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THE DEVELOPMENT OF A NAVY, BUOYANT,  
ANTI-FRAGMENT, BULLETPROOF VEST: PRO-  
TECTION AGAINST LOW-VELOCITY FRAGMENTS,  
SECONDARY (SPALL) FRAGMENT DAMAGE, AND  
30-CALIBER-BALL PROJECTILES

John Silvia, et al

Navy Clothing and Textile Research Unit  
Natick, Massachusetts

November 1972

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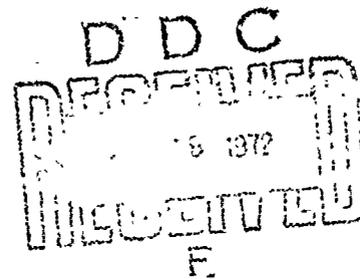
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**THE DEVELOPMENT OF A NAVY, BUOYANT, ANTI-FRAGMENT, BULLETPROOF VEST:  
PROTECTION AGAINST LOW-VELOCITY FRAGMENTS, SECONDARY (SPALL)  
FRAGMENT DAMAGE, AND 30-CALIBER-BALL PROJECTILES**

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**NAVY CLOTHING AND TEXTILE RESEARCH UNIT  
NATICK, MASSACHUSETTS**



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**TECHNICAL REPORT NO. 105**

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NAVY CLOTHING AND TEXTILE RESEARCH UNIT  
NATICK, MASSACHUSETTS

THE DEVELOPMENT OF A NAVY, BUOYANT, ANTI-FRAGMENT,  
BULLETPROOF VEST

Protection Against Low-Velocity Fragments,  
Secondary (Spall) Fragment Damage, and  
30-Caliber-Ball Projectiles

by J. Silvia, D.A.Reins, and J.C.Shampine

Work Unit No.  
523-003-21

Technical Report No.  
105

Approved for public release;  
distribution unlimited

November 1972

I-C.

UNCLASSIFIED

Security Classification

## DOCUMENT CONTROL DATA - R &amp; D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Navy Clothing and Textile Research Unit Natick Laboratories Natick, Massachusetts 01760		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE  THE DEVELOPMENT OF A NAVY, BUOYANT, ANTI-FRAGMENT, BULLETPROOF VEST			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) TECHNICAL REPORT			
5. AUTHOR(S) (First name, middle initial, last name)  John Silvia, Dale A. Reins, and James C. Shampine			
6. REPORT DATE November 1972		7a. TOTAL NO. OF PAGES 229	7b. NO. OF REFS 9
8a. CONTRACT OR GRANT NO.		8b. ORIGINATOR'S REPORT NUMBER(S)	
a. PROJECT NO. 523-003-21		105	
c.		9d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
4.		2-72	
10. DISTRIBUTION STATEMENT  Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES Details of illustrations in this document may be better studied on microfiche.		12. SPONSORING MILITARY ACTIVITY Navy Clothing and Textile Research Unit Natick Laboratories Natick, Massachusetts 01760	
13. ABSTRACT The Navy Clothing and Textile Research Unit (NCTRU) has developed two, experimental, Buoyant, Anti-Fragment, Bulletproof Vests which provide low-velocity protection against mortar shell bursts and secondary fragments (spall), provide protection against 30-caliber, small-arms fire and provide emergency, inherent buoyancy. Each model consists of a carrier which has front and back panels that contain a 30-caliber-ball, body-armor plate, a combination of felt and/or woven ballistic materials and layers of buoyant, unicellular foam. (U)  The vests were developed to replace a "standard ensemble" worn by Navy personnel in Southeast Asia for protection against wounds caused by shrapnel and rifle fire and to provide emergency buoyancy in water. The ensemble consisted of a 40-pound, ceramic, body vest worn over a Navy MAE WEST and under a lightweight "flak" vest. (U)  Physiological, in-house, stress tests conducted on the vests indicated that no significant difference in the amount of stress was noted between the new models and the standard ensemble. Comments by the test subjects indicated, however, that the experimental vests were definitely preferred because the lighter weight and decreased bulk of the vests increased relative comfort. (U)			

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1 NOV 66REPLACES DD FORM 1473, 1 JAN 64, WHICH IS  
OBSOLETE FOR ARMY USE.

