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U. S. NAVAL FLYING GROUND
DANFORTH, VIRGINIA

REPORT NO. 1117

AIRHEAD CHARACTERISTICS

BALLISTICS OF 40-LINE FRAGMENTS

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NPO REPORT NO. 1117

Ballistics of Rod-Like Fragments

PART A

SYNOPSIS

1. Tests of rod-producing warheads have indicated that rod-like fragments become increasingly difficult to obtain in high length/width ratios as fragment velocities rise above the 4000 ft./sec. range. This test is the first of a series planned to further investigate this phenomenon.
2. Under the conditions of this test, 3/8" square rods of 6-1/2" and 12-1/2" lengths were expelled from cylindrical warheads at average velocities of 3430 ft./sec. and 3595 ft./sec., respectively. The only breaking of the rods occurred at the extreme ends.
3. A metallurgical examination of the rods was conducted, including a determination of the hardness pattern extending through the rod from the explosive face to the opposite side. A considerable amount of cold working of the rod material is evident.
4. The design of the warhead will be changed for future work to more nearly approximate a "free-rod" warhead.

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Ballistics of Rod-Like Fragments

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Ballistics of Rod-Like Fragments

PART B

INTRODUCTION

1. AUTHORITY:

This test was authorized by reference (a) and conducted under Task Assignment Nos. NPG-Re3d-442-1-52 and NPG-Re3d-442-1-53, established by references (b) and (c).

2. REFERENCES:

- a. BUORD Conf ltr NP9 Re3d-AM:bc Ser 9607 of 29 June 1950
- b. BUORD Conf ltr NP9 Re3d-WKB:hm Ser 23908 of 4 August 1951
- c. BUORD Conf ltr NP9 Re3d-AM:bc Ser 42653 of 29 July 1952
- d. NPG Conf Report No. 1106 (To be published)
- e. NPG Conf Report No. 949 of 1 April 1952
- f. NPG Conf Report No. 979 of 9 May 1952
- g. NPG Conf Report No. 1009 of 14 July 1952

3. BACKGROUND AND OBJECT OF TEST:

Tests of rod-producing warheads by the Naval Proving Ground and other activities have indicated that rod-like fragments become increasingly difficult to obtain in length/width ratios of 24 or higher as velocities rise above the 4000 ft./sec. range (references (e), (f), and (g)).

Further investigation of this phenomenon indicated that while tapered rods would hold together at somewhat higher velocities than would the usual rectangular rod, the performance at velocities proposed for missile warheads was not yielding design length rods. If this difficulty were insurmountable, the warhead designer would be left with two (2) alternatives; to reduce the initial velocity of the fragments to that which would produce design length fragments, or to design the warheads for rod-like fragments of length/width ratios of as low as 5 up to possibly 12.

To aid in resolving this problem, it was desired to secure information concerning the break-up of rectangular rods expelled under optimum conditions at various velocities.

The Naval Proving Ground has designed, fabricated, and fired the first model of a warhead designed to give some indication of the optimum obtainable length/width ratios in rod-like fragments from warheads.

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Ballistics of Rod-Like Fragments

PART I

DETAILS OF TEST

4. DESCRIPTION OF ITEMS UNDER TEST:

The warheads designed and fabricated for this test are shown in Figures 1-3, inclusive.

The outer wall of each warhead was a single row of rods, made by cutting 3/8" square bar stock (hot rolled AISI C-1025 steel, as received) to the desired length. The rods fit into 1/4" deep grooves in the upper and lower rings and were welded with a single bead (one (1) pass) at each end, around the outside, to insure rigidity of the assembly.

The inner wall, forming the central void, was fabricated of 20 gauge sheet iron. The space between the outer wall of rods and the inner sheet iron wall was loaded with Composition C-3. The one (1) inch top space was also loaded with Composition C-3 after determining the explosive weight in the annular space.

The empty and loaded weights were as follows:

Rd. No.	Rod Length	Empty Wts.	Chg. Sidewall	Chg. Top Layer	Chg. Wt. Total	Total Wt. as Fired
1	6-1/2"	31.16 lb.	7.39 lb.	4.00 lb.	11.39 lb.	42.56 lb.
2	6-1/2"	31.07 lb.	7.34 lb.	3.96 lb.	11.30 lb.	42.36 lb.
3	6-1/2"	31.21 lb.	7.32 lb.	4.10 lb.	11.42 lb.	42.61 lb.
4	12-1/2"	48.94 lb.	14.79 lb.	4.08 lb.	18.87 lb.	67.81 lb.
5	12-1/2"	48.75 lb.	14.90 lb.	4.11 lb.	19.01 lb.	67.75 lb.
6	12-1/2"	48.80 lb.	14.83 lb.	3.89 lb.	18.72 lb.	67.49 lb.

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Ballistics of Rod-Like Fragments

5. PROCEDURE:

Each warhead was placed vertically on a stand, 6 or 7 feet high, at the center of the 30 foot radius fragment velocity arena. The fragment velocities were obtained by photographing, with two (2) high speed cameras, the detonation of the warhead and the subsequent impacts of the fragments on the steel flash plates at a distance of thirty (30) feet. An 1800 r.p.m. synchronous motor clock, and a glow lamp and a one (1) kilocycle per second generator were used to establish the film rates for the cameras.

A pack of cane fiber-board was used to recover a sample of the rods.

After each round the steel flash plates were photographed to show the impacts, and the impacts were then marked so that the impacts of the following round would be distinguishable. The image of the impact has been circled on the photographs, so that the impacts for a single round are readily discernible (Figures 6-17).

6. RESULTS AND DISCUSSION:

Detailed velocity data are given in Table I, Appendix (C). The average velocities were as follows:

Rd. 1	6-1/2" rods	3560 ft./sec.	3470 ft./sec.
Rd. 2	6-1/2" rods	3440 ft./sec.	3450 ft./sec.
Rd. 3	6-1/2" rods	velocity missed because of failure of photographic equipment.	
Rd. 4	12-1/2" rods	3600 ft./sec.	3680 ft./sec.
Rd. 5	12-1/2" rods	3600 ft./sec.	3610 ft./sec.
Rd. 6	12-1/2" rods	3560 ft./sec.	3520 ft./sec.

The average value for the 6-1/2" rods is 3400 ft./sec. and for the 12-1/2" rods 3595 ft./sec.

The impacts on the flash plates were measured after each round, and these measurements are given in Table II, Appendix (D). Photos of the plates are included as Figures 6-17, inclusive. The rods recovered from the cane fiber-board pack are shown in Figures 18 and 19.

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Ballistics of Rod-Like Fragments

The impact lengths, as measured on the plates, indicate that a large percentage of the rods were either tumbling or were traveling with the long axis tilted at random angles from the normal to the trajectory. Hole dimensions, where given in the table, indicate a complete penetration of the flash plate of the length given.

Neither the impacts on the plates nor the rods recovered indicate any break-up of rods except at the extreme ends. The combination of the 1/4" deep grooves in which the rod ends were placed, and the "single-pass" welding bead at the corners formed by the rods and the end plates, offered greater resistance to the release of the rods than was expected or desired. This caused the rods to bend and neck down before pulling out of the upper groove and to break at the weld at the lower end. The strength of the joint at the lower end of the rod probably accentuated the tip-off of the rods, and tended to cause tumbling.

It was originally planned that this first set of warheads would expel rods at a velocity where it was fairly certain the rods would be of design length. The next step was then to be a modification of the present design only by increasing the thickness of the explosive annulus, until the maximum velocity for design length rods was obtained. However, the condition of the rods recovered from this first firing indicated that the design of the warhead must be changed to more nearly approximate a "free-rod" warhead if the optimum results are to be obtained.

One (1) of the 12-1/2" rods recovered from the fiber-board pack was sectioned at a point well removed from the ends. A series of Knoop hardness readings was taken across this section, from a point as close as possible to the rod surface which had been toward the explosive to the opposite side. The values obtained are listed in Table III and Figure 23, and photomicrographs of the rod grain structure are included as Figures 20, 21, and 22. The hardness of the rod material before firing was Rockwell D77, corresponding to a Knoop hardness number of 136 so that there is some increase of hardness throughout the rod thickness, and a maximum hardening of approximately 200 Knoop hardness numbers. It is interesting to note that this hardness pattern closely resembles that obtained in single rod firings from the "rod gun," as shown in reference (d).

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Ballistics of Rod-Like Fragments

Chemical analysis of the rod material indicated the following compositions:

Chemical Analysis

C	P	S
.22 - .27	.012 - .014	.033 - .039

Spectrographic Analysis

Si	Mn	Cr	Ni	Mo	Cu
.16 - .18	.44 - .46	<.09	<.08	<.06	.07

Although this material was ordered as AISI C-1020 steel, the above analysis indicates that it was actually C-1023 steel.

PART D

CONCLUSIONS

7. Under the conditions of this test, 3/8" square rods of 6-1/2" and 12-1/2" lengths were expelled from cylindrical warheads at average velocities of 3480 ft./sec. and 3595 ft./sec., respectively. The only breaking of the rods occurred at the extreme ends.

A metallurgical examination of the rods was conducted, including a determination of the hardness pattern extending through the rod from the explosive face to the opposite side. A considerable amount of cold working of the rod material is evident.

The design of the warhead will be changed for future work to more nearly approximate a "free-rod" warhead.

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Ballistics of Rod-Like Fragments

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Terminal Ballistics Department
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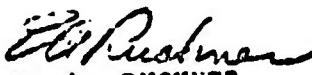
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NPG REPORT NO. 1117

