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COMPARATIVE BALLISTIC PERFORMANCE OF 20MM AP M95 AND 20MM AP M75 PROJECTILES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR (U)

TECHNICAL REPORT NO. WAL TR 160.1/1(c)

BY
DOMINIC A. PICCIONE

MAY 1960

O.O. PROJECT: TB4-005, MATERIALS FOR ARMOR AND PROTECTION AGAINST OTHER HAZARDS
D/A PROJECT: 5B93-32-005

WATERTOWN ARSENAL
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Projectiles - ballistic performance

Ballistic limits - Army

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TITLE

COMPARATIVE BALLISTIC PERFORMANCE OF 20MM AP M95 AND 20MM AP M75 PROJECTILES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR (U)

ABSTRACT

Ballistic testing was conducted to determine the relative performance of the 20MM AP M75 and M95 projectiles against rolled homogeneous steel armor of specification hardness.

Neither type projectile possessed the metallurgical structure or hardness pattern conducive to optimum ballistic performance.

The results obtained indicated that on an energy basis the 20MM AP M75 is approximately 36% superior to the 20MM AP M95 projectile in the 0 - 20° obliquity range, and approximately 12% superior in the 45 - 60° obliquity range.

DOMINIC A. PICCIONE
Mechanical Engineer

APPROVED:

J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

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INTRODUCTION

At the request of the Ordnance Tank-Automotive Command,* Watertown Arsenal Laboratories have conducted a series of ballistic tests to determine the terminal ballistic performance of the 20MM AP M75 and 20MM AP M95 projectiles against rolled homogeneous armor plate of specification hardness. Specific information was desired on the performance of both projectiles against overmatching armor at low obliquities and undermatching armor at high obliquities.

MATERIALS AND TEST PROCEDURE

The armor used was rolled homogeneous armor plate (12" x 12") which conformed to specification MIL-A-12560(ORD) unless otherwise noted.

The 20MM AP M75 projectiles were taken from Lot Al-90-43-AP 20MM AP M75; the M95 projectiles were taken from Lot NP-22-44-20MM M95. Two projectiles of each type were selected at random for microexamination and cross-sectional hardness readings.

Using the Army criteria** to distinguish between partial and complete penetration, ballistic limits were obtained consisting of two partial penetrations and two complete penetrations within a velocity spread of 125 feet per second.

Ballistic tests were conducted at the following conditions:

	Plate Thickness (Inches)	Obliquity (Degrees)	Projectile M75	Projectile M95
Undermatching Plate	3/8	60	X	X
	1/2	45, 60	X	X
	3/4	20, 45, 60	X	X
Overmatching Plate	1	0, 45	X	X
	1	20	X	
	1-1/8	20		X
	1-1/4	0	X	
	1-1/4	20	X	X
	1-1/2	0	X	X
	1-3/4	0	X	

RESULTS AND DISCUSSION

Ballistic Performance

The ballistic data are tabulated in Table I, and the round-by-round results are presented in Appendix A. Ballistic limit versus thickness and obliquity are plotted in Figures 1 and 2, respectively. These graphs clearly

*Ref. Telephone call 26 August 1958 between Mr. H. Spiro of OTAC and Mr. Mardirosian of Watertown Arsenal Laboratories.

**Complete penetration exists whenever light can be seen through the hole in the plate or when any portion of the projectile is visible from the rear of the plate.

show that the 20MM AP M75 projectile defeated all target conditions at lower velocities than the 20MM AP M95. The difference in velocity was 400 - 500 fps in the 0° - 20° obliquity range, whereas in the 45° - 60° range the difference was 100 - 500 fps.

TABLE I

COMPARATIVE BALLISTIC PERFORMANCE OF 20MM AP M75 AND 20MM AP M95 PROJECTILES VERSUS ROLLED HOMOGENEOUS STEEL ARMOR

Thickness (Inches)	Obliquity (Degrees)	Army Ballistic Limit M75	Army Ballistic Limit M95	Penetration Energy* $X10^{-4}$ (Ft-Lb/in.^{3}) M75	Penetration Energy* $X10^{-4}$ (Ft-Lb/in.^{3}) M95	% Superiority M75/M95
3/8	60	1499 S**	1981 S**	5.51	7.58	27.1
1/2	45	1652 S	2169 S	6.70	9.10	26.3
1/2	60	2268 S	2431 S	12.70	11.40	-11.4
3/4	20	1160 I	1601 F	3.32	4.94	32.8
3/4	45	2381 S	2666 S	13.90	14.00	0.714
3/4	60	2865 S	>3060 S	20.20	>18.10	>-11.6
1	0	1453 I	2106 I	5.19	8.56	39.4
1	20	1712 F	--	7.20	--	--
1	45	2600 S	3034 S	16.5	17.8	7.32
1-1/8	20	--	>3080 S	--	>18.4	--
1-1/4	0	1645 I	--	6.69	--	--
1-1/4	20	2898 S	>3000 S	20.6	>17.4	>-18.4
1-1/2	0	2050 I	>2970 S	10.4	>17.1	>39.2
1-3/4	0	>2905 S	--	>20.8	--	--

*Energy = $M V^2 / d^3$

where M = *projectile mass*
V = *ballistic limit (f/s)*
d = *projectile diameter (in.)*

** *S = projectile shattered*
F = projectile fractured
I = projectile intact

Figure 1 also shows the effect of overmatching and undermatching* targets on projectile condition. At the low obliquities the projectiles remained intact when attacking relatively thin armor, but as the armor thickness increased, the projectiles fractured or shattered resulting in the increasing slope of the curves. At the higher obliquities all the rounds shattered, and the curves made no sudden change in slope.

