AD NUMBER: AD0915745
LIMITATION CHANGES
TO: Approved for public release; distribution is unlimited.
FROM: Distribution authorized to U.S. Government agencies only; Test and Evaluation; DEC 1973. Other requests shall be referred to Air Force Materials Laboratory, Wright-Patterson AFB, OH 45433.
AUTHORITY
AFWAL ltr dtd 14 Feb 1983

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE [illegible]00.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

2

AFML-TR-73-248

AD915745

EXPLORATORY DEVELOPMENT LEADING TO IMPROVED MATERIALS FOR SELF-SEALING AIRCRAFT FUEL SYSTEMS

J. D. Ballentine
F. Geerligs
J. R. Kulesia

UNIROYAL, Incorporated

TECHNICAL REPORT AFML-TR-73-248

December, 1973

Distribution limited to U. S. Government agencies only; (test and evaluation); (December, 1973). Other requests for this document must be referred to the Air Force Materials Laboratory, Nonmetallic Materials Division, Elastomers and Coatings Branch, AFML/LNE, Wright-Patterson Air Force Base, Ohio 45433.

AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AFB, OHIO 45433

NOTICE

AFML-TR-73-248

EXPLORATORY DEVELOPMENT LEADING TO IMPROVED MATERIALS FOR SELF-SEALING AIRCRAFT FUEL SYSTEMS

J. D. Ballentine
F. Geerligs
J. R. Kulesia

FOREWORD

This report was prepared by UNIROYAL, Incorporated, Engineered Systems Department, Mishawaka, Indiana, under United States Air Force Contract F33615-71-C-1526. The contract work was performed under project No. 7340, "Nonmetallic and Composite Materials", Task No. 734005, "Elastomers and Compliant Materials", and was administered under the direction of the Elastomers and Coatings Branch, Nonmetallic Materials Division of the Air Force Materials Laboratory, with Mr. T. L. Graham (MBE) as the Project Engineer.

This report covers work performed during the period 1 June 1971 to 1 July 1973. Report Number 73-490-C-1462, 1463, 1464, 1465 - Final Report has been assigned for internal control.

The program at UNIROYAL was conducted under the direction of R. C. Kohrn and his successor Dr. C. T. Chmiel, Manager of the Engineered Systems Laboratory, with J. D. Galloway serving as Project Manager, W. R. Birkey and F. Geerligs as Supervising Chemists, and J. D. Ballentine, E. J. Martens, and J. R. Kulesia as Chemists. Product Engineer was R. E. Dorsch. Laboratory assistance was given by L. J. Parker and K. A. Cannoot.

This technical report has been reviewed and is approved.

MERRILL L. MINGES, Chief
Elastomers and Coatings Branch
Nonmetallic Materials Division
Air Force Materials Laboratory

ABSTRACT

Self-sealing fuel cell constructions were developed with improved capability for sealing wounds inflicted by .50 caliber and 14.5 mm. armour piercing incendiary projectiles but at an increase in weight penalty. All attempts to develop a high temperature (350°F) stable, reliable self-sealing elastomeric fuel cell materials composite were thwarted because of poor adhesion at elevated temperature. Although preliminary screening tests on small specimens pinpointed effective adhesives for bonding candidate high temperature sealants to the fabric reinforced fluoroelastomer cell components, the large test panel composites prepared developed flaws in adhesion on exposure to high temperature and performed unsatisfactorily when gunfire tested for self-sealing reliability at room temperature. After an extensive materials investigation, the effort to develop a lightweight non-flowering self-sealing fuel line resulted in the development of a high density polyethylene tube shielded with a conventional self-sealing fuel line cover materials composite. Gunfire evaluations of this lightweight fuel line materials construction showed it to be effective in sealing wounds inflicted by .50 caliber armour piercing projectiles.

TABLE OF CONTENTS

Section	Title	Page
I	Introduction	1
II	Incendiary Resistant Constructions	3
III	High Temperature Resistant Fuel Cells	9
IV	Self-Sealing Fuel Line Development	23
	A. Damage Control Materials	23
	B. Integral Self-Sealing Fuel Lines	69
	C. Nonmetallic Fuel Lines	80
	D. New Sealants and Reinforcements	97
	E. Fuel Loss Measurement	122
V	Literature Review	124
VI	Conclusions	125
VII	Recommendations	127
	Appendix I - Construction of Incendiary Resistant Test Panels and Test Cells	128
	Appendix II - Details of High Temperature Resistant Fuel Cell Panels	132
	Appendix III - Details of Construction of Experimental Fuel Lines and Fuel Line Covers	135
	Appendix IV - Bibliography	139

PRECEDING PAGE BLANK-NOT FI

LIST OF ILLUSTRATIONS

Figure Number	Title	Page
1	Self-Sealing Construction US-173 After Exposure to Gunfire with Two Rounds of 0.50 Cal. API Ammunition	7
2	US-664 Backing Board After Exposure to Gunfire with 0.50 Cal. API Ammunition	8
3	US-173 Panel Temperature vs. Time at 350° F	21
4	Panel of US-173 Self-Sealing Construction After Exposure to 350° F and Gunfire with 0.50 Cal. AP Projectiles	22
5	Plain Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2	37
6	Plain Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2	38
7	Plain Aluminum Tube, Showing Entrance of 0.30 Cal. AP projectile, Round 3	39
8	Plain Aluminum Tube, Showing Exit of 0.30 Cal. AP Projectile, Round 3	40
9	Butadiene Acrylonitrile Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	41
10	Butadiene Acrylonitrile Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	42
11	Butyl Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	43
12	Butyl Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	44
13	Butyl Rubber Covered Aluminum Tube, Showing Entrance of 0.30 Cal. AP Projectile, Round 4	45
14	Butyl Rubber Covered Aluminum Tube, Showing Exit of 0.30 Cal. AP Projectile, Round 4	46
15	Steel Fiber Reinforced Styrene Butadiene Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	47

LIST OF ILLUSTRATIONS (Cont'd.)

Figure Number	Title	Page
16	Steel Fiber Reinforced Styrene Butadiene Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	48
17	Silicone Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	49
18	Silicone Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	50
19	Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 5	51
20	Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 5	52
21	Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 3 and 4	53
22	Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 3 and 4	54
23	Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2	55
24	Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2	56
25	Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 3 and 4	57
26	Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 3 and 4	58
27	Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2	59

LIST OF ILLUSTRATIONS (Cont'd)

Figure Number	Title	Page
28	Aluminum Tube Covered with One Ply 43.45 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2	60
29	Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances and Exits of 0.30 Cal. AP Projectiles, Rounds 3 and 5, Both of Which Were Glancing Shots	61
30	Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrance and Exit of 0.30 Cal. AP Projectile, Round 4, Which Was a Glancing Shot	62
31	Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2	63
32	Aluminum Tube Covered with One Ply of 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2	64
33	Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	65
34	Aluminum Tube Covered with Two Plies 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3	66
35	Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2	67
36	Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2	68

Figure Number	Title	Page
37	Integral Fuel Lines ASN 961-1 and ASN 961-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Entrance Side.	74
38	Integral Fuel Lines ASN 961-1 and ASN 961-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Exit Side.	75
39	Entrance Wound From Round 1 in Integral Fuel Line ASN 961-1	76
40	Exit Wound From Round 1 in Integral Fuel Line ASN 961-1	77
41	Integral Fuel Line ASN 970 and Silicone Sealant Fuel Line Cover ASN 988 After Gunfire with 0.50 Cal. AP Ammunition. Entrance Side.	78
42	Integral Fuel Line ASN 970 and Silicone Sealant Fuel Line Cover ASN 988 After Gunfire with 0.50 Cal. AP Ammunition. Exit Side.	79
43	Delrin Tube After Gunfire with 0.50 Cal. AP Round	87
44	Entrance Wound Produced by 0.50 Cal. AP Round in Nylon Tube	88
45	Exit Wound Produced by 0.50 Cal. AP Round in Nylon Tube	89
46	Entrance Wound Produced by 0.50 Cal. AP Round in Polyethylene Tube	90
47	Exit Wound Produced by 0.50 Cal. AP Round in Polyethylene Tube	91
48	Inside of Nonmetallic Fuel Line ASN 1021 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition	92
49	Nonmetallic Fuel Lines ASN 1031 and ASN 1032 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.	93
50	Nonmetallic Fuel Lines ASN 1031 and ASN 1032 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.	94
51	Nonmetallic Fuel Lines ASN 1044-1 and ASN 1044-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Entrance Side.	95

Figure Number	Title	Page
52	Nonmetallic Fuel Lines ASN 1044-1 and ASN 1044-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Exit Side.	96
53	Fuel Line Covers ASN 981 and ASN 979 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.	111
54	Fuel Line Covers ASN 981 and ASN 979 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.	112
55	Neoprene Sealant Fuel Lines ASN 989-1 and ASN 989-2 After Gunfire with 0.50 Cal. AP Ammunition. Entrance Side.	113
56	Neoprene Sealant Fuel Lines ASN 989-1 and ASN 989-2 After Gunfire with 0.50 Cal AP Ammunition. Exit Side.	114
57	Fuel Line Covers ASN 976-1 and ASN 976-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.	115
58	Fuel Line Covers ASN 976-1 and ASN 976-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.	116
59	Inside of Fuel Line ASN 1006 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition.	117
60	Inside of Fuel Line ASN 1022 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition	118
61	Inside of Fuel Line ASN 994-4 After Gunfire with 0.50 Cal. AP Ammunition	119
62	Fuel Line Covers ASN 982 and ASN 1012 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.	120
63	Fuel Line Covers ASN 982 and ASN 1012 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal AP Ammunition. Exit Side.	121
64	Fuel Loss Measuring Apparatus	123

SECTION I

INTRODUCTION

In a combat situation aircraft are often struck by shrapnel or small arms fire. In many instances projectiles will penetrate the fuel system causing loss of fuel and possible fire hazards.

Self-sealing fuel containers of rubber and fabric have been available for over thirty years. Several manufacturers supply these containers and have steadily improved their sealing ability while at the same time reducing their weight and thickness. In more recent years self-sealing covers have been developed for fuel lines and other pressurized components of the fuel system.

While both fuel containers and fuel line covers have been developed to a high state, several problem areas remain. These include:

1. Aircraft are flying at speeds where aerodynamic heating is significant. This heat will often cause the premature aging and deterioration of the elastomers and fabrics of fuel containers.

2. Current fuel container and fuel line cover constructions are qualified for protection against 0.50 caliber AP ammunition. The Air Force is interested in constructions which will seal wounds caused by the Russian 14.5 mm API round which causes much more extensive damage due both to its high energy and to its incendiary action.

3. Fuel line covers have to withstand both the pressure of the fuel and the damage caused by distortion of the metal fuel line induced by the passage of the bullet. Fuel pressure effects are reduced by the use of a high strength outer ply on the cover and metal "flowering" is overcome by the use of elastomeric sealant plies of sufficient thickness to extend beyond the area of distortion. More efficient covers which would not require as much sealant to overcome petals and would use lighter weight outer ply materials could reduce the weight and volume penalties to aircraft which employ them.

The object of this contract was the study of various proposed solutions to these problems. Efforts were made to develop fuel container constructions resistant to deterioration at temperatures of 350° F and to develop constructions which would seal wounds caused by incendiary projectiles. Other efforts were aimed toward improving the sealing performance of fuel covers both through damage reducing plies added to standard constructions and through development of plastic or elastomeric fuel lines which do not contain metal to distort into sharp petals upon gunfire.

The research and development were conducted in three phases:

Phase I - Literature Search and Review of Past Work

Phase II - Experimental Evaluation

Phase III - Documentation

SECTION II

INCENDIARY RESISTANT CONSTRUCTIONS

In order to gain familiarity with incendiary gunfire and establish a suitable procedure for experimental tests, a program of gunfire on conventional fuel cell constructions was first undertaken.

The initial incendiary gunfire trial was performed under these conditions:

1. 0.50 caliber gun positioned 75 feet from gunfire structure.

2. 7075 T6 aluminum plate 0.25 inches thick positioned 6 inches in front of gunfire structure.

3. US-664 backing board and US-173 self-sealing construction panels in gunfire structure filled with water.

4. 0.50 caliber armor piercing incendiary ammunition supplied by Air Force.

Five 0.50 caliber API rounds were fired into the gunfire structure. Activation of incendiary material occurred just beyond the striker plate but before entering the structure as shown by burned edges on backing board wounds. Entrance wounds in the US-173 self-sealing panels and US-664 backing board were as follows:

Round Number	Wound Size In Inches	
	US-173	US-664
1	0.7 x 1.2	1.1 x 1.5
2	0.7 x 1.2	0.7 x 1.4
3	0.5 x 1.0	0.6 x 1.2
4	0.5 x 1.5	0.7 x 1.5
5	0.5 x 0.6	1.0 x 1.0

Figures 1 and 2 illustrate the severe damage to the self-sealing panel and the backing board caused by incendiary gunfire. Such damage is beyond the capability of known self-sealing constructions for sealing action.

When the backing board and self-sealing panels were examined closely, they were found to have many sharp fragments of the aluminum striker plate embedded in them. It was felt that much of the damage to the backing board and self-sealing panel was caused by this shrapnel. Based on a published report of the Northrop Corporation, it was determined that a 0.125 inch thick 7075 T6 aluminum plate supported 5 feet from the structure would activate the incendiary material without producing a large amount of shrapnel. In this way, it was hoped, damage caused by the activated incendiary projectile could be studied without additional damage from striker plate shrapnel interfering.

A second incendiary gunfire was therefore carried out identically to the first except for the use of a 0.125 inch thick 7075 T-6 aluminum plate positioned 5 feet in front of the gunfire structure as a striker plate. Tests with cardboard panels had shown that this arrangement caused activation of the incendiary mixture approximately 2.5 feet in front of the target structure. US-664 backing board and US-173 self-sealing panels gunfired with this arrangement showed no aluminum fragments embedded in them after gunfire. Damage to the backing board and self-sealing panel was assumed to have been caused solely by the bullets.

In discussion with AFML personnel it was decided that the damage to fuel cell panels from 0.50 caliber API projectiles is too severe for satisfactory self-sealing action. Therefore, 0.30 caliber API ammunition was ordered and further gunfire of self-sealing panels was performed with this ammunition.

Twenty-four self-sealing panels were fabricated for evaluation of incendiary gunfire resistance. Variables studied were:

1. Number of reinforcement plies

   a) three
   b) four
   c) five

2. Type of reinforcement

   a) Nylon tire cord (UNIROYAL code numbers 314-76-999 and 314-76-904)

   b) Unituff nylon fabric, 3 harness, 17 oz/yd^2 (D-70-527-60)

   c) Unituff nylon fabric, 7 harness, 25 oz/yd^2 (D-70-528-58)

   d) Square woven nylon fabric, 30 oz/yd^2, (D-69-531)

Twelve combinations of the two variables were considered:

	Nylon Tire Cord	Unituff Fabric 15 oz/yd^2	Unituff Fabric 25 oz/yd^2	Sq. Woven Nylon 30 oz/yd^2
3 plies	806-1	806-2	806-3	806-4
4 plies	806-5	806-6	806-7	806-8
5 plies	806-9	806-10	806-11	806-12

Each of the fabrics was calendered with an equal amount of elastomer, and these coated fabrics were assembled with identical amounts of sealant rubber, elastomeric innerliner, and cements to make 36" x 36" fuel cell panels. Two of each of the possible constructions were fabricated. Appendix I, page gives details of the composition of each construction.

These panels were gunfired with 0.30 caliber API ammunition. An aluminum striker plate was positioned 4½ feet in front of the test panel. Activation of the incendiary material occurred immediately beyo. the striker plate and projectiles were burning when they entered the test panels.

The test structures were filled with water. None of the projectiles exited from the structure.

Wounds on the test panels varied in severity from large open holes to small slits. Because the test structures were filled with water rather than fuel, sealing performance could not be evaluated. Panels were rated on their resistance to mechanical damage. This rating was subjective and based on both the size of wounds on each panel and the ability of the panel to hold back the shrapnel from the metal jacket of the API projectile.

The constructions with the highest rating were ASN 806-4 and ASN 806-12. More of the 30 oz/yd^2 square woven fabric which was used in these constructions was ordered. This fabric was calendered with nitrile rubber and used to fabricate standard 2½' x 2½' x 2½' test "cubes" of constructions ASN 806-4 and ASN 806-12.

These cubes were placed in standard test structures with US-664 backing board and aluminum ribbed panels. Because of the aluminum ribbed panels, it was not felt that a striker plate would be needed for gunfire. Firing into the ribbed panel (which is designed to simulate the normal aircraft structure surrounding a fuel cell) was felt to more closely simulate the gunfire experience of actual aircraft than the use of a striker plate several feet removed from the fuel cell cube.

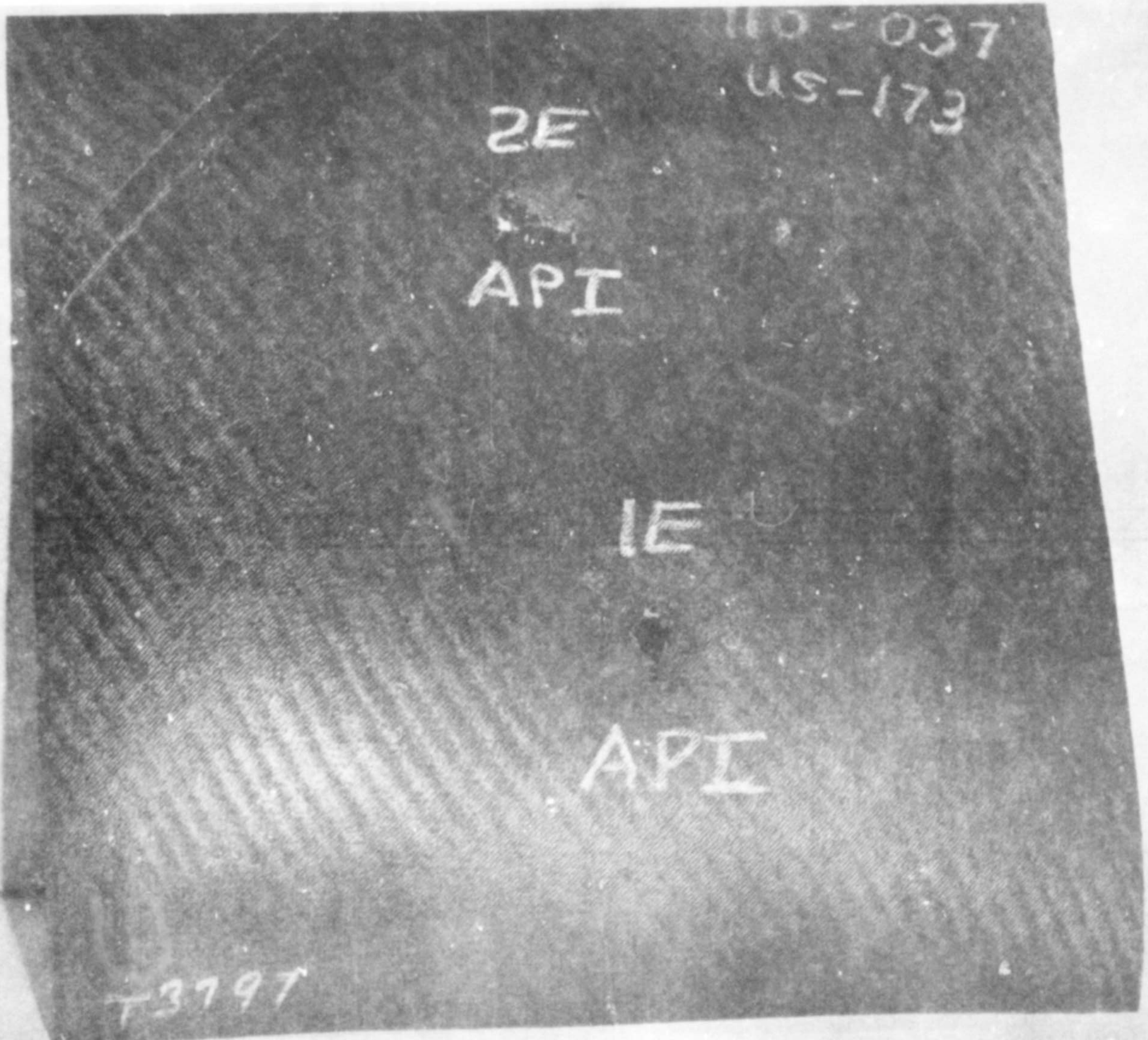
The test cubes were filled with Type I test fluid and gunfired with 0.50 caliber API ammunition. Cube ASN 1028-1 (same construction as panel ASN 806-4) was gunfired first. Two rounds were fired straight into the cube. Both produced entrance wounds which sealed immediately and no exit wounds. Two more rounds were fired through an aluminum striker plate 4½ feet in front of the cube to produce tumbled rounds. The first of these rounds produced an entrance wound which sealed immediately and no exit wound. The second tumbled round entered the cube after passing through one of the ribs of the aluminum panel. The entrance wound did not seal completely but seeped fuel slightly; there was no exit wound.

The cube ASN 1028-2 (same construction as panel ASN 806-12) was gunfired next. The first round was a straight shot which produced an entrance wound that sealed immediately and no exit wound. The second round was fired into the cell at a 45° angle to the surface. This produced an entrance wound which leaked heavily and an exit wound which seeped fuel. Gunfire was terminated at this time because of the fire hazard caused by the heavy fuel loss from the entrance wound.

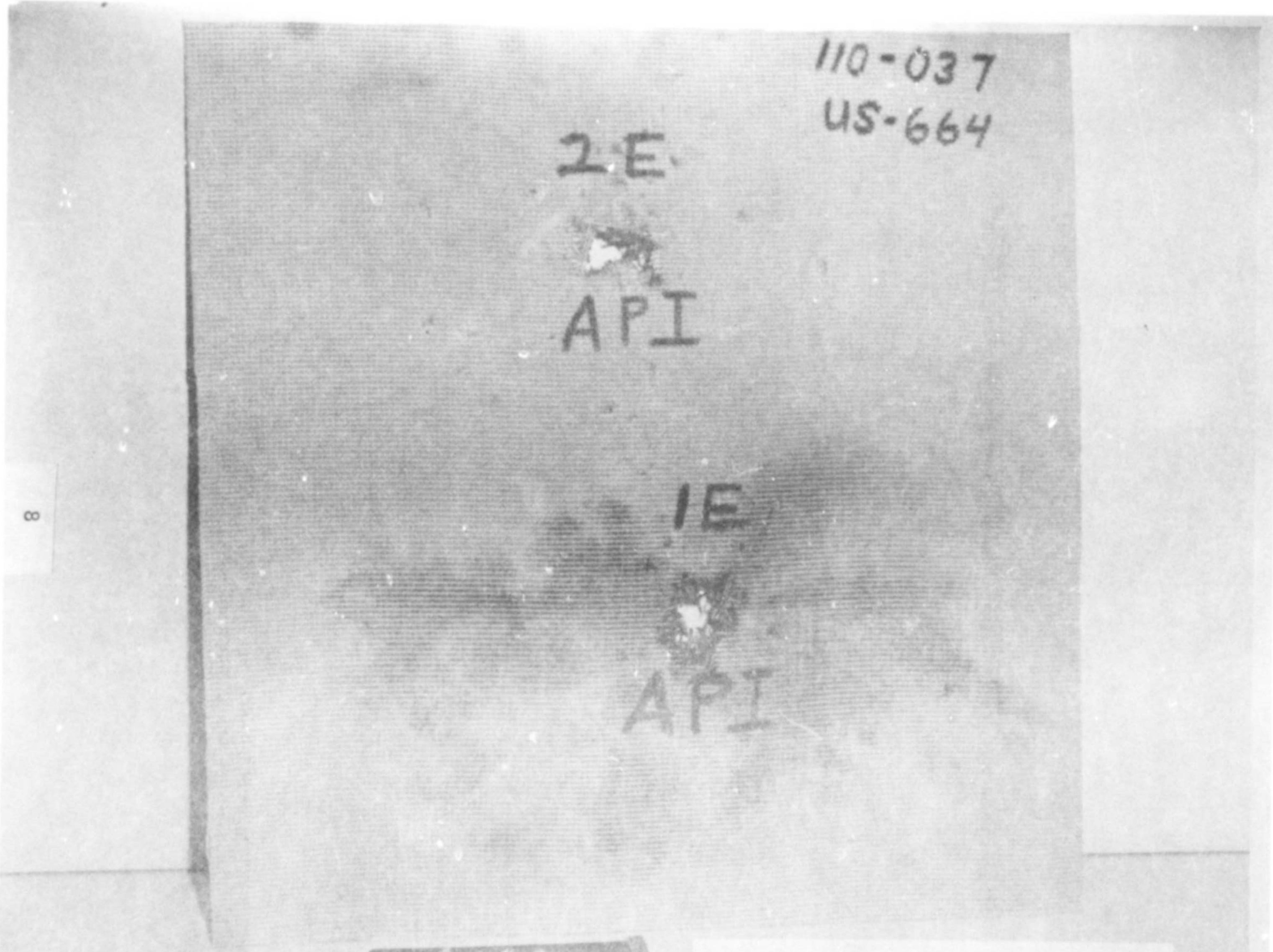
The two cubes were dried out and cleaned and the gunfire wounds patched. The patched cubes were placed in gunfire structures with US-664 backing board and aluminum ribbed panels and filled again with Type I test fluid. Gunfire was then carried out using Russian 14.5 mm API B-32 ammunition supplied by the Air Force. Cube ASN 1028-1 was fired first with four rounds. Round number one was a straight shot which produced an entrance wound that sealed immediately and an exit wound that seeped fuel. Round number two was a straight shot which gave an entrance wound that sealed immediately and an exit wound that seeped slightly. Round number three was a straight shot which produced an entrance wound that sealed immediately and an exit wound that seeped slightly. Round number four was a straight shot which produced an entrance wound that seeped slightly and an exit wound that also seeped slightly.

Cube ASN 1028-2 was gunfired next. The first round was a straight shot which produced an entrance wound that sealed immediately and an exit wound that sealed immediately. The second round was also a straight shot producing entrance and exit wounds that sealed immediately. Round number three was fired into the cube at an angle of 45^o to the front surface. This round produced an entrance wound that sealed immediately and an exit wound that started as a small stream of fuel but slowed to a seep in one minute.

The gunfire performance of these cubes leads to the conclusion that practical 0.50 caliber and 14.5 mm API resistant fuel cell constructions can be developed along the lines of constructions ASN 806-4 and -12.



Photograph No. 1 - Self-Sealing Construction US-173 After Exposure to Gunfire with Two Rounds of 0.50 Cal. API Ammunition



Photograph No. 2 - US-664 Backing Board After Exposure to Gunfire with 0.50 Cal. API Ammunition

SECTION III

HIGH TEMPERATURE RESISTANT FUEL CELLS

The objective of this section of the contract was the development of a self-sealing fuel cell construction which retains its sealing ability after exposure to 350° F temperature. At the same time this construction must have adequate flexibility and sealing ability at temperatures down to -40° F and have sufficient fabric to rubber adhesion to be a practical fuel container.

In order to determine a basis for comparison, the useful life of a conventional fuel cell construction at 350° F was determined. The first tests were performed on conventional, natural rubber sealants. Samples of UNIROYAL 3083 and 3082 sealants were wrapped in aluminum foil and exposed to 350° F in an oven for various lengths of time. After heat aging, the tensile strength, percent elongation at break, and volume swell in Type III test fluid were determined. Table I gives the results of these tests. It can be seen that even one hour exposure to 350° F causes a drastic reduction in the strength of natural rubber sealants.

To determine the effect of 350° F aging on an actual fuel cell construction, a panel of US-173 material was sandwiched between two aluminum plates and heated in a 350° F oven. A thermocouple was placed on the surface of the panel to determine the actual temperature reached. Figure 3 shows that the panel surface did not reach the temperature of the oven until it had been exposed for approximately one hour. The panel was then held at this temperature for one more hour. After cooling, the panel was found to be severely blistered and delaminated as can be seen from Figure 4.

A second panel was placed in the oven for one hour with the panel surface just reaching 350° F at the end of the hour. After cooling, the panel was found to be blistered and delaminated but to a lesser extent than the first panel.

A third panel was placed in the 350° F oven for thirty minutes. The panel surface reached a temperature of 325° F at the end of the thirty minutes. After cooling, the panel was found to have a few small blisters on its surface but no extensive delamination between plies.

The three US-173 panels that were aged at 350° F and one unaged US-173 panel were gunfired with 0.50 caliber AP ammunition to determine the effect of high temperature aging on sealing performance.

Table II gives results of this gunfire test. It is apparent that 350° F aging has a deleterious effect on sealing performance. The effect is most noticeable in the severe tumbled entrance wounds. While the unaged panel sealed such a wound in two minutes, the panel heated for ½ hour required three minutes to seal, that exposed for one hour took 5.5 minutes, and that exposed for two hours required 8 minutes to seal a similar wound.

From these results, it was concluded that the useful life of US-173 in a 350° F environment is less than one hour. Therefore, all high temperature aging tests required for this contract were performed using one hour heating in an oven at 350° F as a base line exposure.

Previous work on contract No. F33615-67-C-1720 had shown that the following materials have potential for use in high temperature fuel cell constructions:

a) Viton B as a fuel resistant coating in place of Acrylonitrile-butadiene elastomers used in conventional cells.

b) Nomex tire cord as a substitute for nylon tire cord reinforcements.

c) Silastic 1125U silicone elastomer as a substitute for material rubber sealants.

In previous work great difficulty had been encountered in attempts to adhere the three components to each other. Work was initiated in searching for suitable adhesives. A UNIROYAL proprietary system was evaluated for bonding Viton B to the Nomex reinforcing fibers. The system, using UNIROYAL 3267 adhesive, produced rubber to fabric peel adhesion strengths in excess of 50 lbs/in. Appendix II gives a description of the materials used and the methods by which adhesion samples were fabricated and tested. Because of the excellent adhesion obtained with this system, it was chosen for use in all further development work.

The problem of obtaining good adhesion between silicone rubber sealant and Viton was expected to be much greater. It was decided to evaluate other elastomers as possible high temperature sealants in hope that one might be found which would combine good sealing performance after high temperature aging with satisfactory adhesion to Viton. Materials were chosen from elastomer types known to have better heat aging resistance than natural rubber. Formulas were written using a low concentration of curing agents to give a cured rubber with a high degree of swell in fuel with sufficient cross-linking to prevent the rubber from dissolving.

The elastomers which were evaluated as sealants were:

1. Butyl HT 1066 (chlorobutyl rubber)
2. Butyl GRI 365 (butyl rubber)
3. Neoprene W (polychloroprene rubber)
4. Royalene 301 (EPDM rubber)
5. Royalene 512 (EPDM rubber)
6. Silastic 1125U (silicone rubber)

Appendix II gives the formula of each elastomer. Table III shows the results of swell determinations in Type III test fluid for each elastomer. The condition of each compound after exposure to 350° F for 24 hours wrapped in aluminum foil is also given.

Examination of the swell and heat aging data showed that the most promising sealants were:

D - Butyl GRI 365
H - Royalene 301
I - Royalene 301
J - Royalene 301
K - Royalene 301
L - Silastic 1125U

In addition, standard 3083 natural rubber sealant was compounded with the addition of 0.5 parts per hundred of rubber of TUEX (tetramethyl thiuram disulfide) as a high temperature stabilizer. When a specimen of this compound was exposed to the 24 hour heat aging test, the rubber deteriorated beyond evaluation. This compound was eliminated from further evaluation.

The remaining candidate elastomers were next evaluated for adhesion to Viton coated Nomex. The adhesives evaluated were:

1. UNIROYAL Viton Adhesion 101143
2. Organoceram Viton Adhesive 6-1023
3. Fairprene 5149
4. Chemlok 607
5. Chemlok 607 plus Fairprene 5149

Table IV gives the results of the adhesion tests.

Based on the adhesion test data, the best sealant/adhesive combinations were determined to be:

1. Butyl HT 1066 + Fairprene 5149
2. Butyl GRI 365 + Chemlok-Fairprene
3. Royalene 301 + Fairprene 5149
4. Royalene 512 + Fairprene 5149
5. Silastic 1125U + Chemlok-Fairprene

Each of these sealant-adhesive combinations was evaluated further by being bonded to Viton coated Nomex, wrapping the composite in aluminum foil, and placing in a 350° F oven for 24 hours. Results of this test are given in Table V. All of the composites were found to have adequate adhesion after heat aging.

Two 36" x 36" panels were fabricated of each sealant-adhesive combination by bonding a Viton coated Nomex tire cord to one side and a Viton coated square woven fabric to the other. Each panel was cured and post-cured in a vacuum blanket.

Several of the panels showed puffed-up areas after post-cure. It is believed that these were caused by gasses formed in the sealant during post-cure which were unable to escape through the cured Viton coatings on both sides of the sealant.

After post-cure the panels were trimmed to size and bolted onto a gunfire structure. The structure was filled with fuel and 0.30 caliber AP projectiles were fired into the panels. Results of the gunfire test are given in Table VI. None of the panels appeared to have adequate gunfire resistance for practical fuel cell constructions.

Post-gunfire evaluations showed that those constructions that were "puffy" deteriorated upon contact with fuel and in some cases delaminated. In all panels it was found that the Viton coated tire cord material developed large holes at gunfire wounds and thus failed to adequately support the sealant for self-sealing action.

Because of the lack of success with Viton coated constructions, it was agreed in discussions with the Project Engineer that experiments should be done on fluorosilicone elastomers because of their reported resistance to hydrocarbon fuels and elevated temperatures. After study of the literature, Dow Corning Silastic LS-2249U was selected for evaluation.

The elastomer was compounded with the proper curative and calendered onto Nomex tire cord. It was found that this elastomer was extremely difficult to handle in mixing and calendering. The tire cord could be calendered on one side only as any attempt to coat the second side would cause the rubber on the first side to peel off.

Eventually a few small pieces of coated tire cord were produced. These were laminated to Silastic 1125U coated tire cord and the composites cured in a hot air oven, a vacuum bag, or a press. Each of the composites was then post-cured in a hot air oven. At the end of post-cure the flurosilicone elastomer was found to be very soft and low in strength. Adhesion values are given in Table VII. It can be seen that the flurosilicone-silicone system requires much more development if it is to be practical for fuel cell use.

Because of the lack of suitable processing methods and the high price of the elastomer, it was decided that further work on high temperature resistant fuel cell constructions would be beyond the scope of this contract. We believe that a high temperature elastomer with better processing characteristics than fluorosilicone and greater ballistic impact resistance than Viton is needed.

TABLE I

HIGH TEMPERATURE AGING
OF CONVENTIONAL SEALANTS

	3082 Sealant Time at 350° F in Hours					
	0	1	2	4	8	24
Tensile Strength, psi	415	250	187	121	120	52
Elongation at Break, %	700	915	775	735	815	590
Volume Swell in Type III Test Fluid, %:						
1 min.	24.1	19.2	11.4	16.2	10.3	13.9
2 min.	31.0	23.2	12.0	16.7	11.8	18.8
5 min.	48.6	38.5	16.5	26.3	20.1	28.4
	3083 Sealant					
Tensile Strength, psi	223	65	50	48	81	25.5
Elongation at Break, %	620	695	780	680	825	395
Swell, %						
1 min.	26.6	26.7	15.5	19.0	23.8	15.7
2 min.	31.6	26.5	17.3	24.3	27.7	16.3
5 min.	49.2	45.7	27.6	31.3	30.2	24.7

TABLE II

EFFECT OF HIGH TEMPERATURE AGING ON SELF-SEALING PERFORMANCE OF US-173 CONSTRUCTION PANELS

The panels were gunfired with 0.50 caliber AP ammunition in a standard gunfire structure filled with JP-4 fuel at ambient temperature (approximately 35° F). US-664 backing board panels were used to support the fuel cell panels.

Panel	Entrance or Exit	Type of Wound	Time to Seal, Minutes
ASN 811-2 (2 hrs. heat aging)	Entrance	Small hole	0.5
	Entrance	Small hole	2.0
	Entrance	Small hole	2.0
	Entrance	1" long from tumble	3.0
	Entrance	2" long from tumble	8.0
ASN 811-1 (one hr. heat aging)	Entrance	Small hole	0.5
	Entrance	Small hole	0.5
	Exit	Small hole	>4.0
	Entrance	1.6" long from tumble	>4.0
	Entrance	2" long from tumble	5.5
ASN 811-3 (one hr. heat aging)	Exit	1.6" long from tumble	0.5
	Exit	1.8" long from tumble	0.5
	Exit	0.9" long from tumble	0.5
	Entrance	2.1" long from tumble	3.0
ASN 811-4 (No heat aging)	Exit	Small hole	0.5
	Entrance	Small hole	2.0
	Exit	1.9" long from tumble	0.5
	Entrance	2.1" long from tumble	2.0

TABLE III

HIGH TEMPERATURE SEALANT EVALUATION

Specimen	Type of Elastomer	Volume Swell in Type III Test Fluid, % Original 1 Min.	2 Min.	5 Min.	After 24 hrs at 350° F 1 Min.	2 Min.	5 Min.	Appearance After 24 hrs. at 350° F
A	Butyl HT 1066	16.6	17.8	30.0	15.3	19.6	29.5	Very tacky, dark brown, smooth surface
B	Butyl HT 1066	16.4	18.2	33.2	16.6	19.6	28.3	Very tacky, mottled brn. color, surface uneven
C	Butyl GRI 365	20.3	23.2	38.1	-	-	-	Badly deteriorated
D	Butyl GRI 365	23.8	24.5	34.0	23.1	29.5	39.8	Some tack, tan color, rough surface with pinholes
E	Neoprene W	12.8	15.1	19.8	4.9	6.4	8.0	No tack, color varies, surface rough
F	Neoprene	10.2	15.4	15.7	6.7	7.2	10.0	No tack, dark brown, surface smooth
G	Neoprene W	8.7	10.8	13.8	3.3	5.8	6.5	No tack, dark brown, surface smooth
H	Royalene 301	26.5	33.7	42.6	15.7	18.0	23.9	No tack, dark brown surface rough
I	Royalene 301	26.4	32.0	41.5	15.1	19.6	31.3	No tack, dark brown, surface rough
J	Royalene 512	23.5	27.7	38.9	11.4	17.4	23.7	No tack, dark brown, surface smooth
K	Royalene 512	26.0	31.3	39.0	13.5	17.2	25.1	No tack, dark brown, surface slightly rough
L	Silastic 1125U	18.8	25.1	39.2	17.1	22.4	32.5	No tack, color unchanged (translucent white), surface smooth

TABLE IV

BOND STRENGTH RATINGS FOR VARIOUS HIGH TEMPERATURE MATERIAL ADHESIVES

Sealant	Adhesive	Was Vacuum Blanket Used?	Bond Strength Rating
ASN 850-A (Butyl HT1066)	101143 (UNIROYAL)	No	Fair
	101143	Yes	Fair
	6-1023 (Organoceram)	No	Fair
	Fairprene 5149	Yes	Good
	Chemlok	Yes	Good
ASN 850-D (Butyl GRI 365)	101143	No	Good
	101143	Yes	Good
	6-1023	No	None
	Fairprene 5149	Yes	Fair
	Chemlok 607	Yes	Good
	Chemlok 607 + Fairprene 5149	Yes	Good
ASN 850-I (Royalene 301)	101143	No	None
	101143	Yes	None
	6-1023	No	None
	Fairprene 5149	Yes	Good
	Chemlok 607	Yes	Good
ASN 850-K (Royalene 512)	101143	No	None
	101143	Yes	Poor
	6-1023	No	None
	Fairprene 5149	Yes	Good
	Chemlok 607	Yes	Good
ASN 850-L (Silastic 1125U)	101143	No	Poor
	6-1023	No	None
	Fairprene 5149	Yes	None
	Chemlok 607	Yes	Good
	Chemlok 607 + Fairprene 5149	Yes	Good

TABLE V

BOND STRENGTH AFTER HEAT AGING

Sealant	Adhesive	Bond Strength Rating After 24 Hours at 350° F	
		Exposed to Air	Wrapped in Foil
ASN 805-A (Butyl HT-1066)	Fairprene 5149	Good	Fair
ASN 850-D (Butyl GRI-365)	Chemlok 607 + Fairprene 5149	Good	Good
ASN 850-I (Royalene 301)	Fairprene 5149	Good	Good
ASN 850-K (Royalene 512)	Fairprene 5149	Good	Good
ASN 850-L (Silastic 1125U)	Chemlok 607 + Fairprene 5149	Good	Good

TABLE VI

RESULTS OF HIGH TEMPERATURE PANEL GUNFIRES

The self-sealing test panels were bolted to a standard gunfire structure with a sheet of UNIROYAL US-667 backing board to provide support. The structure was filled with Type I test fluid at ambient temperature (approximately 45^{0} F). Gunfire was carried out using 0.30 caliber AP ammunition except where noted otherwise.

