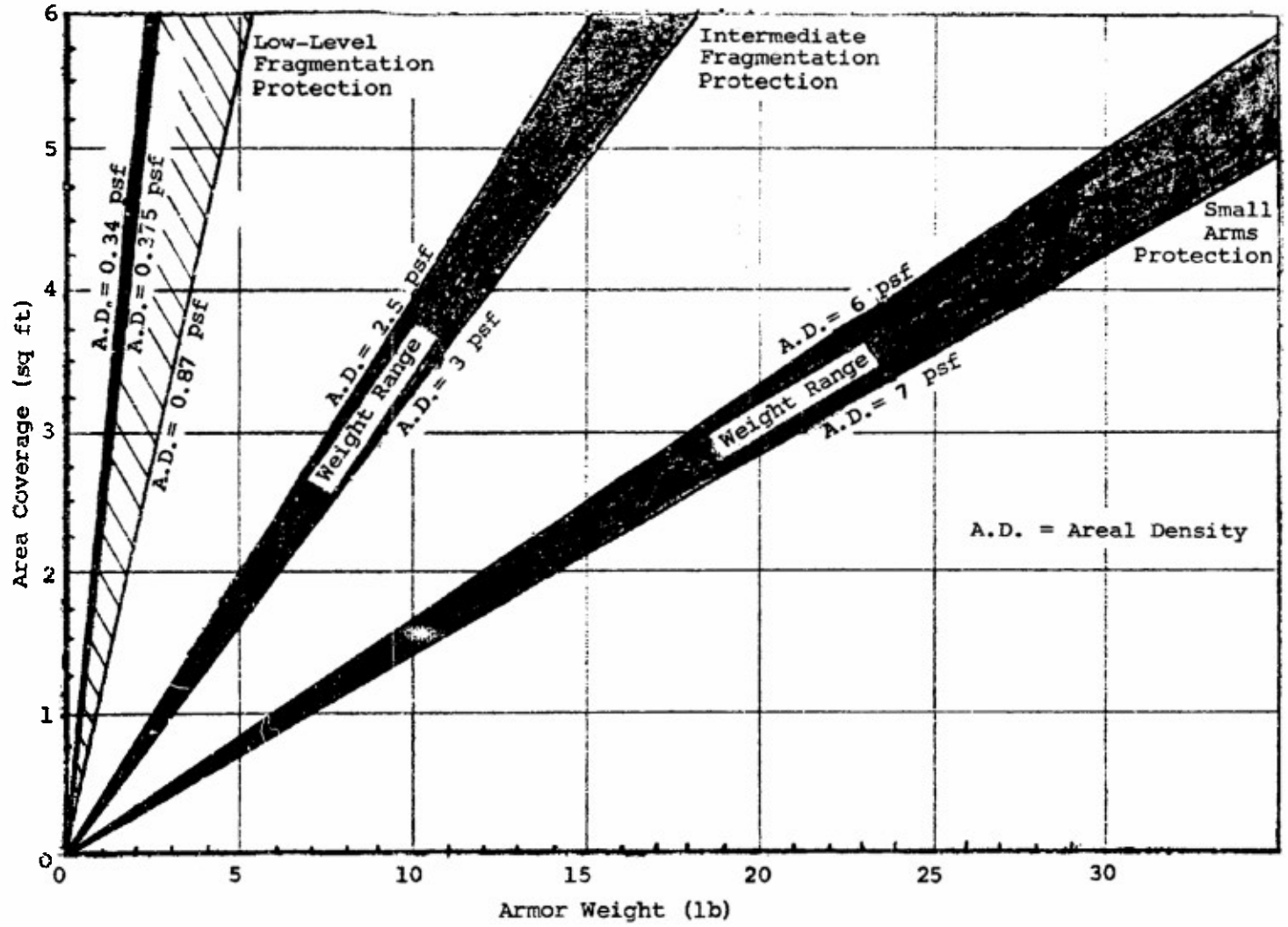

Figure 1. Armor Weight Versus Area Coverage

PART I. SUMMARY OF CONCEPTS AND MODELS FOR VARIABLE ARMOR SYSTEMS

The objective of this program has been the investigation and development of variable armor concepts demonstrated in models using actual ballistic materials, or simulated materials with the same characteristics and weights.

The variable armor systems designed under this program are such that they can be adapted to a particular tactical need, thus allowing troop units to select the level of protection for a particular situation consistent with the performance required of the individual. In addition, the armor can be varied to provide differential protection over parts of the torso so as to concentrate the highest levels over the anatomical regions containing the vital organs.

The concepts and models (Figures 2 through 10) are summarized in Table 1 and described individually in Tables 2 - 9. A summary of the combinations and variations possible between the different concepts is contained in Table 10.

The finished models were donned by a limited sampling of medium-size individuals (height 68-71 inches; weight 154-179 pounds) and gymnasticated through the range of motions described in USANL Technical Report TS-130,[1] which includes various modes of bending, reaching, and firing. These were repeated for each level of protection. The advantages and disadvantages of each concept and model were noted. The results are included in Table 12.

The basic garments were designed to provide at least as much coverage as the standard Army Body Armor fragmentation vest titanium nylon composite. Special attention was given to methods of closure, donning and doffing, and containment of the rigid elements.

The areas and shapes of the rigid elements are consistent with the requirements for protecting the vital organs. Wound Ballistics and Body Armor[2] was used as one source of data to substantiate the element size and location related to vulnerability of vital areas. These elements provide protection to the thoracic and abdominal cavities which include the heart, great blood vessels, lungs, liver, kidneys, spleen, and spinal column.

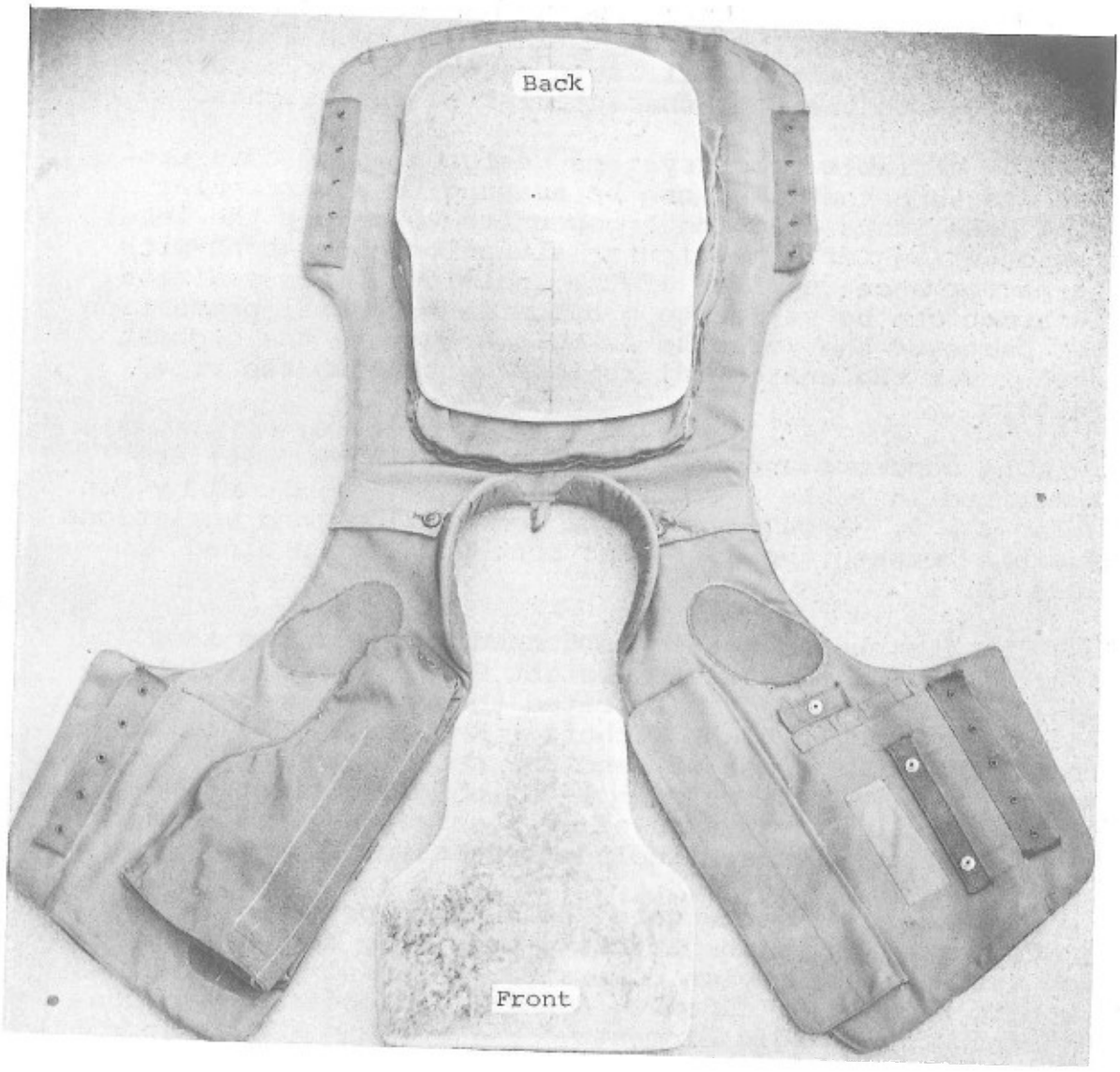

Figure 2. Model A Layout, USANL Fragmentation Vest, Basic Garment and Anatomical Rigid Elements