From the drawings of the M75 and M95 projectiles presented in Figure 3, it will be noted that there is a slight difference in ogival geometry. The M95 has a blunter ogive which should enhance its high obliquity performance capabilities. However, the most significant difference lies in the respective masses of the two projectiles. The M75 has a greater L/D ratio (4.15) and is heavier (0.356 lb.) whereas the M95 has an L/D ratio of 3.07 and a weight of 0.283 lb.

**Overmatching - Plate thickness/Projectile Diameter > 1,*
Undermatching - Plate thickness/Projectile Diameter < 1.

Because of the difference in weight between the two projectiles, the M95 shot should have an 11% higher muzzle velocity to have the same muzzle energy as the M75. However, the actual muzzle velocity is only 9% greater than that of the M75. The discrepancy is due to the fact that when the M95 shot is accelerated to a higher muzzle velocity, the propellant combustion products are also accelerated to a greater velocity.[1] In terms of kinetic energy available for penetration, then, the M95 has 7% less kinetic energy than the M75 at the gun muzzle.

The decay in projectile velocity with increasing distance from the muzzle depends on the projectile shape, its mass, and the air density. For the two projectiles involved, the mass is the more important parameter in standard air. Hence, the M95 (which is the lighter projectile) loses velocity more rapidly than the M75. The initial 9% greater velocity of the M95 decays to 6% at 1000 yards range and to 3% at 1500 yards. In terms of kinetic energy, the initial 7% less energy of the M95 increases to 9% less at 1000 yards range and to 15% less at 1500 yards.

For reasons contained in the preceding two paragraphs, kinetic energy considerations should govern a terminal ballistic comparison of the two projectiles. The energy expended during penetration was determined using the formula indicated in Table I and plotted versus e/d Cos θ to show the effect of plate thickness and obliquity (Figure 4). The plot consists of two sets of curves, one for projectiles which remained intact, the other for those which shattered. These curves show that, on the average, the M75 projectile was 36% superior (requiring less energy) to the M95 when the projectiles remained intact, and 12% superior when the projectiles shattered.

The decrease in superiority of the M75 as the projectile condition goes from intact to shattered can be seen by examining the curve in Figure 5. As the obliquity increases to 45° the tendency for projectile shatter increases and the superiority of the M75 decreases, having an average value of about 10% in the 45° - 60° obliquity range.

Metallurgical Considerations

For optimum ballistic results it has been found[2] that high hardness and toughness can be combined to counteract some of the stresses set up during penetration. This is accomplished by a heat-treatment process which initially forms a uniformly tempered martensitic structure throughout, and by subsequent base tempering develops a differential hardness pattern wherein the hardness varies from 60 - 62 R_c at the ogival section to approximately 40 - 45 R_c at the base. Microexamination of the selected specimens demonstrated that this idealized condition had not been achieved. Analysis of the micro-

[1] *ABBOTT, K. H., Use of Sintered Aluminum Oxide for Armor-Piercing Shot, Watertown Arsenal Laboratories Technical Note WAL 762/679, December 1956.*

[2] *MASCIANICA, F. S., and RIFFIN, P. V., Principles of Armor Protection - 5th Partial Report: Performance of Rolled Homogeneous Armor against Scale-Model Monobloc and Capped Armor-Piercing Projectiles at 0° to 70° Obliquity, (U), Watertown Arsenal Laboratory Report WAL 710/607-4(c), 31 May 1956.*

structure revealed evidence of poor austenization by the presence of extensive regions of pearlite in a matrix of tempered martensite. The metallurgical structure thus encountered is indicative of a brittle material, which is highly susceptible to shatter under impact loading conditions. Typical microstructures of both 20MM AP M75 and 20MM AP M95 projectiles are presented in Figure 6.

Cross-sectional hardness readings taken at regular intervals in three distinct rows parallel to the longitudinal axis for both types of projectiles are recorded in Figure 7. This data indicates that the maximum hardness range extended well beyond the ogival section, sharply dropping off just above the rotating band, indicative of inadequate base tempering. Such a hardness distribution accentuates the shatter tendency of the shot, particularly when subjected to the severe bending stresses developed at high obliquity attack conditions.

A transverse crack was discovered in one of the M75 projectiles. This crack appeared to have formed during the quench operation and propagated during storage based on the appearance and lack of oxidation in the crack system. Nondestructive testing of the remaining group of M75 and M95 projectiles by Magnaglo and Magnaflux methods failed to detect any other cracks.