Panel	Entrance or Exit	Type of Wound	Sealing Performance	Comment
ASN 914I-1	Entrance	1" long from tumble	Stream leak had slowed by 10 min. but had not sealed.	Sealant cored out extensively.
	Entrance	1" long from tumble	Stream leak running for over six minutes.	Sealant cored out extensively.
	Entrance	.25" round hole from .50 cal. AP round	Heavy seeping leak which slowed and ultimately sealed at 4½ minutes.	No coring of sealant.
ASN 914I-2	Exit	1-3/4" long from tumble	Heavy seep which had not sealed in 8 mins.	Little apparent damage to panel. No coring.
ASN 914K-1	Entrance	1" long from tumble	Stream leak which showed no signs of sealing or slowing at 8 minutes.	Sealant cored out extensively.
	Entrance	1¼" long from tumble	Stream leak with no signs of sealing or slowing leakage.	Sealant cored out extensively.
ASN 914D-1	Entrance	.25" round hole from untumbled bullet	Stream leak which slowed slightly but still was a stream at 8 minutes.	Sealant cored out slightly.
	Entrance	1" long from tumble	Stream leak which slowed slightly but was still a stream at 8 minutes.	Sealant cored out slightly.
ASN 914A-1	Entrance	1" long from tumble	Small stream which slowed to a heavy seep at 2 mins. Still a heavy seep at 10 minutes.	Coring out of sealant. Panel delaminated.
	Entrance	1" long from tumble	Heavy stream leak. Still a stream at 8 minutes.	Coring out of sealant. Panel delaminated.

TABLE VI (Cont'd)
RESULTS OF HIGH TEMPERATURE PANEL GUNFIRES

Panel	Entrance or Exit	Type of Wound	Sealing Performance	Comment
ASN 914L-1	Entrance	1½" long from tumble	Heavy stream slowing to a seep. Still a seep at 10 min.	Liner delaminated from sealant in region of wound.
	Entrance	1" long from tumble	Heavy stream slowing to a moderate seep. Still a slight seep at 10 min.	Liner delaminated in area of wound. Extensive coring of sealant.
ASN 914L-2	Entrance	1½" long from tumble	Heavy stream slowing to a seep. Still a small seep at 12 min.	Liner totally delaminated. Sealant cored out extensively.
	Entrance	3/4" long from tumbled 0.30 caliber Ball	Small stream slowing to a moderate seep. Still moderate seep at 8 minutes.	Very slight coring.
	Entrance	7/8" long from tumbled .30 cal. Ball	Damp seal on impact.	Panel delaminated.
	Entrance	1" long from tumbled Ball.	Heavy stream with no signs of sealing or slowing.	Sealant cored out extensively.

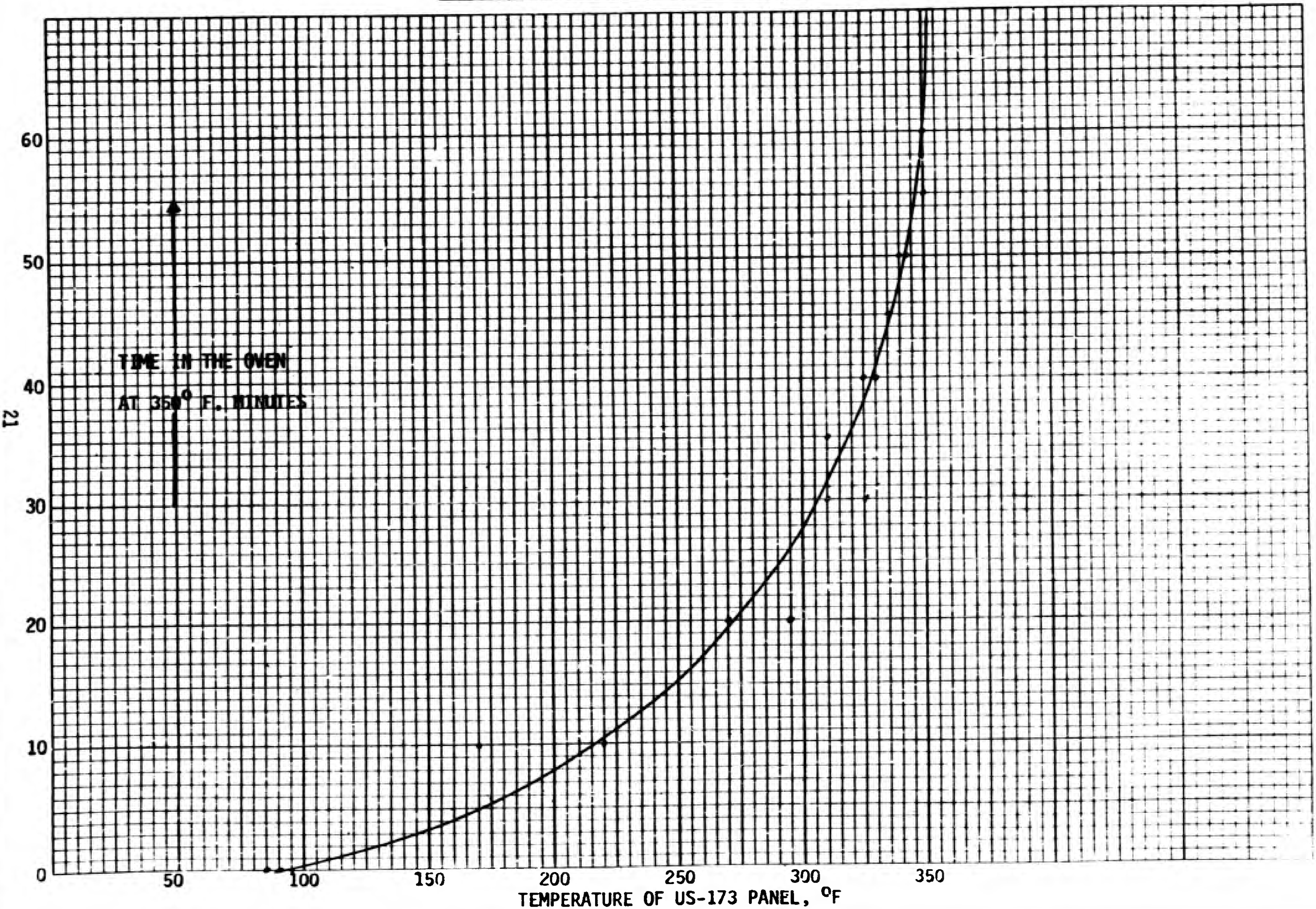
TABLE VII

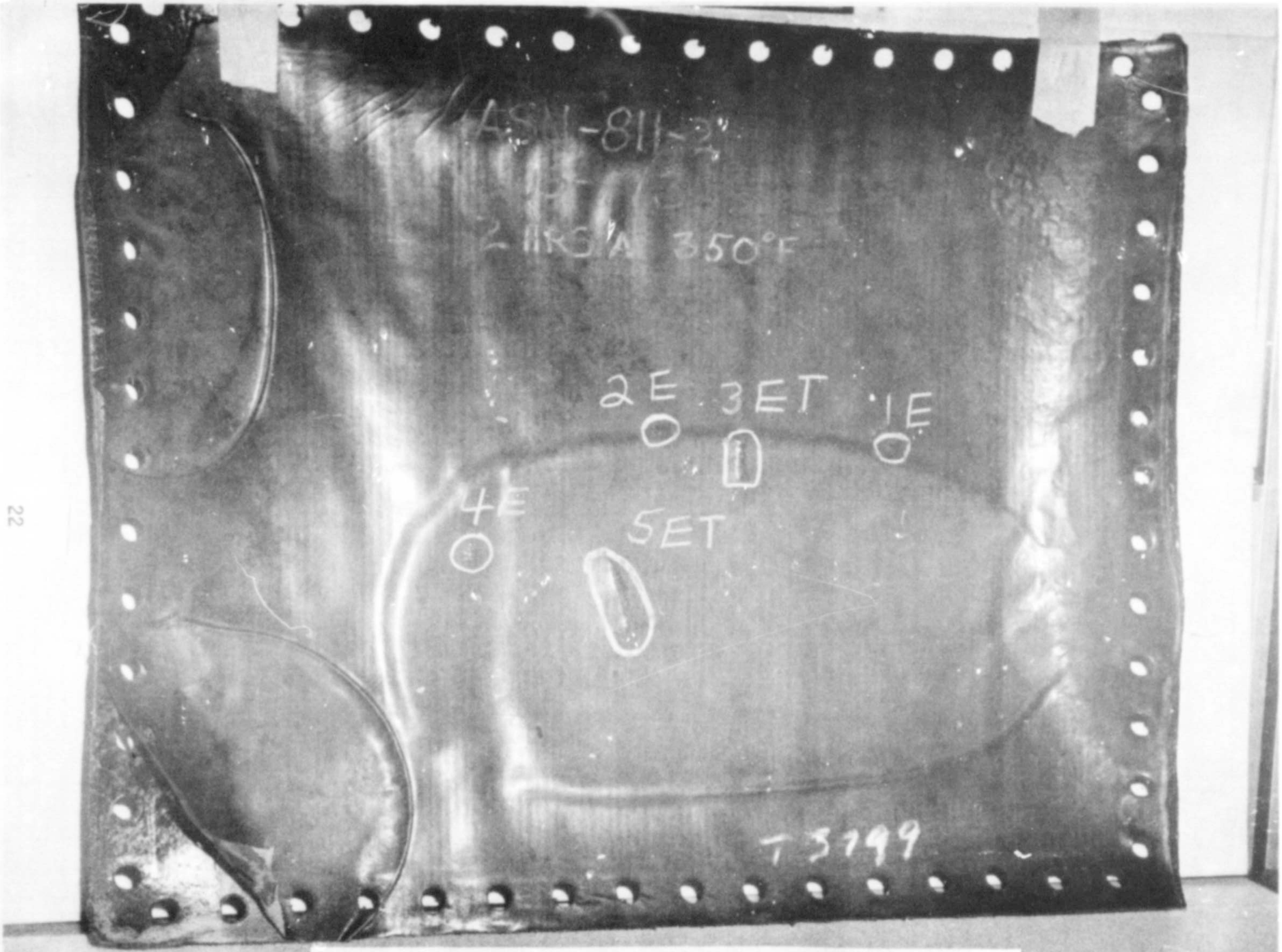
ADHESION OF FLUOROSILICONE COATED NOMEX TIRE CORD TO METHYLSILICONE COATED NOMEX TIRE CORD

Method of Cure	Peel Strength at 2"/minute, lbs. per inch Maximum	Minimum	Average
Oven Cure 400° F for 4 hrs.	1.9	2.5	2.2
	1.0	2.0	1.5
	2.0	2.5	2.3
Vacuum Blanket Cure + 2 Hrs. Post-Cure at 400° F.	3.5	4.0	3.8
	2.0	2.4	2.2
	3.0	4.0	3.5
Press Cure +4 hrs. Post-Cure at 400° F.	3.0	3.6	3.3
	3.5	4.0	3.8
	3.0	3.5	3.3

PHOTOGRAPH NO. 3

US-173 PANEL TEMPERATURE VS. TIME AT 350° F





Photograph No. 4 - Panel of US-173 Sealf-Sealing Construction After Exposure to 350° F and Gunfire with 0.50 Cal. AP Projectiles

SECTION IV

SELF-SEALING FUEL LINE DEVELOPMENT

A. Damage Control Materials

When metallic fuel lines are gunfired, the exit wound is surrounded by sharp "petals" of metal which protrude into the self-sealing cover and hold the sealant away from the wound. In order to seal the wound, the cover is made very thick so that the sealant will extend beyond the "petals". This results in self-sealing fuel lines which produce a considerable weight and volume penalty.

One approach to a solution of this problem is the application of a coating to the metal line which will reduce the "flowering" of the "petals". Such coatings could be of a very resilient material which would push the "petals" back into the wound as they form or a very high modulus material which would not allow the "petals" to form.

Six 2 inch diameter aluminum (6061-T6) fuel lines were covered with the following materials which are 0.060" thick:

1. Butadiene-acrylonitrile rubber (ASN 814-2) Figures 9 and 10
2. Butyl Rubber (ASN 814-3) Figures 11, 12, 13 and 14
3. Steel fiber reinforced styrene/butadiene rubber (ASN 814-4) Figures 15 and 16
4. Silicone rubber (ASN 814-5) Figures 17 and 18
5. Polyurethane impregnated USFlex nylon fabric (ASN 814-6) Figures 19, 20, 21 and 22
6. Epoxy resin impregnated fiberglass woven rovings (ASN 814-7) Figures 23, 24, 25 and 26

These six lines and two uncovered lines, ASN 814-1, Figures 5, 6, 7 and 8, were gunfired with 0.30 caliber AP ammunition while pressurized to 35 psi with JP-4 fuel. Both straight and tumbled rounds were fired through the lines.

Results of gunfire are given in Table VIII. From these results it was concluded that a single ply of polyurethane impregnated 27.75 oz/yd^2 USFlex nylon fabric was the best damage control cover.

An attempt was made to further optimize the polyurethane-fabric damage control cover. Four aluminum fuel lines were covered with the following materials:

1. One ply of 43.25 oz/yd^2 USFlex nylon fabric impregnated with 101,053 polyurethane resin (ASN 853-1) Figures 27, 28, 29 and 30

2. One ply of 43.25 oz/yd^2 USFlex nylon fabric impregnated with 700-4 polyurethane resin (ASN 853-2) Figures 31 and 32

3. Two plies of 27.75 oz/yd^2 USFlex nylon fabric impregnated with 101,053 polyurethane resin (ASN 853-3) Figures 33 and 34

4. Two plies of 27.75 oz/yd^2 USFlex nylon fabric impregnated with 700-4 polyurethane resin. Figures 35 and 36

A. Damage Control Materials (Cont'd.)

Resin 101,053 is a high hardness resin used in US-664 backing boards while 700-4 is a flexible resin developed for good low temperature flexibility in contract F33615-70-C-1205.

The covered lines were gunfired with 0.50 caliber AP straight rounds and 0.30 caliber AP tumbled rounds. Table IX gives results of this gunfire.

Based on these gunfire results, two plies of 27.75 oz/yd^2 USFlex nylon fabric impregnated with 700-4 polyurethane resin was chosen as the best damage control material. Five 2" aluminum tubes were covered with this damage control material which was then covered with self-sealing covers. The following constructions were fabricated:

1. ASN 861-1A
   a) Damage control material - 2 plies 27.75 oz/yd^2 USFlex nylon fabric impregnated with 700-4 polyurethane resin. Warps of the two plies were parallel to the axis of the tubes.

   b) Sealant - 4 plies of 0.063" thick 3083 natural rubber sealant.

   c) Reinforcement - 2 plies of nylon tire cord, NBR coated.

2. ASN 861-1B
   Same as 1.a) except that one of the two damage control plies was applied with the warps perpendicular to the tube axis.

3. ASN 861-2A
   Same as 1.a) except for the substitution of one ply of 27.75 oz/yd^2 USFlex nylon fabric for the two tire cord plies of the reinforcement.

4. ASN 861-2B
   Same as 1.b) except for the substitution of one ply of 27.75 oz/yd^2 USFlex nylon fabric for the two tire cord plies of the reinforcement.

5. ASN 861-3
   Same as 1.b) except for the substitution of two wraps of uniglass style 56-38 woven glass roving impregnated with UNIROYAL 41031 epoxy resin for the two tire cord plies of the reinforcement.

The fuel lines were subjected to gunfire by both 0.50 cal. AP and 0.30 cal. AP ammunition. Performance data is given in Table X. The accuracy of the tumbled 0.30 caliber shots was very low producing many wounds which could not be evaluated.

A. Damage Control Materials (Cont'd.)

On the basis of those shots which could be evaluated, construction ASN 861-3 was eliminated from further consideration. Tumbled rounds caused such extensive damage to the glass fiber reinforcement that sealing action was totally prevented.

Three possible methods for increasing the accuracy of the 0.30 caliber tumbled rounds are:

1. More rigid mounting of the rifle.
2. Placement of the rifle closer to the target.
3. Increasing the diameter of the target tubes.

Covers similar to 861-1A, 1-B, -2A and -2B were fabricated on four 3" diameter aluminum tubes. Two of these covers were gunfired using both 0.50 caliber AP and 0.30 caliber AP ammunition. Performance data for the lines is given in Table XI. Accuracy of 0.30 caliber tumbled shots was not good enough for evaluation of wounds even when using 3" diameter tubes.

It was concluded that a more rigid mount for the rifle is needed before 0.30 caliber tumbled shots can be fired with reasonable accuracy.

From the 0.50 caliber gunfire data, it can be concluded that damage control materials consisting of heavy nylon fabric impregnated with polyurethane resin help to reduce the damage caused by "flowering" of metal fuel lines when impacted by AP projectiles. This reduction in damage causes an improvement in the sealing performance of rubber and fabric self-sealing fuel line covers.

TABLE VIII

.30 Cal. Gunfire Results of Initial Damage Control Experiment (ASN 814)

Damge Control Cover	Round Number	Extent of Tumble of 0.30 Cal. AP Projectile	Entrance Wound Length, in.	Entrance Wound Width, in.	Entrance Height of Flowering, in.	Exit Wound Length, in.	Exit Wound Width, in.	Exit Height of Flowering, in.	Comments
None (ASN 814-1) Figures 5, 6, 7 and 8	1	0	0.30	0.30	0.05	0.30	0.30	0.25	Metal tearing and petals turned away from wound on exit.
	2	¼	0.80	0.30	0.25	1.20	0.70	0.55	Severe metal tearing on entrance and exit, metal petals turned away from wound on exit.
	3	1	3.00	3.50	1.45	1.70	2.30	1.35	Extremely large metal petals turned away from wound with very severe metal tearing on entrance and exit.
Butadiene/Acrylonitrile Rubber (ASN 814-2)	1	0	0.30	0.30	0.05	0.30	0.35	0.20	Slight tearing of metal on exit, very small hole in rubber on entrance.
Figures 9 and 10	2	0	0.30	0.30	0.05	0.30	0.35	0.20	" " " " " "
	3	3/4	Slicing shot that produced a wound 2.0" x 2.8" with severe metal tearing and chunk-out. Large metal petals turned away from the wound.						
Butyl Rubber (ASN 814-3)	1	0	0.30	0.30	0.05	0.30	0.30	0.20	Slight tearing of metal on exit, very small hole in rubber on entrance.
Figures 11, 12, 13 and 14	2	0	0.30	0.30	0.00	0.30	0.30	0.20	" " " " " "
	3	0	0.30	0.30	0.05	0.30	0.35	0.20	" " " " " "
	4	3/4	1.10	0.40	0.15	1.50	1.40	1.00	Small hole in rubber on entrance, severe metal tearing, metal petals turned away from wound and rubber chunk-out on exit.
Steel Fiber Reinforced Styrene/Butadiene Rubber (ASN 814-4)	1	0	0.30	0.30	0.05	0.35	0.30	0.20	Small hole in rubber on entrance, slight metal tearing and small metal petals turned away from wound on exit.
Figures 15 and 16	2	0	0.30	0.30	0.00	0.30	0.30	0.20	" " " " " " " "
	3	¼	0.80	0.40	0.00	1.25	1.40	0.80	Severe tearing of metal with metal petals turned away from wound on exit.

TABLE VIII (Cont'd.)
.30 Cal. Gunfire Results of Initial Damage Control Experiment (ASN 814)

Damage Control Cover	Round Number	Extent of Tumble of 0.30 Cal. AP Projectile	Entrance: Wound Length, in.	Entrance: Wound Width, in.	Entrance: Height of Flowering, in.	Exit: Wound Length, in.	Exit: Wound Width, in.	Exit: Height of Flowering, in.	Comments
Silicone Rubber (ASN 814-5)	1	0	0.30	0.30	0.05	0.30	0.30	0.20	Slight metal tearing with petals turned away from wound on exit.
Figures 17 and 18	2	0	0.30	0.30	0.05	0.30	0.30	0.20	" " " " " "
	3	3/4	1.00	0.40	0.00	1.20	1.60	0.65	Severe metal tearing with metal petals turned away from wound on exit.
Polyurethane Impregnated 27.75 oz/yd² USFlex Nylon Fabric, one ply (ASN 814-6)	1	0	0.30	0.30	0.00	0.30	0.30	0.10	Slight metal tearing and metal petals were turned in toward wound on exit.
Figures 19, 20, 21 and 22	2	0	0.30	0.30	0.05	0.30	0.30	0.10	" " " " " "
	3	½	0.60	0.40	0.00	0.60	0.50	0.40	" " " " " "
	4	½	0.60	0.40	0.00	0.50	0.50	0.45	" " " " " "
	5	3/4	Slicing shot which tore metal from entrance to exit but cover did not open up. Height of flower on exit was 0.80 inches with a wound of 1.0 inch x 0.80 inches. Metal petals were turned away from wound on exit.						
Epoxy Impregnated Fiberglass Woven Rovings (ASN 814-7)	1	0	0.30	0.30	0.00	0.30	0.30	0.15	Slight metal tearing and metal petals turned away from wound on exit.
Figures 23, 24 25 and 26	2	0	0.30	0.30	0.00	0.30	0.30	0.15	" " " " " "
	3	½	0.60	0.45	0.00	0.90	0.50	0.30	Metal tearing and metal petals turned away from wound on exit.
	4	1	1.30	0.45	0.00	1.20	0.70	0.45	Severe metal tearing and large metal petals turned away from wound on exit.

TABLE IX

Gunfire Results of Damage Control Experiment (ASN 853)

Damage Control Cover	Round Number	Projectile Caliber	Extent of Tumble	Entrance Wound Length, in.	Entrance Wound Width, in.	Entrance Height of Flowering, in.	Exit Wound Length, in.	Exit Wound Width, in.	Exit Height of Flowering, in.	Comments
One Ply 43.35 oz/yd² US-Flex Nylon Fabric Impregnated with 101,053 Polyurethane Resin (ASN 853-1) Figures 27, 28, 29 and 30	1	0.50	0	0.50	0.50	0.05	0.50	0.50	0.15	Small puncture in cover on entrance, slight tearing of metal but metal petals not turned from wound on exit.
	2	0.50	0	0.50	0.50	0.05	0.50	0.50	0.20	" " " " " "
	3	0.30	1							Slicing shot which tore metal from entrance to exit but cover did not open up. Height of flower on exit was 0.40 inches. The wound produced by this slicing shot was 2.5 inches x 0.7 inches. One metal petal was turned from wound on exit.
	4	0.30	1							Slicing shot which cut through the cover and grazed the fuel line and punctured it. No flowering.
	5	0.30	1							" " " " " " " " " " " " " " " No flowering.
One Ply 43.25 oz/yd² US-Flex Nylon Fabric Impregnated with 700-4 Polyurethane Resin (ASN 853-2) Figures 31 and 32	1	0.50	0	0.50	0.50	0.00	0.50	0.50	0.15	Small puncture in cover on entrance, slight tearing of metal but metal petals not turned from wound on exit.
	2	0.30	1	1.60	0.70	0.00	1.40	0.70	0.60	Metal tearing on entrance and exit. Metal petals turned from wound on exit.

TABLE IX (Cont'd.)
Gunfire Results of Damage Control Experiment (ASN 853)

Damage Control Cover	Round Number	Projectile Caliber	Extent of Tumble	Entrance Wound Length, in.	Entrance Wound Width, in.	Entrance Height of Flowering, in.	Exit Wound Length, in.	Exit Wound Width, in.	Exit Height of Flowering, in.	Comments
Two Plies 27.75 oz/yd^2 US-Flex Nylon Fabric Impregnated with 101.053 Polyurethane Resin (ASN 853-3)	1	0.50	0	0.50	0.50	0.05	0.50	0.50	0.15	Small puncture in cover on entrance, slight tearing of metal but metal petals not turned from wound on exit.
Figures 33 and 34	2	0.30	1	1.40	0.70	0.00	1.20	0.40	0.35	Small slit in cover on entrance metal tearing but petals not turned from wound on exit.
	3	0.30	1	Slicing shot which tore metal from antrance to exit, but only a long slit was put in the cover. No flowering of the metal occurred. The wound size was 2.1 inches x 0.80 inches						
Two Plies 27.75 oz/yd^2 US-Flex Nylon Fabric Impregnated with 700-4 Polyurethane Resin (ASN 853-4)	1	0.50	0	0.50	0.50	0.00	0.50	0.50	0.15	Small puncture in cover on entrance, slight tearing of metal but metal petals not turned from wound on exit.
Figures 35 and 36	2	0.30	1	1.30	0.60	0.00	1.20	0.30	0.30	Small slit in cover on entrance metal tearing but petals of the flower were restricted from turning away from wound on exit.

NOTES:
1. 2 inch diameter 6065 T6 aluminum fuel lines were used in this experiment.
2. Fuel lines were pressurized to 35 psi with JP-4 fuel during gunfiring.
3. Wound sizes are the maximum dimensions of the hole produced by the projectile in the aluminum fuel line only and do not necessarily indicate the wound size in the damage control cover.
4. Height of flowering indicates the maximum height to which the metal petals extend outward from the outside diameter of the fuel line.

TABLE X

GUNFIRE OF FUEL LINE 861-1A

Fuel Type:	JP-4	Projectile Type:	As Noted
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Reinforcement:	2 plies nylon tire cord

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon with warp parallel to long axis of line.

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^o	0	4 ft. stream closing to damp seal in 15 secs.
		Exit	0^o	0	Dry seal at impact
2	.50 Cal AP	Entrance	0^o	0	Dry seal at impact
		Exit	0^o	0	Dry seal at impact
3	.30 Cal AP	Entrance	0^o	0	Slicing shot, no seal
		Exit	0^o	0	
4	.30 Cal AP	Entrance	0^o	0	Slicing shot, no line damage
		Exit	0^o	0	
5	.30 Cal AP	Entrance	0^o	T	30 sec. - small spray 1 min. - heavy seep Pressure dropped to 24 psi 1/16" stream when pressure was boosted to 35 psi
		Exit	0^o	T	Very hard leak - not evaluated further.

TABLE X (Cont'd)

GUNFIRE OF FUEL LINE 861-1B

Fuel Type:	JP-4	Projectile Type:	As noted
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Reinforcement:	2 plies nylon tire cord

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon with warp perpendicular to long axis of line

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^o	0	Dry seal at impact
		Exit	0^o	0	Glancing. Bad leakage. Plugged.
2	.50 Cal AP	Entrance	0^o	0	Dry seal at impact.
		Exit	0^o	0	Dry seal at impact.
3	.30 Cal AP	Entrance	0^o	T	¼" stream at impact, 2 min. and 3 min. Pressured dropped to about 15 psi.
		Exit	0^o	T	½" stream at impact. Not evaluated further.
4	.30 Cal AP	Entrance	0^o	T)	Bad damage.
		Exit	0^o	T)	Bad leakage.

TABLE X (Cont'd.)

GUNFIRE OF FUEL LINE 861-2A

Fuel Type:	JP-4	Projectile Type:	As noted
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Reinforcement:	1 ply - 27.75 oz/yd^2 USFlex nylon fabric

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon fabric with warp parallel to long axis of line.

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^o	0	Seep at impact. Damp seal at 2 min.
		Exit	0^o	0	Seep at impact. Damp seal at 2 min.
2	.50 Cal AP	Entrance	0^o	0	Damp seal at impact.
		Exit	0^o	0	Dry seal at impact.
3	.30 Cal AP	Entrance	0^o	T)	Slicing shot. Bad damage. Patch placed over hole.
		Exit	0^o	T)	
4	.30 Cal AP	Entrance	0^o	T)	Slicing shot. No damage to line
		Exit	0^o	T)	
5	.30 Cal AP	Entrance	0^o	0	Bad leakage. Patched.
		Exit	0^o	0	Dry seal at impact.
6	.30 Cal AP	Entrance	0^o	T	Dry seal at impact.
		Exit	0^o	T	Fuel sprayed out. No further evaluation.

TABLE X (Cont'd.)

GUNFIRE OF FUEL LINE 861-2B

Fuel Type: JP-4

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon fabric with warp perpendicular to long axis of line.

Projectile Type: As noted

Projectile Velocity: Standard

Reinforcement: 1 Ply - 27.75 oz/yd^2 USFlex nylon fabric

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^o	0	Slight seep at impact. Damp seal at 1½ min.
		Exit	0^o	0	Dry seal at impact.
2	.50 Cal AP	Entrance	0^o	0	Dry seal at impact.
		Exit	0^o	0	Dry seal at impact.
3	.30 Cal AP	Entrance	0^o	T	High slicing shot - large stream. Patched.
		Exit	0^o	T	High slicing shot - large stream. Patched.
4	.30 Cal AP	Entrance	0^o	V. Sl.T	Hard ¼" stream at impact. Patched.
		Exit	0^o	T	Very large leak. Patched. No further evaluation.
5	.30 Cal AP	Entrance	0^o	T	Large stream. No further evaluation.
		Exit	0^o	T	Large stream. No further evaluation.

TABLE X (Cont'd.)

GUNFIRE OF FUEL LINE 861-3

Fuel Type: JP-4

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon fabric with warp perpendicular to long axis of line.

Projectile Type: As noted

Projectile Velocity: Standard

Reinforcement: Uniglas Style 56-38 woven glass rovings - 2 plies

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^0	0	Damp seal at impact.
		Exit	0^0	0	1/32" stream at impact, sl. seep at 1 min., damp seal at 2½ min.
2	.50 Cal AP	Entrance	0^0	0	Dry seal at impact.
		Exit	0^0	0	Dry seal at impact.
3	.30 Cal AP	Entrance	0^0	T	Catastrophic damage from entrance to exit. Damage patched.
		Exit	0^0	T	
4	.30 Cal AP	Entrance	0^0	T	Catastrophic damage at entrance and exit. Testing stopped.
		Exit	0^0	T	

TABLE XI

GUNFIRE OF FUEL LINE 891-1A

Fuel Type: JP-4

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: As noted

Projectile Velocity: Standard

Reinforcement: 1 ply 27.75 oz. USFlex

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon with warp parallel to long axis of line.

Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.50 Cal AP	Entrance	0^o	0	Damp seal at 15 secs.
		Exit	0^o	0	Damp seal at 15 secs.
2	.50 Cal AP	Entrance	0^o	0	Dry seal at impact
		Exit	0^o	0	Dry seal at impact
3	.30 Cal AP	Entrance	0^o	1"	Dry seal at impact
		Exit	0^o	1"	Extremely bad leak; sprayed out. No seal.
4	.30 Cal AP	Entrance	0^o	½"	Dry seal at impact
		Exit	0^o	½"	Bad spray type leak. No seal.

TABLE XI (Cont'd.)

GUNFIRE OF FUEL LINE 891-2A

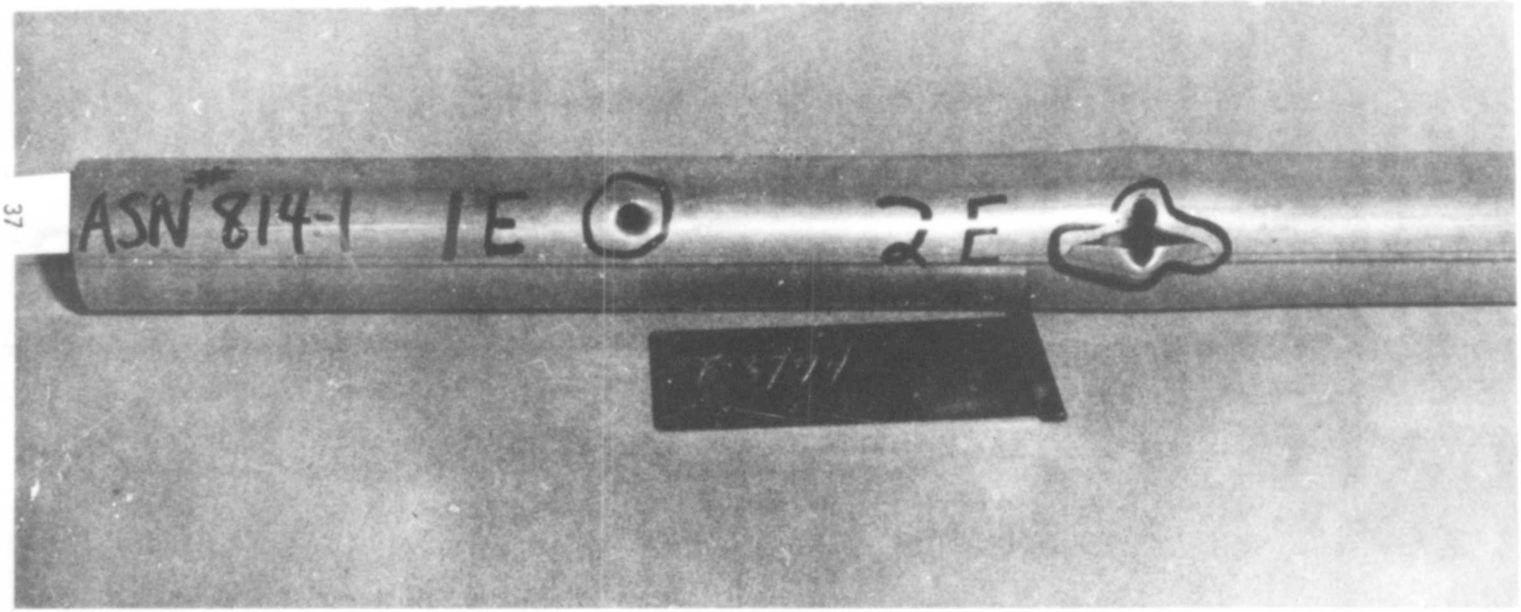
Fuel Type: JP-4 | Projectile Type: As noted

Fuel Temperature: Ambient | Projectile Velocity: Standard

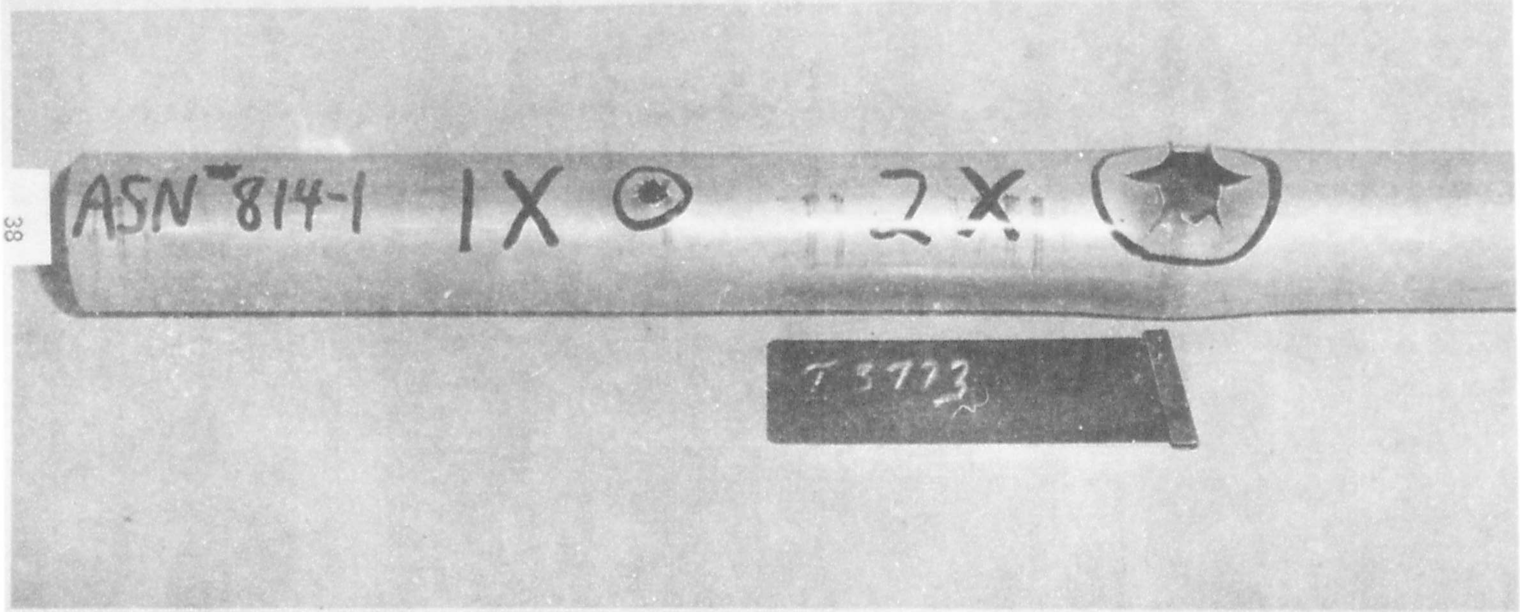
Fuel Pressure: 35 psi | Reinforcement: 2 plies tire cord

Damage Control: 2 plies 27.75 oz/yd^2 USFlex nylon with warp parallel to long axis of tube.

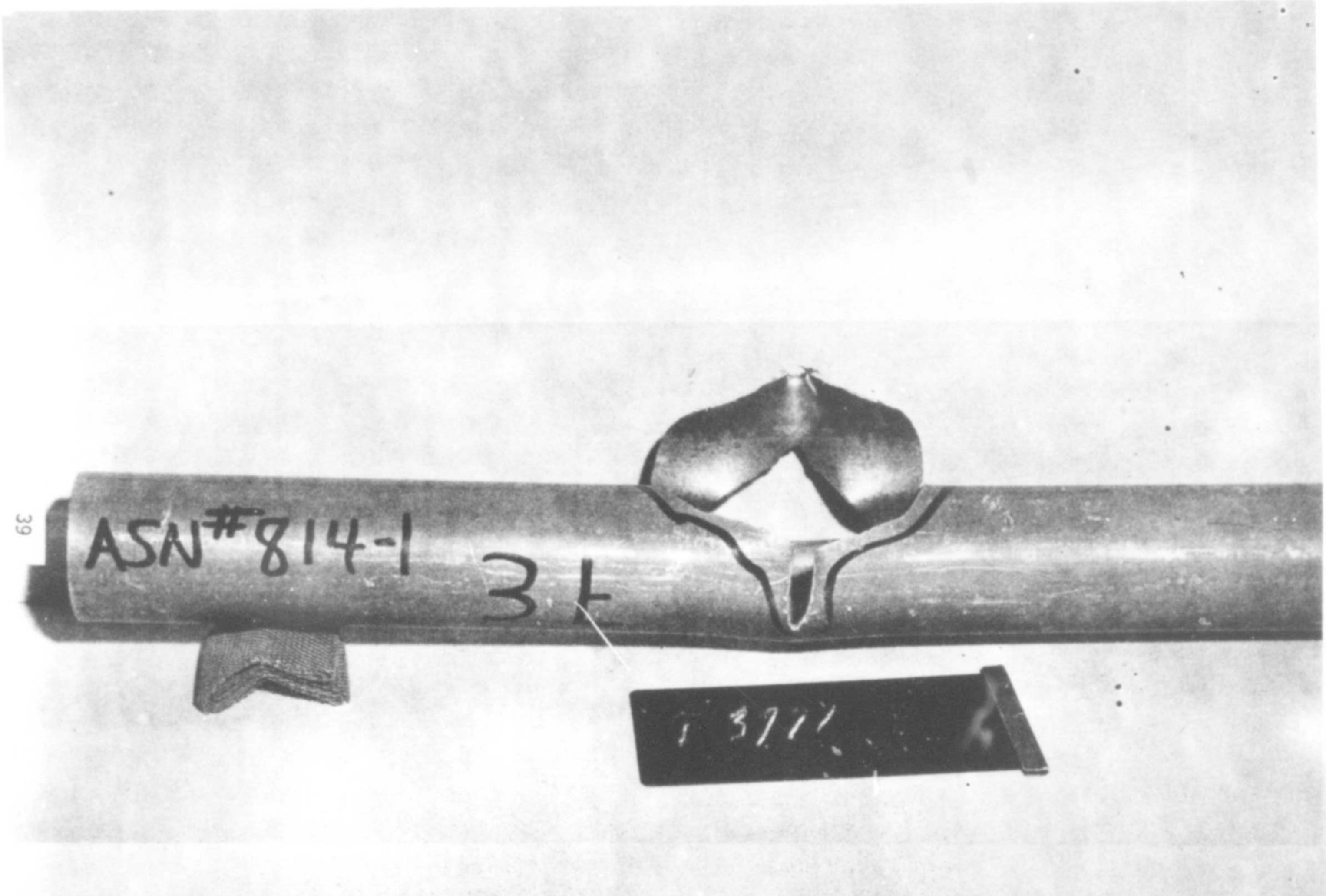
Round No.	Type of Ammo	Type of Wound	Angle of Obliquity	Degree of Tumble	Results
1	.30 Cal AP	Entrance	0^o	½"	Dry seal at impact.
		Exit	0^o	½"	Sprayed badly. No seal.
2	.30 Cal AP	Entrance	0^o	Cannot be measured	Glancing shot, too high, opened large hole.
		Exit	0^o		
3	.30 Cal AP	Entrance	0^o	5/8"	Reduced to heavy seep at one minute.
		Exit	0^o	5/8"	No seal, large spray.



