AD-756 367

BALLISTIC AND SPALL TESTS FOR AIRCREW BODY ARMOR

Thomas H. Judge, et al

Army Natick Laboratories
Natick, Massachusetts

August 1972

AD 756367

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & 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)	2a. REPORT SECURITY CLASSIFICATION
U.S. Army Natick Laboratories Natick, Massachusetts 01760	Unclassified
	2b. GROUP

3. REPORT TITLE

Ballistic and Spall Tests for Aircrew Body Armor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Thomas H. Judge
Paul J. Buttkus

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1972	63	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 1F164207DC52	73-9-CE (C&PLSEL-98)
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Details of illustrations in this document may be better studied on microfiche	U. S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

A new integrated body armor carrier system is designed to reduce spall when the armor plate is impacted by .30 caliber small arms fire. Ballistic tests, when compared to previous data, showed this system exhibited greater spall suppression than the standard aircrew armor in use in Vietnam. Spall suppression was also comparable to that provided by the heavier aircrew armor vest previously recommended as a replacement for the standard item. The standard carrier plate pocket is made of 1-ply of 8.5 ounce nylon/cotton over 1/3-inch ballistic nylon felt.

A previously proposed carrier plate pocket system in 1967 is composed of 3 plies of 14-ounce ballistic nylon over 1/3-inch ballistic nylon felt. The pocket closure flap is made of 1 ply of 14 ounce ballistic nylon.

The above systems also provide secondary fragmentation pr tection to areas of the torso not covered by the plate insert.

Results indicate that the new vest-carrier system made of nylon 128 should be type classified as Standard "A". Injury by flying spall has been reduced, but a continuing program is needed to establish advanced design criteria, textile and other material capabilities to suppress all spall, generated from obliquity strikes on aircrew armor by .30 caliber AP projectiles. In future investigations, the test fire procedure will be modified to maximize spall generation so that the spall reduction system will be evaluated at the most critical conditions.

DD FORM 1 NOV 68 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Ia

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Design	8					
Development	8					
Evaluation	8					
Acceptability	8					
Body armor	9,4		9		4	
Protective clothing	9		9		4	
Protective vest	9		9		4	
Pilots (personnel)	4		4		4	
Aviation personnel	4		4		4	
Flight crews	4		4		4	
Protection	4		4		4	
Ballistics	4					
Nylon fibers	9		9		9	
Felts	9		9		9	
Spalling			8			
Spall tests			8			
Testing			8			
Retarding			8			
Spall supression			8			
Ballistic properties			9			
Armor plate					9	
System					9	
Fiberglass			9			
Ceramics			9			
Splash			9			

Ib

AD_____

TECHNICAL REPORT

73-9-CE

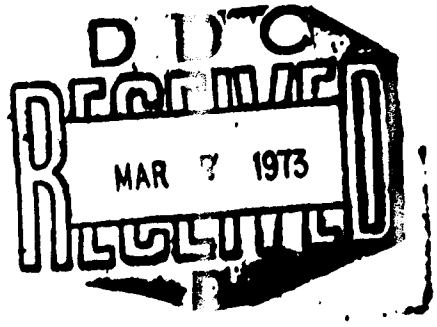
BALLISTIC AND SPALL TESTS FOR AIRCREW BODY ARMOR

by

Thomas H. Judge

and

Paul J. Buttkus



Project Reference:
1F164207DC52

Series: CPLSEL-98

August 1972

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Mass. 01760

FOREWORD

During 1967, the Army Concept Team in Vietnam (ACTIV) requested comments from the U. S. Army Natick Laboratories regarding the wearing of the body armor fragmentation protective vest over the standard aircrew armor to reduce ballistic spall from the ceramic/fiberglass plates. ACTIV was advised that this might be a temporary expedient, but the most satisfactory system would be a redesigned armor vest that suppressed all projectile splash and ceramic spall regardless of where the hit occurred on the plate. This improved system should also provide secondary fragmentation protection to areas of the torso not covered by the present items.

As a result, a new vest-carrier fabricated of 8 ounce, water repellent nylon 128 was introduced at a meeting with OCRD during July of 1970. Preference was expressed for this item over the standard aircrew armor and the initially proposed vest-carrier incorporating 6-ply nylon felt, sealed in a vinyl envelope, as the protective filler. All three systems utilize standard aircrew armor plates and ballistic felt in the plate pockets to retain spall; however, plate pocket construction, fabric weight and number of fabric plies reinforcing the felt between designs vary.

During March-April 1971, spall and ballistic tests were conducted at the U. S. Army Mechanics and Materiels Research Center (AMMRC), Watertown, Massachusetts, on ten aircrew armor vests of the new design. The firing procedure utilized showed that the vests with the 8 ounce, water repellent nylon 128 system exhibited superior spall suppression over the standard aircrew armor. The new vest-carrier is also less bulky and presents fewer wearer and production problems than any alternate system to date. It also satisfies the existing requirements for an aircrew armor system, and is more satisfactory than wearing the standard flak vest over the small arms protective ceramic plates.

The Maintenance Division of the U. S. Army Support Center, Richmond, Virginia, fabricated the new aircrew armor vests used in this evaluation. Acknowledgements are due Messrs. Charles Polley, Anthony DiCologero, Salvatore Favuzza and John Scullin, Ballistic Range personnel at AMMRC, who conducted the test firings. Credit is also given to Captain William Haile, a Researve Officer attached to the U. S. Army Natick Laboratories for training, who reviewed and edited this report and to Captain L. Norris and Mr. P. Durand of C&PLSEL's plastics group for designing and furnishing witness boxes for the testing program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A new integrated body armor plate carrier system is designed to reduce spall when the armor plate is impacted by .30 caliber small arms fire. Ballistic tests, when compared to previous data, showed this system exhibited greater spall suppression than the standard aircrew armor in use in Vietnam. Spall suppression was also comparable to that provided by the heavier aircrew armor vest previously recommended as a replacement for the standard item. The standard carrier plate pocket is made of 1-ply of 8.5 ounce nylon/cotton over 1/3 inch ballistic nylon felt.

A previously proposed carrier plate pocket system in 1967 is composed of 3 plies of 14-ounce ballistic nylon over 1/3 inch ballistic nylon felt. The pocket closure flap is made of 1 ply of 14 ounce ballistic nylon.

The currently proposed carrier plate pocket system consists of 5 plies of 8-ounce, water repellent treated ballistic Nylon 128 over 1/3 inch ballistic nylon felt. The flap pocket is fabricated of 5 plies of 8-ounce, water repellent ballistic nylon 128.

The above systems also provide secondary fragmentation protection to areas of the torso not covered by the plate insert.

Results indicate that the new vest-carrier system made of nylon 128 should be type classified as Standard "A". Injury by flying spall has been reduced, but a continuing program is needed to establish advanced design criteria, textile and other material capabilities to suppress all spall, generated from obliquity strikes on aircrew armor by .30 caliber AP projectiles. In future investigations, the test fire procedure will be modified to maximize spall generation so that the spall reduction system will be evaluated at the most critical conditions.

I. INTRODUCTION

A. Background

The standard .30 caliber AP protective armor for aircrewmen consists of ceramic/fiberglass composite front and back plates contained in a carrier. One ply of ballistic nylon is bonded to the ceramic facing to attenuate spall velocity when a projectile hits the plate (Figures 1 and 2), and the armor plates have a rubber moulding around the periphery to reduce damage if accidentally dropped on the edge. The pocket of the carrier, which holds the armor plate, contains 1/3-inch nylon felt in the front to retain ballistic impacts. In a tactical situation, pilots and co-pilots use the carrier with plates only in the front because the aircraft seats are armored. In contrast, gunners, crewchiefs, and other personnel wear the carrier with both the back and front plates inserted.

During March of 1967, the Army Concept Team in Vietnam (ACTIV) requested comments from the U. S. Army Natick Laboratories regarding the wearing of the body armor fragmentation protective vest over the standard aircrew armor. (1) This request was the result of a UH-1 helicopter being hit by ground fire and a co-pilot suffering disabling injury from ceramic spall. Spcifically, a projectile struck near the edge of the aircrew armor worn by the aircraft commander, the plate shattered and fragments struck the aircraft commander (right seat) in the arm and the co-pilot (left seat) in the eye. Several large pieces of ceramic spall penetrated the plexiglass in the left door of the cockpit. Sharp cornered ceramic fragments from the shattered edge of the plate also caused minor injuries to the crew. The estimated obliquity of the ground fire to the plate was greater than zero degrees.

The problem is two-fold because protection must be added to retain ceramic spall in the plate pocket and to reduce injuries from other flying particles, bullet splash and aircraft structure fragmentation to areas of the torso not covered by the plate. The U. S. Army Natick Laboratories advised ACTIV that for immediate relief to reduce or eliminate spall-related injuries, the Body Armor Fragmentation Protective, 3/4 Collar Vest should be worn over the aircrewman small arms protective armor (Figure 3). This was implemented as an USARV policy. The wearing of two vests, however, created discomfort, was heavy and somewhat constrictive to aviators' freedom of movement. Anticipating this, Natick Laboratories further advised ACTIV that the most satisfactory solution would be a single system designed to eliminate all projectile splash and spall regardless of where the hit occurred on the plate.

Based on the latter approach, Natick Laboratories had prototypes of a new design fabricated and 20 sets were delivered to ACTIV for evaluation in September of 1967. User comments compiled in Reference 1 were generally favorable. The prototype vest-carrier, or initially proposed replacement system consisted of a ballistic filler made of 6-ply lightweight nylon felt in accordance with MIL-C-43635, sealed in a 0.06-inch thick vinyl envelope, with an outer shell of 14-ounce ballistic nylon cloth, MIL-C-12369D(GL).

(1) Yost, DeVerne R., LTC, ART. Final Report - Aircrew Protective Armor (ACA 55/671). Army Concept Team in Vietnam, AAD/SS, APO 96384, dated Jan 1968.

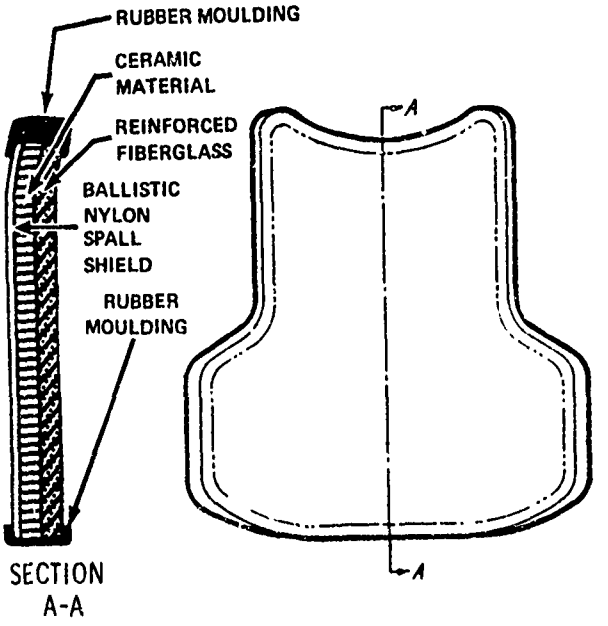


Figure 1. Aircrew Body Armor Plate

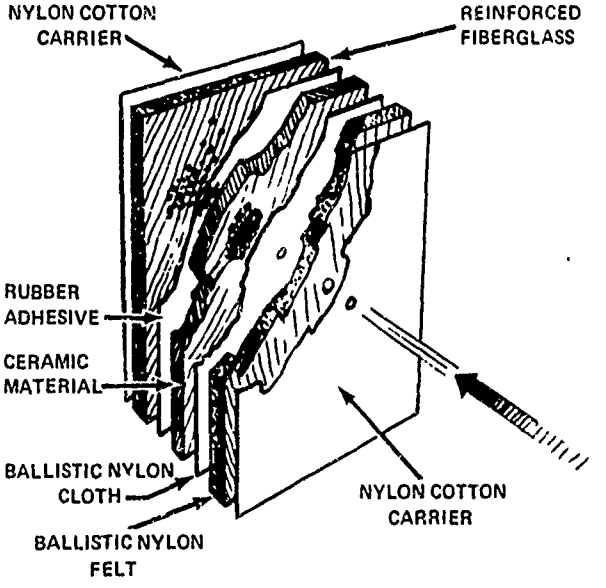


Figure 2. Projectile Retardation

Figure 3. Body Armor Fragmentation Protective Vest with 3/4 Collar (12-ply), 14-ounce ballistic nylon filler)

Sewn onto back and front of the vest were large pockets for inserting .30 caliber protective alumina ceramic/fiberglass plates. The plate pockets were constructed of three plies of ballistic nylon cloth, MIL-C-12369D(GL), which covered the front and extended around the sides of the plate. Because of fold-over or overlap, the sides contained 4 plies or one more than the pocket front. Attached under the cloth plies on the front of the pocket was one layer of 1/3-inch ballistic nylon felt, MIL-F-43539(GL). The cloth plies and felt made up the frontal spall suppression system, and cloth plies along retarded side spall. One shortcoming of the prototype vest-carrier was that the plate pocket closure flap, covering the bottom edge of the plate, contained only one ply of ballistic nylon cloth. The vest weighed approximately 8-3/4 pounds for the size regular, exclusive of the armor plates; vest with front plate weighed approximately 19-3/4 pounds and with back and front plates, 33-34 pounds. The areas of the vest covered by the ceramic/fiberglass plates provided life saving protection against caliber .30 AP projectiles, with a zero degree obliquity V50 of approximately 2850 ft/sec. The portions of the vest, not covered by the armor insert, provide protection against flying spall and fragmentation (17-grain fragment simulator V50 -- approximately 1250 ft/sec.). Casualty reduction studies were not conducted on this item.

To test spall retention characteristics, NLABS and AMMRC conducted a series of ballistic firings. The results are summarized in the Appendix. A type classification review meeting was held at OCRD 23 July 1970, at which time OCRD reviewed all available comments on the proposed aircrew armor vest and the test data (Figures 4 and 5). Concern was evidenced about spall retention, particularly with regard to obliquity edge shots on the ceramic/fiberglass plate. It was decided that more definitive information was needed on bullet impactions 0-2 inches from the plate periphery.

A new 8-ounce, water repellent ballistic nylon material* was then shown in the form of a redesigned prototype vest (Figure 6), for consideration in lieu of the item under review for type classification (Figure 4). In construction, twelve plies of 8-ounce nylon fabric replaced the nylon felt/vinyl envelope as the ballistic filler. The plate pocket spall suppression system previously recommended and consisting of 5 plies of 14-ounce ballistic nylon over 1/3-inch nylon felt was changed to 5 plies of 8-ounce, water repellent nylon over the same felt material. Another change was upgrading the pocket closure flap from one 14-ounce nylon ply to 5 plies of the lighter weight ballistic fabric. The advantages of the 8-ounce nylon are reduced bulk, reduction in production costs, elimination of the vinyl envelope and retention of ballistic properties when wet. Attendees at the classification review meeting tried on the new vest and considerable interest was generated. OCRD personnel expressed preference for this item over any previously recommended alternative to the standard aircrew armor.

*All of the 8-ounce nylon referred to in this report is water repellent treated, high tenacity nylon 128, for which LP/P DES 23-71 (GL) was subsequently promulgated.

Figure 4. Armor, body, aircrewman, front, integrated small arms and fragmentation protective with modified carrier to improve ceramic spall retention.