I-A

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Buoyant, Anti-Fragment, Bulletproof Vest Low-Velocity Protection Mortar-Shell Bursts Secondary (Spall) Fragments 30-Caliber-Ball Projectiles 30-Caliber-Ball, Body-Armor Plate Buoyant, Unicellular Foam Buoyancy Tests Physiological Stress Tests						

I-8

UNCLASSIFIED  
Security Classification

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## THE DEVELOPMENT OF A NAVY, BUOYANT, ANTI-FRAGMENT, BULLETPROOF VEST

### INTRODUCTION

Commander, Naval Ordnance Systems Command, in 1967, requested that the Navy Clothing and Textile Research Unit (NCTRU) modify the existing aircrewman, ceramic, body armor, capable of stopping 30-caliber, armor-piercing projectiles and of providing buoyancy for small-boat crews operating riverine craft in Southeast Asia.(1)

In 1967, there were different combinations of buoyant, ballistic-protective ensembles being worn by Naval personnel in Southeast Asia. These consisted of the standard Navy life jacket worn over the Army fragment-protective vest capable of stopping low-velocity fragments or over the ceramic, body-armor vest capable of stopping 30-caliber, armor-piercing projectiles. The additional bulk and heat stress created by these combinations fatigued the wearer and reduced his operational effectiveness. Consequently, the gear was not worn as a complete unit. (2) Recommendations were made by Chief, Navy Research and Development Unit-Vietnam, in 1967 (3), to substitute a life preserver to be worn under the body armor. This would eliminate the standard Navy life jacket and reduce somewhat the heat stress load. Commander, Naval Force-Vietnam, in early 1968 (4), however, indicated that aircrewmembers were wearing a 40-pound, ceramic, body-armor vest (for ballistic protection) over a standard, Navy, MAE WEST life preserver (for flotation capabilities) and a lightweight, "flak" vest over both items to absorb spall fragments which ricochet from the body armor vest into the face, neck and head of the wearer. The Command further indicated that some means of lightweight survival equipment was needed for both the small-boat crews and helicopter aircrews.

The objectives of supplying buoyancy to aircrewman body armor were satisfied by use of buoyant, unicellular, polyethylene foam to encapsulate body-armor plates. The use of foam solved two basic problems: (a) to a great extent, the foam trapped any spall (projectile fragments) which ricocheted from the ceramic body armor and caused secondary fragment damage to face, neck and arms (5); (b) the amount of foam used overcame the negative buoyancy of the plates and provided up to 25 pounds of positive buoyancy which could not be nullified by the penetration of a projectile--as when the life preserver of the standard ensemble is ruptured by a bullet fragment. Use of the aircrewman armor and the foam resulted in a total weight of only 28 pounds while reports had indicated that body armor being used weighed 40 pounds, plus the weight of the "flak" jacket and MAE WEST life preserver. (3 & 4)

Evaluation of 200 Model I Buoyant, Ballistic, Armor-Piercing, Protective Vests by Chief, Navy Research and Development Unit-Vietnam in 1969 indicated that, although the buoyancy and ballistic protection properties were found to be excellent (many field Commanders requested additional vests for their personnel), some disadvantages were reported. The most serious flaw was a lack of low-velocity fragment protection at the sides, shoulders and the neck. It was recommended that a lesser threat level of protection, such as 30-caliber-ball type, would be acceptable if the disadvantages could be reduced.

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This report will cover the design and construction of the earlier buoyant, ballistic, protective items and the two newer models, a discussion of the various items' protective and physical characteristics, including test data and results, and a physiological stress test of the earlier standard ensemble and the latest two models.

## DESIGN AND CONSTRUCTION

### Standard Ensemble

The standard ensemble (see figure 1) is composed of three protective garments worn together. One is the T-65 aircrewman body armor which consists of front-and-back, body-armor plates possessing a capacity to stop 30-caliber, armor-piercing bullets. The plates are carried in front-and-back panels which contain pockets. The panels and pockets are made of wind-resistant, nylon/cotton, sateen cloth. The front-and-back panels are joined at each shoulder and side by the following closures:

a. Shoulder closures consist of cushion pads of a layer of nylon felt covered by nylon/cotton cloth. Each pad is attached to an adjustable, nylon-webbing strap complete with slider buckle and snap fasteners.

b. Side closures consist of two belly-band-type flaps attached to the back panel by elastic webbing overlapping each other onto the front. Flaps are secured to the front panel and to each other by Velcro tape fasteners.

The second garment, worn over the body armor, is the Army, Fragment-Protective, Body-Armor Vest with 3/4 collar, which consists of a ballistic filler encased in a waterproof filler casing which is inserted into an outer fabric cover. The outer fabric cover has two bellows patch pockets and flaps which are closed by means of snap fasteners. The front opening is secured by a slide fastener covered by a snap-fastener front flap. The sides are secured by adjustable elastic laces. The ballistic filler consists of a right-and-left front and a full back joined at the shoulder to each other and to the 3/4 collar. The back is assembled with 10 plies of 14-ounce woven ballistic nylon. The fronts and the 3/4 collar are assembled from 12 plies of 14-ounce, ballistic nylon. All plies are spot-bonded together with heat and pressure-stitchtacked with a tacking machine.