**U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA**

**Fifteenth Partial Report
on
Warhead Characteristics**

**Fourth Partial Report
on
Ballistics of Rod-Like Fragments**

**Project No.: NPG-Re3d-442-R-53
Copy No.: 14
No. of Pages: 8**

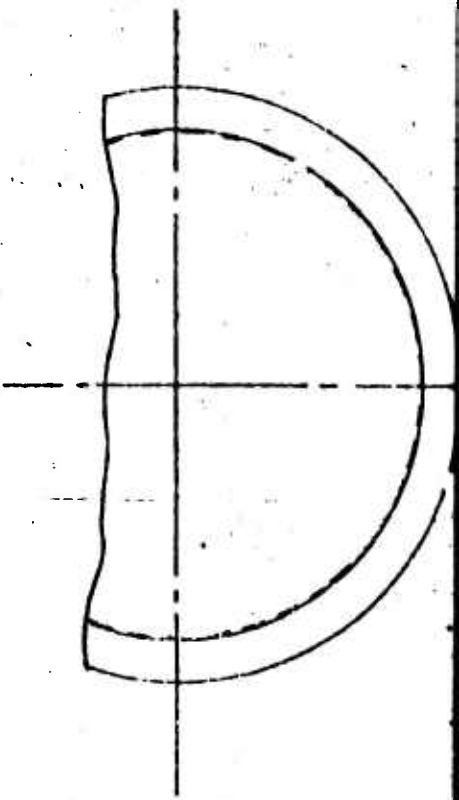
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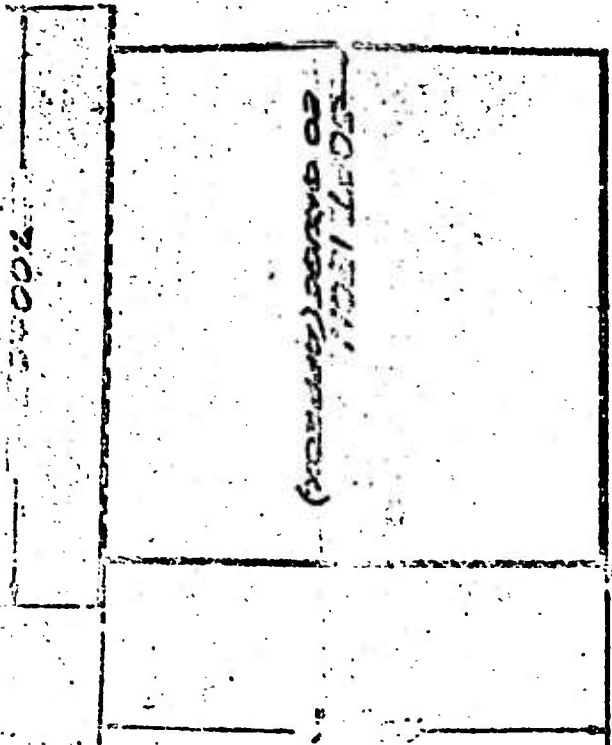
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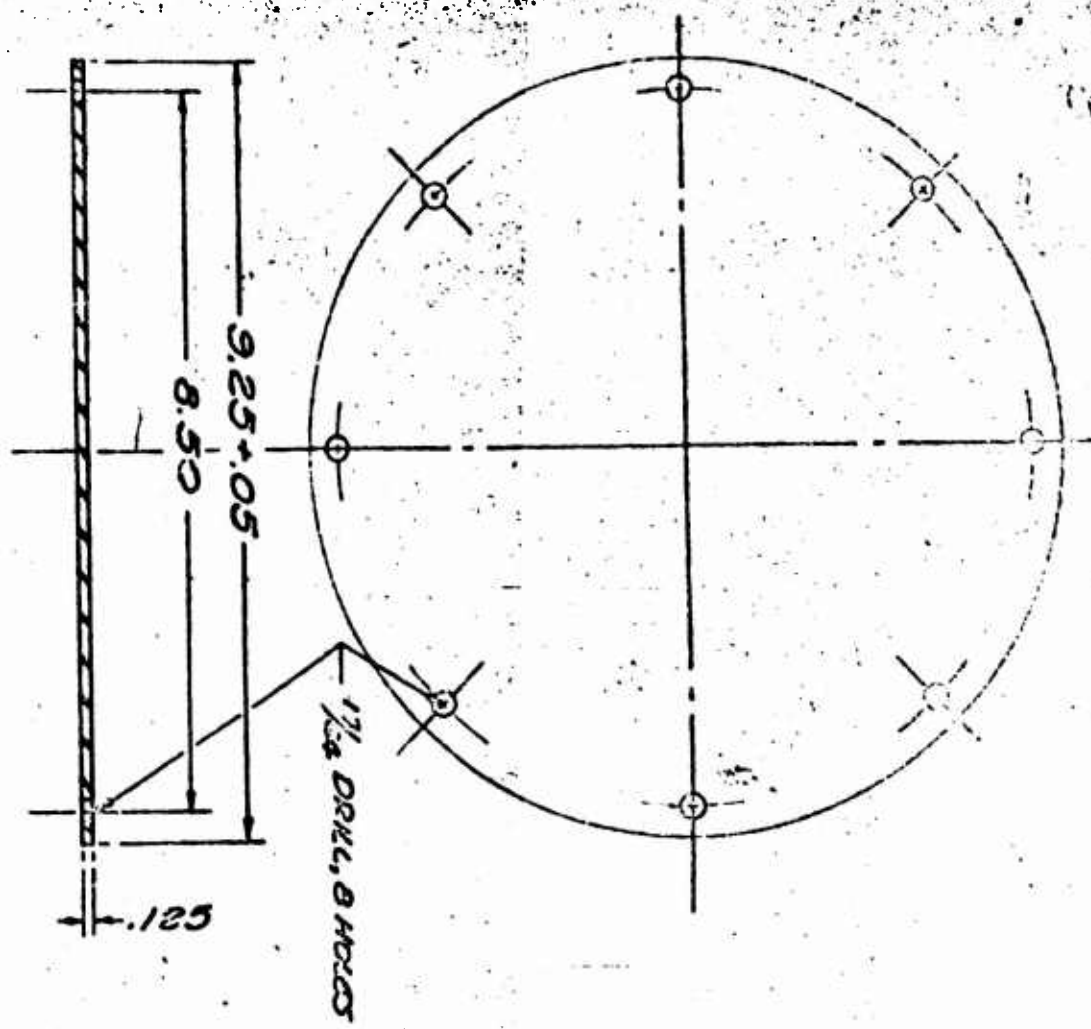
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4.00 ± 0.5

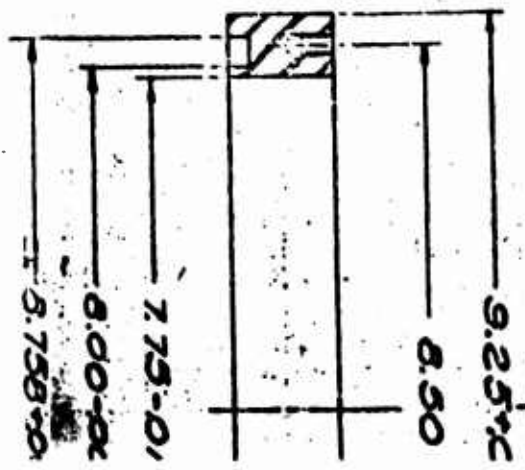
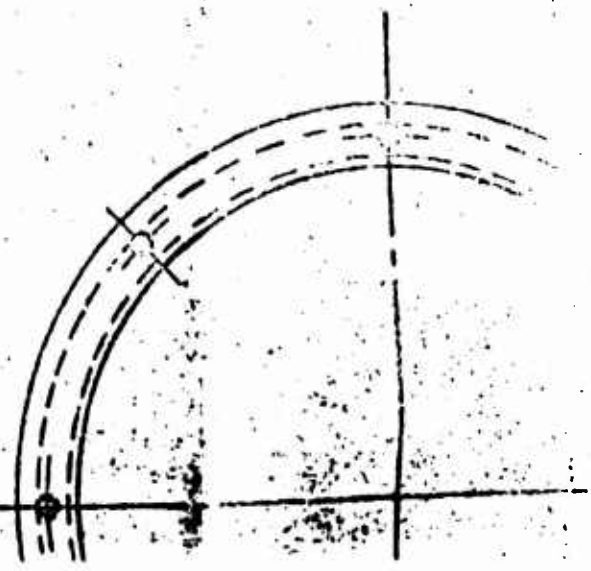


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① COVER PLATE

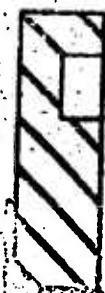


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② TOP RING, BOO RETAILERS

③ BOTTOM RING, BOO RETAINERS

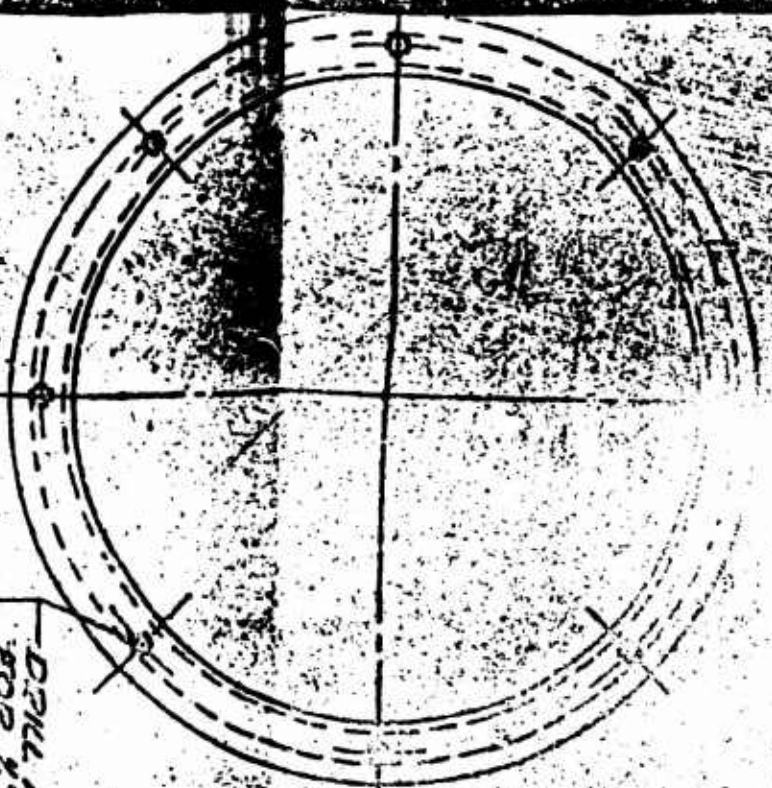


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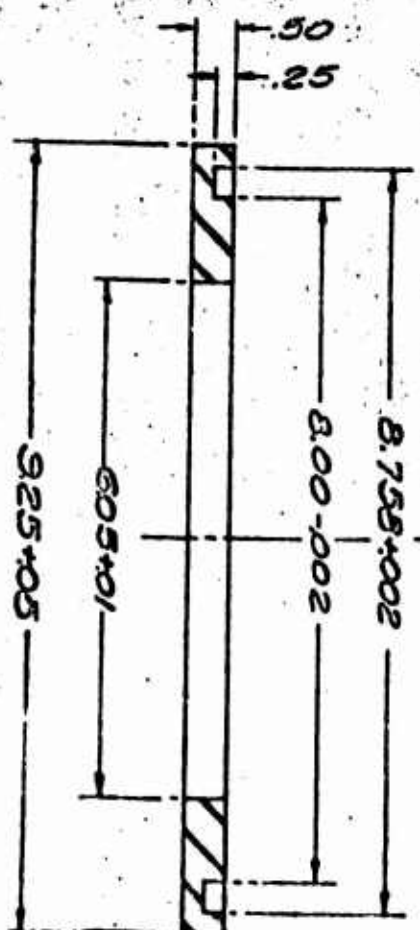
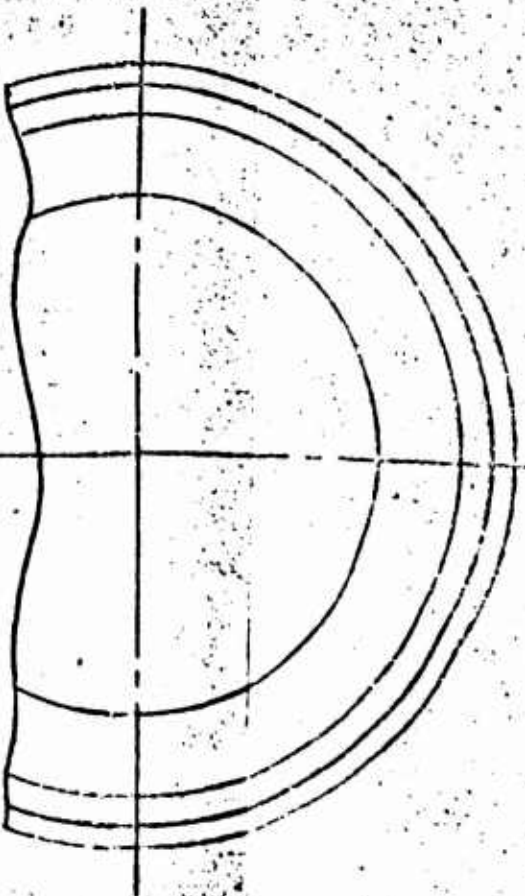
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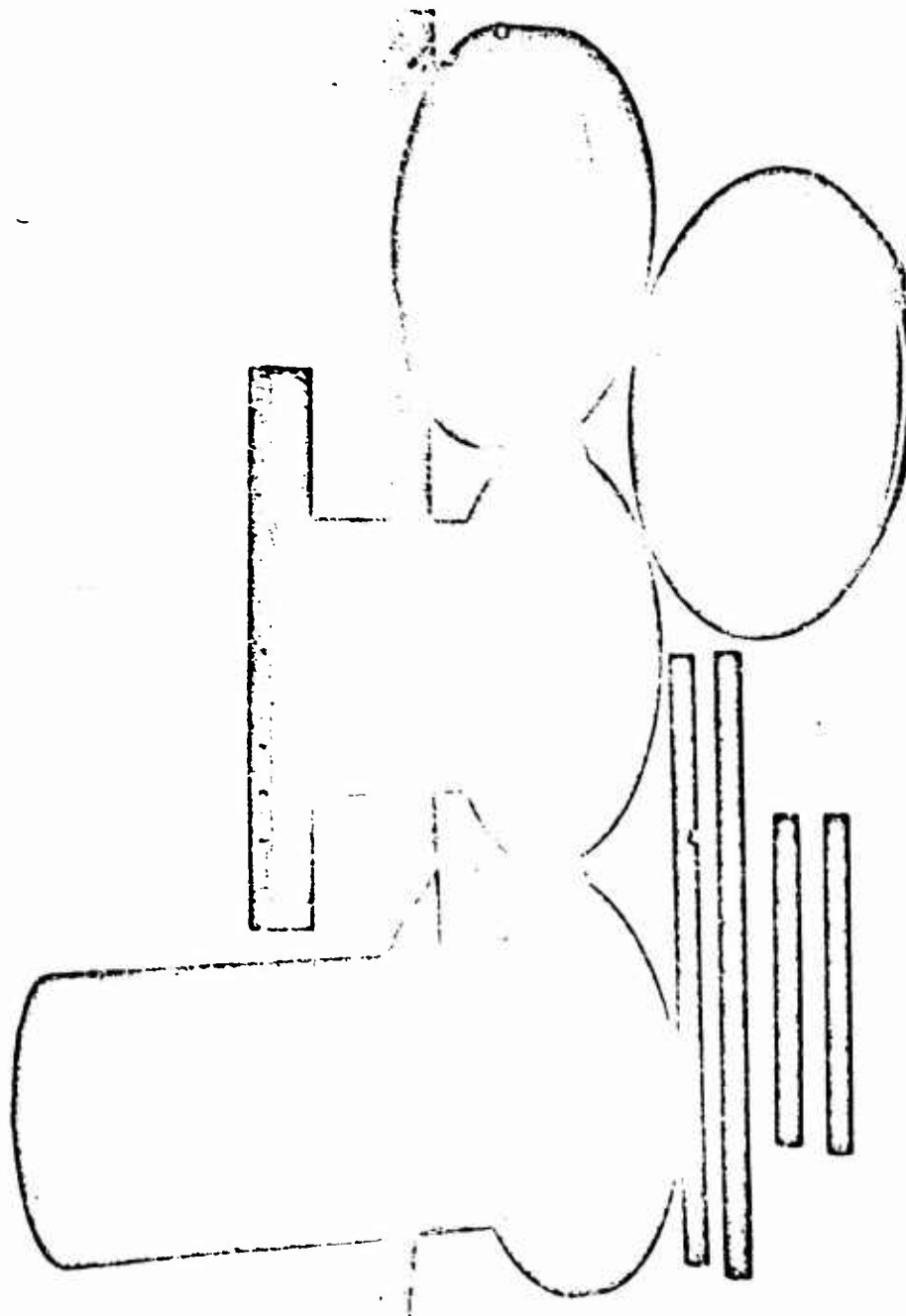