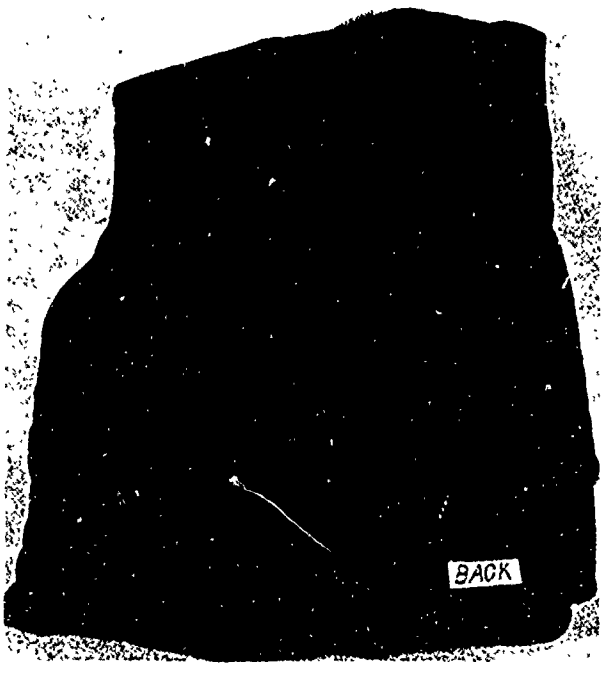


Figure 5. Armor, body, aircrewman, back, integrated small arms and fragmentation protective with modified carrier to improve ceramic spall retention.

To avoid delay of the type classification action and keep within the framework of the IPR and use of product improvement funds, it was agreed, and recommended, that the following actions be implemented:

1. OCRD/ACSFOR would proceed with the present type classification approval, except for the deletion of the back panel of the vest for pilots and co-pilots.

2. No procurements would be made of the redesigned 8-ounce, water repellent nylon type vest until NLABS had demonstrated to OCRD that spall retention characteristics were equivalent to the prototypes evaluated in RVN in 1967 and originally proposed for type classification.

3. Type classification would be approved by OCRD on the present paper with the above actions taken by USANLABS.

B. Test Objective

This testing program was undertaken to determine whether or not an aircrew armor vest fabricated of 8-ounce, type 128 nylon can adequately suppress spall from .30 caliber partial penetrations 0-2 inches from the edge of the armor plate. Plate pocket spall retention characteristics should be better than the standard aircrew armor vest, FSN 8470-935-3183 through -3185, and be at least equal to the replacement vest proposed in the type classification action.

C. Description of Test Items

1. Body Armor, Fragmentation - Small Arms Protective, designed for pilot and co-pilot frontal protection (Figure 6). Vest construction consists of a front and back panel attached at both shoulders with quick-release fasteners and attached at the waist with an overlapping closure of nylon hook and pile tape. The front protective panel can be broken down into a ballistic filler and plate pocket, descriptions of which are given below:

a. Ballistic filler - 12 plies of 8-ounce, water repellent nylon 128, LP/P DES 23-71 (GL), which provides fragmentation protection and covers the front torso, from the upper chest to just above the waistline. Outer shell provides two additional plies--one ply each front and back--of 8-ounce, water repellent nylon 128.

b. Plate pocket front - 5 plies of 8-ounce, water repellent nylon 128, LP/P DES 23-71 (GL) over one layer of 1/3-inch ballistic nylon felt, MIL-F-43539 (GL).

c. Plate pocket sides and closure flap - 5 plies of 8-ounce, water repellent nylon 128, LP/P DES 23-71 (GL).

The plate pocket forms the spall suppression system. The back panel is a NOMEX Raschel Knit fabric. The panel attachments at the right and left shoulders and at the waist are adjustable for maximum comfort. Armor, Aircrew, Small Arms Protective front plates (aluminum oxide, reinforced fiberglass composite, Class 2) FSN 8470-935-3177 through -3179 are inserted in the front pocket. The vests on which ballistic tests were concluded

Figure 6. Body Armor, Fragmentation - Small Arms Protective: designed for Pilot/Co-Pilot Protection

included front plates from two manufacturers.

Although no control items were included in the ballistic firings on the above vest, pertinent descriptive information on other aircrew armor vests is summarized in Tables I and II.

II. TEST PROCEDURE AND RESULTS

A. Preparatory Procedures for Testing

All ballistic testing was performed with .30 caliber armor piercing projectiles fired at approximately 2700 ft/sec. and impacting at a 45° obliquity. The 45° obliquity (two dimensional system) simulated the aircrew wearer leaning forward into the line of fire. Three to four rounds were fired at each front plate pocket. Round 1 was fired at the top center area; rounds 2 and 3 were fired to the far left and right of center. All three rounds hit the ceramic facing approximately 1 inch to 2 inches from the edge of the plate. Round 4, if it was used on the test item, was placed approximately 3-5 inches from the bottom edge of the plate.

Cardboard 0.030-inch thick was formed into a witness box, similar to a pyramidal section, one end being open and cut at a 45° angle to facilitate mounting. The open face of the witness box was placed against the armor and secured in place by holding tabs, presenting the closed end to the line of fire (Figure 7). The projectile passes through the covered front opening prior to impacting the armor. After each round fired, the witness box was removed, held up to a 750-watt light bulb and examined for the number (and size) of penetration holes as an indication of the amount of spall (Figure 8). This count is recorded in the spall penetration column of Table III. The plate pockets were then examined for penetration. The projectile splash and ballistically generated ceramic spall fragments will either be contained within the plate pocket or will perforate the pocket in the general area of the cardboard witness box. The projectile entrance hole, through the front of the cardboard witness box, is easily identified as compared to the spall puncture pattern. A new cardboard witness box was used for each shot and test firings were conducted under 70°F, 50% rh room conditions.

B. Analysis of Spall Suppression

Reference is made to Tables III and IV which show that slightly more than 50 percent of the rounds produced fragments of sufficient velocity to defeat the spall suppression system of 5 plies of 8-ounce nylon 128 and one layer of 1/3-inch ballistic nylon felt. A detailed inspection and evaluation was conducted on three of the aircrew armor vests, the amount of spall embedded in the pocket ballistic felt, and the overall condition of the armor vest pocket and armor plate. The three test items chosen for this evaluation included Vest No. 6, which completely suppressed the spall; Vest No. 1, which released some spall, and Vest No. 2, which lost a large amount of spall.

Figure 7. Spall witness box. Open end is mounted on the face of the plate pocket.

TABLE I

Description of Standard Aircrew Armor Vest and Proposed Replacements

Vest-Carrier	Ballistic Filler	Plate Pocket Construction		
		Front	Sides	Pocket Closure Flap
Standard Aircrew, MIL-C-43544 (GL)	None	1 ply 8.5 oz. nylon cotton over 1 layer 1/3-in. nylon felt.	1 ply 8.5 oz. nylon/cotton	1 ply 8.5 oz. nylon/cotton
Previously proposed replacement (1967)	6 plies lt.wt. nylon felt/vinyl envelope	3 plies, 14 oz. ballistic nylon over 1 layer 1/3-in. nylon felt.	4 plies 14 oz. ballistic nylon	1 ply 14 oz. ballistic nylon
Test item IC 1	12 plies 8 oz. water repellent nylon 128	5 plies 8 oz. water repellent nylon 128 over 1 layer 1/3-in. nylon felt.	5 plies 8 oz. water repellent nylon 128	5 plies 8 oz. water repellent nylon 128

NOTE: All three vest-carriers utilize the standard aircrew armor plates, FSN 8470-935-3177 through -3179. The new vest (IC 1) Was test fired and the spall retention results compared to 1969 data for the other two vests.

TABLE II

Weight of Standard Aircrew Armor Vest and Proposed Replacements

Vest-Carrier	Approximate Weight, Size Regular	
Standard aircrew armor with front plate (Figure A-12a, Appendix)	14-14 1/4 lbs	1,2
Previously proposed replacement (Figure 4), with front plate	19 3/4 - 20 1/4 lbs	1
Test item IC 1, currently proposed replacement (Figure 6) with front plate	16 1/4 lbs	1

1. Weight of aluminum oxide front plate is approximately 11-1/2 pounds and is a constant for all three vests above.

2. Add approximately 9 lbs. if Body Armor Fragmentation Protective Vest with 3/4 collar is worn over the standard aircrew armor.

Figure 5. Ball penetration pattern on witness box cardboard after a typical test firing.

TABLE III

BALLISTIC AND SPALL TEST RESULTS

Body Armor, Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
AMMRC Test No. 260-71, (Figure 10). Plate manufactured by AVCO Corp.	26 Mar 71	1	1	Top Center	1 "	2729	9	Projectile struck plate pocket 1" from edge producing spall penetration at 6 O'clock.
	30 Mar 71	1	2	Left Side	1-1/16"	2663	0	Projectile struck plate pocket 1-1/16" from edge with no spall penetration.
	30 Mar 71	1	3	Right Side	1 "	2669	0	Projectile struck plate pocket 1" from edge with no spall penetration, but stitches ruptured holding felt to pocket.
	30 Mar 71	1	4	Bottom Center	5 "	2675	3	Projectile struck 5" from edge producing spall penetration at bottom edge.
AMMRC Test No. 261-71, (Figure 11). Plate manufactured by AVCO Corp.	26 Mar 71	2	1	Top Center	1-1/4 "	2643	75+	Projectile struck plate pocket 1-1/4" from edge producing numerous penetrations at 6 O'clock.
	30 Mar 71	2	2	Left Side	1 "	2679	3	Projectile struck plate pocket 1" from edge producing spall penetration below nylon pile tape.

TABLE III (Continued)

BALLISTIC AND SPALL TEST RESULTS

Body Armor, Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
AMMRC Test No. 261-71, (Figure 11). Plate manufactured by AVCO Corp. continued	30 Mar 71	2	3	Right Side	1 "	2662	0	Projectile struck plate pocket 1" from edge with no spall penetration.
	30 Mar 71	2	4	Bottom Center	3-7/8 "	2653	25+	Projectile struck plate pocket 3-7/8" in from edge producing spall penetration at bottom of vest approximately 4" from entry of projectile.
AMMRC Test No. 259-71 Plate manufactured by UniRoyal	26 Mar 71	3	1	Top Center	1-3/4 "	2729	7	Projectile struck plate pocket 1-3/4" from edge producing spall penetration at 6 O'clock.
	30 Mar 71	3	2	Right Side	1-1/16"	2682	0	Projectile struck plate pocket 1-1/16" from edge with no spall penetration.
	30 Mar 71	3	3	Left Side	1-3/16"	2701	15	Projectile struck plate pocket 1-3/16" from edge producing spall penetration on left side of pencil pocket in a scattered pattern.
	30 Mar 71	3	4	Bottom Center	5-3/4 "	2689	1	Projectile struck plate pocket 5-3/4" from edge producing spall penetration approximately thru nylon pile tape 4" below.

TABLE III (Continued)

BALLISTIC AND SPALL TEST RESULTS

Body Armor,Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
AMMRC Test No. 262-71, Plate manufactured by UniRoyal.	26 Mar 71	4	1	Top Center	1-1/8 "	2649	1	Projectile struck plate pocket 1-1/8" from edge producing spall penetration.
	30 Mar 71	4	2	Right Side	1-3/16"	2676	0	Projectile struck plate pocket 1-3/16" from edge with no spall penetration.
	30 Mar 71	4	3	Left Side	1-3/16"	2650	0	Projectile struck plate pocket 1-3/16" from edge with no spall penetration.
	30 Mar 71	4	4	Bottom Center	4-3/8 "	2658	1	Projectile struck plate pocket 4-3/8" from edge with spall penetration at bottom of vest.
AMMRC Test No. 263-71, Plate manufactured by UniRoyal.	26 Mar 71	5	1	Top Center	1-1/4 "	2703	1	Projectile struck plate pocket 1-1/4" in from edge producing spall penetration thru felt.
	30 Mar 71	5	2	Left Side	1-1/16"	2680	60+	Projectile struck plate pocket 1-1/16" from edge producing numerous spall penetrations in three areas of vest.
	30 Mar 71	5	3	Right Side	7/8 "	2682	1	Projectile struck plate pocket 7/8" from edge producing only one spall particle hole at edge of nylon pile tape.

TABLE III (Continued)

BALLISTIC AND SPALL TEST RESULTS

Body Armor, Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
AMMRC Test No. 263-71 Plate manufactured by UniRoyal. (Continued)	30 Mar 71	5	4	Bottom Center	2 "	2702	Beyond Count	Projectile struck plate pocket at 2" from edge spalling outward.
AMMRC Test No. 264-71 (Figure 9). Plate manufactured by UniRoyal.	26 Mar 71	6	1	Top Center	1-1/8 "	2674	0	Projectile struck plate pocket 1-1/8" in from edge with no spall penetration.
	26 Mar 71	6	2	Right Side	1-1/4 "	2675	0	Projectile struck plate pocket 1-1/4" in from edge with no spall penetration.
	26 Mar 71	6	3	Left Side	1-1/2 "	2662	0	Projectile struck plate pocket 1-1/2" in from edge with no spall penetration, but stitches ruptured holding felt in plate pocket.
AMMRC Test No. 265-71. Plate manufactured by UniRoyal.	26 Mar 71	7	1	Top Center	1-1/8 "	2660	5	Projectile struck plate pocket 1-1/8" in from edge producing spall penetration thru pencil pocket at 6 O'clock.
	26 Mar 71	7	2	Left Side	1 "	2645	0	Projectile struck plate pocket 1" from edge with no spall penetration. Plate pocket stitching ruptured.

TABLE III (Continued)

BALLISTIC AND SPALL TEST RESULTS

Body Armor, Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
AMMRC Test No. 265-71. Plate manufactured by UniRoyal. (Continued)	26 Mar 71	7	3	Right Side	1/2 "	2684	0	Projectile struck plate pocket 1/2" from edge with no spall penetration. Plate pocket stitching ruptured.
Vest Size: Short AMMRC Test No. 266-71 Plate manufactured by AVCO Corp.	26 Mar 71	8	1	Top Center	1-1/4 "	2648	0	Projectile struck plate pocket 1-1/4" from edge with no spall penetration.
	26 Mar 71	8	2	Right Side	1-3/4 "	2685	5	Projectile struck plate pocket 1-3/4" in from edge with spall penetration.
	26 Mar 71	8	3	Left Side	1-1/4"	2665	15	Projectile struck plate pocket 1-1/4" in from edge producing spall penetration.
Vest Size: Long AMMRC Test No. 267-71. Plate manufactured by AVCO Corp.	26 Mar 71	9	1	Top Center	1 "	2685	2	Projectile struck plate pocket 1" from edge producing spall penetration and rupturing top stitching of pocket to carrier.
	26 Mar 71	9	2	Left side	1-3/4 "	2676	0	Projectile struck plate pocket 1-3/4" in from edge with no spall penetration.
	26 Mar 71	9	3	Right Side	1 "	2692	40+	Projectile struck plate pocket 1" from edge, resulting in down and out spalling.

