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MEMORANDUM REPORT NO. 1-47

PROGRESS REPORT NO. 1
ON DEVELOPMENT OF HIGH VELOCITY
ARMOR-PIERCING PROJECTILES

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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

NPG MEMORANDUM REPORT NO. 1-47

PROGRESS REPORT NO. 1 ON DEVELOPMENT OF
HIGH VELOCITY ARMOR-PIERCING PROJECTILES

Prepared by: J. J. Glancy
Ordnance Engineer

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MEMORANDUM REPORT NO. 1-47

PREFACE

AUTHORIZATION

This study is being carried out under Bureau of Ordnance Task Assignment Re3b-202-1 as authorized by the Bureau of Ordnance in reference (b). A copy of the local directive for this Task Assignment is included in Appendix III.

OBJECT

This progress report is part of a continuing investigation to develop a 3" armor piercing projectile of improved ballistic quality at high striking velocities and high obliquities. The study described herein was conducted in order to gain more information concerning the behavior of currently available 3" AP projectiles when fired against 3" homogeneous armor at high obliquities and high impact velocities up to the maximum presently obtainable.

SUMMARY

Two available lots of 3" M62 Capped AP projectiles and one lot of 3" Mk. 29-2 Capped AP projectiles were tested versus 3" homogeneous armor at 120,000 p.s.i. tensile strength at 30° and 45° obliquity. Ballistic limits were obtained when possible under the above conditions. Striking velocities of the projectiles were then increased in increments above the limit velocities up to the maximum presently obtainable. The condition of projectiles after impact was observed.

In general the terminal ballistic performance of M62 projectiles was poorer than that of Mk. 29-2 projectiles. In terms of BuOrd Sk. 78841, the ballistic limits of M62 projectiles were higher than those of Mk. 29-2 projectiles. Up to the highest impact velocities obtained and reported herein (approximately 2900 ft./sec.), the Mk. 29-2 projectiles showed no shatter, but the M62 projectiles split and broke up on impact even at striking velocities above the limit. The hardness pattern made of one M62 projectile shows a soft area at the nose which probably accounts for the poor performance of the M62 projectiles.

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REFERENCES

- (a) Definitions of Terms Used in the Ballistic Testing of Armor. Revision B. U. S. Naval Proving Ground Report No. 10-46 dated June 1946.
- (b) BuOrd ltr. S78-1(55) Re3 (Re3b-202) dated 30 September 1947 to NPG.
- (c) BuOrd ltr. S78-1(55) Re3 (Re3b-202) dated 8 August 1947 to NPG.
- (d) Office of the Chief of Ordnance ltr. ORDTM dated 28 July 1947 to BuOrd.

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I. INTRODUCTION

The contemplated use of high muzzle velocity guns makes it important that the Army and Navy develop armor-piercing projectiles with satisfactory performance against armor at high striking velocities. The Naval Proving Ground has undertaken the task of developing 3" armor-piercing projectiles with improved ballistic qualities at high striking velocities and high obliquities. Additional information about this task is given in references (b), (c), and (d). This first progress report describes the performance of two existing 3" AP projectiles at striking velocities above limit against 3" homogeneous armor at 30° and 45° obliquity.

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II. MATERIALS AND METHODS

Projectiles:

Chevrolet 14.7 lb. 3" M62 Capped AP Projectile

Lot CM-2-81-1943 and Lot CM-3-59-1943

Olasmobile 13 lb. 3" Mk. 29-2 Capped AP Projectile
Lot 130-1942

Figure 1 is a photograph of these projectiles.

Figure 2 is a hardness pattern of 3" M62 projectile
Lot-2-81-1943.

Plates:

3" Class B Carnegie-Illinois No. X-9021

3" Class B Carnegie-Illinois No. BD-389 1/4

Chemical Analysis of Plates

	C	Mn	P	S	Si	Ni	Cr
C.I. X-9021	.31	.25	.013	.020	.08	3.26	1.43
C.I. BD-389 1/4	.34	.25	.013	.020	.08	4.10	2.23

Physical Properties of Plates

Two 3' x 3' sections from each of the above plates were used in the ballistic tests. The following table lists the arbitrary numbers assigned each of the sections and the physical properties of each plate section:

Table I

Plate	APL Plate No.	Y.S. (.2%)	T.S.	% El.	% RA	BHN	RC
C.I. X-9021	673	102,475	121,650	22.0	60.3	256	23.8
C.I. X-9021	675	101,725	120,800	22.3	62.0	256	23.1
C.I. BD-389 1/4	676	98,600	120,100	24.0	67.9	255	23.1
C.I. BD-389 1/4	677	101,100	120,300	23.0	65.3	256	23.0

Yield Strength (Y.S.), Tensile Strength (T.S.), % Elongation (% El.), and % Reduction of Area (% RA) are the average of two tests. Brinell Hardness Number (BHN) and Rockwell "C" Hardness (Rc) are the average of five readings.

Methods:

All ballistic limits in this report are expressed in terms of $F(e/d, \theta)$ values, where $F(e/d, \theta)$ is defined as follows:

$$F(e/d, \theta) = \frac{41.57 M^{1/2} V_L \cos. \theta}{e^{1/2} d}$$

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NP9-35625 - 3" Projectiles used: Left, 3" Mk. 29-2 AP Capped Lot 130-1942, Manufacturer - Oldsmobile; Right, 3" M62 AP Capped Lot CM-2-81-1943, Manufacturer - Chevrolet.
October 1947

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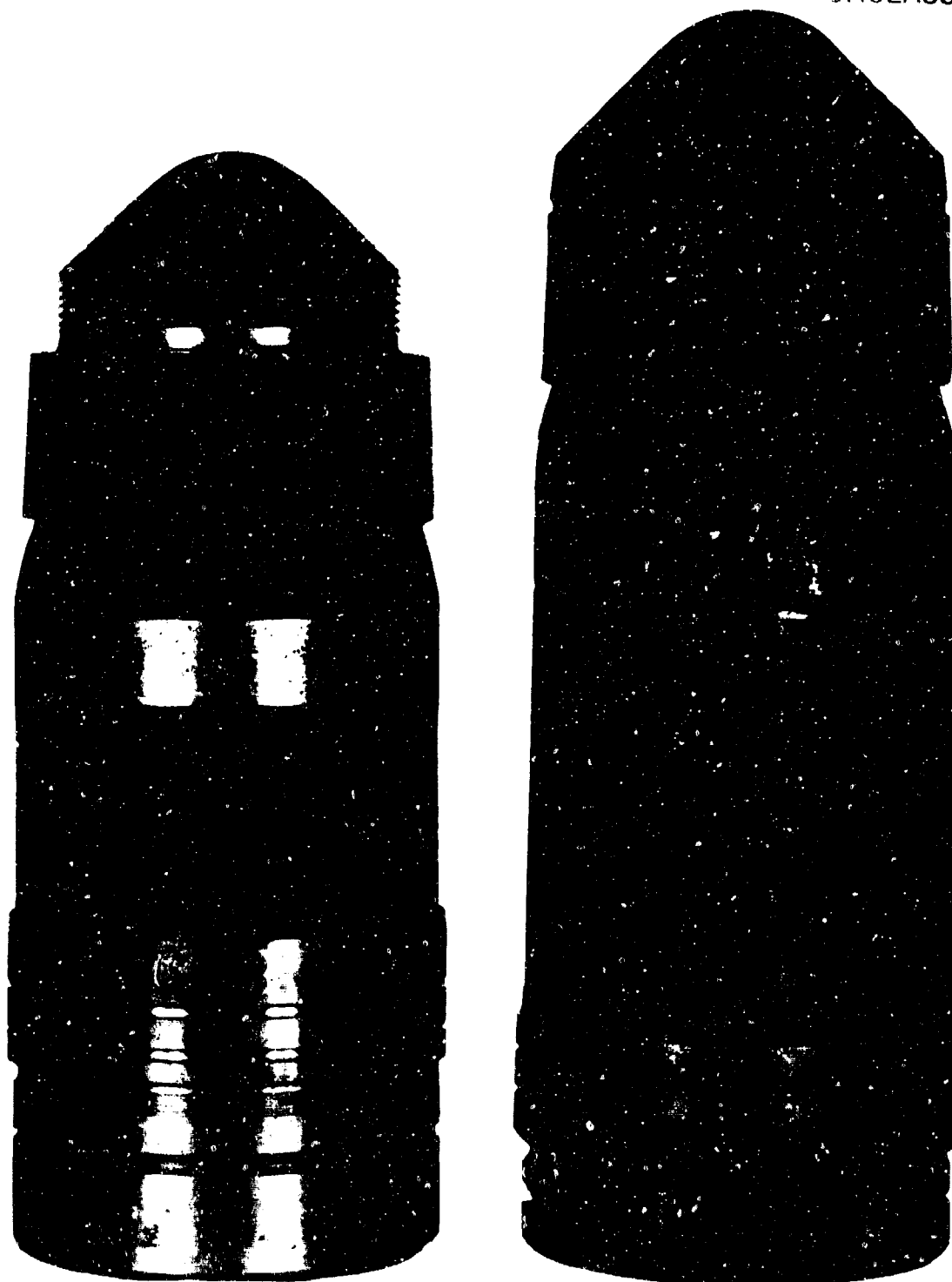


