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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 1106

WARHEAD CHARACTERISTICS

13th Partial Report

- -

TERMINAL BALLISTICS OF ROD LIKE FRAGMENTS

2nd Partial Report

Task Assignment NPG-Re3d-442-1-53

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Terminal Ballistics of Rod Like Fragments

PART A

SYNOPSIS

During the period of this report the technique of projecting single rods was improved, resulting in velocities up to 3000 feet per second. The trajectories were predictable, so that rods could be made to impact on simple targets with the desired orientation, and the points of impact on the rod and the target could be chosen as desired.

A preliminary investigation of notched rods, wherein the notches were formed by cold swaging, indicated that the rods broke at the notches into design lengths.

In the firing of rods against simple targets, preliminary terminal ballistics data were obtained for rods of AISI C-1020 steel. To summarize this information, the results were as follows:

a. 1/2" x 1/2" x 15" rods, when fired broadside at approximately 2000 feet/second to impact against the 1-1/2" face of 24S-T4 aluminum targets, broke targets of 3-1/2" depth but not 4-1/2".

b. 1/2" x 1/2" rods of 4", 8", and 15" lengths, at approximately 2000 feet/second, broke 2" diameter round bars of 24S-T4 aluminum but not 3".

c. 1/2" x 1/2" x 8" rods at approximately 3000 feet/second, broke 3" diameter round bars of 24S-T4 aluminum.

d. 1/2" x 1/2" x 15" rods impacting against the face of 3/4" 24S-T4 aluminum plates gave complete penetrations at velocities above 1740 feet/second.

e. 1/2" x 1/2" x 4" rods penetrated 3/8" mild steel plate, face on, at velocities of 2350 feet/second and higher.

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PART B

INTRODUCTION

1. AUTHORITY:

The tests reported upon were authorized and conducted under references (a), (b), and (c).

2. REFERENCES:

a. BUORD ltr NP9-Re3d-AH:bc of 22 December 1950
b. BUORD Conf ltr NP9-Re3d-WBK:hm Ser 23908 of 4 August 1951
c. BUORD Conf ltr NP9-Re3d-AH:bc Ser 20414 of 10 May 1951
d. BUORD Conf ltr NP9-Re3d-AH:bc Ser 42653 of 29 July 1952
e. NPG Report No. 953 of 16 April 1952

3. BACKGROUND:

a. The work covered by this report is a continuation of that reported upon in reference (e) and supplies further information for the warhead development program as requested by references (a), (b), and (c).

b. Reference (c) extended reference (a) by specifically requesting that investigations continue for the purpose of developing methods for projecting rods at higher reproducible velocities. In addition, the terminal ballistics of rods against simple targets were to be determined for the range of velocities available.

c. With regard to these requirements, the tests performed aimed at the use and the further development of the existing rod projecting methods, in order that higher velocity rods might be obtained, and in order that terminal ballistics data might be determined as functions of various parameters.

4. PERIOD OF TEST:

This report covers the period from April 1951 to October 1951.

PART C

DETAILS OF TEST

5. PROCEDURE AND RESULTS:

Several approaches to the problem of attaining higher rod velocities were explored. The velocities obtained to this time were lower than would be expected from the energy of detonation of the explosive charges used, and it was believed that there was insufficient confinement of the explosive charge.

Confinement by additional explosive was attempted. If the 1/2" x 1-1/2" charge (Figure 1 (a)) was enlarged to 1" x 1-1/2" the additional explosive would be expected to act as confinement of the original charge. Explosive columns of 1" x 1-1/2" x 12" were tried, with two (2) 1/2" x 1/2" x 7" rods. Resulting velocities were erratic in the range above 2000 feet/second. Using the same explosive column with one (1) 1/2" x 1/2" x 7" rod between two (2) 1/4" x 1/2" x 7" spacer rods gave better results, with velocities of the center rod of approximately 2400 feet/second (Figure 1 (b)).

Explosive columns 1-1/2" x 1-1/2" x 9" were used to project three (3) 1/2" x 1/2" x 8" rods. The first results were somewhat erratic, and the results were confused by breaking and tumbling of the two (2) outer rods. These spacer rods were welded into place in the gun and the performance improved, with velocity of the projected rod being approximately 2500 feet/second.

The effect of additional confinement of the explosive column by the use of heavy steel blocks was investigated. Explosive columns 1/2" x 1-1/2" x 20" were positioned vertically, and surrounded by the heavy steel blocks. Velocities were not consistent, and the rods tumbled excessively (Figure 1 (c)). The same arrangement, but with the longitudinal axis of the gun in the horizontal plane, was tried. This resulted in satisfactory rod flight, but with little increase in velocity over the same configuration unconfined.

The use of a larger explosive column plus heavy steel confining blocks was investigated. The design shown in Figure 1 (b) was employed, using a 1" x 1-1/2" x 8" explosive column, and projecting a 1/2" x 1/2" x 8" rod. The explosive was center initiated by a cap placed thru an opening in the back of the channel, thru the confining blocks. The velocities obtained varied from 2600 to 3100 feet/second with this configuration, and the projected rods were curved or badly bent at the centers.

Finally it appeared desirable to enlarge the explosive column to 1-1/2" x 1-1/2" square cross section, and to increase the length to 9" to form a 1" long booster charge for end initiation. The two (2) 1/2" x 1/2" spacer rods were welded to the channel lips, leaving a 1/2" space for the rod to be projected. This configuration projected the rod with good flight characteristics, at velocities of approximately 2500 feet/second without heavy confinement, and 3000 feet/second with heavy steel confinement. This has been the gun used in all subsequent firings at approximately 3000 feet/second.

In addition to the center initiation mentioned previously, other points of initiation were tried. One (1) such method was the placing of four (4) caps along the length of the explosive column and initiating these simultaneously with a high-voltage pulse. An attempt to obtain a plane initiating wave was also tried by making an equilateral triangular array of explosive trains, initiated at one (1) point, arranged to contact the back surface of the explosive column at several points (Figure 1 (d)). Such innovations did not improve upon the existing methods, and in some cases the rods fragmented, or broke, and the rod velocities were lower.

The effect of rod length on velocity was cursorily examined. The 4" and 8" rods were projected satisfactorily by the standard 2000 feet/second gun (1/2" x 1-1/2" x 20" explosive column), but the velocities obtained were consistently higher than those obtained with the 15" rods.

A series of firings was conducted to obtain information concerning the controlled break-up of rods. The rods were 3/8" square, with or without notches along one (1) face, and 8" and 12" long. They were projected from a gun corresponding to the 2000 feet/second standard configuration, but with a more narrow opening. The notches were toward the explosive column, and in some cases the notches themselves were also filled with explosive. Both end and center

initiation of the explosive column were tried. Break-up of the rods was determined by the use of cardboard screens placed in the line of flight, and by investigation of recovered rods. The rods broke at the notches in each case. Velocities of the rod sections varied from 2000 to 2300 feet/second, indicating that the break-up mechanism had an effect upon the velocity of projection.

A few rounds were fired to determine the suitability of the standard configuration for projecting 5/8" x 5/8" x 4" rods. The explosive column was 1-1/2" wide and 1-3/8" deep. The 5/8" rod was fitted into the channel with spacer rods on either side. Velocities were approximately 2000 feet/second and overall performance was similar to the 1/2" wide, 2000 feet/second rod gun.

Most of the guns described were used in damage tests against targets. Targets were of aluminum plate, aluminum round stock, and steel plate. For these tests the plates or bars were positioned at a given distance from the rod gun and were held vertically by bracing at the lower end. Then the rod gun was so aligned that the rod would strike the target with the required orientation. Flight and velocity of rods were checked as necessary by using screens, as described in reference (c). Recovery of rod fragments beyond the target was effected by means of a stack of fiberboard sheets. Figure 2 indicates schematically the components of this set-up. The shield indicated is used when it is desired to stop the fragments of the outer, or spacer, rods.

PART D

CONCLUSIONS

6. During the period of this report the technique of projecting single rods was improved, resulting in velocities up to 3000 feet per second. The trajectories were predictable, so that rods could be made to impact on simple targets with the desired orientation, and the points of impact on the rod and the target could be chosen as desired.

A preliminary investigation of notched rods, wherein the notches were formed by cold swaging, indicated that the rods broke at the notches, into design lengths.

Terminal Ballistics of Rod Like Fragments

In the firing of rods against simple targets, preliminary terminal ballistics data were obtained for rods of AISI C-1020 steel. To summarize this information, the results were as follows:

a. 1/2" x 1/2" x 15" rods, when fired broadside at approximately 2000 feet/second to impact against the 1-1/2" face of 24S-T4 aluminum targets broke targets of 3-1/2" depth but not 4-1/2".

b. 1/2" x 1/2" rods of 4", 8", and 15" lengths at approximately 2000 feet/second broke 2" diameter round bars of 24S-T4 aluminum but not 3".

c. 1/2" x 1/2" x 8" rods at approximately 3000 feet/second broke 3" diameter round bars of 24S-T4 aluminum.

d. 1/2" x 1/2" x 15" rods impacting against the face of 3/4" 24S-T4 aluminum plates gave complete penetrations at velocities above 1740 feet/second.

e. 1/2" x 1/2" x 4" rods penetrated 3/8" mild steel plate, face on, at velocities of 2350 and higher.

Terminal Ballistics of Rod Like Fragments

- -

The tests upon which this report is based were conducted by:
R. E. McCONNELL, Head, Physics Division
Terminal Ballistics Department
F. F. MARK, Physicist, Experimental Physics Branch
Physics Division
Terminal Ballistics Department

This report was prepared by:
R. E. McCONNELL, Head, Physics Division
Terminal Ballistics Department
F. F. MARK, Physicist, Experimental Physics Branch
Physics Division
Terminal Ballistics Department

This report was reviewed by:
R. H. LYDDANE, Director of Research
Terminal Ballistics Department
W. B. ROBERTSON, Lieutenant Commander, USN
Terminal Ballistics Officer
Terminal Ballistics Department
C. C. BRAMBLE, Director of Research, Ordnance Group

APPROVED: J. F. BYRNE
Captain, USN
Commander, Naval Proving Ground

E. A. RUCKNER
Captain, USN
Ordnance Officer
By direction

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NPG REPORT NO. 1106

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

Thirteenth Partial Report

on

Warhead Characteristics

- -

Second Partial Report

on

Terminal Ballistics of Rod Like Fragments

APR 3 1953

Project No.: NPG-Re3d-442-1-53 Date:
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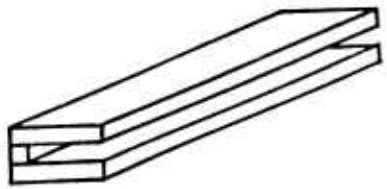
TABLE I

ROD CUT DAMAGE OF 24S-T4 ALUMINUM TARGETS
ROD FLIGHT PARALLEL TO ROLLING DIRECTION

Velocity (ft./sec.)	Target Dimensions		Rod Description	Damage Width & Depth
1890	3/4" plate	15"	1085 RC-40	1" x 1-1/16"
1920	" "	15"	1020 Succeeding rods as received	7/8" x 1-1/16"
2440	" "	8"	"	3/4" x 1"
2330	" "	8"	"	3/4" x 5/8"
3280	" "	8"	"	1" x 1-1/4"
2400	1/2" plate	4"	"	7/8" x 1-1/4"
1910	1-1/2" x 2"	15"	"	3/4" x 1/4", broke
Approx. 2000	1-1/2" x 2"	15"	"	3/4" x 1/4", broke
"	1-1/2" x 3"	15"	"	1/2" deep, broke
2130	1-1/2" x 3"	8"	"	3/4" x 3/8", broke
Approx. 2100	1-1/2" x 3"	4"	"	7/8" x 3/8", broke
Approx. 1950	1-1/2" x 2"	15"	"	7/8" x 3/4", broke
"	1-1/2" x 2-1/2"	15"	"	7/8" x 9/16", broke
"	1-1/2" x 3"	15"	"	3/4" x 3/8", broke
"	1-1/2" x 4"	15"	"	7/8" x 1/2"
"	1-1/2" x 4"	15"	"	1" x 1/2"
"	1-1/2" x 3-1/2"	15"	"	1" x 1/2", broke
"	1-1/2" x 3-1/2"	15"	"	7/8" x 1/2", broke
"	1-1/2" x 3-1/2"	4"	"	3/4" x 3/8"
"	1-1/2" x 3-1/2"	4"	"	1" x 5/8", broke
"	1-1/2" x 3-1/2"	4"	"	3/4" x 9/16"
"	1-1/2" x 3-1/2"	4"	"	3/4" x 3/8", broke
Approx. 2000	1-1/2" x 6"	4"	end hit	3/4" x 3/8"
"	1-1/2" x 6"	4"	center hit	7/8" x 9/16"
"	1-1/2" x 6"	8"	end hit	7/8" x 1/2"
"	1-1/2" x 6"	8"	center hit	1" x 1/2"
"	1-1/2" x 6"	15"		3/4" x 1/2"
"	1-1/2" x 6"	4"	center hit	1" x 3/8"
"	1-1/2" x 6"	4"	end hit	3/4" x 1/4"
"	1-1/2" x 6"	8"	center hit	3/4" x 7/16"
"	1-1/2" x 6"	8"	end hit	7/8" x 1/2"
"	1-1/2" x 6"	15"	center hit	7/8" x 3/8"
"	1-1/2" x 6"	15"	end hit	7/8" x 3/8"
Approx. 2950	1-1/2" x 6"	8"		7/8" x 1-1/4"
"	1-1/2" x 3"	8"	2 rods hit	2-3/4" x 1", broke
"	1-1/2" x 3"	8"	2 rods hit	2-1/2" x 1", broke
"	1-1/2" x 3"	8"		11/16" deep, broke
Approx. 1950	1-1/2" x 6"	5/8" x 5/8" x 4" rod		7/8" x 3/4"
"	1-1/2" x 6"	5/8" x 5/8" x 4" rod		1" x 5/8"

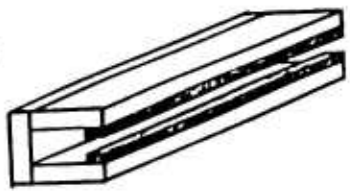
a



½" wide Welded Steel Rod Gun

½" × 1½" explosive column
15" Rods - Confined or Unconfined - 1900 - 2100 ft/sec.
4" - 8" Rods - 2100 ft/sec.

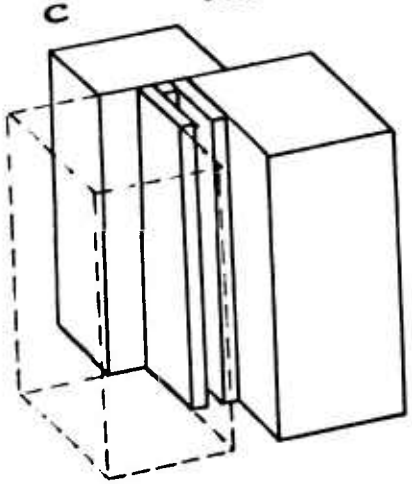
b



1" wide - position of ¼" spacer rods indicated

1" × 1½" × 12" explosive column - end initiated
Two 7" Rods - 2000-2500 ft/sec.
7" Rod Between ¼" Rods - 2400-2500 ft/sec.
Center initiation - 2200-2500 ft/sec
Confined - 2500-3000 ft./sec.

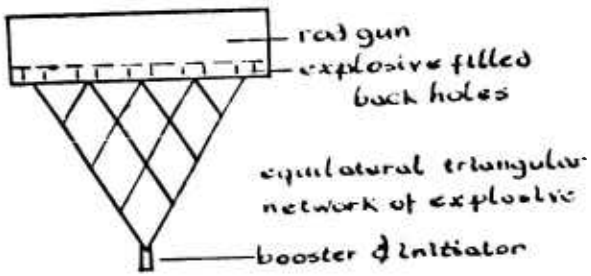
c



Vertically Positioned - Confined rod gun

½" × 1½" × 20" explosive column
2000-2400 ft/sec.

d



2000 ft/sec - Characteristics similar to a.

