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ARMOR PIERCING BULLETS WITH SINTERED CARBIDE CORES

by

J. Leeder

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Abstract

Special bullets, both caliber .30 and .50, of standard A.P. dimensions with sintered carbide cores, were investigated in firings against face-hardened and homogeneous armor plate at normal and oblique impact. Against face-hardened plate at normal impact, the carbide bullets showed far greater penetrating ability for a given energy than the corresponding standard A.P. bullets; while at obliquities the penetrating ability of the carbide bullets relative to that at normal deteriorated more rapidly than that of the standard, the carbide bullets, however, still maintaining an absolute degree of diminishing superiority up to about 30°.

It appears that the superiority of the carbide bullets against face-hardened plate is mainly attributable to the fact that the carbide cores tend to remain intact while the standard shatter during the process of penetration. Against homogeneous plate at normal impact where the factor of core failure did not play any role, the efficiencies of the carbide and standard bullet cores were identical. At obliquities, however the carbide bullets' performance became progressively inferior to that of the standard.

The sharp transition in the obliquity behavior of the carbide bullets against both face-hardened and homogeneous plate is associated with the relative weakness of these hard sintered materials to transverse impact, all cores tending to shatter or pulverize although still retaining sufficient toughness to surpass the standard bullet cores at angles up to 30° against face-hardened plate.

The phenomena exhibited by the carbide bullets show the extent to which penetrations depend upon the resistance of the projectile to breaking up. While the implications of the behavior of the projectile are known, but sometimes not fully appreciated, these experiments tend to give added emphasis to this important matter.

B. INTRODUCTION

1. Previous Tests of Special Carbide Bullets

In the Twenty-eighth Partial Report on Tests of Armor Piercing Bullets and First Report on Tests of Armor Piercing Bullets, Caliber .30 and Caliber .50 with Tungsten Carbide Cores, dated November 25, 1940, special bullets made to the dimensions of Standard A.P. bullets but with varying compositions of sintered carbide cores were tested for their armor penetrating efficiency. Firings were carried out for Watertown Arsenal according to the usual routine test procedure of the Proof Department against varying thicknesses of face hardened plate, for the most part at normal obliquity.

The data of the above tests were partially analyzed and discussed in the memorandum dated December 10, 1941 presented by Mr. Tolch and Mr. Leeder to Mr. Kent of the Ballistic Research Laboratory. It was readily shown that as a whole the bullets with sintered carbide cores were decidedly more efficient in armor penetration at normal impact than the standard small arms A.P. ammunition, the criterion of comparison being essentially the striking energy required for complete penetration.

2. Composition and Physical Properties of Carbide Bullets

The individual grades of compositions tested were basically of the tungsten carbide type (composition WC) differing principally in the type and amount of specific binding constituent employed. The composition of the carbide core materials along with some of their physical properties as furnished by Watertown Arsenal in their letter of December 14, 1940 to Aberdeen Proving Ground are presented in Table I and graphically portrayed in Plot No. 1 for the tungsten carbide base analyses. The physical properties of the latter are generally outstanding as compared to those of the hardened A.P. core steel with respect to the high density, compressive strength, and modulus of elasticity, in addition to the high hardness characteristic of intermetallic compounds. The high hardness and compressive strength, Plot No. 1, decrease rather uniformly with increasing amount of binder whereas the transverse strength increases quite rapidly at first to attain a more or less constant value at the intermediate and larger percentages of binding element. It is to be noted that the so called transverse strength was obtained in a bend test and that the values themselves are probably only of relative significance.

In general the properties of the cobalt grades are somewhat higher than the corresponding quantities for the nickel grades, with the exception of the specific gravities which are practically the same over the entire range of binder.

The physical properties of the standard A.P. steel core material are for comparison:

Hardness,	Rockwell C:	61---------------65
	Rockwell A:	81.5-------------84
Compressive	Strength, p.s.i. :	314,000-----340,000
Modulus of	Elasticity, p.s.i. :	29×10^6
	Specific Gravity = 8.00	

At 6% of binding element, Co or Ni, the compressive strength of the tungsten carbide material is over twice as great as that of the standard steel, and the density greater by almost the same factor. At the higher percentages of binder, the hardnesses of the tungsten carbide grades decrease to enter within the range customary for the standard A.P. steel core, while the densities and compressive strengths exceed the corresponding values for the steel by a multiple of about 1.6.

A composition of unusual interest in Table 1 is that of the complex carbides containing titanium and tungsten carbides, with a density approximately equal to that of the A.P. steel.

Of the carbide core materials listed, only the straight tungsten carbide types were superior to the standard A.P. stock. The results for the complex grade 1835 containing both TiC and WC were ambiguous.

3. Reasons for Further Tests

To confirm the results of these first tests particularly on the carbide cores with a low percentage of binding element that had shown the superior performance as well as to obtain additional data that might aid in defining more definitely the details of the ballistic performance of these bullets as compared with standard A.P. ammunition, further tests described in Firing Record No. 22883, A619 were undertaken. A new lot of the 1774 grade, (9%Ni-91%WC) was supplied for the major portion of the tests; other grades, however, remaining from the first series of tests were also fired to obtain more complete and corroborative information. The second series of tests differed from the first mainly in three respects: (1) particular attention was paid to recovery of bullet fragments and plate punchings, (2) the behavior of the bullets at obliquities was ascertained more fully, and (3) homogeneous plates were included in the test program in addition to face hardened.

C. ARMOR PLATE EMPLOYED IN TESTS

The available pertinent information characterizing all armor plates employed, including that of the initial investigation[1], is given below:

ARMOR PLATE EMPLOYED IN TESTS OF SPECIAL CARBIDE BULLETS

Thick.	Manufacturer	Plate Number		Brinell Hardness Face	Brinell Hardness Back	Test Series[1]	Remarks
			FACE-HARDENED PLATE				
1/4"	Disston	12	Heat 291	555 578	444 444	Second	
3/8"	Disston	3	Heat 1140	555 555	415 415	Second	
1/2"	Disston	1	Heat 1081	555 555	388 388	Second	
1/2"	Disston	5	Heat 1081	601 601	388 401	Second	
1/2"	Disston	D5		555	402	First	
1/2"	Disston	D6		555 555	364 375	First	
1/2"	Disston	D7		555 555	364 375	First	(for obli quity tes
5/8"	Diebold	138-700-344		555	415	First	
1"	Diebold	10729		not given		First	
			HOMOGENEOUS PLATE				
1/2"	Carnegie Ill.	154590 H.	Heat 15353	341		Second	
1/2"	Disston	1	Heat 1147	321		Second	(for some obliquity tests at at 30°)
5/8"	Carnegie Ill.	174947-3	Heat 17503	258		Second	

Note: 1 The tests of the Twenty-eighth Partial Report on Armor Piercing Bullets will be designated as the first series, those of Firing Record 22883, A619 and related tests as the second series. Any reference to the first test series is always designated as such.

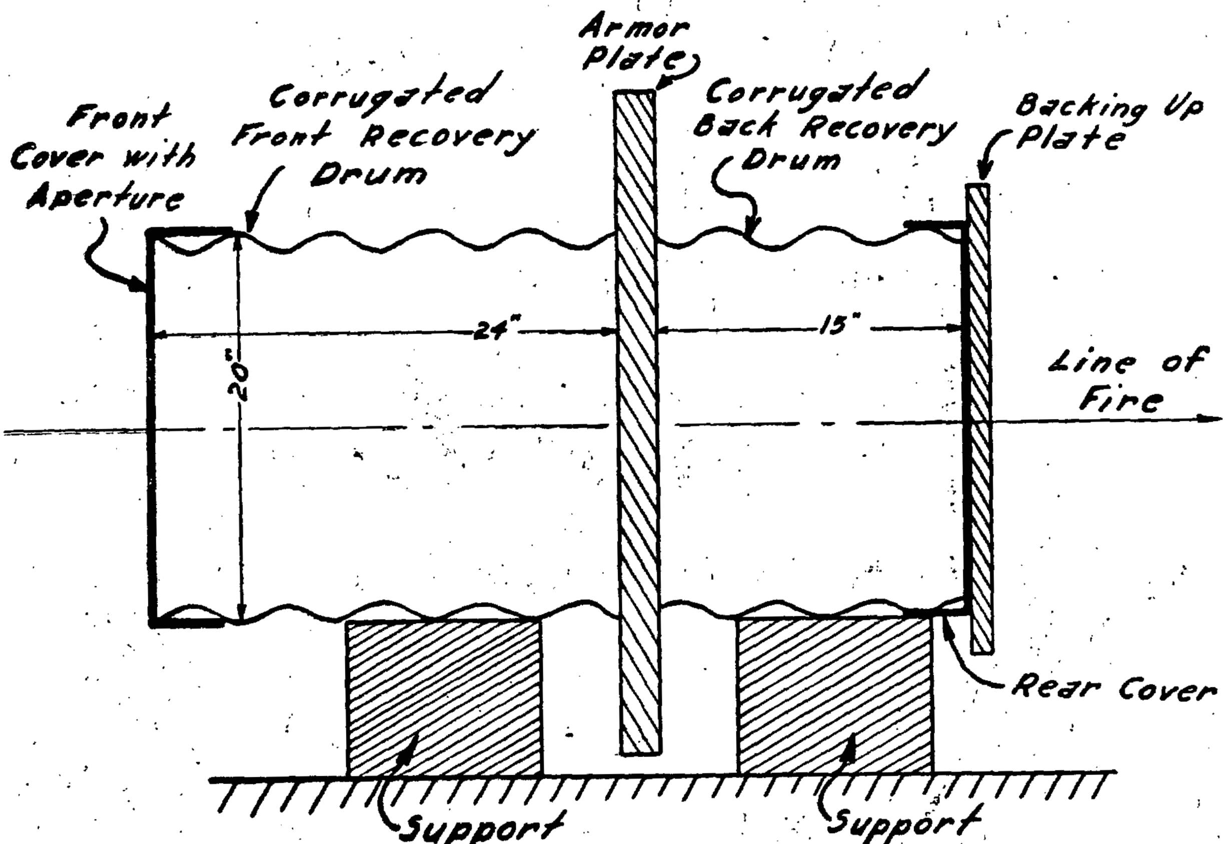
D. EXPERIMENTAL TECHNIQUE. METHOD OF TEST

The quantitative basis of comparison of all bullets involved the determinations of limiting velocities. For this the routine procedure of the Small Arms Section was followed.

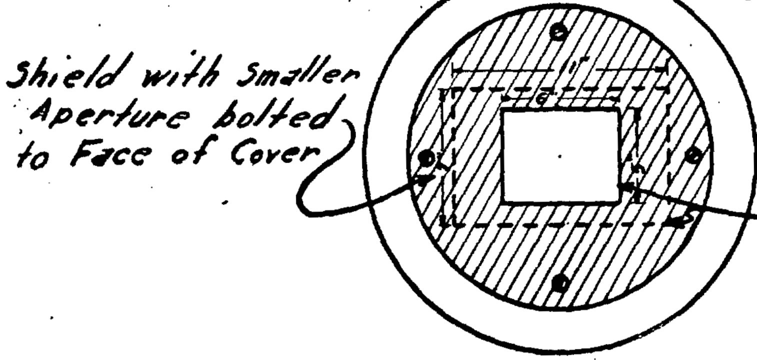
The usually laborious task of recovery of bullet fragments was considerably alleviated by the following scheme: As shown in the accompanying figure, two corrugated steel drums, obtained from standard drain pipes, were utilized, the first being set in front of the armor plate and the second in back. The second recovery drum was backed by 1/2" of armor plate to insure stopping all fragments from any bullet completely penetrating the armor plate. The possibility of course existed that a bullet core or portions thereof might pass through the armor plate and shatter on the backing up plate thereby leading to erroneous results. However, in such a case, it would appear for the most part that the impact suffered by the bullets or fragments on the backing up plate would be slight as compared with the original impact experienced on the armor plate. At all events, this type of recovery scheme for the back was the only one readily practicable at the time and gave apparently satisfactory results.

A cover with a rectangular aperture for the bullet entrance was used for the front drum and in addition a light shield with a smaller entrance aperture could be affixed to the cover to insure a greater recovery in the container of fragments rebounding from the face of the armor plate. This increase in recovery could, however, be secured only at the possible expense of bullets that might be wasted through striking the shield. Where the quantity of experimental bullets was limited, the procedure was to dispense with the shield or even the cover. In a few cases the entire front recovery drum was removed to eliminate the chance of losing a round of an experimental bullet. The recovery drums were employed up to 30 degrees angle of obliquity; at the higher angles, however, difficulty was experienced by the gunner in shooting through the foreshortened aperture and it was necessary to remove the cover entirely from the front drum thereby obtaining fewer fragments than at normal. In the future this trouble could be avoided for the case of higher angles of obliquity by truncating the drums so as to have their axes approximately along the direction of fire.

ARRANGEMENT FOR RECOVERY OF FRAGMENTS



Face View Front Cover



E. EXPERIMENTAL RESULTS

1. Introduction

The extent and emphasis of the experimental program is revealed somewhat by the outline below of the expenditure of ammunition:

EXPENDITURE OF CARBIDE BULLETS

Thick. in Inches	Type of Plate	No. of Plates	Number of rounds fired at Normal	20°	30°
			Caliber - .30 Bullets		
1/4"	[1]F.H.	1	7	5	3
3/8"	F.H.	1	5		
1/2"	F.H.	2	63	31	17
1/2"	[2]Hom.	2	13		6
5/8"	Hom.	1	4		

EXPENDITURE OF CARBIDE BULLETS IN INITIAL INVESTIGATION (TWENTY-EIGHTH PARTIAL REPORT ON ARMOR PIERCING BULLETS)

Thick. in Inches	Type of Plate	No. of Plates	Normal	20°	30°
			Caliber .30 Bullets		
1/2"	F.H.	2	80	9	5
5/8"	F.H.	1	11	3	
			Caliber .50 Bullets		
1"	F.H.	1	36		

[1] F.H. = Face-Hardened
[2] Hom. = Homogeneous

In order to simplify the presentation and discussion, ballistic data, results of recovery, and other information derived from tests of varying thicknesses and types of plates are generally separated by inclusion in different sections although all are interrelated parts of apparently a fairly simple, coherent pattern of behavior. By this necessary process of artificial selection and division into components, their degree of dependence, as well as the aspect of the whole is not continually present or always fully apparent in the report; just as a jig saw puzzle requires the interlocking of numerous sections to create a unified whole, before the correct relationship of the numerous individual members can become more firmly established.

2. Arrangement of Data

Although the actual firing results and notes on recovery are given in Firing Record No. 22883, A619, the data therin have been rearranged somewhat for more convenient presentation, and with the inclusion of a slight amount of additional information are presented in Table II. The data of the continuation of the same test program on 1/4" face-hardened and 1/2" homogeneous plates at 30° obliquity, and a 5/8" homogeneous plate at normal are also embodied in Table II. The detailed results of this table in so far as limiting velocities are concerned are summarized for the individual grades in Table III along with the calculated energy values corresponding to the striking velocity, for both the core and bullet, and the F values for the core which are considered more fully later.

3. Table III: Quantitative Presentation of Data

In Table III the grade designation and composition of the sintered carbide cores are given in columns I and II respectively. A new lot of bullets of grade 1774 (9Ni-91WC) was made particularly for these tests. To determine whether any differences existed in the bullets of the new lot and those of the same grade remaining from the first series of tests, the lots of bullets were kept distinct and the corresponding results always distinguished by separation.

The average weights in grains of the bullets, as given in Column III, were obtained from individual weighings; the average weights of the cores, however, were calculated from the known specific gravity values of the carbide material (Table I), the known specific gravity of standard A.P. core stock, and the information that the carbide cores were made to the specification dimensions of the standard caliber .30 M2, A.P. core. The specific gravity of the standard A.P. stock was taken as 8.00 from an experimental determination. An error of several per cent in the calculated weight of a core is possible due to variation in dimensions alone. One of the cores of grade 55-B (20 Co-80 WC) recovered virtually intact in round No. 22 against the 1/2" face-hardened plate No. 1. weighed about 144 grains (taking into account a slight chip that had broken off), as compared with the calculated value of 140 grains. The agreement is considered as satisfactory and any errors in analysis arising from the calculated weights of cores are held to be negligible as compared with the experimental errors of the remaining data.

The lowest complete, highest partial, and limiting velocities for each grade are given in Columns V, VI, and VII respectively. In most cases data have not been entered in all columns; thus unless there is some feature of interest in the lowest complete and highest partial velocities from which a ballistic limit has been determined, these bracketing values are omitted. Under Column VIII labelled "Designation" the word "Army" or "Navy" is given according as to whether the criterion of complete penetration employed in determining the limiting velocity is that of the Army (light through the armor plate), or the Navy (projectile through the armor plate). On many grades of bullets, particularly at normal impact, both "Army" and "Navy" ballistic limits were determined for a more complete basis of evaluation. At oblique impact no particular attempt was made to determine both limits partly because of the lack of sufficient carbide bullets, and partly due to the greate ambiguity in the determination of the Navy limit when projectile cores shatter as was the case with both the special carbide and standard A.P. bullet cores (to be discussed in more detail in later sections).

4. Use of the Navy F Formula for Analyzing Results Table III

Numerous formulae are available for analyzing the ballistic efficiency of A.P. bullets and in general these formulae suffer severe limitations in the scope of their application. The action of bullets against face-hardened plate is peculiarly troublesome from the point of view of adequate quantitative representation. In the present case wherein all the projectiles being compared have the same dimensions (and this is specially important for the core) the problem of analysi is much simplified since the factor of projectile or core diameter does not require consideration. As a consequence of this, the fundamental basis for comparing the armor penetrating efficiencies of the carbide and standard bullets or cores must essentially be the requisite striking energies for complete penetration. In addition to the striking energies which have been computed for both the core and the bullet, calculations of the Navy "F" values are also included in Table III in view of their wide use in previous Ballistic Laboratory Reports as well as in the reports of the Naval Research Laboratory. The Navy "F" formula is defined for small arms bullets in the following:

$$F = \frac{W^{1/2} V}{2.013\ t^{1/2} d} \cos.\ \theta$$

where W = weight of core in grains
d = diameter of core in inches
t = thickness of plate, inches
θ = angle of obliquity in degrees
V = limiting velocity or ballistic limit in f./s.

This sets the striking energy of the bullet proportional to the ideal volume of hole the projectile would create in passing through the plate, the variable of proportionality, F having units of energy per unit volume or pressure. With respect to the armor penetrating efficiencies of small arms projectiles, calculations are generally based upon the cores of the bullets, neglecting the jacket in so far as its contribution to penetration is concerned. From the given F formula it readily follows that for a given thickness of plat and dimensions of projectile, F^2 is proportional to the strikin energy E so that in the present report the use of F is fundamen tally equivalent to employing the striking energy as a basis of comparison of the projectiles. In Column IX of Table III, F values calculated for the cores of all projectiles are given, the lower F values being associated with the more efficient armor penetrators.

5. Average Performance of Bullets Against 1/2" Face-Hardened Plate

The firings against the 1/2" face-hardened plates were the most comprehensive in number and detail. In addition to the standard, 9 grades of carbide bullets were investigated, including three of the Co-WC type (with 9-20% Co as binder), four of the Ni-WC type (with 6-20% Ni as binder), one of the Fe-WC type (9% Fe as binder), and one of a multiple carbide variety, Co-TiC-WC (15% Co as binder). The average performance of the specific types of bullets against 1/2" face-hardened plate as well as the grand average for all straight tungsten carbide bullets with the standard deviations of all average values are presented in Table IV.

6. Arrangement of Data from First Series of Tests

In the first group of tests, caliber .30 carbide bullets were tested against 1/2" and 5/8" face-hardened plate. The results for these tests excluding that for the types which proved unsatisfactory or for which the data was too erratic, namely grades 1835, X1839, 874A, and X1812TC1, are given in Table III-B of Appendix A with a summary in Table IV-B The presentation of the data therein is similar to that for Tables III and IV to facilitate ready comparison. To re-iterate, where reference is made to any information acquired in this initial research, explicit mention is made of the fact.

7. Average Penetrating Efficiencies of Carbide and Standard Bullets as Determined from All Available Data

From all the available firings against face-hardened and homogeneous plate, a summary of the relative armor penetrating efficiencies at normal impact of standard A.P. bullets, and bullets with sintered carbide cores based on the average performance of all satisfactory grades is shown in Table V and Plot No. 2. Although in the latter the data for 1/4" and 3/8" face-hardened plate were obtained from a less complete set of firings than for the other thicknesses, the results are adequate in indicating the general trend for the survey.

The average F values for the caliber .30 tungsten carbide and standard A.P. bullet cores against face-hardened plate are portrayed as a function of thickness in Plot No. 3. All data for this plot have been taken from the second group of tests, Tables III and IV, with the exception of the results for the 5/8" plate from Table III-B of the first test group. The dotted lines represent the performance of standard caliber .30 A. P. bullets against homogeneous plate with high and low Brinell hardnesses as indicated. The reason for the inclusion of these curves will be discussed in a subsequent section.

F. - I. DISCUSSION OF BALLISTIC RESULTS FACE-HARDENED PLATE, NORMAL IMPACT

1. 1/2" Face-hardened Plate, Normal Impact Ballistic Results Caliber .30 Bullets

The large amount of data for most of the different carbide compositions from both the first and second series of tests in the firings against 1/2" face-hardened plate permits an evaluation of the influence of type and amount of binding constituent on the armor penetrating efficiencies of the carbide cores, and an estimate of the degree of reproducibility of results.

The F values of the carbide bullets for normal impact against 1/2" face-hardened plate as taken from Table III-B, Appendix A, for the first test series, and Table III for the second test series have been represented in Plots No. 4 and 5 as a function of the per cent of binding constituent for each type composition. In each series two face-hardened plates were used and the indication from the choice of the plates (of the same manufacturer and heat) as well as the ballistic limits determined with standard ammunition was that the plates for each series were for practically purposes the same. However the two Disston face-hardened plates employed in the second test series showed with standard .30 M2, A.P. ammunition an average

F value (for the core) of 72000 as compared with 66250 for the two Disston plates of the first series; or based upon energy of the core required for penetration, the former plates required approximately 20% more energy than the latter, which is a significant amount.

1. - a. Detailed Consideration of Results of Initial Investigation

Considering the first series of tests, the F values for the carbide cores with nickel binder are not significantly different from those for the cores with cobalt as binding element. The one sample with 9% iron as binder had within experimental limits practically the same F value as the cobalt and nickel types with the same percentage of binder. This fact in conjunction with the fairly close agreement between the nickel and cobalt series would indicate that the exact nature of the binding constituent is of secondary importance in so far as the penetrating properties of the straight tungsten carbide cores at normal impact are concerned. Moreover, the exact percentage of binder up to about 20% does not appear to be of consequence for penetration at normal. Those compositions with 25% binder were clearly inferior in performance and therefore are not discussed further.

From Table V it follows that the average F for the satisfactory tungsten carbide bullets against the 1/2" face-hardened plate was 8% less than that for the standard .30 M2, A.P. bullets, or, expressed otherwise, the carbide cores required approximately 15% less energy to penetrate the given armor plate than the standard .30 M2, A.P. core. As mentioned previously, calculations based upon the cores of bullets are of significance in determining the relative armor penetrating efficiencies of small arms ammunition. With respect to other factors, such as the powder charge required, consideration of the bullet as a whole is desirable. Therefore, in Table V the relative performance of the carbide and standard bullets as a whole are given, basing the analysis on the striking energies of the respective bullets for complete penetration. This method of comparison rates the bullets with heavy carbide cores even higher inasmuch as the heavy cores constitute a a greater proportion of weight of the entire bullet than is the case with the standard steel cores; and therefore a smaller proportion of energy of the bullet is contained in the ineffectual jacket.

1. - b. Detailed Consideration of Results of Second Test Series

While the differences in penetrating efficiencies of the carbide and standard cores as found in the first series of tests are significant but not particularly startling except in the demand for an adequate explanation, the second group of tests gave rise to differences of a much greater order of magnitude. From Plot No. 5 it follows that the F values for the carbide cores were for all but one grade (that with 13% Ni) appreciably lower than the corresponding values for the same grades in the first test series, (see Plot No. 4), while with standard A.P. ammunition as mentioned on page 15, the 1/2" face-hardened plates employed in the second test series had a greater F value than that of the plates in the first test group. This combination of factors resulted in a greatly increased comparative efficiency rating for the carbide bullets.

Comparing the different grades, the F values for the nickel and cobalt types are practically the same at 9 and 20% binder. At 13% binder, however, departing from the agreement found in the previous tests, the F for the nickel grade is approximately 11% higher than that for the cobalt grade. While the features of fragmentation are to be discussed at length in later sections it may be mentioned here that the cause of this difference as well as the dispersion in results is probably to be attributed to fracture of the bullet cores as dependent upon the complex circumstances reigning at the time of impact. Taken as a whole no significant differences are found between the values for the cobalt and the nickel grades. Likewise confirming the evidence of the first group of tests, the penetration of the bullets at normal against 1/2" face-hardened plate is not influenced to any appreciable extent by the percentage of binding element, nickel or cobalt, in the range from 9 to 20% binder. The value for the 9% iron bearing grade is well within the general limits for the nickel and cobalt grades thus indicating that with respect to penetration at normal, iron is as effective a binding element as nickel or cobalt. With regard to the manufacturing process in reproducing compositions no differences were found in the results for the old and new lots of grade 1774 (9 Ni-91 WC).

Grade 1835 with titanium and tungsten carbides and 15% cobalt as binder is, as noted previously, of particular interest in view of its having approximately the same density as that of the 3% tungsten, standard A.P. steel core stock. The F value for this complex type is also shown on Plot No. 5. In the initial investigation two lots of this grade were tested with an ambiguous outcome; one lot giving an F value 60,800, which agreed fairly closely with that found in the second test series, and the other giving the much higher F value of 71,800. From the recorded observations of the first test series, and the bullet recovery of the second test group, it appeared likely that this disparity could be ascribed to the intrinsic irregular nature of the fragmentation of the bullet cores; grade 1835 apparently possessing a stronger proclivity toward breaking up than the others. The dispersion in the results for the firings of all grades is too large, and the number of samples of this composition tested too few, to determine precisely its relative status. For the purposes of this report however, the available evidence is conclusive in proving that with the weights of cores equal, the armor penetration of the carbide core against face-hardened plate was for the most part superior to that of the standard; from Table IV the F value of grade 1835 was 14% lower than that for the standard A.P. core, or based upon energy, the complex carbide core required approximately 25% less energy for complete penetration of the 1/2" face-hardened plate than the standard.

1. - c. Summary of Conclusions Concerning Influence of Composition of Carbide Bullets from Results at Normal Impact on 1/2" Face-Hardened Plate

Any attempt at comparing the results of the two series of tests is rendered difficult by, first the natural dispersion arising frequently when bullet or core failure occurs, and secondly by the difference in ballistic quality of the 1/2" face-hardened plates employed in the two groups of tests. The features that are considered of most consequence, however, have been proved with a reasonable degree of engineering accuracy, namely, to reiterate:

(1) The tungsten carbide cores with 6 to 20% of binding element are superior to the standard A.P. cores in their penetrating efficiency agains 1/2" face-hardened plate.

(2) Nickel, cobalt, and iron (as indicated from the one grade tested) are equally effective as binding elements for the tungsten carbide.

