REPORT NO. 0-1438

DATE 6 April 1938

FR-1438

SUBJECT

Third Partial Report

on

Light Armor Investigation

Outlining the Effect of the Jacket of the Caliber 30 AP Bullet Upon Penetration of Steels

by

George Irwin

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

April 1938 NRL Report No. 0-1438

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Third Partial Report

on

Light Armor Investigation

Outlining the Effect of the Jacket of the
Caliber 30 AP Bullet Upon Penetration of Steels

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages:	Text - 6 Plates - 6
Authorization:	BuOrd. ltr. S13-1(4/173)Q8 of 13 December 1934.
Date of Investigation:	January 1937 to date.

Prepared by:
George Irwin, Contract Employee.

Reviewed by:
Ross Gunn, Principal Physicist, Acting Superintendent, Mechanics Division

Approved by:
H. M. Cooley, Captain, USN, Director.

Distribution:
BuOrd. (5)
BuEng. (2)

bmb

 [redacted]

ABSTRACT

When devising and testing light weight armor structures for defense against small caliber AP bullets, it is important to know to what degree a structure's effectiveness depends upon the special penetrating characteristics of the projectiles. Special characteristics are presented by small caliber AP bullet penetrations due to the important effects of the copper alloy jacket upon penetration. A study has been made of this factor by comparing impacts of caliber 30 AP bullets upon test plates of mild steel and STS armor with impacts upon the same plates of the AP core of the above bullet minus the jacket. Results obtained show that the jacket does part of the work of penetration and assists penetration by increasing amounts as the velocity increases. This effect, however, is negative (requires increased bullet velocities for penetration compared with the velocity required for penetration by an AP core without the jacket) below a characteristic velocity which increases with the hardness of the armor plate. Hard faced armor, therefore, has an obvious advantage against these small caliber AP bullets.

The above results furnish an explanation for the difference in penetration characteristics of small caliber AP bullets and large projectiles against STS armor plate. In fact, curves of $F(e/d,\theta)$ vs. e/d plotted for impacts of caliber 30 AP cores (minus the jacket) against STS armor plate show close similarity to these curves as obtained for impacts of major caliber projectiles on STS armor plate in spite of the extreme scale ratio.

TABLE OF CONTENTS

APPENDICES

[redacted]

AUTHORIZATION OF PROBLEM

1. This problem was authorized by Bureau of Ordnance letter S13-1(4/173) Q8 of 13 December 1934.

INTRODUCTION

2. Small caliber armor-piercing bullets have relatively a very special construction. General understanding of the functioning of the type of projectile light armor must frequently defeat requires increased knowledge of the effect of the copper alloy jacket upon the penetration of AP bullets. In order to obtain the desired elementary facts with the least confusion of conditions, the test plates were confined to two standard materials, mild steel (annealed boiler plate) and STS armor plate.

3. Caliber 30 AP bullet penetrations of materials like STS armor, cold-rolled steel, mild steel, etc. show a jacket crater. The jacket penetrates various distances into the metal and at extreme velocities the jacket completely penetrates the plate. At oblique angles against STS plate and at all angles against face-hardened armor plate the jacket supports and tends to prevent breakage of the steel core during early stages of impact.

4. It is not at present possible to make a complete study of the latter effect. As a result of the development at the Naval Research Laboratory of a technique for producing and controlling impacts of bare AP cores against plates, it has been possible to study the action of the jacket in cases in which the core does not break.

5. Various thicknesses of mild steel (annealed boiler plate) were penetrated at a wide range of velocities. The residual momenta were recorded by a ballistic pendulum and residual velocities deduced. In order to study impacts by the AP core without the jacket, subject plates were fired at through a thickness of mild steel sufficient to strip off the jacket. The jacket stripping plate was placed normal to the bullet trajectory and one to 1-1/2 inches in front of the test plate. Estimates indicated that the very small changes in trajectory direction imparted by the first plate did not appreciably affect the penetrations in the second plate. There was evidence, however, of angular velocity about a transverse axis which would amount to a considerable deflection of the core axis at larger distances behind the mild steel stripper plate. For instance, the extent of the deviation varied from a few degrees to the order of 40^{o} at 20 inches from the mild steel plate. As a further method of estimating the amounts of axial deviation present at impact, the orientation of the perforations in the second plate were carefully examined. Presumably these orientations will show a larger deviation than will the bullet axis at normal impact. At the separations used (1-1/4"), the deviations shown by the bullet holes were not larger than four degrees except in rare instances. These cases were rejected from the final data.

6. As much as two degrees of yaw, on the average, may have been present when the AP core struck the second plate. The effect of this deviation of the projectile axis, which increases the sectional area punched, is not well known quantitatively. A four percent increase in $F(e/d\theta)$ is perhaps a reasonable estimate for the normal impacts of the AP core. No attempt was made, however, to adjust the data for the effect of this angular deflection. The conclusions drawn are not affected in any important manner by a moderate increase in plate absorption of energy resulting from the increased section of the plate punching. It was assumed, therefore, that, at the small plate separations used, the cores were traveling essentially

true with the original flight direction and with velocities which could be determined from the ballistic pendulum data.

7. The energy absorbed from the incident AP core was obtained as a function of the core energy at impact; first, with full bullets, then with stripped AP cores, striking the same plate. This procedure was carried out for various thicknesses and at two obliquities for mild steel, STS armor plate and STS armor plate reheat-treated to greater hardness.

METHODS

8. The gun, bullets, and ballistic pendulum used for this study are the same as those described in Naval Research Laboratory Report O-1429 of March 1938.

9. The plates used to remove the jacket from the AP core were of thicknesses from 1/4" to 1/2" annealed boiler plate and will be referred to as stripper plates. Data on the residual momenta of cores after penetrating various thicknesses of stripper plate were used to determine the residual velocity curves shown on Plate 1. By use of this chart and several stripper plates, impacts of the stripped AP cores at a desired series of velocities could be obtained. Individual differences between stripper plates were sufficient, however, to justify the use of individual calibration curves for the stripper plates in the final reduction of data to estimate the velocity of the stripped AP core at impact.