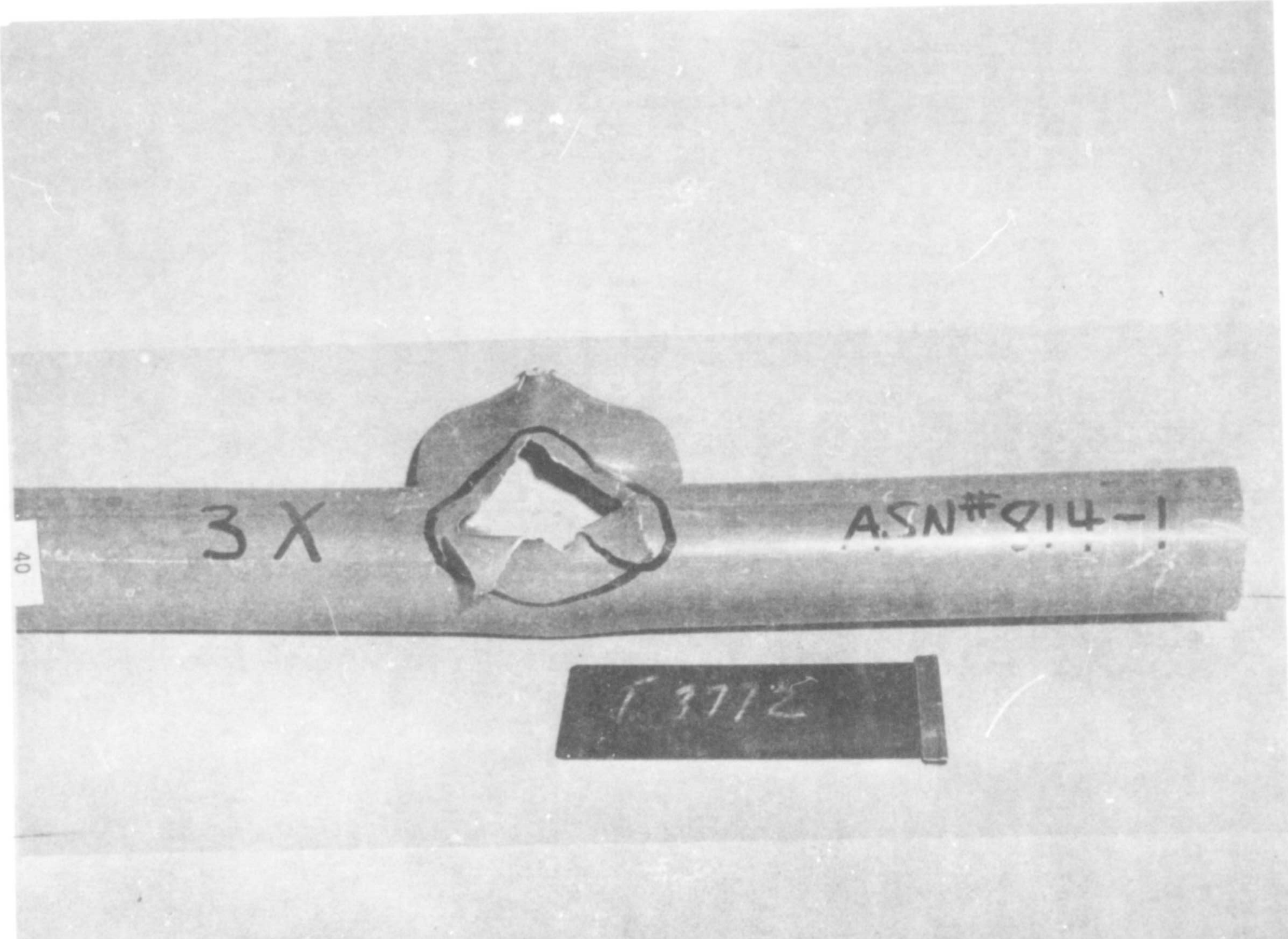
Photograph No. 5 - Plain Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2



Photograph No. 6 - Plain Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2



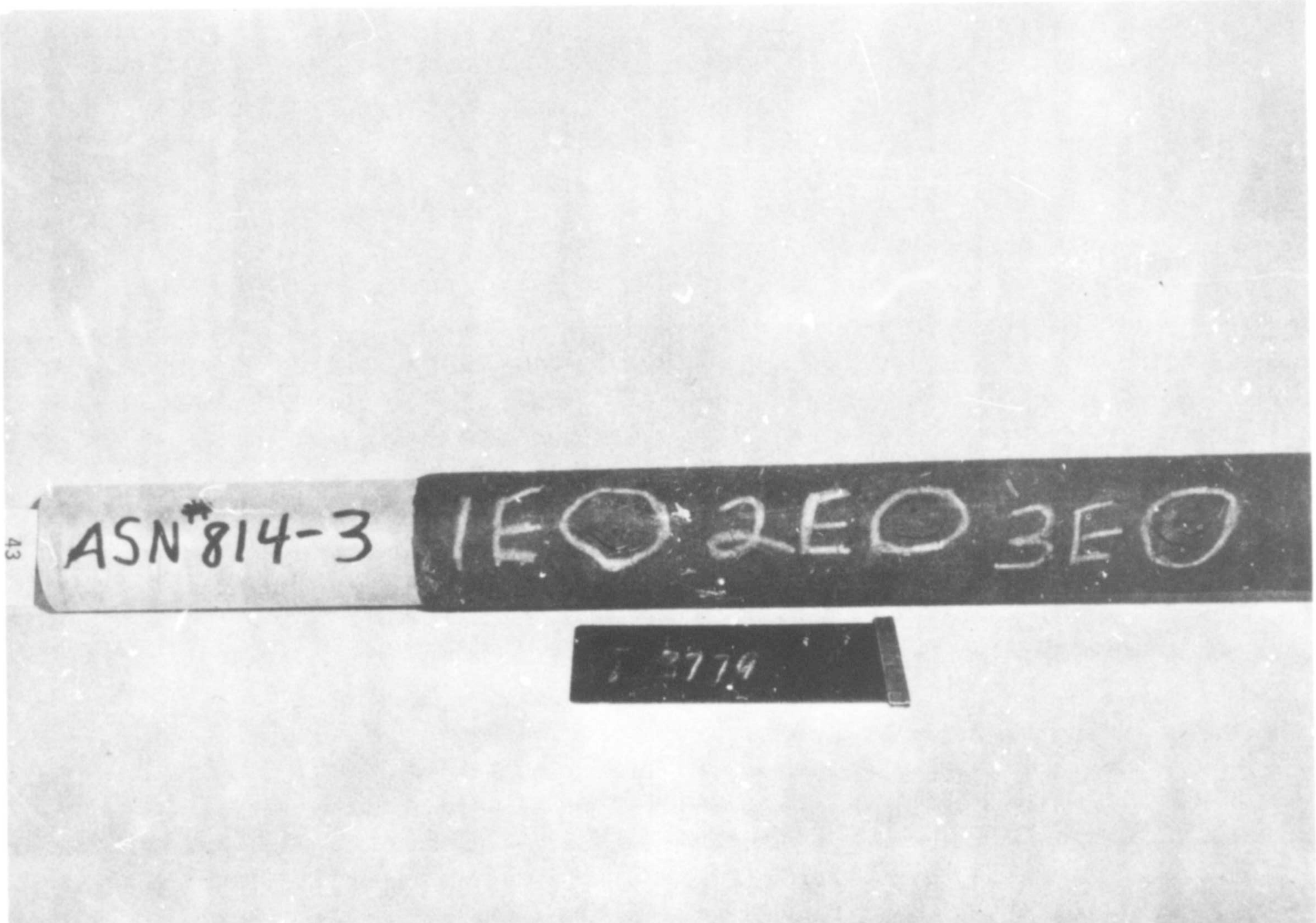
Photograph No. 7 - Plain Aluminum Tube, Showing Entrance of
0.30 Cal. AP Projectile, Round 3



Photograph No. 8 - Plain Aluminum Tube, Showing Exit
of 0.30 Cal. AP Projectile, Round 3

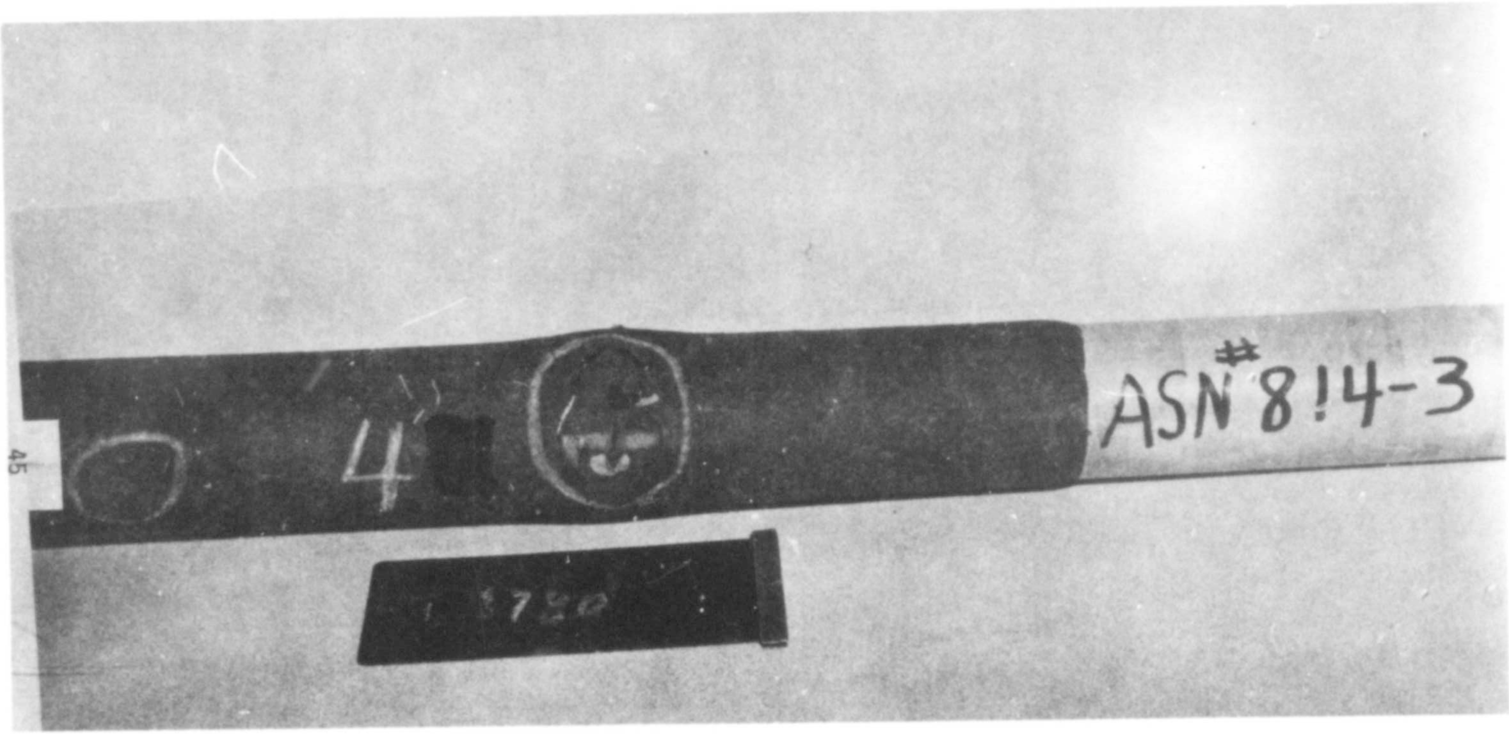
Photograph No. 9 - Butadiene Acrylonitrile Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3

Photograph No. 10 - Butadiene Acrylonitrile Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3

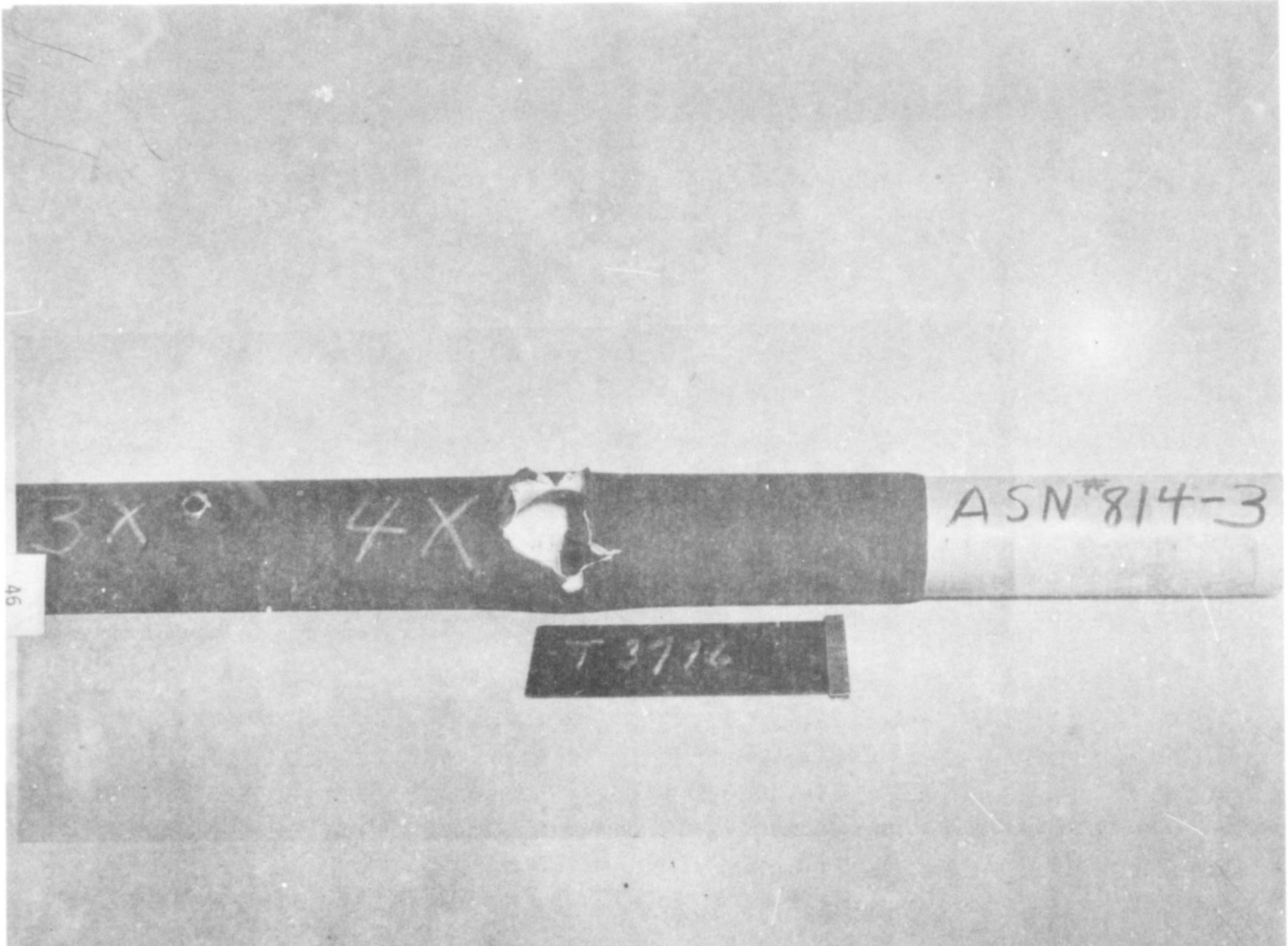


Photograph No. 11 - Butyl Rubber Covered Aluminum Tube,
Showing Entrances of 0.30 Cal. AP
Projectiles, Rounds 1, 2 and 3

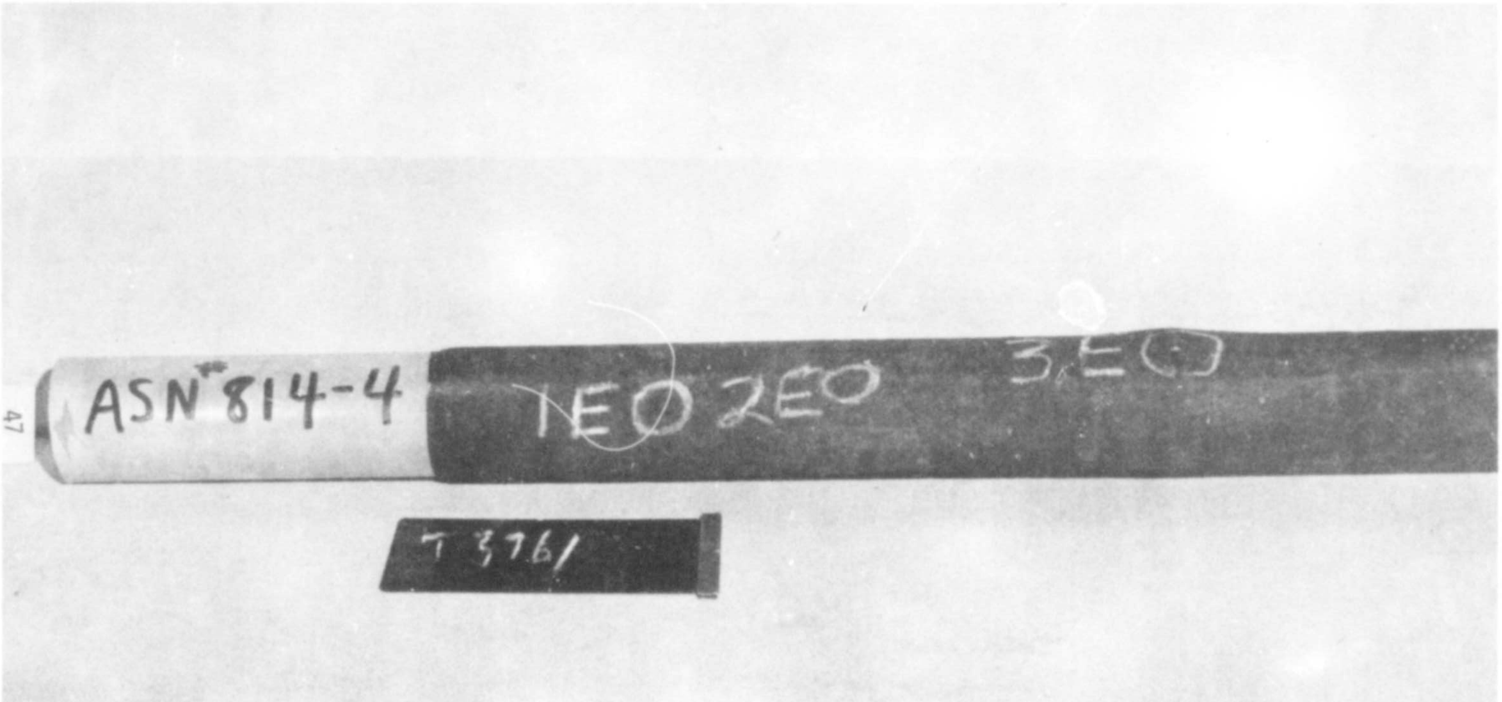
Photograph No. 12 - Butyl Rubber Covered Aluminum Tube,
Showing Exits of 0.30 Cal. AP
Projectiles, Rounds 1, 2 and 3



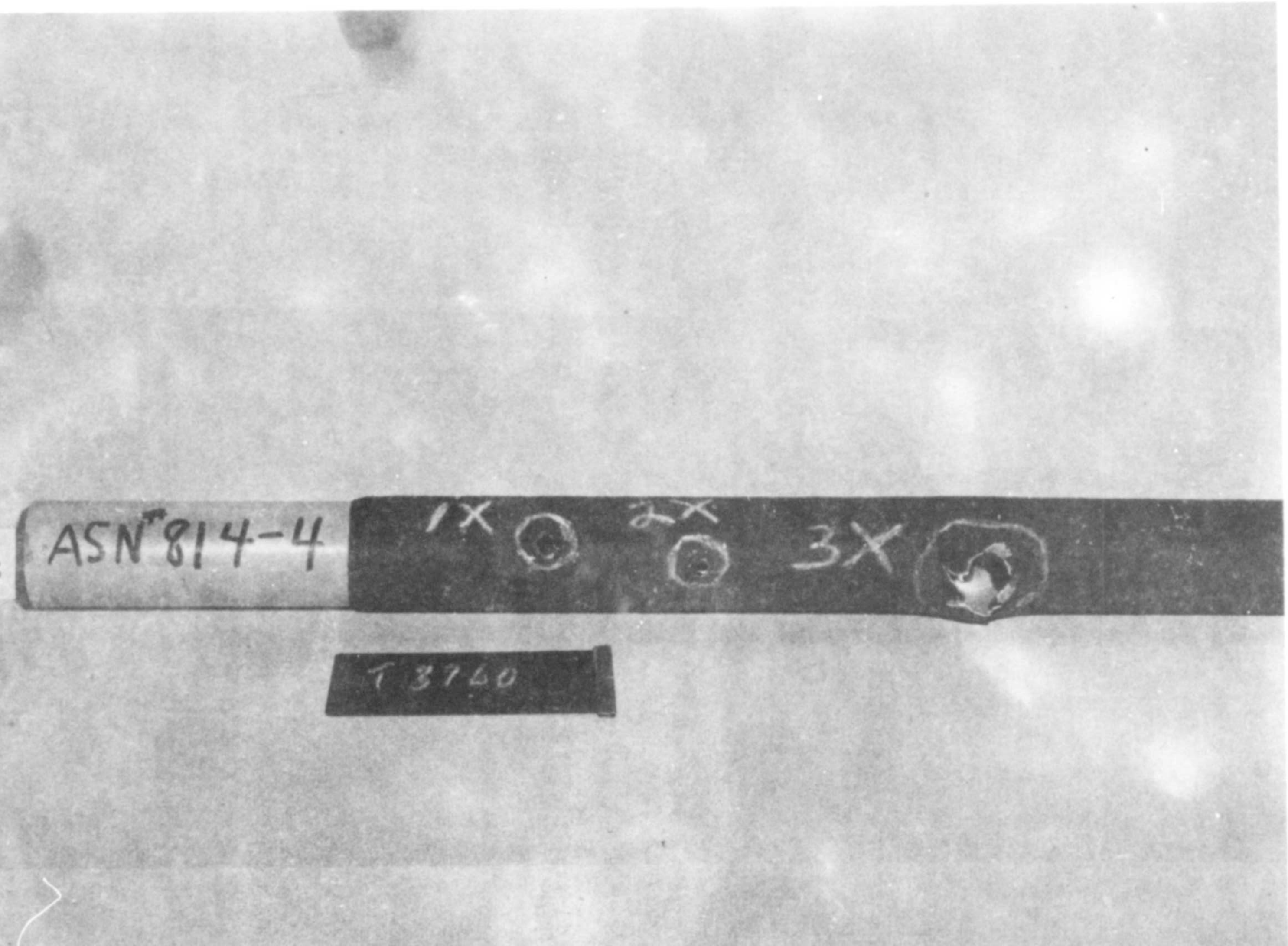
Photograph No. 13 - Butyl Rubber Covered Aluminum Tube, Showing Entrance of 0.30 Cal. AP Projectile, Round 4



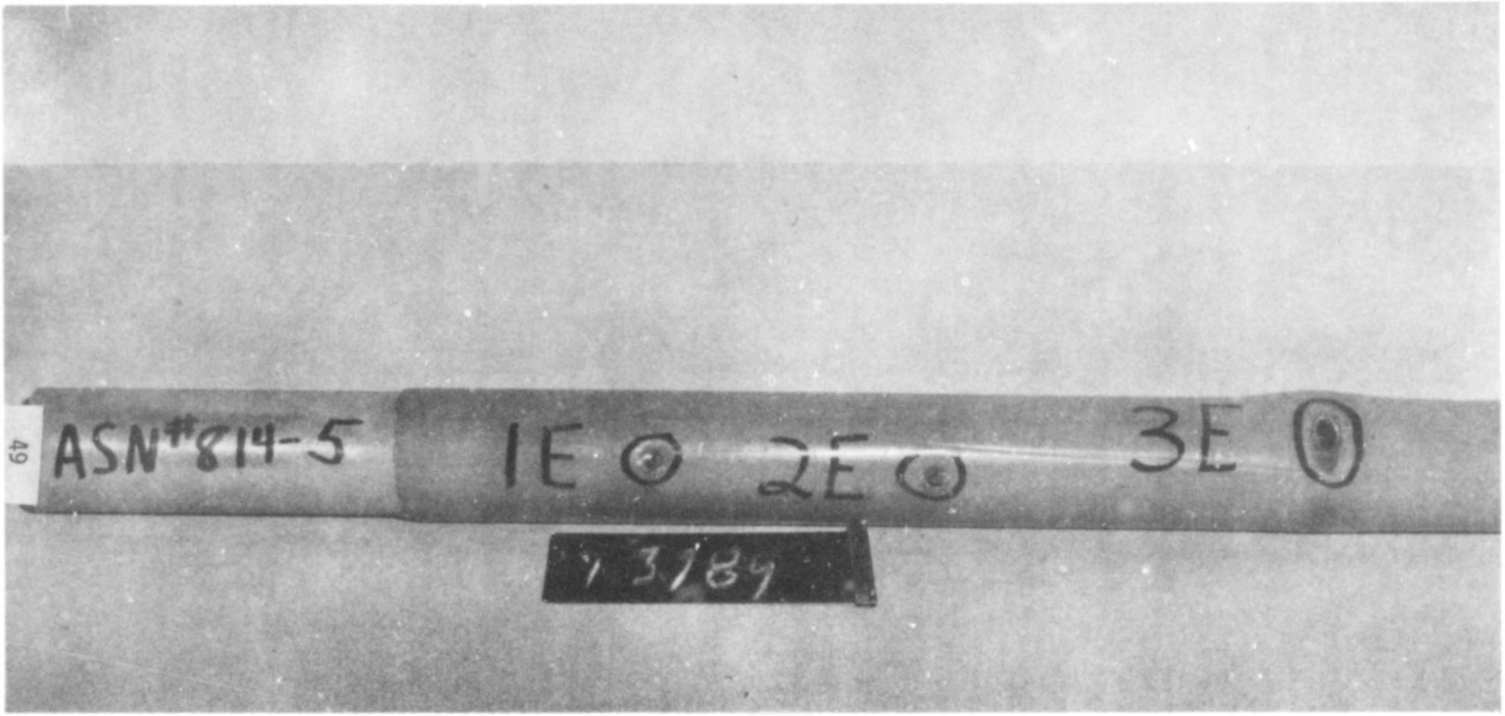
Photograph No. 14 - Butyl Rubber Covered Aluminum Tube,
Showing Exit of 0.30 Cal. AP Projectile,
Round 4



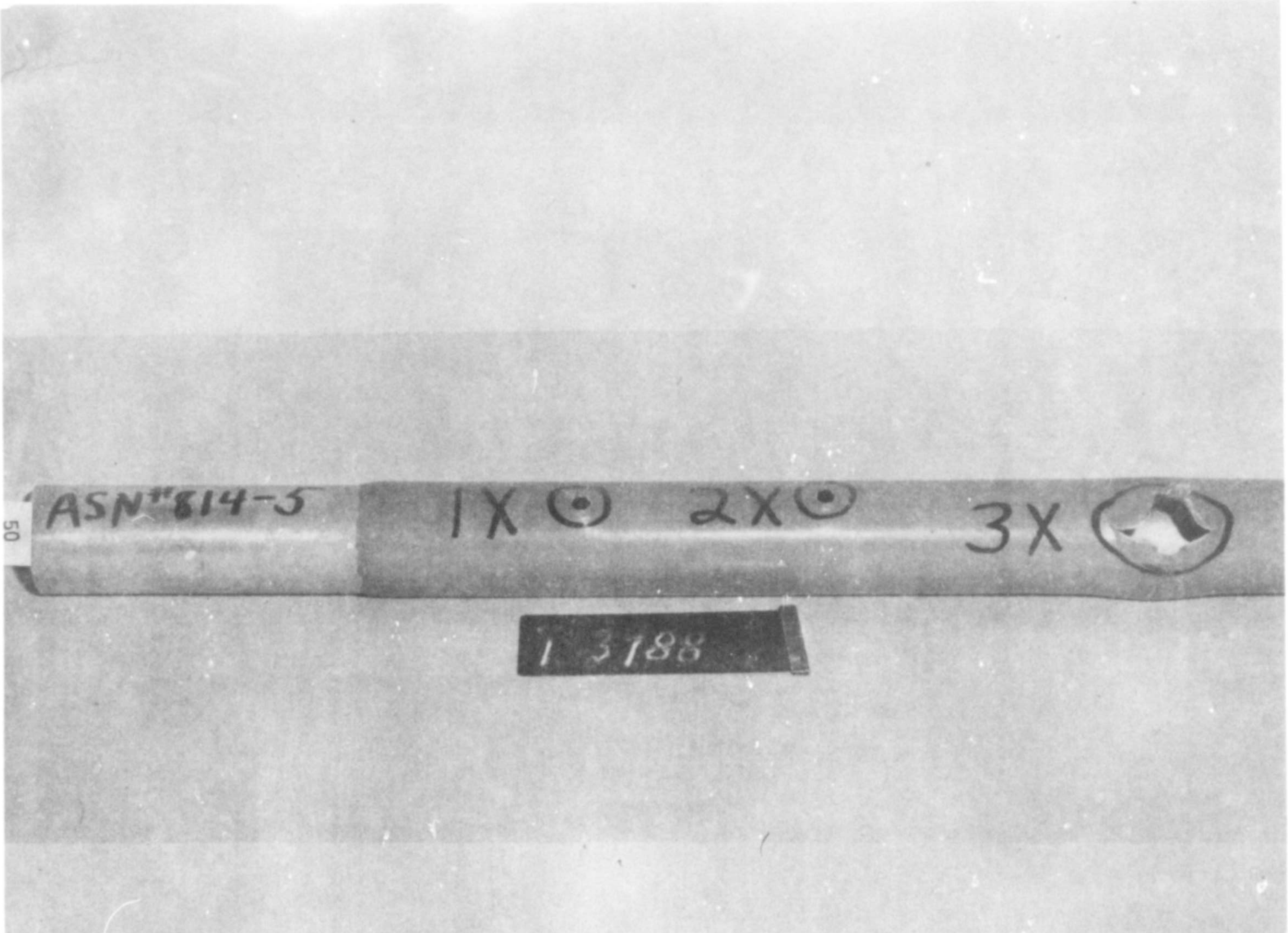
Photograph No. 15 - Steel Fiber Reinforced Styrene Butadiene Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



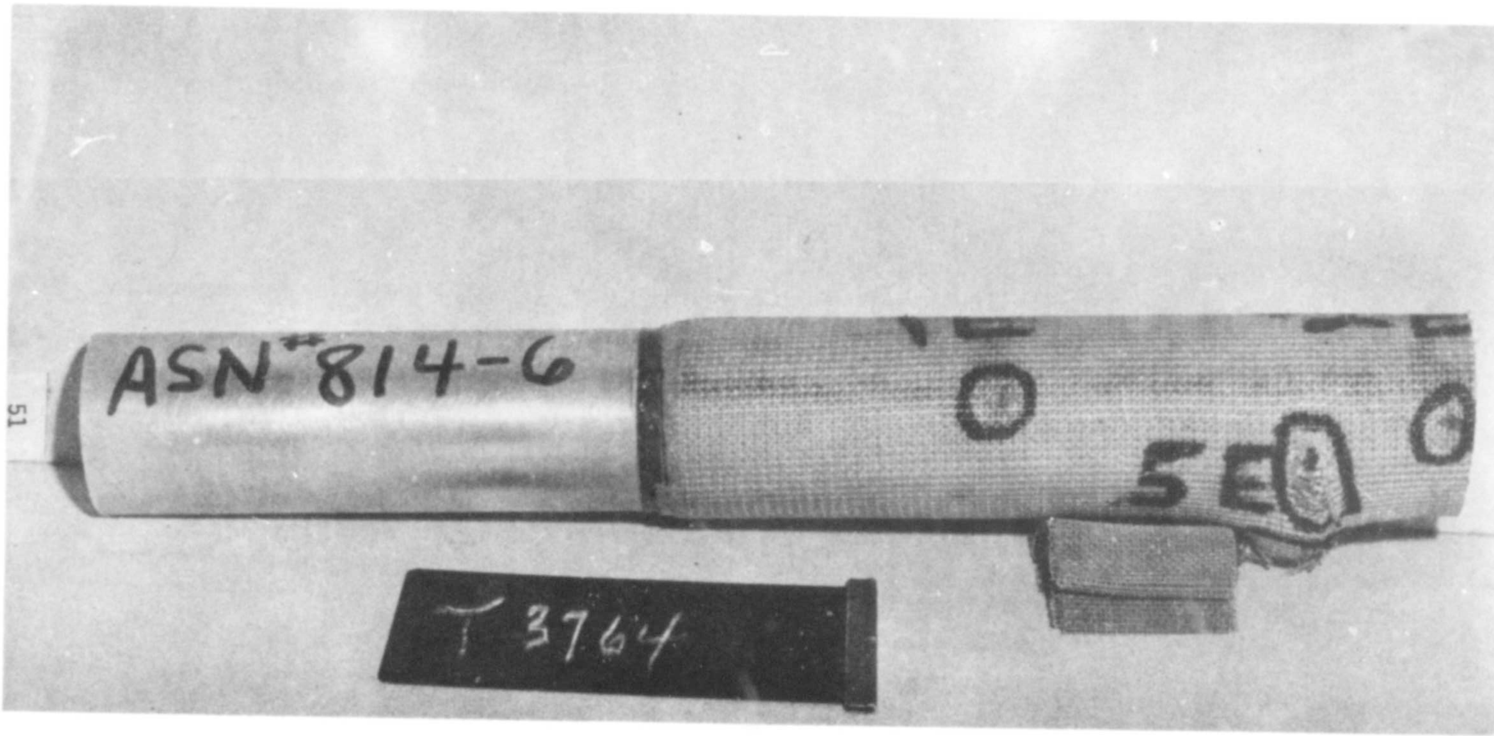
Photograph No. 16 - Steel Fiber Reinforced Styrene Butadiene Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



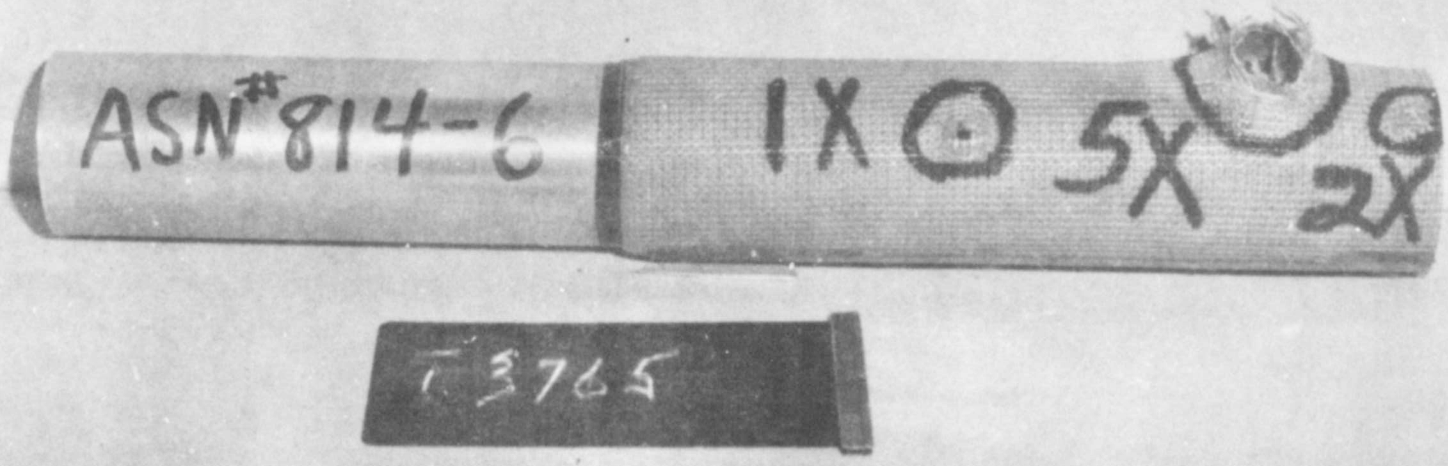
Photograph No. 17 - Silicone Rubber Covered Aluminum Tube, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



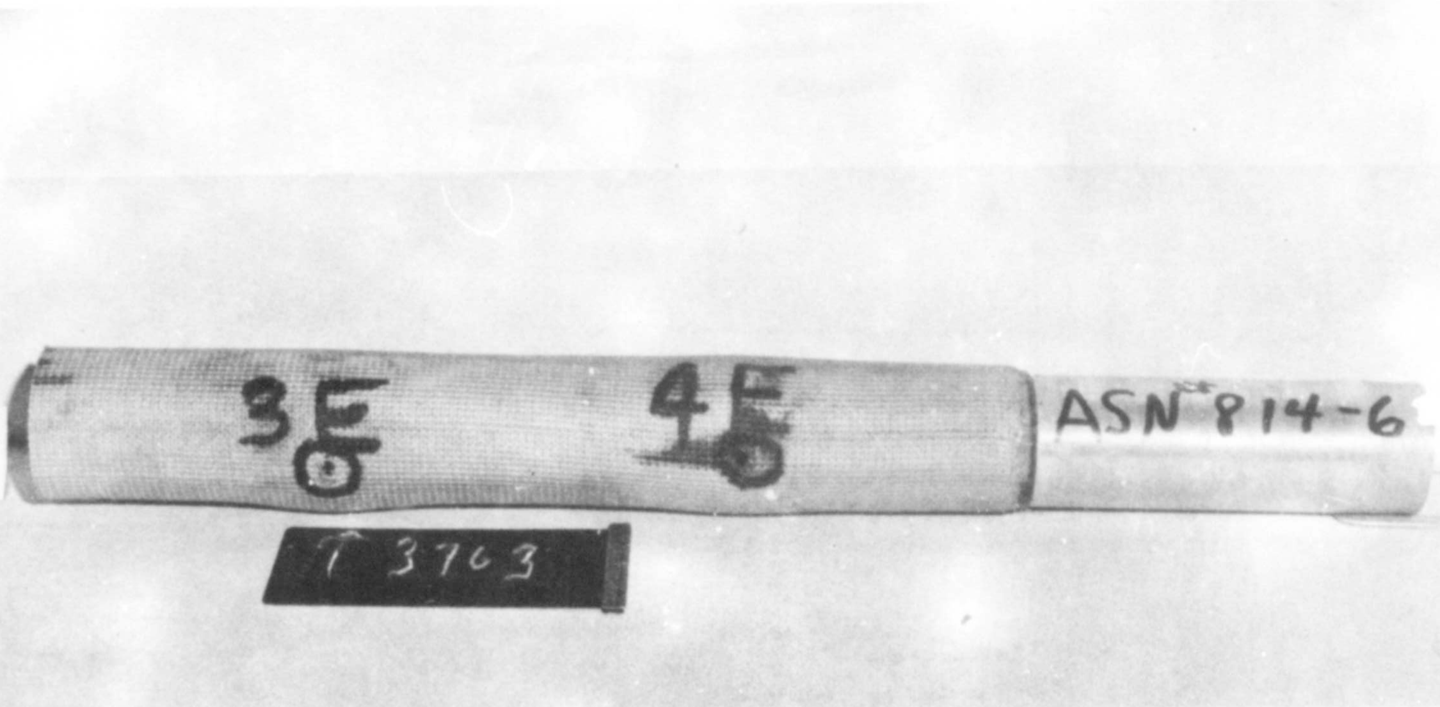
Photograph No. 18 - Silicone Rubber Covered Aluminum Tube, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