(3) The exact percentage of binding constituent in the range from 6 to 20% is not of first order importance.

(4) The explanation for the superior penetrating ability of the carbide bullet cores is not attributable to their greater sectional density than the standard A.P. core; the results for the complex grade 1835 with approximately the same weight of core as the standard necessitates the consideration of other physical properties or characteristics for the solution of the predominantly greater efficiency of the carbide bullets. As will be shown in later sections, the question of the breaking up of the bullet cores seems to be of paramount importance.

2. <u>1/4" and 3/8" Face-Hardened Plate, Normal Impact Ballistic Results, Caliber .30 Bullets</u>

In order to obtain the action of the tungsten carbide bullets against face-hardened plate as a function of thickness, and observe the behavior of the bullets as dependent upon velocity, several additional face-hardened plates were fired in addition to the comprehensive 1/2" face-hardened experiments. Since the latter had indicated that the exact percentage and nature of binding constituent was of secondary importance for normal impact against face-hardened plate, the results obtained with the more limited number of tests at other thicknesses are believed to be fairly reliable in representing the general behavior of the carbide bullets as a whole.

In the second series of tests, 1/4" and 3/8" face-hardened plates were investigated, grade 1774 (9 Ni-91 WC) being employed against the former, and grade 1830 (13 Ni-87 WC) against the latter. The superior performance of the carbide bullets against these plates was even more marked than against the 1/2" face-hardened. For the 1/4" thickness a low enough velocity could not be readily attained to give a partial penetration and therefore enable the determination of a ballistic limit. With this plate, from Table V, the F value for the carbide core was less than .6 that of the standard, and the carbide core required less than .4 of the energy of the standard core for complete penetration.

3. <u>5/8" Face-Hardened Plate, Normal Impact Ballistic Results, Caliber .30 Bullets</u>

In the first group of tests, 5/8" face-hardened plate was investigated with the straight tungsten carbide grade cores, 779 and 1774, containing 9% cobalt and nickel respectively as binding elements. The results for both grades were practically identical thus indicating that for thicknesses of face-hardened plate up to at least 5/8", cobalt and nickel are equally effective as binders with tungsten carbide.

4. <u>Comparison of Results Obtained in First Group of Tests for Tungsten-Carbide Bullets against 1/2" Face-Hardened Plate with General Average Performance</u>

From Plot No. 2 graphically portraying the average performance of the caliber .30 tungsten carbide bullets relative to the standard, it appears that the values in the second test series for 1/2" face-hardened plate may be more representative than those of the initial investigation. The smooth curves that may be drawn through the points for the 1/4", 3/8", and 1/2" plates of the second test series and that for the 5/8" plate of the first series may be a coincidence but on engineering principles some such orderly relationship is probably to be expected, and the results for the 1/2" plate of the first test series depart considerably from the possible relationship among the remaining values (practically a straight line in the case of the F points).

5. 1" Face-Hardened Plate, Normal Impact Ballistic Results, Caliber .50 Bullets

Caliber .50 bullets of the straight tungsten carbide type with nickel and cobalt as binding elements were employed in the first group of tests against 1" face-hardened plates with the results given in Tables III-B and IV-B of Appendix A and graphically illustrated in Plot No. 6. From this set of data, it appears that in confirmation of the previous remarks about the caliber .30 tungsten carbide bullets, nickel and cobalt were equally effective as binders, at least for penetration at normal impact. However, in the case of the caliber .50 bullets, F appeared to increase slowly with increasing percentage of binding constituent. The lowest and therefore the optimum values of F were attained with 6% binder. The average F of the carbide cores was .91 times that of the standard. To institute a comparison of the average penetrating efficiency of the caliber .50 tungsten carbide bullets with that of the caliber .30, the average F value for the caliber .30 bullets was interpolated from Plot No. 2 for an equal ratio of $\frac{t}{d}$ as that obtaining for the caliber .50 bullets against 1" plate with the results as given below:

t = thickness of armor plate
d = diameter of bullet core

Bullet Design	t	d	t/d	Ratio F of Carbide Core / F of Standard Core
.50 M1	1.00"	.428"	2.34	.91
.30 M2	.57"	.245"	2.34	.85

The F values agree fairly closely and this may be of some significance in indicating the order of magnitude of results that could be obtained with caliber .50 carbide bullets.

F. - II. DISCUSSION OF BALLISTIC RESULTS FACE-HARDENED PLATE, OBLIQUE IMPACT CALIBER .30 BULLETS

In the initial investigation only a limited amount of experimentation had been conducted at obliquities; grade 44A (6 Co-94 WC) had been fired at normal, 20°, and 30° against 1/2" face-hardened plate, and grade 779 (9 Ni-91 WC) had been fired at normal and 20° at 5/8" face-hardened plate. The tests were inadequate in number to permit of a reliable estimate of the obliquity characteristics of the carbide bullets, and therefore one of the major objectives in the following series of tests was to gain a more thorough representation. The results of the foregoing are summarized in Table III, and Plot No. 7, No. 8, and No. 9.

1. <u>1/4" Face-Hardened Plate, Obliquity Performance</u>

One grade of the carbide bullets, 1774 (9 Ni-91 WC) was investigated at obliquities of 20° and 30°, the results being graphically shown in Plot No. 7. From the slopes of the F curves of the standard and carbide bullets, it readily follows that the penetrating efficiency of the carbide bullets at oblique impact becomes <u>relatively poorer</u> (i.e. relative to its normal value) than that of the standard; the <u>absolute</u> superiority of the carbide grade, however, is still maintained up to angles of 30° at least. Thus the ratio of the F value of the carbide core to that of the standard increases from .61 or less at normal to .89 at 30°, the latter figure continuing to denote a substantial superiority of the carbide grade.

2. <u>1/2" Face-Hardened Plate, Obliquity Performance</u>

The most extensive series of tests were conducted against the 1/2" face-hardened plate, the results for the different grades being illustrated in Plot No. 8. The increasing spread in F values as the angle of obliquity increases from normal to 30° is apparent. Inasmuch as later sections on recovery of fragments show that at oblique impact all carbide cores shattered, or rather pulverized as distinguished from the behavior at normal, according to past experience large dispersions in the experimentally determined ballistic limits are to be expected as a consequence of the irregular or non-uniform factors influencing the process of fracture. The writer believes that probably the major portion of the variation in results of the carbide grades at obliquity is attributable to features of an accidental nature rather than to inherent differences in the characteristics of the carbide grades. Because of this factor of fragmentation or the associated dispersion mitigating against more precise results, no detailed attempt is made to classify grades or compositions for obliquity performance. The apparent superiority of grade 55-A (13 Co-87 WC) is noted for normal and 20°; at 30°, however, only partial penetrations could be secured. The grades with 13 and 20% nickel showed the poorest performance of all at 20°, the only angle of obliquity at which tests were carried out for these grades, the penetrating efficiency being less than that for the standard. The 9% nickel grade had a low F value at 20°, and the lowest of the group at 30°. The tests evidence that, as with the 1/4" face-hardened plate, the carbide bullet cores at obliquities become relatively poorer penetrators than the standard A.P. In general, however, the absolute superior performance of the carbide cores is maintained up to angles of at least 20°. No complete penetrations could be obtained at 30° with the standard bullets against 1/2" face-hardened plate and therefore a comparison is not possible although the inference from Plot No. 8 is that at this angle, the standard core might surpass the carbide ones; but it is to be noted that with respect to the bullets as a whole, some of the carbide bullets still maintained an appreciable greater efficiency as a consequence of the more favorable weight distribution between core and jacket.

G. RECOVERY OF BULLET FRAGMENTS AND PLATE PUNCHINGS CALIBER .30 FIRINGS, FACE-HARDENED PLATE

1. Presentation of Illustrations

In the second series of tests particular efforts were directed toward the recovery of bullet fragments and plate punchings, the means utilized having been discussed in the section on Experimental Apparatus. The detailed observations on the recovery are noted in Table II wherein the amount of projectile core recovered intact from the base or nose section is indicated in appropriate columns. Some representative photographs of the results of the recovery program, and the types of holes produced by both the carbide and standard cores are presented in the Plate Series, P 1 - P 22, the illustrations for fragment recovery and armor plate corresponding generally to the same rounds. The notation accompanying each illustration has been made complete for a ready appraisal and convenience in reference to Table II. The figures are numbered consecutively for each thickness and type of plate. Complete penetrations are shown from the face and back views of the armor plate. The bullet fragments have been segregated according as to whether they were recovered in the front recovery drum from the face of the plate, or in the rear drum from the back of the plate, with no effort made to separate jacket or plate material from that of the bullet cores. All illustrations of armor plate and fragments are approximately actual size; in the case of the armor plate series, some variations in the scale exist and in addition because of the distortion present in the pictures (areas of armor plate were photographed on 8" x 10" film and the resulting prints cut up for the individual illustrations) accurate measurements are not feasible.

In order to bring out more sharply some aspects of the penetrations in the armor plate, resort was had to the artifice of painting the sides of many of the holes with white paint, and sometimes in placing screens behind the plate to increase the contrast by making the holes themselves photograph dark. A judicious use of such schemes can with somewhat more practice serve admirably to delineate and reveal desired features that might otherwise remain obscured under the practical conditions existing at the time of photography.

2. <u>1/4" Face-Hardened Plate, Normal Impact</u>

The appearances of the penetrations of the standard and the carbide bullets against the 1/4" face-hardened plate, Figure 1, 2 of Plate 1, were quite similar with no gross distinguishing characteristics in shape or dimensions discernible. The recovered fragments of the bullets and the plate punchings, however, revealed well marked differences for the carbide and standard bullets. The results tabulated in Table II showed that the standard cores were breaking up to a greater extent at normal impact than the carbide cores, approximately 3/8" to 1/2" of the bases of the carbide cores remaining intact while the standard cores were breaking up into smaller fragments. Figures 1 - 4 of Plate 13 demonstrate these points, Figure 3 having a substantial portion of the carbide core intact in the partially intact jacket.

The punchings from the standard bullets were approximately cylindrical slugs in shape (The curved surface is to be noted in Figure 1) having roughly a diameter of about 1/4" and a length equal to that of the thickness of armor plate. The punchings from the carbide bullets were smaller in length with less distortion of the sides. The most significant difference, however, is not readily perceptible from Figures 2 and 4 of Plate 13 portraying an end on view of the punchings from the bullet entrance side, the intention being to exhibit the clearly defined impression of the tip of the carbide core, Figure 4, lacking in the case of the punching for the standard, Figure 2. From the accompanying sketches, delineating the general features of the punchings discussed, and the bullet reeovery results, the inference

<u>Sketches of Punchings from Carbide and Standard A.P. Caliber .30 Bullets 1/4" F.H. Plate</u>

Standard, Rd. 4

Tungsten Carbide, Rd. 7

is that the standard cores were shattering in the early stages of penetration on the face-hardened plate, whereas the carbide cores if breaking up, were doing so at a later stage when the process of penetration had been about completely effected; the latter point being indicated by the fact that the tip of the carbide core had practically reached the back surface of the armor plate before the punching was ejected from the rear. This behavior of the carbide and standard cores at normal impact with respect to fragmentation and the aspects of the types of punchings produced proved to be characteristic in the firings against the thicker face-hardened plates as well, with an additional dissimilarity in the appearance of the penetrations.

3. <u>1/4" Face-Hardened Plate, Oblique Impact</u>

For all cases of oblique impact (20° and greater), against both face-hardened and homogeneous plate of the thicknesses included in this investigation, the recovery results denoted clearly a sharp transition in the behavior of the carbide cores on impact; whereas at normal a substantial fraction of the average carbide core remained intact, at obliquities all carbide cores were recovered broken up into fairly coarse fragments (in sizes 1/16" - 3/16") for 20° obliquity, or in a completely pulverized state (particles mostly less than 1/16" in size) for some 20° and all 30° angles of obliquity. The standard bullet cores broke up at all angles of obliquity against the face-hardened plates. Figures 5 and 6 of Plate 14 illustrate the recovery for 20° firings. The penetrations of both the carbide and standard bullets at obliquities against the 1/4" plate were irregular in character (Plates 1 and 2).

4. <u>3/8" Face-Hardened Plate, Normal Impact</u>

The perforations of the 3/8" face-hardened plate by the standard and carbide bullets at normal impact (Figures 1, 3 of Plate 3) displayed distinct differences which were further accentuated in the 1/2" face-hardened plates to be described in the following section, and there shown to be characteristic.

The entrance hole for a complete penetration made by a standard bullet was larger than that made by a carbide core, the former always being greater in diameter than that of the bullet core, the latter in general somewhat less than the diameter of the bullet core (due to the elastic contraction of the plate about the hole after the core has passed through or been removed). The notes on recovery for the 3/8" firings, which were less complete than those of the others in that the back recovery drum was omitted, showed that the standard bullet cores were breaking up or shattering while the carbide cores were breaking up to a lesser degree, up to 1/2" of the base being recovered intact. The punchings from the carbide bullets were typical with respect to the clearly defined penetrations of the carbide cores while the one punching recovered from the standard bullet, Round 5, was peculiar in that there was a clean bored hole within the punching; according to the included sketches.

<u>Sketches of Punchings from Carbide
and Standard A.P. Caliber .30 Bullets
3/8" F.H. Plate</u>

Standard, Rd. 5

Tungsten Carbide, Rd. 8

5. <u>1/2" Face-Hardened Plate Normal Impact</u>

The firings against the 1/2" face-hardened plates were the most extensive in number and appropriate pains were taken to secure a detailed representation of the behavior of of the various **grades** of carbide bullets as well as the standard The appearances of some of the penetrations are given in Plates 4 - 8 and the results on recovery in Plates 15 - 21.

The trend shown in the 3/8" thickness of face-hardened plate has now become very pronounced; the holes made by the standard bullets are generally irregular in shape and appreciably greater in diameter than the core (Plate 4); whereas the perforations made by the carbide bullets (represented in some detail for all grades in Plates 5 - 7) are similar in showing a rather symetrical conical surface with a cleanly formed entrance hole of slightly smaller diameter than that of the core, at the front surface, and an exit hole of approximately 1/2" in diameter at the back surface.

The punchings obtained (Plates 15 - 18) possess to an accentuated degree the distinguishing characteristics of those from the previously discussed thinner face-hardened plates. While the punching from a standard bullet may be a cylindrical slu (Figure 4, Plate 15) as in the samples from the 1/4" face-hardened plate, or a punching from within a larger punching (Figure 2, Plate 15) as in the one example for the 3/8" face-hardened plate, the punchings from the carbide bullets are nearly all alike in having a maximum diameter at the base, corresponding to the rear surface of the armor plate, of about 1/2" and a well defined penetration of the core extending to the base or rear surface (e.g. Figures 9 - 11, Plate 17). Figure 9 and included sketch exemplify practically an ideal punching of the carbide type. Figure 10 is noteworthy in por-

Sketch of Ideal Punching from Caliber .30 Carbide Bullet

1/2" Face-Hardened Plate

Round 23, Plate I

traying the punching from a round wherein the carbide core remained completely intact. The appearances of the penetration (Figure 6, Plate 5) and punching from this round are similar to those of the other carbide firings and constitute an excellent example of the ballistic behavior of high quality face-hardened plate to bullet cores that remain intact.

The general notes in Table II on the recovery of bullet fragments show that the standard cores were breaking up or shattering at normal (Figures 1 and 2, Plate 15) and the carbide cores were breaking up much less, usually about 1/2" - 5/8" sections of their base and smaller portions of the nose remaining intact (e.g. Figures 9 and 11 of Plate 17).

Some exceptions to this general behavior, however, were noted and require an explanation. Thus in Figure 3 of Plate 15, a standard bullet core is shown intact to the same extent as that of many of the carbide cores. But in this case for the standard, the round gave good penetration, being in fact a Navy Complete, with the appearance of the penetration corresponding to the carbide type, so that no contradiction to the thesis of the influence of the fragmenting of the bullet cores results. Further exceptions are noted for those carbide cores, which were in the minority, recovered as badly broken up or shattered as the standard, or even worse (Rounds 38, 51, and 71 against Plate No. 5 illustrated in Figures 12, 13, and 16 of Plates 17 and 18). Round 71 is of special importance as being the firing of the complex carbide grade 1835 with the same density as that of the standard A.P. steel. The perforations produced, however, by these rounds (Figures 7, 8, and 11 of Plates 6 and 7) are those of the carbide type, that for grade 1835, Figure 11, being fairly typical. Round 38 for grade 1695 was a very high velocity Navy Complete to see the effect of increasing the velocity of carbide bullets several hundred f/s beyond that required for complete penetration. Considering all of the features pertaining to the above carbide rounds that shattered at normal and any others, the following pertinent facts are assembled about the usual example of such:

(a) The appearance of the penetration in the armor plate is similar to that for the firing in which the carbide core remained wholly intact (Round 22, Figure 6 of Plate 5)

(b) The appearance of the punching is characteristic of that resulting when the core is known to have remained intact (Round 22, Figure 10 of Plate 17)

(c) The ballistic results agree reasonably well with other rounds wherein the cores are known to have remained mostly intact (as the firings for grade 55-B)

and the resulting deduction is made that the above carbide cores although recovered in the shattered condition must have remained substantially intact for the major portion of the process of penetration in contradistinction to the case for the standard A.P. cores which shatter in the earlier stages.

5. - a. Comparison of Results of Carbide Bullets against Face-Hardened and Homogeneous Plate

Further evidence of an indirect nature is available concerning the action of the carbide bullets against face-hardened plate from the dependence of the average F values of the caliber .30 bullet cores as a function of thickness, Plot No. 3; the average values for the standard bullets against the same face-hardened plate being also included for comparison. Anticipating the results for homogeneous plate, it may be mentioned that under these conditions where the troublesome circumstances of core failure were practically entirely absent for all bullets, the penetrating efficiencies, or F values, for all the carbide and standard bullet cores were identical. On Plot No. 3 the F values for a series of homogeneous plates of high and low Brinell hardnesses have been denoted in the dotted lines to obtain representative limits of performance, the data being taken from the set of comprehensive firings of Carnegie Illinois, embodied in Firing Record No. 20702, A301, January 6 - 21, 1941. In asmuch as the F values for the carbide and standard cores are the same against homogeneous plate, the indication from Plot No. 4 is that from a qualitative and even semi-quantitative aspect the ballistic behavior of the carbide bullet cores against face-hardened plate approximates that of either the standard or carbide cores against homogeneous plate. Also for additional corroboration, the average F value for the caliber .50 tungsten carbide bullet cores fired against 1" face-hardened plate (F = 55,200 from Table IV-B) closely approximates that obtained with standard caliber .50 cores against hard homogeneous plate. These results seem indeed reasonable: that face-hardened plate of good quality, with a face hardened layer that will not spall, should so act in penetration by bullets that remain intact roughly the same as if it were homogeneous plate of the same analysis and hardness as that of the body proper; taking into account the fact that in the face-hardened plate the face layers are so hard as to be inferior to the body of the plate with respect to ballistic resistance.

5. - b. Dissipation of Energy by a Projectile that Shatters

The greater energy required for complete penetration by a projectile that shatters in the initial stage of impact as compared with one that remains intact is assignable to possibly several causes: (a) the energy expended in the shattering or breaking up of the projectile itself, (b) as a result of the shattering, the dispersal of the application of the striking forces over an increased surface area of the armor plate, thus necessitating the ejection of a larger punching (or increased volume of armor plate material) than would have been the case had the projectile stayed intact; the increased work demanded probably bearing some relation to the increment in area of the sheared surfaces of the punching, (c) the relatively inefficient shape of the fragments for armor piercing, and (d) possibly an effect associated with the impact strength of materials as being dependent upon the rate of application of force; some of the current hypotheses, verified partially by experimental evidence, affirming that above certain rates of application of forces (of magnitudes readily attained under the conditions of armor plate firing) the impact resistance of many materials including steel decreases sharply, so that in a situation wherein the projectile initially shatters the rate of application of forces is considerably reduced thereby favoring the impact strength of the armor plate.

All the available experimental evidence indicates then that the appreciable difference in penetrating efficiencies of the standard and carbide bullet cores against face-hardened plate is attributable to the basic factor of premature core failure in the action of the standard. That sectional density probably does not play a role, as might be readily assumed, may be inferred from the results for the complex carbide grade, 1835 with the same weight of core as the standard.

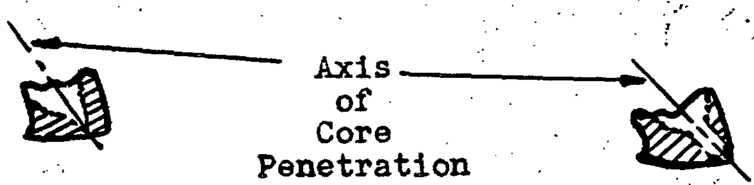
5. - c. Correlation of Ballistic Results for Carbide Bullets with Fragment Recovery

As is evident from the results of recovery, with the exception of a few rounds the carbide cores probably did not remain intact throughout the entire process of penetration, and it would appear therefore that the differences found in the results for the various grades as well as the dispersion or erratic behavior encountered in some rounds are to be ascribed to the breaking up of the carbide cores. The exact stage at which fracture occurred and other details of the action of any given carbide bullet are of course quite impossible to determine fully although the nature of the punching produced and the recovered fragments may furnish important clues. In general, detailed consideration of the features of fragmentation of the carbide bullets from the experimental data available cannot lead to a completely straightforward explanation of the observed differences.

The penetrating efficiencies for the cobalt series follow reasonably closely the state of the recovered cores, the compositions with 13 and 20% cobalt, which possessed the lowest F values of all carbide cores, having a large fraction of an average core remaining intact (the core found completely intact was from the 20% grade). The punchings from the above series and the internal penetrations of the core appeared well formed with no abnormal features. Similarly no serious discrepancies are found in the other firings except those for the 13% nickel grade and the complex grade, 1835 both of which had a rather high F values with a normal amount of intact recovery. A possible explanation for these is advanced on the indicative features of their punchings, the internal penetrations in both cases showing 20° or larger yaw from the normal to what corresponds to the rear surface of the armor plate, as in the accompanying sketches.

<u>Sketches of Punchings from Carbide</u>
<u>and Standard A.P. Caliber .30 Bullets</u>
<u>1/2" F.H. Plate</u>

Lowest Complete Penetrations,
Illustrating Yaw of Bullets in Plate



Grade 1830A, 13%Ni
Round 55, Plate V

Complex Grade 1835
Round 71, Plate V

This interpretation does not account for any of the other rounds for these two grades with high F values and no further attempt is made to do so, the complexity of the actions involved in the penetrations of projectiles that break up making any thorough evaluation too difficult and not very convincing. For engineering reasons the 13% nickel compositions should not be inferior to the 6 or 20% ones so that the spread in F values for the respective cores probably is some measure of the dispersion in results that may arise due to variations in the precise conditions of test as well as in the manufacture of the bullets, although tests of the two lots of grade 1774 (9 Ni-91 WC demonstrated a remarkably close agreement in behavior.

6. <u>1/2" Face-Hardened Plate, Oblique Impact</u>

At all angles of obliquity, the standard and carbide bullet cores broke up or pulverized (Plates 19 - 21) as in the obliquity firings against the 1/4" face-hardened plate. For the 20° firings, from the appearances of the holes produced in the armor plate (Plates 7 - 10) and the nature of the punchings, a rather reasonable explanation of the penetrating efficiencies of the cores in Plot No. 8 may be advanced in that there is a fairly close degree of correlation between the size of the perforations produced and the penetrating efficiencies of the cores, the larger holes and punchings being associated with the least efficient penetrators. The data from Plot No. 8 and the pertinent information from the photographs have been tabulated below:

ROUGH CORRELATION OF SIZE OF PERFORATION AND PUNCHING WITH NAVY F VALUE FOR CARBIDE AND STANDARD BULLET CORES AT 20° OBLIQUITY

Grade	F Value	Size Hole, Punching	Illustrations Armor Plate		Illustrations Punching	
Most Efficient Penetrators, Lowest F Values						
			Fig.	Plate	Fig.	Plat
55A(13Co)	60,600	small	14	8	20	19
1774(9Ni)	66,000	very small	16	9	23	20
Least Efficient Penetrators, Highest F Values						
Standard	78,500	large	12,13	7,8	18,19	19
1830A(13Ni)	83,500	large	17	9	24	20
1831A(20Ni)	85,300	large	17	9		
Results for Which Relationship Does Not Hold						
1695(6Ni)	76,600	small	16	9	22	20
55B(20Co)	67,700	fairly large	15	8	21	20

The correlation in the above table is qualitatively fairly satisfactory with the exception of the two results noted.

At 20° the general absolute superior penetrating efficiency of most of the carbide core bullets is attributed to the fact that although at this angle all cores are recovered shattered or pulverized, the carbide cores showing the best performance remained substantially intact during the greater part of the act of penetration whereas, in contrast, the carbide and standard cores with the poorest performance shattered soon after impact. These statements are inferred from the character of the resulting punchings: the punchings for the cores with the poorest performance, e.g. Figures 18 and 24 of Plates 19 and 20, were slugs with very little penetration of the cores showing therein; while in the punchings from the carbide cores with the best performance, the cores penetrated a considerable distance, e.g. Figure 20 of Plate 19.

At 30° obliquity complete penetrations were obtained with the 9% nickel and 20% cobalt, tungsten-carbide bullets; partial penetrations resulting for the 6% nickel and 13% cobalt grades as shown graphically in Plot No. 8. All cores were recovered pulverized (Plate 21); and concerning the appearanc of the armor plate, the perforations are illustrated in Plate 10. One of the punchings, Figure 26 of Plate 21, indicated very little penetration of the core before fracture occurred; from the other, Figure 28 of Plate 21, no definite conclusions appeared warranted.

7. Correlation of Ballistic Results and Fragment Recovery with Physical Properties of Carbide Bullet Cores

In view of what has been stated concerning dispersion as evidenced in the case of normal impact by the lack of agreement in the relative status of the grades from the ballistic data of the two series of tests, and in the case of oblique impact by the anomalous results of the firings at 30° obliquity against 1/2" homogeneous plates (to be discussed in later sections as well as in several examples pertaining to face-hardened plate; any classification of the various grades with respect to general ballistic efficiency would be insufficiently clear cut and controvertible. Accordingly, beyond the proof of a negative nature expressed previously that sectional density per se cannot account for the prevailing greater efficiency of the carbide bullets against face-hardened plate, no correlation of the physical properties of the carbide core materials, as given in Table I and Plot I, with the complete results of the investigations seems apparent, and any extended analysis could scarcely be very profitable. If, for example, with regard to the obliquity firings, the relative transverse strength of the carbide materials be considered as indicative of the resistance to transverse impact and therefore a possible influence in the action at oblique firings, the high F values for the 13 and 20% Ni grades at 20° are unexplainable, evidently inasmuch as they possess approximately the same transverse strength as the 9% Ni grade with one of the lowest F values at this angle.

Further speculation on this score is not offered other than the writer's belief that the major factor in the carbide cores' behavior distinguishing them from the standard in firings up to about 30° or less against face-hardened plate is their greater resistance to the impact forces during the principal part of the process of penetration, and that this high resistance to normal impact may possibly be associated with their high compressive strength. As the correlation of impact properties of metals at high velocities with statically determined physical properties is relatively in an embryonic state, the above hypothesis is advanced as a conjecture without much basis.