FIG. 1

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NP9 35487

17 OCTOBER 1947

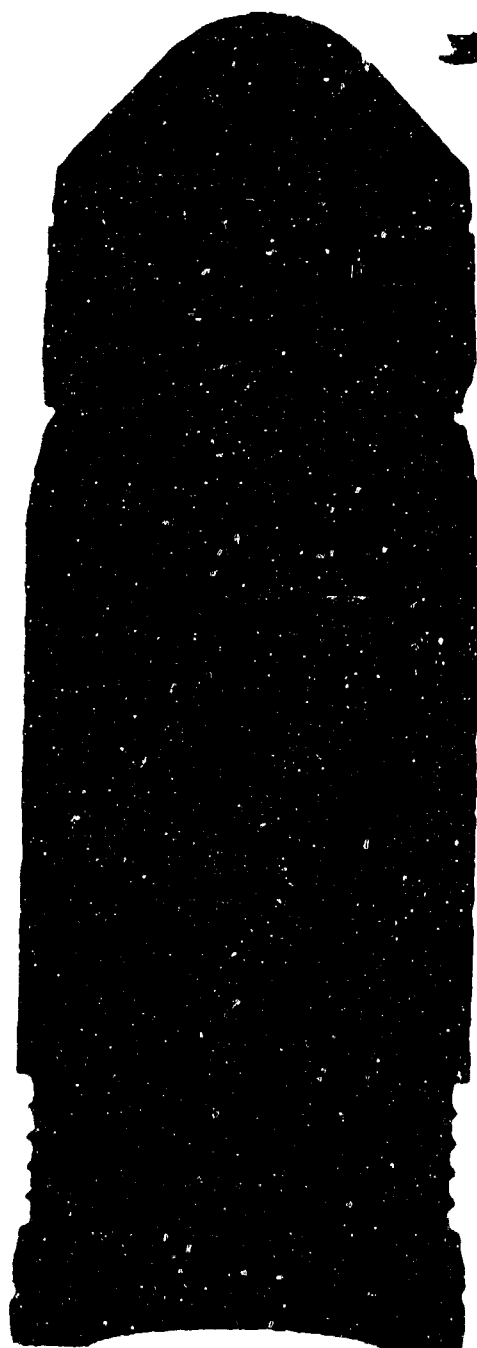
HARDNESS DISTRIBUTION AND MACROSECTION OF

3" AP PROJECTILE M62 MANUFACTURED BY

CHEVROLET LOT No. CM-2-81

Hardness Values: Vickers Pyramid (50 kg.)

Etch: Ammonium Persulphate



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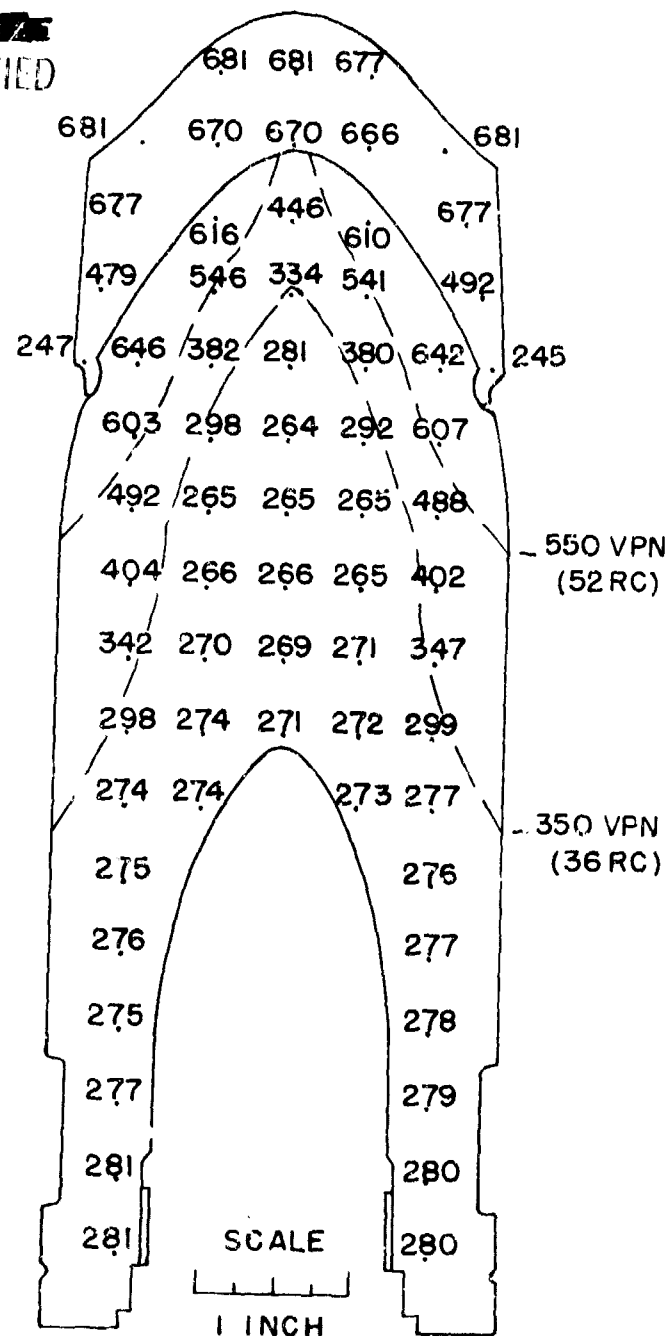


FIG. 2

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Where

M , is the projectile mass in pounds, V_L , is the limit velocity in feet per second (the minimum velocity required for the major portion of the projectile to pass completely through the plate), θ , the obliquity, is the angle between the normal to the plate and the line of flight, e , is the plate thickness in inches at the point of impact, and d , is the diameter of the projectile in inches. All quantities entering on the right side of the defining expression above are susceptible of measurement. The limit penetration coefficient, or F-coefficient, as the method of writing shows, is a function of e/d and θ only. Its usefulness lies in the fact that it is a slowly varying function of these quantities and that its use enables comparison between plates of slightly differing thicknesses tested at slightly differing obliquities by projectiles of slightly differing properties.

The striking coefficient, usually designated by F_s , is defined in the same manner as the F-coefficient except that the velocity entering into the formula is striking velocity rather than limit velocity. It is useful for interpolation in allowing for small changes in obliquity and thickness for the several impacts in a limit determination.

It is customary in the Navy to refer F-coefficients to the empirical expression, derived from a 1931 analysis of penetration data, embodied in Bureau of Ordnance Sketch No. 78841. F-coefficients thus referred are expressed as "% Sk. 78841". In this connection care must be taken not to expect that a plate of average quality will necessarily have a limit of 100%, and by the same token, not to compare limits in % Sk. 78841 taken under widely differing conditions.

More complete information on all the above terms is to be found in reference (a).

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III. RESULTS

The results are given in detail in Appendices I and II and are summarized in Table II.

IV. DISCUSSION:

3" Mk. 29-2 Capped A. P. Projectiles.

Against 3" homogeneous armor at 30° and 45° obliquity the 3" Mk. 29-2 projectiles generally remained intact and effective at striking velocities up to the maximum velocity tested to date, namely, up to approximately 2900 feet per second.

3" M62 Capped A. P. Projectiles.

Against 3" homogeneous armor at 30° and 45° obliquity the M62 projectiles from both lots fired showed a tendency to split and break up at striking velocities up to the maximum velocity tested to date, namely, up to approximately 2700 feet per second.

Future Action.

A lot of M62 projectiles of proven high quality is being procured and tests of this lot should definitely establish the ballistic quality of the M62 projectile. In addition tests of currently available 3" projectiles will continue at higher velocities and other conditions until complete data are obtained.