Figure 1

Appendix A

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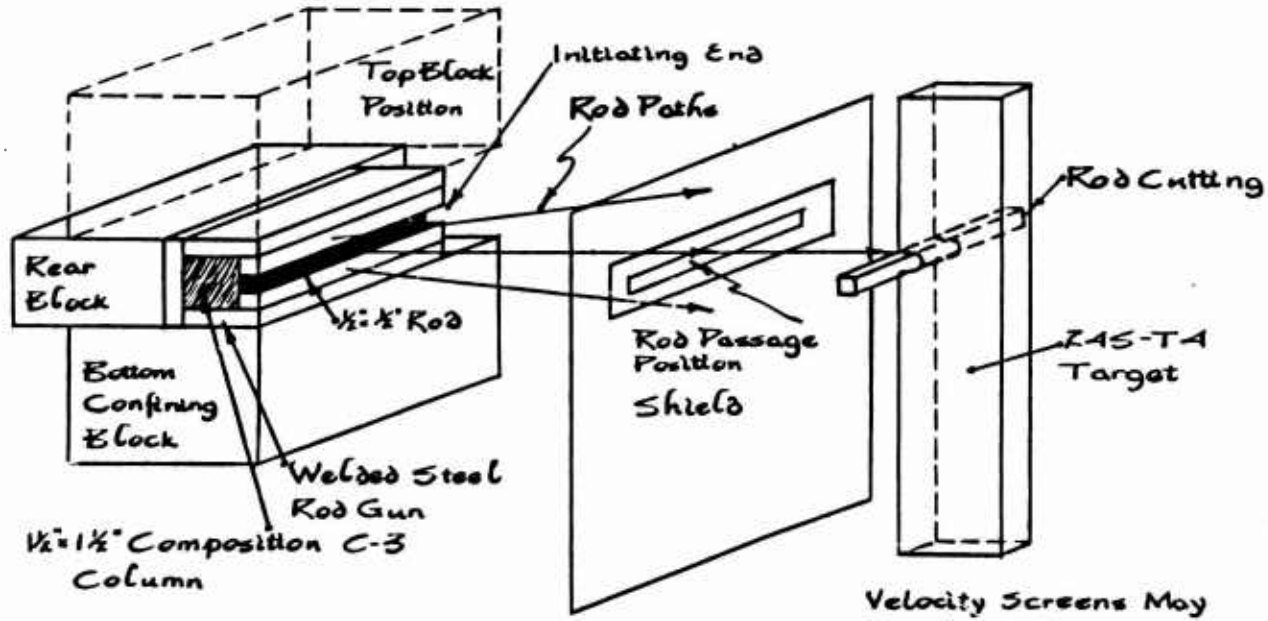

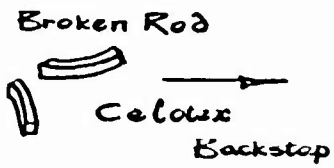

Unconfined - 2500ft/sec.
Confined - 3000ft/sec.
8" Rod, 9" Column, Welded Top & Bottom Rods Give Best Results

⅜"-⅝"-1" Rods from similar unconfined configuration - 1950ft./sec.

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Figure 2

Appendix A

TABLE II

3/8" x 3/8" NOTCHED RODS

3/8" x 1-3/4" Comp. C-3 columns, 8" and 12" long;
3/8" square rods 8" and 12", center initiation, 1 ft. velocity screen baseline (three (3) sets of screens 1 ft. between succeeding sets, 28" charge to set 1).

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
1	.44 lb. 12" un-notched rod	1) 2380 2) 2170 3) 2040	straight, level, broadside	slightly curved, intact
2	.47 lb. 12" notched rod (notches empty)	1) 2350 2) 2040 3) ----	straight, rotating, spreading apart	broke at notches into 3 sections.
3	.44 lb. 12" notched rod (notches filled with Comp. C-3) Rod wt. .45 lb.	1) 2330 2) 2270 3) ----	straight, rotating, spreading apart	broke at notches into 3 sections.
4	.31 lb. 8" notched rod (notch empty)	1) 2670	straight, rotating, spreading apart	broke at notch into 2 sections.
5	.3 lb. 8" notched rod (notch filled with Comp. C-3) Rod wt. .32 lb.		straight, rotating, spreading apart	broke at notch into 2 sections.

TABLE II (Continued)

3/8" x 1-3/4" Comp. C-3 columns, 8" and 12" long;
3/8" square rods 8" and 12", center initiation, 1 ft. velocity screen baseline (three (3) sets of screens 1 ft. between succeeding sets, 28" charge to set 1).

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
6	.3 lb. 8" un-notched rod (6' screen base line)	1) 2140	Broadside, rotating	intact, slightly curved
End Initiation - (5" Booster charge added to explosive column)				
7	.63 lb. 12" notched rod (notches empty) 40" chg. to screen	1) 2200 2) 2080	Rotating	intact, straight, broke at notches into 3 sections rod L, Figure 32, Appendix (F).
8	.48 lb. 8" notched rod (notch empty) 43" chg. to screen	1) 2300	Rotating	intact, straight, broke at notch into 2 sections.

TABLE III

Curve A					Curve B				
Through Center of Specimen					Along Top of Specimen				
Dist. mm.	R_1	R_2	Filar Units	Knoop Hardness	Dist. mm.	R_1	R_2	Filar Units	Knoop Hardness
0.25	962	423	539	175.7	0.54	853	434	419	290.4
0.50	873	364	509	196.9	1.66	961	525	436	274.5
0.75	925	416	509	196.9	1.96	812	424	388	336.8
1.00	788	267	521	188.0	3.65	868	478	390	336.8
1.25	827	304	523	188.0	4.58	835	443	392	336.8
1.50	859	363	496	206.5	5.70	866	474	392	336.8
1.75	885	375	510	196.9	7.65	894	447	447	259.8
2.00	908	414	494	211.6					
2.25	873	388	485	216.9					
2.50	902	400	502	201.7					
2.75	899	408	491	211.6					
3.00	833	349	484	216.9					
3.25	871	418	453	246.3					
3.50	892	456	436	267.0					
3.75	903	472	431	274.5					
4.00	865	455	410	307.7					
4.25	825	407	418	290.4					
4.50	827	434	393	326.7					
4.75	873	469	404	317.0					
5.00	855	463	392	336.8					
5.25	872	472	400	317.0					
5.50	868	475	393	326.7					
5.75	865	465	400	317.0					
6.00	855	473	382	347.4					
6.25	830	442	388	336.8					
6.50	862	460	402	317.0					
6.75	838	455	383	347.4					
7.00	854	459	405	307.7					
7.25	849	462	387	336.8					
7.50	850	474	376	358.5					
7.75	845	460	385	347.4					
8.00	822	438	384	347.4					
8.25	857	475	382	347.4					
8.50	846	461	385	347.4					
8.75	847	424	433	274.5					
9.00									

100 gram load -- 4 mm objective

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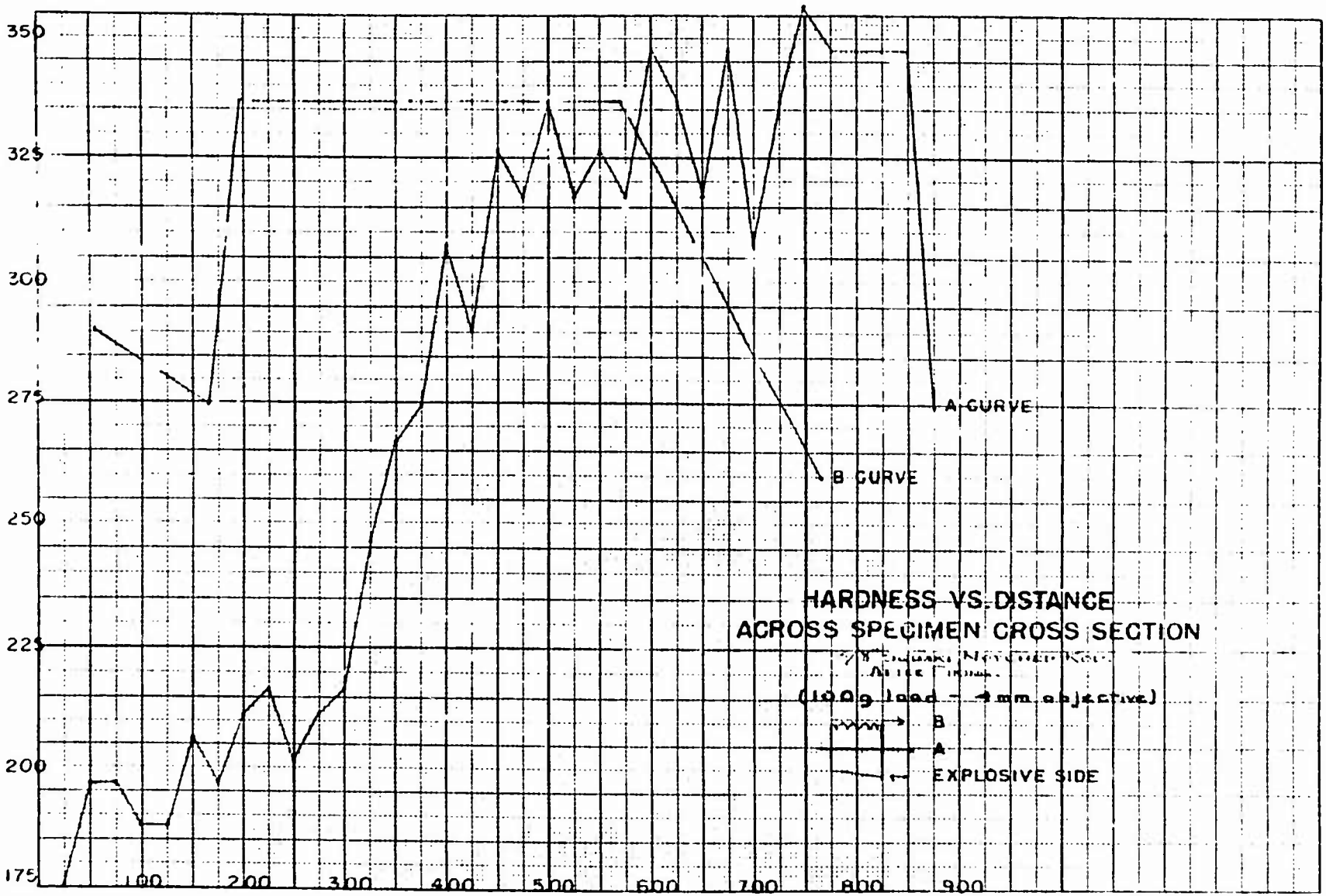

APPENDIX B
FIGURE 5

DISTANCE MM

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NP9-48760

31 July 1951

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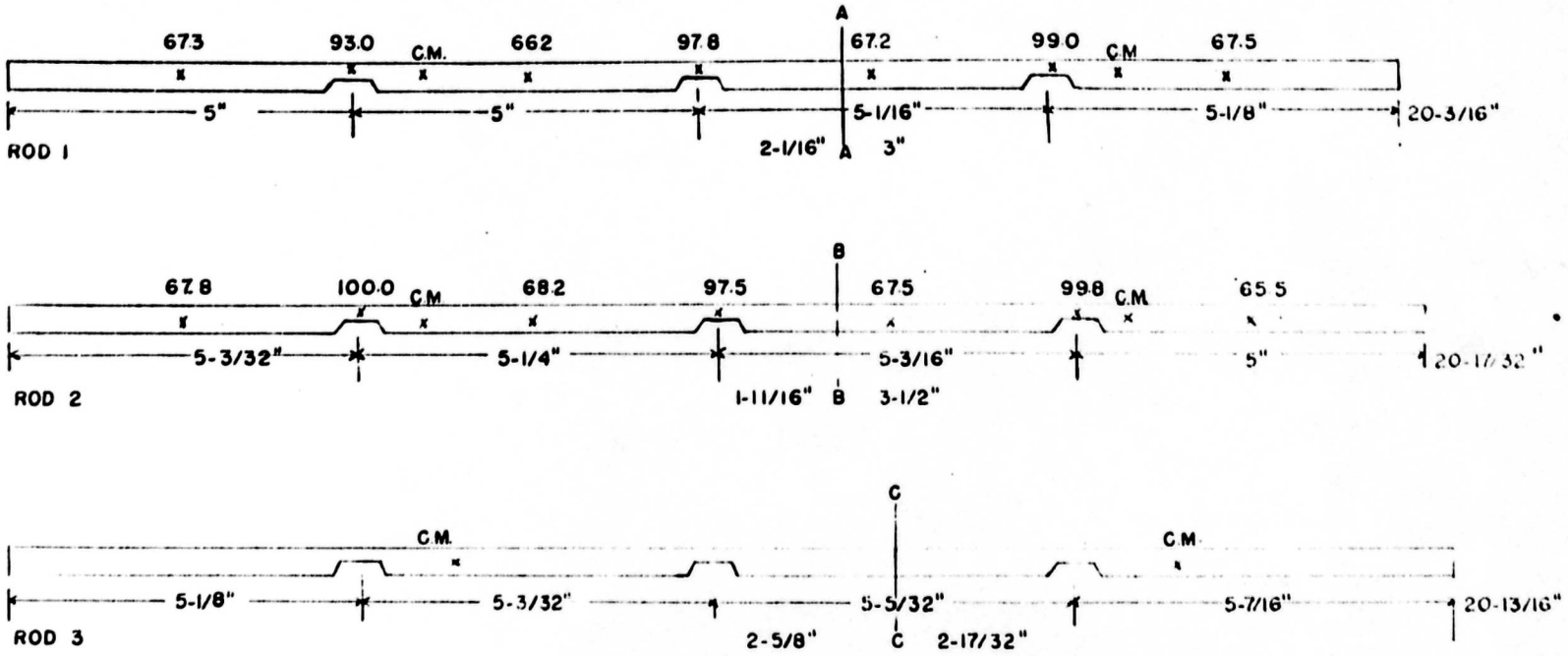
3/8" Square Notched Rod as Received
Figure 4



3/8" SQUARE, NOTCHED
STEEL RODS

ANALYSIS INDICATES MATERIAL IS CARBON STEEL 1010-1020
HARDNESSES AT POINTS INDICATED, ROCKWELL B SCALE

APPENDIX B

FIGURE 5

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TABLE IV

CONFIGURATIONS INVESTIGATED FOR HIGHER VELOCITIES AND IMPROVED FLIGHT CHARACTERISTICS

1" x 1-1/2" x 12" Comp. C-3 column, two (2) 1/2" x 1/2" x 7" rods, 30' baseline 16mm, 6000 frame/sec. camera.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
A-1	1.02 lb.	Top rod 2050 Bottom rod 2150	Spreading, to one side	intact in-flight, curved
A-2	1.03 lb.	Top rod 2310 Bottom rod 2350	Spreading, to one side, rotating	intact in-flight, curved
A-3	1.05 lb.	Both rods 2470	"	"

TABLE IV (Continued)

Vertical positioning, 6" x 6" steel confining blocks around sides of channel (three (3) 2" x 6" plates per side) 1/2" x 1-1/2" x 20" and 1/2" x 1" x 20" explosive columns, 1/2" x 1/2" x 15" rod; 16mm, 6000 frame/sec. camera - 15' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories
B-1 1-1/2" Comp. C-3	.85 lb.		Dropping to one side rotating
B-2	.86 lb.	1990	
B-3	.92 lb.	2510	Dropping to one side
B-4	.81 lb.	2230	
B-5 1" Comp. C-3	.58 lb.	1945	

TABLE IV (Continued)

Vertical positioning, 6" x 6" steel confining blocks around sides of channel 1/2" x 1-1/2" x 20" Comp. C-3 column, 1/2" x 1/2" x 15" rod. 16mm, 6000 frame/sec. camera - 14' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Flash Plate Data
B-6	.9 lb.	2440	Dropping to one side, rotating	3/8" mild steel penetrated
B-7	.89 lb.	2400	"	Same
B-8	.87 lb.	2360	"	Same
B-9	.87 lb.	2385	"	3/8" STS cracked and penetrated

TABLE IV (Continued)

Vertical positioning, 6" x 6" steel confining blocks around sides of 1/2" x 6" x 24" ID channel of 1/2" stock. 1/2" x 1-1/2" x 22" Comp. C-3 column, 1/2" x 1/2" x 15" rod, 16mm, 6000 frame/sec. camera - 13' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Flash Plate Data
B-10	1.00 lb.	2350	Straight, forward tilt	3/8" STS and 1/8" mild steel cracked and penetrated
B-11	.9 lb.	2400	"	
B-12	.9 lb.	2390	"	3/8" STS cut and deformed Rod; 5/3-3 See Figure 30

TABLE IV (Continued)

1/2" x 1-1/2" x 20" column Comp. C-3, 1/2" x 1/2" x 15" rod, channel confined on the sides by 6" x 8" steel blocks and on the back by a 3" x 8" steel block.

Rd.	Explosive Weight	Velocities (ft./sec.)	Rod Data
B-13 6' chg. to screen dist.	.9 lb.	2040	Straight, level, broadside flight, straight, intact rod
B-14 2' chg. to screen	.95 lb.	1) ---- 2) 2140	Broadside flight, curved intact
B-15 Break screen Make screen	.92 lb.	1) 1520 2) 2210	No rotation in-flight, straight, intact
		Unconfined channels	
B-16 3' chg. to screen	.89 lb.	1) ---- 2) 2150	Straight, level, broadside flight, straight, intact
B-17 33" chg. to screen 3 sets of screens 1' baselines covering 5'	.94 lb.	1) 2060 2) 1820 3) 1750	Broadside rotating flight, straight, intact

TABLE IV (Continued)

1" x 1-1/2" x 12" Comp. C-3 column, 1/2" x 1/2" x 7" 1020 rod between two (2) 1/4" x 1/2" rods, 5' velocity screen baseline. 16mm camera - 20' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
C-1 3' chg. to screen	1.02 lb.	1) 2430 2) 2370	Broadside, rotating	Center rod intact and straight, outer rods broke up.
C-2	1.05 lb.	1) 2) 2380	(Similar results to Round C-1)	Rod Curved
C-3	1.03 lb.		(Similar results to Round C-1)	
C-4	1.02 lb.		(Similar results to Round C-1)	
C-5 2' chg. to screen	1.03 lb. Camera	1) 2) 2560) 2425	(Similar results to Round C-1)	
C-6	1.07 lb. Camera	1) 2) 2460) 2445	(Similar results to Round C-1)	

See Figure 31, Spacer Rods.