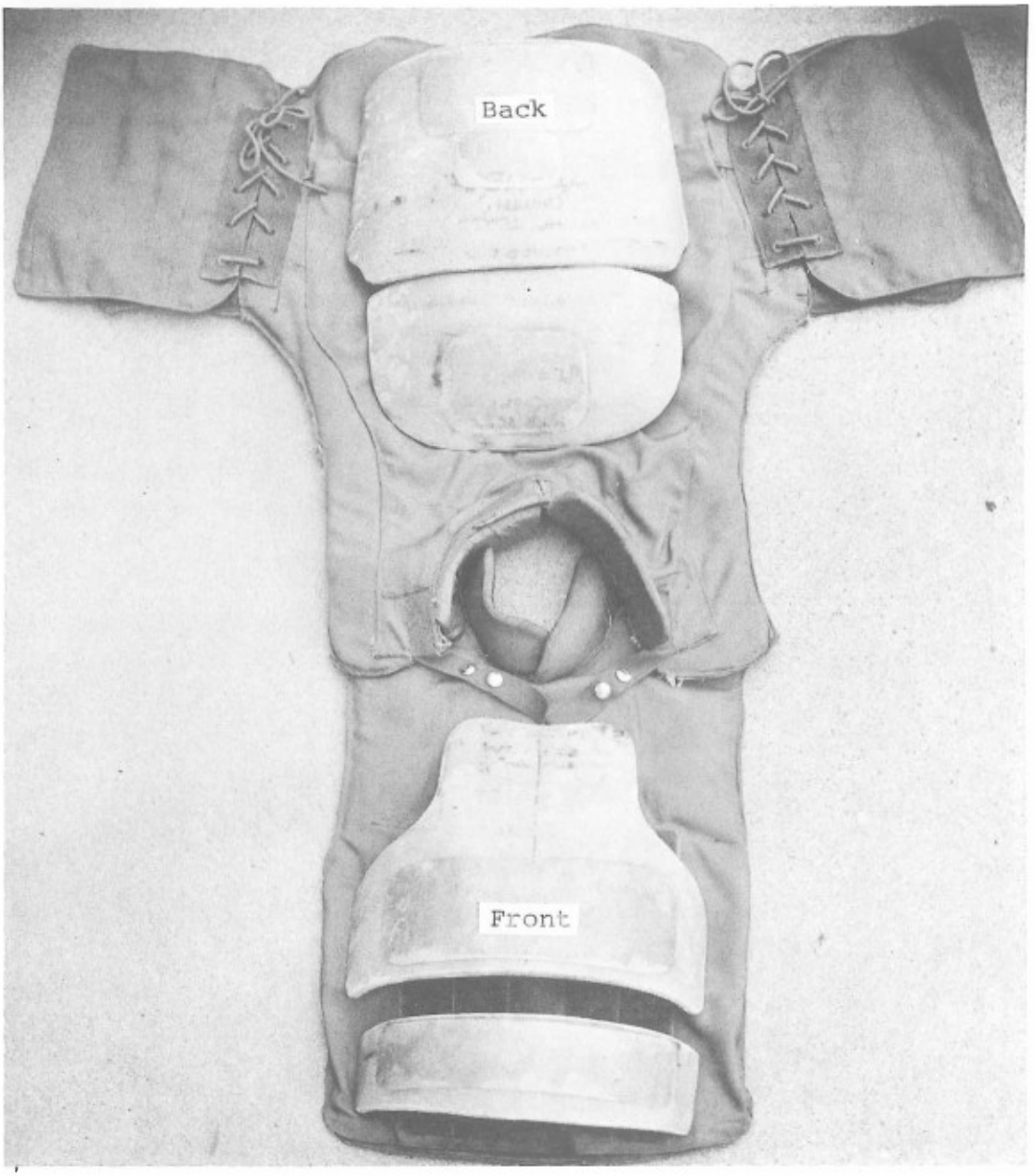

Figure 3. Model B Layout, IITRI Jacket (Modified) Basic Garment and Anatomical Articulated Rigid Elements

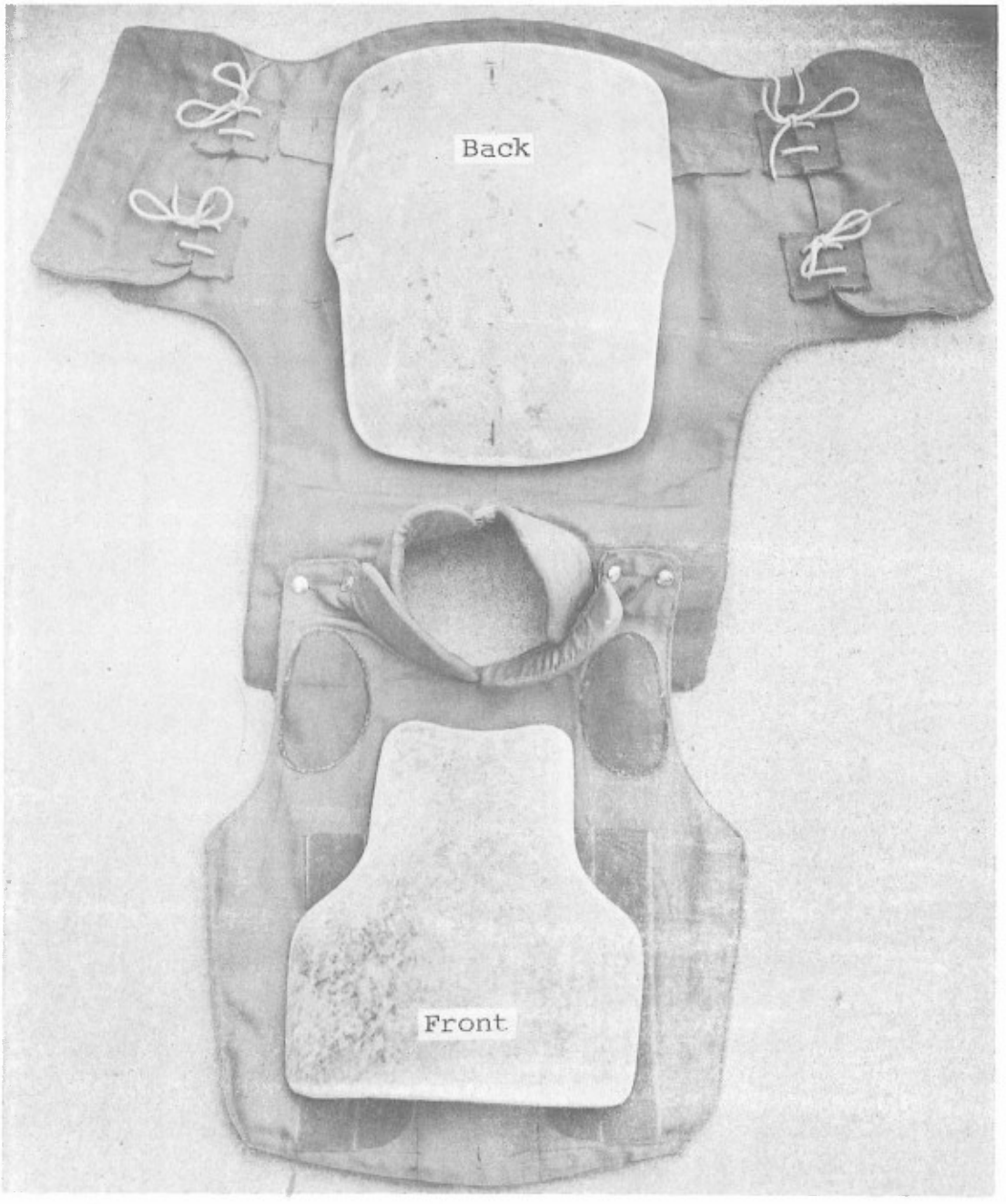

Figure 4. Model C Layout, IITRI Integrated Jacket, Basic Garment and Anatomical Front and Rear Single-Piece Elements

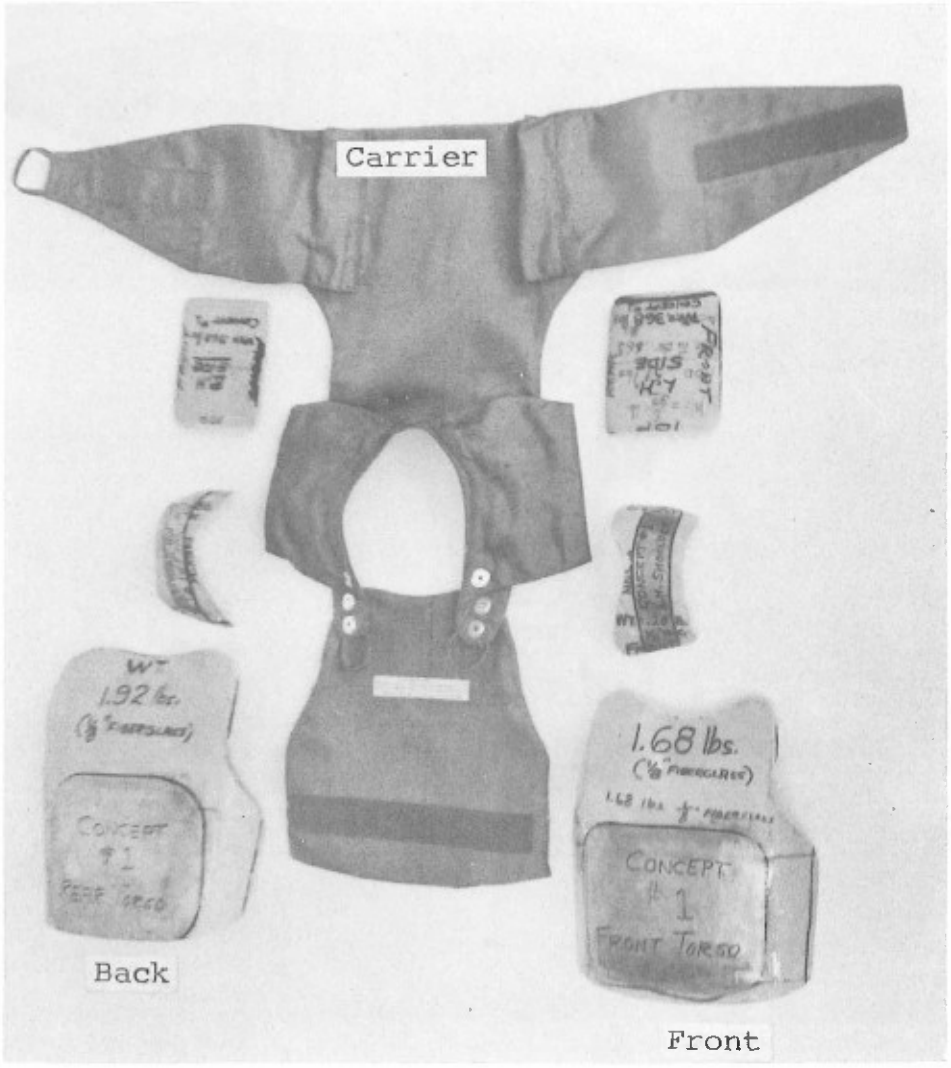

Figure 5. Model D Layout, Basic Carrier with Rigid Elements, Anatomically Contoured