H. ANALYSIS OF DIFFERENCES IN RESULTS AS DETERMINED FROM "ARMY" AND "NAVY" BALLISTIC LIMITS

In sections concerning the ballistic results on face-hardened plates at normal impace, the analysis centered on the efficiencies of penetration based upon limiting velocities determined in accordance with the Army criterion of a complete penetration, and the question arises as to what degree would the comparison of the bullets have to be modified were the Navy criterion of complete penetration employed. From Table III, the data bearing on the relationship between the "Army" and "Navy" results have been outlined below. Some results for obliquity firings are also included where this was found incidentally in the course of the investigations, no particular effort being directed toward this end in view of the difficulty experienced in determining Navy limiting velocities at obliquities when projectiles break up or shatter.

COMPARISON OF RESULTS DETERMINED FROM ARMY AND NAVY CRITERIA OF COMPLETE PENETRATION (from Table III) FACE-HARDENED PLATE

Grade	Angle of Obliquity	"Army" Limit Velocity f/s	"Army" F	$V_{Navy}-V_{Army}$[1] f/s	$F_{Navy}-F_{Army}$
		Thickness 1/4"			
Standard	N	2119	78200	87	3400
1774	N	949 (partial)	>47500	>349	>17500
		Thickness 1/2"			
Standard	N	2755 (Average of two tests)	72000	0	0
779	N	1652	58300	45	1700
55A	N	1522	53000	141	4800
55B	N	1607	54600	98	3200
55B	30°	2623	77000	45	1500
1695	20°	2275	76600	24	900
1774	N	1641	58000	121 (approx.)	4200 (approx.)
	20°	1991	66000	>44	>1600
1830A	N	1749	61000	0	0
1831A	N	1605	54800	0	0
1816	N	1574 (partial)	<55000	>30	>500

Note:

[1] Subscripts "Army" or "Navy" denote which criterion of penetration is employed.

For the 1/4" plate the data are too meager to warrant any conclusions other than that the large differences for the carbide grade can possibly be attributed to the effect of the jacket at these low velocities. In the 1/2" thickness both "Army" and "Navy" results are experimentally identical for the standard bullets and two of the carbide type; for the remaining carbide bullets, the greatest difference between the "Army" and "Navy" F values was on the order of 10% and the average about 6%. The explanation for the generally close agreement, identical in many instances, in striking velocities required for an "Army" or "Navy" complete penetration against face-hardened plate, (in contrast to that against homogeneous) is readily apparent from the examinations of the armor plate and punchings. In obtaining an "Army" complete penetration with a standard bullet, a cylindrical slug of greater diameter than the bullet core (due to breaking up of the core) is expelled from the plate thus leaving a hole through which the core material can pass to make also a "Navy" complete penetration. With respect to the carbide grade bullets, the character of the punchings, showing the internal penetrations of the cores, was discussed in some detail in pages 24-25 . Numerous examples of punchings (some of them illustrated, but not with sufficient clarity in the photographs) were found in which the carbide core had penetrated just to the rear surface, thus making a pin hole in the back of the armor plate and therefore an "Army" complete penetration before the punching was sheared from the plate. The cores of the carbide bullets, however, were hindered somewhat in passing through the armor plate after the punching by possibly forces of a restraining and destructive nature: the armor plate in the immediate vicinity of the entrance hole is constricted by elastic reaction about the bullet core and therefore additional work, which should be slight, is required to complete passage through the armor plate due to the frictional forces; furthermore, if the bullet strikes with slight additional yaw, the core may be broken by the bending forces encountered at the sides of the restricted entrance hole, thus accounting for the large number of sections from the base found in front of the plate. The circumstances affecting the course of the above actions are complex and unpredictable, the data given furnishing an indication as to the limits in behavior that may be expected.

From the results described in this section it would follow that the comparison of the carbide and standard bullets based on "Navy" ballistic limits would deviate quantitatively slightly in that the measure of supremacy of the average performance of the carbide cores would be slightly less than that derived from the "Army" ballistic limits.

I. DISCUSSION OF BALLISTIC RESULTS, CALIBER .30 FIRINGS, HOMOGENEOUS PLATE

In order to obtain an analysis of the relative performance of the carbide and standard cores under conditions wherein core failure would play little if any role, and thereby that the influence of sectional density and possibly other factors dependent upon the physical properties of the core materials might be ascertained, firings against homogeneous plate were included in the second series of tests. The plates tested, of thicknesses 1/2" and 5/8", were chosen from a group of Carnegie Illinois homogeneous armor plates of a given composition type with varying Brinell hardnesses attained by drawing at different temperatures. As stated previously, a comprehensive series of results for the behavior of the entire related group with standard ammunition at normal and obliquities was available from Firing Record No. 20703, A301, January 6-21, 1941.

1. 1/2" Homogeneous Plate, Normal Impact Ballistic Results, Caliber .30 Bullets

The 1/2" homogeneous plate selected for test was of medium Brinell hardness, 341. Two carbide grades were investigated, 1774 (9Ni-91WC), and 1835 (15Co-39TiC-46WC), the former being among the densest of the carbide core materials tested, density 14.57, and the latter among the lightest, having approximately the same density as that of the standard A.P. core stock. The results in Table III show conclusively that well within the experimental errors the F values for both grades of carbide bullets are identical with that for the standard A.P. core. The F values herein discussed were based upon the "Army" limiting velocities. Consideration of the F values based upon the "Navy" limit is hampered somewhat by lack of a sufficiently well defined "Navy" ballistic limit for the carbide bullets due to limitation of ammunition. However, the indication from the data is that the F value for the carbide core, grade 1774, would be practically the same as that for the standard A.P. core, as was indeed found to be the case for firings against the 5/8" homogeneous plate.

2. 1/2" Homogeneous Plate, Oblique Impact Ballistic Results, Caliber .30 Bullets

The oblique performance of the carbide cores against the 1/2" homogeneous plate was determined for grade 1774 (9Ni-91WC) at 30°. Unfortunately the firings on the 1/2" Carnegie Illinois plate had to be discontinued before a ballistic limit could be attained. In the ensuing interval before the tests were resumed, the 1/2" Carnegie plate was removed. A Disston 1/2" homogeneous plate of Brinell hardness 321, and having approximately the ballistic limits with standard ammunition at normal and 30° was selected for the completion of the obliquity tests. With the few carbide bullets remaining a complete penetration was not quite obtained and therefore an estimate based upon the results of the incomplete tests of both plates was made. From Plot No. 9, it follows that the penetrating efficiency of the carbide bullets tested against homogeneous armor plate at obliquities becomes inferior to that of the standard.

3. 5/8" Homogeneous Plate, Normal Impact Ballistic Results, Caliber .30 Bullets

The 5/8" plate obtained from the related group of Carnegie Illinois plate, was the softest of the series having a Brinell hardness of only 258. One carbide grade, 1830 (13Ni-87WC) was employed for the tests. The results from Table II show that again well within the experimental error the energies or F values for the core are identical to the corresponding quantities for the standard core when calculated according to either the "Army" or "Navy" limiting velocities. Of course, if the energies corresponding to the mass of the entire bullet are considered, the standard bullet is less efficient than the tungsten-carbide requiring 1.3 times the energy of the carbide bullet for complete penetration in view of the greater proportion of its energy being dissipated in the ineffective (for armor penetration) jacket material, as pointed out previously on page 15 .

J. RECOVERY OF BULLET FRAGMENTS CALIBER .30 FIRINGS, HOMOGENEOUS PLATE

1. 1/2" Homogeneous Plate, Normal Impact

As expected, in no cases for normal impact was shattering of any of the cores found. Generally the cores of the two grades of carbide bullets were recovered broken approximately in two, the base section falling in front of the plate, and the nose remaining intact, usually in the plate, at the velocities employed. Two of the standard cores behaved in a similar manner while four with a higher striking velocity remained completely intact. Typical examples are illustrated in Figures 1, 2, and 3 of Plate 22.

Observations at the time of test— as stated previously, the plate was removed before further tests at obliquities and illustrations could be secured—revealed no important differences in the character of the perforations produced by the standard or carbide bullets.

As opposed to the case with face-hardened plate, no punchings were formed from the relatively soft homogeneous plate, the process of penetration being essentially of a piercing character with the armor plate possessing sufficient ductility to yield by plastic flow to the bullet cores.

2. 5/8" Homogeneous Plate, Normal Impact

The recovery results were similar to those found for the 1/2" homogeneous plate, the projectile cores remaining either intact or breaking in two with the nose intact in the plate. The appearances of the penetrations in the armor plate are illustrated in Plates 11 and 12. The only difference in the perforations produced by the carbide cores of grade 1830 (13Co-87WC) and the standard, was the slight impression on the face of the armor plate concentric to the entrance hole in the case of the standard. This is undoubtedly due to the impact of the jacket material which had a greater energy in the standard bullets than in the slower and heavier carbide bullets. With respect to the other features of the penetrations such as the flow of metal as revealed from the back, Plate 12, no significant variations could be detected.

For both homogeneous plates, therefore, the inference from the essential similarity in appearances of all perforations, and the complete agreement in F values for standard and carbide cores is that the breaking of the carbide cores in two did not affect adversely the armor penetrating efficiency of these bullets; or expressed otherwise, against homogeneous plates of low and medium Brinell hardnesses at normal impact, both standard and carbide cores remained intact for the greater part of the process of penetration.

3. 1/2" Homogeneous Plate, Oblique Impact

At 30° obliquity, the carbide cores of grade 1774 (9Ni-91WC) were recovered in a pulverized state, as shown in Figure 4 of plate 22, in confirmity with the previously prooved weakness of these cores to transverse impact. Although no standard shots were fired at this obliquity, the results being available from previous firings, it can reasonably be assumed on the basis of numerous tests of the same nature that the standard bullet cores broke up, but did not pulverize. The superiority of the standard cores at obliquities against homogeneous plate is, of course, to be ascribed to the latter fact.

CONCLUSIONS

The superior penetrating efficiency of the carbide bullets against face-hardened armor plate is due to the important feature that in the process of penetration, the carbide bullet cores tend to remain intact, whereas the standard tend to shatter initially. These results corroborate the well known fact that in face-hardened plate, the primary purpose of the face-hardened layer is to shatter an armor piercing projectile in the initial stages of impact; and that when it fails to perform this task, the resulting ballistic resistance of the plate is inferior to that of best quality homogeneous armor.

For homogeneous plate the results are conclusive in indicating that for small arms projectiles the sectional density of the core per se has no influence upon the armor penetrating efficiency thereof; and the extension of this significant implication to projectiles of the major caliber type appears reasonable.

Apart from the economic factors involved, carbide bullets for practical use suffer at the present time severe limitations that are associated with their relative weakness to transverse impact. Thus, for use against aircraft, in which application the airplane skin or covering customarily imparts an appreciable yaw to the perforating bullets, these carbide bullets would probably be unsuitable in view of the poor penetrations that could be expected from them with large striking yaws.

RECOMMENDATIONS

If the advantages to be gained from the characteristic behavior of carbide bullets against face-hardened plate prove to be of importance for any specific applications, further experimentation on practical and academic grounds would be warranted on other metallic carbides and intermetallic compounds that might be economically preferable to tungsten-carbide.

ACKNOWLEDGEMENT

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J. Leeder

J. Leeder

TABLE I

Composition and Physical Properties of Tungsten Carbide Core Material of Experimental Bullets

Grade	Comp. %			Hardness Rock.A	Specific Gravity	Strength Trans. $x10^3$ p.s.i.	Strength Comp. $x10^3$ p.s.i.	Modulus of Elasticity $x10^6$ p.s.i.
	Co	WC						
44A	6	94		90.7	14.85	215	730	84.5
779	9	91		90.0	14.60	300	685	—
55A	13	87		88.0	14.15	325	613	79.0
55B	20	80		86.0	13.50	350	557	--
DM25	25	75		83.5	13.10	300	-	--
	Ni	WC						
1695	6	94		91.5	15.00	185	-	
1774	9	91		89.5	14.57	250	654	--
1830A	13	87		88.0	14.21	243	557	--
1831A	20	80		83.5	13.64	252	475	--
1832A	25	75		81.5	13.25	300	-	--
	Fe	WC						
1816	9	91		91.9	14.20	170	-	--
	Co	TiC	WC					
1835	15	39	46	91.0	8.0	168		
X1839	30	70	—	89.5	5.6	200		
	Ni	W						
874A	5	95		33.5 Rc	18.2	140		
X1812TC1	15	85		40.0 Rc	16.4	125		

Table II

List of Abbreviations Employed

P.	Partial (penetration)
C.	Complete (penetration)
Dia. Pen.	Diameter penetration
Pun. S.	Punching started
S. B.	Slight bulge
M. B.	Medium bulge
L. B.	Large bulge
C.I.P.	Core in Plate
P.T.P.	Passed through Plate
int.	Intact
F. S.	Face spall

A. = Army type complete penetration
N. = Navy type complete penetration
cd.= Diameter of penetration at face of plate is equal to or slightly less than that of the standard caliber .30 M2, A.P. core (.245")

Remarks

1. Under "Results on Plate", the diameters of the penetrations at the face and back of the armor plate are entered in the appropriate columns. To conserve space, any additional remarks concerning the results on the armor plate are made in the same columns Estimated values of yaw refer to the yaw of the projectile hole in the armor plate.

2. Under "Results on Projectile" the attempt is generally made to separate the remarks on the nose and the base sections through inclusion in the appropriate columns. In many cases, however, the amount of space is inadequate and overlapping is necessary. Fragments recovered in front of the plate are noted besides the letter F. while those recovered from the back are noted besides the letter B.

3. In the column under "Striking Velocity", one asterisk sign is used to indicate both the lowest complete and highest partial velocities employed in determining the "Army" type ballistic limit, while double asterisk signs are used to indicate the corresponding velocities for the "Navy" type ballistic limit.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Back	Nose	Base
Primary Sample. Disston Plate No. 12 Heat 291 Thick. 1/4" Face Hardened. Brinell: F555-578, B. 444-444										
1	Standard 30M2			N	2053*	V.S.P.	Went thru recovery drum		F. Broke up 1/4" body recovered	
2	"			N	2181*	C	Tip C.I.P.	P.T.P. 3/16"x1/4"	F. Broke up ~3/16" B. 5/16" int.	body recovered
3	"			N	2206**	C	cd.	3/16"x1/4"	F. Broke up. Several fragments 1/8" recov. B. (clean punching of plate)	
4	"			N	2206**	Navy C	cd.	5/16"x1/4"	F. Portions of jacket. B. 1/4" base int. Several fragments ~3/16" (clean punching of plate)	
5	1774 (new lot)	1	238	N	1298**	C		5/16"x3/8"	F. B. 1/8" fragments	3/8" int.
6	"	2	237.5	N	1246	C		1/4"x5/16"	F. Several small fragments	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen.: Face	Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
				Disston F. H. Plate No. 12. Heat 291. Thick. 1/4" (Cont'd.)						
7	1774 (new lot)	3	236.5	N	1148	C	cd.	1/4" x 5/16"	F. B. 1/8" fragments Punching	7/16" int.
8	1774 (new lot)	5	237.	N	1086	C	cd.	1/4"x5/16"	F. B. 1/4" int.	3/8" int.
9	1774 (new lot)	6	237.	N	1031	C	cd.	1/4"x1/4"	F. B. few small fragments Punching	5/16" int. in jacket
10	1774 (new lot)	7	237.	N	949*	C	cd.	1/4"x1/4"	F. B. few small fragments. Punching	7/16" int. in jacket
11	1774 (new lot)	8	237.	N	821	Missed Plate				
12	1774 (new lot)	10	237.	20°	1062	P			F. 5/16" int. Rest core broke in fair sized fragments	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
				Disston F. H. Plate No. 12. Heat 291. Thick. 1/4" (Cont'd.)						
13	1774 (new lot)	11	237.5	20°	1173.	P			F. Broke up into small fragments	
14	1774	9	236.5	20°	1253*	C	C.I.P.	3/16"x1/4"	F. Broke up into numerous small fragments. B. Few small fragments	
15	1774	12	238.	20°	1210*	P	slight bulge		F. Broke up into few few fragments 3/16" and pulverized	