The third garment, worn under both vests, is a modified LPP-1 Life Preserver which consists of a yoke-type life preserver covered with a nylon-duck fabric to reduce chafing when worn under the T-65 Body Armor Vest. Flotation is attained by oral inflation through a tube provided for this purpose or by a CO<sub>2</sub> manifold assembly system activated by a drawcord which forces a pin to pierce the CO<sub>2</sub> cylinder, releasing CO<sub>2</sub> gas into the front panel and the yoke. The LPP-1, which is put on over the head and secured to the body by a belt assembly positioned at the waist, is worn over the clothing next to the body.

## Model I, Buoyant, Armor-Piercing, Protective Vest

The Model I, buoyant, armor-piercing, protective vest consists of foam-covered, front-and-back, body-armor plates carried in pockets of the vest. (See figure 2.)

The plates are made of outer layers of boron-carbide, ceramic plates bonded to a fiberglass laminate with a spall cover cemented over the ceramic. A one-inch strip of 3/4-inch, unicellular, polyethylene foam is attached around the outer periphery of each plate. One layer of 3/4-inch foam is attached to both sides of each plate. Each layer extends one inch beyond the outer periphery of the plate and is securely bonded to the one-inch strip of foam to prevent water penetration. The foam conforms to the inner and outer contours of the body-armor plates.

The vest is made of nylon/cotton, wind-resistant sateen and has an outer front-and-back pocket into which the foam-covered plates are inserted. Each pocket has a bottom opening secured by Velcro tape. The pockets form an integral part of the front-and-back vest panels which are joined by closures at each shoulder and side. The shoulder closures consist of cushion pads made of 2 layers of the 1/4-inch foam covered by nylon-cotton sateen. Each pad is attached to an adjustable, nylon-webbing strap complete with buckle-and-snap fastener. The right-side closure consists of two flaps secured by an elastic lacing and snap fasteners. The left-side closure consists of two overlapping flaps. The flaps are secured by Velcro tape and snap fasteners. A fragment-protective groin cover made of 12 layers of 14-ounce, woven, ballistic nylon covered by the nylon-cotton sateen is attached to the bottom of the vests. Hold-down straps are attached to the bottom and sides of the vest.

## Model II and II-A, Buoyant, Anti-Fragment, Bulletproof Vests

The Model II, buoyant, anti-fragment, bulletproof vest consists of front-and-back panels which contain ballistic, fragment-protective materials and layers of buoyant foam. The panels are made of an outer ply of ballistic nylon and an inner ply of cotton sateen and are joined to the collar at the neckline. A pocket made of nylon-cotton sateen, into which foam-covered, body-armor plates are inserted, is positioned on the inside of each panel. The left sides of the vest are permanently closed by a hinged flap made of nylon-cotton sateen joined to front-and-back panels. The right side of the back panel of the vest, which is the entry side, is joined to two rows of elastic webbing which are attached to a belly-band flap made of foam covered by nylon-cotton sateen. The left side of the back panel also has a belly-band flap made of foam covered by nylon-cotton sateen which is attached to the foam by two rows of elastic webbing. The vest is closed around the wearer when the right belly-band flap is threaded through a belly-band (belt) loop made of nylon-cotton sateen and overlapped onto the left belly-band flap. (See figure 3.)

The two flaps are secured to each other and to the front panel by a Velcro tape fastener. Shoulder pads, made with two outershells of woven ballistic nylon with 10 layers of woven ballistic nylon sandwiched between, are joined to the vest at the shoulder seam. The left pad is permanently attached to the left front-and-back panel by elastic webbing. The right pad is permanently attached to the back panel by elastic webbing, but to allow entry, the front panel is attached by a snap-fastener, nylon webbing. In addition, a Velcro tape fastener is used to detach and attach the front edge of the right shoulder pad to the front panel. The right side of the collar, which is of a cowl design, is constructed in the same manner as the pads and is split to allow entry. The opening is also secured by a Velcro tape fastener.

The ballistic, fragment-protective materials are inserted in two, coated, nylon-taffeta bags which are constructed of water-impermeable, cemented seams. The outer bag contains five layers of woven, 14-ounce, ballistic, nylon felt and the inner bag contains eight layers of 7-ounce, ballistic, nylon felt. A set of these bags is inserted in each front and back panel. Behind the inner bag in the front panel are positioned two layers of buoyant foam. Behind the inner bag in the back panel is positioned one layer of buoyant foam. A groin protector, made of 12 layers of woven, ballistic nylon constructed in the same manner as the pads and the collar, is attached to the underside of the front panel by snap fasteners and a Velcro tape closure. Hold-down nylon webbing straps are attached to the back panel corners by a triangular piece of Velcro tape and three embedded snaps. Each hold-down strap is stitch-joined to the bottom of the groin protector. Each hold-down strap has a slider buckle for adjustment. The body-armor plates are made of an outer layer of boron-carbide ceramic bonded to fiberglass laminate with a wraparound spall cover cemented over the ceramic. A 1/4-inch buoyant foam is cemented to each side of the plates. These plates protect against 30-caliber, ball-type ammunition.

