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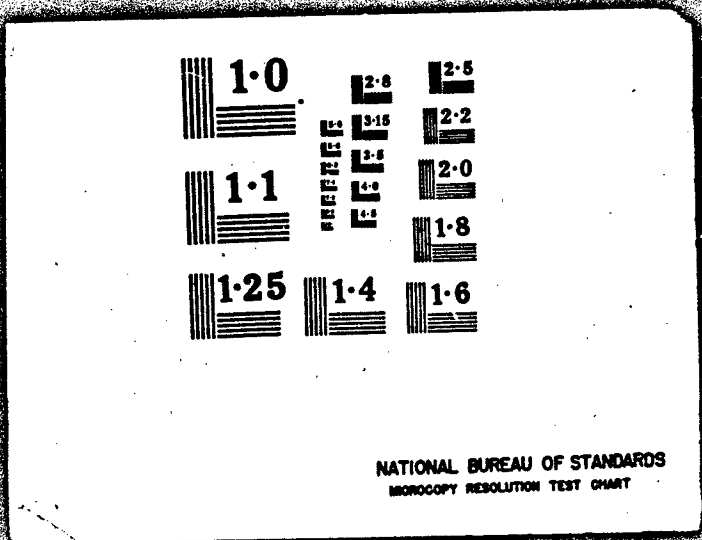

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WARHEAD MECHANISMS STUDY

FINAL REPORT

for

Periods Nov. 1, 1963 - Nov. 24, 1964
and
Nov. 1, 1963 - Nov. 24, 1964

Contract DA-33-019-ORD-3697

Cleveland Procurement District

Technical Supervisor
BALLISTIC RESEARCH LABORATORIES

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ABSTRACT

The results of basic shaped charge studies accomplished under Contract ORD 3697 are presented. Lightly confined precision shaped charges are shown to have greatly improved performance particularly at longer standoff distances. Small shaped charge studies show Scale 1 BRL charges give 87% of Scale 3 penetration and Scale 2 charges give 92% of Scale 3 penetration. It is shown that the principle cause of non-linear penetration for Scales 1, 2, and 3 is the height of explosive over the liner. Pressed RDX is shown to give greater penetration and hole volume than Cast Composition B. Copper Cones with liner wall thicknesses 2-1/2% of the liner diameter are shown to give better performance than 1-1/2% and 3-1/2%. The thinnest Aluminum liners (4.95%) gave the best performance. Aluminum and copper penetration-standoff curves cross over at 12 charge diameters standoff. The evaluation of 40 mm warheads for rapid fire system shows the penetration performance to be below optimum, and to be greatly affected by spitter initiation. Examples of the effects of loading on penetration performance are given. Methods of improving loading procedures are discussed.

In the section on spin compensation the successful development of a 152 mm spin compensating fluted liner is described. The design of a fluted 105 mm liner is described and the degrading effect of a band of explosive at the base of the liner is shown. Related studies of 40 mm fluted liners is discussed briefly.

The results of hypervelocity impact tests on composite targets are presented. Pellet energies of 140 kilojoules, 1 megajoule and 6.1 megajoules were employed against various target material and thickness combinations as well as angle of obliquity. The 140 kilojoule pellets were marginal against some targets while the other two pellet sizes substantially defeated their respective targets (at zero degree obliquity).

The mechanism of the vaporific effect was studied. Conditions were established to produce the vaporific effect at will and to measure the effect. Attempts were made to measure shock pressures. The vaporific effect was shown to be greatly reduced in a nitrogen atmosphere as compared to air.

Test facilities constructed under Contract 3697 are described.

PREFACE

This report is a combined annual and final summary report covering the period from Nov. 1, 1962 to contract completion, Nov. 24, 1964.

The report summarizes the work accomplished under major task groupings such as basic shaped charge studies, spin compensation, hypervelocity impact studies, terminal ballistics studies (Black Box) and the installation of new test facilities.

The text, tables, and figures are combined in one section for each major subject heading. The tables and figures for section I are numbered with the prefix I to identify the section and a sequence number for the order of the table or figure, i.e., table I-I is the first table in section I.

TABLES AND FIGURES

TABLES AND FIGURES

SECTION I

SECTION II

SECTION IV

SECTION V

SECTION I - BASIC SHAPED CHARGES

PRECISION CHARGES

The results of preliminary studies aimed at providing a very light-weight-rocket, shaped charge warhead were reported in the Annual Summary Report, Contract No. DA-33-019-ORD-3697 for the period ending October 31, 1962. The penetration performance for the 3.5 inch diameter, minimum weight charges patterned after the charges provided for the Tripartite Tests were much below expectations. The causes of poor performance of the assemblies were not established; however, it was decided to suspend testing with the particular designs being employed.

A new and a more fundamental program aimed at isolating some of the potential causes of poor shaped charge performance at long standoff was established. The following program was designed to investigate the effects of initiation, explosive loading, liner metallurgy, and precision of liner and assembly:

Quantity	Liner Heat Treat.	Explosives Loading	Initiation
10	As received	Ravenna	M36A1
10	" "	"	M36A1 w/M18
10	" "	"	Prima Cord
10	" "	BRL	M36A1
10	" "	"	M36A1 w/M18
10	" "	"	Prima Cord
40	" "	Penetration standoff curve.	
10	Hot Shot* Anneal	Ravenna	M36A1
10	"	"	M36A1 w/M18
10	"	"	Prima Cord
10	"	BRL	M36A1
10	"	"	M36A1 w/M18
10	"	"	Prima Cord
40	"	Penetration standoff curve.	

*65 Seconds in furnace at 1700° F. followed by water quench.

Liner Source:

All liners were 42° Eastern Tool Co. cold drawn liners supplied by BRL and machined by Firestone.

Tolerances:

Allowable wall thickness variation from liner to liner, .002 in. Allowable wall thickness variation, transverse plan of any liner not to exceed .0002 in. Concentricity of liner to charge cavity not to exceed .002 in. at cone apex.

Target Material:

Homogeneous armor - 300 BHN.

Test Conditions:

Zero spin rate and 10 charge diameter standoff.

A lightly confined 3.3 inch diameter charge (DRC-23-1642) was designed. The copper liners (DRB-23-1753) were machined inside and out from the 105mm liners manufactured by Eastern Tool Manufacturing Co. and supplied by BRL. One hundred of the liners had been flash annealed by BRL to eliminate any preferred crystal orientation in the copper. The bodies (DRB-23-1752) were machined from impact extruded aluminum bodies for the 90mm M371 HEAT Projectile. The shaped charge assembly, liner, and body details are shown in Fig. I-1, I-2 and I-3 of the Appendix following this section.

The machining, assembly and serialization of the cones and bodies were accomplished in predetermined order to preclude extraneous effects from influencing the data. The serial list is contained in the Appendix to Section I.

Detailed inspection of the liners, bodies, booster and initiator holders and the assemblies were conducted. Summary inspection data are shown (Table I-I) in the Appendix to Section I.

Precision charges were loaded with Composition B at Ravenna Army Ammunition Plant in three separate load lots of 10 each. An additional group of rounds was sent to BRL for loading and testing under duplicate conditions.

The charges were test fired at 10 charge diameter standoff using the three different methods of initiation described in the program. The results of the tests are shown in Table I-II. The test data received from BRL are shown in Table I-III.

The differences due to the method of initiation or due to liner heat treatment are not statistically significant. There is no indication that one method of initiation is better than any other method of initiation used. If the liner metallurgy has any effect on the shaped charge performance, it is so small as to be masked by other effects.

A significant difference of approximately 2 inches in depth of penetration between the Firestone loaded and BRL loaded charges is in evidence. The histogram in Fig. I-4 shows that this difference was not the result of a general shift in the level of penetration, but rather the complete absence of results below 12 inches in the BRL firings. The known difference between the test groups at BRL and Firestone is the explosive loading. Differences in the performances of the three Firestone load lots are apparent in Table I-II.

The original program calling for penetration standoff studies was suspended and explosive loading procedures were studied in an attempt to establish a loading procedure that would give uniformly high penetrations at 10 charge diameters standoff. Performance at least equal to the 17.0 inches average penetration obtained by BRL with their best 5-round sub-group was the goal.

Five charges were loaded by Firestone following as closely as possible the method used by BRL. When tested under conditions duplicating those of the first tests with primacord initiation, the average penetration was 12.7 inches with a standard deviation of 3.25 inches. These results represented no improvement over previous tests.

A second group was loaded using a method of loading developed as a result of observations made on sectioned charges described under "Experimental Explosive Loading." Eight rounds tested gave an average penetration of 17.1 inches with a standard deviation of 1.8 inches. This is equal to the best group of five shots reported by BRL and verifies the conclusion that the quality of the explosive charge is of great significance in attempting to achieve maximum effectiveness of the shaped charge. These data are shown in Table I-IV in the Appendix.

The status of hardware supplied on this project during this reporting period is as follows:

Fabrication:

200 each Charge Assemblies DRC-23-1642 were fabricated by Firestone.

Disposition:

140 each Charge Assemblies (empty metal parts) were delivered to BRL. 60 Metal parts were used for firing tests and in loading experiments.

SMALL SHAPED CHARGE STUDIES

The results of a study aimed at evaluating shaped charges .745 and .945 inches in diameter for possible use in a cluster type warhead were reported in the Annual Summary Report for the period ending November 1962. These tests and earlier scaling studies indicated that small shaped charges do not obey the scaling laws when their performance is compared to larger sizes, i.e., charges above 1.5 inches. This fact assumed greater importance because the extensive use of armored personnel carriers or other lightly armored ground and air-borne vehicles in dispersed formation has produced the need for new weapon systems which may be used to attack these vehicles from below, above or from the sides. The light armor and high mobility implies the need for a light weight, small caliber, high cyclic fire rate weapon system with the defeat of light armor as a primary consideration.

Picatinny Arsenal, therefore, funded a study program for the evaluation of shaped charges for use in small warheads and for enhancement of the performance of small shaped charge warheads. The work was assigned to Firestone under the technical supervision of the Ballistic Research Laboratories. The following program was provided:

(1) Hole volume scaling using existing BRL scale charge as follows:

Quantity	Size	Target	Standoff
5	Scale 1	370 BHN Armor	1.5 cal.
5	Scale 1	Mild Steel	"
5	Scale 2	Mild Steel	"
5	Scale 3	Mild Steel	"

Information desired: Hole volume, depth of penetration and hole profile.

(2) Diagnostic studies with 1.1 inch diameter charges to determine the effects of initiation, explosive material and loading techniques.

Quantity	Explosive	Initiation	Loader and Tester
10	RDX (Pressed)	Fig. I-8	P.A.
10	RDX (Pressed)	Fig. I-9	P.A.
10	Comp. B (Cast)	Fig. I-8	P.A.
10	Comp. B (Cast)	Fig. I-9	P.A.
10	RDX (Pressed)	Fig. I-8	Firestone
10	RDX (Pressed)	Fig. I-9	"
10	Comp. B (Cast)	Fig. I-8	"
10	Comp. B (Cast)	Fig. I-9	"

Notes:

a. All at 1.5 charge diameters standoff.

b. All into 370 BHN armor procured by Firestone. Each plate checked for hardness and stamped.

c. All metal parts fabricated and assembled by Firestone. Random sets loaded and tested by Picatinny and Firestone.

d. Standoff tubes and primacord (100 grain) supplied by Firestone.

e. Explosive head one charge diameter (1.1 inches) above theoretical cone apex.

(3) Studies to determine means of controlling hole profile.

Quantity	Liner Material	Liner Thickness % of Charge Dia.	Standoff Charge Diameters
25	Cu.	1-1/2%	1/2, 1-1/2, 2-1/2, 5, 10
25	Cu.	2-1/2%	1/2, 1-1/2, 2-1/2, 5, 10
25	Cu.	3-1/2%	1/2, 1-1/2, 2-1/2, 5, 10
25	Al.	1-1/2% x 3.3	1/2, 1-1/2, 2-1/2, 5, 10
25	Al.	2-1/2% x 3.3	1/2, 1-1/2, 2-1/2, 5, 10
25	Al.	3-1/2% x 3.3	1/2, 1-1/2, 2-1/2, 5, 10
25	Al.-Zn.	Selected	1/2, 1-1/2, 2-1/2, 5, 10

With reference to Part 1 of the program, the scaling studies were conducted into mild steel with standard cylindrical, geometrically-scaled, shaped charge test assemblies previously designed and employed for a BRL scaling study. The test assemblies for scale 1, 2, and 3 are shown in the Appendix in Figures I-5, I-6, and I-7 respectively.

The penetration, hole diameter vs. percent of penetration, and the hole volume for scale 2 and 3 charges are equivalent to each other in non-dimensional terms. The penetration of the scale 2 charge was 96% and the volume was 92% of that expected on the basis of linear scaling. The scale 1 charges did not produce equivalent depth of penetration or hole volume. The depth of penetration was only 87% of the scaled down penetrations produced by the scale 2 and scale 3 charges. The volume of an average hole was .166 cubic inches, or only 60% of what could be expected if linear scaling prevailed. The penetration test data are shown in Table I-V in the Appendix.

In an attempt to determine the cause of non-linearity performance of scale 1 charges, a series of tests were made with scale 1 charges with double length bodies and charges to evaluate the possibility that insufficient explosive head was the cause of poor performance in the smaller chargers. It was reasoned that an absolute minimum length of charge was required for steady state detonation to occur and that in the smaller charges the scaled head of explosive was below the minimum absolute value for Comp. B. The results of this test tend to confirm this conclusion since the penetration and hole volume of this charge was equivalent to that of the scale 2 and scale 3 charges as shown in Table I-V. The hole shape is somewhat different as the entrance diameter for the long charges was substantially smaller than for the short charges. No explanation of this phenomena can be made at this time.

With reference to Part 2 of the program, this study was designed to evaluate some of the factors which may influence the performance of small shaped charges.

The initial phase of the program is concerned with variations in explosives, loading techniques, and initiation. A shaped charge test assembly with a 1.1 inch charge diameter, a one charge diameter head of explosive and a 60° apex angle conical copper liner with a 2.5% liner wall in a heavy confinement body was chosen as the basic shaped charge mechanism. This charge assembly and the two basic methods of initiation investigated are shown in Figs. I-8 and I-9.

Eighty assemblies were manufactured and inspected. The assemblies were divided into four groups of twenty each, two groups of which were shipped to Picatinny Arsenal. A table of random numbers was used to avoid bias in the selection of charges for grouping.

Target armor plate blocks 4 in. x 4 in. x 1 in. were procured and the hardness for each block was determined and stamped on the side of the block. The hardness was in the range of 364-387 BHN, a span of only two measurement units, and since only one test per block was made, the hardness can properly be considered 375 BHN for all pieces. A total of 168 blocks were shipped to Picatinny.

The penetration and hole volume data for Composition B loaded assemblies and for pressed RDX assemblies indicate that there is no significant difference in the method of initiation. Penetrations were 3.2 inches and 3.1 inches with

Comp. B, and 3.4 inches and 3.3 inches with pressed RDX respectively for primacord and T60 initiators. These data are shown in Tables I-VI and I-VII. Tables I-VIII and I-IX continue the results of the Picatinny Arsenal tests.

In the Firestone tests the average performance with Comp. B is 3.15 inches penetration and .22 cubic inch volume as compared to 3.35 inches penetration and .24 cubic inch hole volume for pressed RDX charges. The Picatinny Arsenal tests gave 3.04 inches for Comp. B and 3.58 inches for RDX. Hole volumes were .22 and .24 cubic inch respectively. Radiographs were made of the target for each shot for hole profile, penetration depth, and volume determinations. The program will be continued to completion of part 3 as described in the second paragraph.

With reference to part 3 of the program this study was designed to measure the effects on hole profile of liner material, liner wall thickness, and standoff distance to target.

Copper liners with wall thicknesses 1.5, 2.5, and 3.5 per cent of charge diameter, Figure I-9A and aluminum liners, Figure I-9B with wall thicknesses of 5.0, 8.3, and 11 per cent were assembled and tested in the primacord initiated Assembly used in phase 2, Figure I-8. The charges were press loaded with RDX.

Three or more shots were fired at standoff distances of 1/2, 1-1/2, 3, 6, 9, and 12 charge diameters.

Targets were prepared, radiographed, and traced as in phase 2. The coordinates of the hole diameters at .1 inch intervals were read on a modified oscillograph reader which was coupled to a card punch. The punched cards were processed by an IBM 1620 computer to give detailed hole diameters and incremental hole volumes.

The penetration and hole volume data for three series of copper liners are summarized in Table I-IXA. The penetration-standoff curves are shown in Figure I-9C. Data for the aluminum liners are shown in Table I-IXB and Figure I-9D.

In general it can be concluded that thin wall liners produce slightly greater hole volumes with both copper and aluminum. For penetration the 2-1/2 and 3-1/2% copper liners were superior to the 1-1/2% liners. In the case of aluminum the thin liners gave better penetration at standoff distances greater than about 8 charge diameters.

Optimum standoff for all copper liners was about 6 charge diameters. The thin Aluminum liners gave their best penetrations at 9 charge diameters. The Aluminum liners had less rapid degradation at longer standoff distances, so that at standoff distances exceeding 12 diameters Aluminum gave equal or better penetration than copper. Hole volumes at longer standoff distances also show little difference for coppper and aluminum.

A complete and detailed project report was published on this small shaped charge study. This report was titled "Project Report on Small Caliber Shaped Charge Test Program - Firestone DRD-5".

40MM SHAPED CHARGE STUDIES

This program was commenced in October 1962 and was briefly reported in the preceding summary report.

This experimental program for the design and development of shaped charge warheads for 40mm ammunition was initiated by Picatinny Arsenal through the Ballistic Research Laboratories. The program included design and development of alternate types of shaped charge projectiles. One of the projectiles was to be a conventional gun-launched kinetic energy type projectile launched at a high spin rate. The other projectile was to be a gun-boosted, rocket-assisted projectile (GBR), also spin stabilized. The major effort was to be placed on the gun-boosted type. The principal problem insofar as either type projectile was concerned was considered to be the development of a high efficiency spin compensating shaped charge to fit in the projectile envelope dictated by aeroballistic considerations. The following predicted characteristics pertinent to warhead studies were provided by Picatinny Arsenal.

Characteristics	Conventional Type	GBR*** Type
Caliber	40mm	40mm
Standoff	2.3 in.	2.5 in.
Charge Length	2.0 in.	1.0 in.
Spin Rate	570 rps**	436 rps*
Initiation		Spit Back Fuze
Charge Diameter	1.40 in.	1.40 in.

*Constant spin rate.
**Will degrade approximately 100 rps over usable range.
***Gun boosted rocket.

The program for the development of the 40mm spin compensating warhead was as follows:

I. Preliminary Studies:

Fabricate hardware and conduct static tests for penetration and hole profile for both types of warheads with smooth liners.

II. Liners:

(a) Depending on results of fuze tests may need to conduct additional smooth liner tests for selection and verification of spit-back fuze element.

(b) Evaluate fluted liner design for optimum spin rate (simple conical shape).

(c) Adjust fluted liner design to give desired optimum spin rate. This may involve adjustment of the wall thickness and/or index angle using existing tooling, and it may involve the fabrication of new tooling if a new flute depth is desired.

(d) When the basic fluted liner design is established modify liners by equipping them with spit-back tubes established in Part II, and evaluate statically by initiating with an electric detonator from the rear. This test should include flash radiographs.

(e) Evaluate the same charge as (d) above by initiating through spit-back tube with spitter type initiator. Firing will be by high voltage source to jump charge to electric detonator used to initiate the spitter.

III. Fuze Type Evaluation:

(a) Fire penetration test with spitter type initiator to evaluate ability to initiate charge detonation through various size spit-back tubes, and to obtain penetration performance for each charge.

(b) From above, select best spit-back tube size and repeat above test with smooth control vs. spin compensating liner with spit-back tubes.

(c) If necessary, conduct tests with spitter elements to improve spitter performance. This may include evaluation of materials and shape.

IV. Basic Shaped Charge Studies:

Studies of detonation velocities and shaped charge performance as affected by explosive head, explosive type (RDX vs. Comp. B), confinement, dimensional integrity, and cone angle. Diagnostic tests such as flash radiography of jets to evaluate performance of fluted liner, penetration velocity tests, etc. will be conducted as required within the limitation of the funds provided.

Preliminary Studies:

Penetration tests of the basic shaped charges for the GBR and conventional type projectiles were conducted into homogeneous armor (290 BHN). The GBR test assembly (DRC 23-1591-1) is shown in Fig. I-10 and the conventional test assembly (DRC 23-1540-1) is shown in Fig. I-11.

The GBR type charges with smooth liners equipped with spitback tubes gave 2.9 inches of penetration with a large dispersion. Five conventional type charges (smooth non-compensating liners with a conical apex) gave an average penetration of 4.2 inches. It was not determined whether the differences in performance were due to the cone design, body shape, head of explosive charge, differences in loading or other criteria.

The individual test data are shown in the following table:

40mm Penetration Data - Non-Spinning

Round No.	Charge Type	Liner Type	Standoff (inches)		Penetration (inches)
1	GBR	Conical with	3.25		2.5
2	"	Spitback Tube	-		4.5
3	"				1.8
4	"				3.9
5	"				2.1
6	"				2.6
				Average	2.9
				Maximum	4.5
				Minimum	1.8
				σ	.97
18	Conventional	Conical	3.25		4.9
19	"	"			5.6
20	"	"			3.4
21	"	"			3.6
22	"	"			3.4
				Average	4.2
				Maximum	5.6
				Minimum	3.4
				σ	.90

Target Material	Homo. Armor 290 BHN
Charge	Comp. B - Holston Lot 4-1197
GBR Type	DRC-23-1591-1
Conventional	DRC-23-1540-1

Diagnostic tests of proposed 40mm shaped charges were conducted to suggest ways of improving the basic shaped charge design independently of spin compensation studies.

A test of smooth conical liners in conventional-round assemblies which had been modified for improved component alignment showed no improvement in penetration. The average penetration was 4.3 inches as compared to 4.2

inches in the previous test.

Marked improvement in the performance of the conventional type projectile was achieved by increasing the end confinement. This was accomplished by cementing a .100 inch thick steel ring ahead of the liner flange. The average penetration for this group was 5.0 inches with less than .2 inch standard deviation.

The GBR configuration was tested with smooth conical liners (no spitback tube). The penetration was greatly improved. The average penetration was 5.8 inches and the standard deviation, .2 inches.

The detailed penetration data for the above diagnostic tests are shown in the following table:

Item	Special Feature		Penetration
Conventional Charge with Smooth Conical Liner.	Improved Alignment		4.9
			3.9
			3.1
			4.1
			5.4
		Average	4.3
		σ	.8
Conventional Charge with Smooth Conical Liner.	Added End Confinement (.100 thickness of steel)		5.4
			4.6
			5.3
			5.4
			4.3
		Average	5.0
		σ	.2
GBR Type Charge with Smooth Conical Liner.	No Spitback Tube		5.5
			5.9
			5.6
			6.1
			5.9
		Average	5.8
		σ	.2

Fluted Liners:

A fluted liner design based on scale 2 flute depth studies was made for the 40mm GBR type projectile. Liner DRC-23-1620-1 is shown in Fig.

I-12. The spin rate at optimum performance for this liner was predicted to be 490 rps.

Fifteen rounds were tested in 290 BHN armor and eighteen additional tests were made in mild steel to establish the optimum spin rate. The results of these tests indicate the optimum spin rate to be between 450 and 500 rps. The wide dispersion in the data indicated possible imperfections in loading, although X-rays of the charges did not show cavitation or extensive porosity. Additional rounds were carefully assembled and loaded. They were tested against mild steel at 465 and 493 rps. The results indicated improved performance and optimization of the charge at approximately 465 rps.

Smooth liners tested at 465 rps gave penetrations approximately one-half that of the compensated liners at the same spin rate. Smooth liners, tested at zero spin rate into mild steel, gave about 7 inches or about 5.7 charge diameters.

The test data for the above evaluations are contained in Tables I-X, I-XI, I-XII, and I-XIII of Section I Appendix. The penetration vs. spin rate data are graphically presented in Fig. I-13 of the Appendix, Section I. The 42° fluted liner employed in these tests is shown in Fig. I-12 of Section I Appendix.

Additional tests were made with fluted liners DRC-23-1620-1 in GBR bodies and explosive loaded to an improved casting technique. The tests were at various spin rates between 435 and 480 rps into mild steel target material. The dispersion in the data is substantially reduced and the level of penetration is generally improved; however, the optimum frequency is not clearly defined. The penetration of smooth control liners at zero rps was 7.7 inches and the average penetration from 450 to 480 rps was 4.0 inches. The detailed data for this load lot is shown in Table I-XIV of Section I Appendix.

Fuzing Effects:

Tests were conducted to determine the effect of spitback tube size in the shaped charge performance of the GBR type warhead. Copper liners (42°) with 1/4 in., 3/8 in., and 1/2 in. diameter spitback tubes were assembled in GBR bodies and Comp. B loaded. Tests were also conducted to determine the effect of initiating the charge with a spitter type as compared to initiation with an M36A1 detonator located to the rear of the charge. The summary data are shown in the following tabulation:

Comparison of Effect of Spitback Tube

Spitback Tube Diameter (inches)	Penetration(In.) Base Initiation	Spitter Initiation
1/4 in. Original Test	4.4	
3/8 in. " "	3.7	
1/2 in. " "	2.5	
1/4 in. Repeat	6.7	4.6
3/8 in. "	* 6.7	4.0
1/2 in. "	6.7	3.9

Note: Target Material - Homo Armor (290 BHN)
Standoff - 3.25 inches
* Does not include one low reading

From the above summary and from the detailed data shown in Table I-XVit appears that the first evaluation of the effect of spitback tube size was invalid. Although X-ray inspection of the charges indicated that they were sound casts, it is believed some defect in the charges produced the low level of penetration achieved with the larger diameter spitback tubes. The size of the spitback tube and its effect on the cooling rate of the charge is probably related to the quality of the charge. An improved loading procedure was employed on charges for the repeat tests.

Spitter initiation produced a reduction in performance of approximately 40 per cent. The assemblies employed for this series of tests are shown in Figs. I-11 and I-14. The spitter assembly is shown in Fig. I-15. Table I-XVI presents the detailed results of the spitter tests.

The Final Report on 40 mm Shaped Charge Studies, Firestone Report No. DRD-9 has been published. This report describes the test program and results in detail. The general conclusions are as follows:

1. The GBR projectile design is not an optimum shaped charge design.

2. Spitback fuzing systems tested were inadequate.

3. A loss in penetration performance of approximately 40% was shown for the spitter initiated charges of the GBR design over that for base initiated charges of the same projectile design.

4. Spin compensation for the spin rates required for this item is within the state of the art.

EXPERIMENTAL EXPLOSIVE LOADING

This subject was not reported on in the preceding annual report. The extreme importance of the quality of the explosive charge has become apparent as a result of studies with precision shaped charges and small caliber charges where the effects of assymetries and other degrading conditions are magnified by a scaling effect.

Background:

In striving to reduce the assymetries of the metal components to an absolute minimum for the Precision Charge Program and the Small Caliber Shaped Charge Program, a degree of precision approximately an order of magnitude greater than before has been achieved. The precision charges (3.3 in. dia.) are equipped with liners whose wall thickness variations in any transverse datum plane are less than .0002 in. The axial eccentricity of the liner to the charge is less than .001 in. The small caliber charges are equally precise. The vastly improved quality of the hardware now permits a recognition of the effects of explosive loading whereas this effect was masked by gross axial assymetries in the hardware of the past.

Two particular instances of the serious effects of explosive loading have demonstrated the need for continued research aimed at improvement of the explosive charge. The two instances are the effects of the loading demonstrated in the precision charge program, and the effect of loading on the evaluation of spitback tube size in the 40mm program reported in the previous section. These comparisons are summarized below by load lots.

Component	Penetration - in. - 300 BHN Armor			
(a) Precision 3.3 in. dia. Metal Parts, DRC-1642	14.2(1) σ 1.9	17.0(2) σ 1.2	12.7(3) σ 3.2	17.3(4) σ 1.3
(b) 40mm DRC-1591 W/1/4" Spitback Tube	4.4 σ 1.4	6.7 σ .5		
W/3/8" Spitback Tube	3.7 σ .5	5.3 σ 2.8		
W/1/2" Spitback Tube	2.5 σ .4	6.7 σ .1		

Notes:

(a) Precision charges are:
- (1) Original Firestone load lot.
- (2) BRL original load lot - best of 6.
- (3) Firestone attempt to apply BRL loading procedure.
- (4) Firestone improved loading procedure.

All at 10 charge diameters standoff.

(b) 40mm Charges - 2 separate load lots tested at 3.25 inches standoff.

Objective:

As a result of the gross effect of the explosive charge experienced in the Precision Charge Program and other programs, it was decided to conduct a continuing parallel research and development study to characterize a good cast Composition B explosive charge and establish loading procedures and inspection techniques to produce and identify good charges.

Work Accomplished:

A series of explosive charges including samples of (1), (3) and (4) of precision charges shown in the above tabulation were radiographed, then sectioned, polished and examined for porosity, crystalline structure, color, and other characteristics. The radiographs revealed no differences in the charges; however, the polished sections revealed differences in the color, crystal size, crystal orientation, tendency to crack, and dendrite patterns. The differences result from variations in preheat temperatures of the metal components, melt temperatures, cooling rates, control of heat flow, type of riser, presence of a break-off plate, body material and thickness, and other factors.

Although our studies to date have resulted in limited quantitative results, qualitatively it appears at this time that close-grained charges are superior in performance to coarse-grained castings. Small close-grained castings are inclined to numerous small radial shrinkage cracks. However, this does not appear to affect the performance. The close-grained structure is achieved by rapid controlled cooling which undoubtedly induces internal stresses that result in the cracks.

Explosive Loading - Recommended Forward Program:

Continued experimentation with loading variables to achieve charges that will produce uniformly good performance when used with precision metal component assemblies.

The program of sectioning and polishing the charges should be continued in an attempt to better characterize the charges. Photomicrograph techniques for quantitatively and qualitatively presenting the results of such studies should be considered.

Pressed explosive loading will be employed for smaller charges such as the 1.1 in. dia., 30 mm and 40 mm charges. Press loading will be considered as a means of insuring uniform density about the longitudinal axis of the charge.

SERIAL LIST

The 100 unannealed liners received from BRL were serialized from 1 to 100 and the 100 flash annealed liners were serialized from 1A to 100A. The liners were carried through each machining operation in serial order, alternating annealed and unannealed pieces.

The six machining operations were:

(1) Remove flange and cut to length.
(2) Rough machine inside.
(3) Rough machine outside.
(4) Finish machine inside.
(5) Finish machine outside.
(6) Cut new flange and finish base.

The assemblies were divided into three groups for loading, as follows:

For loading at Ravenna - Odd serial numbers from 1 through 61 and 1A through 61A.

For loading at BRL - Even numbers 2 through 70 and 2A through 70A.

Balance retained, and subsequently shipped to BRL.

The charges loaded at Ravenna were loaded in six load lots, as follows:

Load Lot Number	Serial Numbers
1	1, 1A; 3, 3A; 5, 5A; 7, 7A; 9, 9A; 21, 21A; 23, 23A; 25, 25A; 27, 27A; 29, 29A; 41, 41A; 43, 43A; 45, 45A; 47, 47A; 49, 49A; 11, 11A; 13, 13A; 15, 15A; 17, 17A; 19, 19A; 31, 31A; 33, 33A; 35, 35A; 37, 37A; 39, 39A; 51, 51A, 53, 53A; 55, 55A; 57, 57A; 59, 59A.

The rounds were regrouped for testing after loading, as follows:

Test Group No.	Initiation Method	Serial Numbers
1	M36A1	1, 1A, 3, 3A; 21, 21A; 23, 23A; 41, 41A
2	M36A1 & M18	5, 5A; 7, 7A; 25, 25A, 43, 43A; 45, 45A
3	Primacord	9, 9A; 27, 27A; 29, 29A; 47, 47A; 49, 49A
4	M36	11, 11A; 13, 13A; 31, 31A, 33, 33A; 51, 51A
5	M36A1	15, 15A; 17, 17A; 35, 35A; 53, 53A; 55, 55A
6	Primacord	19, 19A; 37, 37A; 39, 39A; 57, 57A; 59, 59A

Groups 1, 2, and 3 were tested by firing a pair of each group in sequential order, i. e., 1, 1A; 5, 5A; and 9, 9A.

TABLE I-I

Inspection Summary Data
42" Smooth Wall Liners
DRB-23-1753

LINERS

Finished Weight:

	Flash Annealed	As Drawn
Average	278.0 grams	278.0 grams
Std. Dev.	3.7 grams	2.6 grams

Average Wall Thickness Variation:

	Flash Annealed		As Drawn	
	.412(1)	2.85(1)	.412(1)	2.85(1)
Average	.00018"	.00021"	.00027"	.00022"
Std. Dev.	.00008"	.00013"	.00018"	.00016"

Notes:

(1) Transverse datum plane location - inches from the cone base.
(2) Detailed inspection data was acquired for each liner and the data is available at Firestone.

ASSEMBLIES

Concentricity liner I. D. to body I. D.:

Serial Range		Concentricity 3.705 Datum	Concentricity 1.125 Datum
Odd annealed liner assemblies from 1A to 59A inclusive (i.e., 1A, 3A, 5A, etc.)	Avg.	2.1 mils	2.1 mils
	Max.	3.5	3.4
	Min.	1.0	.8
Odd unannealed assemblies from 1 to 59 inclusive (i.e., 1, 3, 5, etc.)	Avg.	1.65 mils	1.73 mils
	Max.	3.50	4.00
	Min.	1.00	.70
Even annealed liner assemblies from 2A to 60 A inclusive	Avg.	1.84 mils	1.84 mils
	Max.	3.50	3.50
	Min.	.80	.80
Even unannealed liner assemblies from 2 to 60 inclusive	Avg.	1.77 mils	1.68 mils
	Max.	3.50	4.50
	Min.	.70	.80

TABLE I-I (pg. 2)

Numerical sequence of annealed liner assembly 61A - 100A inclusive	Avg.	1.42 mils	1.51 mils
	Max.	3.20	2.60
	Min.	.60	.50
Numerical sequence of unannealed liner assemblies 61 - 100 inclusive	Avg.	1.28 mils	1.58 mils
	Max.	2.40	2.50
	Min.	.50	.50

Explosive Loaded Assemblies:

Load Lot	Preheat Temp.	Melt Temp.	Serial Numbers	Loaded Weight (lbs.)	Explosive Charge (lbs.)
1	140° F.	181° F.	Odd 1-9 incl. and Odd 1A-9A incl.	3.59 Avg. 3.60 Max. 3.56 Min.	1.79 Avg. 1.80 Max. 1.77 Min.
2	148° F.	179° F.	Odd 21-29 incl. and Odd 21A-29A incl.	3.60 Avg. 3.62 Max. 3.59 Min.	1.79 Avg. 1.80 Max. 1.79 Min.
3	130° F.	184° F.	Odd 41-49 incl. and Odd 41A-49A incl.	3.60 Avg. 3.60 Max. 3.59 Min.	1.79 Avg. 1.80 Max. 1.79 Min.
4	140° F.	185° F.	Odd 11-19 incl. and Odd 11A-19A incl.	3.59 Avg. 3.61 Max. 3.56 Min.	1.79 Avg. 1.80 Max. 1.78 Min.
5	110° F.	181° F.	Odd 31-39 incl. and Odd 31A-39A incl.	3.59 Avg. 3.60 Max. 3.55 Min.	1.80 Avg. 1.80 Max. 1.79 Min.
6	-	185° F.	Odd 51-59 incl. and Odd 51A-59A incl.	3.58 Avg. 3.59 Max. 3.57 Min.	1.78 Avg. 1.79 Max. 1.76 Min.

TABLE I-II

Initiator Penetration Test Data
(Firestone)

Charge: Firestone 3.3 inch DRC-23-1642
Standoff: 10 Charge Diameters
Target: 300 BHN Armor
Explosive: Cast Comp. B. Lot Hol. 4-1197
Batch No. 4-902

		Initiator			
		M36A1 (in.)	M36A1 M18	Primacord	All
Unannealed Liner		12.1 ○	9.1 ○	---- ○	
		8.8 ○	12.1 ○	14.9 □	
		17.8 □	11.8 □	17.1 □	
		15.1 □	16.2 ▽	12.5 ▽	
		11.9 ▽	18.5 ▽	14.4 ▽	
	$\bar{x}$	13.1	13.5	14.2	13.6
	σ	3.1	3.4	1.9	2.9
Annealed Liner		17.5 ○	12.9 ○	18.4 ○	
		10.9 ○	11.9 ○	13.9 □	
		14.2 □	18.1 □	13.5 □	
		9.5 □	---- ▽	16.1 ▽	
		10.7 ▽	16.5 ▽	16.3 ▽	
	$\bar{x}$	12.6	14.8	14.4	13.9
	σ	2.9	2.5	2.7	2.9
	$\bar{x}$	12.8	14.1	14.3	13.7
	σ	2.9	3.1	2.4	2.9

Load Lot		1 ○	2 □	3 ▽
	$\bar{x}$	12.6	14.6	13.9
	σ	3.1	2.5	2.8

TABLE I-III

Initiator Penetration Test Data
(Ballistic Research Laboratories)

Charge:	Firestone 3.3 inch DRC-23-1642
Standoff:	10 Charge Diameters
Target:	300 BHN Armor
Explosive:	Cast Comp. B

		Initiator			
		M36A1 (in.)	M36A1 M18	Primacord	All
Unannealed Liner		13.1	13.1	14.1	
		14.9	15.0	15.0	
		15.5	15.1	15.9	
		16.0	16.3	16.8	
		16.7	17.3	16.0	
	$\bar{x}$	15.2	15.4	15.6	15.4
	σ	1.2	1.4	.9	1.2
Annealed Liner		12.6	14.1	15.1	
		15.6	14.2	16.5	
		15.8	15.1	16.9	
		15.9	16.2	18.3	
		16.1	16.7	18.4	
	$\bar{x}$	15.2	15.3	17.0	15.8
	σ	1.3	1.0	1.2	1.5
	$\bar{x}$	15.2	15.3	16.3	15.6
	σ	1.3	1.2	1.3	1.9

TABLE I-IV

Penetration Test Data
(Explosive Loading Comparison)

Charge:	Firestone 3.3 inch DRC-23-1642
Standoff:	10 Charge Diameters
Target:	300 BHN
Explosive:	Cast Comp. B Lot Hol. 4-1197, Batch No. 4-902
Loading Procedure:	(1) BRL procedure as observed and applied by Firestone test engineer.
	(2) New Firestone procedure.

(1) Firestone application of BRL loading method:

Charge Serial	Penetration Depth - in.	$\bar{x}$	σ
55	16.4		
59	16.9		
59A	9.9		
31A	9.6		
57A	10.6		
		12.7	3.25

(2) New loading procedure:

Charge Serial	Penetration Depth - in.	$\bar{x}$	σ
11	18.4		
19	13.8		
11A	17.9		
19A	18.1		
31	18.1		
13	14.9		
13A	16.5		
17	18.8		
		17.1	1.8

TABLE I-V

Penetration Test Data
Scale 1, 2, 3 BRL Charges

Item	Penetration (in.)	Scalar Value / Actual Value (per cent)	Hole Volume (cu. in.)	Scalar Value / Actual Value (per cent)
Scale 1	4.4 Avg. 4.6 Max. 4.1 Min. .2 Std. Dev.	87	.1657	60
Scale 1 Double Charge Length	5.1 Avg. 5.4 Max. 4.9 Min. .2 Std. Dev.	101		
Scale 2	9.7 Avg. 9.9 Max. 9.5 Min. .2 Std. Dev.	96	2.0768	92
Scale 3	15.1 Avg. 15.7 Max. 14.1 Min. .7 Std. Dev.	100	7.6039	100

Target Material: Mild Steel

Standoff: 1.5 Calibers

Charge: Comp. B - Holston Lot 4-1197

TABLE I-VI

Penetration and Hole Volume Data

1.1 inch Dia. Shaped Charge
DRC-23-1685 and DRC-23-1686
(Comp. B Charge)

DRC-23-1685

Serial No.	Initiation	Penetration (in.)	Hole Volume (cu. in.)
87	Primacord	3.2	.22
78	"	3.4	.22
15	"	3.4	.23
42	"	3.0	.22
56	"	3.2	.23
70	"	3.3	.23
35	"	3.1	.23
59	"	3.4	.22
24	"	3.0	.24
55	"	2.9	.23
Average		3.2	.23
Standard Deviation		.2	.01

DRC-23-1686

Serial No.	Initiation	Penetration (in.)	Hole Volume (cu. in.)
12	T 60	3.1	.22
69	"	3.1	.20
34	"	3.2	.20
51	"	3.1	.21
61	"	3.1	.21
29	"	3.1	.20
84	"	3.3	.21
40	"	3.0	.21
72	"	3.2	.21
Average		3.1	.21
Standard Deviation		.1	.01

Target: 375 BHN Armor

Standoff: 1.5 Charge Diameters

TABLE I-VII

Penetration Data

1.1 Inch Diameter Shaped Charge
DRC-23-1685 and DRC-23-1686
(RDX Charge)

DRC-23-1685

Serial No.	Initiation	Penetration (in.)	Hole Volume (cu. in.)
19	Primacord	3.6	.23
58	"	3.3	.24
54	"	3.4	.25
73	"	3.4	.24
79	"	3.2	.24
28	"	3.4	.22
86	"	3.2	.24
31	"	3.3	.22
52	"	3.6	.23
93	"	3.3	.24
Average		3.4	.24
Standard Deviation		.1	.00

DRC-23-1686

Serial No.	Initiation	Penetration (in.)	Hole Volume (cu. in.)
46	T 60	3.3	.24
13	"	3.1	.24
76	"	3.1	.26
26	"	2.9	.24
53	"	3.4	.22
65	"	3.3	.24
63	"	3.6	.25
16	"	3.7	.25
81	"	3.2	.24
Average		3.3	.24
Standard Deviation		.2	.01

Target: 375 BHN Armor

Standoff: 1.5 Charge Diameters

TABLE I-VIII

Initiator-Penetration Test (Picatinny)
Primacord Vs. T60 (Comp. B)

PA Shot	FTR Body No.	Explosive Type	Initiator	Pellet No.	Det. Hold No.	Total Penetration (in.)	Total Hole Vol. (Cu. in.)
1	14	Comp. B	Primacord	71	1	3.15	.257
2	17	"	"	72	3	3.15	.219
3	18	"	"	73	8	3.15	.226
4	20	"	"	74	9	3.15	.226
5	21	"	"	75	11	3.15	.234
6	23	"	"	76	13	Low Order	
7	25	"	"	78	16	3.15	.235
8	27	"	"	79	17	3.15	.246
9	30	"	"	80	19	2.95	.234
10	32	"	"	81	24	3.05	.220
11	33	"	T60	2	33	2.85	.219
12	36	"	"	3	36	3.05	.215
13	37	"	"	4	39	2.95	.215
14	38	"	"	5	45	2.95	.207
15	39	"	"	9	51	2.95	.212
16	41	"	"	38	54	2.95	.216
17	43	"	"	51	56	2.95	.214
18	44	"	"	52	61	3.05	.202
19	45	"	"	56	62	2.95	.216
20	47	"	"	57	68	2.85	.216

TABLE I-IX

Initiator-Penetration Test (Picatinny)
Primacord Vs. T60 (RDX)

PA Shot	FTR Body No.	Explosive Type	Initiator	Pellet No.	Det. Hold No.	Total Penetration (in.)	Total Hole Vol. (cu. in.)
21	48	RDX	Primacord	82	25	3.65	.269
22*	49	"	"	83	28	2.15	.261
23*	50	"	"	84	29	2.30	.243
24*	57	"	"	85	30	2.40	.241
25	60	"	"	86	31	3.60	.230
26	62	"	"	87	33	3.70	.233
27	64	"	"	88	37	3.60	.226
28	66	"	"	89	39	3.55	.233
29	67	"	"	90	40	3.75	.236
30	68	"	"	91	41	3.65	.229
31	71	"	T60	66	69	3.70	.229
32	74	"	"	72	72	3.50	.243
33	75	"	"	74	77	3.60	.239
34	77	"	"	75	78	3.60	.246
35	80	"	"	80	79	3.60	.221
36	83	"	"	81	81	3.50	.233
37	85	"	"	82	84	3.55	.220
38	88	"	"	89	85	3.50	.239
39	89	"	"	91	87	3.40	.241
40	91	"	"	92	88	3.45	.240

* Excluded from later statistical analysis because not tested at 1-1/2 CD standoff.