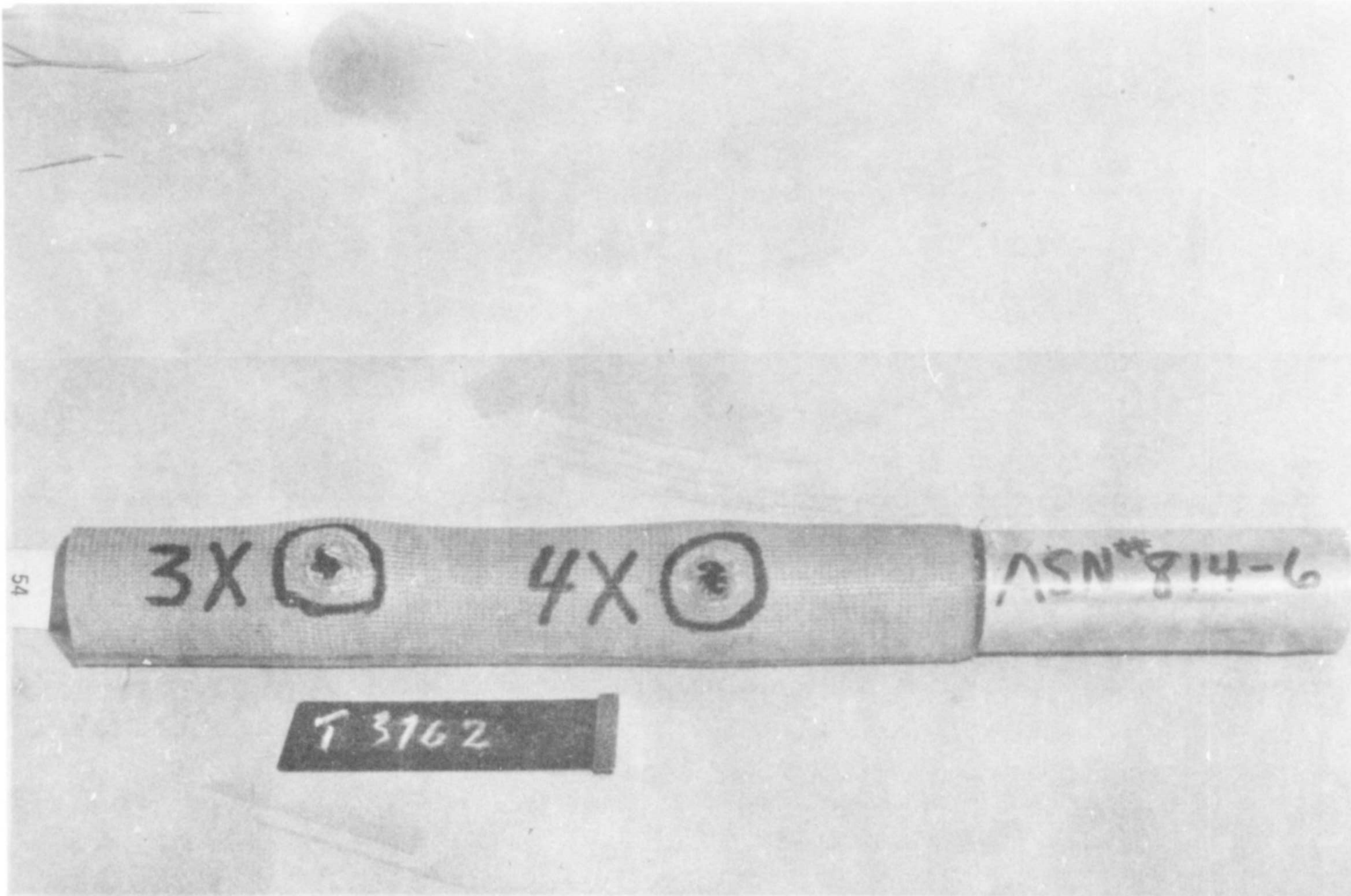
Photograph No. 19 - Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 5



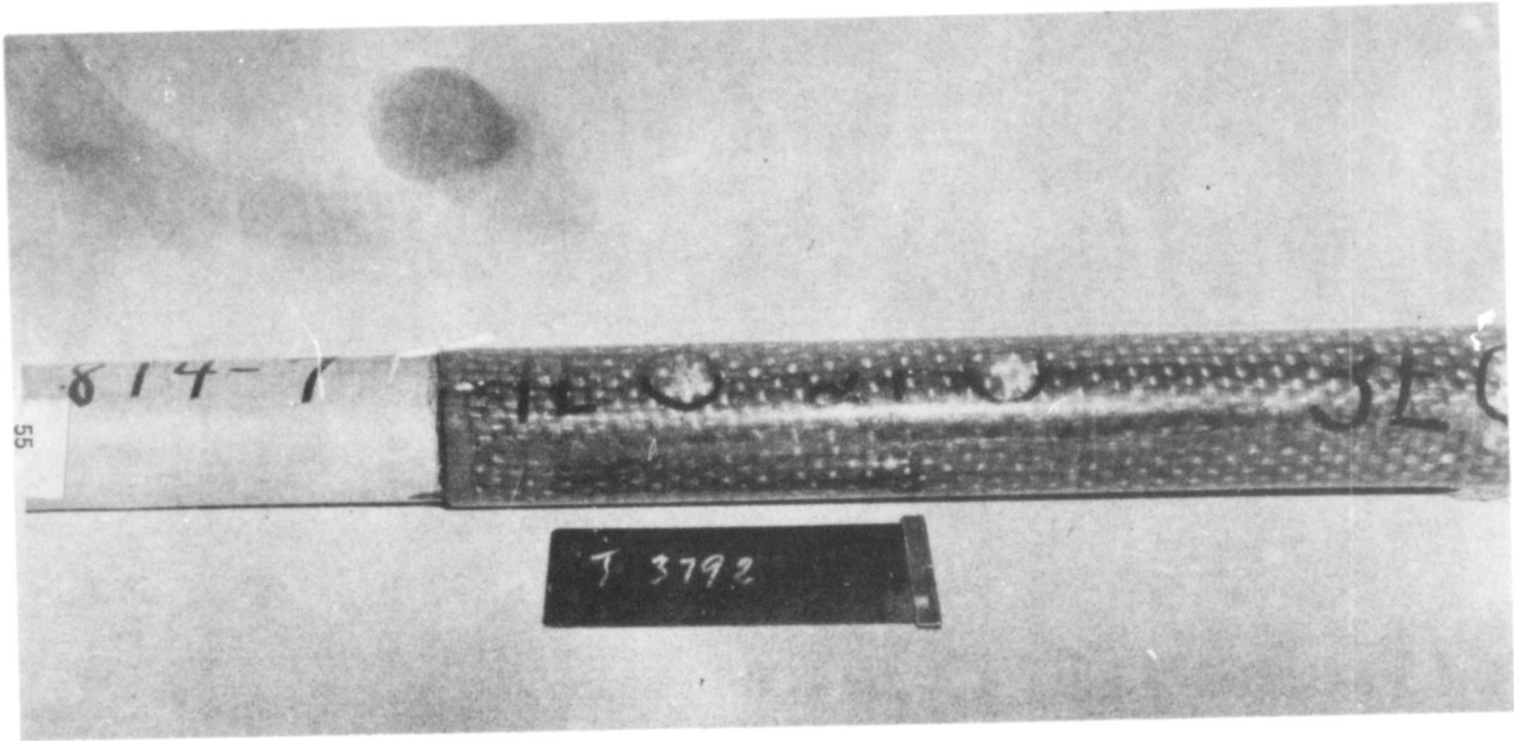
Photograph No. 20 - Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 5



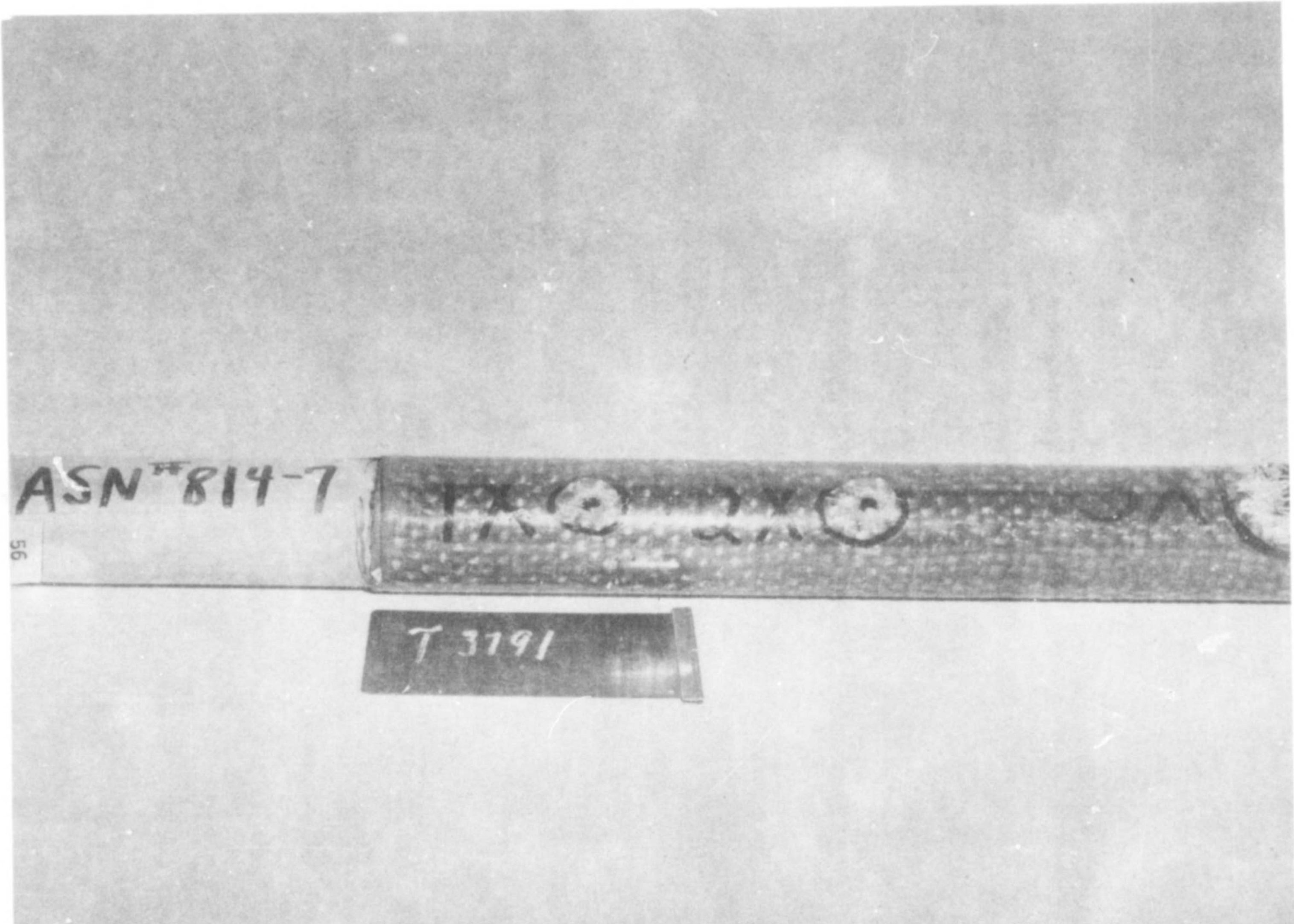
Photograph No. 21 - Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 3 and 4



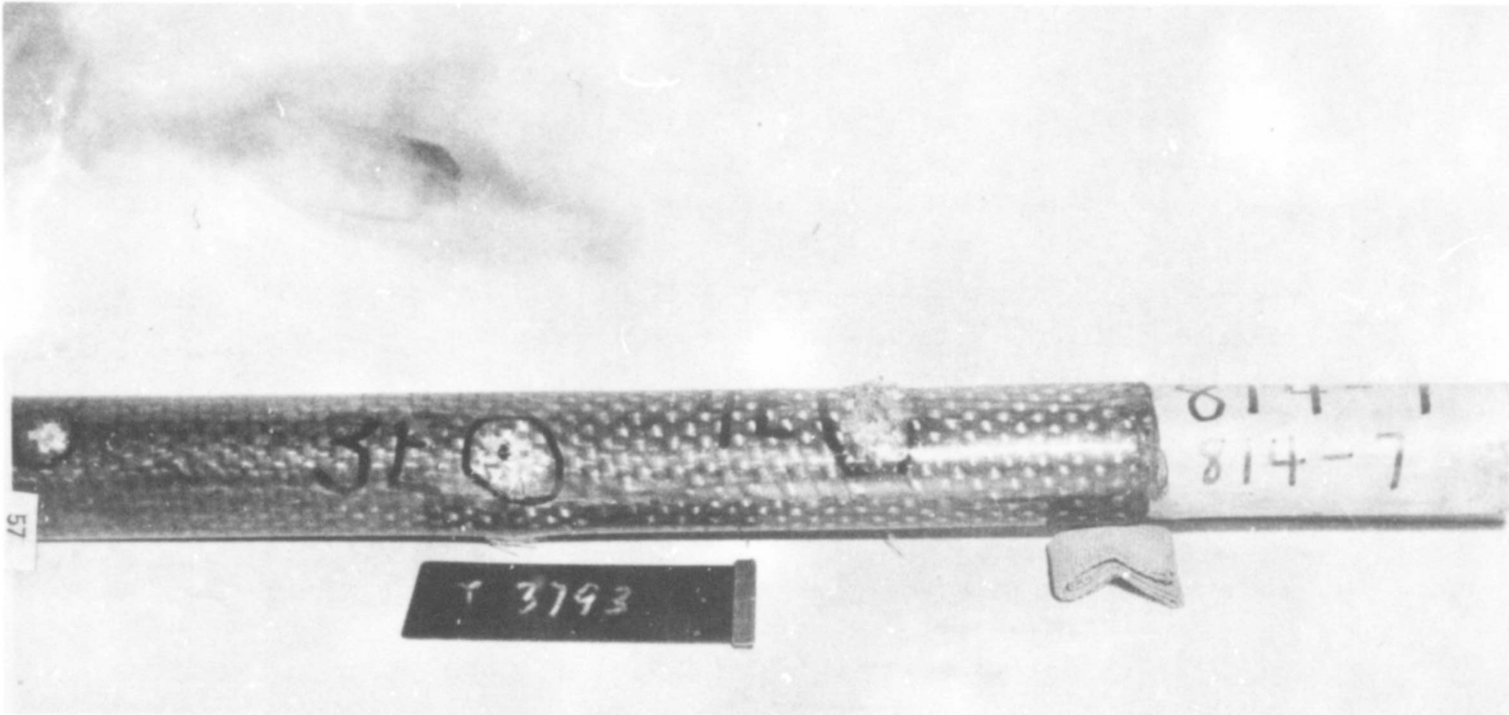
Photograph No. 22 - Aluminum Tube Covered with One Ply of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with Polyurethane, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 3 and 4



Photograph No. 23 - Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2

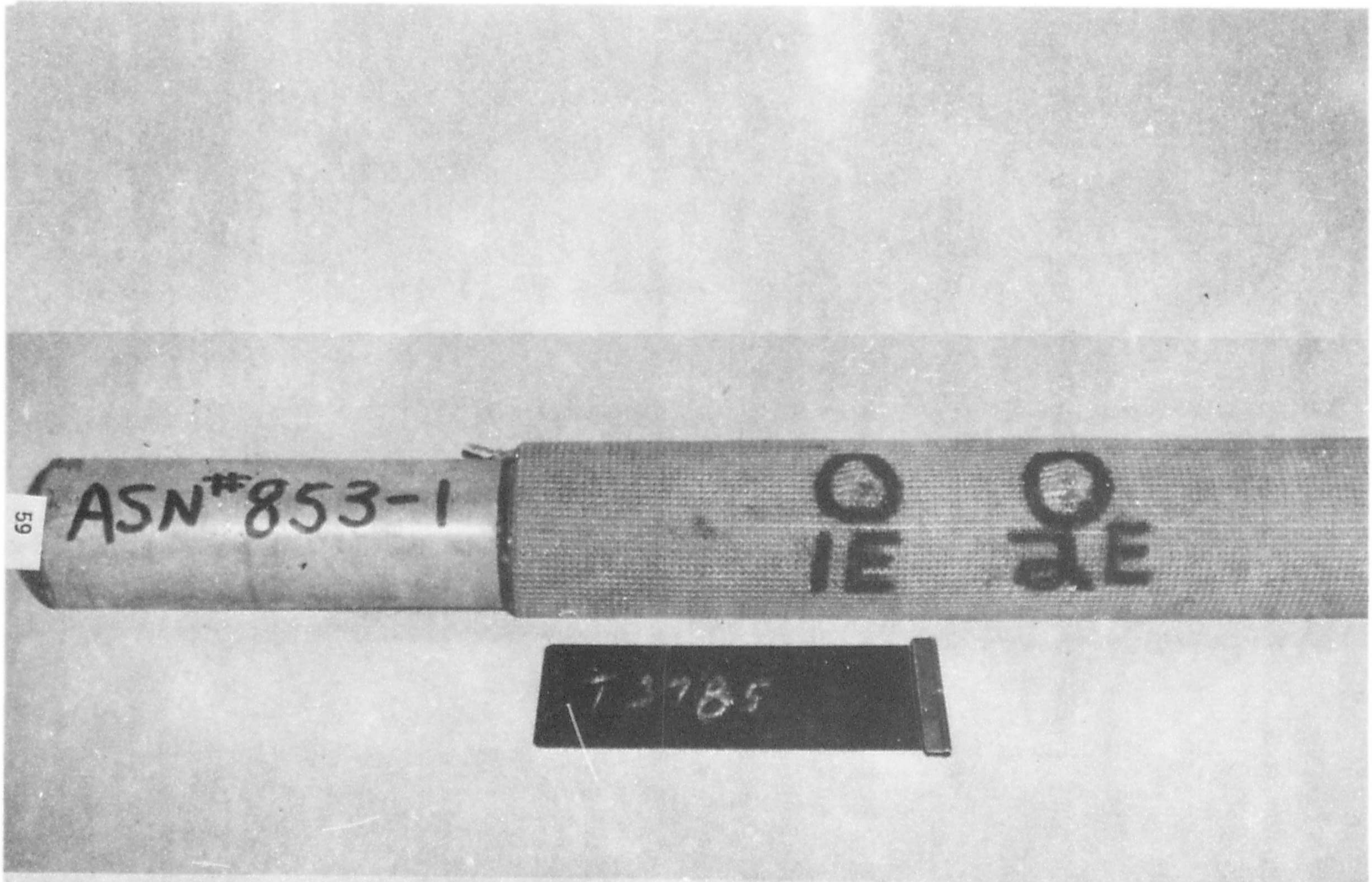


Photograph No. 24 - Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2

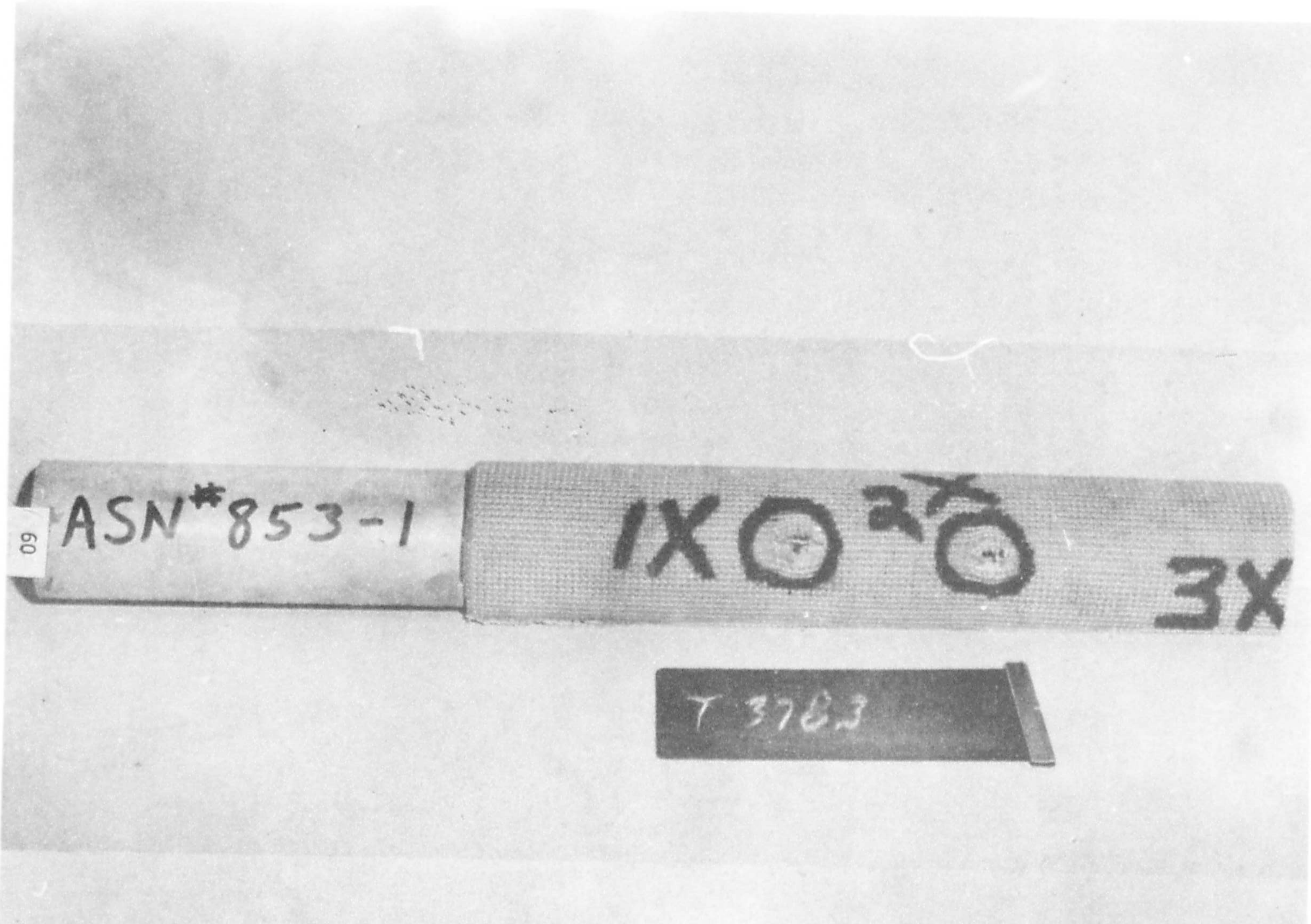


Photograph No. 25 - Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 3 and 4

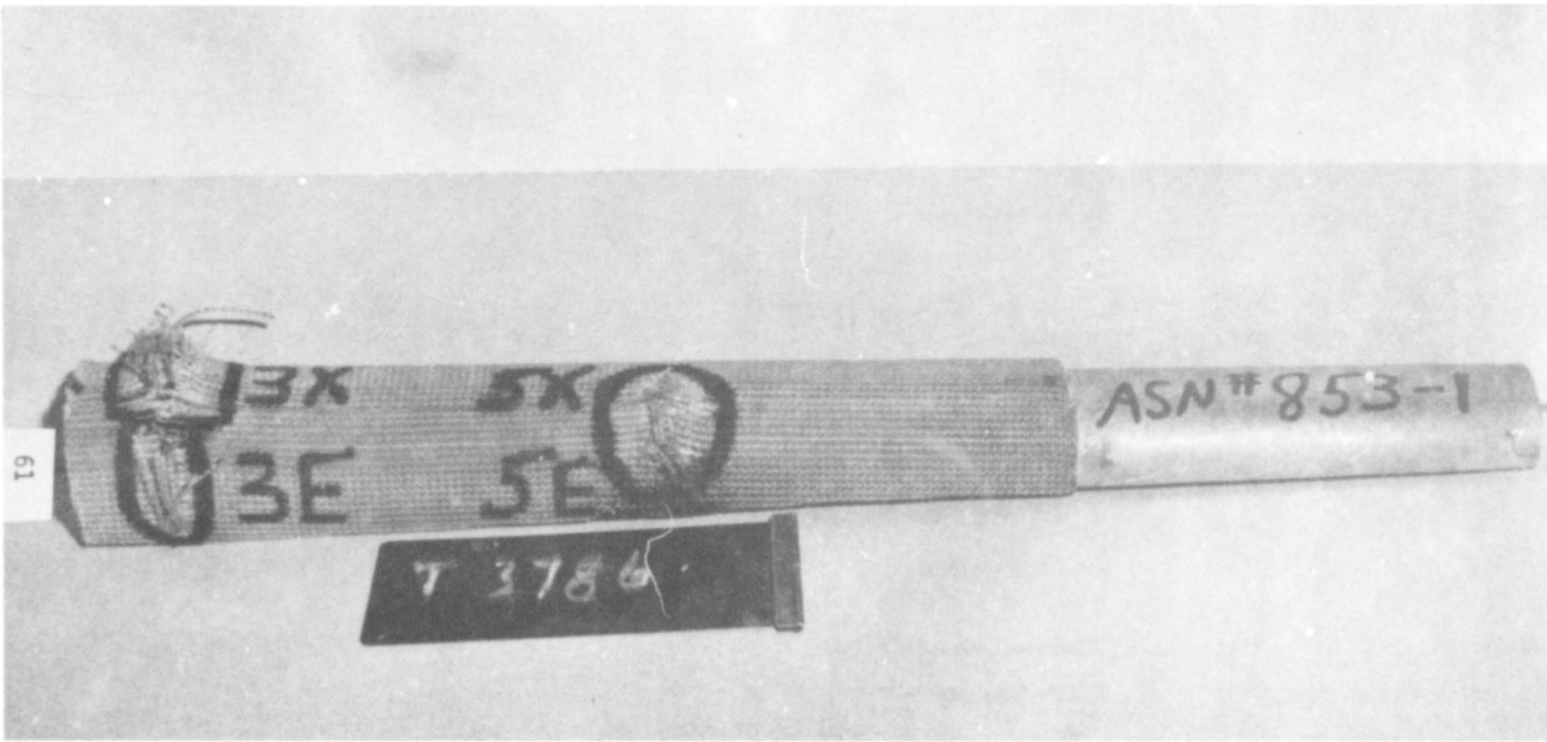
Photograph No. 26 - Aluminum Tube Covered with Epoxy Impregnated Fiberglass Woven Rovings, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 3 and 4



Photograph No. 27 - Aluminum Tube Covered with One Ply 43.35 oz./yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2

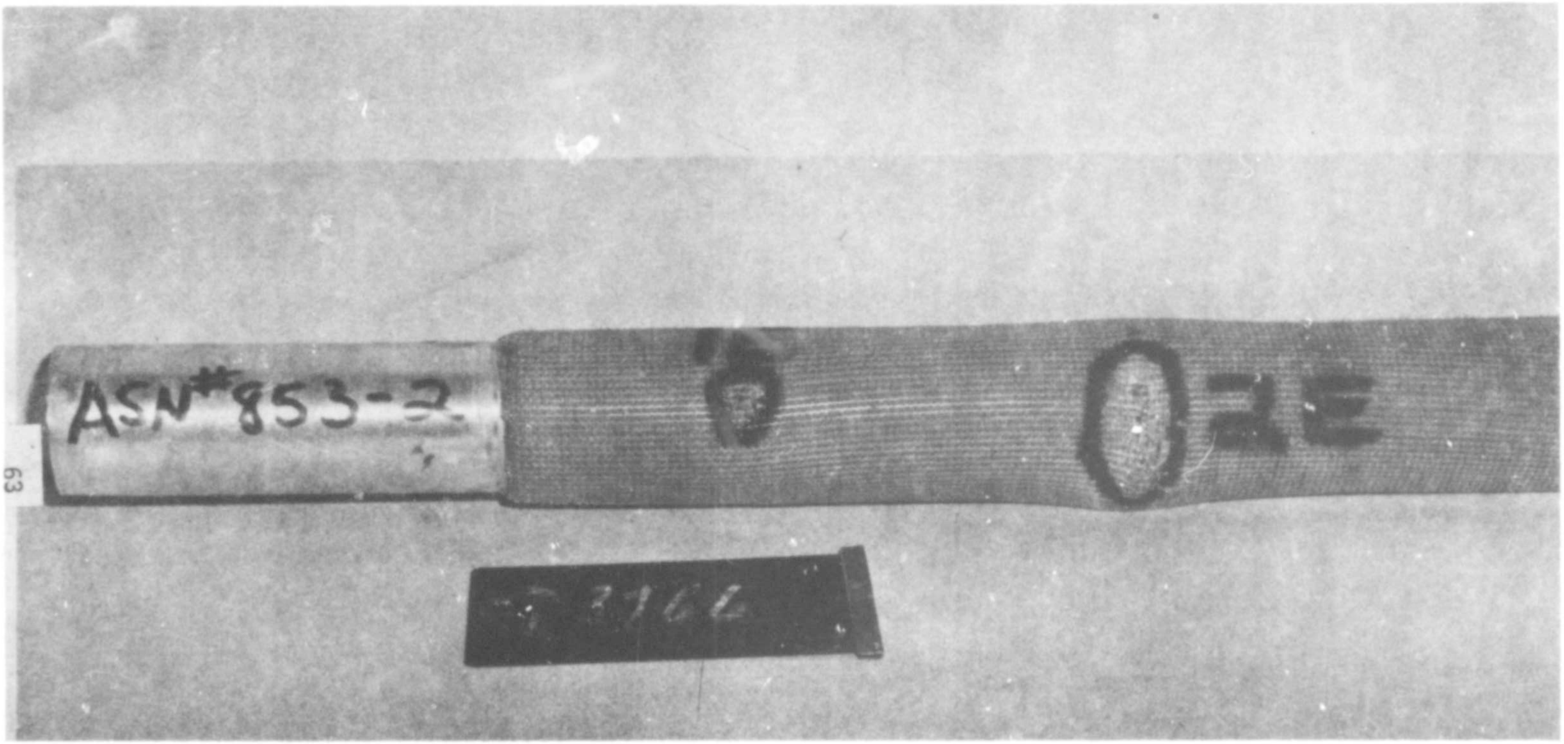


Photograph No. 28 - Aluminum Tube Covered with One Ply 43.45 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2



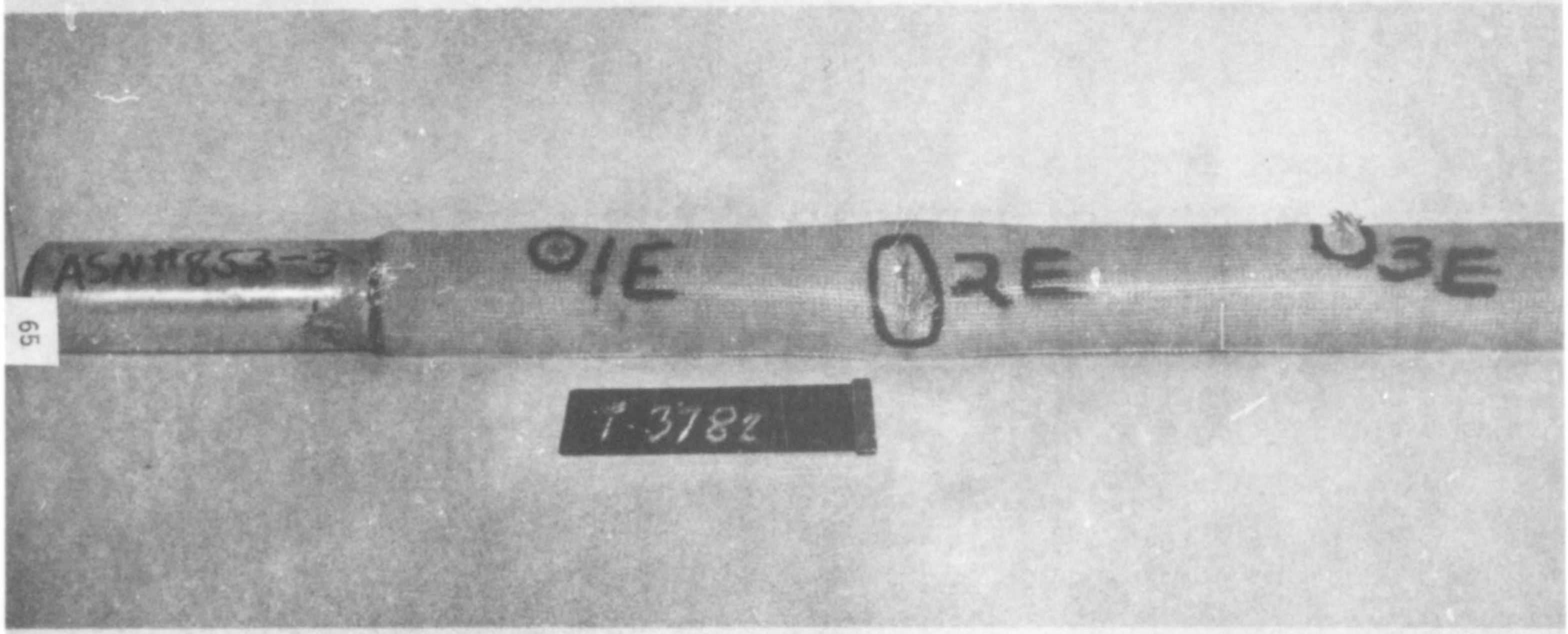
Photograph No. 29 - Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances and Exits of .030 Cal. AP Projectiles, Rounds 3 and 5, Both of Which Were Glancing Shots

Photograph No. 30 - Aluminum Tube Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrance and Exit of 0.30 Cal. AP Projectile, Round 4, Which Was a Glancing Shot

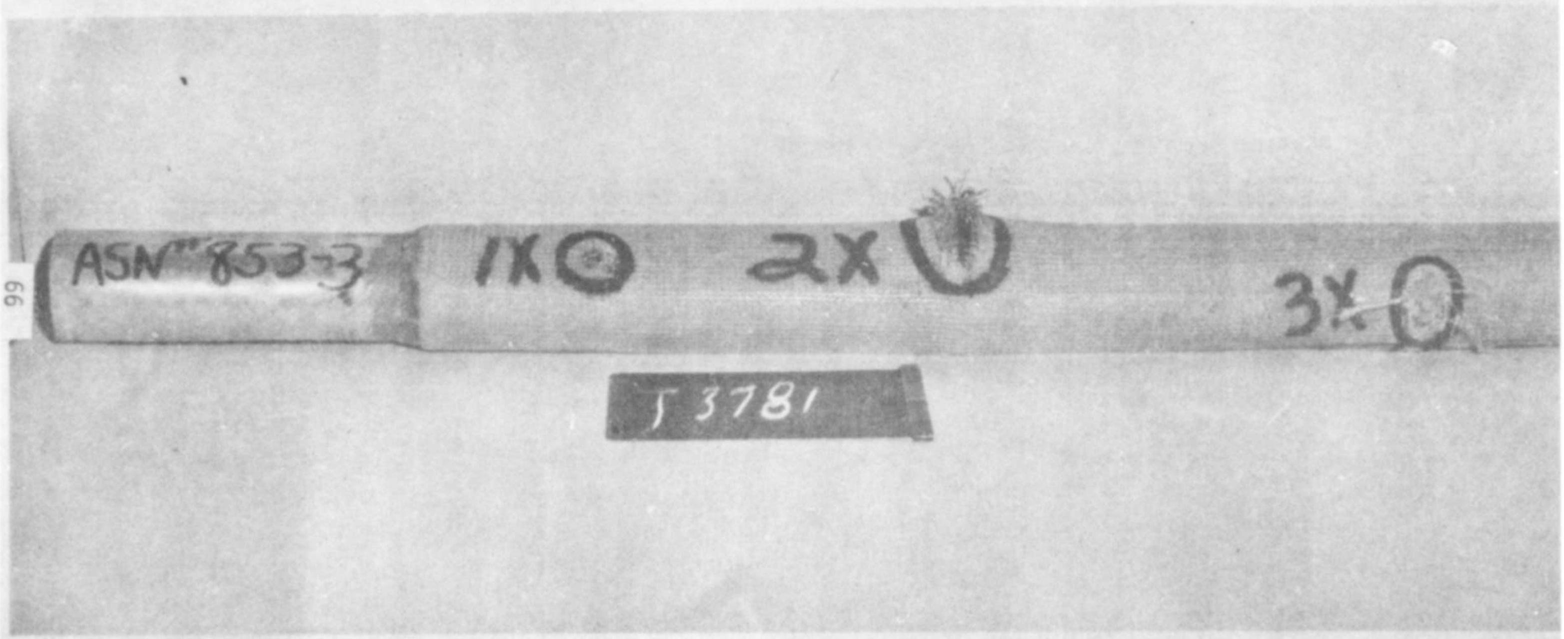


Photograph No. 31 - Aluminum Tube-Covered with One Ply 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2

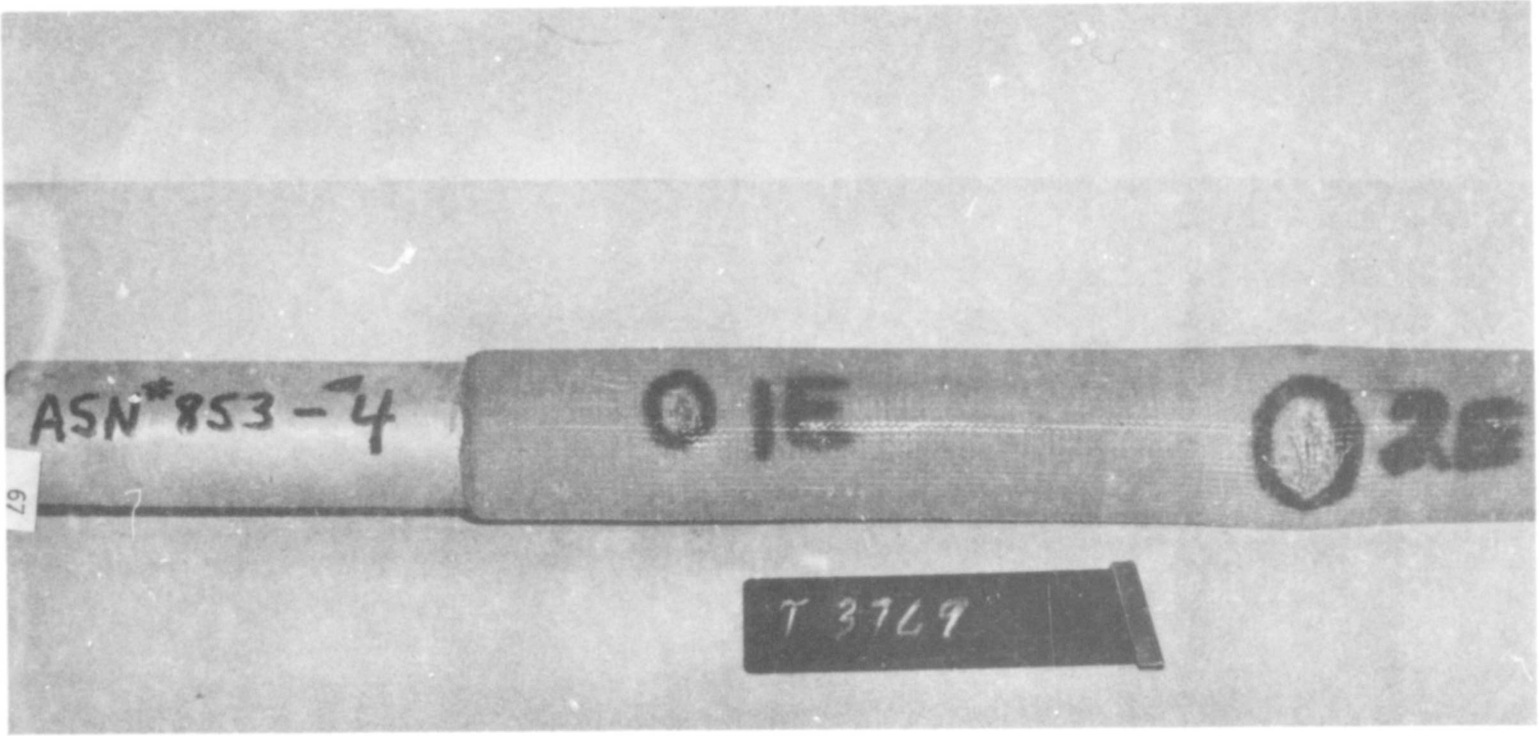
Photograph No. 32 - Aluminum Tube Covered with One Ply of 43.35 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2



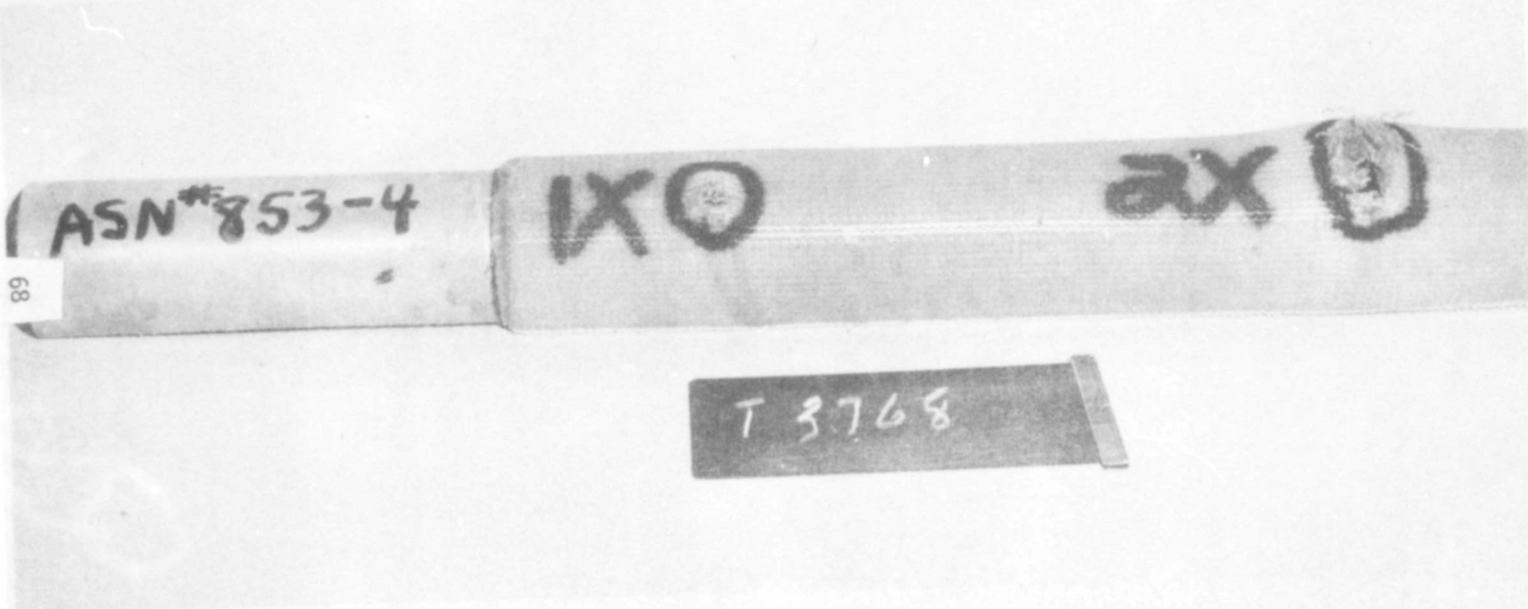
Photograph No. 33 - Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



Photograph No. 34 - Aluminum Tube Covered with Two Plies 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 101,053 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1, 2 and 3



Photograph No. 35 - Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Entrances of 0.30 Cal. AP Projectiles, Rounds 1 and 2



Photograph No. 36 - Aluminum Tube Covered with Two Plies of 27.75 oz/yd^2 USFlex Nylon Fabric Impregnated with 700-4 Polyurethane Resin, Showing Exits of 0.30 Cal. AP Projectiles, Rounds 1 and 2

B. Integral Self-Sealing Fuel Lines

A second approach to the "flowering" problem is the elimination of the metallic fuel line. The concept of an integral self-sealing fuel line consists of a fuel resistant rubber or rubberized fabric liner surrounded by a conventional type fuel line cover. The fuel line and self-sealing cover are manufactured as one integral unit.

