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AIRCRAFT ARMOR

An Analysis of Firings of Rolled Homogeneous Armor Submitted under Specification AN-A-[illegible]

BY

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Watertown Arsenal Laboratory
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AIRCRAFT ARMOR

An Analysis of Firings of Rolled Homogeneous Armor Submitted under Specification ANOS-1

OBJECT

The examination of data resulting from the ballistic testing of rolled homogeneous armor submitted under Specification ANOS-1 with a view toward facilitating the procurement of high quality aircraft armor through a more realistic approach to the specification of ballistic requirements.

SUMMARY

The merits of current ballistic limit criteria are contrasted with the merits of a lethal limit criterion.

The mechanisms by which penetration of armor is effected by a projectile are reviewed and the effects of hardness and plate obliquity (30°) noted.

It is suggested that stipulation of some of the ballistic requirements of Specification ANOS-1 has been made without consideration of certain phenomena associated with the mechanisms of penetration.

It is suggested that a more realistic approach to the specification of ballistic requirements for aircraft armor will be facilitated by the recognition of the following contentions:

1. The criterion of plate quality should be based upon the resistance to lethal penetration as a more accurate measure of plate efficiency than either the Army or Navy limit criteria.

2. Tests at obliquities to determine resistance to penetration utilizing projectiles which break up or shatter upon impact should be discontinued as an inspection device.

3. Tests for resistance to penetration wherein the ratio of plate-thickness to projectile-diameter is less than 0.8 should be discontinued since protection is not offered under these conditions at combat ranges and the best performance under these greatly over-matching projectile conditions is not compatible with the optimum resistance to matching projectiles.

4. Tests for resistance to penetration on a single plate at any one obliquity with more than one type of projectile should be discontinued.

5. The proximity of the explosive charge to the plate in tests to determine the resistance of armor to H.E. shock should be rigidly controlled.

6. The criterion of failure under a projectile-through-plate test at obliquity should be the disclosure of inherent spalling tendencies and not the dimension of the exit diameter.

7. The criterion of failure under a projectile-through-plate test at normal incidence may properly be the dimension of the exit diameter, but assurance must be made that the "jacket effect" attendant at high velocities is avoided.

8. The use of an overmatching projectile in the projectile-through-plate test should be advantageous.

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INTRODUCTION

Considerable difficulty has been experienced by producers of aircraft armor in meeting the ballistic requirements of Specification ANOS-1.[1] In earlier work it has been suggested that some of these requirements have been stipulated without consideration of certain phenomena associated with the mechanisms of penetration.[2]

The present report is an expansion of the earlier contention and in presenting much more data affords a basis for a more realistic approach to the specification of ballistic requirements for aircraft armor.

TEST PROCEDURE

Inasmuch as the testing of armor submitted under Specification ANOS-1 proceeds from day to day, it has been necessary to confine arbitrarily the inclusion of data in this report to those available at the time this study was initiated.

It was decided to collate data on the resistance to lethal penetration of aircraft armor. Since at normal incidence there was no determination of "lethal limit"* and inasmuch as there is substantial agreement between Navy limit and "lethal limit" in the machinable range of hardness, the data at normal are derived from tests conducted under the Navy criterion. For this reason, the data concerning armor of hardness in excess of the machinable range may be deceptive in that they are higher than the real "lethal limits" of armor of this hardness.

At obliquities, the data on plates throughout the entire range of hardness covered represent the lethal limits.

RESULTS

All the data available are set forth in Tables I to X of Appendix 3. Summarized according to graduated ranges of hardness, these data are tabulated in Tables II and III and graphically represented in Figures 3 to 8 and 10 to 13.

These figures show the dependence, at different levels of hardness, of (F), the Thompson Coefficient,[3] and the ratio of plate-thickness to projectile-caliber (e/d) corrected for weight increase necessary to shield a unit area normal to the line of fire (e/d sec θ) and the relationship of those plots to the requirements of the specification.

Figures 14 and 15 have been drawn on the basis of the curves indicated by the data plotted in Figures 3 to 8 and 10 to 13 respectively.

Figures 2 and 9 represent the values of "F" required by Spec. ANOS-1.

*See page 4 - "Ballistic Limit Criteria".

1. Army-Navy Spec. for Homogeneous Armor for Aircraft. ANOS-1. 12/2, 14/42.
2. W.A. 470.5/6469(r), 4/14/43. See Appendix A.
3. The Thompson Coefficient (F), a measure of the penetration efficiency of armor, is determined from the following:

$$F^2 = \frac{m\, V^2 \cos^2 \theta}{e\, d^2}$$

where m equals the weight of the projectile (core) in pounds, V is the limit velocity in feet per second, θ is the angle of obliquity, e is the thickness of the plate in feet, and d is the diameter of the projectile (core) in feet.

DISCUSSION

I. Ballistic Limit Criteria

Fundamental to any discussion of ballistic performance is a consideration of the criterion by which plate failure is to be judged.

The criterion of failure which has been traditional to the testing of armor under the auspices of the Army is such a penetration of the plate by the projectile as will cause an opening on the rear of the plate sufficient to allow the passage of a beam of light.[4]

The Navy, on the other hand, has traditionally required that the projectile completely perforate the plate and, in addition, remain intact,[5] if the plate is to be judged a failure.

For some time there has been considered at this Arsenal a third criterion which has been called the Lethal Limit. In essence, a plate fails by this criterion when the impact of the projectile causes any fragment of the plate or of the projectile to fly from the rear of the plate with potential lethality.

Proponents of the Army criterion and of the Navy criterion have long argued the merits of their respective preferences. There is something to be said in favor of each of these criteria.

The Army limit is without peer as to ease of determination. A novice in proof technique can accurately judge failure by this standard from the very beginning. On the other hand, having determined the ballistic limit by this criterion, has he learned anything of significance?

If he is interested in the performance of armor which is apt to be attacked frequently with lead-ball projectiles, in addition to armor-piercing projectiles, he may well want to know the incident velocity at which impact by an armor-piercing projectile will so affect the armor as to permit the lead-splash of ensuing ball-projectile impacts to penetrate. From the application of this criterion he may determine that velocity.

Otherwise, this standard provides information of little real significance.

4. Armor Plate Proof Technique, Prepared for the Guidance (of) Armor Plate Proof Officers by Arms and Ammunition Division, Proof Dept., Aberdeen Proving Ground, Maryland. 14 December 1940. Page 2.

5. The Penetration of Homogeneous Light Armor by Jacketed Projectiles at Normal Obliquity. U. S. Naval Proving Ground, Dahlgren, Va. Report No. 14-43. 8 July 1943. Page 2.

It is sometimes urged, however, that the use of the Army limit provides a factor of safety in that it affords a margin between the ballistic limit so determined and the velocity at which death-dealing fragments are detached, so that armor designed to resist complete penetration according to this criterion at a certain velocity will protect against lethal penetration at a velocity a given percentage higher. But this is a dangerous presumption, inasmuch as this margin is very variable and often non-existant--for example, when plate failure occurs through shear (punching), the Army limit can be realised only through the release of death-dealing fragments. Since shear failure is characteristic of the penetration of under-matching plates, plates of high hardness, and plates at obliquity to the line of fire, the circumstances may be infrequent when a margin exists between Army limit and Lethal Limit.

The Navy criterion likewise is very well adapted to particular uses. In the sphere of naval ordnance, where the proficiency of a projectile is measured not by its ability to incapacitate personnel merely, but rather by its ability to incapacitate, substantially, an entire section of a vessel through a high order detonation, armor does not fail unless it allows itself to be perforated by an intact projectile. In such an application, the Navy criterion is a realistic one. However, its translation into the realm of small-arms projectiles is difficult to condone.

In considering armor for aircraft it must be recognized that the incapacitation of personnel may well result in the loss of the aircraft. Thus, a criterion by which armor may be deemed passable under an impact which causes death-dealing fragments to be released from the rear of the plate is not a suitable standard by which to judge the ballistic efficiency of aircraft armor. Such a criterion, however, is established when a Navy ballistic limit or such a slight modification of it as is defined in Specification ANOS-1[6] is prescribed.

Figure 1 shows the fragments of plate and projectile which flew off the rear of a 3/8" rolled homogeneous aircraft armor plate (BHN 444) under normal impact at various velocities with cal. .50 AP M2 projectiles. While it took an incident velocity of 1555 feet-per-second (deliverable at a range of 1250 yds. by a gun with muzzle velocity of 2900 feet-per-second) to produce a complete penetration according to the Navy criterion, and a velocity of 1488 f/s (deliverable at 1325 yards) to produce a complete penetration under the criterion established in Specification ANOS-1, an incident velocity of 1230 f/s (deliverable at 1700 yards) was sufficient to detach lethal fragments from the rear of the plate.

At obliquity, the difference is much more pronounced. When steel armor plate is installed at an angle in excess of 20° it has been found to be virtually impossible for a small arms projectile of current production to perforate it and remain intact and undeformed.[7] Thus, data

6. Spec. ANOS-1, 16b, describes a penetration as complete "when the bullet core passes completely through and falls behind the plate". The stipulation, characteristic of the Navy criterion, that the projectile remain intact and undeformed has been omitted.

7. W A Report No. 710/466 "Armor Plate - An Analysis of Firings of Cal. .50 A.P. Ammunition against Homogeneous Armor Plate". C. Zener. 26 November 1942.

on Navy ballistic limits at such obliquities deserve careful scrutiny. During a test of a series of plates (nominal thickness - 5/16") submitted for development under Specification ANOS-1, ballistic limits at 30° obliquity according to the Specification criterion and according to a Lethal Limit criterion were determined.[8] The results are summarized in Table I. The minimum difference between the ballistic limits according to the two criteria was 327 feet-per-second. The maximum difference was 1278 feet-per-second, and the average 771 feet-per-second. This represents an average difference of 800 yards in the ranges at which the two effects may be produced. The table also indicates that an armored plane may be lethally vulnerable at a range more than twice as great as its vulnerability range according to the specification criterion. This may well represent the difference between the pilot's bringing his own armament into play or not.

In attempting the procurement of aircraft armor, therefore, the Lethal Limit, so-called, merits consideration. The Proving Center, Aberdeen Proving Ground, adopting a very realistic attitude in determining the resistance to penetration, at 30° obliquity, of armor submitted under Specification ANOS-1, has, in effect, determined a lethal limit by placing a thickness of duralumin a fixed distance behind the test plate and calling penetration complete when the duralumin has been pierced by fragments resulting from projectile impact. The Naval Research Laboratory has long recognized the inapplicability of the Navy limit criterion to work with small arms projectiles,[9] but the Naval Proving Grounds at Dahlgren, Virginia, apparently* have not entirely relinquished use of that standard in the testing of light armor.

At normal incidence, in the hardness range where plates fail in a ductile manner (and this range is equivalent, roughly, to the so-called machinable range, which has an approximate upper limit at BHN 375) the Lethal Limit and the Navy limit generally coincide. Otherwise, the Navy limits are realized at velocities variably in excess of lethal limits. Thus the determination of the Navy limit of an aircraft armor plate furnishes little information of significance as to the real protection afforded by the armor unless a maximum hardness limit is established and testing confined to normal incidence.

Since it is reasonable to be interested in the lethal limit of aircraft armor, it should also be reasonable to specify a criterion by which this lethal limit may be determined. The specification of a Navy criterion does not accomplish this end, and although the Army criterion might be utilized by ignoring the illusion that a margin exists between the Army limit and the Lethal Limit (for example, by considering the Army limit identical with the Lethal limit), a more logical step would seem to be the specification of a lethal limit criterion. Then a real margin

*See reference 4, footnote page 4.

8. O.O. 470.5/14389. Homogeneous Aircraft Armor Development Plates. 6 May 1943.

9. Navy Dept. Eleventh Partial Report on Light Armor. Naval Research Laboratory, O-2068. 19 May 1943, page 4.

of safety could be assured by considering, for design purposes, the protection afforded by a given thickness of plate to be a certain percentage lower than the lethal limit specified as a requisite to acceptance.

II. Mechanisms of Armor Penetration

A consideration of the mechanisms by which armor may be perforated may also be germane to the present discussion.

There are two extreme types of mechanism by means of which armor may be perforated.[10] The more common type of perforation is accomplished by the projectile's plastically pushing aside the plate material in its path until a hole has been formed sufficient to allow its passage through. This mechanism, substantially, is characteristic of the perforation, at normal incidence, of armor of a hardness within the machinable range by sharp-nosed non-deforming projectiles.

The other extreme is characterized by the plate's failure in shear along a cylindrical surface perpendicular to the plate's surface resulting in the release of a nearly cylindrical plug from the path of the projectile, thus facilitating the projectile's progress through the plate. This is the mechanism by means of which a flat-nosed projectile perforates an undermatching plate at normal incidence.

Variations in the design, composition, heat-treatment and hardness of the projectile, variations in the composition, heat-treatment, hardness and soundness of the armor, variations in the ratio of plate-thickness to projectile-diameter or variations in the obliquity of incidence will produce different combinations of these two basic mechanisms.

At obliquity, impact of small arms projectiles of current design and manufacture with aircraft armor plate results generally in a combination in which the initial stages of perforation are reached by a plastic pushing aside of material and eventual perforation is accomplished through the failure of the plate in shear.

At normal incidence, the perforation of undermatching plate by sharp-nosed projectiles is accomplished by a similar sequence of mechanisms.

The significance of the mechanism by which failure is brought about will be treated later in this report.

III Graphical Representation of Data

A plot of "P" versus e/d enables comparisons to be made among plates of various thicknesses on the basis of the protection afforded by a unit weight of armor shielding a unit area normal to the line of fire, and

10 W.A. Report No. 710/492 "Mechanism of Armor Penetration". Second Partial Report. C. Zener and R. E. Peterson. 31 May 1943

also allows an insight into the mechanisms of penetration characteristic of different values of the ratio of plate-thickness to projectile-diameter ratio.

Thus, at normal incidence, a plot of F values based on penetrations effected by a purely plastic pushing-aside of material of constant physical properties from the path of a non-deforming bullet would result in a horizontal line where, at all values of e/d, F would be constant.[11]

Again, at normal incidence, penetrations resulting from failure of the plate by pure shear would give F values which would fall in a steep curve sloping sharply downward as e/d decreased.[12]

Since, in practice, penetration of current aircraft armor by current small-arms projectiles at normal incidence is never effected completely by either one of the two basic pure mechanisms, a plot of empirical values of F resultant from varying combinations of the two could be expected to fall along a gradual curve tangent at its extremities to the aforementioned plots. Since the height of the horizontal line and the slope and lateral placement of the steep curve are dependent on hardness, so also would be the empirical curve.

At obliquity, the universality of breakage of current small arms projectiles tends to obscure the mechanism of penetration, but eventual failure in shear is apparent at much higher values of e/d than at normal incidence.

A plot of empirical values of "F" determined on steel armor plate at obliquity characteristically tends toward the horizontal at values of e/d which are in excess of a certain critical value which appears to be an inverse function of hardness. Below this critical value, F decreases in the general direction of the origin. Thus, due to the inverse influence of hardness on the critical, the slope of F at lower values of e/d is much steeper in the higher hardness levels.

IV. The Requirements of the Specification

A plot of the values of F required for the various values of e/d at normal incidence and at 30° obliquity is presented in Figures 2 and 9 respectively and reproduced as a dotted line in Figures 3 to 8 and 10 to 13 respectively. The substantial agreement between the values of F required under impact of cal. .30 AP M2 and cal. .50 AP M2 projectiles is notable, but sound.

11 "The Ballistic Properties of Mild Steel, Including Preliminary Tests of Armor Steel and Dural". National Defense Research Committee Report A-111: Progress Report. 20 November 1942. Appendix A, page 47.

12. Ibid, page 49.

Plots of the values of F determined on the basis of lethal limits at normal incidence are presented in the order of increasing levels of plate hardness in Figures 3 to 8 and similar plots based on data at 30° obliquity appear in Figures 10 to 13.

It is customary in the development of a specification for armor to procure typical samples of material, to submit them to tests with the type of projectiles against which they may be expected to be emplaced in service, and, on the basis of these preliminary tests, to stipulate ballistic limits which must be equalled or exceeded if production armor is to be deemed acceptable.

In certain circumstances, (for example, in the stipulation of Army ballistic limits where, over the range of e/d usually subject to test, the limit velocity is substantially a linear function of e/d), the determination of the ballistic limits of the sample plates at a few values of e/d can become a reliable basis for interpolation and extrapolation. However, when a Navy ballistic limit or a lethal limit is to be specified, no such short-cut is reliably available.

Comparison of the graphs drawn from the specification with those based on empirical data leads to the suspicion that the lower end of the specification graphs were determined by extrapolation.

At normal incidence the error is not so evident because even at the lowest values of e/d specified the drop in the value of F which characterizes the predominance of a shear failure in the mechanism of penetration has only begun to assert itself. However, at 30° obliquity, the characteristic slope of F toward the origin begins at a higher value of e/d and, consequently, the disagreement between the specification and empirical data is inevitable.

V. Effect of Hardness on Resistance to Lethal Penetration

A. Normal Incidence

Figures 3 to 8, based on the empirical data recited in Table II, show the effect of hardness upon the ability of armor to meet the resistance requirements of Specification ANOS-1 under impact at normal incidence.

At no hardness level can the requirements for resistance to penetration by both cal. .30 AP M2 and cal. .50 AP M2 projectiles be met at all values of e/d, although armor in the hardness range BHN 346-385 substantially satisfies the specification requirements at all except the lower values of e/d where, it is suspected, the requirements may have been poorly evaluated. At hardnesses below this level resistance to penetration by both projectiles increases with BHN.

At hardnesses above this level the resistance to penetration of armor by cal. .30 AP M2 projectiles continues to increase whereas its resistance to cal. .50 AP M2 projectiles penetration tends to decrease. The precise reason for this divergence is not yet apparent. However, it would seem to be traceable to some inherent difference between the two projectiles with respect to resistance to deformation and shatter.

Figure 14, based on the plots in Figures 3 to 8, graphically demonstrates the dependence of the lethal limit upon plate hardness. The substantially constant differential between the limit values for the two projectiles (in the lower hardness range) is attributable to the difference in the ratios of weight to the cube of the diameter of the two types. (Note the agreement of F values determined by cal. .30 AP M2 and Cal. .50 AP M2 projectile penetration in Figures 3 to 6.)

B. Obliquity - 30°

Figures 10 to 13, based on the empirical data, recited in Table III, show the effect of hardness on the ability of armor to meet the requirements of Specification ANOS-1 under impact at 30° obliquity.

At only the highest hardness level (BHN in excess of 425) can the requirements for resistance be met at all values of e/d tested and, even at this hardness level, extrapolation of the graph raises a question as to whether armor of the lowest e/d covered in the specification would have passed had any been tested in this hardness range.

At all values of e/d increasing hardness improved resistance to penetration at this obliquity. At all levels of hardness, projectile breakage was observed. Since increasing hardness would tend to influence inversely the depth of penetration effected prior to breakage the results are intelligible.

Figure 15, based on the plots in Figures 10 to 13, graphically demonstrates the substantially linear relationship between hardness and limit velocity.

VI. Realistic Specification of Resistance Requirements

In light of the above discussion it is apparent that a measure of realism should be introduced into the specification of resistance requirements under ANOS-1.

Fundamentally, the stipulation of a lethal limit criterion, or a reasonably exact facsimile, should be made. Thus a firm basis for the utilization of armor procured under this specification will be established.

Next, the testing of a single plate for resistance to penetration by two types of projectiles at one obliquity should be discontinued. The divergent behavior of plates under impact of different projectiles as illustrated in Figures 7, 8, and 14 discourages armor manufacturers and disillusions them as to the competency of the specification. On the basis of the data in this and similar studies, requirements may be set up that will assure that plate which passes such standards under impact of one type of projectile will provide satisfactory resistance to the other type of projectile.

From the present data it appears that tests with a cal. .50 AP M2 projectile will substantially predict the minimum resistance to a cal. .30 AP M2 projectile at all levels of hardness whereas tests with the cal. .30 AP M2 projectile will enable prediction of the resistance to cal. .50 penetration only when the armor is of a hardness less than BHN 388, approximately. Since neither projectile should be used when e/d is less than 0.8 (because this is apparently the ratio below which shear failure predominates in the mechanism of penetration, see Figures 5 to 7), plates less than 0.35 inches in thickness would necessarily have to be tested with cal. .30 AP M2 projectiles. In such a case, a limit on hardness would insure a higher degree of predictability of the plate's resistance to cal. .50 AP M2 projectile penetration.

Furthermore, the testing of light armor at obliquity on the basis of resistance to penetration should be discontinued as an inspection device. The factor of projectile breakage lends to such a test an aspect of futility.