TABLE I-IX A

PENETRATION and HOLE VOLUME vs. STANDOFF
1.1-inch Shaped Charge, RDX Explosive
Dwg. No. DRC-23-1685

RDX Loaded 1.1 inch Shaped Charges DRC-23-1685 with 60° Copper Liners. Target: Armor 370 BHN

Standoff (chg.diam.)	Wall Thickness (per cent)	Penetration (in.)			Hole Volume (cu.in.)		
		Max.	Min.	Avg.	Max.	Min.	Avg.
1/2	1.5	2.3	2.2	2.3	.22	.21	.21
	2.5	2.6	2.5	2.6	.26	.23	.25
	3.5	2.5	2.4	2.4	.23	.21	.22
1-1/2	1.5	3.3	3.0	3.1	.23	.20	.21
	2.5	3.3	3.1	3.2	.24	.21	.22
	3.5	3.0	2.9	3.0	.22	.21	.21
3	1.5	3.8	3.2	3.5	.21	.19	.20
	2.5	4.6	4.5	4.5	.20	.18	.19
	3.5	4.2	3.9	4.1	.19	.18	.18
6	1.5	4.2	3.7	4.0	.20	.19	.20
	2.5	4.9	4.6	4.8	.19	.18	.18
	3.5	5.1	4.6	4.8	.16	.15	.16
9	1.5	3.7	2.4	3.2	.20	.15	.18
	2.5	4.6	3.1	3.7	.19	.17	.18
	3.5	4.9	3.2	4.2	.18	.14	.15
12	1.5	3.2	2.4	2.7	.17	.16	.17
	2.5	2.9	1.8	2.3	.18	.15	.17
	3.5	3.0	2.4	2.8	.17	.15	.16

TABLE I - IX B

PENETRATION and HOLE VOLUME vs. STANDOFF
1.1-inch Shaped Charge, RDX Explosive
Dwg. No. DRC-23-1685

RDX Loaded 1.1 inch Shaped Charges DRC-23-1685 with 60° Aluminum Liners. Target: Armor 370 BHN

Standoff (chg.diam.)	Wall Thickness (per cent)	Penetration (in.)			Hole Volume (cu.in.)		
		Max.	Min.	Avg.	Max.	Min.	Avg.
1/2	5.0	1.1	1.0	1.1	.27	.23	.25
	8.3	1.2	1.1	1.2	.27	.26	.27
	11.0	1.1	1.1	1.1	.23	.20	.21
1-1/2	5.0	1.6	1.6	1.6	.29	.27	.28
	8.3	1.6	1.6	1.6	.24	.22	.23
	11.0	1.6	1.6	1.6	.22	.22	.22
3	5.0	2.3	2.3	2.3	.26	.23	.24
	8.3	2.3	2.2	2.2	.23	.21	.22
	11.0	2.2	2.2	2.2	.22	.19	.21
6	5.0	3.0	2.9	3.0	.23	.20	.22
	8.3	3.0	2.8	2.9	.19	.18	.19
	11.0	2.6	2.5	2.5	.16	.15	.15
9	5.0	3.4	3.2	3.3	.19	.18	.18
	8.3	2.9	2.7	2.8	.16	.15	.15
	11.0	2.8	2.4	2.6	.16	.15	.15
12	5.0	3.2	2.9	3.0	.20	.16	.18
	8.3	-	-	-	-	-	-
	11.0	2.3	2.2	2.2	.14	.13	.13

TABLES I-X AND I-XI

Penetration Into Mild Steel and Armor
40mm Fluted Liner - 3.25 in. Standoff
Liner Dwg. No. DRC-23-1620-1

Spin Rate (rps)	Table I-X Penetration (in.) Mild Steel	Table I-XI Penetration (in.) Homo Armor*
400	1.6	0.8
410	1.9	-
420	2.8	1.5
430	2.2	1.1
430	-	1.2
430	-	2.1
440	2.6	1.5
450	1.9	-
460	3.1	-
460	3.0	-
464	3.8	-
464	2.6	-
467	1.9	-
470	3.4	1.8
470	1.8	1.0
475	1.9	-
480	2.1	-
489	2.7	-
490	2.3	1.9
490	-	1.6
490	-	0.9
510	1.6	-
520	-	1.1

*290 Brinell Number

TABLE I-XII

40MM FLUTED LINERS (DRC-23-1620-1)
SECOND LOAD LOT AGAINST
MILD STEEL TARGET AT 3.25 INCH STANDOFF

SPIN RATE (rps)	PENETRATION (in.)
465	4.1
465	4.0
465	4.2
493	3.8
493	2.9

TABLE I-XIII

SMOOTH LINER PENETRATION OF
MILD STEEL AT 3.25 INCH STANDOFF

SPIN RATE (rps)	PENETRATION (in.)
0	6.8
0	6.8
0	7.7*
467	1.7
467	2.1
465	1.9*

*Second load lot.

TABLE I-XIV

40MM FLUTED LINERS (DRC-23-1620-1)
THIRD LOAD LOT AGAINST
MILD STEEL TARGET AT 3.25 INCH STANDOFF

SPIN RATE (rps)	LOAD LOT	PENETRATION (in.)
435	3	3.9
435	3	3.9
450	3	4.2
450	3	3.9
450	3	3.6
460	3	4.1
470	3	3.8
480	3	3.7
480	3	4.3
480	3	4.3

TABLE I-XV

EFFECT OF SPITBACK TUBE DIAMETER AND METHOD OF INITIATION

Test No.	Spitback Tube Dia. - in.	Initiator	Penetration H. A. Inches	Penetration H. A. Avg.
1	1/4"	M36A1 (Base)	5.1	
			5.5	
			5.0	
			2.1	4.4
				*5.2
	3/8"	M36A1 (Base)	4.5	
			3.8	
			3.1	
			3.5	3.7
	1/2"		2.5	
			3.0	
			2.1	
			2.2	2.5
2	1/4"		7.1	
			6.1	
			7.0	6.7
	3/8"		6.5	
			6.8	6.7
	1/2"		6.8	
			7.1	
			6.2	6.7
3	1/4"	Spitter	3.8	
			5.4	4.6
	3/8"		4.3	
			3.6	4.0
	1/2"		3.4	
			4.4	3.9

Note: Target - Homogeneous Armor BHN 290
*Average neglecting maverick value of 2.1 in.
Explosive - Comp. B

TABLE I-XVI

40MM SPITBACK INITIATION
40MM SHAPED CHARGES

COMPARISON OF EFFECT OF SPITBACK TUBE DIAMETER AND METHOD OF INITIATION ON PENETRATION OF ARMOR AT 3.25 INCHES STANDOFF

LINER DWG. NO. DRC-1620

	Penetration	
Spitback Tube (dia.)	Base Initiation (in.)	Spitter Initiation (in.)
1/4 in.	7.1	3.8
	6.1	5.4
	7.0	
3/8 in.	6.5	4.3
	2.6	3.6
	6.8	
1/2 in.	6.8	3.4
	7.1	4.4
	6.2	

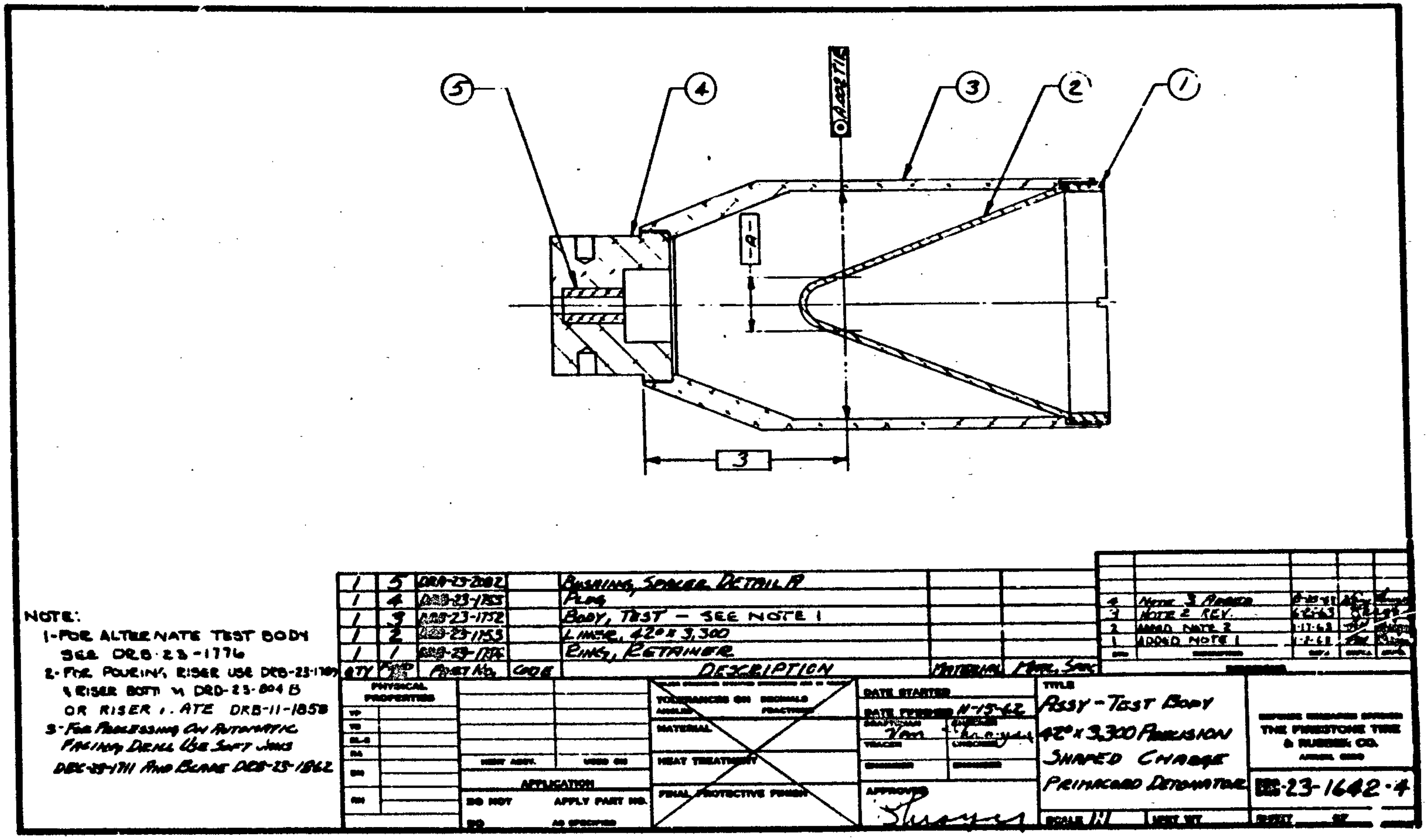


Fig. I-1. Test Body Assembly - 42° x 3.300 in. Precision Shaped Charge.
Dwg. No. DRC-23-1642-4.

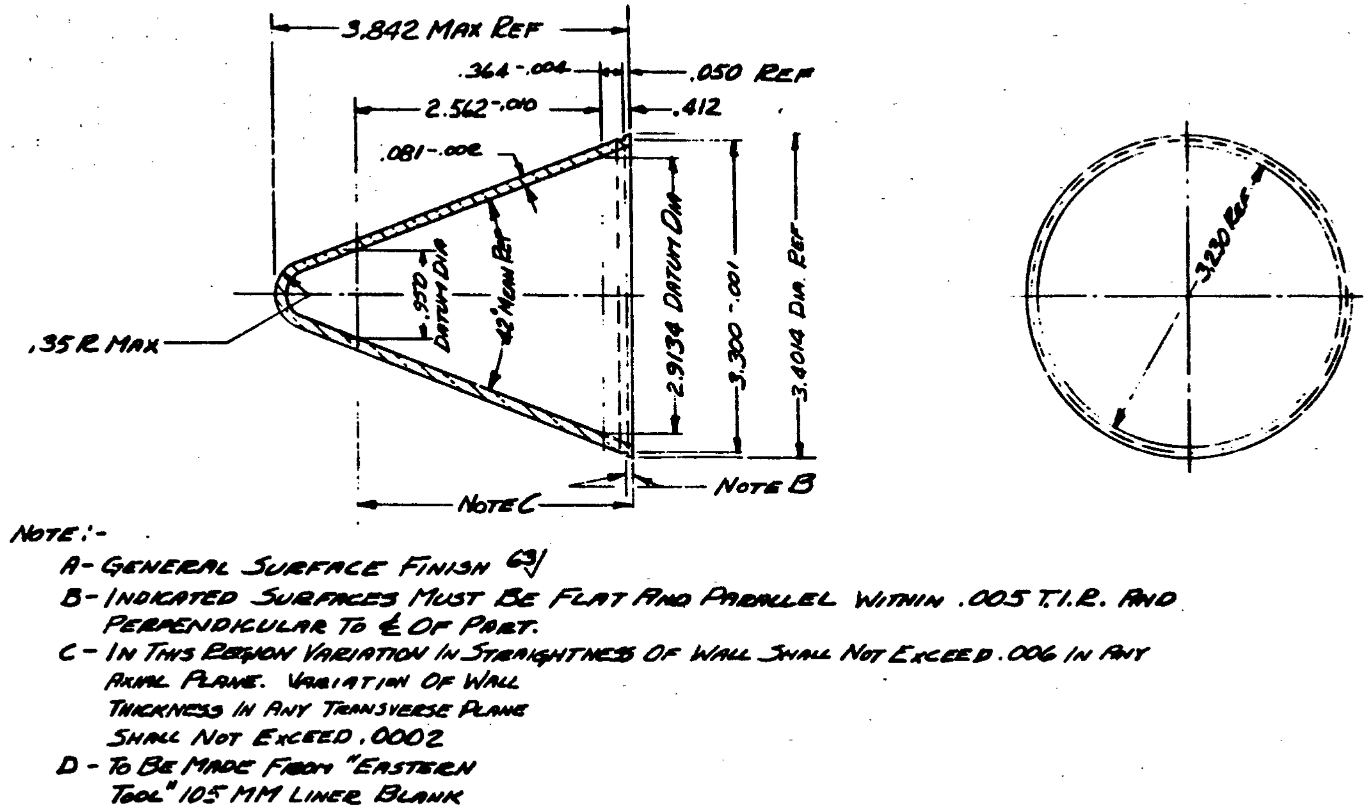


Fig. I-2. Precision Liner, 42° x 3.300-in. diameter. Dwg. No. DRB-23-1753.

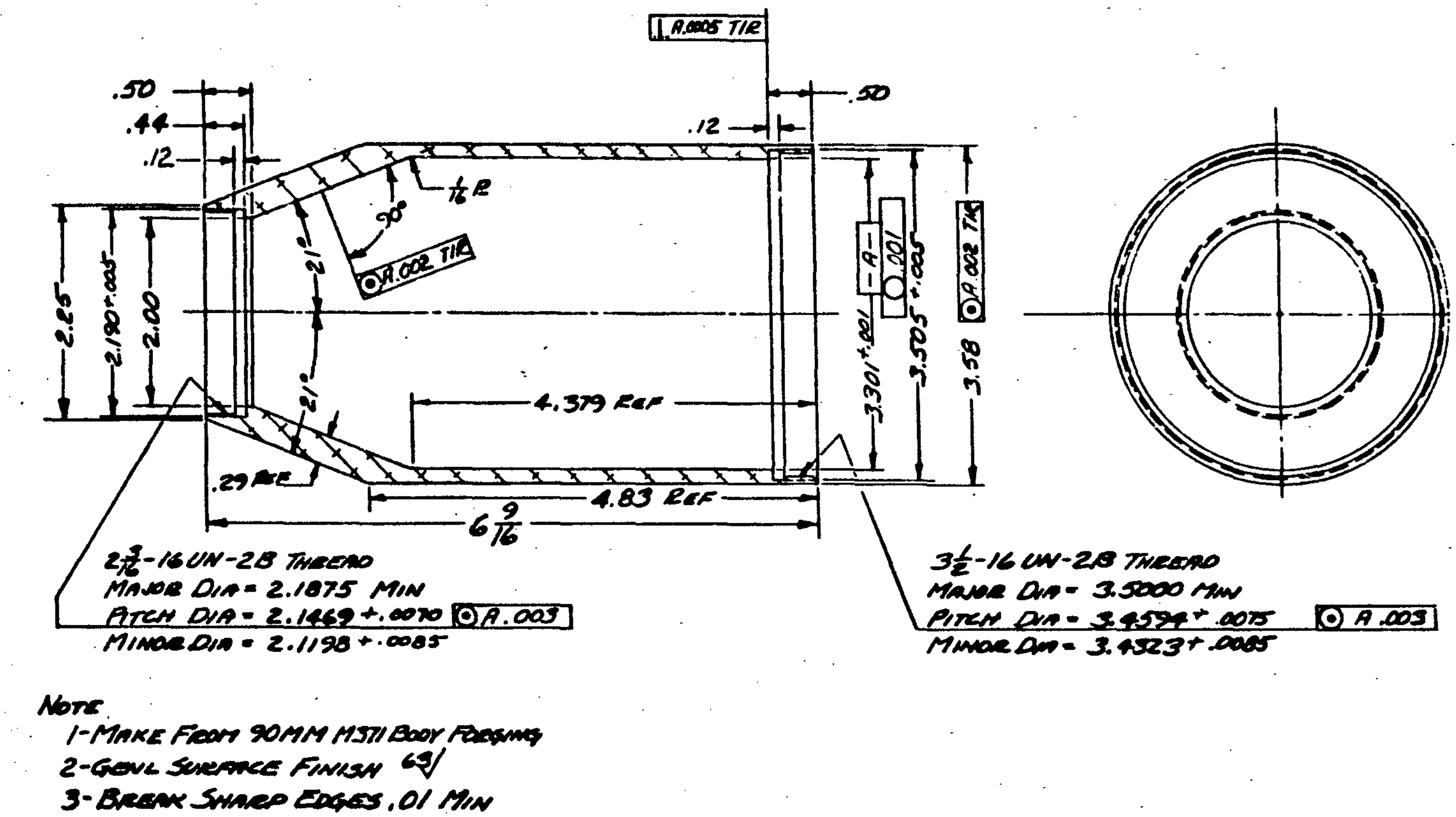
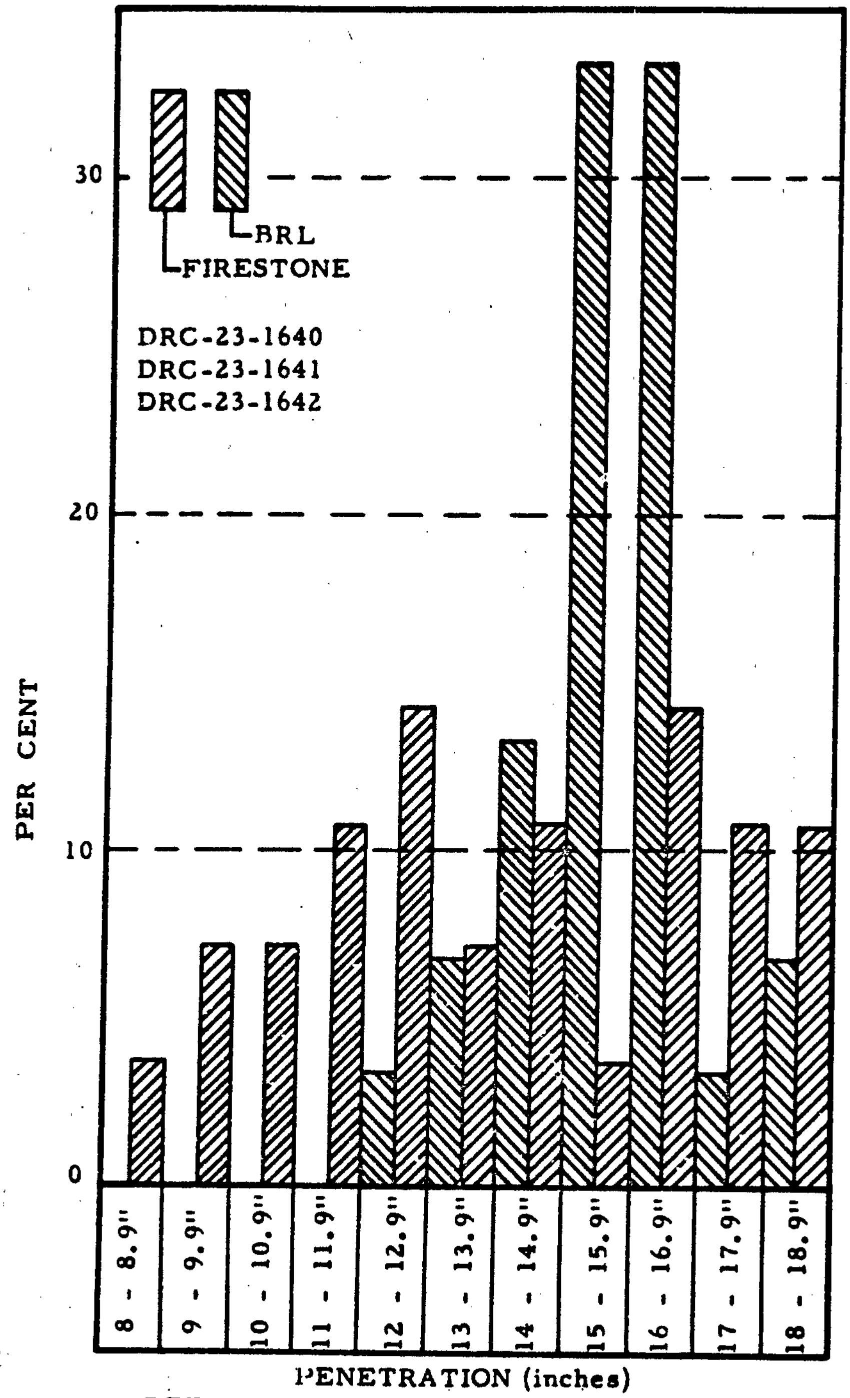


Fig. I-3. Test Body. Dwg. No. DRB-23-1752.



DEPTH OF PENETRATION vs. FREQUENCY
Comparison of BRL and Firestone Tests

Fig. I-4. Comparison of Penetration Depth vs. Frequency. Firestone and BRL Tests. 3.3.in. Precision Charges, 10 Charge Diameter Standoff. Test Assembly Dwg, No. DRC-23-1642.

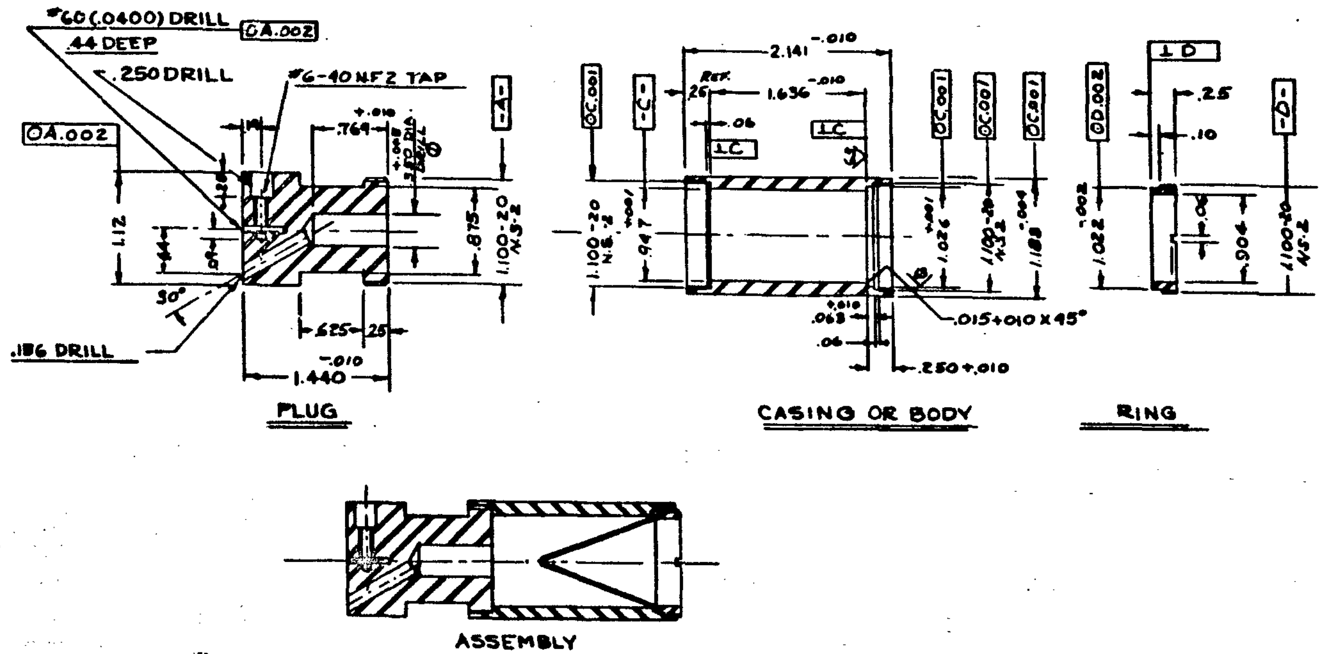


Fig. I-5. Test Body Details and Penetration Assembly, Scale 1.

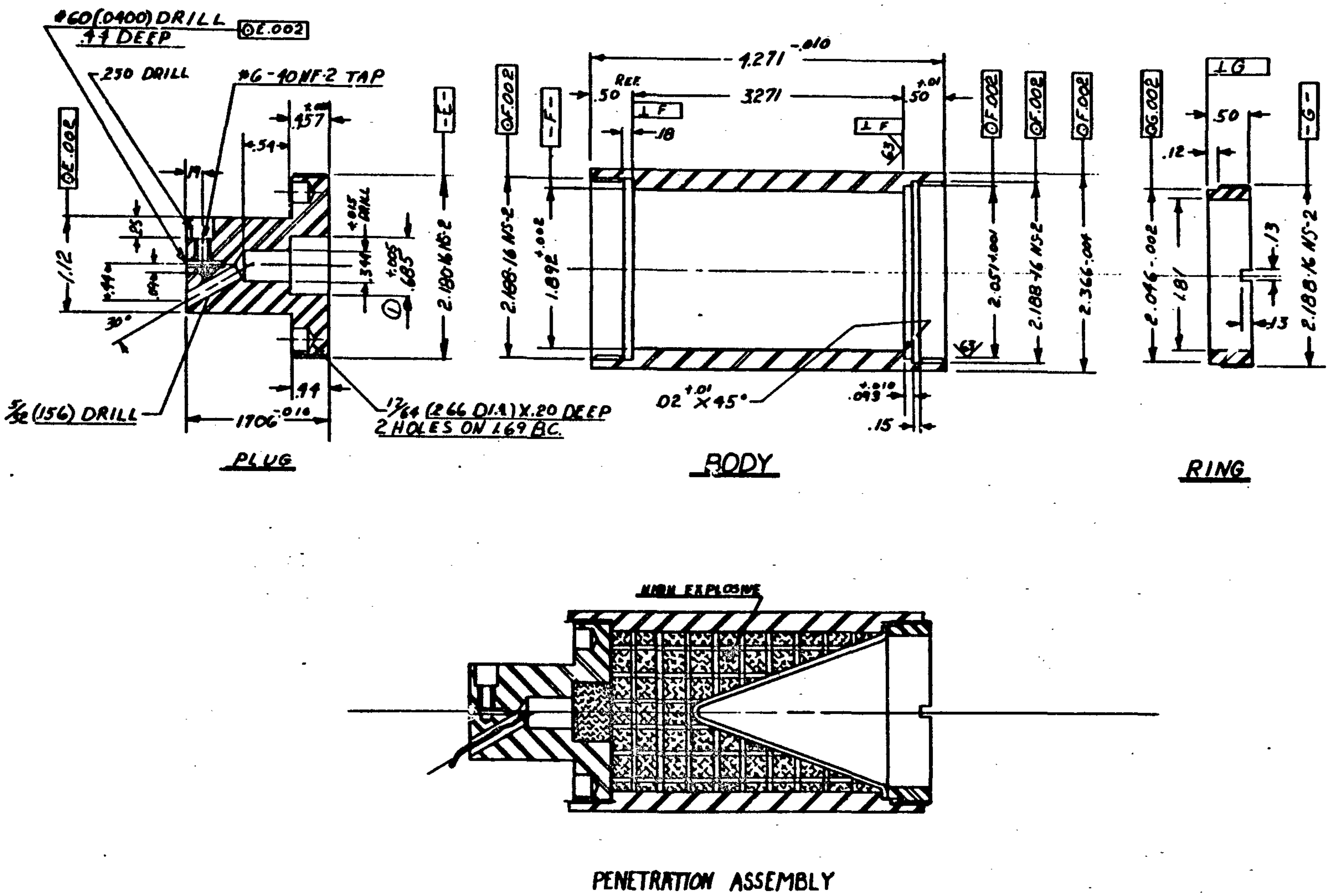


Fig. I-6. Test Body Details and Penetration Assembly, Scale 2.

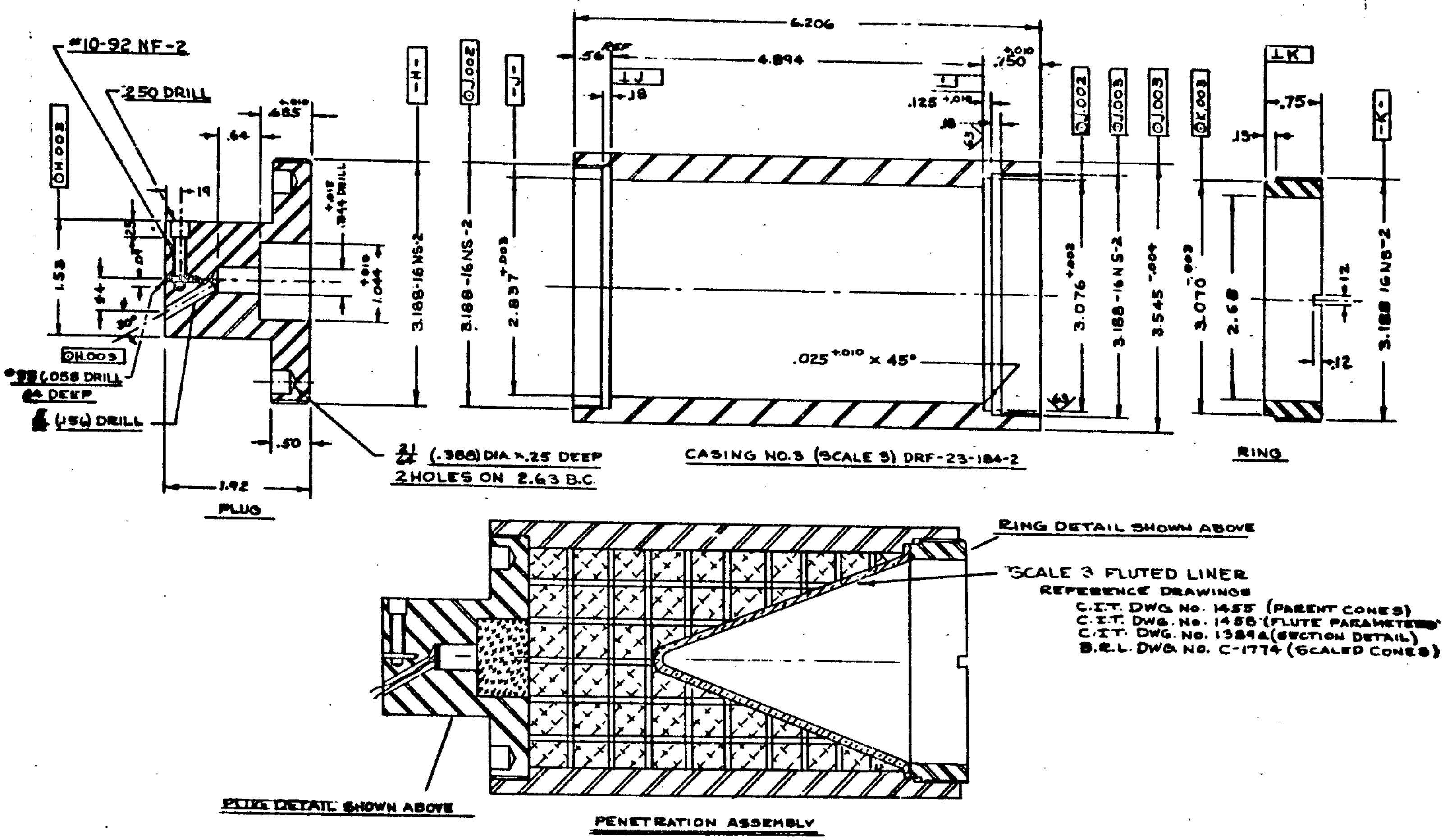


Fig. I-7. Test Body Details and Penetration Assembly, Scale 3.

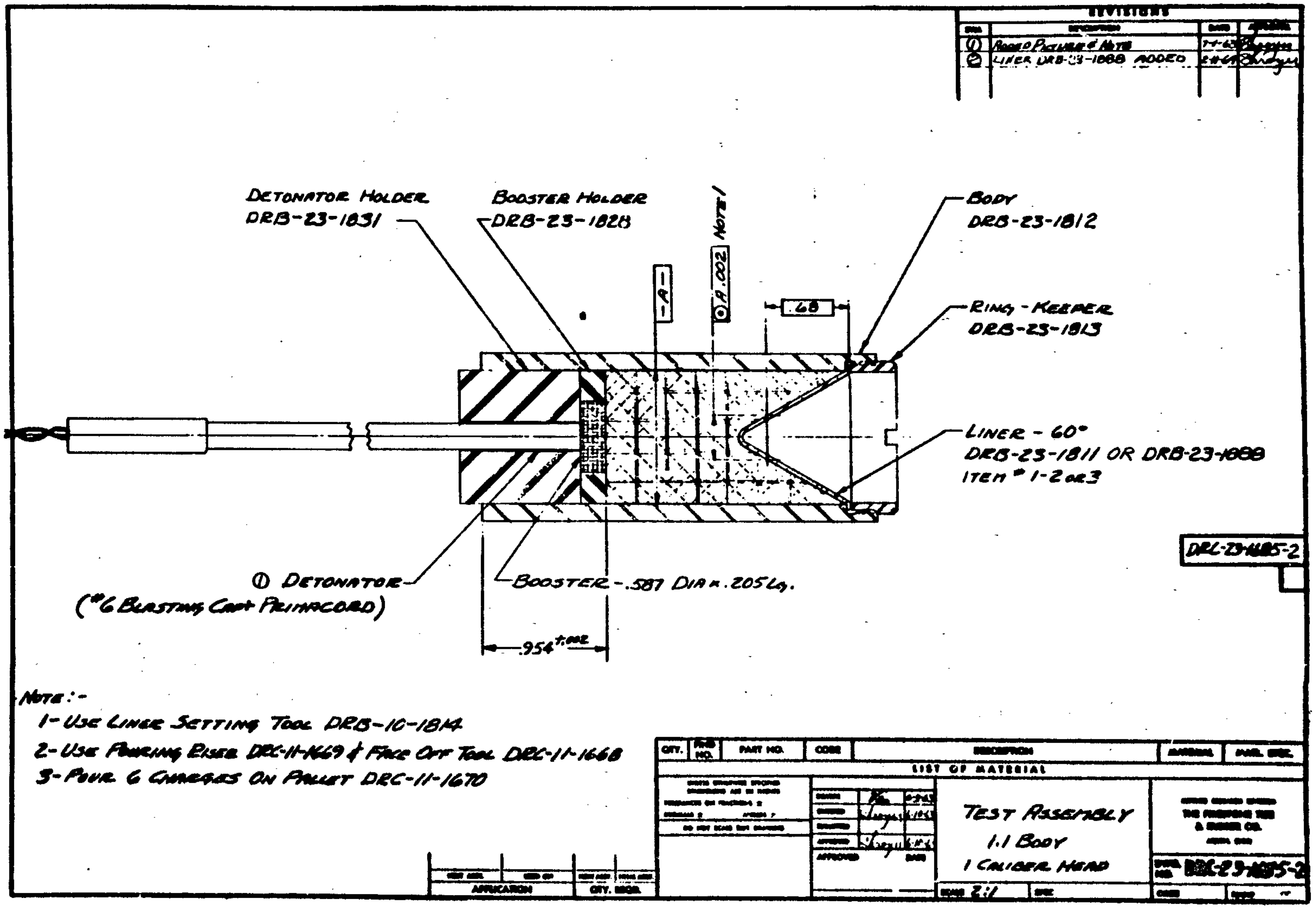


Fig. I-8. Test Assembly - 1.1 in. Body, 1-Caliber Head.
Dwg. No. DRC-23-1685-1.

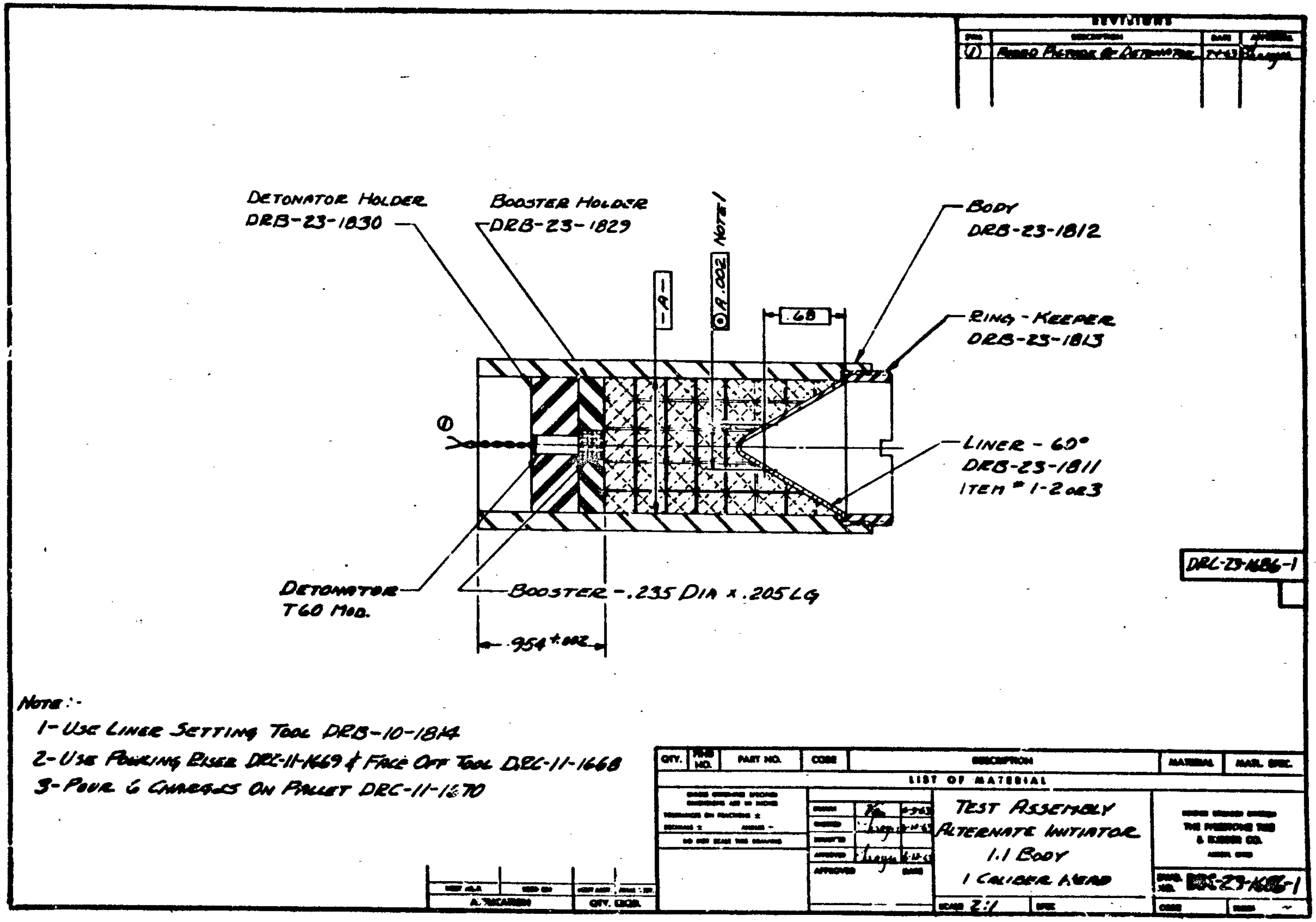
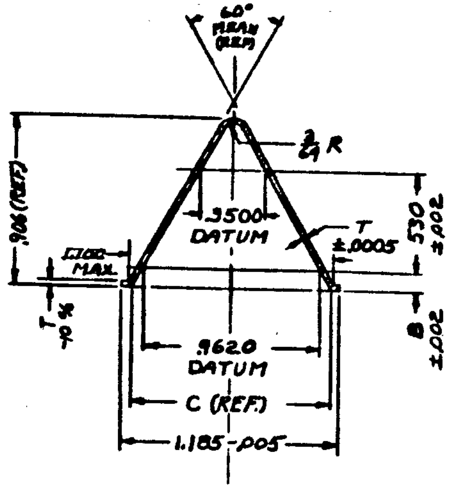


Fig. I-9. Alternate Initiator Test Assembly - 1.1 in. Body, 1-Caliber Head. Dwg. No. DRC-23-1686-1.



ITEM	T	B	C
1	.0165	.092	1.068
2	.0275	.086	1.061
3	.0385	.074	1.047

NOTES:

1. GENERAL FINISH 63
2. MATERIAL: ELECTROLYTIC COPPER, SPEC QQ-C-576 OFHC
3. FACES OF FLANGE SHALL BE FLAT & PERPENDICULAR TO LINER AXIS WITHIN 0°5' OR .002
4. VARIATION IN WALL STRAIGHTNESS SHALL NOT EXCEED .002 IN ANY AXIAL PLANE. VARIATION IN WALL THICKNESS SHALL NOT EXCEED .0005 IN ANY TRANSVERSE PLANE.

Fig. I-9A. Liner, 1.1-inch, 60° Apex Angle. Dwg. No. DRB-23-1811-2.