TABLE III (Continued)

BALLISTIC AND SPALL TEST RESULTS

Body Armor, Aircrew Fragmentation and Small Arms Protective (Nylon 128)

Test Identification	Test Date	Vest* No.	Round No.	Pocket Location	Distance From Edge	V1 (fps)	Spall** Penetration	Remarks
Vest Size: Long AMMRC Test No. 268-71. Plate manufactured by AVCO Corp.	26 Mar 71	10	1	Top Center	1-1/4 "	2672	0	Projectile struck plate pocket 1-1/4" in from edge with no spall penetration.
	26 Mar 71	10	2	Right Side	1-5/8"	2675	0	Projectile struck plate pocket 1-5/8" in from edge with no spall penetration.
	26 Mar 71	10	3	Left Side	3/4 "	2718	0	Projectile struck plate pocket 3/4" from edge with no spall penetration.

* Unless otherwise denoted, vest/plates are size regular.
**The spall produced from these obliquity edge shots was directional and for round 4, impacts closer to the bottom edge resulted in greater spall penetration of the plate pocket.

TABLE IV

Summary of Table III Ballistic and Spall Test Results

Body Armor, Aircrew Fragmentation & Small Arms Protective (Nylon 128)

Vest No.	Total No. of Rounds	Rounds for Which All Spall Was Retained in Plate Pocket	Rounds for Which Exiting Spall Penetrated Plate Pocket
1	4	Rounds 2, 3	Rounds 1, 4
2	4	Round 3	Rounds 1, 2, 4
3	4	Round 2	Rounds 1, 3, 4
4	4	Rounds 2, 3	Rounds 1, 4
5	4	None	Rounds 1, 2, 3, 4
6	3	Rounds 1, 2, 3	None
7	3	Rounds 2, 3	Round 1
8	3	Round 1	Rounds 2, 3
9	3	Round 2	Rounds 1, 3
10	3	Rounds 1, 2, 3	None

Note: All rounds were partial penetrations. Round 4 in all instances produced flying spall, creating a potentially severe hazard to the wearer.

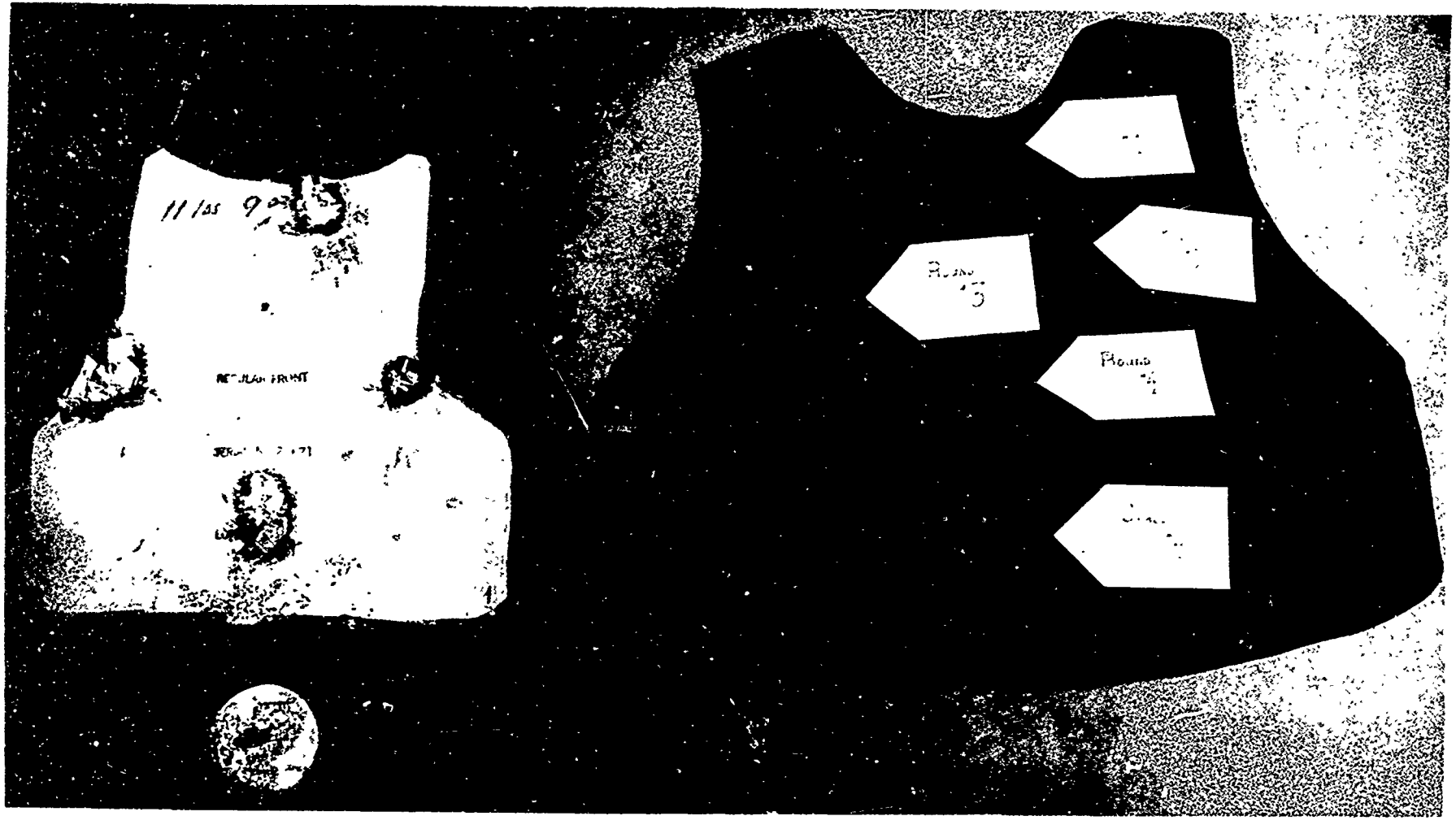


Figure 9. Aircrewman Armor Vest No. 6 - Front vest carrier after test. Armor plate removed after test and free spall contained in plate pocket.

On Vest No. 6, all spall wass suppressed by the plate pocket (Figure 9). Cone-shaped impressions were formed in the ballistic nylon felt by the projectile impact and the shattering of the ceramic plate (Figure 12). These areas of blow-back contained projectile strips and spall embedded in the ballistic nylon felt. On entry, round No. 3 pierced the stitching attaching the felt to the inside front of the pocket, and spall from this round lodged in the fifth or outside ply of the water repellent nylon 128. The weight of the spall particles embedded in the ballistic nylon felt was approximately 1.5 ounces and the weight of loose spall particles found within the armor plate pocket was approximately 2.0 ounces. The rubber edging remained intact and appeared to aid in the spall suppression for round No. 1. A breakdown of spall, particles by weight and size, is detailed in Table VI, column a.

Vest No. 1 failed to retain all the ballistic spall generated (Figure 10). Again, cone-shaped distortions were formed in the ballistic felt opposite the impact area on the armor plate (Figure 13). These distorted areas contained projectile strips and spall embedded in the ballistic nylon felt. The rubber edging on the armor plate cracked, but remained essentially intact and probably contributed to spall suppression on rounds No. 1, 2 and 3. The spall embedded in the ballistic nylon felt had a weight of approximately 2.0 ounces. The weight of the loose ceramic spall, contained within the armor plate pocket, was approximately 1.5 ounces. Spall from round No. 1 penetrated the ballistic nylon felt, 5 plies of the water repellent ballistic nylon 128 and the pencil pocket material. Round No. 4 entered below the pencil pocket and released spall five inches below at the bottom edge of the felt, ripping stitches. All spall from rounds 2 and 3 was suppressed in the plate pocket.

Vest No. 2 lost a considerable amount of spall on rounds 1 and 4 at approximately 4 inches below the point of impact (Figure 11). Spall was contained only on round 3. During rounds 1, 2 and 4, spall penetrated the felt and all plies of the nylon 128. Although spall retention efficacy was marginal, large amounts of ceramic spall and projectile pieces were found embedded in the cone-shaped distortions of the ballistic felt (Figure 14). The rubber edging was not disturbed and probably aided suppression of spall from rounds 2 and 3. The weight of loose spall contained within the armor plate pocket was approximately 1.5 ounces, the same value as the weight of spall embedded in the ballistic nylon felt. A breakdown of spall, particles by size and weight, is detailed in Table IV, column b.

Table V is included after Table IV to provide background information on aircrew armor vests tested two years earlier for spall retention (see Analysis of Test Method).

C. Analysis of Spall Particles

The spall particles observed included pieces of projectile jacket and core. When the projectile strikes the ceramic plate, the jacket is violently stripped. The broken pieces of ceramic and projectile fragments are released outward forming cone-shaped impressions in the ballistic nylon felt within the plate pocket.

TABLE V

Summary of 1969 Ballistic and Spall Results

(Abstracted from Appendix), Front Plates Only

Vest-Carrier	Item	Total No. of Rounds	Rounds for Which All Spall Was Retained in Plate Pocket	Rounds for Which Exiting Spall Penetrated Plate Pocket
Standard Aircrew Armor (old Std "A" w/1/3" wool felt in plate pocket)	1	3	None	Rounds 1, 2, 3
Previously Proposed Replacement - 1967 (Armor, Body, Aircrewman, Integrated)	5	3	Rounds 1, 3	Round 2
Fragmentation Protective Vest Over Standard Aircrew Armor	2 & 3	3	No spall penetrated flak vest. However, ballistic spall did escape through openings between the aircrew armor and fragmentation protective vest.	

NOTE: All rounds were partial penetrations. Only for the test invovling item 3 worn over item 2 were the .30 caliber AP projectiles impacted 0-2 inches from the edge of the plate. Most impactions were 2 ½ inches from the plate periphery. Except for the shot pattern and witness box, the ballistic test procedures were essentially the same for results compiled in Tables IV and V.

TABLE VI

Spall Particle Classification by Size (inches) and Weight (grams)

Sieve Opening (Inches)	Column a Spall Weight (grams) from Vest No. 6	Column b Spall Weight (grams) from Vest No. 2
.157	145.8	202.3
.111	23.4	33.3
.0937	10.4	14.0
.0787	8.3	12.8
.0555	16.9	22.3
.0394	11.8	13.1
.0280	10.6	11.9
.0197	8.6	9.9
.0164	3.6	4.9
.0138	2.3	2.7
.0017	13.5	15.8
Total	255.2 g	343.0 g

NOTE: The U. S. Standard Sieve Series was used in measuring the spall particle size. The weights in columns a and b represent the amount of spall particles that were fine enough to pass through coarser sieve sizes but were larger than the designated sieve opening.

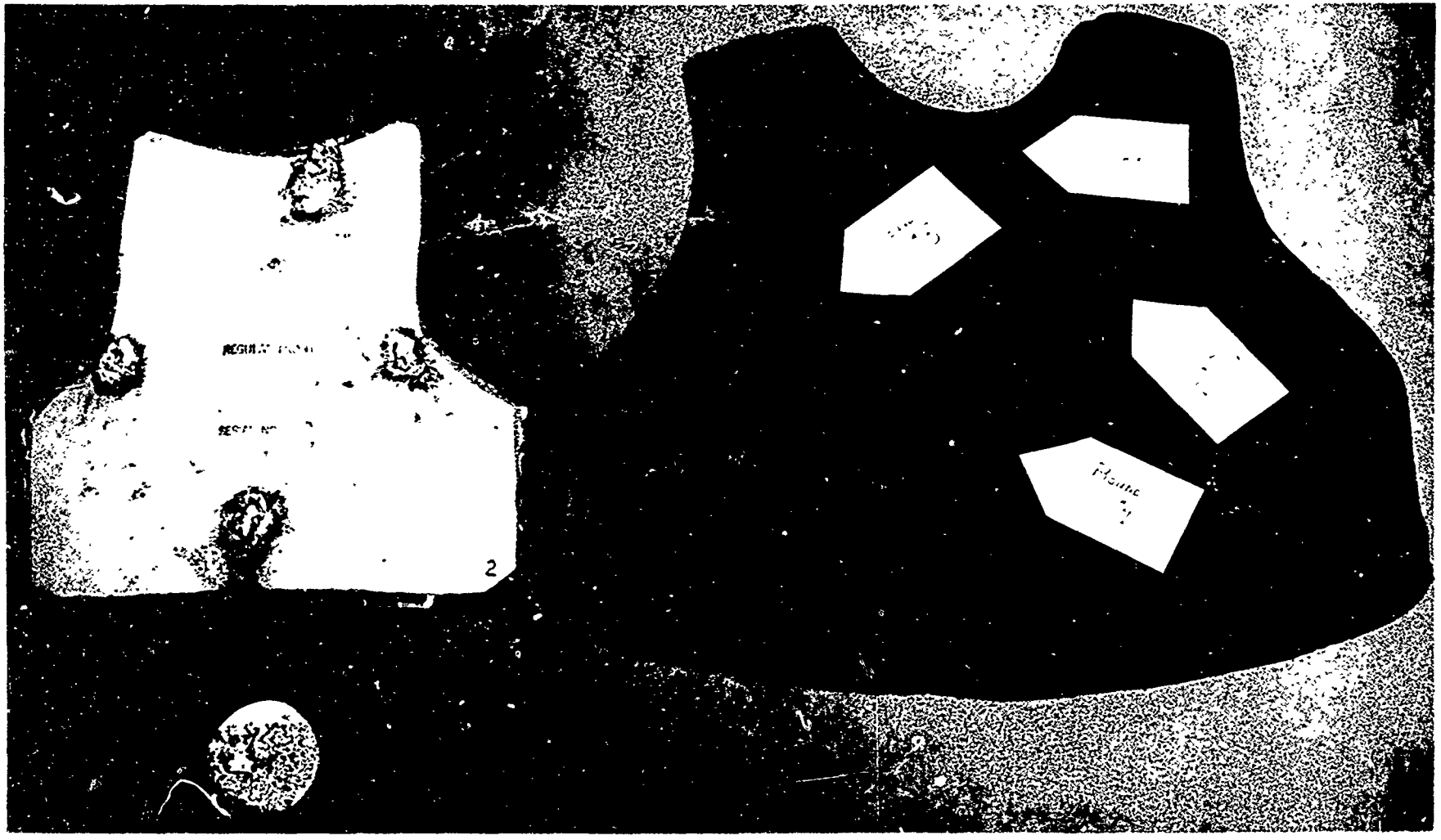


Figure 10. Aircrewman Vest No. 1 - Front vest-carrier, armor plate removed after test firing and retained spall found inside plate pocket.

Figure 11. Aircrewman Armor Vest No. 2 - Front vest carrier after test. Armor plate removed after test and free spall contained in plate pocket.