Study of the composition, heat-treatment, structure and physical properties of armor which will best withstand attack at various service obliquities, not merely by the current service projectiles, but also the best projectiles producible should be the subject of Ordnance Department activity. The tendency toward reduced proof testing, now apparent, should be exploited to this end and the predictability of the resistance of armor to penetration by the best projectiles at obliquity from the data at normal incidence investigated. In no other way will the acceptance of armor subject to attack from more than a single angle be justified.

VII. Effect of Hardness on Resistance to H.E. Penetration

A survey of the results of tests with 20 MM H.E. projectiles at 20° obliquity shows no determinable correlation with hardness. Logically, since failure of sound armor under this test is usually the result of tensile stresses acting tangent to the rear plate surface generated by the bulging effected by the explosion of the H.E. charges, resistance to failure should increase with tensile strength, and accordingly with hardness, until the reduced ductility inherent in the material of increased hardness affects the character of the mechanism by which failure occurs.

However, there is a variability in the test itself which may well affect the value of the results obtained. The lag of only 1/30000 of a second in the explosion of the charge can result in an increase of 3/4" in the proximity of the charge to the plate at the moment of explosion when the projectile is traveling at a rate of 2000 f/s. Recent tests[13] pointedly illustrate the effect of this change in proximity on the results of the explosion.

If the reaction of armor to such an attack is of interest in the procurement of material, and it may well be, a test whereby the H.E. charge is exploded a fixed distance from the plate would be a much more reasonable test. Under such conditions, the variability would be largely confined to the plate and the results therefore much more indicative of the resistance of the plate to this type of attack.

VIII. Projectile-through-Plate Tests

In earlier work at this Arsenal[14] it was noticed that an increase in the obliquity of testing tended more adequately to disclose inherent spalling tendencies in armor. Consequently, a projectile-through-plate test at obliquity was suggested by this Arsenal.*

It was not contemplated that, at obliquity, a stringent criterion of permissible exit diameter would be stipulated. Rather was it intended that failure be based on the disclosure of spalling tendencies in the plate regardless of exit diameter. Apparently, armor has been rejected, however, on the basis of excessive exit diameter in the absence of spalling.[15]

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*See reference 2, footnote page 3.

13. Aberdeen Proving Ground, Maryland. Second Memorandum Report on Proving Center Project No. 2113. 6 Sept. 1943. Photograph #91583. In these tests identical TNT cylindrical charges were detonated 3/4" and 1½" from the plate surface. While the charge detonated 1½" away was successfully withstood, the charge detonated 3/4" nearer the plate surface blew a sizable section out of the plate.

14. Watertown Arsenal Report No. 710/456. Rolled Armor - Ballistic Properties of Rolled Face-Hardened Armor and Rolled Homogeneous Armor of Various Hardnesses at Normal Incidence and at Various Obliquities. J. Sullivan. 28 Sept. 1942. Page 24.

15. Aberdeen Proving Ground Reports A7802, A7805, A7860, A7918, A7920, A8030.

At obliquity, exit diameter may be a function of plate thickness, plate hardness, projectile breakage, and incident yaw.[16] Thus, this dimension is not altogether significant of the quality of the plate.

At normal incidence, projectile breakage and incident yaw do not affect this dimension critically and unusually large exit diameters more accurately indicate plate quality. However, spalling tendency is less sensitive to disclosure at normal incidence and the test at obliquity is to be preferred as a test of steel quality.

At velocities in excess of a critical, the jacket of a small arms projectile is not entirely stripped from the core, but is rolled back into a tight ring which hugs the core during penetration.[17] When this occurs the size and energy of the jacket influence the mechanism of penetration, and failure in shear is generated, a plug approximately equal in diameter to the cumulative diameter of the core and the rolled-up jacket being knocked out of the path of the projectile. Failure of this type naturally affects the size of the exit diameter and tends to obscure the true quality of the plate material.

Therefore, the velocity of the projectile used in this test must be kept enough below this critical to insure the absence of the "jacket effect" and at the same time be sufficiently above the Navy limit velocity to assure a true projectile-through-plate test. In order to achieve this two-fold objective the utilization of a larger caliber projectile in this test may be necessary.

16. W.A. Intraoffice Memorandum. 19 August 1943. See Appendix A.

17. Watertown Arsenal Rolled Armor Report No. 44. "Types of Failure Occurring in the Shock Test of 1/2" Homogeneous Armor with Cal. .50 AP Projectiles." N. A. Matthews. 6 May 1942.

SUMMARY OF DISCUSSION

It is, therefore, suggested by the considerations above that a more realistic approach to the specification of ballistic requirements for aircraft armor may be facilitated by the recognition of the following contentions:

1. The criterion of plate quality should be based upon the resistance to lethal penetration as a more accurate measure of plate efficiency than either the Army or Navy limit criteria.

2. Tests at obliquities to determine resistance to penetration utilizing projectiles which break up or shatter upon impact should be discontinued as an inspection device.

3. Tests for resistance to penetration wherein the ratio of plate-thickness to projectile-diameter is less than 0.8 should be discontinued since protection is not offered under these conditions at combat ranges and the best performance under these greatly overmatching projectile conditions is not compatible with the optimum resistance to matching projectiles.

4. Tests for resistance to penetration on a single plate at any one obliquity with more than one type of projectile should be discontinued. (If, in accordance with contention 3, above, the Cal. .30 AP M2 projectile is used, an upper hardness limit should be stipulated.)

5. The proximity of the explosive charge to the plate in tests to determine the resistance of armor to H.E. shock should be rigidly controlled.

6. The criterion of failure under a projectile-through-plate test at obliquity should be the disclosure of inherent spalling tendencies and not the dimension of the exit diameter.

7. The criterion of failure under a projectile-through-plate test at normal incidence may properly be the dimension of the exit diameter, but assurance must be made that the "jacket effect" attendant at high velocities is avoided.

8. The use of an overmatching projectile in the projectile-through-plate test should be advantageous.

Finally it is urged that, wherever possible, non-ballistic tests be used in the inspection of armor to the end that proof facilities may be made available for development work with armor and projectiles so that the behavior of armor under impact of various projectiles at various obliquities may be correlated with a single ballistic test at normal or, perhaps, even a non-ballistic test and, as a result, the stability of armor in service, under all sorts of attack, may be assured from the results of that one test.

NOTE:

In the tabulation of data in this report, m/d^3 is evaluated in terms of pounds per cubic foot, but, in order to keep e/d dimensionless, both e and d, as used in the latter ratio, are evaluated in terms of inches since e is popularly evaluated in terms of inches.

TABLE I

Comparison of Ballistic Limits Determined According to ANOS-1 Criterion and According to Lethal Limit Criterion - 5/16" Aircraft Armor Impacted with Caliber .50 AP M2 Projectiles at 30°

Gauge	BHN	ANOS-1 Criterion B.L. Ft/Sec.	ANOS-1 Criterion Range* Ft.	Lethal Criterion B.L. Ft/Sec.	Lethal Criterion Range* Ft.	Difference B.L. Ft/Sec.	Difference Range* Ft.
.302	375	1846	2840	1147	5600	699	2760
.306	444	2369	1380	1870	2780	499	1400
.306	444	2666	580	1862	2800	804	2220
.308	461	2540	910	1760	3110	780	2200
.310	410	2205	1830	1373	4480	832	2650
.310	392	2418	1240	1584	3200	834	1960
.312	369	2154	1960	1212	5220	942	3260
.312	461	2187	1860	1638	3500	549	1640
.312	382	2388	1320	1223	5180	1165	3860
.313	382	2214	1800	1290	4880	924	3080
.313	363	2408	1260	1336	4640	1072	3380
.314	381	2087	2140	1760	3100	327	960
.314	408	2201	1840	1729	3200	472	1360
.314	429	2512	980	1462	4120	1050	3140
.314	415	2433	1200	1746	3160	687	1960
.316	341	1949	2540	1215	5220	734	2680
.316	382	2078	2180	1309	4780	769	2600

TABLE I (CONT'D)

Gauge	BHN	ANOS-1 Criterion B.L. Ft/Sec.	ANOS-1 Criterion Range* Ft.	Lethal Criterion B.L. Ft/Sec.	Lethal Criterion Range* Ft.	Difference B.L. Ft/Sec.	Difference Range* Ft.
.317	415	2407	1260	1229	5160	1178	3900
.318	410	2461	1140	1529	3880	932	2740
.318	353	1788	3020	1339	4640	449	1620
.318	401	2379	1350	1465	4100	914	2750
.318	429	2530	940	1799	3000	731	2060
.318	408	2310	1540	1718	3240	592	1700
.319	382	2306	1550	1279	4920	1027	3370
.320	349	2062	2210	1144	5600	918	3390
.320	374	2300	1560	1658	3440	642	1980
.320	382	2090	2140	1349	4580	741	2440
.320	369	2202	1840	1457	4140	745	2300
.320	395	2169	1920	1532	3860	637	1940
.322	418	2064	2200	1683	3360	381	1160
.323	410	2231	1760	1629	3540	602	1780
.325	410	2244	1710	1676	3380	568	1670
.326	351	2186	1880	1241	5100	945	3220
.328	358	2164	1940	1174	5440	990	3500
.328	444	2507	1000	1763	3100	744	2100
.335	408	2165	1940	1796	3000	369	1060
.337	375	2606	740	1328	4680	1278	3940
.341	444	2243	1720	1871	2780	372	1060

*Range at which limit velocity is deliverable by Cal. .50 gun with muzzle velocity 2900 f/s.

TABLE II

Effect of Hardness on Lethal Limits (V_L)

of

Rolled Homogeneous Armor Fired at 0° Obliquity

BHN Range	Cal.	m/d^3	θ	No.	Ave. V_L	Ave. e	Ave. s/d	Ave. e/d cos θ	Ave. F	Reference
Less than 276	.50	1275	0°	2	1436	.375	.875	.875	54,800	Appendix B, Table I
" " "	.50	1275	0°	1	1748	.50	1.167	1.167	57,800	"
" " "	.50	1275	0°	1	1896	.625	1.459	1.459	56,000	"
" " "	.50	1275	0°	2	2158	.75	1.750	1.750	58,300	"
276 to 305	.30	1355	0°	1	1639	.28	1.138	1.138	56,600	Appendix B, Table II
" " "	.50	1275	0°	2	1805	.50	1.167	1.167	59,600	"
" " "	.50	1275	0°	1	1996	.625	1.459	1.459	59,000	"
" " "	.50	1275	0°	2	2246	.75	1.750	1.750	60,600	"
306 to 345	.50	1275	0°	6	1318	.322	.751	.751	54,300	Appendix B, Table III
" " "	.30	1355	0°	1	1427	.19	.772	.772	59,800	"
" " "	.50	1275	0°	3	1502	.375	.875	.875	57,300	"
" " "	.30	1355	0°	2	1612	.265	1.077	1.077	57,200	"
" " "	.50	1275	0°	5	1822	.502	1.172	1.172	60,100	"
" " "	.30	1355	0°	6	1869	.322	1.309	1.309	60,100	"
" " "	.30	1355	0°	4	2486	.502	2.041	2.041	64,000	"
" " "	.50	1275	0°	1	2417	.910	2.123	2.123	59,200	"

TABLE II (CONT'D)

BHN Range	Cal.	m/d3	θ	No.	Ave. V_L	Ave. e	Ave. e/d	Ave e/d cos θ	Ave. F	Reference
346 to 385	.50	1275	0°	23	1314	.319	.744	.744	54,400	Appendix B. Table IV
" " "	.30	1355	0°	4	1327	.185	.752	.752	56,300	"
" " "	.50	1275	0°	27	1481	.376	.877	.877	56,500	"
" " "	.30	1355	0°	4	1639	.254	1.033	1.033	59,400	"
" " "	.50	1275	0°	24	1820	.503	1.174	1.174	60,000	"
" " "	.30	1355	0°	26	1861	.313	1.272	1.272	60,700	"
" " "	.50	1275	0°	1	2177	.625	1.459	1.459	64,400	"
" " "	.30	1355	0°	27	2082	.376	1.528	1.528	62,000	"
" " "	.50	1275	0°	2	2204	.750	1.750	1.750	59,500	"
" " "	.30	1355	0°	24	2525	.503	2.045	2.045	65,000	"
" " "	.50	1275	0°	18	2518	.878	2.049	2.049	62,800	"
386 to 425	.50	1275	0°	19	1304	.316	.737	.737	54,200	Appendix B. Table V
" " "	.30	1355	0°	16	1418	.193	.785	.785	58,900	"
" " "	.50	1275	0°	39	1478	.379	.884	.884	56,100	"
" " "	.30	1355	0°	10	1692	.257	1.045	1.045	60,900	"
" " "	.50	1275	0°	18	1802	.504	1.176	1.176	59,300	"
" " "	.30	1355	0°	32	1917	.306	1.244	1.244	63,300	"
" " "	.50	1275	0°	2	2012	.625	1.458	1.458	59,600	"
" " "	.30	1355	0°	38	2164	.379	1.541	1.541	64,200	"
" " "	.50	1275	0°	3	2308	.747	1.743	1.743	62,400	"
" " "	.30	1355	0°	18	2566	.502	2.041	2.041	66,100	"
" " "	.50	1275	0°	18	2620	.876	2.044	2.044	65,400	"

TABLE II (CONT'D)

BHN Range	Cal	m/d^3	θ	No.	Ave. V_L	Ave. e	Ave. e/d	Ave. e/d cos θ	Ave. F	Reference
More than 425	.50	1275	0°	8	1287	.317	.740	.740	53,400	Appendix B, Table VI
" " "	.30	1355	0°	5	1532	.198	.805	.805	62,900	"
" " "	.50	1275	0°	3	1395	.383	.894	.894	54,300	"
" " "	.50	1275	0°	5	1731	.500	1.167	1.167	57,200	"
" " "	.30	1355	0°	7	1960	.313	1.272	1.272	64,000	"
" " "	.30	1355	0°	3	2209	.383	1.557	1.557	65,200	"
" " "	.30	1355	0°	5	2685	.500	2.033	2.033	69,300	"
" " "	.50	1275	0°	2	2576	.884	2.063	2.063	64,000	"

TABLE III

Effect of Hardness on Lethal Limits (V_L)

of

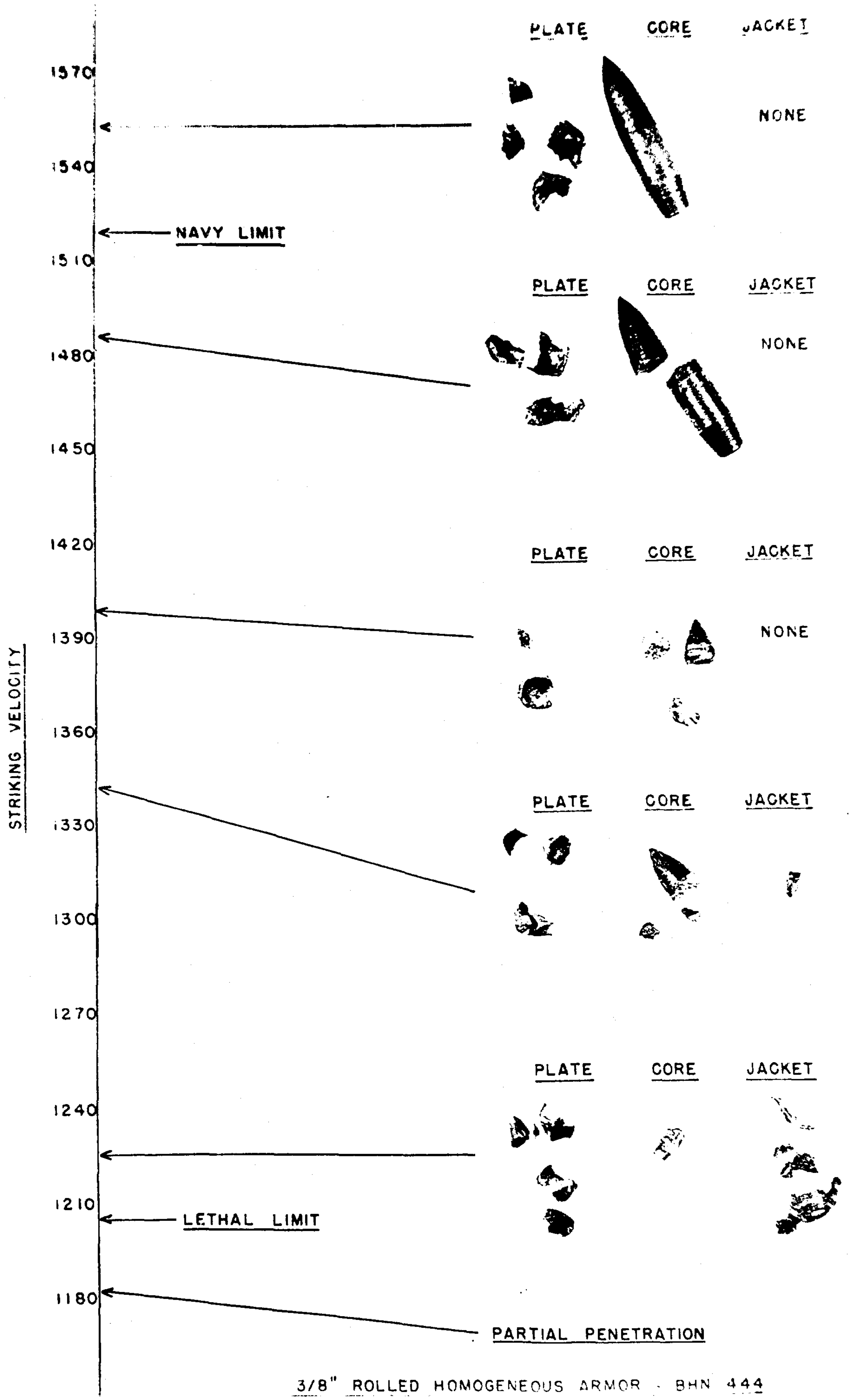
Rolled Homogeneous Armor Fired at 30° Obliquity

BHN Range	Cal.	m/d^3	θ	No.	Ave. V_L	Ave. e	Ave. e/d	Ave. e/d cos θ	Ave. F	Reference
306 to 345	.50	1275	30°	6	1295	.322	.751	.867	46,200	Appendix B, Table VII
" " "	.30	1355	30°	1	1459	.19	.772	.891	52,900	"
" " "	.30	1355	30°	2	1931	.265	1.077	1.244	59,300	"
" " "	.50	1275	30°	4	2367	.502	1.174	1.356	67,500	"
" " "	.30	1355	30°	4	2297	.321	1.305	1.507	64,100	"
346 to 385	.50	1275	30°	20	1340	.320	.747	.863	47,900	Appendix B, Table VIII
" " "	.30	1355	30°	4	1309	.185	.752	.868	48,100	"
" " "	.50	1275	30°	26	1731	.375	.875	1.010	57,200	"
" " "	.30	1355	30°	4	2001	.254	1.033	1.193	62,800	"
" " "	.50	1275	30°	22	2371	.503	1.174	1.356	67,700	"
" " "	.30	1355	30°	26	2375	.312	1.268	1.464	67,200	"
" " "	.30	1355	30°	26	2545	.376	1.528	1.764	65,600	"
386 to 425	.50	1275	30°	21	1490	.317	.740	.854	53,600	Appendix B, Table IX
" " "	.30	1355	30°	16	1558	.193	.785	.906	56,100	"
" " "	.50	1275	30°	35	1866	.378	.882	1.018	61,500	"
" " "	.30	1355	30°	9	2276	.257	1.045	1.207	71,000	"
" " "	.50	1275	30°	15	2415	.503	1.174	1.355	68,900	"
" " "	.30	1355	30°	27	2485	.303	1.232	1.423	71,400	"
" " "	.30	1355	30°	30	2698	.374	1.520	1.755	69,800	"

TABLE III (CONT'D)