10. The AP cores averaged 87.5 grains in weight and 0.255 inches in diameter. It has recently been found possible to fire these AP cores ground to a diameter of 0.245 inches, tinned and finished to a diameter of 0.257 inches, in the caliber .25 rifle previously used for photoclastic study of impacts. The low residual velocities of stripped AP cores obtained at penetrations of stripper plate near the limit velocity were not accurately known. Therefore, limits for the stripped AP core on very thin STS plates were determined with the caliber 25 gun as well as on the 100 yard range with the caliber 30 gun.

DATA OBTAINED

11. Two Aberdeen chronograph screens placed 16 feet apart (second screen at about 90 yards from the gun) were used to measure the velocity of the full bullet at impact. A small correction was applied for loss in velocity between the screens and the plate rack.

12. The pendulum was calibrated by firing full bullets of known weight into it at velocities up to 1500 ft/sec. Since the deflection is only of the order of 2 inches at most, while the pendulum suspension is 72 inches long, the measured momentum was accurately a linear function of the pendulum displacement. Theoretical deduction of the calibration curve, based on the pendulum weight and the 72-inch length from the point of suspension to the level of the indicator, gave essentially the same calibration curve as was determined experimentally. When the weight of the pendulum (originally 65 lbs., now about 120 lbs.) was changed from time to time, the calibration curve was easily redetermined by firing a few bullets of measured velocity directly into the pendulum. Consistency of the data indicated probable errors of about 10 ft/sec. in velocity determinations with the Aberdeen chronograph or with the ballistic pendulum.

13. Penetrations at about 100 ft/sec. intervals from near the limit velocity to the point where the jacket began to penetrate the plate were used to calibrate the stripper plates. Assuming the average core weights to be 87.5 grains, the incident core energy was computed from

$$E = 1.943\ V^2 \times 10^{-4} \quad \text{ft. lbs.}$$

where V was the bullet velocity measured by the Aberdeen chronograph. The pendulum reading was transferred into residual velocity by means of the above formula using residual velocity for V. The difference between the incident and the residual core energies, which is the absorbed core energy, was plotted as a function of incident core energy. These data lead to curves of the nature shown by full lines on Plate 2.

14. It was desired to compare absorbed core energies when full bullets were incident with those when only the bare AP cores were incident for the same group of plates. To do this a stripper plate was fixed 1 to 1-1/2 inches in front of the plate to be tested. Knowing the velocity of the incident full bullet, the residual energy of the core after passing through the stripper plate could be found from curves such as those on plate 2. The residual energy of the core after penetration of the plate under test was found as outlined above by means of the pendulum readings. Thus, curves such as those shown by dashed lines on Plate 2 were determined.

15. When a single thickness of mild steel stripper plate in front of the pendulum was penetrated at high velocity the weight of material striking the pendulum was uncertain. Debris consisting of lead from the nose of the AP bullet, small fragments of the plate material, and (at the highest velocities) fragments of the jacket struck the pendulum. The total weight of such material as determined by partial recovery from the pendulum face and weighing was of the order of 5 grains for a 2200 ft/sec. penetration of 3/8" mild steel. Small adjustments for this error of the high velocity parts of the curves on Plate 2 were made and appeared to improve the consistency of the data using different stripper plate thicknesses.

16. Having determined the curves shown on Plate 2, the core energy absorption curves for full bullets and for stripped cores were determined on STS plates and on a 1/4" thickness of STS hardened to Brinell 375. This procedure was also carried out on all three materials with the projectiles incident at thirty degrees on the test plates. The results are shown on Plates 3 and 4.

17. Other data of interest in connection with this study had been obtained during the early part of 1937. Detailed measurements were made on a large number of partial and complete penetrations into 1/2", 1" and 1-1/4" thicknesses of mild steel with AP caliber 30 bullets. The measurement believed to be of significance with respect to this study was the determination of the position of the bottom of the jacket crater with respect to the flat plate surface near the penetration. Accuracy beyond 0.01 inches was not attempted in the measurement of these depths and the effect of irregularities in impact conditions was several times 0.01 inches. Figure 1 of Plate 5 shows the depth of the crater made by the bullet jacket in mild steel for various incident core energies.

18. As an arbitrary measure of the aid to penetration given by the jacket one may subtract the absorbed core energy when the full bullet was incident, from the absorbed core energy when the stripped AP core was incident on the plate at the same velocity. Such data were obtained from the curves on Plate 2 and have been plotted in Figure 2 of Plate 5.

[redacted]

19. By extending ballistic limit data on STS plate to very thin sections, it was possible to determine $F = M^{1/2}V \cos \theta/e^{1/2}d$ for a range of e/d values from 0.47 to 1.47 at $\theta = 0$. For $\theta = 30^\circ$, only two good values of F, at e/d equal to 0.98 and to 1.47 were available. The values of F as a function of e/d for the two values of θ used are shown in Plate 7. For the purpose of comparison curves of F values for major caliber projectiles as measured at the Naval Proving Ground are also shown on Plate 7.

CONCLUSIONS

20. Two methods of obtaining impacts at controlled velocity with AP cores have been developed and applied to the study of general characteristics of the caliber 30 AP bullet. One method consists in firing at normal incidence through a mild steel plate (annealed boiler plate) which may be 1/4 to 1/2 inches thick. The plates to be tested are subjected to impacts of the AP cores at about 1-1/4" behind the mild steel plate used to remove the jacket. For oblique impacts some parts of the test plate are too far or too close to the stripper plate and the shots must be placed in that region where the plate separation is of the order of 1-1/4 inches. The second method consists of firing AP cores (from the caliber 30 bullet) ground to about 0.245 inches diameter, tinned, and finished to 0.257 inches diameter, in a caliber 25 rifle. This firing is done at a short inside range in the Laboratory. Comparison of plate resistance to penetration for the AP cores and for the full-jacketed bullets for various thicknesses and velocities furnishes data on the effect of the copper alloy jacket upon penetration. Due to some turning of the core and to inequalities in stripper plate material, the method using the stripper plate should not be used where a high order of accuracy is desired.