As a first step, two fuel lines were fabricated without sealant plies to determine the tear and impact resistance of integral type constructions. The liner was a 0.060" thick ply of nitrile rubber coated with a nylon resin to prevent migration of fuel. Over the liner six plies of nitrile rubber impregnated fabric were applied. In ASN 947 this fabric was 27.75 oz/yd^2 USFlex nylon, in ASN 948 it was a 13 oz/yd^2 square woven nylon fabric made of tire cord type yarns. Both lines were fabricated over removable mandrels and given conventional fuel line autoclave cures.

After cure and removal of mandrels, the lines were gunfired while pressurized at 35 psi with Type I test fluid. Since no sealant was provided in the constructions, sealing performance could not be rated. Instead, the lines were evaluated for their resistance to tearing and delamination caused by gunfire impacts and their resistance to delamination caused by fuel leakage. The lines were gunfired with 0.30 caliber AP tumbled rounds, 0.30 caliber Ball straight and tumbled rounds, and 0.50 caliber AP straight rounds. In each case, the wounds produced were small with no tearing observed. There was no sign of delamination either from gunfire impact or fuel leakage through open wounds.

Based on this experience, two more integral lines were fabricated. ASN 961-1 contained the same fabric plies as ASN 947 and ASN 961-2 the same as ASN 948. However, each also contained 0.172" of 3083 natural rubber sealant between plies 3 and 4. Table XII gives the results of gunfire of ASN 961-1 and -2. It was noted that while damage to the lines was slight, self-sealing performance was poor. This was attributed to the large amount of fabric in relation to sealant which may have caused fibers to be driven through wounds allowing fuel to be carried along the fibers as wicks.

ASN 970 was a urethane integral fuel line consisting of a polyurethane film liner, two plies of polyurethane impregnated 27.75 oz/yd^2 USFlex nylon, 0.173" of 3083 natural rubber sealant, and two plies of polyurethane impregnated 27.75 oz/yd^2 USFlex nylon. Table XIII gives details of its gunfire performance. This construction exhibited better sealing performance than ASN 961-1 and -2 but, similar to them, it did not reliably seal wounds even though the wounds were held to small holes by the fabric reinforcements.

ASN 984 was fabricated from 27.75 oz/yd^2 USFlex fabric identical to ASN 961-1 except for the use of 0.252" of 3083 sealant rather than 0.173". Gunfire performance results are tabulated in Table XIV. As in the other integral fuel lines, ASN 984 was unable to reliably seal all wounds. Observation at the time of gunfire suggested that distortion

B. Integral Self-Sealing Fuel Lines (Cont'd.)

of the tube by the pressure of fuel prevented complete closure of the wound by sealants.

Experience has shown that experimental integral fuel lines did not perform their self-sealing functions as efficiently as standard fuel line covers on metal lines. Reasons suggested for this lack of performance are the large amount of fabric relative to sealant rubber and the distortion of the flexible tube by fuel pressure.

TABLE XII

GUNFIRE RESULTS FOR INITIAL INTEGRAL FUEL LINE EXPERIMENT

Fuel Line ASN 961-1

Fuel Type: Type I test fluid
Fuel Temperature: Ambient
Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except as noted
Projectile Velocity: Standard
Construction of Cover: Integral. Fabricated from 6 plies of USFlex nylon & 0.172" 3083 sealant

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Small stream slowing some but remaining a stream.	
	Exit	Seeping leak that did not seal.	
2	Entrance	Heavy seep that did not seal.	Wounds were high in tube.
	Exit	Slight seep that did not seal.	
3	Entrance	Small stream that did not seal.	
	Exit	Heavy seep that did not seal.	
	0.50 cal M33 Ball ammunition		
4	Entrance	Small stream.	
	Exit	Large stream.	

Fuel Line ASN 961-2

Fuel Type: Type I test fluid
Fuel Temperature: Ambient
Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except as noted
Projectile Velocity: Standard
Construction of Cover: Integral. Fabricated from 6 plies of 20 oz/yd^2 square woven nylon and 0.172" 3083 sealant.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Fine spray of fuel slowly opening to a large spray.	
	Exit	Large stream of fuel slowling slightly but still a large stream at 2 min.	
2	Entrance	Small stream opening to a large stream at 2 min.	
	Exit	Large stream with no signs of slowing.	
	0.30 cal. AP tumbled		
3	Entrance	Large gushing stream.	
	Exit	Large gushing stream.	

TABLE XIII

GUNFIRE RESULTS FOR URETHANE INTEGRAL FUEL LINE

Fuel Line ASN 970

Fuel Type: Type I test fluid

Projectile Type: 0.50 cal AP

Fuel Temperature: Ambient

Projectile Velocity: Standard

Fuel Pressure: 35 psi

Construction of Cover: Integral. Fabricated from 4 plies of urethane impregnated US-Flex nylon and 0.173" 3083 sealant.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Heavy seep of fuel slowing to a damp seal at 2 min.	
	Exit	Moderate seep of fuel slowing to a damp seal at 3½ min.	
2	Entrance	Small spray of fuel slowing to a heavy seep at 2 min.	
	Exit	Large spray of fuel with no signs of slowing at 4 min.	
3	-	-	Sliced cover. Did not penetrate liner.
4	Entrance	Very slight seep slowing to a seal at 1 min.	
	Exit	Heavy seep of fuel with no signs of slowing at 5 min.	

TABLE XIV

GUNFIRE RESULTS FOR INTEGRAL FUEL LINE WITH INCREASED SEALANT

Fuel Line ASN 984

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

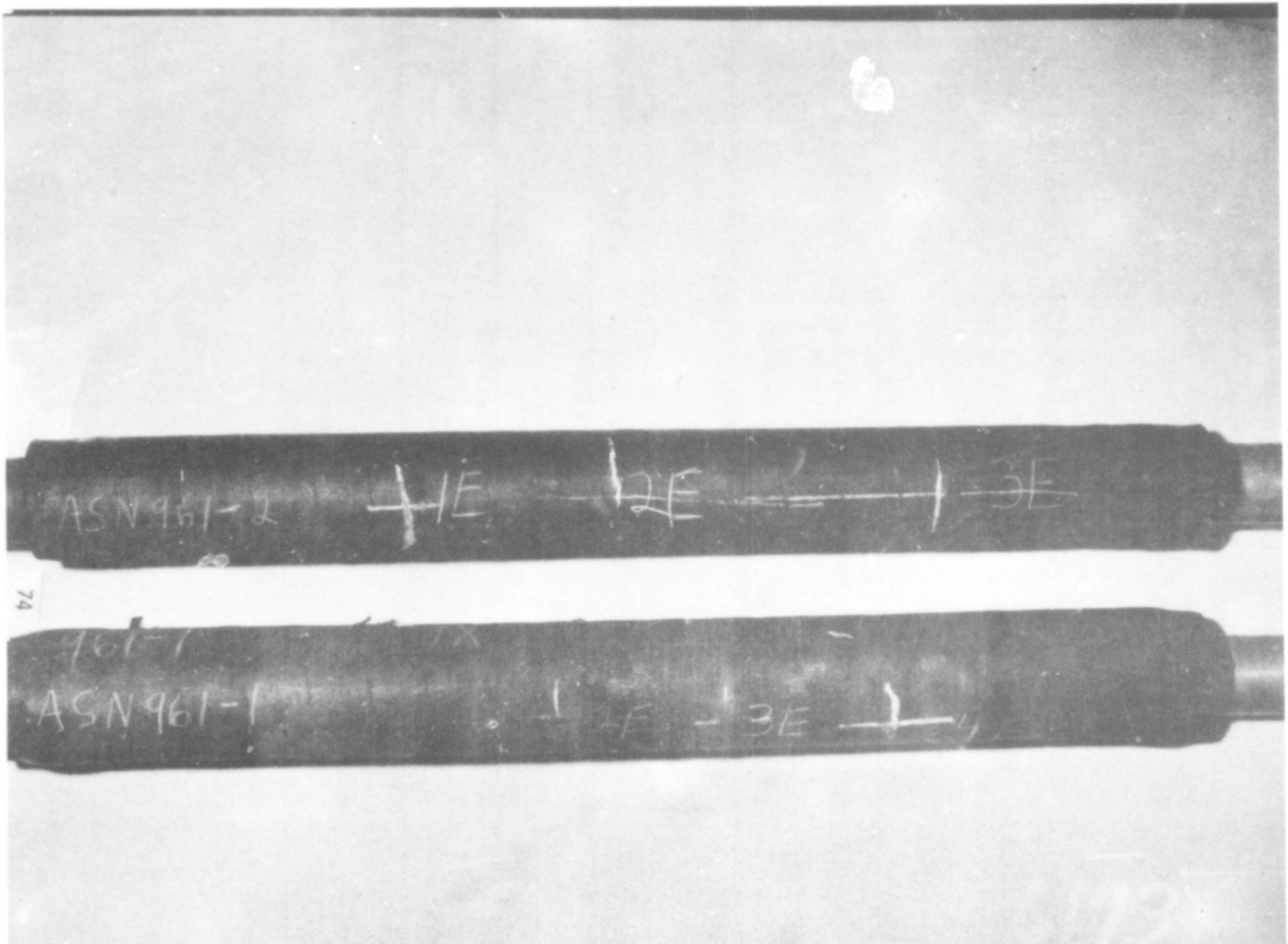
Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except as noted

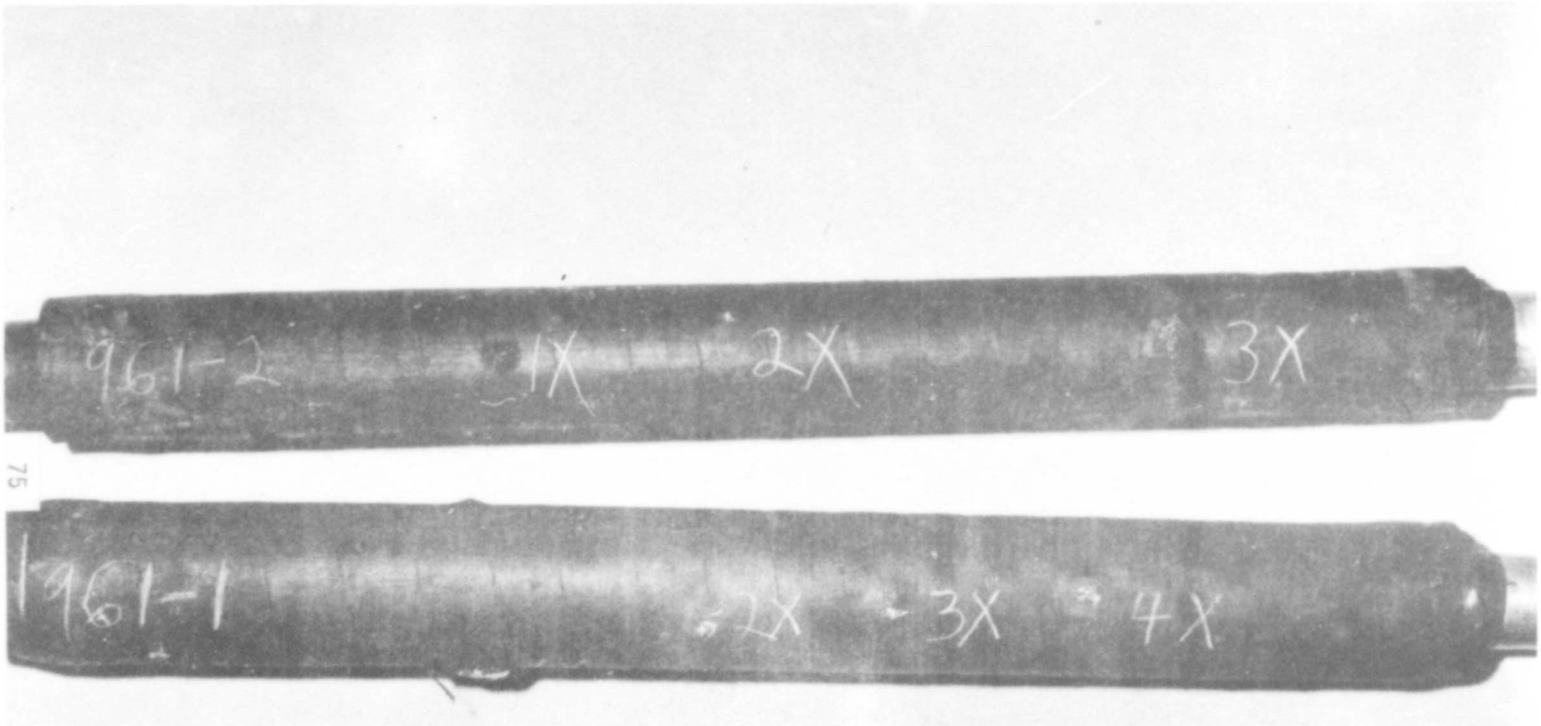
Projectile Velocity: Standard

Construction of Cover: Integral. Fabricated from 6 plies of USFlex nylon and 0.25" of 3083 sealant.

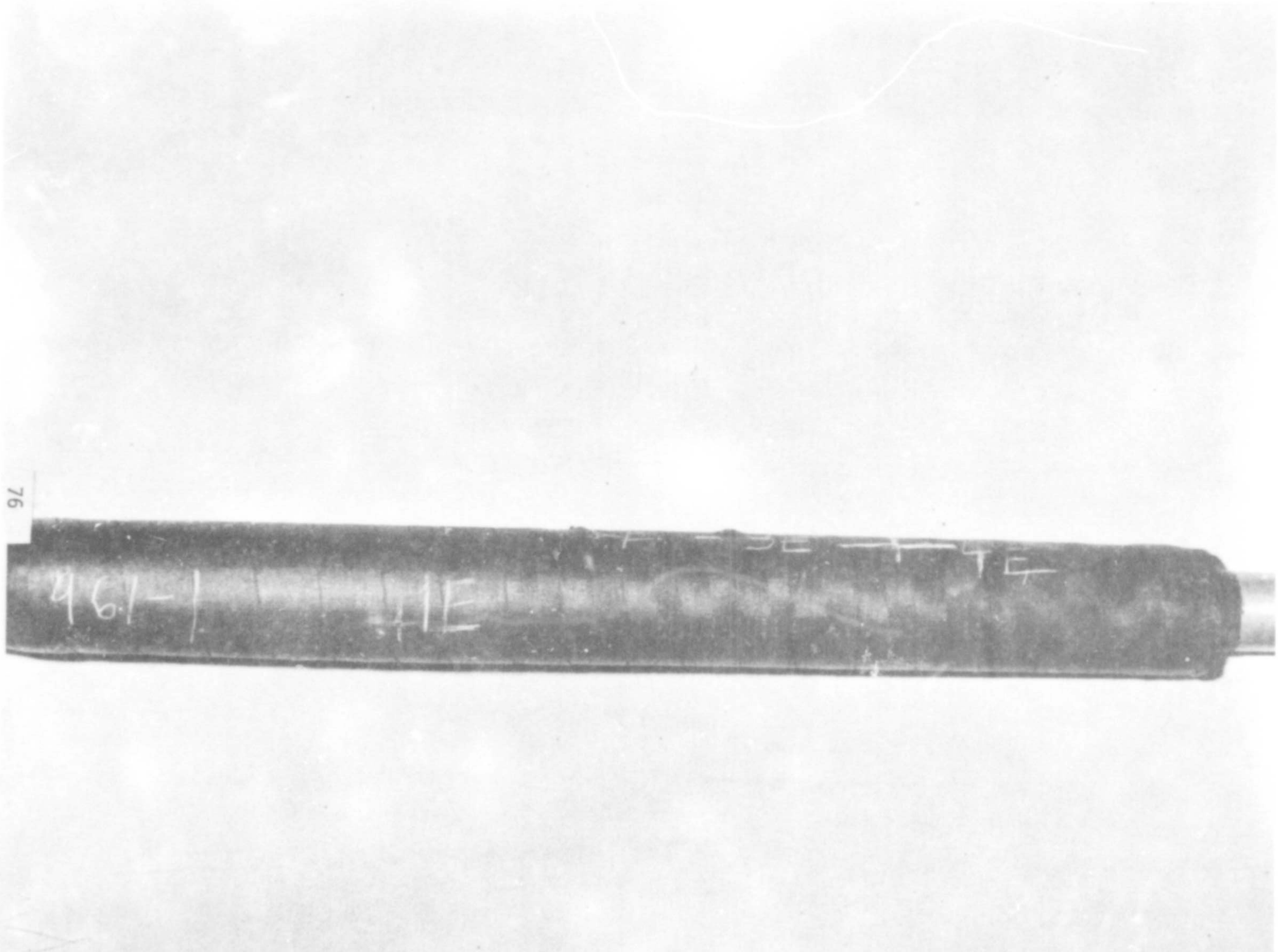
Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Slight seep of fuel increasing to a heavy seep at 1 min.	Wounds are high in tube.
	Exit	Heavy seep with no sign of slowing at 4 min.	
2	Entrance	Slight seep remaining a slight seep at 4 minutes.	
	Exit	Slight seep remaining a slight seep at 4 min.	Exit wound is on an exterior seam of the cover.
3	Entrance	Slight seep slowing to a damp seal at 1 min.	
	Exit	Dry seal.	
4	Entrance	Slight seep which remained a slight seep at 4 min.	
	Exit	Dry seal.	
	0.30 cal. AP tumbled round		
5	Entrance	Small stream.	
	Exit	Large gushing stream.	



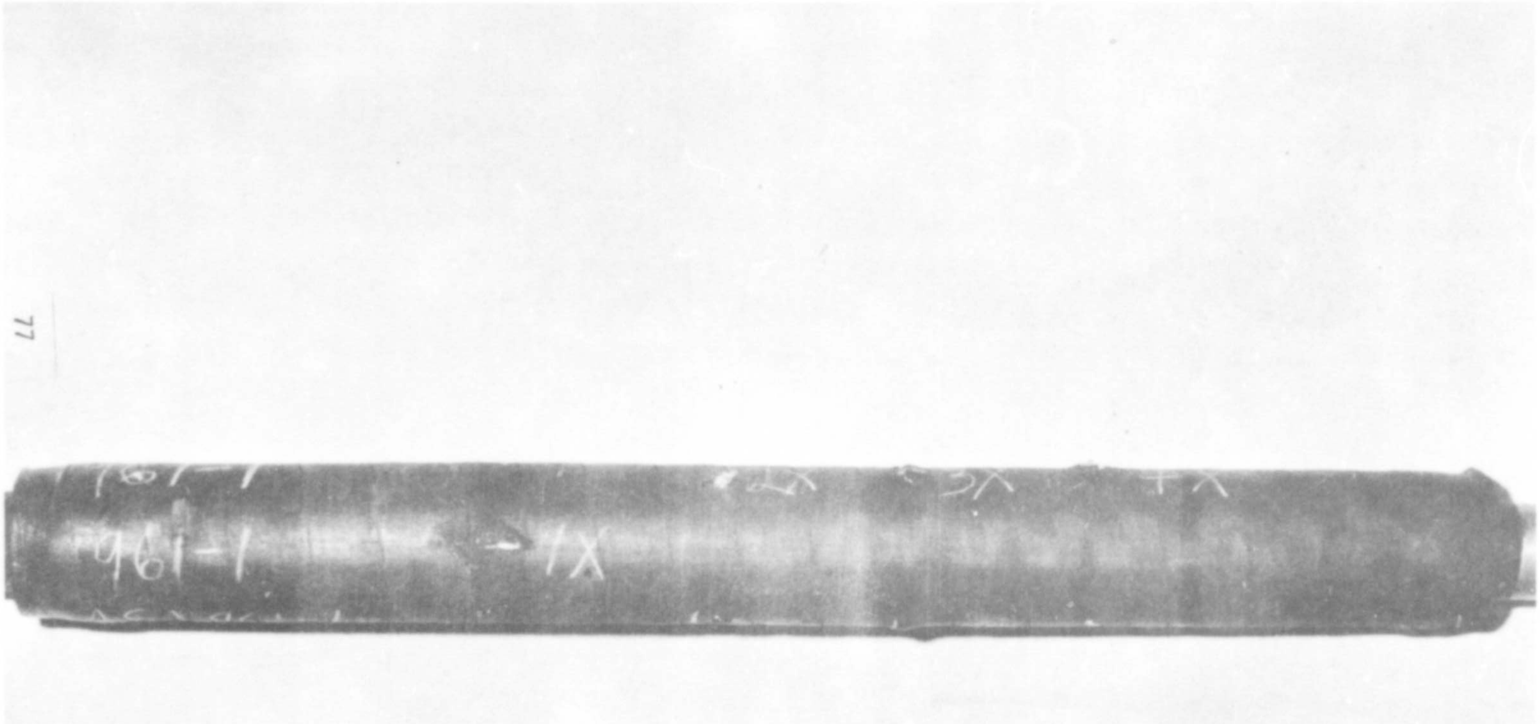
Photograph No. 37 - Integral Fuel Lines ASN 961-1 and ASN 961-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Entrance Side.



Photograph No. 38 - Integral Fuel Lines ASN 961-1 and ASN 961-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Exit Side.

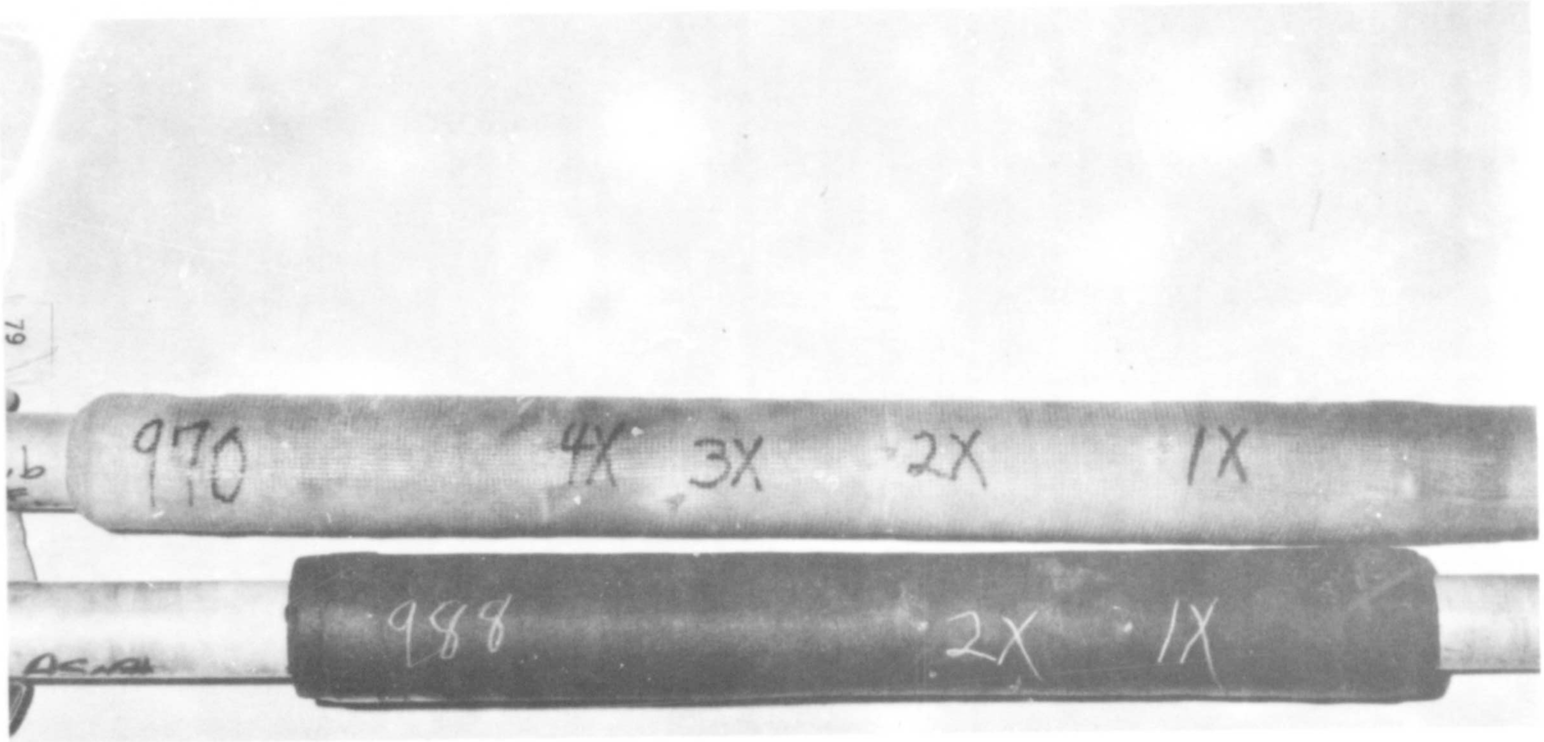


Photograph 39 - Entrance Wound From Round 1 in Integral Fuel Line ASN 961-1



Photograph No. 40 - Exit Wound from Round 1 in Integral Fuel Line ASN 961-1

Photograph No. 41 - Integral Fuel Line ASN 970 and Silicone Sealant Fuel Line Cover ASN 988 After Gunfire with 0.50 Cal. AP Ammunition. Entrance Side.



Photograph No. 42 - Integral Fuel Line ASN 970 and Silicone Sealant Fuel Line Cover ASN 988 After Gunfire with 0.50 Cal. AP Ammunition. Exit Side.

C. Nonmetallic Fuel Lines

An alternative approach to the avoidance of "flowering" of metal fuel lines is the use of plastic fuel lines. The properties of various plastic materials were studied and three were chosen for evaluation. These were Delrin (polyacetal plastic), nylon, and high density polyethylene. All of these resins combine high strength and modulus with a resistance to the solvent effects of hydrocarbon fuels.

Two inch O.D. tubes of each of these plastics were ordered from commercial suppliers. Three foot lengths of each tube were pressurized to 30 psi with water and gunfired with 0.50 caliber AP ammunition.

The Delrin tube shattered extensively cutting the line in half and scattering shards of plastic over the gunfire area.

The nylon tube exhibited a small entrance wound, but the exit wound was much larger than the bullet cross section. The exit wall was shattered radially from the wound and some pieces of plastic had been expelled.

The high density polyethylene tube exhibited two small round holes for entrance and exit wounds. There was no evidence of shattering of the plastic in any portion of the tube.

Because of its excellent resistance to gunfire, high density polyethylene (HDPE) was chosen as the material to be evaluated for nonmetallic fuel lines. The first experiment involved the application of a conventional US-191 fuel line cover to an HDPE tube. The outer surface of the tube was etched with a chromic acid solution to provide a better adhesion surface. After rinsing and drying the tube, a rubber to metal type adhesive was applied and the cover fabricated in the same way as on a metal tube. The completed cover was vulcanized in place on the tube.

This covered tube, ASN 1021, was gunfired and the results of this gunfire test are given in Table XV. Sealing performance was quite good.

Since the nonmetallic fuel line is expected to reduce or eliminate "flowering" as a source of mechanical damage to the self-sealing cover, a second fuel line was fabricated featuring a cover without a rubber liner. In this line, ASN 1031, the rubber sealant rests directly upon the HDPE tube. When this line was cured, it was found that wrinkles had developed in the outer reinforcement ply. This was attributed to the ability of the cover to move during cure due to the lack of adhesion between the sealant rubber and the plastic tube.

Gunfire results for ASN 1031 are given in Table XVI. It can be seen that the first round produced some leakage on the entrance and that there was leakage out of an end closure. The end closure leakage was probably due to the small adhesion area of the end closure on the tube compared to a conventional cover where a large liner area is adhered to the tube preventing the full pressure of fluid inside the cover after a gunfire wound from reaching the end closure adhesion area. When the end closure leakage was halted by application of an external

C. Nonmetallic Fuel Lines (Cont'd.)

clamp, the cover filled with fuel and grew in diameter by pulling all of the wrinkles taut. Three subsequent rounds produced seals on both entrance and exit wounds, while a fourth produced a seal on the exit wound and a very slight seep on the entrance.

It would appear that nonmetallic fuel lines can be protected by much lighter and thinner covers than those used on metal lines.

In the development work on new sealants and reinforcements (discussed below), it was determined that a high resilience ply of rubber has the effect of closing wounds from gunfire. Neoprene rubber was found to be the most effective for this purpose. An HDPE tube was covered with a self-sealing construction consisting of a nitrile rubber liner, sealant rubber, a ply of neoprene rubber, a ply of tire cord coated with a neoprene cement, and a final ply of neoprene rubber.

The gunfire results for this fuel line, ASN 1032, are given in Table XVII. With standard 0.50 caliber AP rounds, the cover gave excellent results. The wounds sealed immediately and had been closed by the neoprene plies so that they were of pinhole size. In the case of the more destructive tumbled and M33 Ball rounds, damage was so extensive that the neoprene was of little help in the sealing process.

In the final experiment with nonmetallic fuel lines, the position of neoprene plies was varied. This was done to determine if the neoprene ply would be most efficient in aiding sealing performance as a liner to reduce damage to the fuel line or as an outer ply to close wounds. ASN 1044-1 consisted of a nitrile rubber liner, sealant rubber, a ply of neoprene rubber, and conventional rubber coated tire cord outer reinforcement as used in US-191. ASN 1044-2 consisted of a neoprene rubber liner, sealant rubber, and the rubber coated tire cord outer reinforcement.

Gunfire data for 1044-1 and -2 is given in Table XVIII. Examination of the results suggests that both approaches work quite well on HDPE tubes. ASN 1044-2 did receive one wound, Exit #4, which did not seal and, in fact, opened up slightly as time passed. This might suggest that the design of -1 is superior because the neoprene ply gives support to the sealant ply and thus reduces its tendency to elongate and permit leakage to increase.

In conclusion, it appears that nonmetallic fuel lines based on high density polyethylene show promise as the basis for self-sealing systems. The absence of "flowering" allows the cover to act much more efficiently in sealing gunfire wounds.

TABLE XV

GUNFIRE RESULTS FOR US-191 COVER ON HIGH DENSITY POLYETHYLENE TUBE

Fuel Line ASN 1021

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except where noted

Projectile Velocity: Standard

Construction of Cover: US-191

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Damp seal immediately.	
	Exit	Damp seal immediately.	
2	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
3			High shot did not penetrate fuel carrying tube.
4	0.50 cal. M33 Ball ammunition Entrance	Dry seal immediately.	
	Exit	Large gushing stream.	Extensive damage to cover and tube.

TABLE XVI

GUNFIRE RESULTS FOR US-191 WITHOUT LINER ON HIGH DENSITY POLYETHYLENE TUBE

Fuel Line ASN 1031

Fuel Type:	Type I test fluid	Projectile Type:	0.50 cal AP
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	30 psi	Construction of Cover:	US-191 with nitrile liner omitted.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Heavy spray of fuel. When pressure was reapplied after repair of end closure, leakage was a slight seep. Still a slight seep at 4 min.	End closure opened at 1 min. Pressure was removed and end closure repaired.
	Exit	Damp seal immediately.	
2	Entrance	Slight seep slowing to damp seal at 1½ min.	
	Exit	Dry seal immediately.	
3	Entrance	Slight seep slowing to damp seal at 1 min.	
	Exit	Dry seal immediately.	
4	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
5	Entrance	Slight seep slowing but not sealing in 4 min.	
	Exit	Dry seal immediately.	

TABLE XVII

GUNFIRE RESULTS FOR HIGH RESILIENCE NEOPRENE TYPE COVER IN HIGH DENSITY POLYETHYLENE TUBE

Fuel Line ASN 1032

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 30 psi

Projectile Type: 0.50 cal except where noted

Projectile Velocity: Standard

Construction of Cover: Liner and sealants identical to US-191 outer reinforcement 0.2" of high resilience neoprene with one ply of tire cord.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	Damage to cover almost invisibly small on both rounds 1 and 2
2	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
3	0.30 cal. AP tumbled round Entrance	High pressure spray.	
	Exit	Slight seep.	
4	0.50 Cal. M33 Ball ammunition Entrance	Slight seep.	
	Exit	Large gushing stream.	

TABLE XVIII

EFFECT OF VARYING POSITION OF NEOPRENE PLIES OF SEALING PERFORMANCE

Fuel Line ASN 1044-1

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 30 psi

Projectile Type: 0.50 cal AP except where noted

Projectile Velocity: Standard

Construction of Cover: nitrile liner, 3083 sealant, neoprene ply, rubber coated tire cord

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Slight dripping of fuel slowed to damp seal at 1 min.	Wound low on tube.
	Exit	Slight dripping of fuel slowed to damp seal at 1 min.	
2	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
3	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately	
4	0.50 cal. M33 Ball ammunition Entrance	Slight seep.	
	Exit	Heavy gushing leak.	Extensive damage to cover and tube.

TABLE XVIII (Cont'd.)