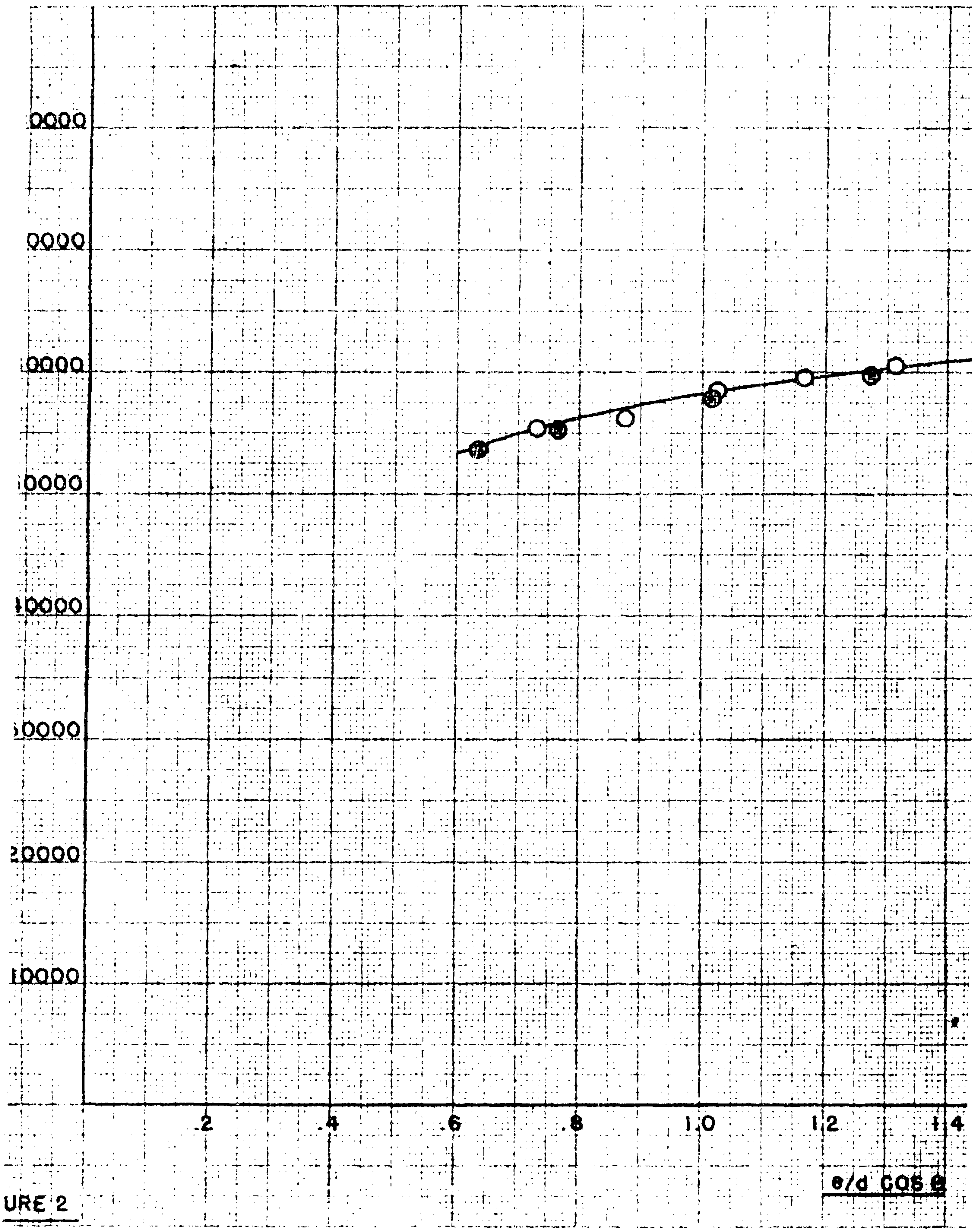
BHN Range	Cal.	m/d^3	θ	No.	Ave. V_L	Ave. e	Ave. e/d	Ave. e/d cos θ	Ave. F	Reference
More than 425	.50	1275	30°	8	1753	.317	.740	.854	63,000	Appendix B, Table X
" " "	.30	1355	30°	5	1968	.198	.805	.930	69,900	"
" " "	.50	1275	30°	3	2104	.383	.894	1.032	68,800	"
" " "	.50	1275	30°	5	2546	.500	1.167	1.348	72,900	"
" " "	.30	1355	30°	8	2684	.317	1.289	1.488	75,400	"
" " "	.30	1355	30°	3	2843	.383	1.557	1.798	72,600	"

Figure 1 - Fragments of plate and projectile thrown from the rear of a 3/8" homogeneous armor plate of hardness BHN 444 under impact of cal. .50 AP M2 projectiles of various velocity at normal incidence. Illustrating that death-dealing fragments may be projected from the rear of a homogeneous plate at velocities considerably less than the Navy limit velocity.



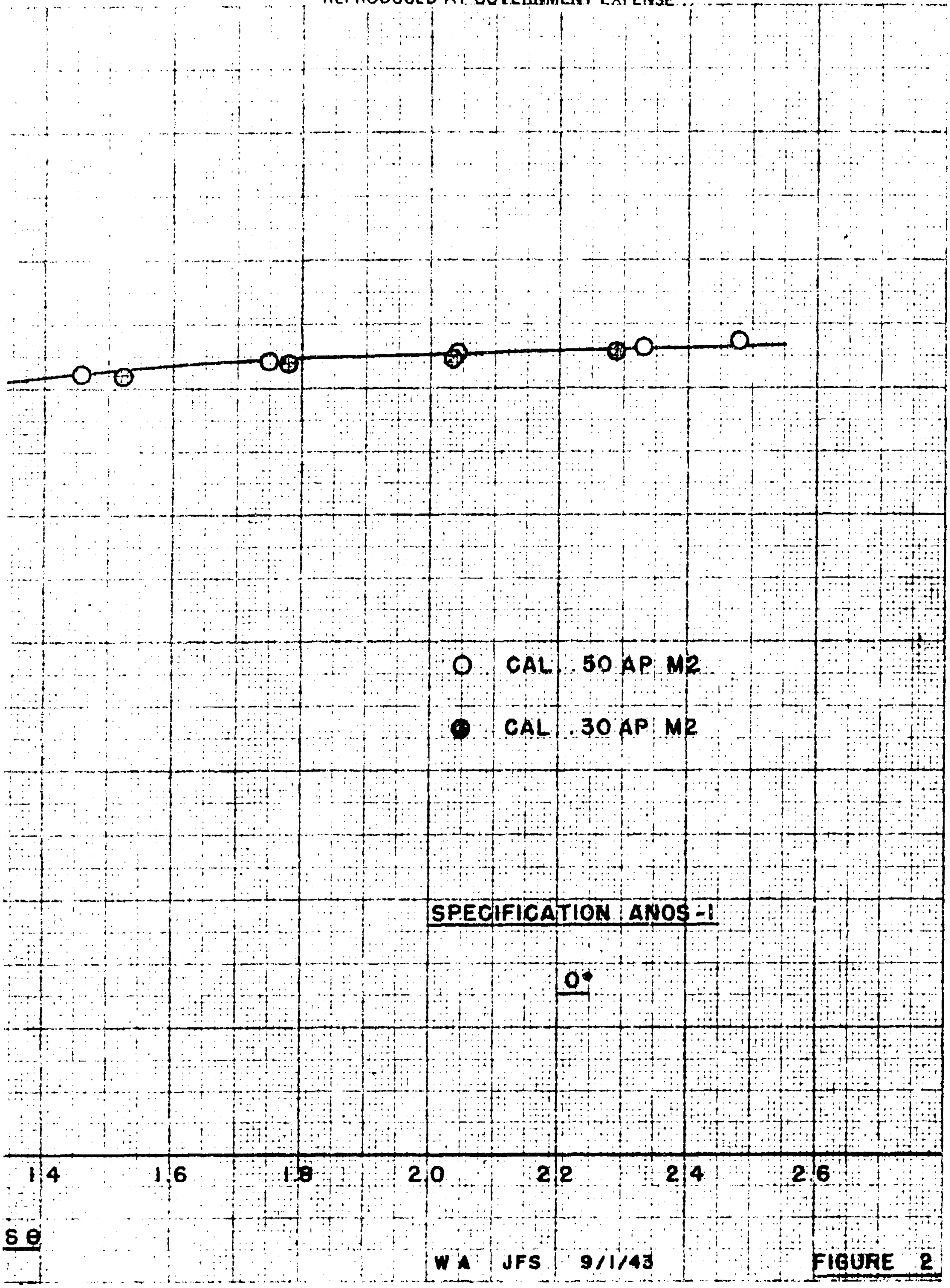
3/8" ROLLED HOMOGENEOUS ARMOR - BHN 444

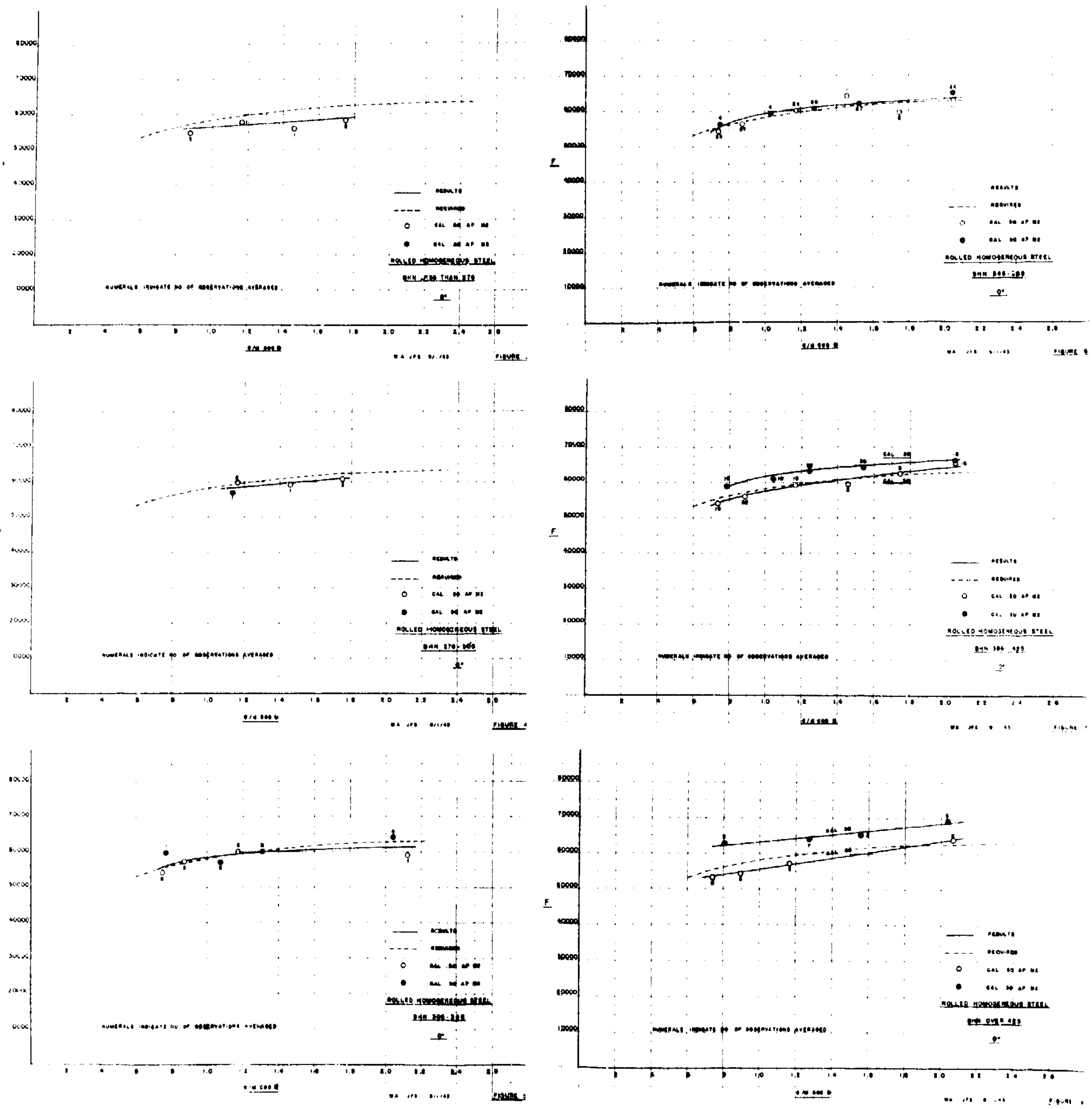
FIGURE 1



0000
0000
0000
0000
0000
0000
20000
10000
.2
.4
.6
.8
1.0
1.2
1.4
e/d COS θ

URE 2


CAL. .50 AP M2
CAL. .30 AP M2
SPECIFICATION ANOS-1
0°
1.4
1.6
1.8
2.0
2.2
2.4
2.6
S θ
W A JFS 9/1/43
FIGURE 2



FIGURES 3 - 8

COMPARISON OF THE PENETRATION RESISTANCE REQUIREMENTS OF SPECIFICATION AN-S
WITH THE RESULTS OF BALLISTIC TESTS ON PLATES OF DIFFERENT HARDNESS RANGES
SUBMITTED UNDER THE SPECIFICATION

NORMAL INCIDENCE

WTN.639-5610

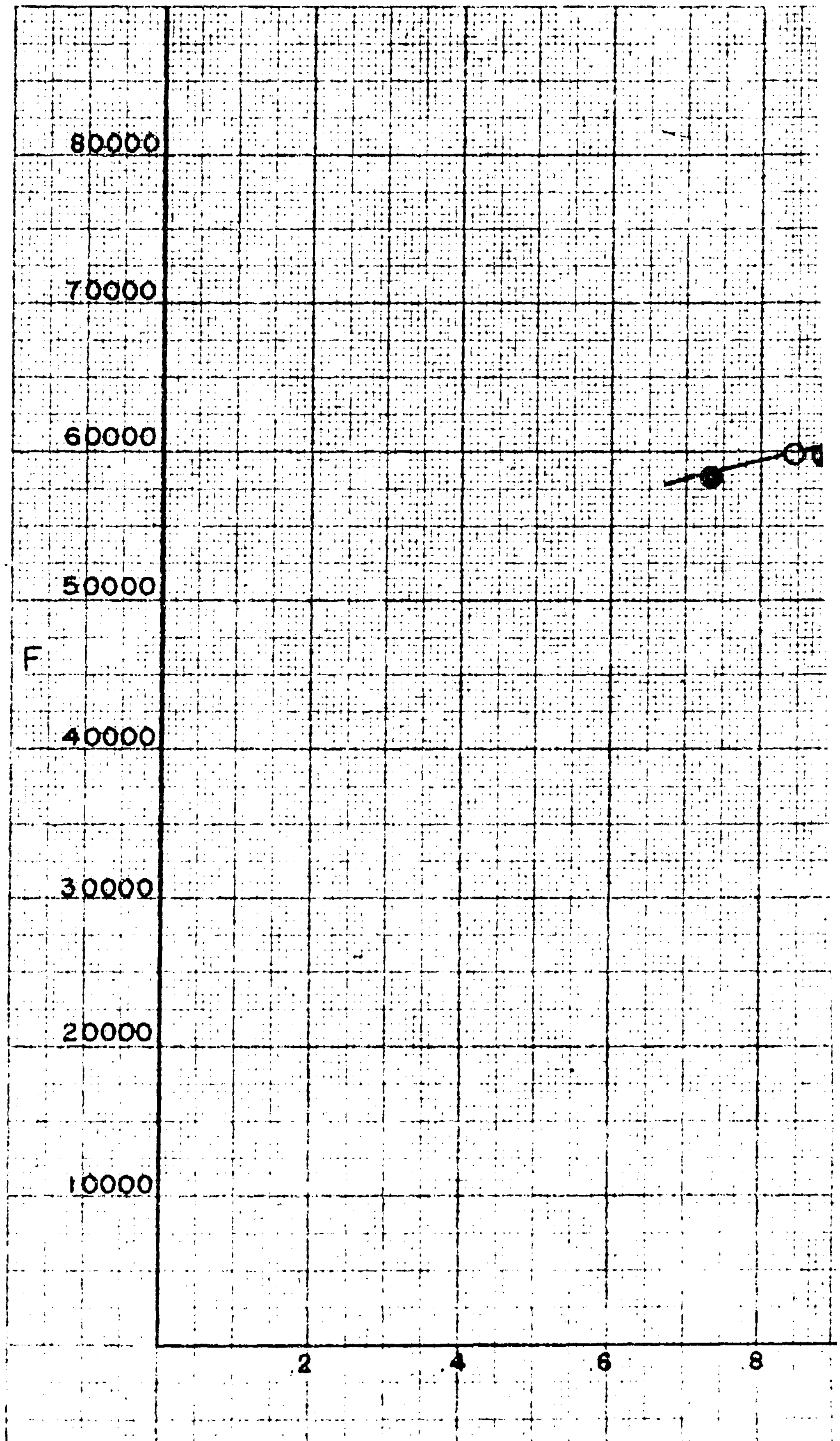
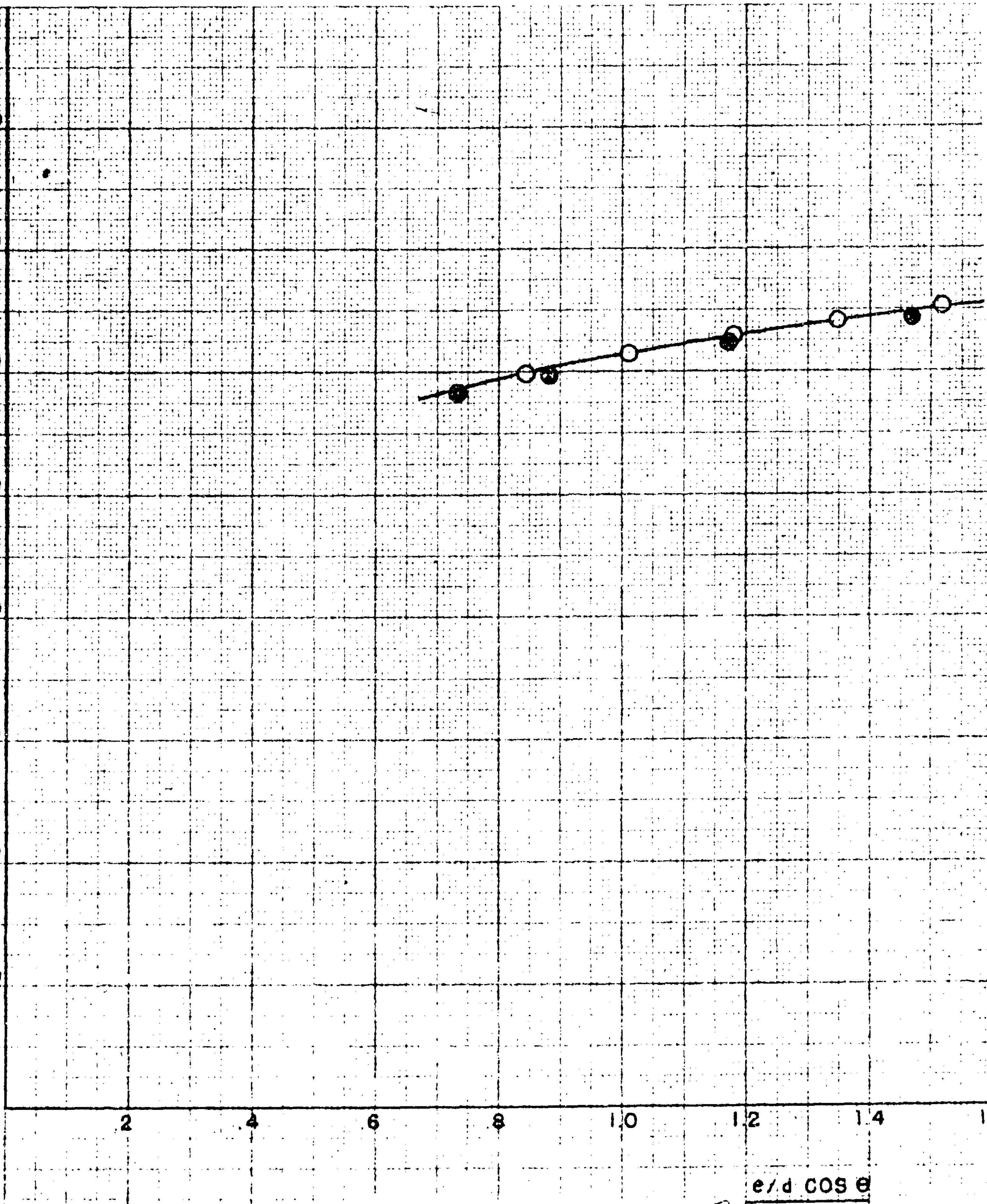
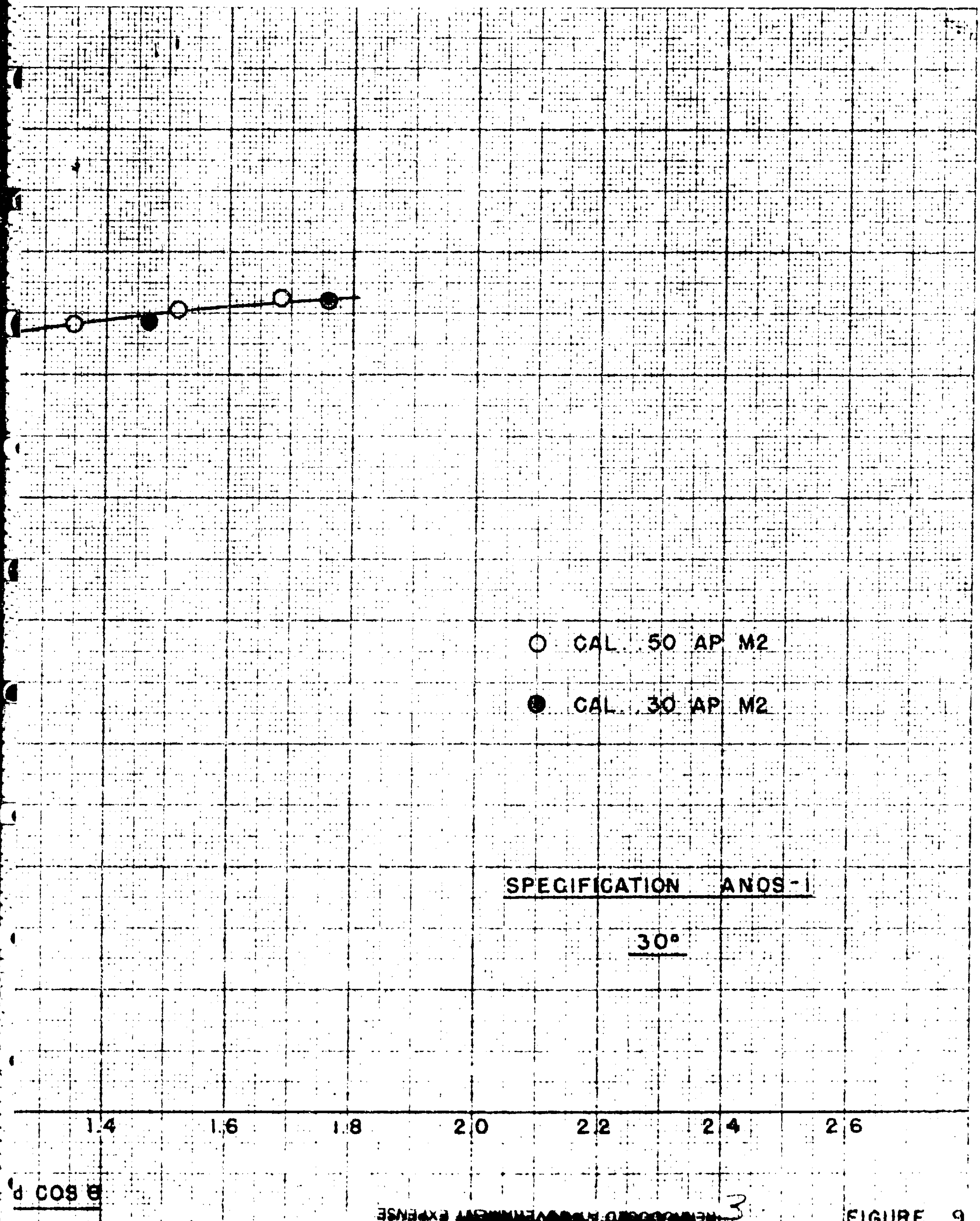