TABLE IV (Continued)

1" x 1-1/2" x 8" Comp. C-3 column, 1/2" x 1/2" x 8" 1020 rod between two (2) 1/4" x 1/2" rods, center initiation, 5" velocity screen baseline, 16mm camera - 20' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
D-1	.7 lb.	1) 2270 2) 2220	Broadside, horizontal, outer rods go off at an angle	All rods intact and curved
D-2	.7 lb.	1) 2290 2) 2240	(Similar results to Round D-1)	
D-3	.74 lb.	1) 2200 2) 2170	(Similar results to Round D-1)	
D-4) Rds. A-1 and A-2, See Table VII Appendix (C). D-5)				
D-6	.72 lb.	1) 2180 2) 2160	(Similar results to Round D-1)	
	Camera	) 2175		

See Figure 30, center initiation.

TABLE IV (Continued)

Same as rounds D
Channels confined by 6" x 8" x 24" steel blocks.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
D-7 28" chg. to screen	.7 lb.	1) 3100 2) 2640	Broadside, rotating	Intact, straight
D-8 30" chg. to screen	.68 lb.	1) 2950	Rotating	Intact, straight
D-9 15-2/3' baseline	.71 lb.			
	Camera	2625	Rotating	Intact, straight
D-10 3 sets of screens 1' baseline over 5'	.71 lb.	1) 2940 2) 2860 3) 2000	Rotating	Intact
Confined channels, 1' velocity screen baseline				
D-11 46" chg. to tgt.	.73 lb.	1) 2630 2) 2440	Broadside, level	Intact, curved Rod 8/17, against 1/2" STS
D-12	.72 lb.	1) ---- 2) 2500		

See Figure 32.

TABLE IV (Continued)

1/2" x 1-1/2" Comp. C-3 column, 1/2" x 1/2", 1020 rod

15" rod, 20" column, initiation by 4 blasting caps along the back of the explosive

Rd E-1: .67 lb. explosive - rod broke up on firing

(Wooden channels 1/4" deep, 20" long, with widths of 1/4", 3/8" and 1/2" and explosive wts. of .1,.15 and .2 lb. Comp. C-3 respectively. Detonation at end with special engineer's blasting cap resulted in high order explosions for all widths.)

8" rod, 10" column, initiated at 5 points along the back by Comp. C-3 paths (1/4" x 1/2") starting from a common origin and branching out into a triangular grid.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
E-2 30" chg. to screen	.48 lb.	2080	Rising to one side, broadside, tilting	Straight, intact
E-3 32" chg. to screen, 1' baseline	.48 lb.	2130	Broadside, dropping	Straight, intact
E-4 32" chg. to screen, 5' baseline	.50 lb.	2030	Broadside, rotating	Straight, intact

See Figure 1 (d), Appendix (A).

TABLE IV (Continued)

1-1/2" x 1-1/2" x 8" Comp. C-3 column, three (3) 1/2" x 1/2" x 8", 1020 rods in channel, center initiation, 5' velocity screen baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
F-1	1.04 lb.	1) 2490 2) 2440	Straight, broadside, rotating (outside rods off at angle)	Intact, straight, with bend in middle due to center detonation, outside rods curved
F-2	1.10 lb.	1) 2530 2) 2500	(Similar results to Round F-1)	
F-3	.99 lb.	1) 2450 2) 2420	(Similar results to Round F-1) (Similar results to Round F-1)	

See Figure 30.

TABLE IV (Continued)

1/2" x 1-1/2" x 20" Comp. C-3 column, 1/2" x 1/2" rod cut into sections, 1' velocity screen baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
G-1 32" chg. to screen 3 sets of screens 1' between succeeding sets	.98 lb.	1) ---- 2) 2130 3) 1920	Broadside, rotating	8" center rod 3-1/2" end rods, intact, straight
G-2 33" chg. to screen 72" chg. to tgt. 2 sets of screens	.97 lb.	1) ---- 2) 2080	(Similar results)	Same (5" rocket motor as target - cut 8/3-1)
G-3 30" chg. to screen	.79 lb.	1940	Broadside, rotating	Three (3) 4" rods, intact, straight
G-4 1" depth explosive 34" chg. to screen	.66 lb.	1890	Broadside, rotating	"
G-5 30" chg. to screen 5' baseline	1.13 lb.	1) 1940 2) 1930	Broadside, rotating	5" outer rods 4" center rod Intact, straight

TABLE IV (Continued)

1-1/2" x 1-1/2" x 8" explosive column, three (3) 1/2" x 1/2" x 8" rods, end initiation, no booster charge, channel sides confined by 6" x 8" x 24" blocks and the back by a 3" x 8" x 24" block, 1' and 5' velocity screen baselines.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
H-1 1' baseline	1.00 lb.	2950	Rotating, spreading apart	Intact, curved
H-2 (See Round B-1 Table IX)				
H-3 (See Round C-1 Table V)				
H-4 28" chg. to screen 5' baseline	.89 lb.	1) 2960 2) 2910	Rotating, spreading apart	Intact, curved
H-5 30" chg. to screen 1' baseline	.93 lb.	3030	Level, rotating, spreading apart	Intact, straight
H-6 30" chg. to screen 5' baseline	.94 lb.	1) 2760 2) 2730	Rotating	Intact, curved

TABLE IV (Continued)

1-1/2" x 1-1/2" x 8" explosive column, three (3) 1/2" x 1/2" x 8" rods, end initiation, no booster charge, channel sides confined by 6" x 8" x 24" blocks and the back by a 3" x 8" x 24" block, 1' and 5' velocity screen baselines. Slotted armor plate shields placed so as to stop top and bottom rods.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data	Shield Data
H-7	.93 lb.				Outside rods stopped, edges of slot knocked out
H-8 3' chg. to shield 2' shield to screen 1' baseline	.95 lb.	1) 2900 2) 2600	Broadside	Straight Intact	(Similar results)
H-9 3' chg. to shield 5' chg. to screen 1' baseline	1.08 lb.	2860	Straight, level rotating	Straight Intact	5/8" STS stopped outer rods.
H-10 9" long column, end initiation	1.01 lb.		Broadside, rotating	Straight Intact	Same. All rods hit shield
H-11 3' chg. to shield	1.18 lb.	3000			Stopped outer rods (See rods 9/7 and 9/8)
Same, Two (2) welded front outside rods - no shield					
H-12 (Outside 1/2" rods) welded) 5' baseline	1.16 lb.	1) 2980 2) 2940	Level, rotating (Outside rods retarded and go at an angle)	Straight, Intact	
H-13 (1" bars welded) 5' baseline 29" chg. to screen	1.17 lb.	1) 2950 2) 2940	(Similar results to Round H-12)		

See Figure 33.

TABLE IV (Continued)

shield, center initiation

m camera 15' baseline

	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
4	.91 lb.	1) 2910	Rotating	Curved, intact
chg to screen baseline	Camera	) 2725		
5	1.07 lb.	2750	Broadside, level	Straight, intact
chg. to screen baseline	Camera	) 2660		
6	1.08	Camera) 2820		

TABLE IV (Continued)

No shield, center initiation

16mm camera 15' baseline

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
H-14	.91 lb.	1) 2910	Rotating	Curved, intact
3' chg to screen				
1' baseline	Camera	) 2725		
H-15	1.07 lb.	2750	Broadside, level	Straight, intact
27" chg. to screen				
5' baseline	Camera	) 2660		
H-16	1.08	Camera) 2820		

TABLE IV (Continued)

1-1/2" x 1-3/8" x 4-1/2" Comp. C-3 column, 5/8" x 5/8" x 4" center rod, end initiation, 1' velocity screen baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Trajectories	Rod Data
I-1 30" chg. to screen	.55 lb.	1940	Broadside, level	Straight, intact
I-2 30" chg. to screen	.55 lb.	1960	(Similar results)	

TABLE V

3/4" THICK 24S-T4 ALUMINUM TARGETS

1/2" x 1-1/2" x 20" and 1/2" x 1" x 20" explosive columns
1/2" x 1/2" x 15" rods, 5' velocity screen baseline

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Rod Data	Target Damage Data (Width x Depth)
A-1 1-1/2"	.9 lb. Comp. C-3		1) 1870 2) 1840	1085 oil quenched from 1500°F, No draw, Rockwell C-40	
A-2	.85 lb.	4/13-2	1) 1890 2) 1840	1085 oil quenched from 1500°F, No draw, Rockwell C-40	1" x 1-1/16"
A-3	.9 lb.	4/13-3	1) 1920 2) 1900	1020, hit 5" from end	7/8" x 1-1/16"
A-4 1"	.6 lb. Comp. C-3	4/13-4	1) 1770 2) 1740	1020	Just penetrated plate face on
A-5	.88 lb.	4/13-5	1) 1990 2) 1950	1020	Just penetrated cracked plate face on

See Appendices (D), (E), and (F) for condition of targets and rods after firing.

See Figures 18, 19, and 30.

TABLE V (Continued)

(Similar to Rounds D, Table IV, Appendix (C)).

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Target Damage Data (Width x Depth)
B-1 50" chg. to tgt.	.7 lb.	7/21-1	1) 2440 (before tgt.) 2) 1790 (after tgt.)	Top: 3/4" x 1/4" Center: 3/4" x 1" Bottom: 1/2" x 1/2"
B-2 50" chg. to tgt.	.7 lb.	7/21-2	1) 2330 (before tgt.) 2) 1560 (after tgt.)	Top: 3/4" x 1/2" Center: 3/4" x 5/8" Bottom: 5/8" x 1/2"
(Similar to Rounds H, Table IV, Appendix (C)).				
C-1 59" chg. to tgt.	1.03 lb.	8/4-2	3280	Top: 7/8" x 1" Center: 1" x 1-1/4" Bottom: 7/8" x 1"

See Figures 18, 19, and 31.

TABLE VI

3" x 3" x 36" REYNOLDS ALUMINUM PLATE, TYPE R301, W TEMPER

1/2" x 1-1/2" x 20" Comp. C-3 column, 1/2" x 1/2" x 15" rod; 1' velocity screen baseline, first set before, second set after target; 4-1/2' charge to target distance. Clad surface of target presented to rod.

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Rod Data	Target Damage Data (Width x Depth)
A-1 1" Comp. C-3 test shot	.58 lb.		1) 1980 2) ----		
A-2 1-1/2" Comp. C-3	.9 lb.	5/12-2	1) 2220 2) 1540	1020 center hit broke into three (3) sections	All Targets unbroken 1" x 3/8"
A-3	.9 lb.	5/12-3	1) 2230 2) 1960	Same	1" x 1/4"
A-4	.97 lb.	5/12-4	1) ---- 2) 1940	1085 Rockwell C-40 center hit	1-3/8" x 5/8"

See Figures 10 to 13, 28 and 29.

TABLE VI (Continued)

1/2" x 1-1/2" Comp. C-3 column in 1/2" x 6" x 24" ID channel, 6" x 6" confining blocks, Vertical positioning, 1/2" x 1/2" x 15" rod. Rod velocity approximately 2400 ft./sec.

Rd.	Explosive Weight	Date	Rod Data	Target Damage Data (Width x Depth)
B-1	1.13 lb.	5/23-1	1090 Rockwell C-40	1" x 1/2" face cut, cuts similar to 7/20, all targets unbroken
B-2	1.10 lb.		Same	Edge cut 1" x 3/4"
B-3	1.23 lb.	5/25-1	Same, Broken on Impact	1" x 1" edge cut broken to show cross section

See Figures 6 and 30.

TABLE VI (Continued)

(Similar to rounds D Table IV, Appendix (C)) 8" rods 1" velocity screen baseline

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Target Damage Data (Width x Depth)
C-1 61" chg. to tgt.	.71 lb.	7/20-2	1) 2500 (before tgt.) 2) 2250 (after tgt.)	Top: 3/4" x 1/4" Center: 1" x 1/4" All targets unbroken
C-2 55" chg. to tgt.	.69 lb.	7/20-3	approximately 2400	Center: 1-1/4" x 3/4" Top: 3/4" x 1/4"
C-3	.69 lb.	7/20-4	"	Center: 1" x 1/4" Bottom: 1-1/4" x 1/2"
			Confined Channels	
C-4 47" chg. to tgt.	.72 lb.	8/16-1	1) 2900 (before tgt.) 2) 1980 (after tgt.)	3" x 5" targets Outside: 3/4" x 5/16" Center: 1-3/8" x 11/16"

See Figures 6, 31, and 32.

TABLE VII

3/8" x 3' x 3' MILD STEEL PLATE

1" x 1-1/2" x 8" Comp. C-3 column, 1/2" x 1/2" x 4" 1020 center rod between two (2) 1/4" x 1/2" rods, 2" rods at either end of center rod, center initiation 1' velocity screen baseline. 16mm camera - 20' baseline.

Rd.	Explosive Weight	Velocities (ft./sec.)	Target Damage Data
A-1 Approx. 5' chg. to plate distance	.72 lb.	1) 2500 (Before target) 2) 510 (after target)	Target face on, penetrated
A-2	.72 lb.	1) 2370 (before target) 2) 2080 (after target)	End hit by rod, target edge on, center hit 5/16" depth, outside hit 1/2" depth
A-3	.71 lb.	2350 Camera) 2410	3/8" M.S. plate (at 20') with 1/8" M.S. backing, both penetrated

TABLE VIII

MISCELLANEOUS 24S-T4 ALUMINUM TARGETS

1" x 1-1/2" x 8" Comp. C-3 column, 1/2" x 1/2" x 4" 1020 center rod between two (2) 1/4" x 1/2" rods, 2" rods at either end of center rod, center initiation 1' velocity screen baseline. 16mm camera - 20' baseline.

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Target Damage Data
A-1	.73 lb.		1) 2470 (before tgt.) 2) 1820 (after tgt.)	3/4" x 3/4" bars, 2" apart in plane perpendicular to flight. Cut through
A-2 18" chg. to tgt.	.7 lb.	7/7-2		1/2" thick plate 1/2" & 3/4" deep outer cuts. 7/8" wide, 1-1/4" deep center cut
A-3 54" chg. to tgt.	.71 lb.	7/19-1	1) 2500 (before tgt.) 2) 1170 (after tgt.)	1-1/2" x 1-1/2" bars, similar to A-1. Broken
A-4 61" chg. to tgt.	.69 lb.	7/20-1	1) 2700 (before tgt.) 2) 2130 (after tgt.)	Same Broken

See Figures 6, 14, 15, 16, 17 and 31.

TABLE IX

1-1/2" THICK, 36" LONG 24S-T4 ALUMINUM PLATE

1/2" x 1-1/2" x 20" Comp. C-3 column, 1/2" x 1/2" x 15" rod,
Rod against 1-1/2" face. 1' velocity screen baseline.

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Rod Data	Target Damage Data (Width x Depth)
A-1 46" chg. to tgt.	.93 lb.	8/2-1	1910	1020 rods	(Rod against 2" wide face) Broke 3/4" x 1/4"
A-2 46" chg. to tgt.	.97 lb.	8/2-2			2" wide. Broke 3/4" x 1/4"
A-3 43" chg. to tgt.	.9 lb.	9/8-1			3" wide cut 1/2" deep, broke
A-4 4' chg. to tgt.	.92 lb.	9/8-2	2130	8" rod 3-1/2" end rods	3" wide. 3/4" x 3/8" broke
A-5 20" chg. to tgt.	.93 lb.	9/8-3		4" center rod 5" end rods	3" wide. 7/8" x 3/8" broke

See Figures 8, 9, 30, and 32.

TABLE IX (Continued)

5' velocity screen baseline - velocity approximately 1950 ft./sec., 14" chg. to tgt.
Target width varying from 2" to 4", rod against 1-1/2" thickness, 15" Rod.

Rd.	Explosive Weight	Date	Target Damage Data (Width x Depth)
A-6	1.12 lb.	10/9-1	2" wide. 7/8" x 3/4" broken
A-7	1.11 lb.	10/9-2	2-1/2" wide. 7/8" x 9/16" broken
A-8	1.11 lb.	10/9-3	3" wide. 3/4" x 3/8" broken
A-9	1.11 lb.	10/9-4	4" wide. 7/8" x 1/2" not broken
A-10	1.12 lb.	10/10-1	4" wide. 1" x 1/2" not broken
A-11	1.13 lb.	10/10-2	3-1/2" wide. 1" x 1/2" broken
A-12	1.11 lb.	10/10-3	3-1/2" wide. 7/8" x 1/2" broken
		(Same, 4" rod shot)	
A-13	1.12 lb.	10/12-1	3-1/2" wide. 3/4" x 3/9" unbroken
A-14	1.12 lb.	10/12-2	3-1/2" wide. 1" x 5/8" broken
A-15	1.15 lb.	10/12-3	3-1/2" wide. 3/4" x 9/16" unbroken
A-16	1.11 lb.	10/12-4	3-1/2" wide. 3/4" x 3/8" broken

See Figures 8, 9, 24, 25, 26, 27, 34 and 35.

TABLE IX (Continued)

(Same as rounds A) 1" and 1-1/2" explosive depths, 6" wide target, all unbroken; shots on edge to 1-1/2" thickness, 20" chg. to target dist. Velocity approximately 2000 ft./sec.

Rd.	Explosive Weight	Date	Rod Data	Target Damage Data (Width x Depth)
B-1 1" depth	.6 lb.	9/14-1	Three (3) 4" rods, end hit center rod	3/4" x 3/8"
B-2	.63 lb.	9/14-2	Three (3) 4" rods, center hit, center rod	7/8" x 9/16"
B-3 1-1/2" depth	.81 lb.	9/14-3	8" center rod, end hit	7/8" x 1/2"
B-4	.82 lb.	9/14-4	8" center rod, center hit	1" x 1/2"
B-5	.88 lb.	9/14-5	15" rod, hit 9" from one (1) end	3/4" x 1/2"
B-6 1" depth, 15" chg. to tgt.	.61 lb.	9/21-1	Three (3) 4" rods, center hit, center rod (Rod tilted)	1" x 3/8"
B-7 14" chg. to tgt.	.62 lb.	9/21-2	Three (3) 4" rods, end hit, center rod	3/4" x 1/4"

See Figures 9, 22, 23, and 33.