21. Data obtained by the above methods show that the AP core penetrates mild steel with smaller energy loss without than with the jacket up to about 1700 ft/sec. velocity. At higher velocities the jacket was an aid to penetration, the effect increasing rapidly as the velocity increased. For a harder material, STS armor plate, the AP core penetrated with less energy absorption with the jacket removed up to velocities of 2000 ft/sec. For successively higher velocities the jacket seemed again to be an increasing aid to penetration with increasing velocity. The experiment was tried on a still harder material, STS armor plate reheat-treated to a hardness of 375 Brinell. Owing to breaking of the bullet, AP cores were used against only one thickness. As far as the experiment was applicable to plate of this degree of hardness, the jacket appeared to become an aid to penetration at about 1900 ft/sec. These experiments indicate that against materials softer than about Brinell 300 and at velocities increasing above a certain velocity characteristic of each material, the jacket of the AP cal. 30 bullet functions as an increasing aid to plate penetration. These characteristic velocities may be a regular increasing function of the hardness, or perhaps of the tensile strength, of the materials. Within the accuracy of the experiment the characteristic velocities mentioned above do not vary with thickness of material.

22. Comparison of the jacket effect upon penetrations in mild steel with measurements of the depth of the jacket crater (discussed above in paragraph 19) indicate a close relationship between the two. Plate 5, Figure 2 shows that, when one takes the differences, $E_c - E_f$ in absorbed core energies with and without the jacket as a measure of the jacket's aid to penetration, the effect of the jacket appears to reach zero at an incident core energy of 575 ft.lbs. Figure 1 on the same plate shows that at this incident core energy, with the full bullet striking the plate, the bottom of the jacket

[redacted]

crater is at the same level as the undisturbed surface of the plate near the bullet hole. Furthermore, the depth of the jacket crater and $E_c - E_f$ increase in somewhat the same manner with increasing velocity.

23. In view of the above results, the effect of the jacket upon bullet penetrations such that the core does not break appears to be to decrease the core energy required for penetration by an amount roughly proportional to depth of the jacket crater. The effect is negative (requires increased core energy for penetration) at low velocities. This means that against caliber 30 AP bullets, thin plate (low limit velocities) will have higher ballistic coefficients and thick plate (high limit velocities) will have lower ballistic coefficients than a solid projectile would show, due to the jacket effect. This effect, therefore, is in agreement with the difference in $F(e/d,\theta)$ curves for large projectiles and for small caliber AP bullets striking STS armor plate.

24. Some trends of importance to qualitative understanding of the caliber 30 AP bullet penetrations are illustrated by the absorbed core energy curves of Plates 2, 3 and 4. The slopes of these curves show that, for the mild steel and soft armor plate studied, the absorbed energy tends to increase with velocity for the solid projectile whereas the slope of the absorption curve is either small or negative for the jacketed projectile. The solid AP core curves show that energy absorption tends to increase more rapidly with incident energy for greater thicknesses and greater obliquities. However, the slopes of the curves are not very accurate due to the scatter of the data. It is quite possible that obliquity and thickness are of less importance in determining the shapes of these curves than the velocity range over which the measurements extended. The fact that the AP core curves definitely show an increase in absorbed energy with increasing velocity indicates a similarity to plate penetrations by major caliber projectiles. (USNI Proceedings, May 1930, page 413, "Ballistic Engineering Problems", L. Thompson.) Other similarities are noted in the following paragraph.

25. A comparison of $F(e/d,\theta)$ versus e/d curves for thin STS plate caliber 30 AP bullet and the solid AP core has been made to those obtained on STS plate with major caliber projectiles. The results plotted in Plate 6 show that curves for the caliber 30 AP core are much more like those for major caliber projectiles than like those for the caliber 30 AP bullet. In fact, when some small average yaw of the AP cores, and differences in projectile design are taken into consideration, the F values for AP cores and for major caliber bullets are in quite fair quantitative agreement.

26. These indications that penetrations by solid hardened steel cores present similar characteristics to those by major caliber projectiles suggest that valuable information applicable not only to heavy armor plate but to the design of projectiles might be obtained from small scale studies. Recent development by this division of an instrument which photographs a displacement-time curve of the projectile throughout the process of penetration, thus permitting determination of the force on the projectile at every stage of penetration, adds greatly to the attractiveness of such a program. A description of uses of this device in the study of light armor structures will be given in a separate report.

SUMMARY

27. When devising and testing light-weight armor structures primarily for defense against small caliber AP bullets, it is important to know to what degree a structure's effectiveness depends upon bullet design. Current models of the caliber 30 AP bullet have about 40% to 50% of the bullet weight in a copper alloy jacket not expected to pass through armor plate but possessing sufficient inertia to have great effect upon the penetration of the bullet core. Tests have therefore been made for the purpose of determining certain general effects of the jacket upon penetration of caliber 30 AP bullets.

28. The experiments were performed at low obliquities using test plates which do not break the steel cores. Results obtained indicate that the jacket is an increasing aid to penetration as the velocity increases. The standard of comparison used was penetration by an AP core with the jacket removed. The effect is roughly proportional to the depth of the crater formed by the jacket around the entrance point of the bullet. At low velocities (less than 2000 ft/sec. for STS armor plate), the AP core without the jacket shows greater penetrating power than the full-jacketed bullet at equal velocities.

29. The velocity at which the jacket appeared to aid passage of the AP core through test plate was 300 ft/sec. greater for STS armor (Brinell 275) than for a softer material, mild steel (Brinell 130). It is probable that a large part of the difference in penetration coefficient of face-hardened bullet-proof plate and STS plate is due to the decreased effectiveness of the jacket against the harder plate materials. Experiments with the caliber 30 AP core against hard plates usually show breakage of the core. Experiments to be reported on spaced plates show some of the advantages to be gained by making use of the jacket effect and the vulnerability of AP cores against hard plates.