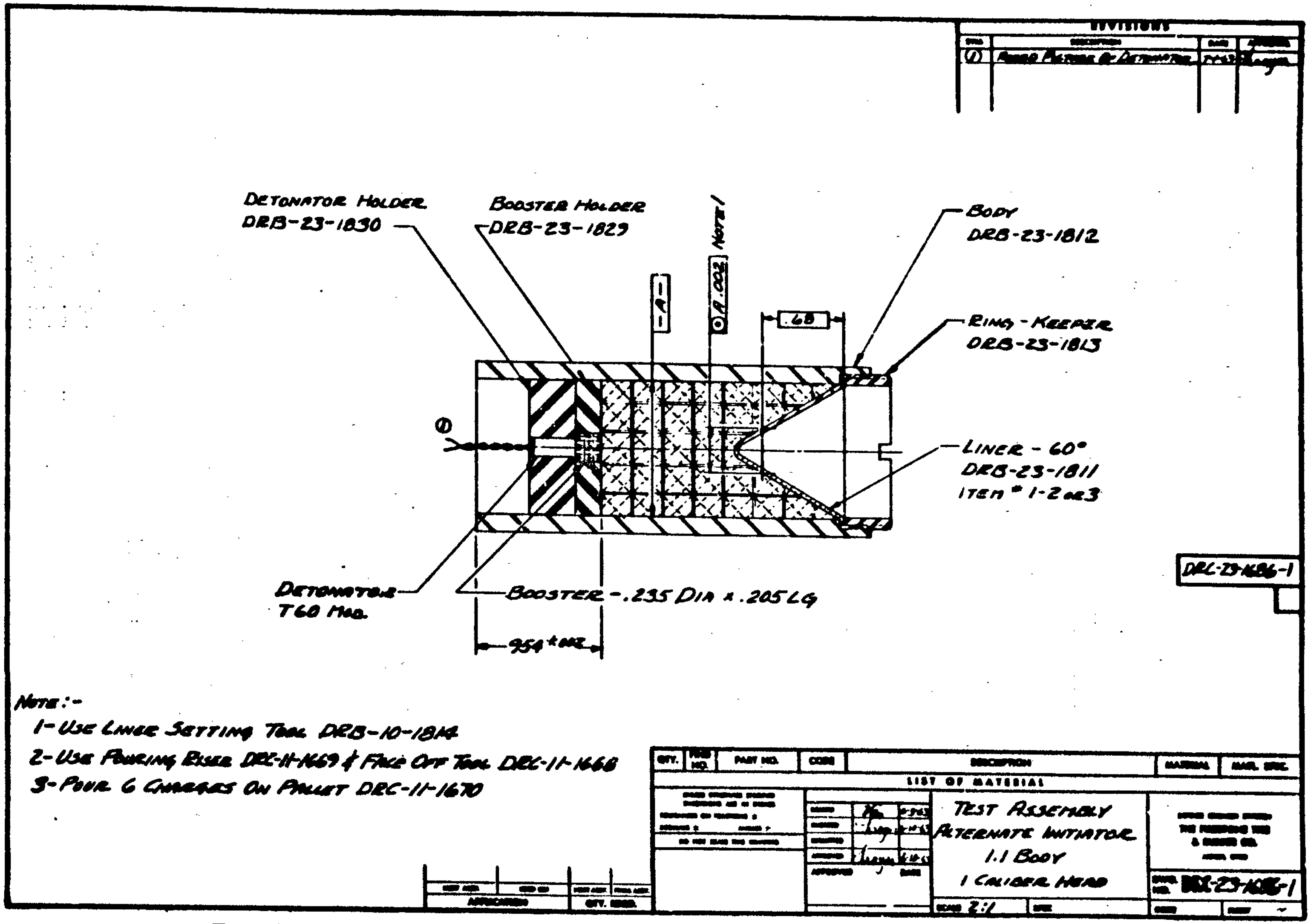
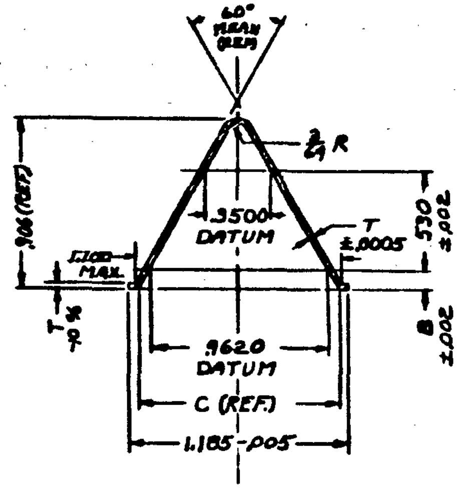


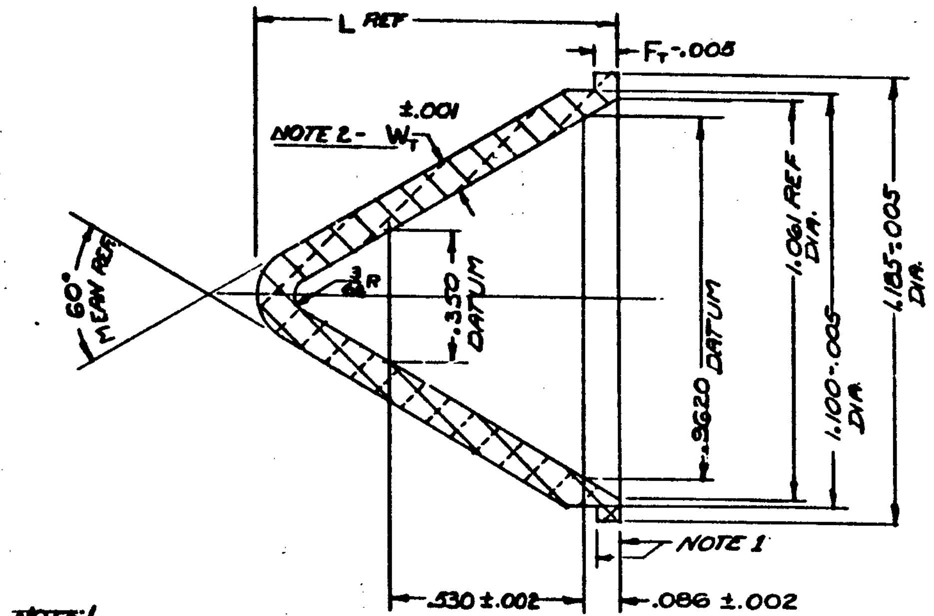
Fig. I-9. Alternate Initiator Test Assembly - 1.1 in. Body, 1-Caliber Head. Dwg. No. DRC-23-1686-1.



ITEM	T	B	C
1	.0165	.092	1.068
2	.0275	.086	1.061
3	.0385	.074	1.047

NOTES:
1. GENERAL FINISH 63
2. MATERIAL: ELECTROLYTIC COPPER, SPEC QQ-C-576 OFHC
3. FACES OF FLANGE SHALL BE FLAT & PERPENDICULAR TO LINER AXIS WITHIN 0°5' OR .002
4. VARIATION IN WALL STRAIGHTNESS SHALL NOT EXCEED .002 IN ANY AXIAL PLANE. VARIATION IN WALL THICKNESS SHALL NOT EXCEED .0005 IN ANY TRANSVERSE PLANE.

Fig. I-9A. Liner, 1.1-inch, 60° Apex Angle. Dwg. No. DRB-23-1811-2.



ITEM	F_T	W_T	L
1	.055	.0545	.9[illegible]7
2	.062	.0910	.9[illegible]3
3	.062	.1215	.9[illegible]4

NOTE:
1. FACES OF FLANGE SHALL BE FLAT & PERPINDICULAR TO LINER AXIS WITHIN 0°5' OR .002
2. VARIATION IN WALL STRAIGHTNESS SHALL NOT EXCEED .002 IN ANY AXIAL PLANE. VARIATION IN WALL THICKNESS SHALL NOT EXCEED .0005 IN ANY TRANSVERSE PLANE.
3. FINISH 63/, BREAK SHARP CORS .02
4. MATL: ALUMINUM ALLOY 1100-0

Fig. I-9B. Liners, 1.1-inch, 60° Apex Angle, .0545, .0910, and .1215-inch Wall Thickness. Dwg. No. DRB-23-1888.

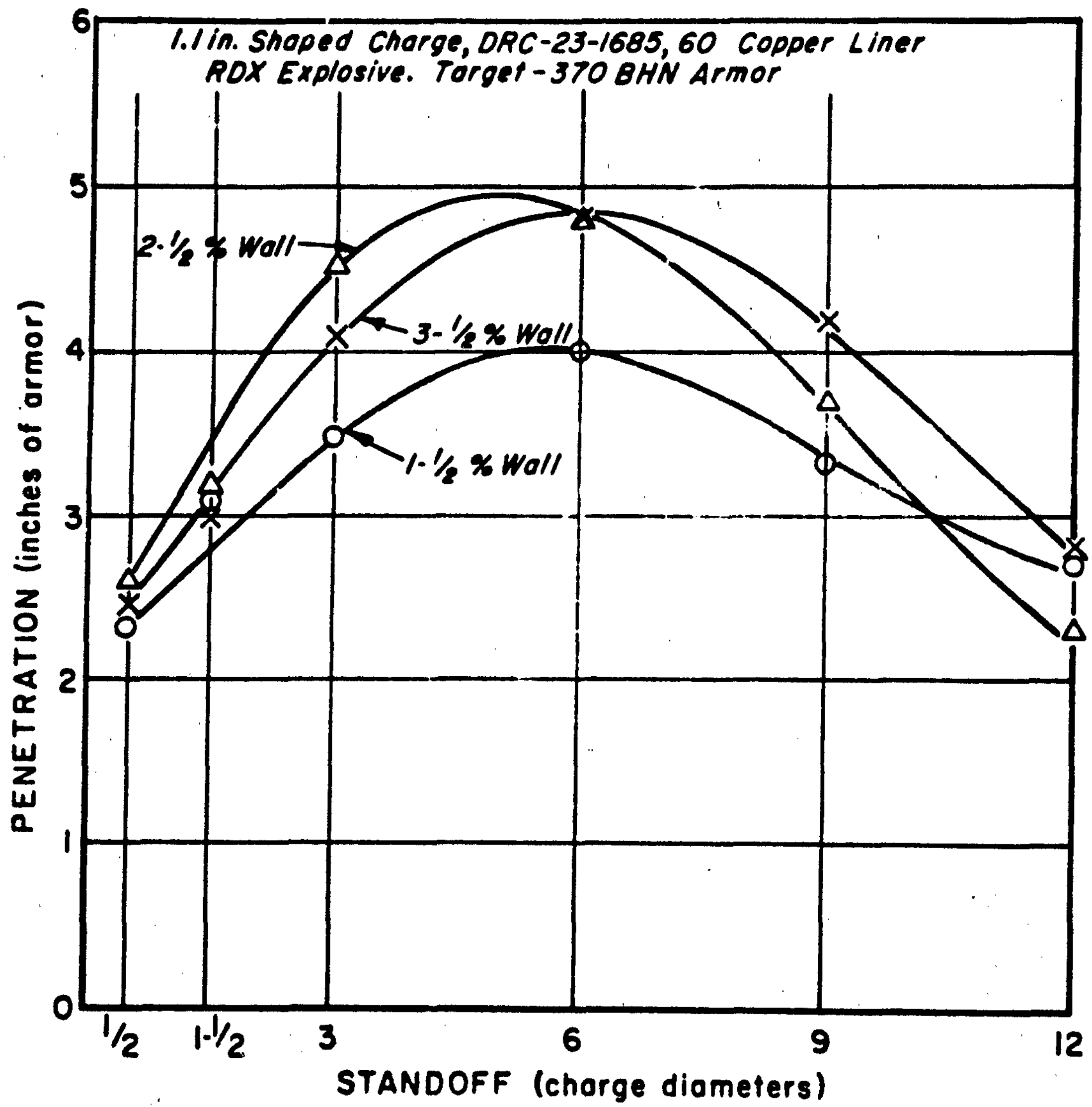


Fig. I-9C. Penetration vs. Standoff. 1.1-inch Shaped Charges, RDX Explosive. 60° Copper Liners with 1-1/2, 2-1/2, and 3-1/2 per cent Walls. Dwg. No. DRC-23-1685.

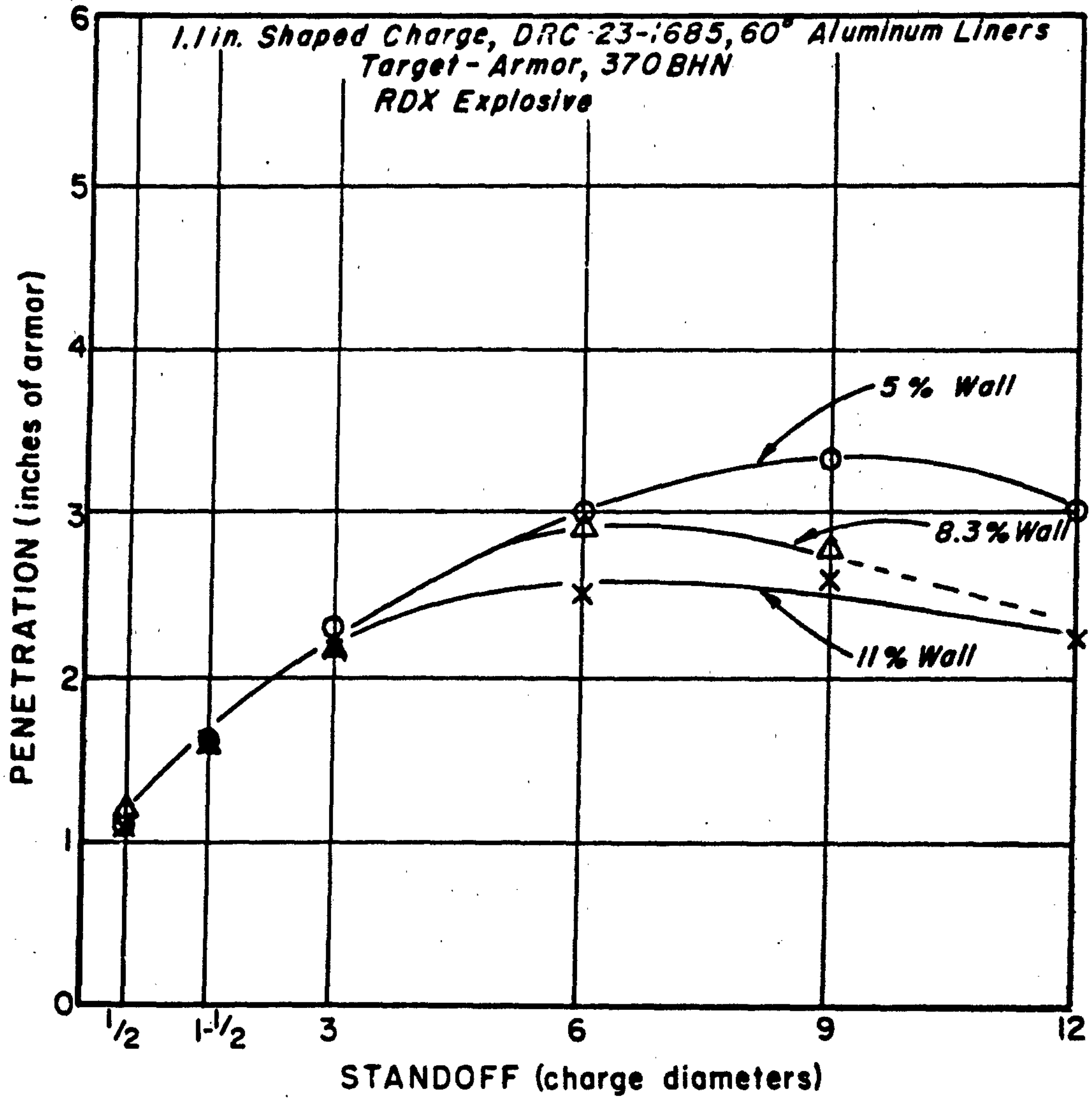


Fig. I-9D. Penetration vs. Standoff. 1.1-inch Shaped Charge, RDX Explosive, 60° Aluminum Liners w/ 5.0, 8.3, and 11.0 per cent Wall Thickness. Dwg. No. DRC-23-1685.

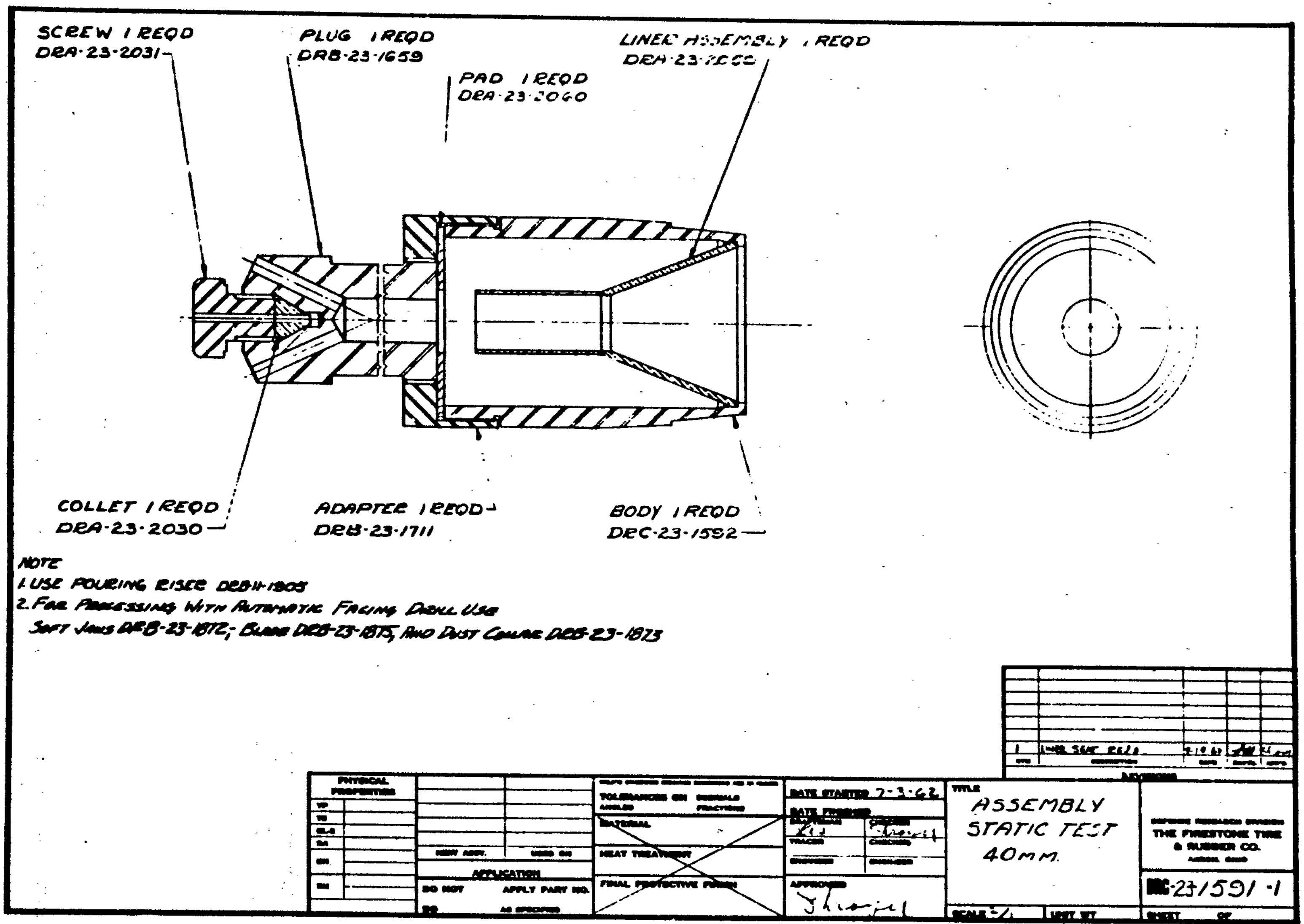


Fig. I-10. Static Test Assembly, 40mm. Liner.
Dwg. No. DRC-23-1591-1.

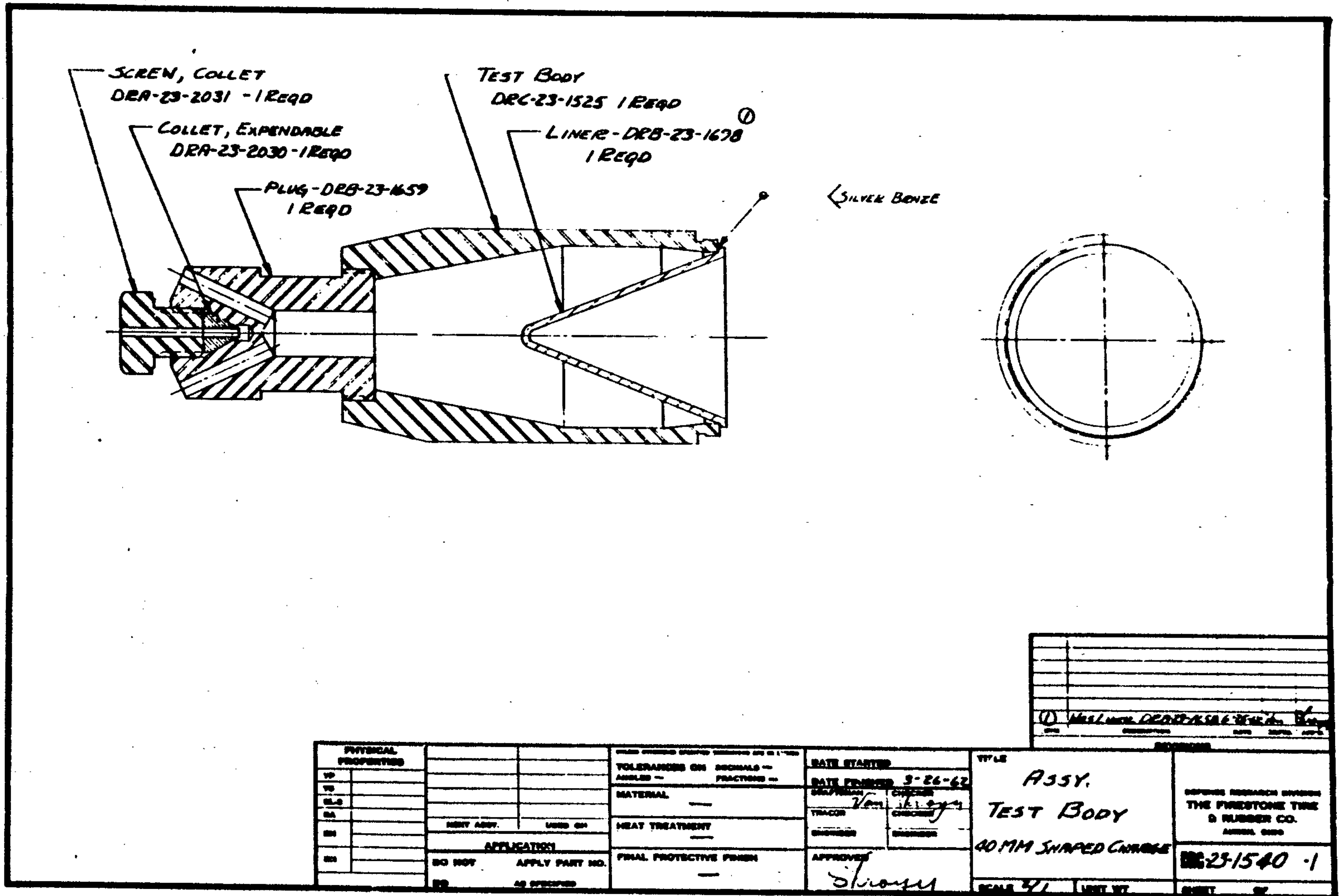


Fig. I-11. Static Test Assembly, 40mm. Liner.
Dwg. No. DRC-23-1540-1.

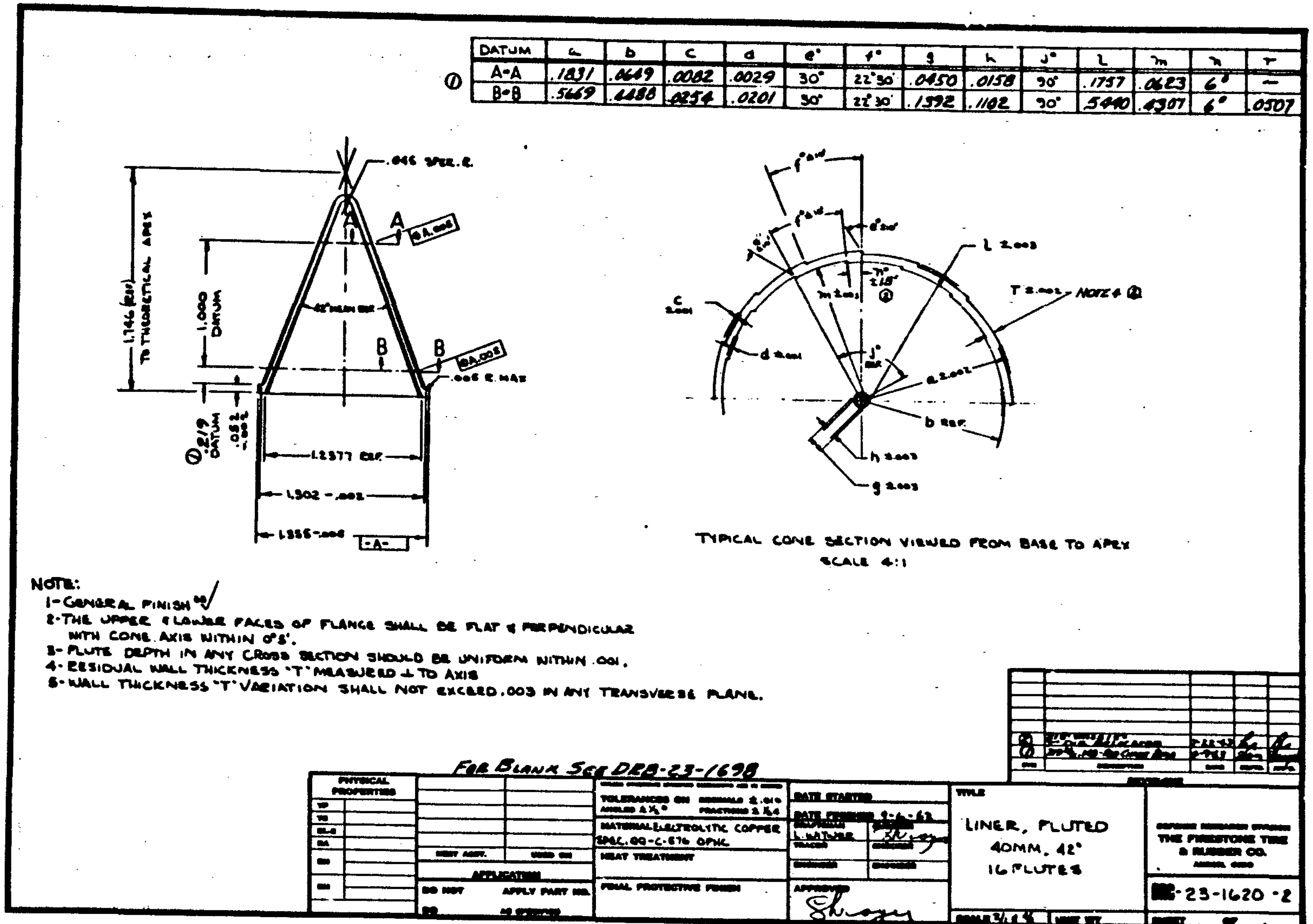
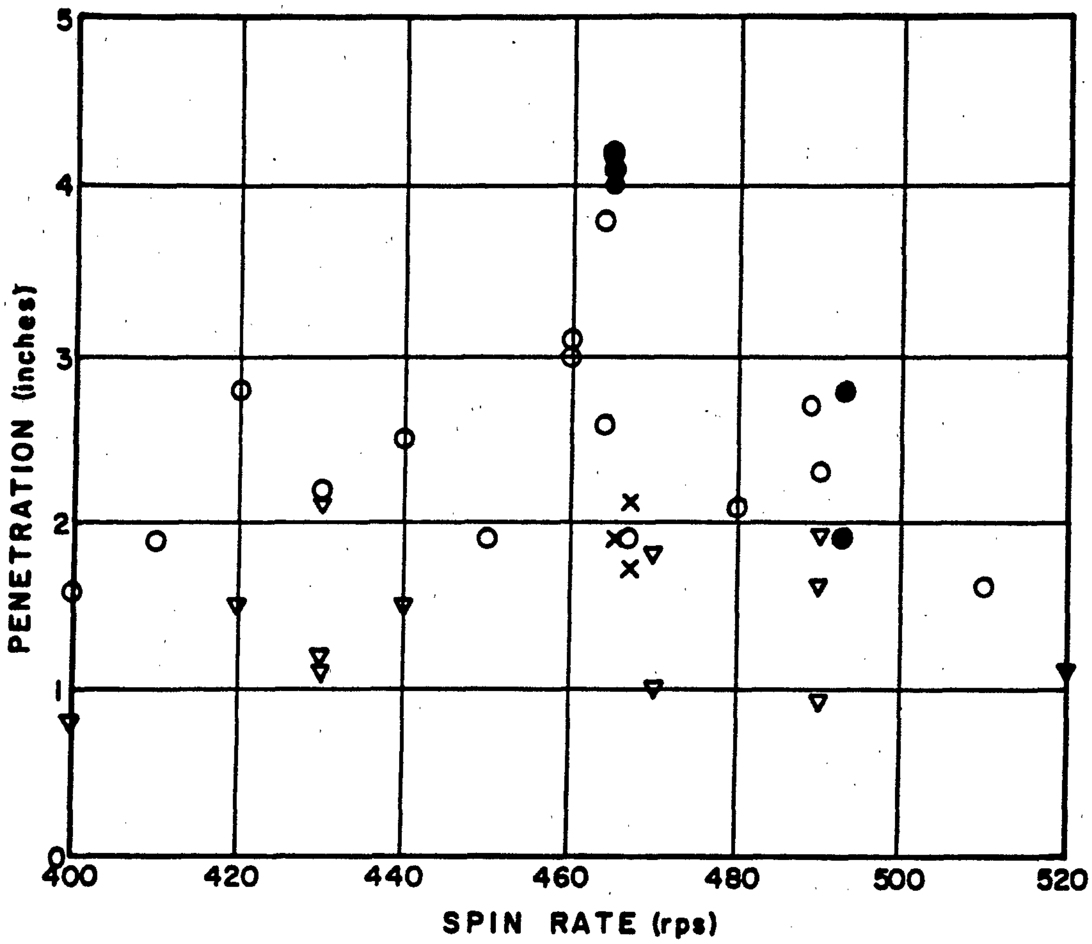


Fig. I-12. Fluted Liner - 40mm, 16 Flutes, 42° Apex.
Dwg. No. DRC-23-1620-2.



LINER	LOAD LOT	TARGET	
Fluted	*1*	*Armor*	▽
Fluted	*1*	*Mild Steel*	○
Smooth	*1*	*Mild Steel*	×
Fluted	*2*	*Mild Steel*	●

Fig. I-13. Penetration vs. Spin Rate. 40mm Fluted Liner. Dwg. No. DRC-23-1620-1.

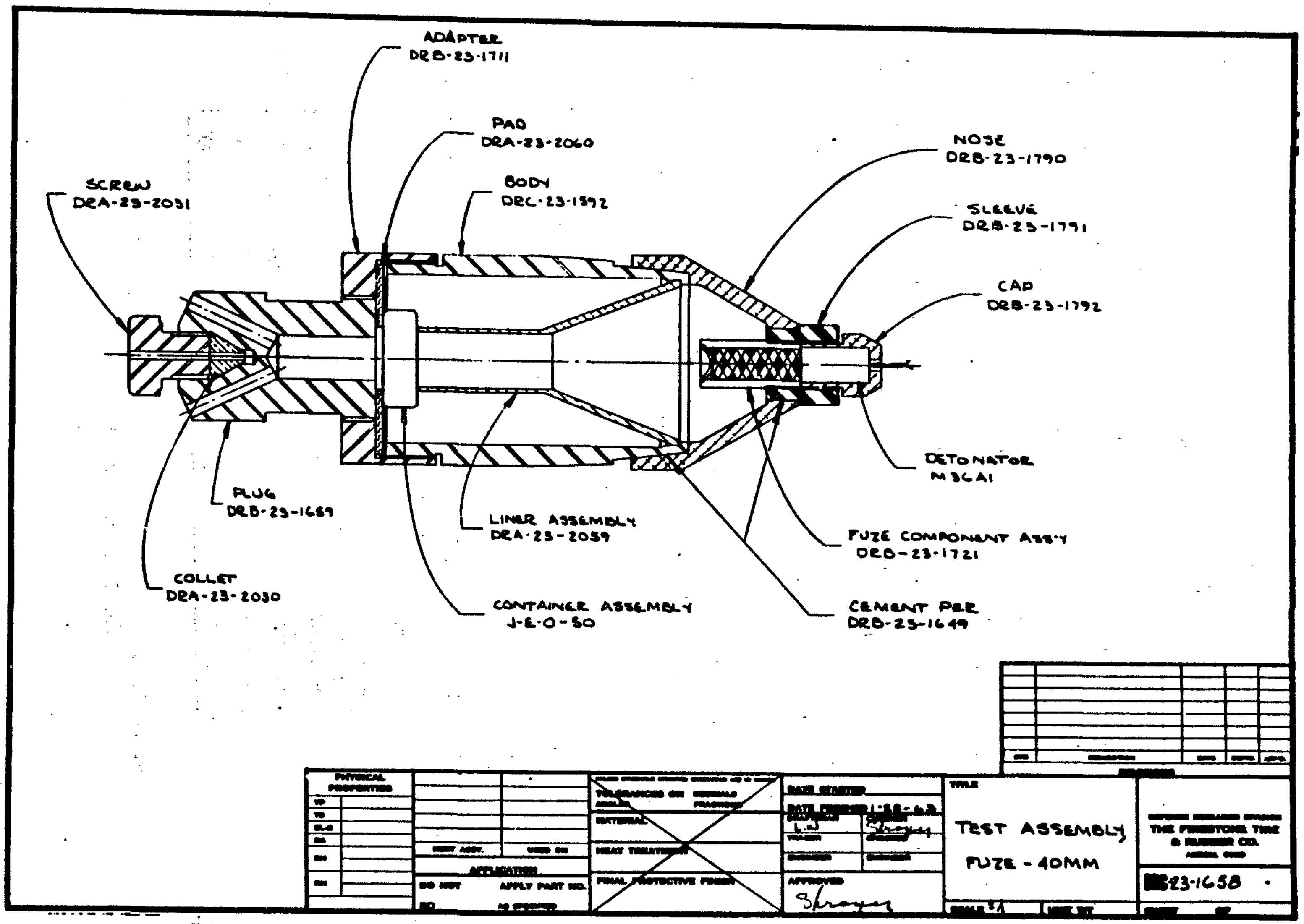
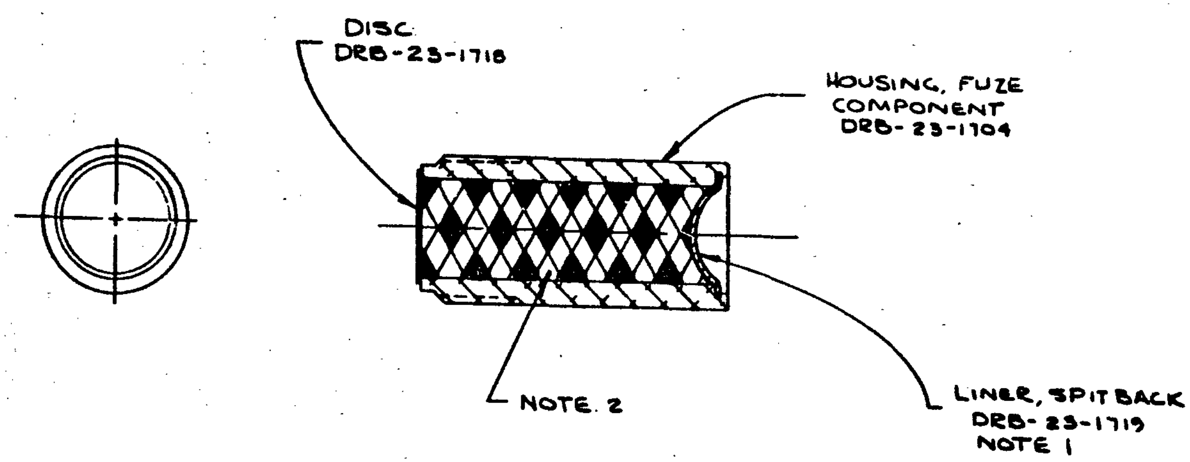


Fig. I-14. Test Assembly - 40mm. Fuze. Dwg. No. DRC-23-1658.



NOTES:
1- CRIMP LINER TO HOUSING 360°
2- LOAD WITH APPROX. 14.21 GRAINS, RDX, SPEC. MIL-R-398, ADVISORY: PRESS AT 10,000 PSI, DENSITY = 1.63 MIN.
3- CHARGE TO BE FLUSH WITH OR BELOW END OF HOUSING.

Fig. I-15. Assembly of Fuze Component. Dwg. No. DRB-23-1721.

SECTION II - SPIN COMPENSATION

FLUTED LINERS FOR 152MM HEAT, XM409

A fixed price contract with Picatinny Arsenal was received early in 1962 for the manufacture of 600 fluted liners for the XM409 projectile. This quantity was later increased to 1,000. The contract based the acceptance of the liners on the penetration performance of the liners when fired statically, and a series of three pilot lots were fired before an acceptable design was achieved. These pilot lots were fired under the scope of work on Contract DA-33-019-ORD-3697 in the static penetration chamber located at Erie Proving Ground. The performance requirements for the liners were that they be capable of penetrating 18.5 inches of mild steel at all spin rates between 95 and 105 rps when fired from the XM409 static test assembly at the built-in standoff of 10 inches.

The performance of the three pilot lots is shown in Table II-I and Fig. II-1. The design parameter varied between pilot lots was the mass of the liner, with a decrease of approximately 25 grams between each lot.

Extensive inspection data were recorded and analyzed for these liners in order to determine realistic tolerances for the liners, both from the standpoint of economy in manufacturing and effect on performance. A summary of these inspection data are presented in Table II-II.

LINER, 105MM PROJECTILE, M456, HEAT-MP

A series of tests were conducted on this contract to determine the cause of the marginal performance of the shaped charge in this projectile as developed and standardized. The typical penetration observed at a spin rate of 15 rps has been about 4.8 charge diameters, or 17 inches of mild steel. Tests fired with fluted liners in a static test assembly produced penetrations of better than 20 inches under the same conditions of spin and standoff, thus indicating that the full potential of the round was not being realized.

A test was fired in April 1963, Program 619, with liners fluted in accordance with DRC-23-1654, Fig. II-2, but with the envelope dimensions of CXP 98461, the Government drawing for the production liner. The rounds fired on this test utilized the M456 assembly except for a spinning adapter on the rear. The purpose of this test was to prove an already demonstrated capability of the fluted liner. The average penetration of these rounds at the optimum frequency was only 17 inches of mild steel, whereas in previous tests the same design liner had given better than 20 inches of penetration in static test assemblies. The detailed test results appear in Table II-III and Fig. II-3. A review of the liner and body designs revealed that the CXP 98461 liner had a maximum cone diameter of 3.45 inches directly over the flange and the M456 body had a diameter of 3.54

inches in the same relative location. This difference in diameters resulted in a band of explosive approximately .045 inches wide over the flange of the liner. Previous experience had proven that such a band can seriously degrade the penetration performance of a shaped charge liner, and a test was planned to investigate the effect in this particular case.

The test, Program 623, to evaluate the effect of the band of explosive was fired utilizing the same liners used in the previous test but with a modified DRC 376 test assembly. The modifications to the test assembly were to adjust the inside diameter of the body so that one group of rounds had an explosive band of .045 inches and the other group had a band of only .005 inches. Five rounds of each group were fired at 8 inches standoff, 15 rps, against mild steel targets. An average penetration of 19.43 inches was achieved with the rounds having the small explosive band and an average of 17.7 inches was observed for the other group, proving that the explosive band in the production round did actually cause a degradation in the liner performance. The detailed test results appear as Table II-IV.

The fluting die was modified to manufacture a liner with a maximum cone diameter of 3.53 inches, and a lot of new liners were fabricated. Tests were fired (Program 637) to compare these liners with those of the previous lot as well as to develop a standoff-penetration curve at the observed optimum frequency. A group of shear formed liners was modified to have the same 3.53 inch maximum cone diameter and fired to determine if a fluted liner really offered any advantages at the low required spin rate. All rounds were in the M456 static test assembly and were fired against mild steel targets.

The results of Program 637a and 637c, presented in Fig. II-4 and Table II-V, prove that the penetration performance of this round had been degraded by the introduction of a band of explosive immediately over the flange of the liner. The average penetration of the rounds having a full sized liner and therefore no band of explosive, was better than 19 inches on Program 637a. The rounds having the .045 inch band of explosive were fired on Program 637c and gave an average penetration of slightly over 17 inches at 15 rps. These results prove the degrading effect of the band of explosive since all the other round parameters were held constant and the magnitude of the degradation is more than can be attributed to the smaller cone diameter.

The penetration results obtained at various standoff distances on Program 637b indicated that something was degrading the liner performance at moderate standoff distances such as six charge diameters. When this became evident, three rounds were modified by machining the shoulder on the spike so that it seated against the locking ring and in effect, acted as additional end confinement. The performance of these three rounds was significantly improved over that exhibited by rounds with the standard locking ring as the sole source of end confinement, thus proving that at even moderate standoff distances the standard locking ring, BXP 115524, affords insufficient end confinement in this round. These data are presented in Fig. II-5 and Table II-VI.

The performance of the full-sized shear formed liners tested on Program 637d, presented in Fig. II-4 and Table II-VII, was not significantly different from that obtained with full-sized fluted liners on Program 637a. Based on these tests there is apparently no advantage in using a fluted liner in this round with its associated low spin rate.

RELATED STUDIES

A. COMPENSATED LINER FOR 40MM DUAL PURPOSE ROUND - XM429

A purchase order was received from the Ordnance Division of AVCO Corporation on July 12, 1963 for services in connection with the development of a fluted liner that would compensate for 212 rps and give better than 2 inches of armor penetration. This liner is to be incorporated in 40mm Projectile, XM429, that AVCO is developing for a helicopter weapon system. The AVCO contract is with the Weapons and Special Projects Laboratory, Picatinny Arsenal. The general design parameters evolved during the study are presented in Table II-VIII.

The first three phases of this project have been successfully completed with the design and development of a spin compensating liner to meet the performance requirements. The original design was adjusted to compensate for changes in the system characteristics and to compensate for adverse effects of spitter type fuze initiation at high angles of obliquity. Production engineering and production tool design is in process.

B. COMPENSATED LINER FOR 40MM RAPID FIRE WEAPON SYSTEM

This program was initiated by Picatinny Arsenal through this contract to develop a compensated liner for a 40mm weapon capable of rapid fire. The liner has a diameter of 1.3 inches and was to have been compensated for 435 rps. A liner design was arrived at based on the work done on scale 2 liners with various basic flute depths. A 42 degree apex angle was decided upon since the standoff was to be 3.25 inches, or about 2-1/2 charge diameters. The index angle was 7 degrees and the basic flute taper was 17.2 mils per inch of vertical height. The mass of the initial liners was 28 grams each. Fig. II-6 shows the other pertinent details of the liner. The explosive charge was to be cast Composition B.

The first group of liners fired showed a large dispersion in penetration results, as can be seen from the data in Table II-IX. Five additional rounds were loaded under closely controlled conditions since it was felt that there might have been some fault with the original load lot. The results of these rounds, presented in Table II-X, indicate that some greater degree of reliability had been achieved with the closer control on the loading procedure.

A third group of these liners was tested against mild steel in order to determine the optimum spin level. While the dispersion between rounds at a given spin level was reasonable, there was no definite optimum spin level displayed, as can be seen from Table II-XI and Fig. II-7; however, it was apparently approximately 450 rps.

A group of liners was then manufactured with a mass 107% of the original group and an index angle of 5.5 degrees instead of 7 degrees. Both changes should have resulted in a lower optimum spin level. Programs 641 and 658 were fired with these liners, the only variable in the two programs being the loading procedure. The data obtained from firing these liners are presented in Table II-XII and Fig. II-8. The spread in the data prevent the determination of the optimum spin level, but it appears to have been lowered more than required as a result of the two design changes.

Since the funds on this project were limited and there had been considerable difficulty encountered with the spitback initiation system, a decision was made to reduce the level of effort on the compensated liner.