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TABLE II
SUMMARY OF BALLISTIC RESULTS

Projec- tile	No. Rounds Fired	Armor	Obl.	VL Limit		Maximum *		Remarks		
				Vel. Ft/Sec	F(e/d,θ) % Sk. 78841	Vel. Ft/Sec	Fs % Sk. 78841			
3" AP M62	8	Homo. T.S. 121,000 p.s.i.	30°	2420	64,500	127	2661	71,000	139.8	Projectiles split or broke up on most impacts.
3" AP Mk.29-2	10	Homo. T.S. 121,000 p.s.i.	30°	2322	58,400	114	2810	70,700	138.6	Projectiles did not shatter or break up on any impact.
3" AP M62	2	Homo. T.S. 120,000 p.s.i.	45°	2611	Greater than 56,800	Greater than 106.2	2611	56,800	106.2	Projectiles broke up and could not penetrate the armor at any striking velocity ob- tained to date.
3" AP Mk.29-2	7	Homo. T.S. 120,000 p.s.i.	45°	2708	55,600	103	2898	59,500	110.5	Projectiles did not shatter or break up on any impact.

Maximum velocity fired to date.

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V. FACILITIES

Certain special tools needed for the fabrication of projectiles are being obtained by the Navy. Procurement of these is proceeding satisfactorily. It is expected that the task of manufacturing the first complete projectile can be undertaken by 1 April 1948.

In addition, steps have been taken to obtain an experimental, high-velocity gun. A 5"/51 caliber gun lined down to 3" caliber has been ordered for this purpose. It will take, however, at least six (6) months to obtain this gun. It is hoped to minimize the time interval before high velocities can be obtained by the temporary use of a 3"/70 gun.

J. J. Glancy
J. J. Glancy
Ordnance Engineer

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APPENDIX I

IMPACT DATA

3" M62 & 3" Mk. 29-2

vs

3" Class B Plate

at

30 ° & 45° obliquity

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SYMBOLS

e - - - - - Plate thickness at impact in inches

θ - - - - - Obliquity. Angle between trajectory and normal to plate at impact.

M - - - - - Projectile mass in lbs.

V_S - - - - - Striking velocity in feet per second.

Pene. - - - - - Depth of penetration in inches measured from front surface normal to plane of plate.

$F(e/d, \theta)$ - - F coefficient - Limit penetration coefficient.

F_S - - - - - The striking coefficient - It is the same as the F coefficient except that striking velocity is used instead of limit velocity.

% - - - - - Limit Penetration F coefficient in % of empirical $F(e/d, \theta)$ value (BuOrd Sk. 78841).

CP - - - - - Complete penetration. Major portion of projectile completely through the plate.

Inc. - - - - - Incomplete penetration. Major portion of the projectile rejected.

SIP - - - - - Projectile stuck in plate.

Intact - - - - - Projectile whole but may be deformed.

Eff. - - - - - Effective. Cavity and base plug not injured. Projectile would detonate if loaded and fuze.

Split - - - - - The projectile split into two or more parts along its longitudinal axis.

For ballistic limit and other definitions see reference (a).

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ARMOR AND PROJECTILE LABORATORY									
NAVAL PROVING GROUND									
DAHLGREN, VIRGINIA									
NP3 35455									
MFG GARRAGE 318 Cl. 13-									
MFG PLATE NO X-9021									
MFG TENSILE STRENGTH (AS)									
(121700) PSI.									
IMPACT DATA									
PROJECTILE									
IMPACT NO.	THICKNESS	CONDITION	MAG MARK MOD	ORIGINAL DIAMETER	FINAL DIAMETER	MASS	CONDITION	OBLIQUITY	STRIKING VELOCITY
4872 3:212	Ragged hole		Olds. 3"	CR-9		13.00	Base cracked, not eff.	30° 22' 2367	Inc. 1.08 57.500 112.7
4873 3:209	Good retelling		YK-29-2	2:980		13.00	Base cracked off, not eff	30° 22' 2428	Inc. 1.08 59.500 118.3
4874 3:206	Petals wiped, Clean hole.		Lot 130	CR-10		13.00	Base cracked off, not eff	30° 22' 2428	Inc. 1.08 59.500 118.3
4875 3:211	Petals wiped, Clean hole.		"	CS-1		13.00	Nose cracked, effective	29° 40' 2571	Op. 1.08 52.800 123.1
4876 3:212	Petals wiped, Clean hole		"	CS-2		13.00	Nose cracked, effective	30° 20' 2542	Op. 1.08 54.200 125.9
4877 3:212	Petals wiped, Clean hole		"	CS-3		13.00	Nose cracked, effective	30° 20' 2747	Op. 1.08 55.500 130.4
4878 3:207	Petals wiped, Clean hole		"	CS-4		13.00	Intact, effective	30° 10' 2655	Op. 1.08 54.400 129.3
4879 3:209	Petals wiped, Clean hole		"	CS-5		13.00	Intact, effective	30° 10' 2817	Op. 1.08 58.400 134.1
4880 3:211	Petals wiped, Clean hole		"	CS-6		13.00	Intact, effective	30° 20' 2879	Op. 1.08 59.800 135.9
4890 3:211	Petals wiped, Clean hole		"	CS-7		13.00	Intact, effective	30° 20' 2920	Op. 1.08 70.200 138.5
VI Min Limit = (114%) (P = 58,400 ± 500)									
VS Min Limit = (119%) (P = 60,500 ± 1000)									
Projectiles did not shatter up to (138.6%) (P = 70,700)									

3:204	0	2	1	3:213
3:214	0	5	6	3:211
3:215	0	5	7	3:205

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APL PLATE NO 305
MFG Carnegie, 3 1/2" O.D.
MFG PLATE NO 30-399
TENSILE STRENGTH
(80,100) PSI

IMPACT DATA

TPC TENSILE STRENGTH
(120,100) PSI

PLATE			PROJECTILE									
IMPACT NO	THICKNESS	CONDITION	MAR. AND MOD.	ORIGINAL DIAMETER	FINAL DIAMETER	MASS	CONDITION	OBLIQUITY	STRIKING VELOCITY	PENETRATION	E/D	STRIKING COEFFICIENT
4893	3/047	Clear hole	4115.8" Cr-9	2890	13.00	Intact, effective	44°40'	2810 Cr.	1.00	57,500	107.5	107.5
4894	3/055	Clear hole	4129.5 Cr-10	2890	13.00	Base cracked, effective	45°00'	2730 Cr.	1.00	55,500	107.9	107.9
4895	3/059	2 5/8" rent.	"	2891	13.00	Base cracked, effective	44°40'	2752 Inc.	1.00	55,500	107.3	107.3
4896	3/053	2 1/2" Pent.	"	2891	13.00	Base gouged, not effective	44°40'	2750 Inc. 3rd.	1.02	55,500	107.6	107.6
4897	3/044	Clear hole	"	2890	13.00	Base gouged, effective	44°40'	2900 Cr.	1.00	59,500	110.3	110.3
4898	3/040	2 1/2" Pent.	"	2892	13.00	Base gouged, effective	44°40'	2972 Inc.	1.02	55,500	105.4	105.4
4899	3/035	R.B. on back	"	2891	13.00	Base gouged, effective	44°40'	2701 Inc.	1.02	57,500	107.3	107.3
VL Min and 72 Min = (1035) (7=55,500)												
Projectiles Did Not Chapter At Velocities "To (2102) (7=59,500)												

34054	3	4	34045
34064	2	5	34041
34053	1	6	34025

APL PLATE NO 577
MFG Carnegle 30 Cl. "B"
MFG PLATE NO 3D-389 (A2)
G TENSILE STRENGTH
(20,300) PSI.