30. Measurements of the penetration properties of the stripped AP caliber 30 core showed certain similarities to penetration properties of large projectiles. As with large projectiles the energy absorbed above the limit of the plate was found to be an increasing function of the impact velocity. The close correspondence of the F(e/d,θ) versus e/d curves of the AP cores (i.e. without jackets) with these curves as determined for major caliber projectiles suggests that more careful experiments with the AP cores which eliminate differences in projectile shape as well as the possibility of yaw might show a complete agreement in spite of the extreme scale ratio.

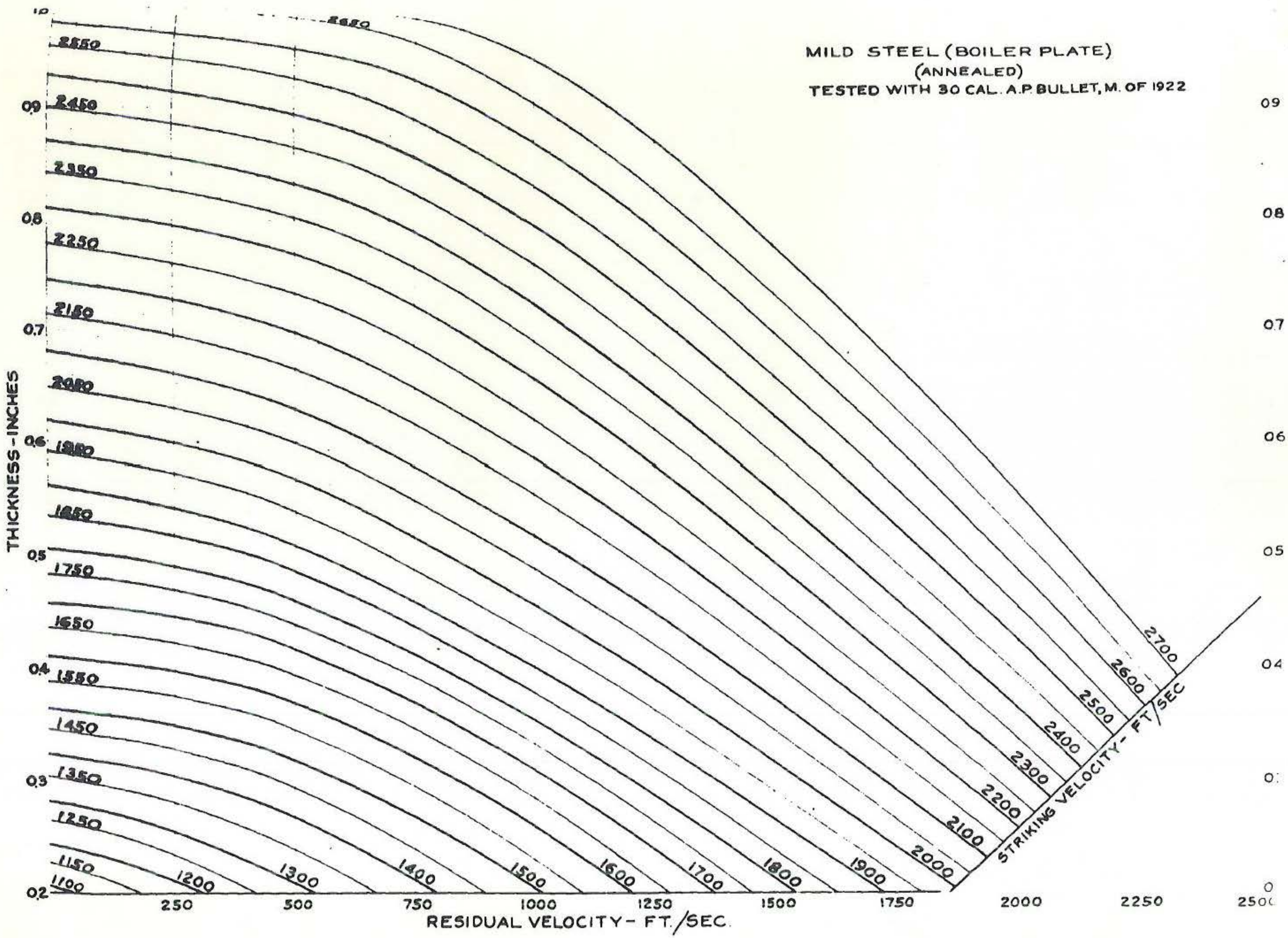


PLATE I

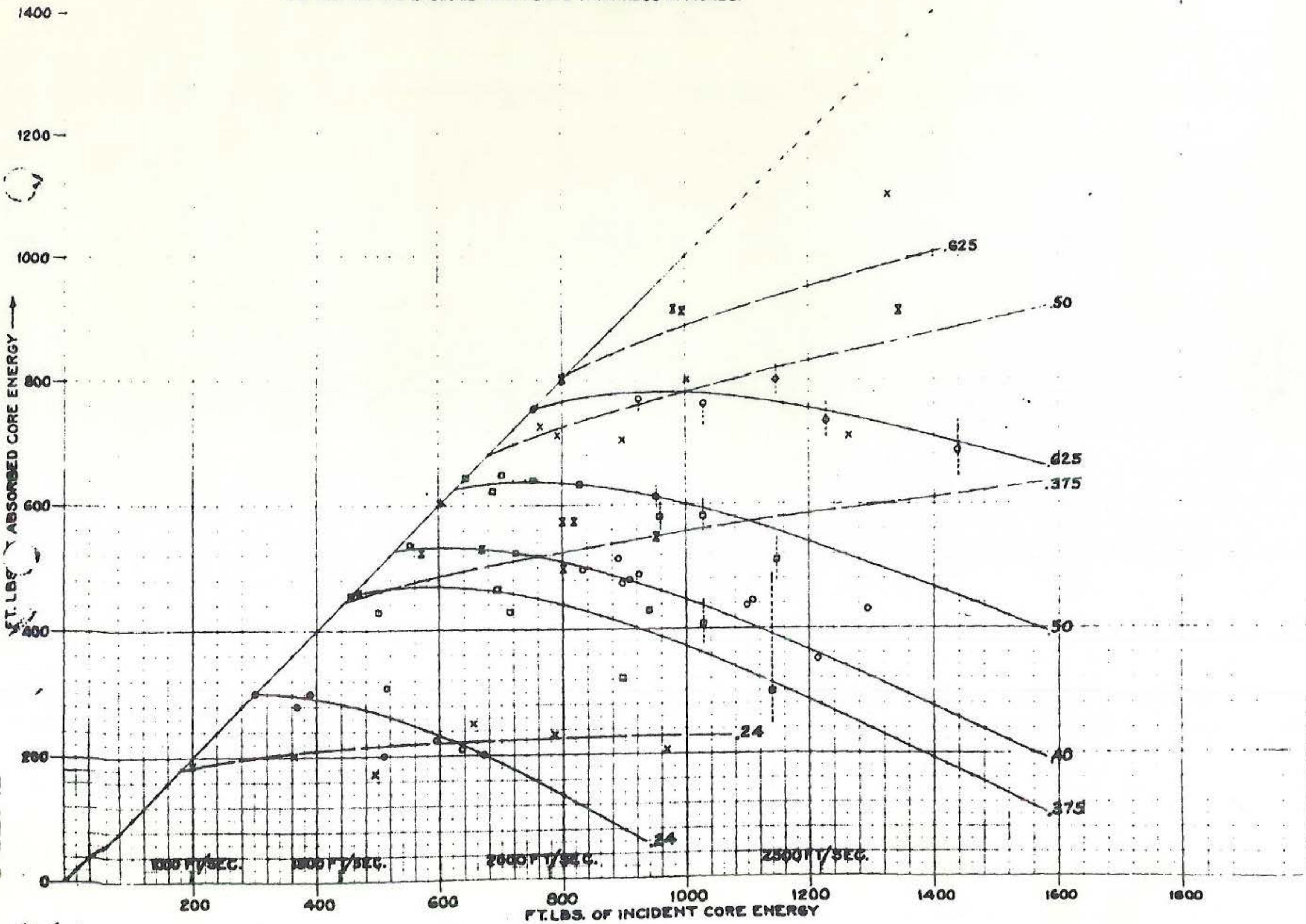
[redacted]

CORE ENERGY LOSSES IN MILD STEEL.

FULL CURVES SHOW ENERGY ABSORBED WHEN ENTIRE JACKETED CAL. .30 AP BULLETS WERE INCIDENT.

DOTTED CURVES " " " " ONLY THE CORES OF THE " " " " " " .

THE CURVES ARE LABELED WITH PLATE THICKNESS IN INCHES.



[redacted]

PLATE 2

S.T.S (NORMAL INCIDENCE)

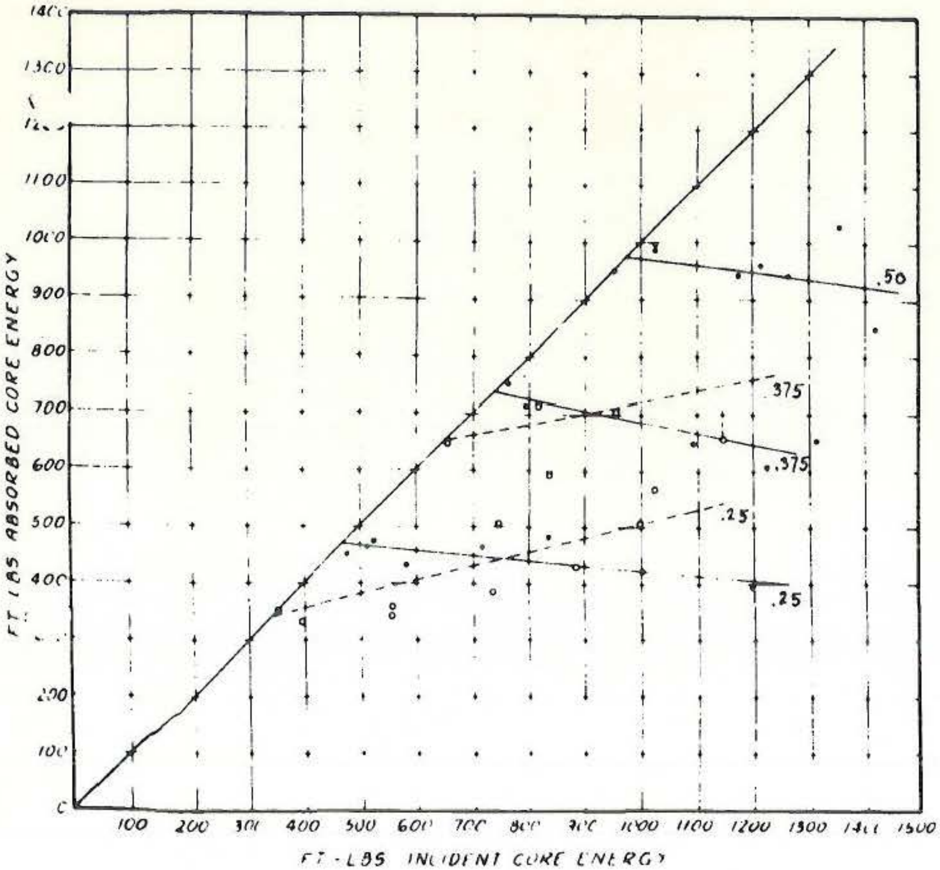


FIG. 1

S.T.S. (30° INCIDENCE)