TABLE IX (Continued)

(Same as rounds A) 1" and 1-1/2" explosive depths, 6" wide target, all unbroken shots on edge to 1-1/2" thickness, 20" chg. to target dist.
Velocity approximately 2000 ft./sec.

Rd.	Explosive Weight	Date	Rod Data	Target Damage Data (Width x Depth)
B-8 1-1/2" depth 17" chg to tgt.	.93 lb.	9/21-3	8" center rod, center hit	3/4" x 7/16"
B-9 15" chg. to tgt.	.93 lb.	9/21-4	8" center rod, end hit	7/8" x 1/2"
B-10 16" chg. to tgt.	.90 lb.	9/21-5	15" rod, center hit	7/8" x 3/8"
B-11 14" chg. to tgt.	.90 lb.	9/21-6	15" rod, end hit	7/8" x 3/8"

See Figures 9, 22, 23, and 33.

TABLE IX (Continued)

(1-1/2" thick 24S-T4)

(See Rounds H, Table IV, Appendix (C)).

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Target Damage Data (Width x Depth)
C-1 57" chg. to tgt. 9" long column, end initiation	.98 lb.	8/4-1	2650	Rods against 3" wide face, cut out large area in breaking
C-2	1.16 lb.	9/15-1	3000	6" wide 7/8" x 1-1/4", unbroken
C-3 46" chg. to tgt.	1.18 lb.	9/15-2		3" wide Outer and center rod hit, 2-3/4" x 1", broken
C-4 50" chg. to tgt.	1.15 lb.	9/18-1		3" wide, 2 hits, 2-1/2" x 1", broken
C-5 50" chg. to tgt.	1.16 lb.	9/18-2		3" wide, top rod hit, 11/16" deep, broken

See Figures 8, 9, 32, 33.

TABLE IX (Continued)

(Same as Round 1, Table IV, Appendix (C)) 5/8" x 5/8" x 4" rods, 6" wide target, shots on edge to 1-1/2" thickness, 14" chg. to target.

Rd.	Explosive Weight	Date	Target Damage Data (Width x Depth)
D-1	.55 lb.	9/26-1	Top: 11/16" x 11/16" Center: 7/8" x 3/4" Bottom: 1" x 1-1/2"
D-2	.55 lb.	9/26-2	Top: 5/8" x 5/16" Center: 1" x 5/8" Bottom: 5/8" x 5/16" (Broke through 9/15 cut)

See Figures 9 and 33.

TABLE X

5" ROCKET MOTOR TUBES

1/2" x 1-1/2" x 20" Comp. C-3 column, 1/2" x 1/2" x 15" rod. 1 ft. velocity screen baseline.

Rd.	Explosive Weight	Date	Velocities (ft./sec.)	Target Damage Data
1- 52" chg. to screens 76" chg. to tgt.	.93 lb.	8/2-3	1) 2) 1770	Cracked
2- 58" chg. to screens 81" chg. to tgt.	.90 lb.	8/2-4	1) 2020 2) 1850	Cut

3- (See Round G-2, Table IV, Appendix (C)).

See Figures 20 and 21.

TABLE XI

2" DIAMETER 24S-T4 ALUMINUM ROUNDS

2000 ft./sec., 1/2" x 1/2", 1020 rods.

Rd.	Explosive Weight	Date	Rod Data	Target Damage Data (Width x Depth)
1 4' chg. to tgt.	.87 lb.	8/22-1	15" rod	Broken, 3/4" x 1/4"
2 56" chg. to tgt.	.91 lb.	8/22-2	15" rod	Broken, 5/8" x 1/4"
3	.90 lb.	8/22-3	8" rod (two (2) 3-1/2" rods either side)	Broken, 3/4" x 1/4"
4 15" chg. to tgt.	.88 lb.	8/23-1	three (3) 4" rods center rod hit round	Broken, 1" x 3/8"

See Figures 7 and 32.

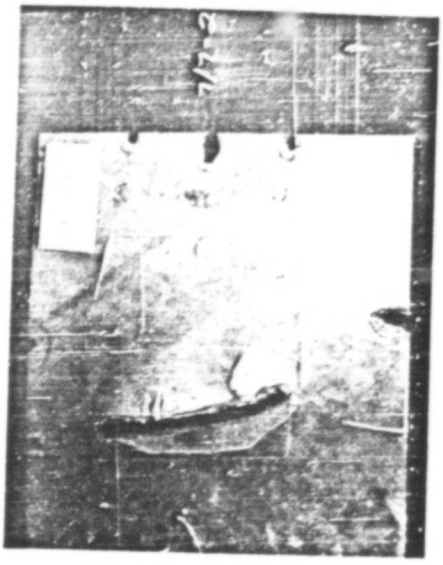
TABLE XII

3" DIAMETER 36" LONG 24S-T4 ALUMINUM ROUNDS

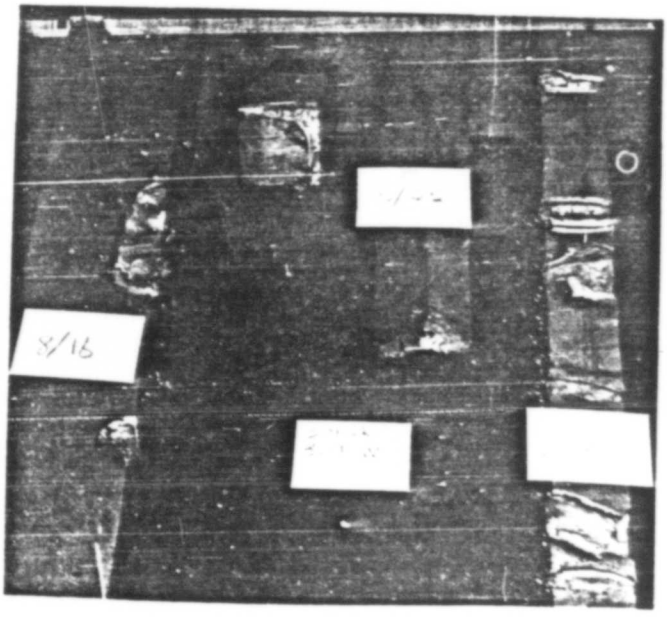
2000 and 3000 ft./sec. rods.

Rd.	Date	Rod Data	Target Damage Data (Cut Width x Depth)
1	10/13-1	8" 3000 ft./sec.	Cut and broken by both center and outer rods 1-1/4" x 1/2"
2 32" chg. to tgt.	10/13-2	Same	(Similar results) 1" deep
3 14" chg. to tgt.	10/17-1	16" 2000 ft./sec.	Unbroken (broken by shock of next round) 1" x 5/16"
4 14" chg. to tgt.	10/17-2	Same	Unbroken, 1-1/4" x 3/8"
5 14" chg. to tgt.	10/17-3	Same	Unbroken, 7/8" x 1/4"

See Figures 7 and 35.



(a) 1/2" Thick, 24S-T4 Aluminum Plate



(b) 3" Thick, R301-W Aluminum Bars

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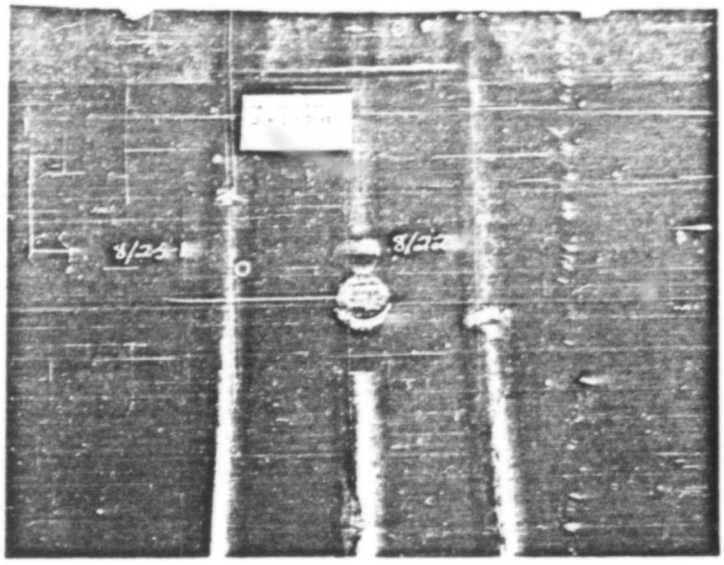
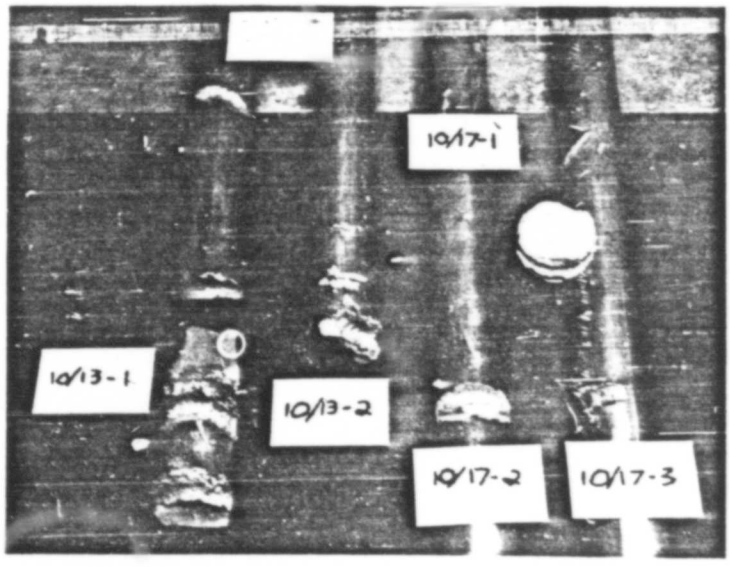
Figure 6

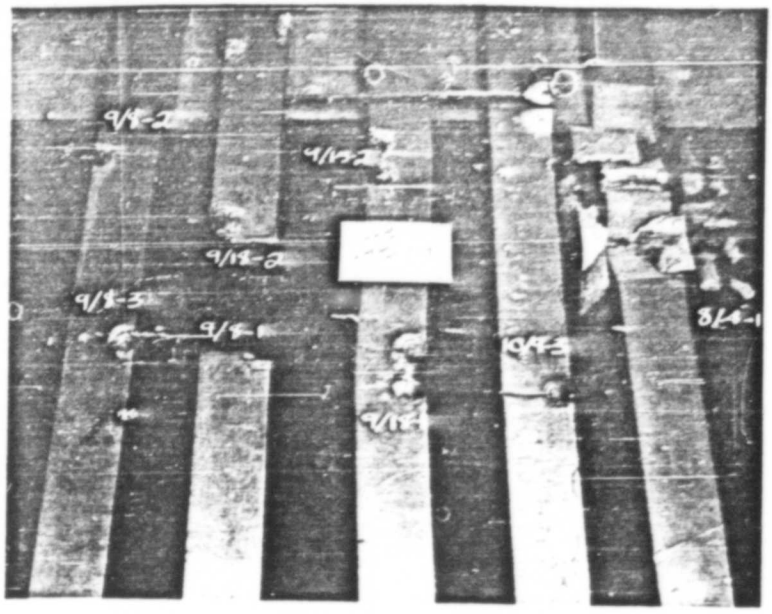


(a) 2" Diameter, 24S-T4 Aluminum Bars

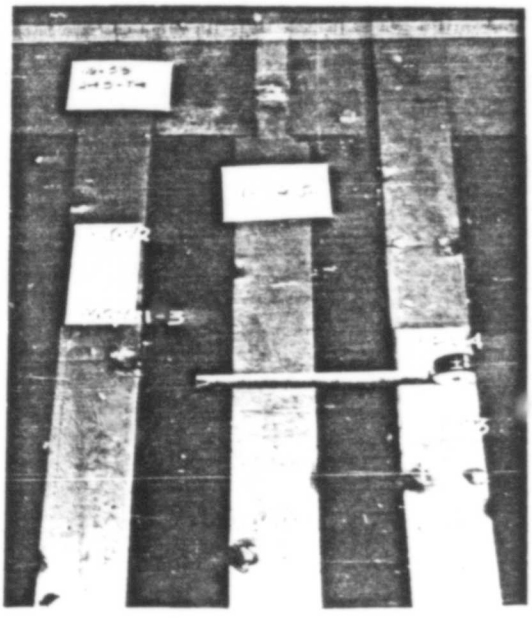


(b) 3" Diameter, 24S-T4 Aluminum Bars

Figure 7



(a) 1-1/2" X 3" 24S-T4 Aluminum Bars



(b) 1-1/2" X 3-1/2" 24S-T4 Aluminum Bars

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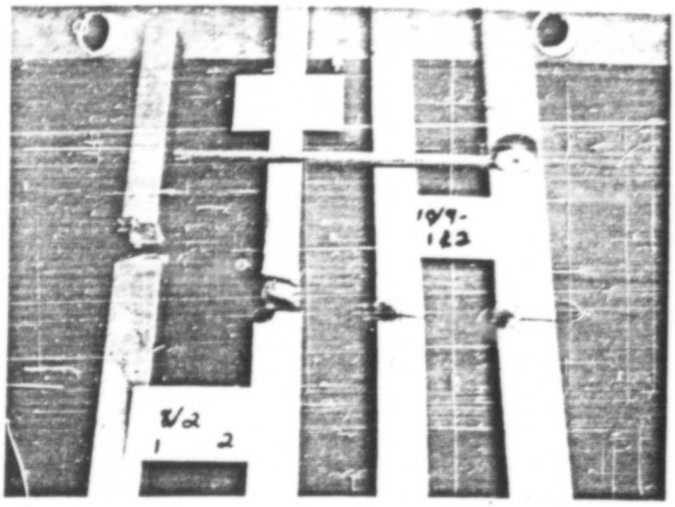
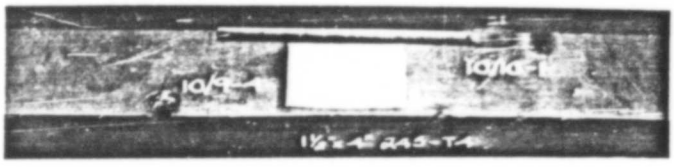
Figure 8



(a) 1-1/2" Thick, 2" and 2-1/2" Wide 24S-T4 Aluminum Bars



(b) 1-1/2" X 4" 24S-T4 Aluminum Bars

(c) 1-1/2" X 6" 24S-T4 Aluminum Bars

Figure 9

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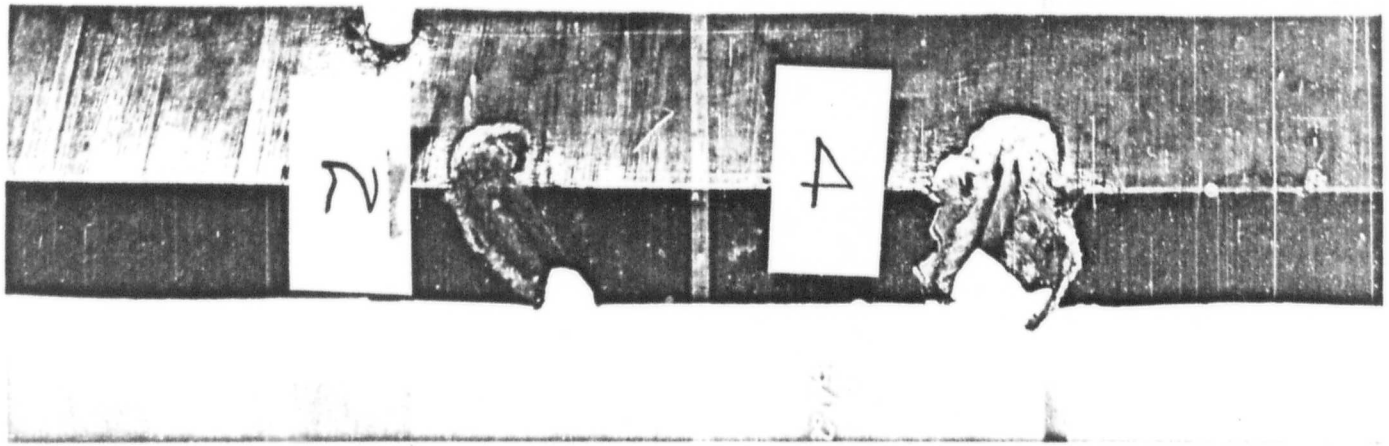
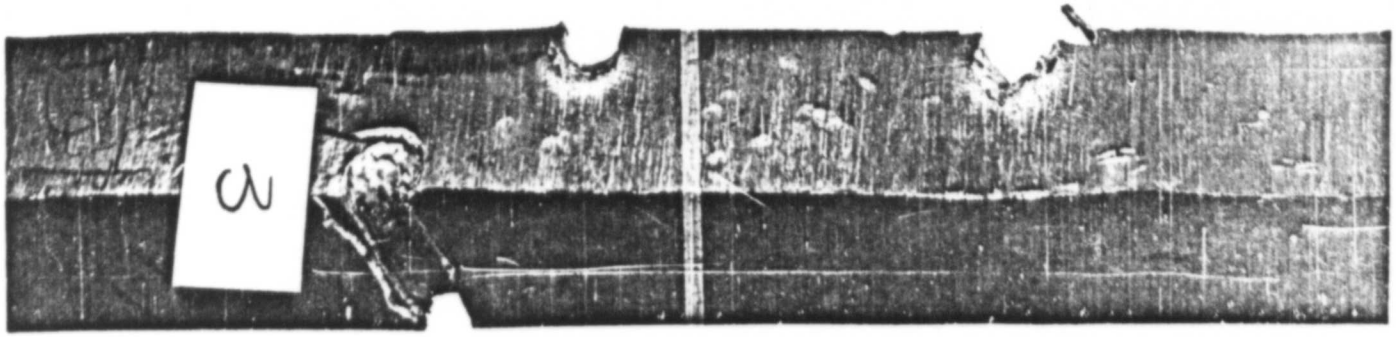
3" X 3" R301-W Aluminum Bar
Figure 10