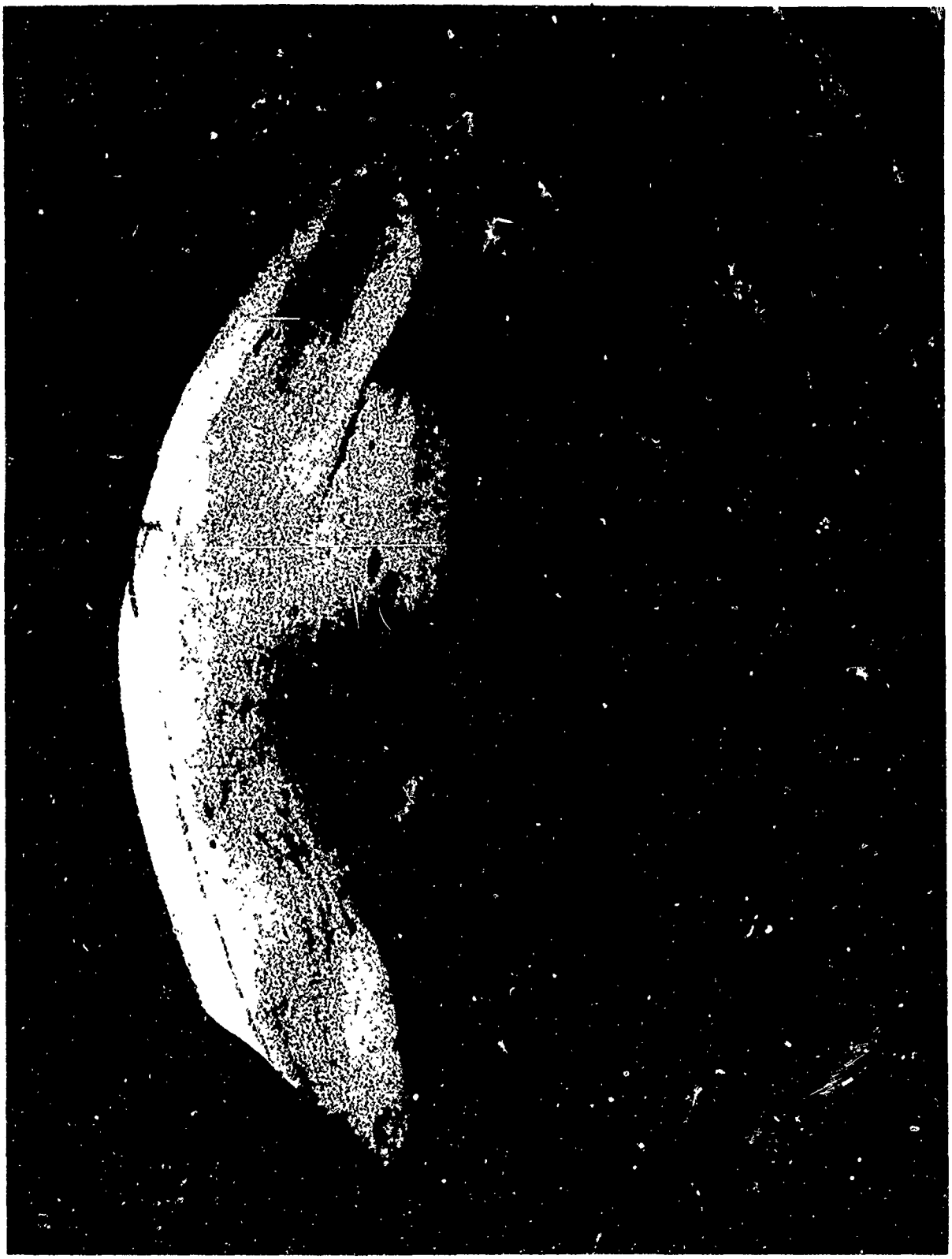


Figure 12. Vest No. 6 - Cone-shaped impressions in pocket felt formed by projectile splash and ceramic spall.

Figure 13. Vest No. 1- Cone-shaped distortions in pocket felt formed by projectile splash and ceramic spall.

Figure 14. Vest No. 2 - Cone-shaped distortions in pocket felt formed by projectile splash and ceramic spall.

From two test vests, one which represented a multiple hit of three shots (Vest No. 6) and the other a multiple hit of four shots (Vest No. 2), spall particles were carefully collected. The spall particles were sifted through the 0.157 to 0.0017 inch U. S. Standard Sieve Series. This permitted the breakdown of spall particles by size and weight, which is shown in Table VI.

Sieve size 0.157-inch was the coarsest utilized and most of the particles remaining in this sieve ranged in size from 1/4-inch to one inch in the longest dimension. The 0.0017-inch sieve contained spall particles of powder size and only a negligible amount passed through this sieve upon shaking. The additional hit on Vest No. 2 accounts for the larger weight of spall particles per sieve size.

D. Analysis of Test Method

Armor plates were ballistically impacted top center, left and right sides 1-2 inches from the edge. The 45° obliquity simulated the aircrewman leaning forward into the line of fire, creating a downward angle of spall generation away from the edge. In this way, maximum energy absorption and ceramic resistance reduced the amount and velocity of ballistically induced spall. To maximize spall, future firings will specify edge shots to be made with the angle of incidence toward the plate periphery. It should be noted that the only edge impact in the direction of obliquity was round 4, Vest No. 5 and the results are cited below:

Impact Distance from Plate Edge	Spall Penetration of Plate Pocket
2 inches	Beyond Count

Penetration was through the five plies of 8-ounce, water repellent, ballistic nylon 128 in the pocket closure clap, at a point where the spall suppression system does not include ballistic nylon felt.

Maximum spall is generated on partial penetration because complete transfer of energy results from the defeated projectiles. 2700 ft/sec was selected for the armor piercing caliber 30 test firings because it was approximately 150 ft/sec less than the rated V50 velocities of the ceramic/fiberglass 2800+ plate. 2800±50 ft/sec impactions may give higher spall velocities (i.e., more energy transferred) but the prospects of defeating the armor is significantly increased. Furthermore, it is believed that striking velocities from tactical enemy small arms, when fired upward toward aircraft, will rarely approach 2650-2700 ft/sec.

The ten vests fired in this screening, which are recapped in Tables III and IV, did not include a control. These 1971 results are not strictly comparable to the 1969 data in the Appendix because the shot pattern and witness boxes were different; however, general comparisons are still possible because, in most other details, the test firing procedures two years apart were essentially the same. Indications but not firm conclusions can be drawn from comparing the two sets of data. Future test firings to evaluate spall suppression systems will include the standard aircrew armor and other control items.

It should be pointed out the data included in the body of this report and the Appendix represent the spall suppression evaluations to date on the aircrew armor vests listed in Table I. Only aluminum oxide/fiberglass armor plates were test fired and there is a possibility, not investigated, that boron carbide or other ceramic type plates may exhibit reduced spalling characteristics.

E. Ballistic Protection 14 Plies of 8-ounce Nylon 128

The V50 of 14 plies of 8-ounce, water repellent nylon 128 (2 ply outer shell plus 12-ply ballistic filler) was approximately 1200 ft/sec, using the 17-grain fragment simulator. Table VII demonstrates that the new vest-carrier (without plate) provides secondary fragmentation protection but at a lower level than the Body Armor Fragmentation Protective, 3/4 Collar Vest. Casualty reduction is more comprehensive and is preferred over V50 as a measure of protection.

TABLE VII

Casualty Reduction Methodology

Plies of Type 128 Nylon, 8 Ounce Cloth Need to be Equivalent to 12 Plies of 14-Ounce Standard Ballistic Nylon at the Same Area Coverage

Munitions Threat	Typical Grenade		Typical Howitzer Projectile		Typical Mortar	
Protection Criteria	Lethal	Series	Lethal	Series	Lethal	Series
Number of Plies	21.7	21.1	20.4	16.0	21.0	18.5

NOTE: The nylon 128 tested was not water repellent treated. However, when fired in panel form under standard conditions (70°F, 50% RH), there is no apparent difference between water repellent versus untreated, 8-ounce nylon 128.

III. CONCLUSIONS

Pertinent findings are summarized below:

A. Neither wearing the body armor fragmentation protective vest over the standard aircrew armor, nor replacing this expedient with the 1967 proposed vest-carrier or current test item will eliminate all ballistic spall.

B. Two of the ten test items suppressed all projectile splash and ceramic spall when ballistically tested. Nineteen of 35 obliquity shots resulted in the emission of spall and, for the ten vests screened, probability of elimination of spall was 45.7%. The 1967 proposed vest-carrier and standard aircrew armor, FSN 8470-935-3183 through -3185, were not test fired as controls.

C. Interpretation of the limited amount of previous data, although not conclusive, did suggest that spall suppression for the test item was comparable to the 1967 proposed vest-carrier and superior to the standard aircrew armor carrier.

D. Fourteen plies of 8-ounce, water repellent nylon 128 (2 plies in outer shell plus 12 plies in ballistic filler) provide secondary fragmentation protection to front and side torso areas not covered by the armor plates. The level of this protection, however, is slightly lower than that afforded by the Body Armor Fragmentation Protective Vest with 3/4 Collar.

E. The test item is lighter in weight than any other fragmentation and small arms protective aircrew armor vest evaluated to date.

F. The plate pocket sides and closure flap on the test item are fabricated of 5 plies of 8-ounce, water repellent nylon 128. The inner layer of ballistic nylon felt on the pocket front does not extend around the edges of the plate, and there is evidence that five plies of nylon 128 alone is insufficient to contain side spall from critical edge shots.

G. A need still exists to establish advanced design criteria, textile and other material capabilities to effect 100 percent suppression of spall generated from obliquity strikes on aircrew armor by .30 caliber AP projectiles.

IV. RECOMMENDATIONS

The following recommendations are submitted:

A. The aircrew armor vest fabricated of 8-ounce, water repellent nylon 128 should be type classified as Standard "A". This system provides improved spall suppression over the aircrew armor presently in use in RVN. It is relatively compact, light in weight and retains its fragmentation protective properties when wet.

B. Increase the number of plies or otherwise improve spall retention capabilities of the plate pocket sides and pocket closure flap on the test items. This will further increase protection against edge spalling.

C. Establish and/or continue R&D programs to investigate the following:

1. Ballistic testing of aluminum oxide, boron carbide and other ceramic type plate composites to determine if ceramic spall can be reduced at the source, without compromising protective requirements.

2. New suppressant materials, material capabilities and requirements for containing 100 percent projectile splash and ceramic spall.

3. Advanced design criteria for spall suppressant systems using existing materials.

4. Design criteria for spall suppressant systems using new materials.

5. Modification of test firing procedure to maximize spall generation. This will provide data for "worst case" conditions at critical obliquities.

A P P E N D I X

SPALL AND BALLISTIC TEST REPORT

FOR

ARMOR, BODY, AIRCREWMAN INTEGRATED SMALL ARMS FRAGMENTATION PROTECTIVE WITH FRONT AND BACK ARMOR PLATES

Edward R. Barron

and

Paul J. Buttkus

23 June 1969

U.S. Army Natick Laboratories
Natick, Massachusetts

TEST PROCEDURE

The Body Armor was rigidly mounted so that it presents its surface normal to the line of fire (0° obliquity) and may be rotated to present a surface up to 60° obliquity to the line of fire.

All testing was performed with the .30 caliber armor piercing projectile impacting at a 45° obliquity (2700-fps) except test No. #1, Round #1, which was impacted at 60° obliquity.

Three rounds were fired at each test item, front and back, total of six rounds. Round 1 was fired at the center area; Round 2 and Round 3 fired on the left and right sides approximately 2 inches to 3 inches from the edge of the armor.

Cardboard 0.030-inch thick was formed to an 18-inch inside diameter tube 12 inches in length; this was lined with 0.002-inch thick witness aluminum foil with the front opening of the tube being covered by the same foil and facing the line of fire (Figure A-1).

The open end of the tube was placed against the armor; the projectile passes from the muzzle through the foil covered front of the tube prior to impacting the armor. After each round fired, the tube was removed and the witness foil held up to a 100-watt light bulb and examined for the number and size of the penetration holes as an indication of the amount of spall (Figure A-2).

The test items were examined for the penetrations caused as a result of outward projectile splash and ceramic spall. The ballistically generated projectile splash and ceramic spall will either be contained within the armor system in the tube, or will penetrate the foil and tube.

The projectile entrance hole, through the front foil cover, is easily identified as compared to the spall puncture pattern. Photographs of the spall impacted foil were taken to provide a permanent record.

DESCRIPTION OF ITEMS TESTED

Item 1 - Armor, Body, Aircrewman, Small Arms Protective, Front and Back Plate with Carrier (Standard A).

This body armor consists of a nylon cotton cloth carrier with fragmentation protective nylon felt shoulder pads. Incorporated in the front and the back of the carrier are large pockets with 1/3 inch wool felt inserts stitched to pockets designed to accommodate rigid anatomically shaped ceramic, reinforced plastic armor plates. The plates have a spall cover of 1-ply ballistic nylon cloth and also rubber edging around the periphery to act as a cushion and to reduce damage to the edges of the plates if dropped accidentally. Weight - 23 lbs.

Item 2 - Armor, Body, Aircrewman, Small Arms Protective, Front and Back Plate with Carrier (Standard A).

Same as Item 1 above except with a 1/3-inch Ballistic Nylon felt inserts in lieu of wool felt inserts stitched in plate pockets. Weight - 23 lbs.

Item 3 - Armor, Body, Fragmentation Protective, 3/4 Collar (12 Ply Ballistic Nylon) (Standard B).

This item was tested over Item 1 and also over Item 2. This vest consists of a ballistic filler made of 12 plies of ballistic nylon cloth, either spot resin laminated or button stitching. The ballistic filler is sealed in a waterproof vinyl envelope. The outer shell and inner of the vest is lightweight nylon cloth. The vest has a 3/4 collar made of 12 plies of ballistic nylon cloth. The vest is designed to provide fragmentation protection against grenade, mortar and shell fragments. Weight - 8 lbs. 11 oz.

Item 4 - Armor, Body, Aircrewman, Integrated Small Arms and Fragmentation Protective with Front and Back Plate.

The vest consists of ballistic inner made of 6 ply lightweight ballistic nylon felt in accordance with MIL-C-43635, 14 Apr 69, with an outer shell of ballistic nylon cloth MIL-C-12369D, which covers the upper front and back of the torso and the waist line. Incorporated in the front and back of the vest are pockets containing 30 cal protective ceramic/fiberglass plates. The pockets are made of three plies of ballistic nylon cloth, MIL-C-12369D, which cover the front and extend around the edges of the plate providing spall protection. The vest weighs 8 lbs 9 ozs. for size regular, exclusive of the armor plates; with a front plate the vest weighs approximately 19 lbs. and with the back plate approximately 29 lbs. Those areas of the vest not covered by the armor plate, provide protection against spall, projectile splash and shell fragments.

Item 5 - (Same as Item 4 except for the addition of a 1/3-inch Ballistic Nylon Felt Insert stitched to the plate pocket.)