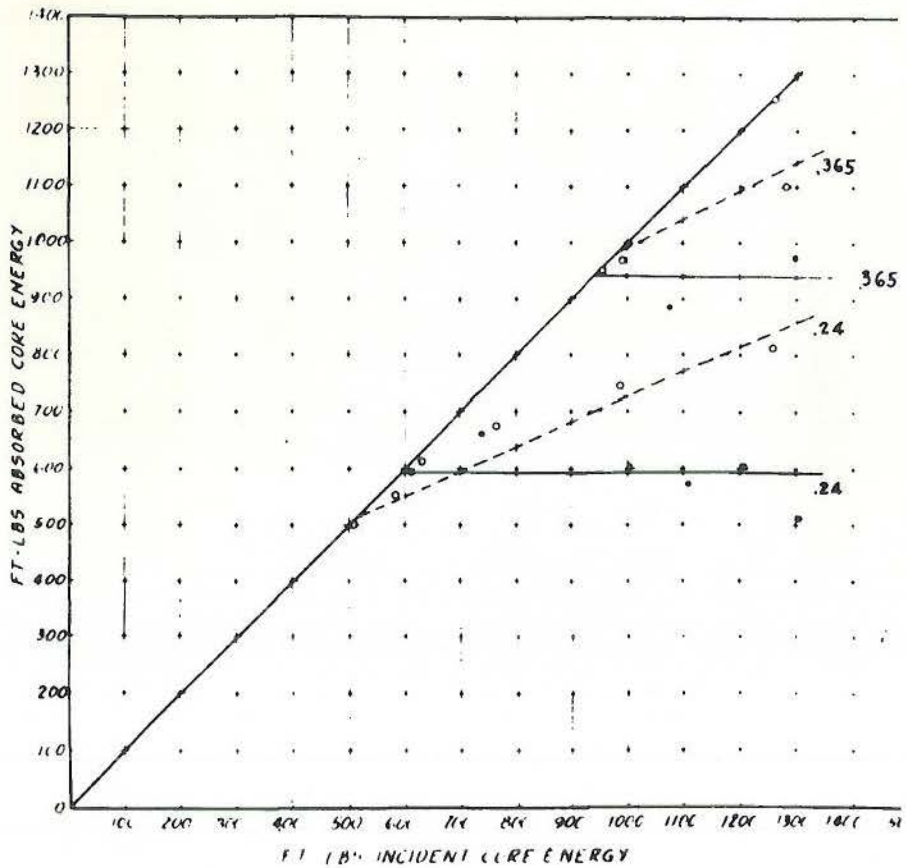


FIG. 2

PLATE 2

[redacted]

MILD STEEL (30° INCIDENCE)

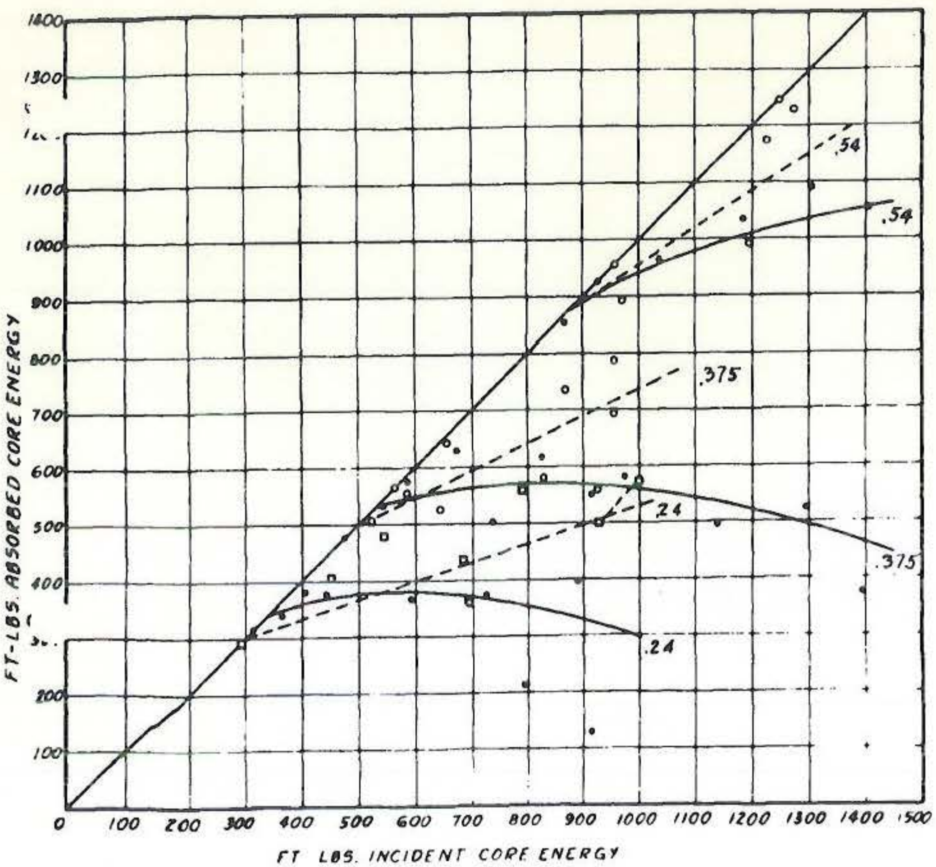


FIG. 1

0.25" STS (HARDENED TO BRINELL 375)