3" X 3" R301-W Aluminum Bar
Figure 11



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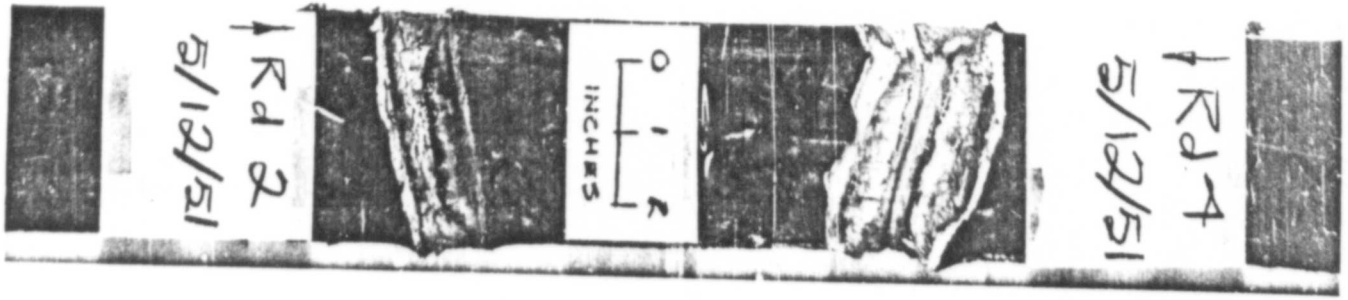
3" X 3" R301-W Aluminum Bar
Figure 12



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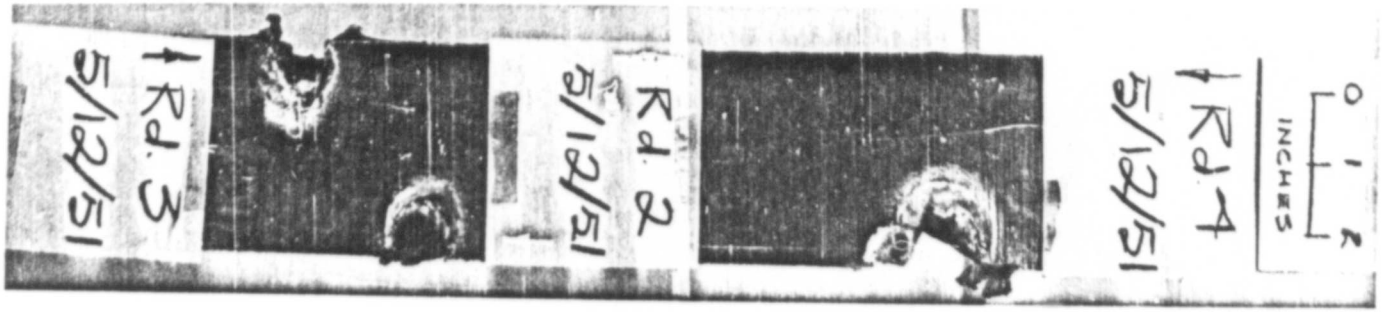
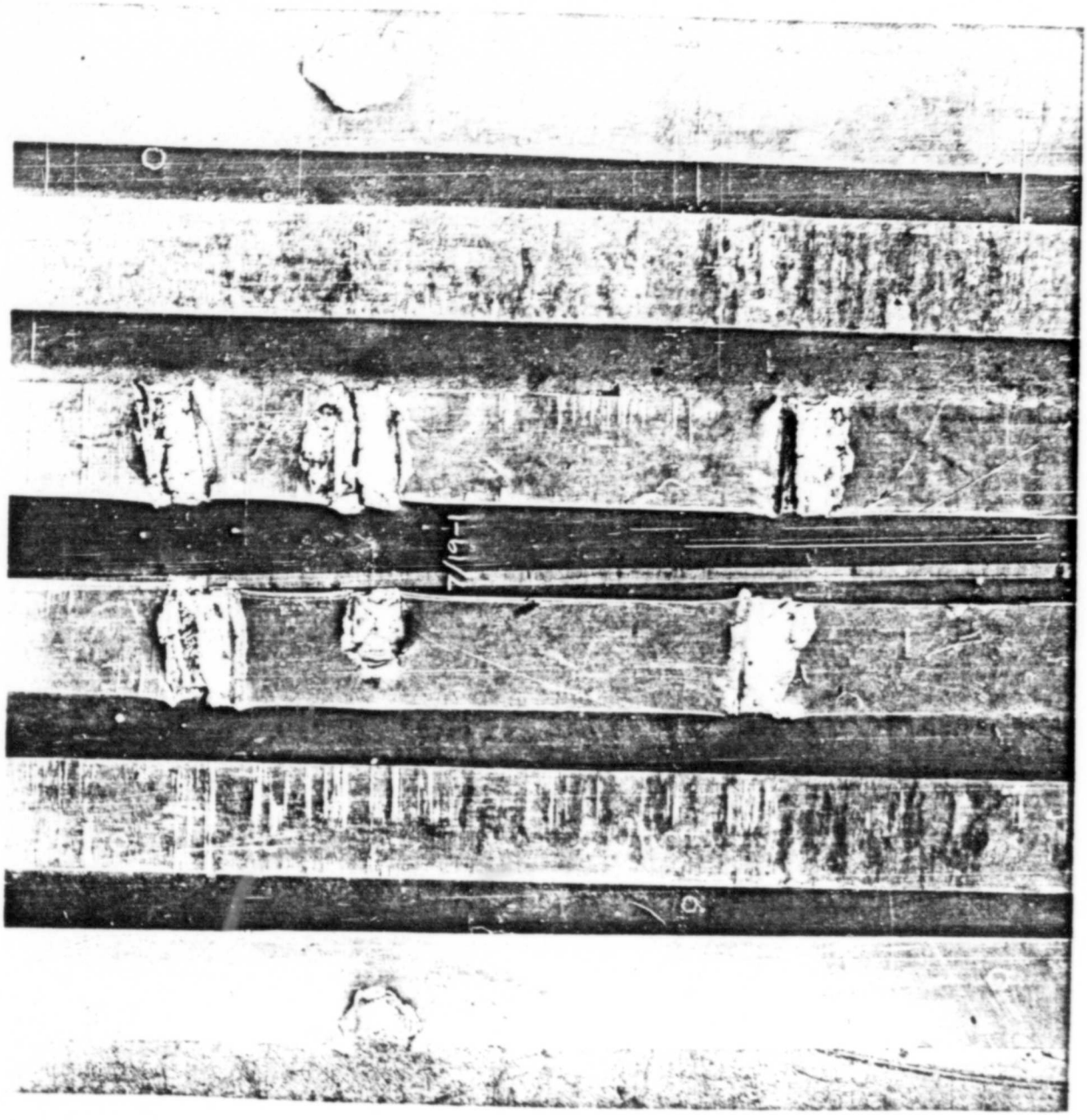
3" X 3" R301-W Aluminum Bar
Figure 13





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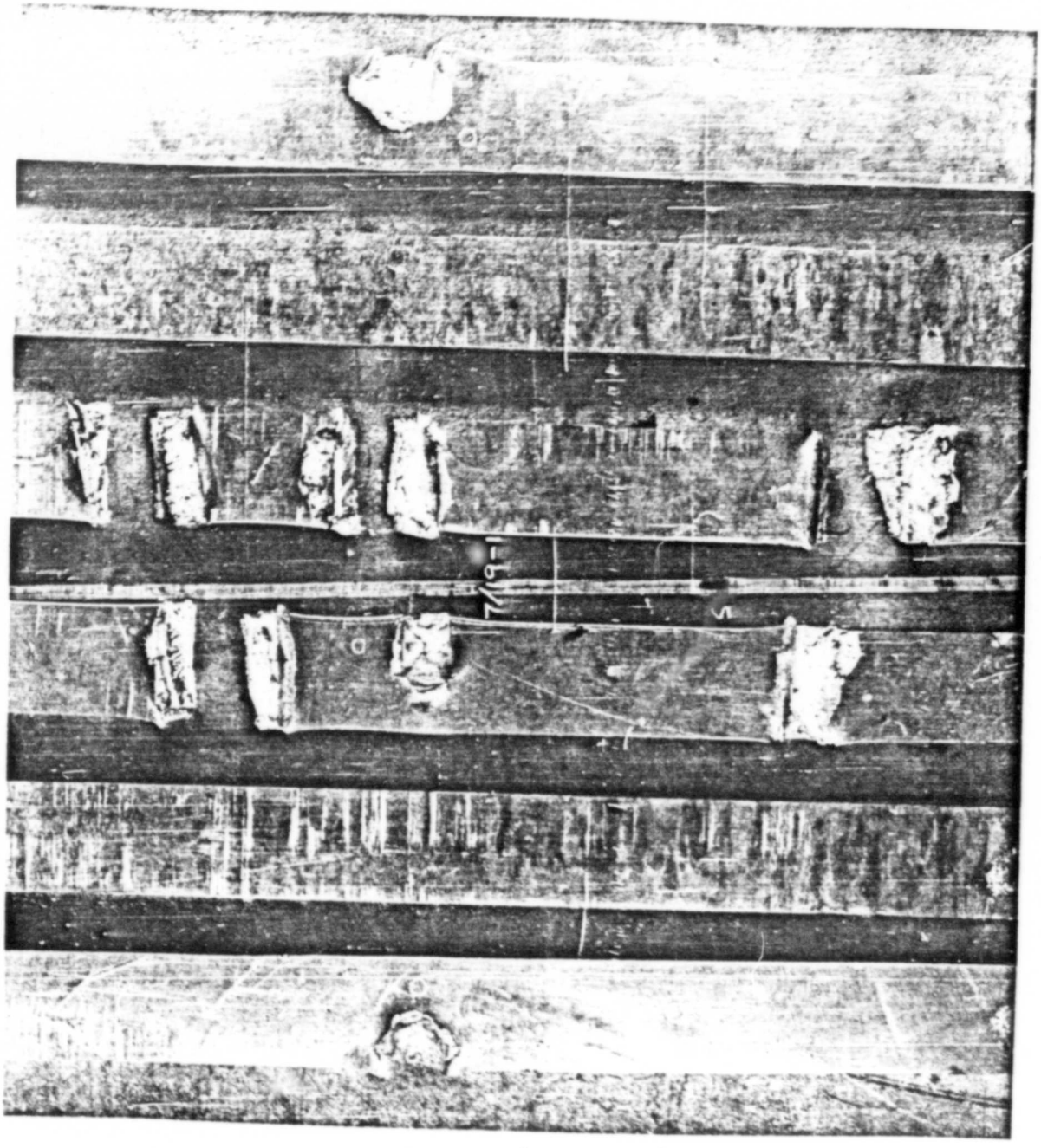
1-1/2" Square 24S-T4 Bars
Figure 14



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1-1/2" Square 24S-T4 Aluminum Bars
Figure 15

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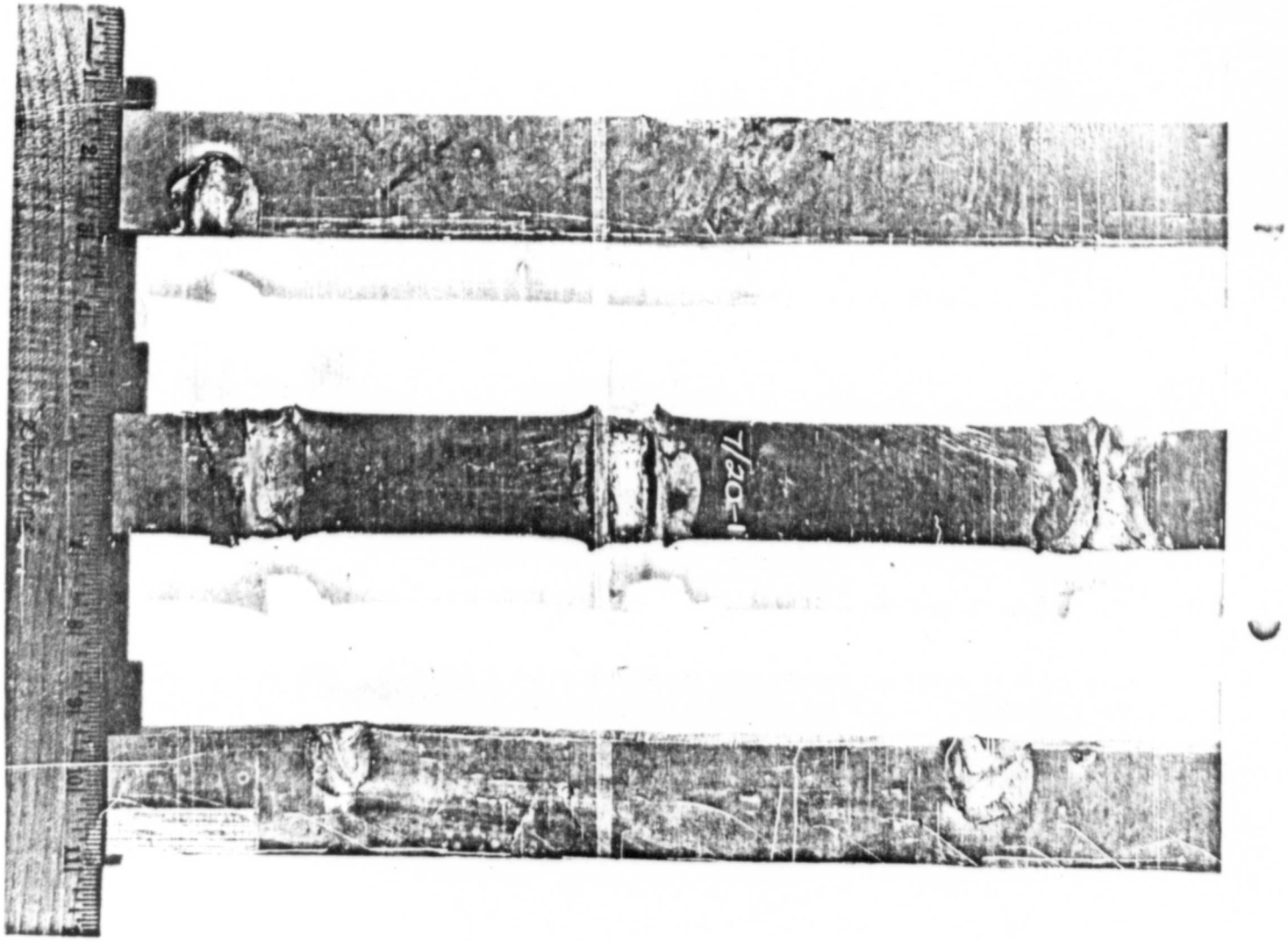
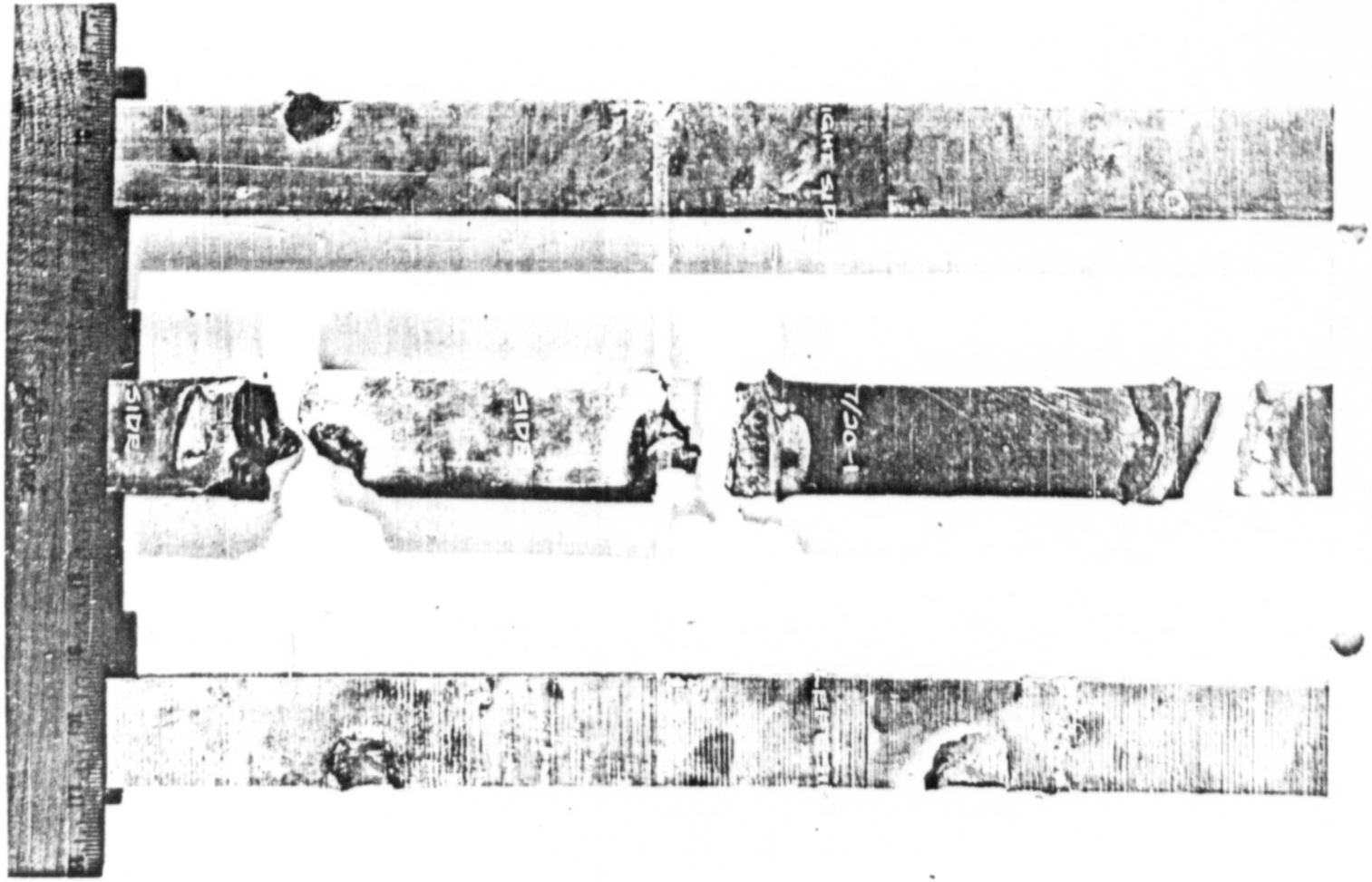
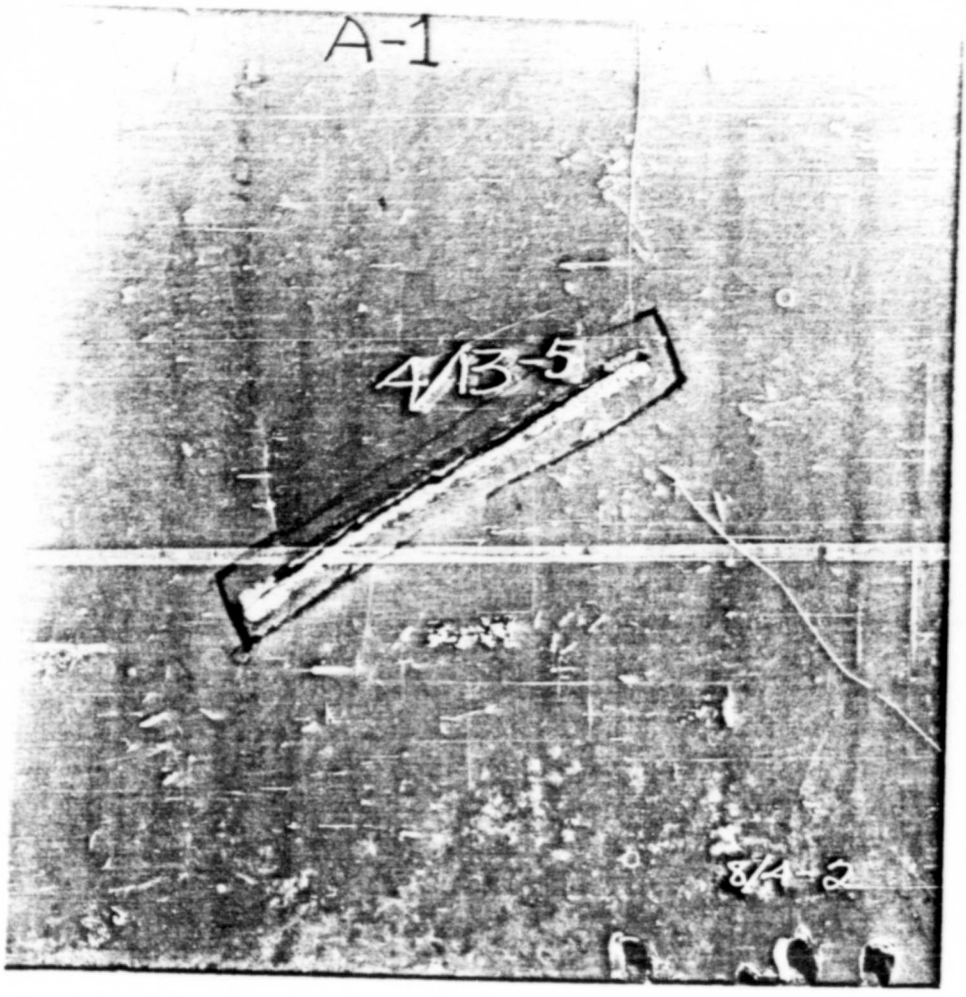
1-1/2" Square 24S-T4 Al· inum Bars
Figure 16



