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AFML-TR-72-56

IMPROVED MATERIALS FOR AIRCRAFT SELF-SEALING FUEL CELL SYSTEMS

R. C. Kohrn
W. R. Birkey
F. Geerligs

UniRoyal, Incorporated

TECHNICAL REPORT AFML-TR-72-56

DECEMBER, 1972

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NOTICE

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FOREWORD

This report was prepared by UNIROYAL, Incorporated, Engineered Systems Department, Mishawaka, Indiana, under United States Air Force Contract F33615-70-C-1205. 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 15 February 1970 through 15 October 1972. Report Number SR-490-72-005 has been assigned for internal control.

The program at UNIROYAL was conducted under the direction of R. C. Kohrn, 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 and R. H. Waelbroeck as Chemists. Product Engineer was R. E. Dorsch and Textile Engineer was A. Q. Khan. Laboratory assistance was given by L. J. Parker and K. A. Cannoot.

This report has been reviewed and is approved.

MERRILL L. MINGES, Acting Chief
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ABSTRACT

A new self-sealing fuel cell construction was developed utilizing a polyether urethane elastomer which exhibited excellent resistance to cracking and "chunking out" at a gunfire test temperature of -40° F. Efforts made to develop a silicone sealant material with good building tack for use in the development of high temperature resistant self-sealing fuel cells are discussed. A limited amount of effort was devoted to investigating the use of non-sealing fuel line jackets as a means of controlling fuel spraying from ruptured fuel lines. Several commercial foams and thermoplastic sheet materials were evaluated as backing boards for the protection of self-sealing fuel cells. Some of the effort was expended in establishing a reliable method of striking fuel lines with tumbled projectiles.

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SECTION I

INTRODUCTION

Many of the aircraft lost in combat situations are the victims of penetration by shrapnel or small arms fire. Penetration of the aircraft fuel system and subsequent fires and explosions figure in a large number of these cases. The development of protective systems by industry and government agencies is an effort to reduce the loss of lives and equipment that result from fuel system ruptures.

The objective of this contract was the development of self-sealing fuel systems, composed of elastomeric materials, which will exhibit improved performance characteristics while imposing minimum weight and volume penalties for a particular level of performance. Effort was continued to develop a polyurethane construction which has better gunfire performance at -40^{o} F than the CN-2 construction outlined in Technical Report AFML-TR-68-356, Part I.

The research and development was conducted in three phases:

Phase I - Literature Search and Review of Past Work

Phase II - Experimental Evaluation

Phase III - Documentation

SECTION II

COMPOUNDING SILICONE FOR IMPROVED TACK

In an attempt to improve the sealing performance of silicone elastomers, a program has been undertaken to compound these elastomers for greater tack. Table I details the experimental design.

TABLE I

EXPERIMENTAL DESIGN - SILICONE COMPOUNDING

			TACKIFIER (PHR)					
			Wingtack 95			Cumar W 2½		
Elastomer	Curative	Level (PHR)	0	10	20	0	10	20
Silastic 437	Cadox TS-50	1.9	L					P
		3.0				A		
	Dicup 40C	1.9			M		F	
		3.0	J					H
Silastic 745	Cadox TS-50	1.9		B				
		3.0		G				
	Dicup 40C	1.9	Q				C	
		3.0						
SE-4360	Cadox TS-50	1.9	D		N			
		3.0						R
	Dicup 40C	1.9	I				K	
		3.0	O		E			

The compounds indicated by letters were mixed. All were press cured for 10 minutes at 300° F except formulations A, B, D, G, L, N, P, R which were cured for 5 minutes at 240° F. Compounds B, E, G, N, P and R did not cure. Volume swell data is given in Table II.

TABLE II

VOLUME SWELL AFTER EXPOSURE TO TYPE III FUEL

Sample	% Swell		
	30 Sec.	1 Min.	2 Min.
A	23.49	33.75	40.64
C	26.67	31.23	37.27
D	22 94	30.95	32.43
F	32.38	34.43	47.83
H	33.33	34.56	46.20
I	25.57	30.92	38.92
J	24.00	29.97	35.73
K	32 63	35.84	39.85
L	28.09	31.79	45.74
M	32.16	41.20	46.86
O	23.41	25.38	30.34
Q	23.49	27.13	35.57

The method used to determine and calculate the swell was described on page 15 of Technical Report AFML-TR-68-356, Part I.

Since the tack of a sealant is thought to assist in sealing a wound, a tack test was performed on each compound. The test is as follows:

a. Cut two strips 2" x 4".
b. Soak strips in Type III fuel for one minute
c. Place one strip on top of the other with release paper between for two inches.
d. Place a 5 lb. weight on the portion not containing the release paper. Allow to stand five minutes.
e. Remove weight and measure force to separate strips on a test machine.

None of the silicone formulations gave a measurable degree of tack when tested as described above.

SECTION III

ELASTOMER COMPOUNDING FOR BETTER HIGH TEMPERATURE RESISTANCE

The goal of the elastomer compounding program was improvement in property retention after exposure to extended heat aging at 350° F. This was approached by substituting different fillers for the carbon black in a suitable compound of each polymer.

The elastomers chosen were all considered suitable for use as liner or cover stocks when properly compounded and cured Paracril B is a medium low acrylonitrile content NBR with a good balance between oil and fuel resistance and flexibility at low temperatures. Vibrathane 5004 is a peroxide-cured millable polyurethane elastomer with good processing characteristics, good performance at low temperatures, and good resistance to dry heat. Adiprene CM is a sulfur curable polyether urethane rubber which exhibits excellent abrasion resistance, low temperature characteristics, and resistance to heat deterioration, weathering, and swelling in oils or solvents. Each of the elastomers is normally compounded with carbon black but is compatible with the types of fillers shown below.

The experimental design that was followed is shown below:

Candidate Elastomer	Control Carbon Black	Experimental Fillers Aluminum Flakes	Hi Sil 233	Mistron Vapor Talc
Paracril B				
Vibrathane 5004				
Adiprene CM				

The formulas shown below were prepared from the experimental design.

Nitrile Compounds	A (Control)	B	C	D
Paracril "B"	100	100	100	100
Statex B (FF Black)	20.3			
SRF Black	50.5			
MT Black	30.4			
Litharge	5.1	5.1	5.1	5.1
Ethylac	6.5	6.5	6.5	6.5
Dibutyl Sebacate	30.4	30.4	30.4	30.4
Superfine Sulfur	1.5	1.5	1.5	1.5
Aluminum Flakes		100		
Hi-Sil 233			100	
Mistron Vapor Talc				100

Peroxide Cured Urethane	A (Control)	B	C	D
Vibrathane 5004	100	100	100	100
Stearic Acid	.30	.30	.30	.30
HAF Black	30			
DiCup 40C	6.0	6.0	6.0	6.0
Aluminum Flakes				30
Hi-Sil 233		30		
Mistron Vapor Talc			30	

NOTE: "D" was not made because of explosion hazards involved in mixing aluminum flakes with peroxides.

Sulfur Cured Urethane	A (Control)	B	C	D
Adiprene CM	100	100	100	100
HAF Black	30			
Cumar W 2½	15	15	15	15
MBTS	4	4	4	4
MBT	1	1	1	1
Sulfur	.75	.75	.75	.75
Caytur 4	.35	.35	.35	.35
Cadmium Stearate	.5	.5	.5	.5
Aluminum Flakes		30		
Hi-Sil 233			30	
Mistron Vapor Talc				30

These compounds were mixed and cured as shown below:

Paracril "A" compound was cured for 60 min. at 276° F. Compounds "B", "C", and "D" were cured for 90 min. at 276° F.

Adiprene CM compound "A" was cured for 60 min. at 287° F. Compounds "B" and "C" were cured for 90 min. at 287° F.

Vibrathane 5004 compound "A" was cured for 45 min. at 305° F. Compounds "B", "C", and "D" were cured for 60 min. at 305° F.

The test data for these compounds is shown in Table III.

TABLE III

TEST DATA FOR ELASTOMER COMPOUNDING EXPERIMENTS

Compound	Gauge	Elongation	Tensile	Median Ten.	Median Elong.	Hardness	300% Modulus	After 96 Hrs. in Type III Fuel @ 158° F. Gauge	Elongation	Tensile	Median Ten.	Median Elong.	Hardness	300% Modulus
Paracril B A	.082	270	1293		270	65	Could not take	.084	230	1075		230	59	Could not take
	.082	270	1341				"	.086	250	1116				"
	.083	270	1446	1341			"	.085	220	1059	1075			"
B	.071	880	451		840	53	175	-	-	-		705	38	135
	.072	830	361				172	.079	710	278				147
	.070	840	400	400			171	.080	700	275	277			140
C	.095	340	2000		340	92	1916	.101	250	1584		220	88	Could not take
	.096	340	2125				1875							"
	.095	370	2189	2125			1832	.096	190	1250	1417			"
D	.077	380	675		380	59	530	.080	320	550		320	54	530
	.074	360	649				562	.081	300	568				568
	.078	400	769	675			564	.081	340	642	568			588
Vibrathane 5004 A	.078	470	2564		470	67	1564	.080	470	1525		480	52	890
	.078	490	2462				1513	.080	500	1550				920
	.078	450	2282	2462			1462	.079	480	1644	1550			982
B	.071	790	2366		810	57	338	.078	820	1718		810	47	185
	.072	810	2722				361	.075	800	1627				192
	.072	810	2694				361	.077	810	1766	1718			192
C	.073	550	2877		530	67	757	.080	470	1375		480	58	515
							712	.080	500	1375				515
	.075	510	3147	3012			720	.080	480	1675	1375			525
Adiprene CM A	.079	710	2557		740	55	456	.100	510	840		530	34	272
	.080	740	2800				475	.099	570	929				238
	.078	740	3179	2800			487	.099	530	909	909			238
B	.077	840	1282		825	55	312	.094	360	234		360		209
	.078	810	1385	1334			313	.089	340	225				220
							256	.090	410	222	234			178
C	.082	760	2488		760	57	268	.093	690	1290		690	36	163
	.083	770	2410				289	.094	690	1362				157
	.084	760	2286	2410			262	.095	710	1326	1326			156
D	.084	780	1786		780	52	310	.096	710	667		710	32	117
	.084	780	1929				286							129
	.084	780	1952	1927			286	.092	710	587	627			117

Paracril B, Adiprene CM and Vibrathane 5004 compounds were subjected to 96 hrs. at 350° F air. After this exposure, the Paracril B compounds had cracked and crumbled and the Adiprene CM compounds had softened and became distorted. Only the Vibrathane 5004 compounds were suitable for physical testing. The test data is shown below after 96 hrs. at 350° F and after an additional 96 hrs. in Type III fuel.

	After 96 hrs. at 350° F							96 hrs. @ 350° F - 96 hrs. in Type III Fuel @ 158°F						
				Median							Median			
Compound	Gauge	Elongation	Tensile	Ten.	Elong.	Hardness	300% Modulus	Gauge	Elongation	Tensile	Ten.	Elong.	Hardness	300% Modulus
Vibrathane 5004	.078	180	1256		210	75	Could not take	.078	220	1179		205	55	Could not take
A	.078	210	1436				"							"
	.079	210	1558	1436			"	.078	190	1000	1090			"
	.069	380	609		330	64	551	.070	430	257		440	33	171
B	.070	320	591				594	.071	440	254				158
	.071	330	877	600		58	558	.069	480	261	257			191
	.073	410	877		410		800	.073	380	493		380	46	477
C	.075	360	827				795	.079	380	506				471
	.074	450	946	877			816	.080	440	525	506			440

SECTION IV

EVALUATION OF PROJECTILE TUMBLING METHODS

Since the new fuel line specification requires tumbled projectile impacts, a new method must be found to tumble projectiles accurately. At present UNIROYAL uses four plywood sheets inclined at various angles in front of the target to tumble the projectile. This system generally tumbles the bullet but at the same time produces an uncertainty in the path of the bullet. Since a fuel line is a much smaller target than a fuel cell, a more accurate system of tumbling was sought.

At the suggestion of Mr. Anspach of Wright-Patterson A. F. B., an extra barrel was procured for the .50 cal. gun at the UNIROYAL test facility. A .30 cal. Model 1903 rifle was also obtained. The barrel from the .30 cal. rifle and the extra barrel for the .50 cal. gun were both machined to remove the rifling and to cut away the upper half of the barrel for one inch at the muzzle.

Removing the rifling eliminates the spin on the bullet and thus reduces the gyroscopic stability of the bullet. Cutting away part of the barrel at the muzzle causes an uneven gas pressure on the bullet as it leaves the barrel, thus initiating tumble. The bullet does not strike any solid objects which can deflect it and, therefore, in the flight path of less than 75 feet provided at the UNIROYAL test facility, there is little chance for deviation from the theoretical trajectory.

Both smooth-bore notched gun barrels were test fired. The guns were clamped in place and fired first to determine if there would be an excessive amount of powder exiting from the muzzle caused by using normal rifle powder in a smooth bored gun. Both guns were fired safely with the bullet following the desired trajectory and not an erratic path.

Both guns were fired at a paper target to determine the degree of tumbling. The .30 cal. gun was fired at approximately 30 ft. from the target and gave full tumbles in all cases. The vertical variation between shots was less than one inch and this apparently can be reduced with greater experience in sighting. The .50 cal. gun was fired at a distance of approximately 60 ft. from the target. Sufficient tumble was imparted to all shots but accuracy was low because the gun mount was not secured rigidly enough.

The notched, smooth barrel has proven to be a method allowing gunfire with consistent tumbling and a fair degree of accuracy. We recommend that gunfire of fuel lines and other small targets with tumbled projectiles be done with a notched, smooth barrel.

SECTION V

SPRAY RESTRICTORS FOR FUEL LINES

The immediate spray of fuel over a large area is one of the most dangerous results of the puncture of a pressurized fuel line. A portion of the contract was applied to a limited evaluation of methods to mechanically restrict heavy spray. Three different types of spray restrictors were fabricated and evaluated.

The ASN 605-1 spray restrictor consisted of a loose urethane/fabric cover provided with a small hose to drain the cover. ASN 605-2 restrictor was similar but was fabricated of nitrile rubber coated fabric.

The ASN 629 restrictor consisted of reticulated polyurethane foam wrapped around a fuel line and coated with a film of urethane. No hose was provided for drainage.

The three restrictors and an uncovered metal fuel line were gunfired with .30 cal. AP ammunition while connected to a 30 psi water line. The uncovered line sprayed a great deal of water for a long distance. See Photograh Number 1 in Appendix III.

With the ASN 605-1 and -2 spray restrictors, however, leakage through the bullet wounds was reduced to a slight dribble with the majority of the leakage draining through the drain hose. See Photographs 2 and 4 in Appendix III. When the drain hose was plugged, the leakage sprayed out through the wounds as in the uncovered lines. See Photographs 3 and 5 in Appendix III.

The ASN 629 restrictor slowed leakage to a small dribble until the foam layer was saturated with water, at which time leakage sprayed out of the wounds again. The time to saturate the foam was less than one minute. See Photograph Number 6 in Appendix III.

While ASN 605-1 and -2 stop spray from a fuel line wound, they do not retain the fuel in the fuel system as a conventional self-sealing cover does. The spray restrictor is intended to prevent fires by preventing fuel from spraying onto hot engine surfaces. The conventional fuel line cover performs this function while at the same time preserving the fuel supply of the aircraft. Since spray restrictors must add some weight and bulk to the aircraft, conventional self-sealing line covers are the best investment considering the greater level of protection they give at a slightly higher weight level and similar volume penalties.

SECTION VI

EVALUATION OF BACKING BOARDS

The backing boards were evaluated by installing one 27" x 33" panel of each in a gunfire structure conforming to MIL-T-5578C. A US-182 test cell was installed within the assembly and .50 cal. AP-M2 ammunition was fired into the backing boards. The backing boards were evaluated for damage and the US-182 test cell was evaluated for sealing performance. The data is shown in Table IV.

1. Evaluation of Thermoplastic Sheets

Fifty caliber gunfires were performed on the following four plastic materials:

a. Nylafil - A nylon sheet reinforced with chopped glass fibers.

b. Nylux - A non-reinforced extruded nylon sheet.

c. A Styrene - Acrylonitrile copolymer reinforced with glass fibers (116-1A).

d. A Styrene - Acrylonitrile copolymer reinforced with asbestos fibers (116-2A).

When gunfired, all except Nylux shattered. The high degree of reinforcement apparently reduced the flexibility to such an extent that the impact of a tumbled round broke the entire sheet into small pieces.

The Nylux sheet did not shatter but in the area of more severe tumbled entrances it did tear radially from the wound. Some evidence was noted of melting of the thermoplastic nylon in the vicinity of wounds but this does not seem significant in regard to the supporting action of the board.

2. Conolite Experimental Backing Boards

Four backing boards were submitted by Conolite for evaluation. These were:

a. X70-29 - A rigid polyurethane foam laminated to a paper backing.

b. X70-48 - A rigid polyurethane foam laminated to a paper backing.

c. X70-30 - A rigid polyurethane foam laminated to a woven glass roving.

d. X70-23 - A conventional backing board similar to Conolite Type I backing board.

The foam type boards (-29,-30, and -48) showed a tendency to chunk-out. That is, large portions of the foam were pulverized and blown away by the impact of the bullet. The glass roving of X70-30 reduced this tendency but did not eliminate it. When the foam is lost, there is no support for the fuel cell wound and consequently no help in sealing. X70-23 gave approximately the same performance as Type I board by Conolite. See Photographs 7-10 in Appendix III.

TABLE IV

GUNFIRE PERFORMANCE OF BACKING BOARDS

Round	Identification	Type of Shot	Size of Wound	Sealing Performance of US-182
1E	Nylafil	Straight	Shattered	Seal in 30 sec.
1X	Nylux	3/4 Tumble		Seal in 30 sec.
2E	Nylafil	Full Tumble	Shattered	Seep at 8 min.
3E	116-1A	Straight	Shattered	Seal in 30 sec.
3X	116-2A	3/4 Tumble	Shattered	Seal in 30 sec.
4E	116-1A	Full Tumble	Shattered	Stream
5E	Nylux	Straight		Seal in 30 sec.
5X	Nylafil	Straight	Shattered	Seal in 30 sec.
6E	Nylux	3/4 Tumble		Mod. stream at 4 min.
6X	Nylafil	3/4 Tumble	Shattered	Seal in 30 sec.
7E	Nylux	3/4 Tumble		Seal in 1 min.
7X	Nylafil	½ Tumble	Shattered	Seal in 30 sec.
8E	Nylux	3/4 Tumble		Stream*
9E	Nylafil	Straight	Shattered	Seal in 30 sec.
9X	Nylux	3/4 Tumble		Seal in 30 sec.
1E	X70-48	Straight		Seal in 30 sec.
1X	X70-30	3/4 Tumble		Seal in 1 min.
2E	X70-48	Straight		Seal in 30 sec.
2X	X70-30	3/4 Tumble		Seal in 30 sec
3E	X70-48	3/4 Tumble		Seal in 2 min.
4E	X70-48	Full Tumble		Stream**
5E	X70-29	Straight		Seal in 30 sec.
5X	X70-23	3/4 Tumble		Seal in 30 sec.
6E	X70-29	3/4 Tumble		Slight seep at 4 min.
7E	X70-29	3/4 Tumble		Seal in 1 min.
8E	X70-30	Straight		Seal in 30 sec.
8X	X70-48	Straight		Seal in 30 sec.
9E	X70-30	Straight		Seal in 30 sec.
9X	X70-48	3/4 Tumble		Slight seep at 4 min.
10E	X70-30	Full Tumble		Stream**
11E	X70-30	3/4 Tumble		Stream**
12E	X70-23	Straight		Seal in 30 sec.
12X	X70-29	3/4 Tumble		Stream**
13E	X70-23	3/4 Tumble		Seal in 30 sec.
14E	X70-23	Full Tumble		Stream**
15E	X70-29	Straight		Seal in 30 sec.
15X	X70-23	Straight		Seal in 30 sec.
16E	X70-29	Straight		Seal in 30 sec.
16X	X70-23	3/4 Tumble		Seal in 30 sec.

*Wound held open by metal, shot disallowed.

**Wound was plugged immediately to prevent excessive loss of fuel.

SECTION VII

EVALUATION OF POLYURETHANE FILMS

In Technical Report AFML-TR-68-356, Part I, it was reported that polyurethane enhanced the gunfire performance of self-sealing constructions when it was used as an innerliner. It also improved the gunfire performance when used to impregnate the outer tire cord. By using polyurethane in a self-sealing construction, it was possible to obtain .50 cal. ambient temperature gunfire performance with a construction which is lighter, thinner, and more flexible than commercially available .50 cal. constructions, however, the polyurethane cracked when gunfired at -40° F with .50 cal. AP-M2 ammunition and performance was below that required in MIL-T-5578C.

In Technical Report AFML-TR-68-356, Part II, it was reported that a cell of polyurethane was developed which combines excellent 20 mm gunfire performance at ambient temperatures with good cell flexibility and light weight. This construction, ASN 522-37, weighed the same as the standard US-173. Early in the current contract, another cell of this construction, cell ASN 630, was fabricated and gunfired at -40° F. After gunfire, the cell was examined and it was found that the innerliner had cracked severely and pulled away from the construction. Effort was then directed toward improving low temperature performance.

Construction CN-2 was used as a baseline. Cell ASN 630 duplicated cell ASN 522-37. In cell ASN 654 the curing system and processing techniques were altered. Details of the construction and gunfire performance follow.

1. Test Cell ASN 630

   a. Construction Details

   Cell ASN 630 is of the same construction as 522-37 reported in Technical Report AFML-TR-69-356, Part II. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane. The construction consists of the following plies:

   0.030" thick V-6007/V-6004 polyurethane innerliner*
   Nylon tire cord with US-3082 and US-3083 sealants
   Nylon tire cord with US-3082 and US-3083 sealants
   Nylon tire cord with US-3082 and US-3083 sealants
   Nylon tire cord with V-6007/V-6004 polyurethane outer cover

   *The liner was made by casting the polyurethane on glass plates. The tire cord plies were positioned at 90° to each other and at 45° to the base of the cell. Adhesive #6218 was used to bond the plies together.

   b. Gunfire of Test Cell

   The gunfire results of cell ASN 630 are shown on page 14.

c. Conclusions or Remarks

After gunfire, the cell was examined and it was found that the innerliner had cracked severely and pulled away from the construction. The low temperature apparently made the liner brittle enough to crack under the impact of tumbled rounds. See Figures 12 and 13 in Appendix III.

2. Test Cell ASN 654

a. Construction Details

Cell ASN 654 was the same construction as CN-2 reported in Technical Report AFML-TR-69-356, Part I except the inner and exterior coatings were modified by changing the curative and method of mixing in hope of overcoming the "chunk-out" problem at -40^{o} F. Methylene dianiline was used as the curing agent instead of 4-4' methylene bis (2-chloroaniline). Also, a solution system was used instead of 100% solids. The construction consists of the following plies:

0.030" thick UNIROYAL 41769 polyurethane
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with UNIROYAL 41769 polyurethane

NOTE: 41769 contains 75% Vibrathane 6007, 25% Vibrathane 6004 and methylene dianiline.

The tire cord plies were positioned at 90^{o} to each other and at 45^{o} to the base of the cell.

b. Gunfire of Test Cell

The gunfire results of cell ASN 654 are shown on page 15.

c. Conclusions or Remarks

After gunfire, the cell was examined. It was found that the innerliner had cracked severely. The innerliner had pulled away from sides 3 and 4, the top, and the bottom where adhesive #6218 was used. Adhesive #3420, the same adhesive used in the original CN-2 construction, was used on sides 1 and 2 and no tendency of innerliner release was noted except at the wound. However, there appeared to be no correlation between gunfire performance and the adhesive used. See figures 14-17 in Appendix III.

After the results of the gunfire testing of these cells were observed, it was decided that to obtain candidate innerliner materials with better elasticity at low temperatures than the urethane compositions used in the above cell constructions, a program of screening candidate materials through a study of their films would be carried out.

TABLE V

GUNFIRE OF TEST CELL ASN 630

Fuel Type: Type I

Fuel Temperature: -40° F

Projectile Type: .50 Cal. AP

Projectile Velocity: Standard

Backing Board: Conolite A60SG4W

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Sealing Performance
1	Entrance	None	0°	Seal in 30 sec.
	Exit	½	0°	Seal in 4½ min.
2	Entrance	Full	0°	Seal in 3 min.
	Exit			No exit
3	Entrance	½	0°	Seal in 45 sec.
	Exit			No exit
4	Entrance	None	45°	Seal in 30 sec.
	Exit	3/4	45°	Seal in 30 sec.
5	Entrance	None	0°	Seal in 30 sec.*
	Exit	3/4	0°	Seal in 2 min.*
6	Entrance	None	0°	Seal in 30 sec.*
	Exit	3/4	0°	Heavy stream, no seal*

*20 mm AP ammunition was used

TABLE VI

GUNFIRE OF TEST CELL ASN 654

Fuel Type: Type I

Fuel Temperature: -42° F

Projectile Type: .50 cal. AP

Projectile Velocity: Standard

Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Const. No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	1	Slight seep in 2 min. Seal in 4 min.	¼" dia. hole
	Exit	3/4	0°	3	Slight stream at 2 min. Coring noted. Wound plugged.	1-3/4" x 1" L tear
2	Entrance	3/4	0°	1	Heavy stream at impact & after 4 min. Wound plugged.	1½" x ¼" tear
	Exit	3/4	0°	3	Slight seep at 30 sec. Seal in 1 min.	2" tear
3	Entrance	3/4	0°	1	Heavy stream at 1 min. Slight stream at 4 min.	1½" x ¼" tear
	Exit	None	0°	3	No exit through aluminum, therefore, sealing performance could not be determined.	1/8" dia. hole
4	Entrance	3/4	0°	1	Heavy stream at 1 min. Wound plugged.	1-3/4" tear
	Exit	Full	0°	4	No exit through aluminum, therefore, sealing performance could not be determined.	2½" tear at corner
5	Entrance	None	45°	3	Heavy seep at 30 sec. & after 4 min.	3/16" dia. hole
	Exit	3/4	45°	2	Slight stream at 1 min. Heavy seep at 4 min.	1¼' tear

3. Preparation of Films

Films based on liquid prepolymers were mixed in liquid form and poured onto clean, level, 12 inch by 12 inch glass plates. The millable gums, Adiprene CM and Vibrathane 5004, were mixed on a rubber mill and cured in a hydraulic press.

The films may be classified under one of two broad headings:

a. Modifications of the polyurethane formulation used in the CN-2 construction, or

b. Other polyurethanes which the vendor claimed had good low temperature flexibility.

The UNIROYAL Mathematical Service Group originated a statistical experimental design plan as shown in Table VII. The numbers in the table refer to films which were prepared.

The objective of the plan is to enable us to predict the relative effect of the following on low temperature brittleness:

a. Various blends of Vibrathane 6007 and 6004

b. Four different curatives

(1) LD-813 (4,4' methylene bis [2-chloraniline])
(2) MDA (methylene dianiline)
(3) V-3005 (a polyol)
(4) G-400 (a polyol)

c. Plasticizer

(1) TP-90 (dibutoxy ethoxy ethyl formal)
(2) DOP (dioctyl phthalate)

d. Type of system

(1) Low solids
(2) High solids

Prior to establishing the experimental design plan in Table VII, a number of trials were conducted to rule out films which were impossible or impractical to make. It was learned that a film from a high solids system using MDA could not be made because the mix gelled almost immediately after the MDA was added. A low solids system using either V-3005 or G-400 was impractical because of the long cure time required - the film had not gelled five days after pouring. Even a high solids system using these polyols required heat to cure within a practical time limit. By practical time limit, we mean gelling within 4 hours and requiring no more than 14 days aging at 72° F to reach optimum cure. Addition of excess solvent lengthens the time for cure since the solvent must be evaporated before optimum cure can be achieved.

TABLE VII

MODIFICATION OF POLYURETHANE USED IN CN-2 CONSTRUCTION

		100% V-6007 0% V-6004				75% V-6007 25% V-6004				50% V-6007 50% V-6004				25% V-6007 75% V-6004				0% V-6007 100% V-6004			
		LD-813	MDA	V-3005	G-400	LD-813	MDA	V-3005	G-400	LD-813	MDA	V-3005	G-400	LD-813	MDA	V-3005	G-400	LD-813	MDA	V-3005	G-400
Low Solids System	No Plast.	696-1				704-1				696-10 704-2 704-4 704-6	721-1			704-5				696-3	721-4		
	Plast #1 (TP-90)									704-3	721-2							704-7			
	Plast. #2 (DOP)									696-11	721-3							704-8			
High Solids System	No Plast.	712-7				712-6				712-3A 712-3B 712-3C		708-1	711-2	712-2				712-1		708-4	721-7
	Plast. #1 (TP-90)									712-4		708-2	711-3								
	Plast. #2 (DOP)									721-5		708-3	711-4								

In deciding how much solvent to use in either system, low solids or high solids, consideration was given to practicality of the system. More specifically, the low solids system was limited in that too much solvent tended to cause "orange peel" or film cracking. "Orange peel" is described as a surface roughness similar in appearance to that of the outer skin of an orange. It usually results when an excessive amount of solvent is present in a film which has already gelled. Rapid evaporation of solvent tends to increase orange peeling. The high solids system was limited in that a 100% solids system with LD-813 or V-3005 failed to spread over the plate's surface because of its extremely high viscosity. Also the 100% solids LD-813 system gelled in approximately two minutes. Since these problems would prohibit the use of such a system in production, enough solvent was added to allow the films to be poured. G-400 was the only curative with which 100% solid systems were practical. The only curative found to be useful in both low and high solid systems was LD-813.

All of the films, except those cured with MDA, were prepared by mixing the components in a single container. Due to the relatively short gel time with MDA systems (3-5 minutes with low solids), it was necessary to dissolve the MDA in a separate solution and to mix the two solutions just prior to pouring the film.

The decision of whether or not to accelerate curing of the films with heat was based on what would be practical in a production process. It was found that all films could be cured at 72^{o} F in the practical time limit described earlier except those using V-3005 or G-400. These were heated in an oven for 3 hours at 250^{o} F. All the films were aged at room temperature for 14 days prior to testing.

The amount of each formulation poured onto the glass plate was calculated so that the film thickness would be 0.040" ± 0.005" thick. In cases where films did not fall within this range, films were poured again using more or less of the final mix. The actual formulations for the films in Table VII are shown in Appendix II. MEK refers to methyl ethyl ketone.

4. Testing of Films for Brittleness (Low Temperature Impact Resistance)

Films were tested for brittleness by a modification of ASTM D-746. Brittleness testing was conducted at -65^{o} F, -85^{o} F, and -95^{o} F. It was felt that at these temperatures, the brittleness test was not sufficiently severe to screen the films to only three or four. With the use of liquid nitrogen, the brittleness test was repeated on the films at -115^{o} F. All but three of the candidate materials failed. Those which did not crack were: 700-4, 700-6 and 700-7.

5. Gunfire of Films

The foregoing method of test for screening the low temperature impact resistance of new candidate elastomer inner liner materials was abandoned in favor of the gunfire test technique as described below:

The test apparatus shown in Appendix III, Figure 11 consists of a 6" x 6" x 20" channel fabricated of aluminum plate. Seventeen wooden frames fit into the channel and can be moved along the axis of the channel. Sixteen urethane films are held in the channel by sandwiching each between frames spaced along the channel. The complete assembly with the films in place is cooled to -40° F for 24 hours or longer. The cooled assembly is then placed before a backstop and a single round of the desired caliber ammunition is fired down the axis of the channel, passing through all the films. The size of the wound in each film is recorded.

While this test cannot simulate the hydraulic ram impact felt in a fuel cell, it is more realistic than the formerly used test in terms of impact energy.

Results of .30 cal. gunfire at -40° F are shown in Table VIII.