TABLE II-I
PENETRATION DATA
PROGRAM 596 (Contract DA-33-019-ORD-3862, 1st Pilot Lot)

Round Number	Serial Number	Spin Rate (rps)	Penetration (in.) Meas.	Max.	Min.	Avg.	R
12636	J 28	70	14.63			14.63	-
12631	J 27	80	19.94			19.94	0
12632	J 17		19.94				
12633	J 20	90	21.56	21.56			
12634	J 29		20.94		20.94		
12630	J 24		21.06			21.18	.62
12616	J 3	96	20.44	20.44			
12620	J 9		19.13		19.13		
12634	J 31		20.38			19.98	1.31
12628	J 18	100	18.00	18.63			
12629	J 25		18.63		18.00	18.31	.63
12618	J 5	105	16.75		16.75		
12619	J 7		17.88	17.88		17.31	1.13
12621	J 10	110	13.13		13.13		
12622	J 11		14.81				
12623	J 12		16.06	16.06			
12624	J 13		14.18				
12625	J 14		15.94				
12626	J 19		14.44				
12627	J 26		15.06			14.80	2.93
12617	J 4	115	14.31			14.31	

TABLE II-I
(Continued)
PENETRATION DATA
PROGRAM 611 (Contract DA-33-019-ORD-3862, 2nd Pilot Lot)

Standoff: 10 inches

Round Number	Serial Number	Spin Rate (rps)	Penetration (in.) Meas.	Max.	Min.	Avg.	R
12691	J 83	90	18.94		18.94		
12697	J 50		20.44	20.44		19.69	1.50
12689	J 73	95	20.06		20.06		
12694	J 65		21.38	21.38		20.72	1.32
12686	J 76	100	18.06		18.06		
12687	J 74		19.25				
12693	J 77		19.88	19.88			
12699	J 58		18.94				
12703	J 60		19.06			19.03	1.82
12690	J 84	105	17.88		17.88		
12695	J 51		18.50	18.50			
12696	J 82		18.25				
12698	J 56		18.06				
12701	J 49		18.06				
12702	J 55		18.00			18.12	.62
12688	J 70	110	15.81				
12692	J 67		15.75		15.75		
12700	J 53		15.94	15.94		15.83	.19

Table II - I (cont.)

PENETRATION DATA

PROGRAM 613 (Contract DA-33-019-ORD-3862, 3rd Pilot Lot)

Standoff: 10 inches

Round Number	Serial Number	Spin Rate (rps)	Penetration (in) Meas.	Max.	Min.	Avg.	R
12766	J 112	85	17.56	17.56			
12767	J 113		14.31		14.31	15.94	3.25
12740	J 122	95	20.31		20.31		
12753	J 93		21.44	21.44			
12758	J 111		21.25				
12768	J 104		17.25	Note 1		21.00	1.13
12760	J 98	98	20.50				
12761	J 99		20.63				
12762	J 106		20.94	20.94			
12769	J 103		20.06		20.06	20.53	.88
12732	J 121	100	14.13	Note 2			
12734	J 107		16.44	Note 2			
12736	J 109		-	Low Order			
12741	J 123		11.81	Note 2			
12754	J 94		14.18				
12756	J 97		14.31				
12757	J 110		13.81				
12759	J 96		16.25				4.63
12765	J 115	102	20.63				
12770	J 101		20.63			20.63	0
12729	J 91	105	17.38	Note 2			
12730	J 92		19.38	Note 2			
12731	J 120		18.63	Note 2			
12755	J 95		20.44				
12763	J 100		20.31				
12764	J 108	105	19.88		19.88		
12771	J 102		20.56	20.56		20.30	.68
12733	J 125	110	16.31	Note 2			
12738	J 118		20.63	Note 2			
12739	J 119		16.25	Note 2		17.73	4.32
12772	J 114		Dropped and Destroyed				
Control Rounds:							
12735	A240C	0	22.63				
12737	A247C		23.88			23.26	1.25

Note 1: Round Number 12768 (J 104) was dropped and the explosive cracked. The penetration was not used in calculating the average.

Note 2: These rounds were not counted since deficiencies were found in the booster alignment in the remaining rounds. The remaining rounds were unloaded, recast and drilled accurately. The rounds fired at 105 rps under the two sets of conditions showed a significant difference statistically, therefore the original rounds were discounted, except at 110 rps where they were the only rounds fired and were needed to complete the curve.

TABLE II-II

INSPECTION SUMMARY

Fluted Liner, .175 in. Wall, 60° Apex

Projectile XM409, 152MM, HEAT-MP
Reference: DRC-23-1692

Index Angle: 6° 50' 3 samples
Flute Depths (perpendicular to liner axis)

Exterior Datum (in. from flange)	Mean Depth	Standard Deviation	Sample Size
.142	.0892	.0008	766
.570	.0795	.0006	985
2.238	.0448	.0007	780
Interior			
.570	.0693	.0006	755
2.238	.0361	.0006	546

Mass (grams)

Mean	Standard Deviation	Sample Size
1018	5	684

Wall Thickness (inches)

Datum (in. from flange)	Mean	Standard Deviation	Sample Size
.570	.1439	.002	684
2.238	.1523	.001	684

Exterior Flute Depth At Eleven Datum Locations

Datum (in. from flange)	Mean Depth	Sample Size
.142	.0892	766
.284	.0857	82
.426	.0821	82
.570	.0795	985
.712	.0762	82
.854	.0732	82
.996	.0700	82
1.138	.0670	82
2.238	.0448	780
2.788	.0326	82

TABLE II-III
PENETRATION DATA

PROGRAM 619

105mm M456
42° Fluted Liner
DRC 23-1654-1
April 16, 1963

2 Charge Diameters Standoff

Round No.	Serial No.	Spin Rate	Penetration (In. M.S.) Meas.	Max.	Min.	Ave.	R
12823	B 114	0	17.06				
12826	B 117		17.06				
12827	B 118		17.19	17.19			
12835	B 126		15.19		15.19	16.63	2.00
12814	B 105	/5	15.19		15.19		
12820	B 111		18.25	18.25			
12829	B 120		18.06				
12836	B 127		17.06				
12840	B 131		17.38			17.19	3.06
12813	B 104	/10	16.13				
12819	B 110		17.06				
12828	B 119		17.31	17.31			
12834	B 125		16.75				
12839	B 130		17.06				
12843	B 134		15.38		15.38	16.62	1.93
12812	B 103	/15	17.13				
12818	B 109		17.75	17.75			
12825	B 116		16.94				
12833	B 124		17.06				
12838	B 129		16.81		16.81		
12842	B 133		16.81			17.08	.94
12811	B 102	/20	17.44	17.44			
12817	B 108		15.31		15.31		
12824	B 115		16.56				
12832	B 123		17.00				
12837	B 128		15.75				
12841	B 132		16.69			16.46	2.13
12810	B 101	/25	16.94				
12816	B 107		17.13	17.13			
12822	B 113		17.00				
12831	B 122		16.13		16.13	16.80	1.00
12809	B 100	/30	15.50		15.50		
12815	B 106		16.69	16.69			
12821	B 112		15.81				
12830	B 121		15.61			15.90	1.19

TABLE II-IV
PENETRATION DATA

PROGRAM 623
105 MM M456
42° FLUTED LINER
DRC 23-1654-1
MAY 13, 1963

SPIN RATE 15 RPS
STANDOFF 8.0"
MILD STEEL TARGET

Round No.	Serial No.	Penetration Meas.	Max.	Min.	Avg.	R
Group I						
12854	B 144	20.31	20.31			
12856	B 146	19.25				
12857	B 152	20.00				
12860	B 164	18.94				
12862	B 166	18.63		18.63	19.43	1.7
Group II						
12855	B 145	17.94				
12858	B 153	17.18		17.18		
12859	B 163	18.06	18.06			
12861	B 165	17.94				
12863	B 167	17.38			17.70	.9

The Group I rounds were a DRC 376 Test Assembly with a sleeve to give a charge diameter of 3.446 in.

The Group II rounds were a DRC 376 Test Assembly bored out to give a charge diameter of 3.540 inches resulting in a .050 inch wide band of explosive over the liner flange.

TABLE II-V

PENETRATION DATA

PROGRAMS 637a and c

Liner: DRC-23-1654-2
Assembly: 105mm, M456
Explosive: Comp. B
Target: Mild Steel, 110 BHN
Standoff: Built-in

Round Number	Serial Number	Spin Rate (rps)	Penetration (in. M.S.) Meas.	Max.	Min.	Avg.	R
637-25	B-275	0	20.06	20.06			
4	B-204		18.25		18.25		
9	B-200		20.00				
14	B-214		19.50				
19	B-217		19.88			19.54	1.81
637- 5	B-205	10	19.63	19.63			
10	B-199		18.75				
15	B-215		19.63	19.63			
20	B-218		18.13		18.13		
24	B-274		18.75			18.98	1.50
637- 1	B-201	15	19.63				
6	B-208		19.00				
11	B-212		19.13				
16	B-216		20.44	20.44			
21	B-270		18.13		18.13	19.27	2.31
637- 2	B-202	20	20.25	20.25			
7	B-209		19.63				
12	B-211		19.50				
17	B-219		15.63		15.63		
22	B-272		16.63			18.33	4.62
637- 3	B-203	30	17.94	17.94			
8	B-210		16.75		16.75		
13	B-213		17.94	17.94			
18	B-220		17.06				
23	B-273		17.88			17.51	1.19
637-39	B-170	15	16.88				
40	B-168		16.38		16.38		
41	B-143		17.06				
42	B-137		17.56				
43	B-135		17.63	17.63		17.10	1.25

TABLE II-VI
PENETRATION DATA

PROGRAM 637b

Liner: DRC-23-1654-2
Assembly: 105mm, M456
Explosive: Comp. B
Target: Mild Steel, 110 BHN
Standoff: Various
Spin Rate: 15 rps

Round Number	Serial Number	Standoff (C. D.)	Penetration (in. M. S.) Meas.	Max.	Min.	Avg.	R
637-26	B-277	1.0	18.38				
27	B-288		17.88		17.88		
28	B-278		19.38				
29	B-285		18.94				
30	B-282		19.50	19.50		18.82	1.62
637-31	B-281	6.0	14.50				
32	B-279		8.94		8.94		
33	B-280		13.69				
34	B-276		15.25	15.25		13.10	6.31
637-35	B-283	10.0	11.44				
36	B-284		14.19	14.19			
37	B-292		11.94				
38	B-291		7.63		7.63	11.30	6.53
637-72	B-293	17.0	6.38				
73	B-294		7.38				
74	B-286		10.00	10.00			
75	B-287		3.88		3.88	6.91	6.12
637-48	B-290	6.0	19.19	19.19			
49	B-289		18.25				
51	B-295		16.38		16.38	17.94	2.81

Note:
Rounds 637-48, 49 and 51 had the shoulder of the spike machined so that the spike seated against the locking ring rather than against the body, thus affording heavy end confinement. This was done to study the effect of the light locking ring on the performance at the longer standoffs.

TABLE II-VII

PENETRATION DATA

PROGRAM 637d

Liner: Shear Formed CXP-98461 (Mod.)
Assembly: 105mm, M456
Explosive: Comp. B
Target: Mild Steel
Standoff: Built-in

Round Number	Serial Number	Spin Rate (rps)	Penetration (in. M.S.) Meas.	Max.	Min.	Avg.	R
637-46	S-203	0	20.25	20.25			
47	S-202		19.13				
57	S-246		19.50				
58	S-249		19.44				
71	S-206		19.00		19.00	19.46	1.25
637-55	S-215	10	20.75				
56	S-214		20.25				
60	S-231		20.88	20.88			
68	S-247		20.00		20.00	20.47	.88
637-63	S-235	15	19.00				
64	S-211		18.50		18.50		
69	S-248		20.00				
44	S-212		20.75	20.75			
45	S-213		20.75			19.80	2.25
637-50	S-210	20	20.88				
52	S-201		19.00				
61	S-232		20.94	20.94			
65	S-208		18.63		18.63		
70	S-207		18.75			19.64	2.31
637-53	S-204	30	17.88		17.88		
54	S-205		18.88	18.88			
62	S-209		18.50				
66	S-234		18.63			18.47	1.00

Table II-VIII

XM429 LINER NOMINAL PARAMETERS

Mass: 20 grams
Apex Angle: 60 degrees
Index Angle: 9.5 degrees
Flute Taper: 17 mils per inch
Diameter: 1.352 inches
Design Optimum Spin: 175-200 rps
Material: Copper

TABLE II-IX

40MM FLUTED LINERS AGAINST 290 BHN ARMOR AT 3.25 INCH STANDOFF

SPIN RATE (rps)	PENETRATION (in.)
400	0.8
420	1.5
430	1.1
430	1.2
430	2.1
440	1.5
470	1.8
470	1.0
490	1.9
490	1.6
490	0.9
520	1.1

TABLE II-X

40MM FLUTED LINERS, SECOND LOAD LOT AGAINST MILD STEEL TARGET AT 3.25 INCH STANDOFF

SPIN RATE (rps)	PENETRATION (in.)
465	4.1
465	4.0
465	4.2
493	3.8
493	2.9

TABLE II-XI

40mm Fluted Liners, DRC-23-1620-1, 2nd, 3rd and 4th Load Lots against Mild Steel at 3.25 inch standoff.

Spin Rate (rps)	Load Lot	Penetration (in. M.S.)	Average (in.)
350	4	2.9	
350	4	2.3	3.1
375	4	3.8	
375	4	3.5	3.6
400	4	3.2	
400	4	4.1	3.6
435	3	3.9	
435	3	3.9	3.9
450	3	4.2	
450	3	3.9	
450	3	3.6	3.9
460	3	4.1	4.1
465	2	4.1	
465	2	4.0	
465	2	4.2	
465	4	4.3	4.2
470	3	3.8	3.8
480	3	3.7	
480	3	4.3	
480	3	4.3	4.1
493	2	3.8	
493	2	2.9	3.4
600	4	2.1	2.1

Table II-XII
PENETRATION DATA

PROGRAM 658

Fuze Line 2, Small Chamber
Defense Research Division
The Firestone Tire & Rubber Company

Test Item: Liner: DRC-23-1620-1 (30 gm)

Test Conditions: Target: Mild Steel (110 BHN)
Standoff: 3.25 inches
Explosive: Base Initiated Comp B

Round Number	Serial Number	Spin Rate (rps)	Penetration (inches M.S.) Meas.	Max.	Min.	Avg.	Range
658-17	F149	220	4.81	4.81			
-18	F148		4.50				
-19	F150		3.75				
-20	F151		3.19		3.19	4.06	1.62
658-1	F131	260	3.50		3.50		
-5	F134		4.25				
-9	F138		4.38	4.38			
-13	F142		3.88			4.00	.88
658-2	F126	300	4.44	4.44			
-6	F135		3.75		3.75		
-10	F139		4.38				
-14	F144		4.13			4.17	.69
658-3	F132	340	3.38				
-7	F136		3.88				
-11	F140		4.13	4.13			
-15	F146		3.25		3.25	3.66	.88
658-4	F133	380	3.94				
-8	F137		4.56	4.56			
-12	F141		3.19		3.19	3.91	1.37

PROGRAM 641

October 30, November 1, 27, 1963
Fuze Line 2, Small Chamber
Defense Research Division
The Firestone Tire and Rubber Company

Test Item: Liner: DRC-23-1620-1 30gm)

Test Conditions: Target: Mild Steel (110 BHN)
Standoff: 3.25 inches
Explosive: Base initiated Composition B

Round Number	Serial Number	Spin Rate (rps)	Penetration (inches M.S.) Meas.	Max.	Min.	Avg.	Range
641-7	F-107	300	3.64		3.64		
-24	F-124		4.50	4.50			
-25	F-125		4.03			4.05	.86
641-6	F-106	320	3.28			3.28	
641-5	F-105	340	3.50	3.50			
-11	F-111		3.47				
-16	F-116		3.28				
-23	F-123		2.25		2.25	3.25	1.25
641-17	F-117	350	2.88				
-18	F-118		3.66			3.27	.78
641-1	F-101	360	4.64	4.64			
-10	F-110		3.18		3.18		
-15	F-115		3.94				
-22	F-122		3.88			3.91	1.46
641-19	F-119	370	2.44				
-20	F-120		2.50			2.47	.06
641-2	F-102	380	4.50	4.50			
-9	F-109		3.75				
-14	F-114		3.44				
-21	F-121		2.94		2.94	3.66	1.56
641-3	F-103	400	3.13				
-8	F-108		2.03			2.58	1.10
641-4	F-104	420	2.94			2.94	
641-12	F-112	440	1.25				
-13	F-113		1.50			1.37	.25
641-26	F-126	360	4.25				
-27	F-127		4.38				
-28	F-128		4.25				
-29	F-129		3.06		3.06		
-30	F-130		4.75	4.75		4.14	1.69

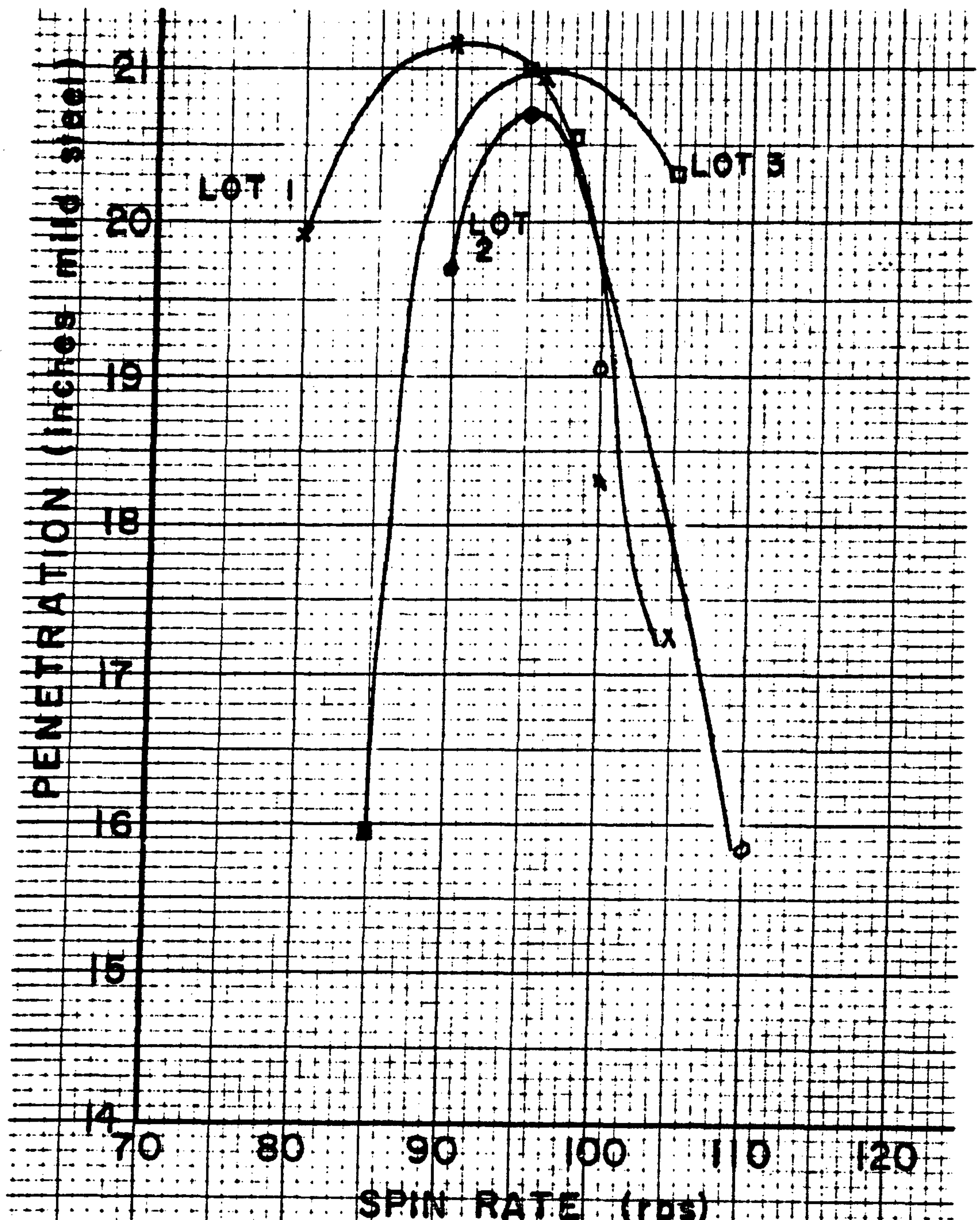


Fig. II-1. Static Penetration Plot - Penetration vs. Spin Rate. XP 117 120 Liner, 60° Apex Angle, .175 in. Wall, 7° Index Angle. Lots 1, 2, and 3.

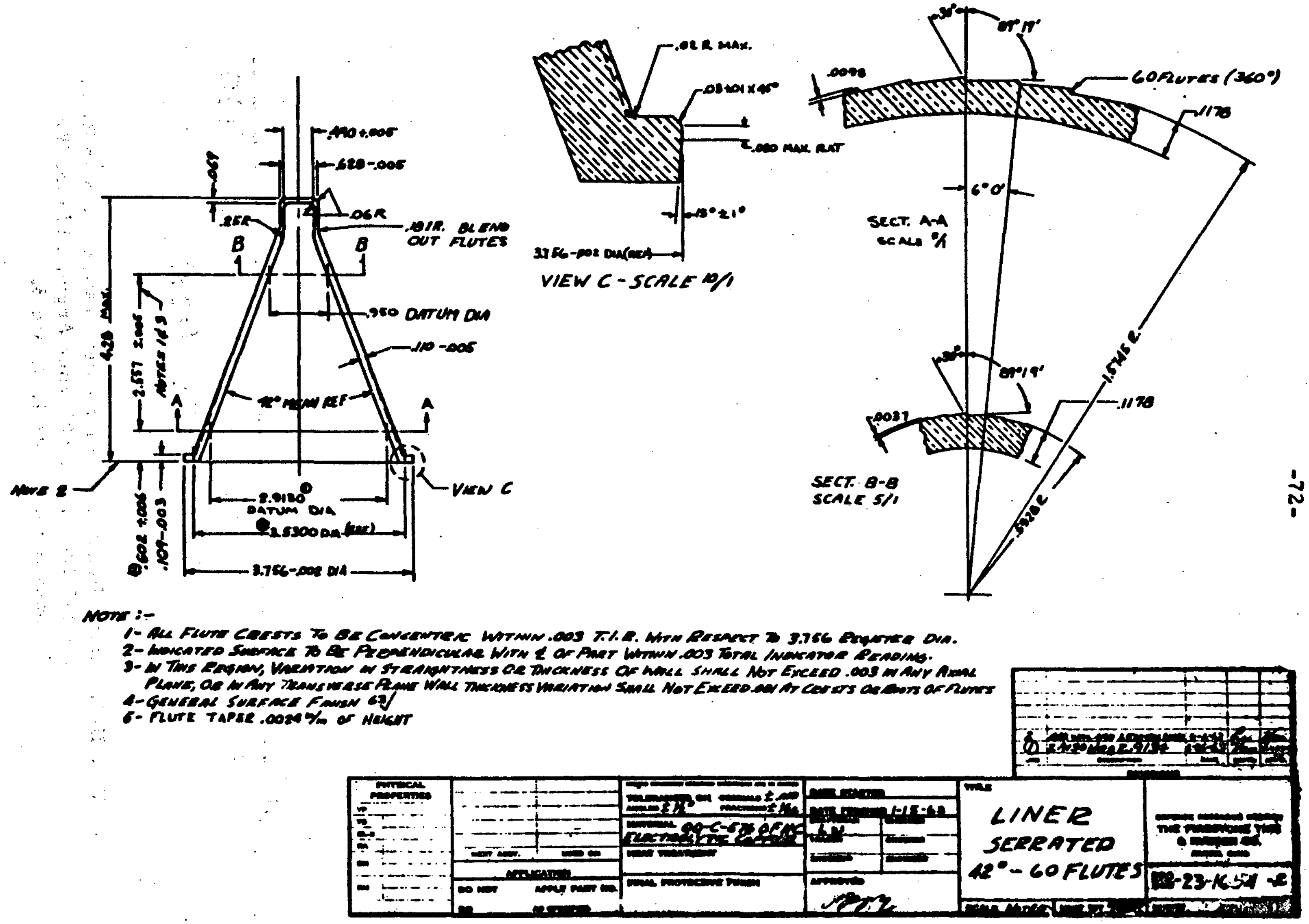


Fig. II-2. Fluted Liner, 42° Apex Angle, .110 in. Wall, 6° Index Angle. Dwg. No. DRC-23-1654-2.

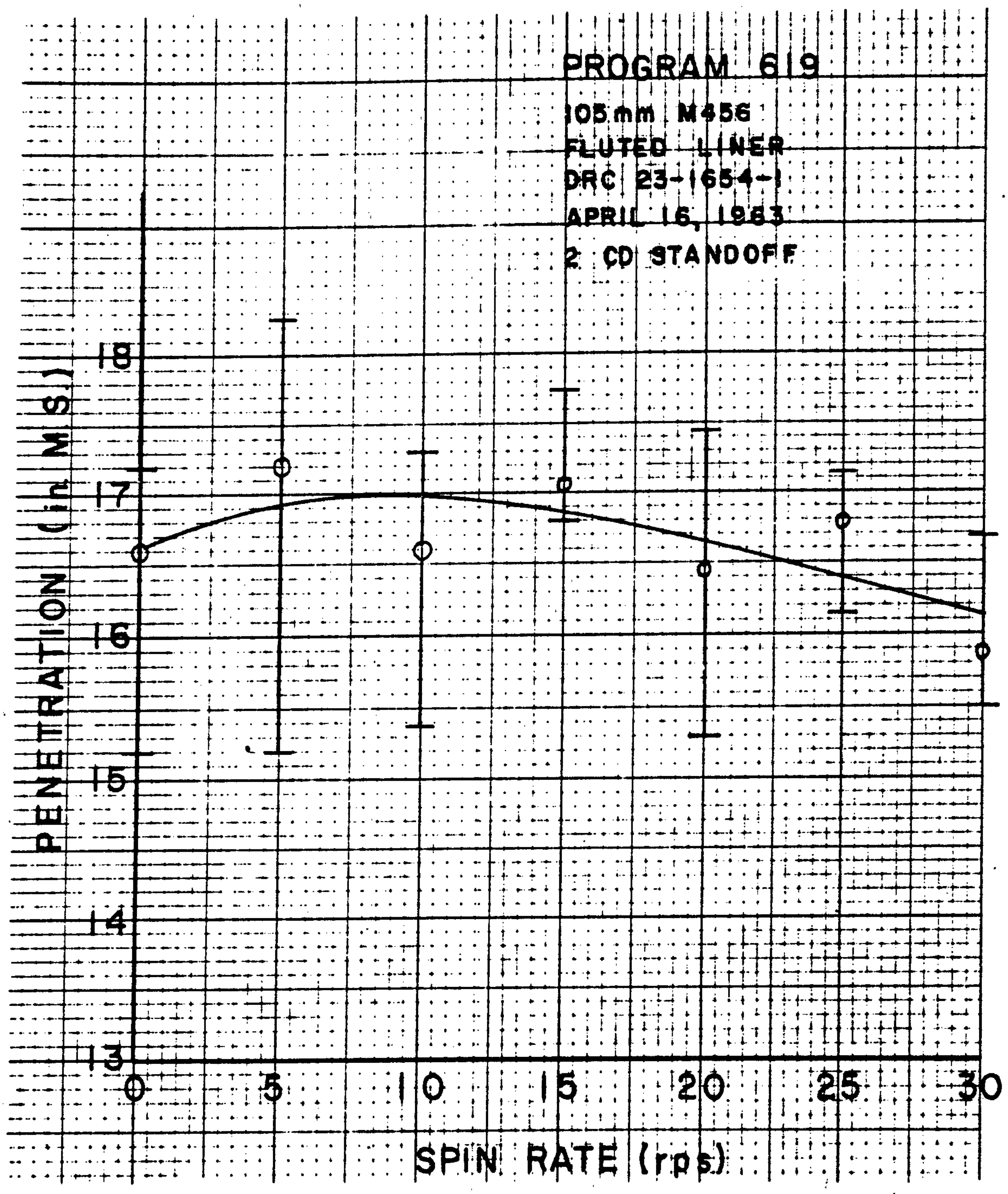


Fig. II-3. Static Penetration Plot - Penetration vs. Spin Rate. Fluted Liner, Dwg. No. DRC-23-1654-1. 42° Apex Angel, 105mm. Standoff - 2 Charge Diameters.

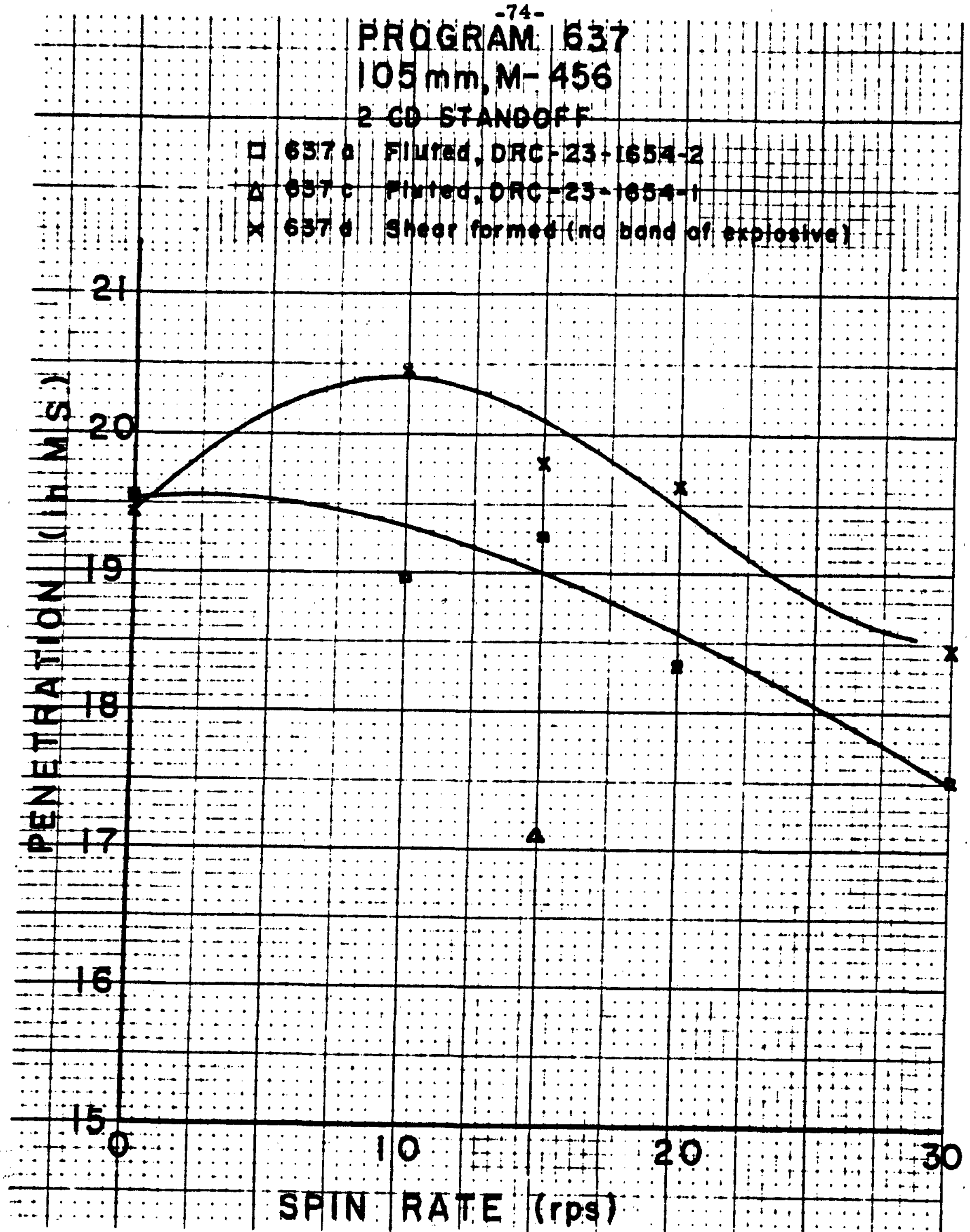


Fig. II-4. Static Penetration Plot - Penetration vs. Spin Rate. 105 mm. Liners. Standoff - 2 Charge Diameters.

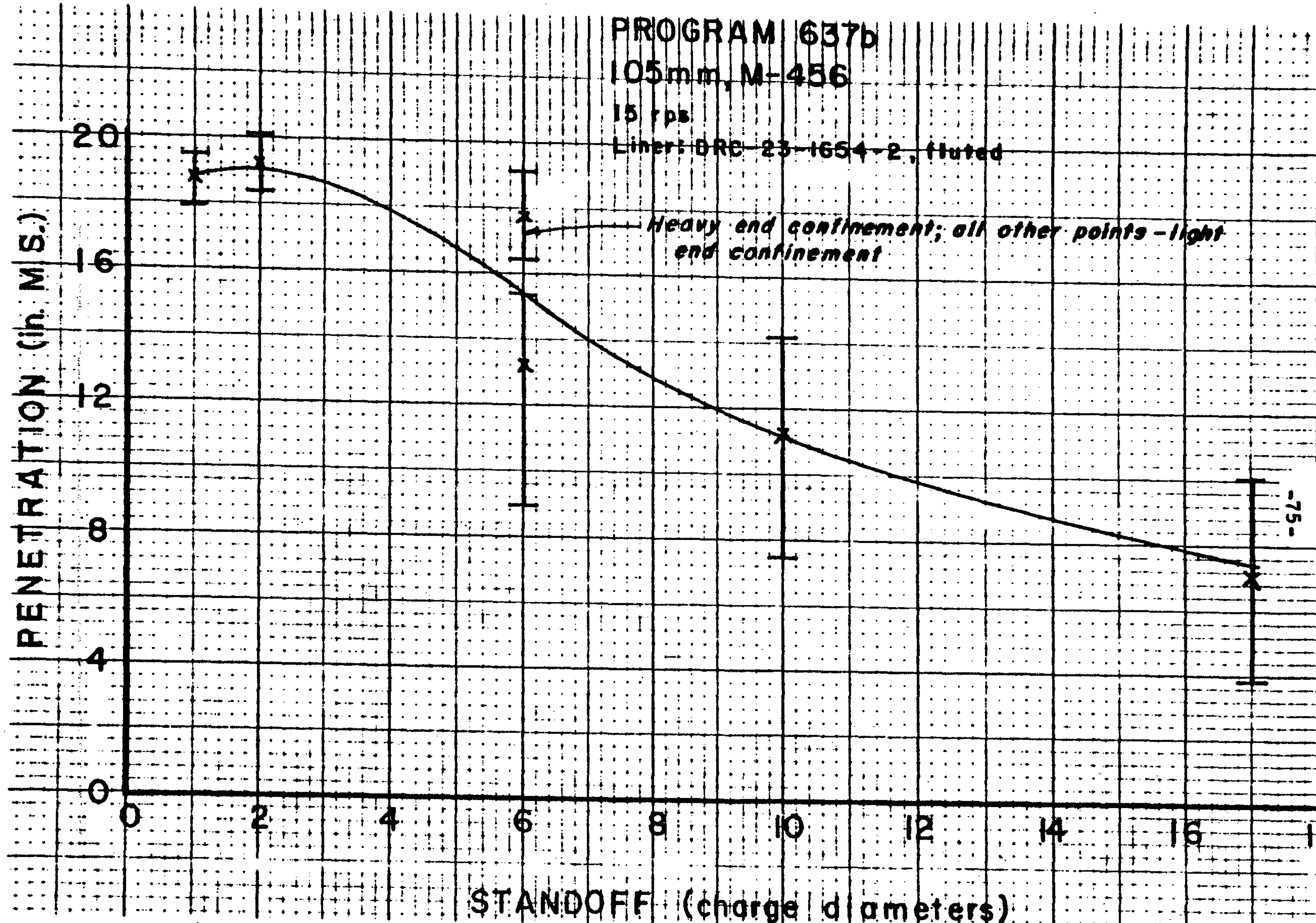


Fig. II-5 Static Penetration Plot - Penetration vs. Standoff.

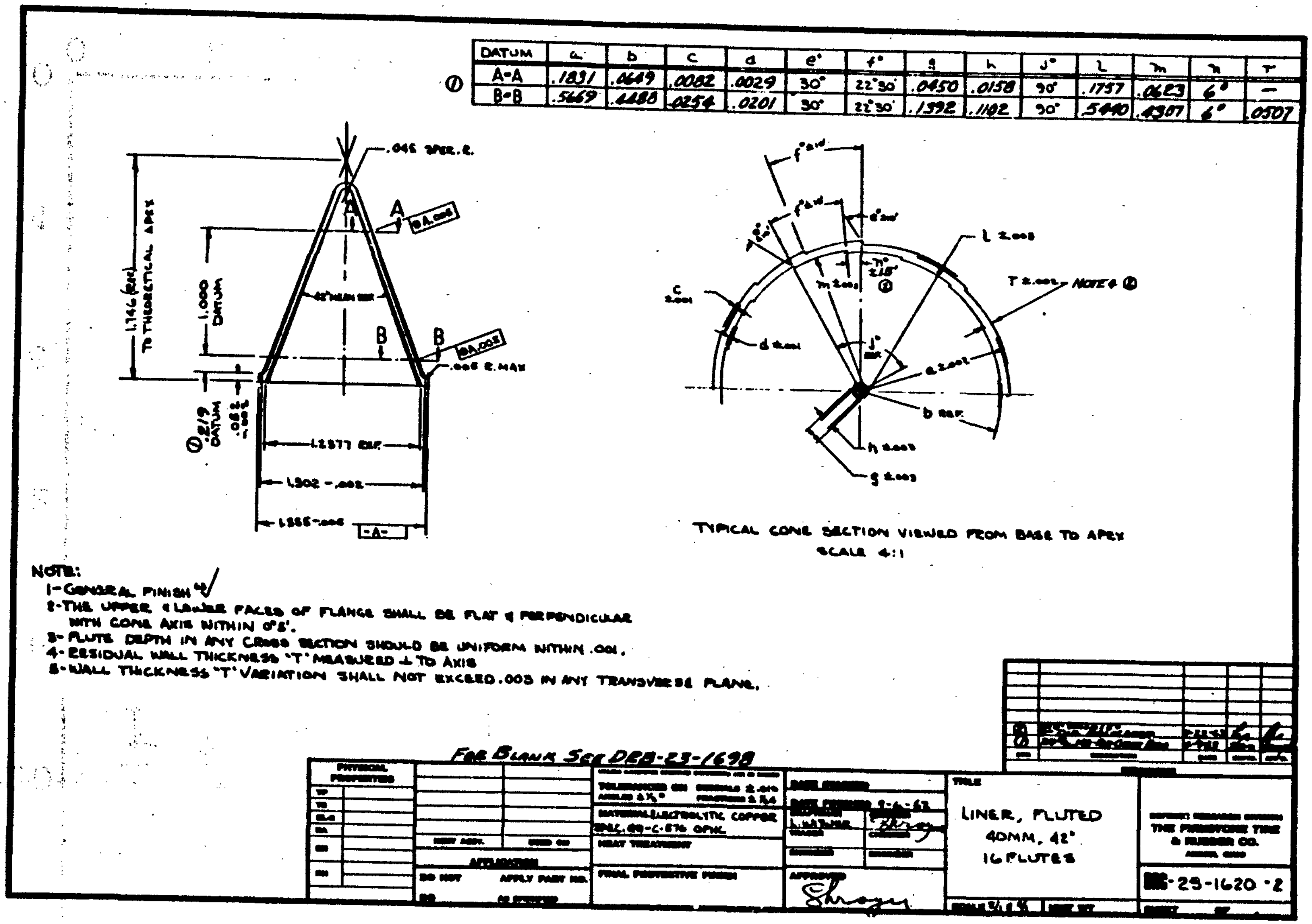


Fig. II-6. Fluted Liner, 40mm., 42° Angle. Dwg. No. DRC-23-1620.

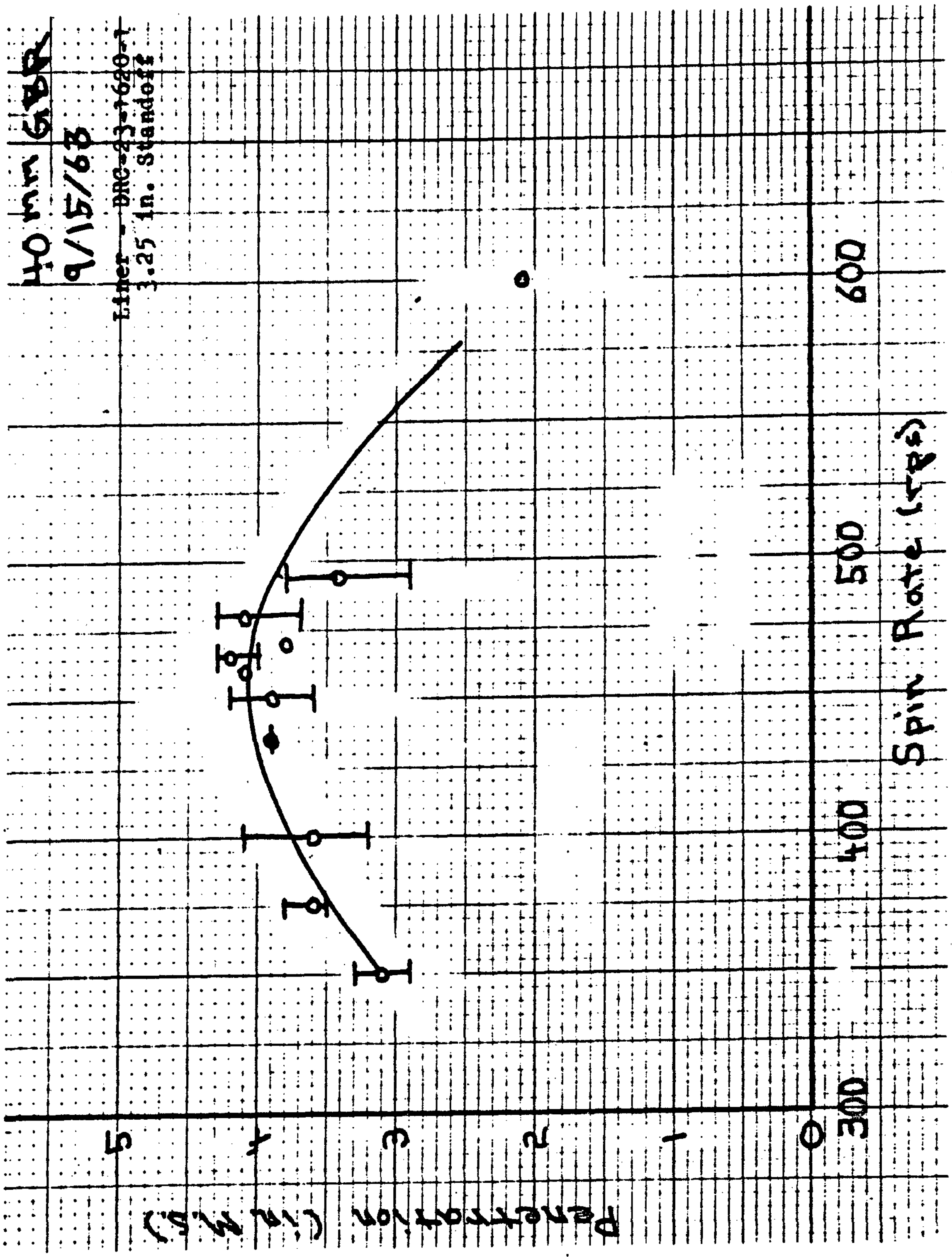


Fig. II-7. Static Penetration Plot - Penetration vs. Spin Rate. DRC-23-1620-1 Liner 40mm. GBR Projectile.