IMPACT DATA

31008	21094	
31020	21090	
31072	31060	

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APPENDIX II

IMPACT PHOTOGRAPHS

3" M62 & 3" Mk. 29-2

vs

3" Class B Plate

at

30° & 45° obliquity

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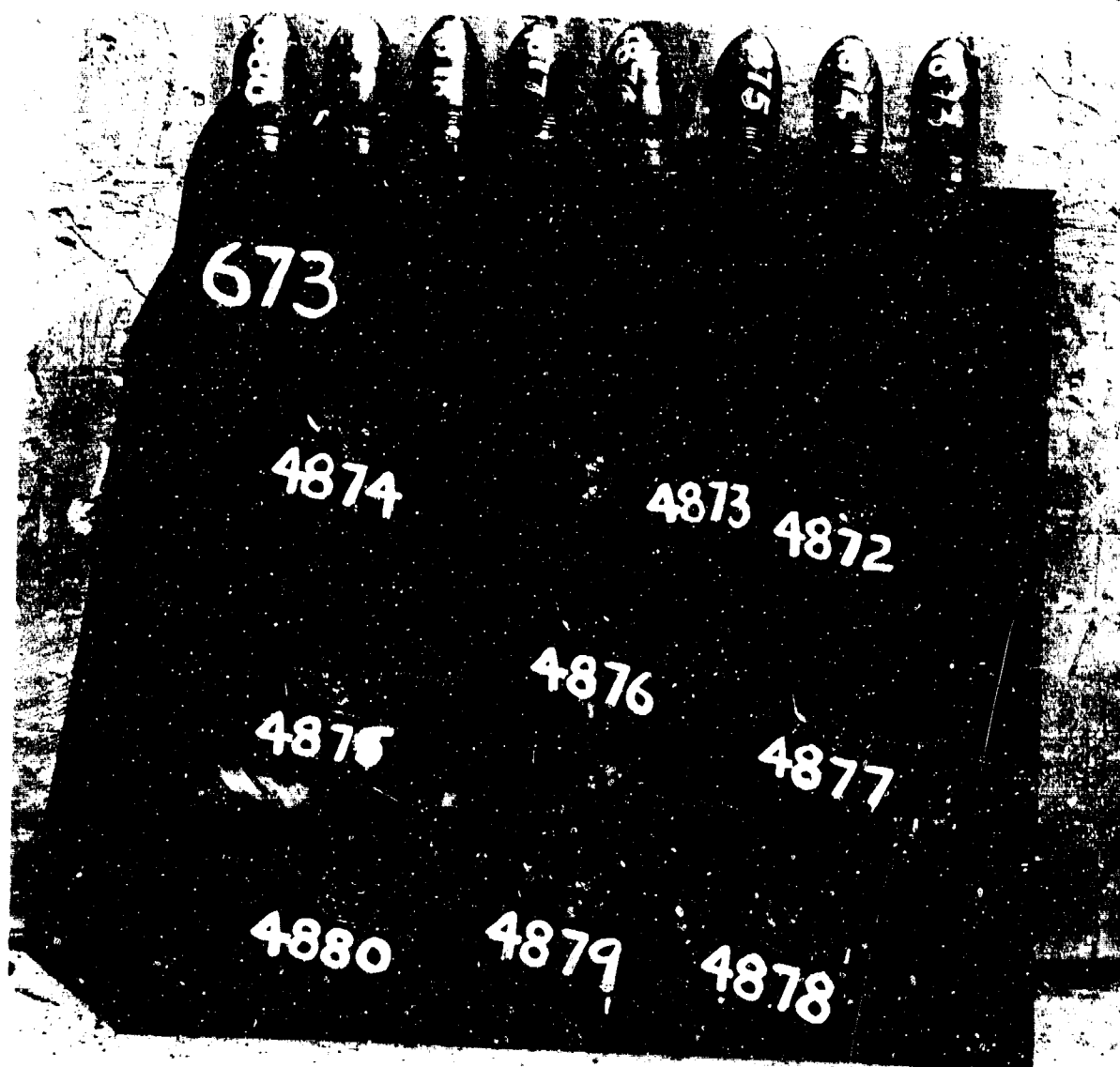


NP9 35361 - APL Plate No. 673 (370 Cl. "B" S.I. No. X9021) W.S. 1-1,700 psi vs.
3" AP Mk. 29-2 Projectiles at 30° Obliquity. FRONT VIEW. See NP9 35373 for back
view.

B.I. No.	"a"	"b"	S.V. (f.s.)	%	Pen.	Proj. Cond.
4872	37212	30°00'	2367	112	S.I.F. 6"	Base Cracked, not eff.
4873	37209	29°30'	2428	116	Cp.	Base Cracked off, not eff.
4874	37206	29°40'	2571	123	Cp.	Nose Cracked, eff.
4875	37211	30°00'	2642	126	Cp.	Nose Cracked, eff.
4876	37212	30°20'	2747	130	Cp.	Nose Cracked, eff.
4877	37212	30°10'	2655	126	Cp.	Intact, eff.
4878	37207	30°15'	2817	134	Cp.	Intact, eff.
4879	37209	30°20'	2879	137	Cp.	Intact, eff.
4880	37211	30°20'	2920	139	Cp.	Intact, eff.

15, 17 Sept. 1947

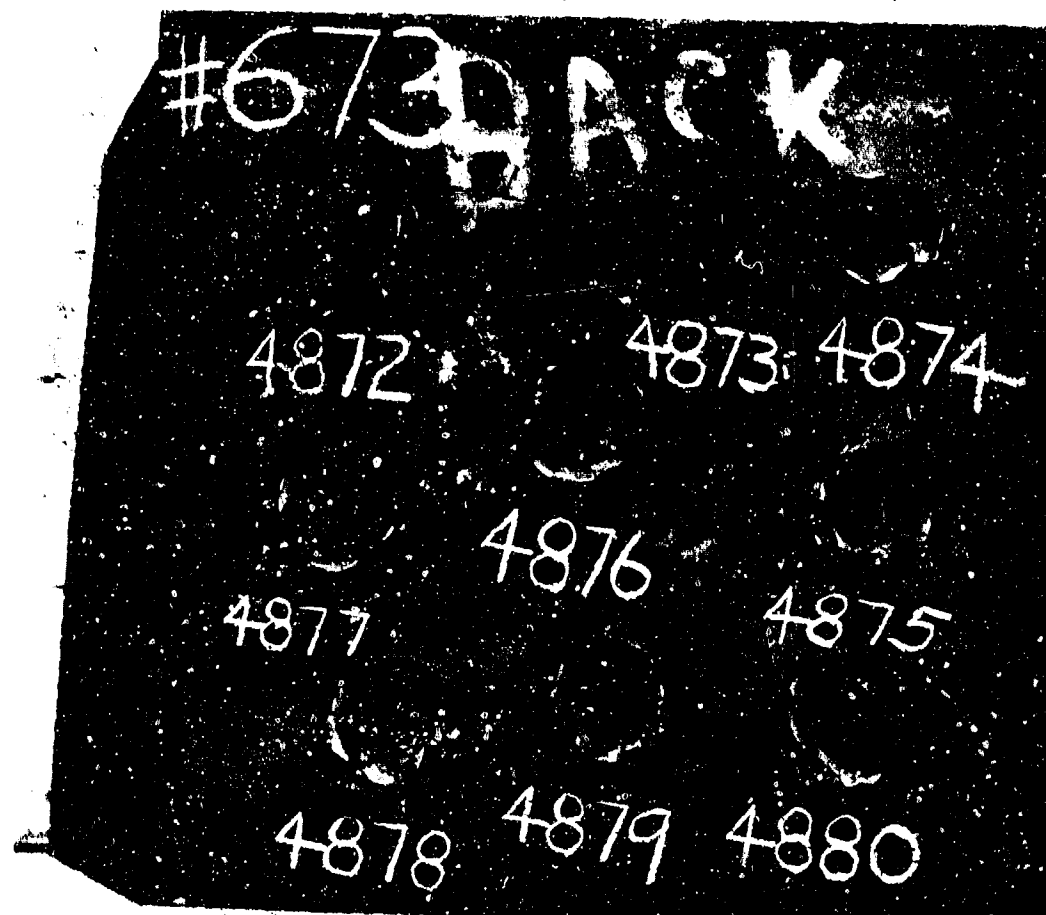
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NF9 35373 - APL Plate No. 473 (JWC 31. "B" C.I. No. X7621) BACK VIEW. See NF9 35371
for front view and data on impacts 4872-80 APL.
15, 17 Sept. 1947