TABLE VIII

RESULTS OF FILM GUNFIRE AT -40^{o} F WITH .30 CAL. AP

Film No. [1]	Size of Wound*	Cracking Near Wound**
696-1	8 mm	None
696-3	5 mm	One 10 mm, one 20 mm
696-10	10 mm	Two 10 mm
696-11	8 x 10 mm	None
700-1	8 mm	Two 15 mm
700-2	9 mm	None
700-3	10 mm	None
700-4	2 mm	None
700-6	2 mm	None
700-7	2 mm	None
704-1	9 mm	None
704-2	8 mm	Two 10 mm
704-3	11 mm	One 15 mm
704-4	11 mm	None
704-5	1 mm	None
704-6	2 mm	None
704-7	2 mm	None
704-8	2 mm	None
708-1	11 mm	One 8 mm
708-2	13 mm	One 6 mm
708-3	9 mm	Two 7 mm, one 15 mm, one 20 mm
708-4	1 mm	None
711-1	2 mm	None
711-3	2 mm	None
711-4	2 mm	None
712-1	1 mm	None
712-2	2 mm	None
712-3A	2 mm	None
712-3B	2 mm	None
712-3C	2 mm	None
712-4	1 mm	None
712-6	11 x 13 mm	None
712-7	11 mm	None
715	1 mm	None
716	1 mm	None
721-1	11 mm	One 15 mm, one 5 mm
721-2	2 mm	One 5 mm
721-3	8 x 11 mm	One 10 mm, two 12 mm, three 15 mm, one 20 mm
721-4	2 mm	None
721-5	11 mm	None
721-6	11 x 33 mm	One 10 mm, one 15 mm
721-7	5 mm	None
722-1	2 mm	None
722-2	9 mm	None
722-4	2 mm	None

(1) See Appendix II for film compositions.

*Wounds are circular and refer to diameter of hole when only one number is given. When two dimensions are given, an irregular hole is indicated. The diameters are the longest axis and the longest dimensions perpendicular to it.

**The cracks occurred radially from the hole.

The films listed above which gave wounds 5 mm or less in diameter and no cracking near the wound were gunfired at -40° F with .50 cal. AP ammunition. The results are given in Table IX.

TABLE IX

RESULTS OF FILM GUNFIRE AT -40° F WITH .50 CAL. AP

Film No.	Size of Wound*	Cracking Near Wound**
700-4	3 mm	Three 4 mm
700-6	4 mm	One 4 mm
700-7	4 mm	Six 3 to 4 mm
704-5	4 mm	None
704-6	13 x 14 mm	One 15 mm
704-7	3 mm	None
704-8	4 mm	None
708-4	3 mm	None
711-1	4 mm	None
711-3	3 mm	None
711-4	3 mm	None
712-1	2 mm	None
712-2	4 mm	One 4 mm
712-3A	4 mm	None
712-3B	5 mm	None
712-3C	5 mm	One 35 mm
712-4	5 mm	None
715	2 mm	None
716	2 mm	None
721-4	3 mm	None
721-7	4 mm	None
722-1	3 mm	None
722-4	3 mm	One 20 mm

* Wounds are circular and refer to diameter of hole when only one number is given. When two dimensions are given, an irregular hole is indicated. The dimensions are the longest axis and the longest dimensions perpendicular to it.

**The cracks occurred radially from the hole.

The following conclusions are drawn from the above work:

1. Films from low solids systems gave low reproducibility.

2. The addition of plasticizers TP-90 and DOP to the film formulation had no effect on gunfire performance.

3. Films cured with V-3005 gave inconclusive results.

Ten films were selected for fabrication of 2' x 2½' x 2½' test cells. The films and the reasons for selecting them are given below:

1. Selected based on brittleness testing at -115° F

   a. 700-4 (V-B602, low solids, LD-813 curative)
   b. 700-6 (V-B605, low solids, LD-813 curative)
   c. 700-7 (V-B600, low solids, LD-813 curative)

2. Selected based on <u>excellent</u> .50 cal. gunfire at -40° F

   a. 712-1 (V-6004, high solids, LD-813 curative)
   b. 715 (Adiprene CM, millable gum, sulfur curative)
   c. 716 (V-5004, millable gum, peroxide curative)

3. Selected based on <u>good</u> .50 cal. gunfire and/or recommendations from the UNIROYAL Mathematical Group's statistical experimental design plan with .30 cal. AP gunfire.

   a. 711-1 (V-6004, high solids, G-400 curative)
   b. 712-3 (50% V-6007, 50% V-6004, high solids, LD-813 curative)
   c. 776 (65% V-6007, 35% V-6004, high solids, LD-813 curative)

4. Selected because curative V-3005 is not represented in any films above. Inconclusive results were obtained in the statistical experimental design plan with .30 cal. gunfire, and good results were obtained with .50 cal. gunfire.

   a. 708-4 (V-6004, high solids, V-3005 curative)

SECTION VIII

DEVELOPMENT OF A POLYURETHANE FUEL CELL

Based on the evaluation of the films which was discussed in Section VII, new construction composites were outlined and the following six test cells were fabricated using the selected candidate elastomers listed on page 22:

a) ASN 766
b) ASN 769
c) ASN 772
d) ASN 773
e) ASN 781
f) ASN 808

Each test cell contained identical self-sealing constructions as opposite sides of the test cube. The other two sides contained a different construction. The gunfire data of these six cells was used to design constructions for seven more test cells:

a) ASN 805
b) ASN 831
c) ASN 854
d) ASN 862
e) ASN 913-1,2
f) ASN 913-3,4
g) ASN 913-5,6

1. Test Cell ASN 766

a. Construction Details

Cell ASN 766 was two different constructions which are outlined below:

Construction 700-4	Construction 700-6
0.030" thick 700-4 film	0.030" thick 700-6 film
Nylon tire cord with US-3082 and US-3083 sealants	Nylon tire cord with US-3082 and US-3083 sealant
Nylon tire cord with 700-4 film coating	Nylon tire cord with 700-6 film coating

The tire cord plies were positioned at 90^{o} to each other and at 45^{o} to base of cell. Adhesive #3420 was used to bond the plies together. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane.

b. Gunfire of Test Cell

The gunfire results of cell ASN 766 are shown on the next page.

c. Conclusions or Remarks

Sealing performance of construction 700-4 was very good. See Table X and figures 18-23 in Appendix III.

TABLE X

GUNFIRE OF TEST CELL ASN 766

Fuel Type: Type I

Fuel Temperature: -40^{0} F

Projectile Type: .50 cal. AP

Projectile Velocity: Standard

Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^{0}	700-4	Seal at impact	1/8" dia hole
	Exit	None	0^{0}	700-4	Seal at impact	½" tear
2	Entrance	½	0^{0}	700-4	Slight seep at 2 min. Seal in 4 min.	1¼" tear
	Exit	-	-	700-4	Exit did not penetrate metal & could not be evaluzted for sealing.	2" tear
3	Entrance	Full	0^{0}	700-4	Heavy stream at impact. Heavy seep in 2 min. Seal in 4 min. Hit edge of hat section	2" tear
	Exit	-	-		No exit	
4	Entrance	Full	0^{0}	700-4	Heavy stream at impact. Slight seep at 2 min. Seal in 2½ min.	2-7/8" tear
	Exit	-	-	700-4	Exit did not penetrate metal & could not be evaluated for sealing.	2" x ½"
5	Entrance	None	0^{0}	700-6	Seal at impact	¼" dia hole
	Exit	Full	0^{0}	700-6	Very heavy stream at impact which did not reduce at 1 min. Wound plugged.	5" tear
6	Entrance	½	0^{0}	700-6	Very heavy stream at impact which did not reduce at 1 min. Wound plugged.	1½" tear
	Exit			700-6	Exit above fuel level.	1-7/8" tear

TABLE X (Cont'd)
GUNFIRE OF TEST CELL ASN 766

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
7	Entrance	3/4	0^o	700-6	Heavy stream at impact. Heavy seep at 2 min. Slight seep at 4 min.	1-7/8" tear
	Exit	-	-	700-6	Exit above fuel level.	2" tear
8	Entrance	None	45^o	700-6	Seal at impact.	¼" dia. hole
	Exit	3/4	45^o	700-4	Slight seep at impact. Seal in 1½ min.	1½" tear
9	Entrance	None	45^o	700-4	Seal at impact.	¼" hole
	Exit	3/4	45^o	700-6	Exit above fuel level.	1" tear

2. Test Cell ASN 769

a. Construction Details

Cell ASN 769 was two different constructions which are outlined below:

Construction 700-7

0.030" thick 700-7 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 700-7 film coating

Construction 712-1

0.030" thick 712-1 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 712-1 film coating

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. Adhesive #3420 was used to bond the plies together. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane.

b. Gunfire of Test Cell

The gunfire results of cell ASN 769 are shown on the next page.

c. Conclusions or Remarks

The innerliner of construction 712-1 cracked extensively as a result of projectile impact. See Figures 24-29 in Appendix III.

3. Test Cell ASN 772

a. Construction Details

Cell ASN 772 was two different constructions which are outlined below:

Construction 712-3

0.030" thick 712-3 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 712-3 film coating

Construction 776

0.030" thick 776 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 776 film coating

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. Adhesive #3420 was used to bond the plies together. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane.

b. Gunfire of Test Cell

The gunfire results of ASN 772 are shown on page 28.

c. Conclusions or Remarks

The innerliner of both constructions cracked extensively as a result of projectile impact. See Figures 30-35 in Appendix III.

TABLE XI

GUNFIRE OF TEST CELL ASN 769

Fuel Type: Type I
Fuel Temperature: -40° F
Projectile Type: .50 Cal. AP
Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	700-7	Seal at impact.	¼" dia. hole
	Exit	3/4	0°	700-7	Exit above fuel level.	2" tear
2	Entrance	None	0°	700-7	Slight stream at impact. Heavy seep at 2 min. Slight seep in 4 min.	¼" dia. hole
	Exit	½	0°	700-7	Moderate seep at impact, Slight seep at 1 min. Seal in 2 min.	2 and 6 exits ran together.
3	Entrance	None	0°	712-1	Moderate seep at impact. Slight seep in 2 min. Seal in 4 min.	¼" dia. hole
	Exit	½	0°	712-1	Moderate seep at impact which did not reduce after 4 min. Chunked out extensively.	1" x ½" tear
4	Entrance	½	0°	712-1	Heavy seep at impact. Slight seep in 2 min. Seal in 4 min. Chunked out.	1¼" tear
	Exit	Full	0°	712-1	Heavy stream at impact which did not reduce at 1 min. Wound plugged.	1½" tear
5	Entrance	Full	0°	712-1	Heavy stream at impact which did not reduce at 1 min. Wound plugged. Chunked out.	2" x 3/8" tear
	Exit	-	-	712-1	Exit did not penetrate metal & could not be evaluated for sealing.	2" tear
6	Entrance	½	0°	700-7	Heavy stream at impact. Slight stream in 4 min. Chunked out.	1" tear
	Exit	3/4	0°	700-7	Exit did not penetrate metal & could not be evaluated for sealing.	2 and 6 exits ran together

The innerliner of construction 712-1 cracked extensively as a result of projectile impact.

TABLE XII

GUNFIRE OF TEST CELL ASN 772

Fuel Type: Type I
Fuel Temperature: -42° F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^{o}	712-3	1/8" stream at impact. Slight stream at 4 min.	¼" dia. hole
	Exit	½	0^{o}	712-3	Very heavy stream at impact which did not diminish. Wound plugged.	1" dia. hole
2	Entrance	None	0^{o}	776	Mod. seep at impact; damp seal in 3 min.	1/8" dia. hole
	Exit	Full	0^{o}	776	Heavy stream at impact; wound plugged.	Large hole
3	Entrance	½	0^{o}	776	Heavy stream; wound plugged.	(two) ¼" dia. holes
	Exit	½	0^{o}	776	No sealing evaluation because no exit through metal.	1-3/8" dia. hole
4	Entrance	½	0^{o}	776	Heavy stream at impact; moderate stream at 2 min.; slight seep at 4 min.	(two) ¼" dia. holes
	Exit	Full	0^{o}	776	No sealing evaluation because no exit through metal.	2" x 2½"
5	Entrance	½	0^{o}	712-3	Slight stream at impact; moderate seep at 2 min.; slight seep at 4 min.	1" x ¼"
	Exit	Full	0^{o}	712-3	Exit above fuel level.	1" x ¼"
6	Entrance	3/4	0^{o}	712-3	Heavy stream at impact. Mod. stream at 4 min.	1-7/8" x ½"
	Exit	-	-	712-3	No sealing evaluation because no exit through metal panel.	½" dia hole

The innerliner of both constructions cracked extensively as a result of projectile impact.

4. Test Cell ASN 773

a. Construction Details

Cell ASN 773 was two different constructions which are outlined below:

Construction 711-1

0.030" thick 711-1 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 711-1 film coating

Construction 708-4

0.030" thick 708-4 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 708-4 film coating

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. Adhesive #3420 was used to bond the plies together. Fabrication of the cell was by hand layup followed by room temperature cure of 711-1 and oven cure of 708-4.

b. Gunfire of Test Cell

The gunfire results of ASN 773 are shown on the next page.

c. Conclusions or Remarks

See Table XIII on the next page and Figures 36-43 in Appendix III.

5. Test Cell ASN 781

a. Construction Details

Cell ASN 781 was two different constructions which are outlined below:

Construction 801-1

0.030" thick 716 film

Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 716 film coating

Construction 801-2

2 oz/sq. yd. nylon fabric coated with a solution of 716
Nylon barrier
Nylon tire cord with US-3082 and 3083 sealants
Nylon tire cord with 716 film coating

The tire cord plies were positioned at 90° to each other and 45° to base of cell. All 716 materials were pre-cured and applied to the cell with #3420 adhesive.

b. Gunfire of Test Cell

The gunfire results of ASN 781 are shown on page 31.

c. Conclusions or Remarks

The innerliner and exterior coatings cracked on all rounds. See Figures 44-49 in Appendix III.

TABLE XIII

GUNFIRE OF TEST CELL ASN 773

Fuel Type: Type I
Fuel Temperature: -44^{o} F
Projectile Type: .50 Cal. AP
Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^{o}	711-1	Mod. stream at 2 min. Very heavy seep at 4 min.	¼" dia hole
	Exit	Full	0^{o}	711-1	Mod. stream at 2 min. Heavy seep at 4 min. Hit hat section.	2½" x 2¼"
2	Entrance	3/4	0^{o}	711-1	Heavy stream at impact. Plugged at 1½ min. Extensive loss of liner.	1½" break
	Exit	None	0^{o}	711-1	Mod. stream after 2 min. Heavy seep at 4 min. Thru hat section. No cracking of innerliner.	3/4" dia hole
3	Entrance	Full	0^{o}	711-1	Heavy stream after 2 min. Wound plugged.	2-3/8" break
	Exit	None	0^{o}	711-1	Above fuel level. No cracking of innerliner.	1-3/4" break
4	Entrance	None	0^{o}	708-4	Slight seep at impact. Seal in 1 min.	
	Exit	Full	0^{o}	708-4	Heavy stream. Wound plugged. Considerable coring.	1½" x 1½" break
5	Entrance	None	0^{o}	708-4	Heavy stream after 4 min. Extensive loss of innerliner.	2¼" break
	Exit	Full	0^{o}	708-4	Exit above fuel level.	2¼" break
6	Entrance	None	0^{o}	708-4	Heavy stream at impact. Wound plugged.	2" break
	Exit	None	0^{o}	708-4	Exit above fuel level. ¼" dia. coring.	3/8" dia. hole

TABLE XIV

GUNFIRE OF TEST CELL ASN 781

Fuel Type: Type I
Fuel Temperature: -43° F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	801-1	Mod. stream at impact. Slight stream at one min. Mod. seep at 4 min. Slight seep at 5 min.	½" dia hole
	Exit	Full	0°	801-1	Heavy stream; wound plugged.	4½" tear
2	Entrance	None	0°	801-2	Moderate stream at impact. Mod. seep at 2 min. Slight seep at 4 min.	¼" dia hole
	Exit	3/4	0°	801-2	Heavy stream at impact. Mod. stream at 2 min. and 4 min.	
3	Entrance	½	0°	801-2	Heavy stream at impact. Mod. stream at 2 min. Damp seal at 4 min.	¼" dia hole
	Exit	3/4	0°	801-2	Heavy stream at impact and at 4 min.	3/4" dia hole
4	Entrance	½	0°	801-2	Heavy stream at impact and at 3 min. Above fuel level at 4 min.	½" dia hole
	Exit	3/4	0°	801-2	Exit above fuel level.	1" x ¼"
5	Entrance	½	0°	801-1	Heavy stream after 2 min. Wound was at fuel level after 4 min.	1¼" x ¼"
	Exit	½	0°	801-1	Exit above fuel level. No exit through metal.	1½" tear

The innerliner and exterior coatings cracked on all rounds.

6. Test Cell ASN 808

a. Construction Details

Cell ASN 808 was two different constructions which are outlined below:

Construction 808-1

0.030" thick 715 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 715 film coating

Construction 808-2

2 oz/sq. yd. nylon fabric coated with a solution of 716
Nylon barrier
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 716 film coating

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. All 715 materials were pre-cured and applied to the cell with #3420 adhesive.

b. Gunfire of Test Cell

The gunfire results of ASN 808 are shown on the next page.

c. Conclusions or Remarks

See comments in Table XV on next page. Also, see Figures 50-53 in Appendix III.

7. Test Cell ASN 805

a. Construction Details

Cell ASN 805 is of one construction which is outlined below:

Construction 700-4

0.030" thick 700-4 film
Nylon tire cord with US-3082 and US-3083 sealants
Nylon tire cord with 700-4 film coating

The tire cord plies were positioned at 90° to each other and 45° to base of cell. Adhesive #3420 was used to bond the plies together. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane.

b. Gunfire of Test Cell

The gunfire results of cell ASN 805 are shown on page 34.

c. Conclusions or Remarks

See Table XVI on page 34 and Figures 54-57 in Appendix III.

TABLE XV

GUNFIRE OF TEST CELL ASN 808

Fuel Type: Type I

Fuel Temperature: -44^0 F

Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^o	808-1	Seal at impact.	3/8" dia hole
	Exit	Full	0^o	808-1	Catastrophic failure. Test terminated	Too large to plug

On entrance panel

Some delamination of tire cord on outside.
Some innerliner cracking on inside.

On exit panel

Extensive cracking of innerliner over entire half of panel.
Extensive loss of innerliner due to cracking and delamination.

TABLE XVI

GUNFIRE OF TEST CELL ASN 805

Fuel Type: Type I
Fuel Temperature: -44° F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^0	700-4	Slight seep at impact. Seal in 2 min.	½" dia. hole with 1/8" dia. Chunked out.
	Exit	-	0^0	700-4	Exit above fuel level.	2" tear Ext. ply only. 1/8" dia. Chunked out.
2	Entrance	Full	0^0	700-4	Heavy stream at impact & continued after 6 min. Wound plugged.	3/8" x 2-1/3"
	Exit	-	-	700-4	No exit through metal.	2" break. No loss of innerliner.
3	Entrance	3/4	0^0	700-4	Heavy stream at impact. Wound plugged.	¼" x 2" with 1/8" dia. Chunked out.
	Exit	-	-	700-4	No exit.	-
4	Entrance	None	0^0	700-4	Seal at impact.	¼" dia. wound. 1/16" dia. chunk out.
	Exit	3/4	0^0	700-4	Heavy seep at impact. Mod. seep at 2 min. Sl. seep at 4 min.	1-7/8" break. No loss of innerliner.
5	Entrance	None	0^0	700-4	Mod. seep at impact. Seal in 1½ min.	1/16" dia. No chunk out
	Exit	Full	0^0	700-4	Heavy stream at impact. Plugged at 3 min.	8" x 6" wound. Tire cord tore in both directions.

8. Test Cell ASN 831

a. Construction Details

One construction was used on this cell. It is outlined below:

Construction 831-1

2 oz. nylon fabric coated with 700-4 urethane compound
1 ct.* 3420 adhesive
3 cts. 3331 nylon barrier
1 ct. 3420 adhesive
0.025" thick 3083 sealant
0.050" thick sealant
5361 tire cord
1 ct. 3420 adhesive
Nylon tire cord coated with 700-4 urethane compound

*Coat

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. Fabrication of the cell was by hand layup followed by room temperature cure of the polyurethane.

b. Gunfire of Test Cell

The gunfire results of cell ASN 831 are shown on the next page.

c. Conclusions or Remarks

See Table XVII on next page and Figures 58-65 in Appendix III.

9. Test Cell ASN 854

a. Construction Details

854-1 Construction

2 oz. nylon fabric with 700-4 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon
1 ct. 3420 adhesive
5361 tire cord
1 ct. 3420 adhesive
Nylon tire cord coated with 700-4 compound

854-2 Construction

0.040" ± 0.005" of 700-4 film
1 ct. 3420 adhesive
3 cts. 3331 nylon
1 ct. 3420 adhesive
5361 tire cord
1 ct. 3420 adhesive
Nylon tire cord coated with 700-4 compound

The tire cord plies were positioned at 90° to each other and at 45° to base of cell. Fabrication of the cell was by hand layup.

b. Gunfire of Test Cell

The gunfire results of cell ASN 854 are shown on page 37.

c. Conclusions or Remarks

See Table XVIII on page 37 and Figures 66-73 in Appendix III.

TABLE XVII

GUNFIRE OF TEST CELL ASN 831

Fuel Type: Type I
Fuel Temperature: -40° F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	831-1	Seal in 3 min. Dry seal in 4 min.	1/8" x 3/8" break
	Exit	Full	0°	831-1	Heavy stream at impact. Wound plugged.	4" semi-circle
2	Entrance	None	0°	831-1	Seal at impact.	1/8" dia. pin hole
	Exit	None	0°	831-1	Seal at impact.	
3	Entrance	None	0°	831-1	Seal at impact.	1/8" x ¼"
	Exit	Full	0°	831-1	Excessive damage.	2" break
4	Entrance	Full	0°	831-1	Heavy stream at impact. Mod. seep at 4 min. Seal in 6 min.	1-5/8" break
	Exit	-	-	831-1	No exit.	-
5	Entrance	Full	0°	831-1	Heavy stream at 3 min. Mod. stream in 6 min. Slight seep in 8 min.	1/8" x 1-7/8" break
	Exit	-	-	831-1	No exit.	1" break
6	Entrance	None	0°	831-1	Heavy stream at 1 min. Wound plugged.	1/8" hole
	Exit	-	-	831-1	At fuel level.	1" x 1-7/8" break
7	Entrance	None	45°	831-1	Seal in 2 min.	1/8" dia.
	Exit	Full	45°	831-1	Extremely great loss of fuel. Large hole in cell.	Extensive

TABLE XVIII

GUNFIRE OF TEST CELL ASN 854

Fuel Type: Type I
Fuel Temperature: -45°F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^o	854-1 Fabric	Dry seal at impact	3/16" hole
	Exit	3/4	0^o	854-1 Fabric	Moderate stream Plugged at 2 min.	1-3/4" tear
2	Entrance	None	0^o	854-1 Fabric	Dry seal at impact	3/16" hole
	Exit	Could not be determined	0^o	854-1 Fabric	Large hole; plugged	4"x4" tear
3	Entrance	None	0^o	854-2 Film	Dry seal at impact	1/8" hole
	Exit	Cannot be determined	0^o	854-2 Film	Large hole, test terminated	5"x5-3/4" tear

Remarks: Considerable tearing of tire cord on exits. Small amount of innerliner cracking. Some loss of film innerliner but not of fabric liner.

10. Test Cell ASN 862

a. Construction Details

Construction 862-1	Construction 862-2
2 oz. nylon fabric painted with 700-4 urethane compound	0.040" ± 0.005" of 700-4 film
1 ct. 3420 adhesive	1 ct. 3420 adhesive
3 cts. 3331 nylon	3 cts. 3331 nylon
1 ct. 3420 adhesive	1 ct. 3420 adhesive
5361 nylon tire cord	5361 nylon tire cord
1 ct. 3420 adhesive	1 ct. 3420 adhesive
Nylon tire cord coated with 700-4 compound	Nylon tire cord coated with 700-4 compound
Nylon tire cord coated with 700-4 compound	Nylon tire cord coated with 700-4 compound

The exterior plies of tire cord were positioned 90° to each other and 45° to the inner tire cord ply. Fabrication of the cell was by hand layup. Cell was allowed to age for 7 days at room temperature and cured in an autoclave for 3 hrs. at 252° F. A water cool down was used.

b. Gunfire of Test Cell

The gunfire results of Cell ASN 862 are shown on the next page.

c. Conclusions or Remarks

See Table XIX on next page and Figures 74-81 in Appendix III.

11. Test Cells ASN 913-1 & 2, 3 & 4, 5 & 6

After the gunfire of test cell 862, it was observed that considerable tearing of tire cord had taken place and that the sealant had "chunked out". It was therefore decided that square woven fabrics, light weight and heavy weight, would be used and the cure would be lengthened to insure complete vulcanization of the natural rubber components such as sealants and adhesives. These features are embodied in the sides of the ASN 913 cells.

TABLE XIX

GUNFIRE OF TEST CELL ASN 862

Fuel Type: Type I
Fuel Temperature: -46° F
Projectile Type: .50 Cal. AP

Projectile Velocity: Standard
Backing Board: Conolite Type I

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^0	862-2 Film	Damp seal in 4 min.	½" break
	Exit	2"	0^0	862-2 Film	Hvy. seep 2 min. misaligned	1-7/8" break
2	Entrance	None	0^0	862-2 Film	Dry seal at impact	¼" break
	Exit	2-1/8"	0^0	862-2 Film	Mod. seep - 4 min.	2¼" break
3	Entrance	1½"	0^0	862-2 Film	Hvy. stream - 2 min.	2¼" break
	Exit	1½"	0^0	862-2 Film	No exit thru metal Could not determine	1¼" x ½" tear
4	Entrance	2"	0^0	862-1 Fabric	Heavy stream	1" x 5/8" tear
	Exit	1½"	0^0	862-1 Fabric	Could not determine No exit thru metal	1-3/4" break
5	Entrance	None	0^0	862-1 Fabric	Dry seal at impact	¼" hole
	Exit	None	0^0	862-1 Fabric	Damp seal in 1 min.	¼" hole
6	Entrance	None	0^0	862-1 Fabric	Dry seal at impact	¼" hole
	Exit	2-3/4"	0^0	862-1 Fabric	Heavy stream	2-1/16" tear
7	Entrance	None	45^0	862-2 Film	Heavy stream did not subside	¼" cored out hole
	Exit	Could not determine	45^0	862-2 Fabric	Heavy stream did not subside	9" tear

Remarks: All tumbled shots caused considerable delamination and tearing of tire cord.

11. Test Cells ASN 913-1 & 2, 3 & 4, 5 & 6 (Cont'd.)

a. Construction Details

Construction 913-1

2 oz. nylon fabric coated with 711-1 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
8 oz. nylon fabric coated with natural rubber →
0.030" 3082 sealant
8 oz. nylon fabric coated with natural rubber ↗
0.025" 3083 sealant
1 ct. 3420 adhesive
8 oz. nylon fabric coated with 711-1 urethane compound ↘

Construction 913-2

2 oz. nylon fabric coated with 700-4 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
8 oz. nylon fabric coated with natural rubber →
0.030" 3082 sealant
8 oz. nylon fabric coated with natural rubber ↗
0.025" 3083 sealant
1 ct. 3420 adhesive
8 oz. nylon fabric coated with 700-4 urethane compound ↘

Construction 913-3

2 oz. nylon fabric coated with 711-1 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
0.030" 3082 sealant
8 oz. nylon fabric coated with natural rubber →
0.025" 3083 sealant
1 ct. 3420 adhesive
27.75 oz. nylon USFlex fabric coated with 711-1 urethane compound →

Construction 913-4

2 oz. nylon fabric coated with 700-4 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
0.030" 3082 sealant
8 oz. nylon fabric coated with natural rubber →
0.025" 3083 sealant
1 ct. 3420 adhesive
27.75 oz. nylon USFlex fabric coated with 700-4 urethane compound →

11. <u>Test Cells ASN 913-1 & 2, 3 & 4, 5 & 6</u> (Cont'd.)

a. <u>Construction Details</u> (Cont'd.)

<u>Construction 913-5</u>

2 oz. nylon fabric coated with 711-1 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
8 oz. nylon fabric coated with natural rubber →
0.050" 3083 sealant
8 oz. nylon fabric coated with natural rubber ↗
1 ct. 3420 adhesive
8 oz. nylon fabric coated with 711-1 urethane compound ↘

<u>Construction 913-6</u>

2 oz. nylon fabric coated with 700-4 urethane compound
1 ct. 3420 adhesive
3 cts. 3331 nylon solution
1 ct. 3224 adhesive
1 ct. 3203-7 adhesive
8 oz. nylon fabric coated with natural rubber →
0.050" 3083 sealant
8 oz. nylon fabric coated with natural rubber ↗
1 ct. 3420 adhesive
8 oz. nylon fabric coated with 700-4 urethane compound ↘

Arrows indicate direction of fabric warp.

Fabrication of cells was by hand layup. Sides coated with 700-4 were air cured overnight. Sides coated with 711-1 were cured by hanging in an air oven for 3 hours at 250° F. Cells were allowed to air cure for 7 days after which they were cured in a pressure autoclave for 6 hours at 270° F. A water cool down was used.

b. <u>Gunfire of Test Cell</u>

The gunfire results of Cell ASN 913-1 through 6 are shown on pages 42, 43 and 44.

c. <u>Conclusions or Remarks</u>

See Tables XX, XXI and XXII, pages 42, 43 and 44, and Figures 82-105 in Appendix III.

TABLE XX

GUNFIRE OF TEST CELL ASN 913-1,2

Fuel Type: Type I
Fuel Temperature: -40°
Projectile Type: .50 Cal. AP
Projectile Velocity: Standard
Backing Board: US-664
Primary feature of cell - 2 oz. nylon liner; 8 oz. nylon reinforcement, both polyurethane coated

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	913-1	Dry seal impact	¼" hole
	Exit	None	0°	913-1	Hvy. seep at 4 min.	4" tear
2	Entrance	1-3/4"	0°	913-1	Hvy. seep at 4 min.	1-7/8" tear
	Exit	1-3/4"	-	913-1	Could not determine No exit thru metal	1-5/8" x 2-1/8" tear
3	Entrance	1-15/16"	0°	913-1	Sl. seep in 4 min.	2" tear
	Exit	1¼"	-	913-1	Could not determine No exit thru metal	1½" x 3/8" tear
4	Entrance	None	0°	913-2	Dry seal at impact	¼" opening
	Exit	1-3/4"	0°	913-2	Sl. Strm at 2 min.	2" break
5	Entrance	1-7/8"	0°	913-2	No seal	5/8" break
	Exit	1-3/4"	0°	913-2	Could not be observed. Bottom fabric failed	½" x 2" break

Remarks: Very little cracking of innerliner occurred. 711-1 coated innerliner showed considerable lack of adhesion. Adhesion of 700-4 coated liner was good. Considerable tearing of 8 oz. reinforcement fabric occurred.

NOTE: This cell was inadvertently fabricated undersize. Because of this, it was supported inadequately in the gunfire structure and the ram caused the bottom fabric to fail.

TABLE XXI

GUNFIRE OF TEST CELL ASN 913-3,4

Fuel Type: Type I
Fuel Temperature: -42^{o} F
Projectile Type: .50 Cal. AP
Primary feature of cell: 2 oz. nylon liner 1 ply 27.75 oz. nylon USFlex reinforcement, both polyurethane coated

Projectile Velocity: Standard
Backing Board: US-664

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0^{o}	913-3	Damp seal at impact	Pinholes
	Exit	1-3/4"	0^{o}	913-3	Shot hit stringer. Severe damage due to misalignment.	2" C-shaped
2	Entrance	None	0^{o}	913-3	Damp seal at impact	Pinhole
	Exit	1-7/8"	0^{o}	913-3	Mod. stream at 4 min.	2" break
3	Entrance	1-3/4"	0^{o}	913-3	Hvy. stream; misaligned	1-3/8" brk.
	Exit	1½"	0^{o}	913-3	Could not determine. No exit thru metal.	1-3/4" C-shaped
4	Entrance	1-3/4"	0^{o}	913-3	Very hvy. seep at 6 min.	1½" break
	Exit	No exit		913-3	No exit	
5	Entrance	None	0^{o}	913-4	Damp seal at impact	¼" break
	Exit	1½"	0^{o}	913-4	Dry seal at impact	4¼" "Y" tear
6	Entrance	1"	0^{o}	913-4	Damp seal at impact	1" break
	Exit	1-1/8"	0^{o}	913-4	Damp seal at impact	1¼" break
7	Entrance	1-3/4"	0^{o}	913-4	Damp seal at impact	1-3/4" brk.
	Exit	No exit		913-4	No exit	

Remarks: In most cases when tumbled bullet entered or exited, there was some "chunking out" of sealant. There were also radial and circumferential cracks in innerliner.