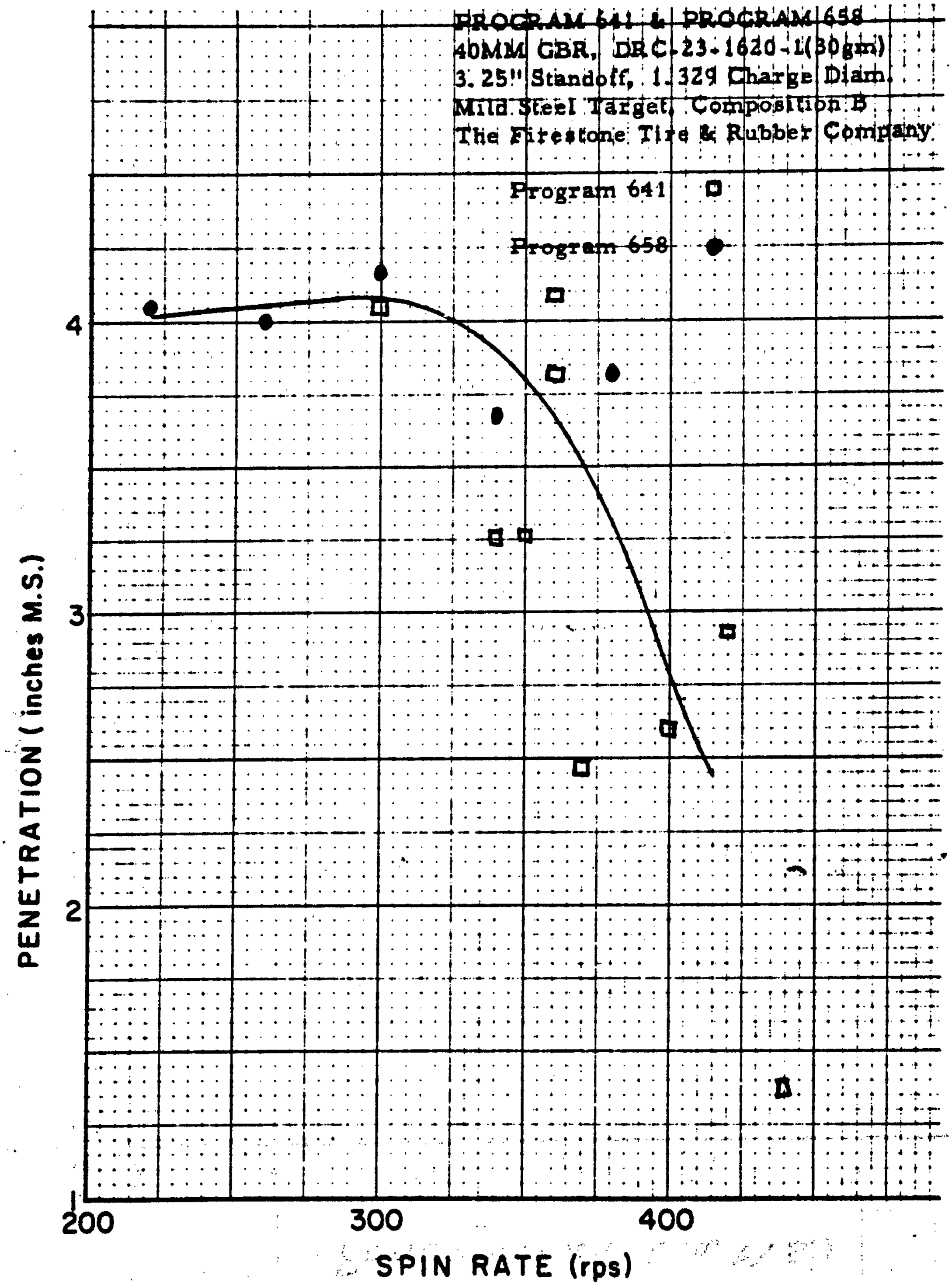


Fig. II-8. **Static Penetration Plot - Penetration vs. Spin Rate. 40mm. GBR Projectile - 30 gm. Liner DRC-23-1620-1.**

SECTION III

HYPERBALLISTICS

INTRODUCTION

This section covers work conducted by the Defense Research Division of The Firestone Tire & Rubber Company on the effects of hypervelocity impact. The project was funded by the Advanced Research Projects Agency under project ARPA-149, and was under the technical supervision of the Ballistic Research Laboratories. A complete detailed report entitled Project Report on Hypervelocity Impact Studies, Firestone DRD-6 was published. A briefer review of the Program follows:

The objective of the project was to provide information on the effect of hypervelocity impact on materials of finite thickness. The data will be used to establish the warhead requirements for killing an armed re-entry vehicle.

Firestone responsibilities on the project were:

(1) Procurement, processing and dispersal of target materials.

(2) Manufacture and shipment of inhibited jet charge assemblies to BRL and Bureau of Mines.

(3) Conduct hypervelocity impact tests on composite targets.

In order to perform the tasks outlined above it was also necessary to conduct design and development work. During the course of the project Firestone was given the additional task of developing a series of three scale 1 inhibited jet charges. However, this work was not completed due to a shift in emphasis on the project.

SUMMARY

Hypervelocity impact tests were conducted against composite targets. The targets were impacted by scale 1, scale 2 and scale 3-1/2 pellets which were projected by inhibited jet charges. The composite targets were composed of ablative type materials cemented to metal backups. The ablative materials (also referred to as primary targets) were polyethylene, nylon fabric-phenolic, glass fabric-phenolic and glass. The metal backups were magnesium, aluminum and steel. Ablative thicknesses of 1 and 2 inches were combined with metal thicknesses of 1/8 and 1/4 inches to give targets ranging from 1-1/8 inches to 2-1/4 inches thick. The pellet masses and velocities resulted in scale 1, scale 2 and scale 3-1/2 pellet energies of 140 kilojoules, 1 megajoule, and 6.1 megajoules respectively.

Samples of the composite target materials (except for polyethylene and glass) were subjected to a series of standard tests for the purpose of identifying the materials for future reference.

SCALE 1 AND SCALE 2 HYPERVELOCITY IMPACT TESTS

The scale 1 and scale 2 hypervelocity impact tests were conducted with composite targets which consisted of an ablative material cemented to a metal backup. The cement was a commercial item called Permatex. The ablatives were polyethylene, nylon fabric-phenolic, glass fabric-phenolic and glass. The metal backups were magnesium, aluminum and steel. A list of the target materials and specifications is given in Table III-I.

The scale 1 pellet which was developed by the Ballistic Research Laboratories was formed from a 42° 1100-0 aluminum liner. The mass and velocity were 3.3 grams and 9.3 km/sec respectively. The scale 2 pellet, which was intended to be a geometric scale-up of the scale 1 pellet, was found to have an average mass of 24.6 grams and a velocity of 9.1 km/sec. A drawing of the scale 2 inhibited jet charge is shown in Fig. III-I.

The scale 1 and scale 2 tests were conducted at zero, sixty and eighty degrees obliquity. The test setup for the hypervelocity impact tests is shown schematically in Fig. III-2, where the dimensions for both scale 1 and scale 2 are given.

The tests were conducted in phases. The tests consisted of firing at groups of composite targets composed of various combinations of ablative and metal backup thicknesses. The test phases were as follows:

Phase	Ablative Thickness (inches)	Metal Backup Thickness (inches)	Obliquity (degrees)
1	2	1/4	0
2	1	1/8	0
3	1	1/8	60
4	2	1/8	0
5	1	1/4	0
6	1	1/8	80

The throat hole size in the primary target (ablative material) is given in Table III-II, where all of the scale 1 and scale 2 data (except for eighty degrees obliquity tests) are summarized. The values listed in Table III-II represent the size of an object which might pass through the hole. When the throat area was not circular, two measurements were taken giving the maximum and minimum dimension. These two numbers were assummed to represent an elliptical area. The diameter of an equivalent circular area was then calculated for the hole size.

The throat sizes in the petalled metal backups are listed in summary Table III-III. They were determined in the same way as those in the primary target. The hole size data for the metal backups are not as accurate as those for the primary target because of the distortion produced during the petalling action. Selected photographs of targets and witness plates are shown in Figures III-3, III-4, and III-5.

It can be seen from the data in Tables III-II and III-III that the damage produced at 60 degrees obliquity is just about the same as that at zero degree obliquity. Another point of interest is that although the glass primary target material shattered in every case, the damage to the metal backup was less than for other ablative materials. General observations regarding both scale 1 and scale 2 tests are listed in a later section of this report.

Data for shots at zero, sixty and eighty degrees obliquity are compared in Table III-IV and III-V. It is seen that the effects of obliquity on the primary target for scale 1 are not as great as might have been expected. In fact, the results at sixty degrees obliquity indicate that the damage is slightly greater, except for steel backed targets. The main effect of high obliquity (80 degrees) on the composite targets was a reduction in damage to the metal backup. If one is concerned with damage due to spall fragments behind the target, then the effects of obliquity become evident even at 60degrees. Witness plates show that the degree of damage and the number of spall particles hitting the witness plates is less at 60 degrees than at zero degrees. In regard to the target damage, the results are similar to scale 1 results in that significant damage is done to the ablative material, but damage to the metal backup is drastically reduced.

Scale 2 Spall Velocity Test

The spall velocity program was conducted in order to obtain an estimate of the spall velocity, as well as the relative number and size of the spall particles which are produced by a scale 2 pellet impacting composite targets. Radiographs of the scale 2 pellet prior to target impact were also obtained.

The spall velocity test was conducted in the large concrete test chamber located at Ravenna Army Ammunition Plant. The scale 2 inhibited jet charge was fired vertically downward into a lower chamber where the target was located, and where the pellet and spall could be radiographed. A schematic of the test setup is shown in Fig. III-7. It is seen that the pellet was radiographed using a cassette resting on the top surface of the composite target. Three cassettes were placed between the bottom surface of the target and the first witness plate in order to radiograph the spall. One radiograph was taken as the spall emerged from the target, then two more were taken simultaneously before the spall hit the first witness plate. The witness plates were 1/4 inch thick steel, 1/2 inch thick steel and 1/2 inch thick aluminum (in the sequence given).

Examples of the pellet and spall radiographs taken are shown in Figures III-8 and III-9 where the spall at two positions beyond the target as well as the pellet which struck the target are shown. The spall velocities, along with the pellet size data, are listed in Table III-VI. The spall velocities given represent the velocity of the leading surface of the spall envelope.

A study of the radiographs and spall velocity data reveals the following trends:

a. Steel backed targets produced the largest particles, while magnesium tended to produce the smallest.

b. The spall particles were smaller, more numerous, and had a higher velocity for thin targets than for thick targets.

c. For thin targets, spall velocities for all of the material combinations were generally high and near the velocity of the incident pellet.

d. For some thin targets there was definite evidence of pellet material being spread along the leading surface of the spall envelope.

e. Steel backed targets produced the lowest spall velocity, while magnesium and aluminum produced the highest velocities.

It was found that the damage to the 1/4 inch thick and 1/2 inch thick steel witness plates depended on composite target thickness as well as target material. The 1/2 inch thick aluminum witness plate was not damaged on any shot. In general, when the target was thin the spall particles were small, tended to be concentrated near the leading surface of the spall envelope, and had a high velocity. A large hole then resulted in the 1/4 inch thick steel witness plate, and localized damage was done to the 1/2 inch thick steel plate located 6 inches beyond the 1/4 inch plate. When thick targets with the denser metal backups were impacted, most of the spall mass was in the lower velocity region of the spall envelope rearward from the leading surface; therefore, damage to the 1/4 inch witness plate was not localized, but spread over a large area. In this case a large number of small holes were made in the 1/4 inch witness plate, and the 1/2 inch thick plate was only superficially damaged. The two types of damage discussed above are illustrated in Figures III-10 and III-11 where photographs of the 1/4 inch thick witness plate are shown for thin and thick target shots.

The material combinations also influence the nature of the damage beyond the target. For example, a combination of 2 inch polyethylene and 1/4 inch magnesium produced damage on the 1/4 inch witness plate equivalent to 1 inch nylon fabric-phenolic and 1/8 inch aluminum.

Scaling

One of the purposes of testing with both scale 1 and scale 2 pellets was to determine whether the damage effects would scale in going from scale 1 pellets with a kinetic energy of 140 kilojoules to a scale 2 pellet which has a kinetic energy of one megajoule. In order to examine scaling, ratios of hole sizes in both ablative and metal backup materials were calculated in order to compare the effect of scale 2 pellets against thick targets and scale 1 pellets against thin targets. Thus, both pellets and targets were scaled. The scaling ratios were calculated from the values shown in summary Tables III-II and III-III. The results are shown in Table III-VII for the primary targets and in Table III-VIII for the metal backups. It is seen that in the ablative materials scaling does occur for five out of nine of the target combinations. In particular, scaling seems to occur for all polyethylene-faced targets. Scaling of the throat sizes in the metal backup is questionable due to the tearing and petalling nature of the failure. It appears to exist for four out of the nine targets; however, only one of the four coincides with targets which scaled for hole sizes in the primary material.

Target Damage

In regard to target damage, it has been found that the scale 1 pellet did significant damage to the magnesium and aluminum backed targets. However, the results against steel backed targets were marginal. The scale 2 pellet defeated all targets and was capable of producing severe damage behind the target.

The following is a list of observations made in regard to scale 1 and scale 2 target damage:

(1) Glass as a primary material allowed the least damage to the metal backups in both scale 1 and scale 2 tests. Two inch glass primary targets prevented perforation of the metal backups on all scale 1 shots.

(2) Magnesium as a metal backup exhibited the least amount of petalling and the smallest hole size. (This is relative to petalled hole sizes in aluminum and steel.)

(3) In regard to spall hole size, magnesium generally showed the largest holes and steel the smallest.

(4) The steel backups showed the greatest petalling damage for scale 2 pellets. This is contrary to scale 1 results where aluminum exhibited the greatest damage. This leads to the conclusion that the scale 1 pellet was marginal for the defeat of steel backed targets.

(5) The throat sizes in the ablative materials tended to be greatest for steel-backed targets. This indicates the presence of a strong reflected shock wave at the ablative-steel interface.

(6) The nylon fabric-phenolic exhibited spall, whereas the glass fabric-phenolic delaminated, but tended to remain attached to the target.

It was observed in scale 1 tests that the backup metal tended to tear (during petalling) along the rolling direction of the sheet. This effect appeared to be random in the scale 2 tests. In some cases the metal backup followed the trend, in others the metal tore predominantly in a direction perpendicular to the rolling direction.

Witness Plate Damage

Damage behind the target was recorded by witness plates. In all of the scale 1 tests and most of the scale 2 tests, the damage was recorded by two 1/4 inch thick 1100-0 aluminum plates (in contact) located 10 inches behind the target. For scale 1 tests the witness plate area was 18 inches x 18 inches. For scale 2 tests the area was 36 inches x 30 inches. The witness plates for the spall velocity test were 4 feet x 4 feet square and were arranged as shown in Figure III-7.

A review of the photographs of scale 1 and scale 2 targets and witness plates, shows that the damage to the aluminum winess plates, behind targets impacted by scale 1 pellets, was marginal. In some cases, both plates were perforated; in the majority of cases they were not. However, for scale 2 tests the damage to the witness plates was severe. Large holes were made through both plates (except for one case) and the plates were badly bent.

Further evidence of the damage potential of the scale 2 pellets was shown by the 1/4 inch thick steel plates used in the spall velocity tests. It was found that the concentrated type of spall damage which produced one large hole at the center of impact on the witness plate was associated with thin low density targets. The thick high density targets resulted in a group of individual perforations of the 1/4 inch steel witness plate which were spread over a larger area than the thin target damage. The latter type of damage was most exemplified by the steel backed targets.

The effects of obliquity on witness plate damage was shown by the shots at 60 degrees and 80 degrees obliquity. It was found that the damage dropped off at 60 degrees obliquity, and that at 80 degrees the witness plate damage was effectively zero. The drop-off in damage is due to a reduction in the spall velocity as well as a reduction in the number of spall particles, as the obliquity angle increases.

It is interesting to note that when the witness plate damage potential was lower (such as at 60 degrees obliquity), there were cases where large relatively-low-velocity fragments penetrated both witness plates. This, even though the probability of damage to the witness plates is less, there is a chance that one or two large lower velocity fragments could cause behind-the-target damage.

SCALE 3-1/2 HYPERVELOCITY IMPACT TESTS

A series of tests was conducted with a scale 3-1/2 inhibited jet charge. This charge was designed to produce a pellet mass of about 150 grams and a pellet velocity of 7.6 km/sec. The charge diameter was 12 inches. The liner was made of 1100-0 aluminum and had a cone angle of 60 degrees. Drawings of the charge and the liner are shown in Figure III-12.

The scale 3-1/2 Charge was tested against four targets as follows:

(1) Aluminum Billet

The first target tested was an aluminum billet (1100-0) which was 26 inches in diameter and 10 inches thick. The aluminum target was backed up by and in contact with a 2 foot x 2foot x 6 inch thick steel block. The base of the liner in the inhibited jet charge was 147.8 inches from the front face of the aluminum.

The scale 3-1/2 pellet produced a large hole in the aluminum and caused the back surface of the 6 inch thick steel backup to spall. Front and back views of the aluminum target are shown in Figures III-13 and III-14. The spall on the back surface of the 6 inch thick steel backup is shown in Fig. III-15.

The damage to the aluminum target was as follows:

Entrance Hole Size	8" x 9"
Throat Size	7-5/8" x 7-1/4"
Exit Hole Size	10-1/2" x 10-1/4"

Damage to the 6" thick steel backup consisted of an identation on the front side (which was in contact with the aluminum) that was 1-3/4 inches in diameter by 1-5/8 inches deep. The back surface spall was 12 inches x 8-1/2 inches in area and 3/4 inch deep.

(2) First Composite Target Test

The next shot was fired at a composite target which had a frontal area of 36 inches by 36 inches and was composed of the following elements:

Material	Thickness
Nylon Fabric-Phenolic	1/2 inch
Mild Steel	1 inch
Hard Lead (6% Antimony)	1/4 inch

The front side of the target and the witness plates are shown in Fig. III-16. The back surface of the target is shown in Fig. III-17. Damage to the target is listed in the following table:

Component	Damage
1/2 inch Nylon Fabric-Phenolic	Throat Size - 8-1/2 inch dia. Front Spall - 10 inch dia.
1 inch Mild Steel	Throat Size - 3-1/2 x 4-1/2 inches Back Spall - 4 x 5-1/2 inches

1/4 inch Hard Lead	Throat Size - 10-1/2 inch dia. 7 Petals - Extreme edge of petals show spall type fracture.

(3) Second Composite Target Test (Explosive Witness Box)

The second composite target was composed of the same materials as for the previous test except that the nylon fabric-phenolic component was 1 inch thick. The charge to aperture plate distance was 85 inches and the charge to target distance was 148 inches.

The witness arrangement for this test was varied to include an aluminum box filled with 24 lbs. of Composition B. The inside dimensions of the box were 10 inches by 10 inches by 4 inches thick. The aluminum was 1/8 inch thick and the front of the box had a 1/2 inch thick layer of natural rubber cemented to it. The target and witness plate array was as follows:

a. Composite Target (1 inch Nylon Fabric-Phenolic, 1 inch Steel, 1/4 inch Hard Lead)

b. 24 inches Air Space

c. 1/2 inch Natural Rubber, 1/8 inch Aluminum, 4 inches Comp. B, 1/8 inch Aluminum (24 lbs. of Comp. B in an Aluminum Box faced with 1/2 inch Rubber)

d. 18 inches Air Space

e. Steel Block - 24 inches by 24 inches by 6 inches thick.

The scale 3-1/2 pellet defeated the composite target and initiated a high order detonation in the explosive filled box. Damage done to the target was as follows:

Target Component	Damage
1 inch Nylon Fabric-Phenolic	Throat Size - 9 x 10 inches Front Spall - 16 x 21 inches
1 inch Mild Steel Plate	Throat Size - 3-1/2 x 4 inches Back Spall - 1-1/2 x 6 inches
1/4 inch Hard Lead	Badly torn and fragmented

The composite target elements are shown in Figure III-18.

(4) Third Composite Target Test (Pellet Radiographed)

The target for the third composite test was identical to the one used for the second composite target test (1 inch nylon fabric-phenolic, 1 inch mild steel, 1/4 inch hard lead). It was decided to obtain radiographs of the scale 3-1/2 pellet prior to stiking the target. Therefore, a special arrangement was made at the test site to do this. A photograph of the test setup is shown in Fig. III-19. The cassettes, which can be seen in the photograph, are heavily reinforced units that were designed to withstand the resultant blast.

Radiographs were obtained of the aluminum pellet after 146 inches and 164 inches of travel with respect to the liner base. The mass of the pellet was estimated to be about 200 grams, and its velocity was found to be 7.8 km/sec. It was found that the pellet was in two major pieces as shown in Fig. III-20. A composite phototgraph of the two sections is shown in Fig. III-21. It is seen that the two pieces fit well together. It is believed that the separation of the pellet was due to the two-piece construction of the aluminum liner. Since the break occurs at about 1/2 the length of the pellet it appears that this information might be used to determine what portion of the liner the pellet comes from.

Damage to the composite target components was as follows:

Target Component	Damage
1 inch Nylon Fabric-Phenolic	Throat Size - 10 x 11-1/2 inches Front Spall - 12 x 16-1/2 inches
1 inch Mild Steel	Throat Size - 3-1/2 x 5-1/2 inches Front Spall - 6 x 7 inches Rear Spall - 5 x 6 inches
1/4 inch Hard Lead	Petalled and broken into 3 major pieces.
First 1/4 inch Witness Plate	Perforated and badly bent.
Second 1/4 inch Witness Plate	Cratered and bent but not perforated.

In conclusion, it can be stated that the scale 3-1/2 tests were very successful in that they showed what kind of damage could be done to a fairly substantial 3-component composite target. The results also indicate that considerable damage could still be produced behind the target. The pellet was radiographed only on the last shot; therefore, there is no way of knowing whether the pellets on the other shots separated. A review of the photographs of the composite targets reveals that the holes in the 1 inch steel component are elongated (keyholed) and that the pellets might also have been in two pieces.

DESIGN AND DEVELOPMENT

A number of inhibited jet charge designs were worked on during the course of this project. These designs included scale 1/2, scale 1, scale 2, scale 3-1/2 and scale 4 inhibited jet charges. The design work mainly consisted of linearly scaling the dimension from the basic scale 1 charge developed by BRL. Firestone's designs incorporated a paper body and in the case of the scale 2 charge the base of the charge was tapered to reduce the amount of explosive.

The various charges are discussed in the following sections.

(1) Scale 1/2 Charge

The scale 1/2 charges (DRC-H-26) were intended to be used primarily by the Bureau of Mines for their part on the ARPA 149 project. The dimensions were determined by linearly scaling down the scale 1 values. Thus, the liner was a 37 degree aluminum cone with a spitback tube. The spitback tube was not scaled down for this design; it was kept at the scale 1 size on recommendation from BRL. A number of these liners were made from annealed flo-turned blanks; however, Bureau of Mines reported that they did not function properly. The remaining liners were then machined out of bar stock and were reported to have functioned properly.

(2) Scale 1 Charge

The scale 1 charge used on all of the target testing is given as DRC-H-16-5. The liner is a 42 degree aluminum cone instead of the 37 degree cone developed by BRL. It was found necessary to decrease the inhibitor height to 1-1/16 inches for the 42 degree liner. The original 37 degree liner used a 1-1/4 inch inhibitor height.

Three scale 1 development charges were designed for the purpose of extending the velocity range of the aluminum pellets and to obtain a copper pellet for target tests. In all cases the pellet was to [illegible].3 grams. The cone angles, expected velocities, and drawing numbers are listed below:

Material	Cone Angle (degrees)	Pellet Velocity (km./sec.)	Dwg. No.
Aluminum (1100-0)	30	10.4	DRC-H-28
" "	60	7.6	DRC-H-27
Copper (OFHC)	37	7.6	DRC-H-29

The drawings were completed and 10 each of the items were fabricated. A few of the 60 degree aluminum lined charges were fired and the pellets were found to be in the expected velocity range. However, the pellets were too long and it was apparent that inhibitor height tests would have to be conducted.

Development work was never completed due to a shift in emphasis to scale 2 test work.

(3) Scale 2 Inhibited Jet Charge

The scale 2 charge was scaled up from the scale 1 charge which had a 42 degree liner. A cross section of the charge was shown in Fig. III-1. Firestone's drawing number is DRD-H-18-4.

After firing a few of the charges in the concrete test chamber with some resultant damage done to concrete structure, it was decided to taper the base end of the charge in order to eliminate part of the explosive. The tapering was accomp lished by fastening a wooden plug inside the paper body prior to loading. This redu the explosive by about 4.5 lbs. out of 17.7 lbs. The charges were fired and found to work well.

Some development testing had to be conducted on the scale 2 inhibitor height in order to obtain the desired pellet mass. The original inhibitor height was 2-1/8 inches which is twice the scale 1 value of 1-1/16 inches. It was found that pellet masses in the range 10.5 to 12.9 grams were obtained with the 2-1/8 inch inhibitor. A series of tests was then conducted to determine the proper value. The data are plotted in Fig. III-22 which gives both pellet mass and pellet aspect ratio as function of inhibitor height. An inhibitor height of 1.790 inches was chose from the curves. This should have given a pellet mass of about 25 grams on an aspect ration of 3.6/1. The average measured values for these two quantities wer 24.6 grams and 3.7/1 respectively.

(4) Scale 3-1/2 Inhibited Jet Charge

The scale 3-1/2 charge was fabricted by modifying an existing 12 inch diameter, 60 degree aluminum liner to incorporate a spitback tube. The two units were assembled by press fitting them together. Several modifications were made in the inhibitor design under direction of BRL. They found that a drastic change had to be made in the inhibitor design in order to obtain proper functioning. The inhibitor, instead of terminating at the base of the liner, had to extend outward fro the base. It was necessary to incorporate a ring of explosive around the extended portion of the inhibitor. This made it necessary to design and fabricate a special mold for this charge.

A special cassette for radiographing the scale 3-1/2 pellet was designed an tested. The design was based on BRL suggestions.

A scale 2 model of the scale 3-1/2 charge (DRC-H-51) was designed. The design did not include the inhibitor and diverter charge (it produced a conventional jet). The purpose of these charges was to test the instrumentation and timing prio to radiographing the scale 3-1/2 pellet.

Five of the units were fabricated and two of them were fired. The value of the models is exemplified by the fact that a radiograph of the scale 3-1/2 pellet was obtained on the first trial, in spite of a rather unusual test setup (the control and power unit were about 600 yards from the X-ray pulsers and tube heads).

(5) Scale 4 Inhibited Jet Charge

Design work was conducted on a scale 4 inhibited jet charge. This charge was to incorporate a tapered charge in order to limit the amount of explosive needed. The liner was to be a 37 degree aluminum cone, 13.6 inches in diameter. Forging drawings were made and 10 forgings were obtained.

Prior to completing the charge assembly drawings it was decided to fabricate some scale 2 models (DRD-H-34, DRD-H-35) of the scale 4 design in order to determine the degree to which the charges could be tapered. Some models were fabricated, but tests were not completed due to termination of the project.

SHIPMENT OF MATERIALS

During the course of this project scale 1/2, scale 1 and a few scale 2 charges were shipped to BRL and Bureau of Mines. In some cases only the liners and inhibitors were shipped instead of the whole charge assembly. A large quantity of composite target materials was shipped to the Bureau of Mines.

TABLE III-I

COMPOSITE TARGET MATERIALS

MATERIAL	TYPE	SPECIFICATION	THICKNESS
Ablatives	High Density		
Polyethylene	-	-	2", 1"
Nylon Fabric-Phenolic	Type V Grade N 1 NEMA-1	L-L-31	2", 1"
Glass Fabric-Phenolic	Type IV, Grade G 3 Semi-Gloss	L-L-31	2", 1"
Glass	Cast	-	2", 1"
Metals			
Steel, Sheet	Type 4130 Hot Rolled, Normalized	MIL-S-18729	1/8", 1/4"
Aluminum Alloy Sheet	Type 2024 - T-4	QQ-A-355C-1	1/8", 1/4"
Magnesium Alloy Sheet	AZ31BH24	-	1/8", 1/4"

TABLE III-II

SUMMARY OF PRIMARY TARGET THROAT SIZES (INCHES) FOR SCALE 1 AND SCALE 2 PELLETS

Primary Target[2]	Metal Backup: Magnesium[1] (1,1/8)	Magnesium (1,1/4)	Magnesium (2,1/8)	Magnesium (2,1/4)	Aluminum[1] (1,1/8)	Aluminum (1,1/4)	Aluminum (2,1/8)	Aluminum (2,1/4)	Steel[1] (1,1/8)	Steel (1,1/4)	Steel (2,1/8)	Steel (2,1/4)
Polyethylene:												
Scale 1 (0°)	2.2	2.2	2.2	2.6	2.5	2.0	2.5	2.5	3.0 2.7	2.6	1.6	2.8 2.5
Scale 1 (60°)	1.7				4.0				3.0			
Scale 2 (0°)	3.6 3.8			4.6 4.3	3.5 4.9			5.1 4.7 4.5	5.0 5.4			5.0 6.1 6.6
Nylon Fabric-Phenolic:												
Scale 1 (0°)	2.4	2.2	1.5	1.2	2.1	2.0	.75	1.0	5.0	4.0	1.5	0.0* .50 2.0
Scale 1 (60°)	3.2				3.5				1.0			
Scale 2 (0°)	4.0 3.9 3.8			4.5 3.8	4.0 4.6			4.1 4.0 5.2	5.5 7.7 7.2			7.4 9.0
Glass Fabric-Phenolic:												
Scale 1 (0°)	2.7	1.8	1.8	1.5	2.0	2.0	1.8	1.7	2.2 2.2	3.1	2.0	1.7
Scale 1 (60°)	3.0				3.2				2.7			
Scale 2 (0°)	4.5 4.5			5.5 5.5	4.0 5.2			6.0 6.0 5.5 5.2	5.4 6.0			7.0 7.0 7.1
Glass[3]												

(1) Ordered pairs represent primary target and metal backup thicknesses.

(2) (60°) - 60° Obliquity. (0°) - 0° Obliquity.

(3) All glass primary targets shattered.

*Cratered, no perforation.

TABLE III-III

SUMMARY OF METALLIC TARGET BACKUP THROAT SIZES (INCHES) FOR SCALE 1 AND SCALE 2 PELLETS

Primary Target[2]	Magnesium[1] (1,1/8)	Magnesium (1,1/4)	Magnesium (2,1/8)	Magnesium (2,1/4)	Aluminum[1] (1,1/8)	Aluminum (1,1/4)	Aluminum (2,1/8)	Aluminum (2,1/4)	Steel[1] (1,1/8)	Steel (1,1/4)	Steel (2,1/8)	Steel (2,1/4)
Polyethylene:												
Scale 1 (0°)	6.9	4.4	6.5	5.9	11.0	2.8	10.3	8.7	5.2	1.2	10.2	4.5
Scale 1 (60°)	5.1				13.0				8.4 8.3			4.0
Scale 2 (0°)	6.2 8.2			14.8 16.7	16.0 17.8			18.1 17.4 18.6	19.1 17.2			18.5 18.3 19.1
Nylon Fabric-Phenolic:												
Scale 1 (0°)	7.4	6.9	7.7	4	10.2	5	10.5	9.5	10.0	2.0	11.0	Bulge
Scale 1 (60°)	9.7				13.0							Bulge Bulge
Scale 2 (0°)	9.1 8.5 12.4			13.2 11.5	21.9 15.5			19.2 16.4 18.8	Bulge 20.5 23.5 22.3			21.5 18.7
Glass Fabric-Phenolic:												
Scale 1 (0°)	4.7	3.0	5.7	4	9.2	3.5	11.1	7.8	9.5 10.8	1.4	Bulge	3.7
Scale 1 (60°)	7.4				13.4				Bulge			
Scale 2 (0°)	13.0 8.6			13.5 14.2	14.7 16.9			15.9 14.5 17.3 17.9	19.8 23.7			14.7 20.3 18.8
Glass:												
Scale 1 (0°)	0 2.5			0	7.5 4.9			0	Bulge 6.9			Bulge
Scale 1 (60°)	4.2				4.6				Bulge			
Scale 2 (0°)	6.1			7.1	19.2			7.9	10.0			14.6

(1) Ordered pairs represent primary target and metal backup thicknesses.
(2) (60°) - 60° Obliquity. (0°) - 0° Obliquity.

TABLE III-IV

TARGET DAMAGE FOR SCALE 1 PELLET AS A FUNCTION OF OBLIQUITY ANGLE

PRIMARY TARGET(1) THROAT SIZE (INCHES)

Obliquity	Metal Backup: 1/8" Magnesium	Metal Backup: 1/8" Aluminum	Metal Backup: 1/8" Steel
0°	2.4	2.1	5.0
60°	3.2	3.5	1.0
80°	1.6(2)	1.7	1.6(2)

METALLIC TARGET BACKUP THROAT SIZE (INCHES)

Obliquity	1/8" Magnesium	1/8" Aluminum	1/8" Steel
0°	7.4	10.2	3.2
60°	9.7	13.0	Bulge
80°	6.1(2)	Bulge	Bulge

(1) Primary Target - 1" Nylon Fabric-Phenolic

(2) Average of two values

TABLE III-V

TARGET DAMAGE FOR SCALE 2 PELLETS
FIRED AT 80 DEGREES OBLIQUITY

Primary Target	Metal Backup	Throat Size in Primary Target	Damage to Metal Backup
2" Nylon Fabric-Phenolic	1/8" Aluminum	2-1/2" X 3-1/2"	3 Petals formed - No Spall (Throat Size - 11-1/4" X 22")
" "	1/4" Aluminum	3-1/8" X 4-5/8"	Bulged and split into 2 pieces
" "	1/8" Steel	2" X 3-1/2"	Bulged 3-3/8"
" "	1/4" Steel	7/8" Deep Hole	Bulged 3/4"

TABLE III-VI

SPALL VELOCITY AND PELLET DATA FOR SCALE 2 PELLETS FIRED AT THICK AND THIN COMPOSITE TARGETS

ABLATIVE MATERIAL	METAL BACKUP	ROUND NUMBER	SPALL VELOCITY (km./sec.)	PELLET MASS (grams)	PELLET LENGTH (inches)	AVERAGE PELLET DIAMETER (inches)	PELLET L/D RATIO
Polyethylene	1/4" Magnesium	676-13	7.6	23.4	2.13	.53	4.00
Nylon Fabric-Phenolic	1/4" Magnesium	676-16	7.3	22.8	2.39	.50	4.82
Glass Fabric-Phenolic	1/4" Magnesium	676-15	5.9	26.0	2.26	.56	4.05
Polyethylene	1/4" Aluminum	676-18	7.9	30.7	2.47	.57	4.32
Nylon Fabric-Phenolic	1/4" Aluminum	676-11,31	5.5(1);4.8(2)	23.1;16.6	2.12;1.56	.54 ; .51	3.93 ; 3.06
Glass Fabric-Phenolic	1/4" Aluminum	676-17	6.6	28.5	2.47	.56	4.38
Polyethylene	1/4" Steel	676-28	6.0	21.9	2.07	.53	3.87
Nylon Fabric-Phenolic	1/4" Steel	676-8	4.9	24.8	1.81	.62	2.92
Glass Fabric-Phenolic	1/4" Steel	676-9	4.5	23.9	2.13	.56	3.81
Polyethylene	1/8" Magnesium	676-29	8.0	26.5	1.96	.60	3.26
Nylon Fabric-Phenolic	1/8" Magnesium	676-27	10.4(3)	20.1	2.09	.50	4.21
Glass Fabric-Phenolic	1/8" Magnesium	676-19	8.3	29.8	2.21	.61	3.64
Polyethylene	1/8" Aluminum	676-30	8.4	24.8	1.96	.58	3.36
Nylon Fabric-Phenolic	1/8" Aluminum	676-26	7.6	28.9	1.96	.63	3.12
Glass Fabric-Phenolic	1/8" Aluminum	676-21	7.9	26.4	1.81	.63	2.88
Polyethylene	1/8" Steel	676-23	8.3	26.7	1.82	.62	2.92
Nylon Fabric-Phenolic	1/8" Steel	676-25	7.7	23.5	2.21	.52	4.25
Glass Fabric-Phenolic	1/8" Steel	676-22	7.2	22.2	2.11	.62	3.43
			Avg.	24.6		Avg.	3.70
			S.D.	3.47		S.D.	.58

(1) Spall envelope not well determined.

(2) Refire - Good spall envelope definition - small pellet.

(3) Possibly error in time data.

TABLE III-VII

RATIOS OF HOLE SIZES(1) IN PRIMARY TARGETS
FOR SCALE 1 AND SCALE 2 PELLETS
(ZERO DEGREES OBLIQUITY)

Primary Target	Metal Backup Magnesium	Metal Backup Aluminum	Metal Backup Steel
Polyethylene	2.0	1.9	2.0
Nylon Fabric-Phenolic	1.7	2.1	1.6
Glass Fabric-Phenolic	2.0	2.8	3.2

(1) The hole sizes in thick targets (2,1/4) produced by Scale 2 pellets divided by the hole sizes in thin targets (1,1/8) produced by Scale 1 pellets.

TABLE III-VIII

RATIOS OF HOLE SIZES(1) IN METAL BACKUPS
FOR SCALE 1 AND SCALE 2 PELLETS
(ZERO DEGREES OBLIQUITY)

Primary Target	Metal Backup Magnesium	Metal Backup Aluminum	Metal Backup Steel
Polyethylene	2.3	1.6	2.7
Nylon Fabric-Phenolic	1.7	1.8	2.0
Glass Fabric-Phenolic	2.9	1.8	1.8

(1) The hole sizes in thick targets (2,1/4) produced by Scale 2 pellets divided by the hole sizes in thin targets (1,1/8) produced by Scale 1 pellets.

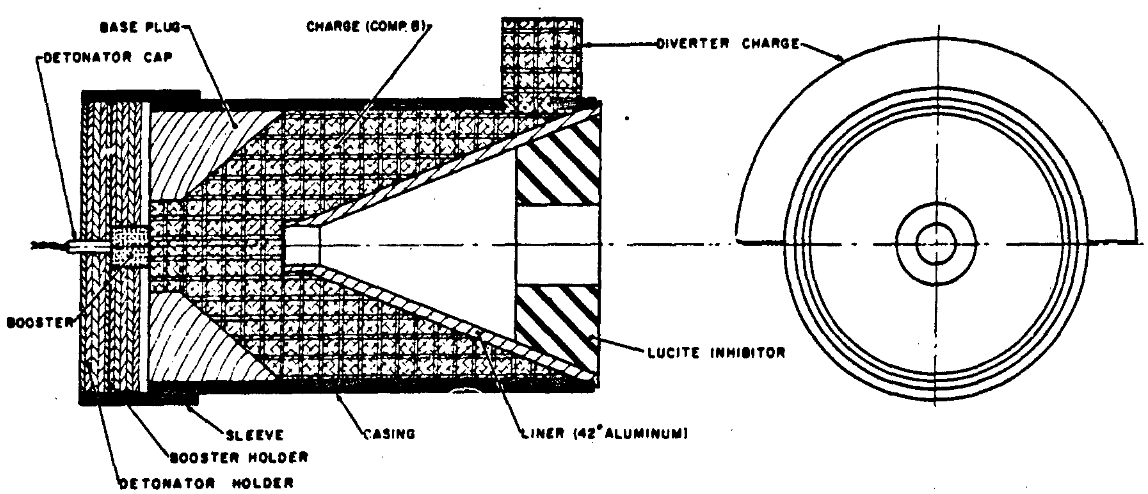
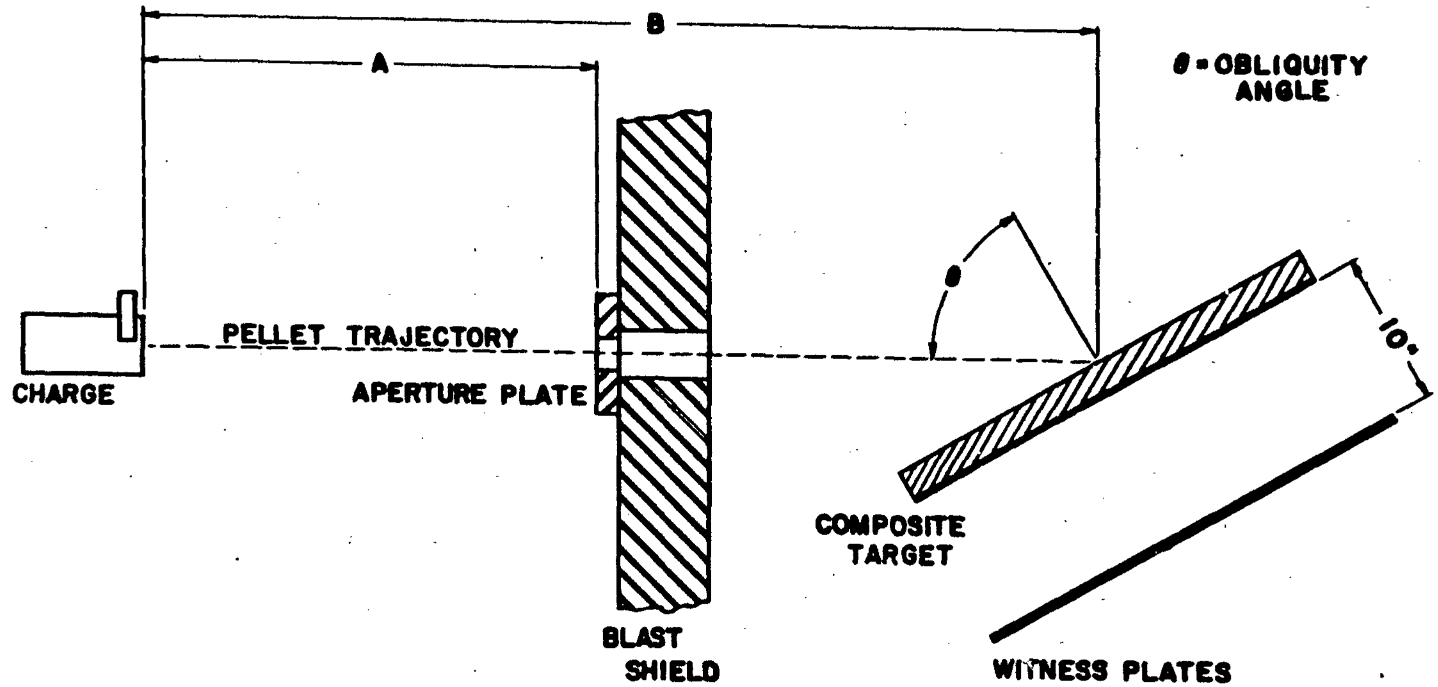


Fig. III-1. Scale 2 Inhibited Jet Shaped Charge Assembly. 42° Apex Angle, Aluminum Liner.



DIM.	A	B
SCALE 1	20"	42"
SCALE 2	40"	84"

Fig. III-2. Arrangement for Hypervelocity Impact Tests at 0, 60, and 80 degrees Angle of Obliquity.