Table II [illegible] and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	[illegible] of Obl.	[illegible]	Result on Plate: Pen.	Dim. of Pen.: [illegible]	Dim. of Pen.: [illegible]ck	Result on Projectile: Nose	Result on Projectile: [illegible]se
				Disston R. H. Plate No. [illegible], Heat 291, Thick. 1/4" (cont'd)						
16	Standard 30M2			20°	2461	C.	Hit bulge in front container and then plate 1/4"x1/4"	5/16"x3/8"	F. Poor recovery. Pulverized material B. Poor recovery, few small fragments (complete punching)	
17	"			20°	2525	C	Went thru front container and then plate 1/4"x1/4"	1/4"x5/16"	F. Poor recovery, pulverized material. B. Poor recovery, few small fragments.	
18	"			20°	2314*	C.		1/4"x5/16"	F. Pulverized material, 1/4" int. B. Few small fragments, complete punching.	
19	"			20°	[illegible]66*	P			F. Broke up into small fragments ~1/8", and pulverized material	
20	1774 (old lot)	9	2355	20°	1199	P	Medium bulge		F. Broke up into few small fragments ~1/8", and pulverized material.	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	[illegible]	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Dim. of Pen. [illegible]		Nose	Base
							Diam.	Thick		
	Disston F. H. Plate No. [illegible], Heat 291, Thick. 1/4" (Cont'd)									
21	Standard 30M2			30°	2505*	C		3/16"x3/16"	F. Shattered B.	
22	"			30°	2480	P	Slight bulge		F. Shattered	
23	"			30°	2481*	P	Slight bulge		F. Shattered	
24	Standard (warm up round)			30°	2713	C		5/16"x3/8"	P.T.P.	
25	1774 (new lot)	42	236.5	30°	1601*	P	Depth	Pen.3/16"	No recovery attempted	
26	"	43	236.5	30°	1780	C		1/4"x7/16"	No recovery attempted	
27	"	44	238	30°	1694*	C		1/4"x5/16"	No recovery attempted.	
	Disston Plate No. 3, Heat 1140, Thick. 3/8"									
	Face Hardened F. 555-555, B. 415-415									
1	Standard .30M2, A.P.			N	2306	P	S.B.		F.	Fair amount of shattered material
2	"	"		N	2335	P	C.I.P. Pun. S.		F.	Fair amount of shattered material
3	"	"		N	2357	P	S.B. Little C.I.P.	of nose	F.	Fragment of base int. Remainder proj. shattered.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen.: Face	Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
	Disston F. H. Plate No. 3, Heat 1140, Thick. 3/8" (Cont'd)									
4	Standard .30M2, A.P.			N	2374*	P			F. Shattered.	
5	"	"		N	2386*	C	1/4"x3/8"	3/8"x1/2"	F. P.T.P. and Shattered probably. punching	1/4" int.
6	1830	16	232.5		1248	Missed plate				
7	1830	17	233		1311	C	1/4"x1/4"	5/16"x3/8"	F. Remainder P.T.P. and shattered	1/2" int.
8	1830	18	234.5		1232	C	cd.		F. nose P.T.P. and shattered. Punching	3/8" int.
9	1830	23	234		1234	P	C.I.P. Pun.	S.	F. Remainder broke up	1/4" fragments of base int.
10	1830	24	239.5		1231*	C	cd.	5/16"x3/8"	F. 1/4" near nose int. No recovery drum. Punching.	
11	1831-A	19	226.5		1214*	P	No. B 1/4"x1/4"	1/4"x3/8"	No recovery attempted..	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	[illegible]	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
	Disston Plate No. 1, Heat 1081, Thick. 1/2"									
	Primary Sample. Face Hardened. Brinell F.555-555 B. 388-388									
1	Standard .30M2			N	3175	C	1/2"x7/16"	1/2"x9/16"	F. Numerous fragments. 1/8" ~ 1/4" nose int. B. Small amount of pulverized material. large punching	
2	"			N	2555	P			F.	3/16" int. Remainder core broke into small fragments and shattered.
3	"			N	2695	P	Pun. S.		F. Numerous small fragments 1/16" - 1/8" and coarse pulverized material	
4	779	4	234.5	N	1748	Navy C	cd.	1/2"x9/16"	F. Jacket material and few fragments B. 3/8" int.	3/8" int. large punching
5	779	5	235	N	1482	P	C.I.P. Pun. S.		F. nose int. in plate	5/8" int.
6	779	6	233.5	N	1622*	P	C.I.P. Pun. S.		F. Nose int. in plate	9/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
						Disston F. H. Plate No. 1. Heat 1081. Thick. 1/2" (Cont'd.)				
7	779	7	236.5	N	1712**	Navy C	1/2"x1/2"	1/2"x1/2"	F. Jacket material and small amount pulverized material B. 1/4" section near nose Int. Punching	9/16" int.
8	779	9	234.5	N	1681*	C Navy P	C.I.P. cd.	3/8"x7/16"	F. Small amount of pulverized material B. Numerous fragments ~1/16" Punching with tip of nose in it.	
9	Standard .30M2			N	2793**	Navy C	1/4"x1/4"	7/16"x7/16"	F. Small amount of pulverized material B. 5/16" section near nose Int. Punching	9/16" int.
10	Standard .30M2			N	2778**	P both A. and N.	C.I.P., Slight bulge		F. Numerous fragments	1/4" sliver intact small 1/16" - 1/[illegible]
11	779	Not marked	236.5	N	1770	Navy C	cd.	7/16"x1/2"	F. Fair amount of pulverized material B. 1/4" body int.	7/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Core No.	Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile: Nose	Base
Disston F. H. Plate No. 1, Heat 1081, Thick. 1/2" (Cont'd.)										
12	55A	1	231.	N	1803	Navy C	cd.	7/16"x1/2"	F. Small amount of pulverized material B. 1/8" tip int. Excellent punching	1/2" int.
13	55A	2 on boat tail	230.5	N	1662**	Navy C	cd.	7/16"x7/16"	F. Numerous small fragments B. 6 fragments 1/8" - 3/16" from base region. Tip of nose in punching.	
14	55A	2 on base	230.5	N	1663**	C	C.I.P.	1/4"x1/2"	F. B. Several small fragments. Partial punching.	5/8" int.
15	55A	3 on boat tail	228.5	N	1535*	C	C.I.P. cd.	1/4"x5/16"	F. B. Tip int. In punching	5/8" int.
16	55A	4 on boat tail	230.5	N	1462	P	C.I.P. Pun. started. Yaw about 20° Depth Pen.=1/4"		F. Destroyed	9/16" int.
17	55A	5 on boat tail	232.5	N	1460	P	Before striking plate passed thru shield of drum.		F.	1/2" int.
18	55A	6 on boat tail	232.	N	1464	P	C.I.P Large bulge Depth Pen.=3/8"		F. int. in plate	5/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Stk. Vel.	Result on Plate Pen.	Result on Plate Diam. of Pen. Face	Result on Plate Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
	Disston F. H. Plate No. 1, Heat 1081, Thick. 1/2" (Cont'd.)									
19	55A	7 on boat tail	231.	N	1515	P	Before striking plate passed thru shield of drum C.I.P. Large bulge pun. started		F. int. in plate	11/16" int.
20	55A	3 on boat tail	230	N	1509*	P	Slight bulge Yaw about 15° Depth Pen.=7/16"		F. destroyed	5/8" int.
21	55B	1	225.5	N	1741	C	cd.	1/2"x1/2"	F. B. Point destroyed 3/8" remainder int. Excellent Punching	1/2" int.
22	55B	2	226.5	N	1736**	Navy	cd.	7/16"x1/2"	B. Projectile intact. Punching	
23	55B	2X	223.5	N	1673**	C	C.I.P.	1/2"x1/2"	F. B. 1/2" complete nose int. Complete punching	9/16" int.
24	55B	3	223.5	N	1568	P	C.I.P. Pun. S		F. int. in plate	7/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
				Disston F. H. Plate No. 1. Heat 1081. Thick. 1/2" (Cont'd.)						
25	55B	4	224.	N	1590*	P.	C.I.P., Pun. S.		F.	3/4" int.
26	55B	6	221.5	N	1623*	C	C.I.P.,	3/8"x7/16"	F. B. Fragments of nose, tip broken. Punching	1/2" int. in plate
27	1774 (new lot)	13	237.5	N	1637	P	Passed through shield of recovery drum. Hit plate with large yaw.		F. Pulverized	
28	1774 (new lot)	14	236	N	1771**	C	C.I.P., 1/4"x5/16"	5/16"x7/16"	F. B. Several fragments 3/16" Punching	7/16" int.
29	1774 (new lot)	15	236	N	1713	C	C.I.P., 1/4"x5/16"	5/16"x7/16"	F. B. Tip destroyed. ~ 3/16" fragments. Punching.	9/16" int.
30	1774	16	237.5	N	1634*	P	C.I.P., Pun. S.		F. Nose int. In plate	1/2" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Str. Vel. f.s.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Dim. of Pen.		Nose	Base
							Face	Back		
Disston F. H. Plate No. 1, Heat 1081, Thick. 1/2" (Cont'd.)										
31	1774 (new lot)	17	238.	N	1657*	C	Hit wood on yaw frame	3/8"x1/2"	F. B. Tip nose punching, remainder 5/16" int.	1/2" int.
32	Standard .30M2			20°	2954	P	Hit on edge of recovery drum, and hit in previous impact.		F. Pulverized. One fragment ~1/8"	
33	Standard .30 M2			20°	2956	P			F. Pulverized. One fragment ~1/8"	
34	Standard .30M2			20°	3150**	P both A. and N.	Slight bulge		F. Broke up small fragments ~1/16" and pulverized material.	
35	Standard .30M2			20°	3213	Navy C	7/16"x7/16"	7/16"x7/16"	F. Fair amount of pulverized material B. Punching	3/8" int.
36	Standard .30M2			20°	3185**	C both A and N.	7/16"x1/2"	7/16"x1/2"	F. Fair amount of pulverized material B. Destroyed	7/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
Disston F. H. Plate No. 1, Heat 1081, Thick. 1/2" (Cont'd.)										
37	55A	4 on base	231.	20°	1783	P	C.I.P., M.B. F.S. ≈ 1/2"x1/2"		F. Broke into small fragments ~ 1/16" and pulverized	
38	55A	5 on base	231.	20°	1854*	P	C.I.P.		F. Large amount pulverized	
39	55A	4 on boat tail	233.	20°	1860*	C	C.I.P. (Hit on front of recovery drum before striking plate)	1/4"x5/16"	F. Large amount pulverized B. 1/8" tip int. Few small fragments. Small punching	
40	55A	1 on boat tail	231.	20°	1929	P	Little S.B.	C.I.P., F.S. ≈ 1/2"x15/16"	F. Few fragments 1/16" - 1/8". Large amount pulverized	
41	55A	9 on base	232	20°	1924	C	C.I.P.	1/4"x5/16"	F. 3/8" nose int. in plate Remainder pulverized	3/16" int.
42	55B	6	223	20°	2010	P			F. Remainder pulverized and coarse fragments. B. Portion of punching.	1/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
			Disston F. H. Plate No. 1. Heat 1081, Thick. 1/2" (Cont'd.)							
43	55B	4X	225	20°	2070	P		S. B.	F. 3/8" int. Remainder coarse fragments, 1/16"-1/8" and pulverized	
44	55B	7	226.5	20°	2111*	P			F. Very tip shattered, 1/8" remainder int. Shattered.	
45	55B	7X	223.5	20°	2153*	C	F.S. = 5/16"x9/16"	1/2"x3/4" 3/8"x9/16"	F. Shattered fragments B. 1/8" tip int. Remainder nose shattered. Punching	
46	Standard .30M2			30°	3214	P	Pun. S		F. Shattered	
47	55A	12	231.	30°	2203	P	S.B.		F. Pulverized	
48	55A	11	229	30°	2402	P	Pun. S		F. Pulverized	
49	55A	13	232	30°	2448	P	S.B.		F. Pulverized	
50	55A	14	232	30°	Lost	P	S.B.		F. Pulverized	
51	55A	15	229.5	30°	2681*	P	S.B.		F. Shattered	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Core No.	Wt. Grns.	Angle of Obliq.	Vel. f.s.	Result on Plate: Pen.	Dim. of Pen.: Face	Back	Result on Projectile: Nose	Base
	Disston F. H. Plate No. [illegible] Heat 1081. Thick. 1/2" (Cont'd.)									
52	55-B	8	224	30°	[illegible]**	Navy C	F.S.=7/16"x7/8" 1/2"x13/16"	3/8"x5/8"	F. Shattered material. B. Large amount pulverized material. Punching.	
53	55-B	9	223	30°	2649**	C both F. and B.	5/16"x[illegible]/16"	5/16"x3/8"	F. B. Small amount pulverized material. Punching.	Broke up in front of plate
54	55-B	10	223.5	30°	2596*	P			F. Pulverized	
55	55-A	16	230	30°	2678*	P	F.B. Pun. S.		F. Pulverized	
	Disston Plate No. [illegible] Heat 1081 Thick. 1/2"									
	Primary Sample, Face Hardened. Brinell F. 601-601, B. 401-388									
1	Standard .30M2			30°	3197	P			F. Pulverized	
2	1695	1	240.5	30°	2543	P	F.B.		F. Pulverized	
3	1695	3	242	30°	2579	P	F.B. Depth	Pen.3/16"	F. Pulverized	
4	1695	5	241	30°	2607	P	Depth	Pen. 3/16"	F. Pulverized	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Result on Plate: Diam. of Pen.: Face	Result on Plate: Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)										
5	1774 (new lot)	18	237	30°	2633	C	F.S.= cd.	3/8"x5/8" 1/4"x3/8"	F. Shattered fragments. pulverized material, portion punching	
6	1774 (new lot)	19	235.5	30°	2539*	C Hit recovery drum		5/16"x7/16"	F. Pulverized material. B. Pulverized material. Punching	
7	1774 (new lot)	20	237	30°	2489	P.	S.B.		F. Pulverized	
8	1774 (new lot)	22	238	30°	2536*	P.	S.B. Depth	Pen.=1/8"	F. Pulverized	
9	1774 (new lot)	23	234.5	30°	2574	P.	Depth	Pen.=3/16"	F. Pulverized	
10	1774	24	236.5	20°	2035*	C	C.I.P., 1/4"x1/4"	F.S.=1" 3/16"x5/16"	F. Shattered material. portion front punching B. 1/8" of tip int. Small amount of pulverized material. Small punching	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Result on Plate: Diam. of Pen.: Face	Result on Plate: Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
		Disston F. H. Plate No. 5, Heat 1081, Thick. 1/2" (Cont'd.)								
11	1774 (new lot)	25	235.	20°	2008	P.	S.B. Hit recovery drum		F. Pulverized	
12	1774 (new lot)	26	236.5	20°	1967*	P.	C.I.P., Depth	S.B. Pen.= 3/16"	F. Pulverized	
13	1774 (new lot)	27	237.5	20°	2008	P.	F.S.= 3/8" x13/16"	S.B. Hit shield on recov-ery drum	F. Pulverized	
14	Standard 30M2			20°	3193*	P.	S.B. Depth	Pen.= 3/16"	F. Pulverized	
15	Standard 30M2			20°	3210*	C	7/16"x9/16"	7/16"x9/16	F. Pulverized B. 3/16" tip int. Fair sized fragments from nose probably. Large Punching	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen.		Nose	Base
							Face	Back		
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Continued)										
16	1695	6	241	20°	2252*	P.			F. Pulverized	
17	1695	7	241	20°	2297**	C. both A. and N.	F. Imp. 1/2"x5/8"	3/8"x3/8" Hit recovery drum	F. Pulverized B. Smaller amount pulverized material. Divided Punching	
18	1695	8	241	20°	2297**	C. both A. and N.	F. Imp. 3/4"x3/4"	5/16"x3/8"	F. Shattered B. Pulverized material. Punching	
19	1830-A	1	232.5	20°	2231	P.			F. 3/16" tip int. Shattered. portions of F. 8.	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)									
20	1830-A	3	230.5	20°	2345	P.	Hit on edge previous round		F. Shattered. numerous fragments of plate	
21	1830-A	4	234.	20°	2397	P.			F. Pulverized. portions F. S.	
22	1830-A	5	233.	20°	2448	P.			F. 1/8" tip almost int. Shattered.	
23	1830-A	6	231.5	20°	2566*	C.	F. Imp. 9/16"x9/16"	3/8"x1/2"	F. Pulverized B. Shattered Large Punching	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)										
24	1830-A	7	232.5	20°	2521*	P.	S. B.		F. Shattered.	
25	1831-A	7	225.5	20°	2603	P.	Pun. S.		F. Shattered.	
26	1831-A	2	227.	20°	2666*	C.	F. Imp. 9/16"x3/4"	3/8"x1/2"	F. Pulverized, large amount B. Shattered. Large Punching	
27	1831-A	5	227.5	20°	2632*	P.	Pun. S.		F. Shattered.	
28	1816	13	234	20°	2567	Navy C.	F. Imp. 5/8"x5/8"	7/16"x7/16"	F. Shattered. B. Fair amount pulverized material Punching Medium Size	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen.: Face	Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
				Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)						
29	1816	14	233	20°	2522	Navy C.	F. imp. 1/2"x1/2"	7/16"x1/2"	F. Fair amount of pulverized material B. Good amount of pulverized material Punching Fair Size	
30	1816	16	233.5	20°	2429	Navy C.	F. imp. 9/16"x9/16"	5/16"x3/8"	F. Small amount pulverized material B. Fair amount of pulverized material Small Punching	
31	1816	15	236.5	20°	2487	Navy C.	F. imp. 11/16"x11/16"	1/4"x3/8"	F. Good amount of shattered material B. Fair amount of pulverized material Punchings	
32	1816	18	235.5	20°	2316**	Navy C.	F. imp. 11/16"x11/16"	5/16"x7/16"	F. Good amount of shattered material B. Fair amount of pulverized material Punchings	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Core No.	Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)									
33	1816	19	233	20°	2092**	P.			F. Shattered	
34	Standard .30M2			N.	2832	Navy C.	F. S. = 3/8"x3/8"	5/8" 7/16"x1/2"	F. Shattered fair amount B. Fragments, ≈1/16"-1/8". Large Punching	1/4" int.
35	Standard .30M2			N.	*2740*	C. both A and N		7/16"x9/16"	F. Mostly jacket material B. 1/2" int. Fragments of Punching	7/16" int.
36	Standard .30M2			N.	2660	P.			F. Remainder broke up Several fragments ~1/8"	5/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Result on Plate: Diam. of Pen. Face	Result on Plate: Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" Cont'd.									
37	Standard .30M2			N.	2708**	P. both A. and N.	C.I.P.	Pun. S.	F. Shattered.	1/8" int.
38	1695	10	241.5	N.	2044	Navy C.		3/8"x3/8"	F. Mostly jacket material B. Rest core shattered Small Punching	3/8" fragment of base int.
39	1695	11	241.5	N.	1840	Navy C.	F. S. Cd.	= 1/2"x9/16 3/8"x7/16	F. Mostly jacket material and spall B. 5/16" fragment of tip int. Remainder, broken. Punching Fragments	3/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Back	Nose	Base
			Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)							
40	1695	12	240.5	N.	1765**	Navy C.	Cd.	3/8"x7/16"	F. Mostly jacket material B. 1/4" frag. int. near nose Remainder shattered	1/8" int.
41	1695	13	240.5	N.	1574*	C.	C.I.P.	7/16"x7/16"	F. B. 1/4" near nose int. Tip in complete Punching	7/16" int.
42	1695	15	240.	N.	1425	P.	C.I.P.,	S.B.	F. Mostly jacket material	
43	1695	16	241.5	N.	1424	P.	C.I.P., Depth pen.= 3/8"	S.B.	F. Nose int. in plate	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)									
44	1695	18	241.5	N.	1460	P.	C.I.P., S.B. Hit drum		F. Nose int. in plate Fair amount of shattered material	
45	1695	19	238	N.	1440	P.	C.I.P., Pun. S.		F. Nose int. in plate Small amount of shattered material	3/8" int.
46	1695	20	240	N.	1556*	P.	C.I.P., M. B.		F. Fair amount shattered material	7/16" frag. int.
47	1695	21	241.5	N.	1657**	C.	C.I.P.	3/8"x7/16"	F. B. 3/16" frag. intact 7/16" Punching	5/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)									
48	1774 (old lot)	1	235.5	N.	1638*	P.	C.I.P.,	Pun. S.	F. int. in plate	9/16" int.
49	1774 (old lot)	4	235.	N.	1702	C.	cd.	3/8"x7/16"	F. Remainder mostly jacket material B. Small amount of shattered fragments 3/8" Punching	7/16" int.
50	1774 (old lot)	5	235.	N.	1560	P.	C.I.P.,	Pun. S.	F. int. in plate Remainder mostly jacket material	5/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
				Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)						
51	1774 (old lot)	3	237.5	N.	1644*	C.	F.S.= Cd.	1/2"x7/8" 5/16"x7/16	F. Small amount of shattered material F.S. fragment B. Fair amount of shattered fragments 5/16"x3/8" Punching	
52	1774 (old lot)	11	235.5	N.	1711**	C.	Cd.	7/16"x1/2"	F. Remainder jacket material B. 1/2" int.	9/16" int.
53	1774 (old lot)	12	238.5	N.	1692	C.	F.S.= Cd.	3/8"x3/4" 7/16"x7/16"	F. B. 1/4" Sect. near tip. int. 7/16"x1/2" Punching	3/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)										
54	1774 (old lot)	3	239	N.	1818**	Navy C	Cd.	7/16"x9/16"	F. Mostly jacket material B. 1/4" near tip int. Remainder broke up Punching	7/16" int.
55	1830-A	8	232.5	N.	*1767*	C both A and N	Cd.	7/16"x1/2"	F. Mostly jacket material B. 5/16" section body int. Remainder broke up Punching	7/16" int.
56	1830-A	20	232.	N.	*1730*	P. both A and N	C.I.P.	Pun. S.	F. int. in plate	7/16" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
Disston F. [illegible]. Plate No. 5. Heat 1081 Thick. 1/2" (Cont'd.)										
57	1830-A	12	231	N.	1847	Navy C.	Cd.	3/8"x7/16"	F. Mostly jacket material B. Remainder shattered Punching	7/16" Int.
58	1830-A	19	233.5	N.	2431	Navy C.		5/16"x3/8"	F. B. Poor recovery	
59	1831-A	6	226	N.	*1623*	C. both A and N.	Cd.	3/8"x7/16"	F. Mostly jacket material B. Tip destr. 3/8" Sect. near tip int. Punching	9/16" int.
60	1831-A	4	227	N.	1259	P.			F. Broke up	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Back	Nose	Base
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)										
61	1831-A	8	228	N.	1587**	P. both A and N			3/8" int.	lost
62	1831-A	17	228.5	N.	2480	Navy C.		3/8"x7/16	F. Mostly jacket material B. Remainder broke up	3/8" fragment of base int.
63	1831-A	11	227	N.	1665	P.	C.I.P.,	Pun. S.	F. Projectile was int. Rnd. 65 knocked out 5/8" base	
64	1831-A	21	227.5	N.	1687	C.	C.I.P.	5/16"x7/16"	F. Nose in plate B. Tip of nose int. Punching	1/2" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Result on Plate: Diam. of Pen. Face	Result on Plate: Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
	Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)									
65	1816	24	235	N.	Lost	Hit on edge of Rd. 63 making it complete			F. Projectile shattered B. Projectile shattered Punching	
66	1816	22	231	N.	1732	Navy C.	Cd.	5/16"x7/16"	F. Fair amount shattered. B. Greater amount of pulverized core material. Punching	
67	1816	21	232.5	N.	1633**	Navy C.	Cd.	1/"x1/2"	F. Mostly jacket material B. 3/8" body int. Punching	3/8" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
Disston F. H. Plate No. 5, Heat 1081. Thick. 1/2" (Cont'd.)										
68	1816	20	234	N.	*1574*	C. Navy P.	Cd.	3/8"x7/16"	F. B. 1/4" fragment near nose. Small amount of broken up material. Tip nose in Punching	1/2" int.
69	1835	12	169.5	N.	2368*	P.	C.I.P.	Pun. S.	F. Nose int. in plate	1/2" int.
70	1835	10		N.	2430	C.	C.I.P.	5/16"x7/16"	F. Small amount of broken up material Body proj. in plate B. 3/16" Section near nose int. Small amount of pulverized material	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Result on Plate: Diam. of Pen. Face	Result on Plate: Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
Disston F. H. Plate No. 5. Heat 1081. Thick. 1/2" (Cont'd.)										
71	1835	9	168	N.	2399**	C.	Cd.	7/16"x1/2"	F. Fair amount broken up material B. 3/16" Sect. near nose int. Small amount of broken up material Punching	
72	1835	8	167	N.	2472	C.	Cd.	3/8"x1/2"	F. 3/16" Sect. body int. B. Broken up fragments. 3/16" Sect. body int. Punching	3/8" int.
73	1835	4	166	N.	2670	P.	S.B.		F. Projectile broke up and pulverized	
74	1835	14	169	N.	2597	C.	C.I.P.	1/4"x1/4"	F. B. 3/8" int. few fragments	Base int. in plate

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
Carnegie Illinois Plate No. 154590H. Heat 15353. Thick. 1/2" Homogeneous. Brinell 341										
1	1835	7	168	N.	2110	P.	C.I.P., S.B.		F. int. in plate	Lost
2	1835	4	169	N.	2159*	P.	C.I.P., S.B.		F. Nose int. in plate	3/8" int.
3	1835	9	168.5	n.	2309	C.	C.I.P.	1/16"x1/16"	F. 1/2" nose int. in plate	Lost
4	1835	11	167.5	N.	2259*	C.	C.I.P.	1/32"x1/32"	F. Nose int. in plate	1/2" int.
5	Standard .30M2			N.	2210*	P.	S.B.		F. Nose int. in plate	1/2" int.
6	Standard .30M2			N.	2292	C.	C.I.P.	1/32"x1/32"	F. Nose int. in plate	1/2" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen.		Nose	Base
							Face	Back		
Carnegie Illinois Homogeneous Plate No. 15490 H. Thick. 1/2" (Continued)										
7	Standard .30M2			N.	2227*	C.		Pin Hole	F. Core intact	
8	Standard .30M2			N.	2472*	C.	C.I.P.	1/8"x1/8"	F. " "	
9	Standard .30M2			N.	2612	Navy C.		1/4"x1/4"	F. B. Core intact	
10	Standard .30M2			N.	2532*	Navy C.		1/4"x1/4"	F. B. Core intact	
11	1774 (new lot)	28	2 38.5	N.	1516	P.	C.I.P.		F. Broke up	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile: Nose	Result on Projectile: Base
	Carnegie Illinois Homogeneous Plate No. 154590 H. Thick. 1/2" (Cont'd.)									
12	1774 (new lot)	34	236	N.	Lost	C.	C.I.P.	1/16"x1/16"	F. Nose int. in plate	1/2" int.
13	1774 (new lot)	35	237.5	N.	1636	P.	Hit drum		F. Pulverized	
14	1774 (new lot)	29	236.5	N.	*1574	P.	C.I.P. Slight crack on back		F. Nose int. in plate	7/16" base int.
15	1774 (new lot)	30	236	N.	*1666	C.	C.I.P.	1/32"x1/32"	F. 7/16" nose int. in plate	
16	1774 (new lot)	31	236.5	N.	*1956*	Navy C.		1/4"x1/4"	B. Proj. broke up into fragments 1/16" ~ 1/8" Small Punching	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet: Grade	Bullet: Core No.	Bullet: Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate: Pen.	Diam. of Pen.: Face	Diam. of Pen.: Back	Result on Projectile: Nose	Result on Projectile: Base
		Carnegie Illinois Homogeneous Plate No. 154590 H. Thick. 1/2" (Cont'd.)								
17	1774 (new lot)	32	237	N.	1736***	C.	C.I.P.	1/8"x1/8"	F. Nose int. in plate	3/8" int.
18	1774 (new lot)	33	236	N.	1691	C.	C.I.P.	1/16"x1/16"	F. Nose int. in plate	7/16" int.
19	1774 (new lot)	41	237	N.	1571	P.	C.I.P.		F. Nose int. in plate	
20	1774 (new lot)	37	236	30°	2626	C.		1/4"x5/16"	F. Pulverized material on both sides B.	
21	1774 (new lot)	38	236.5	30°	2514	C.		1/4"x3/8"	F. B. More broken and pulverized fragments than in front	
22	"	39	236.5	30°	2250	C.	C.I.P.	1/8"x1/8"	F. 1/2" nose int. in plate. Lost	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
			Disston Plate No. 1, Heat 1147, Thick. 1/2" Homogeneous - Brinell 321							
1	Standard .30M2			30°	2884*	C.		3/8"x7/16"	Nose P.T.P.	Destroyed
2	Standard .30M2			30°	2831	P.	S.B.		Little C.I.P. 1/4" nose int.	Destroyed
3	Standard .30M2			30°	2867*	P.	M.B.		Little C.I.P. Broke up	
4	1774 (old lot)	12	238.5	30°	2123	P.	S.B.		Proj. shattered according to observers	
5.	1774 (new lot)		237	30°	2228	P.	S.B.		Proj. shattered according to observers	

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet			Angle of Obliq.	Strik. Vel.	Result on Plate			Result on Projectile	
	Grade	Core No.	Wt. Grns.			Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Nose	Base
Disston Homogeneous Plate No. 1. Heat 1147. Thick. 1/2" (Cont'd.)										
6	1774 (old lot)	8	229.5	30°	2295	P.	Depth Pen. 5/32"		Shattered	
7	1774 (old lot)	7	229.	30°	2295	P.	Depth Pen. 3/16"		Shattered	

Note that low weight of above two rounds may be due to imperfect cores.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
	Carnegie Illinois Plate No. 174947-3. Heat 17503. Thick. 5/8" Homogeneous - Brinell 321									
1	1830	9	232.5	N.	1668*	P.	C.I.P., M.B.		F. 9/16" int. in plate	3/8" int.
2	1830	10	231.5	N.	1707*	C.	C.I.P.	1/32"x1/32"	F. 5/8" int. in plate	7/16" int.
3	1830	13	230.5	N.	1800**	Navy P.	C.I.P.	3/16"x3/16"	Proj. int. in plate 1/8" base sticking out of plate	
4	1830	14	232.	N.	1866**	Navy C.		1/4"x1/4"	Base in plate 1/16" from face	1/2" int.

Table II Detailed Firing Data and Notes on Recovery

Rnd.	Bullet Grade	Bullet Core No.	Bullet Wt. Grns.	Angle of Obliq.	Strik. Vel.	Result on Plate Pen.	Diam. of Pen. Face	Diam. of Pen. Back	Result on Projectile Nose	Result on Projectile Base
				Carnegie Illinois Homogeneous Plate No. 179947-3, Thick. 5/8" (Cont.)						
5	Standard .30M2	A.P.		N.	2535	Navy C		1/4"x1/4	Pr. P.T.	P., intact
6	Standard .30M2	A.P.		N.	2465**	Navy P		1/8"x1/8	Pr. intact 5/16" base from plate	protruding
7	Standard .30M2	A.P.		N.	2482**	Navy C	C.I.P.	1/4"x1/4"	Nose P.T.P.	1/2" int.

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Face Hardened Plate

I Grade	II Comp.	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V L.C. (Velocity)	VI T.P. (Velocity)	VII Limit (Velocity)	VIII Desig.	IX F Core	X Striking Energy ft. lb.: Bullet	X Striking Energy ft. lb.: Core
		Caliber .30 against Disston Plate No. 12 Heat 291 Thick. 1/4" Face Hardened. Brinell: F. 555-578, B. 444-444									
1774 (New lot)	Ni 9, WC 91	237.	151.	N	949			Army	<47500.	<475	<302.
"		238.		N		1298		Navy	>65000.	>886	>565
"		237		20°			1232	Army	57500	796	507.
(Old lot)		235.5		20°		1199		A and N		>757.	>482
(New lot)		237.		30°			1647	Army	71100	1420	910.
	(Average	237.)									
Standard .30M2		165.	83.	N	2181	2053	*2119	Army	78200	1640.	826
				N			2206	Navy	81600	1790.	900.
				20°			2290	Army	79500	1920	965.
				30°			2493	Army	79700	2260.	1140.

* From previous firings.

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Face Hardened Plate

I Grade	II Comp.	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V L.C. Velocity	VI H.P. Velocity	VII Limit Velocity	VIII Desig.	IX E Core	X Striking Energy Ft. Lb.: Bullet	X Striking Energy Ft. Lb.: Core
Caliber .30 against Disston Plate No. 3 Heat 1140 Thick. 3/8" Face Hardened. Brinell: F. 555-555, B. 415-415											
Standard .30M2		165	83	N			*2345	Army			
				N	2386	2374	2380	Army			
				N (Average)			2363	Army	71500.	2040.	1030.
1830	Ni/13 WC/87	234	147.	N			1220	Army	49000.	765.	486.

* From previous firings.

Table III Ballistic [illegible] Carbide [illegible] Bullets [illegible] Face Hardened Plate

I Grade	II Comp.		III Av. Weight in Grains Bullet	III Av. Weight in Grains Core	IV Angle of Obliq.	V G.C. Velocity	VI T.P. Velocity	VII Limit Velocity	VIII Desig.	IX F Core	X Striking Energy ft. lb. Bullet	X Striking Energy ft. lb. Core
			Caliber .30 against Disston Plate No. 1 Heat 1081 Thick. 1/2" Face Hardened Brinell: F. 555-578, B. 444-444									
779	Co 9	WC 91	234.	152.	N			1652	Army	58300	1420	920.
			235.		N			1697	Navy	60000	1500.	970.
	(Average		235.)									
55-A	13	87	229.	147	N			1522	Army	53000	1180	760.
			230.5		N			1663	Navy	57800	1410	905
			232.		20°			**1857 approx.	Army	60600.	1760	1110
			229.5		30°		2681		Army	>80600	>3660	>2340
	(Average		230.)									
55-B	Co 20	WC 80	223.	140	N			1607	Army	54600	1280	800
			225.		N			1705	Navy	57800	1440	905.
			225.		20°			2132	Army	67700	2250.	1410
			223.5		30°			2623	Army	77000	3410	2140
			223.5		30°			2668	Navy	78500	3530.	2200
	(Average		224.									

** Erratic results.

Table III Ballistic [illegible] Carbine [illegible] Standard A.P. Bullets Against Face Hardened Plate

I Grade	II Comp.	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V L.C. Velocity	VI N.P. Velocity	VII Limit Velocity	VIII Desig.	IX F Core	X Striking Energy ft. lb.: Bullet	X Striking Energy ft. lb.: Core
Disston Face Hardened Plate No. 1 Heat 1081 Thick. 1/2" (cont'd)											
Standard .30M2		165.	83.	N			2786	A and N	72900.	2840.	1430.
				20°			3168	A and N	78000	3660.	1840.
				30°		3214			>72600	>3780.	>1900.

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Face Hardened Plate

I Grade	II Comp. %		III Av. Weight in Grains: Bullet	Core	IV Angle of Obliq.	V L.C. (Velocity)	VI H.P. (Velocity)	VII Limit (Velocity)	VIII Desig.	IX F Core	X Striking Energy ft. lb.: Bullet	Core
			Caliber .30 against Disston Plate No. 5 Heat 1081 Thick. 1/2" Face Hardened. Brinell: F. 601-601, B. 401-388									
1695	Ni 6	WC 94	240.25	156	N			1565	Army	56200.	1320.	850.
			241.		N	1765	1574		Navy	(63400. -56500.)	(1680. -1340.)	(1070. -860.)
			241.		20°			2275	Army	76600.	2780.	1780.
			241.		20°			2297	Navy	77500.	2840.	1810.
			241.		30°		2607		Army	>80700.	>3680.	>2340.
	(Average		241.)									
1774 (Old lot)	9	91	236.5	151	N			1641	Army	58000.	1420.	905.
			237		N	1818	1711	1762 approx.	Navy	62200.	1640.	1040.
(1774 New lot)	9	91	237		N			+1646	Army			
					N		1771		Navy			
			236.5	151	20°			1991	Army	66000.	2080.	1330.
			236.5		20°		2035		Navy	>67600.	>2170.	>1390.
			237.		30°			**2538	Army	**77600.	**3400.	**2160.
	(Average		237.)									
1830-A	13	87	232.25	147	N			1749	A and N	61000.	1570.	996.
			232.		20°			2544	Army	83500.	3320.	2100.
	(Average		232.)									

\+ Limit Velocity against similar 1/2" F.H. Disston Plate No. 1.

** Erratic Results.

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Face Hardened Plate

I Grade	II Comp. %	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V L.C. Velocity	VI U.P. Velocity	VII Limit Velocity	VIII Desig.	IX P Core	X Striking Energy Ft. lb.: Bullet	X Striking Energy Ft. lb.: Core
		Caliber .30 against Disston Plate No. 5. Heat 1081 Thick. 1/2" Face Hardened. Brinell: F. 601-601. B. 401-388									
1831-A	Ni 20, WC 80	227	141	N			1605	A and N	54,800	1300	808
		227.2		20°			2649	Army	85,300	3540	2200
	(average 227)										
1816	Fe 9, WC 91	234	147	N	1574			Army	<55,000	<1290	<810
		233		N	1633	1574	1604	Navy	56,000	1330	836
		234		20°	2316	2092		Army	-75,700 68,500	-2780) 2260)	-1750) -1420)
		235.5		20°	2316			Navy	<76,000	<2780	<1750
	(average 234)										

Table III Ballistic Data for Carbide and Standard A.P. Bullets Against Face Hardened Plate

I Grade	II Comp. %	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V S.C. (Velocity)	VI P.P. (Velocity)	VII Limit (Velocity)	VIII Desig.	IX P Core	X Striking Energy Ft. lb.: Bullet	X Striking Energy Ft. lb.: Core
Caliber .30 against Disston Plate No. 5. Heat 1081. Thick. 1/2" Face Hardened. Brinell: F. 601-601 B. 401-388											
1835	15 Co, 39T, C+46WC	1687	83	N	2399	2368	+2384	Army	62300	2120	1040
Standard .30M2		165	83	N			2724	A and N	71200	2700	1360
				20°			3202	Army	79000	3760	1890
Standard .30M2		165	83	aN			2755	A and N	72000	2760	1390
				a20°			3185	Army	78500	3720	1870

a = average for 1/2" F.H. Plates, Disston No. 1 and No. 5.