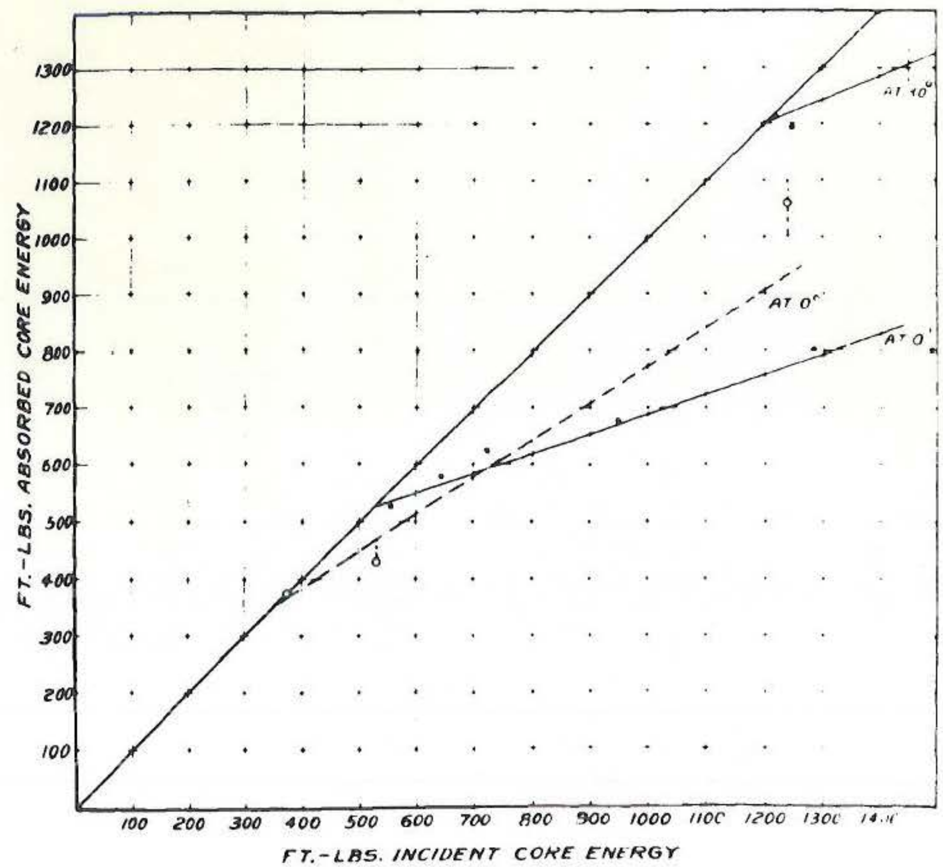


FIG. 2

[redacted]

PLATE 4.