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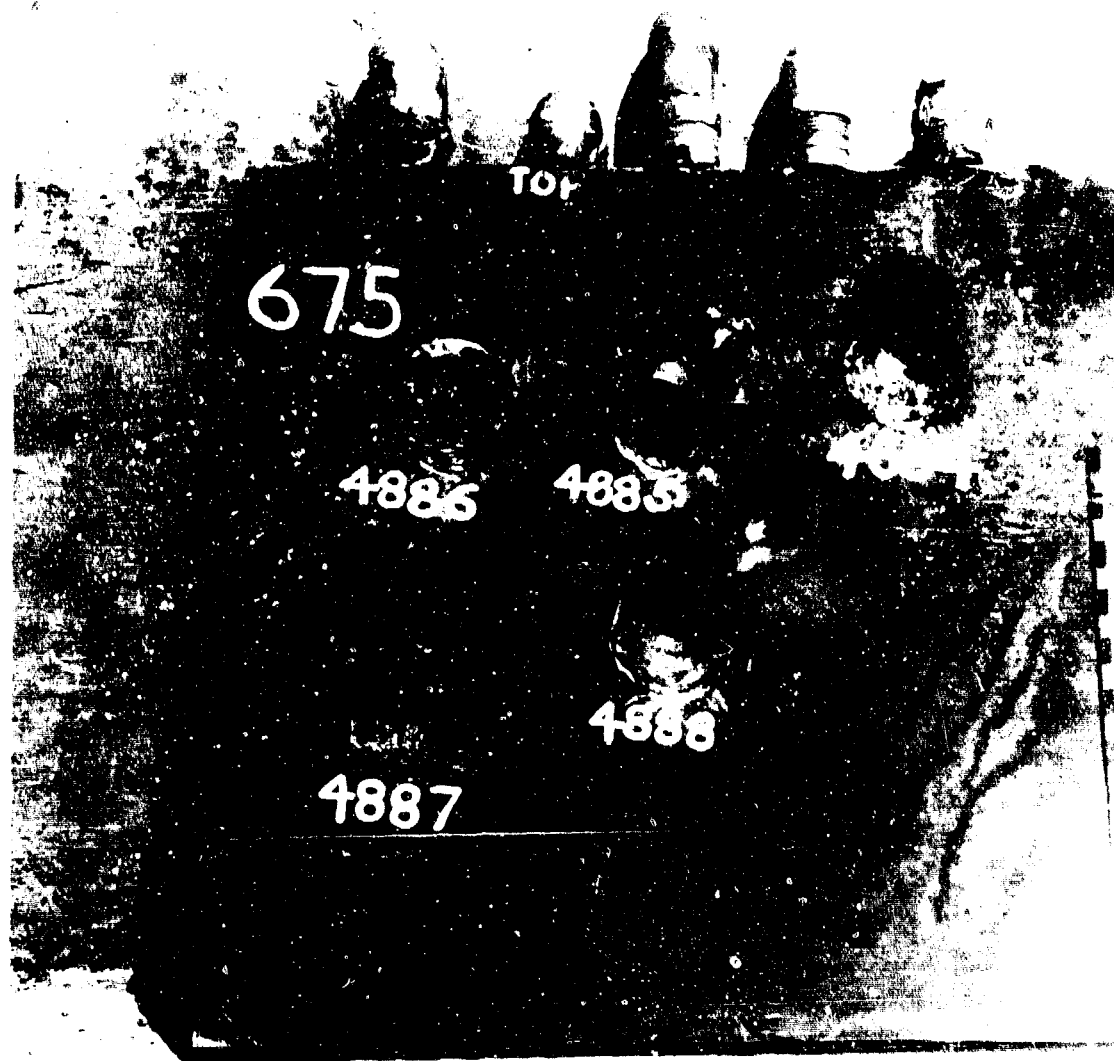


NP9 35437 - APL Plate No. 675 (380 Cl. "B" C.I. No. X9021) T.S. 120,800 psi vs.
3" AP M62 and 3" Mk. 29-2 AP Projectiles at 30° Obliquity. FRONT VIEW. See NP9 35438
for back view.

B.I. No.	"e"	"g"	S.V.(f.s.)	$\frac{1}{2}$	Pene.	Proj. Cond.
4884 APL	37207	30°10'	2423	123	Inc. 3-1/2"	Split, not eff.
4885	37209	30°10'	2522	128	Comp. B.I.P.	Broken, split, not eff.
4886	37211	30°10'	2649	134	Comp.	Broken, split, not eff.
4887 Mk.29-2	37197	30°10'	2606	125	Comp.	Intact, eff.
4888	37204	30°20'	2740	137	Comp.	Broken, split, not eff.

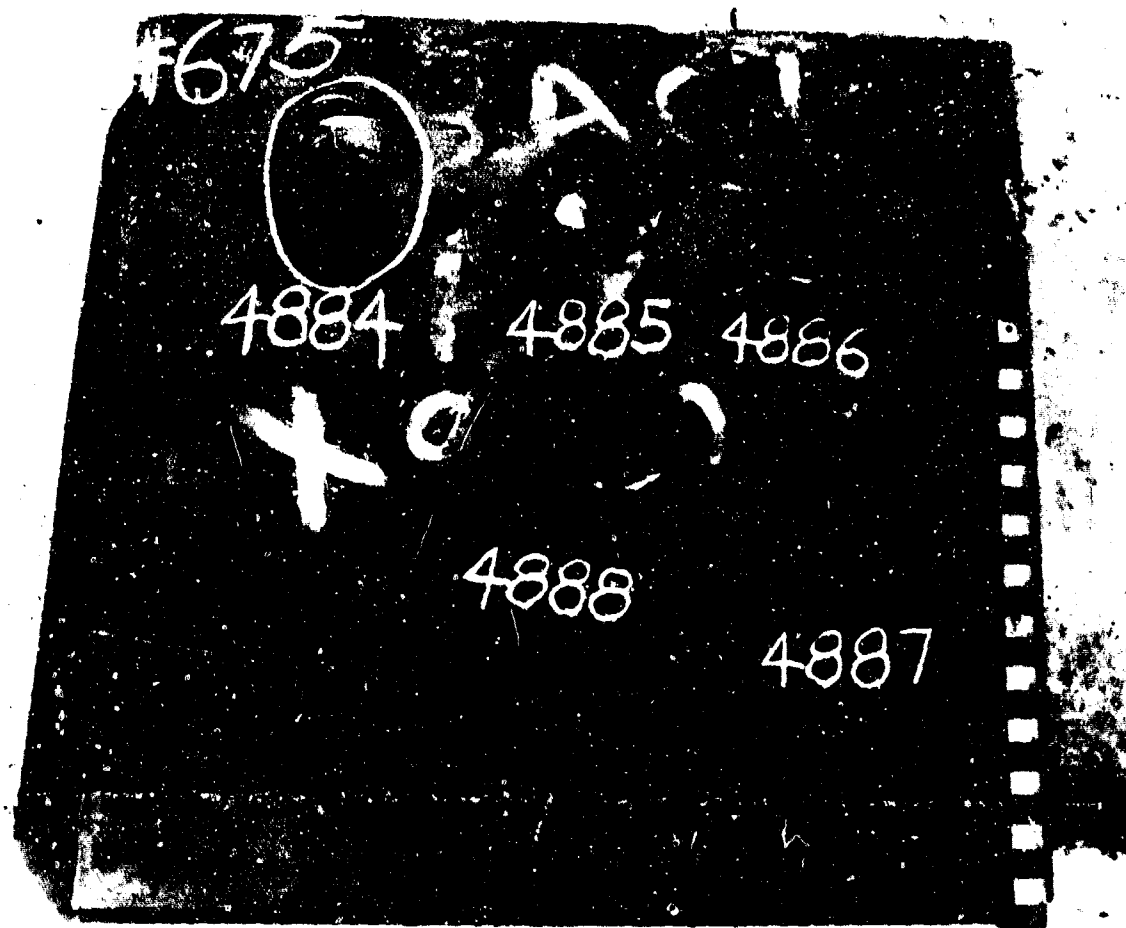
17, 18 Sept. 1947

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NP9 35438 - APL Plate No. 675 (370 Cl. "B" C.I. No. X9021) BACK VIEW. See NP9 35437
for front view and data on impacts 4884-88 APL.
17, 18 Sept. 1947