The Model II-A is basically similar in design to the Model II vest, except for the following:

The ballistic, fragment-protective materials and two-bag system are changed. The II-A vest contains 15 layers of 8-ounce, lightweight, ballistic, woven nylon, treated with a hydrophobic finish sealed in a coated, nylon-taffeta bag with water-impermeable seams in each front-and-back panel. An extra layer of 1/4-inch, buoyant foam is inserted in each panel. The outer shells of each panel use the lightweight, ballistic, woven nylon and the pads, collar and groin protector. The pads, collar and groin protector use 14 layers of lightweight, ballistic, woven nylon as the filler, instead of the 10 layers of ballistic, woven nylon. (See figure 4.)

#### BALLISTIC PROTECTION CHARACTERISTICS

The standard ensemble uses the standard, aircrewman, body-armor plates which provide protection against 30-caliber, armor-piercing projectiles. The Army Fragment Protection Vest, which is worn over the aircrewman armor, protects the neck, shoulders and sides against low-velocity fragments.

caused by grenade and mortar shell bursts. The Army vest, in addition, protects the eyes, face and neck against secondary fragments (spall) caused by bullet fragments which ricochet from the body-armor plates.

The Model I vest also provides armor-piercing protection by using the aircrewman, body-armor plates. No low-velocity, fragment protection is provided in areas other than the ones covered by the body-armor plates and groin protector. Spall caused by bullet fragments ricocheting from the plates, however, is contained by the 3/4-inch, unicellular foam which encapsulates the plates (5). Groin protection against low-velocity fragments and secondary fragments is provided by 12 layers of 14-ounce, woven, ballistic nylon.

The Model II vest uses the Army Ground Troops body armor which provides protection against 30-caliber-ball projectiles. Low-velocity, fragment protection is provided by a sealed, two-bag system in each front-and-back panel and by 12 layers of 14-ounce, woven, ballistic nylon in each collar, shoulder pads and groin protector. Spall protection is achieved by the layers of unicellular, polyethylene foam, one attached to each side of the body-armor plates with the remaining layers positioned behind the bags. Additional spall protection is provided by the layers of ballistic materials inserted in the bags. This doubles the protection provided by the standard ensemble. The shoulder pads, cowl collar and groin protector also give protection against spall.

The Model II-A vest provides the same ballistic protection as the Model II vest except that the fragment-protective and foam component is deployed differently. The two-bag system is eliminated in the Model II vest and a highly experimental, woven, ballistic, nylon material that weighs only 8 ounces is used. This fabric is treated with a hydrophobic finish. Fifteen layers of this material are sealed in a coated, nylon-taffeta bag, and, together with layers of unicellular polyethylene foam, are inserted in the front-and-back panels of the vest. An extra layer of foam is included in each panel. The 14-ounce, woven, ballistic nylon used in the outer shells of each panel, the cowl collar, shoulder pads and groin protector are also replaced by the 8-ounce, woven, ballistic nylon.

## BUOYANCY

### Description of Test Procedures

Buoyancy testing was conducted in the CTRU Marine Chamber with the use of a chain hoist to raise and lower the test items into the water. Ballast was attached to the item to produce negative buoyancy. A spring scale was used to record all test results reported in this section. The procedure was to establish the weight of the ballast in water and the weight of the test item with the ballast in water. Various combinations of test items and ballast were checked. All test results were recorded with the items and ballast completely submerged in water.

## Test Results

Table I is a tabulation of test results using the above test procedures to determine the relative buoyancy of the standard ensemble and the Model I, II and II-A vests.

Table I. Buoyancy of Standard Ensemble and Model I, II and II-A Vests

A. Standard Ensemble

Weight of standard ensemble with life preserver non-inflated with ballast in water	43 lbs. 0 oz.
Weight of standard ensemble with life preserver inflated with ballast in water	<u>-16 lbs. 12 oz.</u>
Buoyancy of life preserver	+26 lbs. 4 oz.
Buoyancy of life preserver in water	26 lbs. 4 oz.
Weight of standard ensemble in water with life preserver non-inflated	<u>-10 lbs. 0 oz.</u>
Buoyancy of standard ensemble with life preserver inflated	+16 lbs. 4 oz.

B. Model I - Buoyant Armor-Piercing Protective Vest

Weight of ballast in water	30 lbs. 10 oz.
Weight of ballast and Model I vest in water	<u>- 5 lbs. 10 oz.</u>
Buoyancy of Model I vest	+25 lbs. 0 oz.

C. Model II - Buoyant Anti-Fragment Bulletproof Vest

Weight of ballast in water	36 lbs. 7 oz.
Weight of ballast and Model II vest without plates in water	<u>- 2 lbs. 0 oz.</u>
Buoyancy of Model II vest without plates	+34 lbs. 7 oz.
Weight of ballast in water	36 lbs. 7 oz.
Weight of ballast and Model II vest with plates in water	<u>- 5 lbs. 0 oz.</u>
Buoyancy of Model II vest with plates	+31 lbs. 7 oz.