CONCLUSIONS

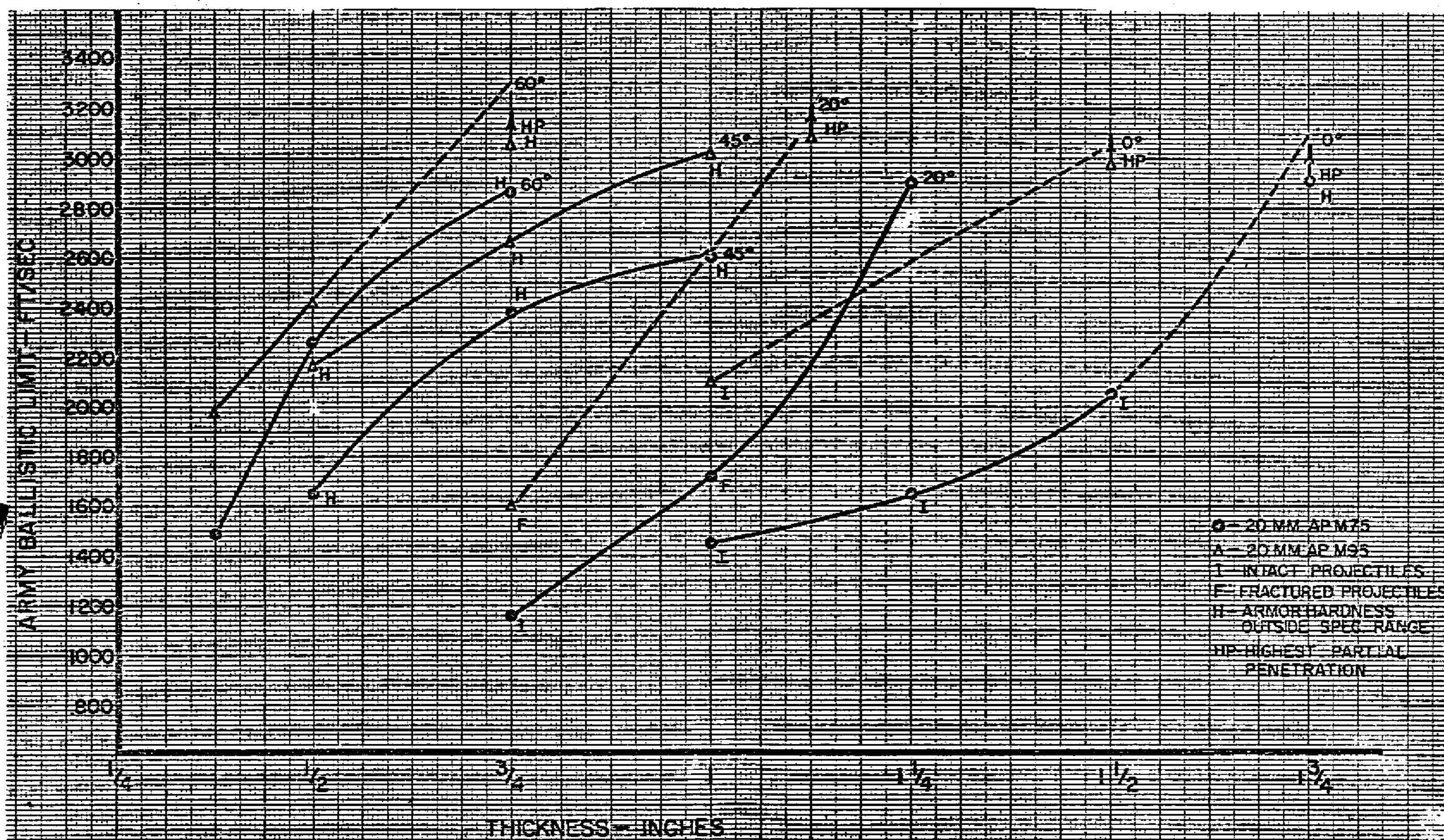
1. On an energy basis, the 20MM AP M75 is approximately 36% superior to the M95 projectile in the 0^o - 20^o obliquity range and approximately 12% superior in the 45^o - 60^o obliquity range.

2. The 20MM AP M75 and M95 projectiles examined did not have the metallurgical structure or hardness pattern conducive to optimum ballistic performance.