1-1/2" Square 24S-T4 Aluminum Bars
Figure 17





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3/4" Thick 24S-T4 Aluminum Plate
Figure 18

A7

4/13 - IV

III

4/13

II

4/13

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3/4" Thick 24S-T4 Aluminum Plate
Figure 19

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5" Rocket Motor Tube
Figure 20

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5" Rocket Motor Tube
Figure 21

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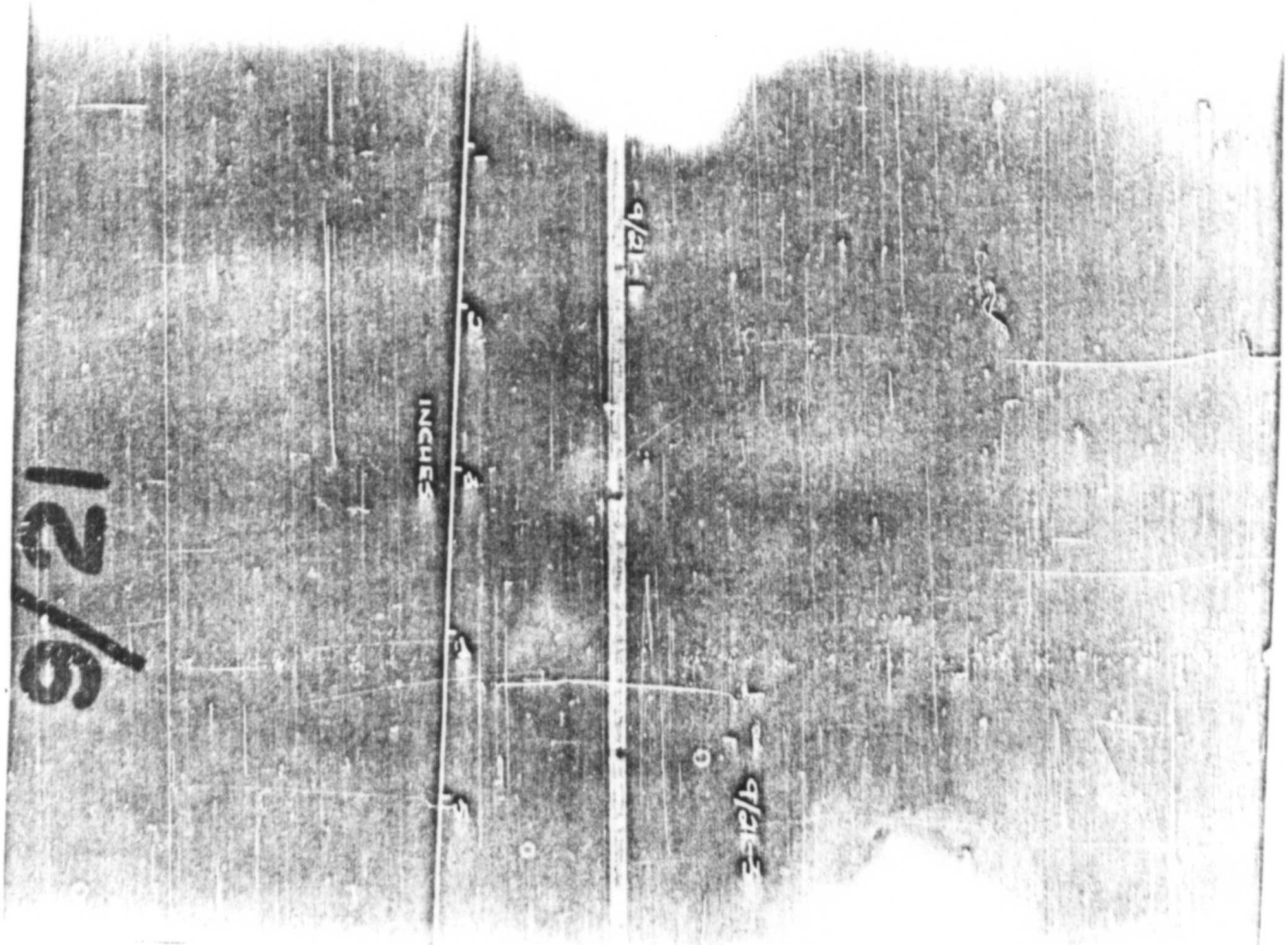
Radiograph of 1-1/2" X 6" 24S-T4 Aluminum Bar
Figure 22



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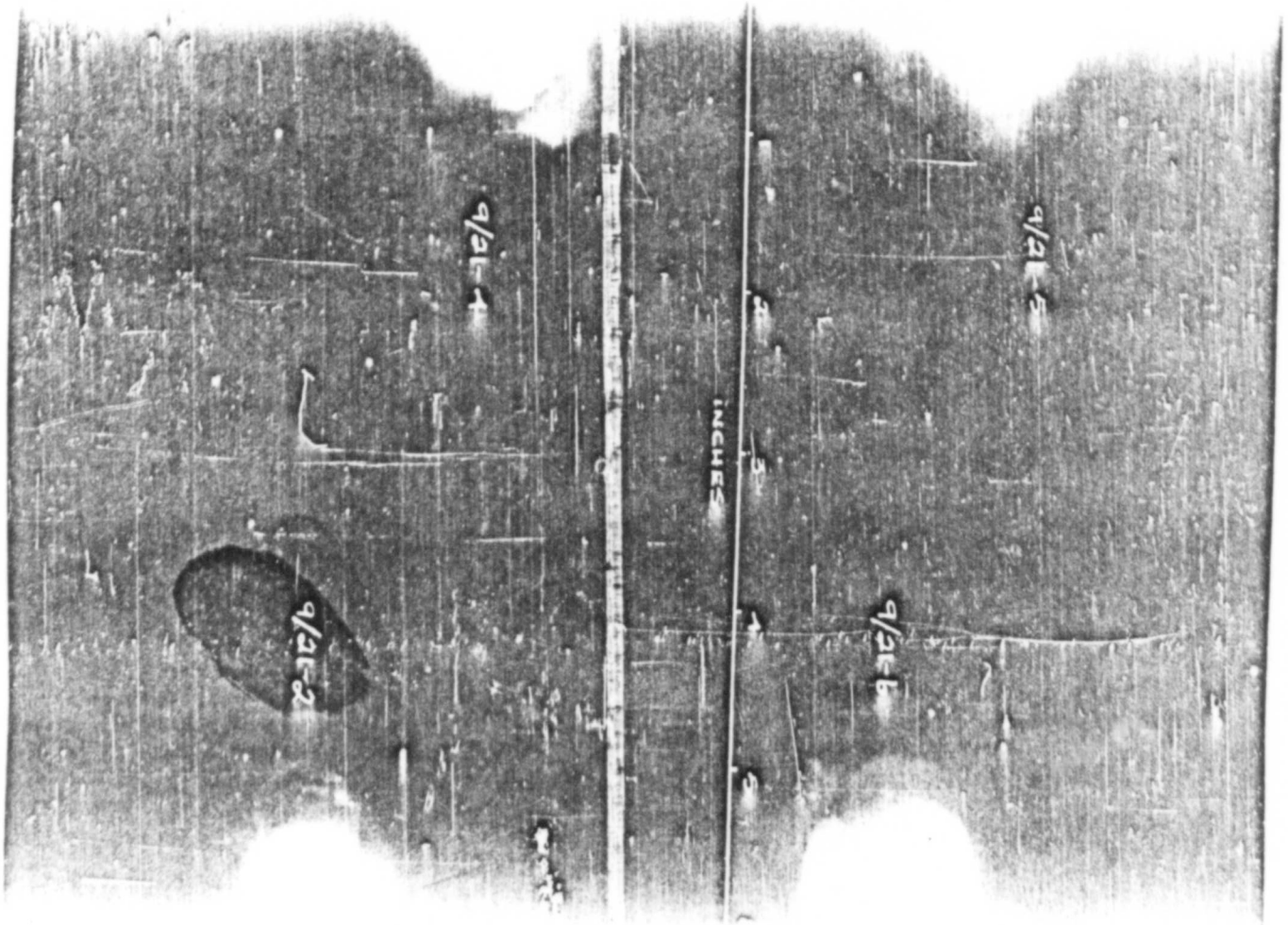
Radiograph of 1-1/2" X 6" 24S-T4 Aluminum Bar
Figure 23



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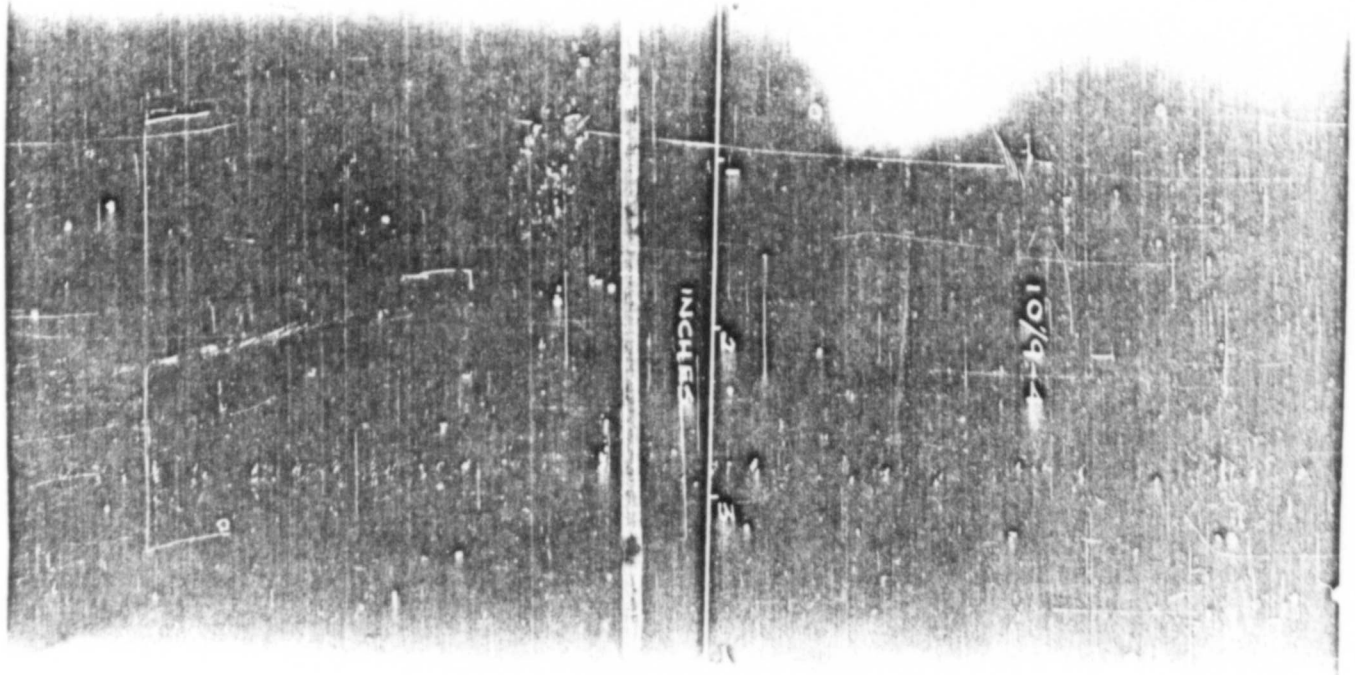
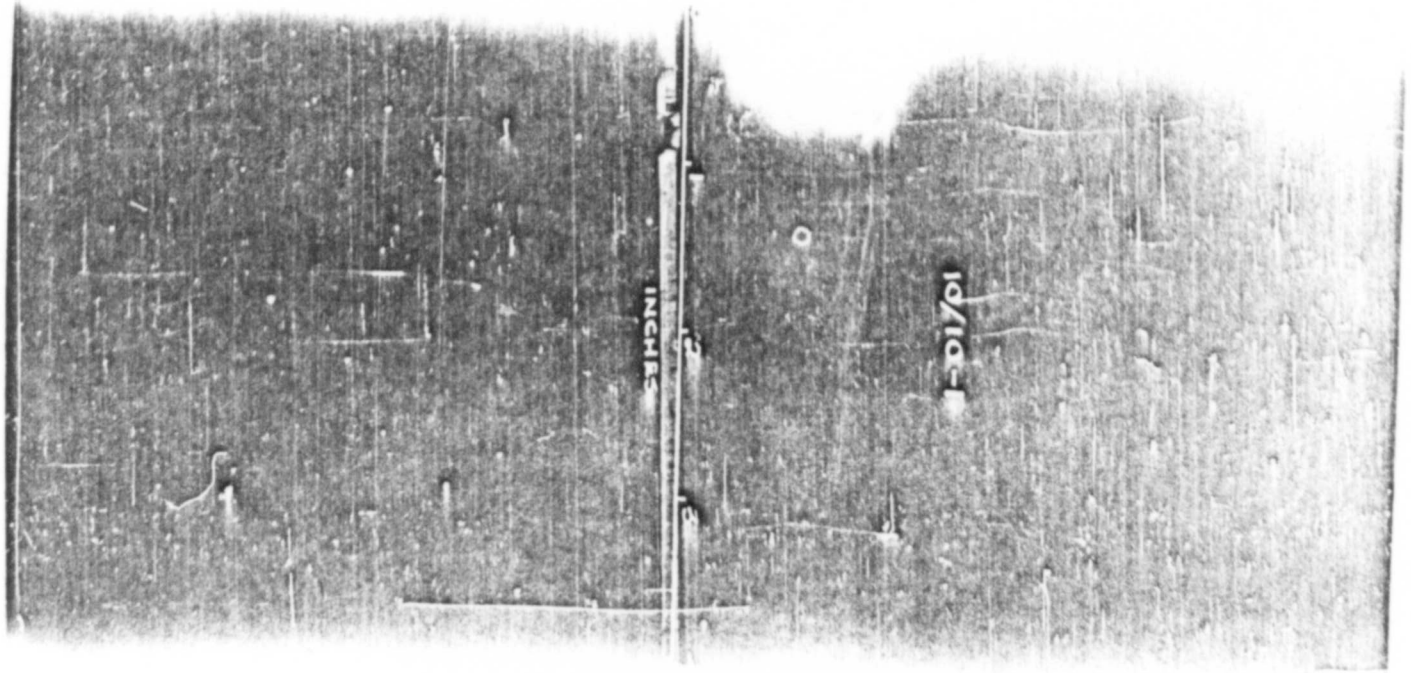
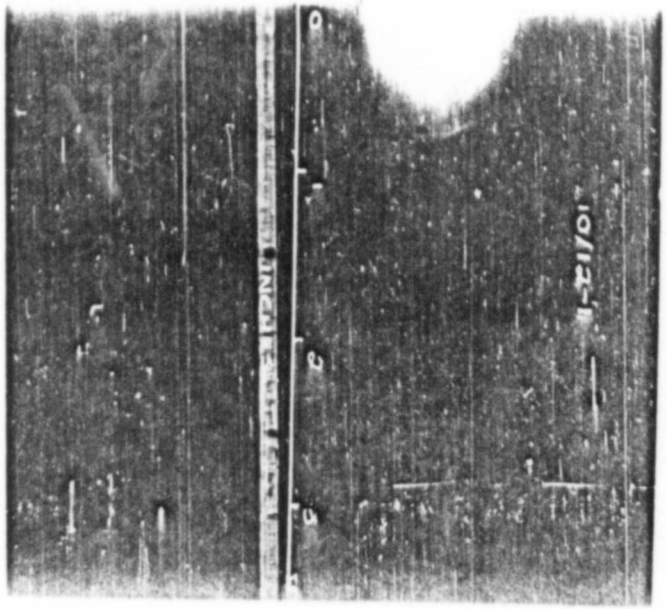
Radiograph of 1-1/2" X 4" 24S-T4 Aluminum Bar
Figure 24