D. Model II-A - Buoyant Anti-Fragment Bulletproof Vest

Weight of ballast in water	31 lbs. 9 oz.
Weight of ballast and Model II-A vest without plates in water	<u>- 7 lbs. 8 oz.</u>
Buoyancy of Model II-A vest without plates	+24 lbs. 1 oz.
Weight of ballast in water	31 lbs. 9 oz.
Vest with plate in water	<u>-12 lbs. 0 oz.</u>
Buoyancy of Model II-A vest with plates	+19 lbs. 9 oz.

## DISCUSSION OF BUOYANCY

The standard ensemble has a positive buoyancy of 16 pounds, 4 ounces, with the life preserver fully inflated. The standard ensemble has a negative buoyancy of 10 pounds, if the life preserver is not inflated, or is deflated because of pinhole puncture.

The Model I vest has inherent positive buoyancy of 25 pounds. This buoyancy is achieved by the complete encapsulation of the front-and-back body-armor plates with 3/4-inch, buoyant, unicellular, polyethylene foam. The foam is extended 1 inch beyond the periphery of the plate and cemented with adhesives to provide a watertight seal with the plates and the 1-inch extension. Consequently, the buoyancy of the foam cannot be reduced to any extent by projectile penetrations and the vest retains its flotation properties indefinitely.

The Model II vest has a positive buoyancy of 31 pounds, 7 ounces, with the body-armor plates inserted in the pockets and 34 pounds, 7 ounces, without the plates. The inherent buoyancy of the unicellular, polyethylene foam is 8 pounds. The remaining buoyancy is achieved by the volume displacement of water produced by the bulk of the two sealed bags in each panel. This buoyancy is not inherent and can be reduced by punctures made by fragments, projectiles, etc. A test was made to determine the buoyancy characteristics of an earlier vest after 35 fragment penetrations using both static-buoyancy pool tests and subjective swim tests in the NCTRU pool. Buoyancy of the perforated vest was considered satisfactory when worn in the pool immediately after the vest had been subjected to an 18-hour, static-immersion test in the NCTRU pool. In addition, the positive buoyancy of the perforated vest was recorded as indicated in Table II. The NCTRU buoyancy test procedures using the chain hoist and spring balance were employed with the perforated vest being completely submerged.

Table II. Static-Buoyancy Test Results of the Perforated Vest in NCTRU Pool

<u>Immersion Time</u>	<u>Positive Buoyancy*</u>
Initial	35 lbs.
10 minutes	27 lbs. 8 oz.
30 minutes	27 lbs. 13 oz.
1 hour	20 lbs. 0 oz.
1 hour, 30 minutes	19 lbs. 12 oz.
18 hours	19 lbs. 12 oz.

\*It was determined that 15 pounds of the positive buoyancy resulted from the inherent buoyancy of the foam component.

The Model II-A vest has a positive buoyancy of 19 pounds, 9 ounces, with the body-armor plates inserted in the pockets and 24 pounds, 1 ounce, without the plates. The inherent buoyancy of the unicellular, polyethylene foam is 13 pounds, 9 ounces. The buoyancy of the sealed bags in each vest is 10 pounds, 8 ounces. Earlier flotation tests conducted at NCTRU (6) reported

that 5 pounds of static buoyancy is considered marginal, 8-10 pounds is considered adequate, and 15 pounds is considered excellent. Based on these results, there will be sufficient inherent buoyancy resulting from the foam alone. The buoyancy resulting from the sealed bags, even if punctured, can be considered a margin of safety.

#### WEIGHT

All weight-in-air weighings, except for the Model I vest, were conducted by NCTRU physiologists on a gram-weight scale located in the NCTRU Environmental Chambers. The weights were taken during the conducting of a physiological-stress-comparison test on the standard ensemble and the Model II and II-A vests. The Model I vest was not included in this test because it lacked the required, low-velocity, fragment-protection characteristics of the other items.

The standard ensemble, consisting of the standard, aircrewman, body-armor vest worn over a modified LPP-1 life preserver with a standard, Army, fragmentation-protective vest, with a 3/4 collar worn over the other two parts, weighed 48.3 pounds.

The Model I vest, complete with foam-encapsulated, body-armor plates and groin protector, weighed 28 pounds. (This reading is based on earlier recorded weighings.)

The Model II vest, complete with foam-covered, body-armor plates and groin protector, weighed 30.3 pounds.

The Model II-A, complete with foam-covered, body-armor plates and groin protector, weighed 29.3 pounds.

#### DISCUSSION OF WEIGHTS

Based on the weighings, it is clearly evident that a significant reduction in dead-weight load has been achieved by the development of the Model I, II and II-A vests. The Model I vest has the greatest reduction, 20.3 pounds, but the least overall protection. Models II and II-A, which provide the best all-around protection against fragments and bullets, have reduced the dead-weight load 18 to 19 pounds. Based on all available information, this is the lowest weight that can be presently achieved. Until such time as a breakthrough is made on the development of a lightweight, bullet-proof component, very little further reduction of the dead load can be achieved.