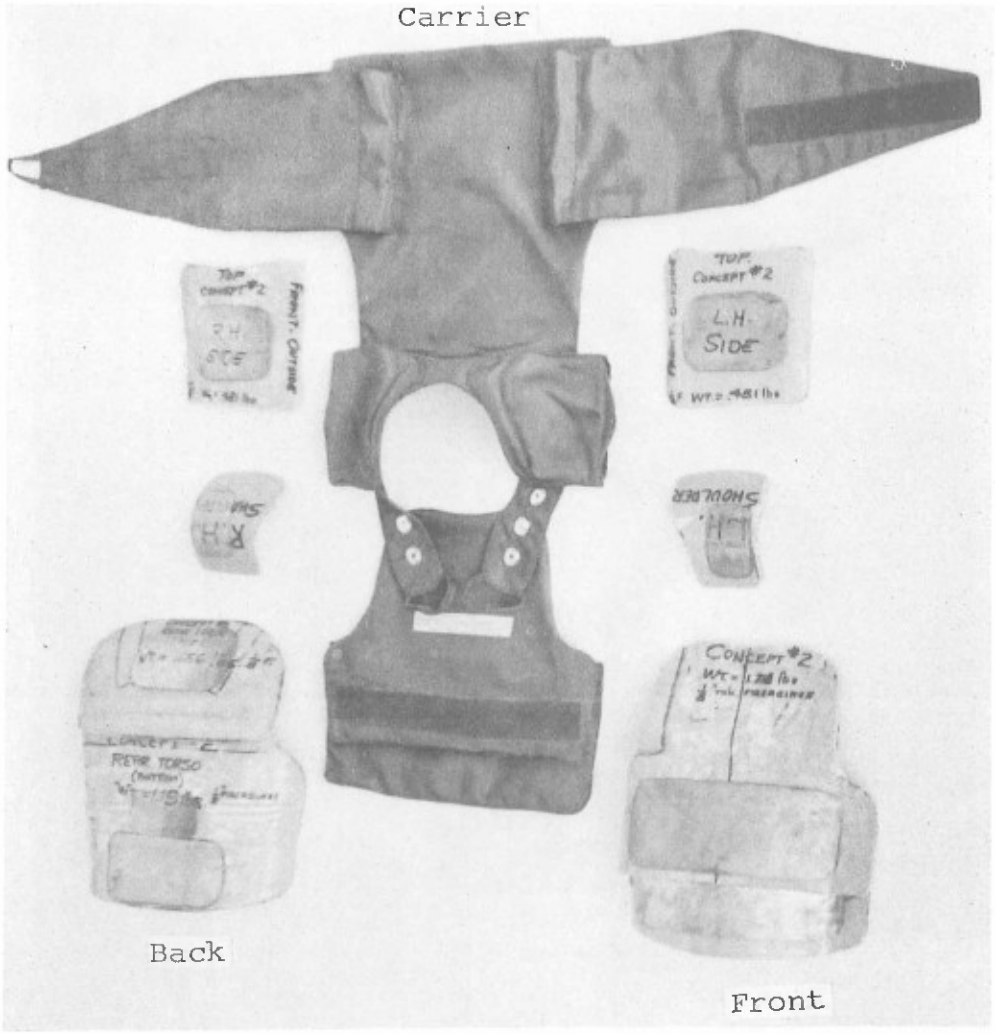

Figure 6. Model E Layout, Basic Carrier with Rigid Articulated Elements (Anatomically Contoured)

Figure 7. Model F, Maximum Protection Overlay Worn over Basic Jacket (Models D or E)

Figure 8. Model H, Basic Carrier with Front and Rear Elements Removed (Anatomically Contoured)

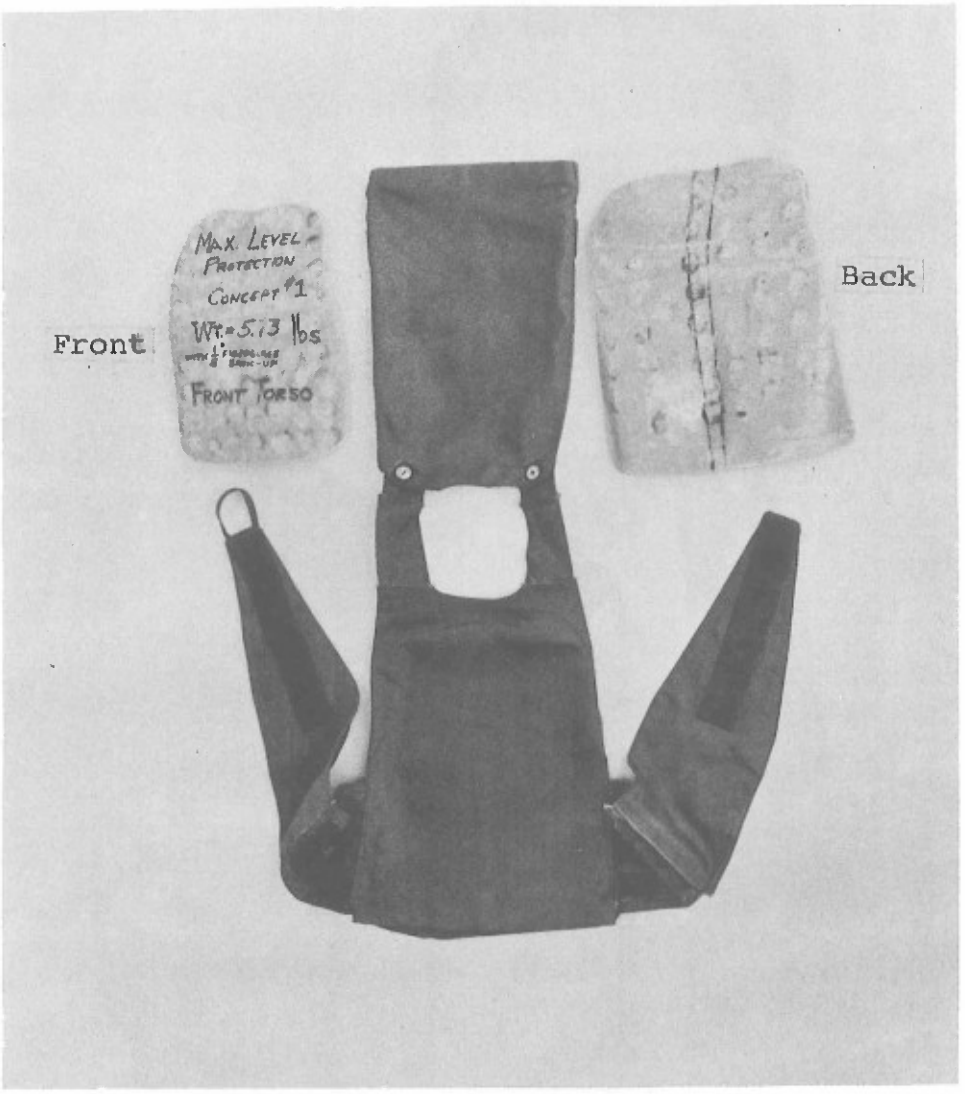

Figure 9. Model G Layout, Basic Carrier with Rigid Overlay Elements (Small-Arms Protection)

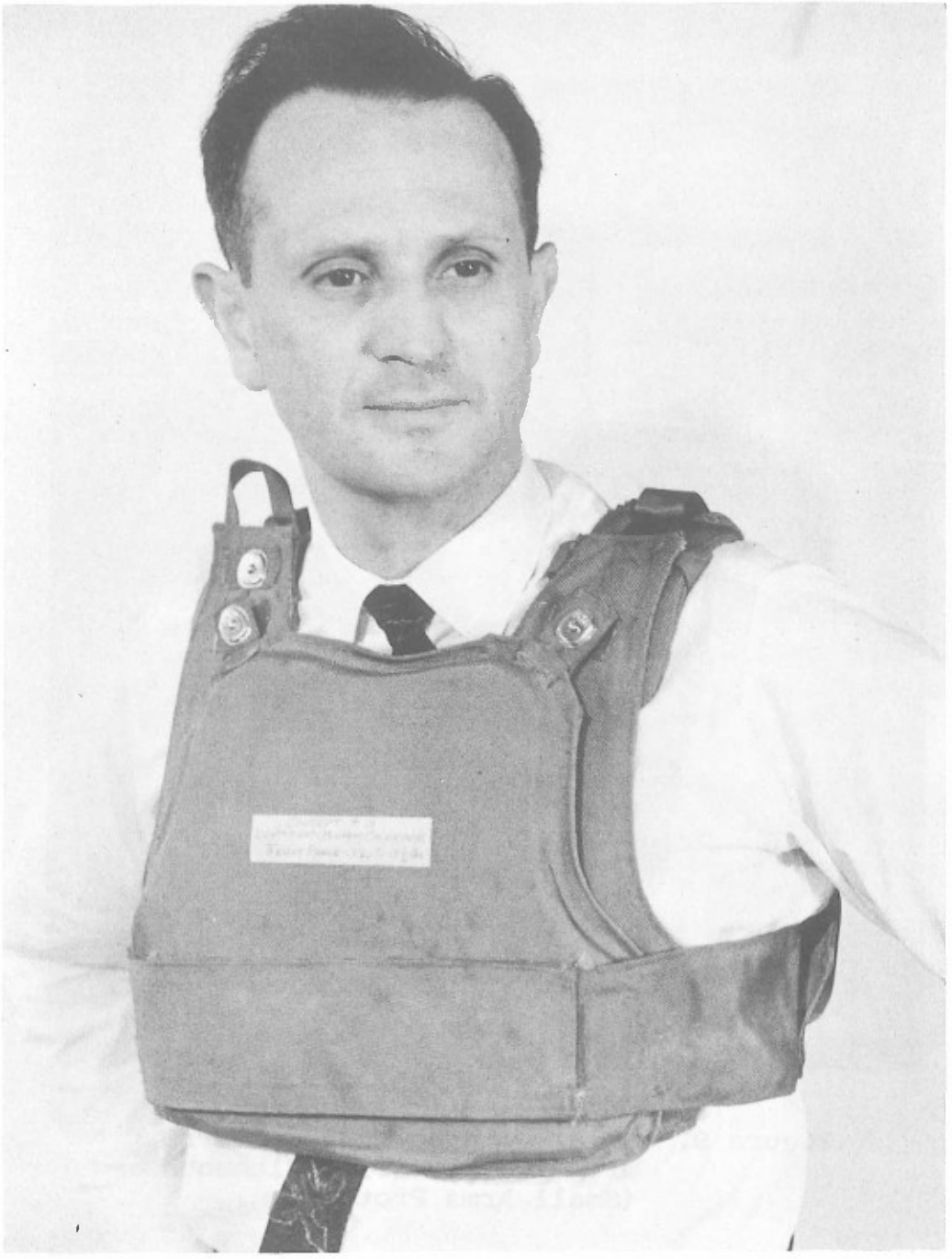

Figure 10. Model H, Rigid Front Element Overlay, Reduced Area Coverage (Small-Arms Protection)

Table 1

CONCEPT AND MODEL DESCRIPTION, AREA COVERAGE AND WEIGHT

Concept	Model	Description	Table No.	Figure No.	Total Area Coverage (sq ft)	Total Weight (lb)
1	A	USANL Fragmentation Vest (Modified) - Front Closure	2	2	5.75	4.8 to 20.2
	B	IITRI Jacket (Modified) Addition to Peripheral Protection	3	3	5.75	2.3 to 20.7
	C	IITRI Integrated Jacket (Basic Garment + Pocketed Elements)	4	4	5.75	4.8 to 20.2
2	D	IITRI Rigid Element Jacket (Nonarticulated Elements)	5	5	3.89	1.8 to 22
	E	IITRI Rigid Element Jacket (Articulated Elements)	6	6	3.77	1.8 to 21.1
	F	Model D with Maximum and Minimum Coverage Overlays Model E with Maximum and Minimum Coverage Overlays	7	7,9	3.89	18.3 to 26.2
3	G	Rigid Element Overlay Worn with Basic Garment (Small Arms)	8	8	5.75	4.8 to 20.6
	H	(Reduced Coverage) Rigid Element Overlay Worn with Basic Garment - Small Arms	9	9 and 10	5.75	4.8 to 16.3

Table 2

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT;
CONCEPT 1A, MODIFIED USANL FELT JACKET,*
NONARTICULATED RIGID ELEMENTS

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	5.75	---	4.8 to 5
Low Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.17	5.75	5.5 to 6.5	10.3 to 11.5
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.17	5.75	13 to 15.2	17.8 to 20.2

*Reference Figure 2.
**Includes area of basic garment.
***Includes weight of basic garment.