TABLE XXII

GUNFIRE OF TEST CELL ASN 913-5,6

Fuel Type: Type I
Fuel Temperature: -38° F
Projectile Type: .50 Cal. AP
Primary features of cell: 2 oz. nylon liner, 3 plies 8 oz. nylon reinforcement, all polyurethane coated

Projectile Velocity: Standard
Backing Board: US-664

Round No.	Type of Wound	Extent of Tumble	Angle of Obliquity	Construction No.	Sealing Performance	Size of Wound
1	Entrance	None	0°	913-5	Dry seal in 1 minute	<1/8" hole
	Exit	1-7/8"	0°	913-5	Hvy. stream 4 min. Misaligned	5-5/8" "H" hole
2	Entrance	1¼"	0°	913-5	Dry seal at 2 mins.	1¼" break
	Exit	(1)	-	-	No exit on metal.	-
3	Entrance	1-13/16"	0°	913-5	Hvy. seep at 4". Sealed in 10 mins.	3¼" "S" shaped
	Exit	1½"	-	-	No exit in metal	2¼" break
4	Entrance	1-5/8"	0°	913-5	Damp seal at impact. Dry seal in 1 minute.	2¼" "L" break
	Exit	1"	0°	913-5	No exit in metal	2-3/8" "L" break
5	Entrance	None	0°	913-6	Damp seal at impact	<¼" hole
	Exit	None	0°	913-6	Damp seal at impact	1" x 1¼" "X" tear
6	Entrance	None	0°	913-6	Damp seal at impact	<¼" hole
	Exit	None	0°	913-6	Slight seep at 2 min.	1-5/8" x 1" "X" break
7	Entrance	None	0°	913-6	Damp seal at impact	<¼" hole
	Exit	None	0°	913-6	Tear developed in bottom near radius	2" break

(1) Exited cell on radius

SECTION IX

LITERATURE REVIEW

A search of recent reports, articles and vendor information was made to uncover new materials and processes applicable to fuel system protection. A number of the more interesting and useful facts are summarized below. A list of references is given in Appendix IV.

a. Isoprene - acrylonitrile copolymers and polystyrene-polybutadiene-polystyrene block copolymers give high tensile strengths in the absence of reinforcing fillers. The process of self-reinforcement in these polymers is attributed to the alignment of a large number of polymer chains in the stretching direction.

b. Of the available high temperature resistant elastomers, only Viton fluorocarbon elastomer and selected silicone and fluorosilicone elastomers seem worthy of further evaluation and compounding. Other available materials fail to provide the properties required in most self-sealing fuel system applications.

c. The use of additives to promote tack in silicone compounds is not reported in the available literature. Suppliers of silicone rubber were unable to provide information concerning the compatibility of silicones with common tackifying resins.

d. The choice of the proper peroxide curative is essential if a silicone is to be hot air vulcanized, compounded with black fillers, or stored uncured for long periods of time before use. Dicumyl peroxide and 2,4-dichlorobenzoyl peroxide are two good candidates and were used in the silicone compounding program.

SECTION X

CONCLUSIONS

The innerliner shattering problem encountered with the relatively lightweight polyester urethane self-sealing fuel cell at a -40° F gunfire test temperature (developed under a previous contractual program) was resolved. A self-sealing fuel cell construction with a Vibrathane B602 (a polyether urethane elastomeric material) fabric reinforced innerliner and outer cover proved to be shatter proof at a -40° F gunfire test temperature. This material construction, however, is subject to tearing when penetrated by tumbling projectiles. Self-sealing reliability of this fuel cell construction, it is felt, can be improved by developing a processing technique wherein the fibrous reinforcing materials are not impregnated with the polyether urethane elastomeric coating material.

Silicone rubber is an excellent candidate material for use as a sealant in the development of high temperature resistant fuel cells. It swells at a desired rate in fuel and is resistant to deterioration at elevated temperatures. The problem, however, of adhering this type of sealant to other fuel cell components has not been resolved. Attempts to impart building tack using various resins were unsuccessful.

The commercially available foams and thermoplastic sheet materials evaluated were not as effective as the backing board material composites developed for the protection of self-sealing fuel cells under a previous contract with UNIROYAL.

Non-sealing loosely fitted fuel line jackets were found to be effective for controlling the flow path of fuel spurting from ruptured fuel lines. The self-sealing materials composite approach, however, is considered to be the most practical method for protecting aircraft fuel line systems and reducing the chance of the occurrence of a fire which can result when fuel lines are punctured by small arms projectiles.

A limited amount of effort was devoted to improving gunfire test techniques for the evaluation of candidate self-sealing fuel lines. A notched smooth-bore gun barrel proved to be a good method for controlling the flight path of a tumbling projectile and the probability of striking candidate fuel lines with projectiles in a tumbled manner.

SECTION XI

RECOMMENDATIONS

1. Search the literature for other candidates to improve the tack of silicone rubber. If none are revealed, investigate other elastomers as high temperature sealant candidates which may be compounded for tack.

2. Continue with efforts to find an elastomer which will withstand exposure to air at 350^{o} F, will perform acceptably under gunfire (.50 cal. or .30 cal.), and is less expensive than the fluorocarbon elastomers evaluated in previous contracts.

3. Gunfire fuel lines and other small targets with tumbled projectiles using a notched, smooth bore barrel. Effort should be made to improve the accuracy.

4. Select conventional fuel line covers over spray restrictors.

5. Consider the new conventional style backing board as well as standard commercial boards.

6. Continue development efforts on a fuel cell made of polyurethane coated high tear-strength fabrics on a subsequent development contract.

APPENDIX I

TEST DATA ON FILMS USED IN CELLS

WEIGHT AND THICKNESS OF CELL CONSTRUCTIONS

TABLE XXIII

TEST DATA ON ORIGINAL FILMS

Film No.	Thickness (inch)	Original Tensile psi Values	Original Tensile psi Median	Ultimate Elong. % Values	Ultimate Elong. % Median	300% Modulus (psi)	Shore A Hardness	Die C Tear	Non-Volatile Gum Residue (mg/100 cc) (Type III)	Stoved Gum (mg/100cc) (Type III)	Permeability fl oz/sq. ft.^{2}/day
	0.031	1613		290		1510		100	8.6	3.2	2.769
3010	0.031	1742	1613	330	310	1506	66	110	9.4	3.8	2.204
	0.030	1600		310							2.201
	0.035	3943		490		434		116	1.4	0.4	4.800
700-4	0.031	4451	3943	520	490	439	68	119	2.2	0.8	4.419
	0.035	3714		490		411					5.013
	0.029	5724		490		1076		190	1.8	0.6	4.242
700-6	0.029	5379	5652	480	485	1021	77	190	1.4	0.4	4.360
						1034					4.962
	0.036	1389		650		155		77	4.8	0.8	1.444
700-7	0.034	1000	1195	640	645	182	61	67	5.8	1.2	1.927
						176					1.920
	0.042	3048		730		562		233	9.0	6.8	0.135
708-4	0.043	3209	3122	720	720	549	77	239	9.8	7.6	0.137
	0.041	3122		610		702					0.134
	0.048	1333		580		200		49	9.6	0.8	0.105
711-1	0.046	1130	1231	590	585	165	48	42	9.0	0.6	0.127
						200					0.126
	0.036	5000		560		611		194	6.6	0.8	0.101
712-1	0.041	4585	5000	560	560	595	70	180	6.6	1.2	0.116
	0.039	5179		570		666					0.116
	0.041	4537		550		585		167	4.4	1.4	0.031
712-3	0.040	4450	4450	550	550	600	65	175	5.4	1.8	0.028
	0.043	3814		530		605					0.026
	0.037	4108		530		1554		257	173.2	111.8	1.413
715	0.036	4722	4415	580	555	1643	65	214	179.2	113.6	1.381
						1633					1.373
	0.040	4850		470		2550		268	9.6	2.4	0.125
716	0.041	5268	5231	480	480	2634	70	244	9.2	2.4	0.131
	0.039	5231		490		2462					0.130
	0.041	4878		520		615		179	5.2	1.2	0.042
776	0.040	4300	4878	540	530	550	68	173	5.0	1.2	0.001
	0.042	4905		530		619					0.037

TABLE XXIV

TEST DATA ON FILMS AFTER 72 HRS. IN OZONE
(50 Parts Ozone/100 Million Air)

Film No.	Tensile Strength (psi) Values	Tensile Strength (psi) Median	Ultimate Elongation (%) Values	Ultimate Elongation (%) Median	300% Modulus (psi)
3010	1542 1294	1418	340 300	320	1462 1188 1271
700-4	3706 4000 3760	3760	490 490 490	490	424 384 352
700-6	4357 5000 4714	4714	480 490 470	490	1014 1028 928
700-7	842 947 875	875	620 630 630	630	189 195 150
708-4	3463 3442 4143	3463	730 730 790	730	595 512 552
711-1	2455 2150 2273	2273	550 540 540	540	291 300 282
712-1	3795 3257 3474	3474	580 550 580	580	615 628 526
712-3	7555 7538 7586	7555	530 500 500	500	945 923 1103
715	4286 4555 3833	4286	550 560 510	550	1577 1644 1611
716	4476 4150 4462	4462	420 470 420	420	2733 2520 2595
776	6000 5500	5750	550 530	540	666 500 703

TABLE XXV

TEST DATA ON FILMS AFTER 1 WEEK IN HUMIDITY CHAMBER
(100^o F, 100% R.H.)

Film No.	Tensile Strength (psi) Values	Tensile Strength (psi) Median	Ultimate Elongation (%) Values	Ultimate Elongation (%) Median	300% Modulus (psi)
3010	1667 1611 1600	1611	350 330 320	330	1478 1578 1531
700-4	4483 5217	4850	480 510	495	443 455 365
700-6	5000 6000 4896	5000	480 470 460	470	857 900 897
700-7	1273 1030 1111	1111	670 620 650	650	209 170 179
708-4	3080 3366	3223	690 700	695	632 556 573
711-1	2700 2217	2459	580 540	560	230 260 278
712-1	3500 2976 3400	3400	590 580 580	580	550 488 470
712-3	6666 6500 7317	6666	490 500 520	500	933 937 780
715	3833 4000 3676	3833	510 530 500	510	1611 1670 1718
716	5333 5641 5026	5333	480 510 460	480	2615 2769 2718
776	5667 5778 6121	5778	540 550 540	540	611 555 727

TABLE XXVI

TEST DATA ON FILMS AFTER 300 HRS. IN WEATHEROMETER

Film No.	Tensile Strength (psi) Values	Tensile Strength (psi) Median	Ultimate Elongation (%) Value	Ultimate Elongation (%) Median	300% Modulus (psi)
3010	1813 1871	1842	270 260	265	Broke before 300% elong.
700-4	1667 1120	1394	480 480	480	250 288 180
700-6	1030 688	859	380 320	350	727 638 571
700-7	750 750 828	750	490 490 510	490	320 287 289
708-4	1633 1808 1720	1720	640 700 630	640	555 538 560
711-1	1897 1455	1676	570 520	545	236 273 293
712-1	2146 1900 2146	2146	510 510 530	510	527 500 498
712-3	3866 3667 3318	3667	460 460 470	460	933 893 927
715	4432 4000 4229	4229	500 490 500	500	1500 1816 1874
716	4955 4545 4558	4558	450 440 440	440	3243 2773 2884
776	3000 3272 3086	3086	490 460 480	480	647 630 663

TABLE XXVII

TEST DATA ON FILMS AFTER 30 DAYS IN SOIL BURIAL

Film No.	Tensile Strength (psi) Values	Tensile Strength (psi) Median	Ultimate Elongation (%) Values	Ultimate Elongation (%) Median	300% Modulus (psi)
3010	2242 2121 2125	2125	350 340 370	350	2036 2024 1837
700-4	4696 4000 5000	4696	510 510 500	510	435 345 433
700-6	4643 4857 5185	4857	460 490 480	480	914 928 919
700-7	1143 1143	1143	630 610	620	200 170 157
708-4	300 233	267	110 90	100	Samples broke before 300% elong.
711-1	488 558	523	450 460	455	263 223
712-1	1220 2668	1944	490 570	530	380 438
712-3	372 414	393	180 180	180	Samples broke before 300% elong.
715	4000 4211 4235	4211	530 550 540	540	1526 1663 1705
716	1316 333	825	300 140	220	Samples broke before 300% elong.
776	3895 3842	3869	510 510	510	516 526

TABLE XXVIII

TEST DATA ON FILMS AFTER EXPOSURE TO WATER AT 158^{o} F

Film No.	7 Days Tensile Strength (psi) Value	7 Days Tensile Strength (psi) Median	7 Days Ultm. Elong. (%) Value	7 Days Ultm. Elong. (%) Median	7 Days 300% Modulus (psi)	14 Days Tensile Strength (psi) Value	14 Days Tensile Strength (psi) Median	14 Days Ultm. Elong. (%) Value	14 Days Ultm. Elong. (%) Median	14 Days 300% Modulus (psi)
3010	1513 1722	1618	300 300	300	1513 1722	1222 1444	1333	280 270	275	-
700-4	2722 3375	3049	530 540	535	267 253 275	2083 2312 2222	2222	560 560 550	560	200 213 281
700-6	4785 4286 4387	4387	490 500 500	500	743 709 722	3785 4571	4178	500 550	525	657 725 757
700-7	689 882	786	680 710	695	152 153 152	828 897 727	828	750 750 750	750	139 138 133
708-4	2186 2085 2435	2186	350 820 870	850	437 442 443	1385 1660	1523	890 1110	1050	369 377 374
711-1	1561 1535	1548	530 570	550	224 214 227	1532 1231	1382	560 550	555	256 249 222
712-1	2558 1767	2163	620 600	610	316 233 307	2564 2375 2744	2564	690 690 700	690	267 287 288
712-3	5217 4800 4428	4800	540 550 570	550	487 457 476	4278 4950	4614	600 620	610	420 467 410
715	3657 3889 3789	3789	550 560 570	560	2606 2544 2453	4051 4095	4073	490 510	500	1969 1819 1524
716	4341 4976	4659	480 500	490	2731 2500 2975	4000 3773 3814	3814	500 500 490	500	1836 1791 1805
776	3743 3589 3621	3621	600 580 590	590	338 287 346	4316 4000 4242	4242	660 650 670	660	336 300 291

TABLE XXIX

TEST DATA ON FILMS AFTER EXPOSURE TO TYPE III FUEL AT 158° F

Film No.	7 Days: Tensile Strength (psi) Value	7 Days: Tensile Strength (psi) Median	7 Days: Ultm. Elong. (%) Value	7 Days: Ultm. Elong. (%) Median	7 Days: 300% Modulus (psi)	14 Days: Tensile Strength (psi) Value	14 Days: Tensile Strength (psi) Median	14 Days: Ultm. Elong. (%) Value	14 Days: Ultm. Elong. (%) Median	14 Days: 300% Modulus (psi)
	1471		280		Broke before 300%	969		310		897
3010	1371	1421	290	285		1000	1000	350	350	775
						1030		360		861
	2882		500		352	2666		520		300
700-4	2788	2835	490	495	412	2800	2800	560	520	307
					412	2882		510		305
	3212		470		788	4581		520		941
700-6	2727	2969	450	460	897	3548	4065	490	505	851
					909					727
	1053		660		232	1297		680		287
700-7	955	1004	650	655	218	1500	1399	700	690	335
					225					300
	2082		790		506	1959		850		588
708-4	1855	1957	780	780	509	1786	1959	840	850	507
	1957		760		470	2085		860		596
	1045		490		273	1167		480		258
711-1	1128	1087	550	520	174	1000	1084	490	485	250
					224					112
	3823		590		459	2927		640		468
712-1	3529	3657	580	590	435	3285	3128	650	640	457
	3657		590		434	3128		620		451
	3706		510		706	5027		560		670
712-3	4049	3950	510	510	615	4250	4842	540	540	650
	3958		510		630	4842		540		663
	3091		430		1909	3568		490		1556
715	2579	2684	450	450	1516	3588	3588	510	510	1600
	2684		450		1621	3657		510		1566
	3122		360		2420	3130		390		2336
716	3143	3132	370	365	2343	4195	3663	450	420	2295
					2302					2273
	3100		560		410	3900		570		480
776	3056	3100	550	560	378	3538	3538	570	570	482
	3514		560		378	3400		560		450

TABLE XXX

WEIGHT AND THICKNESS OF CELL CONSTRUCTIONS

Cell Number	Construction Number(s)	Weight (lbs/sq. ft.)	Thickness (inch)
ASN 630	522-37[1] (film)	1.23	0.235
ASN 654	654 (film)	0.87	0.165
ASN 766	700-4 (film)	0.78	0.153
	700-6 (film)	0.71	0.139
ASN 769	700-7 (film)	0.73	0.138
	712-1 (film)	0.85	0.154
ASN 772	712-3 (film)	0.77	0.152
	776 (film)	0.76	0.154
ASN 773	711-1 (film)	0.91	0.162
	708-4 (film)	0.86	0.155
ASN 781	801-1 (film)	0.85	0.144
	801-2 (fabric)	0.60	0.111
ASN 805	700-4 (film)	0.74	0.145
ASN 808	808-1 (film)	0.78	0.150
	808-2 (fabric)	0.56	0.111
ASN 831	831 (fabric)	0.88	0.175
ASN 854	854-1 (fabric)	0.55	0.106
	854-2 (film)	0.75	0.139
ASN 862	862-1 (fabric)	0.72	0.140
	862-2 (film)	0.94	0.182

(1) See Technical Report AFML-TR-69-356-Part II

Panel No.	Wt., lb/ft^2	Thickness, Inches
913-1a	0.90	0.165
c	0.86	0.162
913-2b	0.82	0.152
d	0.81	0.152
913-3a	0.87	0.165
c	0.99	0.182
913-4b	0.91	0.168
d	0.94	0.170
913-5a	0.75	0.137
c	0.81	0.150
913-6b	0.76	0.147
d	0.79	0.150

APPENDIX II

DESCRIPTION OF FILMS

696-1

	grams
MEK	177
V-600	200
LD-813	23

696-3

	grams
MEK	177
V-6004	200
LD-813	23

696-10

	grams
MEK	177
V-6007	100
V-6004	100
LD-813	23

(696-1, 696-3, 696-10:) Poured 180 grams on glass plate

696-11

	grams
MEK	167
V-6007	100
V-6004	100
DOP Plasticizer	10
LD-813	23

Degassed and poured 180 grams of the mix onto a level glass plate. Covered the plate and cured the film at 72° F. We intended to evaluate both plasticizers at a level of 10 parts plasticizer per 100 parts of prepolymer. Since this film was made before the inconsistency was noted, we decided to test it. We did not then make a film of this formulation using 10 parts of plasticizer because the one with 5 parts revealed that the DOP was incompatible - the DOP separated from the solution and the surface became very oily.

700-1

Part A

	grams
Vibrathane A-731	100
MEK	75

Part B

	grams
MEK	50
LD-813	17

Mixed A and B together and poured 180 grams in glass plate.

700-2

	grams
Vibrathane V-6005	200
MEK	177
LD-813	18

Poured 180 grams on glass plate.

700-3

Part A	grams	Part B	grams	
Vibrathane A-744	100	MEK	50	Mixed A and B together and poured 180 grams on glass plate.
MEK	75	LD-813	17	

700-4

	grams
Vibrathane VB-602	200
MEK	177
LD-813	17

Poured 180 grams on glass plate.

700-6

Part A	grams	Part B	grams	
Vibrathane VB-605	100	MEK	58.5	Mixed A and B together and poured 180 grams on glass plate.
MEK	75	LD-813	8.5	

700-7

	grams
Vibrathane VB-600	200
MEK	177
LD-813	24

704-1

	grams
MEK	170
V-6007	150
V-6004	50
LD-813	23

704-2

	grams
MEK	170
V-6007	100
V-6004	100
LD-813	23

Poured 180 grams on glass plate (700-7, 704-1, 704-2)

704-3

	grams
MEK	170
V-6007	100
V-6004	100
TP-90 plasticizer	20
LD-813	23

704-4

	grams
MEK	170
V-6007	100
V-6004	100
LD-813	23

704-5

	grams
MEK	170
V-6007	50
V-6004	150
LD-813	23

704-6

	grams
MEK	170
V-6007	100
V-6004	100
LD-813	23

704-7

	grams
MEK	170
V-6004	200
TP-90 plasticizer	20
LD-813	23

704-8

	grams
MEK	170
V-6004	200
DOP plasticizer	20
LD-813	23

Poured 180 grams on glass plate.

708-1

	grams
MEK	25
V-6007	50
V-6004	50
V-3005	26

708-2

	grams
MEK	25
V-6007	50
V-6004	50
TP-90 plasticizer	10
V-3005	26

708-3

	grams
MEK	25
V-6007	50
V-6004	50
DOP plasticizer	10
V-3005	26

708-4

	grams
MEK	25
V-6004	100
V-3005	26

Pour all of mixture on glass plate

711-1

	grams
V-6004	200
G-400	28

Poured 145 grams on glass plate located in an oven. Covered plate and heated mixture for 3 hours at 250^{o} F.

711-3

	grams
V-6004	100
V-6007	100
TP-90 plasticizer	20
G-400	28

Poured 145 grams on glass plate located in an oven. Covered plate and heated mixture for 3 hours at 250^{o} F.

711-4

	grams	
V-6004	100	Poured 145 grams on glass plate located in an oven. Covered plate and heated mixture for 3 hours at 250° F.
V-6007	100	
DOP plasticizer	20	
G-400	28	

712-1

	grams
V-6004	200
MEK	50
LD-813	23

712-2

	grams
V-6004	150
V-6007	50
MEK	50
LD-813	23

712 - 3A, B and C

	grams
V-6004	100
V-6007	100
MEK	50
LD-813	23

712-4

	grams
V-6004	100
V-6007	100
TP-90 plasticizer	20
MEK	50
LD-813	23

712-6

	grams
V-6004	50
V-6007	150
MEK	50
LD-813	23

712-7

	grams
V-6007	200
MEK	50
LD-813	23

Poured 155 grams on glass plate.

<u>715</u>

	parts
Adiprene CM	100
HAF Carbon Black	30
Cumar W 2½	15
MBTS	4
MBT	1
Sulfur	0.75
Caytur 4	0.35
Cadmium stearate	0.50

Mixed on a laboratory rubber mill and cured in a press for 60 min. at 287° F.

<u>716</u>

	parts
Vibrathane 5004	100
Stearic acid	0.25
HAF Carbon Black	20
DiCup 40C	4

Mixed on a laboratory rubber mill and cured in a press for 30 min. at 320° F.

<u>721-1</u>

Part A	grams	Part B	grams
V-6007	50	MDA	9
V-6004	50	MEK	151
MEK	100		

<u>721-2</u>

Part A	grams	Part B	grams
V-6007	50	MDA	9
V-6004	50	MEK	151
TP-90 plasticizer	10		
MEK	100		

<u>721-3</u>

Part A	grams	Part B	grams
V-6007	50	MDA	9
V-6004	50	MEK	151
DOP plasticizer	10		
MEK	100		

Mixed A and B together and poured 295 grams on glass plate.

721-4

Part A	grams	Part B	grams	
V-6004	100	MDA	18	Poured 308 grams of Part C on glass plate.
MEK	100	MEK	82	

Part C	ratio
Part A	4
Part B	1

721-5

	grams
V-6004	100
V-6007	100
DOP plasticizer	20
MEK	50
LD-813	23

Poured 155 grams on glass plate.

721-6

Part A	grams	Part B	grams
Vibrathane VB-621	100	MEK	49.5
MEK	75	LD-813	17.5

Mixed A and B together and poured 183 grams on glass plate.

721-7

	grams
V-6004	200
G-400	28

Poured 125 grams on glass plate located in an oven. Covered the plate and heated mixture for 3 hours at 250° F.

722-1

	grams
V-6004	100
V-6007	100
MEK	170
LD-813	23

722-2

	grams
V-6004	100
V-6007	100
MEK	170
Celluflex FR-2	20
LD-813	23

722-4

	grams
V-6004	100
V-6007	100
MEK	170
Tricresyl Phosphate	20
LD-813	23

(722-1, 722-2, 722-4:) Poured 165 grams on glass plate

776

	grams
V-6004	70
V-6007	130
MEK	75
LD-813	23

Poured 155 grams on glass plate.

APPENDIX III

ILLUSTRATIONS

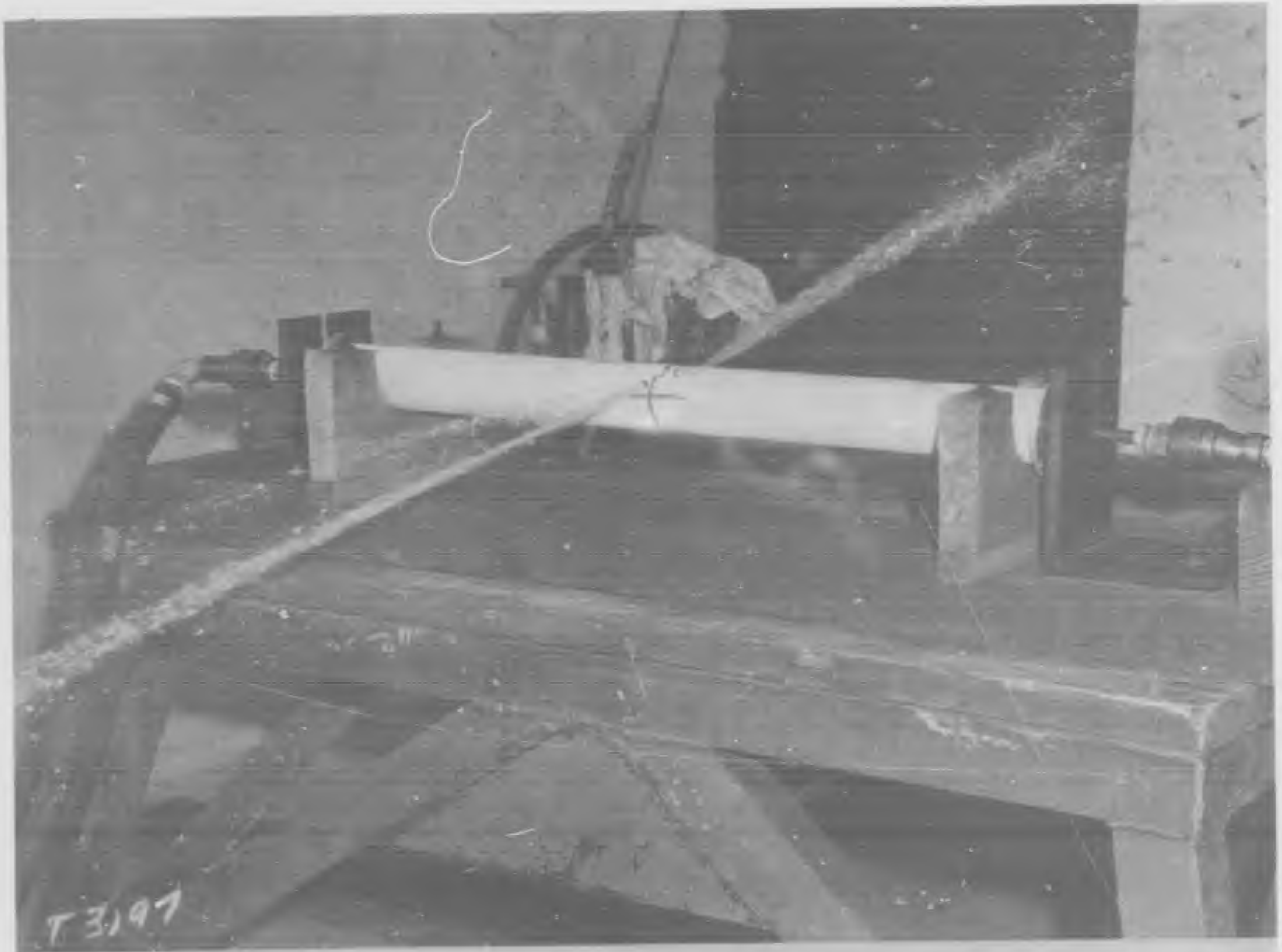

Figure 1 - Leakage From Pressurized, Uncovered Aluminum Fuel Line After Gunfire

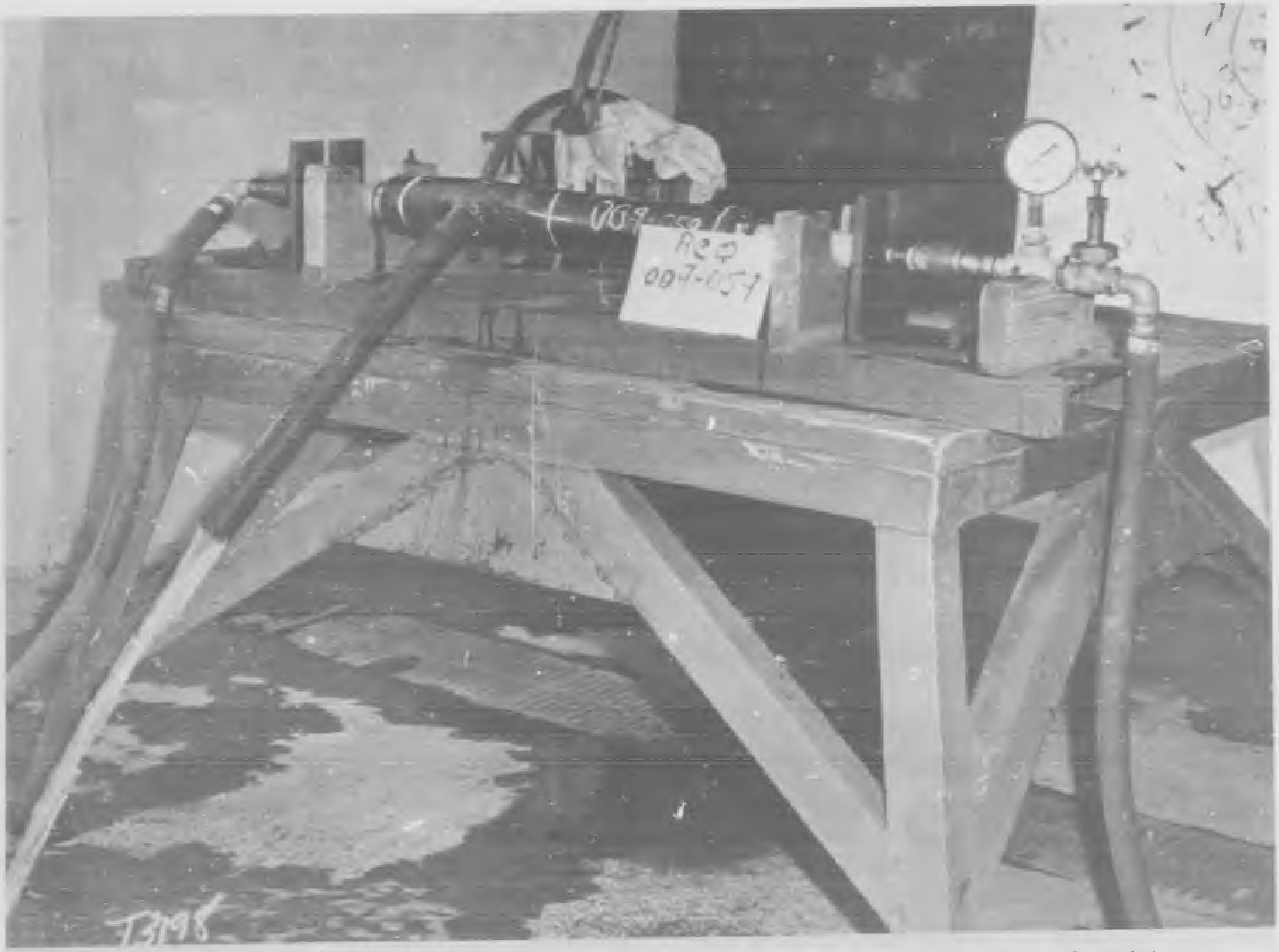

Figure 2 - Leakage From Pressurized Aluminum Fuel Line Covered with ASN 605-1 Spray Restrictor