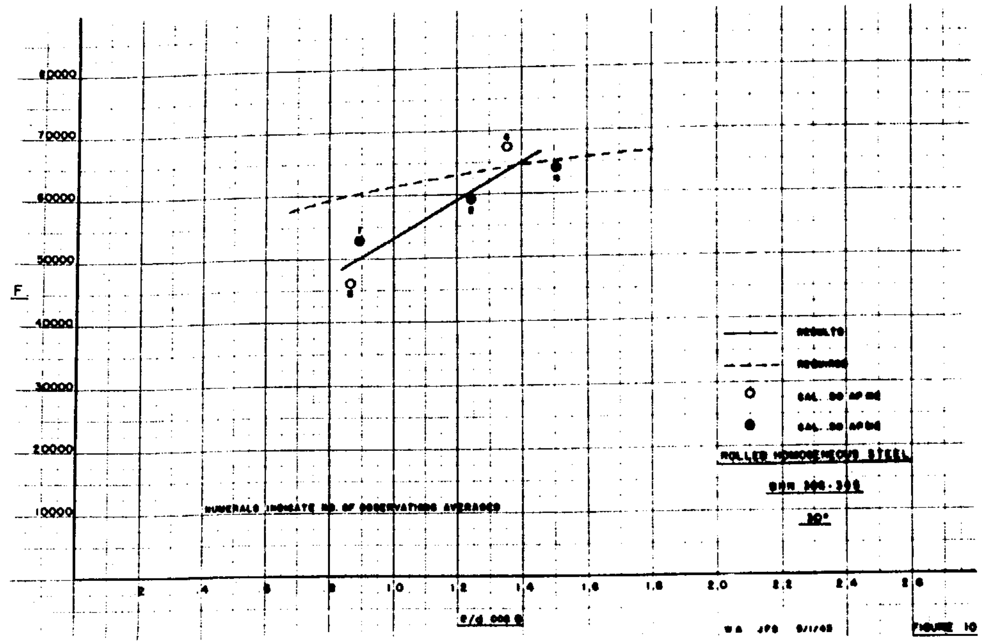
FIGURE [illegible]

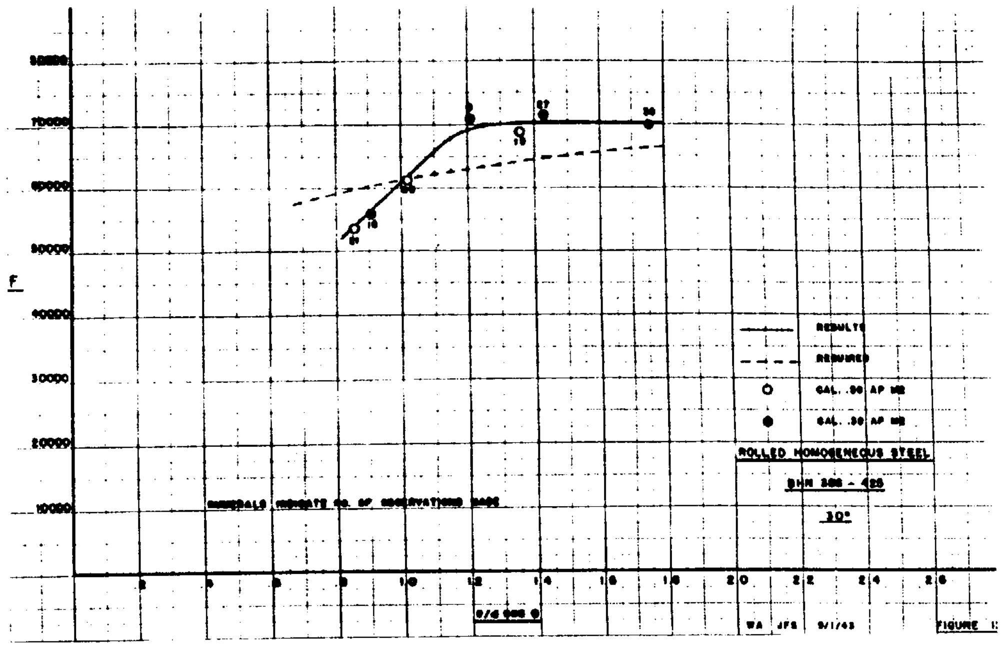

.2
.4
.6
.8
1.0
1.2
1.4
e/d COS θ

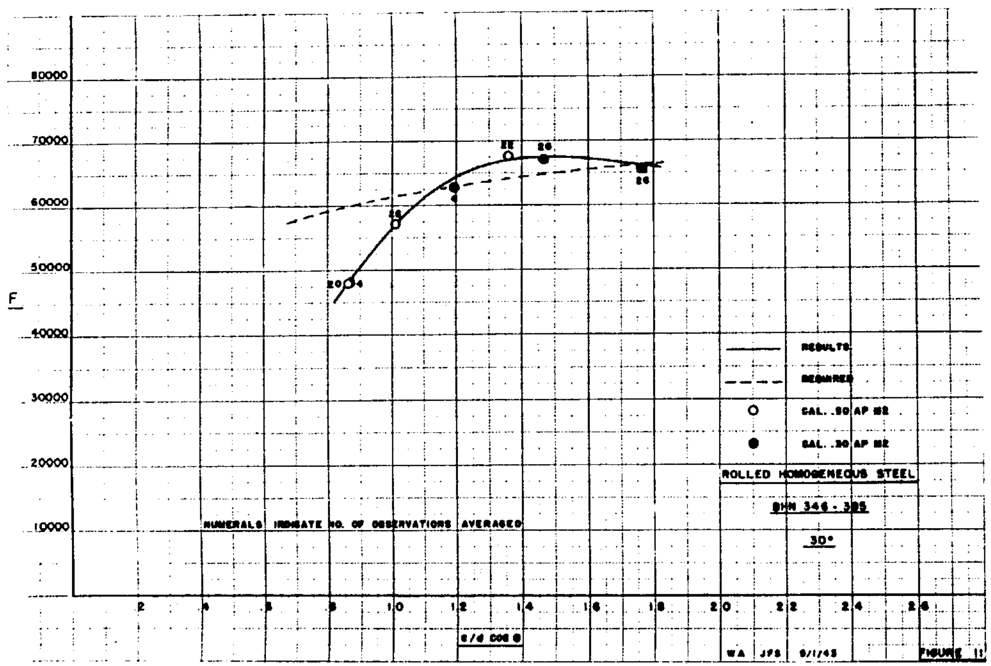


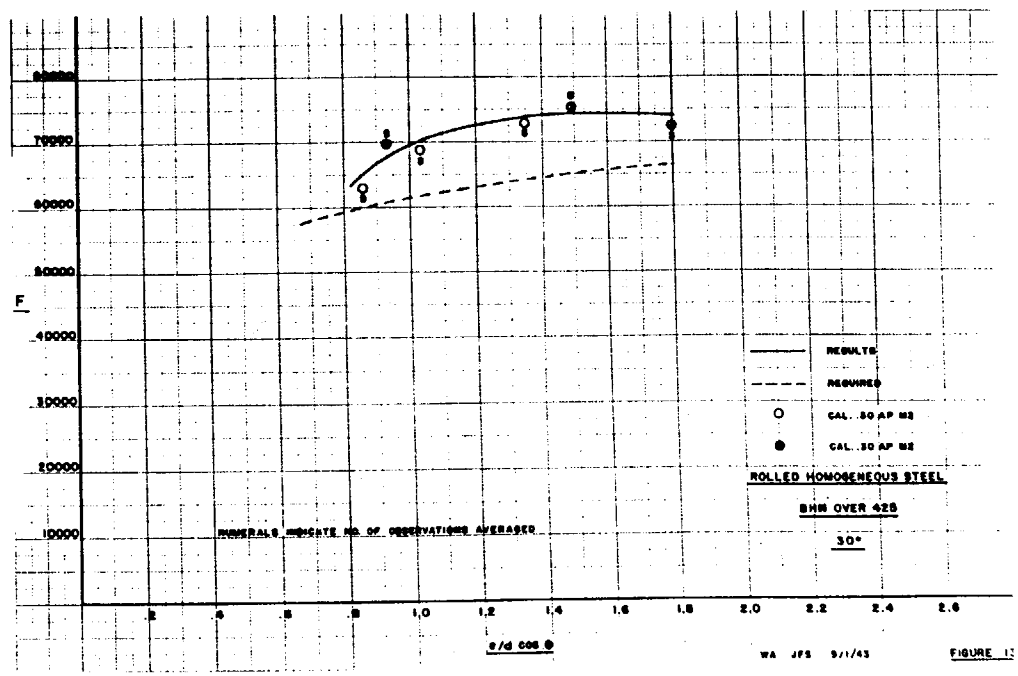
CAL. .50 AP M2
CAL. .30 AP M2
SPECIFICATION ANOS-1
30°
1.4
1.6
1.8
2.0
2.2
2.4
2.6
d COS θ

FIGURE 9







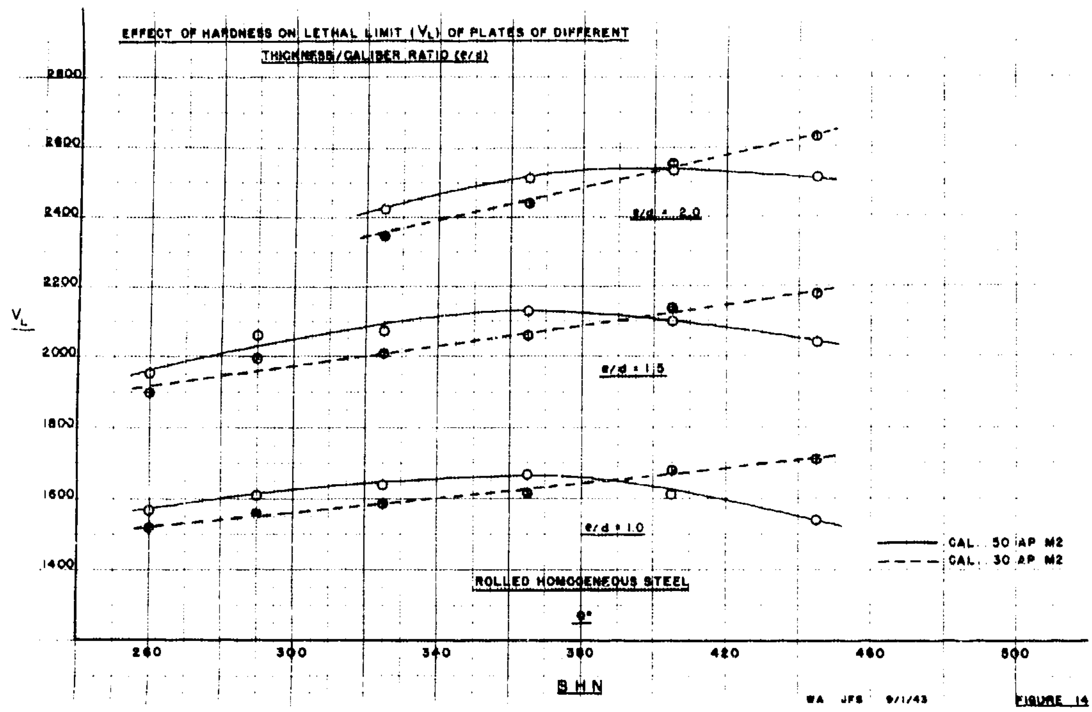


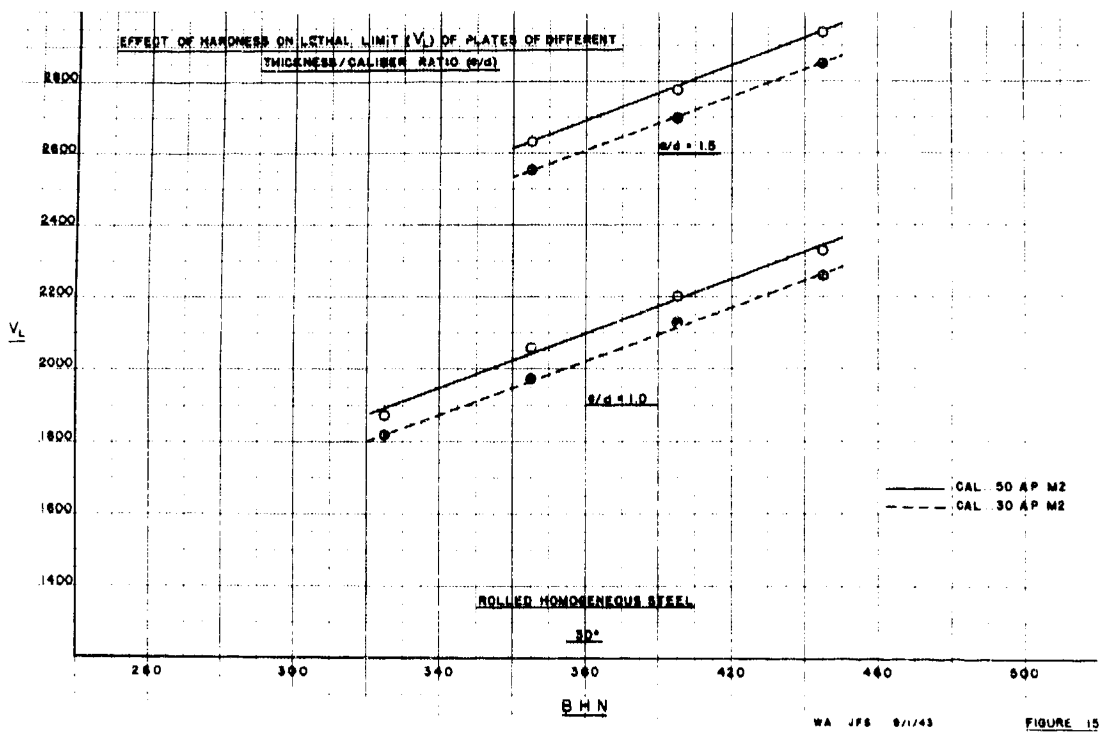
FIGURES 10-13

COMPARISON OF PENETRATION RESISTANCE REQUIREMENTS OF SPECIFICATION AN0S-1 WITH THE RESULTS OF BALLISTIC TESTS ON PLATES OF DIFFERENT HARDNESS RANGES SUBMITTED UNDER THE SPECIFICATION

OBLIQUITY - 30°

WTN.639-5608



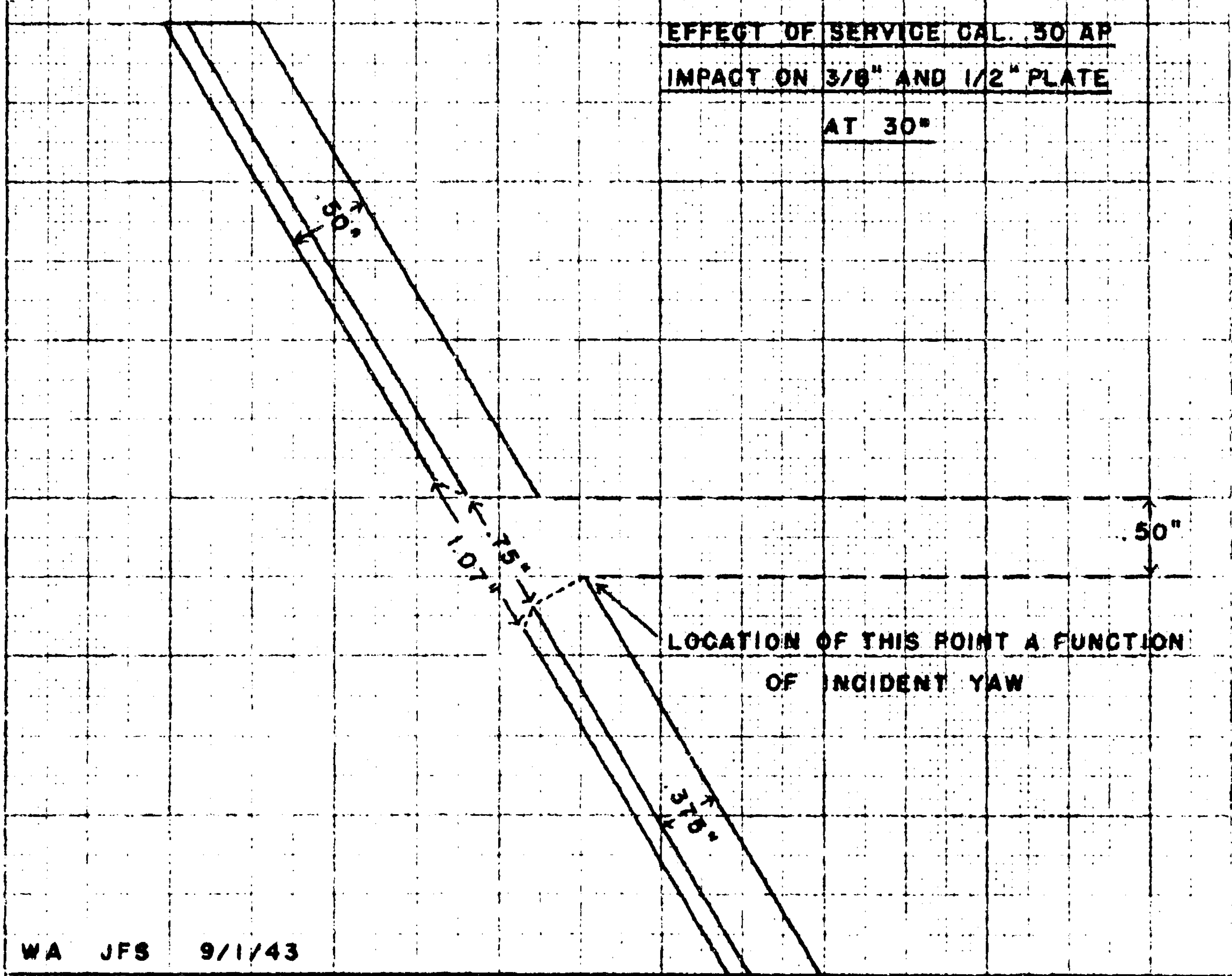


FIGURES 14, 15

EFFECT OF HARDNESS ON LETHAL LIMIT (V_L) OF PLATES OF DIFFERENT THICKNESS/CALIBER RATIO (e/d)

WTN.639-5609

AT NORMAL INCIDENCE AND AT 30° OBLIQUITY



Penetrations resultant from service velocity impact of Cal. .50 AP M2 projectiles upon 3/8" and 1/2" rolled homogeneous plate (BHN 360) at 30° obliquity were visually examined and exit diameter measured. Cross-sectionally, failure seemed to occur along a surface coincident with the upper longitudinal surface of the projectile in flight and along a surface perpendicular to the face of the plate at the lowest point of initial contact between the lower longitudinal surface of the projectile and the plate. This sketch shows that failure along such surfaces would result approximately in the exit diameters recorded. The lowest point of initial contact between the lower longitudinal surface of the projectile and the plate may be re-located by incident yaw.