#### PHYSIOLOGICAL STRESS OF THE STANDARD VS. MODELS II AND II-A

NCTRU personnel conducted physiological stress comparisons on the standard ensemble and on the Model II and II-A vests to determine if the lighter weight and more compact construction lessens the heat stress imposed, if there is a measurable difference between the two models of the improved garment, and if the test subject prefers one of the three protective items.

Tests were performed in the NCTRU Environmental Test Chambers at temperatures of 70° and 100° F. Wind speed was 3 to 5 knots. Relative humidity was 40 to 50 percent.

Nine different test subjects wore the following clothing under the three types of protective items being tested:

Cotton boxer shorts  
Nylon stretch socks  
Standard Navy work shoes  
Work jumper  
Work trousers

#### ACTIVITY LEVELS

During the tests, the following activity levels were maintained:

a. Sitting quietly with movements similar to those which might be made while standing watch.

b. Walking 10 minutes of each 20 at a rate of 1.5 mph to simulate light work and movement about an assigned task.

Test subjects, volunteers from the Army Natick Laboratories test subject pool, were young men of an age and training considered typical of the personnel who would be wearing the clothing ensembles under combat conditions.

Prior to beginning each test, subjects underwent the following general procedure:

a. After subjects rested quietly for a minimum of 15 minutes, BMR was taken.

b. Blood pressure was recorded.

c. Heart and respiration rates were recorded.

d. Urine sample was collected and specific gravity and protein concentration were recorded.

e. Nude body weight was determined on a Toledo scale accurate to  $\pm 10$  grams.

f. Rectal temperature was measured with a clinical thermometer.

g. Copper-constantan thermocouples were applied to the skin at the following 10 locations (7):

- |                  |                             |                     |
|------------------|-----------------------------|---------------------|
| 1. instep        | 5. back (sub-scapular area) | 8. lower arm        |
| 2. calf          | 6. chest (sub-mammary area) | 9. middle fingertip |
| 3. lateral thigh | 7. upper arm                | 10. left cheek      |
| 4. medial thigh  |                             |                     |

h. A copper-constan thermocouple covered with a No. 16 French rubber catheter was inserted approximately 15 cm into the rectum.

i. Three, Telectrode, disposable-type, EKG electrodes were attached to the sternum in a vertical line between the fourth and sixth ribs. The area of electrode placement was washed with a 70-percent alcohol solution and the epidermis scratched lightly (without drawing blood or producing an erythema) to reduce the skin resistance (8).

j. Two, Telectrode, disposable-type, EKG electrodes were attached at the side over the sixth and seventh intercostal areas for the purpose of recording respiratory movements. The method of application was as described in "i" above.

k. Experimental clothing was donned according to the test schedule.

l. Weight of the fully clothed subject was taken on a Toledo scale accurate to  $\pm 10$  grams.

Upon completion of the above procedure, subjects entered the conditioning room and were attached through lead extensions to the recording console. After remaining quiet for 10 to 15 minutes while physiological baselines were recorded, they entered the test chamber where the first test records were taken and labeled as zero time. Parameters of heart and respiration rates, EKG, skin and rectal temperatures were monitored continuously and on an expanded scale each 10 minutes for the two-hour test period.

When the two-hour exposure period was completed, the subjects returned to an anteroom where they were immediately weighed with and without clothing, a BMR was taken, and blood pressure, respiration and heart rates were recorded. A total-volume urine sample was obtained and the subjects rested for 15 minutes before being dismissed.

In addition to the monitoring of the above parameters, the following measurements were calculated:

a. Mean skin temperature--computed every 10 minutes as the weighted average of the 10 skin thermocouples according to the formula described by Hardy and Dubois (7).

b. Body temperature--computed each 10 minutes as 0.8 times the rectal temperature plus 0.2 times the weighted skin temperature (9).

c. Total weight loss--difference between the initial and final nude weights.

d. Evaporative weight loss--difference between initial and final clothed weights.

e. Evaporative ratio--weight loss by evaporation divided by total weight loss expressed as a percentage.

f. Body weight deficit--total weight loss divided by initial nude weight expressed as a percentage.

g. Body heat storage ( $Q_s$ )--computed from the equation:

$$Q_s = \frac{\Delta T_B \times 0.83 \times Wt}{A\theta}$$

$$Q_s = K \text{ cal/m}^2/\text{hr}$$

$$\Delta T_B = \text{Change in body temperature (}^\circ\text{C)}$$

$$0.83 = \text{Specific heat of body}$$

$$Wt = \text{Weight of test subject (kg)}$$

$$A = \text{Body area of test subject (m}^2\text{)}$$

$$\theta = \text{Time of exposure converted to hours}$$

#### TEST RESULTS AND DISCUSSION

The results of the physiological data are summarized in Table III.