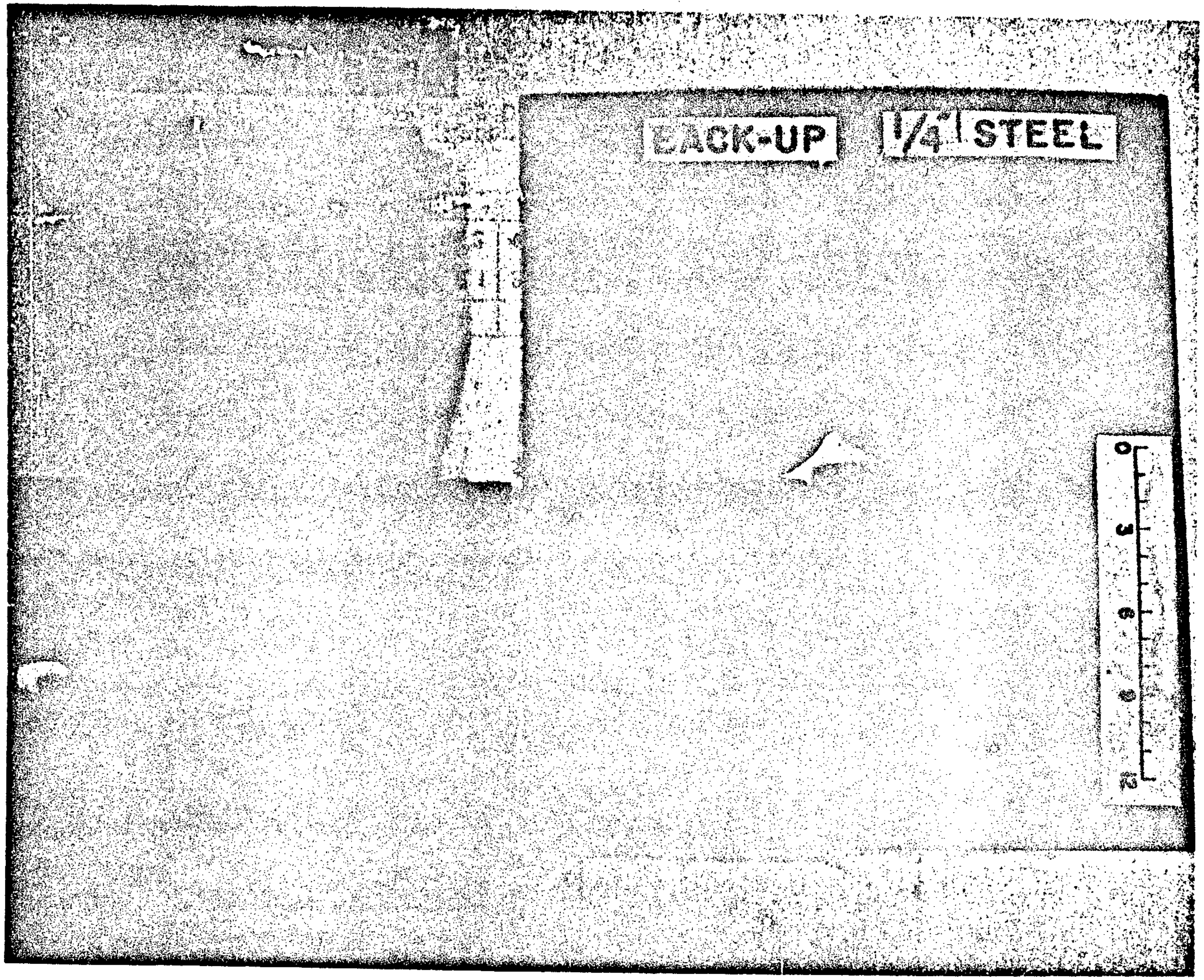


Fig. III-3. Target Damage Produced by Scale 1 Pellet at Zero degree Angle of Obliquity. Target: 2-in. Polyethylene, 1/4-in. Steel Backup, 1/4-in. Aluminum Witness Plate.

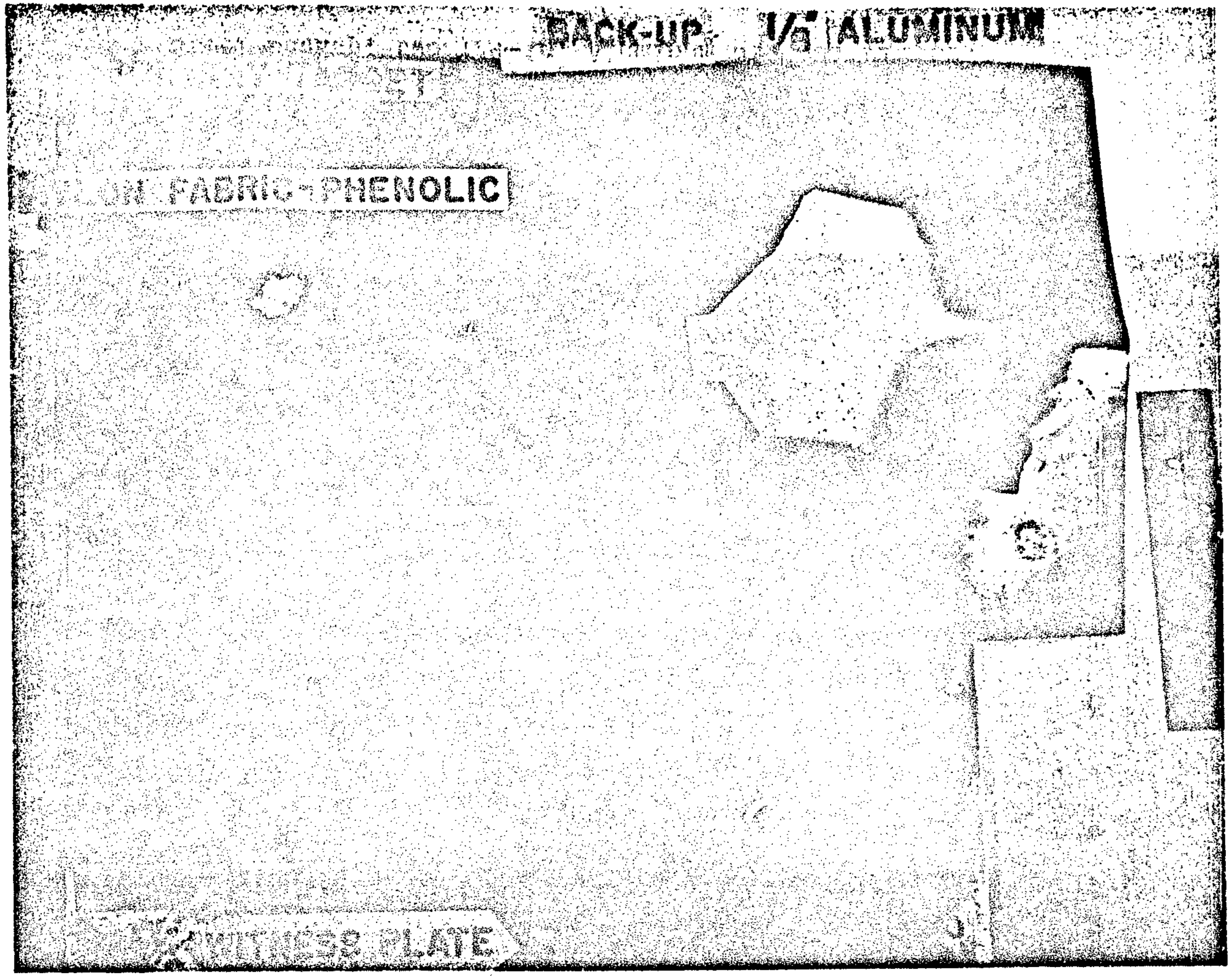


Fig. III-4. Target Damage Produced by Scale 1 Pellet at Zero degree Angle of Obliquity. Target: 1-in. Nylon Fabric-Phenolic, 1/8-in. Aluminum Backup, two 1/4-in. Aluminum Witness Plates.

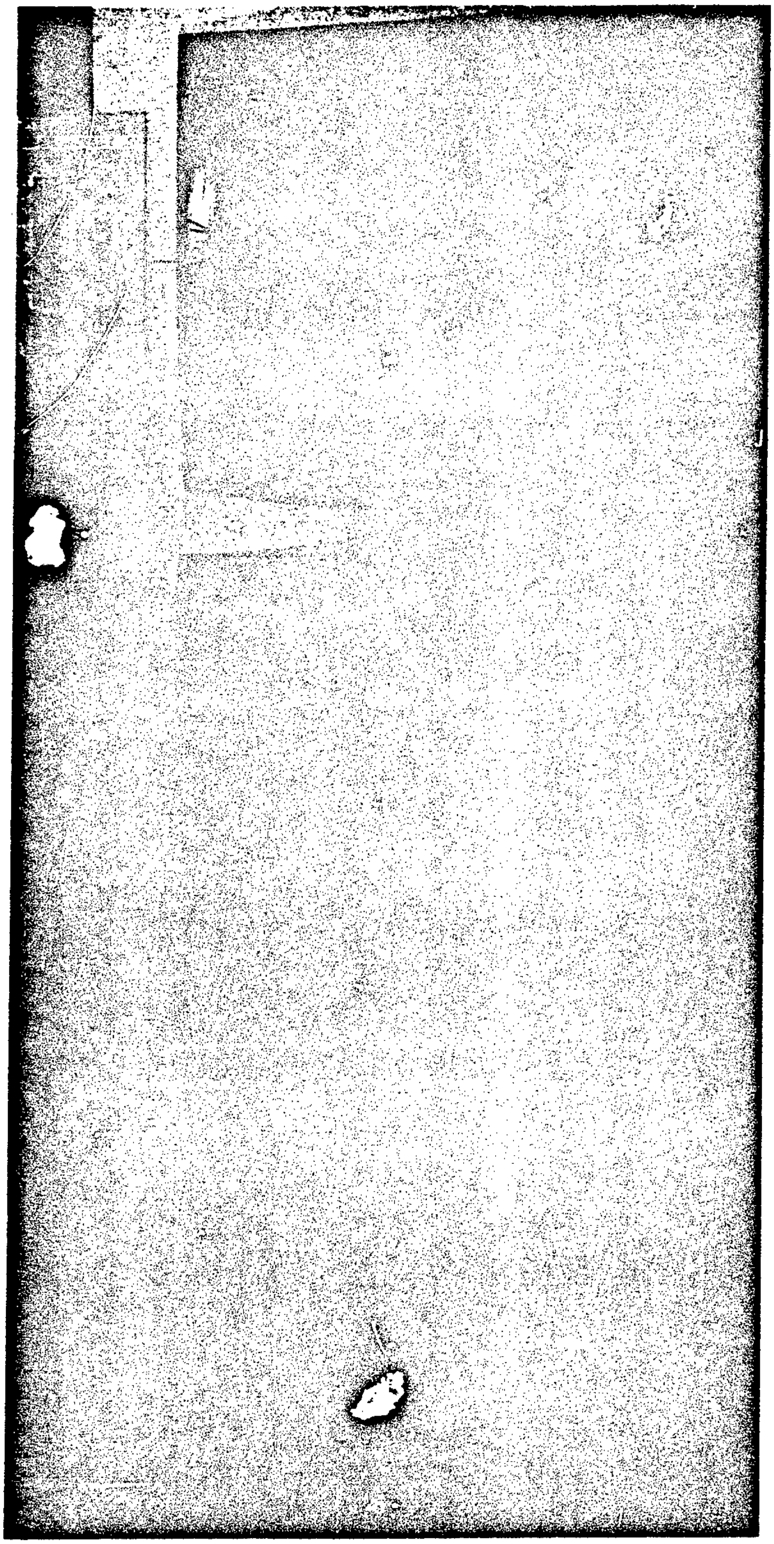


Fig. III-5. Target Damage Produced by Scale 2 Pellet at Zero degree Angle of Obliquity. Target: 1-in. Polyethylene, 1/8-in. Steel Backup, two 1/4-in. Aluminum Witness Plates.

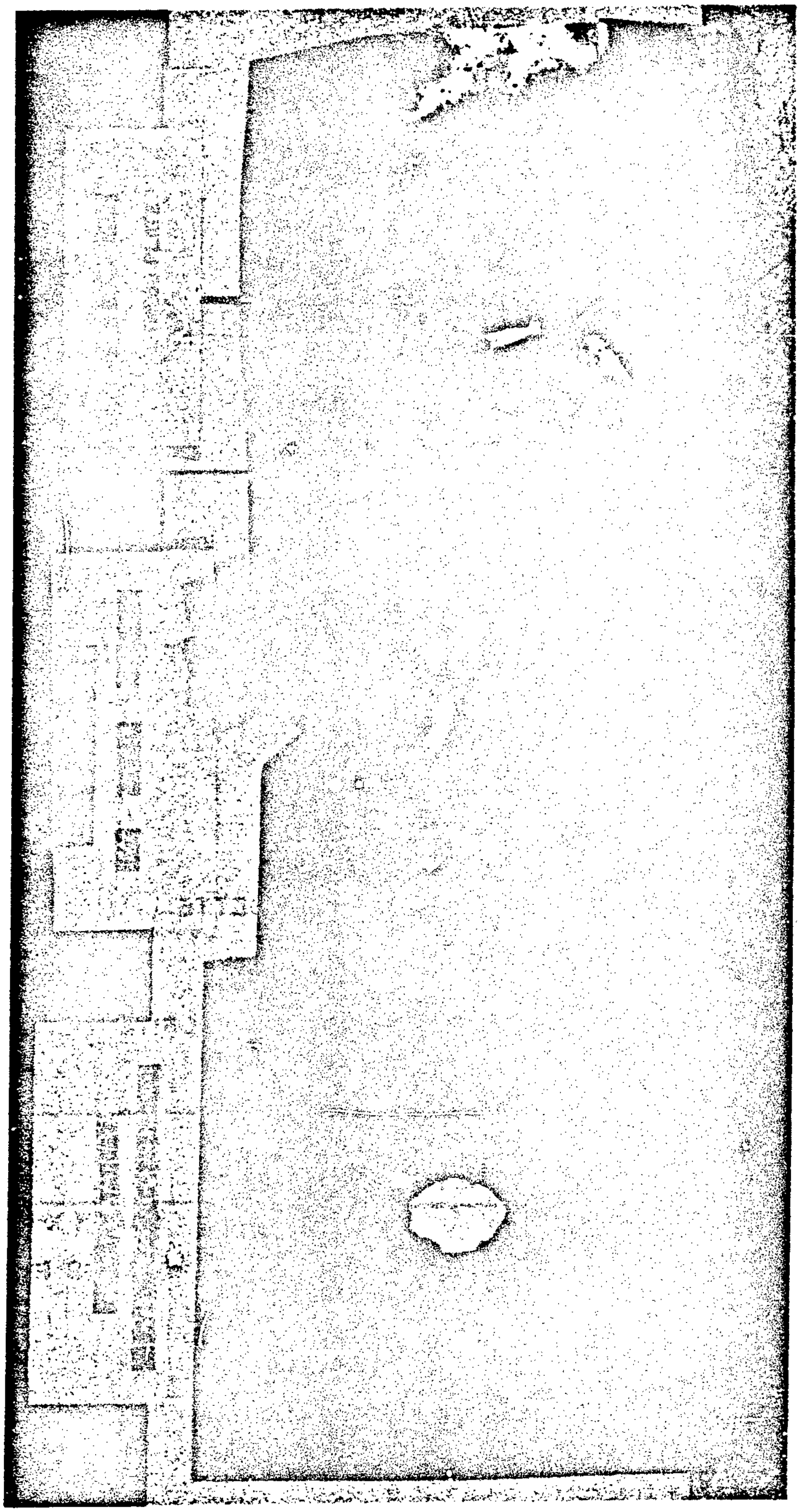


Fig. III-6. Target Damage Produced by Scale 2 Pellet at Zero degree Angle of Obliquity. Target: 2-in. Nylon Fabric-Phenolic, 1/4-in. Steel Backup, two 1/4-in. Aluminum Witness Plates.

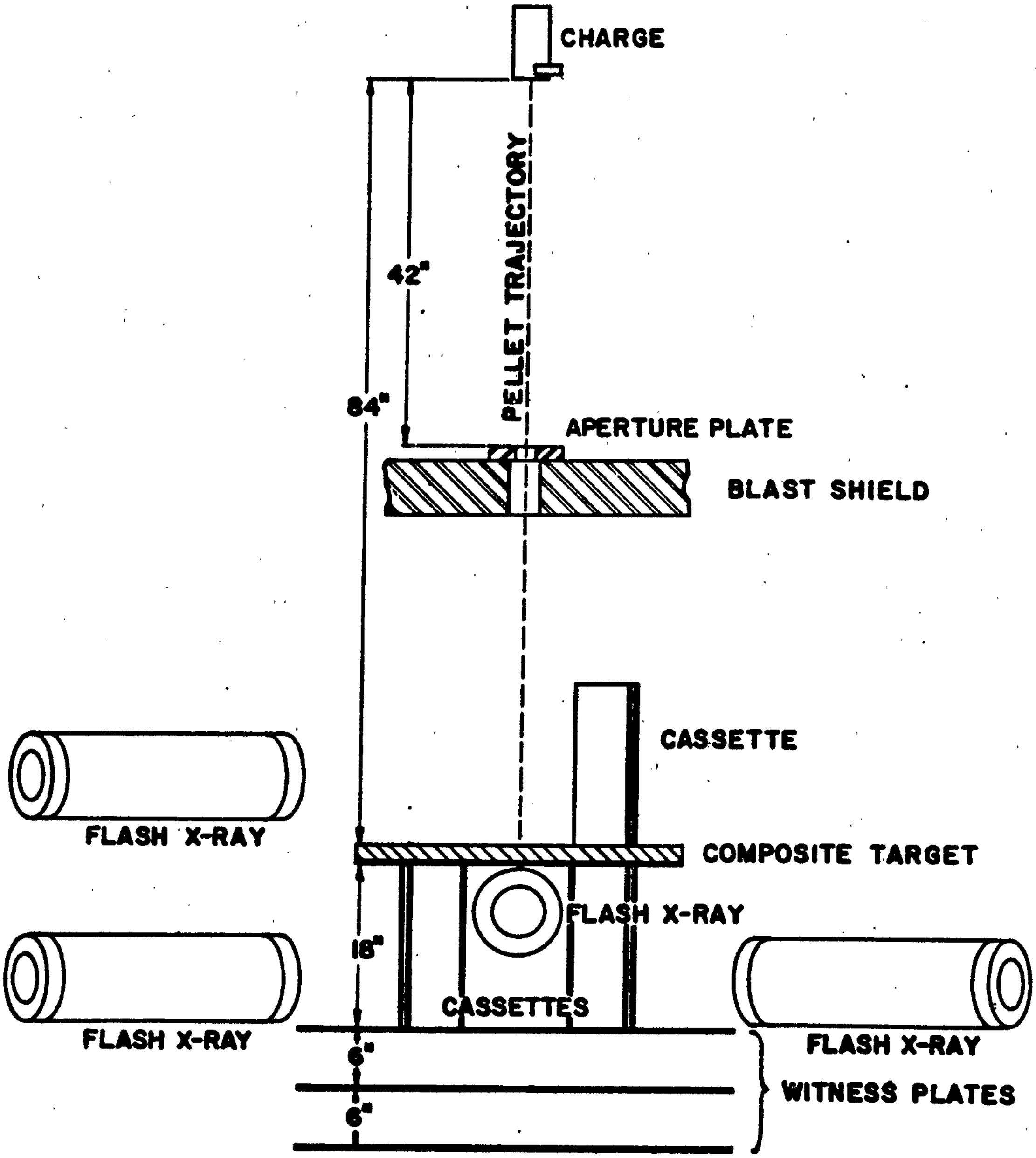
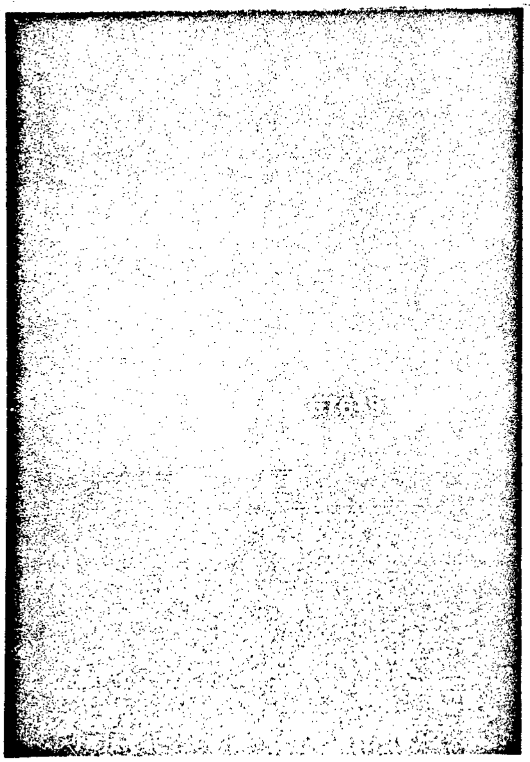
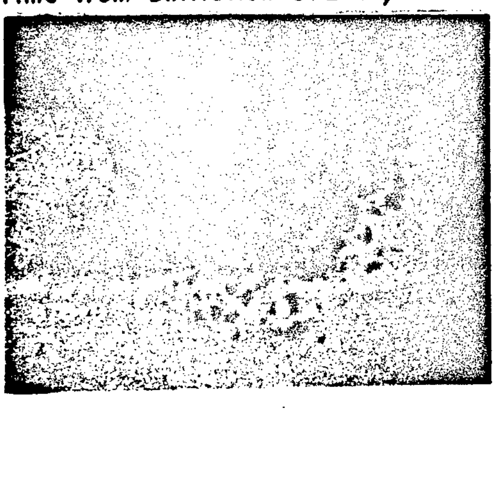


Fig. III-7. Test Arrangement for Spall Velocity Tests.

PELLET
Round No. *676-9* Pellet Mat'l.: *Aluminum*
Mass: *23.9 gm.* Velocity: *9.1 km/sec. (Nom.)*
Time from Initiation: *255.1 μsec.*
Distance from Liner Base to Pellet Nose: *74.8 in.*



FIRST SPALL RADIOGRAPH
Ablative Material: *Glass Fabric-Phenolic (2".*
Metal Backup: *Steel (1/4").*
Time from Initiation: *312.8 μsec.*



SECOND SPALL RADIOGRAPH
Time from Initiation: *349.2 μsec.*
Spall Velocity: *4.5 km/sec.*

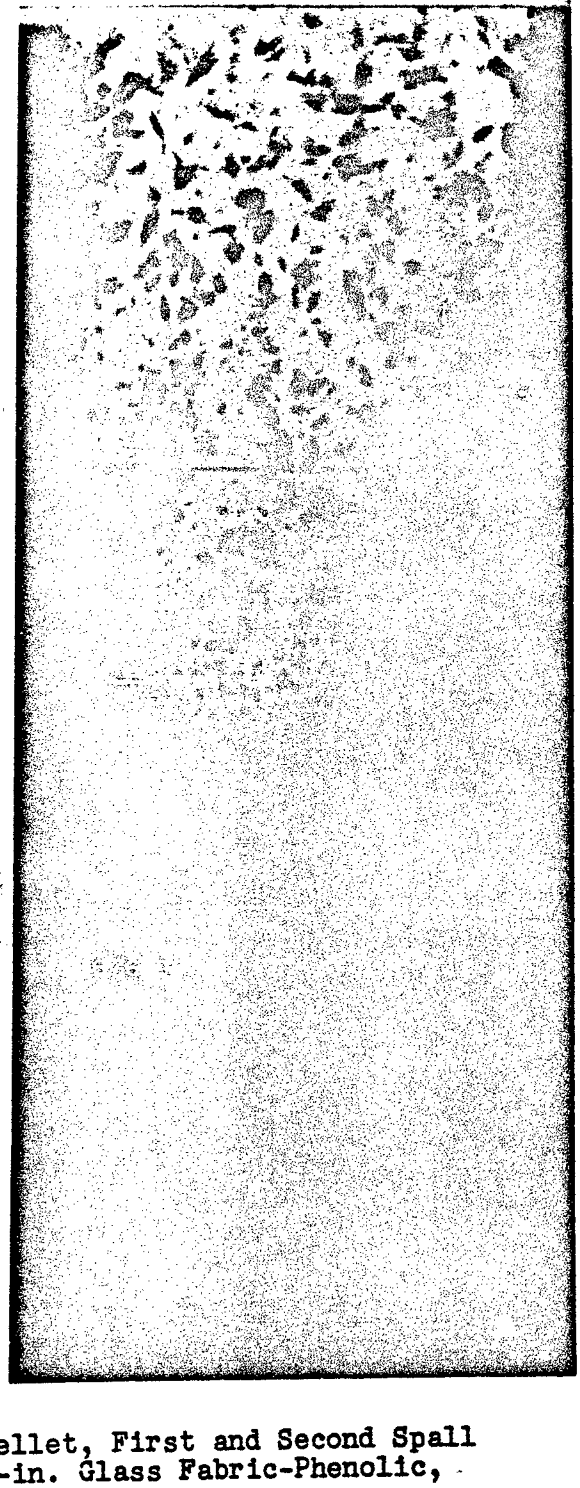
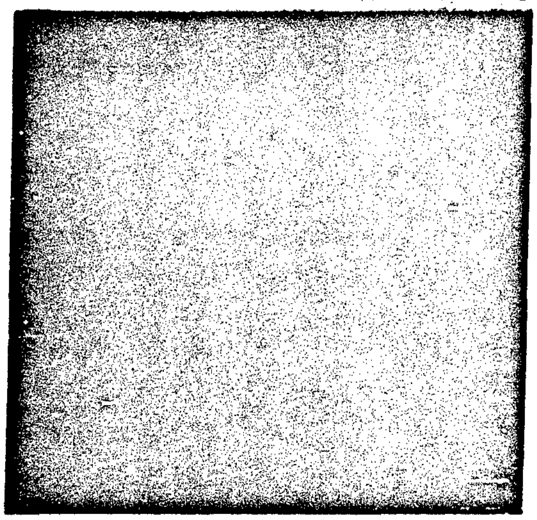


Fig. III-8. Radiograph of Scale 2 Pellet, First and Second Spall Radiographs. Target: 2-in. Glass Fabric-Phenolic, 1/4-in. Steel Backup.

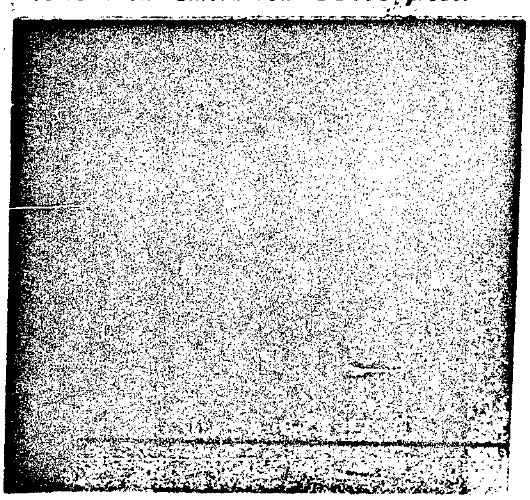
PELLET

Round No. 676-17 Pellet Mat'l.: Aluminum
Mass: 28.5 gm. Velocity: 9.1 km/sec (Nom)
Time from Initiation: 255.3 µsec.
Distance from Liner Base to Pellet Nose: 75.0 in.



FIRST SPALL RADIOGRAPH

Ablative Material: Glass Fabric-Phenolic (2").
Metal Backup: Aluminum (1/4").
Time from Initiation: 307.3 µsec.



SECOND SPALL RADIOGRAPH

Time from Initiation: 337.3 µsec.
Spall Velocity: 6.6 km/sec.

Fig. III-9. Radiograph of Scale 2 Pellet, First and Second Spall Radiographs. Target: 2-in. Glass Fabric-Phenolic, 1/4-in. Aluminum Backup.

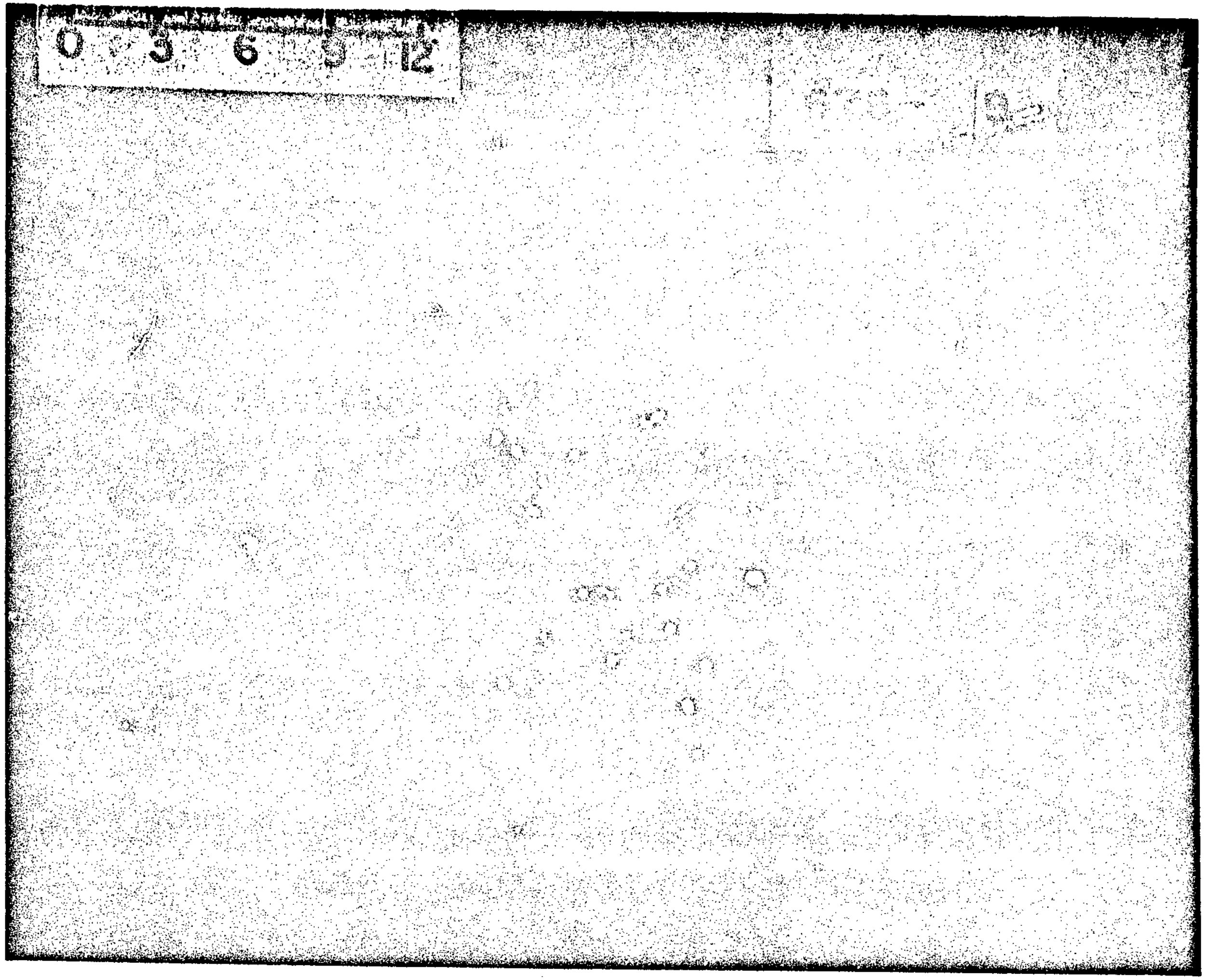


Fig. III-10. Spall Damage to 1/4-in. Steel Witness Plate. Located 18-inches beyond Target. Target: 2-in. Glass Fabric-Phenolic, 1/4-in. Steel Backup.

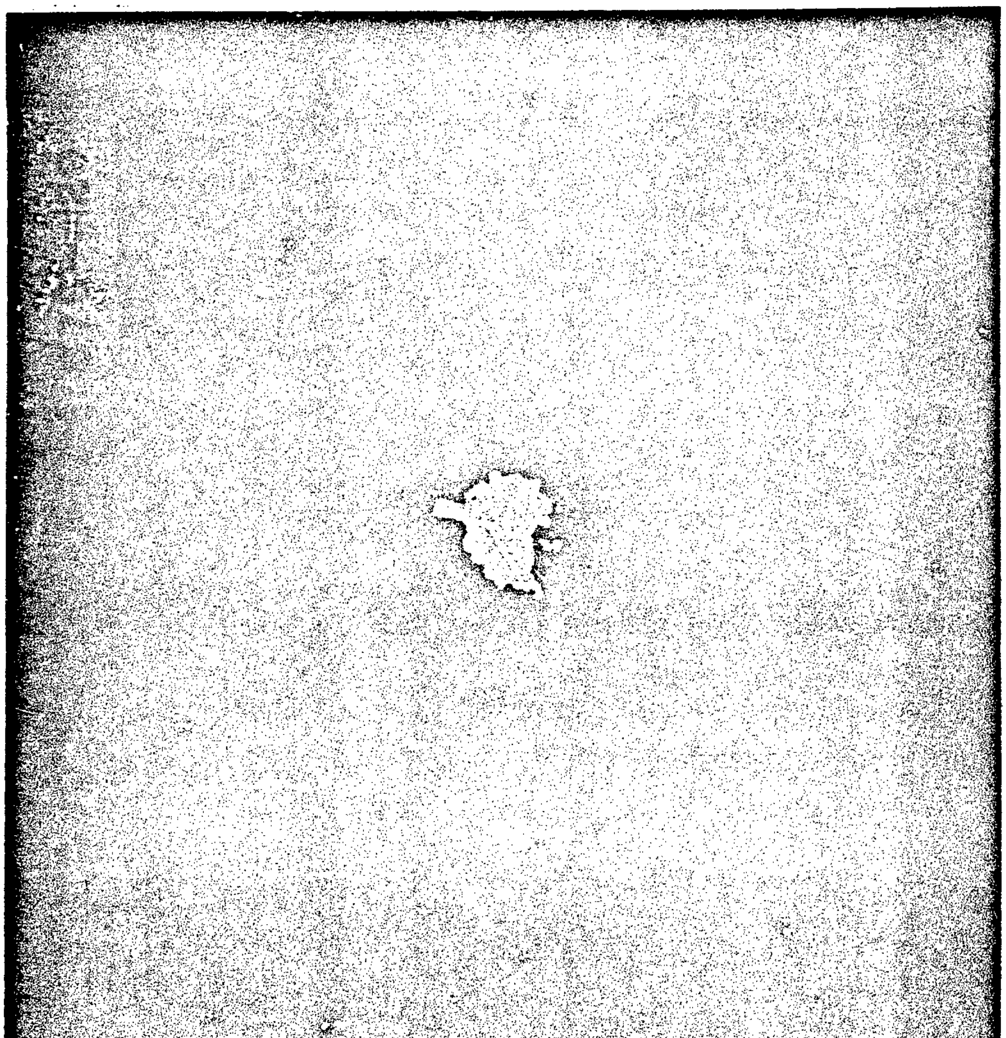


Fig. III-11. Spall Damage to 1/4-in. Steel Witness Plate. Located 18-inches beyond Target. Target: 1-in. Polyethylene, 1/8-in. Magnesium Backup.

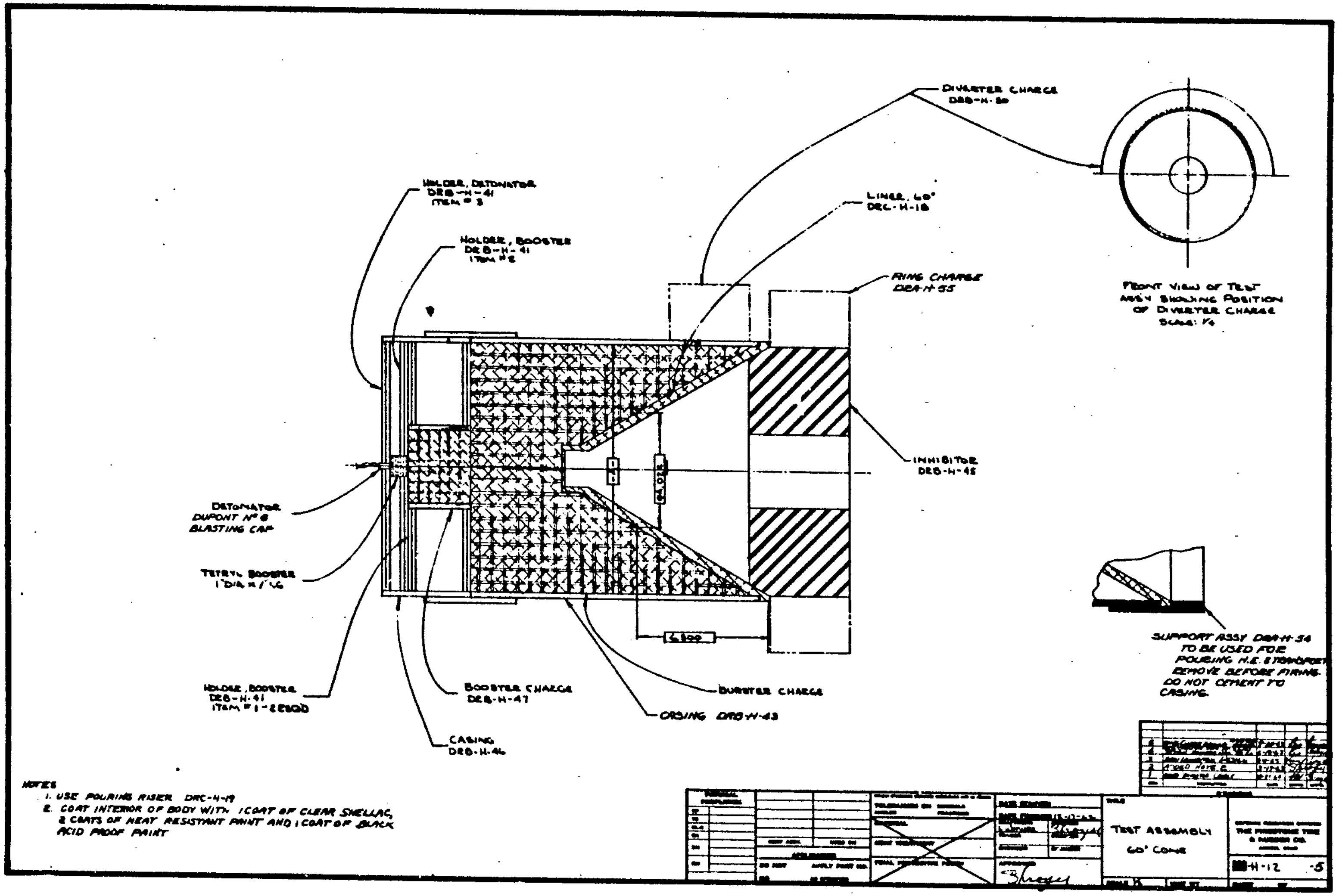
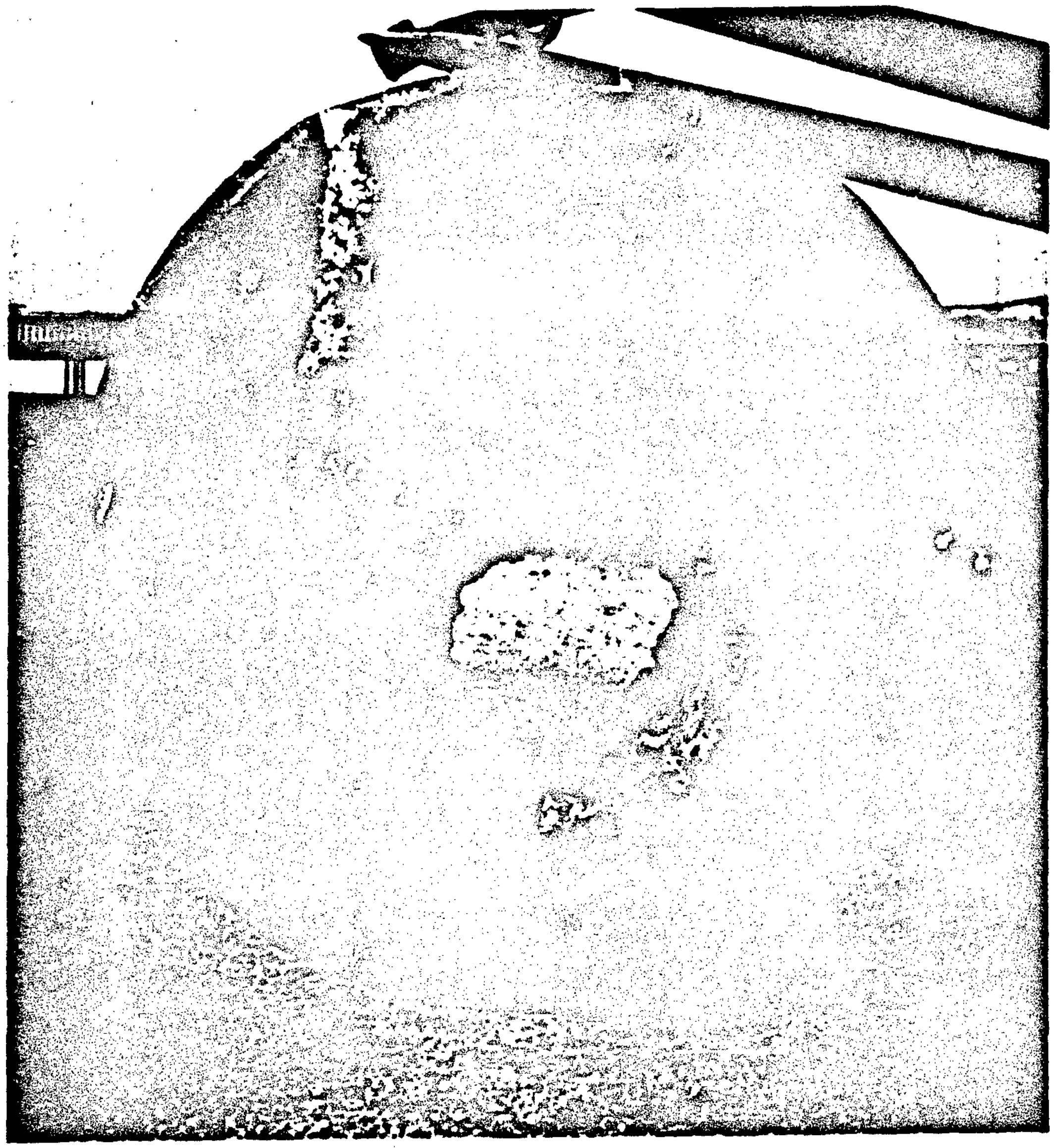


Fig. III-12. Test Assembly - Scale 3-1/2 Inhibited Jet Charge.
Dwg. No. DRD-H-12-5.



Aluminum Target (Front). Damage Produced by Scale 3-1/2 Pellet.

Fig. III-13.

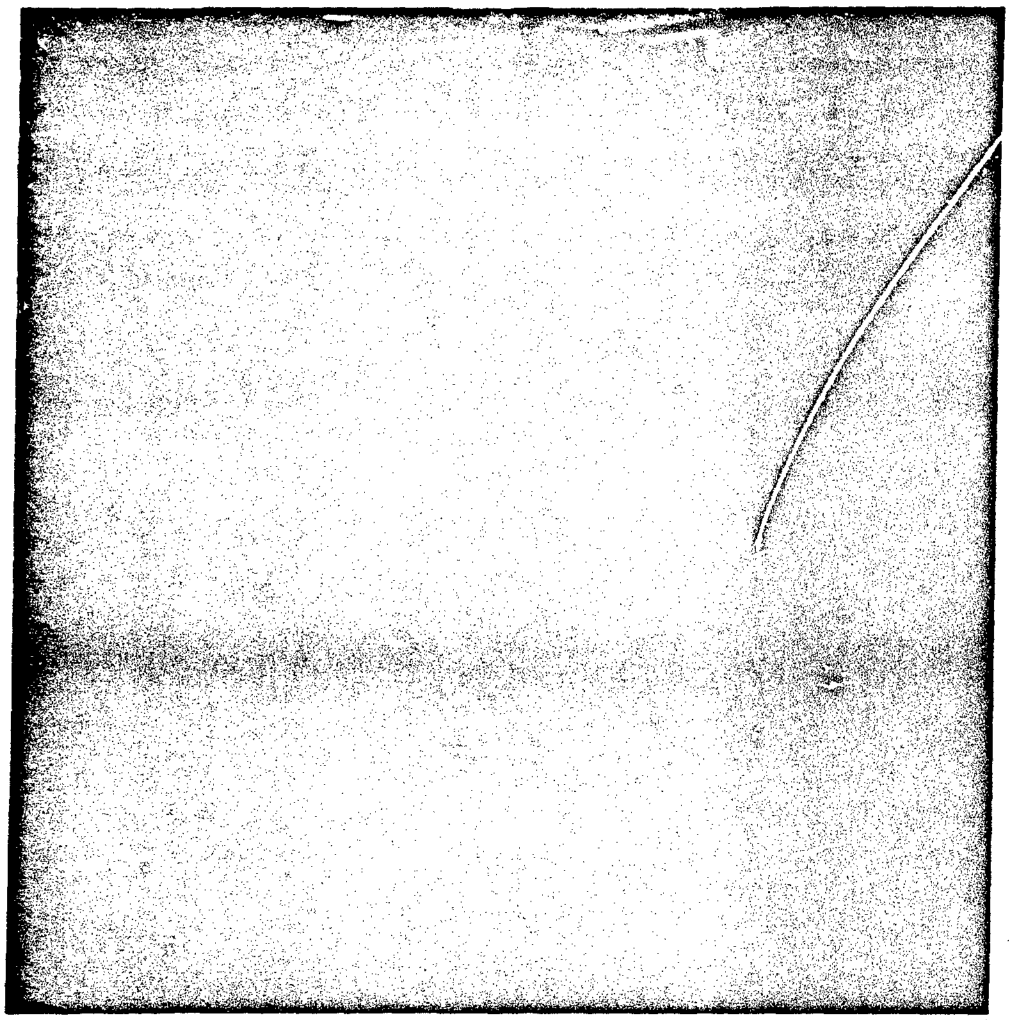


Fig. III-14. Aluminum Target (Back). Damage Produced by Scale 3-1/2 Pellet.