PENETRATION BY THE JACKET OF CAL. .30 AP BULLET IN MILD STEEL (ANNEALED BOILER PLATE

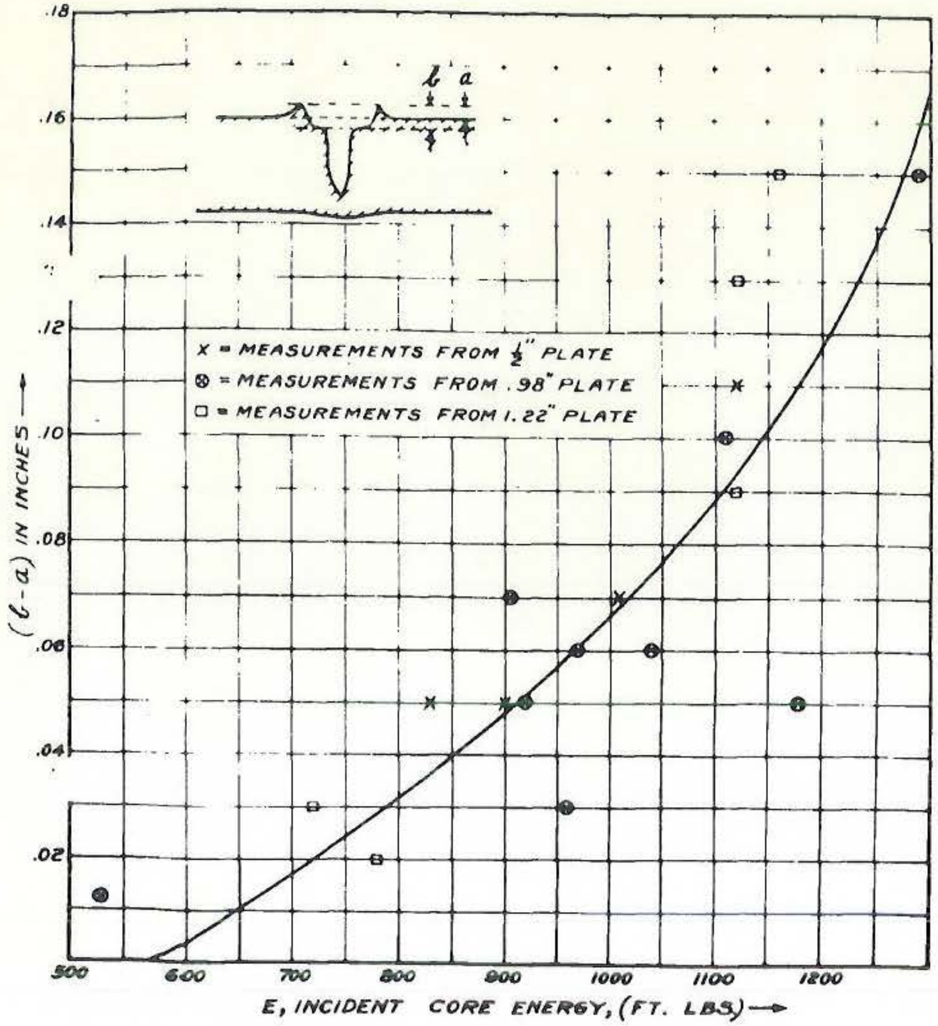


FIG. 1

JACKET EFFECT UPON PENETRATIONS OF MILD STEEL (NORMAL IMPA

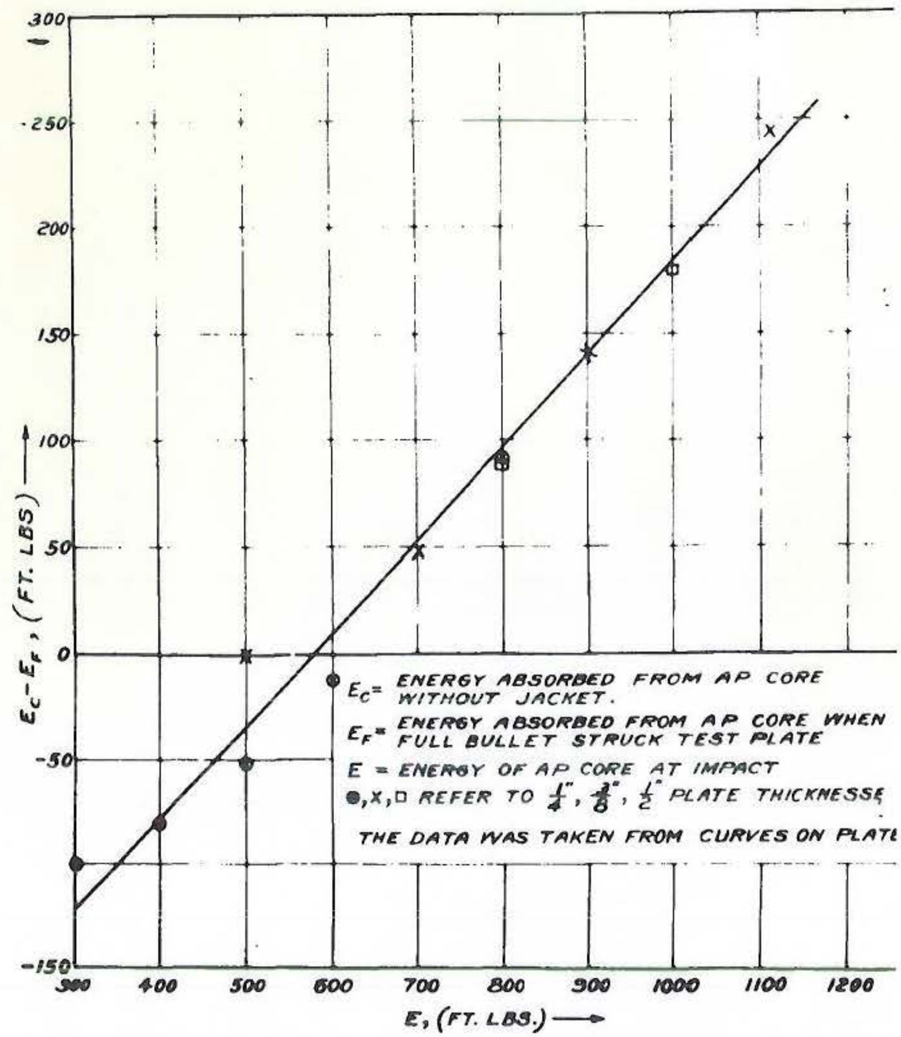


FIG.

DECLASSIFIED

[redacted]

PLATE 5

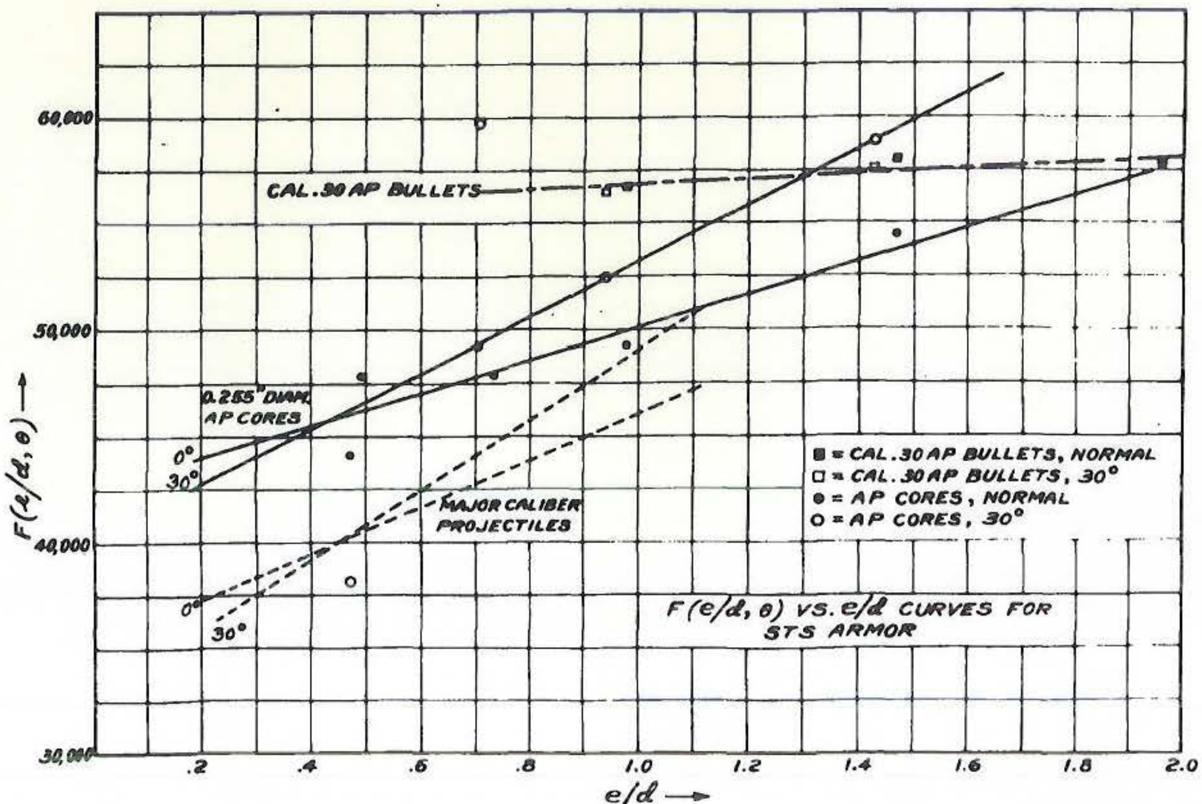

60,000
50,000
40,000
30,000
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
e/d →
F(e/d, θ) →
CAL .30 AP BULLETS
0.255" DIAM. AP CORES
0°
30°
MAJOR CALIBER PROJECTILES
■ = CAL .30 AP BULLETS, NORMAL
□ = CAL .30 AP BULLETS, 30°
● = AP CORES, NORMAL
○ = AP CORES, 30°
F(e/d, θ) VS. e/d CURVES FOR STS ARMOR

PLATE 6