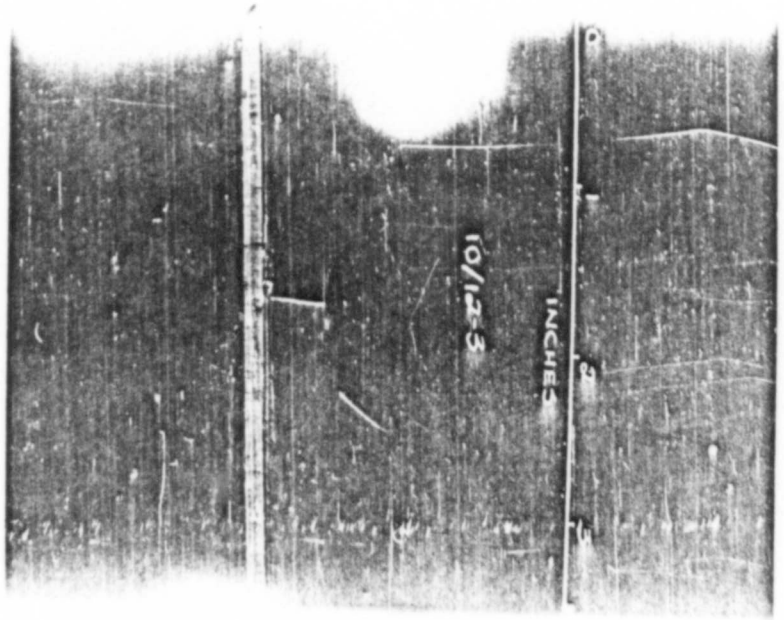
Radiograph of 1-1/2" X 4" 24S-T4 Aluminum Bar
Figure 25

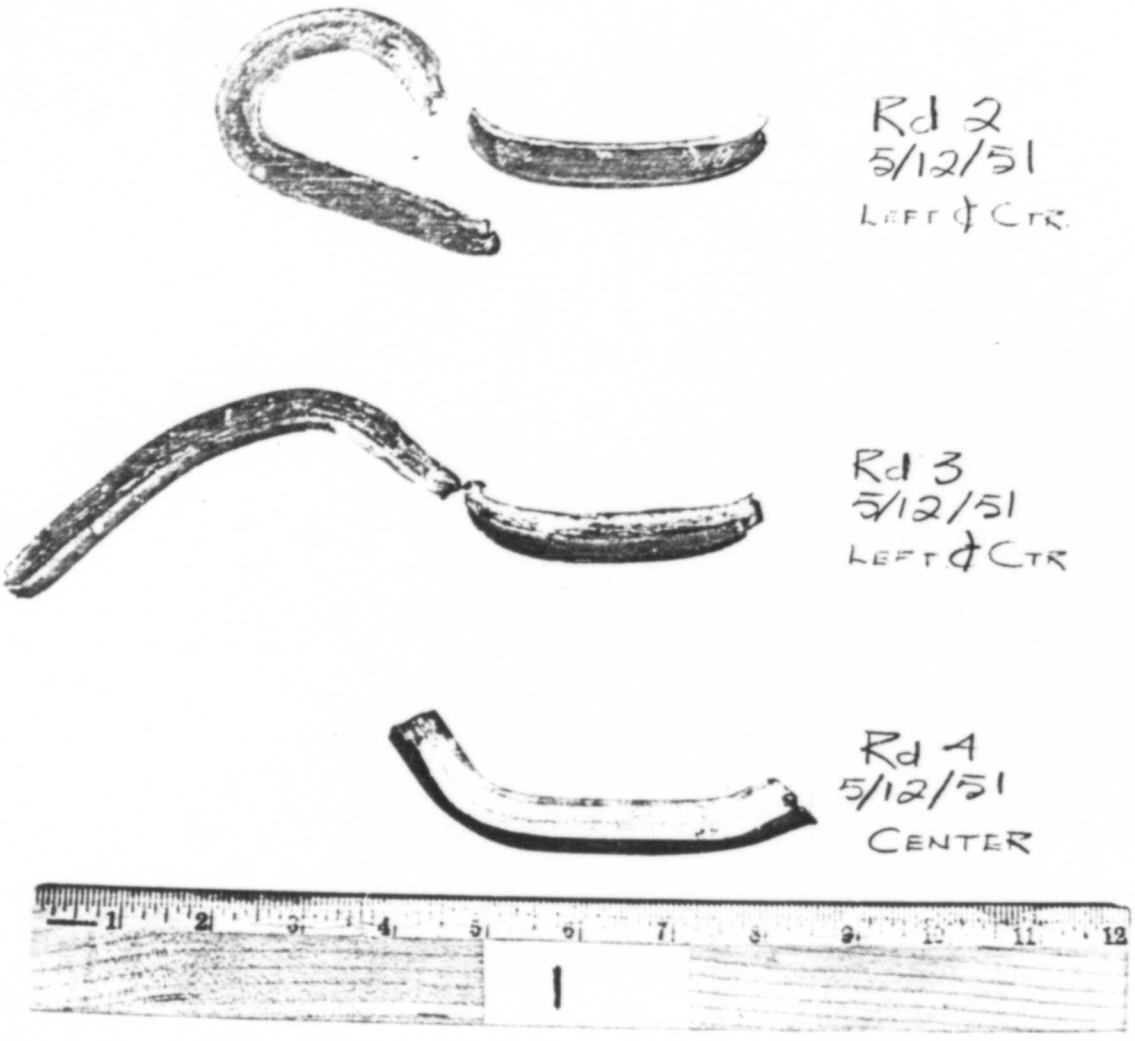


Radiograph of 1-1/2" X 3-1/2" 24S-T4 Aluminum Bar
Figure 26



Radiograph of 1-1/2" X 3-1/2" 24S-T4 Aluminum Bar
Figure 27





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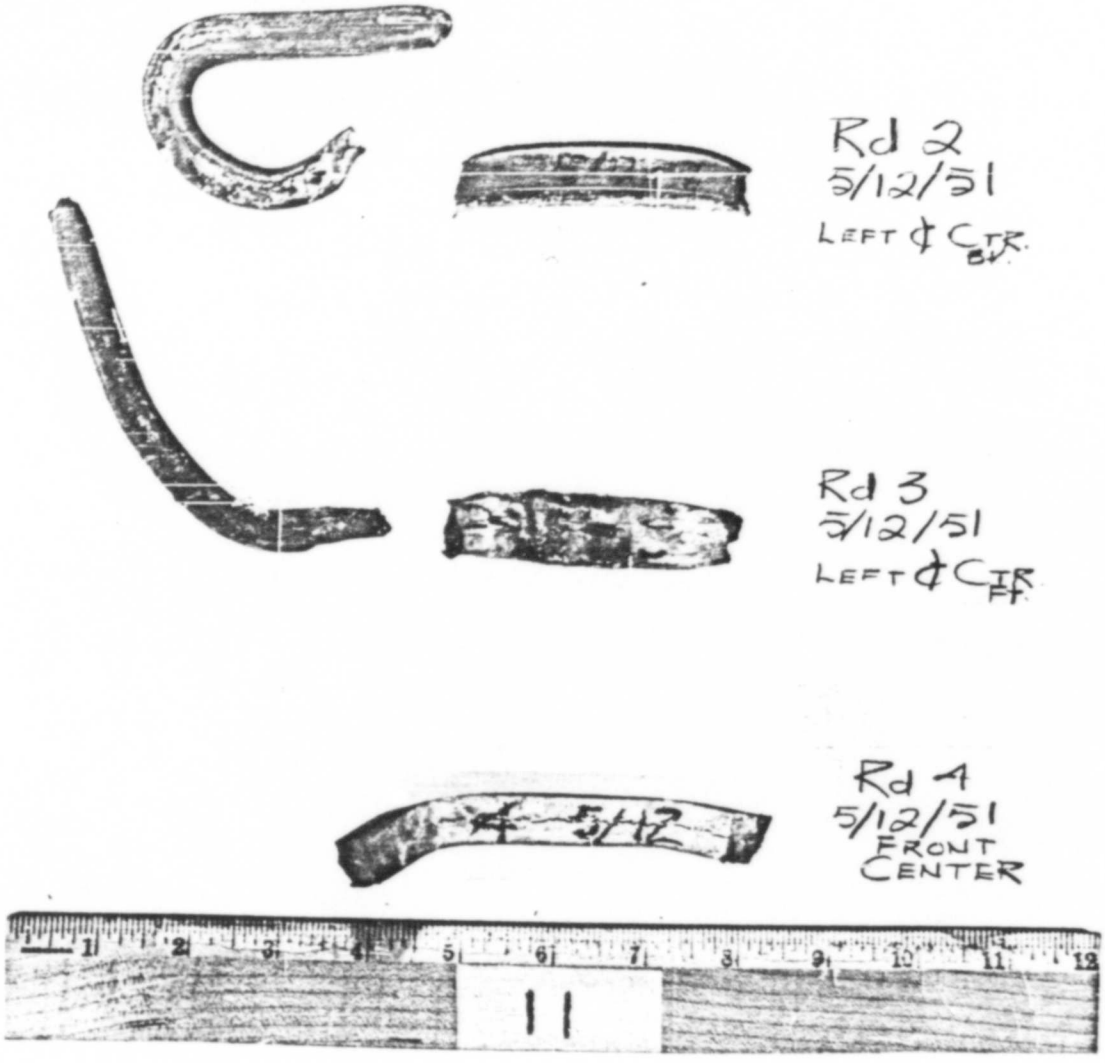
Recovered Rods from R301-W Shots
Figure 28



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Rods Recovered from R301-W Shots
Figure 29