TEST RESULTS

Item	Description	Results
1	Armor, Body Aircrewman, Small Arms Protective, Front and Back plate w/carrier (Std A)(1/3" wool felt insert) Test 1 and 2	Evidence of heavy spall at 6 o'clock on witness foil and penetrations of the carrier. Test No. W152-69 W153-69 (Figure A3-A6)

	Armor, Body, Aircrewman, Small Arms Protective, Front and Back plate w/carrier (Std A)(1/3" wool felt insert) Plus Item 3	No evidence of spall on witness foil. Many penetrations of carrier as a result of spall. (Figure A7)
3	Armor, Body, Fragmentation Protective 3/4 Collar (12 Ply Ballistic Nylon) (Std B) Test 3 and 4	No penetrations of outer vest. All spall contained between the two items. Test No. 161-69, 162-69
5	Armor, Body, Aircrewman, Integrated Small Arms and Fragmentation protective with 1/3" Ballistic Nylon Felt insert stitched in plate pockets Test 5 and 6	Front - Rounds 1 & 3 no spall on witness foil or punctures of vest. Round 2 slight spall at 6 o'clock on witness foil and slight penetration on vest. Back - Rounds 1 & 2 no spall on witness foil or punctures of vest. Round 3 slight spall at 6 o'clock on witness foil and slight penetration on vest. Test No. W165-69, W167-69 (Figure 8A-11A)
2	Armor, Body, Aircrewman, Small Arms Protective Front and Back Plate w/carrier (Std A)(1/3" Ballistic Nylon felt insert stitched in plate pocket) Plus Item 3	There was no evidence of face spall to the front or sides. Spall contained between the 2 vests but with foil witness plate under and to the rear of the target, excessive spall was noted on Round 3. Front Spewing out from between the Aircrew armor and the nylon vest at 6 o'clock. Test No. W170-69 (Figure A12-A14)
3	Armor, Body, Fragmentation Protective 3/4 Collar (12 Ply Ballistic Nylon)(Std B) Test 7 and 8	
4	Armor, Body, Aircrewman, Integrated Small Arms and Fragmentation Protective, w/3-ply Ballistic Nylon cloth stitched in plate pocket. Test 9 and 10	Evidence of heavy spall at 6 O'clock on witness foil. Many penetrations of carrier as result of spall. Test No. W173-69, W174-69 (Figure A15-A18)

CONCLUSIONS

The results of the test established the following:

a. That Item #5, integrated vest with a plate pocket formed by 3-ply of ballistic nylon fabric lined with a layer of ballistic nylon felt yielded effective spall suppression when compared to the present standard aircrew armor.

b. The system described above is far superior to the present prescribed procedure of wearing the twelve ply ballistic nylon vest over the ceramic armor. Obliquity shots evidenced that although outcoming spall did not penetrate the vest, excessive spall, dependent upon the area hit, would exit through the bottom or top openings of the vest creating a potentially severe hazard to the wearer.

PAUL BUTTKUS
Physical Science Technician

EDWARD R. BARRON
Chief, Body Armor Branch

SPALL EVALUATION
Side view of test set-up

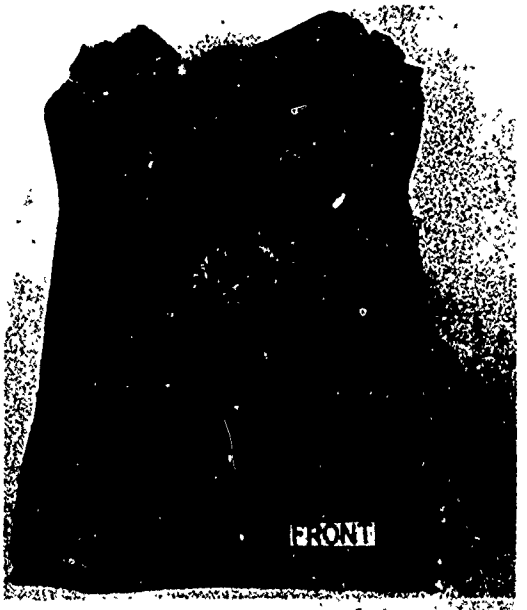
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

19-066-236/AMC-69

Figure A-1.


SPALL EVALUATION
Oblique view of test set-up
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-044-235/AMC-69

Figure A-2



SPALL EVALUATION
No. 1 Armor, body, aircrewman, front,
with wool felt insert.
(Before firing)

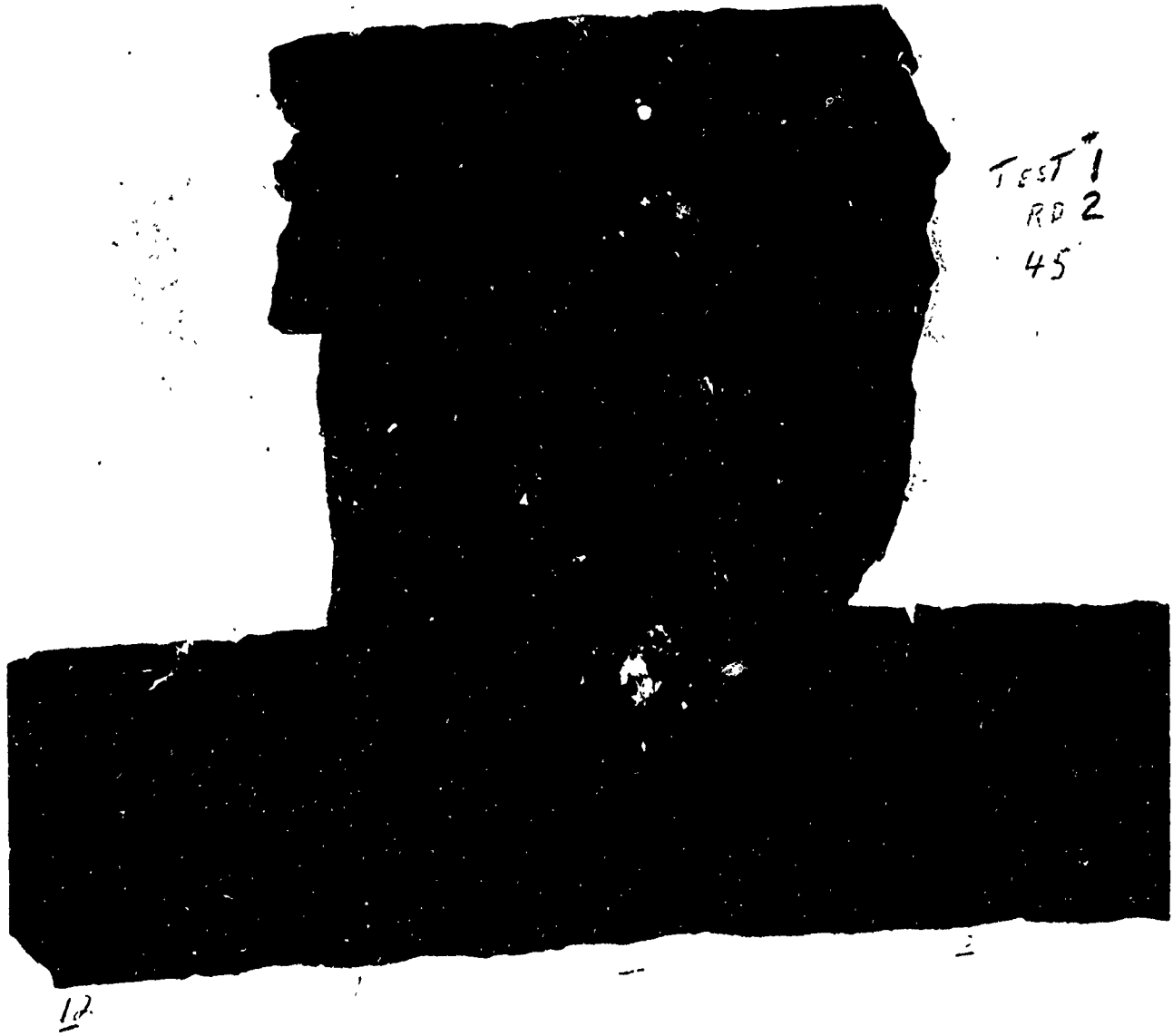
Figure A-3 (a)

Figure A-3 (b)

SPALL EVALUATION
No. 1 Armor, body, aircrewman, front,
with wool felt insert.
Fired with caliber .30 AP M2
at 45 degree obliquity.
Partial at 2714 ft/sec
Test No. W152-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

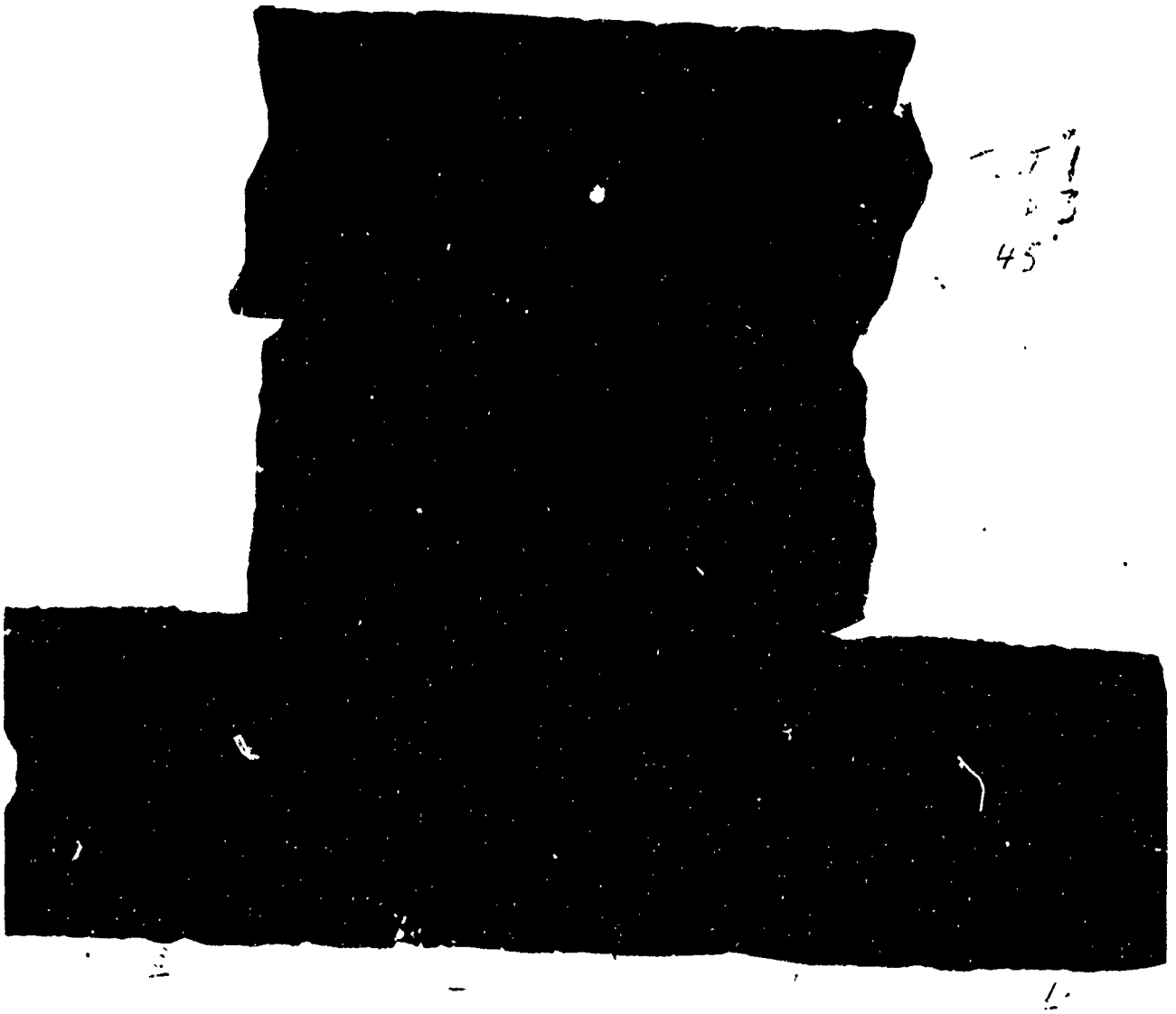
SPALL EVALUATION
Test 1, Round 1
Test No. W152-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-251/AMC-69

Figure A-4 (a)



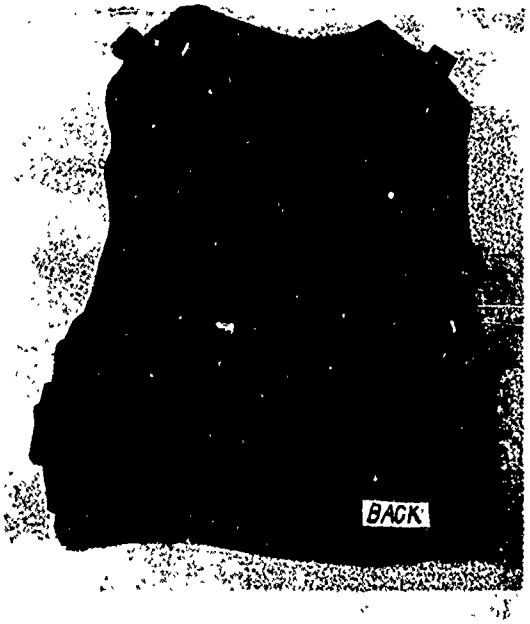
SPALL EVALUATION
Test 1, Round 2
Test No. W152-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-250/AMC-67

Figure A-4 (b)



SPALL EVALUATION
Test 1, Round 3
Test No. W152-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-249/AMC-69

Figure A-4 (c)



SPALL EVALUATION
No. 2 Armor, body, aircrewman, back, with wool felt insert.
(Before firing)

Figure A-5 (b)

Figure A-5 (c)

SPALL EVALUATION
No. 2 Armor, body, aircrewman, back, with wool felt insert.
Fired with caliber .30 AP M2 at 45 degree obliquity.
Partial at 2650 ft/sec
Test No. W153-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

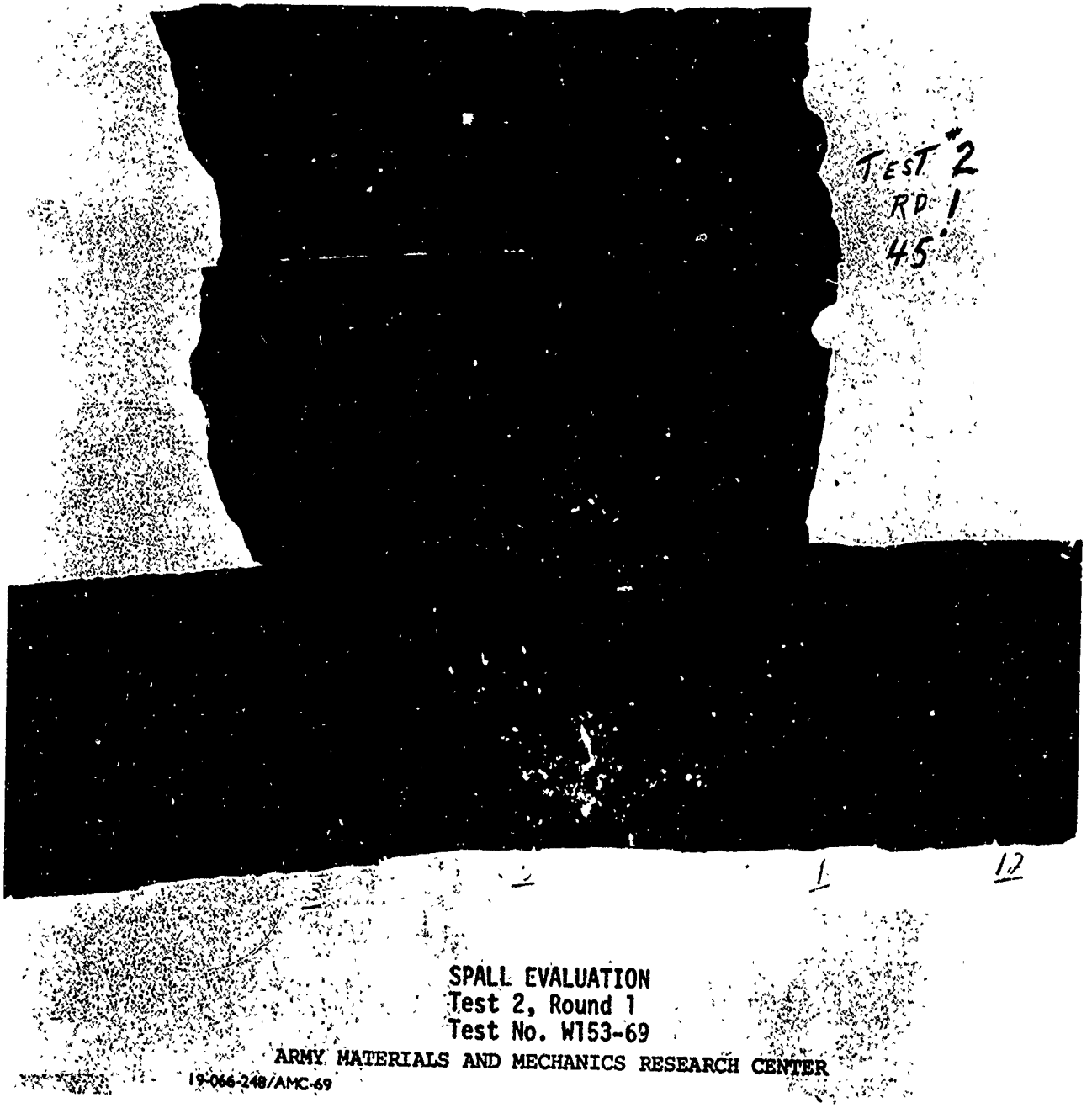

TEST #2
RD 1
45°
SPALL EVALUATION
Test 2, Round 1
Test No. W153-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-248/AMC-69