Table 3

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT;
CONCEPT 1B, IITRI MODIFIED JACKET,*
ARTICULATED RIGID ELEMENTS

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	3.20	---	2.3 to 2.8
Low-Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.55	5.75	6.4 to 7.7	8.7 to 10.5
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.55	5.75	15.3 to 17.9	17.6 to 20.7

*Reference Figure 3.
**Includes area of basic garment.
***Includes weight of basic garment.

Table 4

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT;
CONCEPT 1C, IITRI INTEGRATED JACKET,*
BASIC CARRIER + NONARTICULATED RIGID ELEMENTS

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	5.75	---	4.8 to 5
Low-Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.17	5.75	5.5 to 6.5	10.3 to 11.5
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.17	5.75	13 to 15.2	17.8 to 20.2

*Reference Figure 4.
**Includes area of basic garment.
***Includes weight of basic garment.

Table 5

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT; CONCEPT 2D, IITRI RIGID ELEMENT JACKET,* NONARTICULATED

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	1.03	---	1.8 to 2
Low-Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.86	3.89	7.2 to 8.5	9 to 10.5
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.86	3.89	17.2 to 20	19 to 22

*Reference Figure 5.

**Includes area of basic garment.

***Includes weight of basic garment.

Table 6

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT; CONCEPT 2E, IITRI RIGID ELEMENT JACKET,* ARTICULATED

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	1.14	---	1.8 to 2
Low-Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.74	3.88	6.8 to 8.2	8.6 to 10.2
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.74	3.88	16.4 to 19.1	18.2 to 21.1

*Reference Figure 6.

**Includes area of basic garment.

***Includes weight of basic garment.

Table 7

COMBINED LEVELS OF PROTECTION, AREA COVERAGE AND WEIGHT; CONCEPT 2F, MODELS D AND E WITH OVERLAY ELEMENTS* MAXIMUM AND REDUCED AREA OVERLAYS

Combined Levels of Protection	Total Area Coverage (sq ft)	Total Weight (lb)	Figure No.
Model D with Low-Level and Increased Fragmentation + Model G Small Arms Protection - Overlay	3.89	22.2 to 26.2	7
Model D with Low-Level and Increased Fragmentation + Model H (Reduced Coverage) Small Arms Protection - Overlay	3.89	18.5 to 21.9	8
Model E with Low-Level and Increased Fragmentation + Model G Small Arms Protection - Overlay	3.77	22.0 to 25.8	7
Model E with Low-Level and Increased Fragmentation + Model H (Reduced Coverage) Small Arms Protection - Overlay	3.77	18.3 to 21.5	8

*Reference Figures 9 and 10.

Table 8

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT;
CONCEPT 3G, RIGID ELEMENT OVERLAY,*
MAXIMUM AREA, SMALL-ARMS PROTECTION

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	5.75	---	4.8 to 5
Low Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	2.22	5.75	5.5 to 6.6	10.3 to 11.6
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	2.22	5.75	13.3 to 15.6	18.1 to 20.6

*Reference Figure 9.
**Includes area of basic garment.
***Includes weight of basic garment.

Table 9

PROTECTIVE LEVELS, AREA COVERAGE AND WEIGHT;
CONCEPT 3H, RIGID ELEMENT OVERLAY,*
REDUCED AREA, SMALL-ARMS PROTECTION

Levels of Protection	Area Coverage (sq ft)		Weight (lb)	
	Rigid Elements	Total**	Rigid Elements	Total***
Low-Level Fragmentation (Areal Density: 0.84 to 0.87 psf)	---	5.75	---	4.8 to 5
Low-Level Fragmentation + Increased Fragmentation (Areal Density: 2½ to 3 psf)	1.61	5.75	4 to 4.8	8.8 to 9.8
Low-Level Fragmentation + Small Arms Protection (Areal Density: 6 to 7 psf)	1.61	5.75	9.6 to 11.3	14.4 to 16.3

*Reference Figure 10.
**Includes area of basic garment.
***Includes weight of basic garment.

Table 10

POSSIBLE ARMOR COMBINATIONS, WEIGHT AND AREA SUMMARY

Combinations	System Weight (lb)		Area Covered by Rigid Elements (sq ft)	Total Area Covered (sq ft)
	min	max		
1	4.88	5.0	---	5.75
2	5.43	7.51	2.17	2.17
3	7.13	8.7	0.90	5.75
4	8.06	8.81	1.27	5.75
5	8.58	10.11	2.17	2.17
6	9.32	10.18	0.74	5.75
7	10.16	11.16	0.88	5.75
8	10.28	11.3	0.90	5.75
9	9.72	11.34	1.62	1.62
10	10.31	12.51	2.17	5.75
11	9.88	12.6	2.17	2.17
12	9.87	12.69	2.17	2.17
13	10.71	13.67	2.17	2.17
14	10.83	13.81	2.17	2.17
15	12.51	13.9	1.27	5.75
16	11.97	15.04	1.78	1.78
17	13.46	15.11	2.17	5.75
18	12.90	15.15	2.01	2.01
19	13.03	15.2	2.17	2.17
20	14.60	16.34	1.62	5.75
21	13.06	16.41	2.17	2.17
22	14.76	17.6	2.17	5.75
23	14.75	17.69	2.17	5.75
24	15.15	18.85	2.17	2.17
25	15.28	18.9	2.17	2.17
26	16.21	19.01	2.17	2.17
27	17.91	20.2	2.17	5.75
28	18.46	22.71	2.17	2.17
29	20.03	23.85	2.17	5.75
30	23.34	27.71	2.17	5.75

Table 10 (Cont.)

Low-Level Fragmentation (5½ - 6 oz/sq ft Carrier Wt)	Increased Fragmentation (2½ - 3 psf)		Small Arms Protection (6 - 7 psf)	
	Front	Back	Front	Back
X				
	X	X		
X	X			
X		X		
		X	X	
X			X*	
X				X*
X			X	
			X*	X*
X	X	X		
	X			X
	X	X	X*	
	X	X		X*
	X	X	X	
X				X
	X		X*	X*
X		X	X	
		X	X*	X*
			X	X
X			X*	X*
	X	X		X
X	X			X
X	X	X	X*	
	X	X	X*	X*
	X		X	X
		X	X	X
X			X	X
	X	X	X	X
X	X	X	X*	X*
X	X	X	X	X

*Reduced Area Coverage

PART II. PARAMETERS RELATED TO DEVELOPMENT OF VARIABLE ARMOR SYSTEMS

A number of basic principles must be applied in the development of variable armor for the infantryman. Design considerations must be evolved accordingly, based on the type of hazard the infantryman may be exposed to, and the areas of the body which require protection.

Personnel wearing armored garments must be able to perform their required tactical duties without degradation of performance. Human factors parameters are, therefore, extremely important. A subject must be able to articulate adequately and fire a weapon effectively. The armor must be comfortable, versatile, relatively light, easily donned and doffed, particularly in the case of wounded personnel, and generally acceptable to the Army personnel who will use it.

A. Wound Ballistics Considerations

1. Hazard Study

The mortality and morbidity of war wounds depend on the wounding agent and the anatomic region involved. It has been known that in all conflicts since the Civil War, shell fragments cause the greatest number of wounds, and small arms projectiles cause the greatest number of deaths. The relative morbidity of small arms fire to shell fragmentation is about one to four. The relative mortality of small arms fire to shell fragmentation is about two to one. In the Korean conflict, mortars and grenades accounted for the majority of those killed in action by small-arms fire. These figures vary somewhat with the type of combat tactics, but they are applicable to continued aggressive land warfare. In combat in which patrolling action predominates, casualty incidence due to small arms tends to rise.

2. Vulnerability

The number of wounds, particularly to the thorax and abdomen, is closely related to the mortality rate, that is, the rate almost doubles if more than one wound occurs. Data show that hits on the thorax and abdomen account for about 30 per cent of the wounds among men wounded in action and 46 per cent among those killed in action. The data further show the incidence of thoracic wounds to be considerably higher than those of the abdomen (Table 11).

Table 11

REGIONAL DISTRIBUTION AND TYPES OF WOUNDS
IN MEN WOUNDED AND KILLED IN ACTION

A. Disabling Wounds				
Region Wounded	% without Armor		% with Armor	
Head	14.4		14.2	
Neck	3.0		2.5	
Thorax	19.0		8.7	
Abdomen	11.0	30.0	10.8	19.5
Upper extremities	25.0		28.3	
Lower extremities	27.0		35.0	
Genitalia	0.6		0.5	
Type or Cause of Wound				
Multiple wounds	53.0		59.0	
Small arms missile	15.3		15.4	
Shell fragment	84.7		84.6	
B. Lethal Wounds				
Region Wounded	% without Armor		% with Armor	
Head	39.0		38.0	
Face	1.0		8.0	
Neck	3.0		8.0	
Thorax	37.2		26.0	
Abdomen	9.2		6.0	
Upper extremities	2.0		4.0	
Lower extremities	7.		8.0	
Buttocks	1.5		2.0	

B. Anthropometric and Sizing Considerations

The prototype jacket and models were designed to fit the median man as described by anthropometric data from Army Reports No. 180[3] and EP-150,[4] and the USAF Report AMRC-TDR-63-55.[5] Reference 5 contains supplementary data necessary for the design of the rigid elements.

The over-all dimensions for the basic garments were taken from the experimental lightweight felt fragmentation vest and standard fragmentation vests supplied by USANL. This was done in order that the armor designs utilizing a basic garment might be compared to existing protective garments from the standpoint of size and coverage.