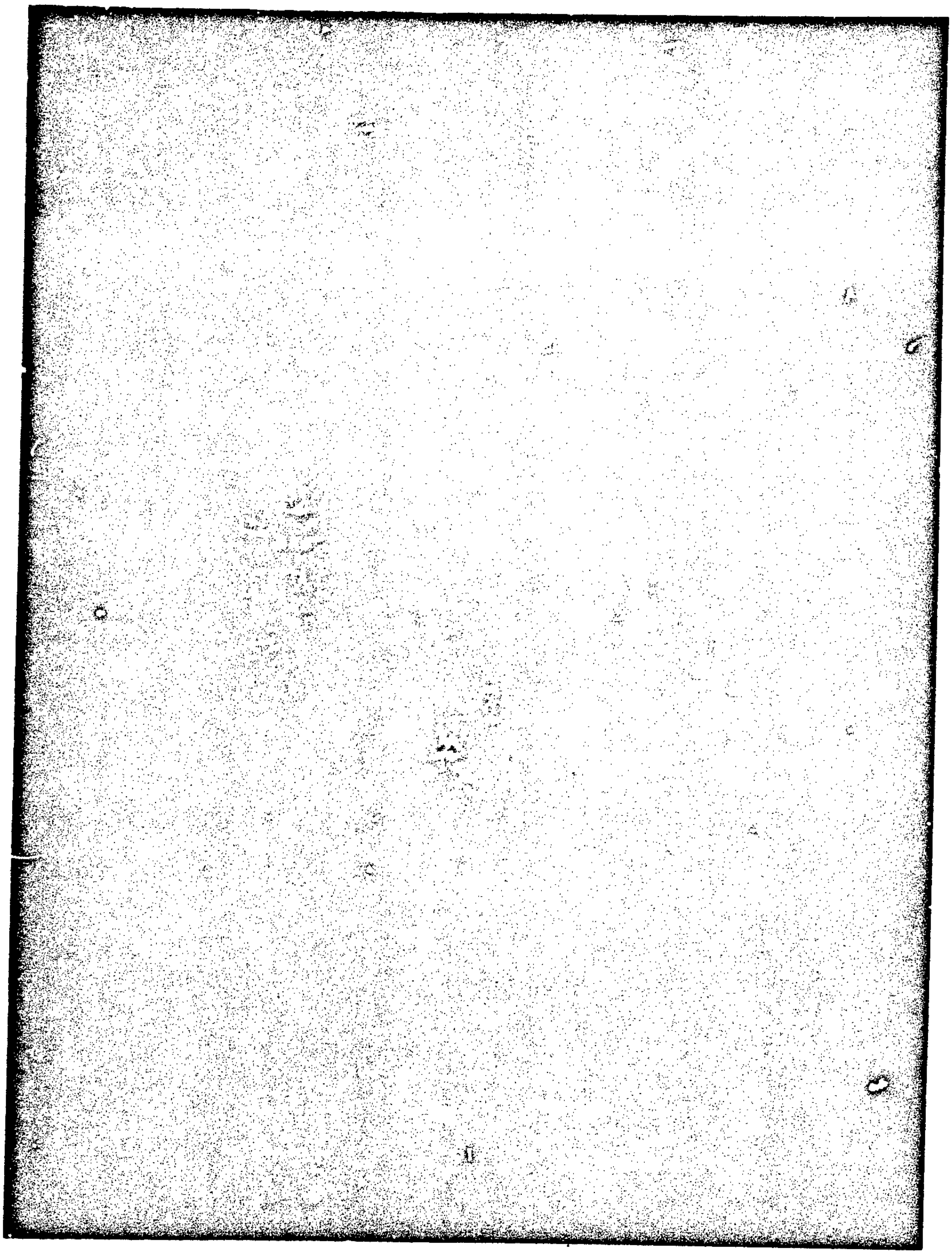


Fig. III-15. Steel Backup Plate (Back View). For Scale 3-1/2 Aluminum Target Test.

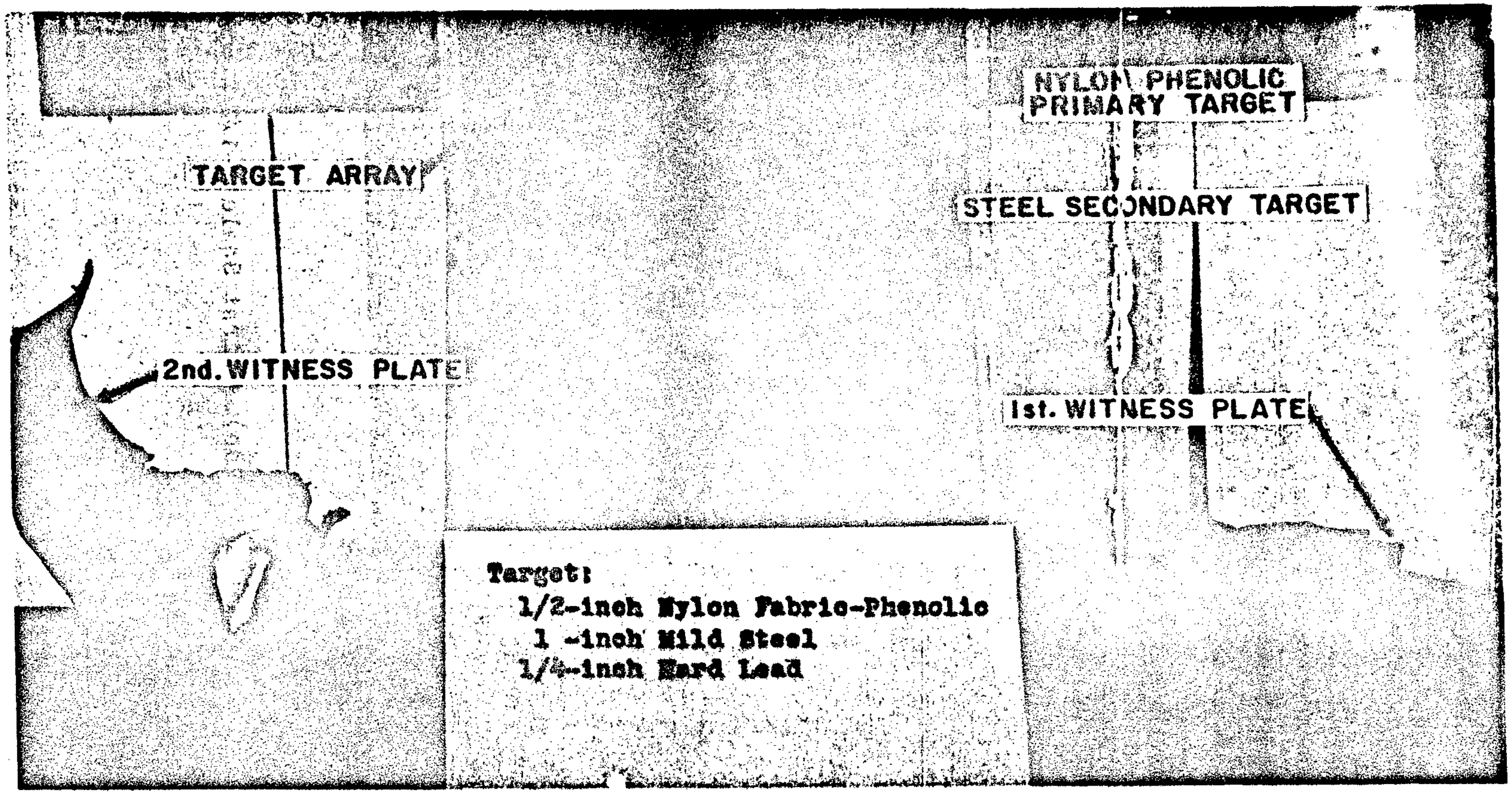


Fig. III-16. Target and Witness Plate Damage (Front Side). First Scale 3-1/2 Composite Target Test.

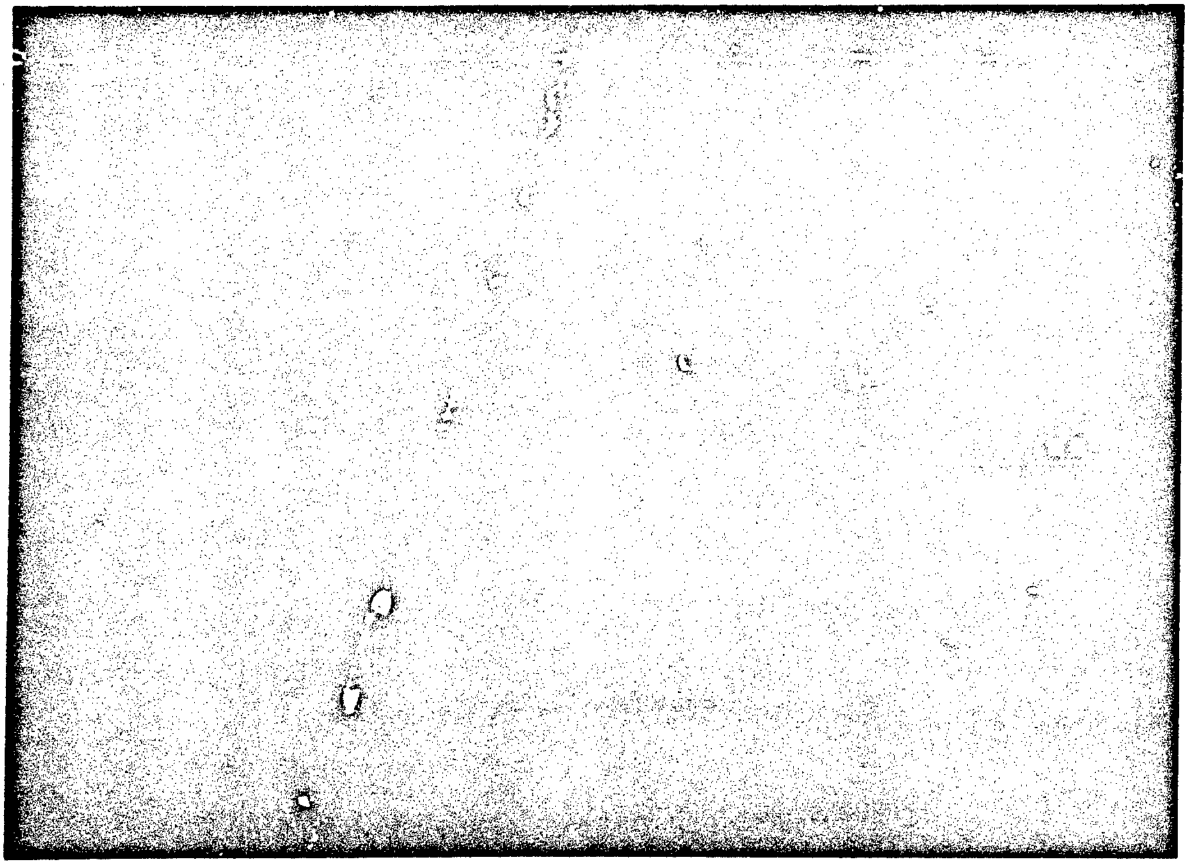
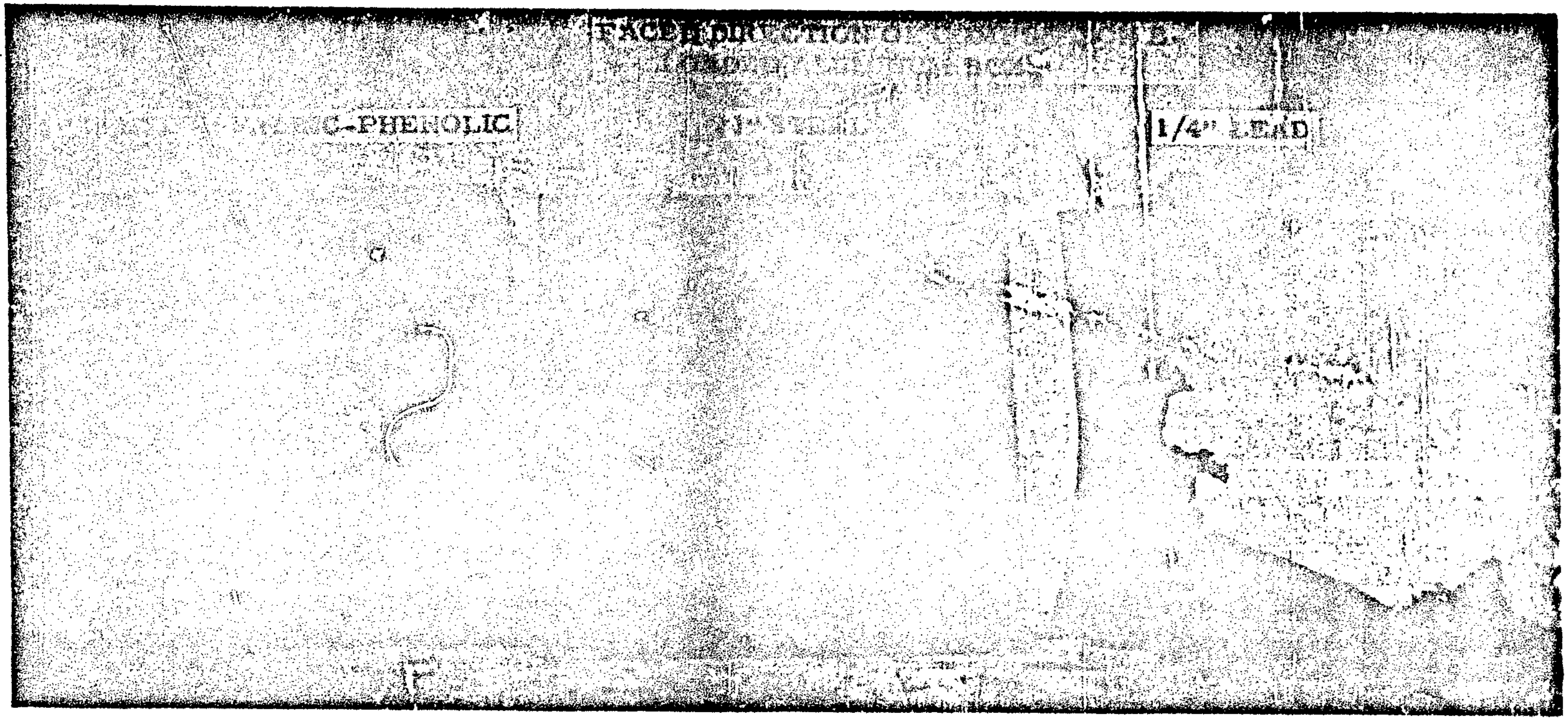


Fig. III-17. Target Damage (Back Side). First Scale 3-1/2 Composite Target Test.



TARGET: 1" NYLON FABRIC-PHENOLIC
1" STEEL
1/4" HARD LEAD

Fig. III-18. Target Damage. Second Scale 3-1/2 Composite Target Test.

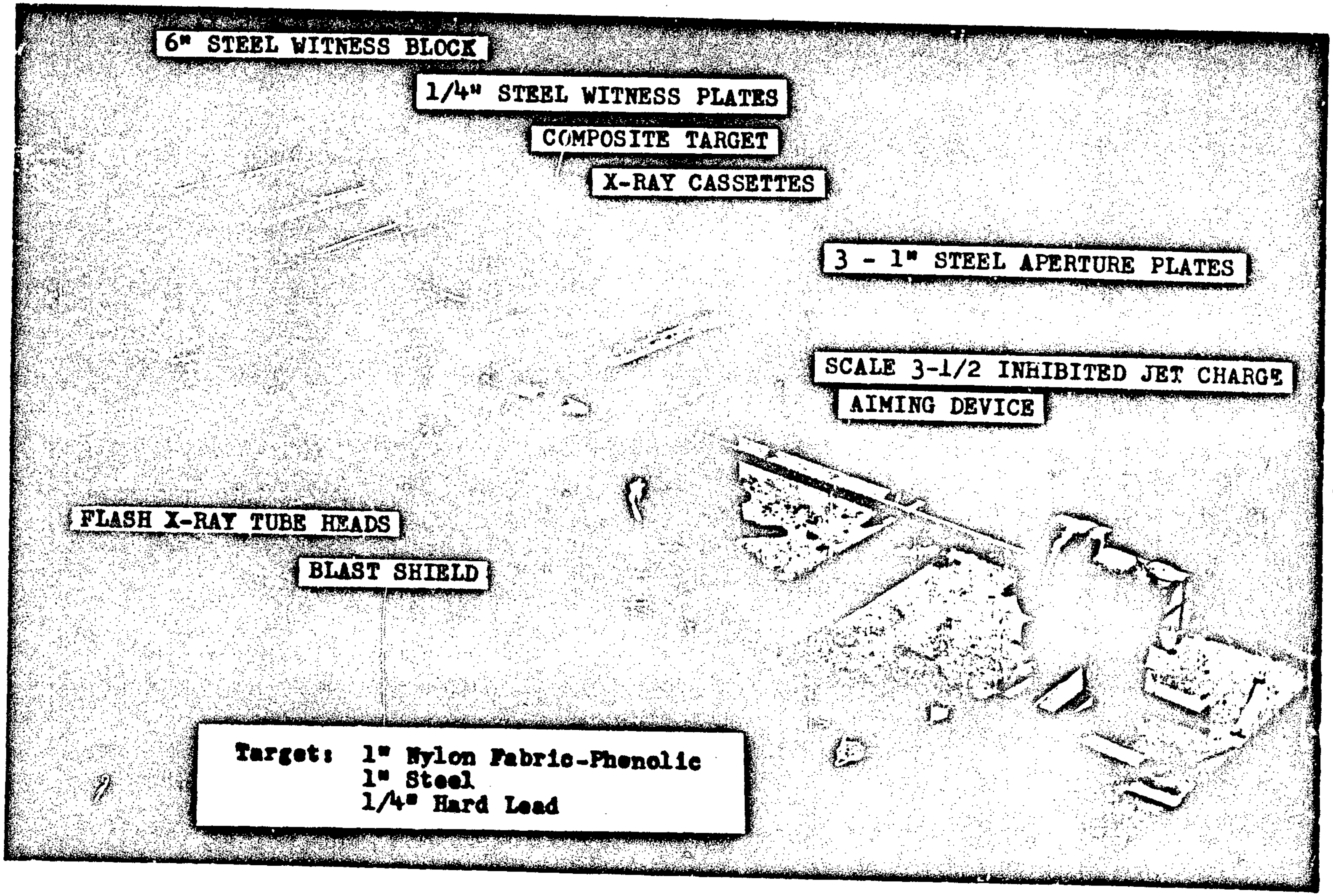


Fig. III-19. Test Setup for Third Scale 3-1/2 Composite Target Test (Pellet Radiographed).

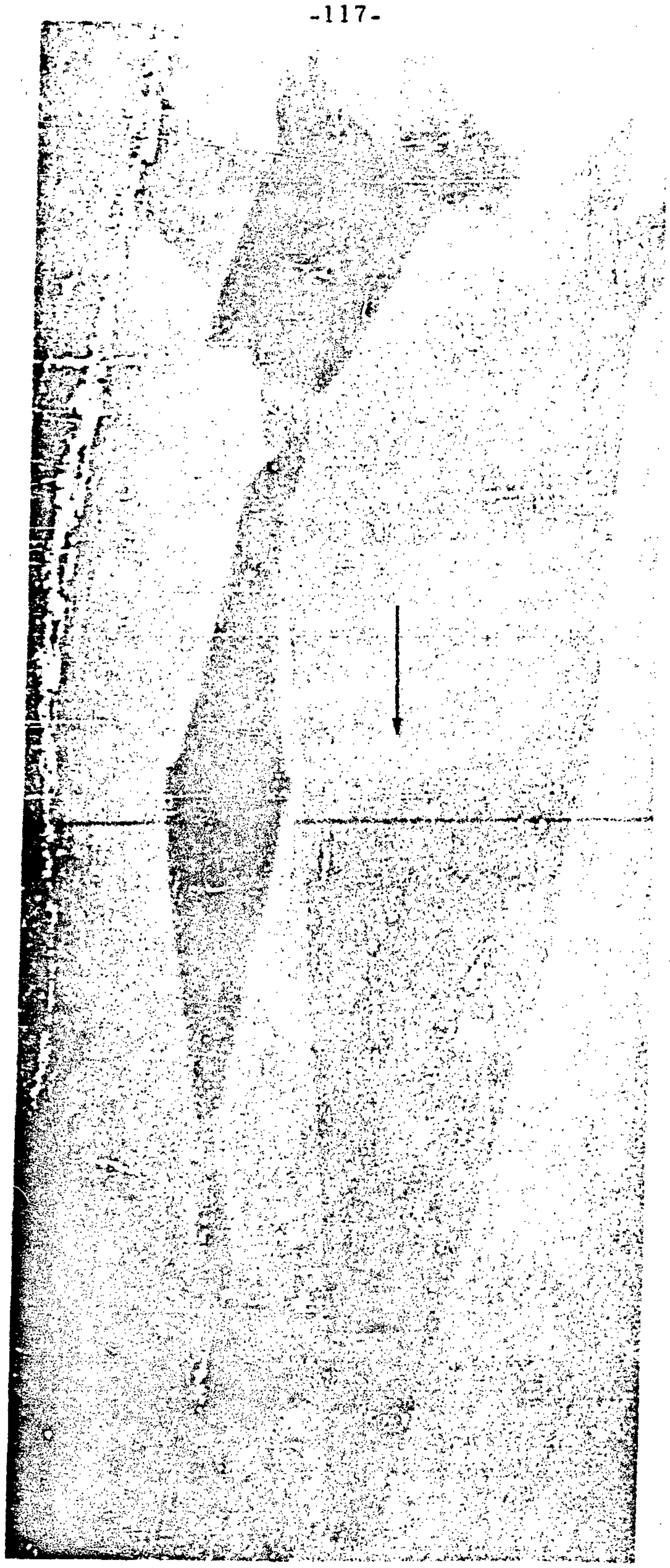


Fig. III-20. Scale 3-1/2 Inhibited Jet Pellet after 146 inches Travel.

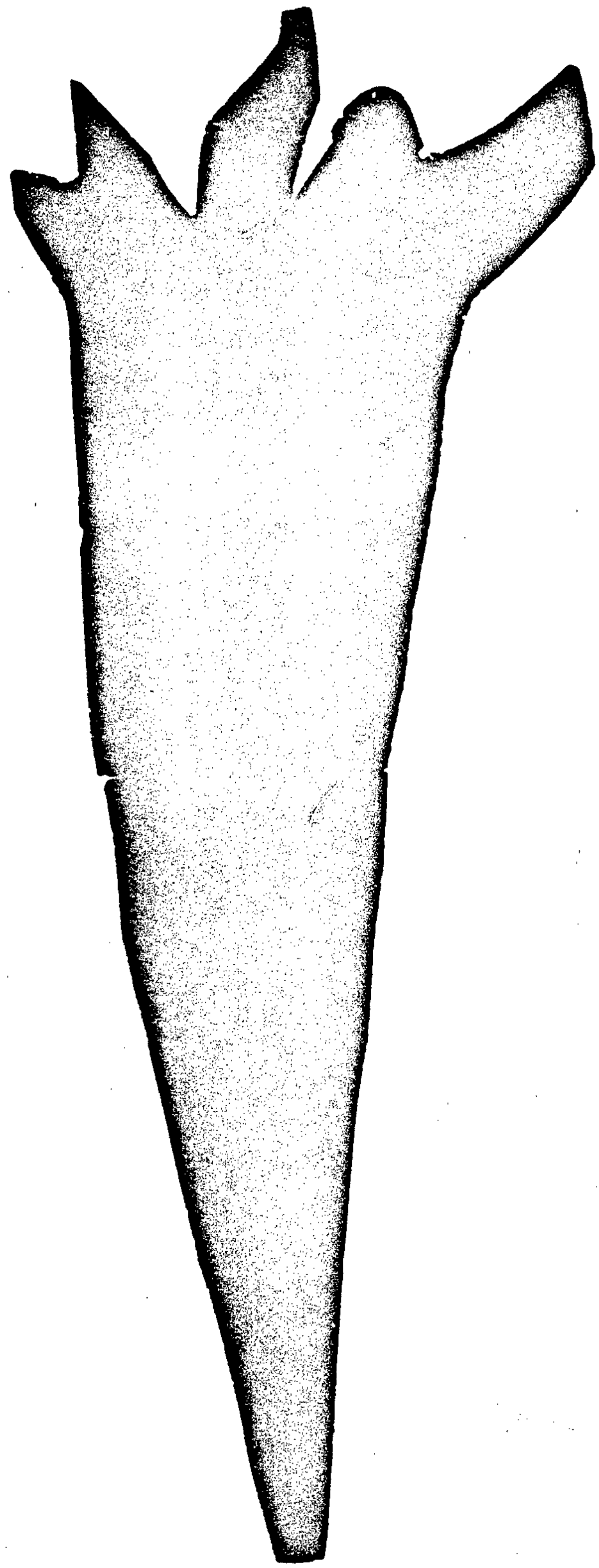


Fig. III-21. Composite Photograph of Scale 3-1/2 Inhibited Jet Pellet.

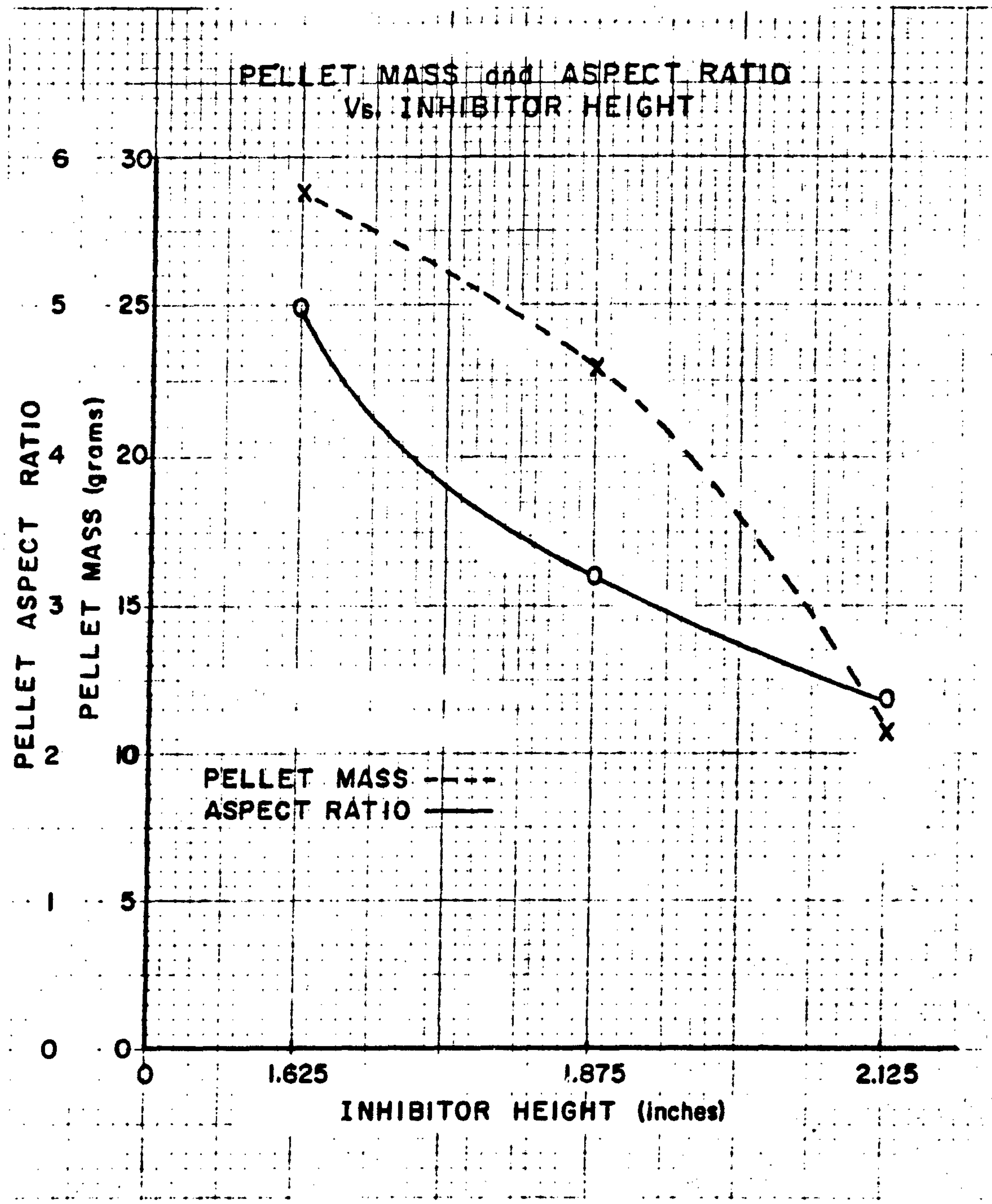


Fig. III-22. Pellet Mass and Aspect Ratio vs. Inhibitor Height for Scale 2 Inhibited Jet Charge.

SECTION IV

TERMINAL BALLISTIC INSTRUMENTED CHAMBER (BLACK BOX)

INTRODUCTION

The objective of the Black Box project was to study the mechanism of the vaporific effect which is produced in an enclosure when the metal structure of the enclosure is struck by a hypervelocity pellet. Specifically, the goals of the project were:

Determine the mechanism or mechanisms which produce the vaporific effect.

Assuming two or more mechanisms exist, determine the contributions of each.

Measure the effect and arrive at a standardized measure of the effect.

A number of shots were fired into the test box using various pellet projectors. The vaporific effect was first achieved using the BRL Design No. 12 charge. Long term pressures (not peak shock pressures) of 20 psi to 48 psi were obtained in air which was originally at ambient pressure and temperature.

Later tests were conducted with a modified BRL Design No. 26 pellet projector. This design tended to produce a more consistent pellet. Tests were conducted in air and nitrogen at ambient pressures and temperatures. It was found that the vaporific effect was greatly diminished by the nitrogen. This indicated that oxidation of metal fragments is a major factor in the vaporific effect.

A study was made of the problem of measuring shock pressures inside the test box. It was concluded (mainly based on information obtained from a BRL specialist) that it was a very difficult problem and that shock pressure data should be studied as a separate problem. It was suggested that shock waves be studied photographically at first in order to determine their magnitude and direction. This could be done outside the test box since the initial shock wave motion would be independent of confinement.

DETAILED TEST RESULTS

Achievement of Vaporific Effect

A number of shots have been fired into the test box using various designs of hypervelocity pellet projectors. The vaporific effect was first detected using BRL design No. 12 (Fig. IV-1). Measurements of pressure, temperature and relative light intensity were recorded using oscilloscopes connected to the output of various transducers. A list of the equipment used and pertinent physical data are given in Tables IV-I and IV-II. The results listed in Table IV-III show that the time duration of the light output is at least a factor of 15 smaller than the pressure duration time. The pressure recorded is the long term pressure as opposed to a shock pressure. It was found that a dense white smoke existed in the test box after each shot which produced the vaporific effect. A spectroscopic analysis was made of dust collected from the bottom of the box. It was found that aluminum oxide and iron oxide were both present (the pellet was steel; the target plate was aluminum).

Shock Pressure Measurement Study

When the data were presented to BRL, it was pointed out that although Firestone had measured the long term pressure, it was also desired to measure shock pressures. A Kistler Model 601 pressure transducer had been used to collect the pressure data. The pressure time curve, displayed on an oscilloscope and photographed with a Polaroid camera, exhibited a lot of superimposed "hash." It was suggested that if the gage (pressure transducer) were shock mounted, the major portion of the "hash" might disappear and make it possible to detect the shock pulse.

Attempts were made to shock mount the gage using pieces of flexible plastic tubing, but it was not possible to eliminate the "hash" altogether. It appeared that the problem was related to the response of the gage to the shock pulse. This was verified by suspending the gage in air (using strings) and detonating a tetryl pellet about 3 feet away from it. The superimposed frequency was found on the resultant pressure time curves.

A visit was made to BRL to talk to a specialist in the measurements of blast pressures. It was his opinion that the measurement of shock pressures inside a test box would be extremely difficult. The following is a summary of his reasons:

1. A quartz crystal is generally used as a pressure transducer and in general the shock wave will tend to hit the gage face-on, i.e., the shock pulse will reflect from the gage face. When this happens the gage responds not only with the "hash" mentioned above, but it also overshoots, i.e., it will indicate a pressure higher than the incident peak shock pressure.

2. Even if it were possible to calibrate such a gage to take into account the overshoot, the angle at which the shock wave strikes the gage would not be known. It is necessary to know this angle in order to evaluate the true peak shock overpressure.

3. It was recommended that the shock problem be studied photographically at first, in order to determine the velocity and direction of the wave. It is possible to estimate the shock overpressure (assuming ideal gas condition) once the shock velocity is known.

As a result of the above information it was agreed to continue with the program measuring only the long term pressure inside the test box. Shock wave studies would be conducted separately.

Test Results in Nitrogen and Air

A test program was then conducted wherein hypervelocity pellets were fired at the test box filled with either air or nitrogen. The pellet was projected from a modified BRL Design No. 26 projector (Fig. IV-2). Pertinent physical data are given in Table IV-IV, and test results are summarized in Table IV-V. It is seen that the measured long term pressure in air is more than four times greater than for nitrogen. This indicates that oxidation plays an important role in the vaporific effect. This was further indicated by the appearance of metal fragments and craters in the 1/4" steel stop plate at the back of the box. The fragments and the craters had a "clean" look as opposed to the dull appearance of oxidized metal.

In conclusion, it has been found that a significant vaporific effect can be achieved on a rather small scale (test box volume = .30 ft.^{3}) and that the system can be used to study the mechanism of the vaporific effect. Initial tests have shown that substituting nitrogen for air in the box greatly inhibits the effect.

FUTURE PROGRAM

It is planned to conduct tests in various gases including argon and oxygen-nitrogen mixtures of various ratios. It is also planned to test under conditions of partial vacuum in the test box, in order to simulate various altitudes above sea-level.

An effort will also be made to reduce the amount of "hash" on the pressure time curve. This might be done by trying a different type of pressure transducer, or by using some type of filtering technique.

TABLE IV-I

LIST OF EQUIPMENT

1. Test Box - Dwg. DRD-H-9
2. Air Cavity Pellet Projector - Dwg. DRB-H-72
3. Kistler Pressure Transducer - Model 601
4. Kistler Charge Amplifier - Model 566
5. Mo-re' Fine-Wire Thermocouple - Model 201-3-1/8-.001-K
6. IP 22 Photo Multiplier Tube
7. Oscilloscopes - Tektronix Type 523, Tektronix Type 545, Hewlet Packard Model 130A

TABLE IV-II

PHYSICAL DATA LIST

Pellet Material - 1020 Steel

Pellet Mass (as machined) - 1.01 gms.

Flying Pellet Mass - not determined

Pellet Velocity(1) - 5.01 km./sec.

Target - 1/16 inch 6061 T6 Aluminum

Back Plate of Test Box - 1/4 inch Mild Steel

Volume of Test Box - .30 ft.^{3} = 8.4 liters

(1)BRL Data

TABLE IV-III

TEST RESULTS IN AIR USING
BRL DESIGN NO. 12 PELLET

	Pressure[1]		Temperature			Light	
Round	Peak (psi)	Duration (millisec.)	Ambient (° F.)	Peak (° F.)	Duration (millisec.)	Relative[2] Peak Intensity (percent)	Duratic (millisec
602-43	32	55	68	178	≫45	-	>3.3
602-44	48	55	-	-	-	550	>3.3
602-4/5[3]	26	35	65	191	≫45	520	3.4
602-47	-	-	72	125	≫45	410	3.2
602-48	20	-	72	112	≫45	340	1.4

(1) Rise above ambient.

(2) Measured relative to flashbulb output from inside test box.- Flashbulb rated at 1,200,000 lumens intensity and 63,000 lumen seconds energy output.

(3) Witness plate 1/32 inch aluminum.

TABLE IV-IV

PHYSICAL DATA LIST

Pellet Material - 1020 Steel

Pellet Mass (as machined) - .71 gms.

Flying Pellet Mass(1) - .57 gms.

Pellet Velocity(2) - 5.1 km./sec.

Target - 1/16" 6061T6 Aluminum

Back Plate of Box - 1/4" Mild Steel

Volume of Test Box - .30 ft.^{3} = 8.4 liters

(1) Based on recovery work done at BRL where it was found that BRL Design No. 26 Pellet retained about 80 per cent of its original mass.

(2) Measured with shorting screens.

TABLE IV-V

TEST RESULTS IN AIR AND NITROGEN USING BRL DESIGN NO. 26 (MOD.)

		Pressure[1]			Temperature				Light	
Round No.	Gas	Peak (psi)	Time to Peak (millisec.)	Duration (millisec.)	Ambient (°F.)	Increase (°F.)	Time to Peak (millisec.)	Duration (millisec.)	Relative[2] Peak Intensity (percent)	Duration (millis.)
602-67	Air	24	5	90	- - - - - - - - - - Not Taken - - - - - - - - - - - - - -					
602-68	"	40	5	59	- - - - - - - - - - Not Taken - - - - - - - - - - - - - -					
602-69	"	31	5	74	77	198	22	180+	550	8.5
602-70[3]	"	25	3-4	50	- - - - - - - Off Scale - - - - - - - - - -				- Missed - - - -	
602-71	"	28	3-4	34	78	237	8	140	570	8.5
602-72[3]	Nitrogen	3.4	9	34	74	53	16	80	-[4]	-
602-73	"	8.5	6	64	78	75	8	160	-[4]	-
602-74	"	7.5	7.5	80	78	61	8	140	.43[5]	.78

(1) Rise above ambient.

(2) Measured relative to flashbulb output inside test box - flashbulb rated at 1,200,000 lumens intensity and 63,000 lumen seconds energy output.

(3) Not a clean hit, pellet hit edge of hole in protector plate.

(4) Oscilloscope sensitivity not high enough.

(5) Intensity drops to about 1/5 of this value in 120 microseconds.

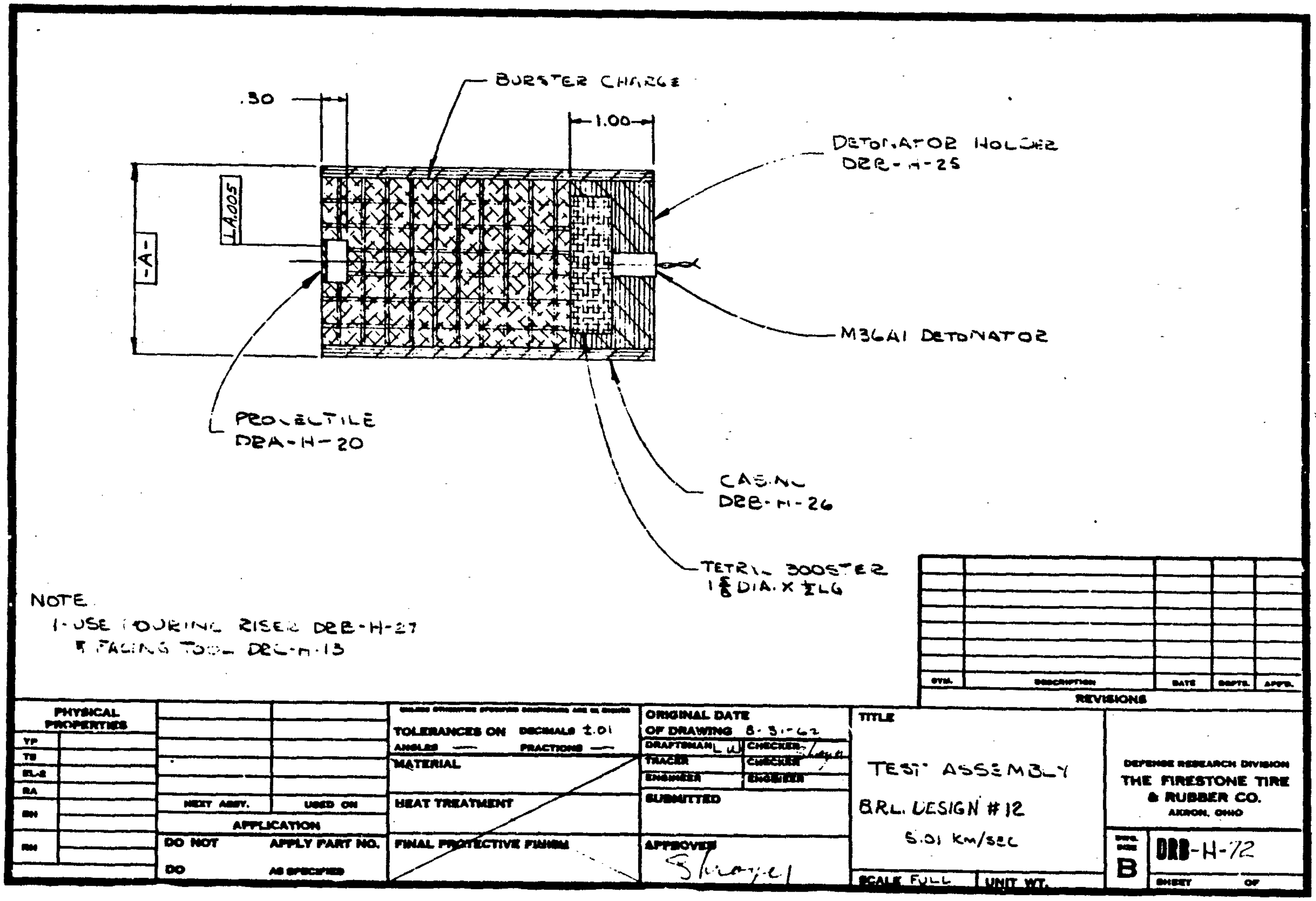


Fig. IV-1. Test Assembly, BRL Design No. 12.