Figure A-6 (a)

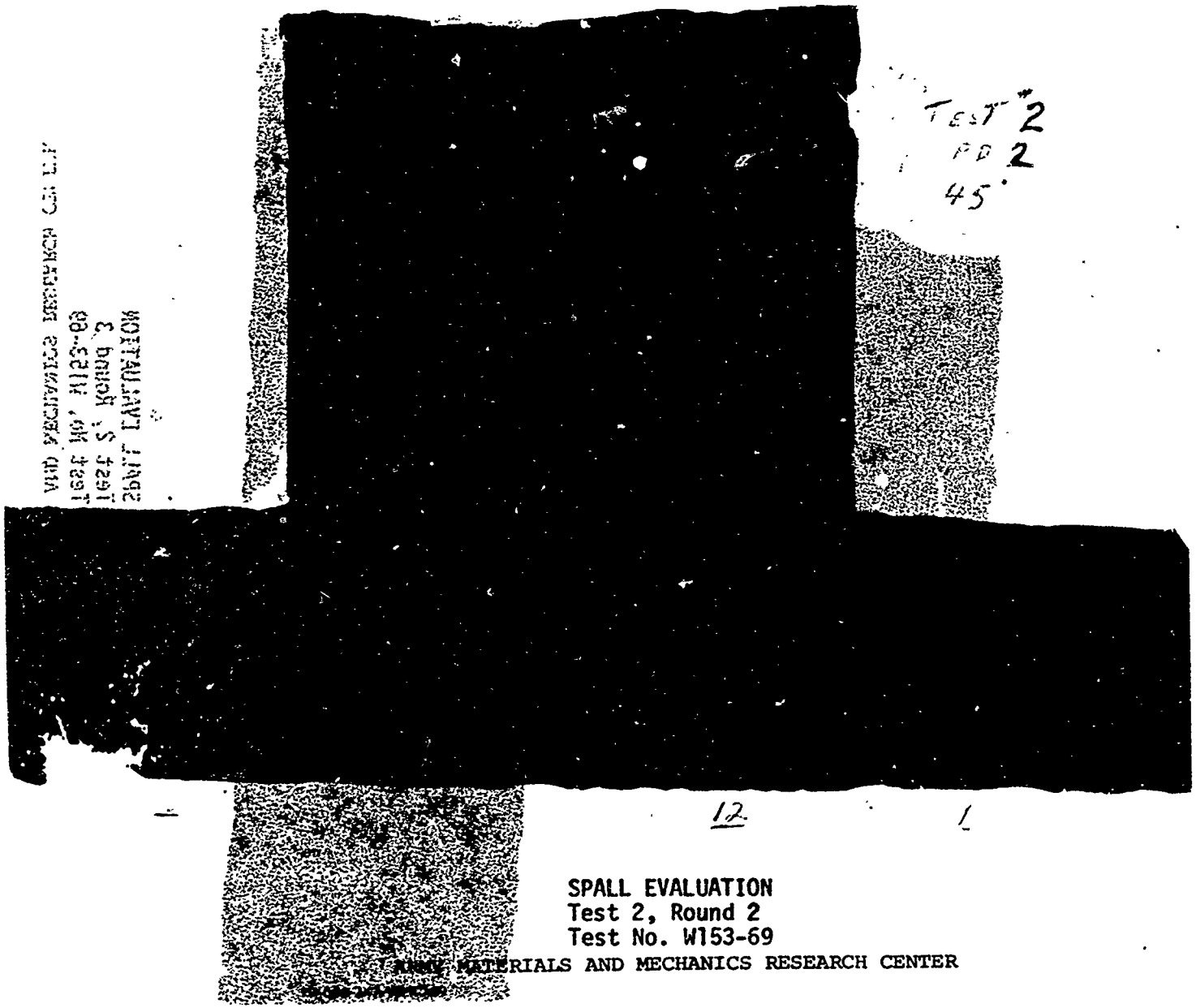
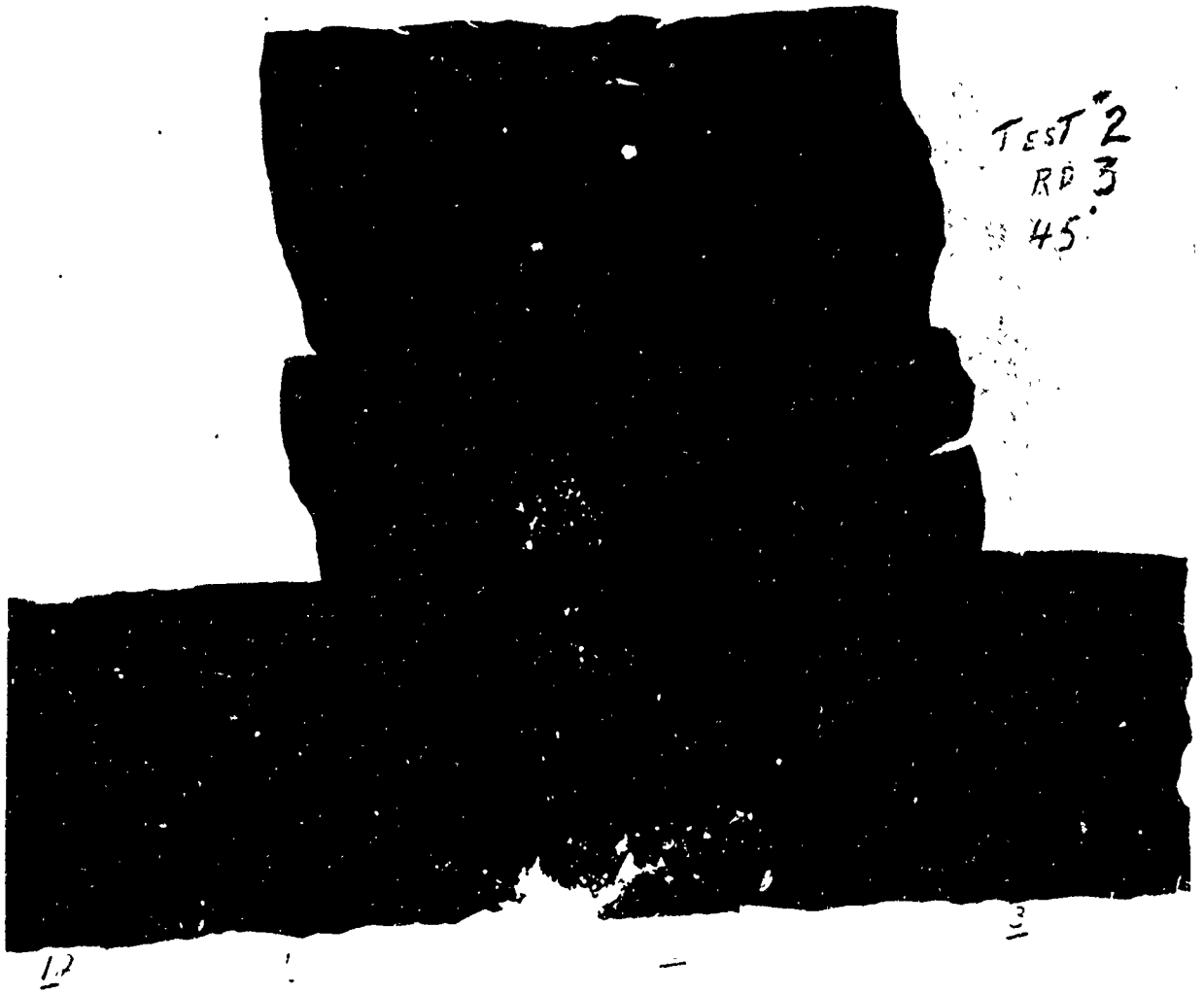

TEST #2
RD 2
45°
12
1
SPALL EVALUATION
Test 2, Round 2
Test No. W153-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

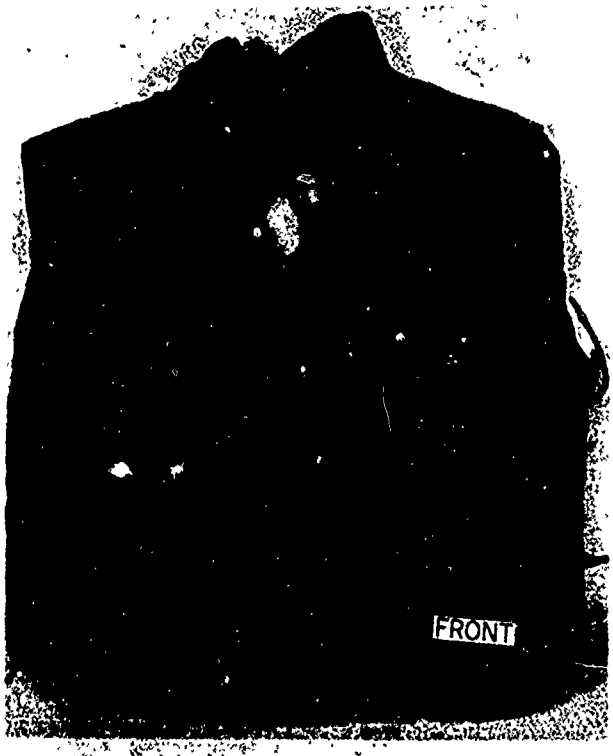
Figure A-6 (b)



SPALL EVALUATION
Test 2, Round 3
Test No. W153-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-246/AMC-69

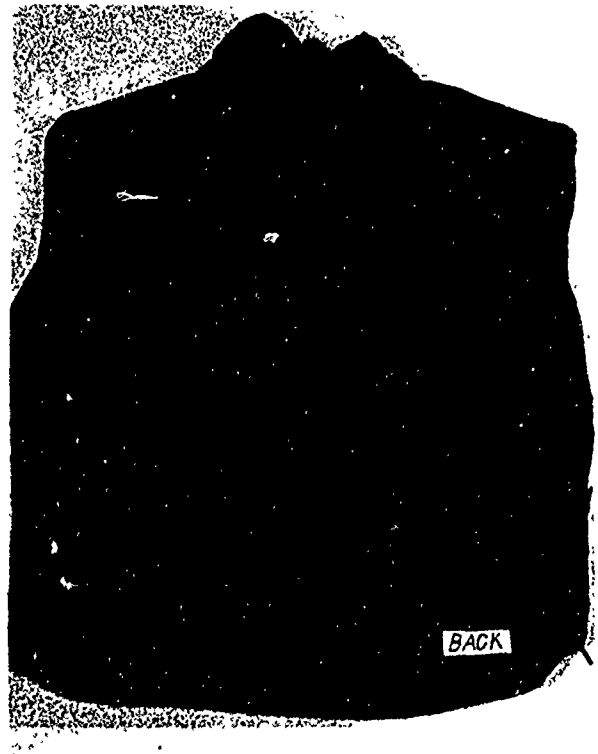
Figure A-6 (c)

Figure A-7 (a)

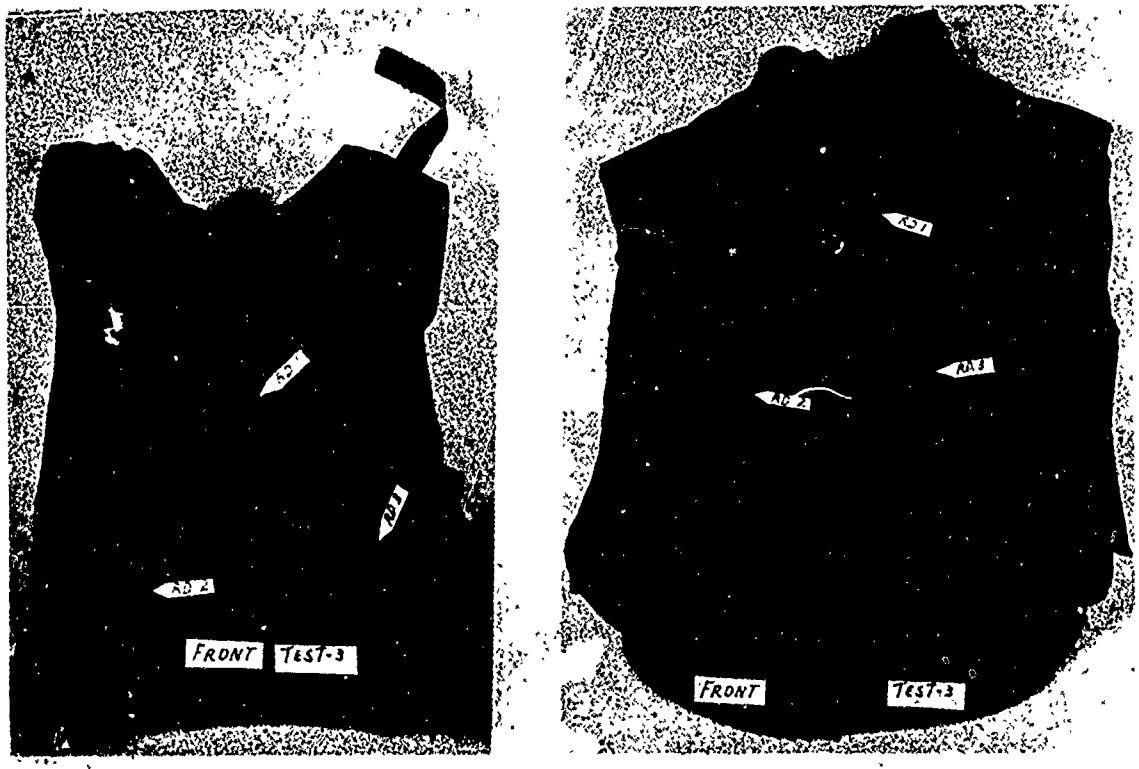


SPALL EVALUATION
No. 3 Armor, body, aircrewman, front, with wool felt insert and standard 12 ply nylon vest with 3/4 collar.
(Before firing)

Figure A-7 (b)