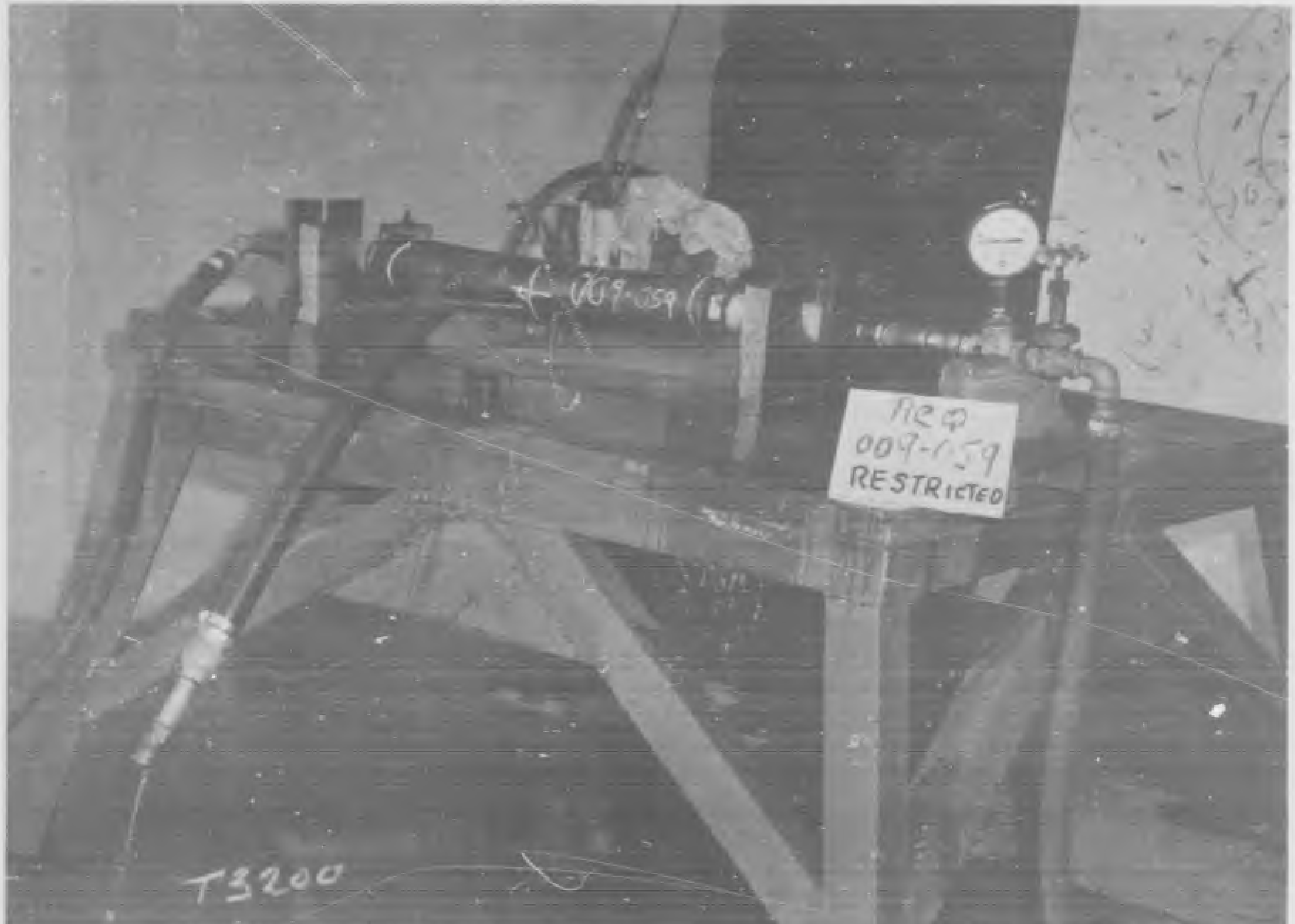

Figure 3 - Leakage from Pressurized Aluminum Fuel Line Covered with ASN 605-1 Spray Restrictor with Drain Hose Plugged

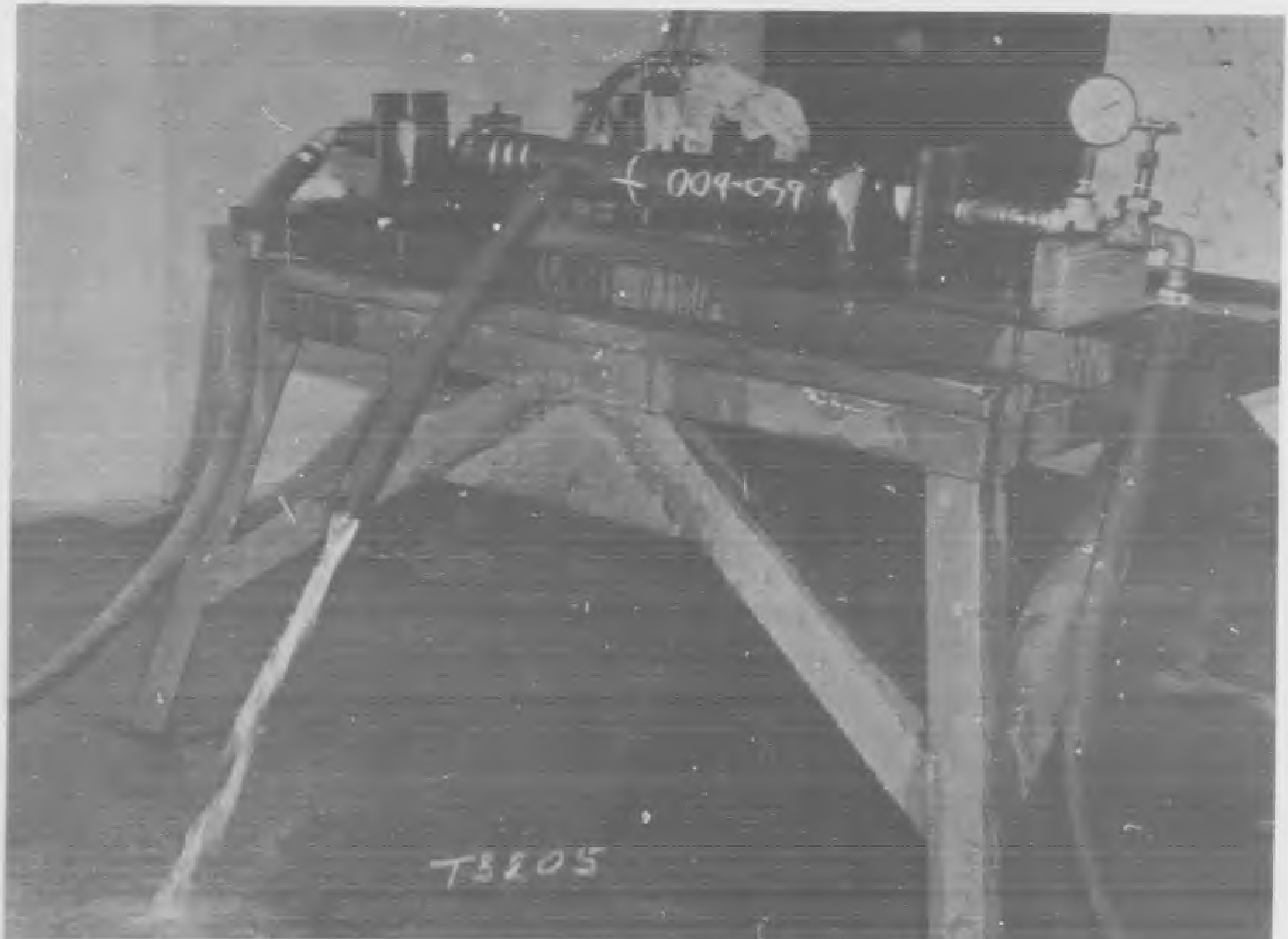

Figure 4 - Leakage from Pressurized Aluminum Fuel Line Covered with ASN 605-1 Spray Restrictor

Figure 5 - Leakage From Pressurized Aluminum Fuel Line Covered with ASN 60S-2 Spray Restrictor with Drain Hose Plugged

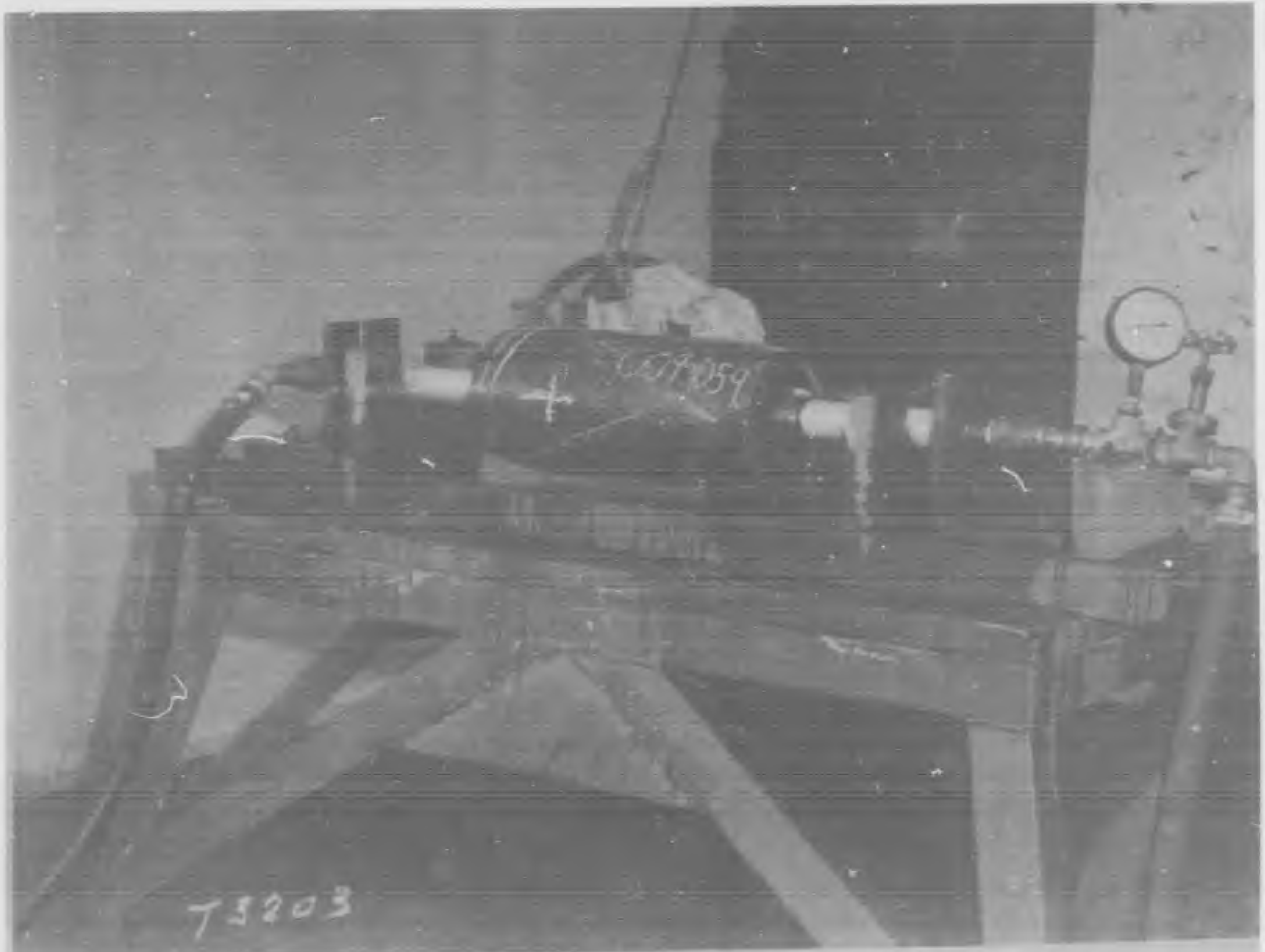

Figure 6 - Leakage From Pressurized Aluminum Fuel Line Covered with ASN 620 Spray Restrictor