FIGURE 16

APPENDIX A

CORRESPONDENCE

C O P Y

Sullivan/amv

RESTRICTED

April 14, 1943

W.A. 470.5/6469(r)
Laboratory(NAM)

Subject: Analysis of Failures of Armor Plates Submitted under Specification ANOS-1

To: Chief of Ordnance, U.S.A.
Pentagon Building
Washington, D. C.

Attn: SPOTB

1. It has been noticed at this arsenal that manufacturers submitting armor plates for test under Specification ANOS-1 have had little or no success in furnishing passable plates at thicknesses of 3/16" and 5/16" whereas they have had some success in providing acceptable armor at the intermediate 1/4" gauge.

2. At first glance this fluctuation in results tends to be puzzling, but upon further investigation and analysis an explanation appears.

3. By plotting the familiar "F" coefficient of Thompson versus values of $e/d \cos \theta$ some insight into the mechanism of armor perforation may be had. A typical plot of these values based on data from tests of production plates fired at 30° in accordance with Specification ANOS-1 is appended as Chart I.

4. It will be noted that beyond a certain critical value of $e/d \cos \theta$ the merit coefficient tends to remain fairly constant while at values less than the critical the merit coefficient falls off rapidly as $e/d \cos \theta$ decreases.

5. The constancy of the "F" function beyond a critical point seems to indicate a mechanism of perforation wherein the projectile, acting like a wedge, effects progress through the metal by pushing it aside. Against a steel of constant physical properties this type of mechanism would produce constant "F" values.

6. However, in the region where the merit coefficient falls off rapidly there apparently is operative a different mechanism. Here perforation appears to be effected by the plate's failure in shear because of the unequal contest between overmatching projectile and plate.

RESTRICTED

C O P Y

Thus, the greater the ratio of projectile caliber to plate gauge the quicker shear failure (punching) will occur and a lower "F" value will result.

7. This sequence of mechanisms is characteristic of all types of steel in perforation although the exact course of a plot of "F" coefficients is a function of the physical properties of the steel and the obliquity of the test. Generally, with an increase in hardness, the point indicative of the demarcation from mechanism to mechanism will move from left to right on the chart and the level at which the "F" values tend to be constant will be higher. An increase in obliquity will produce a similar effect.

8. A plot of the "F" coefficient resultant from theoretical samples of armor which would satisfy the requirements of Specification ANOS-1 when tested at 30° is imposed upon Chart I. It is apparent that no allowance has been made for a change of mechanism below a critical value of e/d cos θ. This is understandable inasmuch as the bulk of ballistic testing is conducted under conditions where e/d cos θ exceeds the critical and testing under the Army criterion does not reveal the phenomenon.

9. However a comparison of the results with the requirements indicates the improbability of producing acceptable plate with e/d cos θ values less than that at which the performance curve cuts the requirement curve. Under the provisions of Specification ANOS-1, 3/16" plate subjected to Cal. .30 AP M2 firing at 30° and 5/16" plate subjected to Cal. .50 AP M2 firing at 30° will have values of e/d cos θ less than the intersection value assuming a range of hardness comparable to that of the plates now being furnished. Since 1/4" plate tested under this specification is subject to Cal. .30 AP M2 fire alone its e/d cos θ values are above the characteristic critical.

10. In the light of paragraph 7, above, it will be realized that the path of the performance curve may be altered by varying the hardness of the armor. In this way, it may be contended, the demarcation point between the mechanisms could be moved to the left by lowering the hardness of the armor and that portion of the curve where "F" values tend to be constant would extend over the e/d cos θ values of 3/16" and 5/16" plate. This argument is valid except that it ignores the fact that coincident with a lowering of plate hardness there is a lowering of the level at which the "F" values flatten out. This resultant level may well fall below the requirement level with the result that at all values of e/d cos θ the requirements could not be met. There is however some possibility that this adjustment could be made, and if testing were conducted at but one obliquity a solution might lie therein.

11. However, as obliquity is varied so also is the path of "F" values varied. Assuming that the path of the performance curve at one obliquity was satisfactorily adjusted to the requirement curve by manipulating the hardness of the plates, the results of this manipulation would be reflected in the path of the performance curve at a second obliquity. There is sound basis for believing that the latter curve would not readily align with its requirement curve. Indeed by manipulation of the hardness levels amazing results may be obtained. For example, it is possible for the performance curve at normal to exceed the performance curve at 30° at certain values of e/d and at certain levels of hardness, resulting in a ballistic limit at normal in excess of the obliquity limit. In an attempt to suit plate to the requirements of the specification such results actually have been recorded. This otherwise mysterious behavior has been attributed by a bewildered test personnel to poor plate quality or poor projectile quality.

12. An analysis of the behavior of various types of steel in perforation leads to the conclusion that the probability of producing armor 3/16" or 5/16" thick that will satisfy the current requirements of Specification ANOS-1 is so low that it is economically unfeasible for a manufacturer to attempt to do so.

13. Thus, if one expects to procure plate under this specification the ballistic requirements need immediate revision. Such a revision must recognize the phenomenological indications of the performance curves. Better yet a test requiring a reasonable penetration resistance at normal incidence with matching projectiles coupled with a high-speed projectile-through-plate test at obliquity would probably afford a better criterion of the real quality of plate in the critical gauges than any combination of resistance tests which could be devised.

For the Commanding Officer:

H. H. ZORNIG
Colonel, Ordnance Dept.
Director of Laboratory

1 Incl. - Chart I
cc - Office, Chief of Ordnance-SPOTC
Proving Center,
attn.: Capt. M. J. Zweig

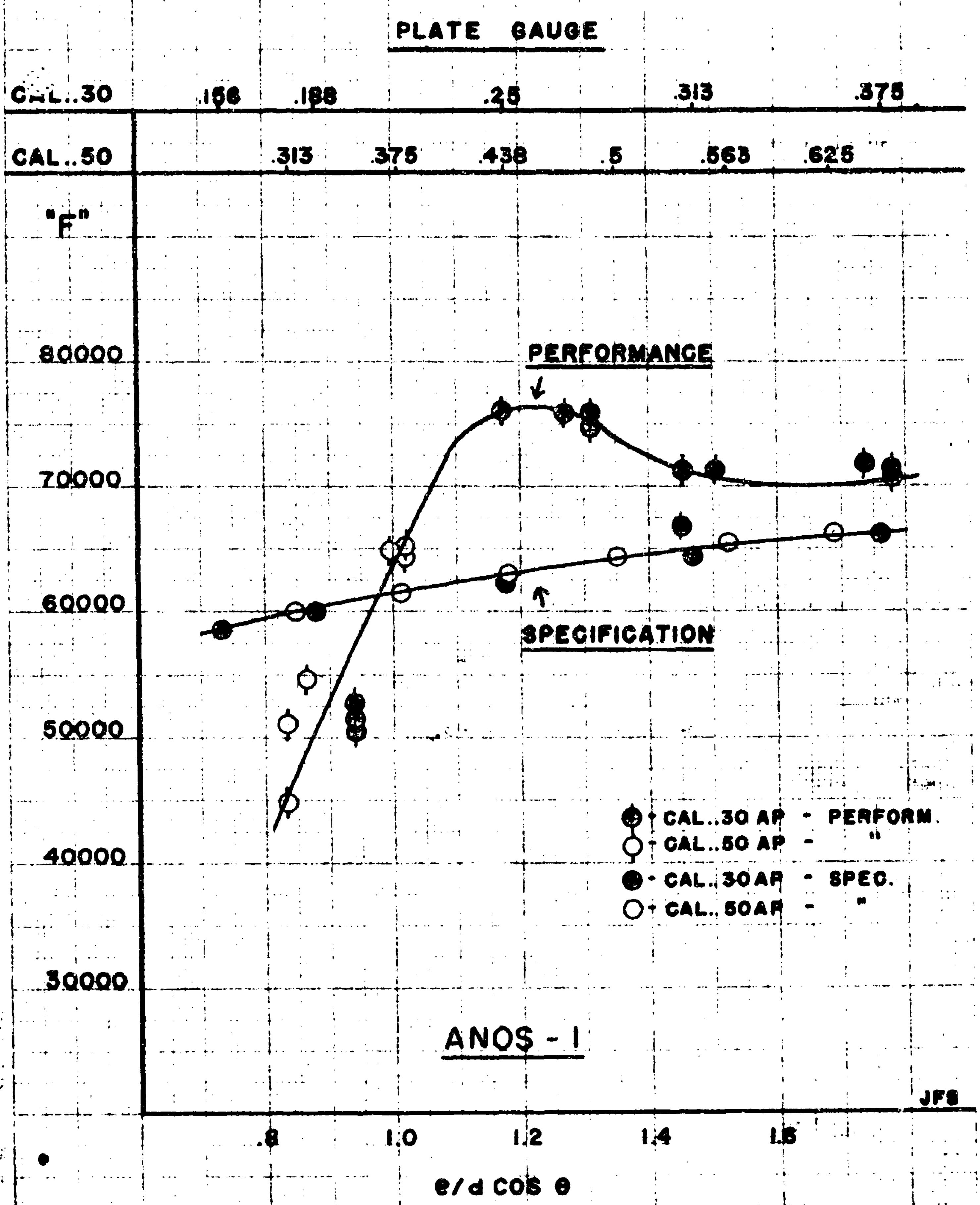


PLATE GAUGE
CAL..30
.156
.188
.25
.313
.375
CAL..50
.313
.375
.438
.5
.563
.625
"F"
80000
70000
60000
50000
40000
30000
PERFORMANCE
SPECIFICATION
CAL..30 AP - PERFORM.
CAL..50 AP - "
CAL..30 AP - SPEC.
CAL..50 AP - "
ANOS - I
JFS
.8
1.0
1.2
1.4
1.6
e/d COS θ
θ = 30°
CHART I

COPY

O.O. 470.5/4613 (r)
Attn. SPOTB
WA 470.5/6469 (r) 1st Ind.

Webster/glw
2300

War Department, Ordnance Office, Washington, D. C., June 5, 1943

To: Commanding Officer, Watertown Arsenal, Watertown, Mass.

1. The phenomenological condition pointed out in basic communication is one of the two places for armor ballistic obliquity tests where anomalous dispersion occurs. It has been brought to the attention of some interested persons. The curve shown for 0-30° compares for the hard homogeneous armor very favorably with the similar curve for face-hardened armor shown on Plate 5 of Report No. 1745 (Eighth Partial Report on Light Armor), a copy of which is in the possession of the Laboratory. The curve at normal has a much more rapid rise to the crown near an e/d ratio of unity, while the 30-degree curve rises more slowly reaching unity at about e/d equal to 1.15. This anomalous situation has been noted both by the Navy and Army in past tests.

2. Changes in the specification AN-OS-1 to facilitate production testing are to be made in accordance with letter sent to Watertown Laboratory under date of May 15, 1943, file WA 114/12505.

3. It is requested that the curve at 0° under the same conditions as that for that at 30° be superimposed on Chart 1 and submitted with relevant data.

By order of the Chief of Ordnance:

G. Elkins Knable
Col., Ord. Dept.
Assistant

1 Incl
w/drawn

COPY

Sullivan/amv

WAR DEPARTMENT
WATERTOWN ARSENAL
WATERTOWN, MASS.

INTRAOFFICE MEMORANDUM

August 19, 1943

FROM: Mr. J. F. Sullivan

TO: Major N. A. Matthews

SUBJECT: Effect of Service Velocity Cal. .50 AP M2 Projectile Impact upon Armor Plates of Different Thicknesses.

In the application of the Projectile-through-Plate test at 30° obliquity, recommended by this Arsenal at an earlier date, it was not contemplated that the criterion of a two-caliber exit hole diameter be adhered to. Rather was it envisioned that plate failure be based on spalling tendencies revealed in the plate by such an obliquity test.

A study of the results of firing the cal. .50 AP M2 projectile through a 3/8" and a 1/2" plate at service velocity at this obliquity reveals a tendency of the exit-hole dimension to be affected by the plate gauge, and theoretical considerations indicate that plate hardness and projectile yaw may also be factors affecting this dimension.

It was observed that at service velocity these plates (in the hardness range BHN 340-360) failed in shear with the surfaces of shear tending to follow a definite pattern. Considering the case where 30° obliquity is effected by tilting the plate away from the gun by pivoting it around its bottom edge a cross-section of the perforation would show that the upper surface of shear tends to be parallel to the line of fire and to align with the upper longitudinal surface of projectile in flight. The lower shear surface tends to be perpendicular to the plate surface and to originate at the point of lowest contact between the projectile and the plate.

Thus the rear dimension resulting from such a shear failure would tend to increase with plate thickness, all other factors remaining constant including the shear pattern. Plate hardness, which influences projectile deflection and projectile yaw, by relocating the point of lowest contact between projectile and plate surface, may also affect the exit-hole dimension.

During recent firings at plates (3/8" and 1/2" thick) the major exit-hole dimensions were observed to be 3/4" and 17/16" respectively. The appended sketch illustrates a shear pattern which might produce such results.*

It is therefore recommended that plates be failed under this test on the basis of spalling and not on the basis of excessive exit-hole dimension when the punching is clean and the structure of the steel is otherwise apparently sound.

*This sketch has been re-drawn as Figure 16 of W.A. Report 710/493(this report).

COPY

APPENDIX B

DATA

CONTENTS

CORRIGENDA -- APPENDIX B

Table	Sheet	Column	Line	Correction
IV	2	e	22	.383 for .382
IV	4	e/d	13	1.333 for 1.353
V	1	V_L	15	1338 for 1388
V	6	Data	9	456 for 450
VII	1	Cal.	14	.30 for .50
VIII	3	Data	30	A6612 for 6612
VIII	3	Data	31	A6612 for 6612
VIII	3	e/d	35	1.305 for 1.30
VIII	4	Data	7	14389 for 14489
IX	1	e	12	.317 for .318
IX	1	e/d	12	.740 for .742
X	1	e/d	25	1.268 for 1.262
X	1	e	31	.380 for .350

Appendix B, TABLE I

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

of

Hardness Less Than BHN 276 Fired at 0° Obliquity

Cal.	m/d3	BHN	θ	VL	e	e/d	Data Source
.50	1275	241	0°	1464	.375	.875	W.A. 710/456
.50	1275	245	0°	1407	.375	.875	W.A. 710/456
.50	1275	261	0°	1748	.50	1.167	W.A. 710/456
.50	1275	255	0°	1896	.625	1.459	W.A. 710/456
.50	1275	269	0°	2185	.750	1.750	W.A. 710/456
.50	1275	271	0°	2130	.750	1.750	W.A. 710/456

Appendix B, TABLE II

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

of

Hardness BHN 276 to 305 Fired at 0° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	285/302	0°	1639	.28	1.138	A.P.G. A5379
.50	1275	282	0°	1770	.50	1.167	W.A. 710/456
.50	1275	302	0°	1840	.50	1.167	W.A. 710/456
.50	1275	302	0°	1996	.625	1.459	W.A. 710/456
.50	1275	302	0°	2242	.75	1.750	W.A. 710/456
.50	1275	304	0°	2250	.75	1.750	W.A. 710/456

Appendix B, TABLE III

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor of Hardness BHN 306 to 345 Fired at 0° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	332/340	0°	1237	.312	.728	A.P.G. A6179
.50	1275	313	0°	1301	.313	.730	A.P.G. A5982
.50	1275	340	0°	1304	.315	.735	O.O. 470.5/14389
.50	1275	341	0°	1323	.316	.737	A.P.G. A6722
.30	1355	341	0°	1427	.19	.772	A.P.G. A6538
.50	1275	340	0°	1374	.333	.777	A.P.G. A6722
.50	1275	341	0°	1370	.34	.793	A.P.G. A6722
.50	1275	329	0°	1522	.375	.875	W.A. 710/456
.50	1275	331	0°	1472	.375	.875	W.A. 710/456
.50	1275	341	0°	1511	.375	.875	W.A. 710/456
.30	1355	340	0°	1592	.26	1.057	A.P.G. A6095
.30	1355	302/331	0°	1632	.27	1.098	A.P.G. A5379
.50	1275	321/363	0°	1769	.49	1.144	A.P.G. A6045
.50	1275	321	0°	1901	.50	1.167	W.A. 710/456
.50	1275	340	0°	1769	.50	1.167	A.P.G. A6095
.50	1275	341	0°	1814	.509	1.188	O.O. 470.5/14389
.50	1275	321	0°	1859	.510	1.190	O.O. 470.5/14389
.30	1355	332/340	0°	1881	.312	1.268	A.P.G. A6179
.30	1355	313	0°	1898	.313	1.272	A.P.G. A5982
.30	1355	340	0°	1842	.315	1.280	O.O. 470.5/14389
.30	1355	341	0°	1798	.316	1.285	A.P.G. A6722
.30	1355	340	0°	1906	.333	1.354	A.P.G. A6722
.30	1355	341	0°	1889	.34	1.382	A.P.G. A6722
.30	1355	321/363	0°	2448	.49	1.992	A.P.G. A6045
.30	1355	340	0°	2403	.50	2.033	A.P.G. A6095
.30	1355	341	0°	2583	.509	2.069	O.O. 470.5/14389
.30	1355	321	0°	2508	.510	2.073	O.O. 470.5/14389
.50	1275	331/341	0°	2417	.910	2.124	O.O. 470.5/14389

Appendix B, TABLE IV

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

of

Hardness BHN 346 to 385 Fired at 0° Obliquity

Cal.	m/d^3	BHN	θ	VL	c	e/d	Data Source
.50	1275	375	0°	1216	.30	.700	A.P.G. A6671
.50	1275	375/388	0°	1342	.302	.705	O.O. 470.5/14389
.50	1275	375/388	0°	1297	.312	.728	A.P.G. A6179
.50	1275	369	0°	1304	.312	.728	A.P.G. A6179
.50	1275	382	0°	1248	.313	.730	A.P.G. A5957
.30	1355	363	0°	1266	.18	.732	A.P.G. A6504
.30	1355	363	0°	1269	.18	.732	A.P.G. A6504
.50	1275	375/387	0°	1305	.314	.733	A.P.G. A5982
.50	1275	363/375	0°	1286	.315	.735	A.P.G. A6722
.50	1275	375/388	0°	1214	.316	.737	A.P.G. A6722
.50	1275	353	0°	1283	.318	.742	A.P.G. A6722
.50	1275	375/387	0°	1277	.319	.744	A.P.G. A6722
.50	1275	363/388	0°	1346	.32	.747	A.P.G. A6612
.50	1275	349	0°	1355	.320	.747	A.P.G. A6612
.50	1275	360/388	0°	1314	.320	.747	A.P.G. A6178
.50	1275	375/388	0°	1342	.320	.747	A.P.G. A6178
.50	1275	364/375	0°	1321	.320	.747	A.P.G. A6178
.50	1275	363/388	0°	1294	.321	.749	O.O. 470.5/4634
.50	1275	375	0°	1357	.322	.751	A.P.G. A6722
.50	1275	[illegible]	0°	1327	.325	.758	A.P.G. A6722
.50	1275	351	0°	1339	.326	.761	O.O. 470.5/14389
.50	1275	358	0°	1367	.328	.765	O.O. 470.5/14389
.50	1275	375	0°	1377	.329	.768	O.O. 470.5/14389
.30	1355	363/388	0°	1378	.19	.772	A.P.G. A6701
.30	1355	363/401	0°	1395	.19	.772	A.P.G. A6701
.50	1275	351/364	0°	1329	.333	.777	O.O. 470.5/14389
.50	1275	363/388	0°	1379	.337	.786	O.O. 470.5/14389
.50	1275	375	0°	1357	.353	.824	O.O. 470.5/14389