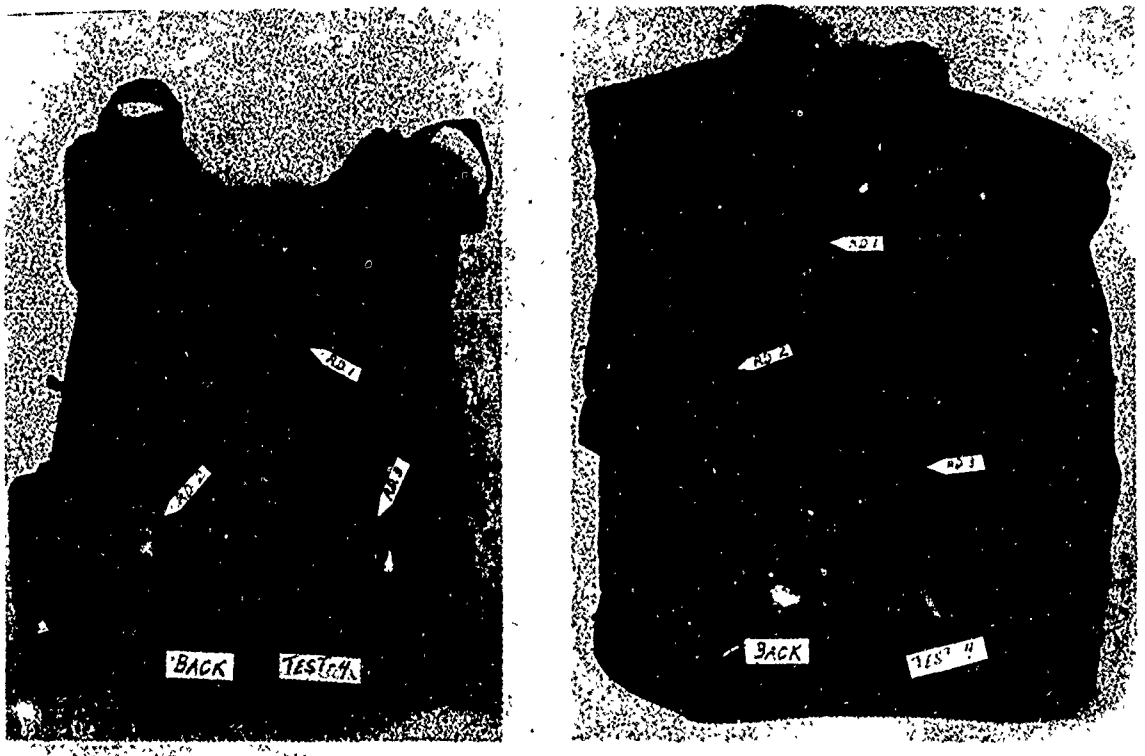
SPALL EVALUATION
No. 4 Armor, body, aircrewman, back, with wool felt insert and standard 12 ply nylon vest with 3/4 collar.
(Before firing)



SPALL EVALUATION
No. 3 Armor, Body, Aircrewman, Front,
with wool felt insert and
standard 12 ply nylon vest
with 3/4 collar.
Fired with caliber .30 AP M2
at 45 degrees obliquity.
Partial at 2697 ft/sec
Test No. W161-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

Figure A-7

(c) (d)



SPALL EVALUATION
No. 4 Armor, body, aircrewman, back, with wool felt insert and standard 12 ply nylon vest with 3/4 collar.
Fired with caliber .30 AP M2 at 45 degrees obliquity.
Partial at 2716 ft/sec
Test No. W162-69

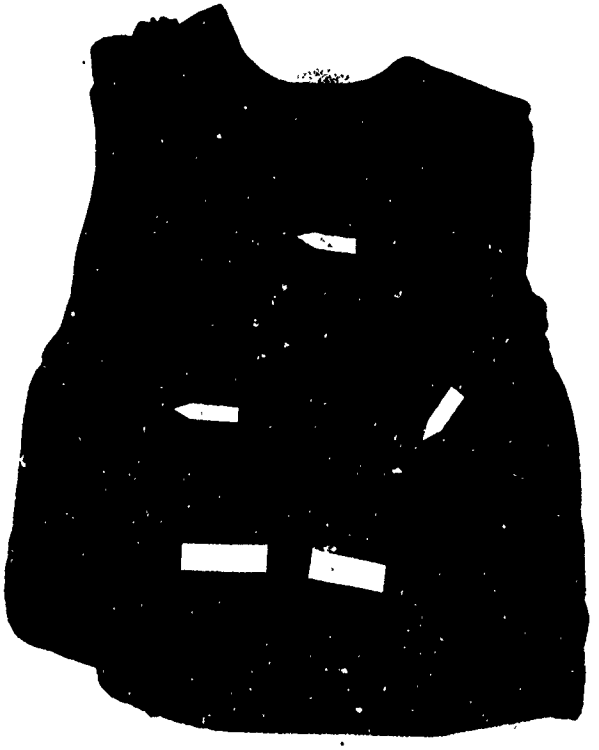
Figure A-7

(e) (f)

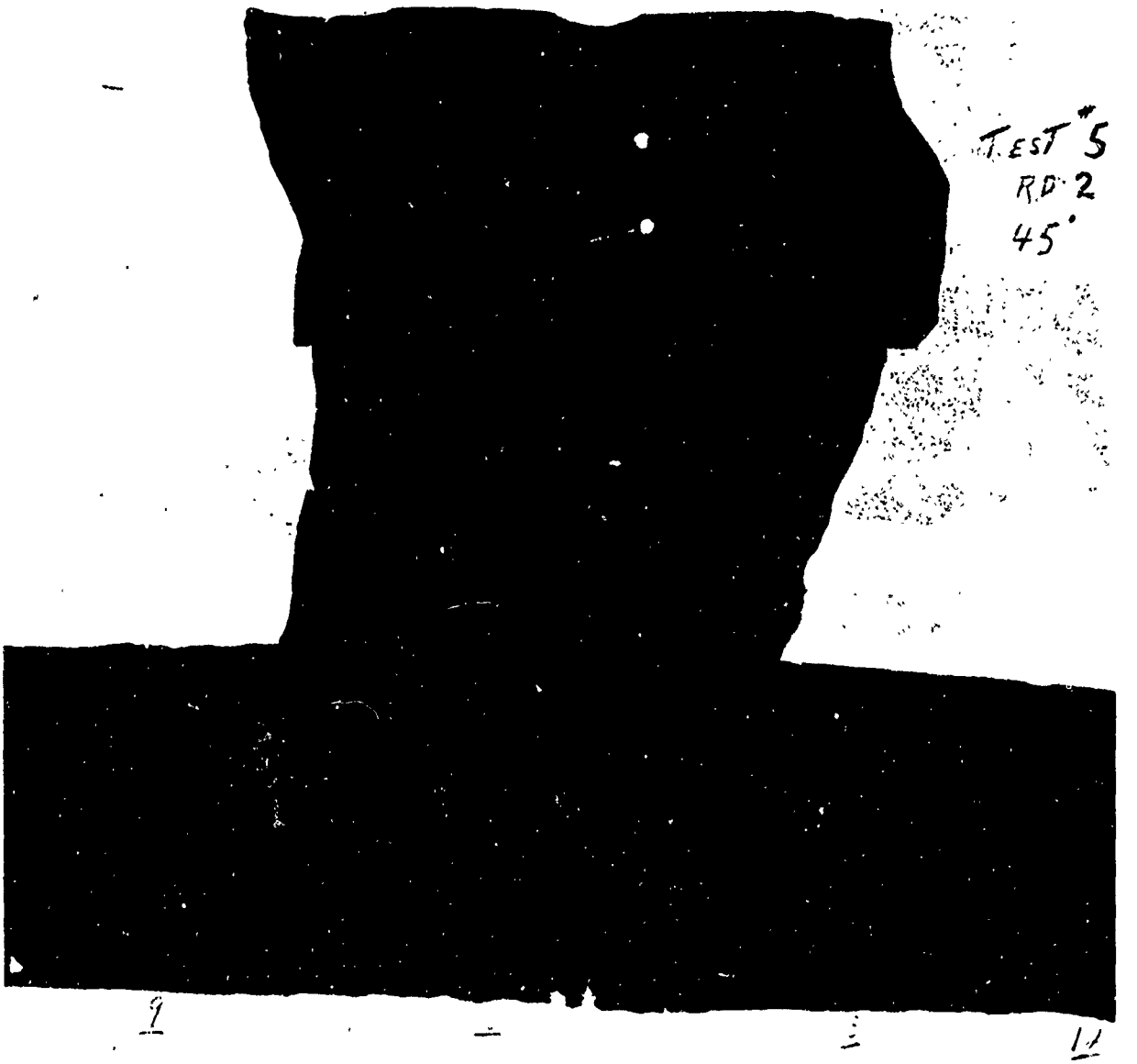
Figure A-8 (a)

SPALL EVALUATION
No. 5 Armor, body, aircrewman, front, integrated small arms and fragmentation protective with modified carrier and nylon felt insert.
(Before firing)

Figure A-8 (b)



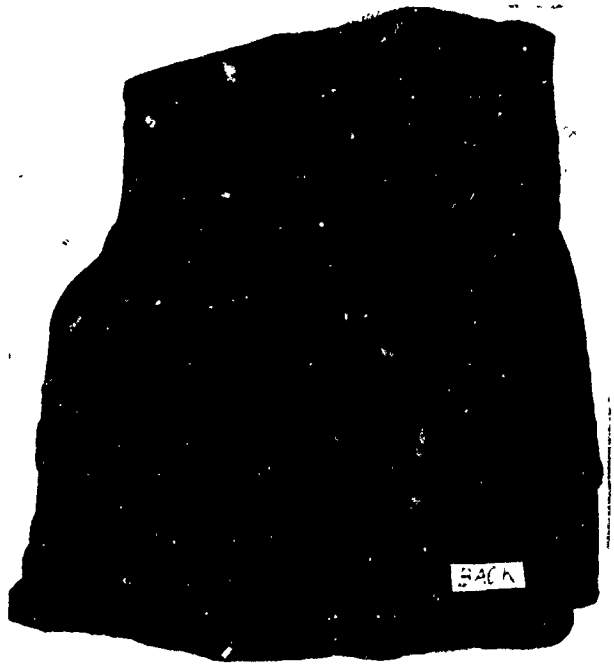
SPALL EVALUATION
No. 5 Armor, body, aircrewman, front, integrated small arms and fragmentation protective with modified carrier and nylon felt insert.
Fired with caliber .30 AP M2 at 45 degrees obliquity.
Partial at 2682 ft/sec
Test No. W165-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER



SPALL EVALUATION
Test 5, Round 2
Test No. W165-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-245/AMC-69

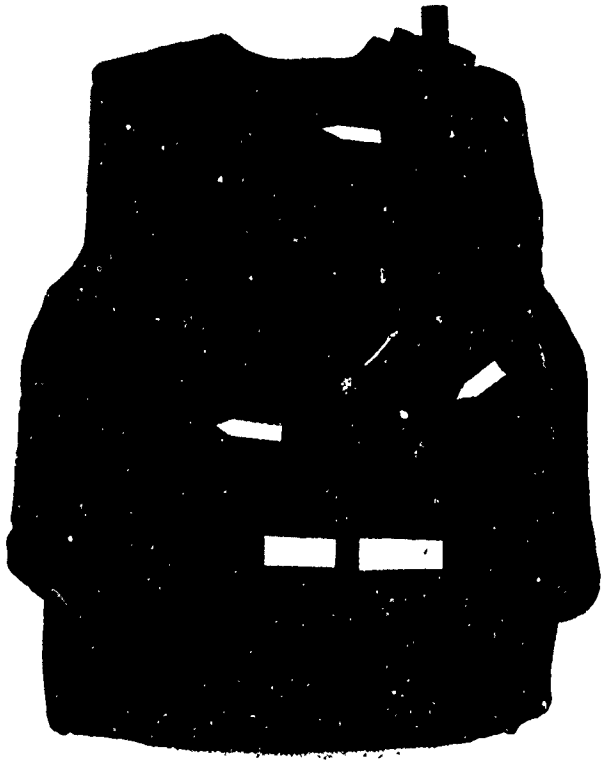
Figure A-9

Figure A-10 (a)



SPALL EVALUATION
No. 6 Armor, body, aircrewman, back, integrated small arms and fragmentation protective with modified carrier and nylon felt insert.
(Before firing)

Figure A-10 (b)



SPALL EVALUATION
No. 6 Armor, body, aircrewman, back, integrated small arms and fragmentation protective with modified carrier and nylon felt insert.
Fired with caliber .30 AP M2 at 45 degrees obliquity.
Partial at 2671 ft/sec
Test No. W167-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