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1 May 1952

NP9-51530

Photograph of Representative Warhead Components.
Figure 2

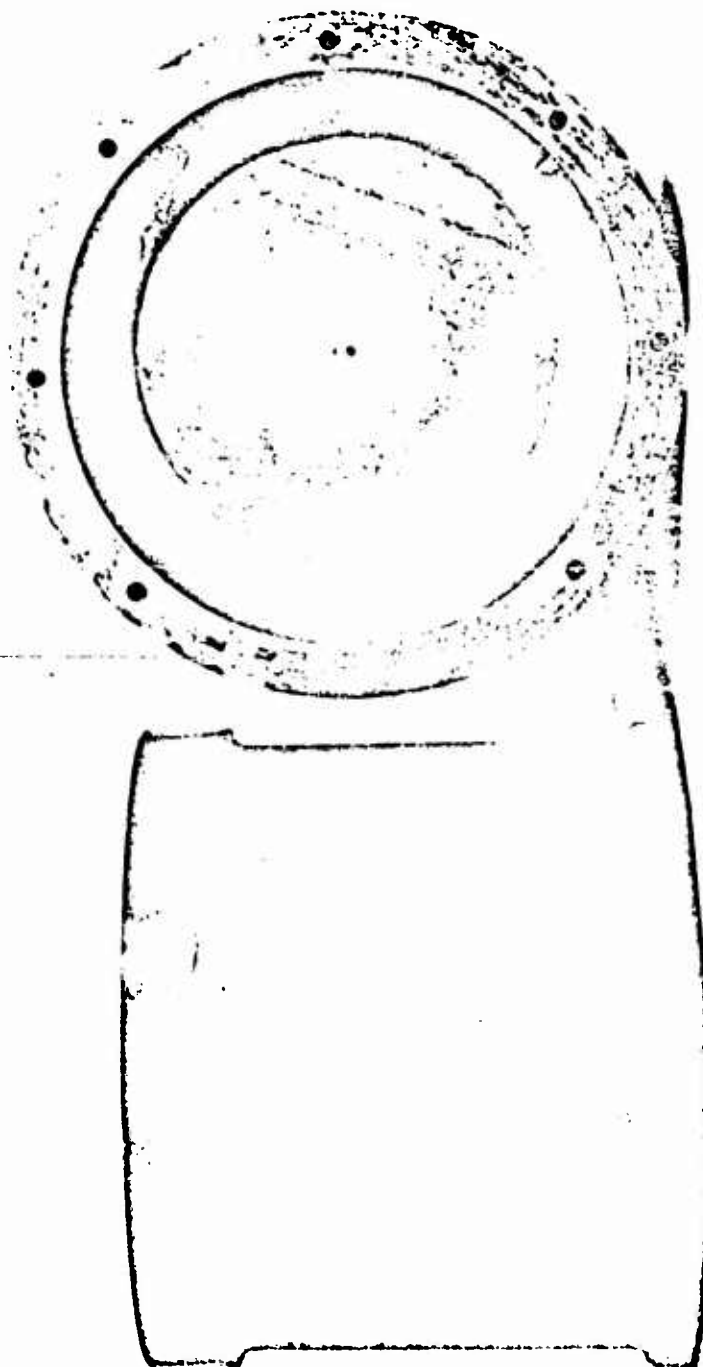


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Photograph of Assembled Warhead.
Figure 3

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Photograph of Velocity Arena. The flash plates are on the right and left sides, the cane fibre board recovery pack and the 6-1/2" warhead, in position for firing, are in the center.

Figure 4



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Photograph of Velocity Arena after firing of three 6-1/2" warheads. The first round of the 12-1/2" warheads is in position for firing.

Figure 5



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Ballistics of Rod-Like Fragments

TABLE I

FRAGMENT VELOCITY DATA

35mm Fastax Camera

4680 frames per sec.

Rd. 1, Camera 1

6-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

38

7

3700

39

14

3600

40

3

3510

41

2

3420

42

1

3340

43

3

3260

Median

3530 ft./sec.

Average

3560 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4680 frames per sec.

Rd. 1, Camera 2

6-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (f/s)

39

7

3600

40

9

3510

41

2

3420

42

2

3340

43

1

3260

44

1

3190

45

1

3120

Median

3440 f/s/sec.

Average

3470 f/s/sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fictax Camera

4670 frames per sec.

Rd. 2, Camera 1

6-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (f/s)

39

4

3596

40

11

3500

41

5

3420

42

1

3340

43

2

3260

44

1

3180

45

1

3110

Median

3420 ft./sec.

Average

3440 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4713 frames per sec.

Rd. 2, Camera 2

6-1/2" Rods

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (ft./s)</u>
39	2	3620
40	11	3540
41	9	3450
42	2	3370
43	2	3290
44	1	3210
45	2	3140
Median		3450 ft./sec.
Average		3450 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Pastax Camera

4730 frames per sec.

Rd. 4, Camera 1

12-1/2" Rods

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (f/s)</u>
37	4	3840
38	7	3730
39	9	3640
40	5	3550
41	4	3460
42	2	3380
43	2	3300
44	1	3220
Median		3510 ft./sec.
Average		3600 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4763 frames per sec.

Rd. 4, Camera 2

12-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (f/s)

37

6

3860

38

7

3760

39

5

3660

40

2

3570

41

3

3480

42

3

3400

Median

3660 ft./sec.

Average

3500 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4690 frames per sec.

Rd. 5, Camera 1

12-1/2" Rods

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (ft./sec.)</u>
37	2	3600
38	10	3700
39	11	3610
40	3	3520
41	0	--
42	2	3350
43	2	3270
Median		3620 ft./sec.
Average		3600 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4775 frames per sec.

Rd. 5, Camera 2

12-1/2" Rods

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (f/s)</u>
37	1	3870
38	9	3770
39	9	3670
40	5	3580
41	3	3490
42	3	3410
43	2	3330
44	1	3180
Median		3650 ft./sec.
Average		3610 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4789 frames per sec.

Rd. 6, Camera 1

12-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (f/s)

38

2

3780

39

11

3680

40

4

3590

41

2

3500

42

4

3420

43

3

3340

44

2

3260

Median

3560 ft./sec.

Average

3560 ft./sec.

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Ballistics of Rod-Like Fragments

TABLE I (Continued)

35mm Fastax Camera

4692 frames per sec.

Rd. 6, Camera 2

12-1/2" Rods

Frame in Which
Hit Occurred

No. Fragments

Velocity (f/s)

38

6

3700

39

9

3610

40

5

3520

41

1

3430

42

5

3350

43

3

3270

44

1

3200

Median

3510 ft./sec.

Average

3520 ft./sec.

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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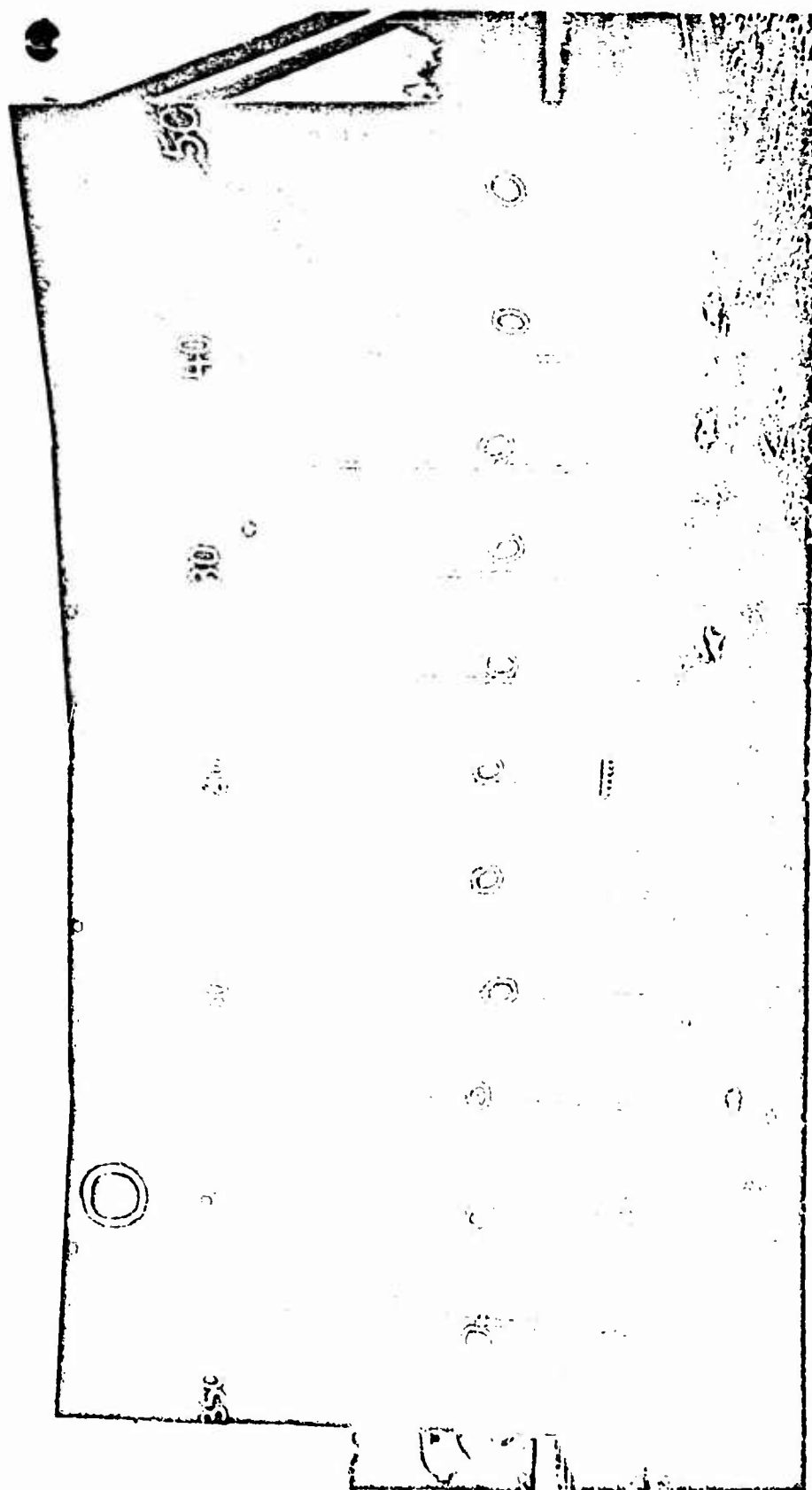
APPENDIX D