\+ Erratic

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Homogeneous Plate

I Grade	II Comp.	III Av. Weight in Grains: Bullet	III Av. Weight in Grains: Core	IV Angle of Obliq.	V L.C. (Velocity)	VI T.P. (Velocity)	VII Limit (Velocity)	VIII Desig.	IX F Core	X Striking Energy ft. lb.: Bullet	X Striking Energy ft. lb.: Core
	Caliber .30 against Carnegie Illinois Plate No. 154590 H. Heat 15353. Thick. 1/2" Homogeneous Brinell: 341										
1774 (New lot)	Ni 9, WC 91	236.2	151	N	1666	1574	1620	Army	57,200	1380	882
		236.7		N	1956	1736		Navy	61,400 - 59,000	2020 - 1590	1290 - 1010
		236.5		30°	*2250			Army	<68,700	<2660	<1700
	(average 236)										
1835	15 Co+39TiC +46WC	168	83	N	2259	2159	2209 approx.	Army	57,700	1820	900

* Note: From further results, on 1/2" Disston Homogeneous Plate No. 1, on following page 93, the indication is that the limiting velocity for 30° is approximately 2250 f/s.

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Homogeneous Plate

I Grade	II Comp. %	III Av. Weight in Grains Bullet	III Core	IV Angle of Obliq.	V L.C. Velocity	VI H.P. Velocity	VII Limit Velocity	VIII Desig.	IX F Core	X Striking Energy ft. lb. Bullet	X Core
Caliber .30 against Carnegie Illinois Plate No. 154590 H. Heat 15353. Thick 1/2" Homogeneous. Brinell: 341 (Con'd)											
Standard .30M2		165	83	N	2227	2210	2219	Army			
				*N	2206	2175	2191	Army			
				N (average)			2205	Army	57,600	1780	895
				N	2532	2472	2502	Navy	65,300	2280	1150
				*30°			2879	Army	65,100	3020	1520

* Results from A.P.G. Firing Record on Armor Plate No. 20703, A301, Jan. 6-21, 1941 for same plate.

Table III Ballistic [illegible] Carbine [illegible] against [illegible] Plate

I Grade	II Comp.		III Av. Weight In Grains Bullet	Core	IV Angle of Obliq.	V [illegible]	VI [illegible]	VII Limit	VIII Desig.	IX [illegible] Core	X Striking Energy Ft. lb. Bullet	Core
						Velocity						
			Caliber .30 against Disston Plate No. 1. Heat 1147. Homogeneous. Brinell 321								Thick. 1/2"	
Standard .30M2			165	83	N			*2264	Army	59200	1880	945
					30°			2875	Army	65000	3030	1520
1774	Ni 9	WC 91	238	151	30°		2228		Army	>69600	>2600	>1670

* From previous firing results

Table III Ballistic Data for Carbide and Standard A.P. Bullets against Plate

I Grade	II Comp. %		III Av. Weight in Grains Bullet	III Av. Weight in Grains Core	IV Angle of Obliq.	V E.C. Velocity	VI N.P. Velocity	VII Limit Velocity	VIII Desig.	IX F Core	X Striking Energy ft. lb. Bullet	X Striking Energy ft. lb. Core
Caliber .30 against Carnegie Illinois Plate No. 174947-3 Heat 17503 Thick. 5/8" Homogeneous Brinell 258												
Standard .30M2			165	83	N			*2280	Army	53400	1900	958
								2474	Navy	57800	2240	1130
1830	Ni 13	WC 87	232	147	N			1688	Army	52700	1470	930
					N			1833	Navy	57300	1730	1100

* From previous results, Firing Records 20703, A301.

Table IV Summary of Ballistic Data for General Types of Carbide and Standard A.P. Bullets

1/2" Face-Hardened Plate, Caliber .30 Bullets

General Composition (Core)	No. of Grades Tested	Average F (Core)	Std. Dev.	Average Striking Energy Bullet Ft./Lb.	Std. Dev. Ft./Lb.	Average Striking Energy Core Ft./Lb.	Std. Dev. Ft./Lb.
Co -WC	3 / 9-20%Co	55300	2200	1290.	99.	827.	21.
Ni - WC	4 / 6-20%Ni	57500	2300	1400.	107.	890.	22.
Fe - WC	1 / 9%Fe	<55000	-	<1290.	-	<810.	-
Combined average of tungsten carbide cores above	8 (Up to 20% binder)	*56400	2400	1350.	-	857.	23.
Co-TiC-WC	1 / 15%Co	62300	-	2120	-	1040	-
Std. 30 M2 A.P.	2 Tests	72000	800	2760.	60	1390	30.

Table V. Relative Armor Penetrating Efficiencies at Normal Impact of Bullets with Sintered Carbide Cores, and Standard A.P. Bullets. (Values Based on Average Performance of all Satisfactory Carbide Grades from Tables II and III which are to be Consulted for Details).

Thickness	Caliber Bullet	F carbide core / F standard core	Energy carbide core / Energy standard core	* Energy carbide bullet / Energy standard bullet
		Face-Hardened Plate		
1/4"	.30	.608	.366	.29
3/8"	.30	.685	.472	.375
1/2"	.30	.784	.616	.490
(1) 1/2"	.30	.924	.855	.676
(1) 5/8"	.30	.892	.805	.627
(1) 1"	.50	.915	.834	.672
		Homogeneous Plate		
1/2"	.30	.998	.995	.776 for grade 177; 1.02 for grade 183
5/8"	.30	.986	.970	.774

* Note that this ratio depends upon the mass of the core as well as its armor penetrating efficiency.

(1) From first test series, "Twenty-eighth Partial Report on Armor Piercing Bullets

Appendix A

To Tables

Tables

for

First Series of Tests on Carbide Bullets.

Twenty-Eighth Partial Report on Tests of Armor Piercing Bullets, November 25, 1940

Note that numbering of tables and column headings correspond to similar tables in main body of report for second series of tests, Firing Record 22883, A619.

Table III-B. Ballistic Data for Tungsten Carbide and Standard A.P. Bullets against Face-Hardened Plate.

Grade	Comp. %		Av. wt. in Grains Bullet	Core	Ballistic Limit	F Core	Striking Energe Ft. Lb. Bullet	Core
			Cal. .30 against 1/2" Face Hardened Plate[1] - 100 Yard Range					
	Co	WC						
44A	6	94	234	154	1668	59000	1440	947
779	9	91	235	152	1750	61700	1590	1030
55A	13	87	233	147	1748	60600	1570	1000
55B	20	80	225	140	1817	61500	1650	1020
DM25	25	75	220	136	1917 app.	64000 app.	1790 app.	1100 app.
	Ni	WC						
1695	6	94	241	156	1741	62500	1620	1050
1774	9	91	237	151	1675 app.	59000 app.	1470 app.	945 app.
1830A	13	87	233	147	1768	61600	1610	1020
1831A	20	80	227	141	1807	61700	1640	1030
1832A	25	75	220	138	>2130	>71600	>2200	>2140
	Fe	WC						
1816	9	91	234	147	1754	61000	1600	1010
Standard 30M2 A.P.			165	83	2537	66250	2350	1180

[1] average of 2

Table III-B. Ballistic Data for Tungsten Carbide and Standard A.P. Bullets against Face Hardened Plate.

Grade	Comp. %		Av. wt in Grains Bullet	Av. wt in Grains Core	Ballistic Limit	F Core	Striking Energy, Ft. Lb. Bullet	Striking Energy, Ft. Lb. Core
Cal. .30 against 5/8" Face Hardened Plate[a] - 100 Yard Range								
	Co	WC						
779	9	91	235	152	2051	65000	2210	1420
	Ni	WC						
1774	9	91	237	151	2069	65500	2260	1440
Standard - 30M2 A.P.			165	83	3123	73200	3570	1780

Table III-B. Ballistic Data for Tungsten Carbide and Standard A.P. Bullets against Face Hardened Plate.

Grade	Comp. %		Av. wt. in Grains Bullet	Av. wt. in Grains Core	Ballistic Limit	F Core	Striking Energy Ft. Lb. Bullet	Striking Energy Ft. Lb. Core
			Cal. .50 against 1" Face Hardened Plate[3] - 100 Yard Range					
	Co	WC						
44A	6	94	1078	756	1651	52700	6520	4580
779	9	91	1084	745	<1813	<57500	<7870	<5420
55A	13	87	1059	722	1772	55300	7360	5020
55B	20	80	1025	690	1860	56800	7900	5300
DM25	25	75	1016	670	Not Determined			
	Ni	WC						
1695	6	94		765	Not Determined			
1774	9	91	1085	745	1736[d]	55000[d]	7250[d]	4970[d]
1830A	13	87	1065	725	1732	54000	7080	4800
1831A	20	80	1049	696	1869	57200	8100	5380
1832A	25	75		676	Not Determined			
Standard - 50 M1 A.P.			750	408	2577	60400	1100	6010

NOTES: 1. The cobalt bearing series, and the iron bearing samples (Grade 1 816) were fired against Disston plate, No. D5 - Brinell face 555, back 402. The nickel bearing series was fired against Disston plate, No. D6, Brinell face 555, back 370.

The ballistic limits of both plates as determined with standard 30 M2 A.P. Bullets in 2 tests were practically identical.

2. Diebold 5/8" face hardened plate No. 138-700-344, Brinell face 555, back 415.

Table III-B. (Cont'd) Ballistic Data for Tungsten Carbide and Standard A.P. Bullets against Face Hardened Plate.

NOTES:

3. Diebold 1" face hardened plate No. 10729, Brinell hardnesses not given.

4. The weight of core was calculated using the value of 8.05 for the density of the standard 3% W stock for the standard 30 M2 A.P. core, the densities of the tungsten carbide material as furnished in Table 1, and the information that the tungsten carbide cores were made to the dimensions of the standard 30 M2 A.P. cores.

app. Approximate value. Results of firings for two lots utilized.

d. Doubtful value. Low complete 1824 f/s.
High partial 1647 f/s.

Table IV-B Summary of Ballistic Data for General Types of Tungsten Carbide Bullets, and Standard A.P. Bullets.

General Composition (Core)	No. of Grades Tested	Average F Core	Std. Dev.	Average Striking Energy Bullet ft. lb.	Std. Dev. ft. lb.	Average Striking Energy Core ft. lb.	Std. Dev. ft. lb.
Cal. .30 against 1/2" Face Hardened Plate							
Co-WC	4 (6-20% Co)	60700	980	1560	76	1000	30
Ni-WC	3 (6-20% Ni)	62000	290	1623	13	1033	13
Fe-WC	1 (9% Fe)	61000	--	1600	--	1010	--
Combined average of tungsten carbide cores above	8 (up to 20% binder)	61200	880	1590	62	1010	28
Std. 30M2, A.P.	2 (Tests)	66250	250	2350	22	1180	11

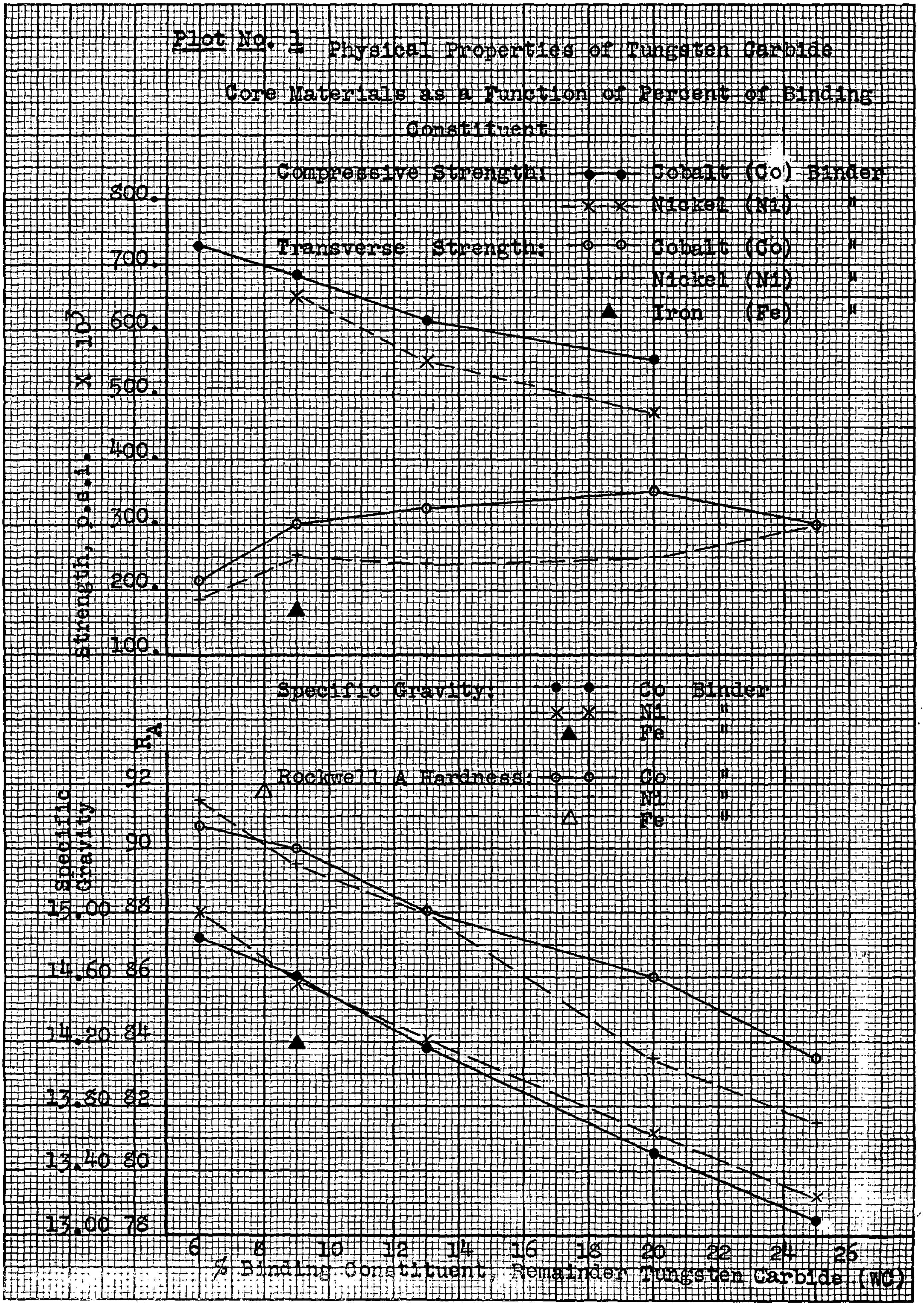
Table IV-B Summary of Ballistic Data for General Types of Tungsten

Carbide Bullets, and Standard A.P. Bullets.

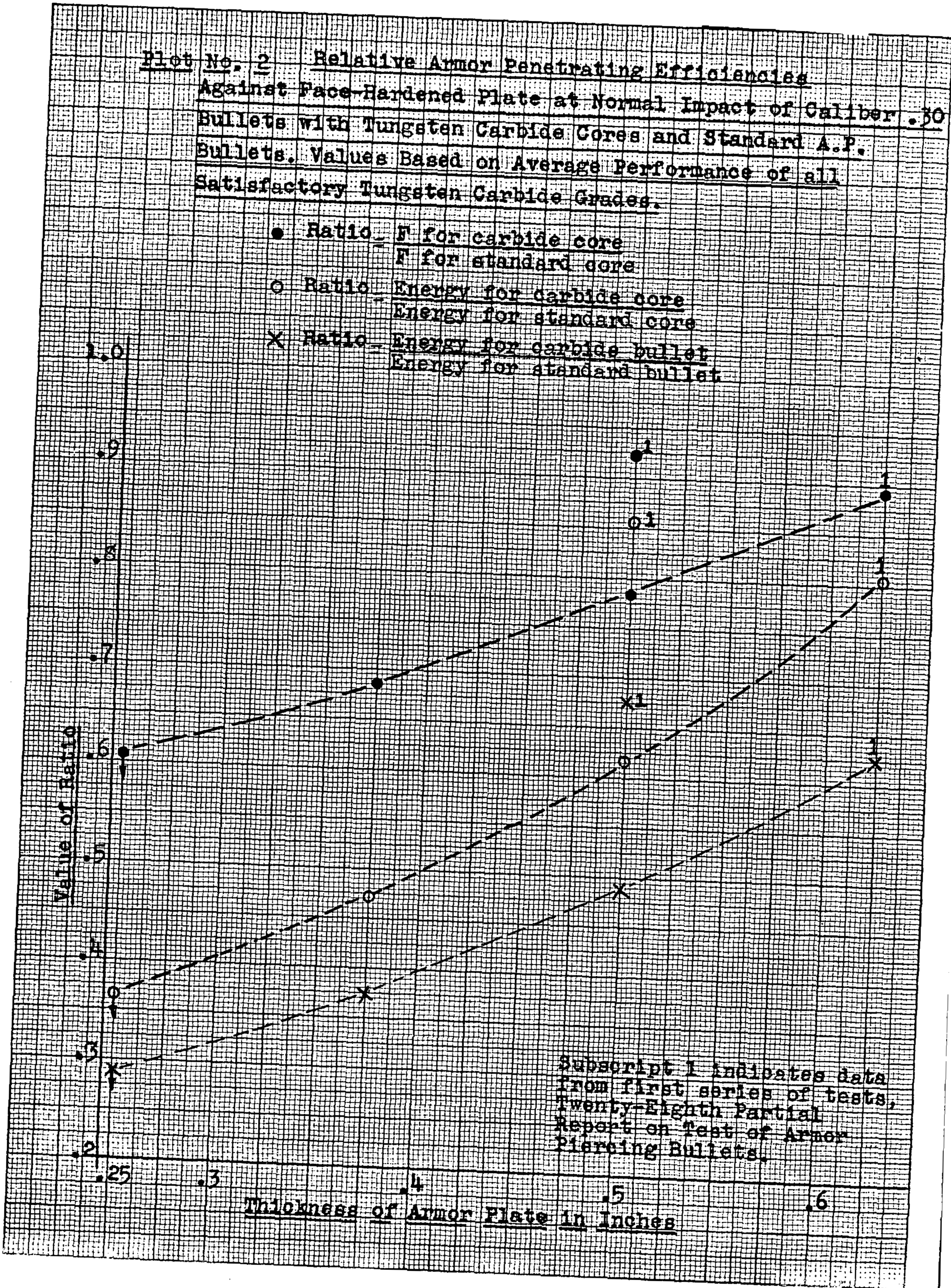
General Composition (Core)	No. of Grades Tested	Average F Core	Std. Dev.	Average Striking Energy Bullet ft. lb.	Std. Dev. ft. lb.	Average Striking Energy Core ft. lb.	Std. Dev. ft. lb.
Caliber .30 against 5/8" Face Hardened Plate							
Co-WC	1 (9% Co)	65000	--	2210	--	1420	--
Ni-WC	1 (9% Ni)	65500	--	2260	--	1440	
Combined average of tungsten carbide cores above	2	65250	250	2235	25	1430	10
Std. 30M2, A.P.	1	73200	--	3570	--	1780	--

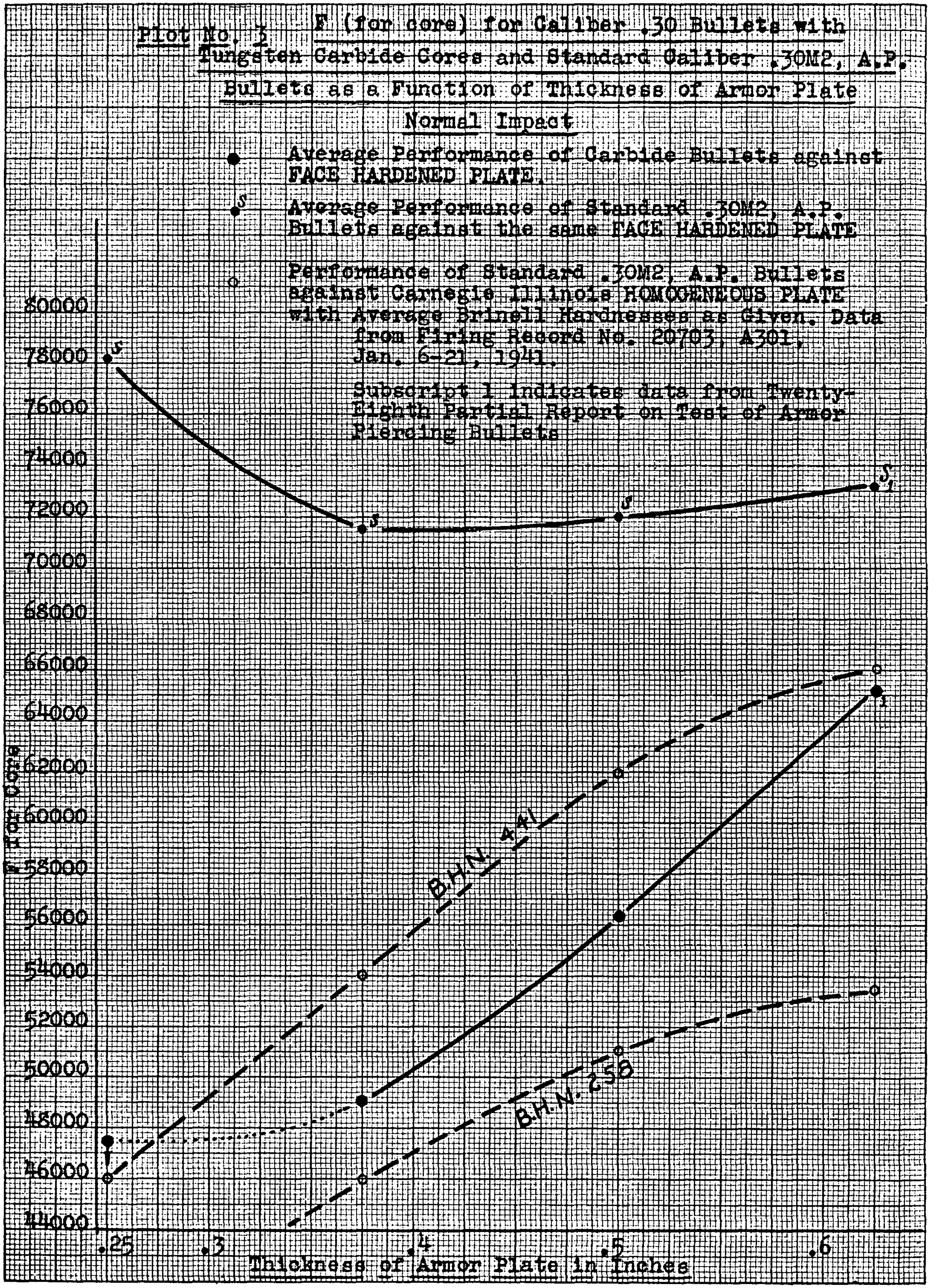
Table IV-B Summary of Ballistic Data for General Types of Tungsten Carbide Bullets, and Standard A.P. Bullets.

General Composition (Core)	No. of Grades Tested	Average F Core	Std. Dev.	Average Striking Energy Bullet ft. lb.	Std. Dev. ft. lb.	Average Striking Energy Core ft. lb.	Std. Dev. ft. lb.
Cal. .50 against 1" Face Hardened Plate							
Co-WC	3 (6-20% Co)	55000	1600	7260	570	4970	502
Ni-WC	2 (13-20% Ni)	55600	1600	7590	510	5090	290
Combined average of tungsten carbide cores above	5 (up to 20% binder)	55200	1660	7392	480	5016	298
Std. 50M1, A.P.	1 Test	60400	--	11000	--	6010	--



Plot No. 1 Physical Properties of Tungsten Carbide
Core Materials as a Function of Percent of Binding
Constituent
Compressive Strength: Cobalt (Co) Binder
Nickel (Ni) "
Transverse Strength: Cobalt (Co) "
Nickel (Ni) "
Iron (Fe) "
Strength, p.s.i. X 10[3]
800.
700.
600.
500.
400.
300.
200.
100.
Specific Gravity: Co Binder
Ni "
Fe "
Rockwell A Hardness: Co "
Ni "
Fe "
Specific Gravity
RA
92
90
15.00 88
14.60 86
14.20 84
13.80 82
13.40 80
13.00 78
6
8
10
12
14
16
18
20
22
24
26
% Binding Constituent, Remainder Tungsten Carbide (WC)

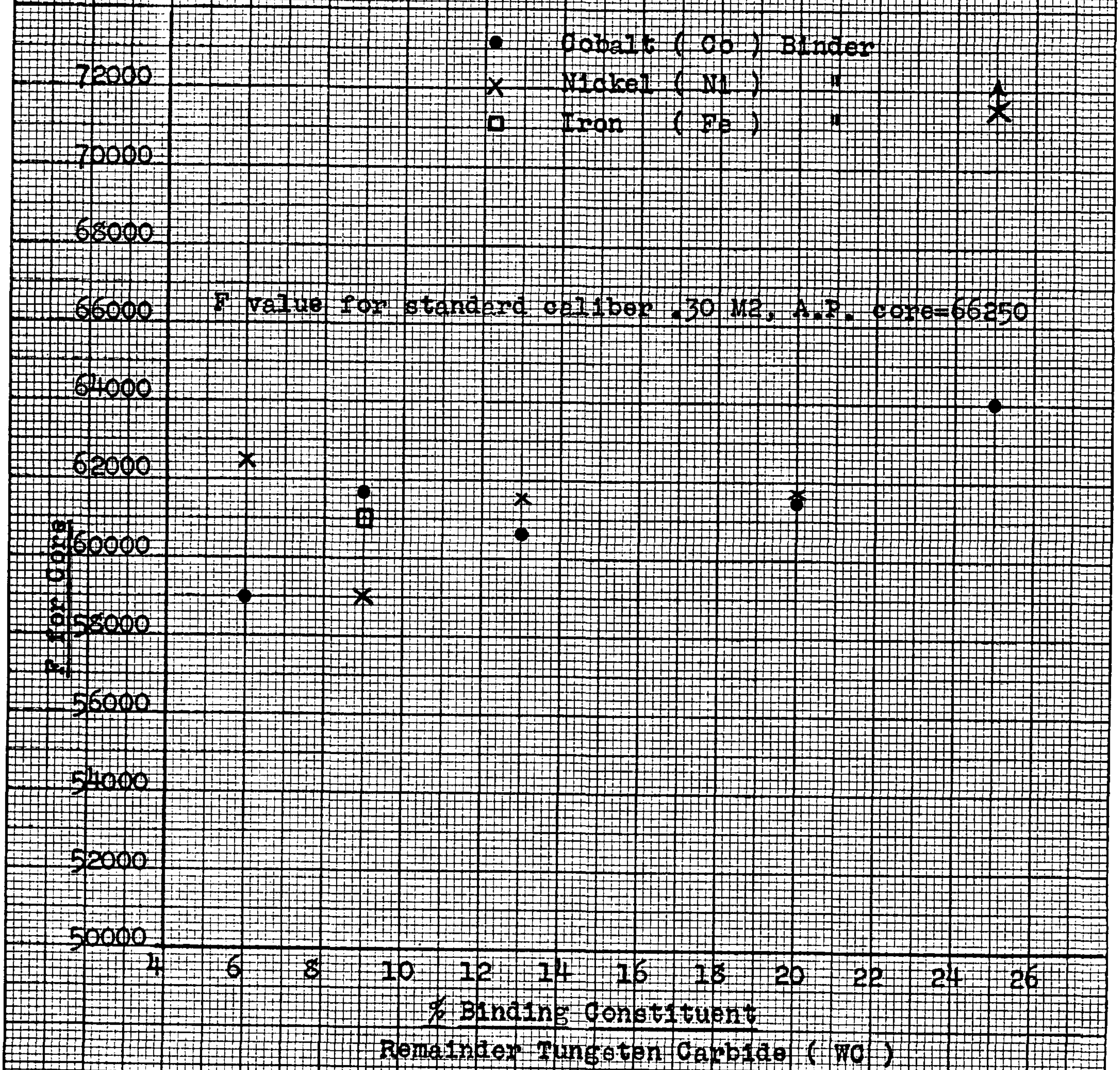

Plot No. 2 Relative Armor Penetrating Efficiencies Against Face-Hardened Plate at Normal Impact of Caliber .30 Bullets with Tungsten Carbide Cores and Standard A.P. Bullets. Values Based on Average Performance of all Satisfactory Tungsten Carbide Grades.
● Ratio = F for carbide core / F for standard core
○ Ratio = Energy for carbide core / Energy for standard core
× Ratio = Energy for carbide bullet / Energy for standard bullet
Value of Ratio
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.25
.3
.4
.5
.6
Thickness of Armor Plate in Inches
Subscript 1 indicates data from first series of tests, Twenty-Eighth Partial Report on Test of Armor Piercing Bullets.