Fuel Line ASN 1044-2

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

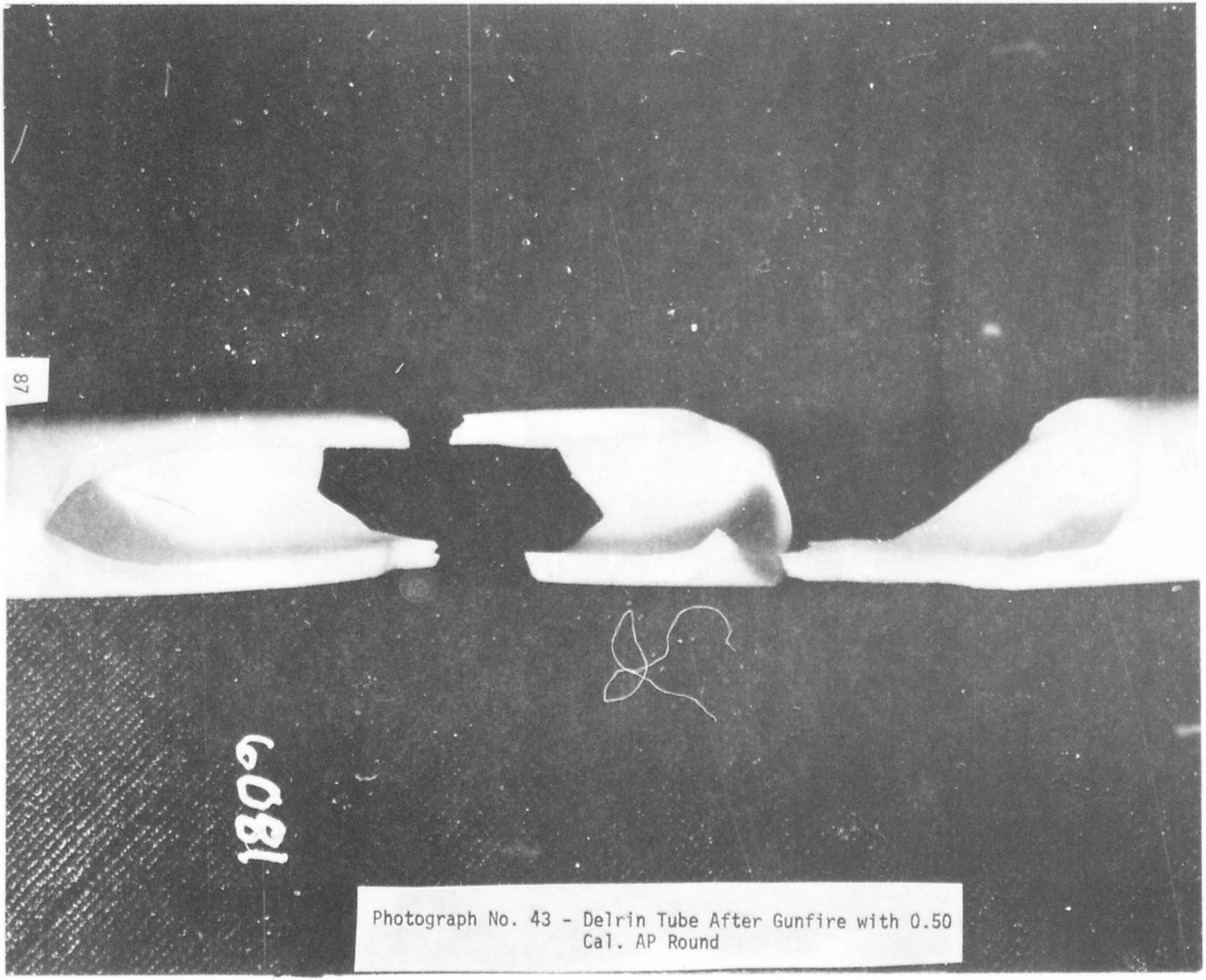
Fuel Pressure: 30 psi

Projectile Type: 0.50 Cal AP except where noted

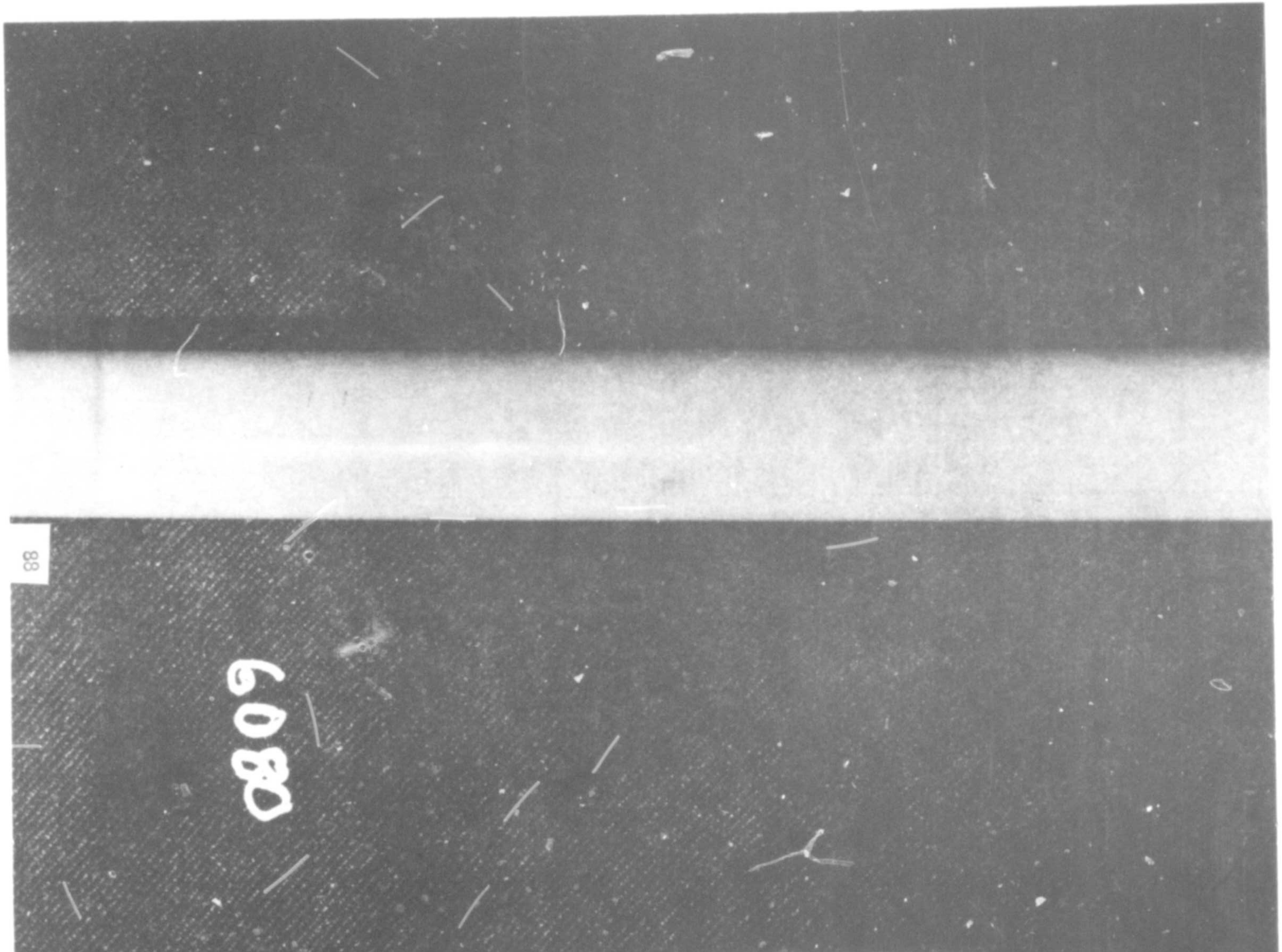
Projectile Velocity: Standard

Construction of Cover: neoprene liner, 3083 sealant, rubber coated tire cord

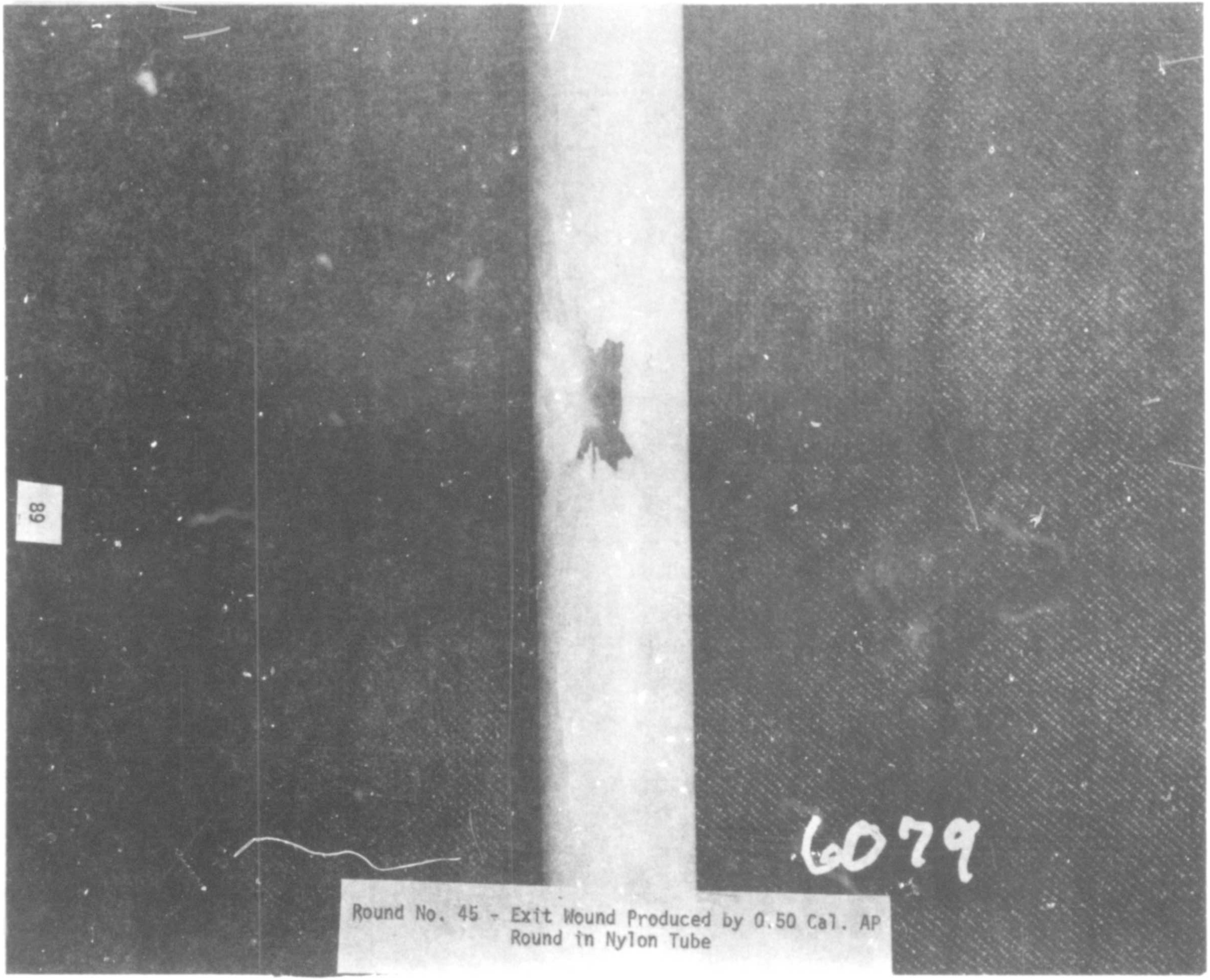
Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	Wounds slightly low on tube.
	Exit	Slight drip of fuel slowing to damp seal at 1 min.	
2	Entrance	Dry seal immediately.	Wounds slightly low on tube.
	Exit	Dry seal immediately.	
3	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
4	Entrance	Dry seal immediately.	
	Exit	Fine stream of fuel opening to a larger stream at 2 min.	
5	0.50 cal. M33 Ball ammunition Entrance	Slight drip of fuel.	
	Exit	Large gushing leak.	Extensive damage to cover and tube.



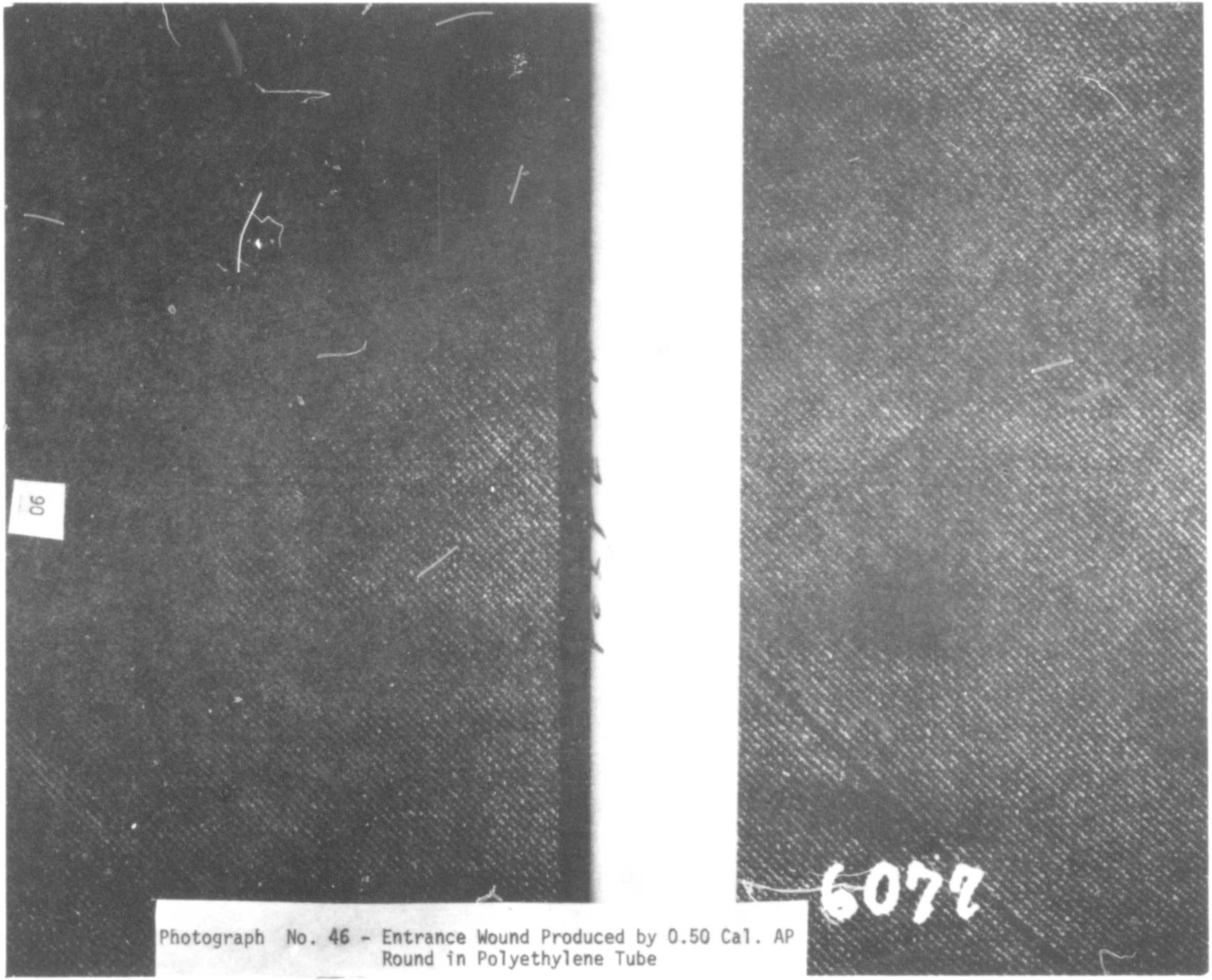
Photograph No. 43 - Delrin Tube After Gunfire with 0.50 Cal. AP Round



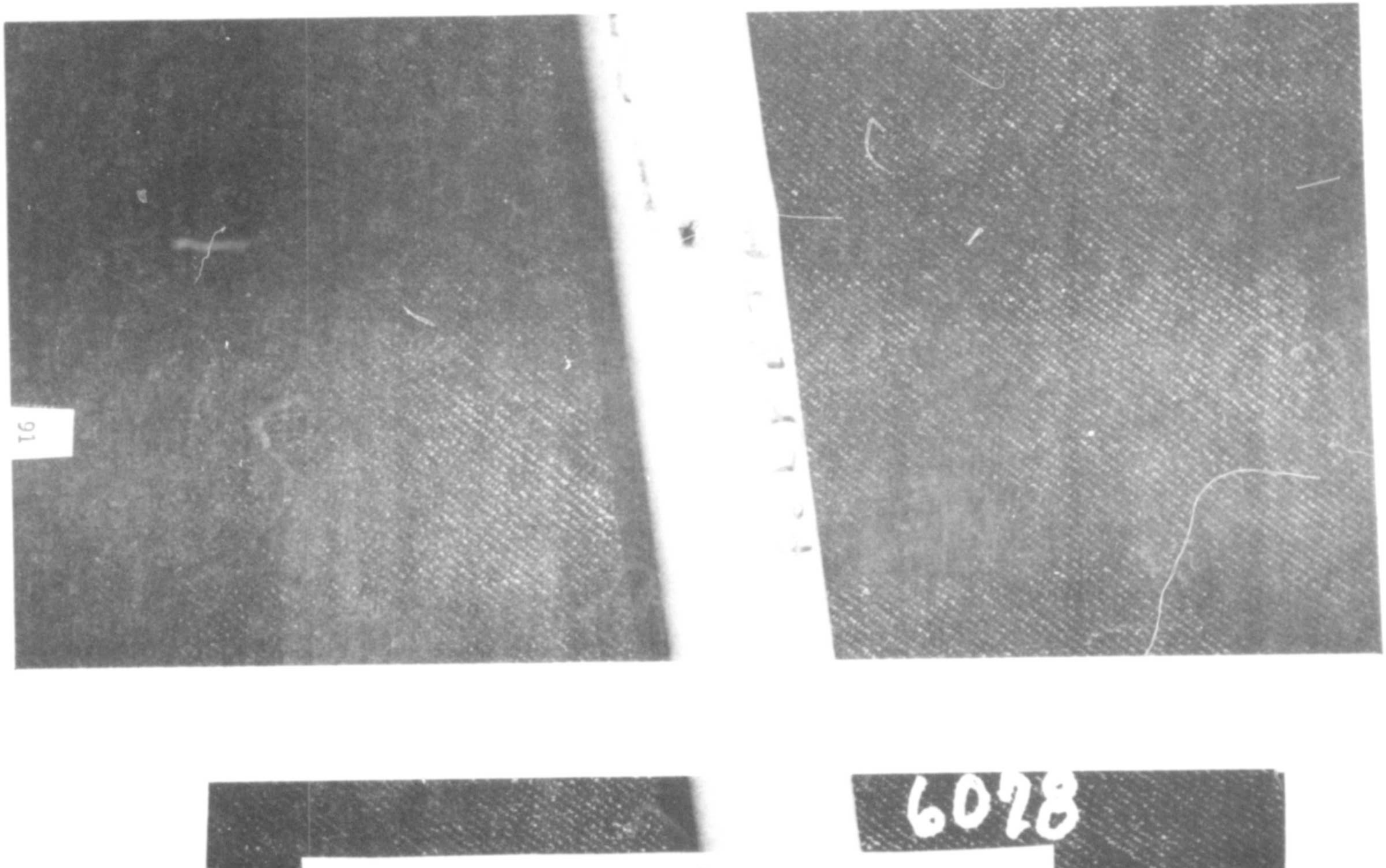
Photograph No. 44 - Entrance Wound Produced by 0.50 Cal.
AP Round in Nylon Tube



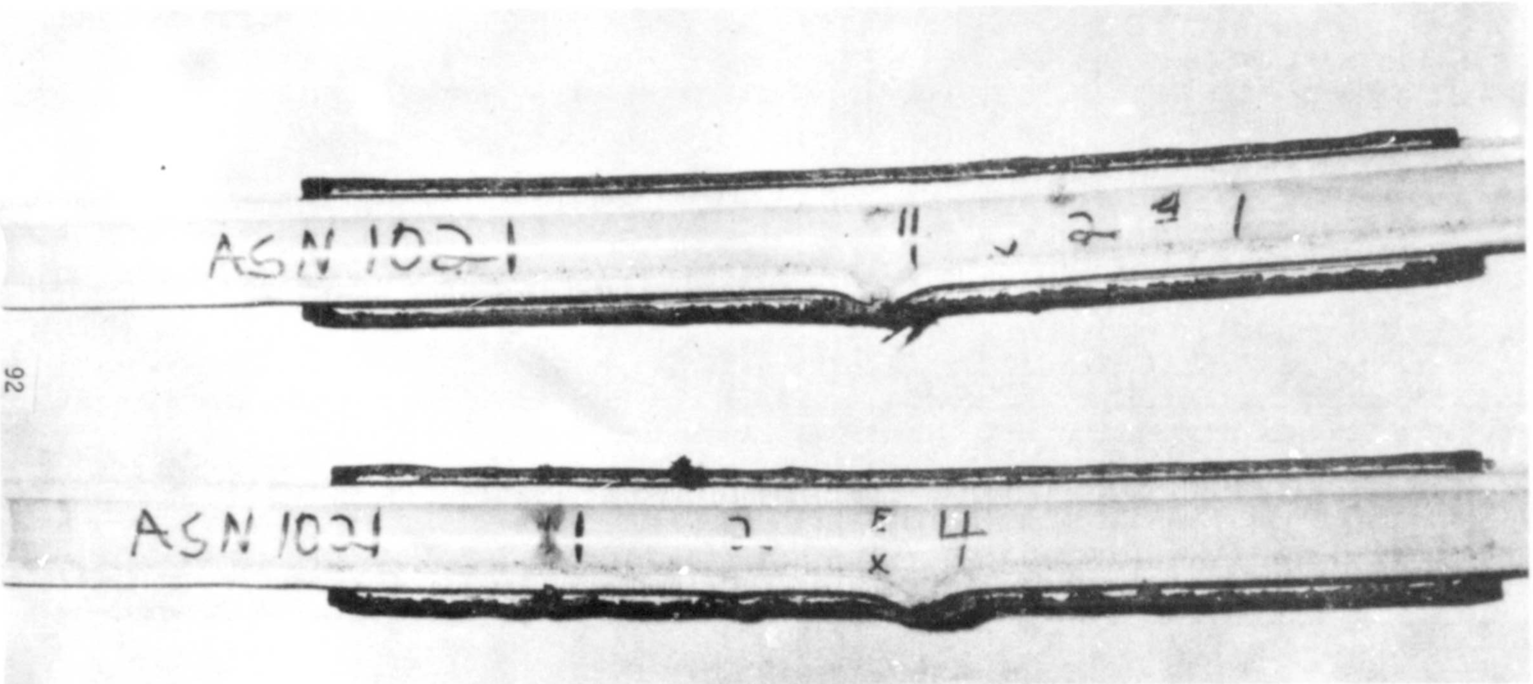
Round No. 45 - Exit Wound Produced by 0.50 Cal. AP
Round in Nylon Tube



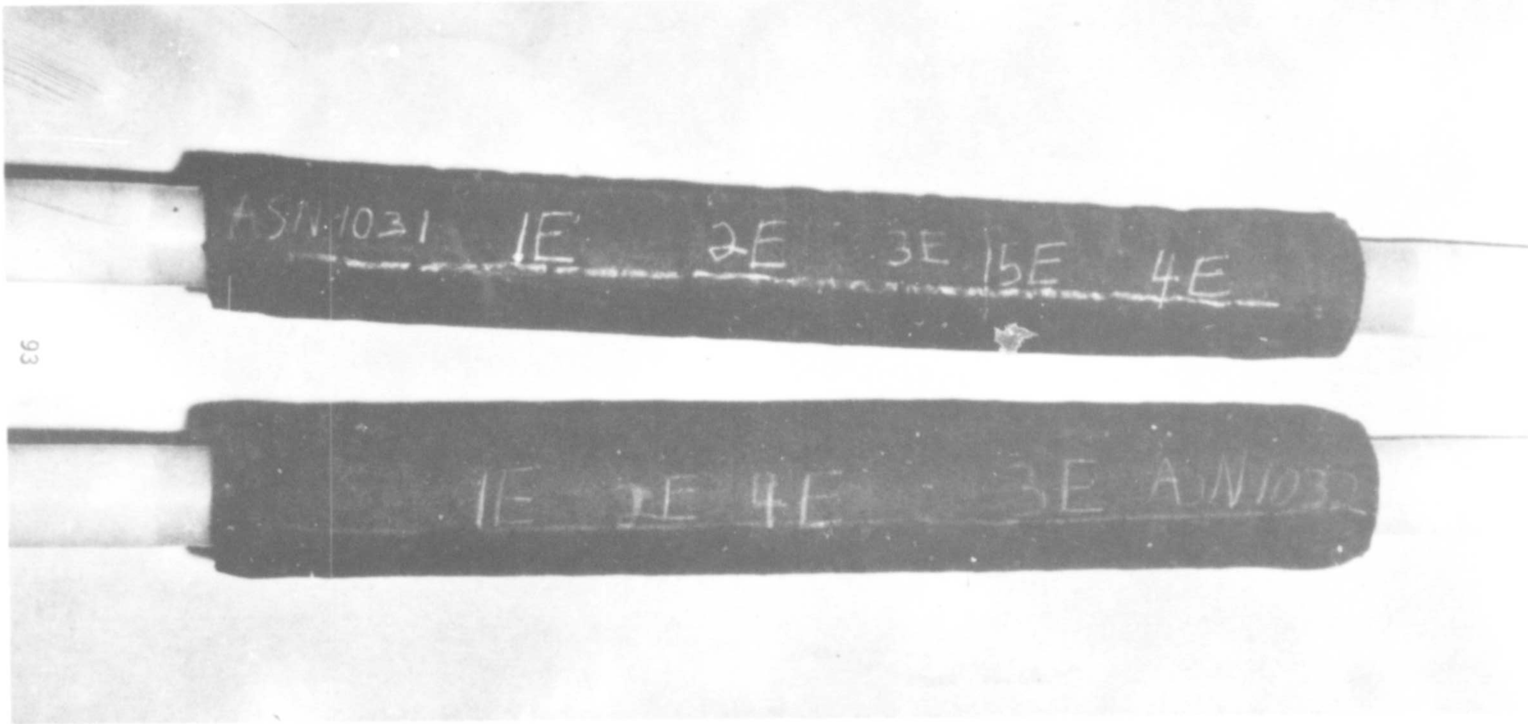
Photograph No. 46 - Entrance Wound Produced by 0.50 Cal. AP Round in Polyethylene Tube



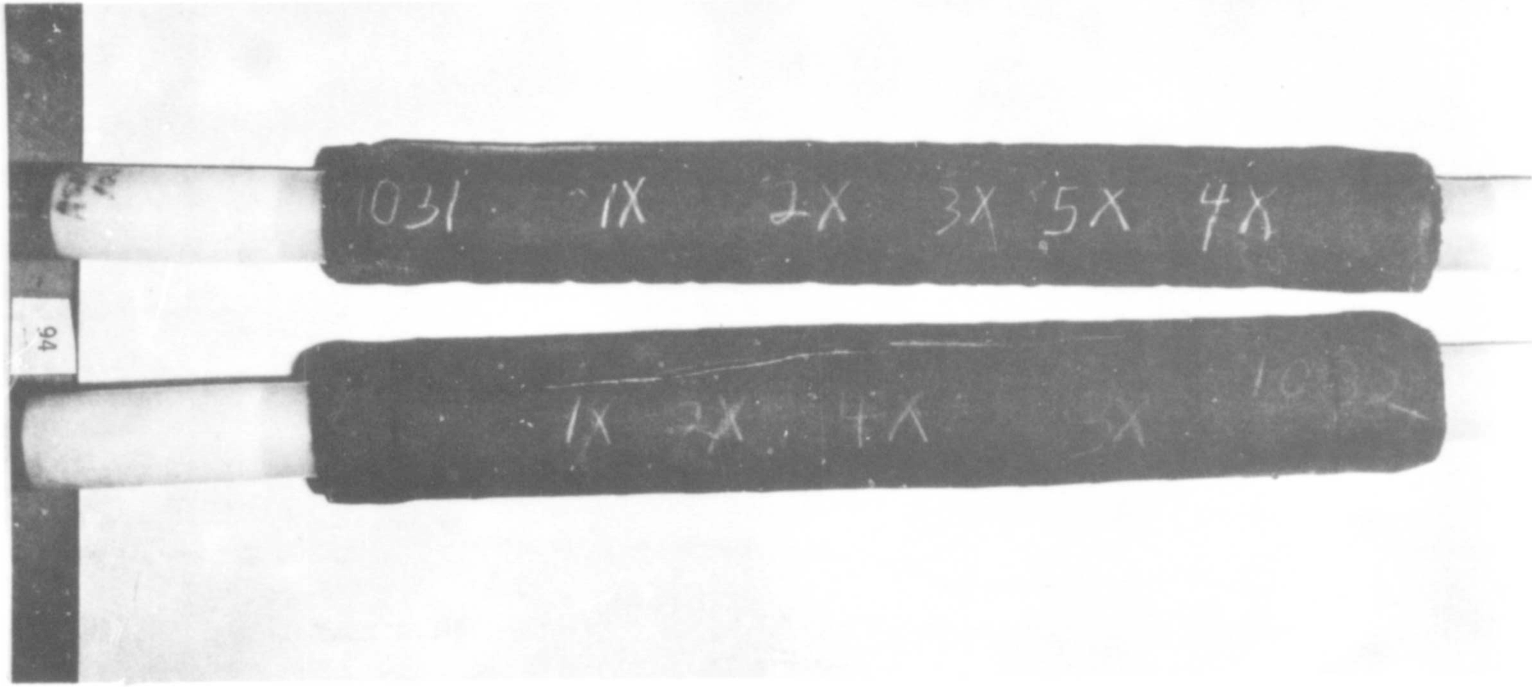
Photograph No. 47 - Exit Wound Produced by 0.50 Cal. AP Round in Polyethylene Tube



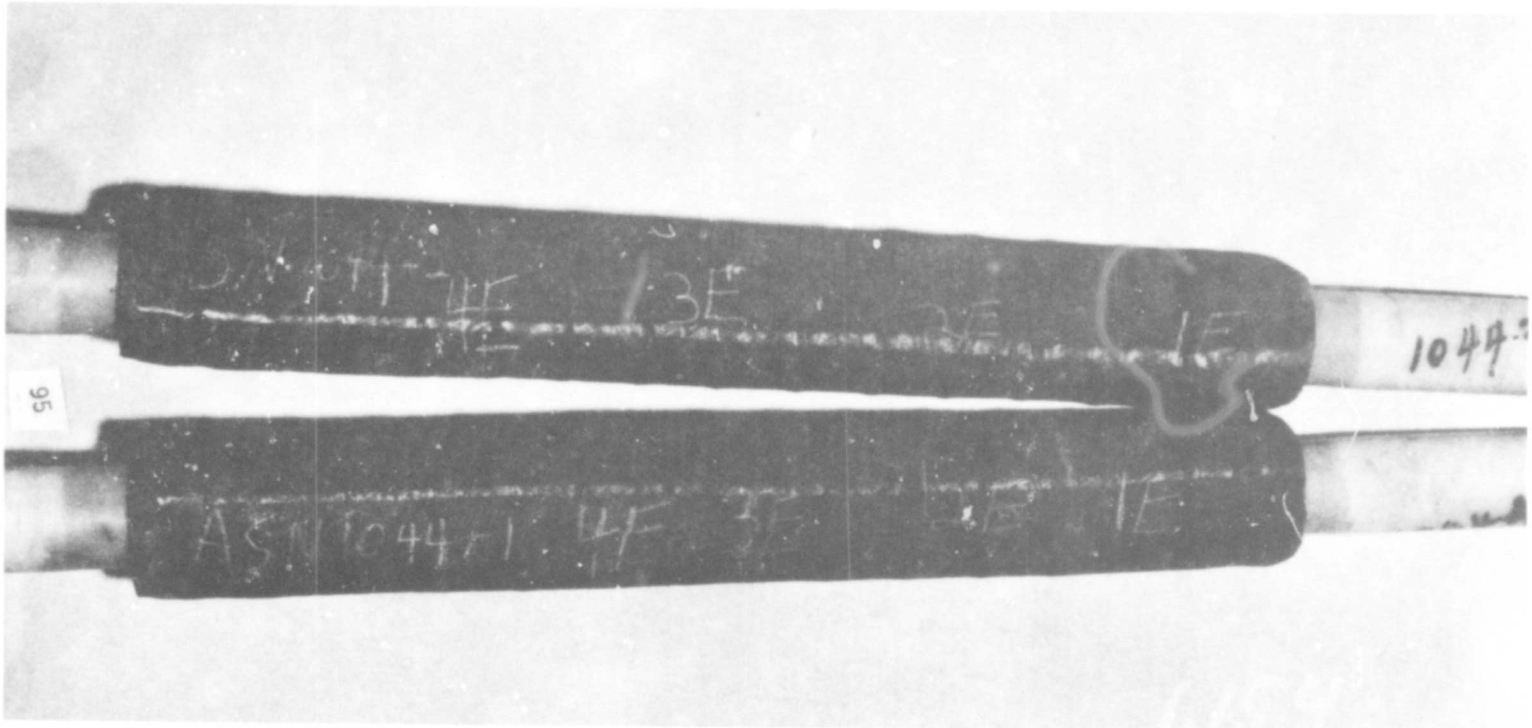
Photograph No. 48 - Inside of Nonmetallic Fuel Line ASN 1021 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition



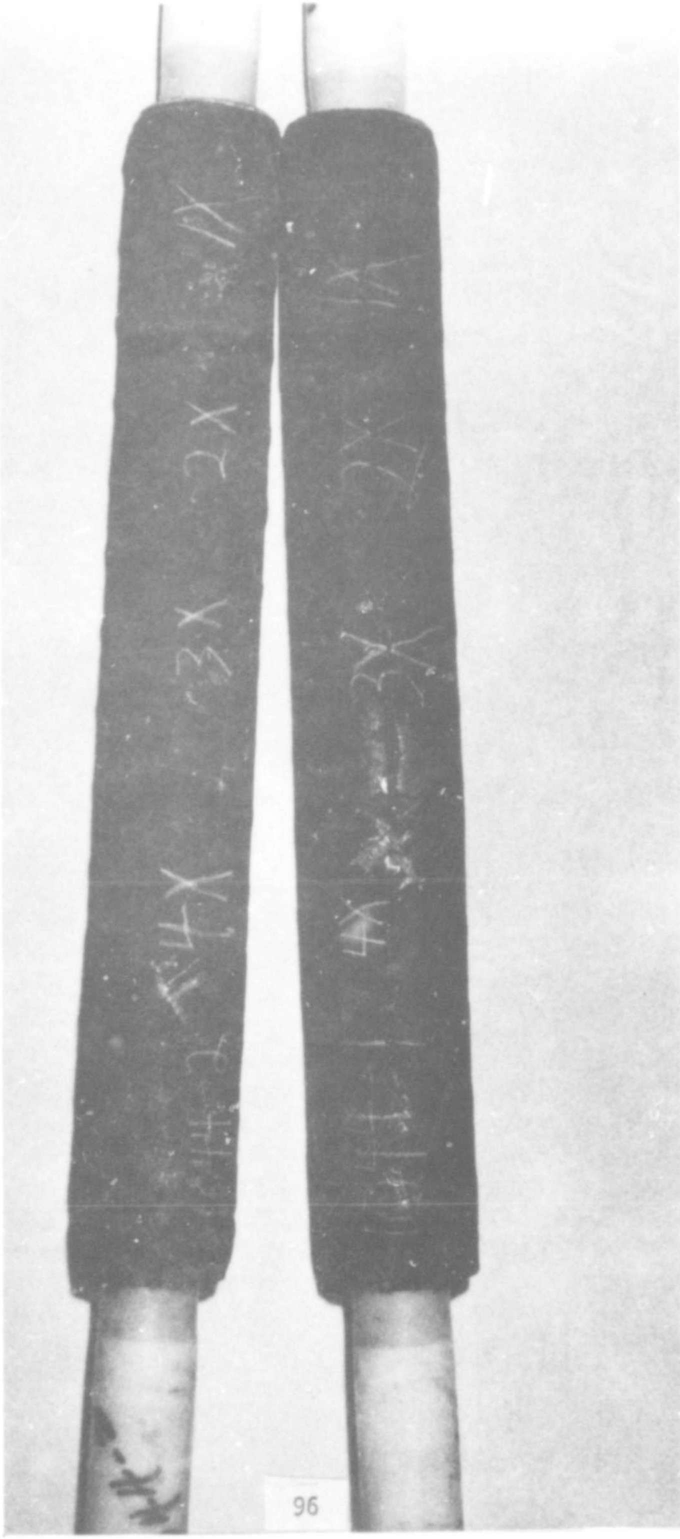
Photograph No. 49 - Nonmetallic Fuel Lines ASN 1031 and ASN 1032 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.



Photograph No. 50 - Nonmetallic Fuel Lines ASN 1031 and ASN 1032 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.



Photograph No. 51 - Nonmetallic Fuel Lines ASN 1044-1 and ASN 1044-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Entrance Side.



Photograph No. 52 - Nonmetallic Fuel Lines ASN 1044-1 and ASN 1044-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition. Exit Side.

D. New Sealants and Reinforcements

Efforts were made to evaluate new materials for the sealant and reinforcement plies of self-sealing fuel lines. Current commercial constructions employ a sealant of partially cured natural rubber and a reinforcing ply over this composed of a rubber coated tire cord (unilateral) fabric.

Experience with fuel lines has shown that an immediate seal is generally needed because in contrast to self-sealing fuel cells, a wound which is leaking to any extent will rarely slow down and ultimately seal. It was decided that resilient materials are needed to provide a "snap" to close the wound mechanically so the sealant's natural tack can provide a complete seal. A standard natural rubber sealant formula was modified to include a higher level of sulfur curative and a rubber cure accelerator so that a more complete cross-linking and, therefore, a more resilient sealant material could develop in a normal fuel line cure cycle. This sealant material was incorporated into a US-191 fuel line cover holding all other factors constant.

Gunfire performance data is given for ASN 981 in Table XIX. Sealing performance was not as good as that shown by standard US-191 covered lines under the same conditions. This may be due to the reduced tack and swell of the more highly cured rubber of ASN 981 or to insufficient increase in resilience over standard sealant coupled with the reduction in tack and swelling.

Another approach to the mechanical closure of wounds is to increase the swell rate of the sealant. Literature search failed to reveal any elastomer which combined a fast swell in hydrocarbon fuels with the adhesive tack of natural rubber. However, it was noted that foamed elastomers can be saturated with natural rubber cements and compressed. When a hydrocarbon fuel contacts the natural rubber cement, the cement softens and the foam springs back to its normal dimensions. Experiments showed that this action is quite rapid and large increases in volume can be expected.

The fuel line ASN 979 was fabricated with a standard nitrile rubber liner, a one inch thick sheet of polyurethane foam compressed to one quarter of its normal thickness, .025" of 3083 sealant rubber, and the standard tire cord reinforcement used in US-191. After cure, the cover was found to have some wrinkles on the outer ply but otherwise was satisfactory.

Gunfire results for this line are given in Table XX. The sealing performance of the cover was poor. There did not seem to be any contribution from the precompressed foam. This may be due to an inability of the foam to expand fully when exposed to the full pressure of fuel in a confined area. The porous nature of the foam also detracted from sealing action.

Silicone elastomers had been shown in earlier work on the high temperature fuel cell section of this contract to be a promising sealant candidate.

D. New Sealants and Reinforcements (Cont'd.)

A fuel line cover, ASN 988, was fabricated substituting an equal thickness of Silastic 1125U elastomer for 3083 sealant in a US-191 construction. The silicone rubber was protected from contamination by the nitrile rubber of the liner and tire cord plies by enclosing it in an envelope of paper. The completed cover was cured and after cure was found to have the appearance of a normal fuel line cover.

Results of the gunfire of ASN 988 are given in Table XXI. Sealing performance of the cover was poor. This may be due to the very low tack of silicone elastomers.

In work on improved reinforcement plies for fuel line covers (described below), it was discovered that a high resilience neoprene ply would provide the "snap" to mechanically close a gunfire wound. In the case of straight entrance and exit wounds, the wound would be closed to a pinhole size so as to be barely noticeable. This led to the hypothesis that a very thick layer of this neoprene compound might close a bullet wound to such an extent as to seal off fuel leakage. Two fuel lines were designed upon this premise. ASN 989-1 was a 2 inch O.D. aluminum tube covered with a nitrile rubber liner and a ½ inch thick ply of high resilience neoprene. ASN 989-2 was a tube of high resilience neoprene with walls one inch thick applied over a nitrile rubber liner with no metal tube.

Gunfire results for these lines are given in Table XXII. While both covers received wounds that were barely visible, these wounds leaked a fine spray of fuel. The pressure on the fuel apparently was sufficient to force fuel through the very fine channels against the resistance of the neoprene. It appears that the tack of natural rubber sealant is quite important in preventing fuel leakage through a wound.

In the field of improved reinforcements, development was aimed at evaluation of elastomers and elastoplastics which show high resilience. If the outer reinforcement springs back over the wound, it will give more support to the sealant and thus force any swelling of the sealant in a direction which closes the wound.

The first approach to this concept was the application of a jacket of neoprene rubber over a standard fuel line cover. In ASN 976-1 a 0.1 inch thick ply of a high resilience neoprene compound was applied over the outer tire cord reinforcement of a US-191 fuel line cover. The cover was cured with the neoprene in place.

Gunfire results for ASN 976-1 are given in Table XXIII. Sealing performance of the construction was excellent on 0.50 caliber AP wounds. Damage to the cover was very slight with the neoprene ply having a tendency to close over the wounds leaving only a pinhole visible on the outer surface of the cover.

In ASN 976-2 the standard tire cord reinforcement plies were omitted and the neoprene ply applied directly over the sealant. Gunfire results

D. New Sealants and Reinforcements (Cont'd.)

given in Table XXIII show that this construction had poor sealing performance. When wounded fuel from the metal tube tended to accumulate under the neoprene ply and stretch it. This distortion of the cover allowed leakage to occur.

To overcome the stretching tendency of the neoprene, ASN 1006 was fabricated with a 0.1 inch thick neoprene ply on the sealant, one ply of neoprene cement coated tire cord over this ply, and an outer 0.1" thick ply of neoprene. The results of gunfire are given in Table XXIV. Sealing performance was excellent in wounds caused by straight 0.50 caliber AP rounds. There was no tendency for the neoprene plies to stretch under fuel pressure.

The high resilience neoprene compounds were based on general purpose neoprene GN. A special grade of neoprene with a very high crystallinity and many of the properties of balata rubber is occasionally used for golf ball covers and similar applications. This neoprene HC can be compounded similarly to neoprene GN in some cases. A neoprene GN formulation was prepared on the laboratory mill and found to be too hard to be fabricated into sheets for wrapping around fuel lines. A new formula was then written replacing a portion of the neoprene GN in the previously used high resilience formula with neoprene HC. This compound was softer and could be used to fabricate fuel line covers.

The cover fabricated as ASN 1022 was identical to ASN 1006 except for the substitution of the HC/GN blend for the all GN neoprene plies. Gunfire results in Table XXV show that sealing performance on wounds caused by 0.50 caliber AP rounds was excellent. As in the case of ASN 1006, damage to the cover was slight with wounds being barely detectable. Little difference could be detected between the gunfire resistance of ASN 1022 and ASN 1006.

Certain elastoplastic materials exhibit a resilience and elongation characteristic of elastomers combined with the high tensile strength and modulus of plastics. It was proposed that reinforcement plies of these materials be applied to fuel line covers.

In order to establish a basis for comparison, a true elastomer, nitrile-butadiene rubber was first evaluated. In construction ASN 994-4 a US-191 type fuel line cover was fabricated with a 0.25 inch thick ply of 3010 nitrile rubber compound (the same rubber used in the liner of US-191 construction) substituted for the tire cord reinforcement plies. Table XXVI details the gunfire performance of this line. As was the case with unsupported neoprene plies, the rubber reinforcement could be stretched by the fuel pressure in the cover and thus did not hold the sealant in place.

In ASN 982 Surlyn plastic film was substituted for the tire cord reinforcement plies of US-191. Surlyn is an ionomer resin with the sharp melting point of an ionic compound combined with the flexibility and

D. New Sealants and Reinforcements (Cont'd.)

tensile elongation properties of a polymer.

In Table XXVII the gunfire performance of ASN 982 is indicated. It was found that under the high velocity impact of gunfire, Surlyn exhibits brittleness. This is characteristic of many plastics which have a critical rate of extension beyond which they behave in a glassy manner; shattering rather than deforming.

In ASN 1012 Roylar E-9 sheet of 0.1 inch thickness was substituted for the tire cord reinforcements of US-191. Roylar E-9 is a polyurethane elastoplastic with an extremely high tensile strength and modulus combined with a great resistance to hydrocarbon fuels.

The gunfire test data in Table XXVIII shows that the Roylar covered line exhibited the same weakness as neoprene and nitrile covered lines; the reinforcement ply stretched under fuel pressure providing little reinforcement to the sealant.

In conclusion, then, it will be noted that a fuel line cover incorporating a tire cord reinforced neoprene outer ply produces the best sealing performance of all fuel line candidates gunfired. Tumbled rounds and 0.50 caliber M33 Ball rounds produce damage beyond the sealing ability of any known fuel line cover.

TABLE XIX

GUNFIRE RESULTS FOR US-191 COVER WITH MORE HIGHLY CURED SEALANT

Fuel Line ASN 981

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except where noted

Projectile Velocity: Standard

Construction of Cover: US-191, with modified sealant containing extra sulfur and accelerators.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Damp seal immediately.	
	Exit	Small stream slowing to heavy seep, still heavy seep at 4 min.	
2	Entrance	Dry seal immediately.	
	Exit	Small stream slowing to heavy seep.	
3	0.30 cal AP tumbled round Entrance	Large gushing stream.	High shot slicing top of cover.
	Exit	Large gushing stream.	