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1 May 1952

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Photograph of Left-hand Flash Plates after Round 1,
Figure 6

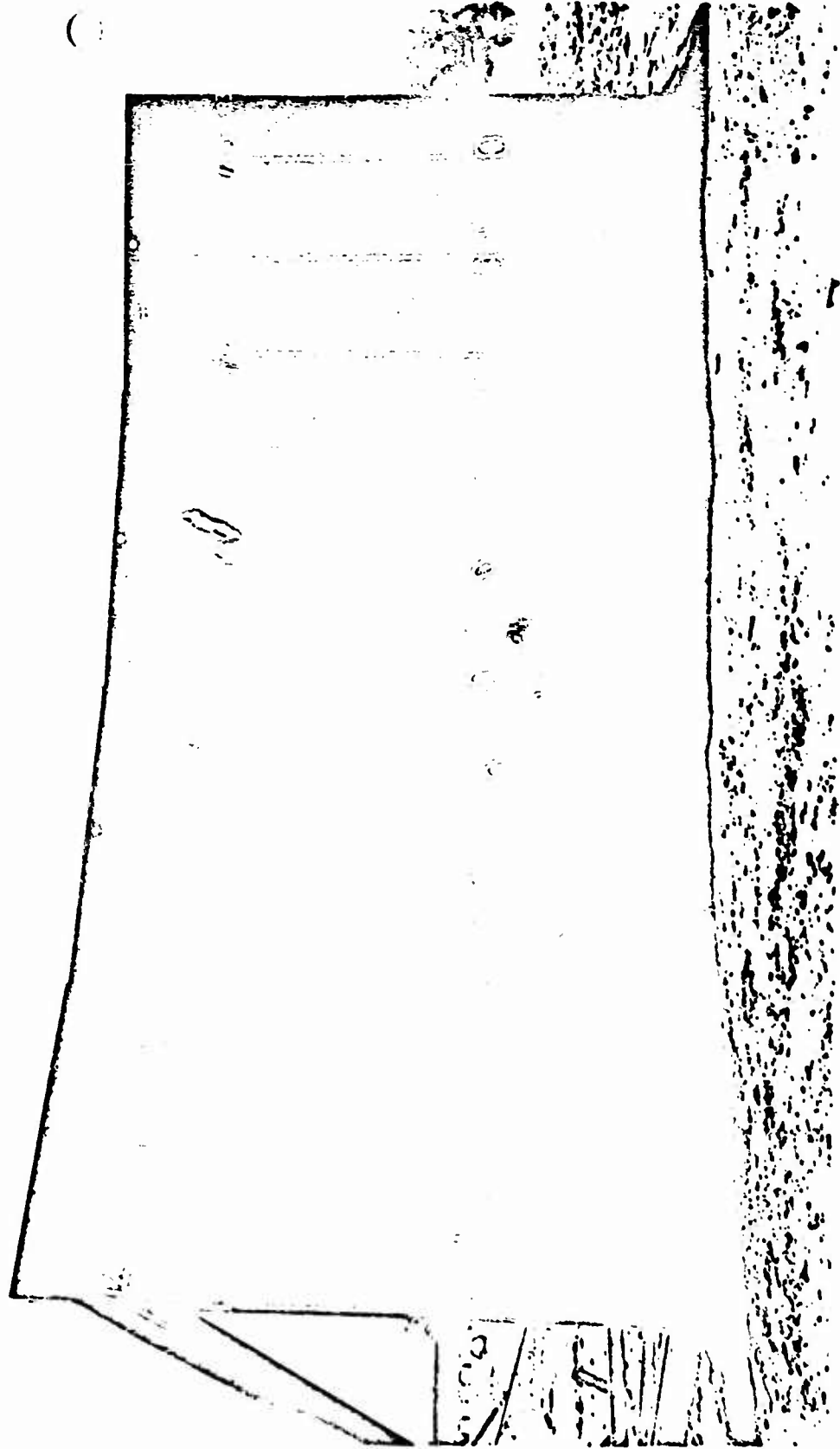


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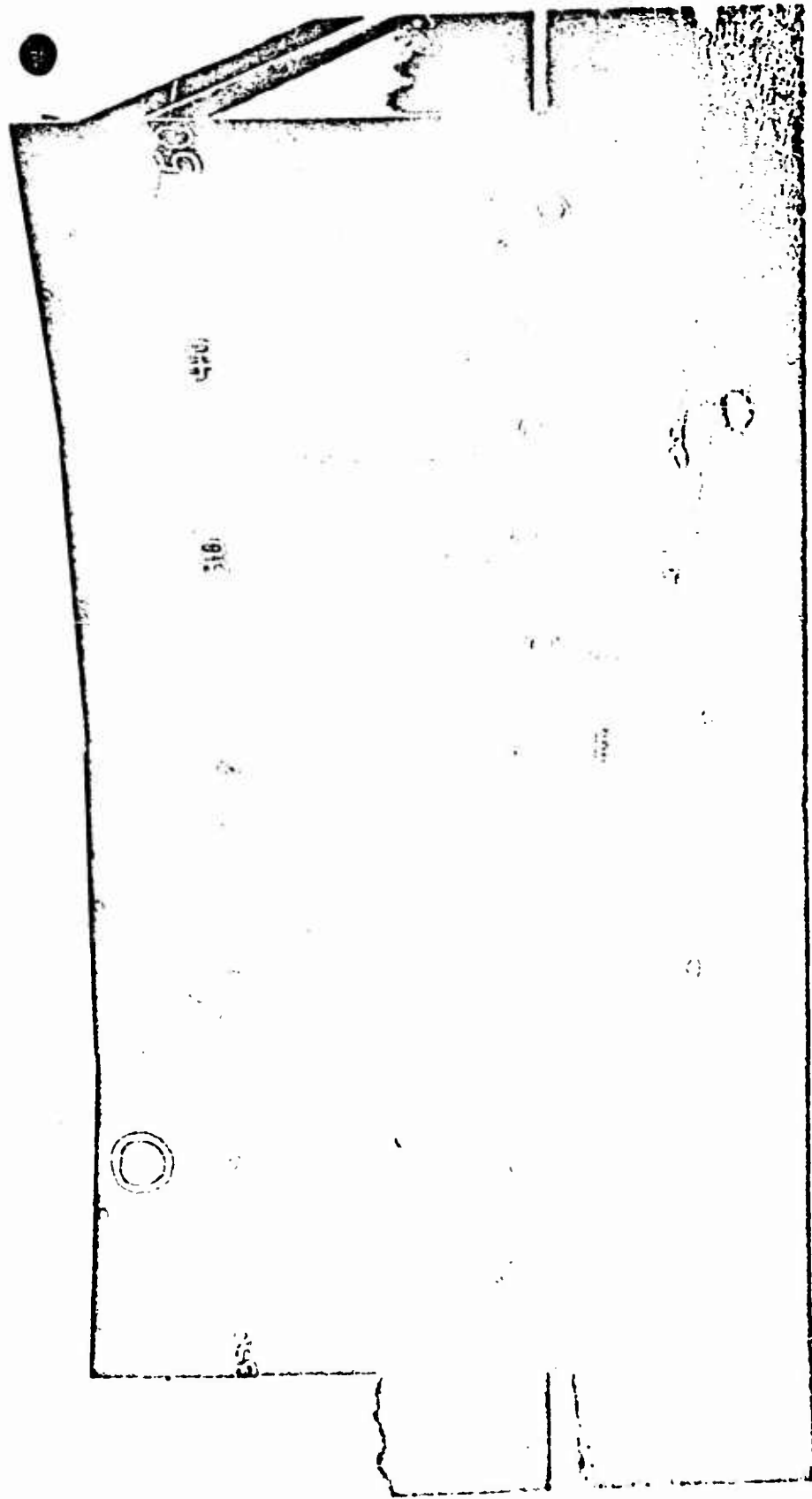
Photograph of Right-hand Flash Plates after Round 1.
Figure 7



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Photograph of Left-hand Flash Plates after Round 2.
Figure 8



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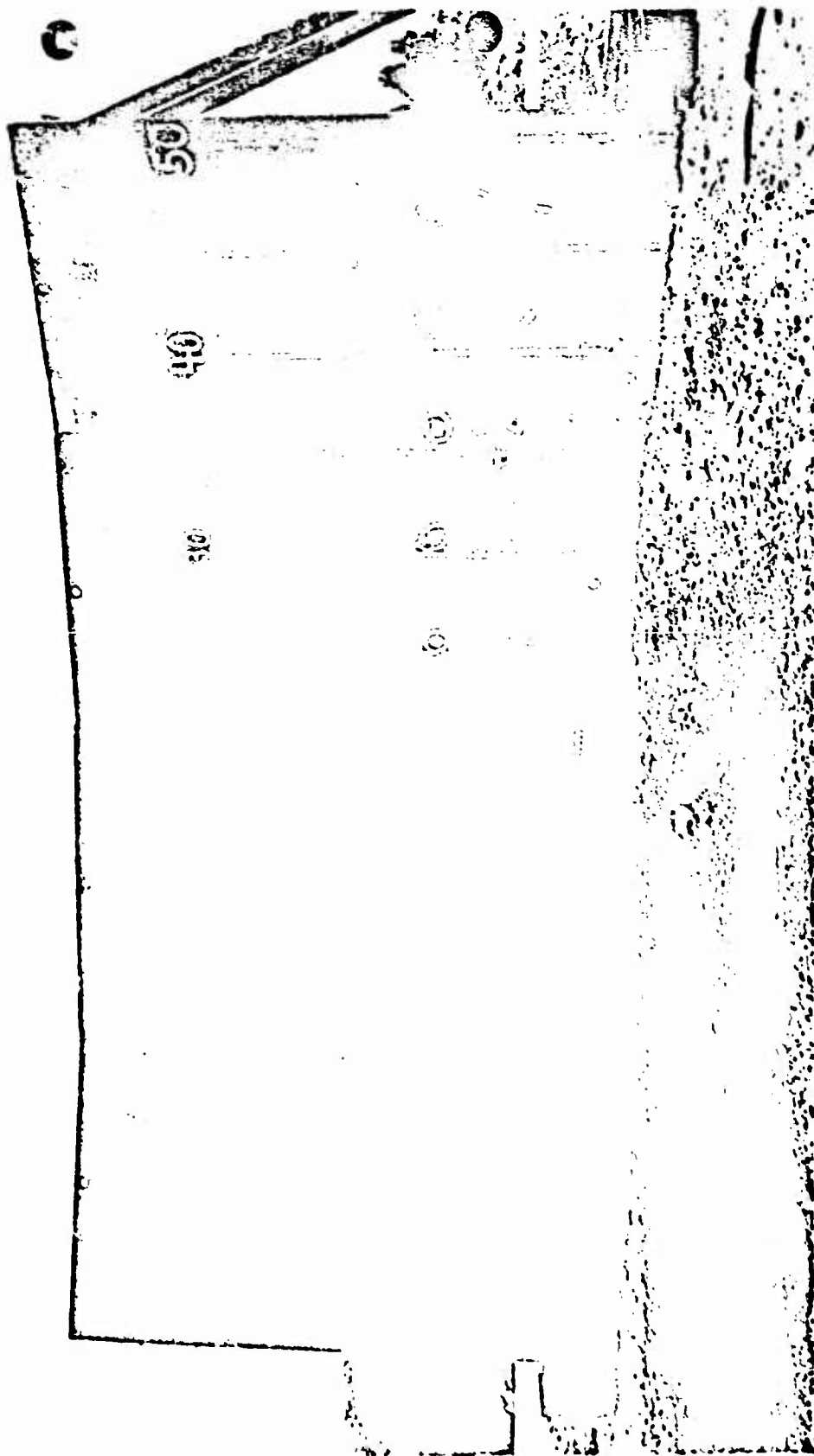
Photograph of Right-hand Flash Plates after Round 2.
Figure 9