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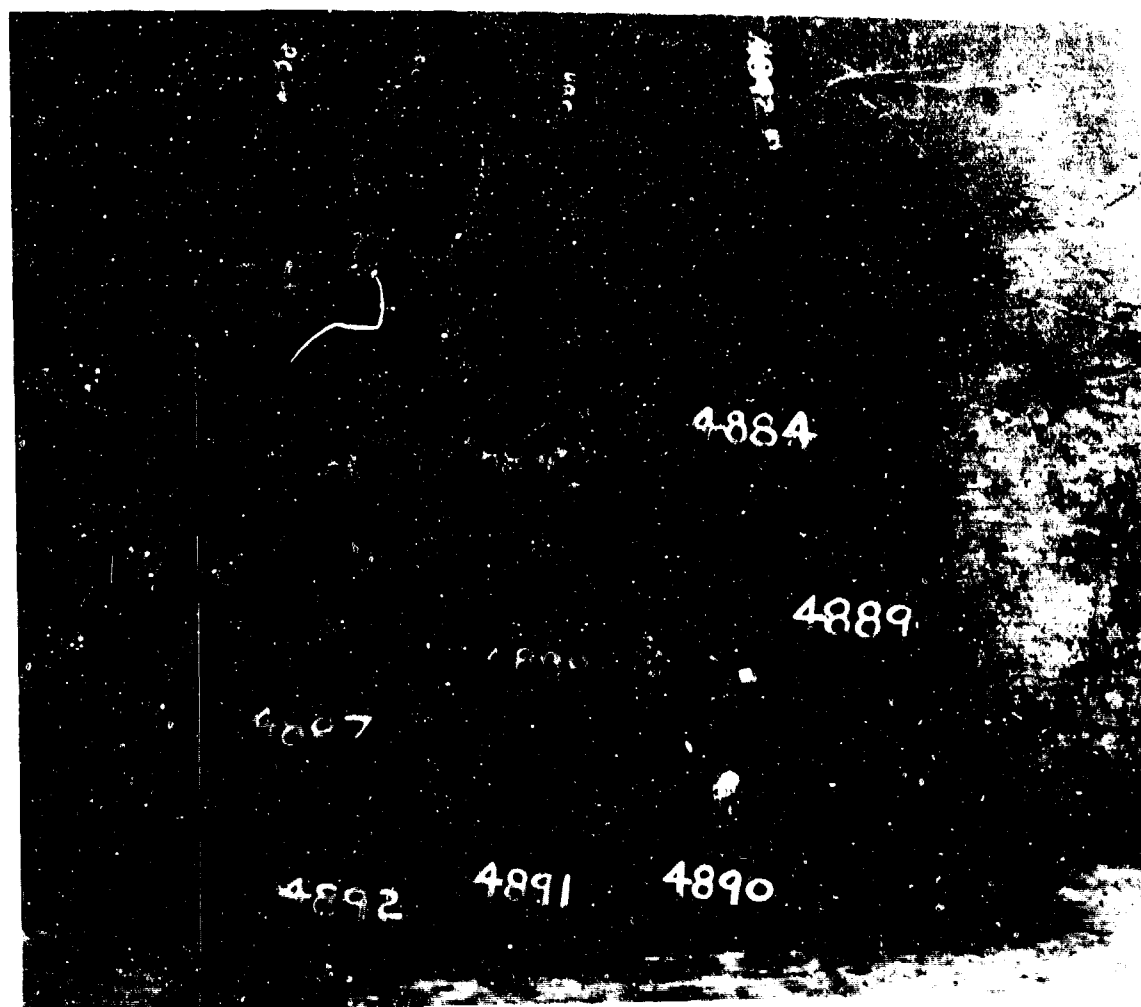


NP9 35439 - APL Plate No. 675 (340 Cl. "B" C.I. No. X9021) T.I. 176,890 1st "9".
 3" AP M62 and 3" Mk. 29-2 AP Projectiles at 30° Obliquity. FRONT VIEW. See also 35440
 for back view.

B.I. No.	"a"	"b"	S.V. (f.s.)	g	Pene.	Proj. Cond.
4884 APL	37207	30°10'	2423	123	Ino. 3-1/2"	Split, not eff.
4885	37209	30°10'	2522	128	Comp. B.I.P.	Broken, split, not eff.
4886	37211	30°10'	2649	134	Comp.	Broken, split, not eff.
4887 Mk. 29-2	37197	30°10'	2606	125	Comp.	Intact, eff.
4888	37204	30°20'	2740	137	Comp.	Broken, split, not eff.
4889	37203	29°40'	2618	133	Comp.	Body cracked, eff.
4890	37200	29°40'	2496	127	Ino. 2-3/4"	Split, not eff.
4891	37199	29°40'	2627	134	Ino.	Split, not eff.
4892	37197	30°10'	2755	140	Comp.	Nose split, eff.

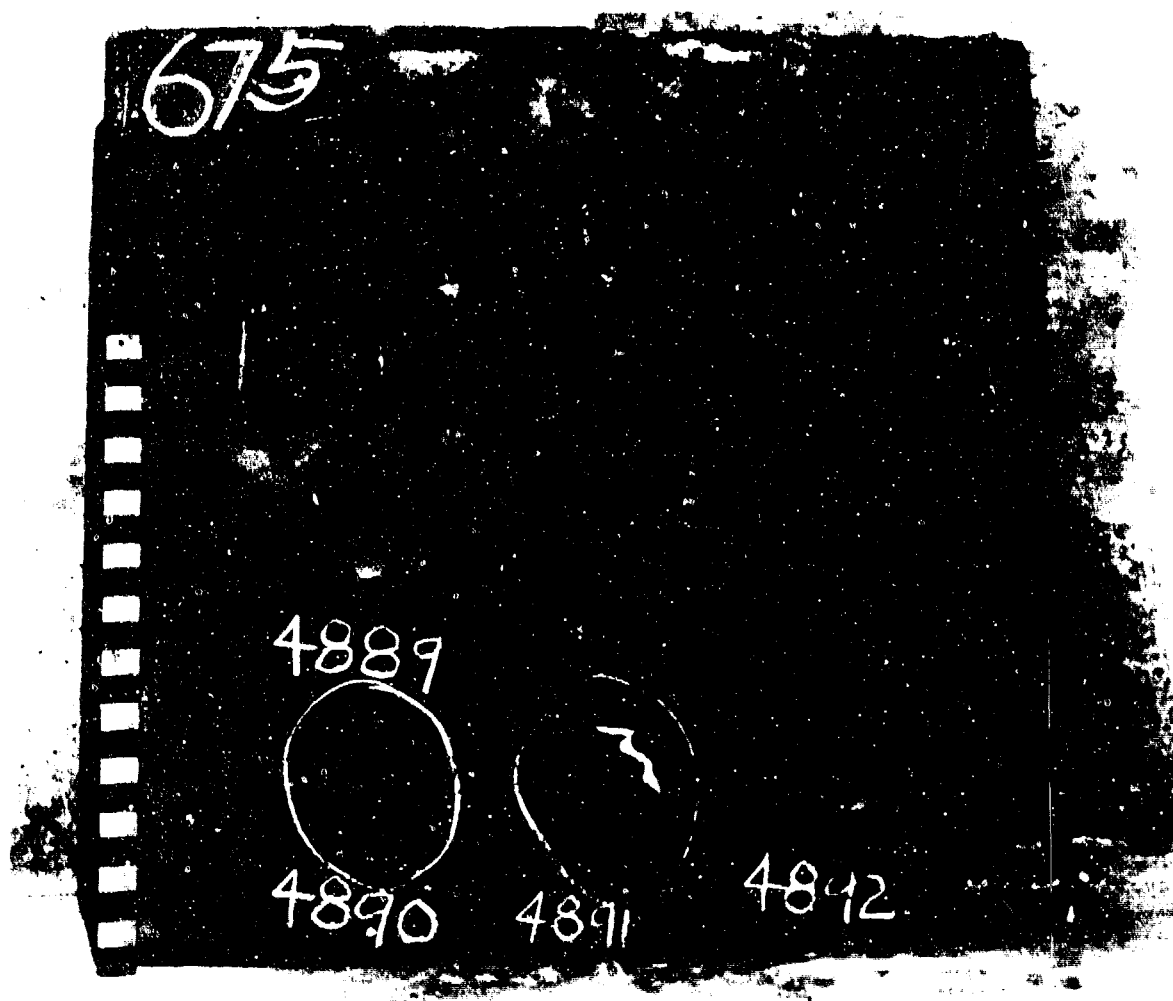
17, 18, 22 Sept. 1947

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NPV 35430 - APL Plate No. 675 (STO 01."B" C.I. No. 49(21) BACK VIEW. See NPV 35439
for front view and data on impacts 4884-92 APL.
17, 18, 21 Sept. 1947