Figure 7 - Conolite X70-29 Backing Board After Gunfire

Figure 8 - Conolite X70-48 Backing Board After Gunfire

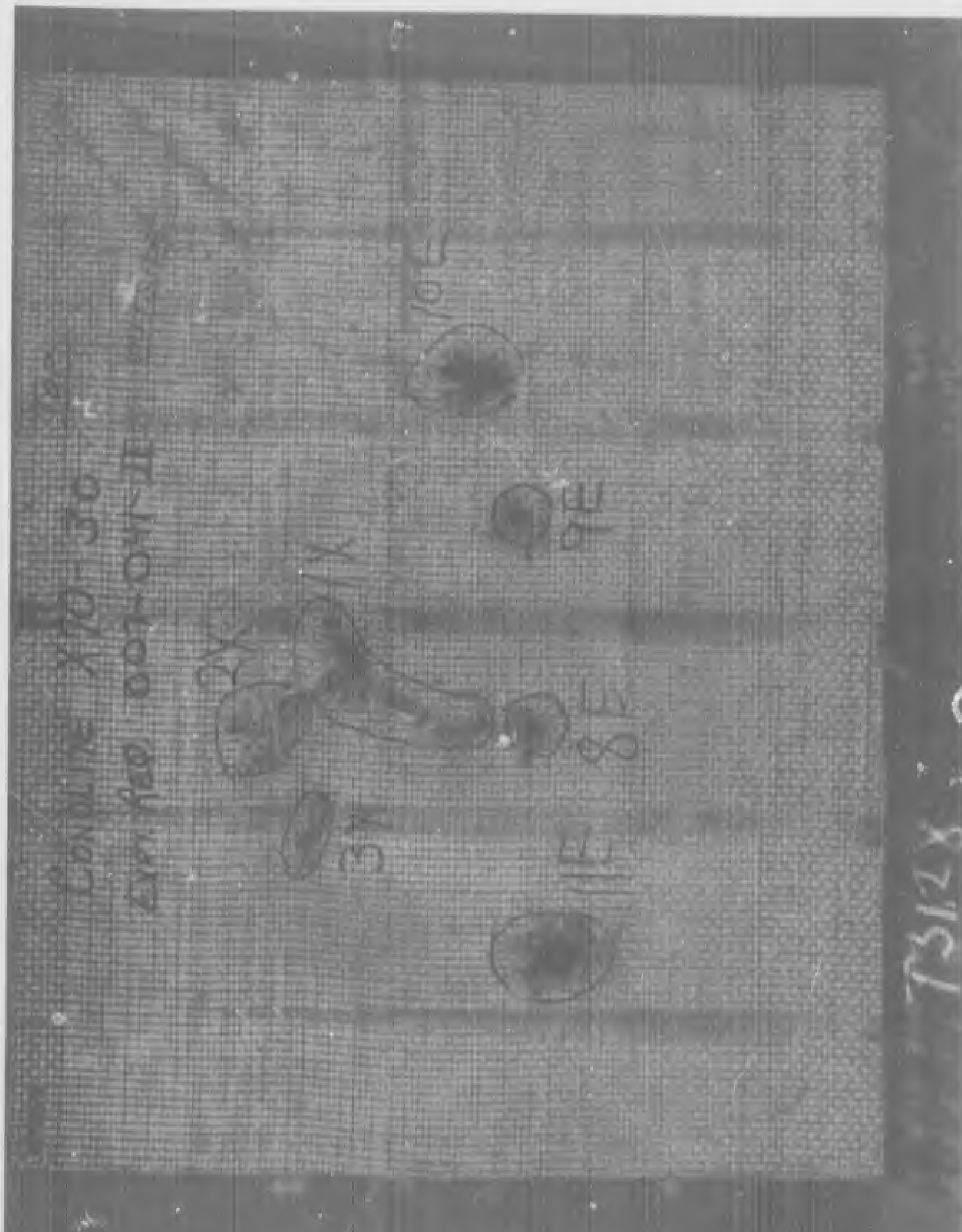

Figure 9 - Conolite X70-30 Backing Board After Gunfire

Figure 10 - Conolite X70-23 Backing Board After Gunfire

Figure 11 - Trailing Fill Baffle Set-Up

Figure 12 - Sides A & B of Test Cell ASN 630 After Gunfire

Figure 13 - Sides C & D of Test Cell ASN 630 After Gunfire

Figure 14 - Side A of Test Cell ASN 654 After Gunfire

Figure 15 - Side B of Test Cell ASN 654 After Gunfire

Figure 16 - Side C of Test Cell ASN 654 After Gunfire

Figure 17 - Side D of Test Cell ASN 654 After Gunfire

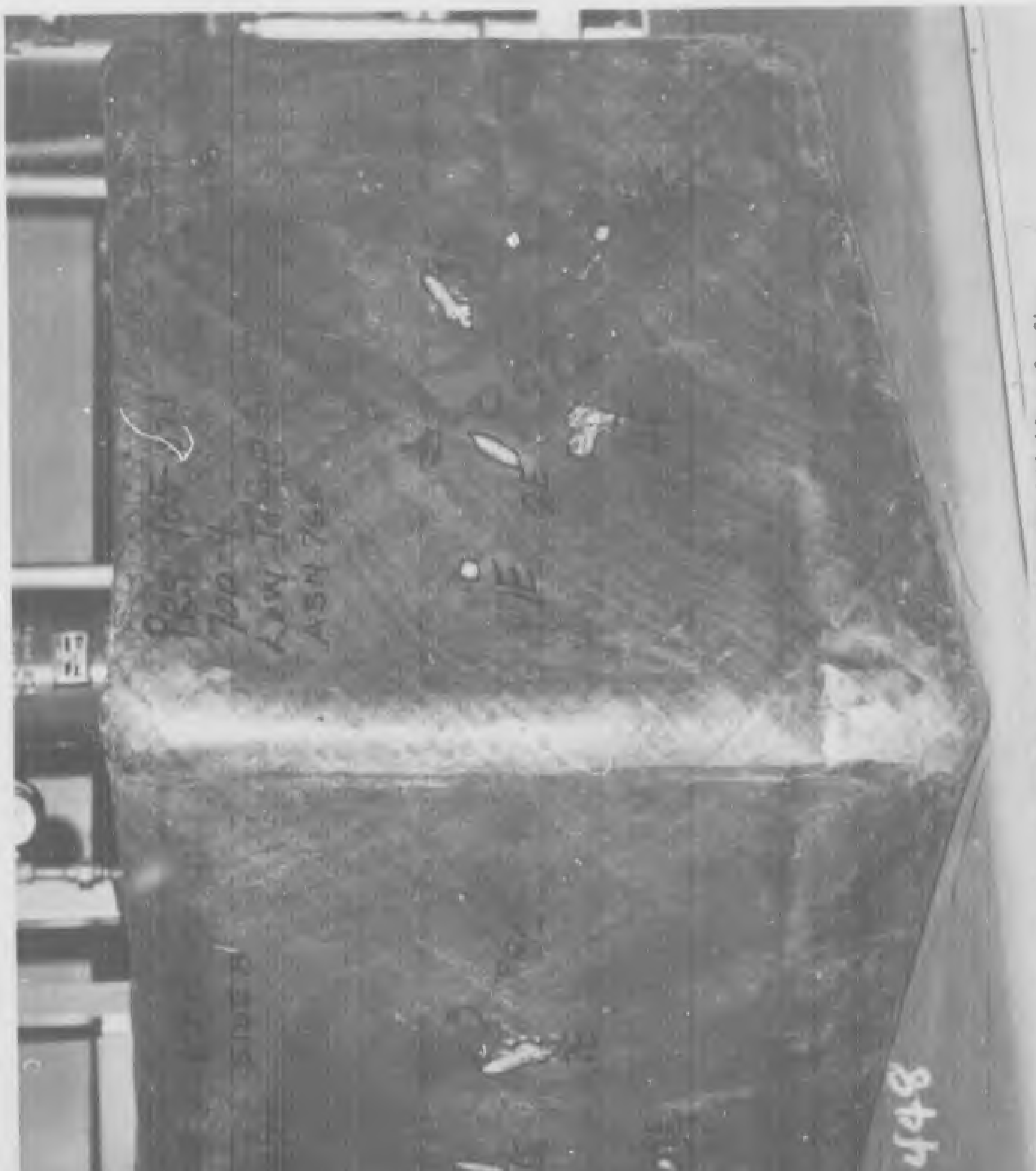

Figure 18 - Sides A & B of Test Cell ASN 766 After Gunfire

Figure 19 - Inside of Side A of Test Cell ASN 766 After Gunfire

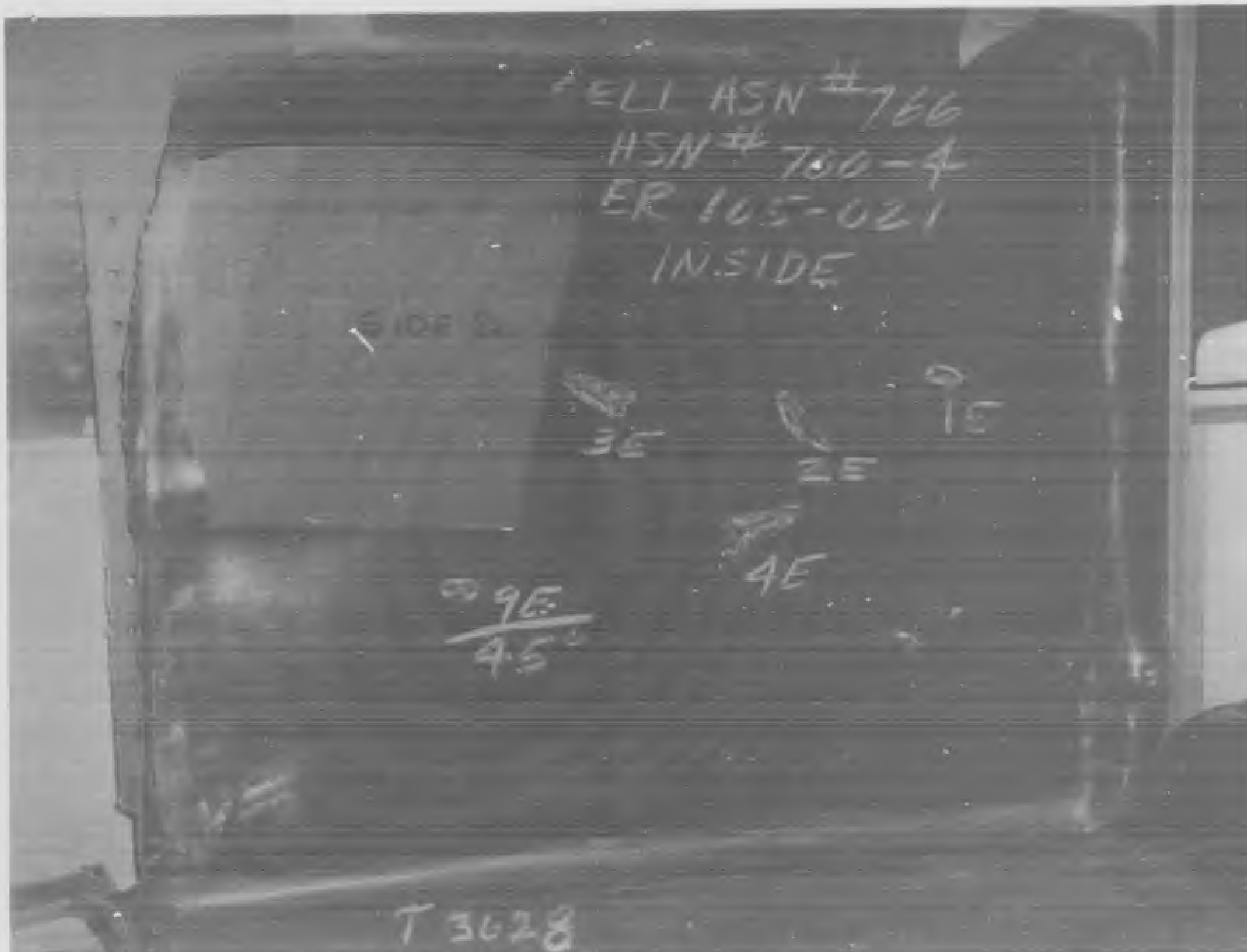

Figure 20 - Inside of Side B of Test Cell ASN 766 After Gunfire

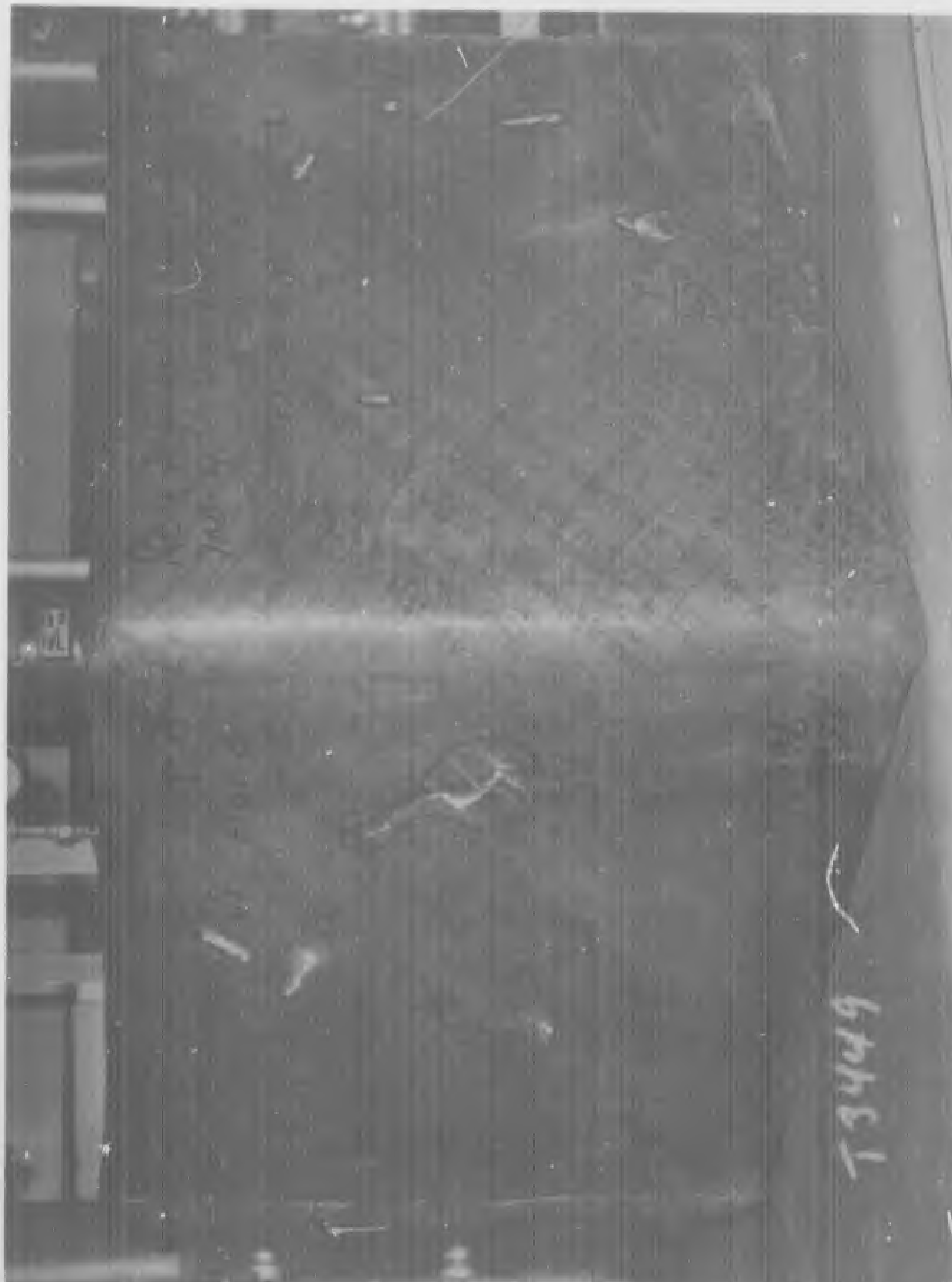

Figure 21 - Sides C & D of Test Cell ASN 765 After Gunfire

Figure 63 - Inside of Side C of Test Cell 15C704 After Dunking

Figure 23 - Inside of Side D of Test Cell ASN 766 After Runfire

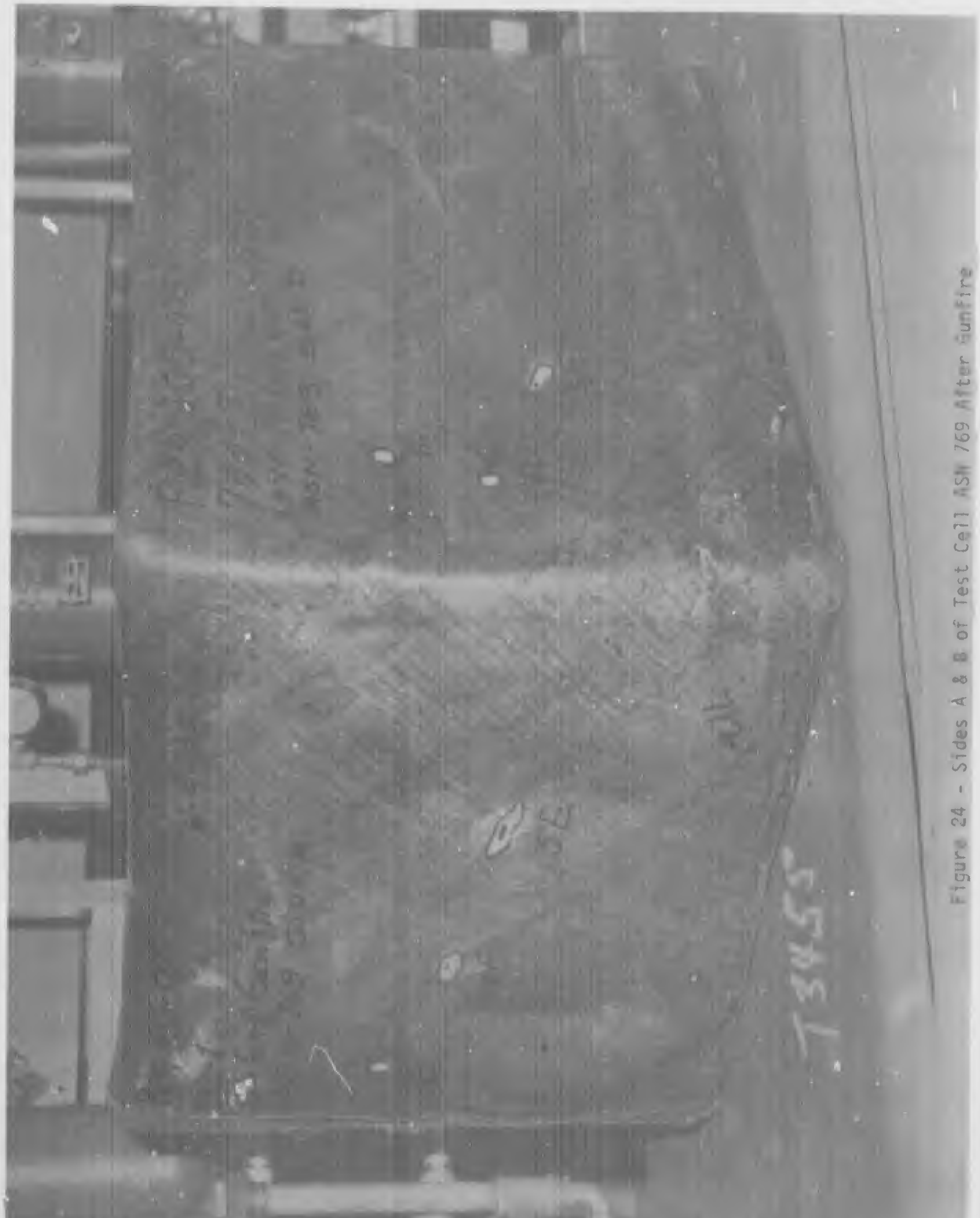

Figure 24 - Sides A & B of Test Cell ASN 769 After Gunfire

Figure 25 - Inside of Side A of Test Cell ASN 769 After Gunfire

Figure 26 - Inside of Side B of Test Cell ASN 769 After Gunfire

Figure 27 - Sides C & D of Test Cell ASN 769 After Gunfire

Figure 28 - Inside of Side C of Test Cell ASN 769 After Gunfire

Figure 29 - Inside of Side D of Test Cell ASN 769 After Gunfire

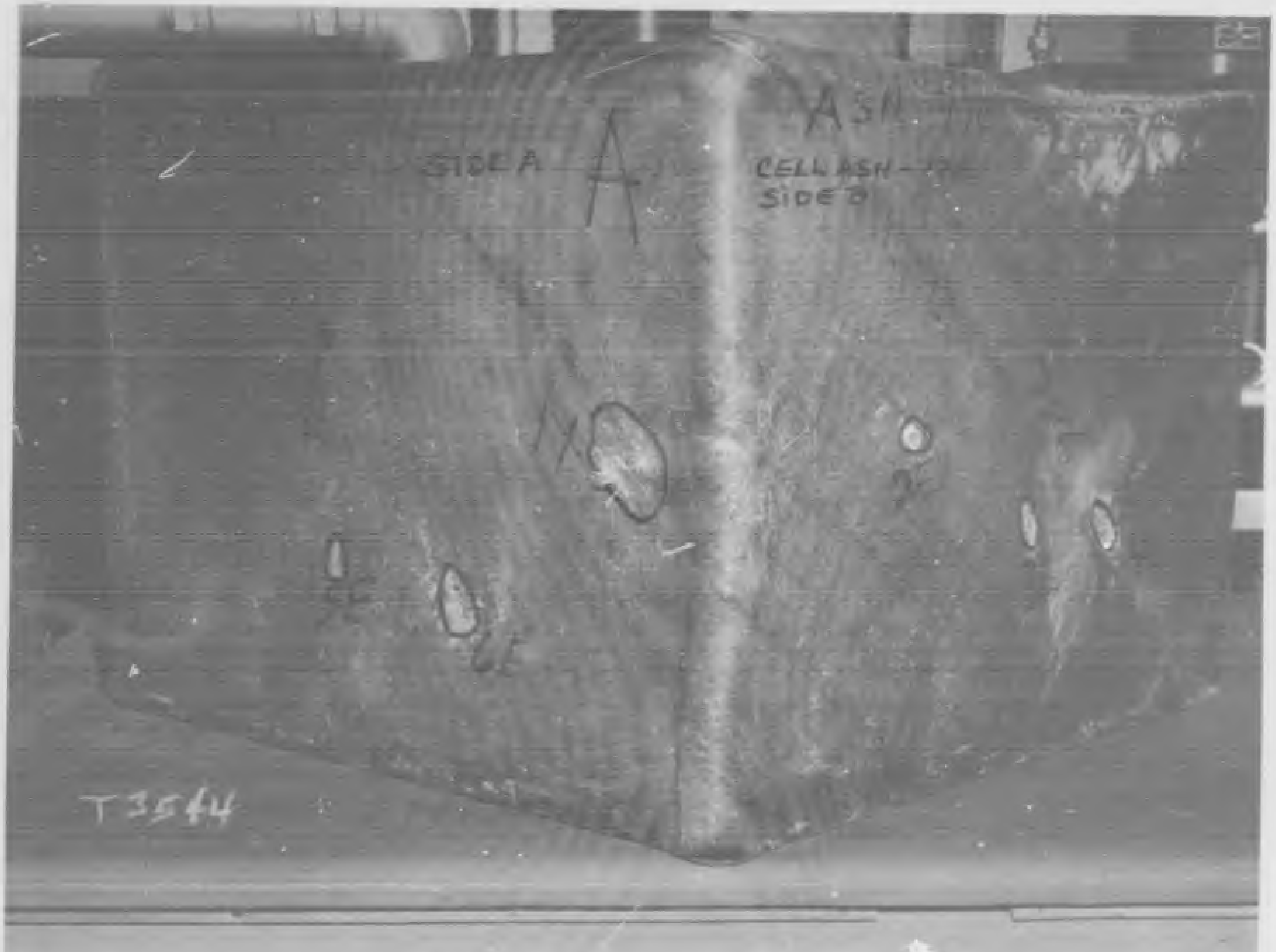

Figure 30 - Sides A & B of Test Cell ASN 772 After Gunfire

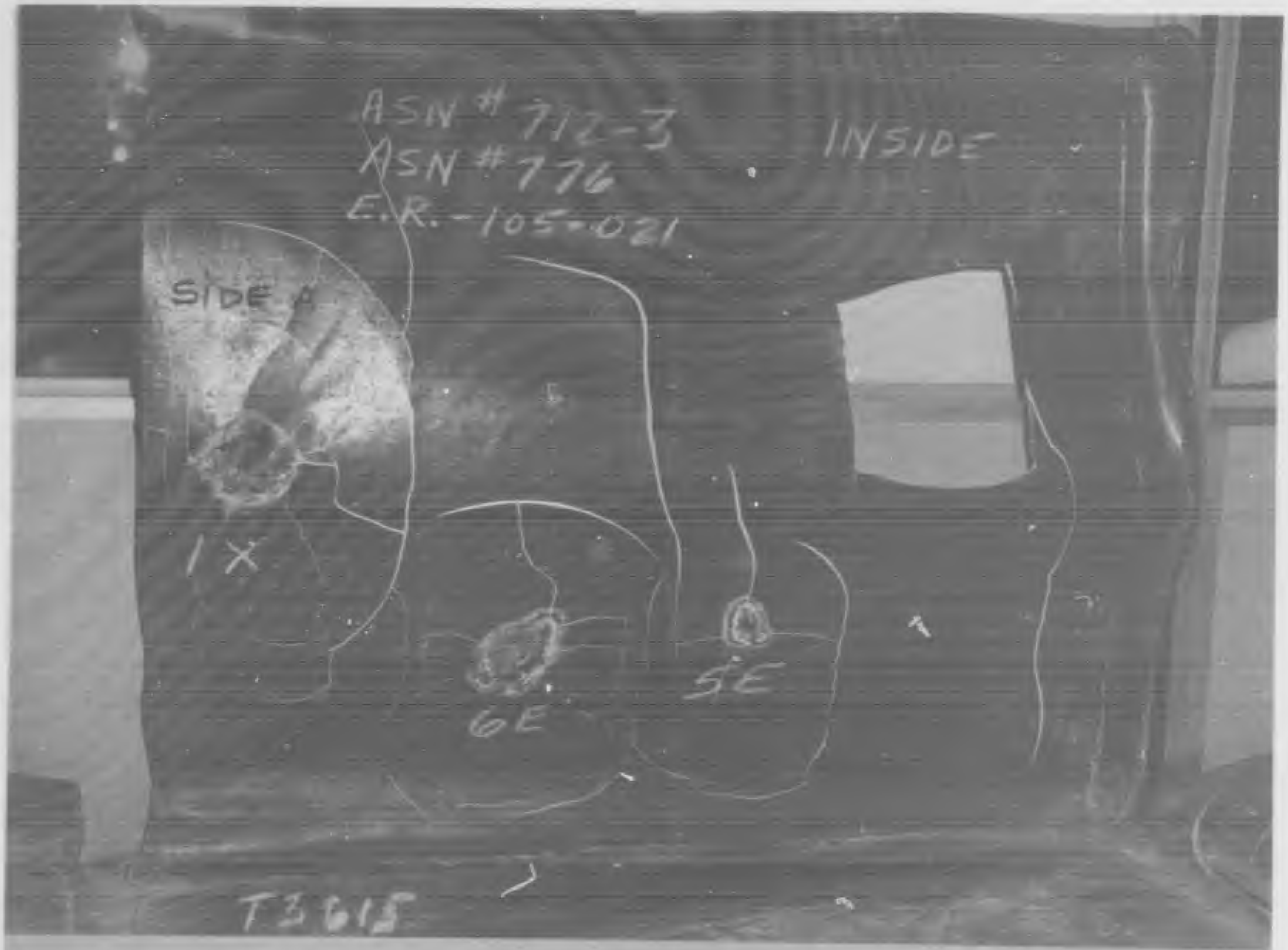

Figure 31 - Inside of Side A of Test Cell ASN 772 After Gunfire

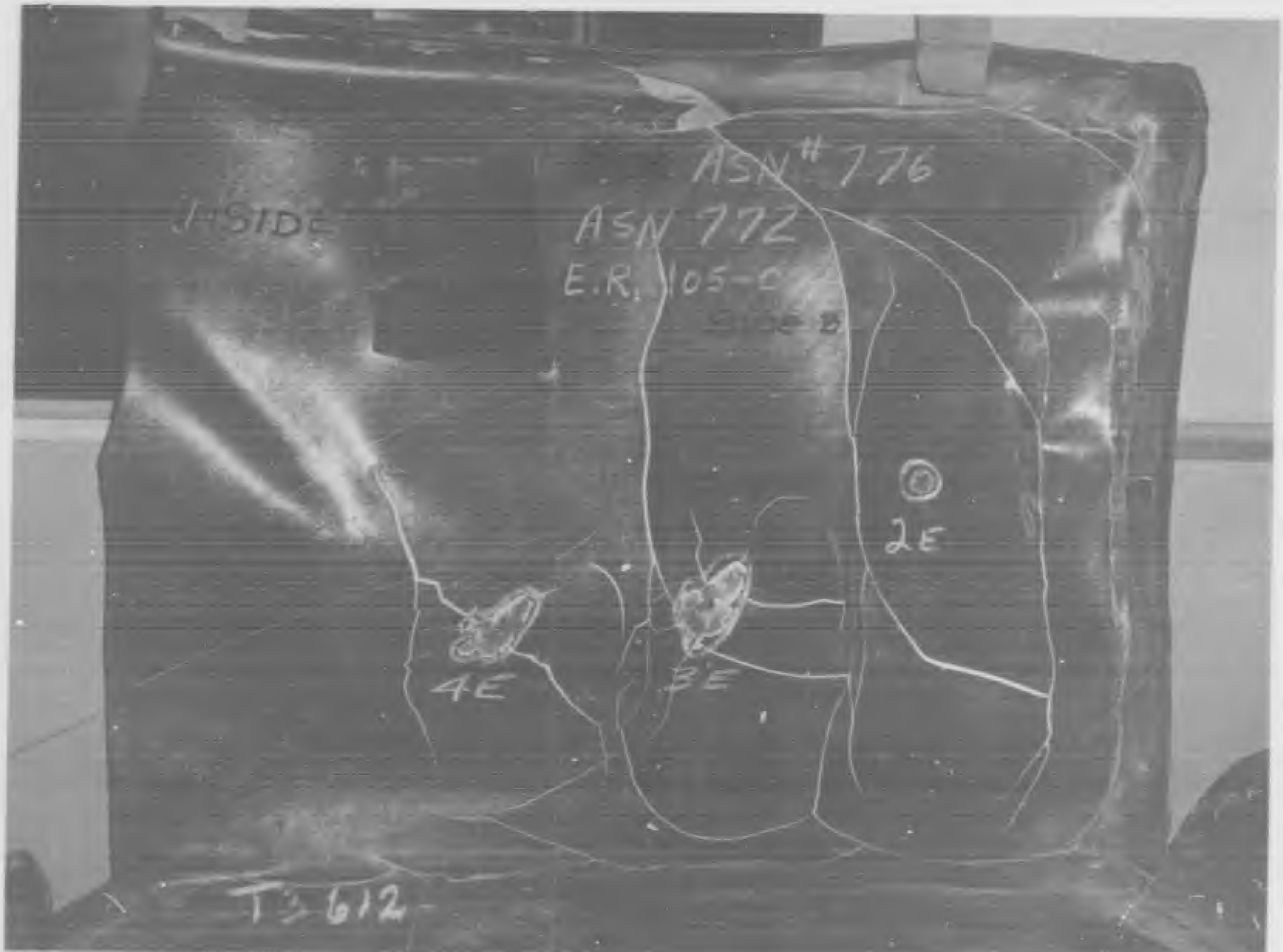

Figure 32 - Inside of Side B of Test Cell ASN 772 After Gunfire

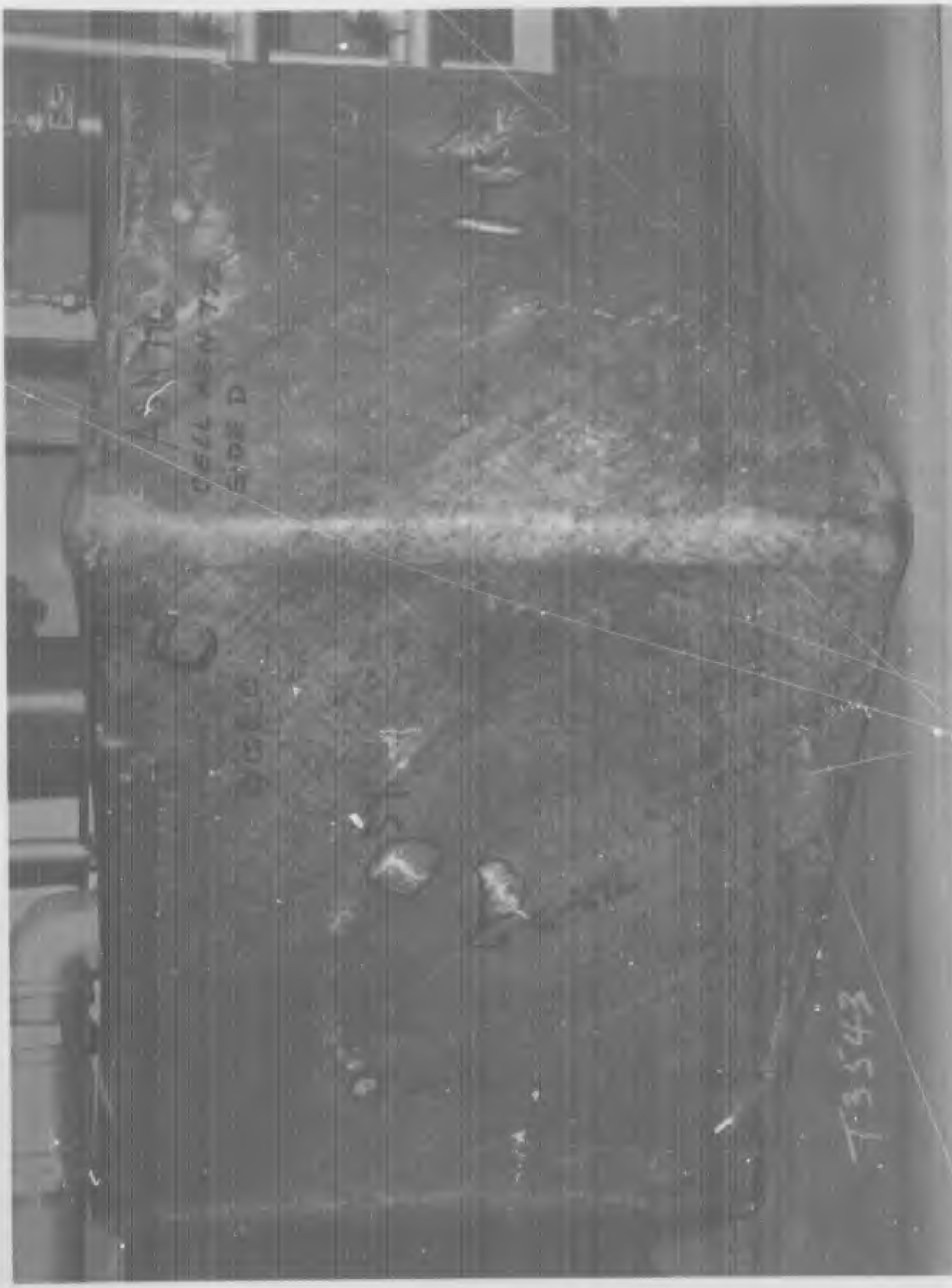

Figure 33 - Sides C & D of Test Cell ASN 772 After Gunfire

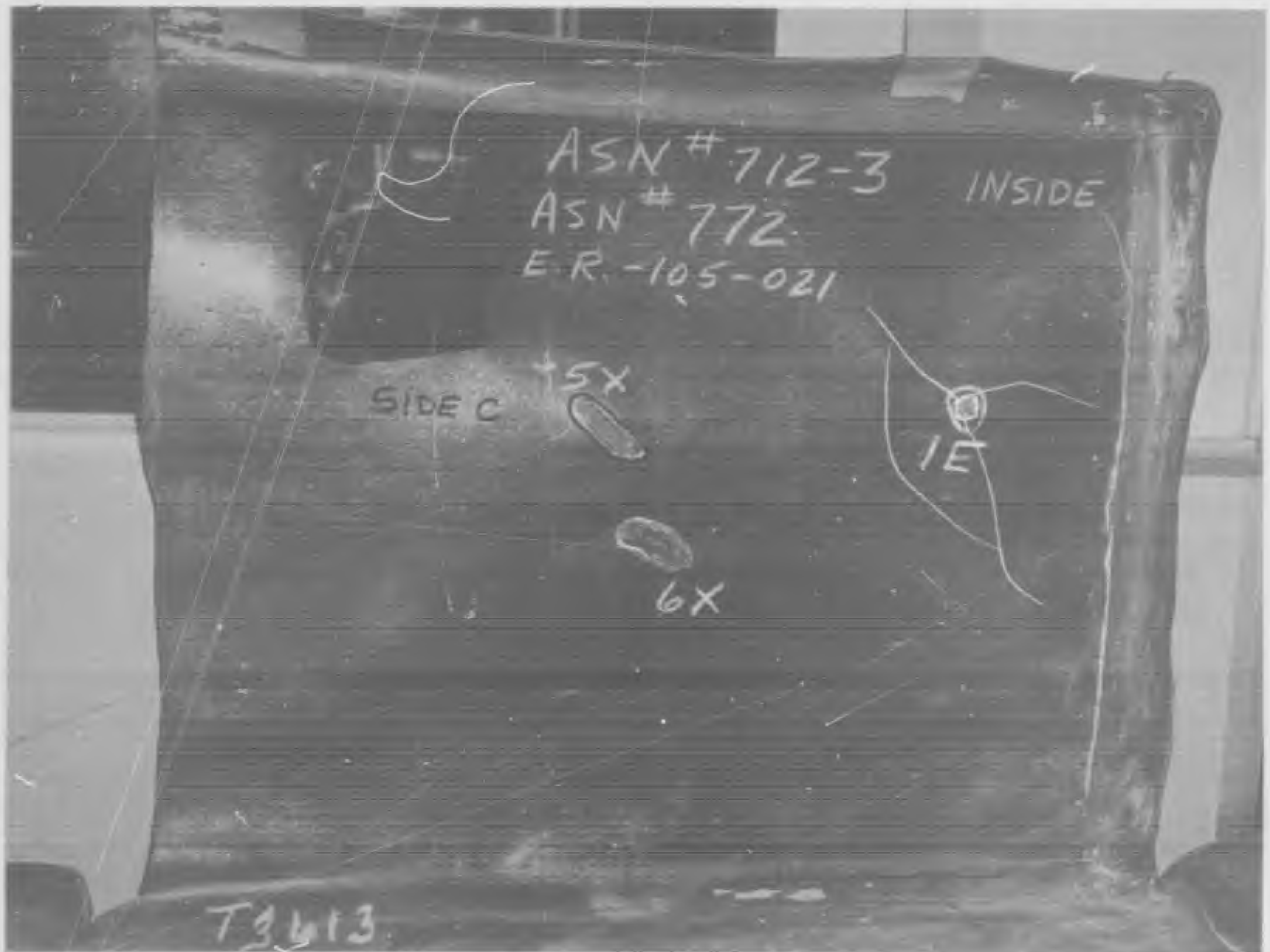

Figure 34 - Inside of Side C of Test Cell ASN 772 After Gunfire

Figure 35 - Inside of Side D of Test Cell ASN 772 After Gunfire

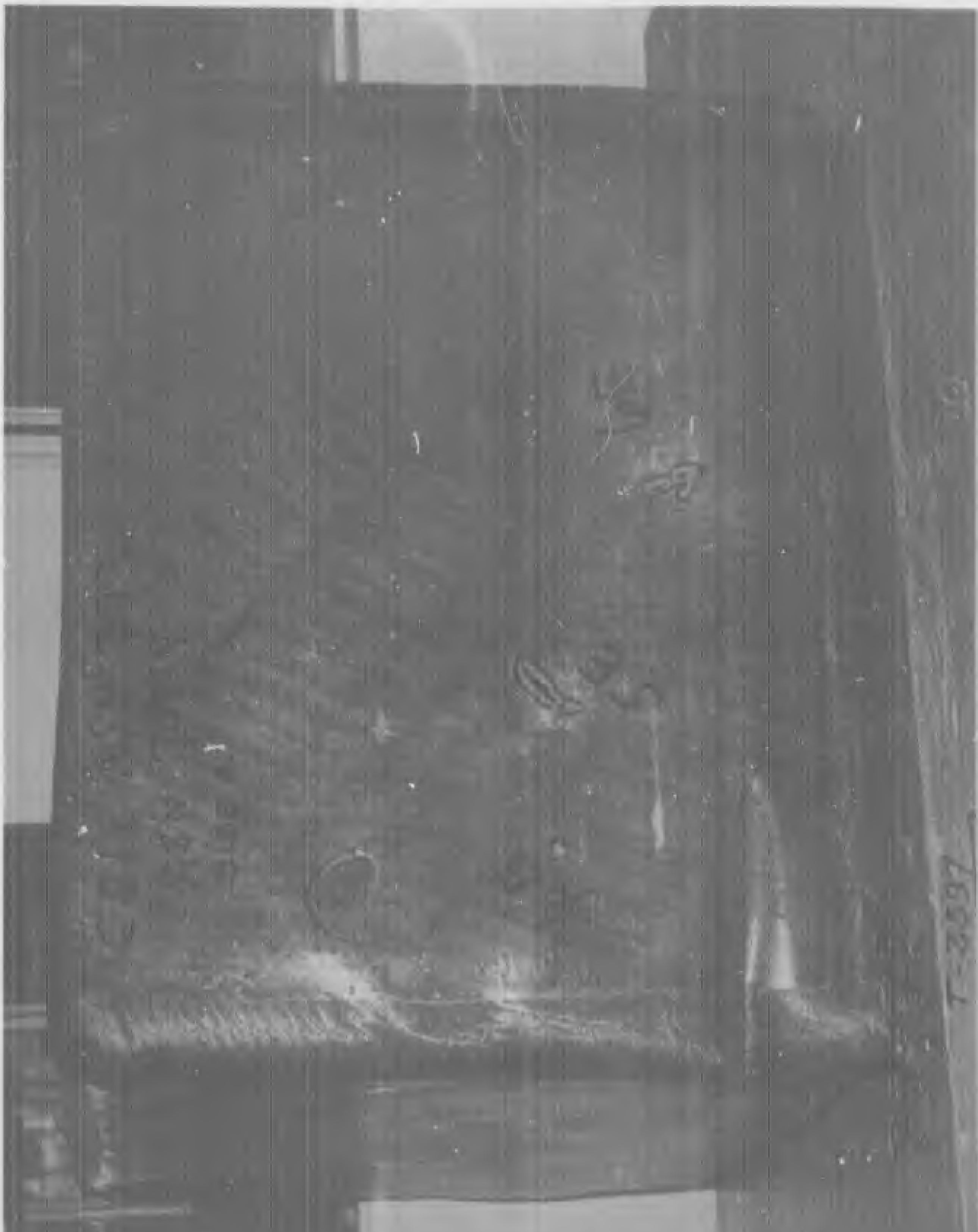