The design of the large one-piece rigid elements for intermediate and maximum levels of protection required the use of complex, three-dimensional shapes. The anthropometric and sizing data for the design of the flexible garments could not be directly applied to these rigid shapes. Principles and techniques developed under the aircrew armor program[6] for the fabrication of anatomical torso elements were used. Of primary concern was the design of the profile and cross-section shapes.

C. Human Factors Considerations

1. Mobility

The body shapes, dimensions and movements to which the protective garment must conform were given appropriate consideration in the systems designs.

The basic garment, consisting of flexible ballistic materials, imposes little restriction on mobility. Articulation is accomplished by the buckling or flexing of these materials.

The configurations of the rigid elements, on the other hand, are such that they do not cover areas of maximum articulation and therefore need not be articulated. Changes in body contour due to articulation are accommodated in the element shapes.

USANL Technical Report TS-130[1] was used as a source of data for the range of body movements and associated changes in body dimensions.

2. Weight

Factors which contributed to reducing the systems weight were the elimination of plate overlap, anatomical contouring, and plate size.

Weight can also be adjusted to the users' requirements by the ability to select materials of varying areal densities, and by the addition or removal of ballistic elements.

Weight ranges for different element and material combinations are given in Table 10.

3. Comfort

Wearer comfort is directly related to the distribution of armor weight on the body. The basic garment, in addition to providing low-level fragmentation protection, also serves as padding for the rigid elements.

The anatomical contour of the rigid elements serves to localize the armor weight at regions of the torso best suited for load bearing, i.e., chest, back, shoulders, while providing adequate clearances over such sensitive areas as the spine, shoulder blades, sternum and clavicles.

The ability to ventilate is another factor affecting comfort. Ventilation can be accomplished in the overhead-donning models by releasing the velcro closure and allowing the front element to hang freely. This feature does not result in a temporary loss of protection as in the vest-donning models which must be opened at the front.

4. Donning and Doffing

The ability to quickly don and doff the protective garment is a feature of the type of closure used. Overhead-donned models with side closures and shoulder breaks and a vest-donned model with front closure have been fabricated.

Overhead-donning best lends itself to the use of large, one-piece front and back elements. There is the disadvantage, however, of having to remove the helmet in donning. The jacket is easily broken at the shoulder for rapid doffing; however, the shoulder break must then be reconnected for donning.

It is not necessary to remove the helmet with the vest-donned model; however, it is clumsy to handle and requires more time to don and doff than the overhead models.

In both of the above concepts, the closures are conveniently located, utilize velcro fasteners which require no threading or unthreading, can be quickly secured or released, and are jam-proof.

5. Access to Wounds

Both the overhead and vest-donned models permit rapid access to wounds. In the vest model, the front closure can be opened and the side laces cut to expose the torso. In the overhead models, the shoulders can be broken and the side closures opened, or elastic side laces cut, whichever is more direct.

D. Materials Parameters

Variability of protection is achieved by using materials of varying areal densities, flexible or rigid, over the anatomical regions containing the vital organs and in peripheral areas. The protection provided and the areal densities considered are divided into three distinct levels:

1. Low-level fragmentation protection, 5-1/2 to 6 oz per sq ft (Flexible material for protection to vital organs and peripheral torso areas)

2. Increased fragmentation protection, 2-1/2 to 3 psf (Rigid material for protection of vital organs)

3. Small arms protection, 6 to 7 psf (Rigid material for protection of vital organs).

PART III. DESIGN CHARACTERISTICS OF VARIABLE ARMOR CONCEPTS AND MODELS

A. Concept 1

Concept 1 (Tables 2, 3 and 4) utilizes a basic flexible garment with pockets in front and back to accept rigid elements. The basic garment is capable of providing low-level fragmentation protection to vital and nonvital areas of the torso at a minimum weight. The protection of vital areas can be selectively upgraded to defend against increased fragmentation hazards or small arms fire by inserting rigid ballistic elements into the pockets which are an integral part of the basic garment. The weight of the upgraded system is solely a function of the areal density of the rigid materials since the areas and configurations of the pockets are fixed.

A feature of this concept is that variability can be achieved within a single garment. This advantage, however, is partially offset by the necessity, in some instances, of having to remove the basic garment in order to vary the levels of protection, thus increasing the user's vulnerability.

Three models, A, B and C, were fabricated to demonstrate the workability of this concept.

Model A

Model A (Table 2; Figures 2, 11, 12 and 13) is a modified version of the USANL felt fragmentation jacket which is vest-type donning with velcro front closure and side adjustment. Pockets to support the rigid elements are sewn to the outer covers. Because of the front closure, the front pocket is only sewn to the right side of the front. With the rigid elements inserted, the front is secured at the left side with snap fasteners. This was later improved by replacing the snaps with a vertical flap which overlaps the pocket and is secured at the centerline with a velcro fastener. With the rigid element removed, the pocket can be folded in on itself and closure accomplished in the normal manner.

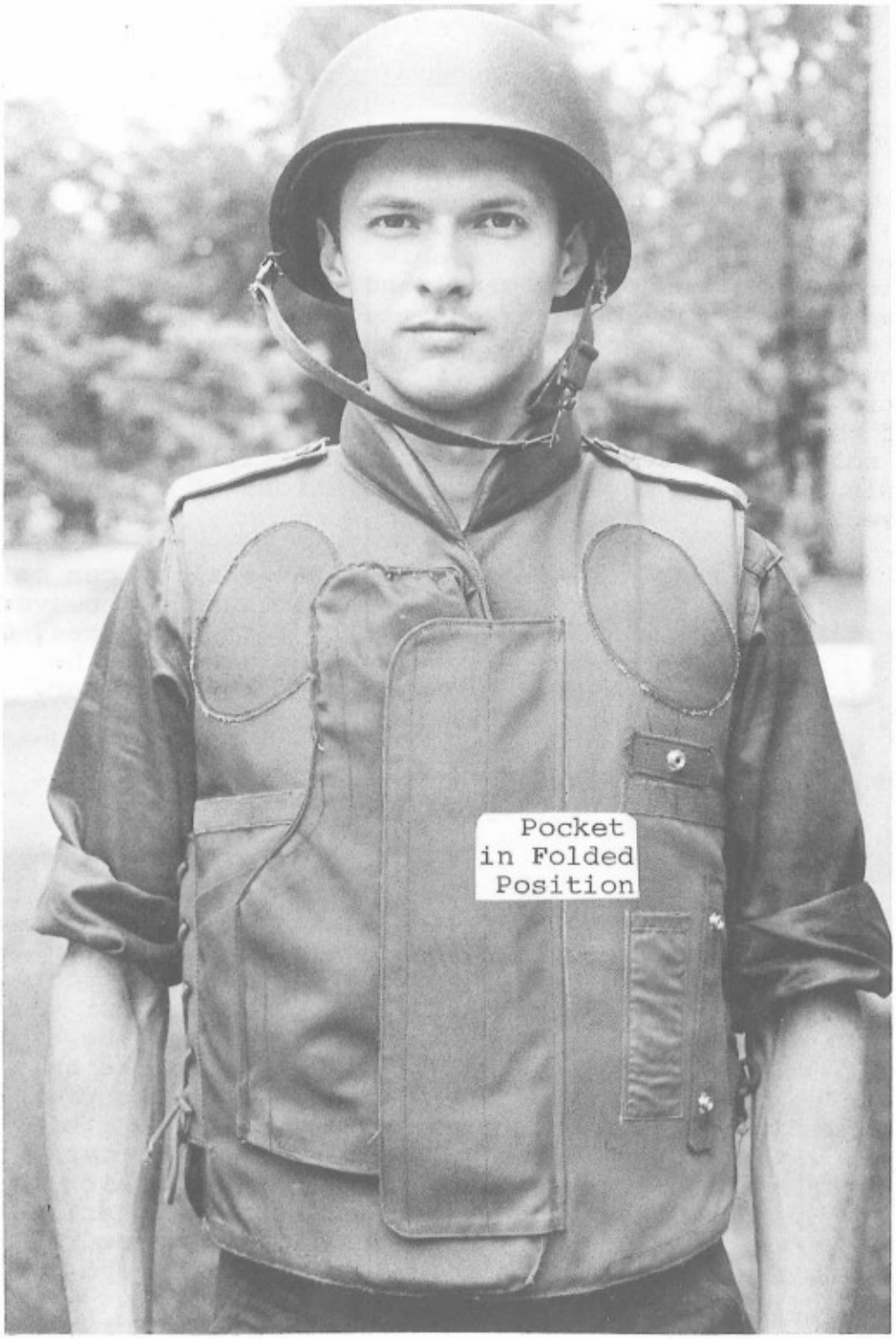

Figure 11. Model A, USANL Fragmentation Vest (Modified), Front Closure, Showing Folding Pocket, without Rigid Element