TABLE III. SUMMARY OF PHYSIOLOGICAL DATA

TYPE II-A

TYPE II

STANDARD

Parameter	Temp.	Activity	Mean	tstd.dev.	N*	Mean	tstd dev.	N*	Mean	tstd.dev.	N*
Changes in mean Wt. Skin Temp. °C	100°	Walking	3.6	0.47	5	3.8	0.39	5	4.1	0.39	7
		Sitting	3.6	0.66	6	4.0	0.42	7	3.16	0.57	5
	70°	Walking	0.4	0.19	6	1.0	0.46	7	-0.1	0.59	5
		Sitting	-0.6	0.39	6	-0.1	0.74	6	-0.8	0.46	6
Change in Rectal Temp.	100°	Walking	1.28	0.32	6	1.07	0.64	6	1.2	0.10	6
		Sitting	0.5	0.32	5	0.6	0.66	7	0.3	0.40	6
	70°	Walking	0.2	0.14	6	-0.3	0.22	5	0.1	0.29	6
		Sitting	-0.2	0.2	6	-0.3	0.22	7	-0.2	0.23	6
Change in Mean Body Temp	100°	Walking	1.7	0.37	7	1.52	0.52	5	1.8	0.24	6
		Sitting	1.3	0.25	5	1.3	0.37	7	0.8	0.38	5
	70°	Walking	0.1	0.18	7	0.1	0.26	6	0.1	0.12	6
		Sitting	-0.4	0.10	6	-0.2	0.2	7	0.3	0.17	6
Change in Nose Wt.	100°	Walking	1.21	0.07	6	1.04	0.16	6	1.11	0.11	6
		Sitting	0.64	0.10	6	0.61	0.12	5	0.57	0.16	5
	70°	Walking	0.20	0.06	7	0.20	0.07	7	0.21	0.06	6
		Sitting	0.15	0.03	7	0.13	0.02	8	0.14	0.03	4
% Body Wt. Loss	100°	Walking	0.79	0.03	5	0.67	0.10	6	0.70	0.08	7
		Sitting	0.39	0.06	5	0.40	0.08	5	0.37	0.10	5
Fe: Hr	10°	Walking	0.14	0.03	7	0.13	0.04	7	0.12	0.05	7
		Sitting	0.10	0.02	7	0.10	0.01	8	0.08	0.03	5
Evapora-tion	100°	Walking	47.7	7.0	6	52.7	4.8	5	53.5	6.2	7
		Sitting	61.0	7.6	5	59	2.1	7	51.4	9.9	4
Ratio	70°	Walking	67.4	15.1	6	63.4	5.8	3	64.2	10.4	6
		Sitting	57.9	8.5	5	71.7	8.9	6	77.0	13.1	3
Heat Storage	100°	Walking	27.3	6.0	6	24.5	8.0	5	28.4	4.0	6
		Sitting	20.2	4.0	5	21.4	6.0	5	23.3	6.0	5
K cal/m <sup>2</sup> /hr	70°	Walking	3.0	2.0	7	2.3	4.0	6	0.8	2.0	6
		Sitting	-6.1	2.0	6	-5.3	4.0	7	-5.3	3.0	6
Change in Heart Rate	100°	Walking	35.0	12.0	6	29.0	9.0	6	26.0	15.0	7
		Sitting	7.0	8.0	5	4.0	7.0	6	5.0	4.0	6
	70°	Walking	1.0	6.0	7	2.0	7.0	6	-4.0	8.0	5
		Sitting	-16.0	6.0	4	-23.0	9.0	7	-18.0	6.0	5

\*N = Number of Tests

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Nine test subjects wore each of the three types of body-armor protective garments at two levels of activity and at temperatures of 70° and 100° F. Under conditions of these tests; there was no statistically significant difference in the stresses imposed among the three protective garments.

The subjective observations of the test subjects regarding the decreased weight and bulk and increased ease of movement and comfort of new model vests over the standard ensemble; which is also borne out by field observations of the NCTRU physiologists, indicate that the observed differences would be magnified when more strenuous workloads, e.g., boatcrews involved in a "fire fight," would be imposed. The differences in comfort and convenience parameters would then become significant advantages for the new model vests over the standard ensemble.

#### SUBJECTIVE COMMENTS

The standard ensemble was the least comfortable of the three items.

Test subjects agreed that the lighter weight and decreased bulk of both Models II and II-A made them preferable to the standard ensemble. Test subjects also agreed that little difference could be felt between the Type II and II-A garments.

The following subjective comments regarding the weak holding power of the Model II and II-A vest closures were noted during the test:

a. The Velcro snap-fastener closure assemblies over the shoulder did not hold.

b. When snap fasteners were used; two problems became evident:

1. The snaps were not strong enough to withstand the weight and continued use. As a result, by the time the tests were finished, several snaps had broken.