Appendix B, TABLE IV (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	363/375	0°	1462	.360	.840	O.C. 470.5/14389
.50	1275	363/375	0°	1491	.36	.840	A.P.G. A6701
.50	1275	363/388	0°	1431	.363	.847	O.O. 470.5/14389
.50	1275	350	0°	1492	.370	.863	O.O. 470.5/14389
.50	1275	361	0°	1479	.370	.863	O.O. 470.5/14389
.50	1275	347	0°	1449	.370	.863	A.P.G. A6095
.50	1275	363/388	0°	1247	.37	.863	A.P.G. A5883
.50	1275	351/364	0°	1472	.372	.868	O.O. 470.5/14389
.50	1275	340/351	0°	1504	.372	.868	O.O. 470.5/14389
.50	1275	363	0°	1505	.375	.875	O.O. 470.5/14389
.50	1275	364	0°	1512	.375	.875	O.O. 470.5/14389
.50	1275	350	0°	1522	.376	.877	O.O. 470.5/14389
.50	1275	364/375	0°	1479	.376	.877	O.O. 470.5/14389
.50	1275	363	0°	1497	.378	.882	O.O. 470.5/14389
.50	1275	363	0°	1507	.379	.884	O.O. 470.5/14389
.50	1275	350	0°	1528	.380	.887	O.O. 470.5/14389
.50	1275	363	0°	1450	.380	.887	O.O. 470.5/14389
.50	1275	375/388	0°	1492	.380	.887	O.O. 470.5/14389
.50	1275	356	0°	1512	.380	.887	O.O. 470.5/14389
.50	1275	365/375	0°	1546	.38	.887	A.P.G. A6236
.50	1275	354	0°	1514	.382	.891	O.O. 470.5/14389
.50	1275	364/375	0°	1526	.382	.894	O.O. 470.5/14389
.50	1275	352/363	0°	1520	.384	.896	O.O. 470.5/14389
.50	1275	349	0°	1495	.388	.905	O.O. 470.5/14389
.50	1275	375/387	0°	1523	.394	.919	O.O. 470.5/14389
.50	1275	363/388	0°	1476	.396	.924	O.O. 470.5/14389
.30	1355	354	0°	1606	.244	.992	A.P.G. A6499
.30	1355	363	0°	1592	.25	1.016	A.P.G. A6592
.30	1355	375	0°	1660	.251	1.020	A.P.G. A6609
.30	1355	375/388	0°	1699	.27	1.098	A.P.G. A6715
.50	1275	375	0°	1705	.486	1.134	O.O. 470.5/14389
.30	1355	363/388	0°	1838	.28	1.138	A.P.G. A6715
.30	1355	363	0°	1688	.28	1.138	A.P.G. A5958

Appendix B, TABLE IV (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	375/388	0°	1839	.490	1.144	O.O. 470.5/14389
.50	1275	364	0°	1779	.493	1.151	O.O. 470.5/14389
.50	1275	375	0°	1748	.494	1.153	O.O. 470.5/14389
.50	1275	363/375	0°	1768	.496	1.158	O.O. 470.5/14389
.50	1275	375/388	0°	1802	.496	1.158	O.O. 470.5/14389
.50	1275	380	0°	1818	.498	1.162	O.O. 470.5/14389
.50	1275	375/387	0°	1849	.498	1.162	O.O. 470.5/14389
.50	1275	375	0°	1817	.498	1.162	O.O. 470.5/14389
.50	1275	364	0°	1818	.500	1.167	O.O. 470.5/14389
.50	1275	367	0°	1828	.50	1.167	O.O. 470.5/14389
.50	1275	340/351	0°	1823	.500	1.167	O.O. 470.5/14389
.50	1275	372	0°	1819	.500	1.167	O.O. 470.5/14389
.50	1275	364	0°	1808	.502	1.172	O.O. 470.5/14389
.50	1275	363/388	0°	1789	.502	1.172	O.O. 470.5/14389
.50	1275	375/387	0°	1850	.504	1.176	O.O. 470.5/14389
.50	1275	341/375	0°	1853	.504	1.176	O.O. 470.5/14389
.50	1275	363/388	0°	1859	.504	1.176	O.O. 470.5/14389
.30	1355	363/388	0°	1798	.29	1.179	A.P.G. A6617
.30	1355	363/388	0°	1802	.29	1.179	A.P.G. A6715
.30	1355	363/388	0°	1782	.29	1.179	A.P.G. A6498
.30	1355	375/388	0°	1851	.29	1.179	A.P.G. A6498
.50	1275	364	0°	1837	.510	1.190	O.O. 470.5/4634
.50	1275	375/388	0°	1829	.515	1.202	O.O. 470.5/4634
.50	1275	383	0°	1851	.518	1.209	O.O. 470.5/4634
.50	1275	375	0°	1835	.52	1.214	A.P.G. A5648
.50	1275	375/388	0°	1886	.520	1.214	A.P.G. A5648
.30	1355	375	0°	1807	.30	1.220	A.P.G. A6671
.30	1355	375/388	0°	1903	[illegible]	1.228	O.O. 470.5/14389
.50	1275	352	0°	[illegible]	.530	1.237	A.P.G. A6612
.30	1355	375/388	0°	1886	.312	1.268	A.P.G. A6179
.30	1355	369	0°	1797	.312	1.268	A.P.G. A6179
.30	1355	388	0°	1833	.313	1.272	A.P.G. A5957
.30	1355	375/387	0°	1856	.314	1.276	A.P.G. A5982
.30	1355	363/375	0	1835	.315	1.280	A.P.G. A6722

Appendix B, TABLE IV (CONT'D)

Cal.	w/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	375/388	0°	1876	.316	1.285	A.P.G. A6722
.30	1355	353	0°	1844	.318	1.29	A.P.G. A6722
.30	1355	375/387	0°	1867	.319	1.297	A.P.G. A6722
.30	1355	363/388	0°	1909	.32	1.301	A.P.G. A6612
.30	1355	349	0°	1896	.320	1.301	A.P.G. A6612
.30	1355	360/388	0°	1990	.320	1.301	A.P.G. A6178
.30	1355	375/388	0°	1928	.320	1.301	A.P.G. A6178
.30	1355	364/375	0°	1892	.320	1.301	A.P.G. A6178
.30	1355	363/388	0°	1785	.321	1.305	O.O. 470.5/4634
.30	1355	375	0°	1886	.322	1.309	A.P.G. A6722
.30	1355	352	0°	1874	.325	1.321	A.P.G. A6722
.30	1355	351	0°	1850	.326	1.325	O.O. 470.5/14389
.30	1355	358	0°	1837	.328	1.353	O.O. 470.5/14389
.30	1355	375	0°	1900	.329	1.337	O.O. 470.5/14389
.30	1355	363/388	0°	2036	.337	1.370	O.O. 470.5/14389
.30	1355	375	0°	2035	.353	1.435	O.O. 470.5/14389
.50	[illegible]	359	0°	2177	.625	1.459	W.A. 710/456
.30	1355	363/375	0°	2111	.360	1.463	O.O. 470.5/14389
.30	1355	363/375	0°	2019	.36	1.463	A.P.G. A6701
.30	1355	363/388	0°	2048	.363	1.476	O.O. 470.5/14389
.30	1355	[illegible]	0°	1998	.370	1.504	O.O. 470.5/14389
.30	1355	[illegible]	0°	2057	.370	1.504	O.O 470.5/14389
.30	1355	347	0°	2000	.370	1.504	A.P.G. A6095
.30	1355	363/388	0°	2088	.37	1.504	A.P.G. A5883
.30	1355	351/364	0°	2036	.372	1.512	O.O. 470.5/14389
.30	1355	340/351	0°	2014	.372	1.512	O.O. 470.5/14389
.30	1355	[illegible]	0°	2134	.373	1.524	O.O. 470.5/14389
.30	1355	[illegible]	0°	2148	.375	1.524	O.O. 470.5/14389
.30	1355	359	0°	2103	.376	1.528	O.O. 470.5/14389
.30	1355	364/375	0°	2074	.376	1.528	O.O. 470.5/14389
.30	1355	363	0°	2089	.378	1.537	O.O. 470.5/14389
.30	1355	363	0°	2117	.379	1.541	O.O. 470.5/14389
.30	1355	360	0°	2108	.380	1.545	O.O. 470.5/14389

Appendix B, TABLE IV (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	363	0°	2188	.380	1.545	O.O. 470.5/14389
.30	1355	375/388	0°	2199	.380	1.545	O.O. 470.5/14389
.30	1355	356	0°	2116	.380	1.545	O.O. 470.5/14389
.30	1355	365/375	0°	2096	.38	1.545	A.P.G. A6236
.30	1355	354	0°	2048	.382	1.553	O.O. 470.5/14389
.30	1355	364/375	0°	2070	.382	1.553	O.O. 470.5/14389
.30	1355	352/363	0°	2044	.384	1.561	O.O. 470.5/14389
.30	1355	349	0°	2027	.388	1.577	O.O. 470.5/14389
.30	1355	375/387	0°	2172	.394	1.602	O.O. 470.5/14389
.30	1355	363/388	0°	2147	.396	1.610	O.O. 470.5/14389
.50	1275	363	0°	2136	.750	1.750	W.A. 710/456
.50	1275	378	0	2272	.750	1.750	W.A. 710/456
.50	1355	375	0°	2438	.486	1.976	O.O. 470.5/14389
.50	1275	363/388	0°	2513	.852	1.988	O.O. 470.5/14389
.30	1355	375/388	0°	2490	.490	1.992	O.O. 470.5/14389
.50	1275	364	0°	2463	.858	2.002	O.O. 470.5/14389
.30	1355	364	0°	2446	.493	2.004	O.O. 470.5/14389
.30	1355	375	0°	2561	.494	2.008	O.O. 470.5/14389
.50	1275	352/363	0°	2333	.863	2.014	O.O. 470.5/14389
.30	1355	363/375	0°	2507	.496	2.016	O.O. 470.5/14389
.30	1355	375/388	0°	2587	.496	2.016	O.O. 470.5/14389
.50	1275	352/363	0°	2535	.864	2.016	O.O. 470.5/14389
.30	1355	380	0°	2534	.498	2.024	O.O. 470.5/14389
.30	1355	375/387	0°	2482	.498	2.024	O.O. 470.5/14389
.30	1355	375	0°	2502	.498	2.024	O.O. 470.5/14389
.50	1275	341/375	0°	2539	.868	2.026	O.O. 470.5/14389
.50	1275	363	0°	2527	.870	2.030	O.O. 470.5/14389
.30	1355	340/351	0°	2448	.500	2.033	O.O. 470.5/14389
.30	1355	370	0°	2449	.500	2.033	O.O. 470.5/14389
.30	1355	[illegible]	0°	2508	.500	2.033	O.O. 470.5/14389
.30	1355	[illegible]	0°	2503	.50	2.073	O.O. 470.5/14389
.50	1275	364	0°	2553	.871	2.033	O.O. 470.5/14389
.50	1275	352	0°	2447	.872	2.035	O.O. 470.5/14389
.50	1275	375/393	0°	2628	.872	2.035	O.O. 470.5/14389
.30	1355	[illegible]	0°	2476	.502	2.041	O.O. 470.5/14389

Appendix B, TABLE IV (CONT'D)

C-1.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	363/388	0°	2504	.502	2.041	0.0. 470.5/14389
.30	1355	375/387	0°	2580	.504	2.049	0.0. 470.5/14389
.30	1355	341/375	0°	2524	.504	2.049	0.0. 470.5/14389
.30	1355	363/388	0°	2559	.504	2.049	0.0. 470.5/14389
.50	1275	375/387	0°	2554	.878	2.049	0.0. 470.5/14389
.50	1275	363/388	0°	2538	.880	2.054	0.0. 470.5/14389
.50	1275	352/363	0°	2596	.880	2.054	0.0. 470.5/14389
.50	1275	364	0°	2506	.884	2.063	0.0. 470.5/14389
.50	1275	363/388	0°	2436	.888	2.072	0.0. 470.5/14389
.30	1355	364	0°	2497	.510	2.073	0.0. 470.5/4634
.50	1275	375/387	0°	2567	.890	2.077	0.0. 470.5/14389
.30	1355	375/388	0°	2574	.515	2.093	0.0, 470.5/4634
.50	1275	363/388	0°	2495	.898	2.096	0.0. 470.5/14389
.50	1275	375/387	0°	2566	.900	2.100	0.0. 470.5/14389
.30	1355	383	0°	2567	.518	2.106	0.0. 470.5/4634
.30	1355	375	0°	2579	.52	2.114	A.P.G. A5648
.30	1355	378/388	0°	2662	.520	2.114	A.P.G. A5648
.50	1275	375/387	0°	2527	.922	2.152	0.0. 470.5/14389
.30	1355	352	0	2567	.530	2.154	A.P.G. A6612

Appendix B, TABLE V

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

of

Hardness BHN 386 to 425 Fired at 0° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	388/401	0°	1326	.30	.700	A.P.G. A6715
.50	1275	388/401	0°	1190	.31	.723	A.P.G. A5975
.50	1275	402/418	0°	1187	.31	.723	O.O. 470.5/14389
.50	1275	388/401	0°	1365	.31	.723	A.P.G. A6177
.50	1275	381/402	0°	1295	.31	.723	O.O. 470.5/14389
.50	1275	388/401	0°	1287	.31	.723	A.P.G. A6179
.50	1275	388/401	0°	1380	.313	.730	A.P.G. A5957
.50	1275	401	0°	1356	.313	.730	A.P.G. A5982
.30	1355	388/401	0°	1309	.18	.732	A.P.G. A6346
.50	1275	401/415	0°	1325	.314	.733	O.O. 470.5/14389
.50	1275	415	0°	1294	.314	.733	O.O. 470.5/14389
.50	1275	415	0°	1315	.317	.740	O.O. 470.5/14389
.50	1275	402/418	0°	1386	.318	.742	O.O. 470.5/14389
.50	1275	401	0°	1302	.318	.742	O.O. 470.5/14389
.50	1275	388/401	0°	1388	.320	.747	O.O. 470.5/14389
.50	1275	418	0°	1188	.322	.751	O.O. 470.5/14389
.50	1275	388/429	0°	1327	.323	.754	O.O. 470.5/14389
.50	1275	388	0°	1209	.324	.756	A.P.G. A6722
.50	1275	402/418	0°	1377	.325	.758	O.O. 470.5/14389
.30	1355	388	0°	1441	.19	.772	A.P.G. A6338
.30	1355	375/401	0°	1379	.19	.772	A.P.G. A6338
.30	1355	388/401	0°	1406	.19	.772	A.P.G. A6345
.30	1355	388/401	0°	1393	.19	.772	A.P.G. A6346
.30	1355	388/401	0°	1350	.19	.772	A.P.G. A6580
.30	1355	388	0°	1414	.19	.772	A.P.G. A6580
.30	1355	388/401	0°	1406	.19	.772	A.P.G.A6580
.30	1355	401	0°	1406	.19	.772	A.P.G. A6580
.30	1355	401	0°	1406	.19	.772	A.P.G. A6580
.30	1355	363/401	0°	1401	.20	.813	A.P.G. A6180
.30	1355	363/401	0°	1373	.20	.813	A.P.G. A6181
.30	1355	388/401	0°	1466	.20	.813	A.P.G. A6182

Appendix B, TABLE V (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	415/415	0°	1766	.20	.813	A.P.G. A6097
.30	1355	415/415	0°	1375	.20	.813	A.P.G. A6097
.30	1355	415/415	0°	1402	.20	.813	A.P.G. A6097
.50	1275	401/415	0°	1325	.335	.836	O.O. 470.5/14389
.50	1275	401	0°	1345	.359	.838	O.O. 470.5/14389
.50	1275	387	0°	1460	.36	.840	A.P.G. A6616
.50	1275	402	0°	1485	.36	.840	A.P.G. A6687
.50	1275	402	0°	1467	.36	.840	A.P.G. A6687
.50	1275	388/401	0°	1471	.36	.840	A.P.G. A6410
.50	1275	388/401	0°	1357	.36	.840	A.P.G. A6045
.50	1275	393/401	0°	1407	.37	.863	O.O. 470.5/14389
.50	1275	401	0°	1497	.37	.863	A.P.G. A6337
.50	1275	388/401	0°	1510	.37	.863	A.P.G. A6701
.50	1275	387	0°	1541	.37	.863	A.P.G. A6616
.50	1275	402	0°	1421	.37	.863	A.P.G. A6687
.50	1275	402	0°	1469	.37	.863	A.P.G. A6687
.50	1275	387/418	0°	1432	.372	.868	O.O. 470.5/14389
.50	1275	402/430	0°	1332	.374	.873	O.O. 470.5/14389
.50	1275	415	0°	1500	.376	.877	W.A. 710/456
.50	1275	387/402	0°	1533	.376	.877	O.O. 470.5/14389
.50	1275	388/429	0°	1467	.377	.880	O.O. 470.5/14389
.50	1275	401/415	0°	1444	.378	.882	O.O. 470.5/14389
.50	1275	387/418	0°	1503	.380	.887	O.O. 470.5/14389
.50	1275	415	0°	1318	.380	.887	O.O. 470.5/14389
.50	1275	388	0°	1524	.38	.887	A.P.G. A6648
.50	1275	394	0°	1528	.38	.887	A.P.G. A6041
.50	1275	388/401	0°	1512	.38	.887	A.P.G. A6227
.50	1275	388/415	0°	1415	.38	.887	A.P.G. A6612
.50	1275	402/418	0°	1541	.384	.896	O.O. 470.5/14389
.50	1275	388/415	0°	1529	.384	.896	O.O. 470.5/14389
.50	1275	415	0°	1406	.386	.901	O.O. 470.5/14389
.50	1275	388/415	0°	1481	.386	.901	O.O. 470.5/14389
.50	1275	402/418	0°	1367	.388	.905	O.O. 470.5/14389
.50	1275	388/401	0°	1489	.388	.905	O.O. 470.5/14389

Appendix B, TABLE V (CONT'D)

Cal.	m/d^3	BHN	θ	VL	e	e/d	Data Source
.50	1275	388	0°	1532	.39	.910	A.P.G. A6553
.50	1275	388/401	0°	1587	.39	.910	A.P.G. A6521
.50	1275	387/402	0°	1540	.39	.910	A.P.G. A6678
.50	1275	402	0°	1546	.39	.910	A.P.G. A6716
.50	1275	387/418	0°	1507	.39	.910	O.O. 470.5/14389
.50	1275	388/401	0°	1519	.396	.924	O.O. 470.5/14389
.50	1275	401	0°	1542	.396	.924	O.O. 470.5/14389
.50	1275	401	0°	1520	.396	.924	O.O. 470.5/14389
.50	1275	387	0°	1599	.400	.933	O.O. 470.5/14389
.30	1355	388/415	0°	1673	.24	.976	A.P.G. A6410
.30	1355	375/401	0°	1555	.24	.976	A.P.G. A6612
.30	1355	388/401	0°	1705	.25	1.016	A.P.G. A6451
.30	1355	401	0°	1731	.25	1.016	A.P.G. A6239
.30	1355	388/401	0°	1667	.25	1.016	A.P.G. A6580
.30	1355	415	0°	1613	.256	1.040	O.O. 470.5/14389
.30	1355	422	0°	1578	.27	1.098	A.P.G. A6767
.30	1355	388/401	0°	1874	.27	1.098	A.P.G. A6498
.30	1355	401	0°	1714	.27	1.098	A.P.G. A6715
.30	1355	388/401	0°	1810	.27	1.098	A.P.G. A6176
.50	1275	391	0°	1828	.486	1.134	O.O. 470.5/14389
.30	1355	388	0°	1792	.28	1.138	A.P.G. A6280
.30	1355	388	0°	1794	.28	1.138	A.P.G. A6281
.30	1355	388/401	0°	1818	.28	1.138	A.P.G. A6639
.30	1355	388	0°	1756	.28	1.138	A.P.G. A6639
.30	1355	388/401	0°	1815	.28	1.138	A.P.G. A5959
.30	1355	363/401	0°	1709	.28	1.138	A.P.G. A5960
.30	1355	397	0°	1834	.280	1.138	A.P.G. A6090
.30	1355	388	0°	1856	.280	1.138	A.P.G. A6139
.30	1355	394	0°	1791	.280	1.138	A.P.G. A6140
.50	1275	388	0°	1844	.496	1.158	O.O. 470.5/14389
.50	1275	388/415	0°	1633	.498	1.162	O.O. 470.5/14389
.50	1275	415	0°	1522	.500	1.167	W.A. 710/456
.50	1275	402	0°	1833	.500	1.167	O.O. 470.5/14389
.50	1275	389	0°	1822	.500	1.167	O.O. 470.5/14389
.50	1275	402	[illegible]	1831	.504	1.176	O.O. 470.5/14389