3. An increase in the mass of the 20MM AP M95 projectile would increase its exterior and terminal ballistic performance.

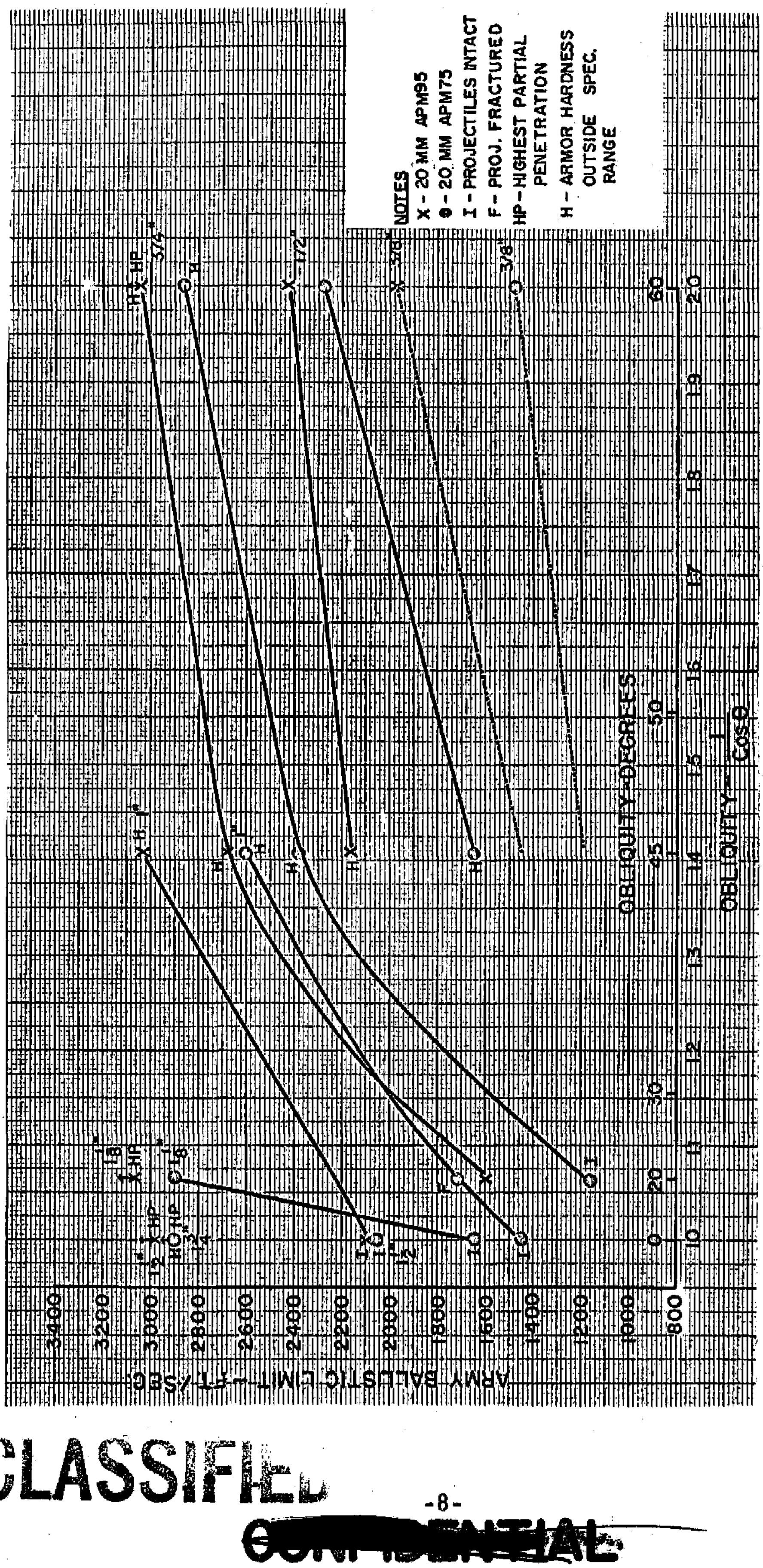
RECOMMENDATIONS

It is recommended that projectiles made in the future be heat-treated and tempered to insure a tempered martensitic structure throughout and a uniform hardness pattern of 60 - 62 Rockwell C from the nose to the bourrelet, with a gradual decrease in hardness from the bourrelet to the base, which would have a hardness of 40 - 45 R_c.



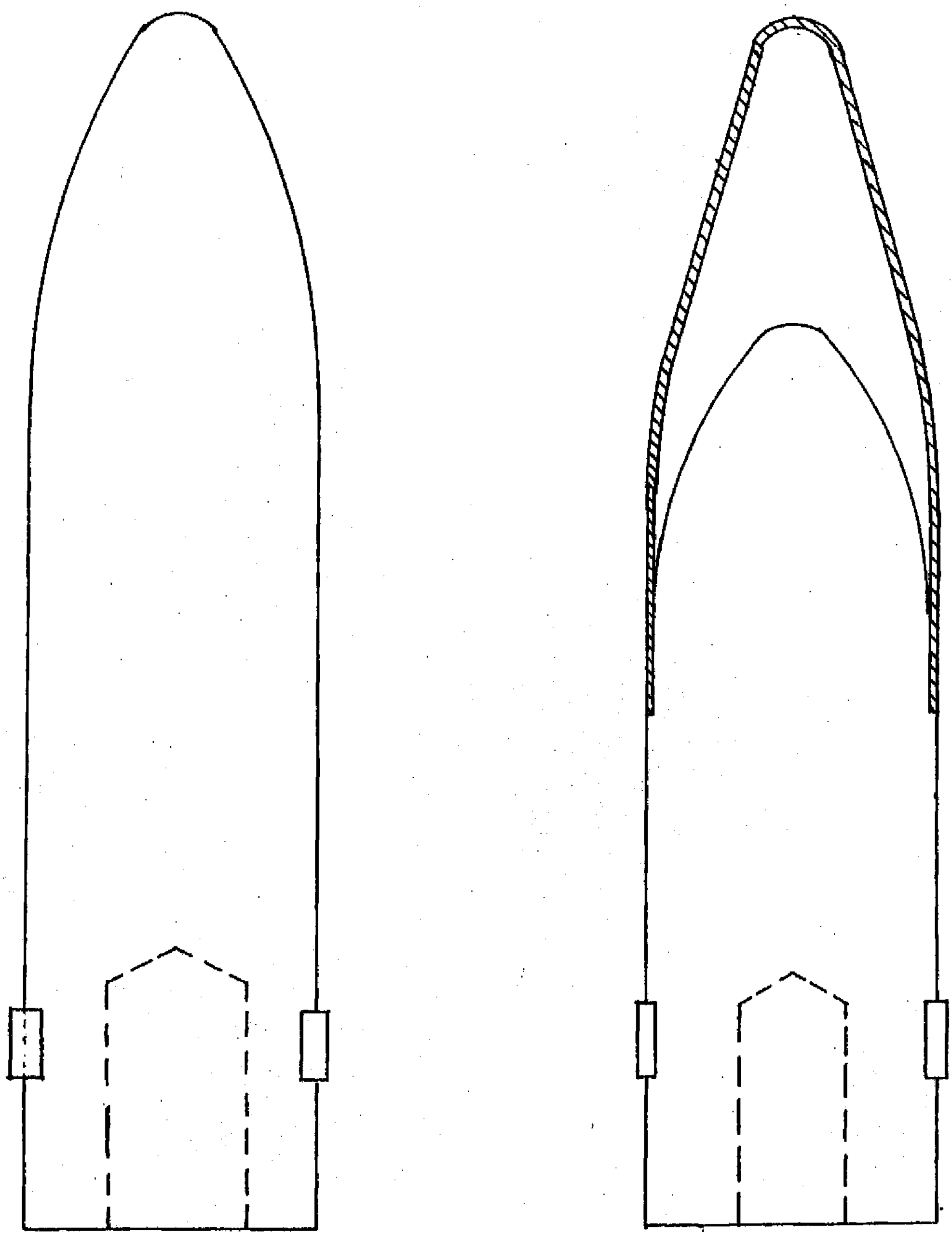
BALLISTIC PERFORMANCE OF 20MM AP M75 AND 20MM AP M95 PROJECTILES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR