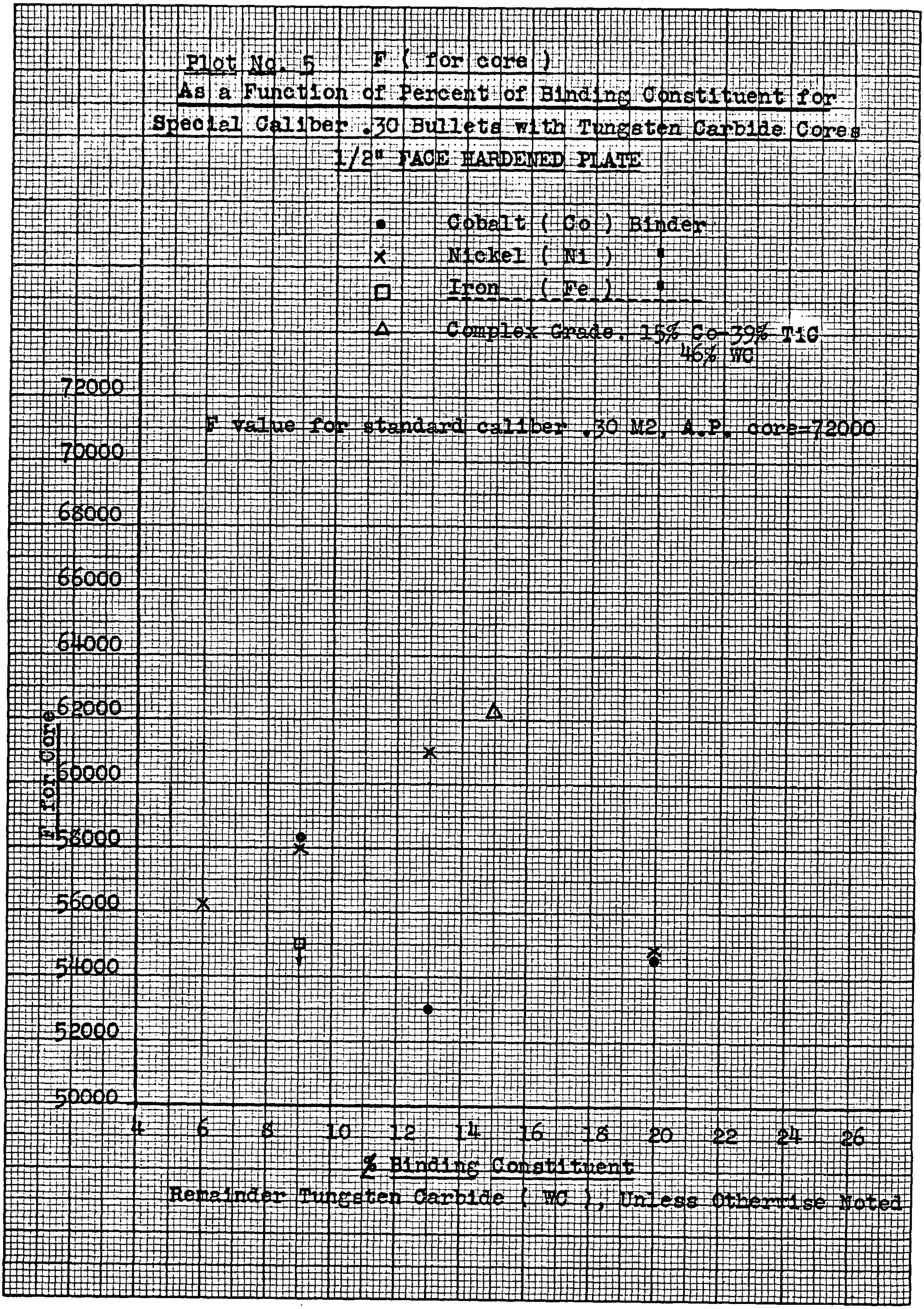

Plot No. 3 F (for core) for Caliber .30 Bullets with Tungsten Carbide Cores and Standard Caliber .30M2, A.P. Bullets as a Function of Thickness of Armor Plate
Normal Impact
Average Performance of Carbide Bullets against FACE HARDENED PLATE.
Average Performance of Standard .30M2, A.P. Bullets against the same FACE HARDENED PLATE
Performance of Standard .30M2, A.P. Bullets against Carnegie Illinois HOMOGENEOUS PLATE with Average Brinell Hardnesses as Given. Data from Firing Record No. 20703, A301, Jan. 6-21, 1941.
Subscript 1 indicates data from Twenty-Eighth Partial Report on Test of Armor Piercing Bullets
80000
78000
76000
74000
72000
70000
68000
66000
64000
62000
60000
58000
56000
54000
52000
50000
48000
46000
44000
B.H.N. 441
B.H.N. 258
.25
.3
.4
.5
.6
Thickness of Armor Plate in Inches

Plot No. 4 F (for core)
As a Function of Percent of Binding Constituent for Special Caliber .30 Bullets with Tungsten Carbide Cores

1/2" FACE HARDENED PLATE

(Data from Twenty-Eighth Partial Report on Test of Armor Piercing Bullets, November 25, 1940.)



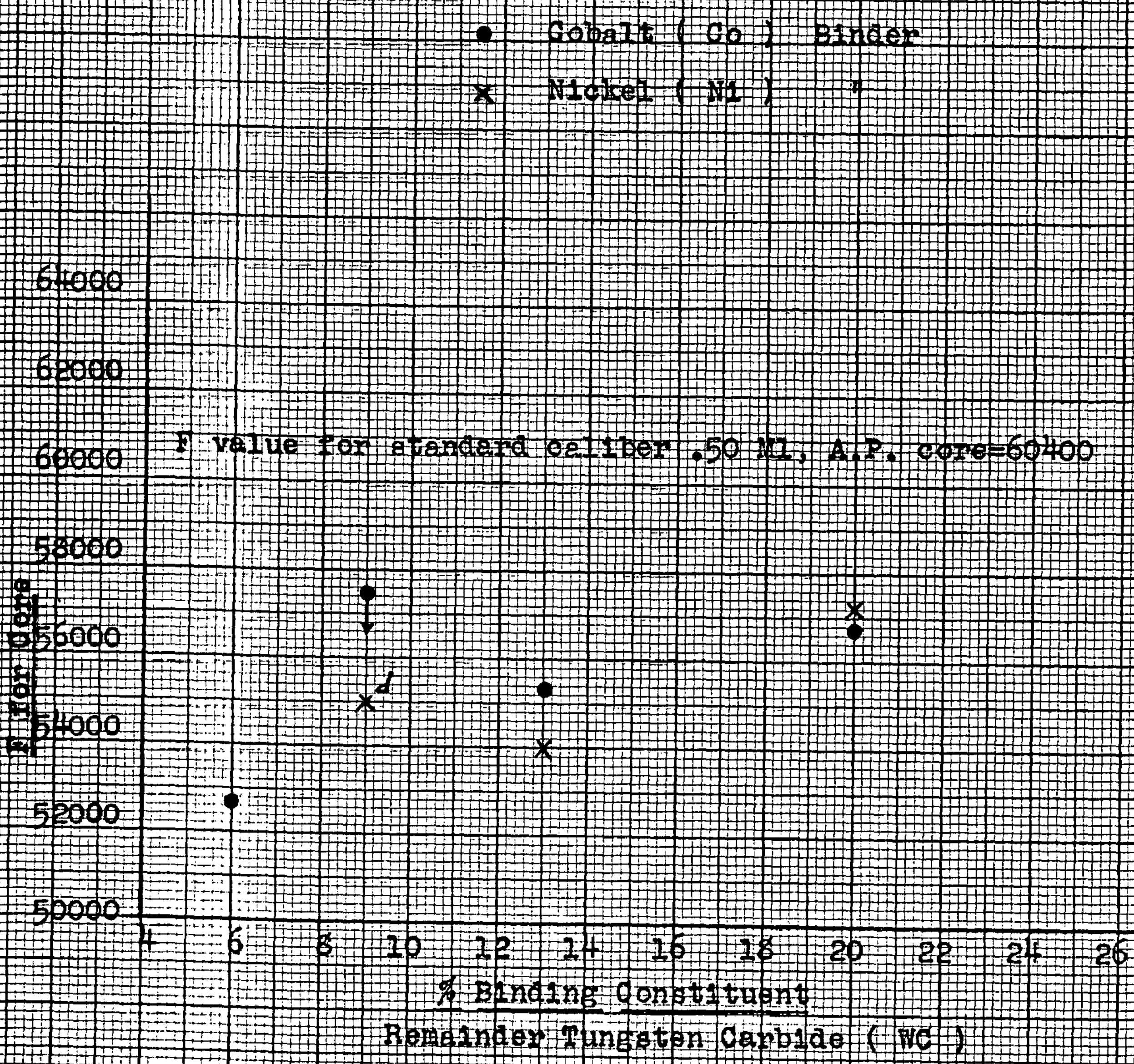

Plot No. 5 F (for core)
As a Function of Percent of Binding Constituent for
Special Caliber .30 Bullets with Tungsten Carbide Cores
1/2" FACE HARDENED PLATE
● Cobalt (Co) Binder
x Nickel (Ni) "
□ Iron (Fe) "
△ Complex Grade. 15% Co-39% TiC 46% WC
F value for standard caliber .30 M2, A.P. core=72000
F for Core
72000
70000
68000
66000
64000
62000
60000
58000
56000
54000
52000
50000
4
6
8
10
12
14
16
18
20
22
24
26
% Binding Constituent
Remainder Tungsten Carbide (WC), Unless Otherwise Noted

Plot No. 6   F (for core)

As a Function of Percent of Binding Constituent for Special Caliber .50 Bullets with Tungsten Carbide Cores

1" FACE HARDENED PLATE

(Data from Twenty-Eighth Partial Report on Test of Armor Piercing Bullets, November 25, 1940.)



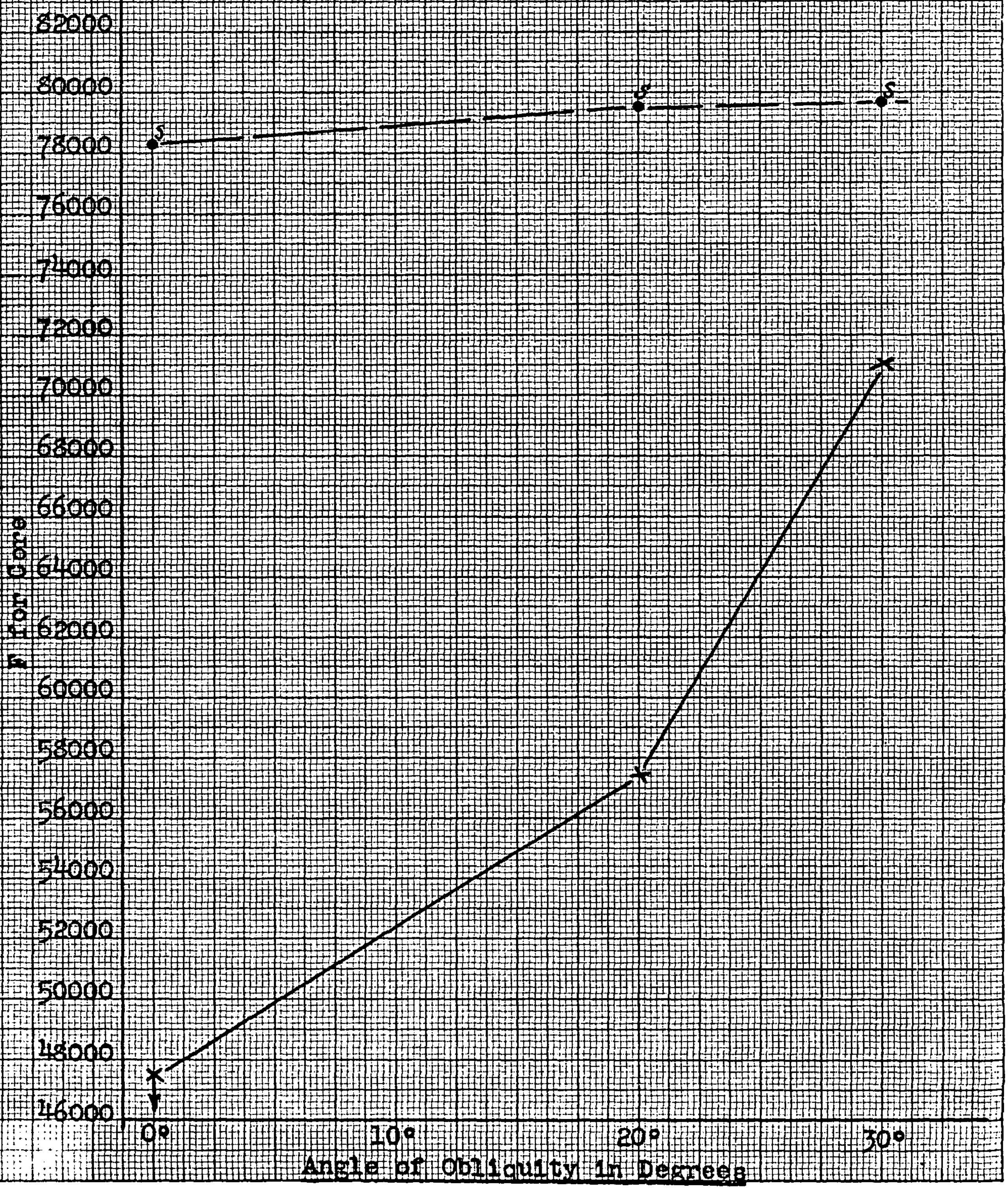
d=doubtful, insufficient data

Plot No. 7 F (for core) for Caliber .30 Bullets with Tungsten Carbide Cores and Standard Caliber .30M2, A.P. Bullets as a Function of Angle of Obliquity

1/4" FACE HARDENED PLATE

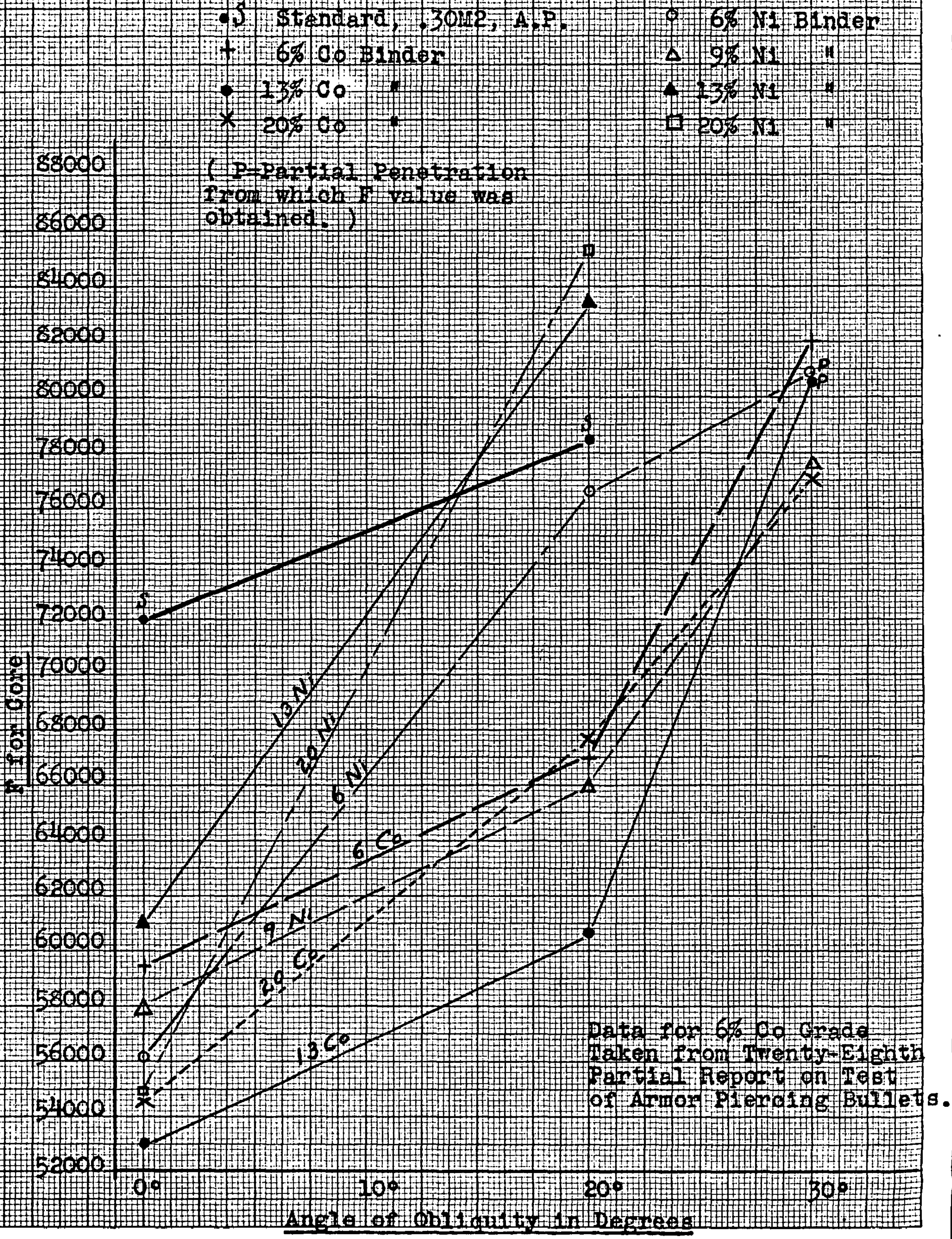
•S Standard .30M2, A.P.

X 9% Nickel Binder, Grade 1774 Carbide Core

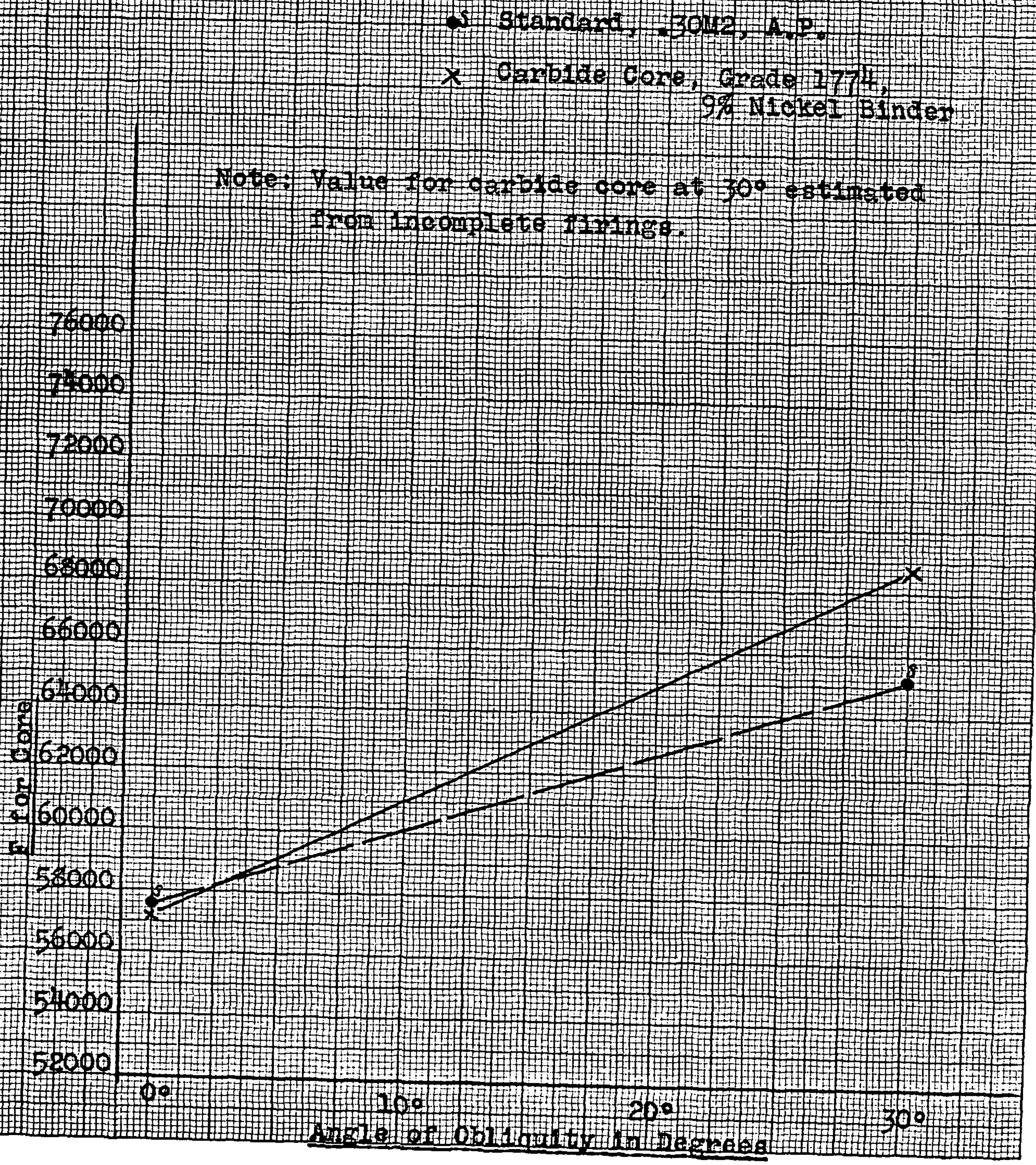


Plot No. 8 F (for core) for Caliber .30 Bullets with Tungsten Carbide Cores and Standard Caliber .30M2, A.P. Bullets as a Function of Angle of Obliquity

1/2" FACE HARDENED PLATE



Plot No 9   F (for core) for Caliber .30 Bullets with Tungsten Carbide Cores and Standard Caliber .30M2, A.P. Bullets as a Function of Angle of Obliquity
1/2" HOMOGENEOUS PLATE
Brinell Hardness=341



Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/4" FACE HARDENED PLATE

FACE | BACK

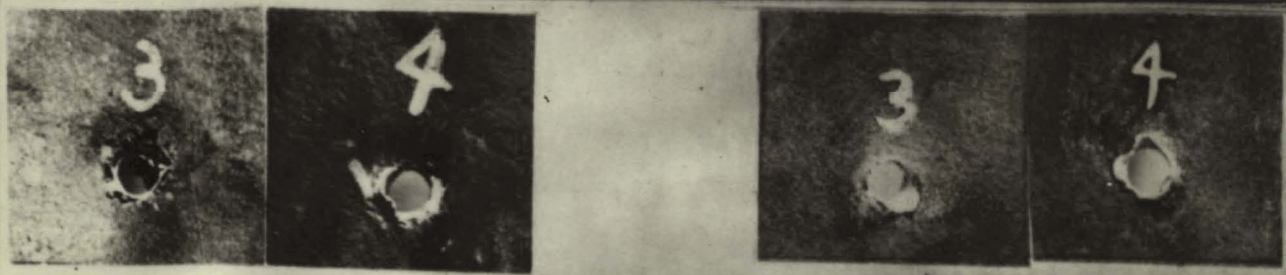


Fig.1 Grade: Standard Normal Impact

Round	Velocity	Penetration
3	2206	Complete
4	2206	Navy Complete

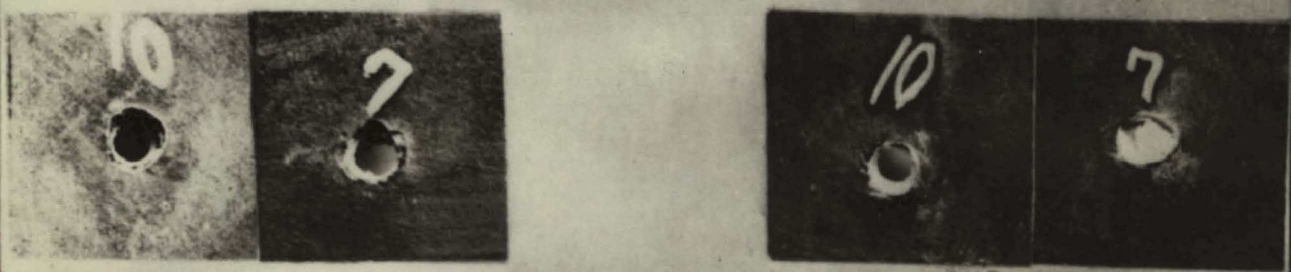


Fig.2 Grade: 1774 (9Ni-91WC) Normal Impact

Round	Velocity	Penetration
10	949	Complete
7	1148	Complete

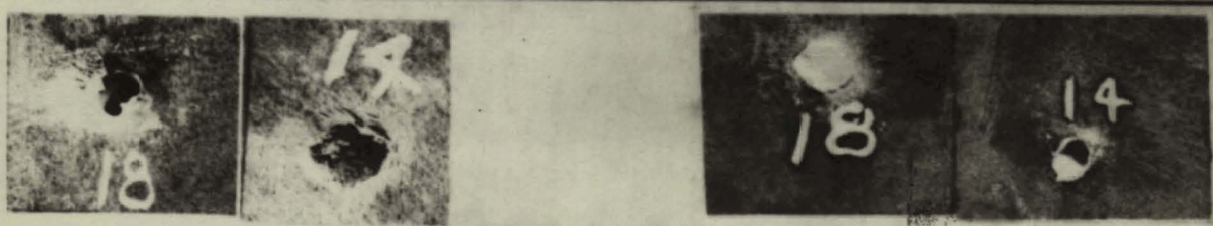


Fig.3 Angle of Obliquity, 20°

Grade	Round	Velocity	Penetration
Standard	18	2314	Complete
1774	14	1253	Complete

Plate I

55222

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/4" FACE HARDENED PLATE

FACE

BACK

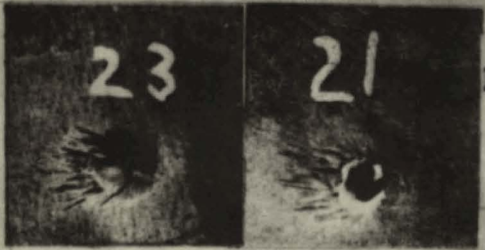


Fig.4 Grade: Standard Obliquity, 30°

Round	Velocity	Penetration
23	2481	Partial
21	2505	Complete

Fig.5 Grade: 1774 (9Ni-91WC) Obliquity, 30°

Round	Velocity	Penetration
27	1694	Complete
26	1780	Complete

Plate 2

55223

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

3/8" FACE HARDENED PLATE

FACE **BACK**

Fig.1 Grade: Standard Normal Impact

Round	Velocity	Penetration
3	2357	Partial
4	2374	Partial
5	2386	Complete

Fig.2 Grade: 1830 (13Ni-87WC) Normal Impact

Round	Velocity	Penetration
9	1234	Partial
11	1214	Partial

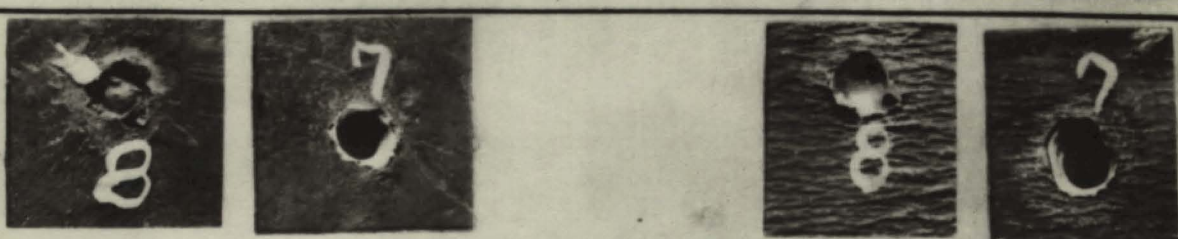


Fig. 3 Grade: 1830 (13Ni-87WC) Normal Impact

Round	Velocity	Penetration
8	1232	Complete (Core in Plate Painted White)
7	1311	Complete