Figure 36 - Side A of Test Cell ASN 773 After Gunfire

Figure 37 - Inside of Side A of Test Cell ASN 773 After Gunfire

Figure 38 - Side B of Test Cell ASN 773 After Gunfire

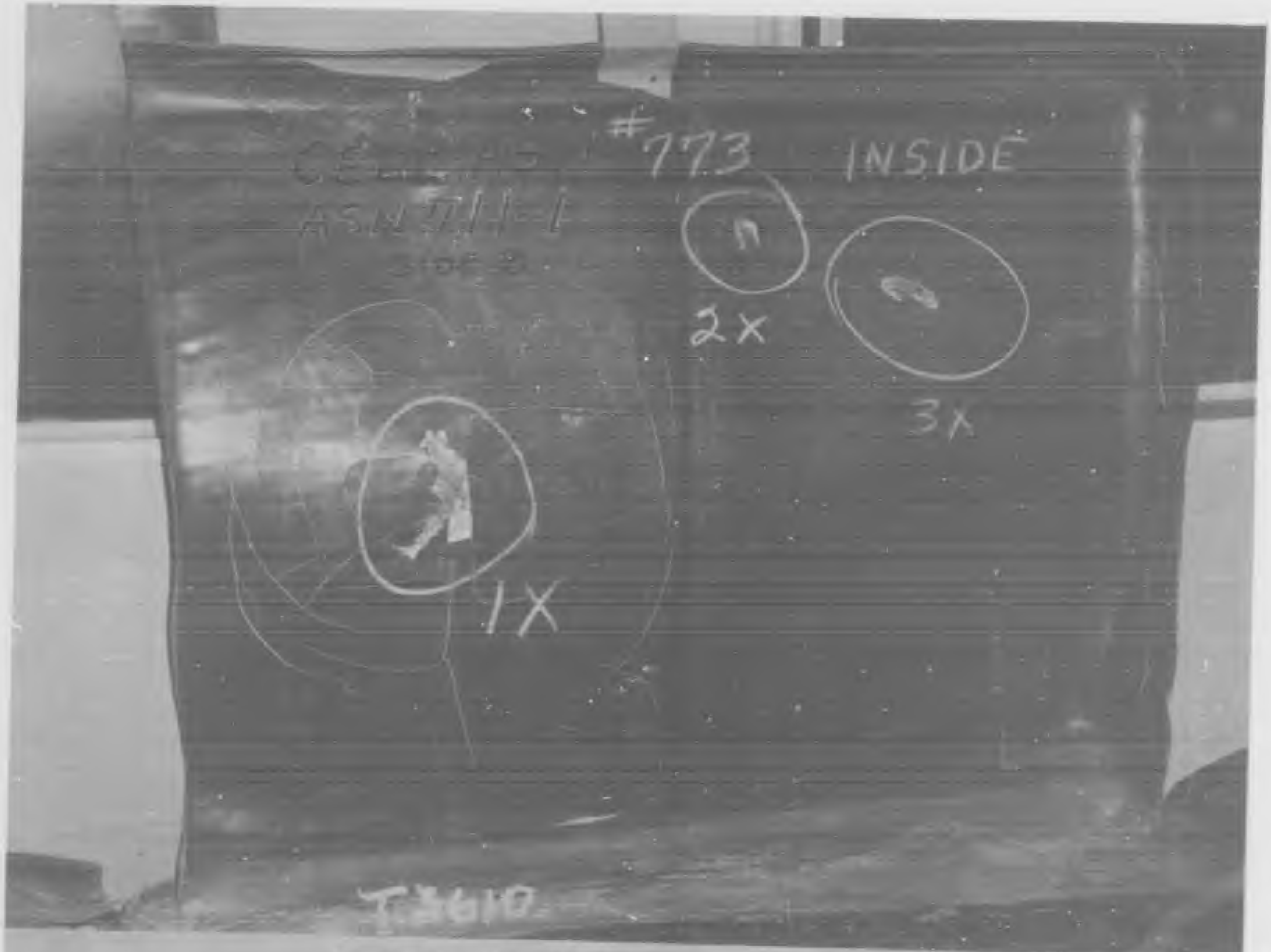

Figure 39 - Inside of Side B of Test Cell ASN 773 After Gunfire

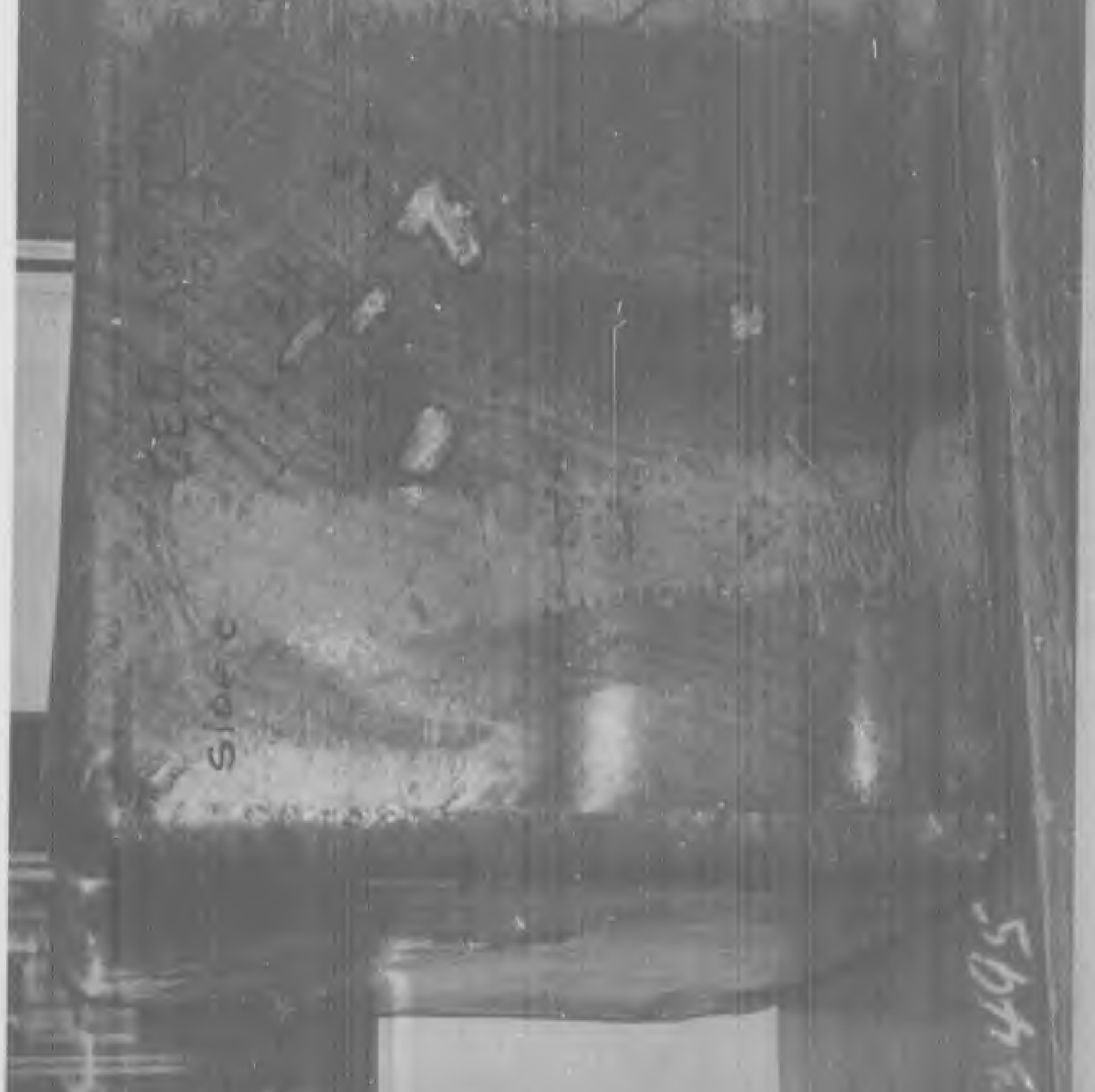

Figure 40 - Side C of Test Cell ASN 773 After Gunfire

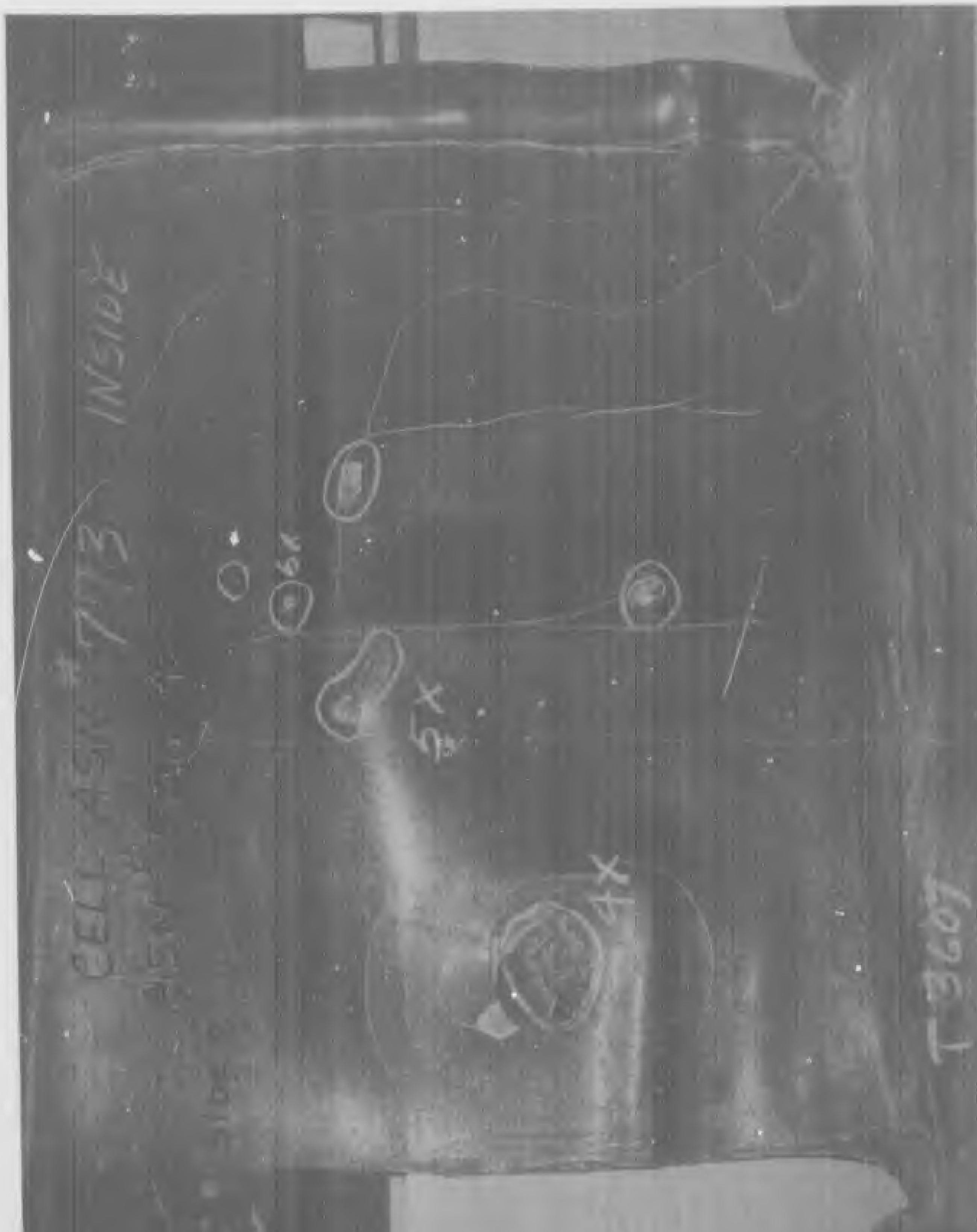

Figure 41 - Inside of Side C of Test Cell ASM 773 After Gunfire

Figure 42 - Side D of Test Cell AGN-173 After Testing

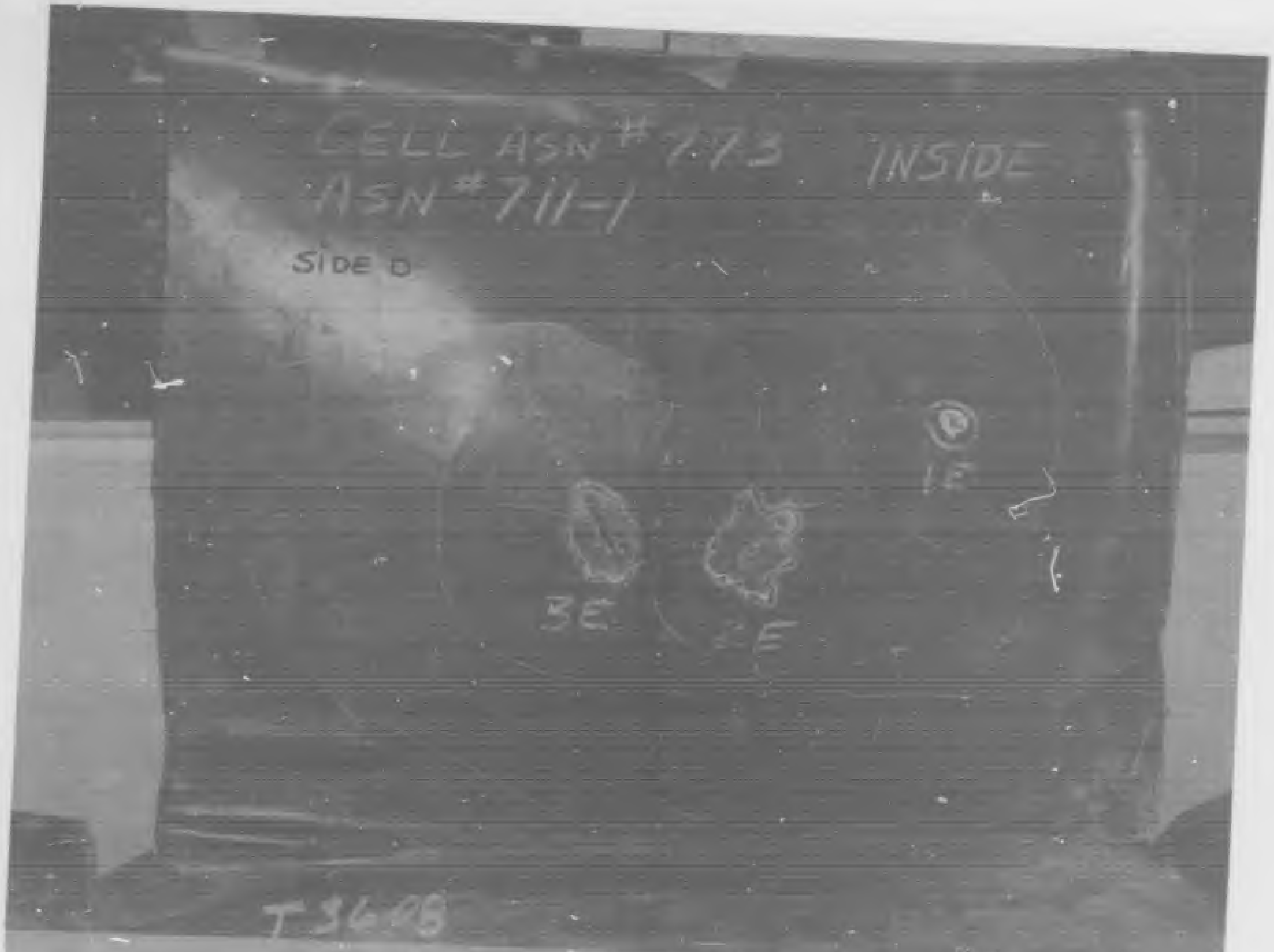

Figure 43 - Inside of Side D of Test Cell ASN 772 After Firing

Figure 44 - Sides A & B of Test Cell USN 781 After Hotfire

Figure 45 - Inside of Side A of Test Cell ASM 761 After Gunfire

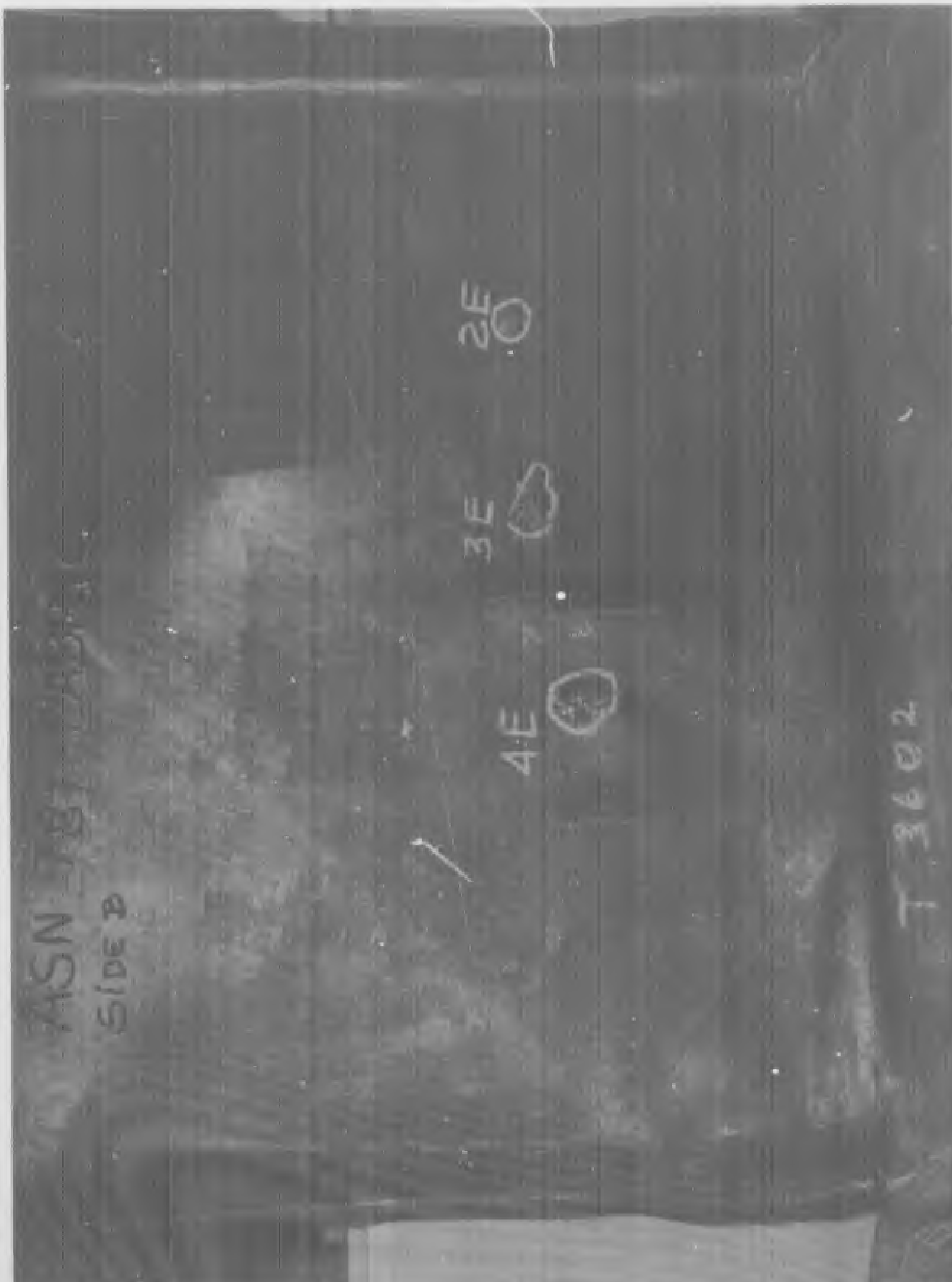

Figure 46 - Inside of Side B of Test Cell ASN 781 After Gunfire

Figure 47 - Sides C & D of Test Cell ASN 781 After Gunfire

Figure 48 - Inside of Side C of Test Cell ASN 781 After Gunfire

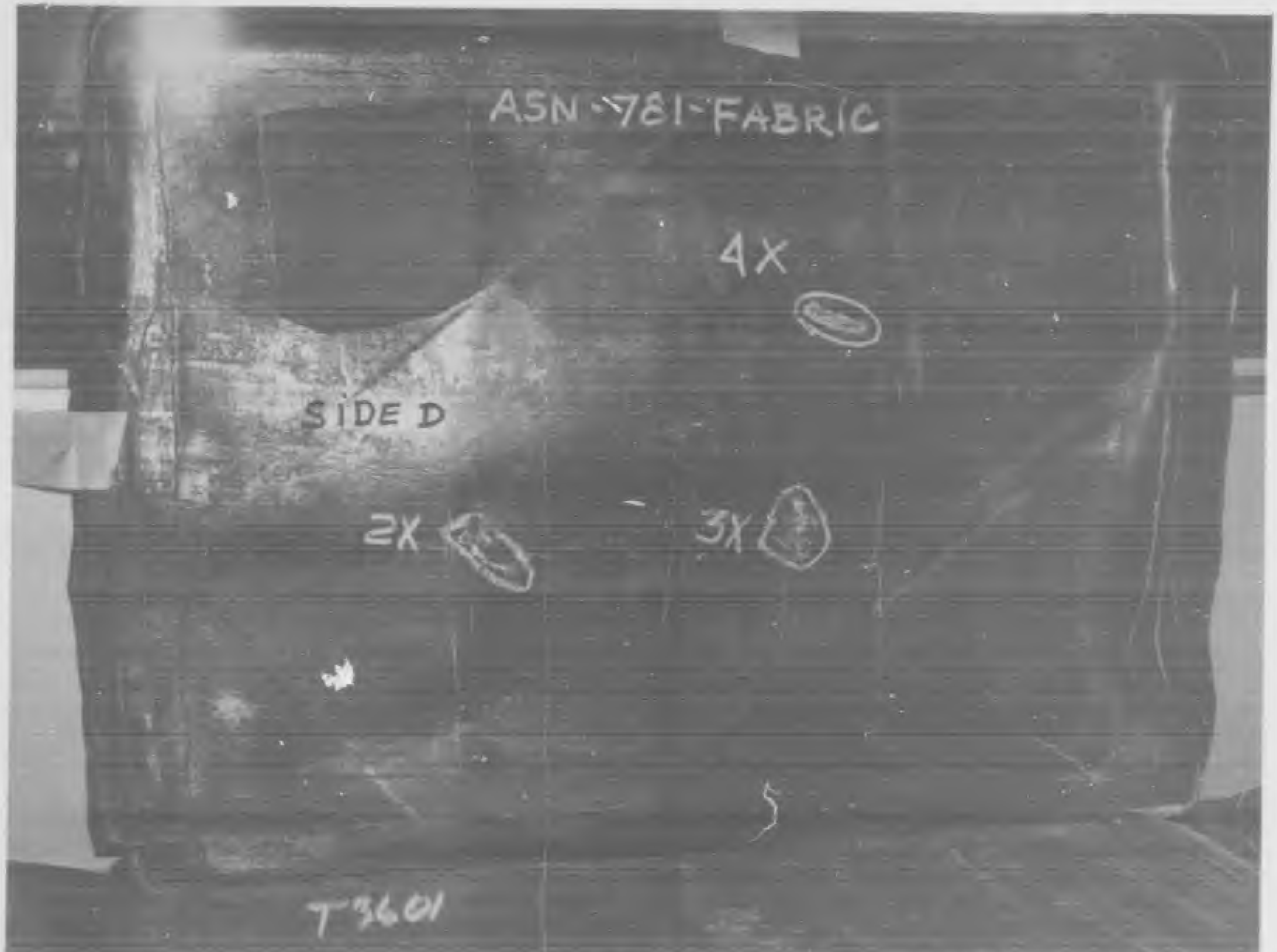

Figure 49 - Inside of Side D of Test Cell ASN 781 After Gunfire

Figure 50 - Side A of Test Cell ASN 808 After Gunfire

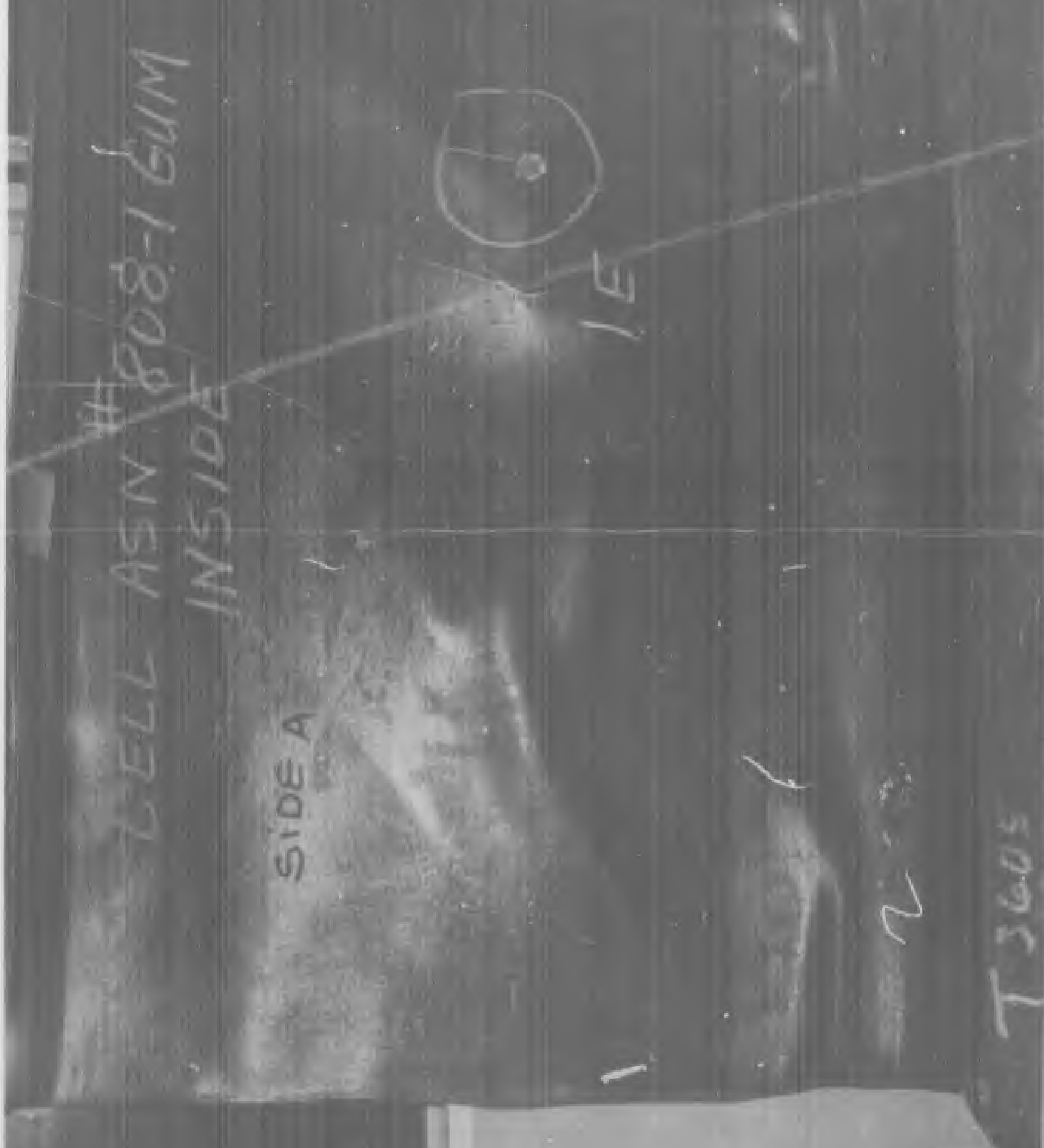

Figure 51 - Inside of Side A of Test Cell ASN 808 After Gunfire

Figure 52 - Side C of Test Cell ASN 808 After Gunfire

Figure 63 - Inside of Side C of Test Cell ASN 808 After Gunfire

Figure 54 - Side A of Test Cell ASN 805 After Gunfire

Figure 55 - Inside of Side A of Test Cell ASN 805 After Gunfire

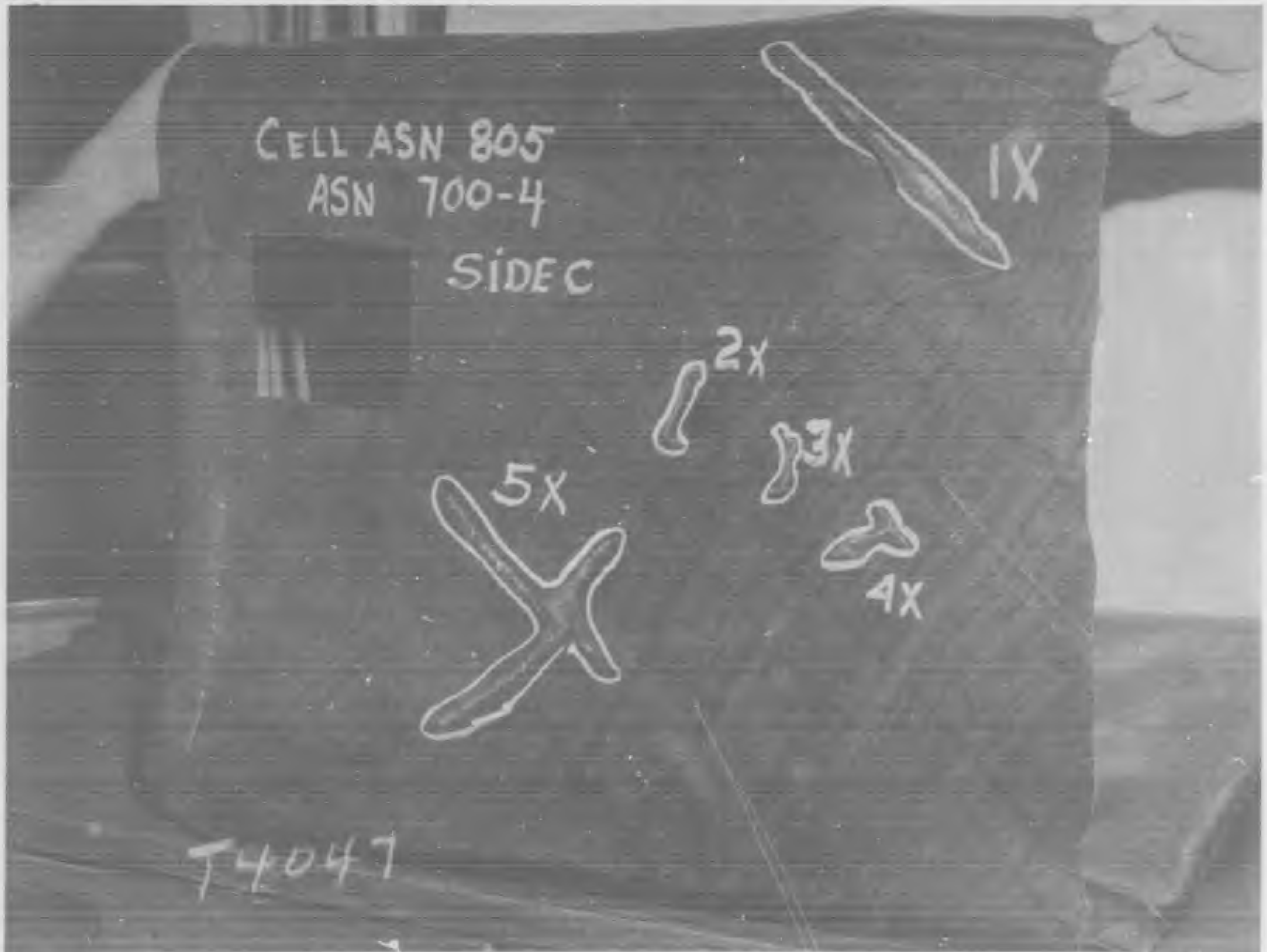

Figure 56 – Side C of Test Cell ASN 805 After Gunfire

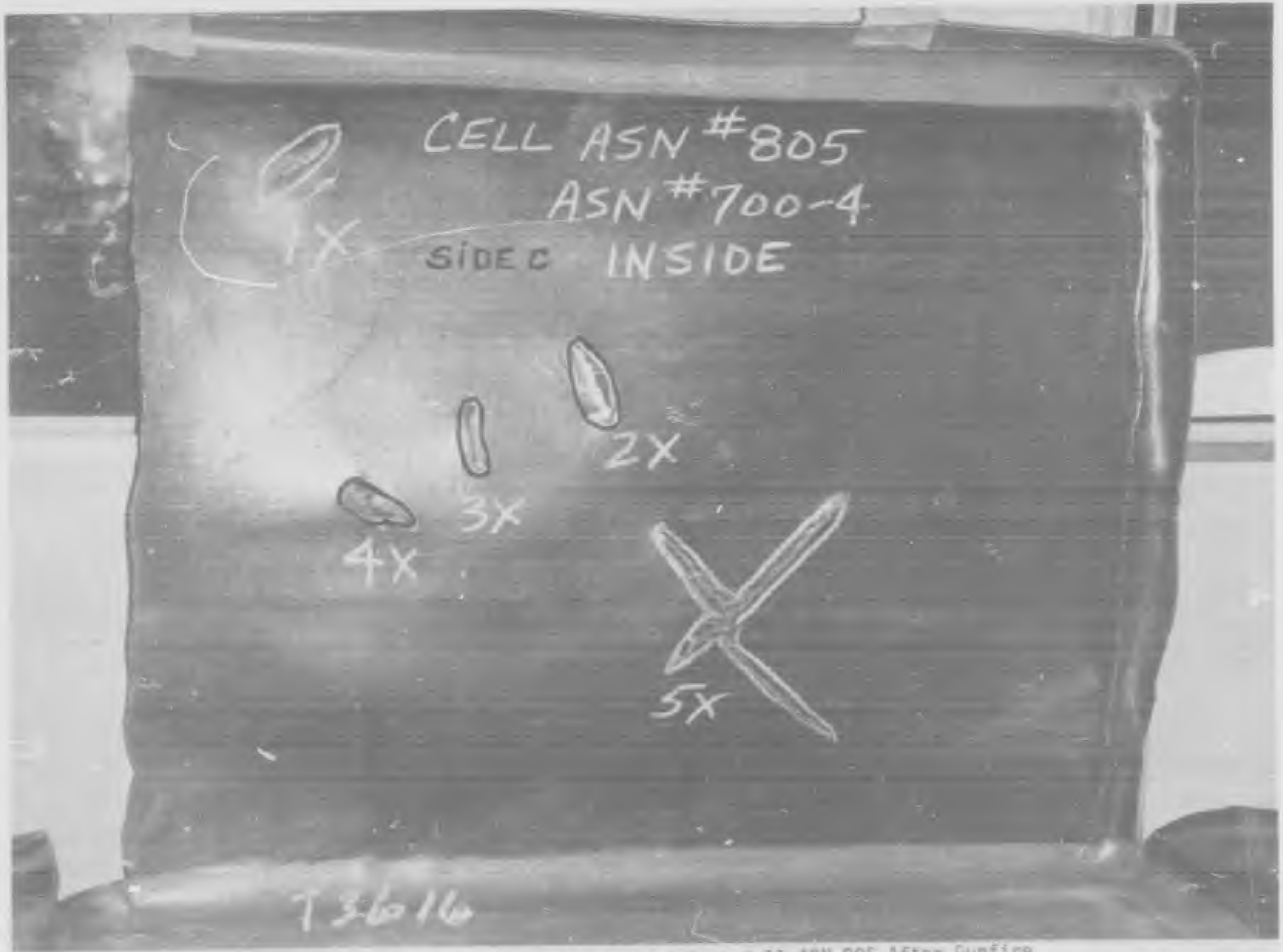

Figure 57 - Inside of Side C of Test Cell ASN 805 After Gunfire

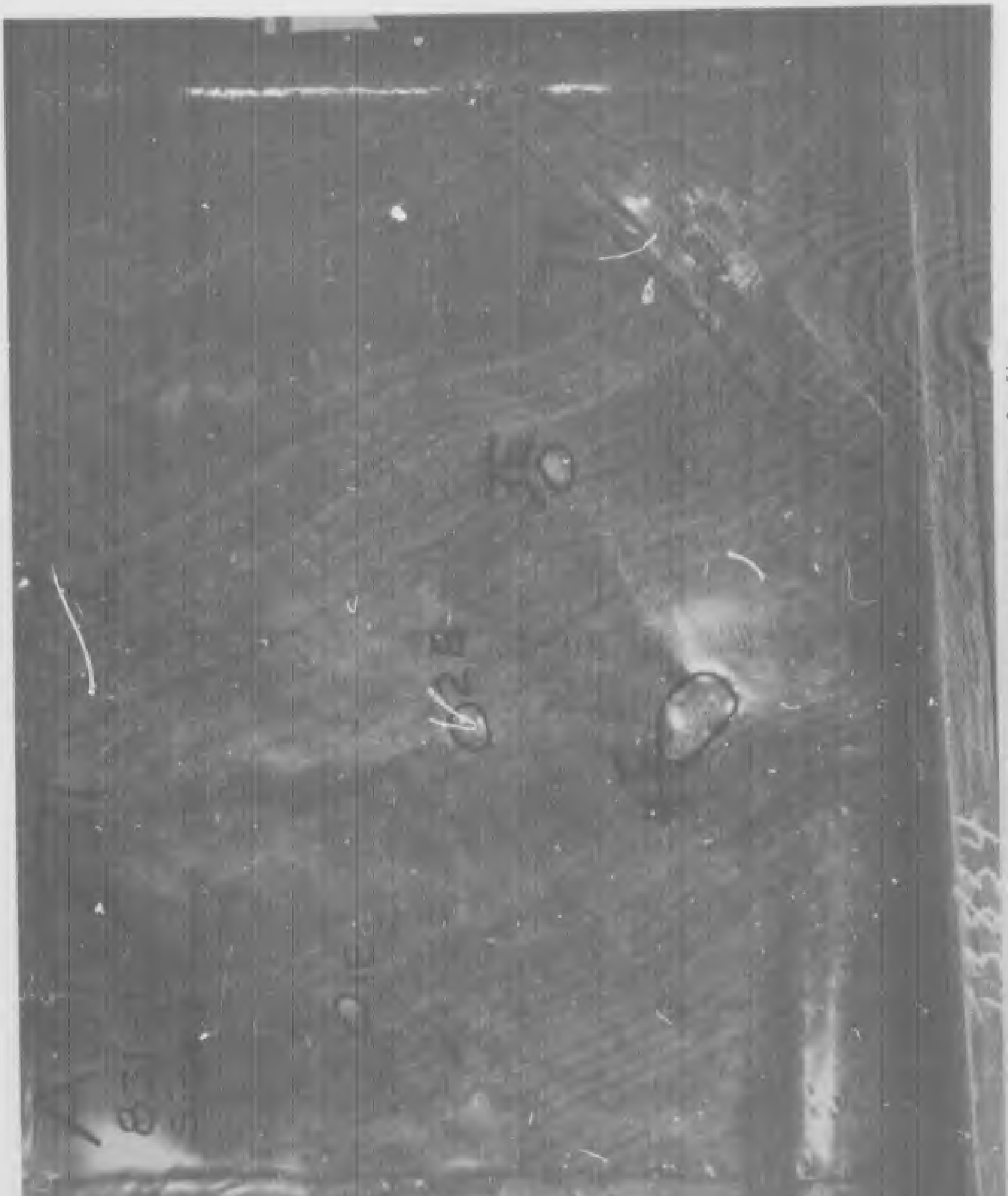

Figure 58 - Side 1 of Test Cell ASN 831 After Gunfire

Figure 59 - Inside of Side 1 of Test Cell ASN 831 After Gunfire

Figure 60 - Side 2 of Test Cell ASM 831 After Gunfire

Figure 61 - Inside of Side 2 of Test Cell ASN 831 After Gunfire

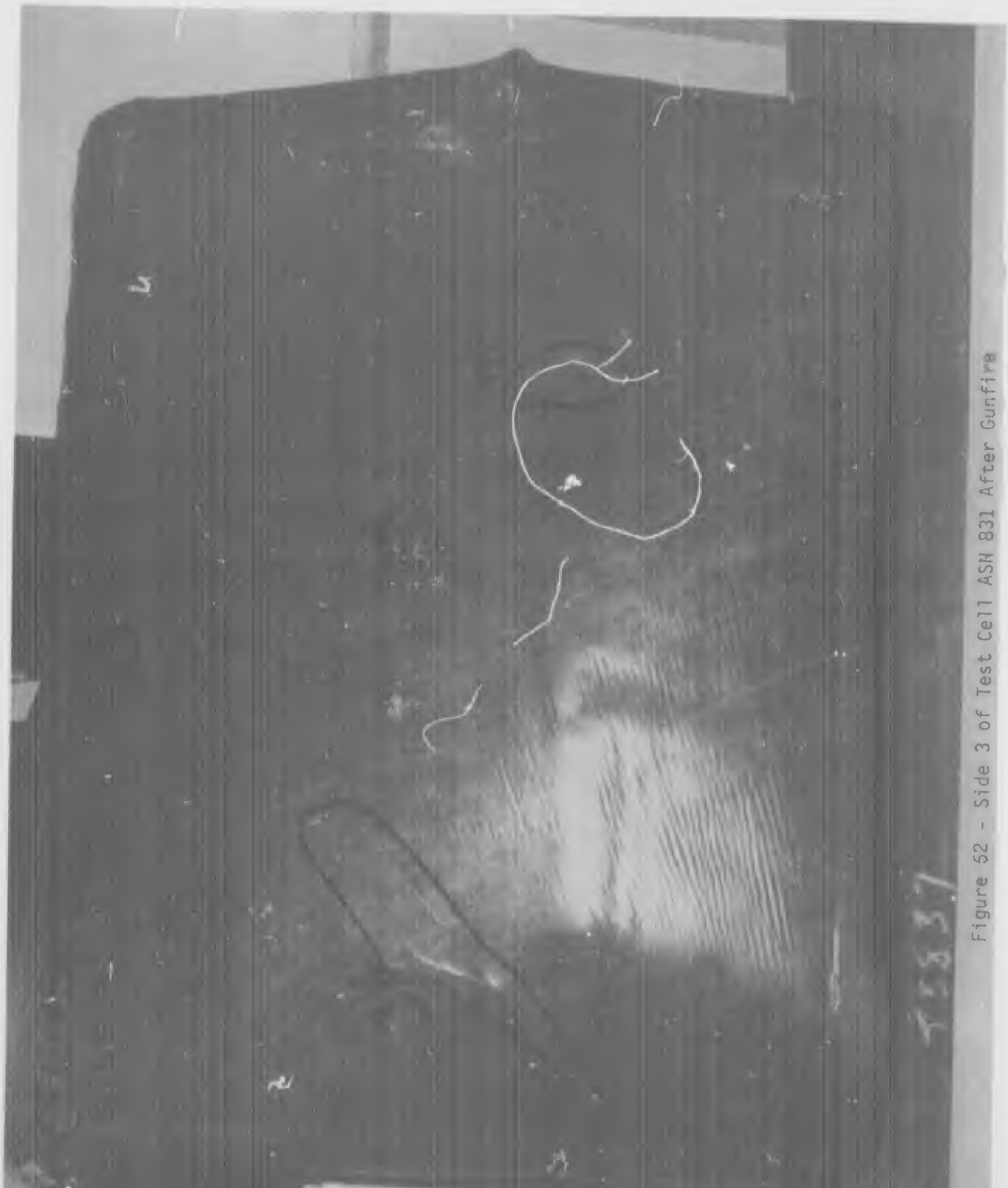

Figure 52 - Side 3 of Test Cell ASN 831 After Gunfire

Figure 63 - Inside of Side 3 of Test Cell ASN 831 After Gunfire

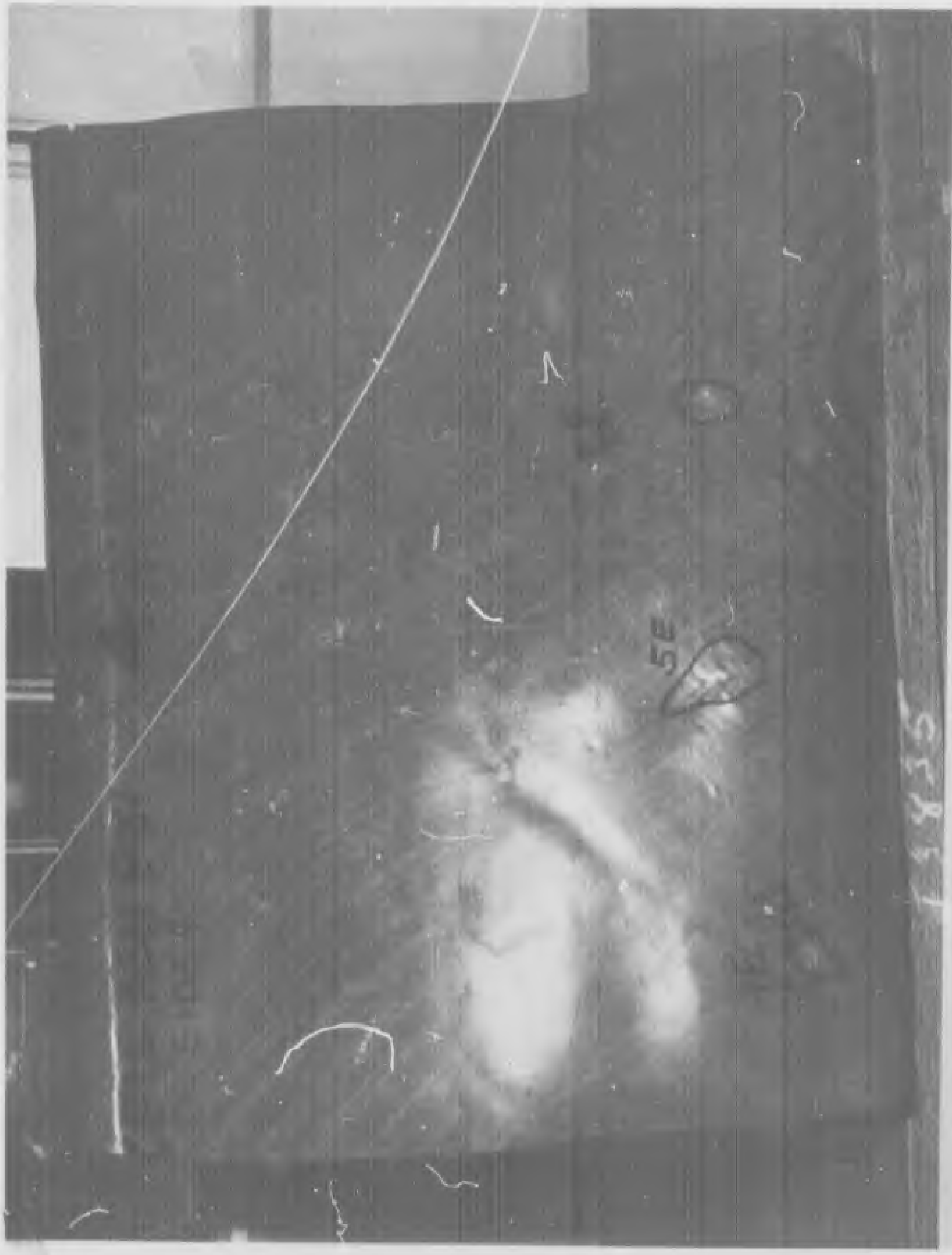