Appendix B, TABLE V (CONT'D)

Cal.	m/d^3	BHN	θ	VL	e	e/d	Data Source
.50	1275	388	0°	1849	.504	1.176	O.O. 470.5/14389
.50	1275	384	0°	1772	.506	1.181	O.O. 470.5/14389
.50	1275	388/401	0°	1854	.506	1.181	O.O. 470.5/14389
.50	1275	387	0°	1853	.506	1.181	O.O. 470.5/14389
.50	1275	415	0°	1860	.506	1.181	O.O. 470.5/14389
.50	1275	387/415	0°	1773	.507	1.183	O.O. 470.5/14389
.50	1275	418	0°	1757	.510	1.190	O.O. 470.5/14389
.50	1275	401/415	0°	1810	.510	1.190	O.O. 470.5/4634
.50	1275	401	0°	1886	.510	1.190	O.O. 470.5/4634
.50	1275	387/418	0°	1844	.510	1.190	O.O. 470.5/14389
.50	1275	388/415	0°	1868	.52	1.214	A.P.G. A6612
.30	1355	388/401	0°	1889	.30	1.219	A.P.G. A6639
.30	1355	388/401	0°	1855	.30	1.219	A.P.G. A6715
.30	1355	388/401	0°	1912	.31	1.260	A.P.G. A5957
.30	1355	402/418	0°	2084	.31	1.260	O.O. 470.5/14389
.30	1355	388/401	0°	1918	.31	1.260	A.P.G. A6177
.30	1355	381/402	0°	1963	.31	1.260	O.O. 470.5/14389
.30	1355	388/401	0°	1876	.31	1.260	A.P.G. A6179
.30	1355	388/401	0°	1938	.313	1.272	A.P.G. A5957
.30	1355	401	0°	1973	.313	1.272	A.P.G. A5982
.30	1355	401/415	0°	1991	.314	1.276	O.O. 470.5/14389
.30	1355	415	0°	1953	.314	1.276	O.O. 470.5/14389
.30	1355	401	0°	1899	.315	1.280	A.P.G. A6722
.30	1355	415	0°	1950	.317	1.289	O.O. 470.5/14389
.30	1355	402/418	0°	2141	.318	1.293	O.O. 470.5/14389
.30	1355	401	0°	2018	.318	1.293	O.O. 470.5/14389
.30	1355	401/415	0°	1947	.318	1.293	O.O. 470.5/14389
.30	1355	401	0°	1964	.32	1.301	A.P.G. A6178
.30	1355	388/401	0°	1951	.32	1.301	O.O. 470.5/14389
.30	1355	418	0°	1995	.322	1.309	O.O. 470.5/14389
.30	1355	388/429	0°	2086	.323	1.313	O.O. 470.5/14389
.30	1355	388	0°	1902	.324	1.317	A.P.G. A6722
.30	1355	402/418	0°	1985	.325	1.321	O.O. 470.5/14389
.30	1355	401/415	0°	1991	.335	1.362	O.O. 470.5/14389

Appendix B, TABLE V (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	409	0°	2024	.625	1.458	W.A. 710/456
.50	1275	415	0°	1999	.625	1.458	W.A. 710/456
.30	1355	401	0°	2056	.359	1.459	O.O. 470.5/14389
.30	1355	387	0°	2099	.36	1.463	A.P.G. A6616
.30	1355	402	0°	2097	.36	1.463	A.P.G. A6687
.30	1355	402	0°	2151	.36	1.463	A.P.G. A6687
.30	1355	388/401	0°	2100	.36	1.463	A.P.G. A6410
.30	1355	388/401	0°	2100	.36	1.463	A.P.G. A6045
.30	1355	393/401	0°	2105	.37	1.504	O.O. 470.5/14389
.30	1355	401	0°	2156	.37	1.504	A.P.G. A6337
.30	1355	388/401	0°	2222	.37	1.504	A.P.G. A6701
.30	1355	387	0°	2104	.37	1.504	A.P.G. A6616
.30	1355	402	0°	2137	.37	1.504	A.P.G. A6687
.30	1355	402	0°	2104	.37	1.504	A.P.G. A6687
.30	1355	387/418	0°	2277	.372	1.512	O.O. 470.5/14389
.30	1355	402/430	0°	2142	.374	1.520	O.O. 470.5/14389
.30	1355	387/402	0°	2182	.376	1.528	O.O. 470.5/14389
.30	1355	388/429	0°	2212	.377	1.533	O.O. 470.5/14389
.30	1355	401/415	0°	2231	.378	1.536	O.O. 470.5/14389
.30	1355	415	0°	2210	.380	1.545	O.O. 470.5/14389
.30	1355	387/418	0°	2100	.380	1.545	O.O. 470.5/14389
.30	1355	388	0°	2082	.38	1.545	A.P.G. A6648
.30	1355	394	0°°	2153	.38	1.545	A.P.G. A6041
.30	1355	388/401	0°	2234	.38	1.545	A.P.G. A6227
.30	1355	388/415	0°	2119	.38	1.545	A.P.G. A6612
.30	1355	402/418	0°	2158	.384	1.561	O.O. 470.5/14389
.30	1355	388/415	0°	2135	.384	1.561	O.O. 470.5/14389
.30	1355	415	0°	2235	.386	1.569	O.O. 470.5/14389
.30	1355	388/415	0°	2235	.386	1.569	O.O. 470.5/14389
.30	1355	402/418	0°	2131	.388	1.577	O.O. 470.5/14389
.30	1355	388/401	0°	2117	.388	1.577	O.O. 470.5/14389
.30	1355	388	0°	2129	.39	1.585	A.P.G. A6553
.30	1355	388/401	0°	2262	.39	1.585	A.P.G. A6521

Appendix B, TABLE V (CONT'D)

Cal.	m/d3	BHN	θ	VL	e	e/d	Data Source
.30	1355	387/402	0°	2153	.39	1.585	A.P.G. A6678
.30	1355	387/418	0°	2136	.390	1.585	0.0. 470.5/14389
.30	1355	402	0°	2135	.39	1.585	A.P.G. A6716
.30	1355	388/401	0°	2123	.396	1.610	0.0. 470.5/14389
.30	1355	401	0°	2229	.396	1.610	0.0. 470.5/14389
.30	1355	401	0°	2338	.396	1.610	0.0. 470.5/14389
.30	1355	387	0°	2326	.400	1.626	0.0. 470.5/14389
.50	1275	388	0°	2344	.742	1.731	A.P.G. A6010
.50	1275	388	0°	2318	.750	1.750	W.A. 710/450
.50	1275	388	0°	2263	.750	1.750	W.A. 710/456
.30	1355	391	0°	2541	.486	1.976	0.0. 470.5/14389
.30	1355	388	0°	2491	.488	1.984	A.P.G. A6642
.50	1275	387	0°	2545	.852	1.988	0.0. 470.5/14389
.50	1275	419	0°	2624	.864	2.016	0.0. 470.5/14389
.30	1355	415	0°	2640	.496	2.016	0.0. 470.5/14389
.30	1355	388	0°	2557	.496	2.016	0.0. 470.5/14389
.30	1355	388/415	0°	2683	.498	2.024	0.0. 470.5/14389
.50	1275	422	0°	2669	.868	2.026	0.0. 470.5/14389
.50	1275	387/402	0°	2630	.868	2.026	0.0. 470.5/14389
.50	1275	363/444	0°	2649	.870	2.030	0.0. 470.5/14389
.50	1275	363/444	0°	2553	.870	2.030	0.0. 470.5/14389
.30	1355	402	0°	2559	.500	2.032	0.0. 470.5/14389
.30	1355	389	0°	2506	.500	2.032	0.0. 470.5/14389
.50	1275	387	0°	2572	.871	2.033	0.0. 470.5/14389
.50	1275	426	0°	2679	.872	2.035	0.0. 470.5/14389
.50	1275	415	0°	2588	.873	2.037	0.0. 470.5/14389
.50	1275	413	0°	2714	.874	2.040	0.0. 470.5/14389
.50	1275	402/418	0°	2560	.875	2.042	0.0. 470.5/14389
.50	1275	388	0°	2622	.876	2.044	0.0. 470.5/14389
.50	1275	387/402	0°	2603	.876	2.044	0.0. 470.5/14389
.50	1275	394	0°	2640	.876	2.049	0.0. 470.5/14389
.30	1355	402	0°	2547	.504	2.049	0.0. 470.5/14389
.30	1355	388	0°	2498	.504	2.049	0.0. 470.5/14389
.50	1275	387/418	0°	2798	.880	2.054	0.0. 470.5/14389
.30	1355	384	0°	2454	.506	2.057	0.0. 470.5/14389
.30	1355	388/401	0°	2503	.506	2.057	0.0. 470.5/14389

Appendix B, TABLE V (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	387	0°	2478	.506	2.057	O.O. 470.5/14389
.30	1355	415	0°	2587	.506	2.057	O.O. 470.5/14389
.30	1355	375/415	0°	2654	.507	2.061	O.O. 470.5/14389
.50	1275	415	0°	2584	.887	2.070	O.O. 470.5/14389
.30	1355	418	0°	2568	.510	2.073	O.O. 470.5/14389
.30	1355	401/415	0°	2615	.510	2.073	O.O. 470.5/4634
.30	1355	401	0°	2656	.510	2.073	O.O. 470.5/4634
.30	1355	387/418	0°	2652	.510	2.073	O.O. 470.5/14389
.50	1275	385/401	0°	2519	.906	2.114	O.O. 470.5/14389
.50	1275	418	0°	2605	.908	2.119	O.O. 470.5/14389

Appendix B, TABLE VI

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

Hardness Greater Than BHN 425 Fired at 0° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	444	0°	1286	.306	.714	O.O. 470.5/14389
.50	1275	444	0°	1335	.306	.714	O.O. 470.5/14389
.50	1275	461	0°	1302	.308	.719	O.O. 470.5/14389
.50	1275	461	0°	1289	.312	.728	O.O. 470.5/14389
.50	1275	429	0°	1311	.314	.733	O.O. 470.5/14389
.50	1275	429	0°	1275	.318	.742	O.O. 470.5/14389
.50	1275	444	0°	1310	.328	.765	O.O. 470.5/14389
.30	1355	444	0°	1391	.19	.772	A.P.G. A6538
.50	1275	444	0°	1189	.341	.796	O.O. 470.5/14389
.30	1355	415/444	0°	1643	.20	.813	A.P.G. A6097
.30	1355	415/444	0°	1495	.20	.813	A.P.G. A6097
.30	1355	415/444	0°	1534	.20	.813	A.P.G. A6442
.30	1355	415/444	0°	1597	.20	.813	A.P.G. A6442
.50	1275	429	0°	1378	.380	.887	O.O. 470.5/14389
.50	1275	444	0°	1432	.380	.887	O.O. 470.5/14389
.50	1275	444	0°	1375	.390	.910	O.O. 470.5/14389
.50	1275	415/444	0°	1723	.494	1.153	O.O. 470.5/14389
.50	1275	429	0°	1655	.496	1.158	O.O. 470.5/14389
.50	1275	429	0°	1744	.500	1.167	O.O. 470.5/14389
.50	1275	429	0°	1780	.500	1.167	O.O. 470.5/14389
.50	1275	444	0°	1755	.510	1.190	O.O. 470.5/14389
.30	1355	444	0°	1984	.306	1.244	O.O. 470.5/14389
.30	1355	444	0°	1985	.306	1.244	O.O. 470.5/14389
.30	1355	461	0°	1927	.308	1.252	O.O. 470.5/14389
.30	1355	461	0°	1933	.312	1.268	O.O. 470.5/14389
.30	1355	429	0°	1930	.314	1.276	O.O. 470.5/14389
.30	1355	429	0°	1996	.318	1.293	O.O. 470.5/14389
.30	1355	444	0°	1966	.328	1.333	O.O. 470.5/14389
.30	1355	444	0°	2030	.341	1.386	O.O. 470.5/14389
.30	1355	429	0°	2192	.380	1.545	O.O. 470.5/14389
.30	1355	444	0°	2267	.380	1.545	O.O. 470.5/14389

Appendix B, TABLE VI (CONT'D)

Cal.	m/d3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	444	0°	2167	.390	1.585	O.O. 470.5/14389
.30	1355	415/444	0°	2632	.494	2.008	O.O. 470.5/14389
.30	1355	429	0°	2668	.496	2.016	O.O. 470.5/14389
.30	1355	429	0°	2752	.500	2.033	O.O. 470.5/14389
.30	1355	429	0°	2669	.500	2.033	O.O. 470.5/14389
.50	1275	429	0°	2568	.880	2.054	O.O. 470.5/14389
.50	1275	429	0°	2584	.838	2.072	O.O. 470.5/14389
.30	1355	444	0°	2702	.510	2.073	O.O. 470.5/14389

Appendix B, TABLE VII

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor of Hardness Greater Than BHN 306 to 345 Fired at 30° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	332/340	30°	1205	.312	.728	A.P.G. A6179
.50	1275	313	30°	1336	.313	.730	A.P.G. A5982
.50	1275	340	30°	1319	.315	.735	O.O. 470.5/14389
.50	1275	341	30°	1215	.316	.737	A.P.G. A6722
.30	1355	341	30°	1459	.19	.772	A.P.G. A6538
.50	1275	340	30°	1331	.333	.777	A.P.G. A6722
.50	1275	341	30°	1365	.34	.793	A.P.G. A6722
.30	1355	340	30°	2031	.26	1.057	A.P.G. A6095
.30	1355	302/331	30°	1831	.27	1.098	A.P.G. A5379
.50	1275	321/343	30°	2507	.49	1.144	A.P.G. A6045
.50	1275	340	30°	2242	.50	1.167	A.P.G. A6095
.50	1275	341	30°	2328	.509	1.188	O.O. 470.5/14389
.50	1275	321	30°	2390	.510	1.190	O.O. 470.5/14389
.50	1355	313	30°	2493	.313	1.272	A.P.G. A5982
.30	1355	340	30°	2259	.315	1.280	O.O. 470.5/14389
.30	1355	341	30°	2202	.316	1.285	A.P.G. A6722
.30	1355	341	30°	2235	.34	1.382	A.P.G. A6722

Appendix B, TABLE VIII

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor of Hardness Greater Than BHN 346 to 385 Fired at 30° Obliquity

Cal.	m/d3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	375/388	30°	1349	.302	.705	O.O. 470.5/14389
.50	1275	375/388	30°	1223	.312	.728	A.P.G. A6179
.50	1275	369	30°	1212	.312	.728	A.P.G. A6179
.50	1275	382	30°	1290	.313	.730	A.P.G. A5957
.30	1355	363	30°	1388	.18	.732	A.P.G. A6504
.30	1355	363	30°	1310	.18	.732	A.P.G. A6504
.50	1275	375/387	30°	1760	.314	.733	A.P.G. A5982
.50	1275	363/375	30°	1408	.315	.735	A.P.G. A6722
.50	1275	353	30°	1339	.318	.742	A.P.G. A6722
.50	1275	375/387	30°	1279	.319	.744	A.P.G. A6722
.50	1275	389	30°	114[illegible]	.320	.747	A.P.G. A6612
.50	1275	3[illegible]0/388	30°	1658	.320	.747	A.P.G. A6178
.50	1275	375/388	30°	13[illegible]9	.320	.747	A.P.G. A6178
.50	1275	3[illegible]/375	30°	1457	.320	.747	A.P.G. A6178
.50	1275	3[illegible]3/38[illegible]	30°	1180	.321	.749	O.O. 470.5/4634
.50	1275	375	30°	1404	.322	.751	A.P.G. A6722
.50	1275	352	30°	1399	.325	.758	A.P.G. A6722
.50	1275	351	30°	1241	.326	.761	O.O. 470.5/14389
.50	1275	358	30°	1174	.328	.765	O.O. 470.5/14389
.50	1275	375	30°	[illegible]	.329	.768	O.O. 470.5/14389
.30	1355	363/388	30°	1248	.19	.772	A.P.G. A6701
.30	1355	363/401	30°	1290	.19	.772	A.P.G. A6701
.50	1275	[illegible]	30°	[illegible]	.333	.777	O.O. 470.5/14389
.50	1275	[illegible]	30°	132[illegible]	.337	.786	O.O. 470.5/14389
.50	1275	37[illegible]	30°	1[illegible]	.353	.824	O.O. 470.5/14389
.50	1275	363/375	30°	1685	.360	.840	O.O. 470.5/14389
.50	1275	363/375	30°	1693	[illegible]	.840	A.P.G. A6701
.50	1275	363/3[illegible]	30°	[illegible]015	.363	.847	O.O. 470.5/14389

Appendix B, TABLE VIII (CONT'D)

Cal.	m/d3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	350	30°	1608	.370	.863	O.O. 470.5/14389
.50	1275	361	30°	1756	.370	.863	O.O. 470.5/14389
.50	1275	347	30°	1369	.370	.863	A.P.G. A6095
.50	1275	363/384	30°	1714	.37	.863	A.P.G. A5883
.50	1275	351/36[illegible]	30°	1901	.372	.868	O.O. 470.5/14389
.50	1275	340/351	30°	1810	.372	.868	O.O. 470.5/14389
.50	1275	363	30°	1738	.375	.875	O.O. 470.5/14389
.50	1275	364	30°	1916	.375	.875	O.O. 470.5/14389
.50	1275	350	30°	1865	.376	.877	O.O. 470.5/14389
.50	1275	364/375	30°	1844	.376	.877	O.O. 470.5/14389
.50	1275	363	30°	1898	.378	.882	O.O. 470.5/14389
.50	1275	363	30°	1791	.379	.884	O.O. 470.5/14389
.50	1275	350	30°	1642	.380	.887	O.O. 470.5/14389
.50	1275	363	30°	1827	.380	.887	O.O. 470.5/14389
.50	1275	375/388	30°	1780	.380	1887	O.O. 470.5/14389
.50	1275	356	30°	1688	.380	.887	O.O. 470.5/14389
.50	1275	364/375	30°	1592	.38	.887	A.P.G. A6236
.50	1275	354	30°	1807	.382	.891	O.O. 470.5/14389
.50	1275	364/375	30°	1719	.383	.894	O.O. 470.5/14389
.50	1275	[illegible]	30°	1535	.384	.896	O.O. 470.5/14389
.50	1275	343	30°	1605	.388	.905	O.O. 470.5/14389
.50	1275	375/387	30°	1552	.394	.919	O.O. 470.5/14389
.70	1355	364	30°	1845	.244	.992	A.P.G. A6499
[illegible]	1355	363	30°	1961	.25	1.016	A.P.G. A6592
[illegible]	1355	375	30°	2024	.251	1.020	A.P.G. A6609
[illegible]	1355	375/388	30°	2175	.27	1.098	A.P.G. A6715
[illegible]	1355	[illegible]	30°	2371	[illegible]	1.138	A.P.G. A6715
[illegible]	1355	363	30°	[illegible]	.28	1.138	A.P.G. A5958
.50	1275	375/388	30°	2477	.490	1.144	O.O. 470.5/14389
[illegible]	1275	[illegible]	30°	2273	.493	1.151	O.O. 470.5/14389
.50	1275	375	30°	2737	.494	1.153	O.O. 470.5/14389
.50	1275	[illegible]/376	[illegible]	[illegible]	.496	1.157	O.O. 470.5/14389
[illegible]	[illegible]	375/353	30°	2332	.496	1.158	O.O. 470.5/14389

Appendix B, TABLE VIII (CONT'D)