Plate 3

55224

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE | BACK

Fig.1 Grade: Standard

Plate	Round	Velocity	Normal Impact Penetration
1	1	3175	Complete

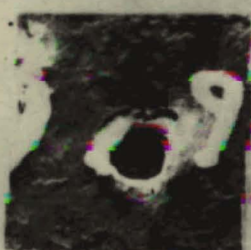


Fig.2 Grade: Standard

Plate	Round	Velocity	Normal Impact Penetration
1	9	2793	Navy Complete

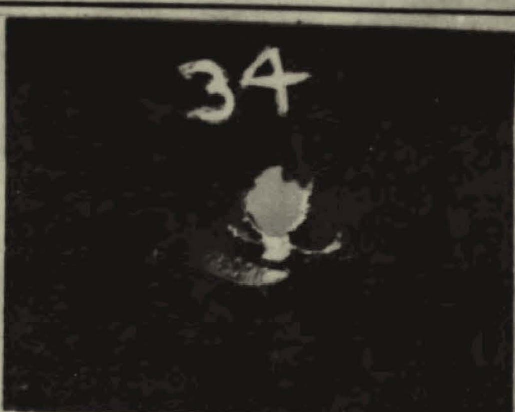


Fig.3 Grade: Standard

Plate	Round	Velocity	Normal Impact Penetration
5	34	2832	Navy Complete

Plate 4

55225

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE BACK

Fig. 4 Grade: 779 (9Co-91WC) Normal Impact

Plate	Round	Velocity	Penetration
1	4	1748	Navy Complete

Fig. 5 Grade: 55A (13Co-87WC) Normal Impact

Plate	Round	Velocity	Penetration
1	15	1535	Complete
1	13	1662	Navy Complete
1	12	1803	Higher Velocity Navy Complete

Fig. 6 Grade: 55B (20Co-80WC) Normal Impact

Plate	Round	Velocity	Penetration
1	23	1673	Complete
1	22	1736	Navy Complete

Plate 5

55226

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE BACK

Fig.7 Grade: 1695 (6Ni-94WC) Normal Impact

Plate	Round	Velocity	Penetration
5	40	1765	Navy Complete
5	38	2044	High Velocity Navy Complete

Fig.8 Grade: 1774 (9Ni-91WC) Normal Impact

Plate	Round	Velocity	Penetration
5	51	1644	Complete
5	54	1818	Navy Complete

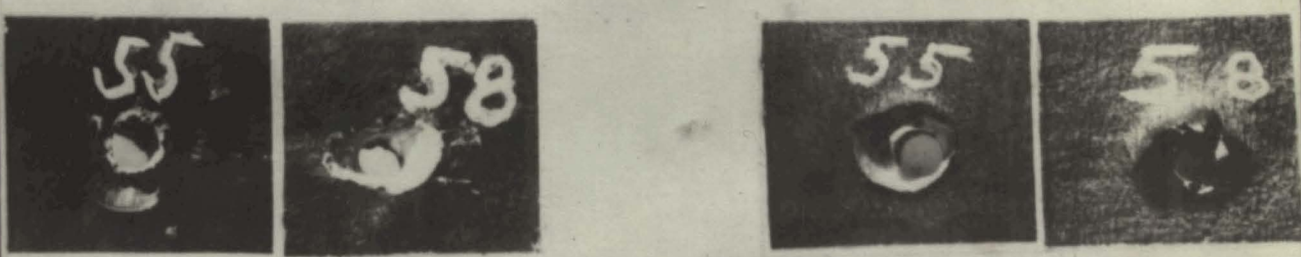


Fig.9 Grade: 1830A (13Ni-87WC) Normal Impact

Plate	Round	Velocity	Penetration
5	55	1767	Army and Navy Complete
5	58	2431	High Velocity Navy Complete

Plate 6

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE BACK

Fig.10 Grade: 1816 (9Fe-91WC) Normal Impact

Plate	Round	Velocity	Penetration
5	68	1574	Complete
5	67	1633	Navy Complete

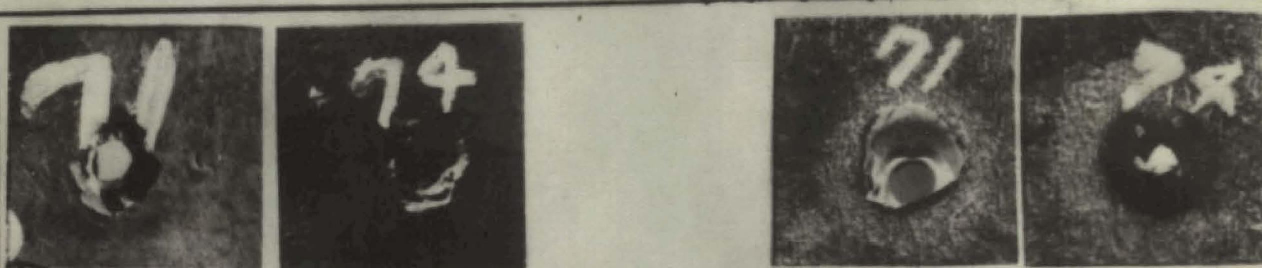


Fig.11 Grade: 1835 (15Co-39TiC-46WC) Normal Impact

Plate	Round	Velocity	Penetration
5	71	2399	Complete
5	74	2597	Complete, C.I.P.

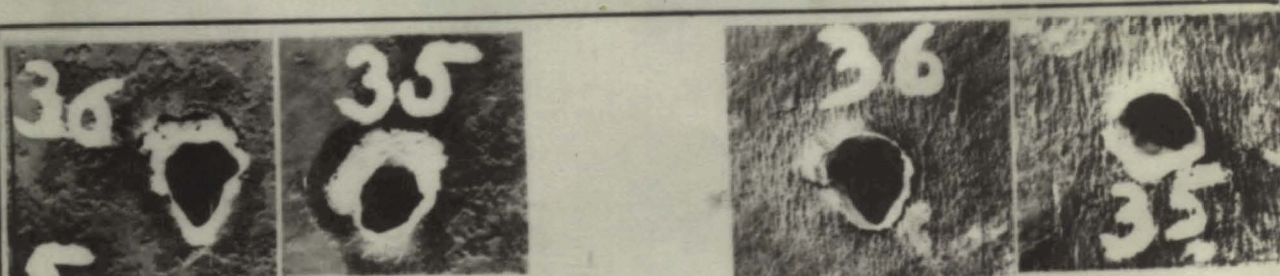


Fig.12 Grade: Standard Obliquity, 20°

Plate	Round	Velocity	Penetration
1	36	3185	Navy Complete
1	35	3213	Navy Complete

Plate 7

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE | BACK

Fig.13 Grade: Standard — Obliquity, 20°

Plate	Round	Velocity	Penetration
5	15	3210	Complete

Fig.14 Grade: 55A (13Co-87WC) — Obliquity, 20°

Plate	Round	Velocity	Penetration
1	39	1860	Complete

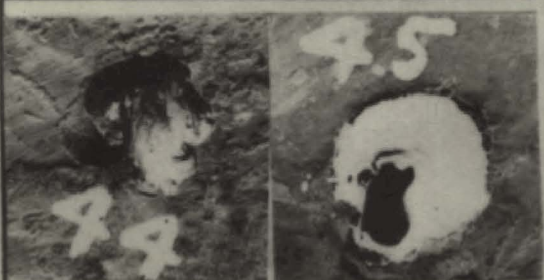


Fig.15 Grade: 55B (20Co-80WC) — Obliquity, 20°

Plate	Round	Velocity	Penetration
1	44	2111	Partial
1	45	2153	Complete

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE BACK

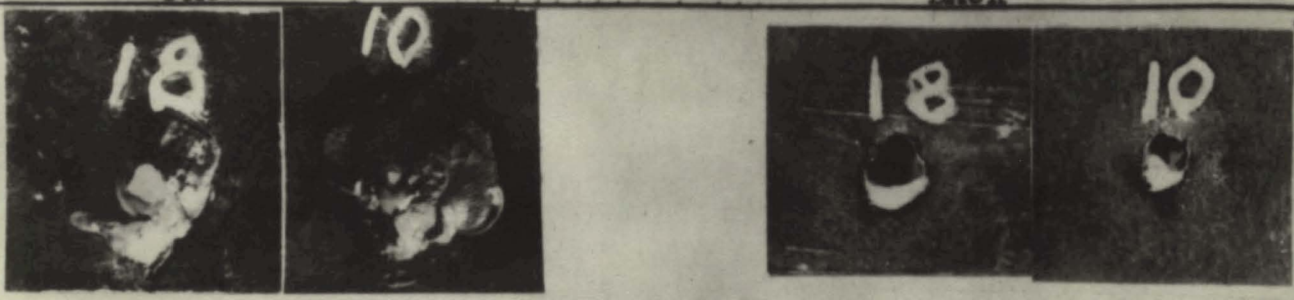


Fig.16 Obliquity, 20°

Grade	Plate	Round	Velocity	Penetration
1695(6Ni)	5	18	2297	Army and Navy Complete
1774(9Ni)	5	10	2035	Complete

Fig.17 Obliquity, 20°

Grade	Plate	Round	Velocity	Penetration
1830A(13Ni)	5	23	2566	Complete
1831A(20Ni)	5	26	2666	Complete

Fig.18 Grade: 1816 (9Fe-91WC) Obliquity, 20°

Plate	Round	Velocity	Penetration
5	33	2092	Partial
5	32	2316	Navy Complete

Plate 9

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

FACE | BACK

Fig.19 Grade: Standard Obliquity, 30°

Plate	Round	Velocity	Penetration
5	1	3197	Partial

Fig.20 Grade: 55B (20Co-80WC) Obliquity, 30°

Plate	Round	Velocity	Penetration
1	54	2596	Partial
1	53	2649	Complete
1	52	2686	Navy Complete

Fig.21
Grade: 1695(6Ni-94WC) Obliquity, 30°

Plate	Round	Velocity	Penetration
5	2	2543	Partial
5	3	2579	Partial
5	4	2607	Partial

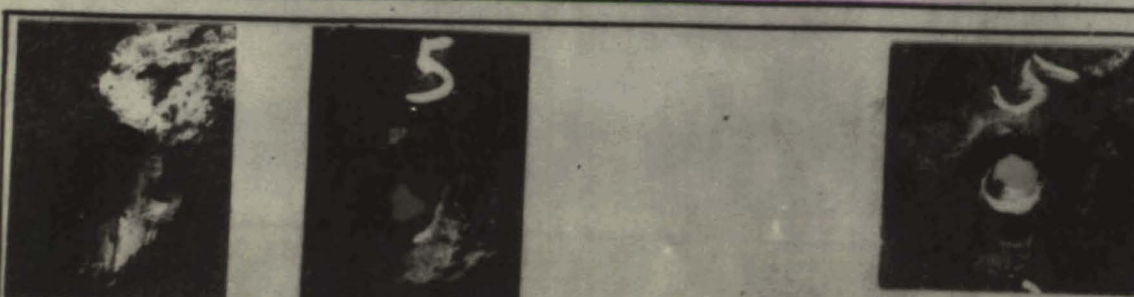


Fig.22 Grade: 1774 (9Ni-91WC) Obliquity, 30°

Plate	Round	Velocity	Penetration
5	8	2536	Partial
5	5	2633	Complete

Plate 10

55231

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores

5/8" HOMOGENEOUS PLATE
Brinell Hardness = 258

FACE OF PLATE

Normal Impact

Grade	Round	Velocity	Penetration
1830 (13Co)	1	1668	Partial. Core in Plate
"	2	1707	Complete.Core in Plate
"	3	1800	Complete.Core in Plate
"	4	1866	Navy Complete
Standard	5	2535	Navy Complete
"	6	2465	Navy Partial
"	7	2482	Navy Complete

Note that core in plate is painted white for contrast

Plate 11

55232

Photographs of Armor Plate Fired Against with Caliber .30M2, A.P. Standard Bullets, and Special Bullets with Carbide Cores.

5/8" HOMOGENEOUS PLATE
Brinell Hardness = 258
BACK OF PLATE

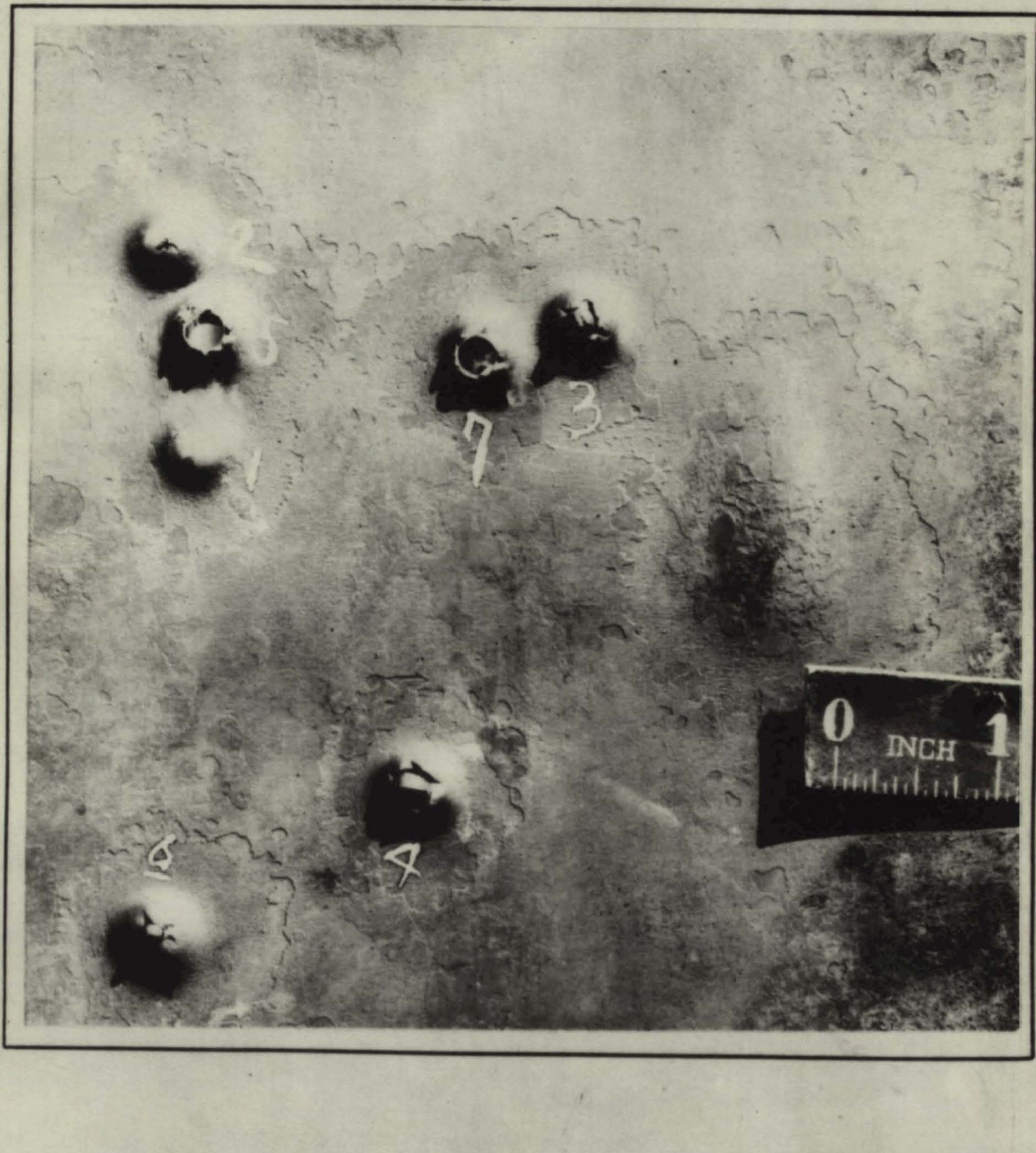


Plate 12

55233

[illegible] of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets With Carbide Cores.

1/4" FACE HARDENED PLATE

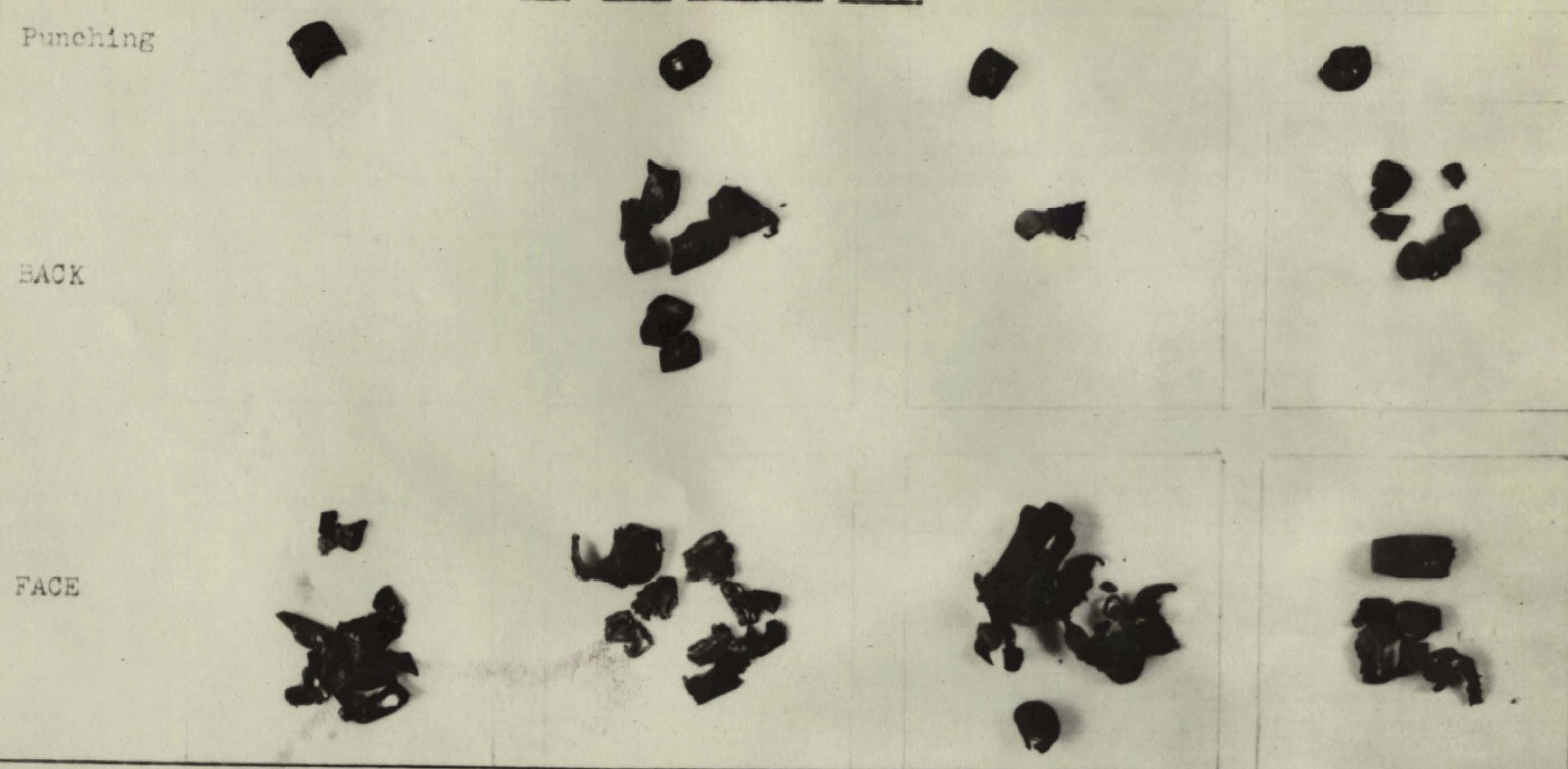


Figure:	1	2	3	4
Grade:	Standard	Standard	1774 (9Ni-91WC)	1774
Obliquity:	Normal	Normal	Normal	Normal
Round:	3	4	10	7
Velocity:	2206	2206	949	1148
Penetration:	Complete	Navy C.	Complete	Complete

51268

Plate 13

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores

1/4" FACE HARDENED PLATE

Punching

BACK

FACE

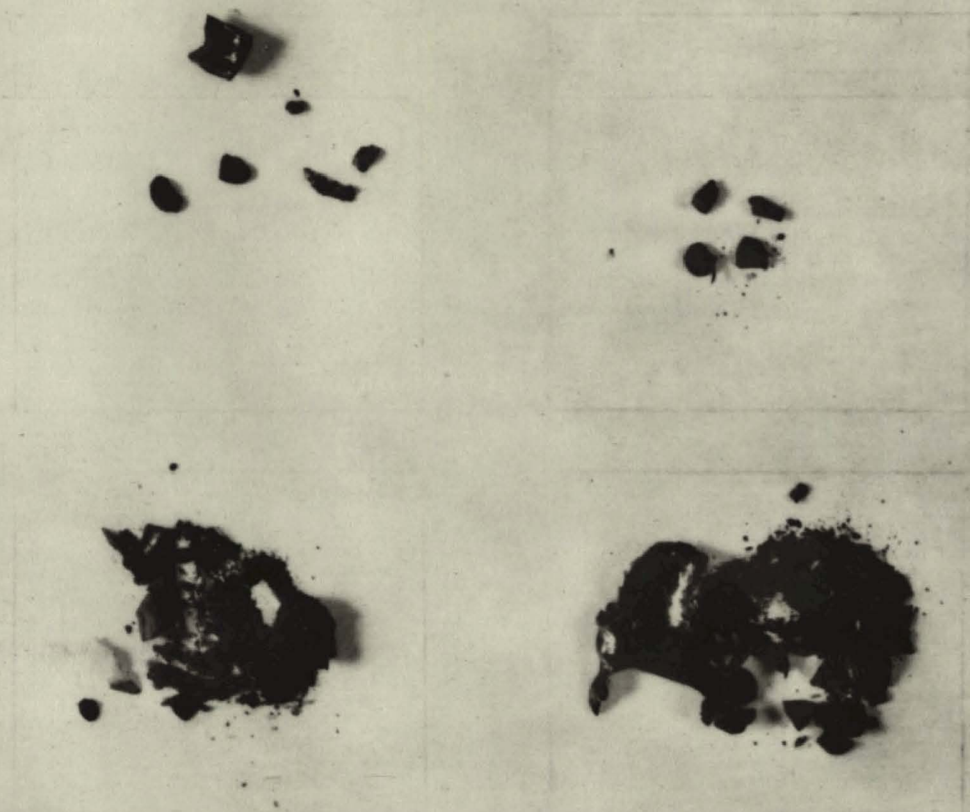


Figure:	5	6
Grade:	Standard	1774 (9Ni-91WC)
Obliquity:	20°	20°
Round:	18	14
Velocity:	2314	1253
Penetration:	Complete	Complete

51264

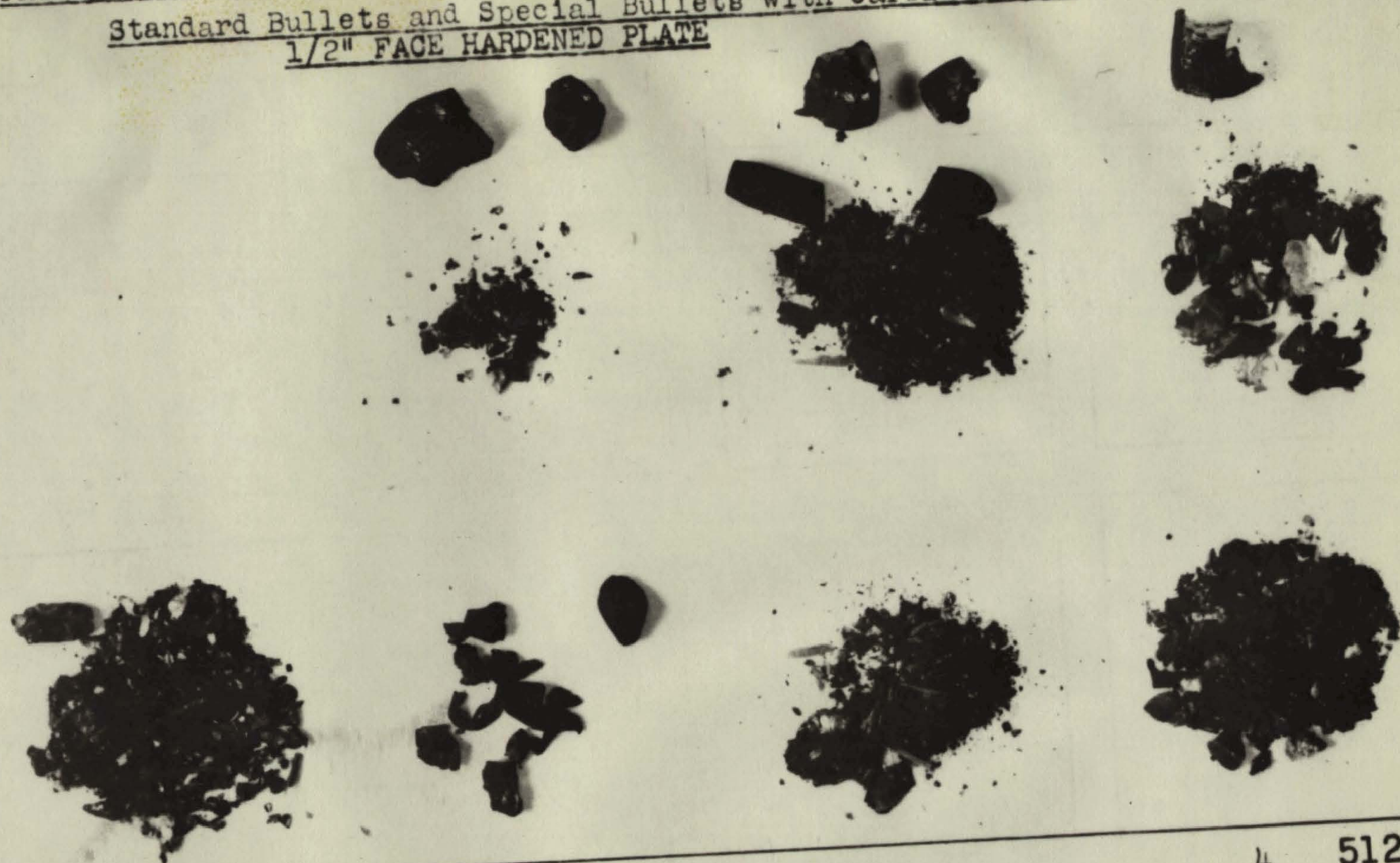
Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores
1/2" FACE HARDENED PLATE

Punching

BACK

FACE



51270

Figure:	1	2	3	4
Grade:	Standard	Standard	Standard	Standard
Obliquity:	Normal	Normal	Normal	Normal
Plate:	I	I	I	V
Round:	10	1	9	34
Velocity:	2778	3175	2793	2832
Penetration:	Partial	Complete	Navy Complete	Navy C.