TABLE XX

GUNFIRE RESULTS FOR FUEL LINES COVER INCORPORATING PRECOMPRESSED FOAM

Fuel Line ASN 979

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 Cal AP

Projectile Velocity: Standard

Construction of Cover: Nitrile rubber liner, urethane foam saturated with natural rubber cement and compressed, 0.025" sealant, rubber coated tire cord.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Large stream, no reduction in 4½ min.	Leakage also through seams and wrinkles on cover.
	Exit	Large stream, no reduction in 4½ min.	
2	Entrance	Slight seep with no signs of sealing in 4 minutes.	
	Exit	Slight seep with no signs of sealing in 4 minutes.	

TABLE XXI

GUNFIRE RESULTS FOR FUEL LINE COVER WITH SILICONE SEALANT

Fuel Line ASN 988

Fuel Type:	Type I test fluid	Projectile Type:	0.50 Cal AP
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Construction of Cover:	US-191 with Silastic 1125U substituted for natural rubber sealant.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Small stream slowing to heavy seep at 4 minutes.	
	Exit	Large stream slowing to small spray. Still spray at 7 min.	
2	Entrance	Heavy seep.	
	Exit	Large spray.	

TABLE XXII

GUNFIRE RESULTS FOR FUEL LINES COVERED WITH NEOPRENE PLIES FOR MECHANICAL SEALING

Fuel Line 989-1

Fuel Type:	Type I test fluid	Projectile Type:	0.50 cal AP
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Construction of Cover:	nitrile rubber liner, 0.5" neoprene ply

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Large spray of fuel.	Wounds almost invisibly small but fuel forces through them to give a high pressure spray.
	Exit	Large spray of fuel.	

Fuel Line ASN 989-2

Fuel Type:	Type I test fluid	Projectile Type:	0.50 cal AP
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	35 psi	Construction of Cover:	Integral type with center hose of nitrile rubber surrounded by 1" of neoprene

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Fine, high pressure spray.	Wounds are almost invisibly small but pressure forces fuel through.
	Exit	Fine, high pressure spray.	

TABLE XXIII

GUNFIRE RESULTS FOR INITIAL EXPERIMENT WITH HIGH RESILIENCE NEOPRENE PLIES

Fuel Line ASN 976-1

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 cal AP except where noted

Projectile Velocity: Standard

Construction of Cover: US-191 with additional ply of 0.1" neoprene over outer reinforcement.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	Very little damage
	Exit	Dry seal immediately.	visible on cover except
2	Entrance	Dry seal immediately.	for last round which was
	Exit	Dry seal immediately.	a high slicing shot.
3	0.50 cal M2 Ball ammunition Entrance	Dry seal immediately.	
	Exit	Dry seal immediately	
4	0.50 cal M2 Ball ammunition Entrance	Dry seal immediately.	
	Exit	Large stream.	Slicing type high shot.

Fuel Lines ASN 976-2

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 cal. AP except where noted

Projectile Velocity: Standard

Construction of Cover: Liner & sealant of US-191 covered with ply of neoprene gum in place of rubber coated tire cord.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Large stream.	Cover puffed-up full of
	Exit	Large stream	fuel. No support for
2	0.30 cal AP tumbled round Entrance	Large gushing stream.	sealant from cover outer ply.
	Exit	Large gushing stream.	Second round was high slicing shot.

TABLE XXIV

GUNFIRE RESULTS FOR FUEL LINE COVER HAVING AN OUTER PLY OF REINFORCED NEOPRENE

Fuel Line ASN 1006

Fuel Type:	Type I test fluid	Projectile Type:	0.50 cal AP except where noted
Fuel Temperature:	Ambient	Projectile Velocity:	Standard
Fuel Pressure:	30 psi	Construction of Cover:	Liner & sealant of US-191 with an outer ply of neoprene reinforced by one ply of tire cord.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
2	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
3	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
4	0.50 cal. M33 Ball ammunition Entrance	Heavy gushing stream.	Extensive damage to cover. Especially the exit wound.
	Exit	Heavy gushing stream.	
5	0.30 cal. AP tumbled round Entrance	Gushing spray.	High, slicing shot. Did extensive damage to cover and tube.
	Exit	Gushing spray.	

TABLE XXV

GUNFIRE RESULTS FOR FUEL LINE COVER WITH REINFORCED NEOPRENE GN/HC PLY

Fuel Line ASN 1022

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 30 psi

Projectile Type: 0.50 Cal AP except where noted

Projectile Velocity: Standard

Construction of Cover: Liner & sealant of US-191 with outer ply of tire cord reinforced neoprene GN/HC blend.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
2	Entrance	Dry seal immediately.	
	Exit	Dry seal immediately.	
3	0.30 cal AP tumbled round Entrance	Dry seal immediately.	Severe damage to cover and tube at exit wound.
	Exit	Heavy spray of fuel.	
4	0.50 cal. M33 Ball ammunition Entrance	Damp seal immediately.	
	Exit	Heavy gushing leak.	Severe damage to cover and tube at exit wound.

TABLE XXVI

GUNFIRE RESULTS FOR FUEL LINE COVER HAVING OUTER PLY OF NITRILE RUBBER

Fuel Line ASN 994-4

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 30 psi

Projectile Type: 0.50 Cal. AP

Projectile Velocity: Standard

Construction of Cover: Liner & sealant of US-191 with outer ply of 3010 nitrile rubber gum.

Round No.	Type of Wound	Sealing Performance	Comments
1	-	-	High shot. Did not break fuel line.
2	Entrance	Large stream.	Cover puffed-up from fuel pressure, no support for sealant.
	Exit	Large stream.	
3	Entrance	Large spray.	
	Exit	Small stream.	

TABLE XXVII

GUNFIRE RESULTS FOR FUEL LINE COVER HAVING OUTER PLY OF SURLYN IONOMER

Fuel Line ASN 982

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

Fuel Pressure: 35 psi

Projectile Type: 0.50 Cal. AP except where noted

Projectile Velocity: Standard

Construction of Cover: Liner & sealant of US-191 with outer ply of Surlyn sheet.

Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Dry seal immediately.	
	Exit	Slight seep opening to a spray at 1-3/4 min.	Surlyn was cracked around wound.
2	Entrance	Dry seal immediately.	
	Exit	Small spray slowly increasing.	
3	0.30 cal. AP tumbled round Entrance	Large gushing leak.	High, slicing shot cutting cover away from tube. Surlyn torn in area of wound.
	Exit	Indistinguishable from entrance because of slicing wound.	

TABLE XXVIII

GUNFIRE RESULTS FOR FUEL LINE COVER HAVING OUTER PLY OF ROYLAR THERMOPLASTIC URETHANE

Fuel Line ASN 1072

Fuel Type: Type I test fluid

Fuel Temperature: Ambient

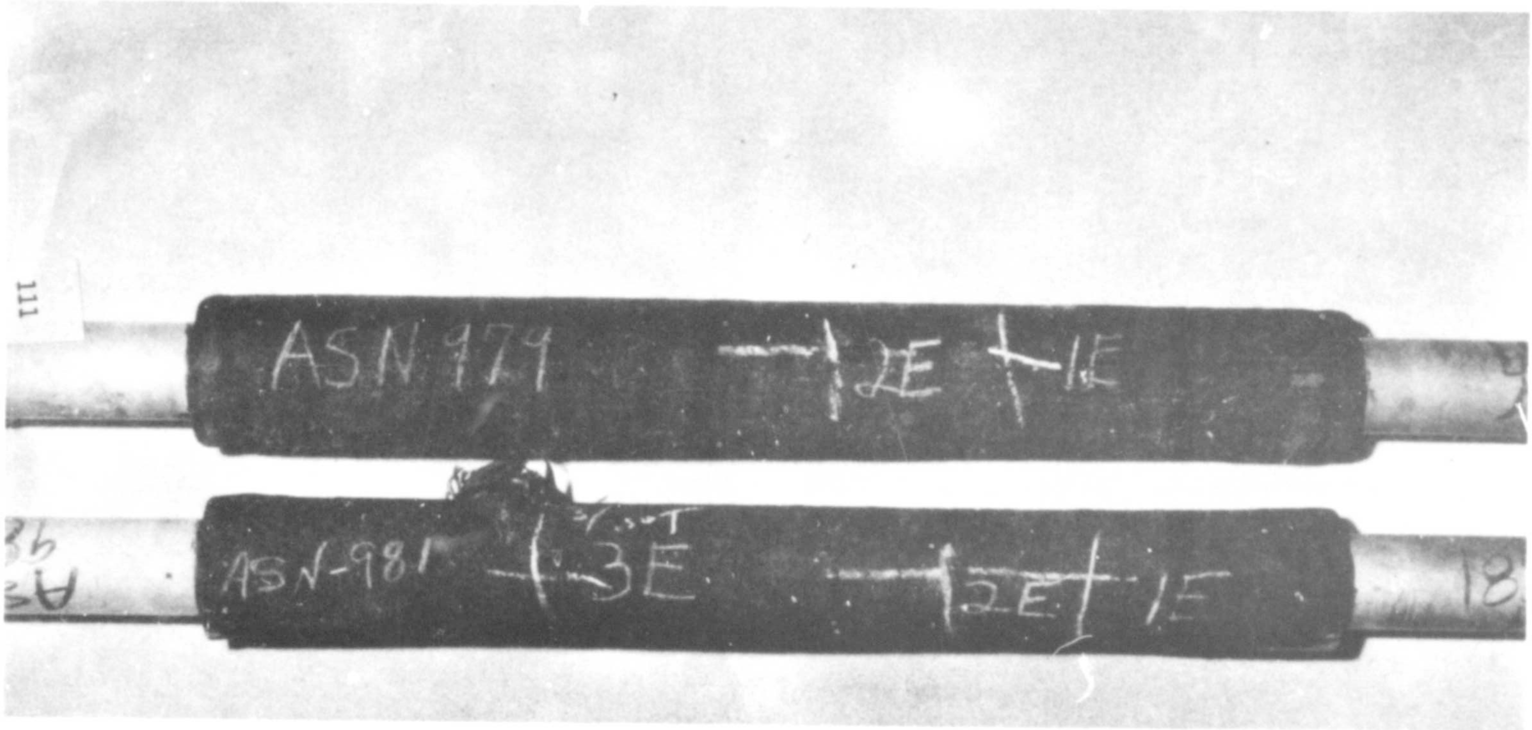
Fuel Pressure: 30 psi

Projectile Type: 0.50 Cal. AP

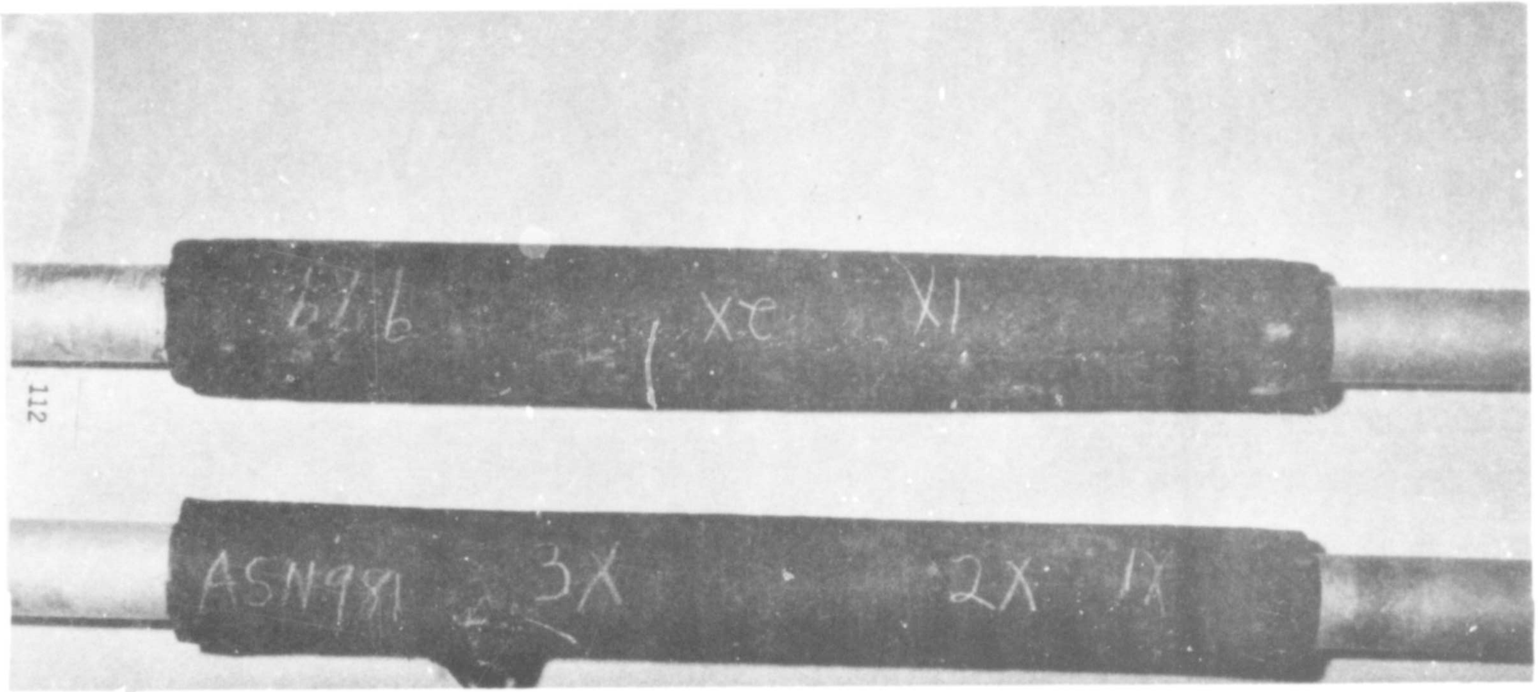
Projectile Velocity: Standard

Construction of Cover: Liner & sealant of US-191 with outer ply of Roylar E-9 elastoplastic urethane sheet.

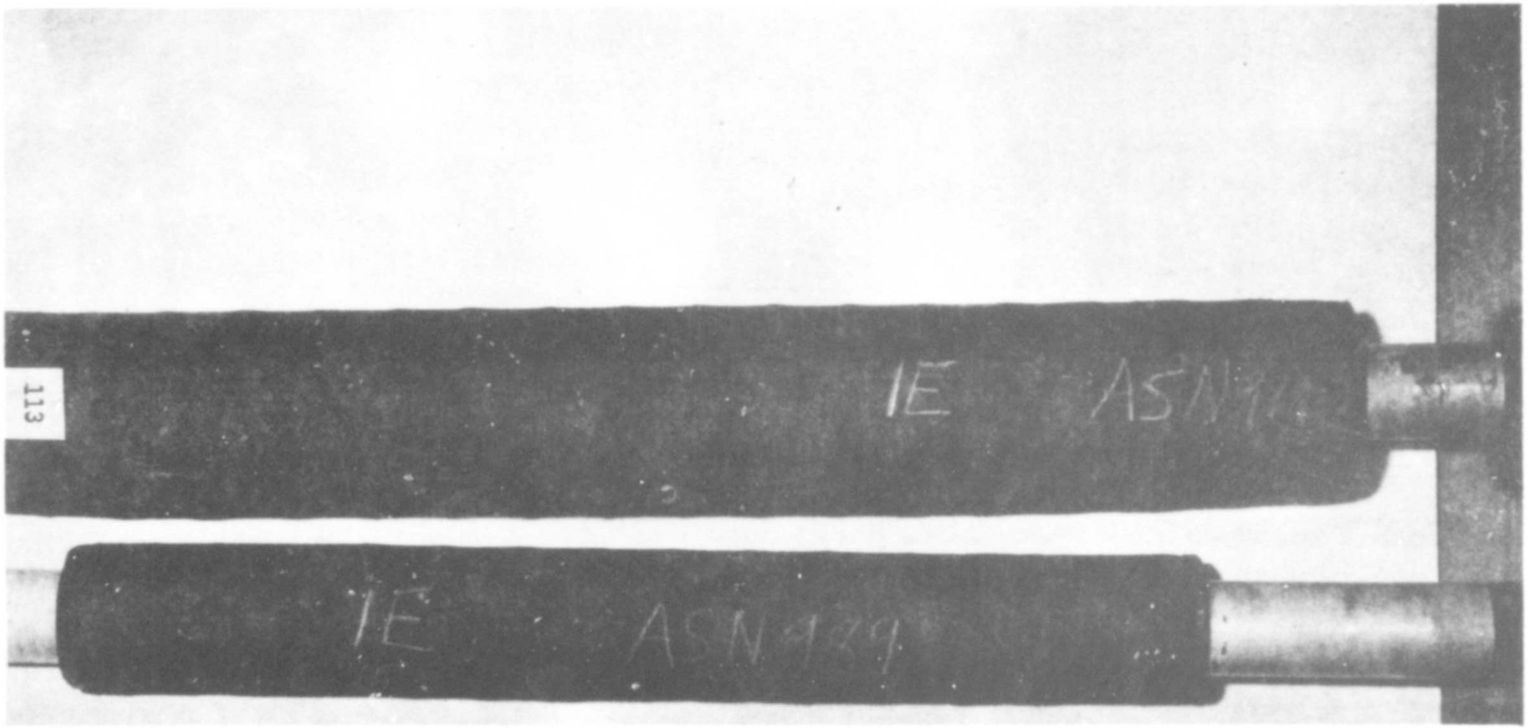
Round No.	Type of Wound	Sealing Performance	Comments
1	Entrance	Small spray of fuel	Cover puffed-up from fuel pressure. Outer ply did not support sealant.
	Exit	Dry seal immediately.	
2	Entrance	-	High, slicing shot opened cover and released fuel from it.



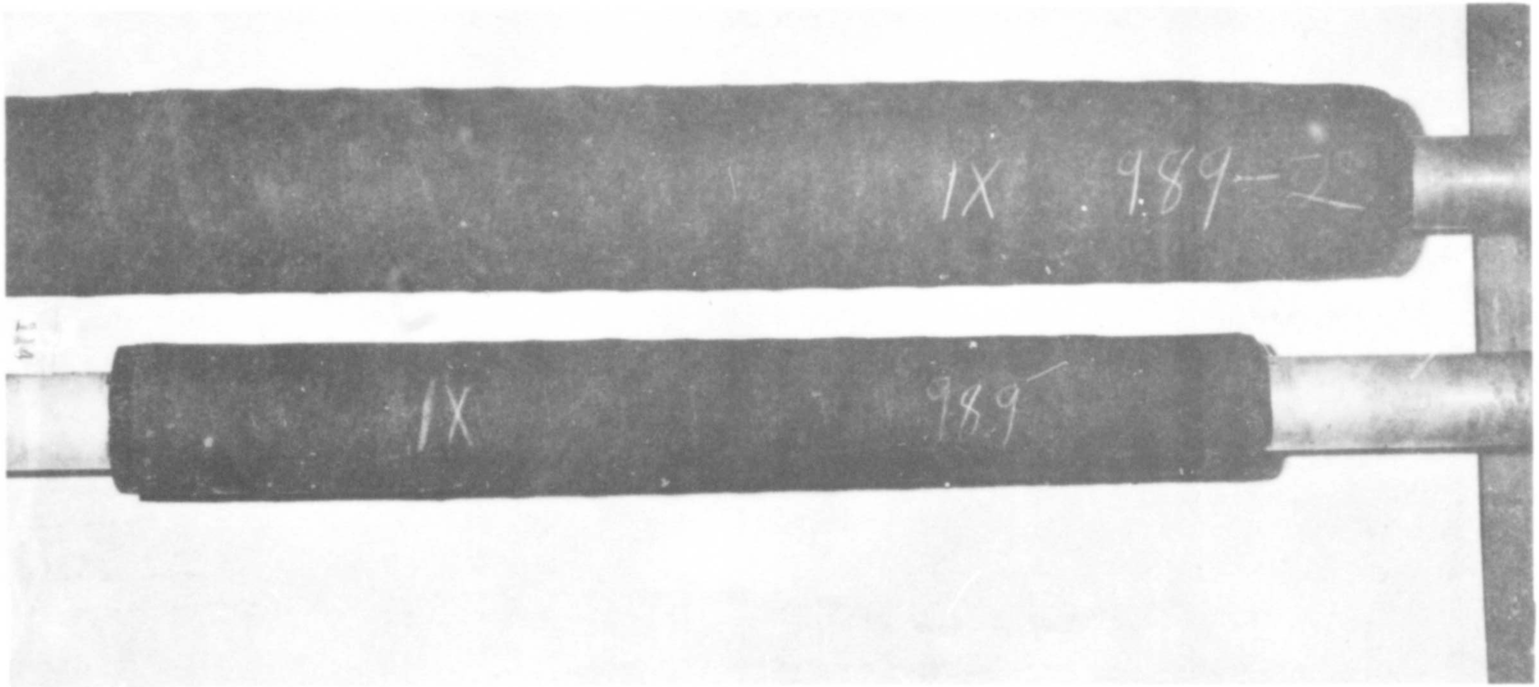
Photograph No. 53 - Fuel Line Covers ASN 981 and ASN 979 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.



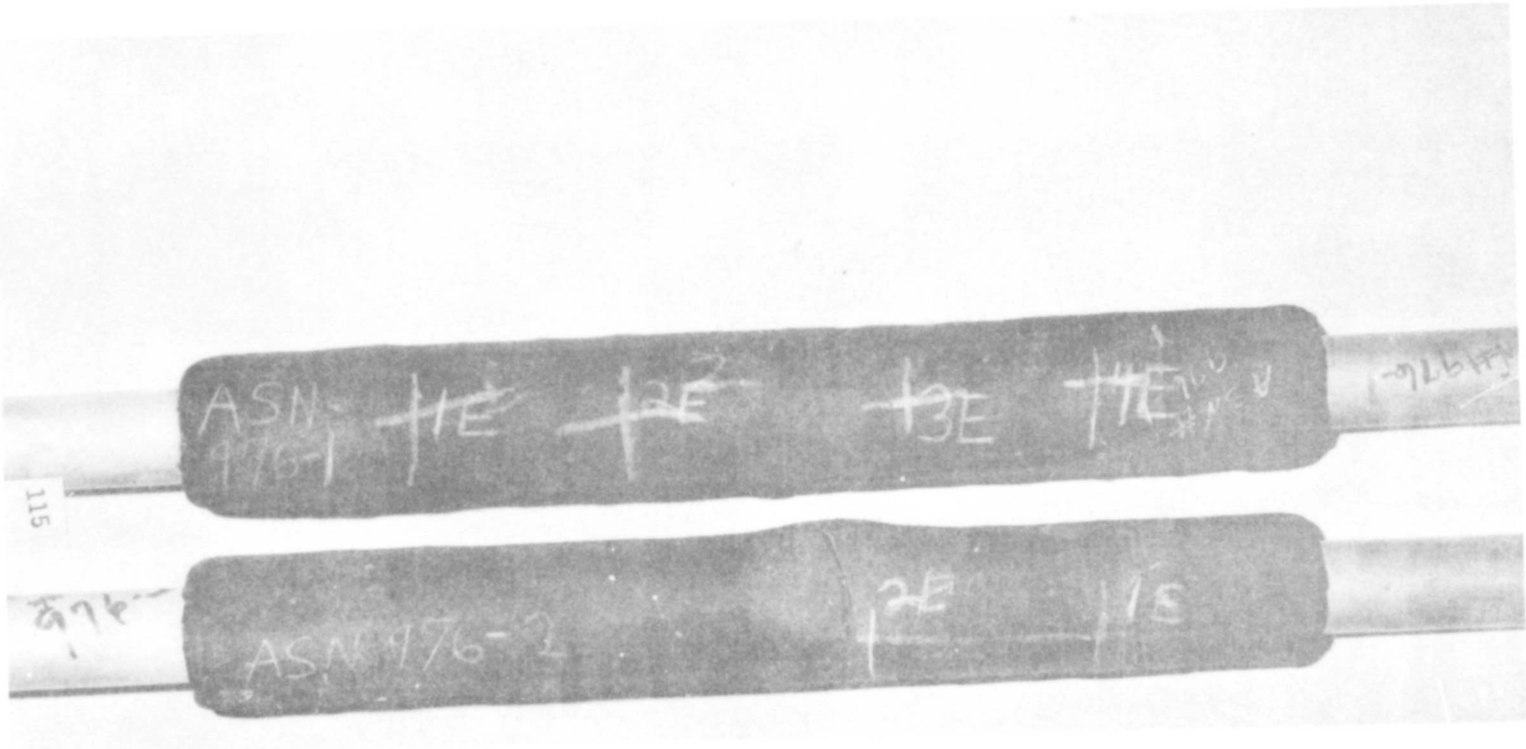
Photograph No. 54 - Fuel Line Covers ASN 981 and ASN 979 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.



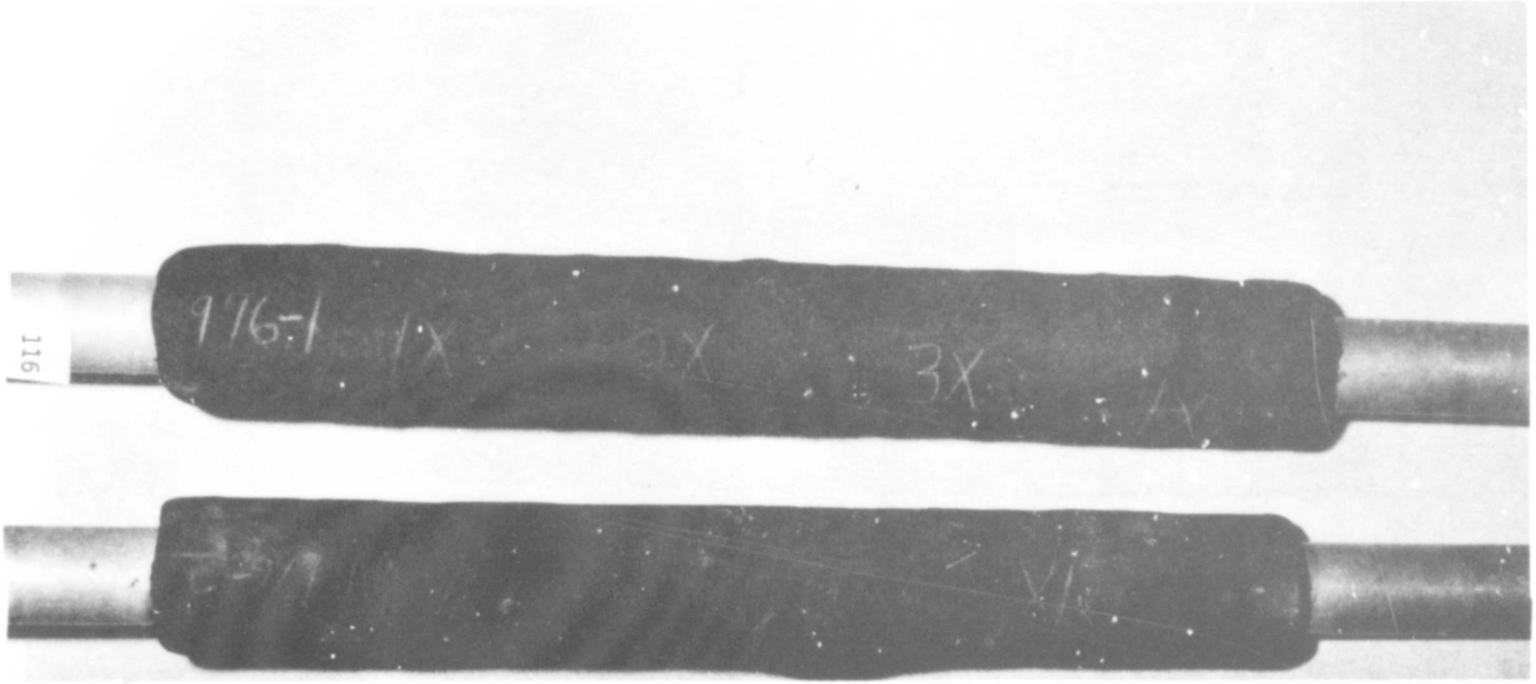
Photograph No. 55 - Neoprene Sealant Fuel Lines ASN 989-1 and ASN 989-2 After Gunfire with 0.50 Cal. AP Ammunition. Entrance Side.



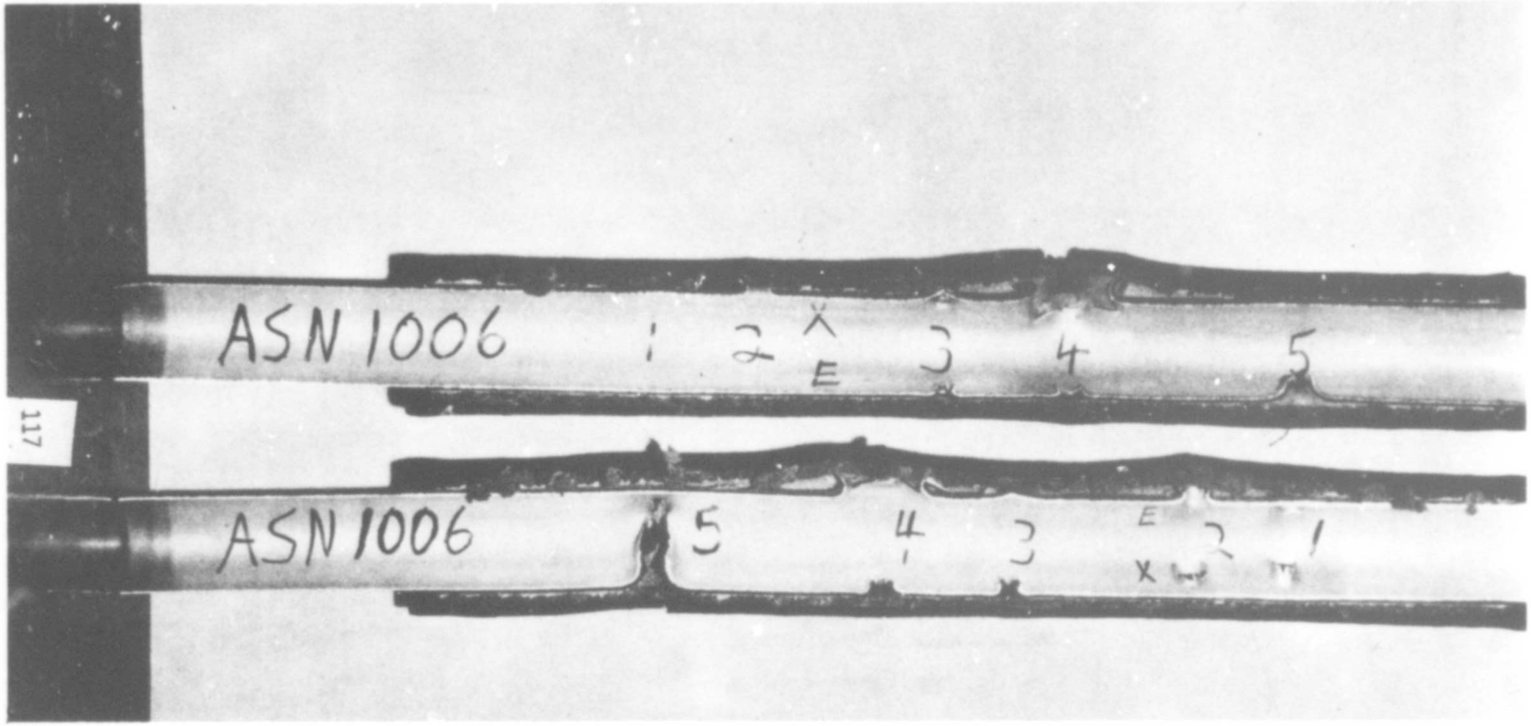
Photograph No. 56 - Neoprene Sealant Fuel Lines ASN 989-1 and ASN 989-2 After Gunfire with 0.50 Cal. AP Ammunition. Exit Side.



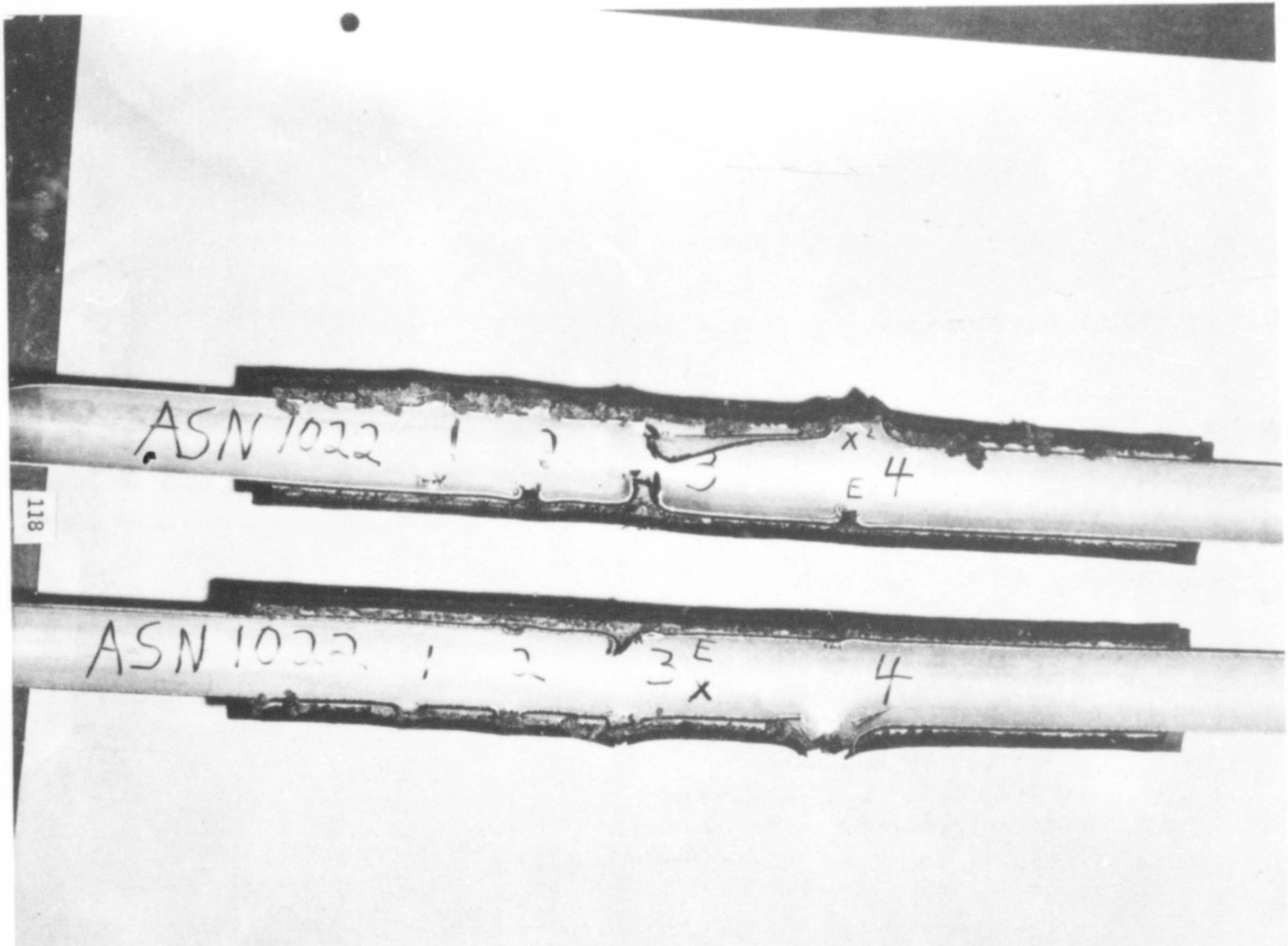
Photograph No. 57 - Fuel Line Covers ASN 976-1 and ASN 976-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.



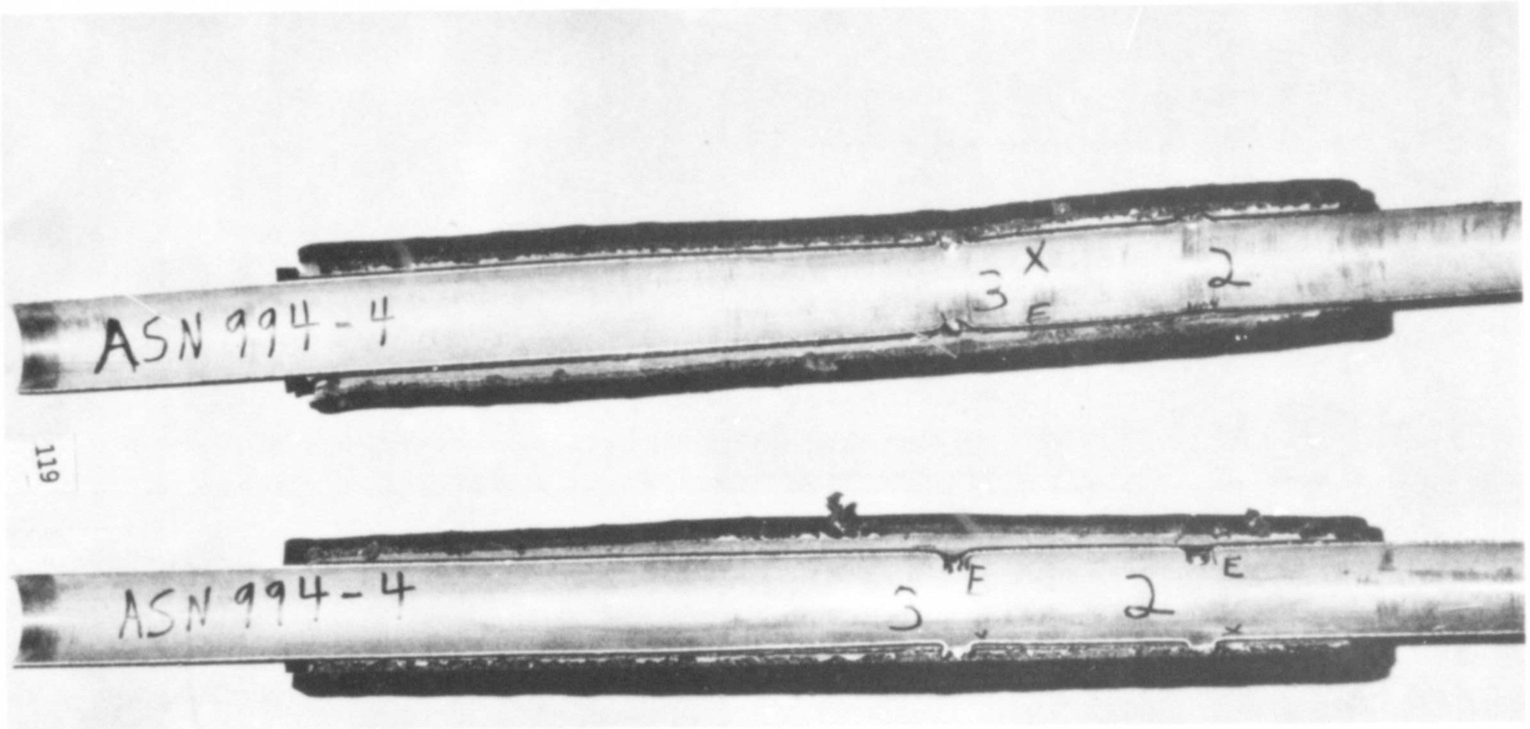
Photograph No. 58 - Fuel Line Covers ASN 976-1 and 976-2 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.