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Photograph of Left-hand Flash Plates after Round 3.
Figure 10

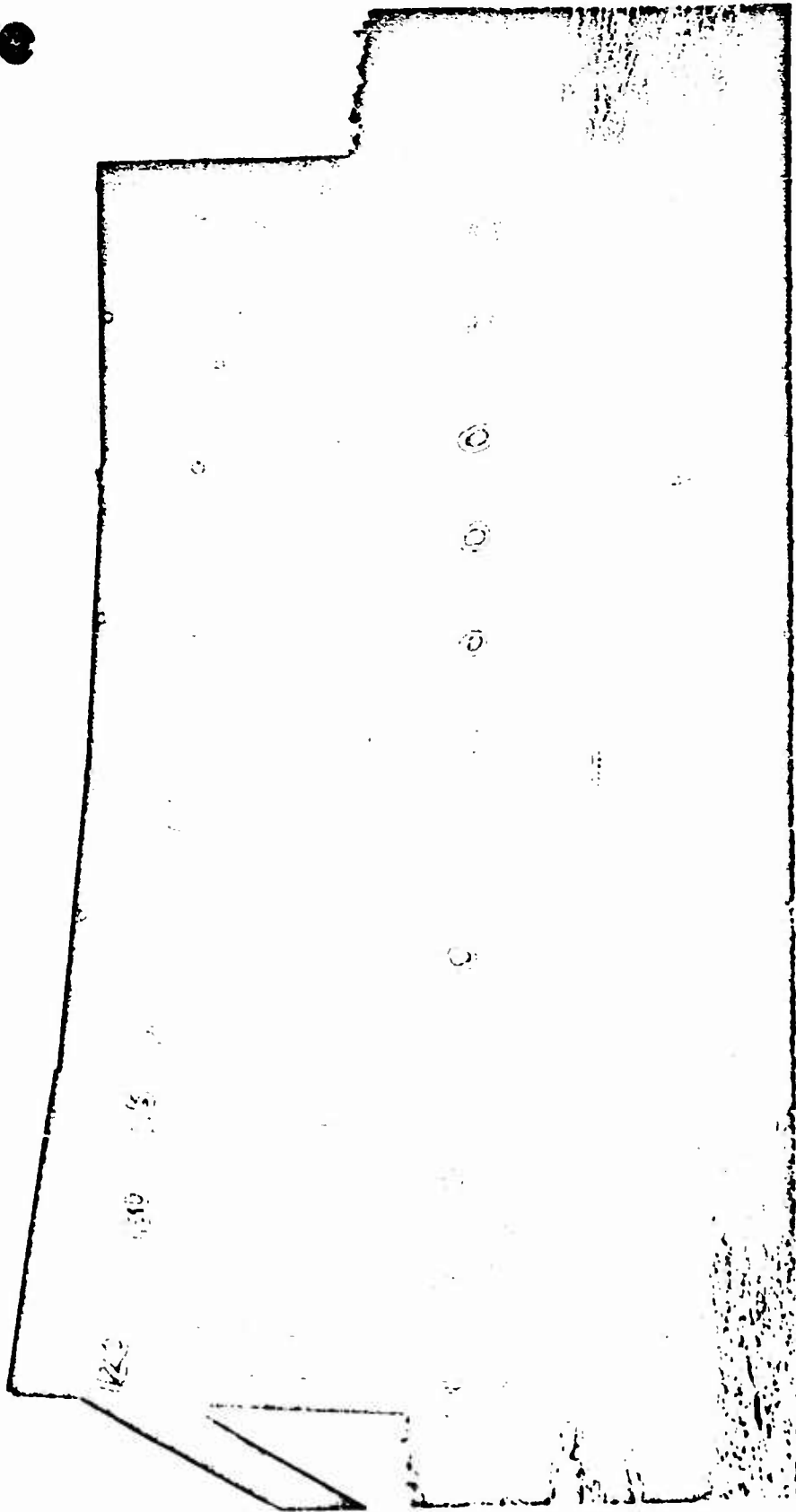


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Photograph of Right-hand Flash Plates after Round 3.
Figure 11

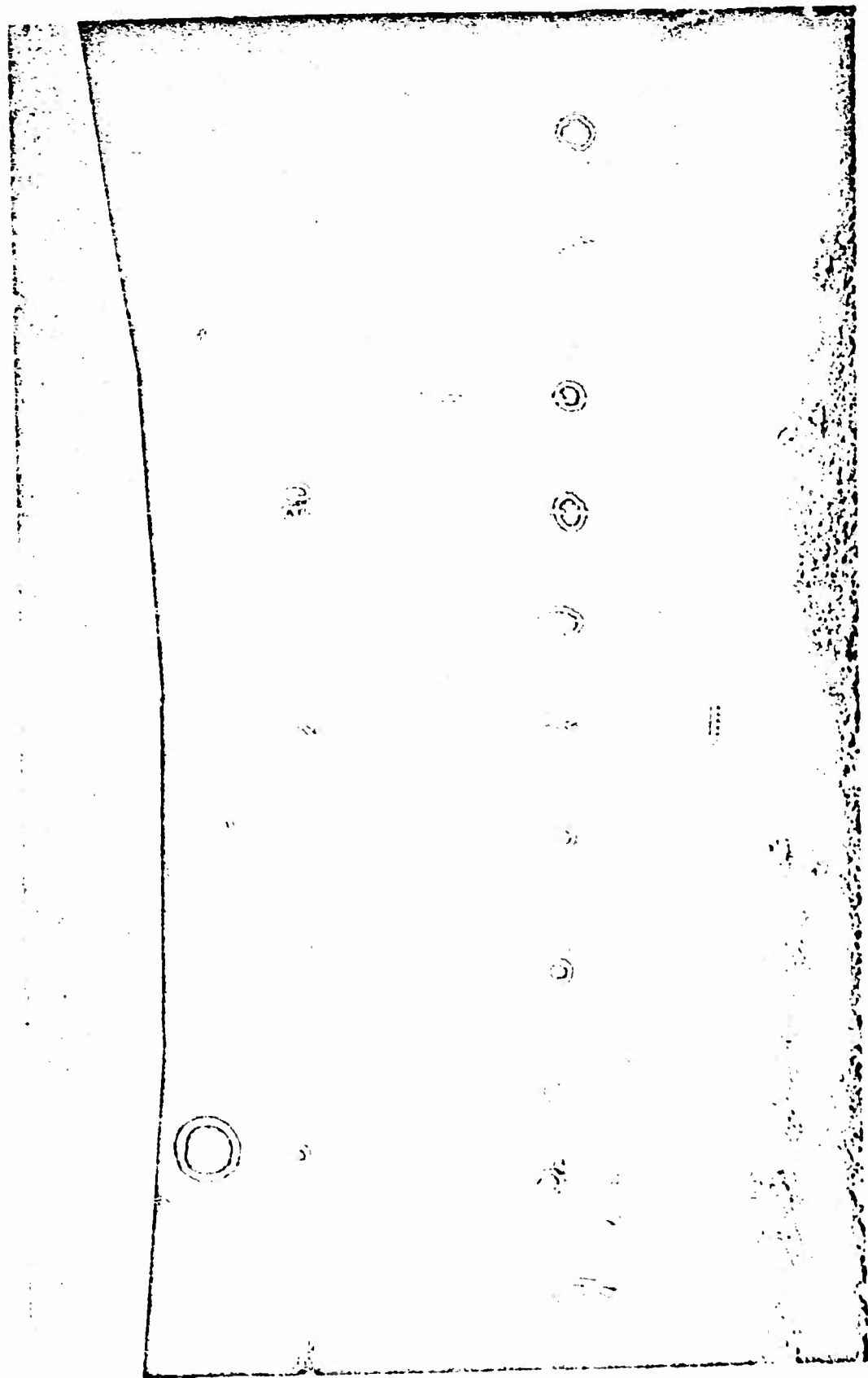


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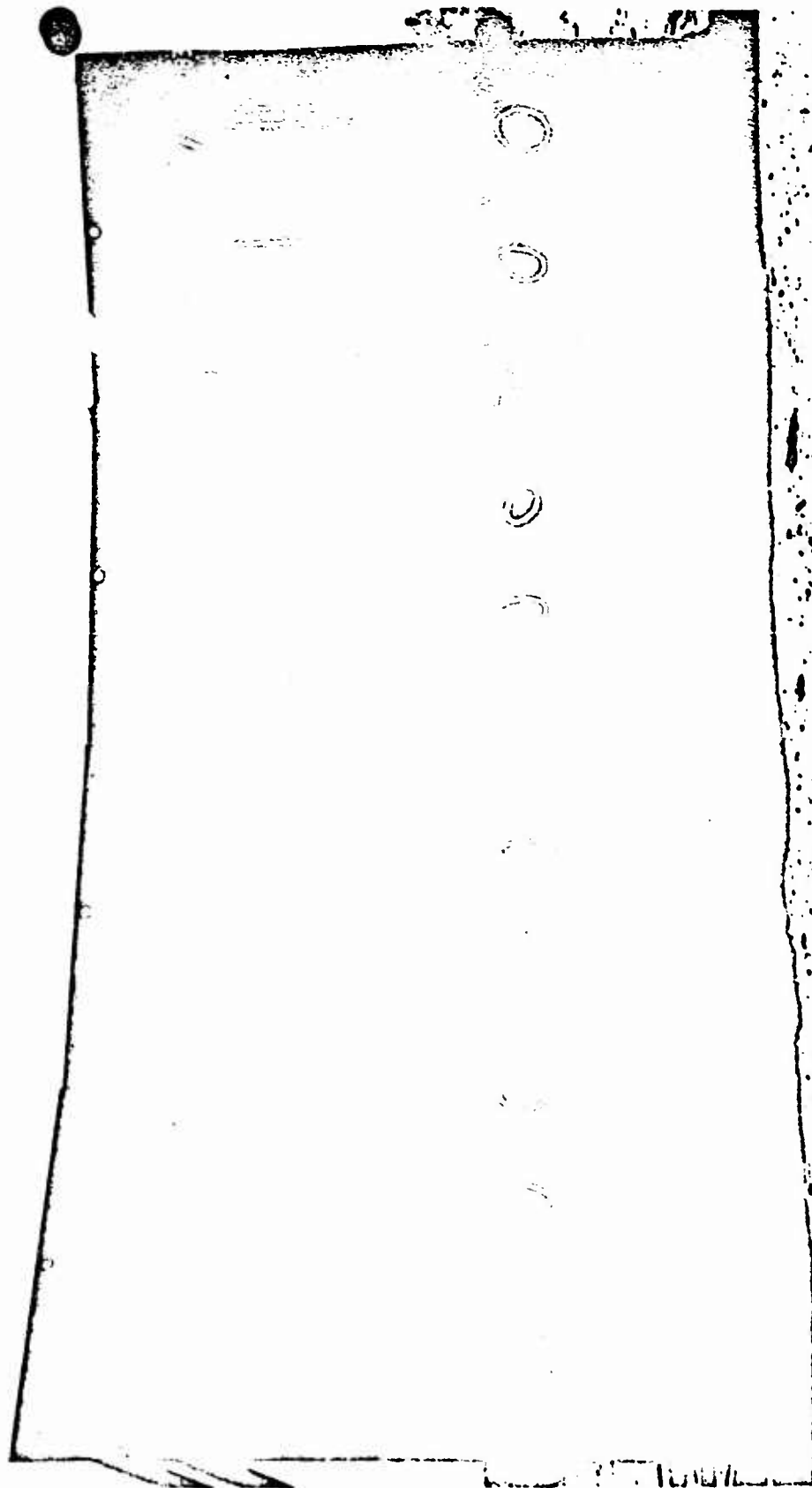
Photograph of Left-hand Flash Plates after Round 4.
Figure 12