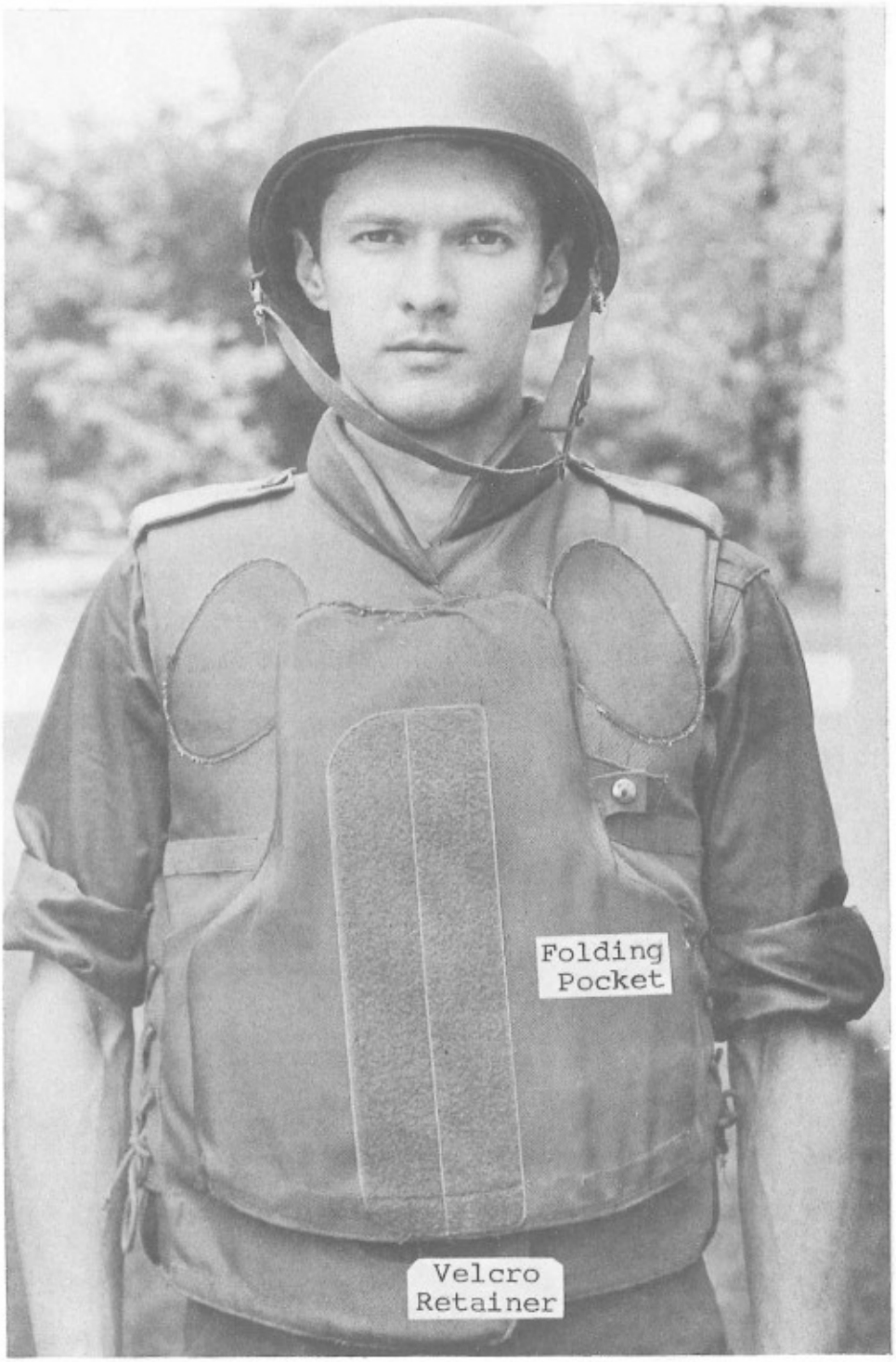

Figure 12. Model A, USANL Fragmentation Vest (Modified), Front Closure Showing Rigid Single-Piece Front Element Retained in Pocket (Anatomically Contoured)

Figure 13. Model A, USANL Fragmentation Vest (Modified), Rigid Single-Piece Rear Element Retained in Pocket (Anatomically Contoured)

The simulated ballistic elements used in this model represent the maximum level of protection; areal density, 6 - 7 psf. They are anatomically contoured and provide front coverage from the iliac crest to the suprasternum and back coverage from the iliac crest to the base of the neck. Sufficient material has been removed in the scye area to permit shouldering of the rifle.

The excessive thickness build-up along the front centerline does not allow the front element to lie comfortably against the body. It is suggested that the felt be skived in this area to reduce thickness or that the cross section of the rigid element be modified.

The vest-donning feature permits the jacket to be donned and doffed without necessitating removal of the helmet, as in the overhead-donning models; however, it does prove to be more unwieldy than overhead donning.

Model B

Model B (Table 3; Figures 3, 14 and 15) consists of an overhead-donning basic garment with front and rear pockets to accept flexible or rigid ballistic elements. Low-level fragmentation protection (felt) is provided for the non-vital peripheral areas as an integral part of the garment. Low-level protection can also be applied to the vital torso areas by inserting flexible ballistic elements into the pockets. A split collar of flexible ballistic material provides neck protection.

Vertical flaps with velcro fasteners at either side of the front centerline are used for closure. Elastic laces at the sides permit expansion in girth to allow for size variations and articulation. Shoulder breaks with directional snap fasteners permit rapid doffing. An elastically closed slit was incorporated in the rear felt element at the base of the neck to permit expansion of the head opening durdonning and to eliminate the need for adjustment at the shoulders.

The simulated rigid elements used in this model represent the intermediate level of protection, 2-1/2 - 3 psf. These elements were taken from Model E for

Figure 14. Model B, IITRI Jacket (Modified), Peripheral Protection Added, Overhead Donning, Rigid Articulated Front Elements

Figure 15. Model B, IITRI Jacket (Modified), Rigid Articulated Rear Elements Retained in Pocket (Anatomically Contoured)

use in this model. Both front and rear elements are articulated to increase comfort in bending. Coverage is provided from the iliac crest to the suprasternum in front and from the iliac crest to the base of the neck in back. Sufficient clearance is provided in the scye area to permit shouldering of the rifle.

Although the elimination of felt in areas covered by the rigid elements results in a slight weight reduction, it is accompanied by a decrease in comfort resulting from the lack of padding.

Model C

Model C (Table 4; Figures 4, 16 through 19) consists of an overhead-donning basic garment with pockets front and rear to accommodate rigid ballistic elements. Low-level fragmentation protection is provided for vital and nonvital areas of the torso when worn without the rigid elements. Neck protection is provided by a split collar of flexible ballistic material. Shoulder breaks with snap fasteners permit rapid doffing. Vertical flaps with velcro fasteners at each side of the front centerline are used for closures, and elastic laces are used at the sides to permit adjustability in girth.

The rigid elements used in this model are the same as those used in Model A. Large, one-piece elements are used to eliminate the need for overlapping plates which result in increased weight, thickness, and bulk. The elements are retained in their pockets by velcro closures at the bottom of the pockets.

Model C was gymnasticated through the range of motions required of the combat infantryman, including the shouldering of his weapon. Some of these movements and positions are shown in Figures 20 through 23.

B. Concept 2

Concept 2 (Tables 5, 6 and 7) consists of rigid elements in a carrier which can be worn separately or with an overlay of rigid elements. No basic garment is worn in this concept. Fragmentation or small arms protection is provided for vital areas. Low-level fragmentation can be provided at the sides and shoulders by inserting flexible ballistic material into pockets in the carrier. Levels of protection for vital areas can be varied by changing elements in their carrier or by selection of overlays.

Figure 16. Model C, IITRI Integrated Jacket, Removable Single-Piece Front and Rear Elements, Side Closure, Overhead Donning

Figure 17. Model C, IITRI Integrated Jacket, Rigid Rear Element Retained in Integrated Pocket, Single Piece (Anatomically Contoured)

Figure 18. Model C, IITRI Integrated Jacket, Reduced Area Coverage, Front Element Permits Shouldering of Rifle

Figure 19. Model C, IITRI Integrated Jacket, Side Adjustment, Shoulder Break (Auxiliary Protective Coverage)

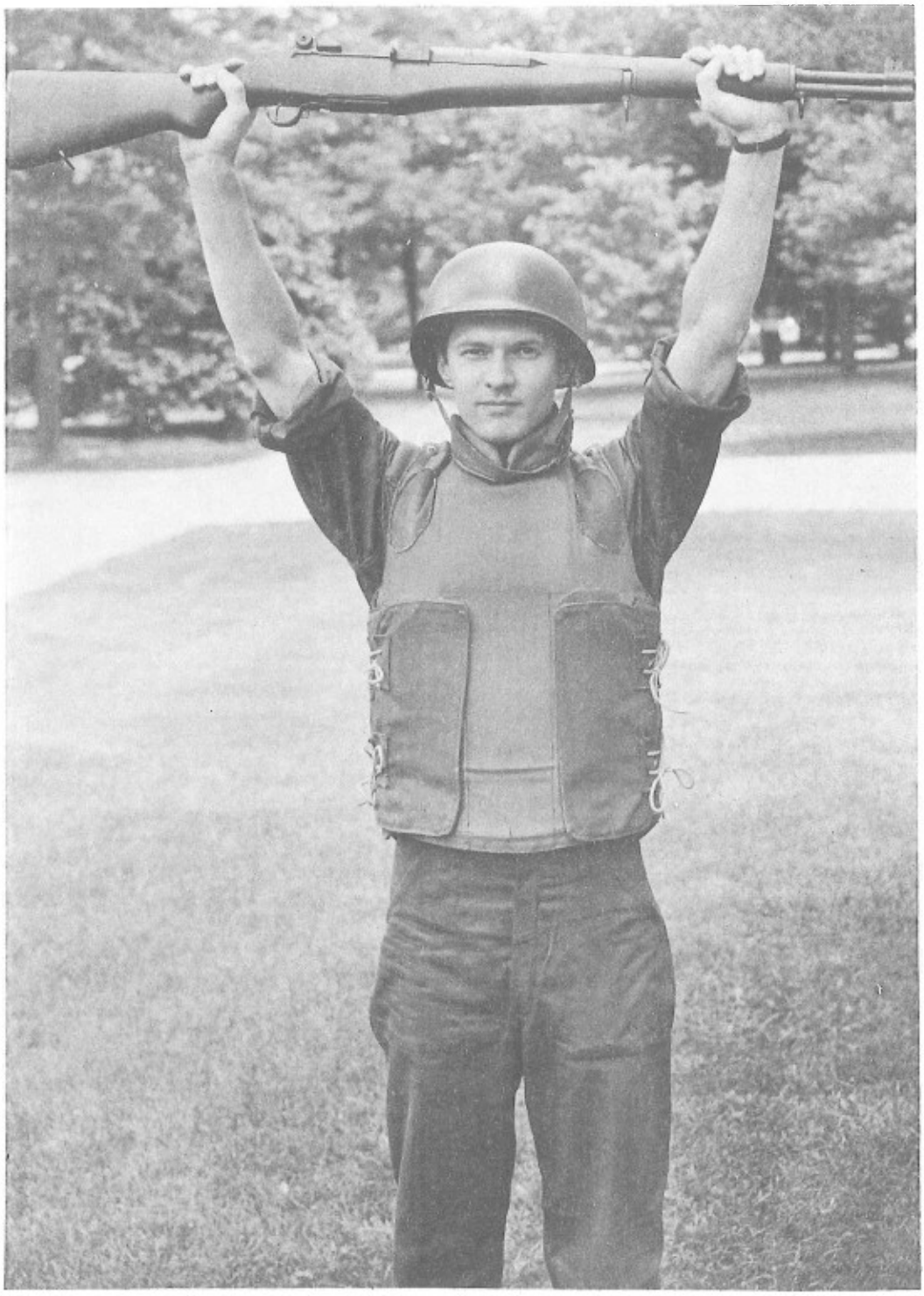

Figure 20. Model C, IITRI Integrated Jacket, Shoulder Articulation While Gymnasticating

Figure 21 Model C, IITRI Integrated Vest, Standing Firing Position

Figure 22. Model C, IITRI Integrated Vest,
Kneeling Firing Position
Note Articulation of Basic Garment at Waist

Figure 23. Model C, IITRI Integrated Vest, Prone Firing Position

Three models, D, E and F, were fabricated to demonstrate this concept.

Model D

Model D (Table 5; Figures 5, 24 and 25), which consists of rigid front, back, side and shoulder elements suspended in a carrier, simulates increased fragmentation protection to vital and nonvital torso areas. Coverage is provided from the iliac crest to the suprasternum in front and the iliac crest to the base of the neck in back.