Cal.	m/d3	BHN	θ	VL	e	e/d	Data Source
.50	1275	380	30°	2339	.498	1.162	O.O. 470.5/14389
.50	1275	375/387	30°	2345	.498	1.162	O.O. 470.5/14389
.50	1275	375	30°	2449	.498	1.162	O.O. 470.5/14389
.50	1275	367	30°	2096	.50	1.167	O.O. 470.5/14389
.50	1275	340/351	30°	2394	.500	1.167	O.O. 470.5/14389
.50	1275	372	30°	2271	.500	1.167	O.O. 470.5/14389
.50	1275	364	30°	2302	.500	1.167	O.O. 470.5/14389
.50	1275	364	30°	2478	.502	1.172	O.O. 470.5/14389
.50	1275	363/388	30°	2488	.502	1.172	O.O. 470.5/14389
.50	1275	375/387	30°	2423	.504	1.176	O.O. 470.5/14389
.50	1275	341/375	30°	2495	.504	1.176	O.O. 470.5/14389
.50	1275	363/388	30°	2365	.504	1.176	O.O. 470.5/14389
.30	1355	363/388	30°	2467	.29	1.179	A.P.G. A6617
.30	1355	363/388	30°	2104	.29	1.179	A.P.G. A6715
.30	1355	363/388	30°	2362	.29	1.179	A.P.G. A6498
.30	1355	375/388	30°	2283	.29	1.179	A.P.G. A6498
.50	1275	364	30°	2276	.510	1.190	O.O. 470.5/4634
.50	1275	375/388	30°	2365	.515	1.202	O.O. 470.5/4634
.50	1275	383	30°	2424	.518	1.209	O.O. 470.5/4634
.50	1275	375	30°	2234	.52	1.214	A.P.G. A5648
.50	1275	378/388	30°	2428	.520	1.214	A.P.G. A5648
.30	1355	375	30°	2451	.30	1.220	A.P.G. A6671
.30	1355	375/388	30°	2651	.302	1.228	O.O. 470.5/14389
.30	1355	375/388	30°	2531	.312	1.268	A.P.G. A6179
.30	1355	369	30°	2361	.312	1.268	A.P.G. A6179
.30	1355	382	30°	2615	.313	1.272	A.P.G. A5957
.30	1355	363/375	30°	2237	.315	1.280	A.P.G. A6722
.30	1355	353	30°	2167	.318	1.293	A.P.G. A6722
.30	1355	375/387	30°	2400	.319	1.297	A.P.G. A6722
.30	1355	363/388	30°	2318	.32	1.301	A.P.G. 6612
.30	1355	349	30°	2177	.320	1.301	A.P.G. 6612
.30	1355	360/388	30°	2674	.320	1.301	A.P.G. A6178
.30	1355	375/388	30°	2651	.320	1.301	A.P.G. A6178
.30	1355	364/375	30°	2422	.320	1.301	A.P.G. A6178
.30	1355	363/388	30°	2070	.321	1.30	O.O. 470.5/4634

Appendix B, TABLE VIII (CONT'D)

Cal.	m/d³	BHN	θ	V_L	e	e/d	Data Source
.30	1355	375	30°	2358	.322	1.309	A.P.G. A6722
.30	1355	352	30°	2195	.325	1.321	A.P.G. A6722
.30	1355	351	30°	2083	.326	1.325	0.0. 470.5/14389
.30	1355	358	30°	2262	.328	1.333	0.0. 470.5/14389
.30	1355	375	30°	2449	.329	1.337	0.0. 470.5/14389
.30	1355	363/388	30°	2653	.337	1.370	0.0. 470.5/14389
.30	1355	375	30°	2553	.353	1.435	0.0. 470.5/14489
.30	1355	363/375	30°	2546	.360	1.436	0.0. 470.5/14389
.30	1355	363/375	30°	2584	.36	1.463	A.P.G. A6701
.30	1355	363/388	30°	2594	.363	1.476	0.0. 470.5/14389
.30	1355	350	30°	2242	.370	1.504	0.0. 470.5/14389
.30	1355	361	30°	2385	.370	1.504	0.0. 470.5/14389
.30	1355	347	30°	2339	.370	1.504	A.P.G. A6095
.30	1355	363/388	30°	2686	.37	1.504	A.P.G. A5883
.30	1355	351/364	30°	2546	.372	1.512	0.0. 470.5/14389
.30	1355	340/351	30°	2393	.372	1.512	0.0. 470.5/14389
.30	1355	363	30°	2666	.375	1.524	0.0. 470.5/14389
.30	1355	364	30°	2624	.375	1.524	0.0. 470.5/14389
.30	1355	350	30°	2595	.376	1.528	0.0. 470.5/14389
.30	1355	364/375	30°	2447	.376	1.528	0.0. 470.5/14389
.30	1355	363	30°	2543	.378	1.537	0.0. 470.5/14389
.30	1355	363	30°	2515	.379	1.541	0.0. 470.5/14389
.30	1355	350	30°	2562	.380	1.545	0.0. 470.5/14389
.30	1355	363	30°	2857	.380	1.545	0.0. 470.5/14389
.30	1355	375/388	30°	2593	.380	1.545	0.0. 470.5/14389
.30	1355	356	30°	2425	.380	1.545	0.0. 470.5/14389
.30	1355	365/375	30°	2515	.38	1.545	A.P.G. A6236
.30	1355	354	30°	2823	.382	1.553	0.0. 470.5/14389
.30	1355	364/375	30°	2597	.382	1.553	0.0. 470.5/14389
.30	1355	352/363	30°	2379	.384	1.561	0.0. 470.5/14389
.30	1355	349	30°	2403	.388	1.577	0.0. 470.5/14389
.30	1355	375/387	30°	2618	.394	1.602	0.0. 470.5/14389
.30	1355	363/388	30	2563	.396	1.610	0.0. 470.5/14389

Appendix B, TABLE IX

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor

of

Hardness Greater Than BHN 385 to 425 Fired at 30° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	388/401	30°	1230	.31	.723	A.P.G. A5957
.50	1275	402/418	30°	1373	.310	.723	O.O. 470.5/14389
.50	1275	388/401	30°	1409	.31	.723	A.P.G. A6177
.50	1275	381/402	30°	1584	.310	.723	O.O. 470.5/14389
.50	1275	388/401	30°	1230	.31	.723	A.P.G. A6179
.50	1275	388/401	30°	1342	.313	.730	A.P.G. A5957
.50	1275	401	30°	1308	.313	.730	A.P.G. A5982
.30	1355	388/401	30°	1379	.18	.732	A.P.G. A6346
.50	1275	401/415	30°	1796	.314	.733	O.O. 470.5/14389
.50	1275	415	30°	1746	.314	.733	O.O. 470.5/14389
.50	1275	401	30°	1206	.315	.735	A.P.G. A6722
.50	1275	415	30°	1329	.318	.742	O.O. 470.5/14389
.50	1275	402/418	30°	1529	.318	.742	O.O. 470.5/14389
.50	1275	401	30°	1465	.318	.742	O.O. 470.5/14389
.50	1275	401/415	30°	1718	.318	.742	O.O. 470.5/14389
.50	1275	401	30°	1530	.3[illegible]	.747	A.P.G. A6178
.50	1275	38[illegible]/401	30°	1532	.320	.747	O.O. 470.5/14389
.50	1275	418	30°	1[illegible]3	.322	.751	O.O. 470.5/14389
.50	1275	388/4[illegible]9	30°	1629	.3[illegible]3	.754	O.O. 470.5/14389
.50	1275	388	30°	1279	.324	.756	A.P.G. A6722
.50	1275	402/418	30°	1676	.325	.758	O.O. 470.5/14389
.30	1355	388	30°	1539	.19	.772	A.P.G. A6338
.30	1355	375/401	30°	1307	.19	.772	A.P.G. A6338
.30	1355	388/401	30°	1310	.19	.772	A.P.G. A6345
.30	1355	388/401	30°	1576	.19	.772	A.P.G. A6346
.30	1355	388/401	30°	1495	.19	.772	A.P.G. A6580
.30	1355	388	30°	1495	.19	.772	A.P.G. A6580
.30	1355	388/401	30°	1445	.19	.772	A.P.G. A6580
.30	1355	401	30°	1684	.19	.772	A.P.G. A6580
.30	1355	401	30°	1357	.19	.772	A.P.G. A6580
.50	1275	401/415	30°	1796	.335	.782	O.O. 470.5/14389

Appendix B, TABLE IX (CONT'D)

Cal.	m/d³	BHN	θ	V_L	e	e/d	Data Source
.30	1355	363/401	30°	1488	.20	.813	A.P.G. A6180
.30	1355	363/401	30°	1454	.20	.813	A.P.G. A6181
.30	1355	388/401	30°	1422	.20	.813	A.P.G. A6182
.30	1355	415/415	30°	1925	.20	.813	A.P.G. A6097
.30	1355	415/415	30°	1697	.20	.813	A.P.G. A6097
.30	1355	415/415	30°	1858	.20	.813	A.P.G. A6097
.50	1275	401	30°	1648	.359	.838	O.O. 470.5/14389
.50	1275	387	30°	1386	.36	.840	A.P.G. A6616
.50	1275	402	30°	1858	.36	.840	A.P.G. A6687
.50	1275	402	30°	1561	.36	.840	A.P.G. A6687
.50	1275	388/401	30	1697	.36	.840	A.P.G. A6410
.50	1275	388/401	30°	1790	.36	.840	A.P.G. A6045
.50	1275	393/401	30°	1830	.370	.863	O.O. 470.5/14389
.50	1275	401	30°	1946	.37	.863	A.P.G. A6337
.50	1275	388/401	30°	1926	.37	.863	A.P.G. A6701
.50	1275	387	30°	1362	.37	.863	A.P.G. A6616
.50	1275	402	30°	1791	.37	.863	A.P.G. A6687
.50	1275	402	30°	2027	.37	.863	A.P.G. A6687
.50	1275	387/418	30°	2202	.372	.868	O.O. 470.5/14389
.50	1275	402/430	30	1712	.374	.873	O.O. 470.5/14389
.50	1275	387/402	30°	2019	.376	.877	O.O. 470.5/14389
.50	1275	388/429	30°	2050	.377	.880	O.O. 470.5/14389
.50	1275	401/415	30°	2098	.378	.882	O.O. 470.5/14389
.50	1275	387/418	30°	1798	.380	.887	O.O. 470.5/14389
.50	1275	415	30°	1746	.380	.887	O.O. 470.5/14389
.50	1275	394	30°	1957	.38	.887	A.P.G. A6041
.50	1275	388/401	30°	1989	.38	.887	A.P.G. A6227
.50	1275	388/415	30°	1880	.38	.887	A.P.G. A6612
.50	1275	402/418	30°	1995	.384	.896	O.O. 470.5/14389
.50	1275	388/415	30°	1784	.384	.896	O.O. 470.5/14389
.50	1275	415	30°	2003	.386	.901	O.O. 470.5/14389
.50	1275	388/415	30°	1975	.386	.901	O.O. 470.5/14389
.50	1275	402/418	30°	1743	.388	.905	O.O. 470.5/14389
.50	1275	388/401	30°	1697	.388	.905	O.O. 470.5/14389

Appendix B, TABLE IX (CONT'D)

Cal.	m/d³	BHN	Θ	V_L	e	e/d	Data Source
.50	1275	388	30°	1967	.39	.910	A.P.G. A6553
.50	1275	388/401	30°	2256	.39	.910	A.P.G. A6521
.50	1275	337/418	30°	1840	.390	.910	O.O. 470.5/14389
.50	1275	337/402	30°	1846	.39	.910	A.P.G. A6[illegible]78
.50	1275	338/401	30°	1785	.395	.924	O.O. 470.5/14389
.50	1275	401	30°	2017	.395	.924	O.O. 470.5/14389
[illegible]	1275	401	30°	2133	.395	.924	O.O. 470.5/14389
[illegible]	1355	3[illegible]/415	30°	2223	.24	.976	A.P.G. A6410
.30	1355	375/401	30°	2031	.24	.976	A.P.G. A6612
.30	1355	3[illegible]/401	30°	2134	.25	1.016	A.P.G. A6451
[illegible]	1355	401	30°	2411	.25	1.016	A.P.G. A6239
.30	1355	388/401	30°	2349	.25	1.016	A.P.G. A6580
[illegible]	1355	422	30°	2252	.27	1.098	A.P.G. A6767
.30	1355	3[illegible]8/401	30°	2453	.27	1.098	A.P.G. A6498
[illegible]	1355	401	30°	2136	.27	1.098	A.P.G. A6715
.30	1355	378/401	30°	2491	.27	1.098	A.P.G. A6176
.50	1275	331	30°	2373	.486	1.134	O.O. 470.5/14389
.30	1355	388	30°	25[illegible]	.28	1.138	A.P.G. A6280
.30	1355	388	30°	2559	.28	1.138	A.P.G. A6281
.30	1355	388/401	30°	2482	.28	1.138	A.P.G. A6639
.30	1355	358	30°	2375	.28	1.138	A.P.G. A6639
.30	1355	338/401	30°	2469	.28	1.138	A.P.G. A5959
.30	1355	3[illegible]3/401	30°	2[illegible]90	.28	1.138	A.P.G. A5960
.30	1355	397	30°	2370	.28	1.138	A.P.G. A6090
.30	1355	3[illegible]	30°	2589	.28	1.138	A.P.G. A6139
.30	1355	394	30°	2[illegible]50	.28	1.138	A.P.G. A6140
[illegible]	1275	[illegible]	30°	226[illegible]	.488	1.139	A.P.G. A6642
[illegible]	1275	[illegible]18	30°	2[illegible]66	.496	1.158	O.O. 470.5/14389
[illegible]	127[illegible]	[illegible]	30°	2[illegible]70	.496	1.158	O.O. 470.5/14389
[illegible]	[illegible]	[illegible]	30°	2317	[illegible]	1.167	O.O. 470.5/14389
[illegible]	12[illegible]	[illegible]	30°	[illegible]	.50[illegible]	1.176	O.O. 470.5/14389
[illegible]	1275	[illegible]	30°	2206	.504	1.176	O.O. 470.5/14389
[illegible]	1275	[illegible]	30°	232[illegible]	.506	1.181	O.O. 470.5/14389
[illegible]	127[illegible]	3[illegible]	[illegible]	245[illegible]	.50[illegible]	1.181	O.O. 470.5/14389
[illegible]	1275	[illegible]	30°	[illegible]29	.50[illegible]	1.181	O.O. 470.5/14389
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.181	O.O. 470.5/14389

Appendix B. TABLE IX (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	415	30°	2542	.506	1.190	O.O. 470.5/4634
.50	1275	401	30°	2629	.510	1.190	O.O. 470.5/4634
.50	1275	387/418	30°	2466	.510	1.190	O.O. 470.5/14389
.50	1275	388/415	30°	2605	.52	1.214	A.P.G. A6612
.30	1355	388/401	30°	2609	.30	1.220	A.P.G. A6639
.30	1355	388/401	30°	2279	.30	1.220	A.P.G. A6715
.30	1355	402/418	30°	2277	.310	1.260	O.O. 470.5/14389
.30	1355	388/401	30°	2355	.31	1.260	A.P.G. A6177
.30	1355	388/401	30°	2509	.31	1.260	A.P.G. A6179
.30	1355	388/401	30°	2563	.313	1.272	A.P.G. A5957
.30	1355	401	30°	2397	.313	1.272	A.P.G. A5982
.30	1355	415	30°	2499	.314	1.276	O.O. 470.5/14389
.30	1355	401	30°	2522	.315	1.280	A.P.G. A6722
.30	1355	415	30°	2607	.317	1.289	O.O. 470.5/14389
.30	1355	402/418	30°	2545	.318	1.293	O.O. 470.5/14389
.30	1355	401	30°	2459	.318	1.293	O.O. 470.5/14389
.30	1355	401/415	30°	2688	.318	1.293	O.O. 470.5/14389
.30	1355	401	30°	2545	.32	1.301	A.P.G. A6178
.30	1355	388/401	30°	2682	.320	1.301	O.O. 470.5/14389
.30	1355	418	30°	2311	.322	1.309	O.O. 470.5/14389
.30	1355	388	30°	2512	.324	1.317	A.P.G. A6722
.30	1355	402/418	30°	2550	.325	1.321	O.O. 470.5/14389
.30	1355	387	30°	2468	.36	1.463	A.P.G. A6616
.30	1355	402	30°	2620	.36	1.463	A.P.G. A6687
.30	1355	402	30°	2627	.36	1.463	A.P.G. A6687
.30	1355	388/401	30°	2514	.36	1.463	A.P.G. A6410
.30	1355	388/401	30°	2626	.36	1.463	A.P.G. A6045
.30	1355	401	30°	2765	.37	1.504	A.P.G. A6337
.30	1355	388/401	30°	2790	.37	1.504	A.P.G. A6701
.30	1355	387	30°	2523	.37	1.504	A.P.G. A6616
.30	1355	402	30°	2660	.37	1.504	A.P.G. A6687
.30	1355	402	30°	2599	.37	1.504	A.P.G. A6687
.30	1355	387/418	30°	2961	.372	1.512	O.O. 470.5/14389
.30	1355	402/430	30°	2715	.374	1.520	O.O. 470.5/14389
.30	1355	387/402	30°	2623	[illegible]	[illegible]	O.O. 470.5/14389

Appendix B, TABLE IX (CONT'D)

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.30	1355	401/415	30°	2761	.378	1.537	O.O. 470.5/14389
.30	1355	394	30°	3784	.38	1.545	A.P.G. A6041
.30	1355	388/401	30°	2754	.38	1.545	A.P.G. A6227
.30	1355	388/415	30°	2718	.38	1.545	A.P.G. A6612
.30	1355	402/418	30°	2735	.384	1.561	O.O. 470.5/14389
.30	1355	388/415	30°	2800	.384	1.561	O.O. 470.5/14389
.30	1355	415	30°	2848	.386	1.569	O.O. 470.5/14389
.30	1355	388/415	30°	2999	.386	1.569	O.O. 470.5/14389
.30	1355	402/418	30°	2636	.388	1.577	O.O. 470.5/14389
.30	1355	388	30°	2536	.39	1.585	A.P.G. A6553
.30	1355	388/401	30°	2888	.39	1.585	A.P.G. A6521
.30	1365	387/402	30°	2631	.39	1.585	A.P.G. A6678
.30	1355	387/418	30°	2681	.390	1.585	O.O. 470.5/14389
.	1355	388/401	30°	2509	.396	1.610	O.O. 470.5/14389
.30	1355	401	30°	2763	.396	1.610	O.O. 470.5/14389
.30	1355	401	30°	2859	.396	1.610	O.O. 470.5/14389
.30	1355	387	30°	2488	.400	1.626	O.O. 470.5/14389

Appendix B, TABLE X

Summary of Lethal Limits (V_L) of Rolled Homogeneous Armor of Hardness Greater Than BHN 425 Fired at 30° Obliquity

Cal.	m/d^3	BHN	θ	V_L	e	e/d	Data Source
.50	1275	444	30°	1862	.306	.714	O.O. 470.5/14389
.50	1275	444	30°	1870	.306	.714	O.O. 470.5/14389
.50	1275	461	30°	1760	.308	.719	O.O. 470.5/14389
.50	1275	461	30°	1638	.312	.728	O.O. 470.5/14389
.50	1275	429	30°	1462	.314	.733	O.O. 470.5/14389
.50	1275	429	30°	1799	.318	.742	O.O. 470.5/14389
.50	1275	444	30°	1763	.328	.765	O.O. 470.5/14389
.30	1355	444	30°	1970	.19	.772	A.P.G. A6538
.50	1275	444	30°	1871	.341	.796	O.O. 470.5/14389
.30	1355	415/444	30°	2052	.20	.813	A.P.G. A6097
.30	1355	415/444	30°	2066	.20	.813	A.P.G. A6097
.30	1355	415/444	30°	1848	.20	.813	A.P.G. A6442
.30	1355	415/444	30°	1905	.20	.813	A.P.G. A6442
.50	1275	429	30°	2073	.380	.887	O.O. 470.5/14389
.50	1275	444	30°	2202	.380	.887	O.O. 470.5/14389
.50	1275	444	30°	2036	.390	.910	O.O. 470.5/14389
.50	1275	415/444	30°	2459	.494	1.153	O.O. 470.5/14389
.50	1275	429	30°	2320	.496	1.158	O.O. 470.5/14389
.50	1275	429	30°	2839	.500	1.167	O.O. 470.5/14389
.50	1275	429	30°	2497	.500	1.167	O.O. 470.5/14389
.50	1275	444	30°	2613	.510	1.190	O.O. 470.5/14389
.30	1355	444	30°	2864	.306	1.244	O.O. 470.5/14389
.30	1355	444	30°	2756	.306	1.244	O.O. 470.5/14389
.30	1355	461	30°	2539	.308	1.252	O.O. 470.5/14389
.30	1355	461	30°	2725	.312	1.262	O.O. 470.5/14389
.30	1355	429	30°	2629	.314	1.276	O.O. 470.5/14389
.30	1355	429	30°	2594	.318	1.293	O.O. 470.5/14389
.30	1355	444	30°	2580	.328	1.333	O.O. 470.5/14389
.30	1355	444	30°	2782	.341	1.386	O.O. 470.5/14389
.30	1355	429	30°	2801	.380	1.545	O.O. 470.5/14389
.30	1355	444	30°	2790	.350	1.545	O.O. 470.5/14389
.30	1355	444	30°	2939	.390	1.585	O.O. 470.5/14389