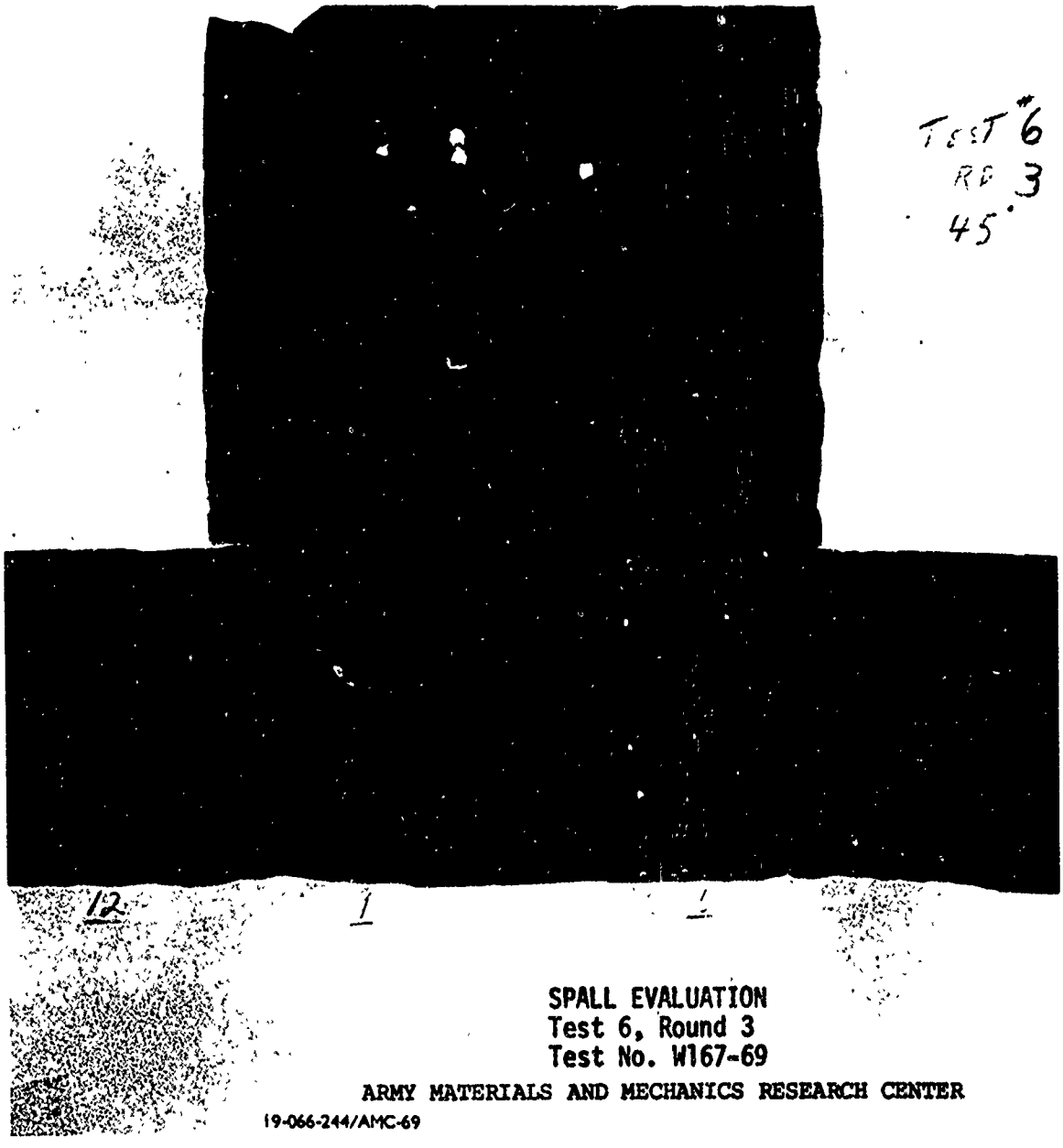
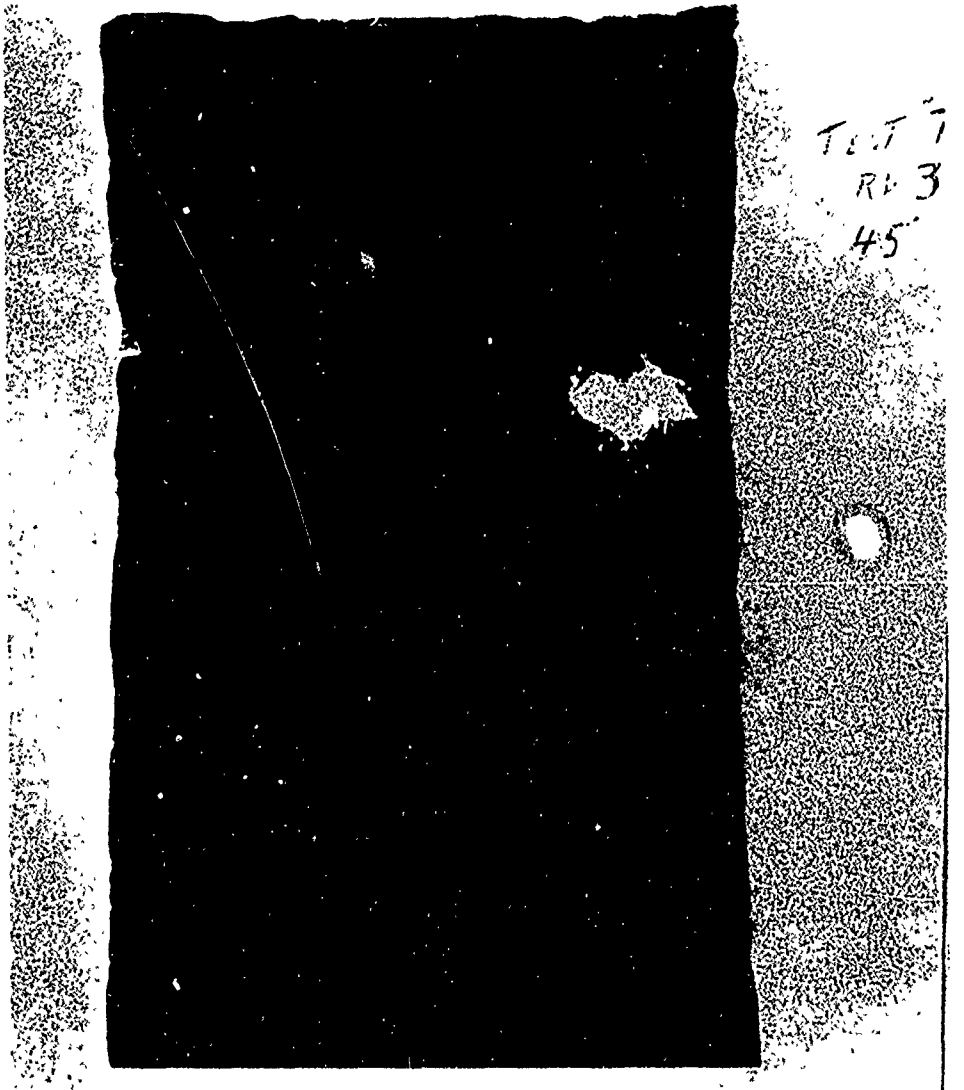

TEST #6
RD 3
45°
12
1
1
SPALL EVALUATION
Test 6, Round 3
Test No. W167-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-244/AMC-69

Figure A-11

SPALL EVALUATION
No. 7 Armor, body, aircrewman, front,
with nylon felt insert plus
standard 12 ply nylon vest
with 3/4 collar.
Fired with caliber .30 AP M2
at 45 degrees obliquity.
Partial at 2680 ft/sec
Test No. W170-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

Figure A-12

(a) (b)

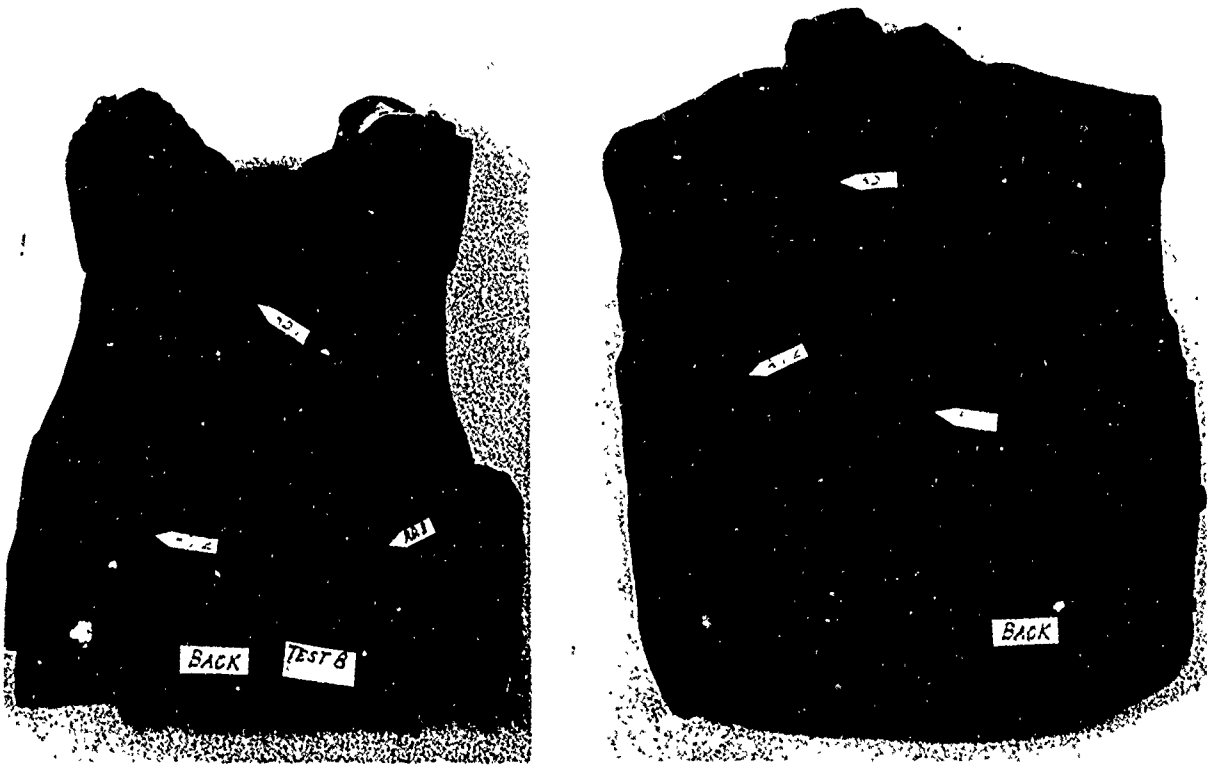


SPALL EVALUATION
Test 7, Round 3
Test No. 170-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

19-066-243/AMC-69

Figure A-13

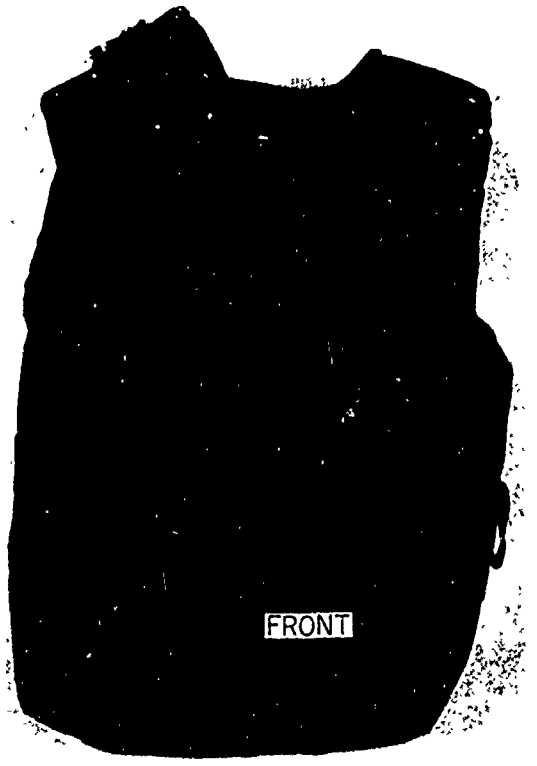


SPALL EVALUATION
No. 8 Armor, body, aircrewman, back,
with nylon felt insert plus
standard 12 ply nylon vest
with 3/4 collar.
Fired with caliber .30 AP M2
at 45 degrees obliquity.
Partial at 2682 ft/sec
Test No. W171-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

Figure A-14

(a) (b)

Figure A-15 (a)



SPALL EVALUATION
No. 9 Armor, body, aircrewman, front, integrated small arms and fragmentation protective. Modified carrier 4 ply ballistic nylon.
(Before firing)

Figure A-15 (b)

SPALL EVALUATION
No. 9 Armor, body, aircrewman, front, integrated small arms and fragmentation protective with modified carrier 4 ply ballistic nylon.
Fired with caliber .30 AP M2 at 45 degrees obliquity.
Partial at 2656 ft/sec
Test No. W173-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

SPALL EVALUATION
Test 9, Round 1
Test No. W173-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

19-066-242/AMC-69

Figure A-16 (a)

65

SPALL EVALUATION
Test 9, Round 2
Test No. 173-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

19-066-241/AMC-69

Figure A-16 (b)

SPALL EVALUATION
Test 9, Round 3
Test No. W173-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-240/AMC-69

Figure A-16 (c)

SPALL EVALUATION
No. 10 Armor, body, aircrewman, back, integrated small arms and fragmentation protective. Modified carrier 4 ply ballistic nylon.
(Before firing)

(a)

SPALL EVALUATION
No. 10 Armor, body, aircrewman, back, integrated small arms and fragmentation protective with modified carrier 4 ply ballistic nylon.
Fired with caliber .30 AP M2 at 45 degrees obliquity.
Partial at 2722 ft/sec
Test No. W174-69
ARMY MATERIALS AND MECHANICS RESEARCH CENTER

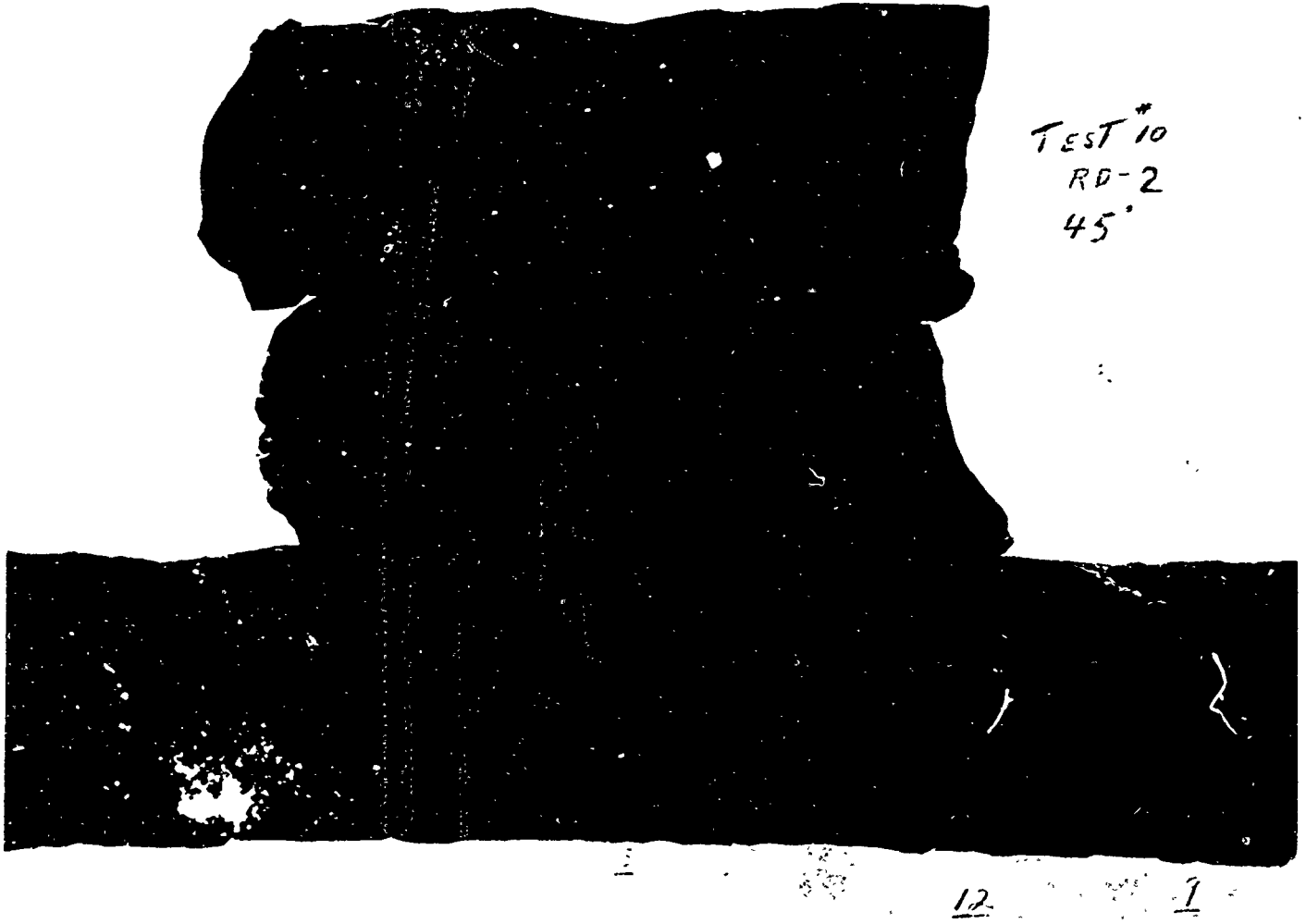
(b)

Figure A-17

SPALL EVALUATION
Test 10, Round 1
Test No. W174-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

19-066-239/AMC-69



SPALL EVALUATION
Test 10, Round 2
Test No. W174-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-238/AMC-69

Figure A-18 (b)

SPALL EVALUATION
Test 10, Round 3
Test No. W174-69

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
19-066-237/AMC-69

Figure A-18 (c)