FIGURE 1



BALLISTIC PERFORMANCE OF 20MM AP M75 AND 20MM AP M95 PROJECTILES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR

FIGURE 2



20MM AP M75 AND 20MM AP M95 PROJECTILES

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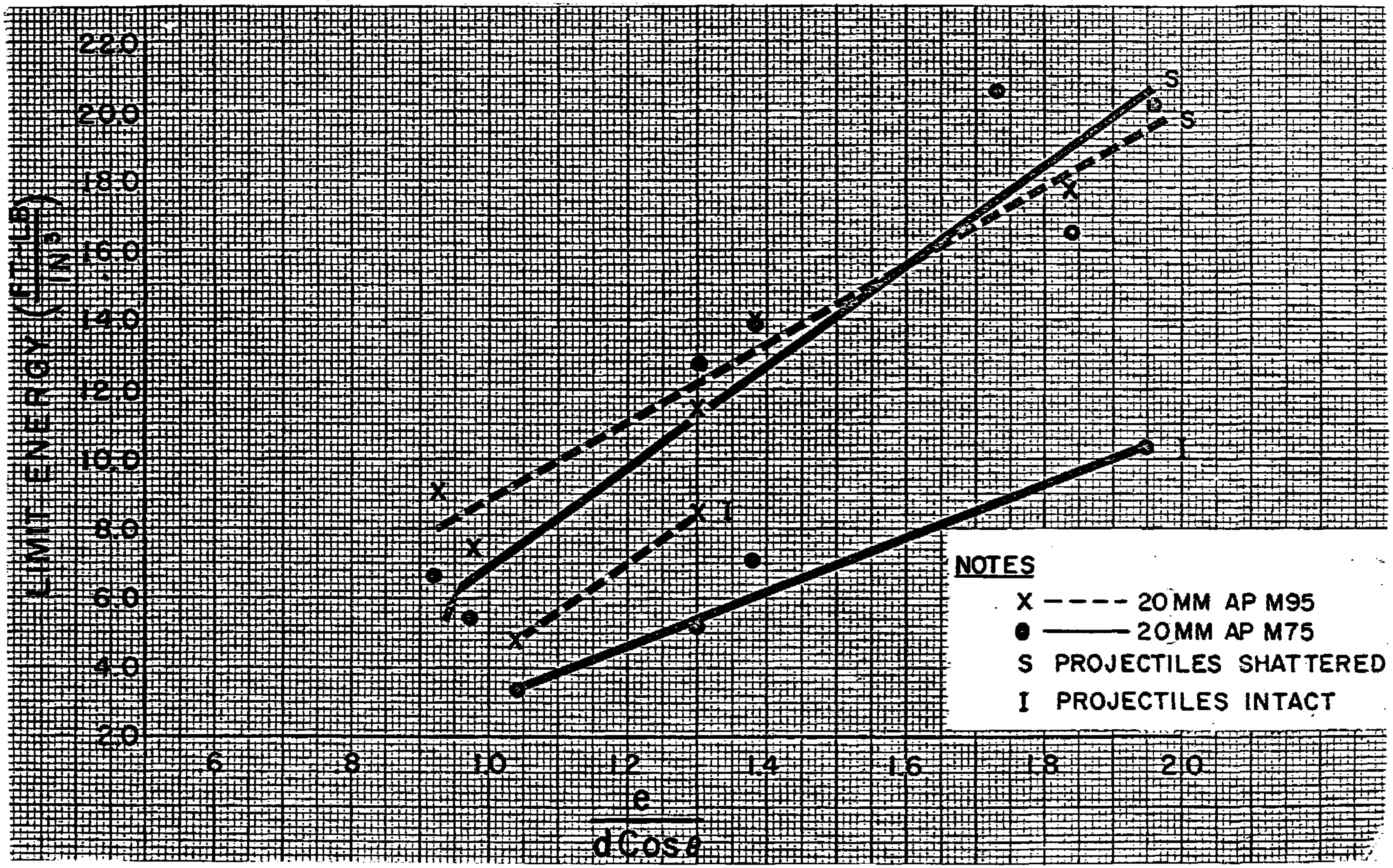