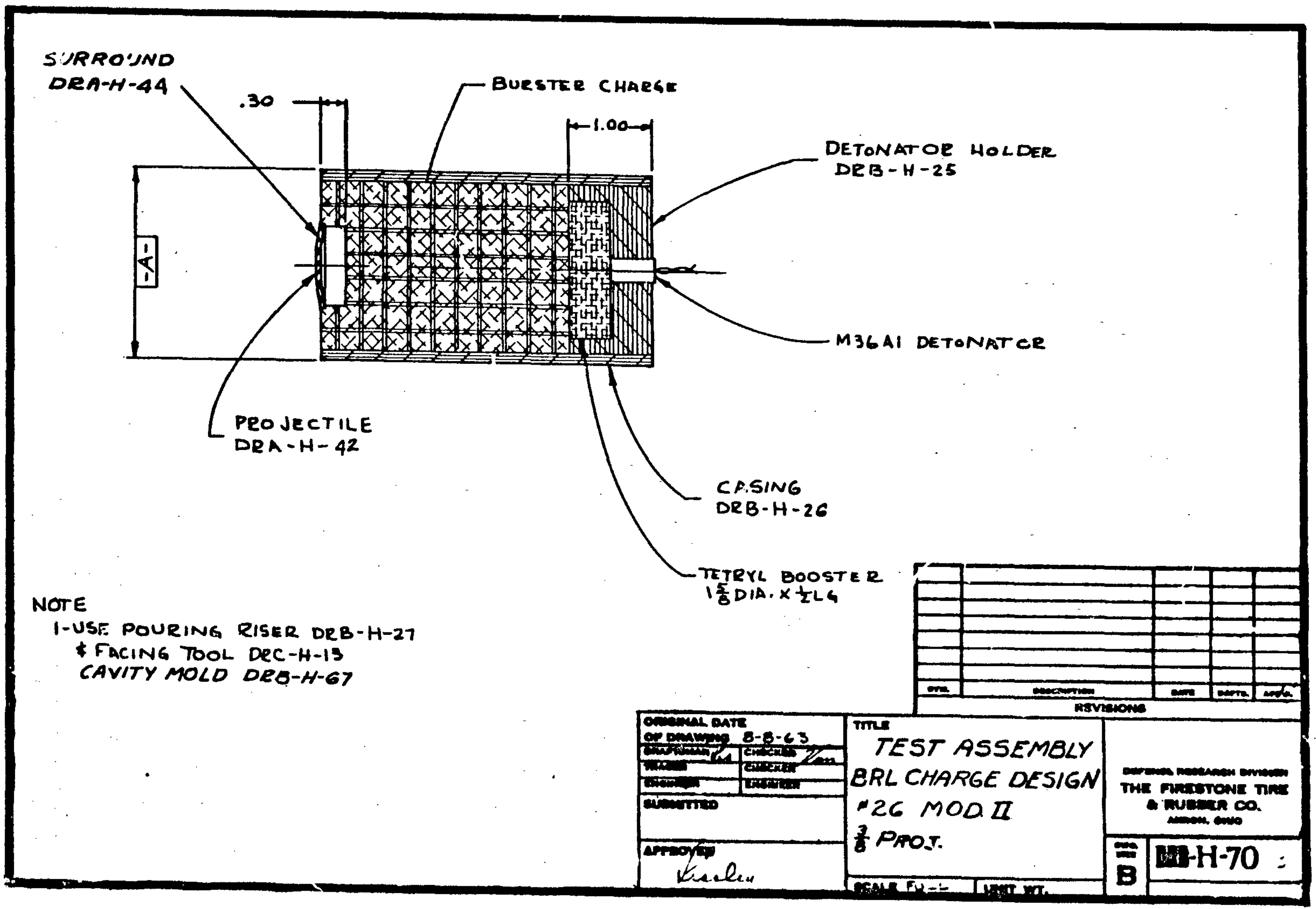


Fig. IV-2. Test Assembly, BRL Design No. 26, Mod. II.

SECTION V - TEST FACILITIES

INTRODUCTION

Use Agreements negotiated between the Cleveland Procurement District and the Ravenna Army Ammunition Plant 10 October 1961 extended the use of Fuze Line 2, to include testing of explosive devices.

Modification No. 2, Contract 3697 dated 21 July 1961 provided for the fabrication and installation of a portable explosion chamber for testing small shaped charges. Modification No. 5 of the contract provided for the installation of an additional larger explosion chamber and auxiliary apparatus including instrumentation. Modification No. 12 provided for installation of a new more versatile test chamber for conducting tests of beamed fragment charges and other explosive charges.

The installation of the above facilities has been completed to provide the government with the necessary facilities in one location for ammunition assembly propellant and high explosive loading, and static testing of explosive actuated devices. The three test chambers constructed and equipped under contract 3697 are described in the following paragraphs:

SMALL DETONATION CHAMBER

This test facility is a concrete and steel structure adjacent to Building 2 F 12 in which bare or cased high explosive charges up to 2 lbs. can be detonated. This facility is equipped with a three channel, 300 kv, flash X-Ray system, electronic timers, raster sweep oscilloscopes, oscilloscopes, and other instrumentation. This includes a spin fixture and internal fragmentation chamber to permit detonation of cased charges while they are being spun at high rates. This facility is used to conduct static tests of spinning and non-rotating charges at various standoff distances for penetration hole volume, jet velocity and jet character.

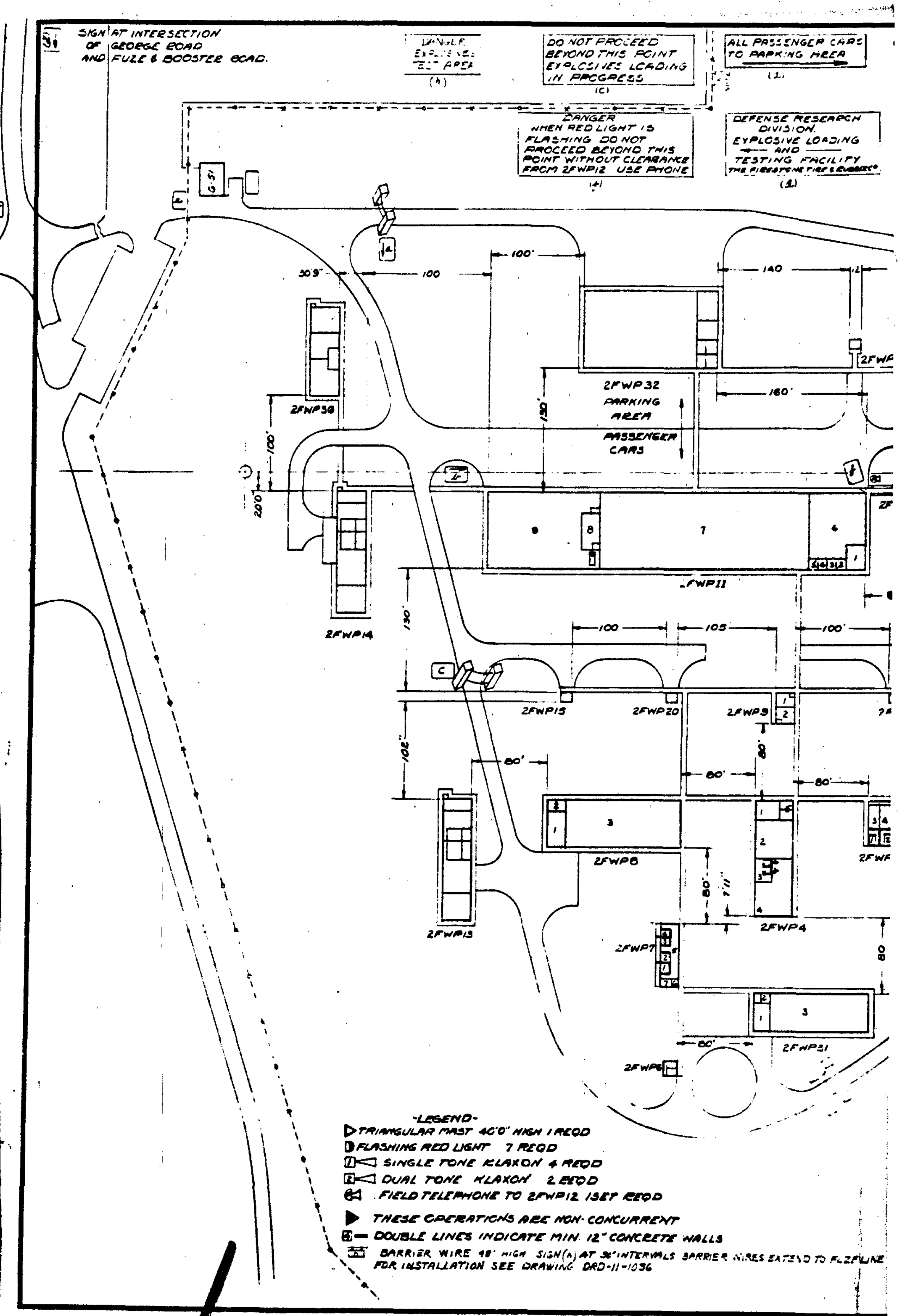
Penetration-time measurements, detonation velocity measurements, "black box" studies and other experiments with small charges are conducted in this chamber. Its location is shown in Figure V-1.and a front view in Figure V-2.

LARGE DETONATION CHAMBER

This test chamber is a large, monolithic, reinforced concrete, steel lined structure located approximately 200 feet from the control point in Building 2 F 12. This facility has an upper chamber in which cased and uncased explosive charges up to 20 lbs. are detonated. A spin fixture is located in this chamber to permit spinning charges to simulate warhead in-flight conditions. The facility also has a lower chamber where four channels of 300 kv x-ray equipment are located to flash radiograph shaped charge jets and other explosion products which are directed through an aperture into the field of view of the x-ray tubes. Techniques and equipment have also been developed for flash radiographing the actual detonation process and explosive to metal component interaction during the liner collapse process. Testing of shaped charges for target penetration, effects of spin, penetration-time, jet velocity, jet break-up time, spall envelope character and for other information is done in this chamber. This chamber is equipped with an air blower and atmosphere sampling equipment which permits the testing of such hazardous materials as beryllium. This facility is shown in Figure V-1 and V-2. Figure V-3 shows the upper level of the reinforced concrete structure. Figure V-4 shows the steel lined upper level of the facility and Figure V-5 shows the lower level with part of the x-ray equipment.

NEW OPEN TEST RANGE

This facility is located in the Southwest Corner of Fuze Line 2 as shown in Figure V-1. It is constructed of steel and earth and includes a reinforced concrete personnel and instrument shelter house and control room. The facility was designed for maximum versatility. Observation of projectiles, jets, fragments or other missiles over a distance of 100 feet with flash x-ray, framing camera, streak camera or other instrumentation is a principle advantage of this facility. Figure V-6 shows the aperture in the barrier wall, the projectile flight path and the viewing apertures for x-ray etc. Figure V-7 shows the butt, "catchers mitt", provided to stop projected particles. This facility also includes a spin fixture for testing spinning charges, and apertures for x-ray viewing of detonation phenomena occurring within the chamber. Figure V-8 shows the inside of the chamber prior to installation of the spin fixture and aperture covers. An overall view of the Open Test Range is shown in Figure V-9.



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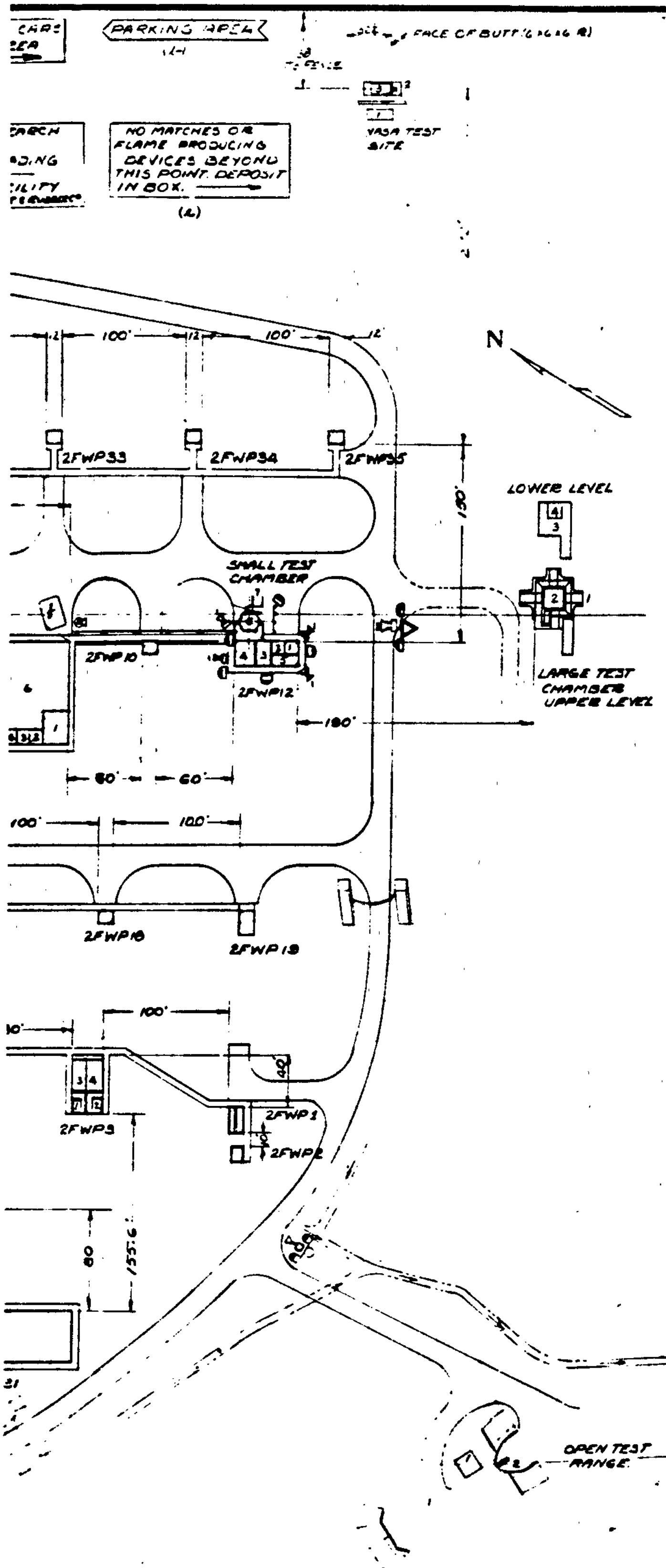

CLASS & DIV.   DRF 11-212-5

EXPLOSIVES & PERSONNEL LIMITS

FIRE FIGHTING SYMBOL	BLDG	BAY	UTILITY	MATL CLASS	CPRTE	TEAMS
	LARGE TEST CHAMBER	1	ROUND ASSY	H.E. 20LB	2	0
		2	ROUND ARMG & TEST	H.E 20LB	1	0
		3	INSTR & EQUIP		0	3
		4	CASSETTE HOLDER		0	3
	2FWP1		SERV. MAG FOR OPEN TEST CHMBR	H.E 100#	2	1
	2FWP2		VACANT			
④	2FWP3	1	PRESS LOADNG & LAB OVEN	H.E 50# CL10	0	2
	REF-	2	PRESS LOADNG & (CONT CHE-REM CONT)	H.E 1# OR ONE SHELL	1	2
	RAI DRWG	3	SHELL ASSY (80 SHELLS)	H.E 100LB	5	5
	A-2375	4	TEST SHELLS OR SHELL FUZES	H.E ½LB	2	2
③	2FWP4 REF- RAI DRWG A-2388	1	STORAGE, INERT CART. CASES PROPELLANT POWDER	600 LB CL 2	3	5
		2	POWDER SCALE / CRIMP & DECRIMP	140 LB CL 2 / 100 LB CL10	3	5
		3	DISASSEMBLY & PULL APART		3	5
		3A	POWDER SCREEN & BALL MILL	15LB BLK PWDR	0	1
		3B	VACANT			
		4	AIR COMPRESSOR			
		5	TOILETS.			
	2FWP6		STORAGE, LOAD TOOLS EQUIP (NO EXPL)		0	2
④	2FWP7 REF- DRD-23-809 RAI DRWG A-2375	1	SMALL MELT KETTLE	HE 50LB CL.9	1	1
			EXPERIMENTAL COOLING UNIT	H.E 20LB CL10	1	1
		2	LARGE MELT KETTLE	H.E 100LB CL9	2	2
		3	VACUUM UNIT	HE 5LB CL9	1	0
		4	SECTIONING SAW / FACE OFF-2A SHELLS	HE 3LB CL10 / HE 28.8LB CL10	1	0
		5	INSP POUR, COOL ETC	H.E 100LB CL10	5	6
		6	TOILET			
7		7	BLDG OFFICE, TELEPHONE & STEAM GENERATOR			
	2FWP8 REF- DRD-23-809 RN. A-2388	1	SHOP OFFICE			
		2	TOILET			
		3	PACKAGING & SHIPPING	H.E. 100LB CL10	5	5
③	2FWP9	1	STORAGE, PROP POWDER	150 2	0	2
		2				
	2FWP10		STORAGE, DETONATORS	H.E 10LB CL.8	0	1
	2FWP11	1	OFFICE-TELEPHONE.			
		2	STORAGE-PHOTO SUPPLIES			
		3	DARK ROOM-FILM DEV.			
		4	REST ROOM			
		5	LOCKER ROOM			
		6	SHOP & MISC STORAGE			
		7	IDLE EQUIP. STORAGE			
		8	BOILER, BLOWER, MAIN ELECT PAN. ROOM			
		9	VACANT			
④	2FWP12	1	SERV. MAGAZINE (1 DAY SUPP)	H.E. 50LB	1	1
		2	FIRING COMPONENTS (INERT)		0	2
		3	CONTR & INSTR (SMALL CHAMBER) TELEPH.		2	2
		4	WORK & STORAGE AREA (NO EXPL.)		0	3
		5	CONTR & INSTR. (LARGE CHAMBER)		2	2
		6	ROUND ARMG & TEST	H.E 2LB	2	0
		7	ROUND ASSY	H.E 2LB	1	1
	2FWP13		VACANT			
	2FWP14		VACANT			
④	2FWP15		STORAGE	SCRAP H.E 100LB CL.9	0	2
④	2FWP18		STORAGE, EXPL. DEVICES (POURED RDS)	100LB CL9	0	2
	2FWP19		VACANT			
④	2FWP20		STORAGE	BULK H.E 100LB CL9	0	2
	2FWP31		VACANT REF- RAI. DRWG A-2375			
	2FWP32		VACANT			
1	2FWP33		STORAGE	FLAMMABLE MATLS CL.1	-	2
④	2FWP34		STORAGE	BOOSTERS 25LB CL.8	0	1
④	2FWP35		SERV MAG	EXPL CHGS 100LB (1 DAY) CL8		2
	2FWP36		VACANT			
	6-51		VACANT			
	OPEN TEST RANGE	1	CONTROL ROOM & PULSERS (XRAY			4
		2	EXPLOSION CHAMBER	H.E 16LB	3	
	NASA TEST SITE	1	CONTROL ROOM-RECORDING INSTRMTS		3	2
		2	EXPLOSION AREA	H.E 6LB (CASED)	2	0
		3	XRAY PULSERS & TARGET CHAMBER		2	1

2

	REVISIONS			
5	NASA TEST SIDE ADDED	10-18-66		
4	[illegible]	6-9-64		
4	GENERAL REVISION	4-15-64		
3	[illegible]	4-1-66		
2	OPEN TEST RANGE ADDED	3/11/64		
1	GENL REVISION	2/24/64		

TITLE: GENERAL LAYOUT-DEFENSE RESEARCH EXPL LOADG & TEST'G FACILITY W/INTER LINE DIST. FUZE LINE #2 R.O.P.

DEFENSE RESEARCH DIVISION
THE FIRESTONE TIRE & RUBBER CO.
AKRON, OHIO

F   DRF-11-212-5

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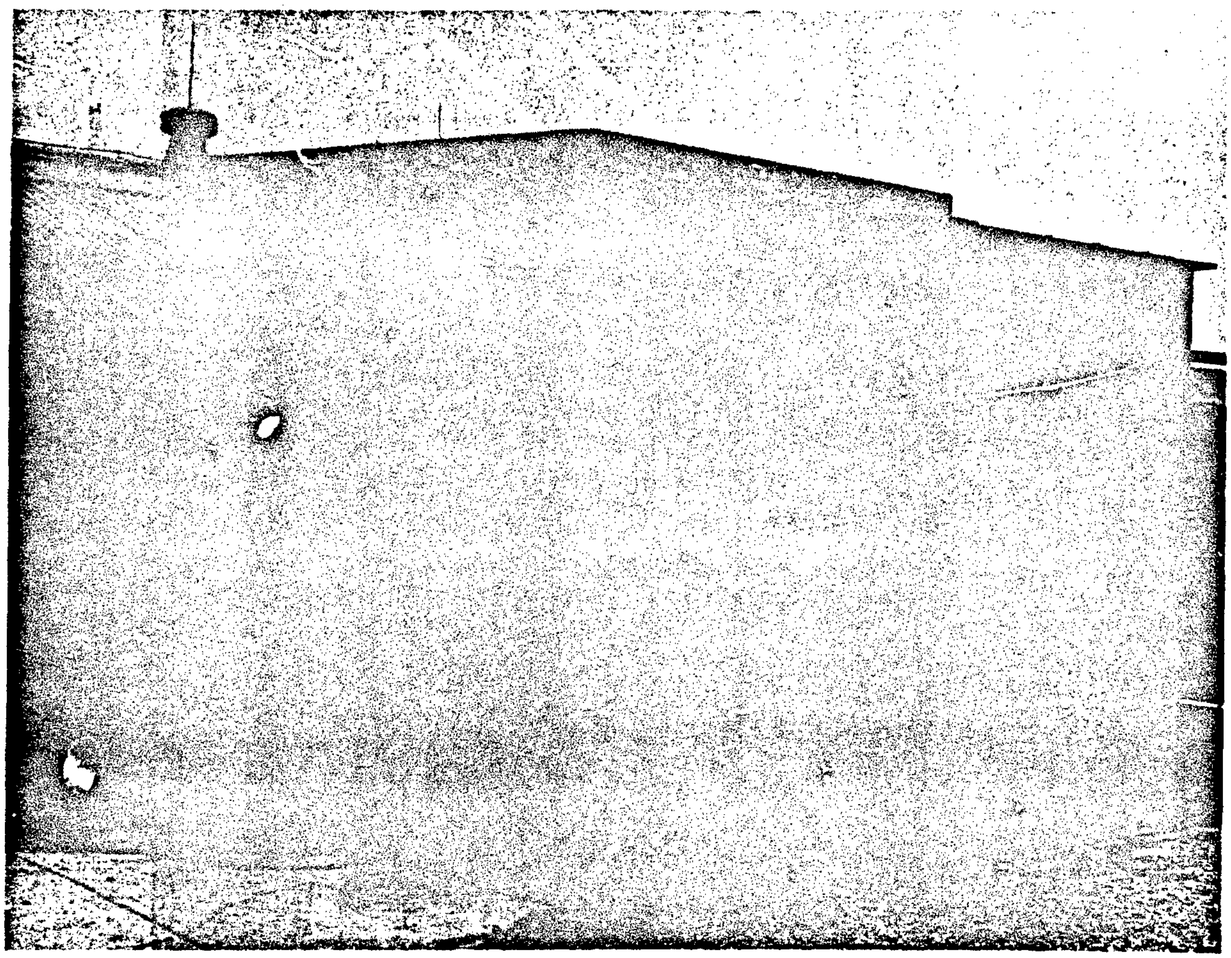

Fig. V-2. Exterior view of small test chamber.

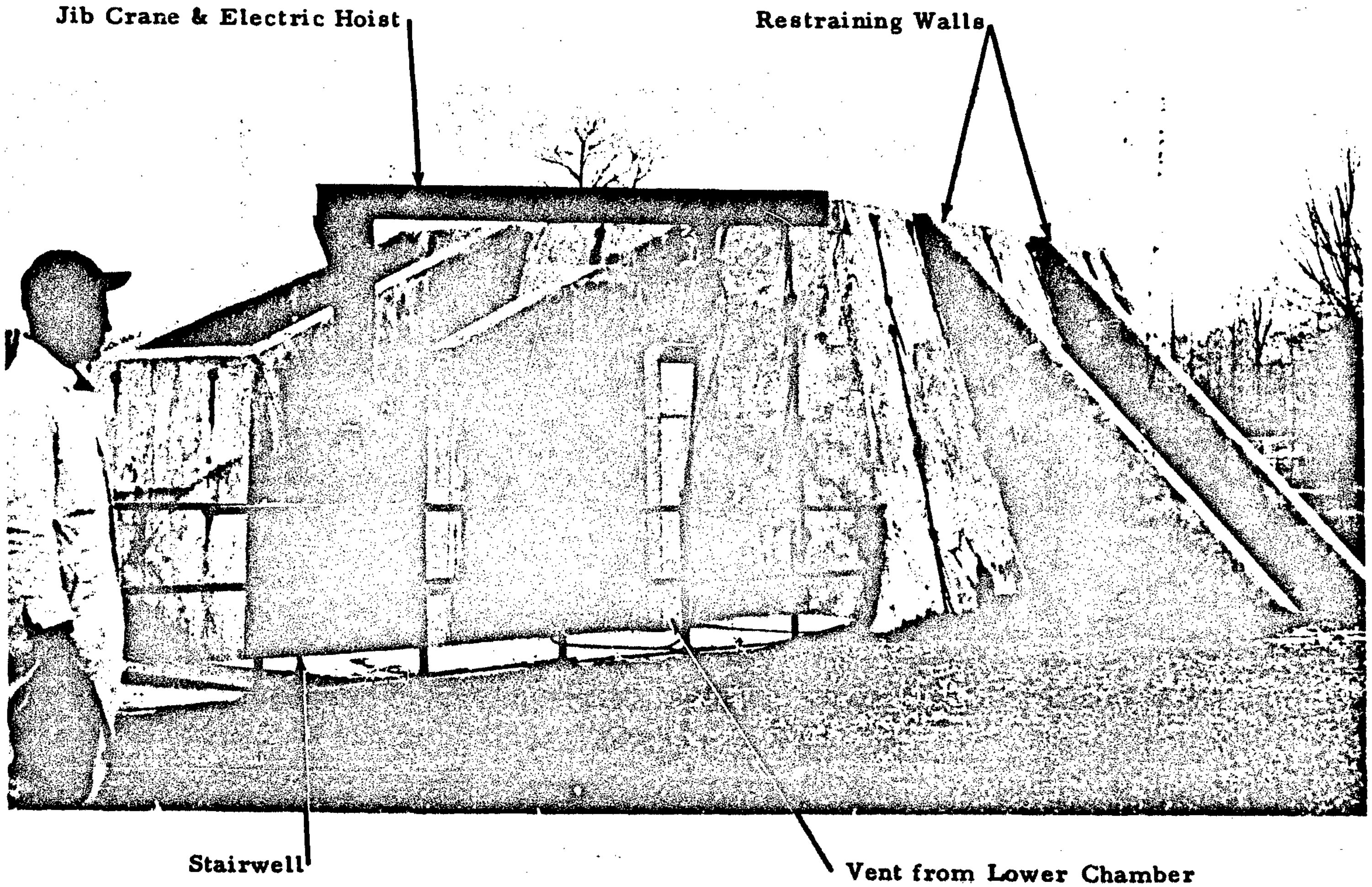

Fig. V-3. Exterior view of large test chamber.

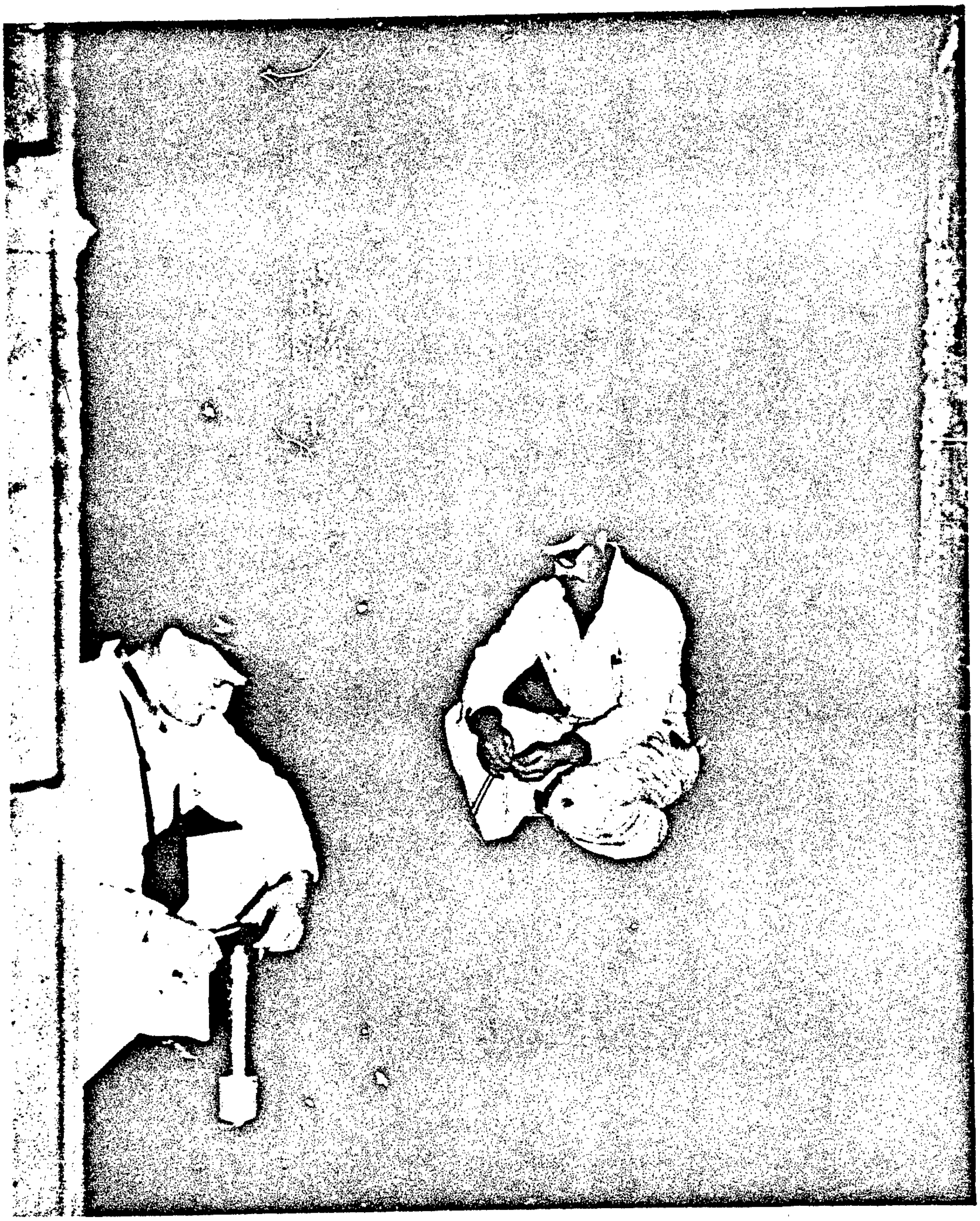

Fig. V-4. Preparation of explosive charge in upper level of large test chamber.

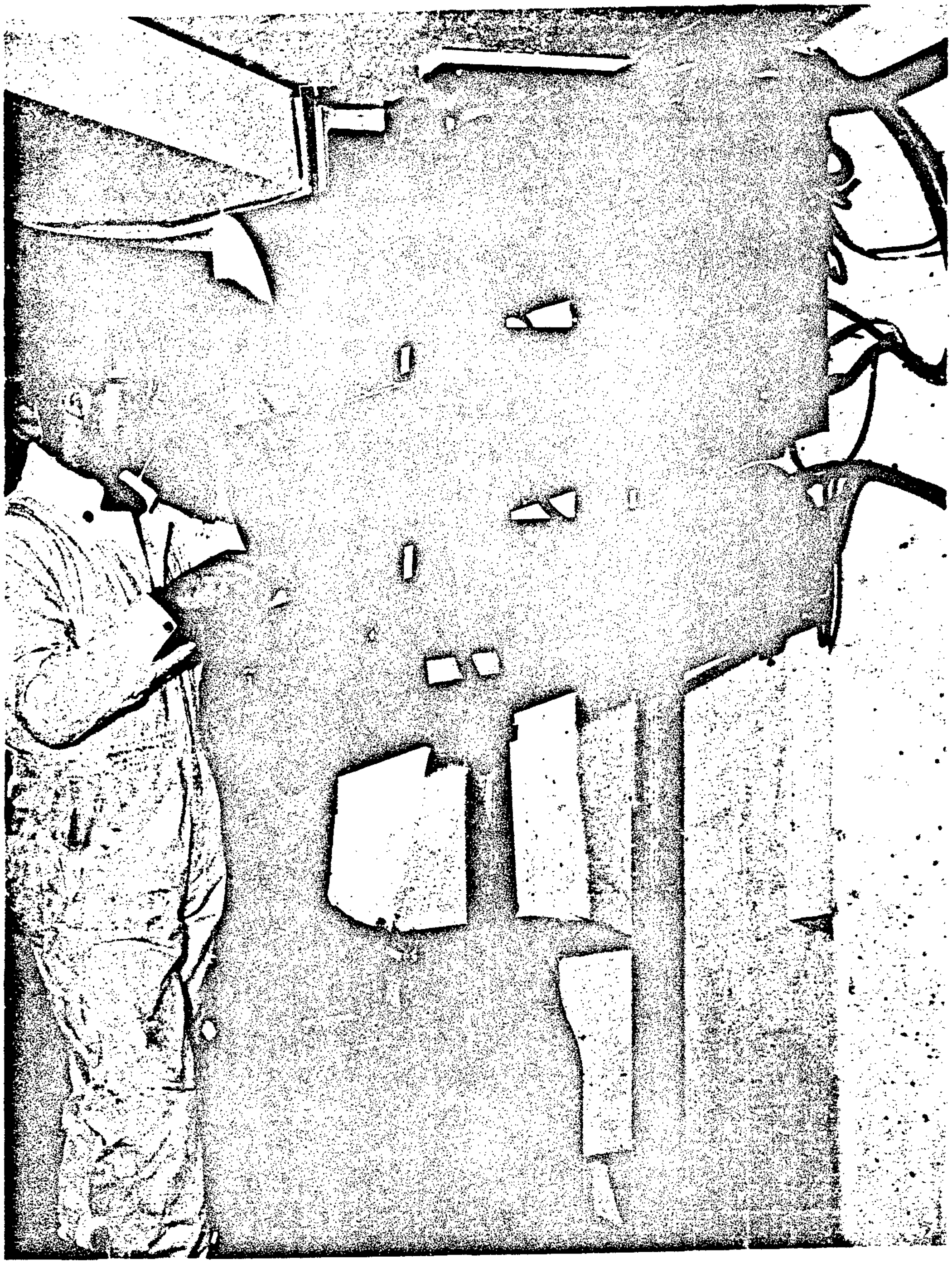

Fig. V-5. View in X-ray cubicle of large test chamber. Final alignment of 300 kv pulsers aimed through a single slot.

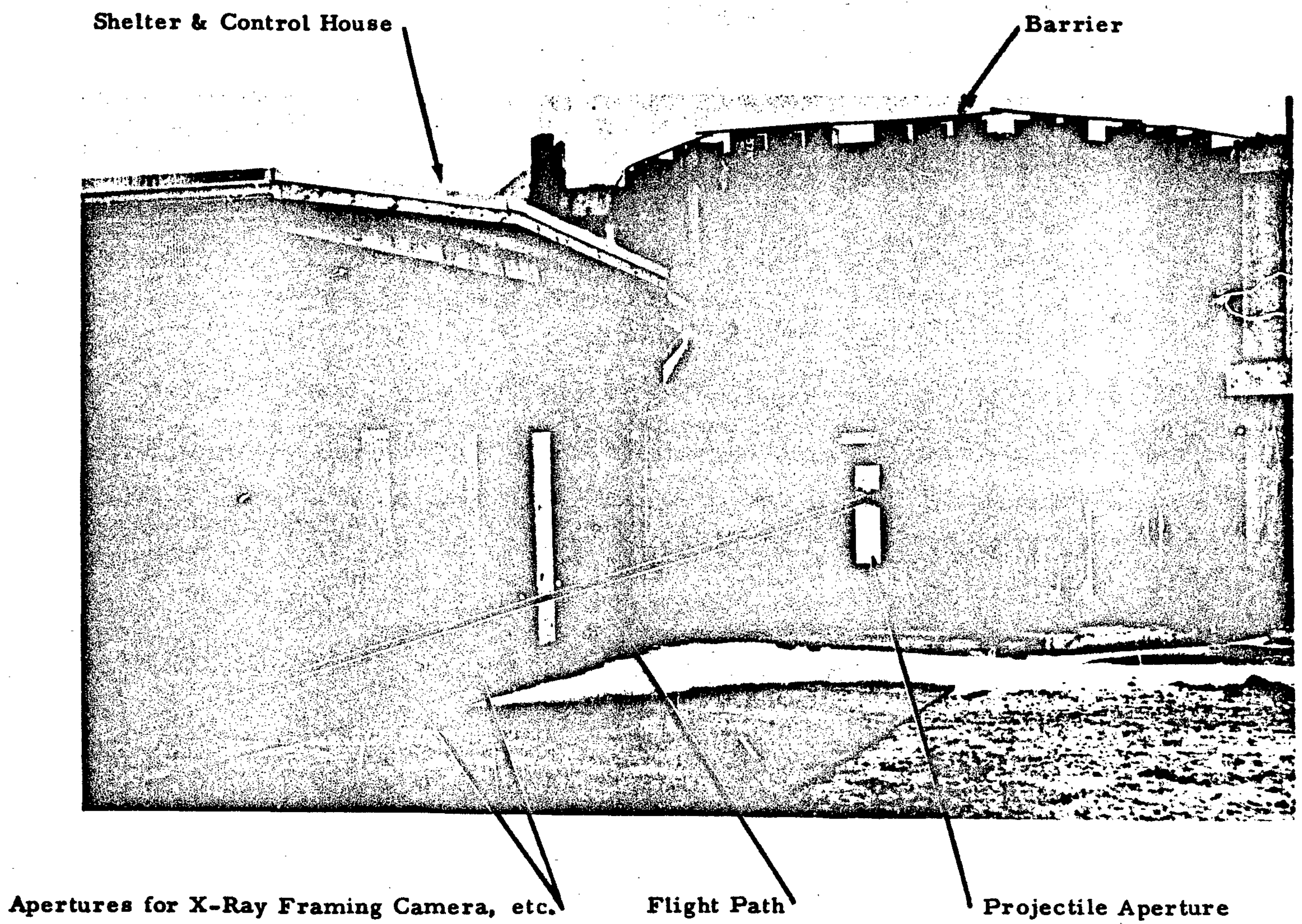

Fig. V-6. Open air test area. View showing detonation shield and control building.

Steel Faced, Earth Backed Butt

Fig. V-7. Backstop - open air test range.

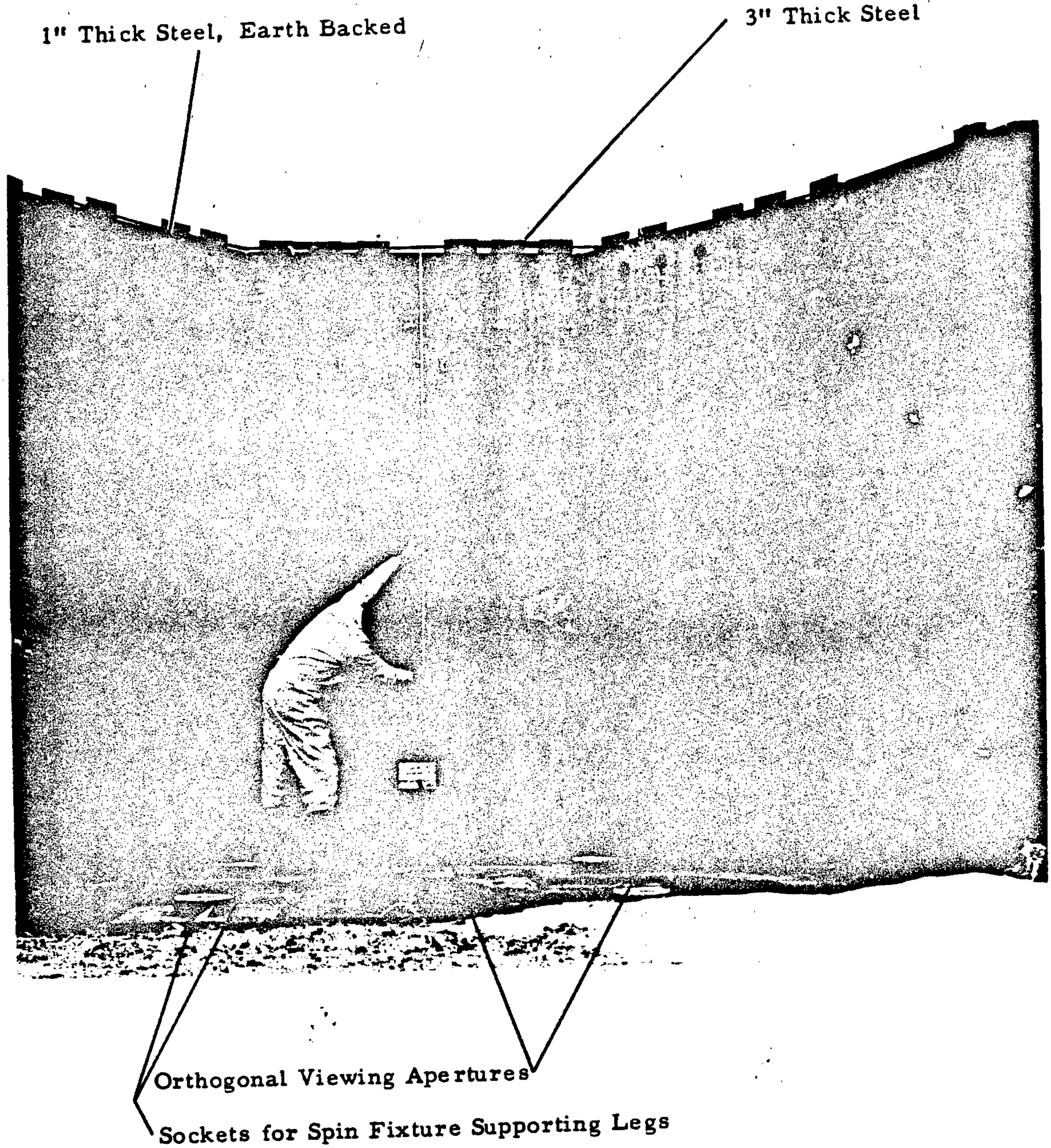

Fig. V-8. Detonation Area - open air test site.

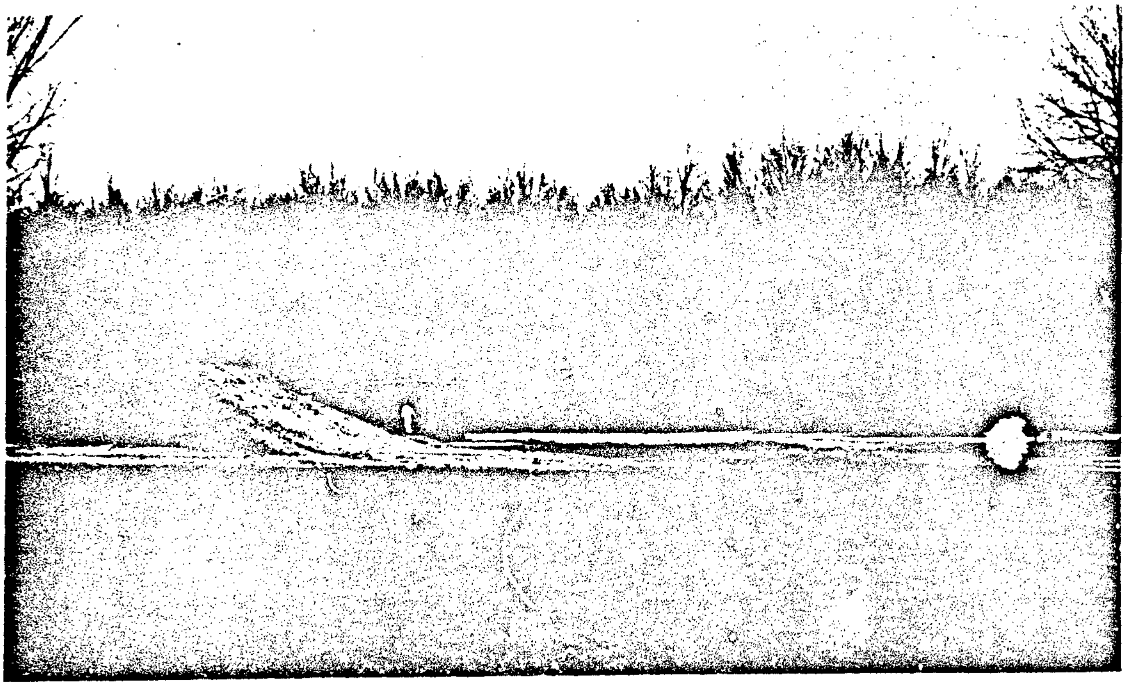

Fig. V-9. Overall view - open air test range.

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13. ABSTRACT

The results of basic shaped charge studies accomplished under Contract ORD-3697 are presented. (U)

The successful development of a 152MM spin compensating fluted liner is described. (U)

Hypervelocity impact tests on composite targets are presented. Pellet energies up to 6.1 megajoules were used. (U)

The mechanism of the vaporific effect was studied. (U)

Test facilities are described. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
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