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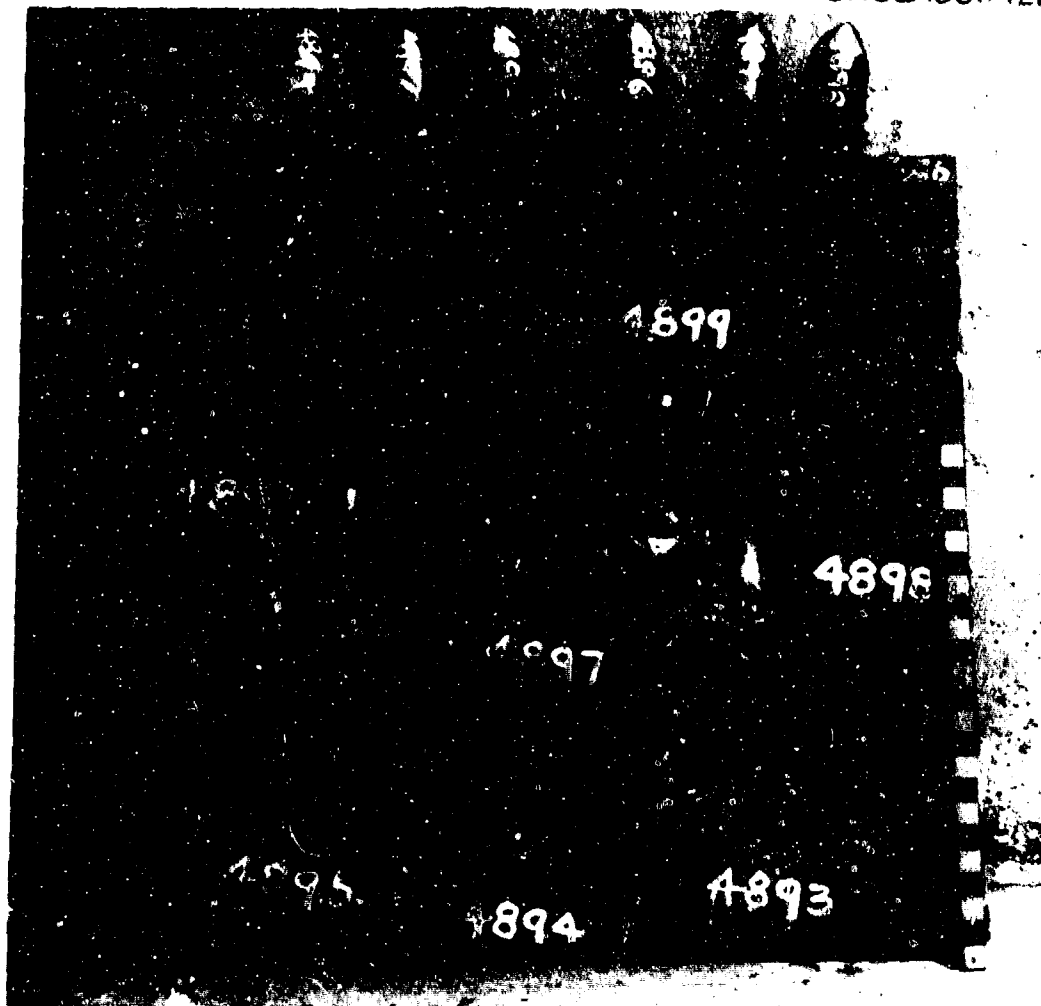
NPS 15441 - APL Plate No. 676 (370 Cl. "F" Cl. No. BD 389) vs. 3" Mk. 29-2 AP Projectiles at 45° Obliquity. FRONT VIEW. See NPS 15442 for back view.

<u>B.I. No.</u>	<u>"e"</u>	<u>"u"</u>	<u>S.V. (f.s.)</u>	<u>%</u>	<u>Pene.</u>	<u>Wrd. Cond.</u>
4893 API.	37047	44°40'	2810	107	Comp.	Intact, eff.
4894	37035	44°00'	2730	103	Comp.	Base Cracked, eff.
4895	37059	44°40'	2752	104	Inc. 2-5/8"	Base Cracked, eff.
4896	37053	44°40'	2750	104	Inc. 2-3/4"	Base gouged, not eff.
4897	37044	44°40'	2900 (est.)	111	Comp.	Base gouged, eff.
4898	37040	44°45'	2772	106	Inc. 2-3/4"	Base gouged, eff.
4899	37035	44°40'	2701	103	SIP 2-5/8"	Base gouged, eff.

22, 23 Sept. 1947

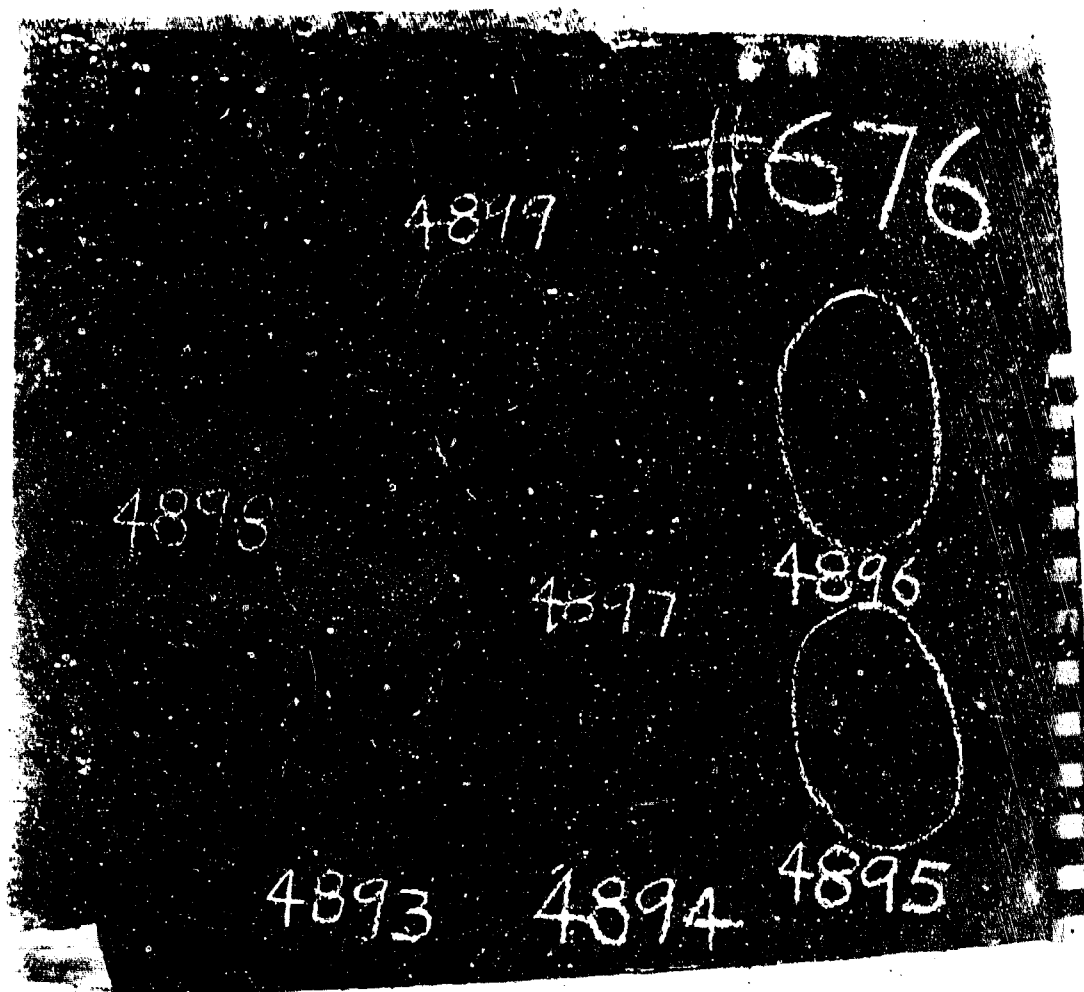
22, 23 Sept. 1967

UNCLASSIFIED



NP9 35442 - APL Plate No. 676 (37C Cl. "B" C.I. No. BD 389 1/4) BACK VIEW. See
NP9 35441 for front view and data on impacts 4893-99 APL.
22, 23 Sept. 1947