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Photograph of Right-hand Flash Plate after Round 4.
Figure 13

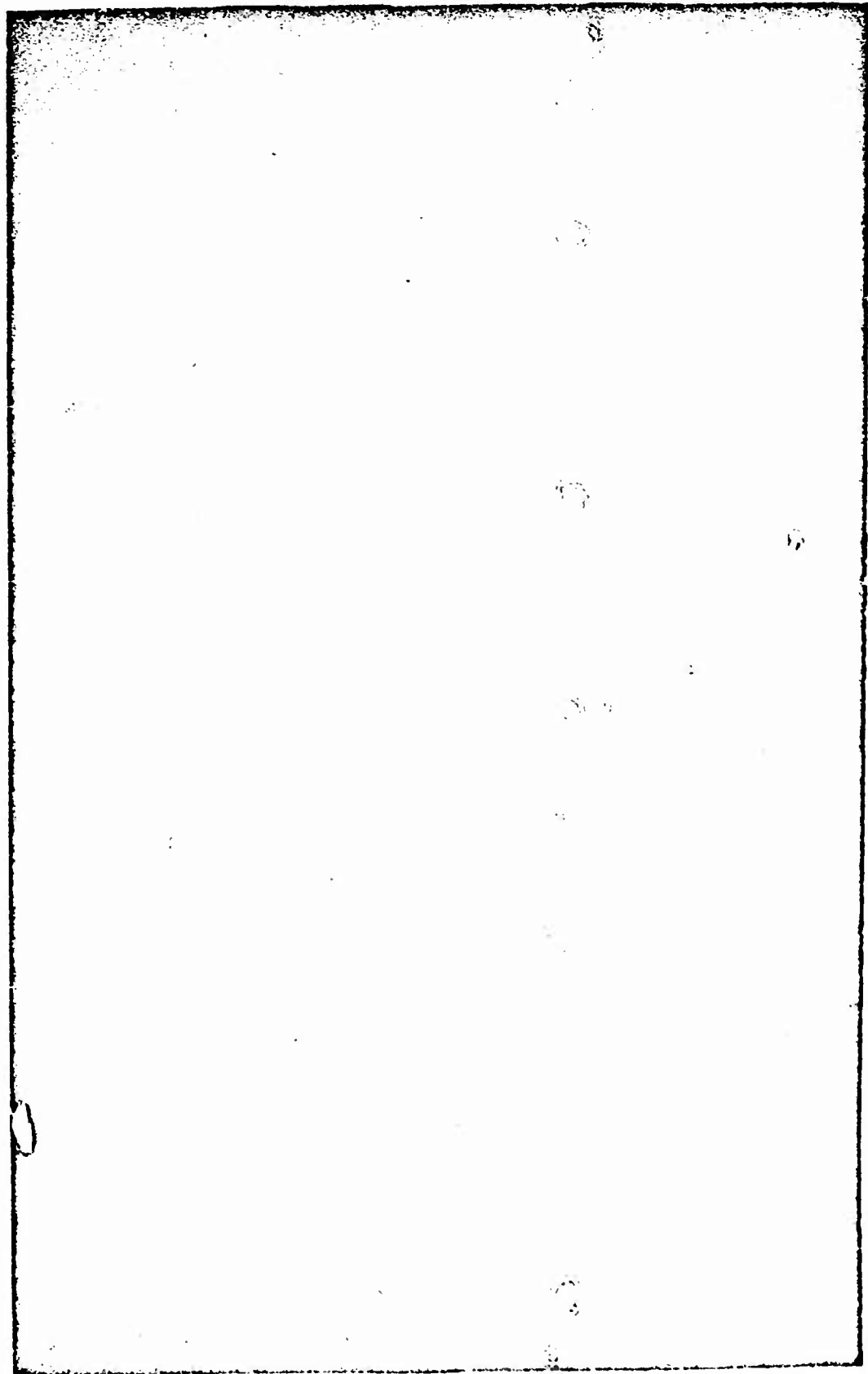


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Photograph of Left-hand Flash Plate after Round 5.
Figure 14

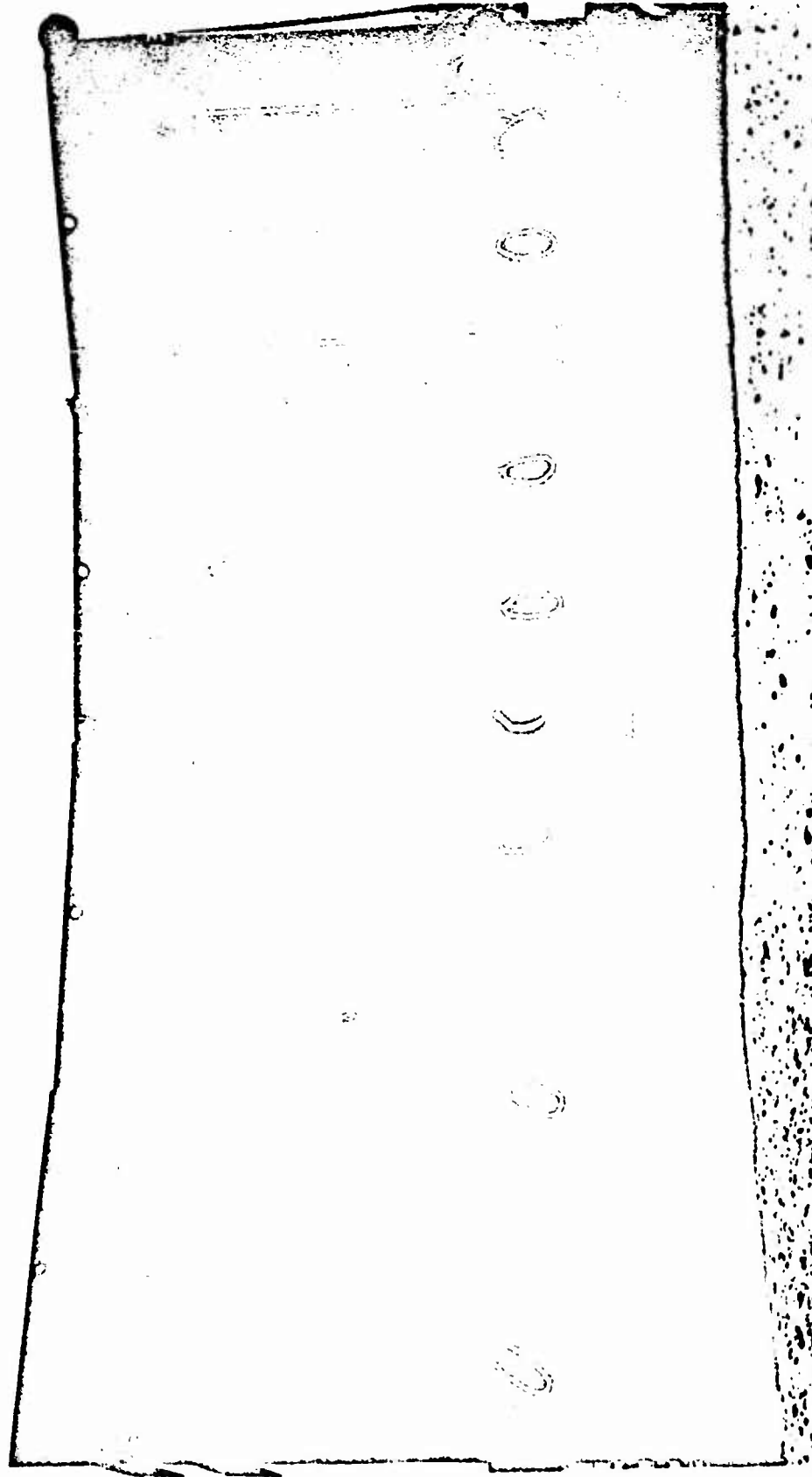


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Photograph of Right-hand Flash Plate after Round 5.
Figure 15