LIMIT ENERGY VERSUS e/d Cos θ FOR 20MM AP M75 AND 20MM AP M95 PROJECTILES

FIGURE 4

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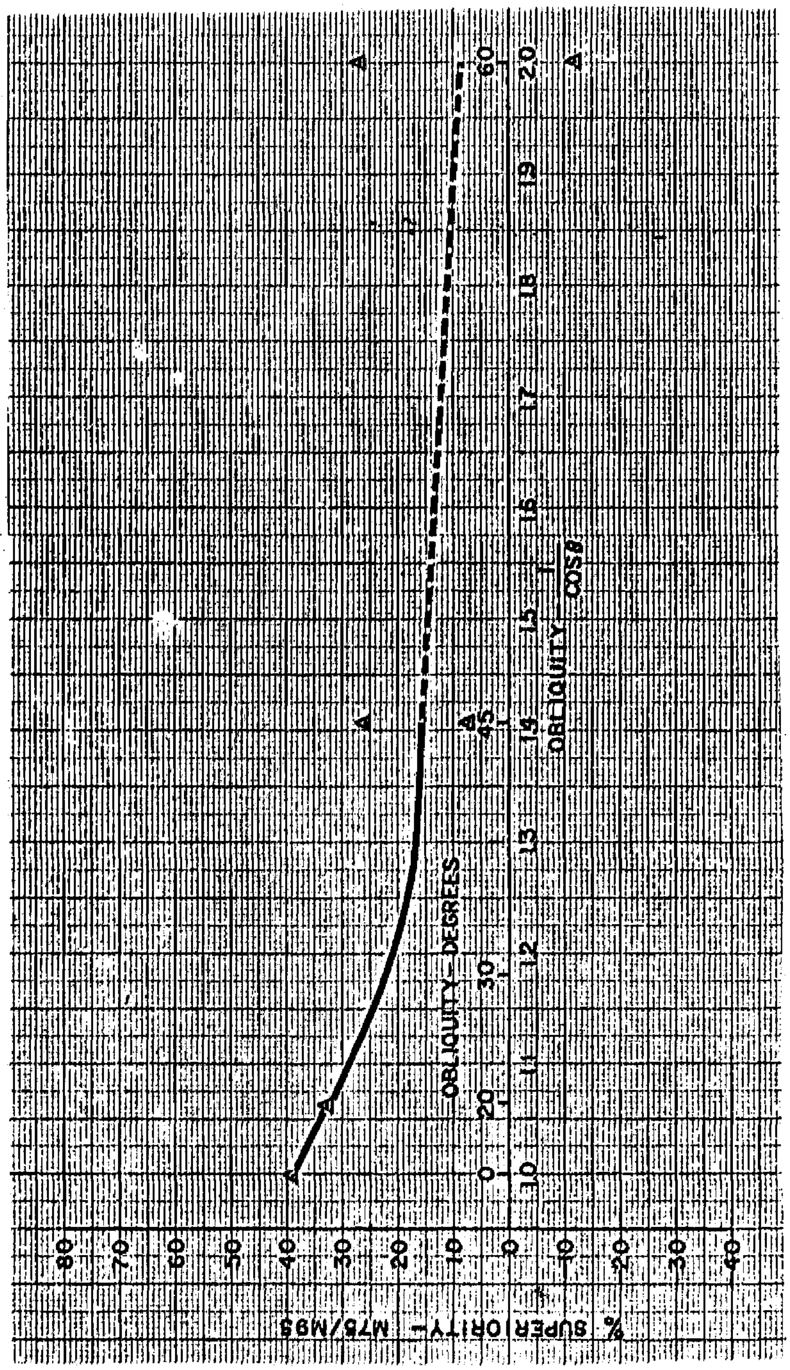

PERCENT SUPERIORITY OF THE 20MM AP M75 PROJECTILE OVER THE 20MM AP M95 AT VARIOUS OBLIQUITIES

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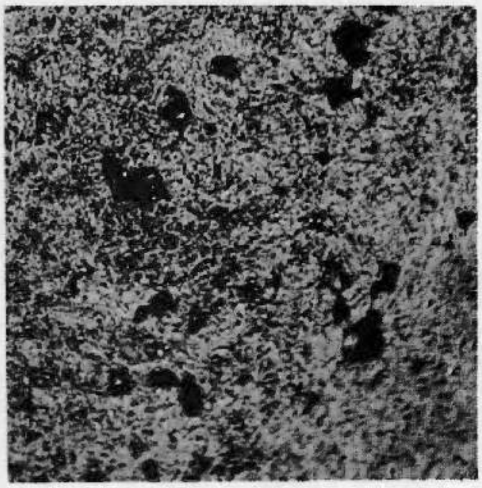
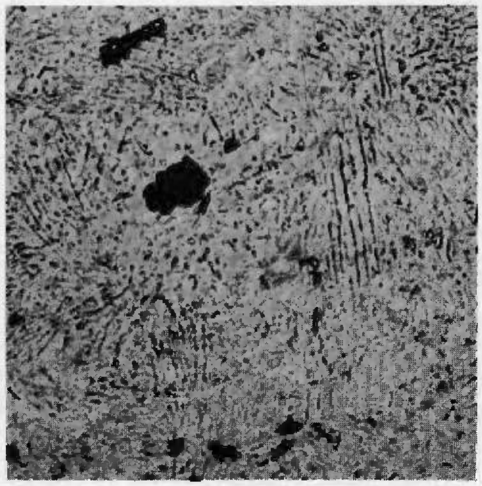
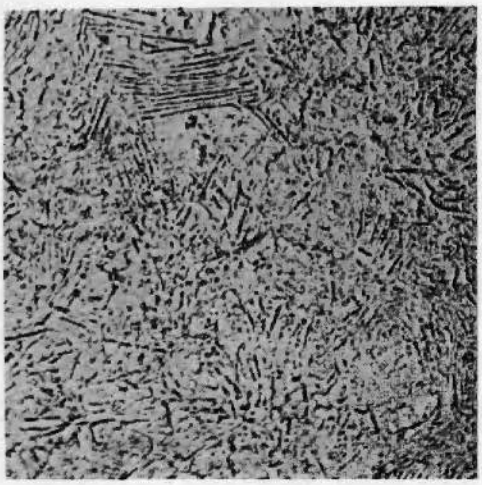
FIGURE 5