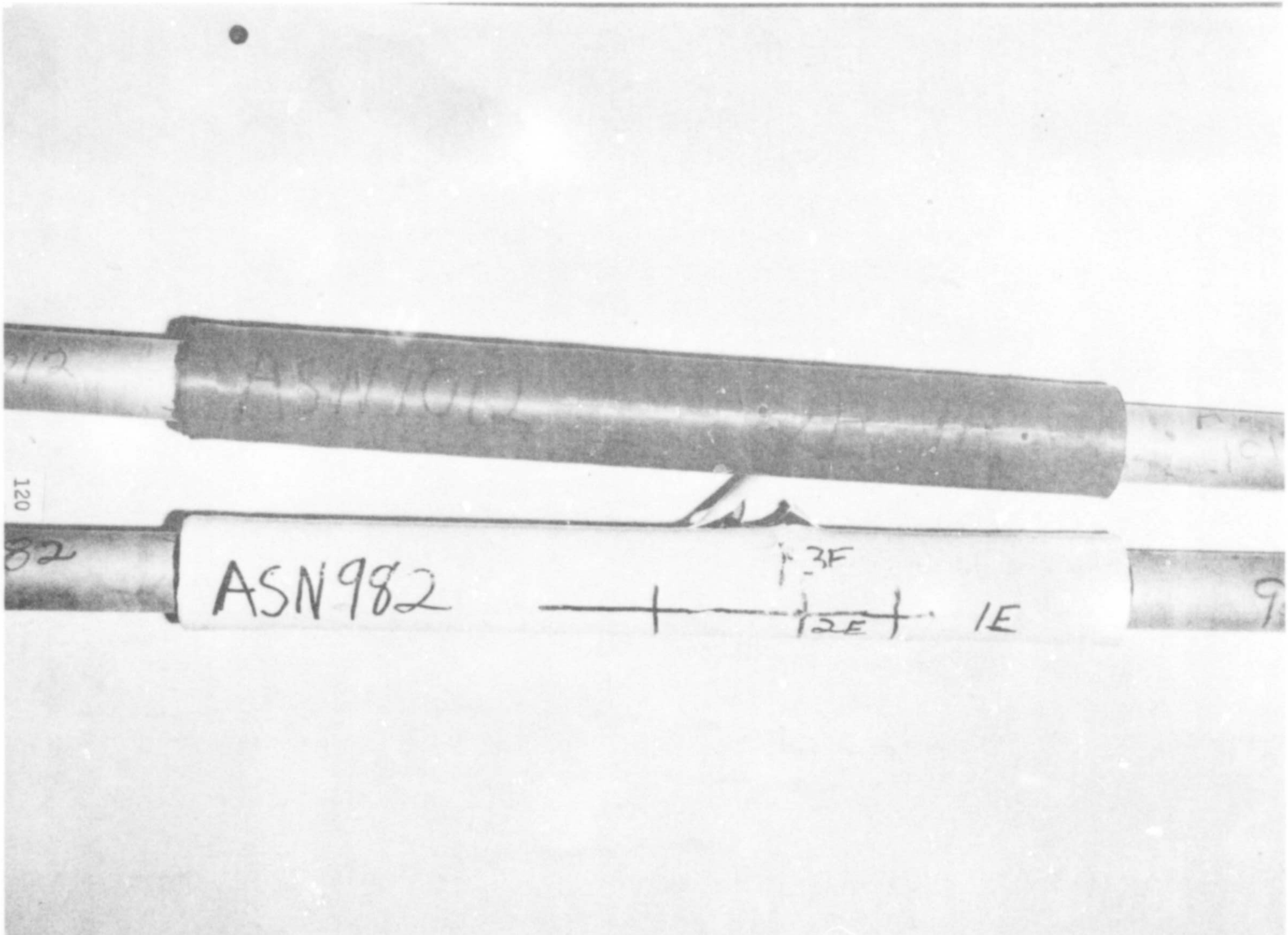
Photograph No. 59 - Inside of Fuel Line ASN 1006 After Gunfire with 0.50 Cal. AP and M33 Ball Ammunition and Tumbled 0.30 Cal. AP Ammunition



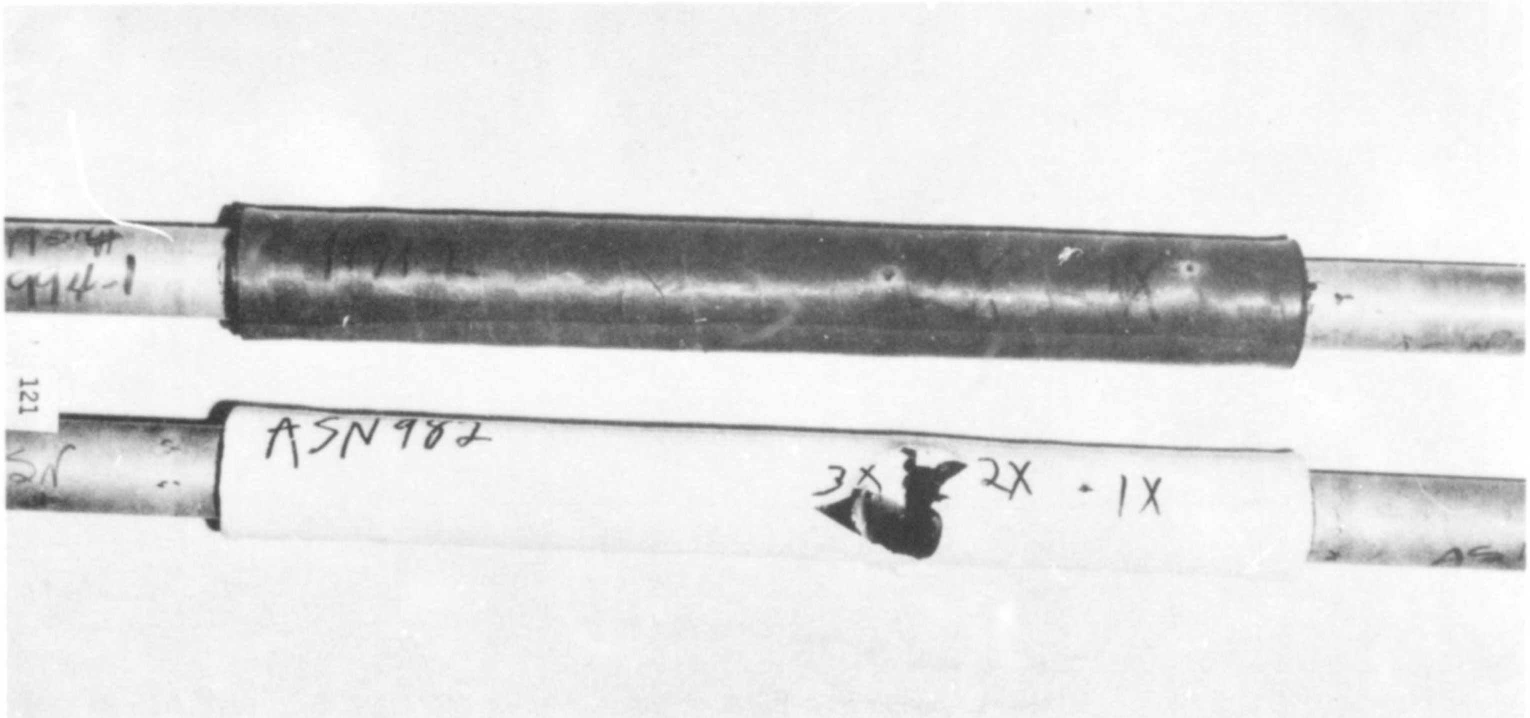
Photograph No.60 - Inside of Fuel Line ASN 1022 After Gunfire with
0.50 Cal. AP and M33 Ball Ammunition and Tumbled
0.30 Cal. AP Ammunition



Photograph No.61 - Inside of Fuel Line ASN 994-4 After Gunfire
with 0.50 Cal. AP Ammunition



Photograph No. 62 - Fuel Line Covers ASN 982 and ASN 1012 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Entrance Side.



Photograph No. 63 - Fuel Line Covers ASN 982 and ASN 1012 After Gunfire with 0.50 Cal. AP Ammunition and Tumbled 0.30 Cal. AP Ammunition. Exit Side.

E. Fuel Loss Measurement During Gunfire of Self-Sealing Fuel Lines

Proposed specifications for self-sealing fuel lines include various gunfire tests with measurement of fuel loss. A fuel loss measurement apparatus was designed by the UNIROYAL Product Engineering Department and assembled for use in this contract.

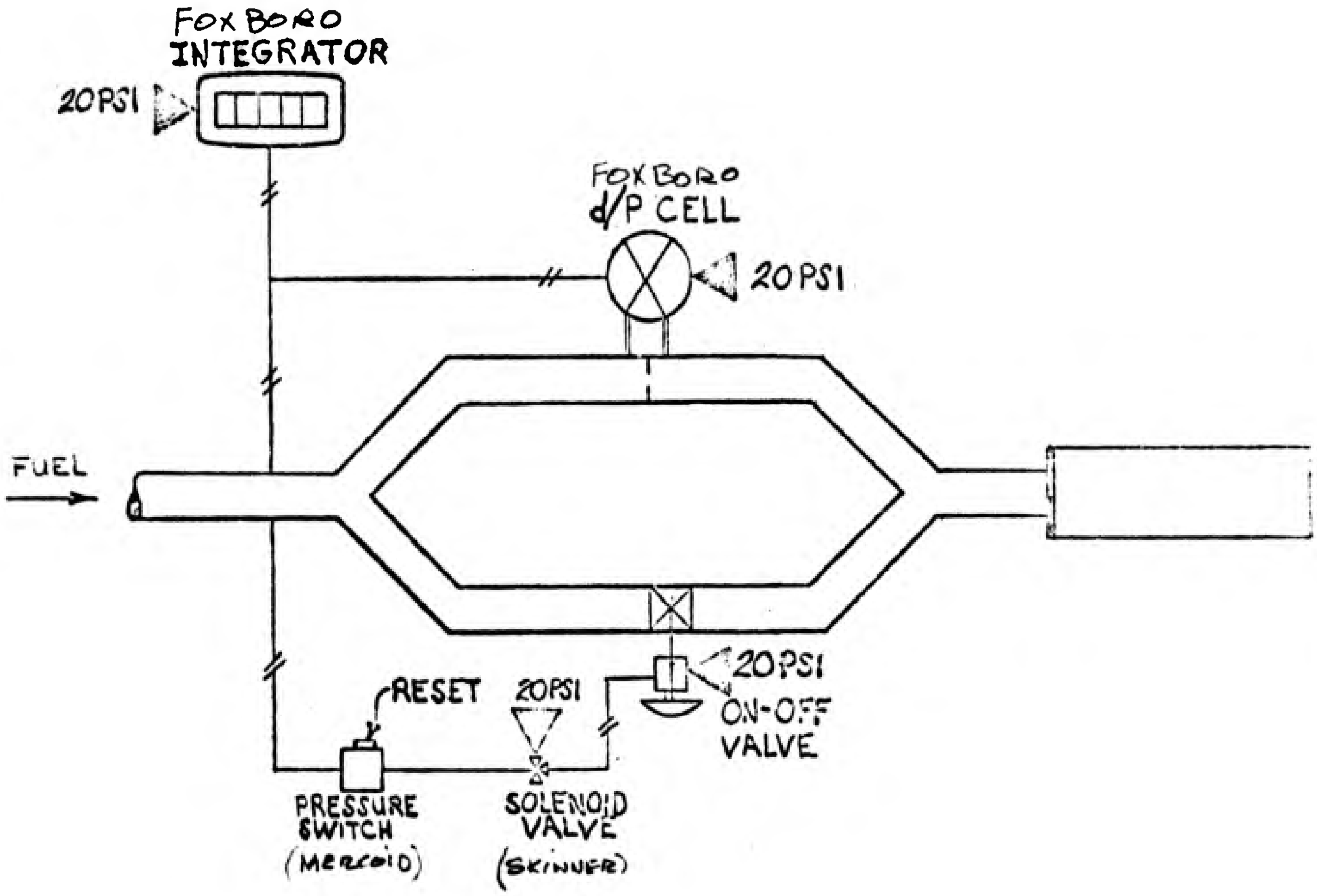
The apparatus consists of a Foxboro Model 13A1 pneumatic differential pressure flow transmitter (d/P cell), a Foxboro Model 14A pneumatic flow integrator, a Skinner chuck type electric solenoid valve, a Mercoid Model APR-41-153L pressure switch, an air operated on-off valve, and a filter-regulator set to provide instrument quality compressed air (see Figure). The differential pressure flow transmitter will produce a variation in air pressure proportional to the square of the change in fluid flow through it. The flow integrator converts this air pressure into an indication of flow rate and then integrates the flow rate over a period of time to produce an indication of total volume of fluid flow. The integrator is also equipped with a limit devise which transmits a pneumatic signal when a preset volume of fluid has been sensed. This signal activates the Mercoid switch which controls a bypass around the d/P cell.

In operation the apparatus was calibrated to indicate flow in terms of cubic centimeters. The d/P cell was set to give no signal at the flow rate established through an undamaged fuel line. It was assumed that any increase in fuel flow would be due to leakage of fuel through wounds caused by gunfire. The d/P cell would produce a signal proportional to the square of this increase in flow rate, and the flow rate integrator would convert this signal to an indication of total increase in fuel flow caused by the rounds. In other words, this would be an indication of actual leakage. The limit control on the integrator was set at 2000 cc, which was the maximum leakage allowed in the proposed specification. If this value was exceeded, the limit signal from the integrator would activate a bypass around the d/P cell and indicate failure of the fuel line in gunfire testing.

In actual gunfire testing several weaknesses of the apparatus were noted, most of them traceable to the high sensitivity of the d/P cell. It was found that movement of the hoses connecting the pump, loss measurement apparatus, and fuel line to the source of fuel caused a pressure change in the system sufficient to register as a flow on the integrator. The impact of a man's foot on a hose would also register on the integrator. In addition, it was found that the flow rate of a practical fuel pump varied sufficiently during the period of a gunfire test to cause leakage indications.

It was found that many fuel line wounds indicated losses of over 2000 cc in a short period of time. Other wounds gave no indications of loss. We concluded that the apparatus, as designed, was too sensitive for use in a practical gunfire situation and, therefore, gave erroneous results as a result of interference signals. A simple collection pan for collecting leaking fuel is probably sufficient for most fuel line gunfire tests.

FIGURE 64



Photograph No. 64 - Fuel Loss Measuring Apparatus

SECTION V

LITERATURE REVIEW

A search of recent reports, articles, and vendor information was made to uncover new materials and processes applicable to fuel system protection and data on incendiary gunfire of fuel filled systems. Some of the more interesting conclusions are:

a) Neoprene, butyl, chlorobutyl, and EPDM rubbers exhibit greater resistance to elevated temperatures than natural rubber and have a significant degree of swell in hydrocarbon fuels.

b) Fairprene adhesive has shown some utility in adhering silicone elastomers to other materials.

c) Urethane resins which combine high strength with resistance to impact can be formulated.

d) API ammunition can be activated by firing through an aluminum plate. Activation occurs a few feet beyond the aluminum plate.

A Bibliography of literature surveyed is given in Appendix IV, page 139.

SECTION VI

CONCLUSIONS

1. Activated 0.50 caliber API rounds cause damage to fuel cell panels too great for evaluation. It was agreed to use 0.30 caliber API ammunition to evaluate panels.

2. Damage to test panels from API rounds is largely due to shrapnel from the activating striker plate or the metal jacket of the bullet.

3. Self-sealing constructions fabricated from three to five plies of 30 oz/yd^2 nylon square woven fabric seem capable of sealing wounds from both 0.50 caliber and Russian 14.5 mm B32 API ammunition.

4. The maximum useable life of a conventional self-sealing fuel cell construction (US-173) at 350^o F is less than one hour.

5. Chlorobutyl rubber, butyl rubber, EPDM rubber, and silicone rubber were found to have suitable swell rates in hydrocarbon fuel for use as fuel cell sealants. They also exhibited resistance to degradation in 24 hours exposure to 350^o F.

6. Fairprene 5149 and a combination of Fairprene 5149 and Chemlok 607 were found to be good adhesives for bonding high temperature sealants to Nomex.

7. Evaluation of gasses by sealants during post-cure heating was found to cause bubble formation and loss of adhesion in high temperature resistant panels.

8. Gunfire resistance of Viton coated Nomex tire cord is low. The coated fabric showed a tendency to tear when impacted by 0.30 caliber AP bullets.

9. Fluorosilicone elastomers are difficult to process using conventional rubber handling techniques.

10. The accuracy of smooth bore, notched muzzle rifles used to produce tumbled rounds is too low to give consistent results in fuel line gunfires. More rigid mountings for the guns may improve accuracy.

11. Two plies of a 27.75 oz. USFlex weave nylon fabric impregnated with polyurethane resin and wrapped around an aluminum tube produce a reduction in "flowering" of the tube in gunfire. This reduction in "flowering" allows self-sealing covers to produce sealed wounds more easily.

12. Integral fuel lines which combine the fuel carrying line with the self-sealing materials in one construction appear to produce low sealing efficiency due to the large amount of fabric in relation to the sealant rubber.

13. High density polyethylene tubes when gunfired with 0.50 caliber AP

ammunition receive only small hole wounds. They do not "flower" as in metal lines, and they do not shatter as more brittle plastic lines do.

14. High density polyethylene tubes covered with self-sealing fuel line covers seal 0.50 caliber AP wounds quickly.

15. Neoprene rubber plies in a fuel line cover tend to close gunfire wounds. This contributes to greatly improved sealing ability.

16. While neoprene plies close gunfire wounds to pinhole size, they are not sufficient by themselves to cause sealing.

17. The fuel line fluid loss measurement apparatus as designed is too sensitive for practical gunfire use. Very slight variations in flow caused by shocks to the flexible hoses or by pump speed variation indicate a fuel loss.

SECTION VII

RECOMMENDATIONS

1. Build many more API resistant fuel cell test cubes. Gunfire these cubes with both 0.50 caliber and 14.5 mm API rounds to gain knowledge of the requirements of API gunfire.

2. Attempt to develop suitable processing methods for fluorosilicone rubbers.

3. Investigate newer high temperature fuel resistant materials for their suitablility as fuel cell materials.

4. Fabricate more fuel lines with urethane-fabric damage control plies and determine if an improved fuel line construction can be developed in this manner.

5. Fabricate fuel lines with neoprene plies. Determine if the improvement in wound sealing ability is sufficient to justify the weight of neoprene added.

6. Evaluate commercial possibilities of high density polyethylene fuel lines for aircraft.

7. In fuel line gunfires requiring the measurement of fuel loss, an enclosure should be fabricated to trap all leakage and channel it to a collector where the volume of leakage can be directly measured.

APPENDIX I

CONSTRUCTION OF INCENDIARY RESISTANT FUEL CELL TEST PANELS AND TEST CUBES

The four fabrics chosen for evaluation were all processed identically. Each was coated with a rubber cement and a thin layer of rubber was applied by a calender. The inner plies were coated with natural rubber on both sides, while the outer plies were calendered on one side with natural rubber and on the other side with an acrylonitrile-butadiene rubber.

Two 36" x 36" panels were fabricated of each construction. After gunfire evaluation, a 2½' x 2½' x 2½' test cube was fabricated of ASN 806-4 and one of ASN 806-12.

The constructions were:

Material — Orientation of Warps of Fabric plies

1. ASN 806-1 1.15 lb./ft.^{2}

UNIROYAL 3010 Nitrile Rubber Liner (0.030")
UNIROYAL 3082 Natural Rubber Sealant (0.040")
UNIROYAL 5231 (Nylon Tire Cord Coated with Sealant)
UNIROYAL 3083 Sealant (0.50)
UNIROYAL 5231 (Nylon Tire Cord Coated with Sealant)
UNIROYAL 5232 (Nylon Tire Cord Coated on one side with sealant, on other side with Nitrile)

2. ASN 806-2 1.29 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
Coated D70-527 Unituff fabric (D-602)[1]
UNIROYAL 3083 Sealant (0.050")
Coated D70-527 Unituff fabric (D-602)[1]
Coated D70-527 Unituff fabric (D-601)[1]

3. ASN 806-3 1.47 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
Coated D70-528 Unituff fabric (D-604)[2]
UNIROYAL 3083 Sealant (0.050")
Coated D70-528 Unituff Fabric (D-604)[2]
Coated D70-528 Unituff Fabric (D-603)[2]

4. ASN 806-4 1.63 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
Coated D-69-531 Square Woven Fabric (D-606)[3]
UNIROYAL 3083 Sealant (0.050")
Coated D69-531 Square Woven Fabric (D-606)[3]
Coated D69-531 Square Woven Fabric (D-605)[3]

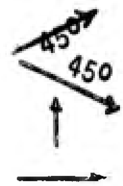
Material	Orientation of Warps of Fabric Plies

5. ASN 806-5 1.29 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
UNIROYAL 5231 Tire Cord
UNIROYAL 3083 Sealant (0.050")
UNIROYAL 5231 Tire Cord
UNIROYAL 5231 Tire Cord
UNIROYAL 5232 Tire Cord

6. ASN 806-6 1.45 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
UNIROYAL D-602 Coated Unituff Fabric[1]
UNIROYAL 3083 Sealant (0.050")
UNIROYAL D-602 Coated Unituff Fabric[1]
UNIROYAL D-602 Coated Unituff Fabric[1]
UNIROYAL D-601 Coated Unituff Fabric[1]



7. ASN 806-7 1.72 lb./ft.^{2}

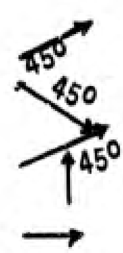
UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
UNIROYAL D-604 Coated Unituff Fabric[2]
UNIROYAL 3083 Sealant (0.050")
UNIROYAL D-604 Coated Unituff Fabric[2]
UNIROYAL D-604 Coated Unituff Fabric[2]
UNIROYAL D-603 Coated Unituff Fabric[2]

8. ASN 806-8 2.09 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
UNIROYAL D-606 Coated Square Woven Fabric[3]
UNIROYAL 3083 Sealant (0.050")
UNIROYAL D-606 Coated Square Woven Fabric[3]
UNIROYAL D-606 Coated Square Woven Fabric[3]
UNIROYAL D-605 Coated Square Woven Fabric[3]

9. ASN 806-9 1.43 lb./ft.^{2}

UNIROYAL 3010 Liner (0.030")
UNIROYAL 3082 Sealant (0.040")
UNIROYAL 5231 Tire Cord
UNIROYAL 3083 Sealant (0.050")
UNIROYAL 5231 Tire Cord
UNIROYAL 5231 Tire Cord
UNIROYAL 5231 Tire Cord
UNIROYAL 5232 Tire Cord



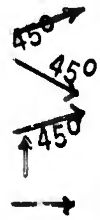
Material	Orientation of Warps of Fabric Plies

10. ASN 806-10 1.64 lb./ft.^{2}

UNIROYAL	3010 Liner (0.030")
UNIROYAL	3082 Sealant (0.040")
UNIROYAL	D-602 Coated Unituff Fabric[1]
UNIROYAL	3083 Sealant (0.050")
UNIROYAL	D-602 Coated Unituff Fabric[1]
UNIROYAL	D-602 Coated Unituff Fabric[1]
UNIROYAL	D-602 Coated Unituff Fabric[1]
UNIROYAL	D-601 Coated Unituff Fabric[1]

11. Asn 806-11 2.32 lb./ft.^{2}

UNIROYAL	3010 Liner (0.030")
UNIROYAL	3082 Sealant (0.040")
UNIROYAL	D-604 Coated Unituff Fabric[2]
UNIROYAL	3083 Sealant (0.050")
UNIROYAL	D-604 Coated Unituff Fabric[2]
UNIROYAL	D-604 Coated Unituff Fabric[2]
UNIROYAL	D-604 Coated Unituff Fabric[2]
UNIROYAL	D-603 Coated Unituff Fabric[2]



12. ASN 806-12 2.42 lb./ft.^{2}

UNIROYAL	3010 Liner (0.030")
UNIROYAL	3082 Sealant (0.040")
UNIROYAL	D-606 Coated Square Woven Fabric[3]
UNIROYAL	3083 Sealant (0.050")
UNIROYAL	D-606 Coated Square Woven Fabric[3]
UNIROYAL	D-606 Coated Square Woven Fabric[3]
UNIROYAL	D-606 Coated Square Woven Fabric[3]
UNIROYAL	D-605 Coated Square Woven Fabric[3]

Characteristics of the fabrics used in these constructions are:

1. Style: D70-527
   Yarn: 840/2 Filament Nylon, Warp and Fill
   Weave: 3 Harness Unituff (UNIROYAL Patent)
   Finish: Scoured and Heat Set
   Weight: 15 oz/yd^2
   Gauge: 0.034"
   Construction: 32 x 31
   Grab Tensile Strength: Warp 1200 lbs.
   Fill 1100 lbs.

2. Style: D70-528
   Yarn: 840/3 Filament Nylon, Warp and Fill
   Weave: 7 Harness Unituff (UNIROYAL Patent)
   Finish: Scoured and Heat Set
   Weight: 25.0 oz/yd^2
   Gauge: 0.070"
   Construction: 35 x 34
   Grab Tensile Strength: Warp 2250 lbs.
   Fill 1750 lbs.

3. Style: D69-531

Style:	D69-531		
Yarn:	840/4 Filament Nylon, Warp and Fill		
Weave:	2 x 2 Basketweave		
Finish:	Scoured and Heat Set		
Weight:	30.0 oz/yd^2		
Gauge:	0.058"		
Construction:	31 x 27		
1" Ravel Strip Tensile Strength:		Warp	1200 lbs.
		Fill	1000 lbs.
Grab Tensile Strength:		Warp	1800 lbs.
		Fill	1900 lbs.

APPENDIX II

DETAILS OF HIGH TEMPERATURE RESISTANT FUEL CELL PANELS

A. The UNIROYAL Viton compound 101,070 used in high temperature experiments was composed of:

Viton B
FEF Carbon Black
Maglite D
Sulfur
Dibutyl Sebacate
Calcium Stearate
Curative

B. The Nomex tire cord had the following characteristics:

1. Warp

   a) 1200 denier duPont Nomex
   b) 600 filament twisted 6.0 TPI "Z"
   c) 2 ply twisted 3.0 TPI "S"
   d) 25 ends per inch
   e) 29 lb. single end tensile strength
   f) 2.6% single end elongation at 10 lbs.
   g) 32.5% single end ultimate elongation

2. Filling

   a) 20/1 cotton
   b) 4 ends per inch

3. Weave: Plain

4. Width: 36 inches

5. Weight: 8.5 oz/yd^2

C. Viton to Nomex adhesion samples were prepared by the following process:

1. Nomex tire cord was pretreated with UNIROYAL proprietary adhesion system.

2. 0.010 inch of 101,076 Viton compound was calendered onto each side of tire cord.

3. The coated tire cord plies were bonded together with UNIROYAL 3267 cement.

4. Specimens were vulcanized in a standard fuel cell cure cycle.

5. 2 inch wide peel specimens were cut and the Viton gum cut to the tire cord at the beginning of the peel area.

6. The plies were peeled apart at 2 inches/minute on a standard tensile test apparatus.

D. The candidate high temperature sealant elastomers were compounded according to the formulas given in the table below:

HIGH TEMPERATURE SEALANT EVALUATION

ASN 850

Ingredient	Formulation (parts by weight) A	B	C	D	E	F	G	H	I	J	K	L
Butyl HT 1066	500	500										
Butyl GRI 365			500	500								
Neoprene W					500	500	500					
Royalene 301								500	500			
Royalene 512										500	500	
Silastic 1125U												500
Kadox 72	7.5	15.0	25.0	25.0	25.0	25.0	25.0					
Zinc Stearate	7.5	15.0										
Hypalon 40			20.0									
Stearic Acid			25.0	25.0	2.5	2.5	2.5					
ST-137 Resin			25.0	25.0								
Neozone A					10.0	10.0	10.0					
Maglite D					20.0	20.0	20.0					
NA 22 Accelerator						0.5	1.0					
MBTS									2.5		2.5	
Spider Brand Sulfur								2.5	2.5	2.5	2.5	
Cadox TS-50												5.0

E. Construction of High Temperature Resistant Self-Sealing Panels

The high temperature resistant panesl which were fabricated for gunfire tests had the following constructions:

ASN 914A 1.39 lb/ft^2

Liner - 2 oz/yd^2 Nomex square woven fabric coated with UNIROYAL
Viton compound 101,076
Sealant - 0.040" of UNIROYAL chlorobutyl compound ASN 850A
Nomex tire cord Viton coated with warps at 45^o to bottom
Sealant - 0.050" of UNIROYAL chlorobutyl compound ASN 850A
Nomex tire cord, Viton coated with warps vertical
Nomex tire cord, coated with Viton 101,076 with warps horizontal

ASN 914D 1.50 lb/ft^2

Liner - 2 oz/yd^2 Viton coated Nomex fabric
Sealant - 0.040" of UNIROYAL butyl compound ASN 850D
Nomex tire cord, Viton coated with warps 45^o to bottom
Sealant - 0.050" of UNIROYAL butyl compound ASN 850D
Nomex tire cord, Viton coated with warps vertical
Nomex tire cord, Viton coated with warps horizontal

ASN 914I 1.07 lb/ft^2

Liner - Viton coated 2 oz. Nomex fabric
Sealant - 0.040" of UNIROYAL EPDM compound ASN 850I
Nomex tire cord, Viton coated with warps 45^o to bottom
Sealant - 0.050" of UNIROYAL EPDM compound ASN 850I
Nomex tire cord, Viton coated with warps vertical
Nomex tire cord, Viton coated with warps horizontal

ASN 914K 0.97 lb/ft^2

Liner - Viton coated 2 oz. Nomex fabric
Sealant - 0.040" of UNIROYAL EPDM compound ASN 850K
Nomex tire cord, Viton coated with warps 45^o to bottom
Sealant - 0.050" of UNIROYAL EPDM compound ASN 850K
Nomex tire cord, Viton coated with warps vertical
Nomex tire cord, Viton coated with warps horizontal

ASN 914L 1.35 lb/ft^2

Liner - Viton coated 2 oz. Nomex fabric
Sealant - 0.040" of UNIROYAL silicone compound ASN 850L
Nomex tire cord, Viton coated with warps 45^o to bottom
Sealant - 0.050" of UNIROYAL silicone compound ASN 850L
Nomex tire cord, Viton coated with warps vertical
Nomex tire cord, Viton coated with warps horizontal

F. Fluorosilicone Elastomer

The fluorosilicone elastomer evaluated was Dow-Corning Silastic LS-2249U. In order to vulcanize the elastomer 1.2 parts of Cadox TS-50 peroxide was added per 100 parts of elastomer. This is the amount recommended in Dow-Corning literature for obtaining maximum resistance to high temperatures.

APPENDIX III

DETAILS OF CONSTRUCTION OF EXPERIMENTAL FUEL LINES AND FUEL LINE COVERS

A. Integral Self-Sealing Fuel Lines

ASN 947 1.92 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Fuel barrier - painted nylon resin
Reinforcement - six plies of 27 75 oz/yd^2 USFlex weave nylon fabric saturated with a nitrile rubber cement
Outer ply - .008" 3061 nitrile rubber

ASN 948 1.38 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Fuel barrier - painted nylon resin
Reinforcement - six plies of 13 oz/yd^2 square woven nylon fabric saturated with nitrile rubber cement
Outer ply - .008" 3061 nitrile rubber

ASN 961-1 2.90 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Fuel barrier - painted nylon resin
Reinforcement - three plies 27.75 oz/yd^2 USFlex weave nylon fabric saturated with nitrile rubber cement
Sealant - 0.173" 3083 natural rubber
Reinforcement - three plies 27.75 oz/yd^2 USFlex weave nylon fabric saturated with nitrile rubber cement
Outer ply - 0.008" 3061 nitrile rubber

ASN 961-2 2.36 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Fuel barrier - painted nylon resin
Reinforcement - three plies 13 oz/yd^2 square woven nylon fabric saturated with nitrile rubber cement
Sealant - 0.173" 3083 natural rubber
Reinforcement - three plies 13 oz/yd^2 square woven nylon fabric saturated with nitrile rubber cement
Outer ply - 0.008" 3061 nitrile rubber

ASN 970 2.78 lb/ft^2

Liner - 41,794-1 polyurethane film
Reinforcement - two plies 27.75 oz/yd^2 USFlex nylon fabric saturated with 700-4 urethane resin solution
Sealant - 0.173" 3083 natural rubber
Reinforcement - two plies 27.75 oz/yd^2 USFlex nylon fabric saturated with 700-4 urethane resin solution

ASN 984 3.23 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Fuel barrier - painted nylon resin
Reinfrocement - three plies 27.75 oz/yd^2 USFlex weave nylon fabric saturated with a nitrile rubber cement
Sealant - 0.252" 3083 natural rubber
Reinforcement - three plies 27.75 oz/yd^2 USFlex weave nylon fabric saturated with a nitrile rubber cement
Outer ply - 0.008" 3061 nitrile rubber

B. Nonmetallic Fuel Lines

These fuel lines were high density polyethylene tubes 2" OD, 1½" ID. Each tube was etched with a chromic acid solution. The liner (if used) and end closures were cemented to the tube with UNIROYAL 3288 cement.

ASN 1021 (US-191 construction) 1.89 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

ASN 1031 1.66 lb/ft^2

Liner - None
Sealant - 0.250" 3083 natural rubber
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

ASN 1032 3.21 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Outer Ply - UNIROYAL 5231/5232 rubber coated nylon tire cord
Resilient ply - 0.100" 101,059A high resilience neoprene compound

ASN 1044-1 3.21 lb/ft^2

Liner - 0.040" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Resilient ply - 0.100" 101,059A high resilience neoprene compound
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

ASN 1044-2 2.85 lb/ft^2

Liner - 0.100" 101,059A high resilience neoprene compound
Sealant - 0.250" 3083 natural rubber sealant
Outer ply - UNIROYAL 5231/5232 rubber coated tire cord

C. <u>New Sealants and Reinforcements</u>

Except where noted, the covers were fabricated over 2" OD aluminum tubes.

<u>ASN 976-1</u> 5.33 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Reinforcement - UNIROYAL 5231/5232 rubber coated nylon tire cord
Outer ply - 0.250" 101,059A high resilience neoprene compound

<u>ASN 976-2</u> 5.00 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Reinforcement - none
Outer ply - 0.250" 101,059A high resilience neoprene compound

<u>ASN 979</u> 1.79 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Precompressed foam - 1" thick polyurethane open cell foam saturated with natural rubber cement and compressed to 0.250" thickness
Sealant - 0.250" 3083 natural rubber
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

<u>ASN 981</u> 2.02 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" natural rubber compounded with 3 parts sulfur per hundred of rubber and Captax accelerator. Zinc oxide, stearic acid, and resins were added to improve cure.
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

<u>ASN 982</u> 1.99 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Outer ply - 0.050" Surlyn polyionomer film

<u>ASN 988</u> 2.27 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" Silastic 1125U
Outer ply - UNIROYAL 5231/5232 rubber coated nylon tire cord

<u>ASN 989-1</u> 6.98 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - None
Outer ply - 0.500" 101,059A high resilience neoprene compound

ASN 989-2 13.60 lb/ft^2

An integral line with no aluminum tube in the center area which was gunfired

Liner - 0.060" 3010 nitrile rubber
Sealant - None
Outer ply - 1.00" 101,059A high resilience neoprene compound

ASN 994-4 3.17 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Outer ply - 0.250" 3010 nitrile rubber

ASN 1006 4.45 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.25" 3083 natural rubber
Resilient ply - 0.100" 101,059A neoprene
Reinforcement - one ply of nylon tire cord saturated with neoprene cement
Outer ply - 0.100" 101,059A neoprene

ASN 1012 2.28 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Outer ply - 0.100" Roylar E-9 sheet

ASN 1022 4.45 lb/ft^2

Liner - 0.060" 3010 nitrile rubber
Sealant - 0.250" 3083 natural rubber
Resilience ply - 0.100" neoprene GN/HC blend
Reinforcement - one ply of nylon tire cord saturated with neoprene cement
Outer ply - 0.100" neoprene GN/HC blend

APPENDIX IV

Bibliography of Literature Survey

1. Butler, J. M., et. al., "Thermally Resistant Polymers for Fuel Tank Sealants", Monsanto Research Corp., N70-19871, July, 1969.

2. Cooper, F. M., et. al., "Survivable Fuel Tank Systems Selection Technique, R. and D. Design Handbook Report", Volume I, North American Rockwell Corp., Los Angeles, Calif., AD 870-916, March, 1970.

3. Custard, G. H., "A Vulnerability Evaluation of Emulsified Fuels For Use In Army Aircraft", Falcon Research and Development Company, Denver, Colorado, AD 670-935, April, 1968.

4. Kohrn, R. C., Birkey, W. R., and Butz, R. L., "Improved Materials for Aircraft Self-Sealing Fuel Cell Systems", UNIROYAL, Inc., Mishawaka, Ind., Technical Report AFML-TR-68-356, Part I, November, 1968.

5. Kohrn, R. C., Birkey, W. R., and Ballentine, J. D., "Improved Materials for Aircraft Self-Sealing Fuel Cell Systems", UNIROYAL, Inc., Mishawaka, Ind., Technical Report AFML-TR-68-356, Part II, March 1971.

6. Hassell, J. A., Boni, K. A., Kuhlmann, H. W. and Mueller, E. R., "Prediction of Service Life of Polymeric Sealant Compositions For Fuel Tanks in Aerospace Structures From Measurements of Viscoelastic Properties", Battelle Memorial Institute, N70-27360, August, 1969.

7. Heitz, R. M., and Manire, V. B., "Self-Sealing Systems for Integral Fuel Tanks", Northrop Corp., Technical Report AFML-TR-68-183, Part I, July, 1968.

8. Heitz, R. M., and Neubert, R. W., "Self-Sealing Systems for Integral Fuel Tanks", Northrop Corp., Technical Report AFML-TR-68-183, Part II, December, 1970.

9. Holten, A. J., "Ignition Characteristics of the .50 - Caliber API-M8 Versus 2024-T3 Aluminum Plate", Air Force Materials Laboratory, Wright-Patterson AFB, Ohio, AFML-TR-68-223, September, 1968.

10. Ipson, T. W. and Wittrock, E. P., "Response of Non-Woven Synthetic Fiber Textiles to Ballistic Impact", Denver Research Institute, Colorado, USA-NLABS-TR-67-8-CM, July, 1966.

11. Nestor, L. J., "Investigation of Turbine Fuel Flammability Within Aircraft Fuel Tanks", Naval Air Propulsion Test Center, Philadelphia, Pa., Federal Aviation Administration Report No. ADS-67-7, July, 1967.

12. Raes, M. C., Semenak, N. S. and Urs, S. V., "Development of Solvent Resistant Sealants", Olin Mathieson Chemical Corp., New Haven, Conn., AD 665-683, February, 1968.

13. Recht, R. F. and Newell, W. G., "Reduction of Hazard From Secondary Fragments Created by Ballistic Penetration of Aircraft", Denver Research Institute, Colorado, USAAVLABS-TR-67-49, October, 1967.

14. Schwartz, S. S. and Crepeau, P. C., "Self-Sealing and Sealants for Aerospace Vehicles", Hughes Aircraft Co., Culver City, Calif., AFML-TR-66-77, Part II, February, 1966.

15. Steingiser, S., Hanna, G. L. and Steinmetz, E. A., "Processing, Application, and Evaluation of Sealants for Fuel Tanks in Advanced Aerospace Structures", Sixth Quarterly Progress Report, Monsanto Research Corp., N70-31925, June, 1970.

16. Stevens, M. R., Fisher, H. D. and Breen, B. P., "Investigation of Materials Combustibility, Fire and Explosion Suppression In A Variety of Atmospheres", Dynamic Science, Division of Marshall Industries, Monrovia, Calif., AFAPL-TR-68-35, May, 1968.

17. Wenze, A. B. and Clough, N., "Target Pressure and Damage Data From Impacts by Explosively Propelled Projectiles", Lewis Research Center, Cleveland, Ohio, N68-25819, June, 1968.

18. Wilde, A. E., et. al., "Dynamic Response of a Constrained Fibrous System Subjected to Transverse Impact, Part I, Transient Responses and Breaking Energies of Nylon Yarns", Fibers and Polymers Division, Army Materials and Mechanics Research Center, Watertown, Mass., AD 716-983, November, 1970.

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)
Uniroyal, Inc.
Mishawaka, Indiana

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
IMPROVED MATERIALS FOR AIRCRAFT SELF-SEALING FUEL CELL SYSTEMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Technical Report - 1 June 1971 to 1 July 1973

5. AUTHOR(S) (First name, middle initial, last name)
J. D. Ballentine, F. Geerligs, J. R. Kulesia

6. REPORT DATE

7a. TOTAL NO. OF PAGES

7b. NO. OF REFS
18

8a. CONTRACT OR GRANT NO.
F33615-71-C-1526

b. PROJECT NO.
7340

c. Task No. 734005

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AFML-TR-73-248

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT Distribution limited to U.S. Government agencies only (test and evaluation); December 1973. Other requests for this document must be referred to the Air Force Materials Laboratory, Nonmetallic Materials Division, Elastomers and Coatings Branch, AFML/MBE, Wright-Patterson Air Force Base, Ohio 45433.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

Self-sealing fuel cell constructions were developed with improved capability for sealing wounds inflicted by .50 caliber and 14.5 mm. armour piercing incendiary projectiles but at an increase in weight penalty. All attempts to develop a high temperature (350°F) stable, reliable self-sealing elastomeric fuel cell materials composite were thwarted because of poor adhesion at elevated temperature. Although preliminary screening tests on small specimens pinpointed effective adhesives for bonding candidate high temperature sealants to the fabric reinforced fluoroelastomer cell components, the large test panel composites prepared developed flaws in adhesion on exposure to high temperature and performed unsatisfactorily when gunfire tested for self-sealing reliability at room temperature. After an extensive materials investigation, the effort to develop a lightweight non-flowering self-sealing fuel line resulted in the development of a high density polyethylene tube shielded with a conventional self-sealing fuel line cover materials composite. Gunfire evaluations of this lightweight fuel line materials construction showed it to be effective in sealing wounds inflicted by .50 caliber armour piercing projectiles.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Elastomeric						
Self-Sealing						
Fuel Cell						
Fuel Lines						
Non-Flowering						
Lightweight						

UNCLASSIFIED
Security Classification