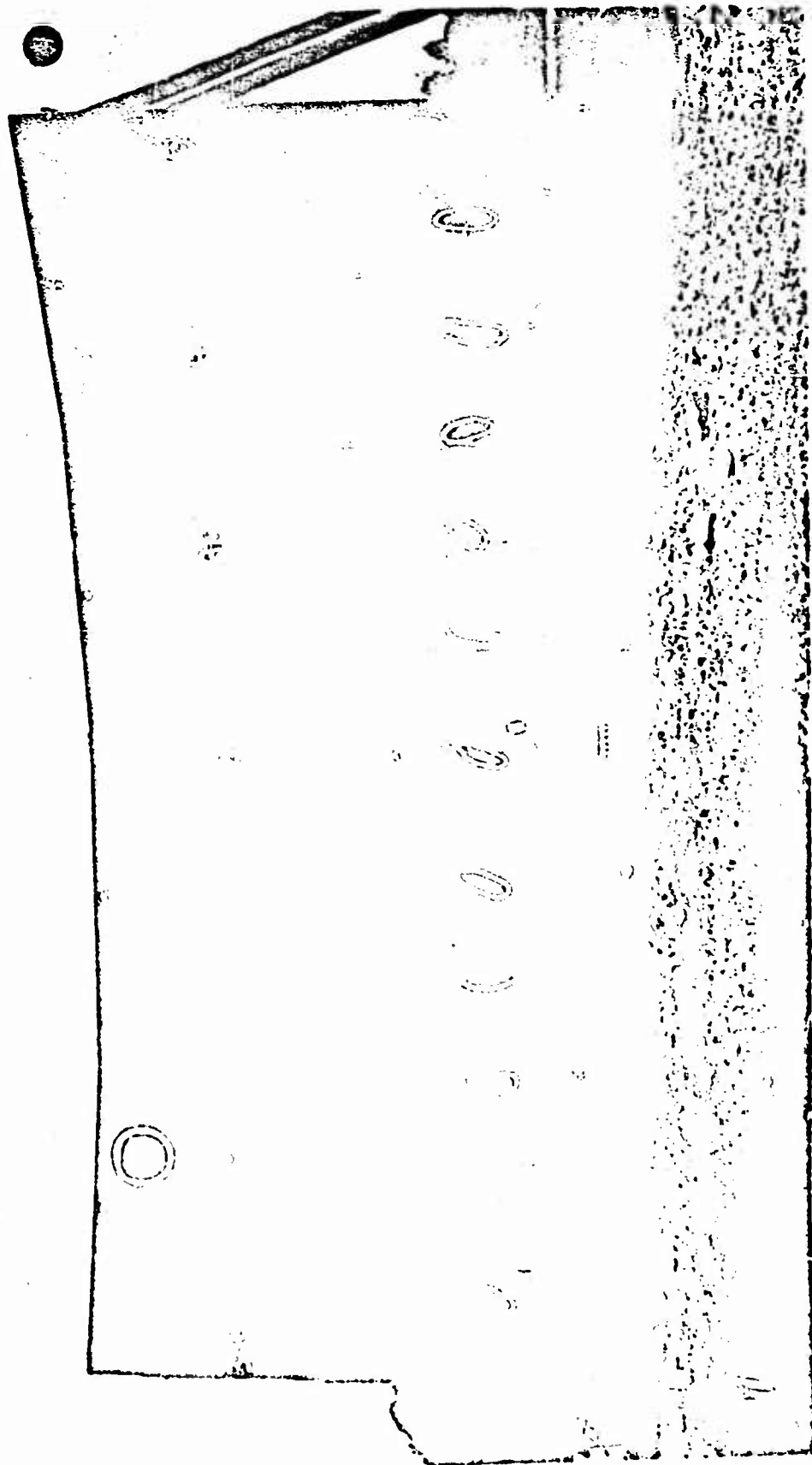


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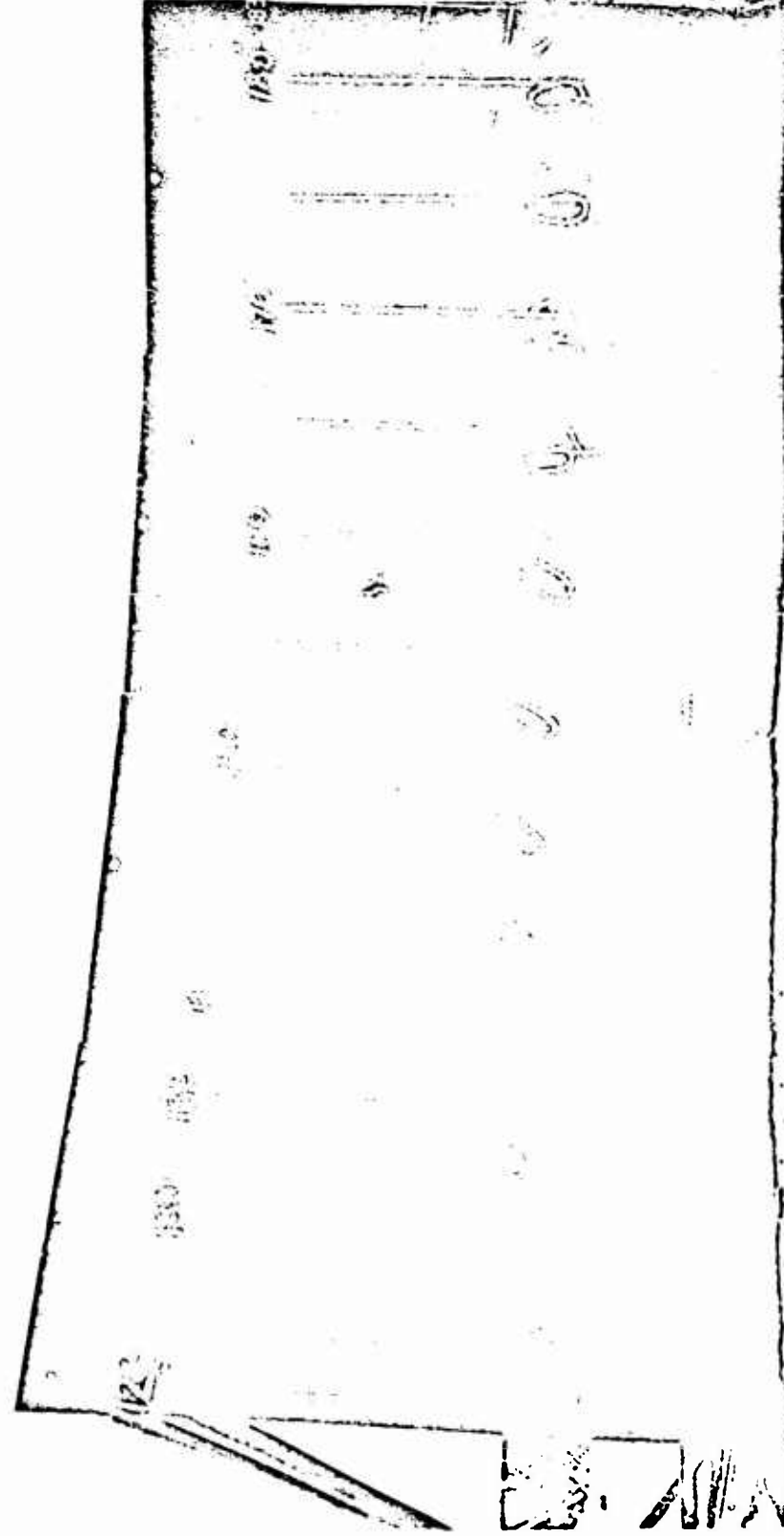
Photograph of Left-hand Flash Plate after Round 6.
Figure 16



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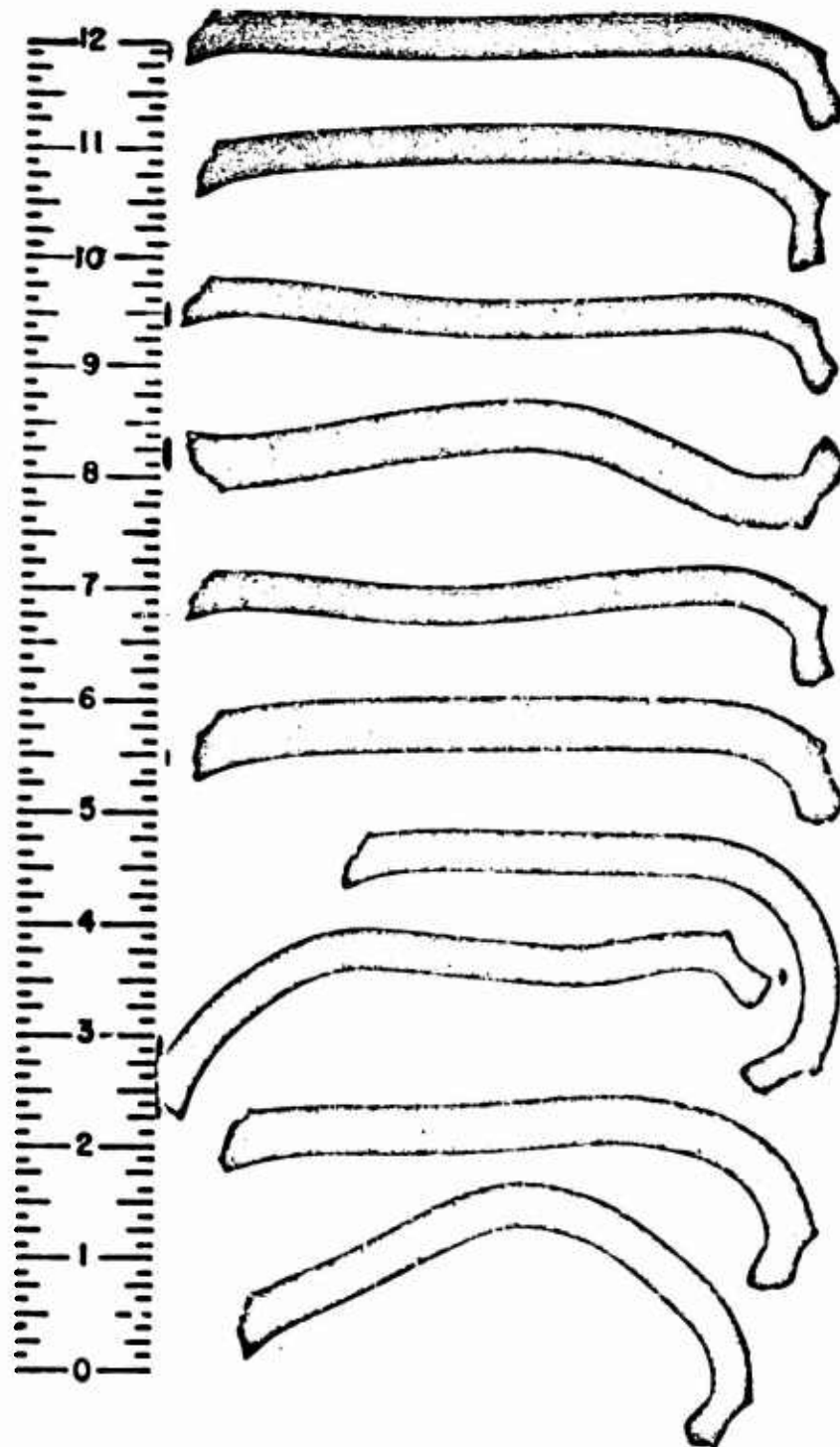
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Photograph of Right-hand Finish Plate after Round 6.
Figure 17



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Photograph of Rods Recovered in Fibre Board from Hounds 1, 2, and 3.
Figure 18



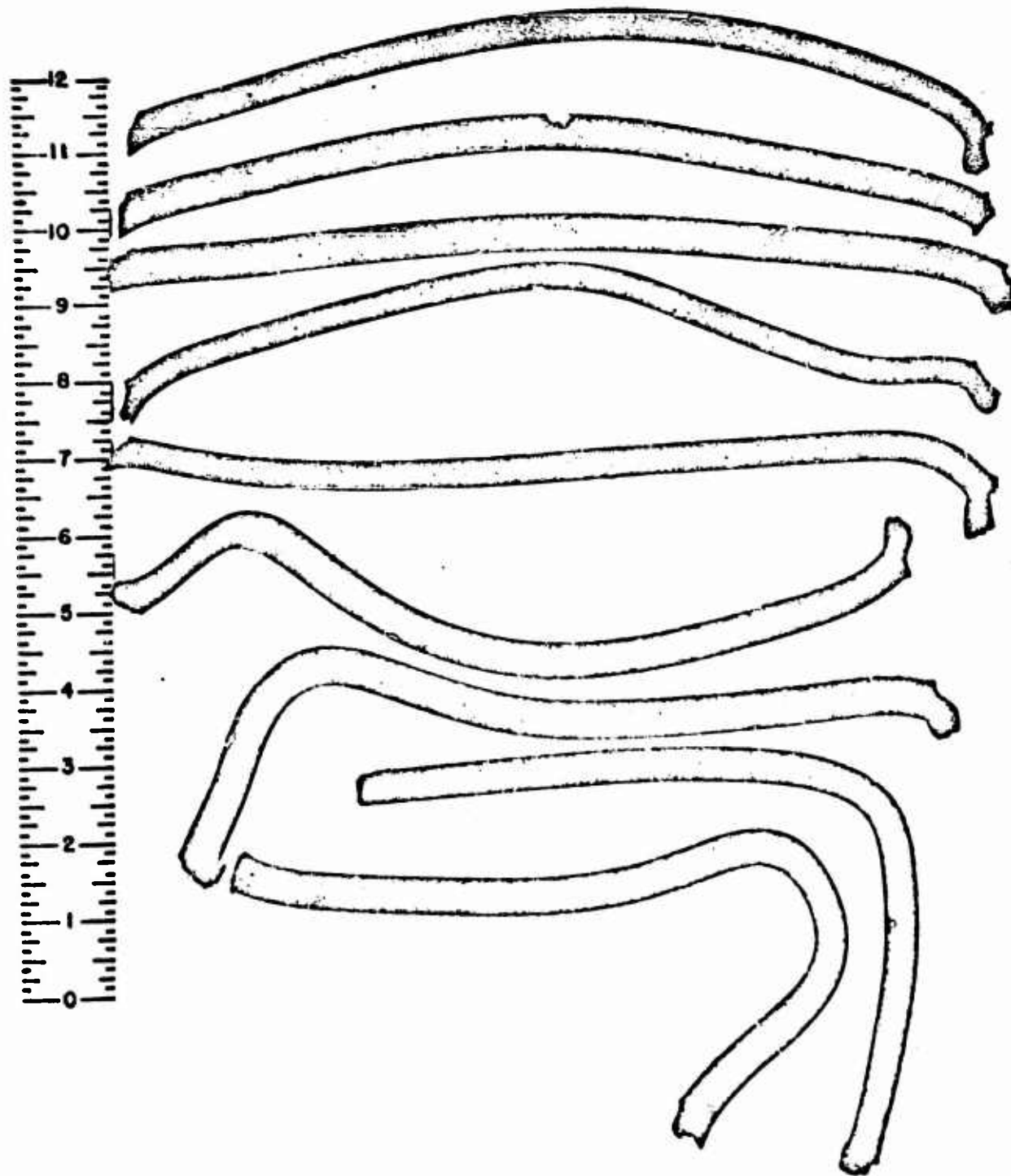
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Photograph of Rods Recovered in Fibre Board from Rounds 4, 5, and 6.