Figure 64 - Side 4 of Test Cell ASN 831 After Gunfire

Figure 65 - Inside of Side 4 of Test Cell ASN 531 After Cutting

Figure 66 - Side A of Test Cell ASN 854 After Gunfire

Figure 67 - Inside of Side A of Test Cell ASN 854 After Gunfire

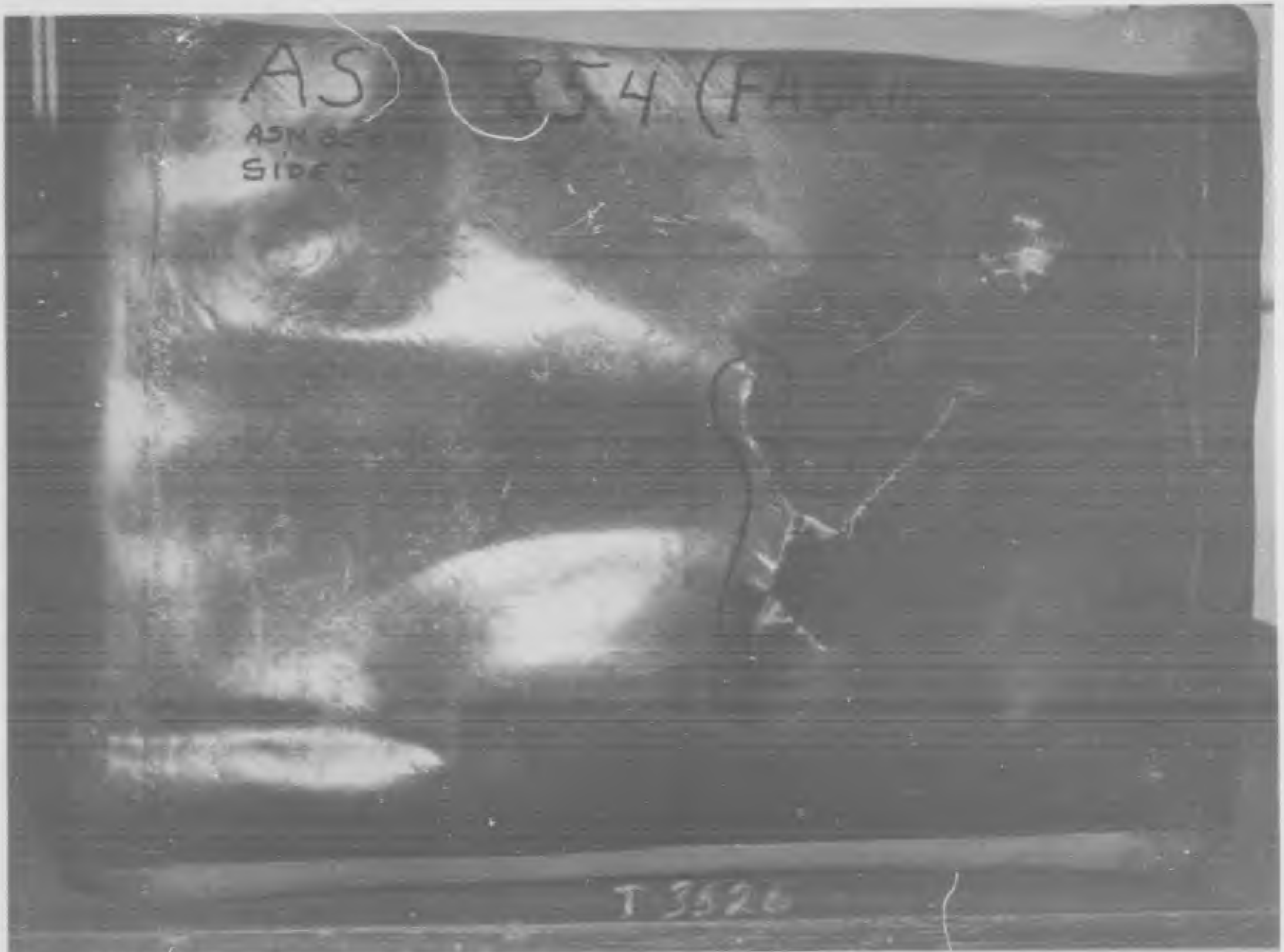

Figure 68 - Side C of Test Cell ASN 854 After Gunfire

Figure 69 - Inside of Side C of Test Cell ASN 854 After Gunfire

Figure 70 - Side B of Test Cell ASN 854 After Gunfire

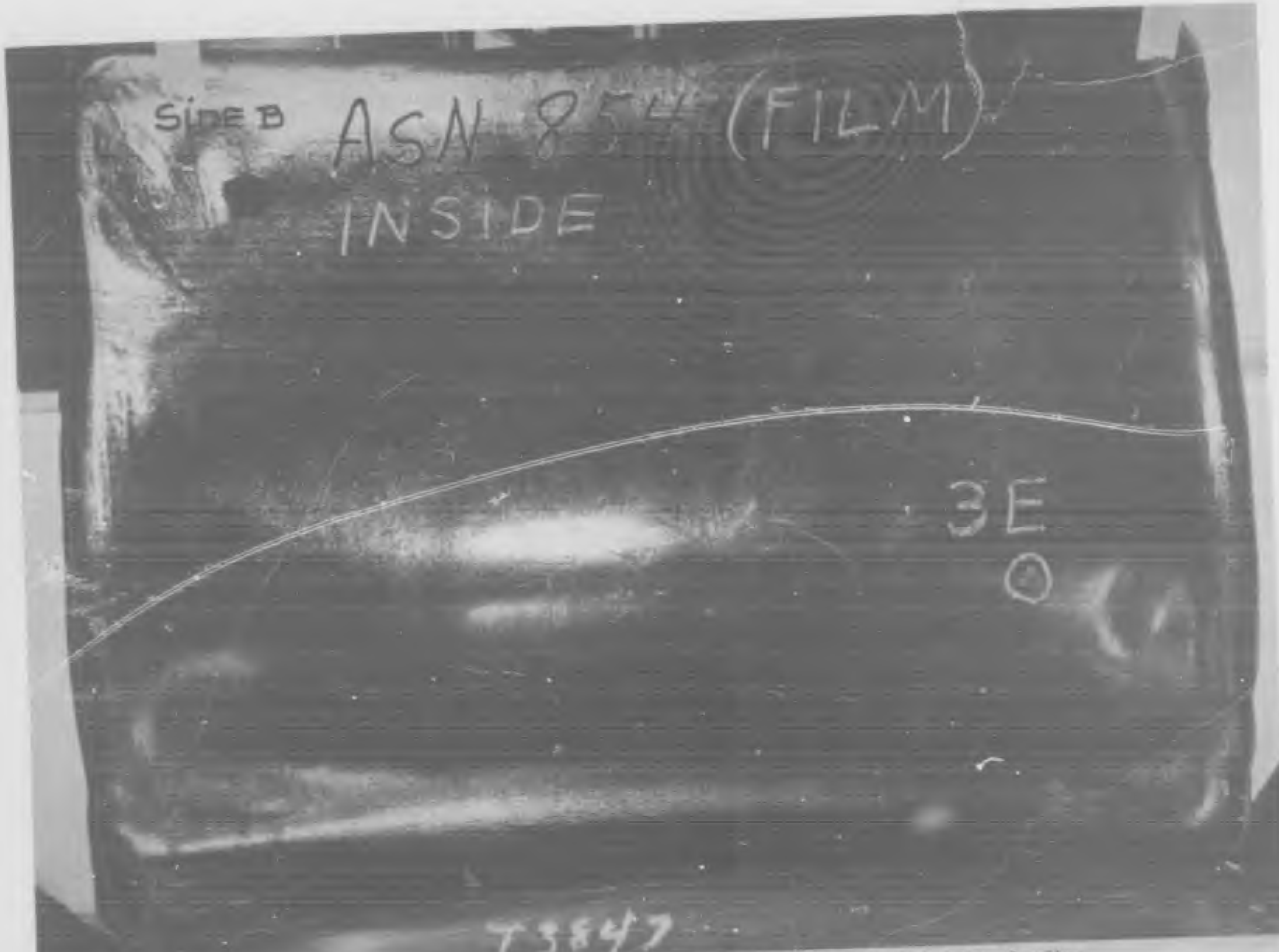

Figure 71 - Inside of Side B of Test Cell ASN 854 After Gunfire

Figure 72 - Side D of Test Cell ASN 354 After Gunfire

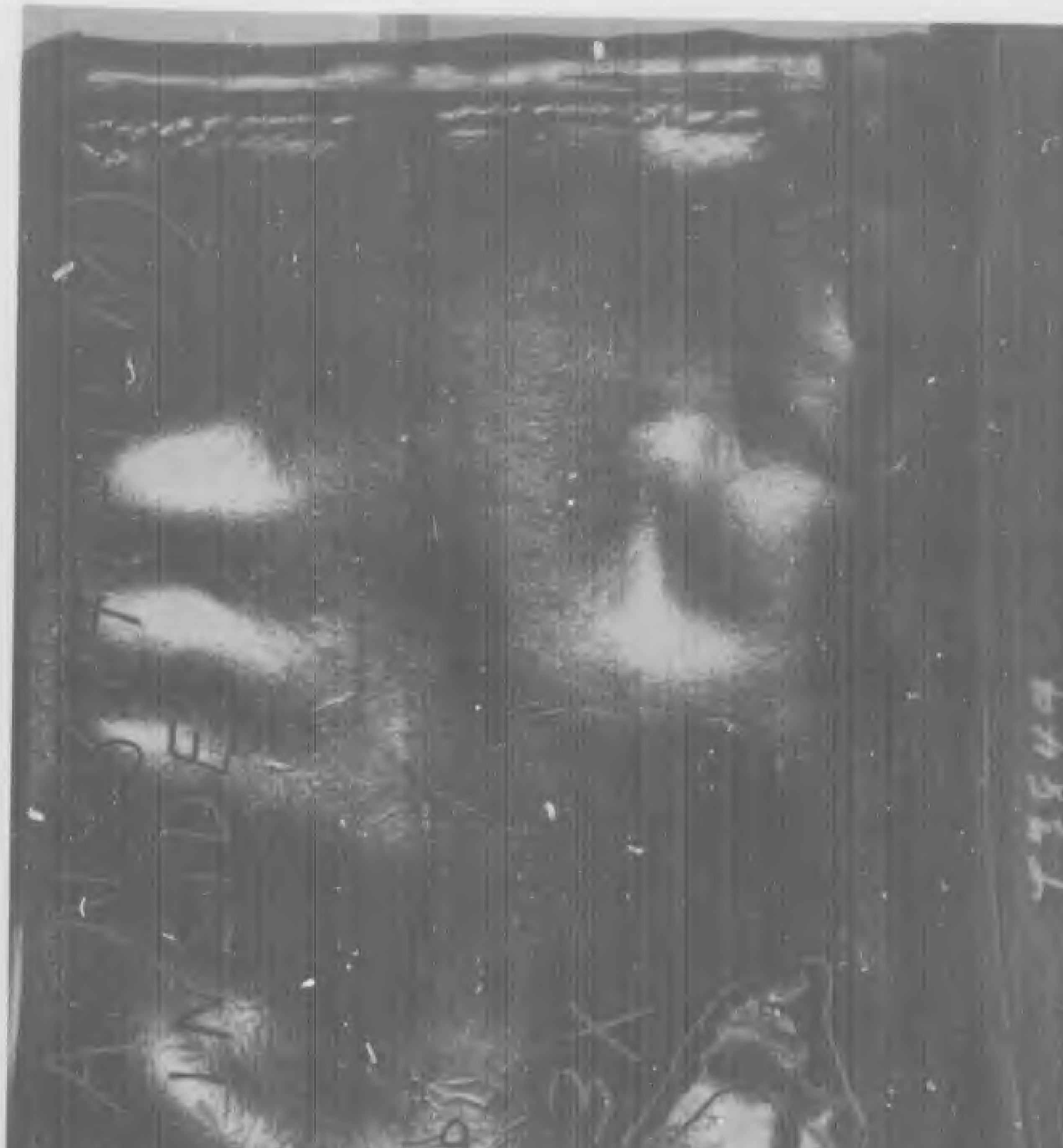

Figure 73 - Inside of Side D of Test Cell ASN 854 After Gunfire

Figure 74 - Side A of Test Cell ASN 862 After Gunfire

Figure 75 - Inside of Side A of Test Cell ASN 862 After Gunfire

Figure 76 - Side C of Test Cell ASN 862 After Gunfire

Figure 77 - Inside of Side C of Test Cell ASN 862 After Gunfire

Figure 78 - Side B of Test Cell ASN 862 After Gunfire

Figure 79 - Inside of Side B of Test Cell ASN 862 After Gunfire

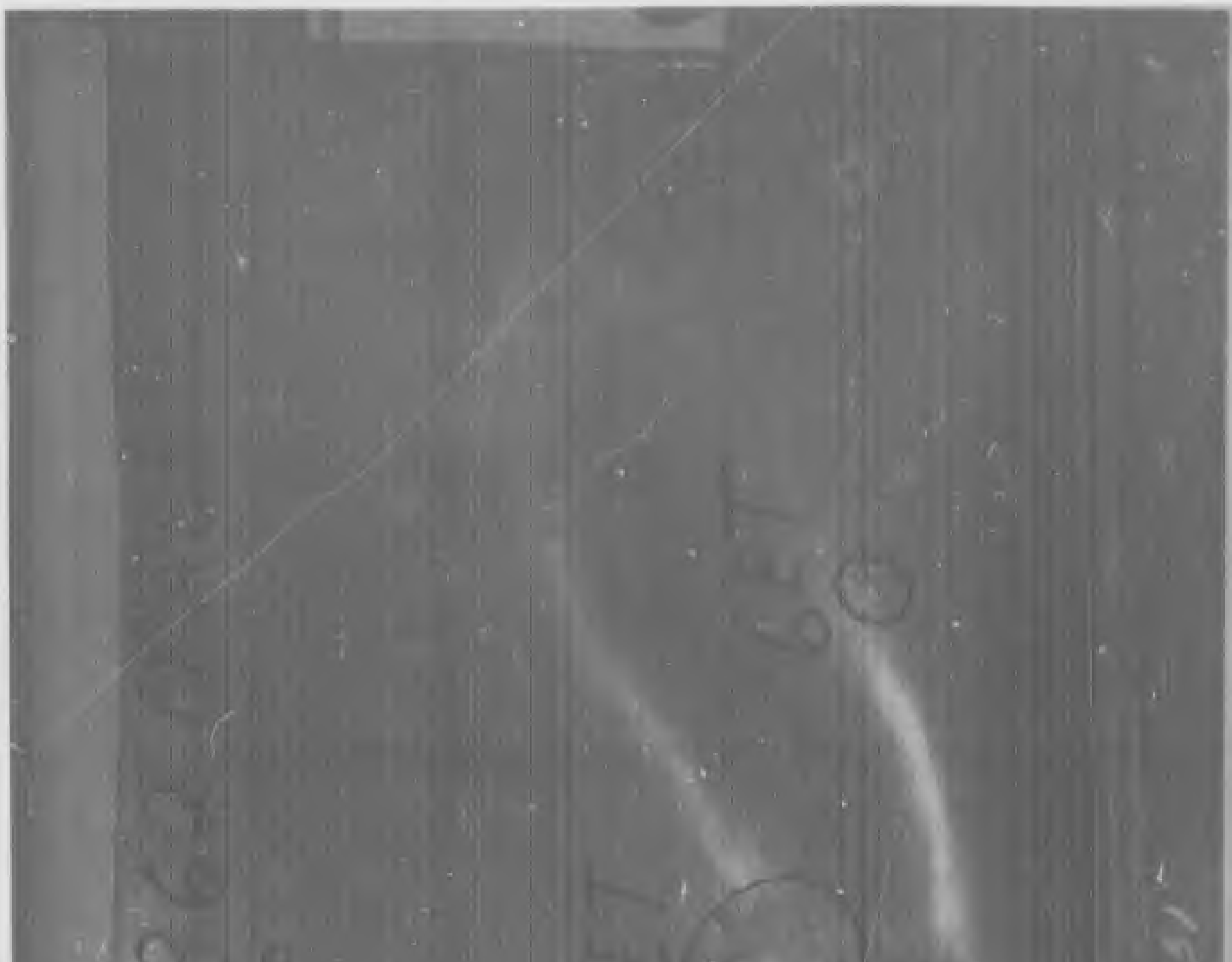

Figure 80 - Side D of Test Cell ASN 862 After Gunfire

Figure 81 - Inside of Side D of Test Cell ASN 662 After Lighting

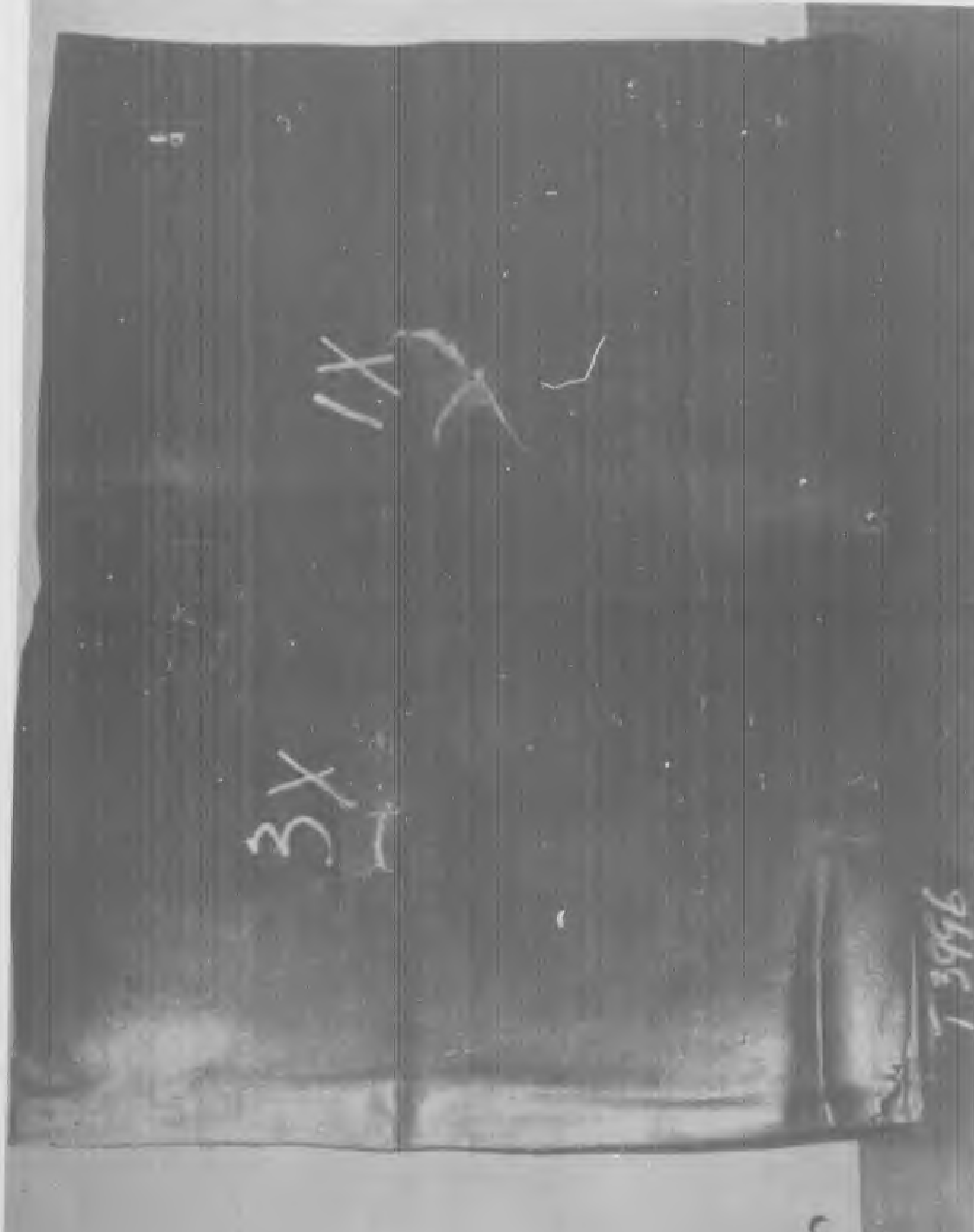

Figure 82 - Side A of Test Cell ASN 913-1,2 After Gunfire

Figure 83 - Inside of Side A of Test Cell ASN 913-1,2 After Gunfire

Figure 84 - Side C of Test Cell ASN 913-1,2 After Gunfire

Figure 85 - Inside of Side C of Test Cell ASN 913-1,2 After Gunfire

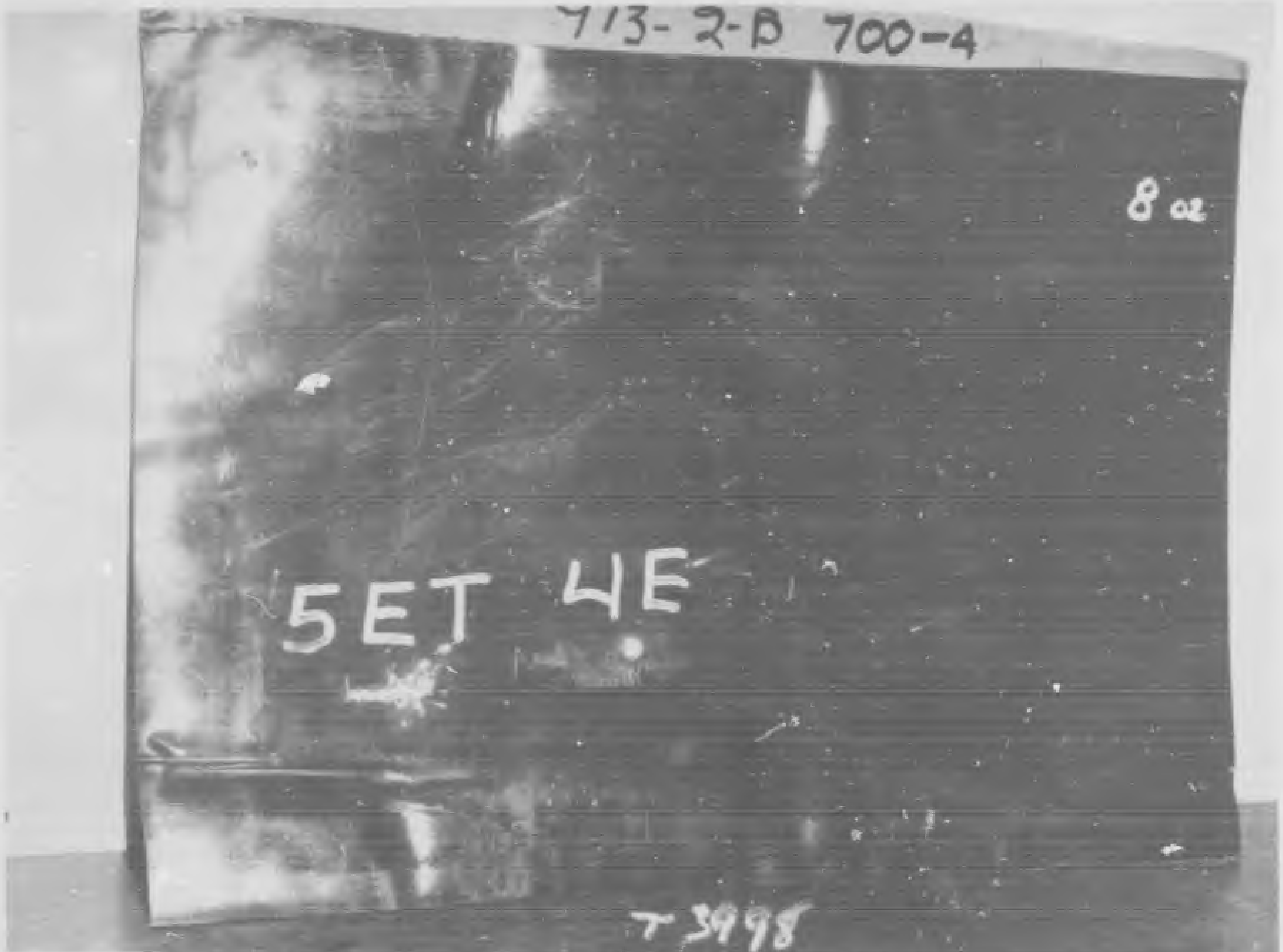

Figure 86 - Side B of Test Cell ASN 913-1,2 After Gunfire

Figure B7 - Inside of Side B of Test Cell ASN 913-1,2 After Gunfire

Figure 88 - Side D of Test Cell ASN 913-1,2 After Gunfire

Figure 89 - Inside of Side D of Test Cell ASN 913-1,2 After Gunfire

Figure 90 - Side A of Test Cell ASN 913-3,4 After Gunfire

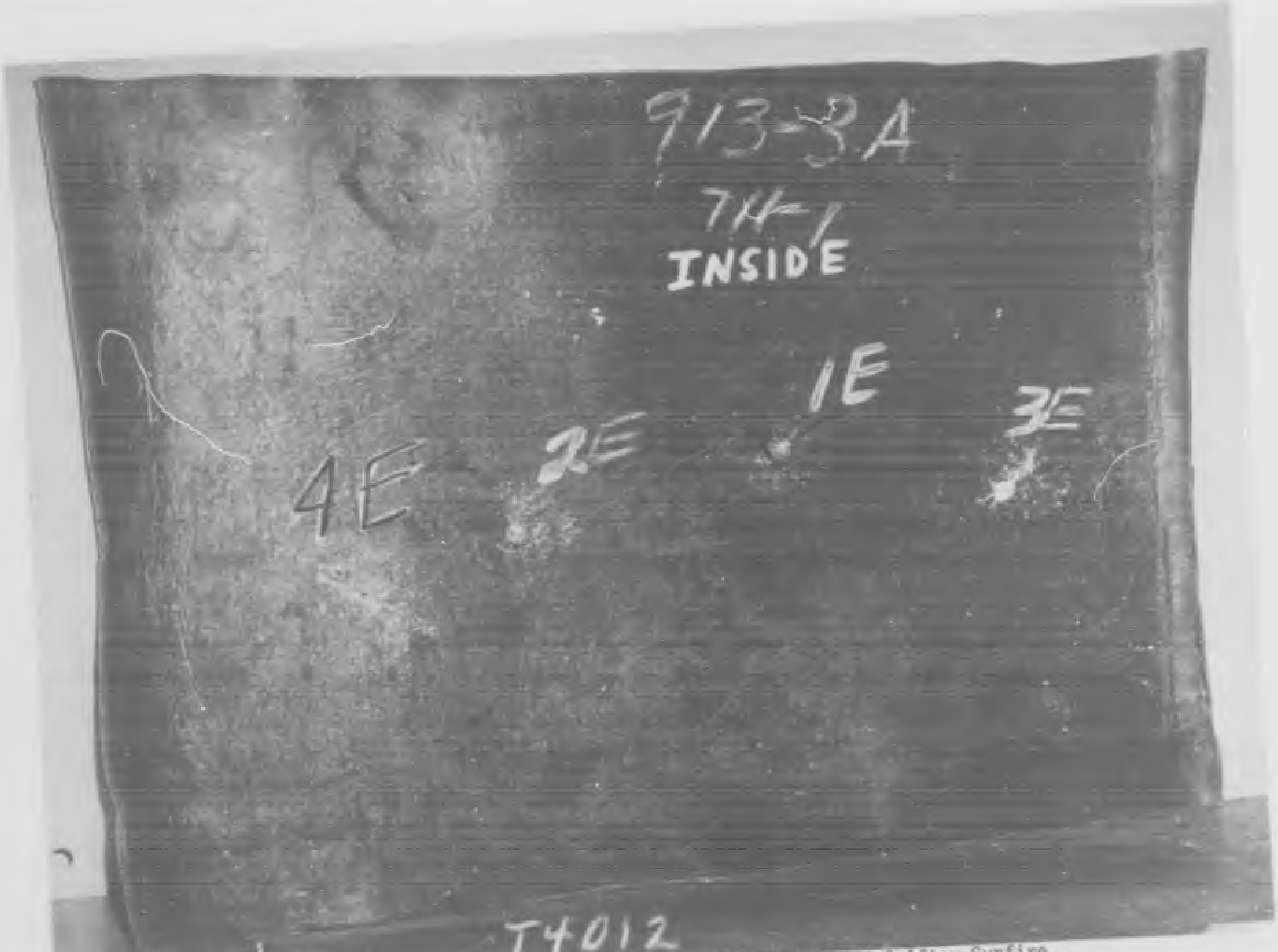

Figure 91 - Inside of Side A of Test Cell ASN 913-3,4 After Gunfire

Figure 92 - Side C of Test Cell ASN 913-3,4 After Gunfire

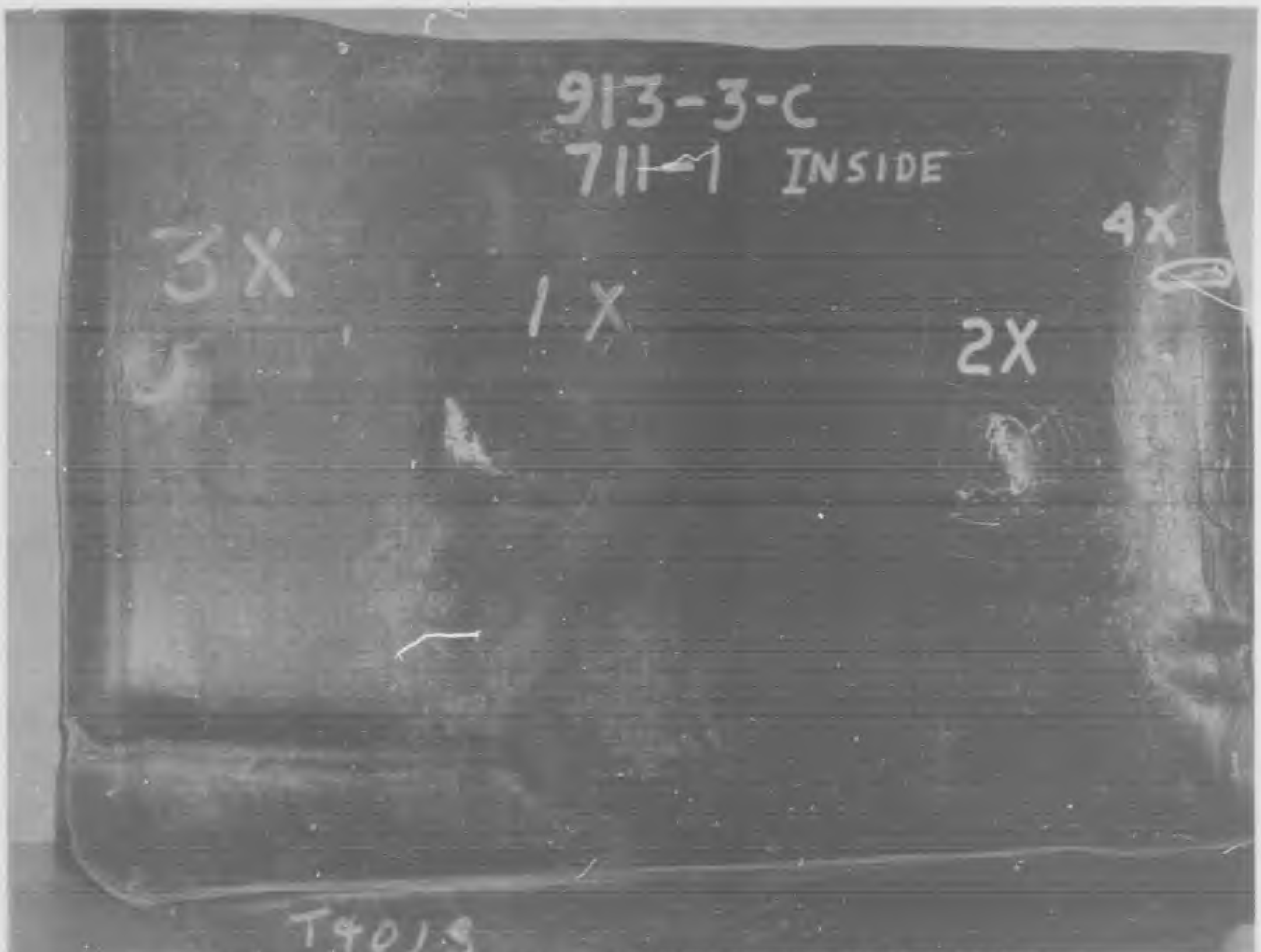

Figure 93 - Inside of Side C of Test Cell ASN 913-3,4 After Gunfire