The carrier is overhead donning with quick-release shoulder breaks. It is secured at the waist with overlapping straps and velcro fasteners.

Model E

Model E (Table 6; Figures 6, 26 and 27), which consists of rigid articulating front and back elements, shoulder and side elements suspended in a carrier, simulates increased fragmentation protection. Coverage is provided from the iliac crest to suprasternum in front and from the iliac crest to the base of the neck in back. The articulation of the front and rear elements aids in bending by adding flexibility to the elements.

The carrier is overhead donning with quick-release shoulder breaks. It is secured at the waist with overlapping flaps and velcro fasteners.

The front and back elements are similar to those used with Model B, Concept 1.

Model F

Model F (Table 7; Figures 7 and 8) consists of Models D and E worn in combination with Models G and H of Concept 3 as overlays.

C. Concept 3

Concept 3 (Tables 8 and 9) utilizes a basic flexible garment which can accept an overlay of rigid ballistic elements. The basic garment is capable of providing low-level fragmentation protection to vital and nonvital torso areas. The protection of vital areas can be selectively upgraded

Figure 24. Model D, IITRI Rigid-Element Jacket, Nonarticulated, Overhead Donning

Figure 25. Model D, IITRI Rigid-Element Jacket, Rigid Single-Piece Rear Element

Figure 26. Model E, IITRI Rigid-Element Jacket, Articulated, Overhead Donning

Figure 27. Model E, IITRI Rigid-Element Jacket, Rigid Articulated Rear Elements

to defend against increased fragmentation or small arms by an overlay of rigid ballistic elements suspended in an independent carrier.

Both area coverage and levels of protection can be varied. This feature permits the user to optimize weight in the selection of a system to protect against an anticipated hazard.

Another feature of the overlay concept is that the user does not have to remove the basic garment when changing levels of protection. The overlay can also be quickly doffed compared with the time required to remove pocketed elements.

The overlay concept has the disadvantage of being a two-garment system requiring additional fasteners and closures as compared with a single-garment system.

Two models, G and H, were fabricated to demonstrate the workability of this concept. These models are used with the basic garments for models A and C.

Model G

Model G (Table 8; Figure 9) consists of rigid front and back elements suspended in a carrier and simulates small arms protection, 6 - 7 psf. Coverage is provided from the iliac crest to the suprasternum in front and the iliac crest to the base of the neck in back.

The carrier is overhead donning with shoulder breaks for quick release. It is secured at the waist with overlapping straps and velcro fasteners.

Model H

Model H (Table 9; Figures 10 and 28), which consists of rigid front and back elements externally fastened to a carrier, simulates small-arms protection. It differs from Model G in that area coverage has been reduced to provide front and back thoracic protection only.

The carrier is overhead donning with shoulder breaks for quick release. It is secured to the torso with overlapping straps and velcro fasteners.

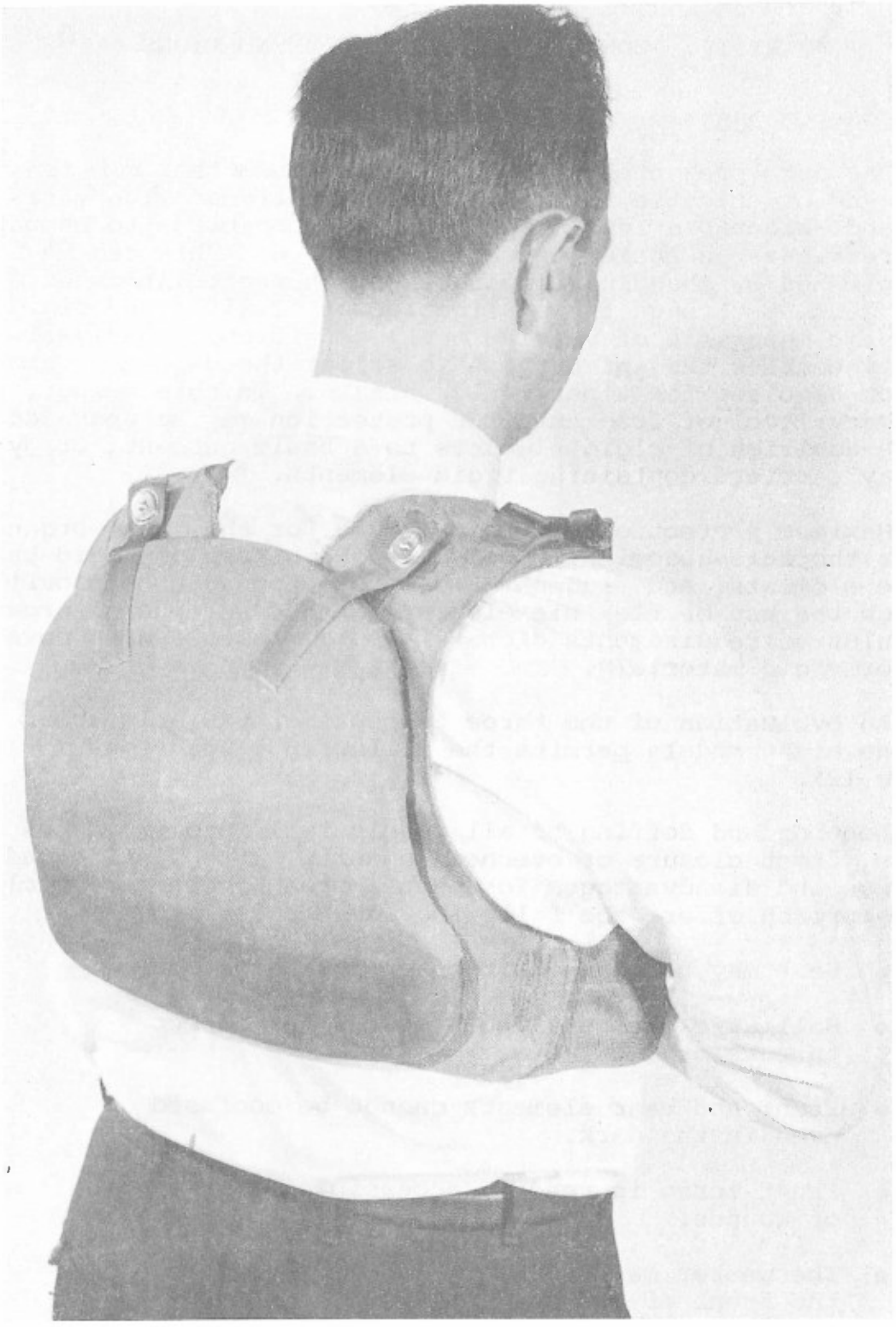

Figure 28. Rigid Rear Element Overlay, Reduced Area Coverage (Small-Arms Protection)

PART IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The data presented in this report indicate that it is feasible and practicable to provide the infantryman with variable and selectable levels of ballistic protection to combat different hazards including small-arms fire. This can be accomplished by changing the ballistic characteristics of a basic garment through the application of flexible and rigid ballistic materials of varying areal densities. This variability enables the infantryman to select the degree of protection required for a particular hazard. In this manner, a primary level of fragmentation protection may be upgraded by the addition of rigid elements to a basic garment, or by overlay carriers containing rigid elements.

Maximum protection can be provided for the vital organs of the thoracic-abdominal torso through the use of rigid ballistic elements, and fragmentation protection can be provided through the use of flexible elements in the peripheral areas. Articulation requirements dictate the permissible area coverage for rigid materials.

An evaluation of the three concepts of variable armor and the eight models permits the following conclusions (Table 12).

Donning and doffing of all models fall into two categories, front closure or overhead donning, with distinct advantages and disadvantages for each approach. The front closure approach offers the following advantages:

- Vest may be donned without removing helmet.
- Ballistic elements are stable with respect to each other.
- Front and rear elements cannot be confused even in the dark.
- Front torso is readily accessible for treatment of wounds.
- The wearer may ventilate easily by opening the front of the garment.

Table 12

EVALUATION OF VARIABLE ARMOR CONCEPTS AND MODELS

	Advantages	Concept	1			2			3	
		Model	A	B	C	D	E	F	G	H
1	One garment system		X	X	X					
2	Easily donned		X	X	X	X	X	X	X	X
3	Easily doffed		X	X	X	X	X	X	X	X
4	Level of protection can be changed without removing basic garment								X	X
5	Reduced bulk		X	X	X					
6	Basic garment serves as padding		X	X	X				X	X
7	Minimum restriction to mobility and articulation		X	X	X	X	X	X	X	X
	Disadvantages									
1	Two-garment system					X	X	X	X	X
2	Helmet must be removed while donning			X	X	X	X	X	X	X
3	Basic garment must be removed to change levels of protection		X	X	X					
4	No basic garment					X	X	X		
5	Increased bulk					X	X	X	X	X

The disadvantages of the front closure approach are as follows:

- Donning is difficult with heavy ballistic element in the jacket.
- Donning and doffing time is slow.
- The front closure requires some type of overlap at the juncture. This introduces additional bulk which detracts from comfort, and also obviates some of the benefits of the anatomical shape of the front torso armor.
- Protection is compromised when the front closure is opened.
- The jacket must be removed to change the back elements, thereby increasing the wearer's vulnerability.

Model A of Concept 1 (Figure 2) falls into the front closure category.

The overhead donning approach has the following advantages:

- The heavy elements can be handled more securely and balanced more readily while donning and doffing.
- The sides of the jacket may be opened for ventilating.
- Protection is not compromised when ventilating.
- Accessibility to anterior or posterior wounds is excellent because of the shoulder breaks and side fasteners which may be opened quickly and easily.
- Front and rear elements may be changed without removing the jacket.

The disadvantages of the overhead donning approach are as follows:

- The helmet must be removed while donning the jacket, thereby compromising protection of the wearer.
- Rotating the jacket on the wearer to change back elements is time-consuming and difficult.

- It is possible to confuse front and rear elements when donning.

Models B through H fall into the overhead-donning category.

A significant conclusion which may be drawn from the preceding study is that a basic garment which utilizes flexible ballistic materials should be worn under or in conjunction with the heavier ballistic rigid elements. The effect of this padding improves comfort immeasurably, and the rigid elements need not fit the body as precisely. The basic garment provides peripheral protection, augmenting the coverage provided by the rigid elements. When the rigid elements are properly integrated with a basic garment, stability is provided with reduced bulk and maximum comfort.

Variability may be realized quickly and easily with a broad range of ballistic elements which may be selected to fit the particular hazard. Models A, B, C, G and H utilize a basic "low-level fragmentation" garment. Our conclusion is that the use of a basic garment is highly desirable. Whether the elements are integrated into the jacket or applied through the use of overlays, the basic garment is still desirable. The overhead-donning approach, in our estimation, is superior to the front-closure approach because of the ease of donning and the increased stability of the jacket while wearing either front or rear elements alone.