Figure 19



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Ballistics of Rod-Like Fragments

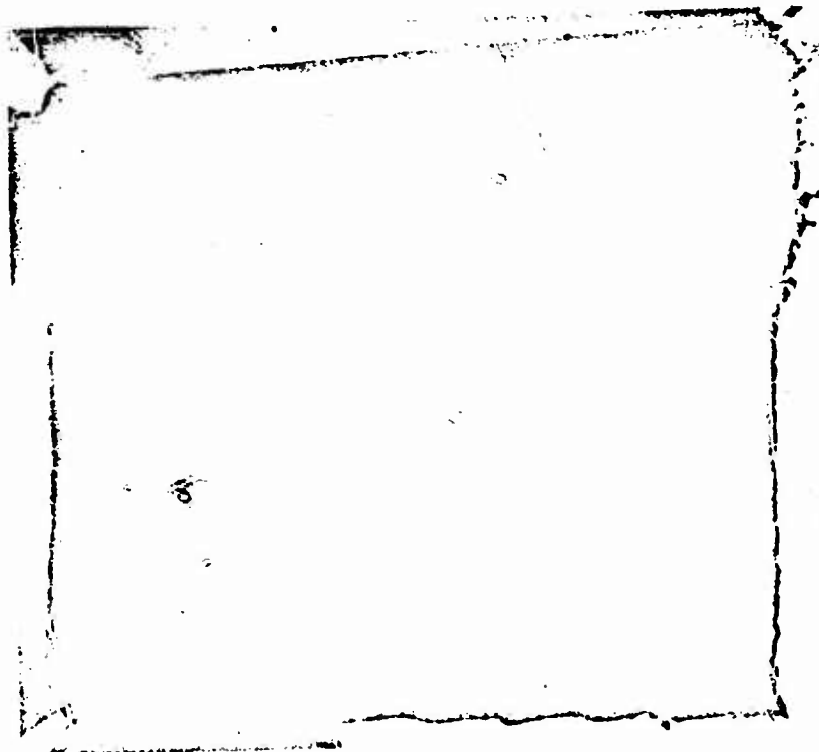
TABLE III

HARDNESS VS. DISTANCE ACROSS ROD CROSS SECTION

Distance from Explosive Face (mm)	Specimen No. C-736 1 Kg. Load, 10.25mm Objective			
	R-1	R-2	P.V.	Knoop Hardness
0.10	868	407	461	320
0.20	855	406	449	336
0.30	850	394	456	326
0.40	865	416	449	336
0.50	865	417	448	338
0.75	872	420	452	332
1.00	873	403	470	308
1.25	870	405	465	314
1.50	865	400	465	314
1.75	865	403	462	317
2.00	865	404	461	320
2.25	871	402	469	308
2.50	876	396	480	294
2.75	878	396	482	291
3.00	872	398	474	302
3.25	877	388	489	284
3.50	868	390	478	297
3.75	876	388	488	286
4.00	869	383	486	289
4.25	868	385	483	291
4.50	867	385	482	291
4.75	870	390	480	294
5.00	869	389	480	291
5.25	863	384	479	297
5.50	661	389	472	305
5.75	864	386	478	297
6.00	855	388	467	311
6.25	866	387	479	297
6.50	866	383	483	291
6.75	875	373	502	269
7.00	907	347	560	216
7.25	910	344	566	211
7.50	906	347	559	217
7.75	895	347	548	226
8.00	892	348	544	229
8.25	887	347	540	232
8.50	886	345	541	231
8.75	900	318	582	190
8.83	Edge of Specimen			

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APPENDIX F



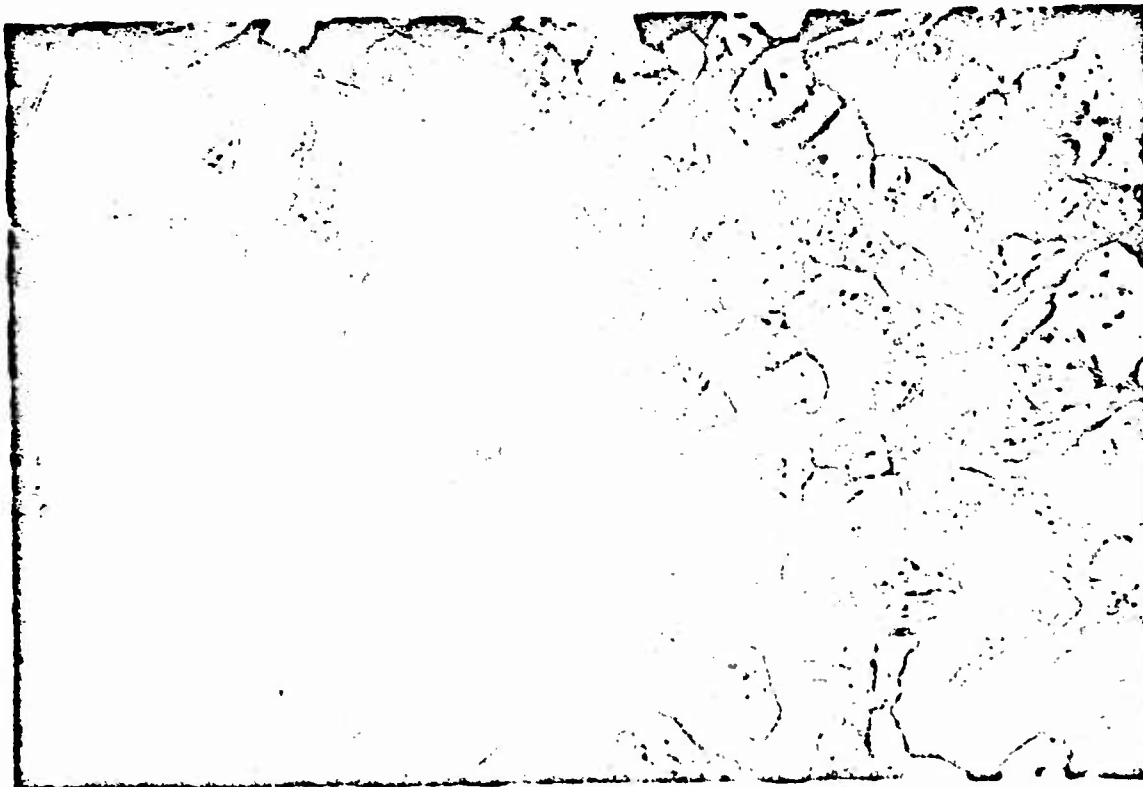
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Photomicrograph of cross-section of rod after firing. Explosive face is at the left. Dark band at the right is the soft region. (Nital-picral etch, 15X).

Figure 20



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1 December 1952

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Photomicrograph of severely worked portion of rod (left-hand side of Figure 20) showing considerable effects of cold working. The dark grains are pearlite, the light grains ferrite (Nital etch, 1000X).

Figure 21



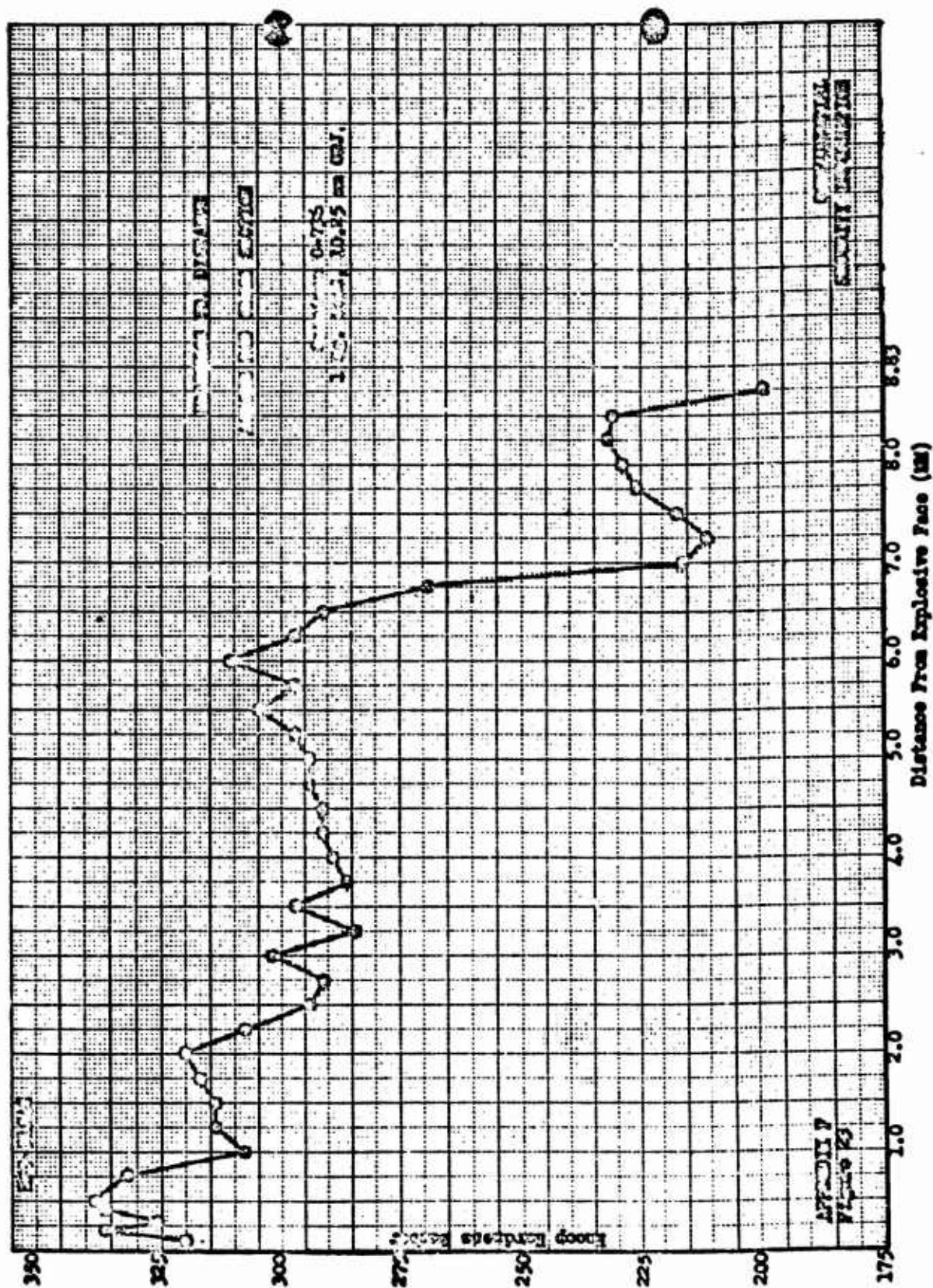
NP9-51550

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Photomicrograph of softer portion of rod (right-hand side of Figure 20) showing some twinning and indicating moderate cold working. (Nital etch, 1000X).

Figure 22



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Ballistics of Rod-Like Fragments

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