2. The snaps for the crotch protection need to be positioned so that the wearer himself can fasten them.

c. Slider buckles used to adjust the fit of the ensemble slipped while in use and needed fairly constant attention.

#### CONCLUSIONS AND RECOMMENDATIONS

The Navy Clothing and Textile Research Unit has developed two, experimental, Buoyant, Anti-Fragment, Bulletproof Vest Models, which provide low-velocity, fragment protection against grenade and mortar-shell bursts, and small-arms protection against 30-caliber, ball ammunition. They do not, however, supply protection against armor-piercing projectiles.

The new vests exceed the buoyancy protection provided by the standard ensemble. The inherent buoyancy of the new vests will be constant even when the vests are penetrated by projectiles or fragments while the buoyancy of the standard ensemble is nullified under those conditions.

The new vests are easier to don or doff, have less bulk, are lighter in weight, and have improved relative comfort when compared with the standard ensemble.

Physiological stress tests of the protective garments indicated no significant statistical differences between the items when tested under low to moderate conditions, but subjective observations of the test subjects and field observations made by the NCTRU physiologists during the testing indicate that differences observed, which cannot be considered statistically significant under existing test conditions, would be magnified when more strenuous workloads, e.g., activity during a "fire fight," were imposed.

The design weaknesses evidenced while the new model vests were being worn require the redesign of the vests to incorporate newly improved Velcro tape with greater holding power, non-slip buckles and a more positive closure than snap fasteners.

The development work on the Model II and II-A vest is being suspended as of June 1972, because the deactivation of Navy small boat crews operating riverine craft in Southeast Asia preclude further development of the Buoyant Ballistic Body Armor.

There is, however, a great need for a breakthrough in body armor development which reduces the 20-pound weight of the 30-caliber-ball-protective, ceramic, body armor. A few ounces can possibly be removed but the dead weight of 20 pounds makes the vest nearly impossible to wear over an extended period of time. As a result of the excessive weight, the Velcro tape closures open during periods of great activity, snap fasteners lose their holding power, and special "difficult-to-operate" slider buckles must be used.

But, in conclusion, it should be stated that, if an emergency arises in which there is a definite need for the ballistic and buoyancy protection provided by the Model II vests, these vests are the lightest, and the easiest to don and doff, and have the most all-around protective and buoyancy capabilities of all the special protection items discussed in this report.

APPENDIX A: ILLUSTRATIONS

A-1

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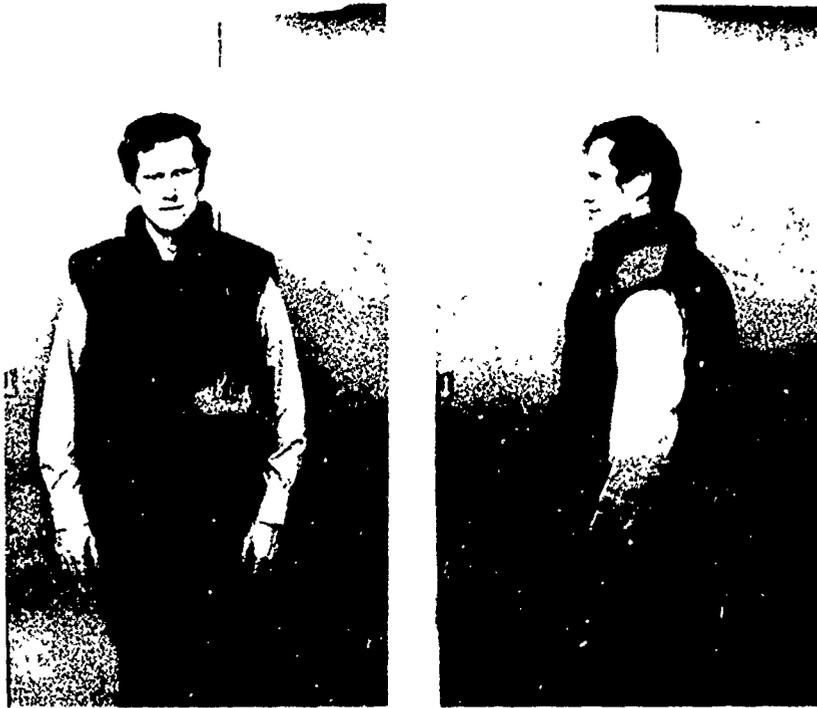


Figure 1. Front and Side Views of Standard Ensemble.

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Figure 3. Front and Side Views of Model II, Buoyant, Anti-Fragment, Bulletproof Vest.



Figure 1. Front and side views of Model 1, helmet, armor-protective, fire-resistant.



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Figure 4. Front and Side Views of Model II-A, buoyant, Anti-Fragment, Bulletproof Vest.

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