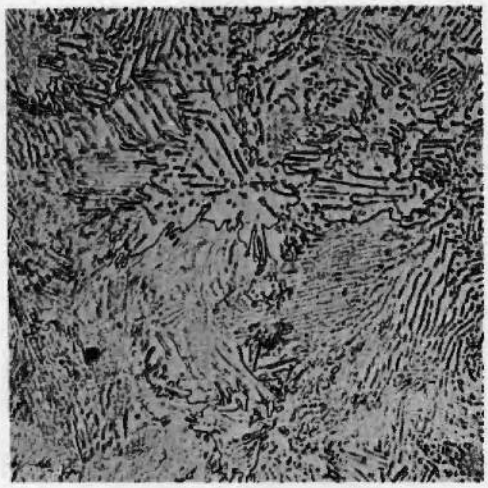
M75A X1000



M75B X1000

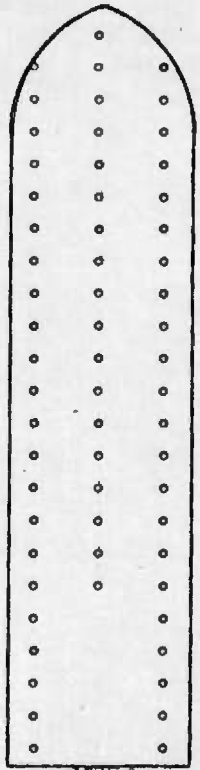


M95A X1000



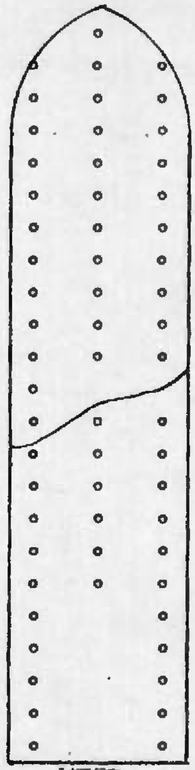
M95B X1000

MICROSTRUCTURE OF 20MM AP M75 AND M95 PROJECTILES.
ETCHANT: 4% PICRAL + HCl



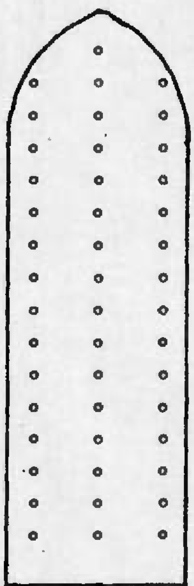
M75A

	63.0	
63.4	63.0	62.5
61.2	62.3	61.7
52.8	56.0	60.5
53.3	57.0	59.2
56.6	58.4	60.0
53.0	55.3	58.4
55.2	57.4	59.0
59.5	60.6	60.3
56.0	58.3	60.0
57.2	59.2	59.8
61.3	60.2	60.2
61.8	62.0	62.2
59.7	59.0	60.5
61.3	58.5	58.0
18.3	19.0	19.5
19.0	19.4	19.0
19.4	20.0	19.5
19.0		19.0
20.0		20.2
18.6		19.0
19.0		19.0
19.0		19.4



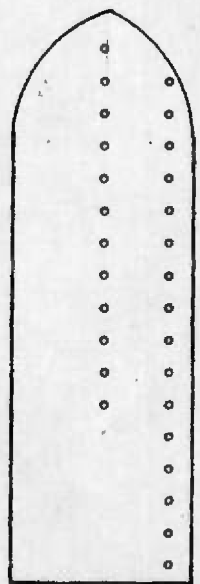
M75B

	64.0	
64.0	64.0	64.0
63.8	63.8	64.0
63.8	63.8	64.0
63.6	63.7	63.6
63.3	63.5	63.4
63.6	63.6	63.4
63.4	63.5	63.5
63.6	63.7	63.5
63.5	63.3	63.3
63.4	63.0	63.4
63.6		----
63.2	62.5	62.7
61.2	61.6	62.4
90.2*	90.6*	89.7*
90.6*	90.5*	90.0*
90.6*	90.4*	89.4*
90.2*	91.0*	90.5*
94.0*		94.0*
94.9*		95.0*
91.0*		91.0*
89.8*		89.2*
88.6*		88.2*



M95A

	60.3	
60.2	60.1	60.2
60.5	60.2	60.4
60.2	60.6	60.2
60.2	60.4	60.4
60.0	60.0	60.0
59.0	59.1	59.2
57.5	57.4	57.7
54.7	55.0	54.7
33.3	35.0	34.0
87.0*	87.2*	88.5*
89.0*	88.3*	88.0*
90.8*	90.5*	91.2*
90.8*	89.7*	90.2*
88.4*	88.8*	88.0*
88.3*	89.2*	88.5*



M95B

60.2	
59.6	59.8
59.5	58.6
59.6	59.8
60.2	60.0
59.2	60.4
59.8	60.0
56.3	58.2
56.0	57.0
98.4*	95.4*
92.2*	92.2*
92.6*	92.5*
	93.0*
	95.0*
	92.8*
	92.4*
	92.5*

----Specimen split in two.
*Rockwell B readings.