Figure 94 - Side B of Test Cell ASN 913-3,4 After Gunfire

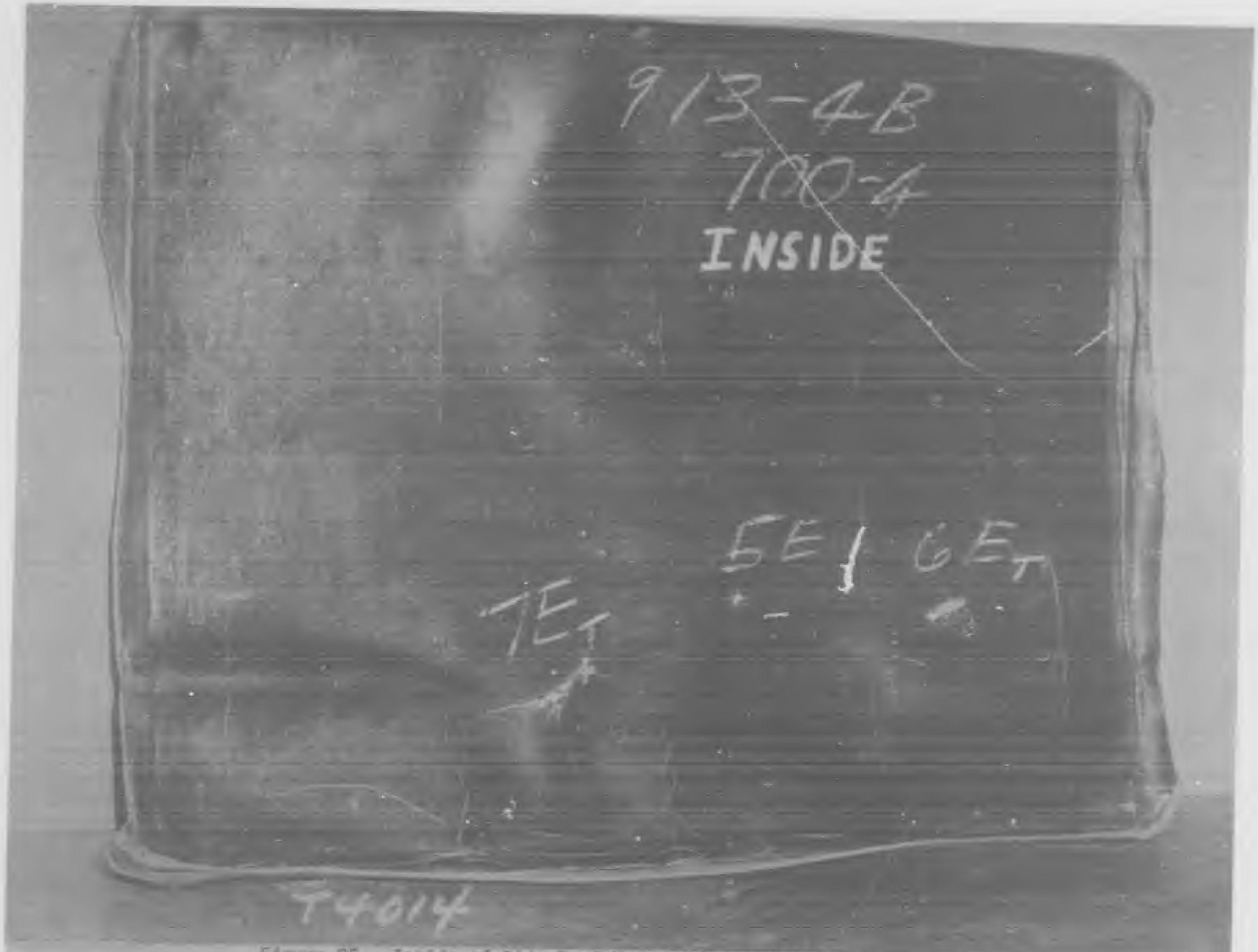

Figure 95 - Inside of Side B of Test Cell ASN 913-3,4 After Gunfire

Figure 96 - Side D of Test Cell ASN 913-3,4 After Gunfire

Figure 97 - Inside of Side D of Test Cell ASN 913-3,4 After Gunfire

Figure 98 - Side A of Test Cell ASN 913-5,6 After Gunfire

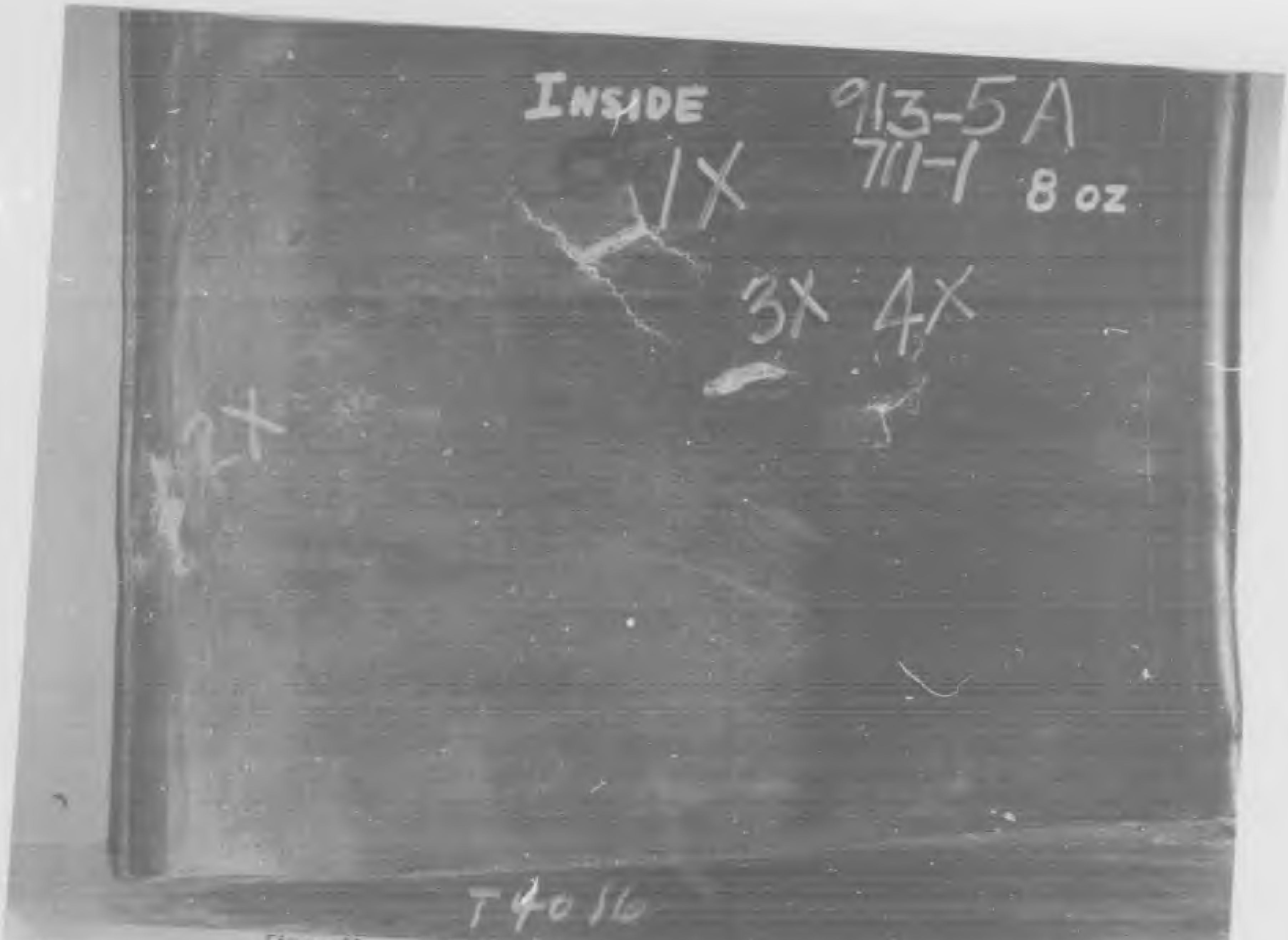

Figure 99 - Inside of Side A of Test Cell ASN 913-5,6 After Gunfire

Figure 100 - Side C of Test Cell ASN 913-5,6 After Gunfire

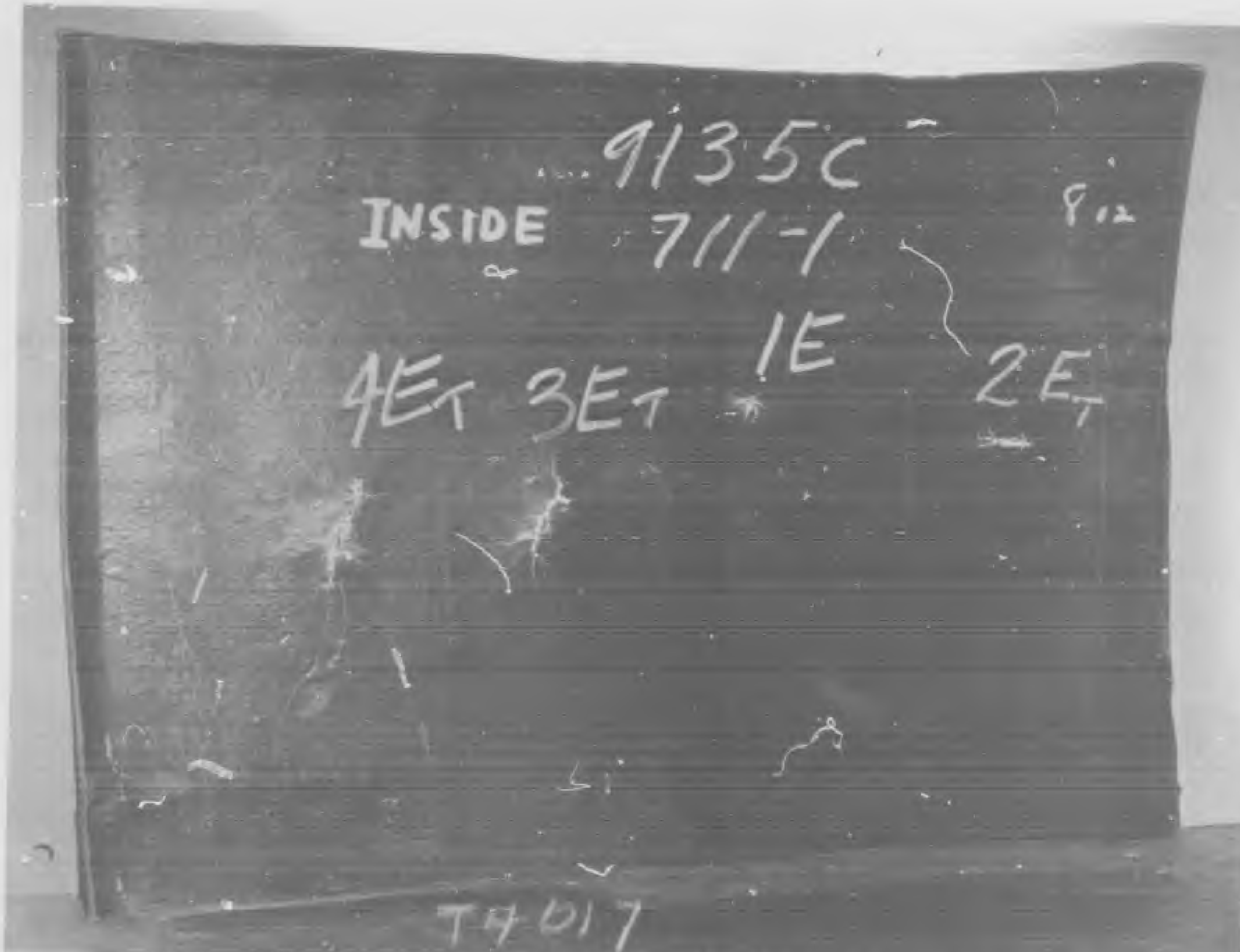

Figure 101 - Inside of Side C of Test Cell ASN 913-5,6 After Gunfire

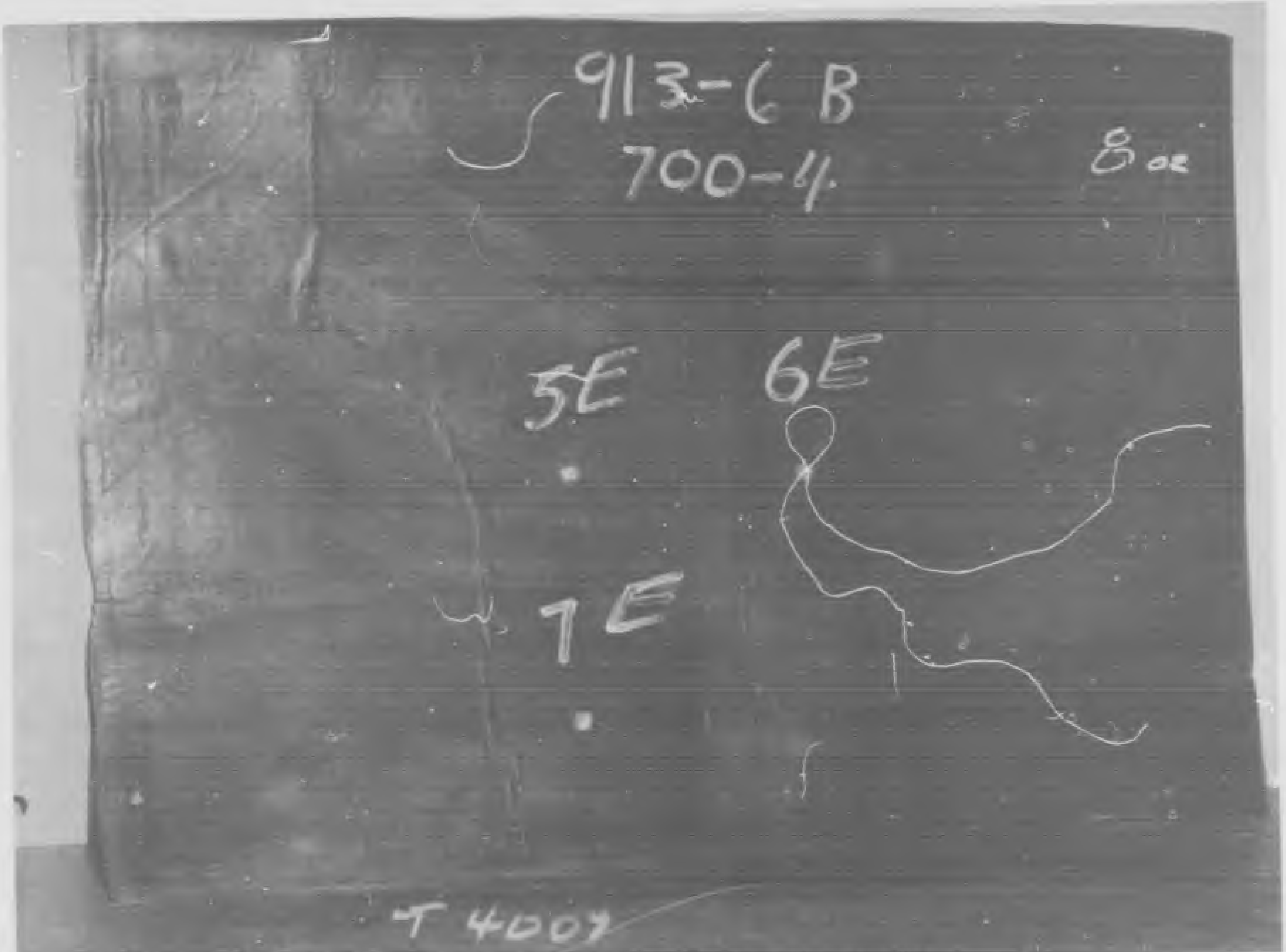

Figure 102 - Side B of Test Cell ASN 913-5,6 After Gunfire

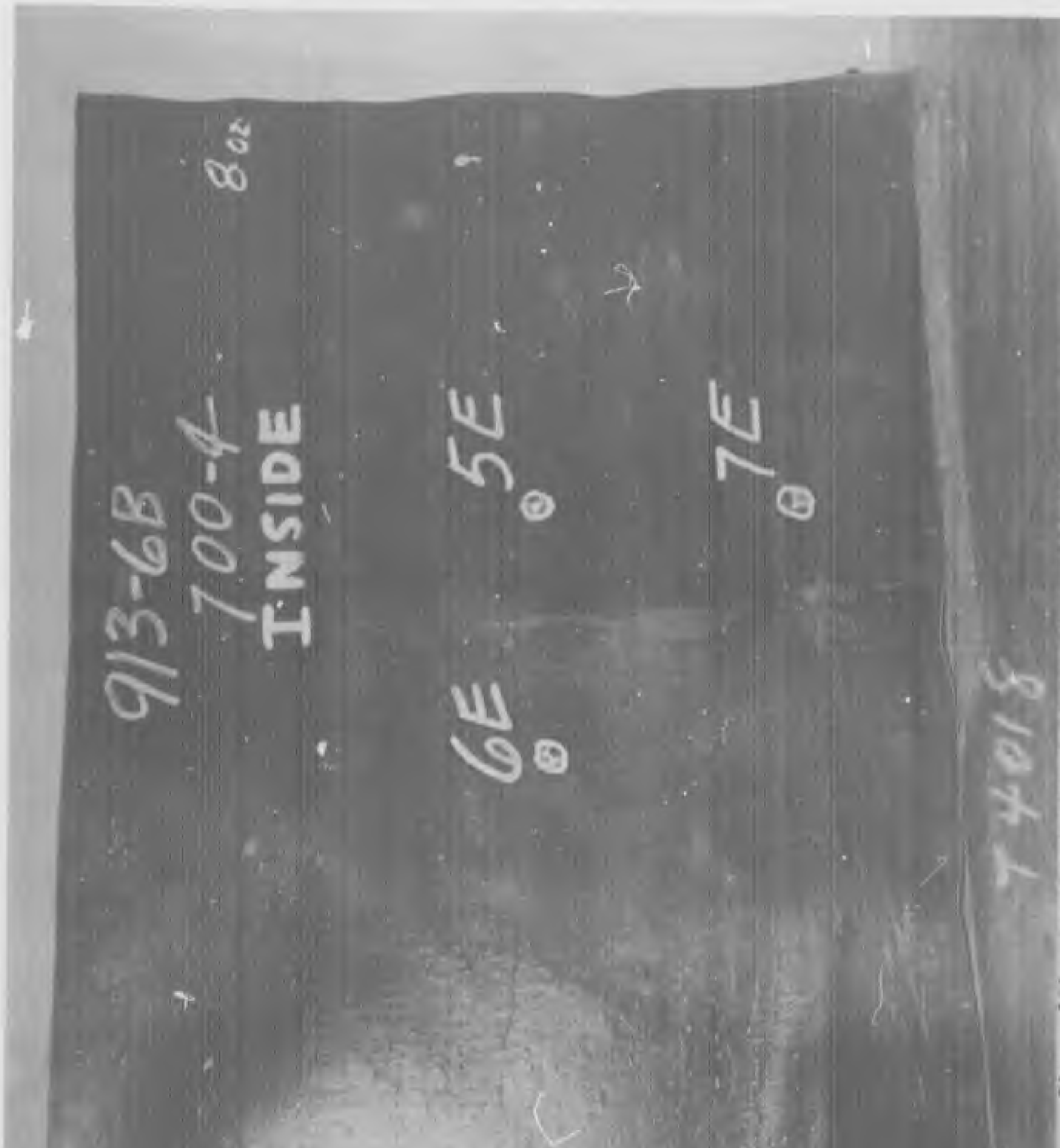

Figure 103 - Inside of Side B of Test Cell ASN 913-5,6 After Gunfire

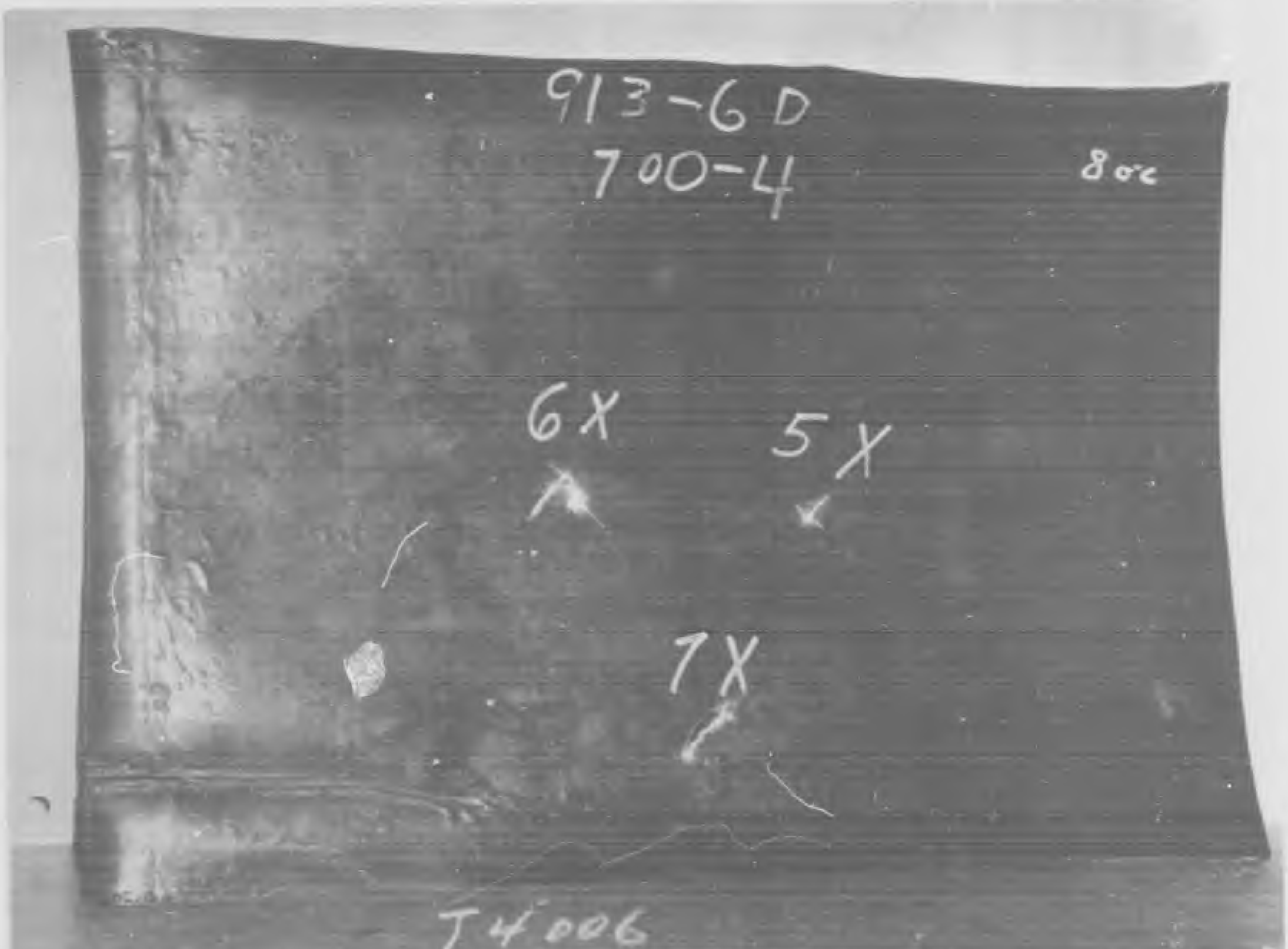

Figure 104 - Side D of Test Cell ASN 913-5,6 After Gunfire

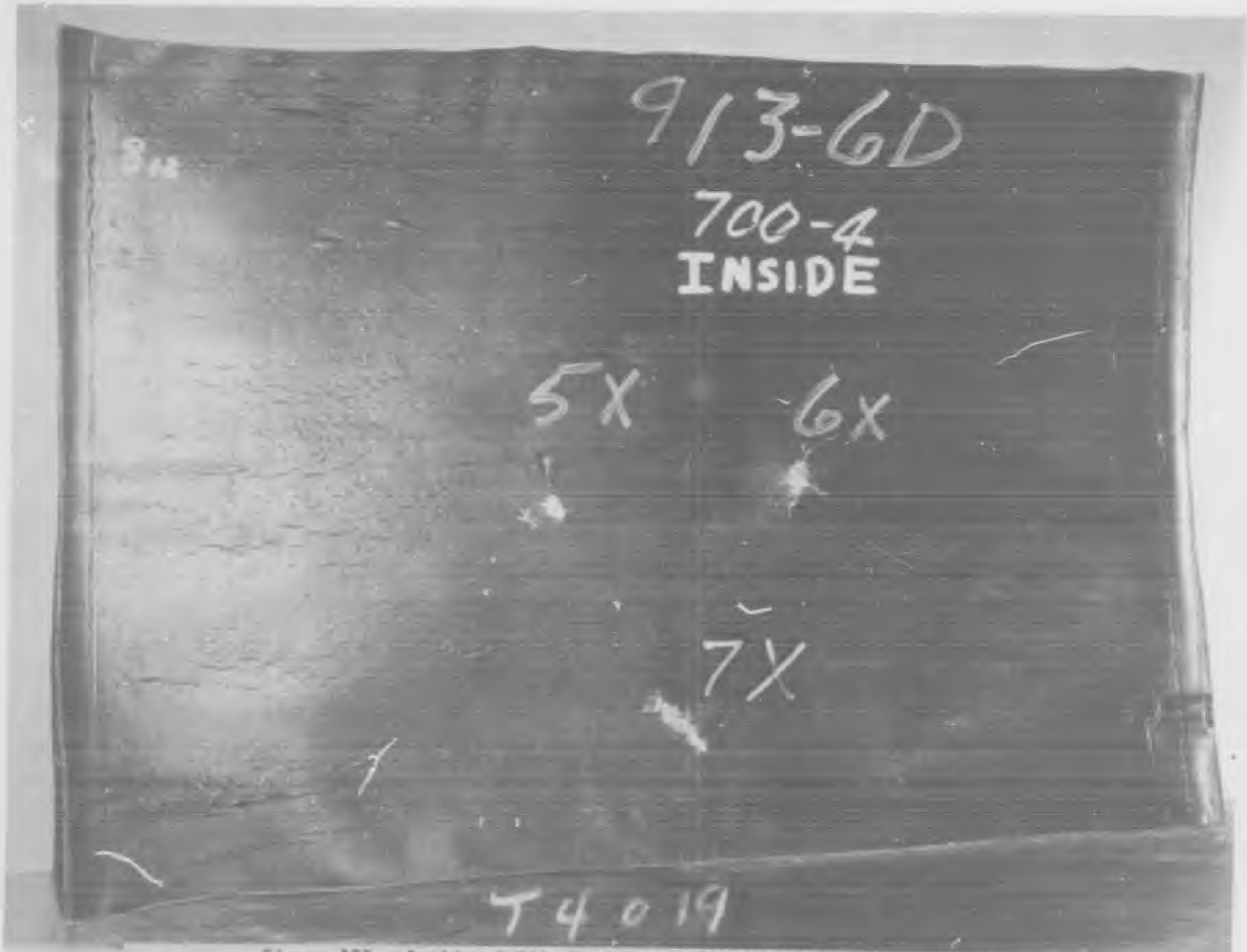

Figure 105 - Inside of S'de D of Test Cell ASN 913-5,6 After Gunfire

APPENDIX IV

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BIBLIOGRAPHY

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13 ABSTRACT

A new self-sealing fuel cell construction was developed utilizing a polyether urethane elastomer which exhibited excellent resistance to cracking and "chunking out" at a gunfire test temperature of -40° F. Efforts made to develop a silicone sealant material with good building tack for use in the development of high temperature resistant self-sealing fuel cells are discussed. A limited amount of effort was devoted to investigating the use of non-sealing fuel line jackets as a means of controlling fuel spraying from ruptured fuel lines. Several commercial foams and thermoplastic sheet materials were evaluated as backing boards for the protection of self-sealing fuel cells. Some of the effort was expended in establishing a reliable method of striking fuel lines with tumbled projectiles.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Self-Sealing Aircraft Fuel Tanks Sealants Backing Boards High Temperature Composites						

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