The use of single-piece front and rear ballistic elements improves the ballistic integrity of the elements. Butting or overlapping of plates introduces vulnerable areas, increased complexity in design, and excessive bulk.

The integrated jacket (Model C, Figure 4) combines most of the desirable features required in a versatile and acceptable variable armor concept.

B. Recommendations

The preceding effort has highlighted four areas germane to variable infantry armor which we feel merit future investigation and development work. The four areas are as follows:

1. Variability Design Studies

   a. Design concepts or approaches which will simplify handling, insertion or attachment of ballistic elements to a carrier or basic garment.

b. Approaches which will facilitate varying the protective elements more easily, particularly the rear ballistic element, without removal of the basic carrier.

2. Closure and Suspension Design Study

a. Investigate the possibility of combining the advantages of the overhead and side-closure donning jackets into an apron-type closure jacket (Figure 29).

b. Improved closure approaches to facilitate rapid donning and doffing in normal and emergency conditions, including adaptability of the armor for medical treatment of the torso under combat conditions.

c. Closure approaches which will minimize vulnerability while varying elements, or while donning and doffing.

3. Compatability Studies

a. A study to establish whether the protective garments developed can be used in conjunction with the equipment normally carried by the infantryman. Items such as canteens, bedrolls, grenade and ammunition belts, weapons, and mess equipment must be considered since the efficiency of the fighting man must not be compromised through the use of protective clothing.

b. The possibility of developing an integrated carrier which uses a rigidized frame similar to a rucksack carrier, to which armored elements may be fastened quickly and easily to achieve variability (Figure 30).

4. Armor Configuration Studies

a. Investigate the possibility of using a basic carrier design and standardized rigid element configurations in other armor applications, such that a universal armor system approach applicable to all military services would be evolved.

b. Conduct operational studies to establish whether a universal armor system based on the variable armor concept would be practical for all services.

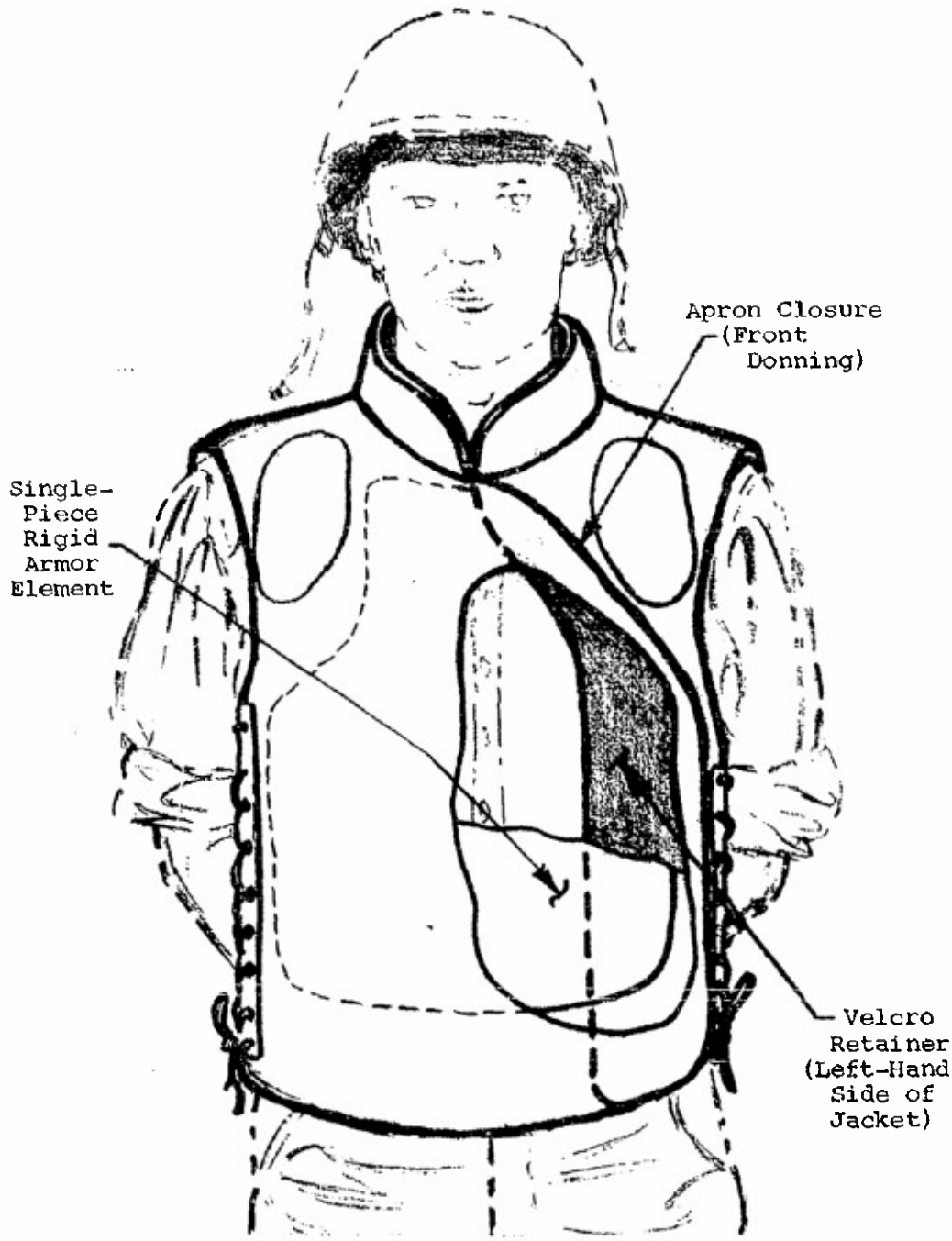

Figure 29. Recommended Variable Armor Concept, Apron Closure

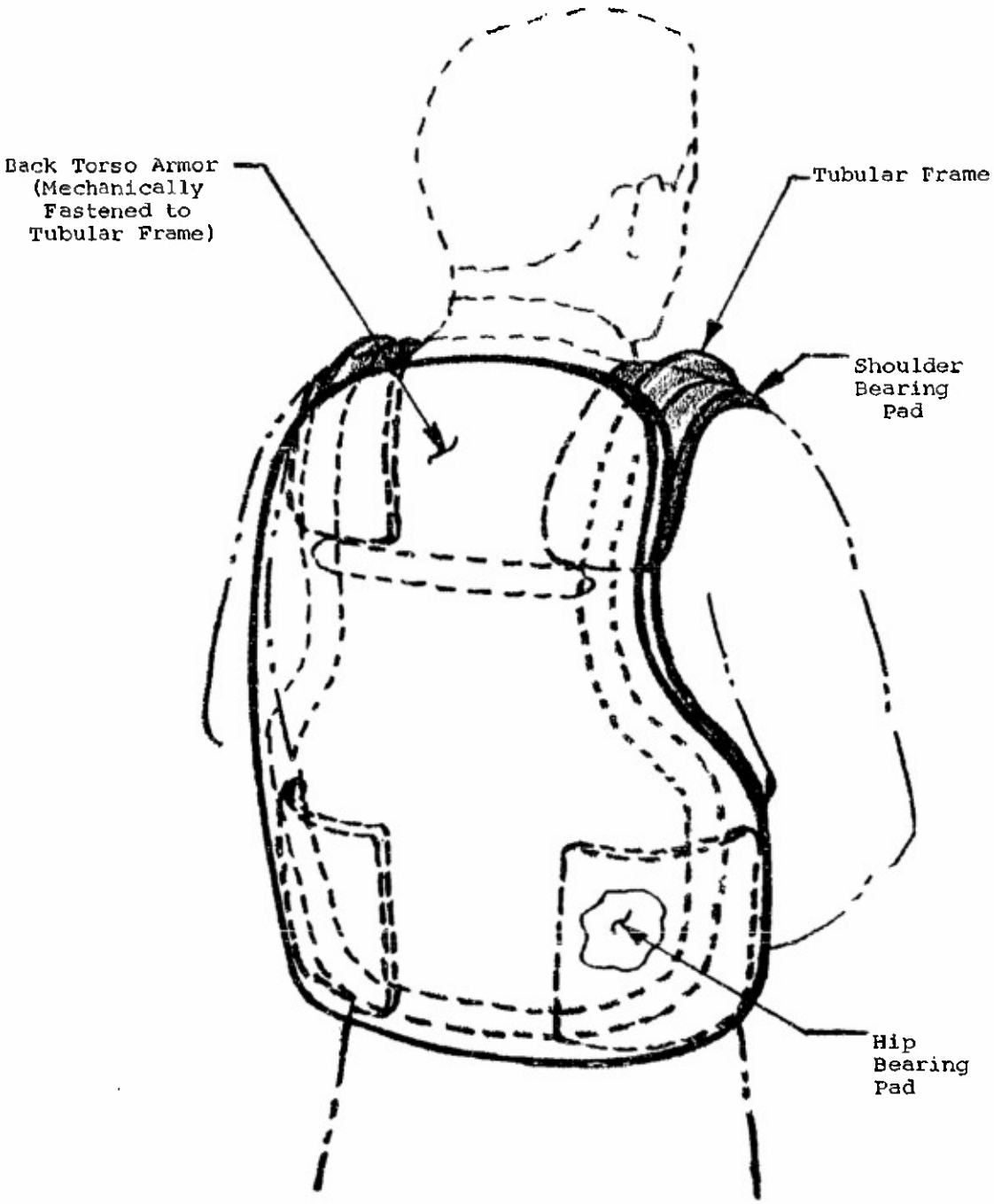

Figure 30. Projected Rigidized Frame Approach

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13. ABSTRACT

This program was directed toward investigating the feasibility of "Variable Armor Concepts" which would provide selective and variable levels of protection to the infantryman. Concepts of variable armor comprising differential protection were originated. Guidelines are suggested for improved future families of infantry protective garments. They are not intended to suggest an optimum design but to portray the results of preliminary investigation. These results enable the investigator to conduct a trade-off study which will form the basis for an optimum approach in a finalized system. Variability of ballistic protection is accomplished through several approaches.

Rigid elements of varying areal densities are inserted into pockets of a basic ballistic garment. The basic garment provides protection against low-level fragmentation for the posterior and anterior thoracic-abdominal torso and peripheral areas. Rigid or flexible elements of varying areal densities are inserted into a basic carrier resulting in differential protection. Flexible elements for low level fragmentation protection are provided in the peripheral areas; rigid elements for the anterior and posterior torso are employed to protect the vital organs from small arms fire. A basic flexible garment for maximum coverage and low-level fragmentation protection is combined with overlay rigid elements of varying area densities and area coverage, in a separate carrier.

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