ROCKWELL C HARDNESS PATTERN OF 20MM M75 AND M95 PROJECTILES

FIGURE 7

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APPENDIX A

ROUND-BY-ROUND BALLISTIC DATA FOR 20MM AP M75 AND M95 PROJECTILES AGAINST ROLLED HOMOGENEOUS STEEL ARMOR

	20MM AP M75				20MM AP M95			
Plate	Velocity (f/s)	Projectile Condition	Plate Hardness (BHN)	Ballistic Limit	Velocity (f/s)	Projectile Condition	Plate Hardness (BHN)	Ballistic Limit
3/8" - 60°	1445 pp	S*	388	1499	1920 pp	S	388	1981
	1510 pp	S			1945 pp	S		
	1520 cp	S			2010 cp	S		
	1520 cp	S			2050 cp	S		
1/2" - 45°	1570 pp	S	321	1652	2120 pp	S	321	2169
	1675 pp	S			2150 pp	S		
	1680 cp	-			2195 cp	S		
	1685 cp	-			2210 cp	S		
1/2" - 60°	2210 pp	S	341	2268	2370 pp	S	363	2431
	2235 pp	S			2410 pp	S		
	2290 cp	S			2435 cp	S		
	2335 cp	S			2510 cp	S		
3/4" - 20°	1125 pp	I	331-341	1160	1560 pp	-	331-341	1601
	1155 pp	I			1610 pp	-		
	1155 cp	I			1595 cp	-		
	1205 cp	I			1640 cp	-		
3/4" - 45°	2310 pp	S	302	2381	2615 pp	S	302	2666
	2375 pp	S			2650 pp	S		
	2415 cp	S			2690 cp	CIP-F		
	2425 cp	S			2710 cp	S		
3/4" - 60°	2880 pp	S	277	2865	2770 pp	S	277	>3060
	2850 cp	S			2965 pp	S		
					3060 pp	S		
1" - 0°	1425 pp	-	331-341	1453	2060 pp	I	331-341	2106
	1480 cp	-			2115 pp	F		
					2120 cp	I		
					2130 cp	I		
1" - 20°	1630 pp	-	277	1712				
	1740 pp	-						
	1735 cp	CIP-F						
	1745 cp	CIP-F						

****NOTES:*** *I - Projectile intact*
S - Projectile shattered
F - Projectile fractured
- - No projectile condition obtained
CIP - Core in plate
> - Highest partial penetration

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APPENDIX A (Continued)

20MM AP M75 Velocity (f/s)	Projectile Condition	Plate Hardness (BHN)	Ballistic Limit	20MM AP M95 Velocity (f/s)	Projectile Condition	Plate Hardness (BHN)	Ballistic Limit
			1-1/8" - 20°				
				2215 pp	S	277	>3080
				2575 pp	S		
				2845 pp	S		
				3080 pp	S		
			1-1/4" - 0°				
1595 pp	I	302-311	1645				
1600 pp	I						
1690 cp	I						
1695 cp	I						
			1-1/4" - 20°				
2865 pp	S	-	2898	2440 pp	S	-	>3000
2900 pp	S			3000 pp	S		
2885 cp	S						
2940 cp	-						
			1-1/2" - 0°				
1965 pp	I	-	2050	2380 pp	S	-	>2970
2075 pp	F			2970 pp	S		
2190 pp	S						
1960 cp	I						
2000 cp	I						
2110 cp	F						
			1-3/4" - 0°				
2360 pp	S	285	>2905				
2550 pp	S						
2695 pp	S						
2905 pp	S						
			1" - 45°				
2550 pp	S	240-255	2600	2945 pp	S	240-255	3034
2580 pp	S			3050 pp	S		
2630 cp	-			3040 cp	CIP-F		
2640 cp	-			3100 cp	-		

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REPLY TO
ATTENTION OF

RDRL-WMP-E

10 October 2014

MEMORANDUM FOR Chief, ARL Security Office, RDRL-LOA-I, Aberdeen Proving Ground, MD 21005

SUBJECT: Status Confirmation for WAL-TR-160.1/1 by Dominic A. Piccione

1. Reference: Dominic A. Piccione, "Comparative Ballistic Performance of 20mm AP M95 and 20mm AP M75 Projectiles against Rolled Homogeneous Steel Armor (U)", WAL-TR-160.1/1, dated May 1960.

2. In October 2014, a review of the referenced document was completed by subject matter experts (SMEs) in ARL/WMRD. Their purpose was to determine if this report has the appropriate classification and downgrading.

3. Based on the age of the document and the subject being obsolete projectiles produced during World War II, the document is appropriately marked as UNCLASSIFIED and should be considered approved for public release with unlimited distribution.

4. The POC for this request is Matthew Burkins, matthew.s.burkins.civ@mail.mil, 410-278-6224.

PATRICK M. SWOBODA
Chief, Armor Mechanisms Branch