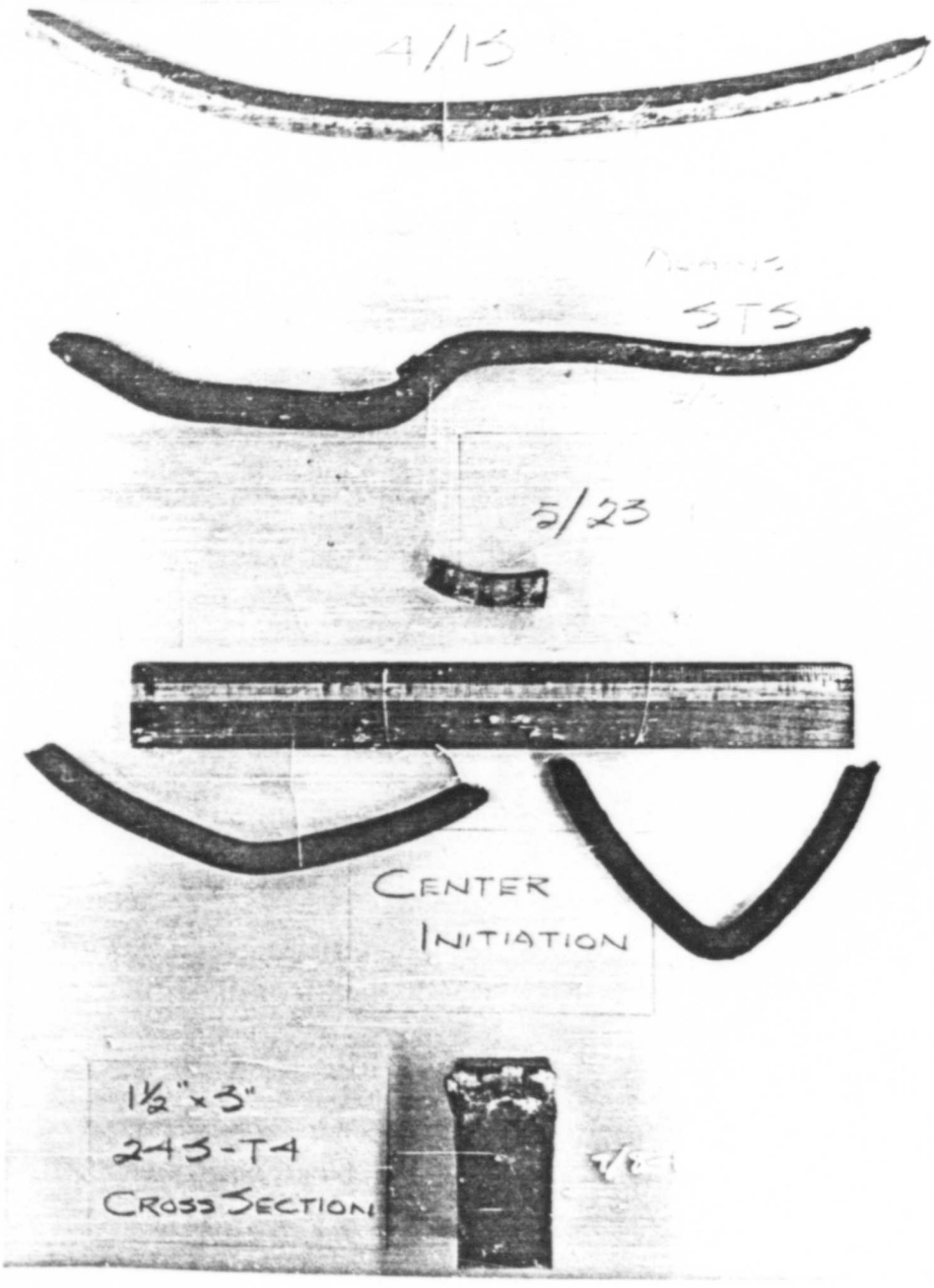

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Figure 30

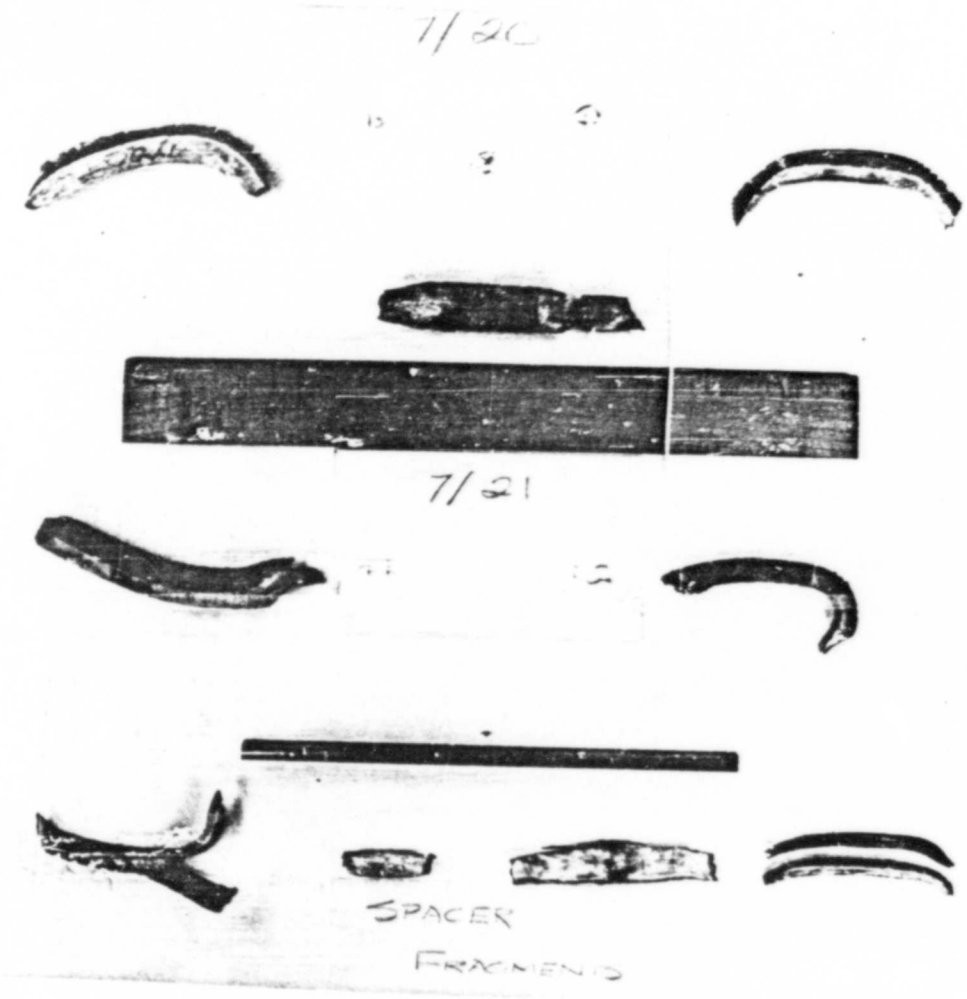

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Figure 31

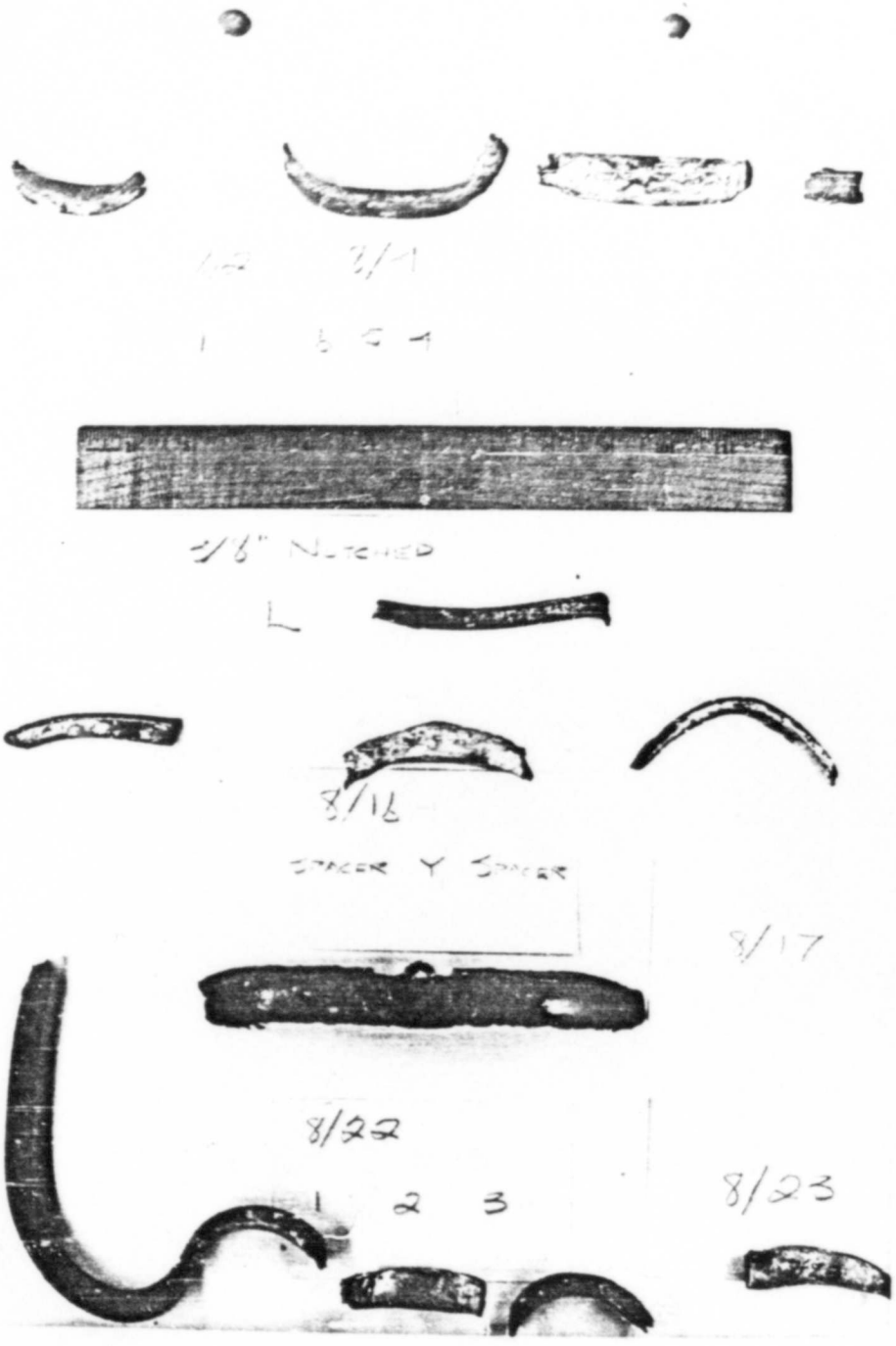

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Figure 32

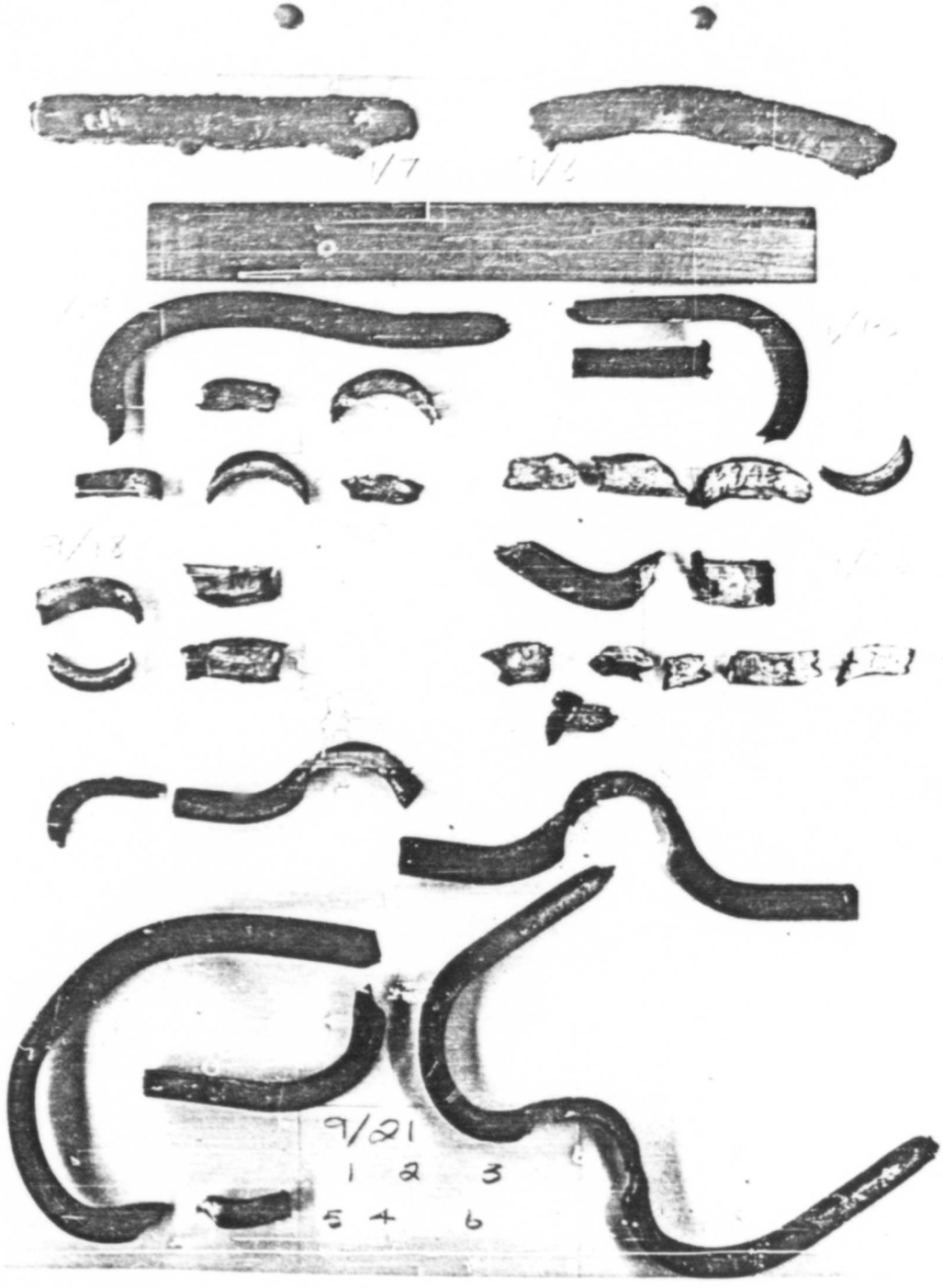

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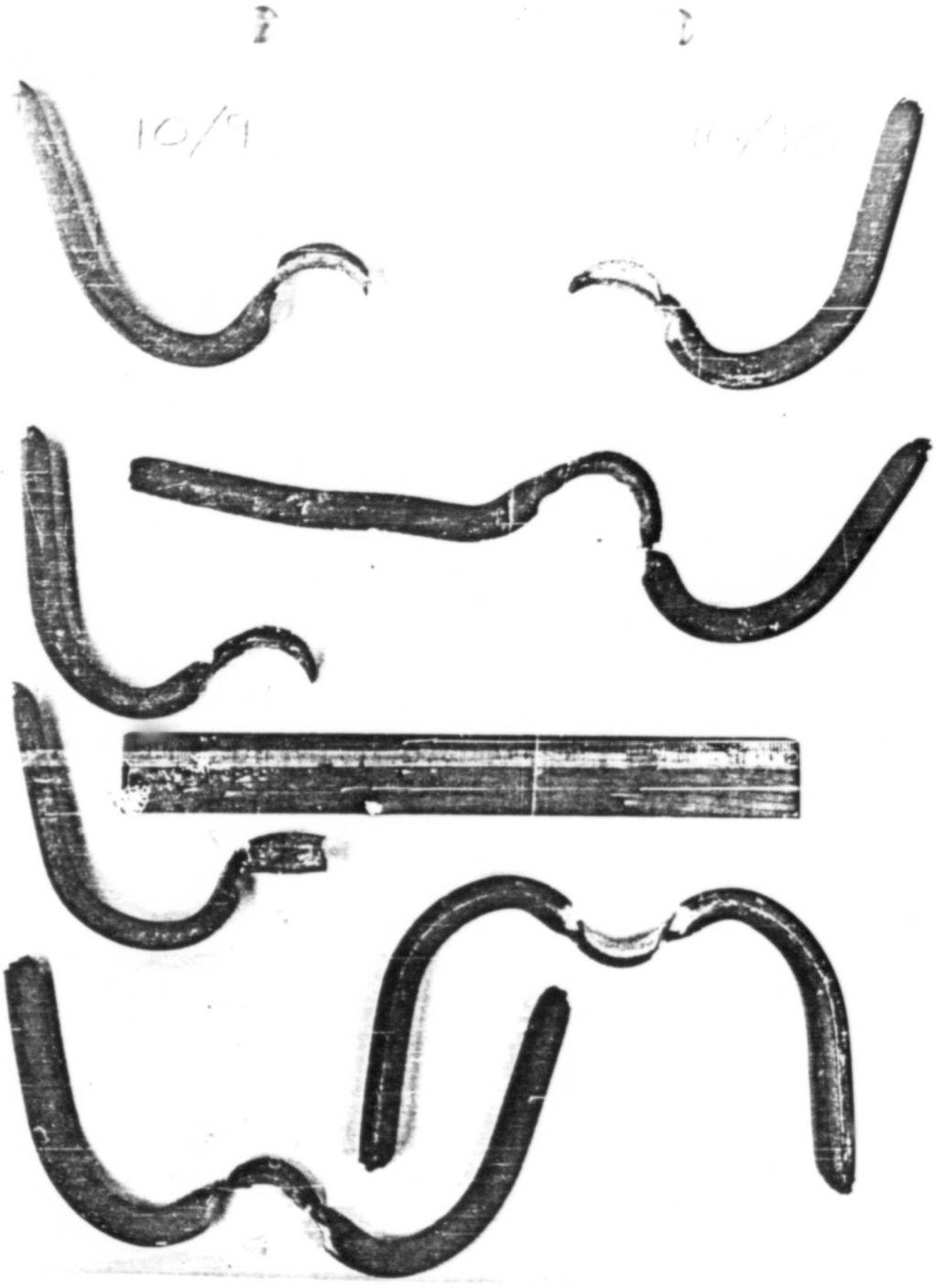
Figure 33



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Recovered Rods Shot Against 1-1/2" Thick Aluminum Bars
Figure 34

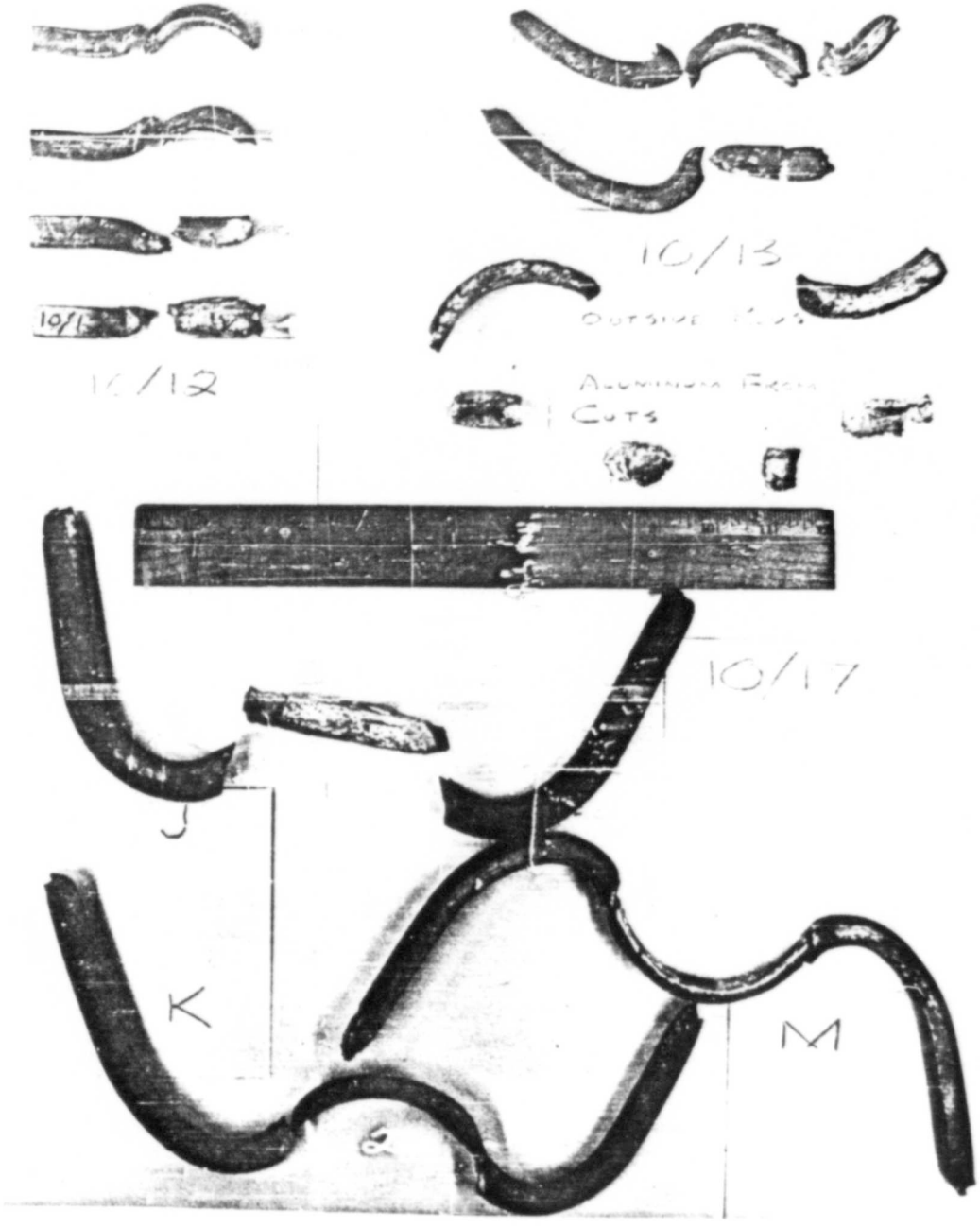

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Figure 35

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