~~SECRET~~
UNCLASSIFIED

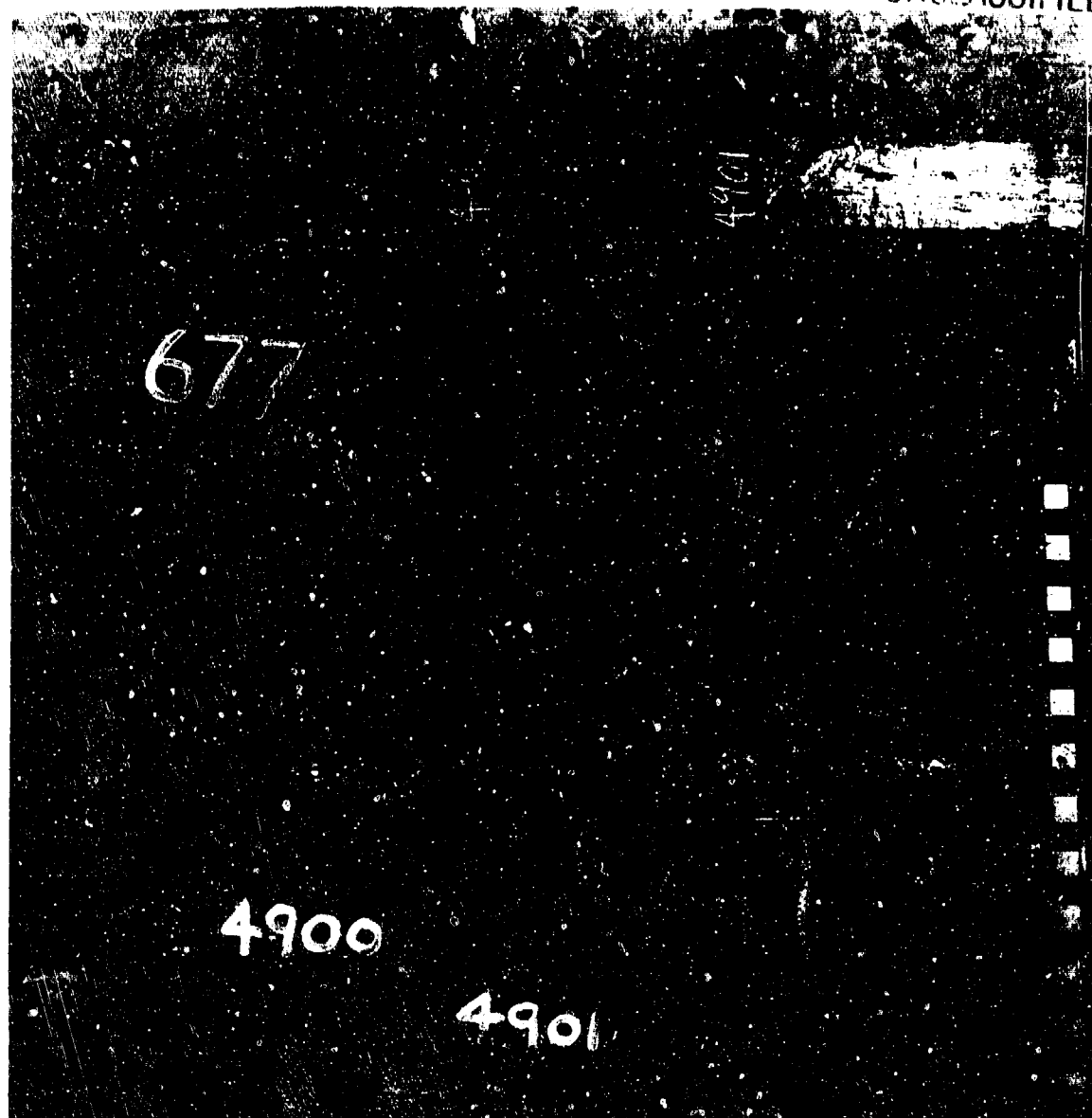


NP9 35485 - APL Plate No. 677 (37C Cl. "B" C.I. No. BD 389-1/4) T.S. 120,300 psi
 vs. 3" M62 AP Projectiles at 45° Obliquity. FRONT VIEW. See NP9 35486 for back
 view.

<u>B.I. No.</u>	<u>"e"</u>	<u>"θ"</u>	<u>S.V.(f.s.)</u>	<u>%</u>	<u>Pene.</u>	<u>Proj. Cond.</u>
4900 APL	3"005	45°00'	2487	101	Ino.	Shattered, not eff.
4901	3"013	45°40'	2649	106	Ino.	Shattered, not eff.

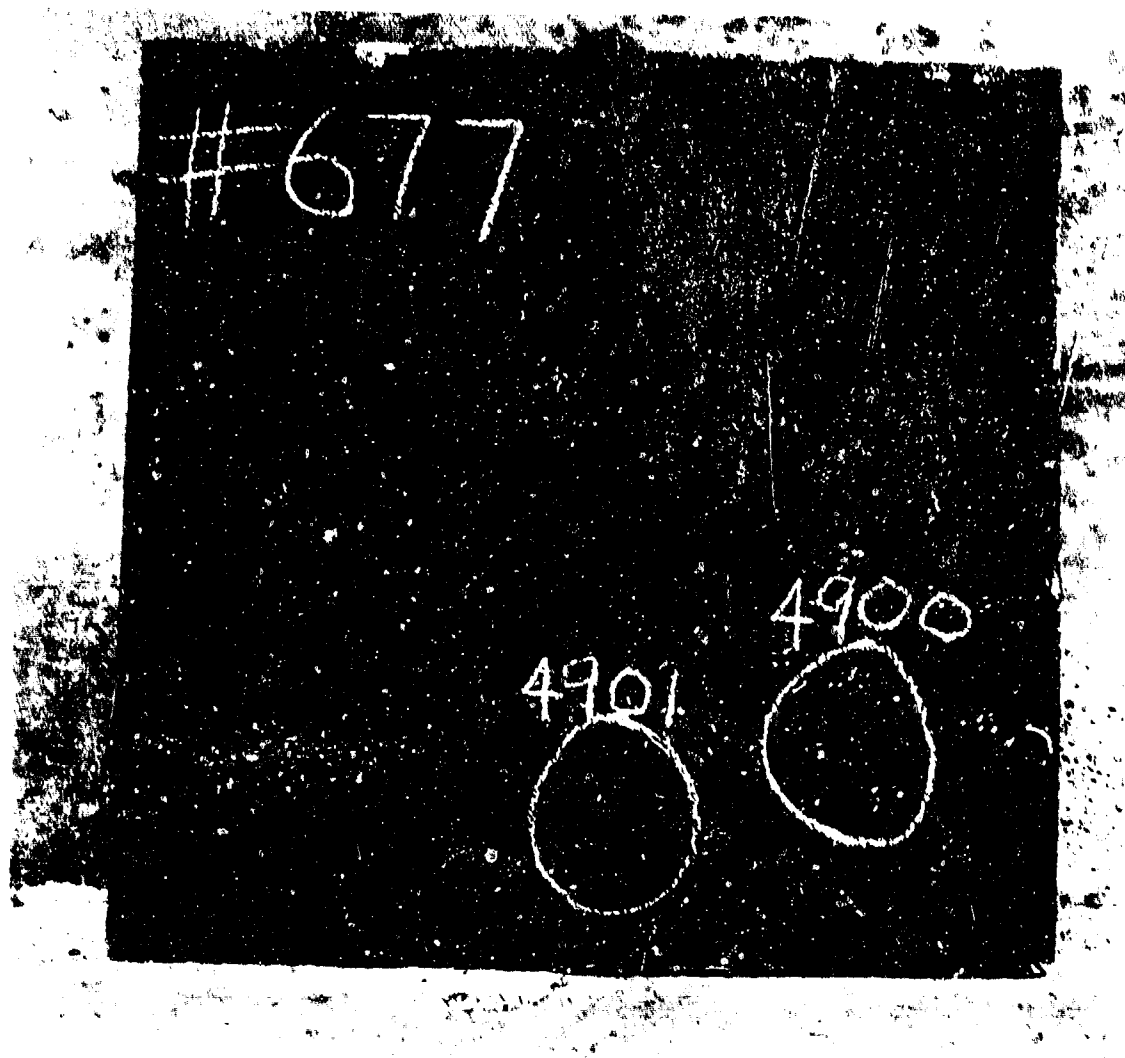
24 Sept. 1947

UNCLASSIFIED



NP9 35486 - APL Plate No. 677 (370 Cl. "B" C.I. No. 389-1/4) BACK VIEW. See
NP9 35485 for Front View and data on impacts 4900-01 APL.
24 Sept. 1947

~~SECRET~~
UNCLASSIFIED

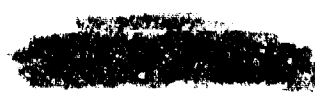


MEMORANDUM REPORT NO. 1-47

APPENDIX III

LOCAL DIRECTIVES

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MEMORANDUM REPORT NO. 1-47

C O P Y

U. S. NAVAL PROVING GROUND

DAHLGREN, VIRGINIA

15 September 1947

PROJECT TL-3212-1.2

Directive for Tests Nos. 1 and 2.

1. In order to gain more information concerning the behavior of presently available 3" AP projectiles as a preliminary to evolving new designs, it is desired to test the 3" AP Mk. 29-2 and 3" AP M62 projectiles against Class A and Class B armor, with particular attention to the highest striking velocities obtainable.

2. Until the completion of this series of tests, the procedure to be followed in firing will be to determine the limit on the plate, increase the velocity in approximately 200 f.s. steps to the maximum attainable, then fire additional rounds as necessary to explore the "shatter region" more fully. The 3"/50 gun and Mk. 29-2 and M62 projectiles will be used.

3. Test No. 1 will be fired under the following conditions: 3" Class B plate, of approximately 120,000 psi tensile strength, at 30° obliquity. Test No. 2 will be fired under the same conditions, except that the obliquity will be 45°.

J. G. FRANKLIN
Armor Officer

Copy to: BO, XO, TO, TL(3), TK.