Plate 15

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores

1/2" FACE HARDENED PLATE

Punching

BACK

FACE

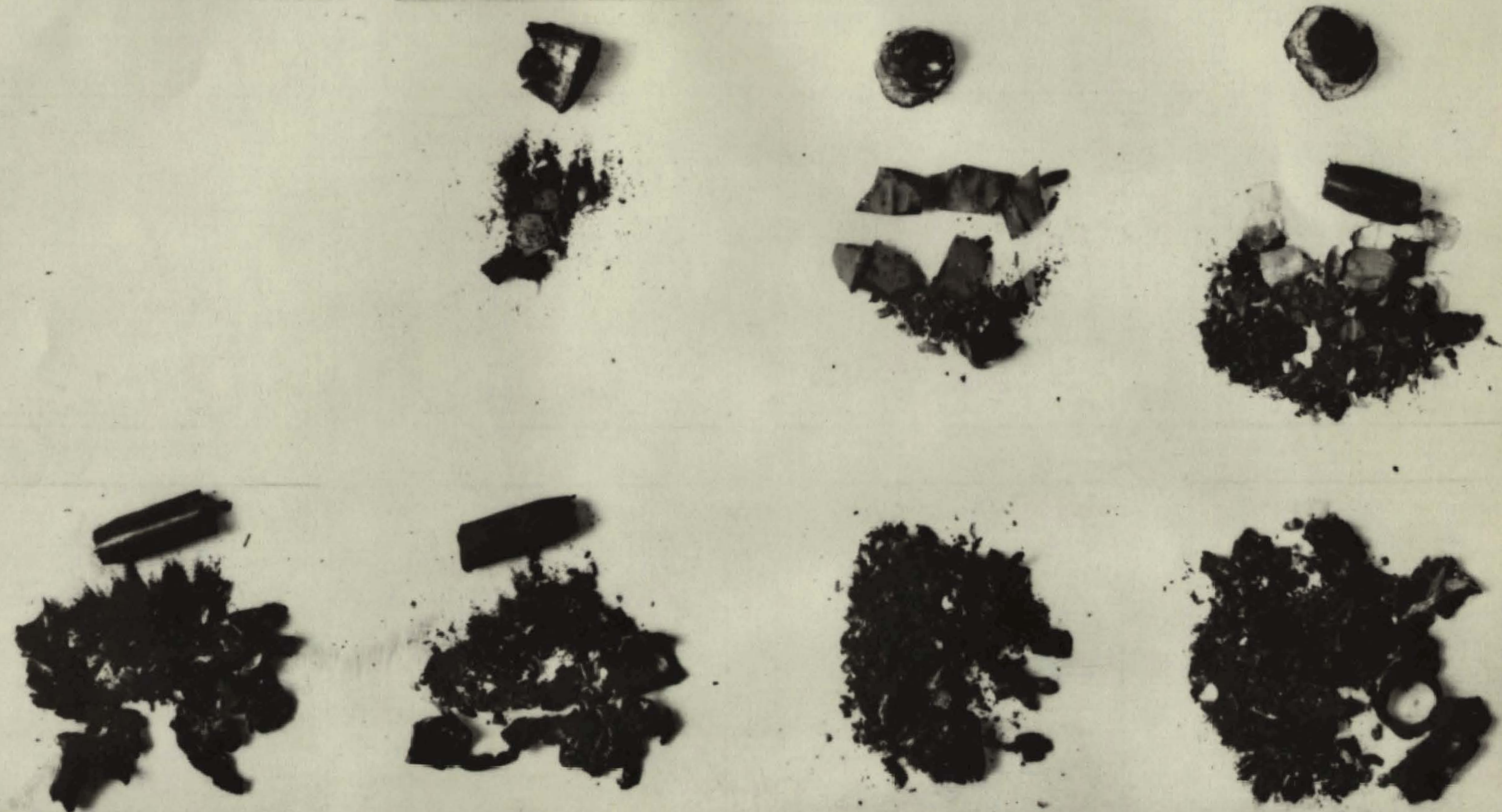


Figure:	5	6	7	8
Grade:	55A (13Co-87WC)	55A	55A	55A
Obliquity:	Normal	Normal	Normal	Normal
Plate:	I	I	I	I
Round:	20	15	13	12
Velocity:	1509	1535	1662	1803
Penetration:	Partial	Complete	Navy C.	Navy C.

51265

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2 A.P.

Standard Bullets and Special Bullets with Carbide Cores

1/2" FACE HARDENED PLATE

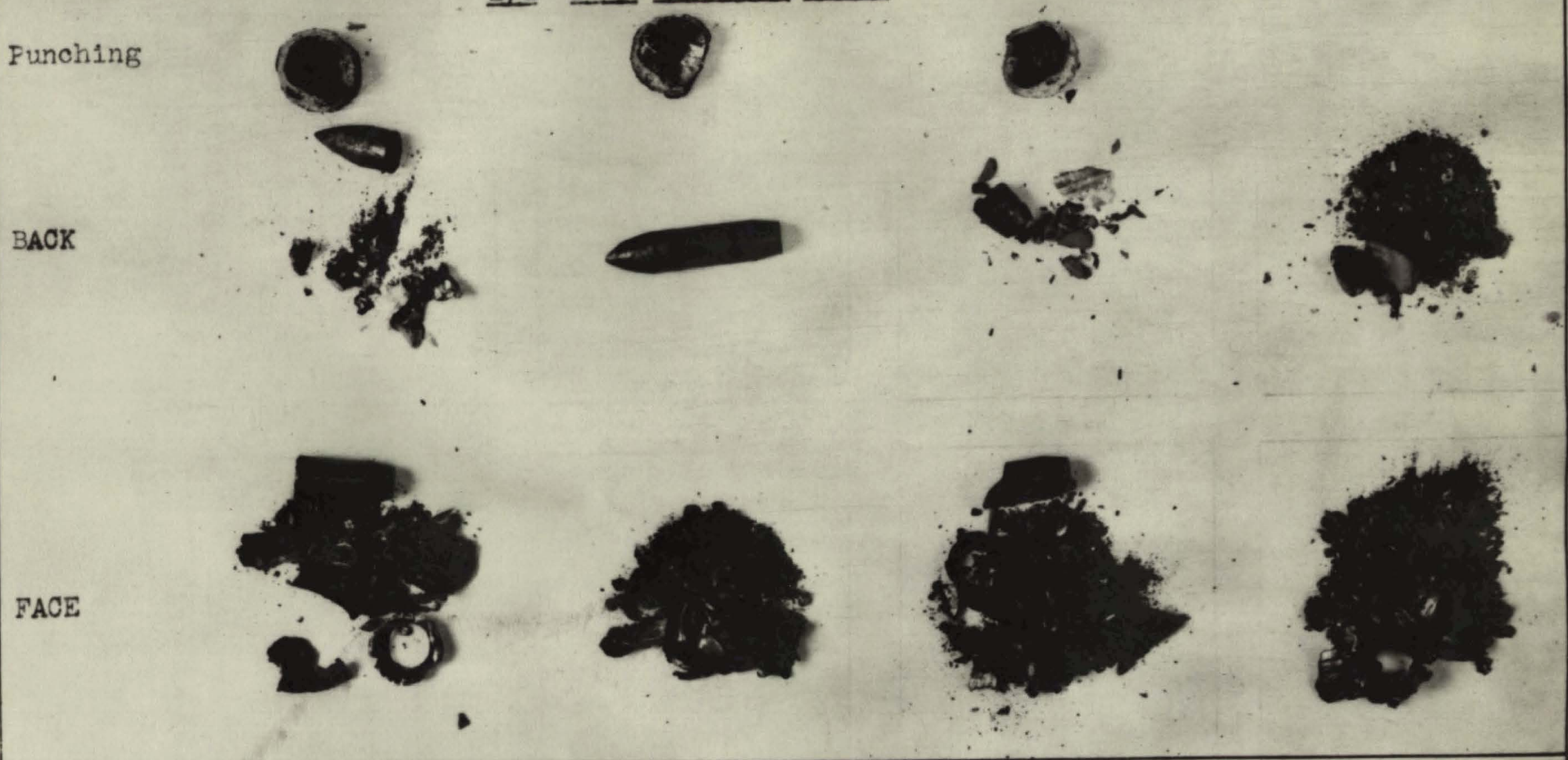


Figure:	9	10	11	12	51266
Grade:	55B (20Co-80WC)	55B	1695 (6Ni-94WC)	1695	
Obliquity:	Normal	Normal	Normal	Normal	
Plate:	I	I	V	V	
Round:	23	22	41	38	
Velocity:	1673	1736	1574	2044	
Penetration:	Complete	Navy C.	Complete	Navy C	

Plate 17

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores.
1/2" FACE HARDENED PLATE

Punching

BACK

FACE

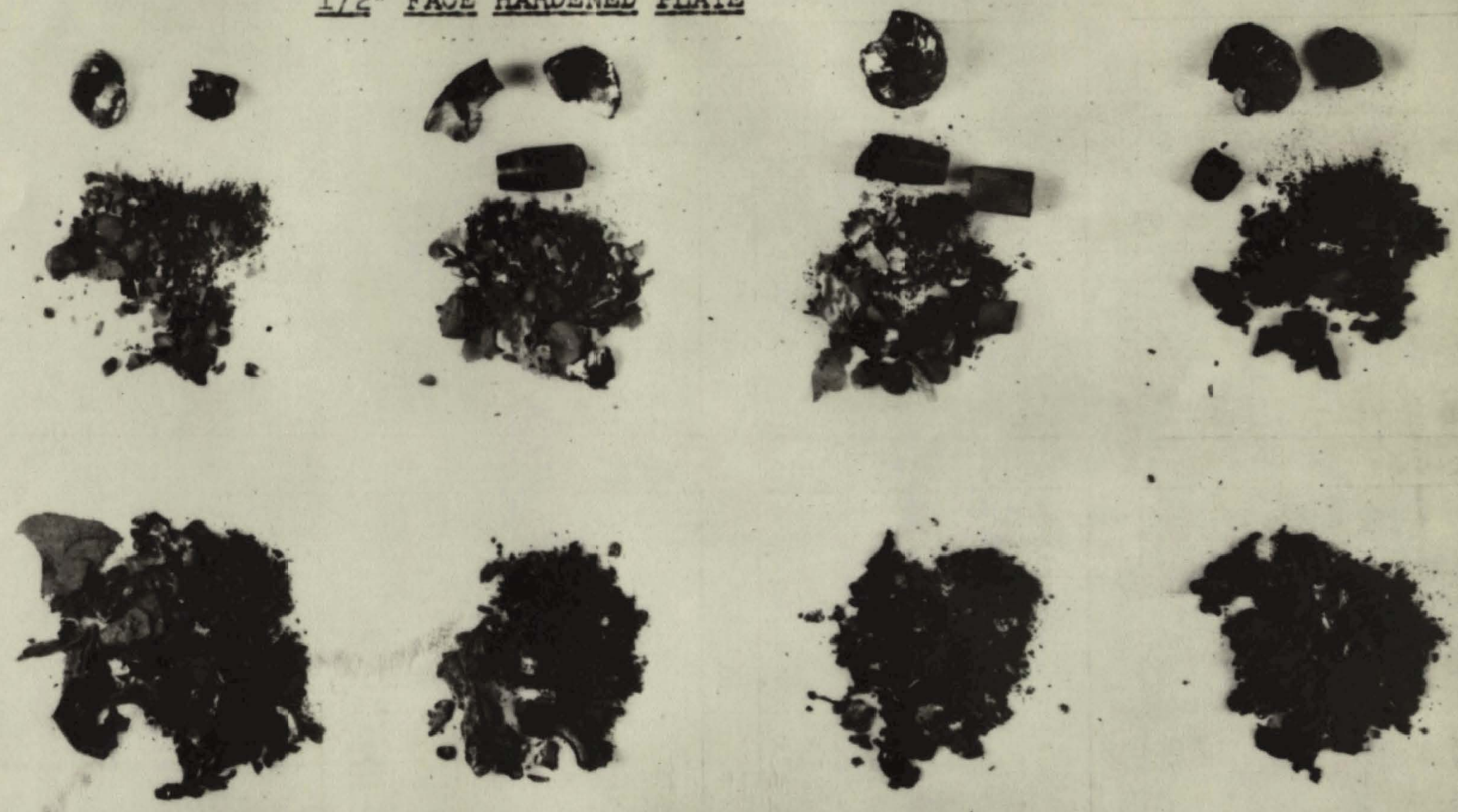


Figure:	13	14	15	16
Grade:	1774 (9Ni-91WC)	1774	1830A (13Ni-87WC)	1835
Obliquity:	Normal	Normal	Normal	Normal
Plate:	V	V	V	V
Round:	51	54	55	71
Velocity:	1644	1818	1767	2399
Penetration:	Complete	Navy C.	Navy C.	Complete

51267

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

Punching

BACK

FACE

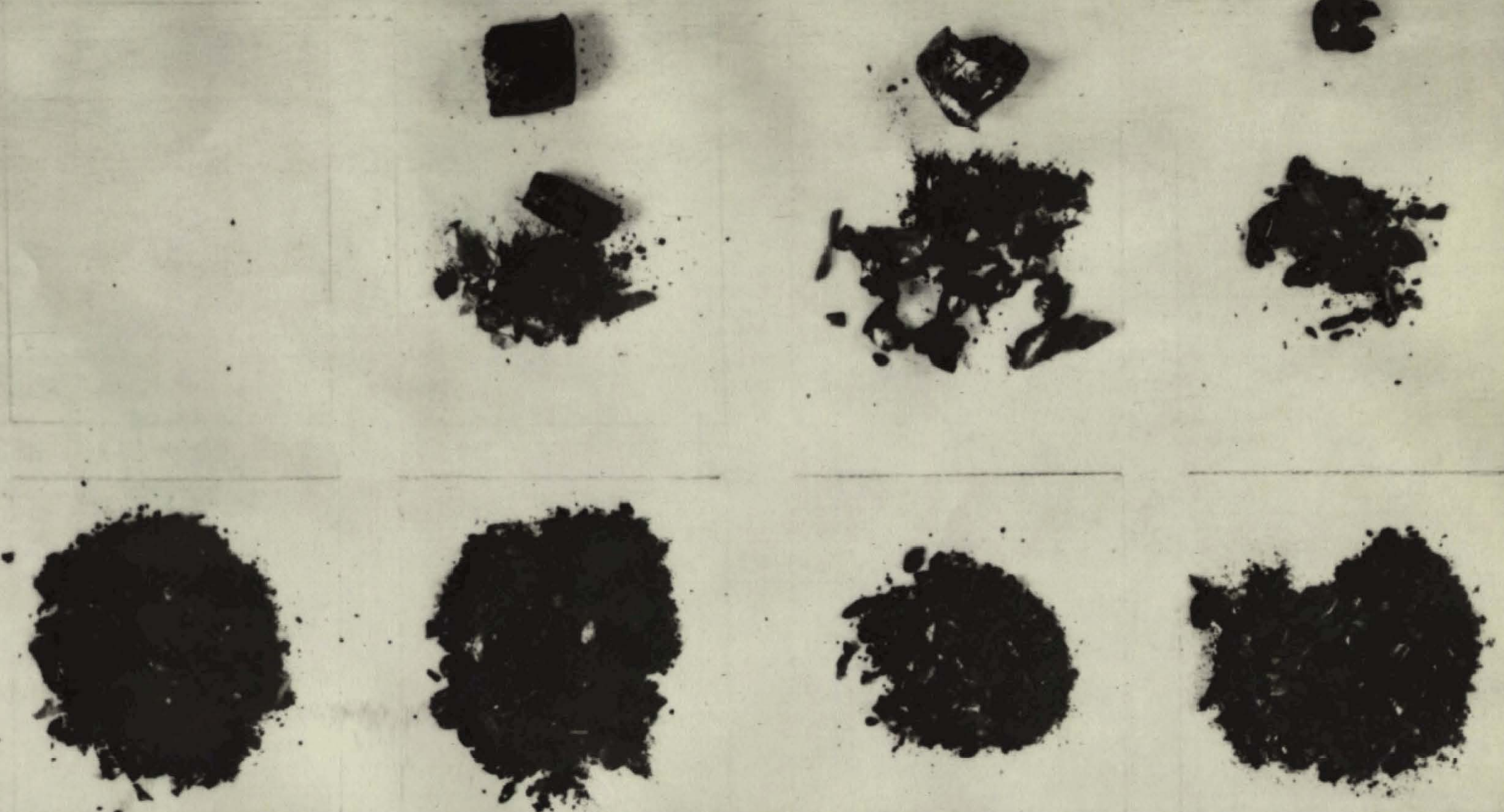


Figure:	17	18	19	20
Grade:	Standard	Standard	Standard	55A (13Co-87WC)
Obliquity:	20°	20°	20°	20°
Plate:	I	I	V	I
Round:	34	36	15	39
Velocity:	3150	3185	3210	1860
Penetration:	Partial	Navy C.	Complete	Complete

51269

Plate 19

Photographs of Fragments of Armor Plate and Bullets. Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

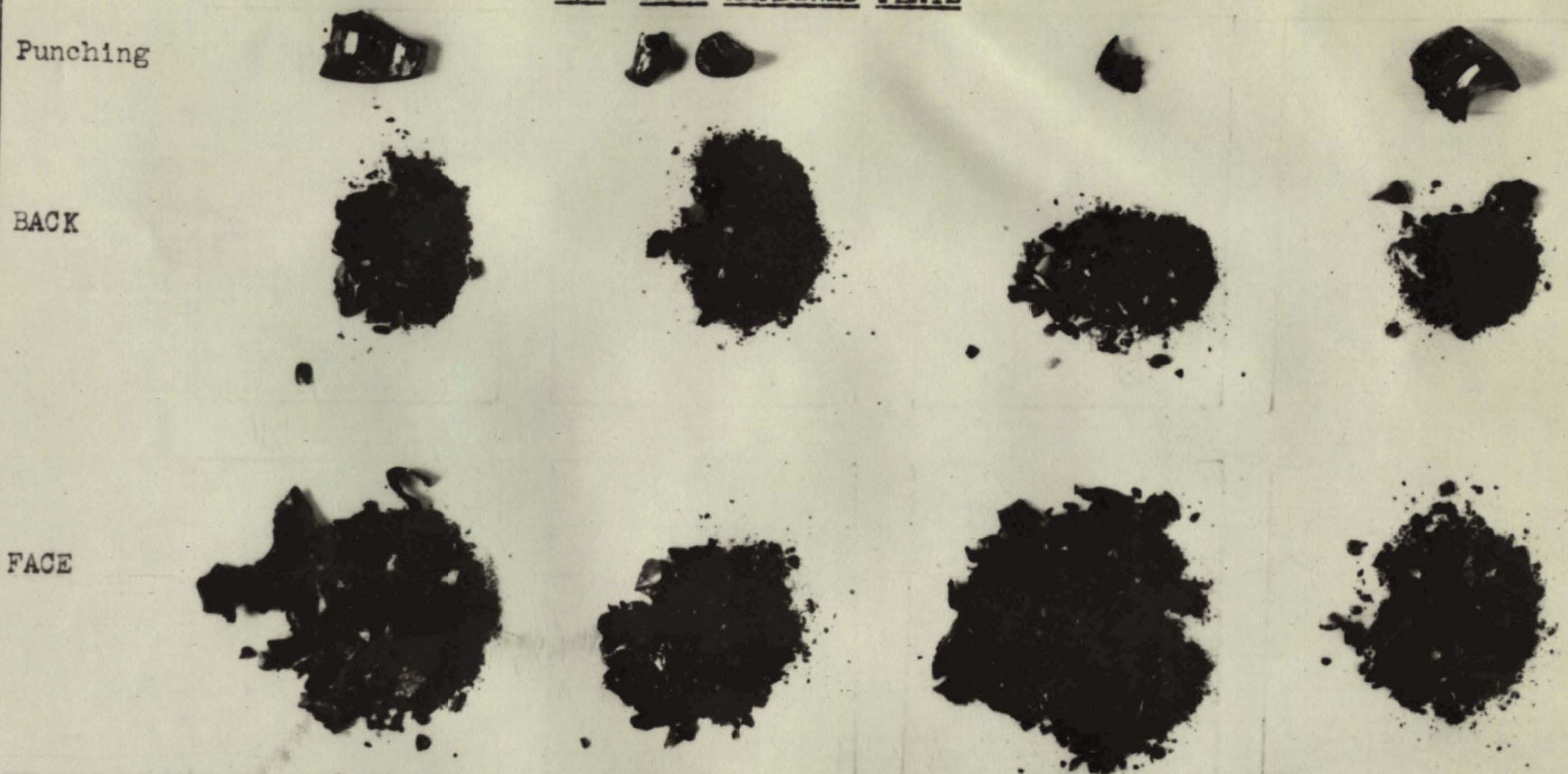


Figure:	21	22	23	24 51271
Grade:	55B (20Co-80WC)	1695 (6Ni-94WC)	1774 (9Ni-91WC)	1830A (13Ni-87WC)
Obliquity:	20°	20°	20°	20°
Plate:	I	V	V	V
Round:	45	18	10	23
Velocity:	2153	2297	2035	2566
Penetration:	Complete	Complete	Complete	Complete

Plate 20

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores.

1/2" FACE HARDENED PLATE

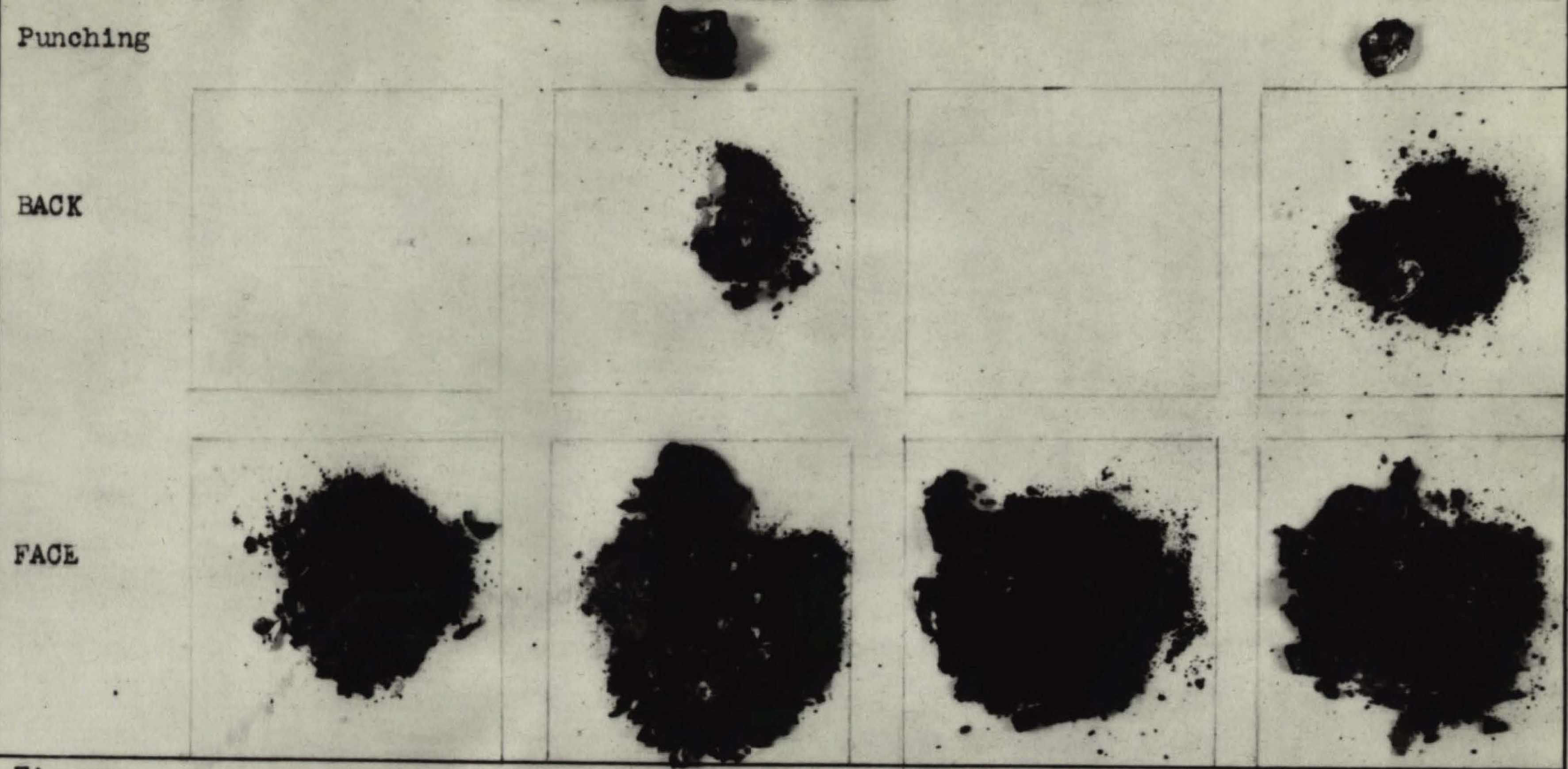


Figure:	25	26	27	28
Grade:	Standard	55B (20Co-80WC)	1774 (9Ni-91WC)	1774
Obliquity:	30°	30°	30°	30°
Plate:	V	I	V	V
Round:	1	53	7	5
Velocity:	3197	2649	2489	2633
Penetration:	Partial	Complete	Partial	Complete

51272

Plate 21

Photographs of Fragments of Armor Plate and Bullets, Caliber .30M2, A.P.

Standard Bullets and Special Bullets with Carbide Cores.

1/2" HOMOGENEOUS PLATE

Punching

BACK

FACE

(nose intact in plate)

(nose intact in plate)

Figure:	1	2	3	4
Grade:	Standard	Standard	1774 (9Ni-91WC)	1774
Obliquity:	Normal	Normal	Normal	30°
Round:	5	7	18	21
Velocity:	2210	2227	1691	2514
Penetration:	Partial	Complete	Complete	Complete

51273

Plate 22