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Problem B-11

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ARMOR PLATE - FACE HARDENED

Ballistic and Metallurgical Investigation of
Experimental Low Alloy Face Hardened Armor

OBJECT

To determine a suitable low-alloy composition for thin face hardened armor, including a comparison of the ballistic and metallurgical properties of armor from seven experimental heats of steel.

REFERENCES

This work was undertaken at the recommendation of the Subcommittee on Rolled Aircraft Armor of the Ferrous Metallurgical Advisory Board. A summary of the meeting at which the recommendation was made and other pertinent correspondence are shown as appendices.

CONCLUSIONS

1. Of the compositions studied, those steels which satisfactorily withstood all the ballistic tests were the 3% Ni-Cr-Mo and the 3% Ni-Mo types. The steels showing some promise, but whose results were not as consistent, were the 2% Ni-Mo-V and the 1-1/4% Cr-Mo-V types.

2. There was no correlation between the composition of the plates investigated and their resistance to the standard penetration and shock test. The ballistic limits of all plates were in excess of the requirements while their resistance to shock was somewhat erratic.

3. The nickel bearing steels (2-3% nickel) and the Cr-Mo-V composition were more effective in resisting the impacts of yawed caliber .50 AP M2 projectiles than the other non-nickel bearing steels.

4. The water quenched face hardened plates showed more evidence of brittleness under the shock of yawed impacts than the oil quenched plates.

5. The armor plate carburized in the liquid salt bath showed more of a tendency to face spall under the standard penetration test than the plate pack carburized at the final gage or in slab form before rolling to the final gage.

6. The following correlation between ballistic and metallurgical properties was observed:

a. The satisfactory performance of the nickel bearing steels is due to a satisfactory combination of hardness and toughness of the core associated with a uniform tempered martensitic structure.

The satisfactory performance of the Cr-Mo-V composition was due a satisfactory combination of hardness and toughness of the core and the presence of only a small amount of ferrite in a tempered martensitic structure of the core.

c. The unsatisfactory performance of the non-nickel bearing steels was generally associated with a low core hardness and segregations of ferrite in the core.

d. The tendency to face spall of the non-nickel bearing steels when carburized in liquid salt baths was associated with the presence of a large amount of undissolved carbides in the carburized case. An annealing cycle or case migration treatment prior to the ballistic heat treatment would probably eliminate this carbide condition by diffusing the carbide into the plate.

e. No correlation was found between the small amounts of retained austenite in the carburized cases of the plates and their ballistic behavior.

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INTRODUCTION

In connection with a program to determine the effect of yawed impacts of Caliber .50 armor piercing bullets on armor plate of selected low alloy compositions as outlined at the meeting of the Research Subgroup for Light Aircraft Armor, held in Philadelphia, Pa., December 3, 1941, a series of 3/8" face hardened armor plates of low alloy content were fabricated and subsequently tested and examined at Watertown Arsenal. In order to compare the effect of various carburing methods and heat treatments on the ballistic performance of this experimental armor, the services of three armor plate manufacturers were enlisted to assist in the fabrication.

Ballistic results have been reported previously, to industrial members of the Subcommittee on Rolled Armor. This report has been written in order to have a record of the complete ballistic and metallurgical study of the seven compositions referred to below.

Seven experimental ingots of various low alloy compositions were cast at Watertown Arsenal and forwarded to Henry Disston & Sons, Inc., where the greater part of each was rolled into 3/8" plate for subsequent heat treatment by other firms. The remaining acceptable product of each ingot, rolled into 1" slabs, was pack carburized by Disston and thereafter rolled into the final 3/8" gage. Of the original plate rolled into final gage without carburization, some from each ingot were processed by Diebold Safe and Lock Company, by pack carburizing the plate in its final thickness, and some from each ingot were processed by the Breeze Corporations, by liquid carburizing in a salt bath. The heat treatments used by the three fabricators were similar except for the quenching operation.

Disston quenched the plates in water or in oil depending upon the composition, Diebold oil quenched the plates, and Breeze employed a delayed oil quenching process to lessen the tendency toward face spalling. Details of the fabrication of the plates are described in Inclosure A. Plates from each of the seven heats treated by Disston were submitted in the standard size of 36"x36"x3/8", while plates from each of the seven heats treated by Breeze, were submitted as 18x18x3/8", the other portions having been consumed in the company's pilot tests.

There is shown in Table I a schedule of the experimental plates, tested and examined at Watertown Arsenal, which are considered in this report. The details of fabrication are considered in Inclosure A, and correspondence with the fabricators is contained in Appendix A.

TEST PROCEDURE

1. Ballistic Tests

Ballistic tests were conducted at Watertown Arsenal on the groups of plates treated by Disston, Diebold, and Breeze as follows:

a. First, two army ballistic limits were obtained, one at each of two opposite corners of each plate, using caliber .30 M2 plate-testing armor piercing bullets fired at normal from a conventional caliber .30 Mann barrel.

b. Second, a shock test was conducted on the center or opposite corners of each plate by the normal impact of one or two bursts of five rounds from a caliber .30 machine gun using service caliber .30 M2 armor piercing bullets.

c. Third, an army ballistic limit was obtained on the center of each plate by the yawed impacts of caliber .50 M2 plate-testing armor piercing bullets fired through tipping screens from a caliber .50 BMG M2 barrel.

In some cases, because of the absence of an undamaged area, the determination of an actual ballistic limit with yawed caliber .50 A.P. bullets was impossible on the Breeze plates, which had been submitted in the reduced size of 18"x18". Machine gun shock tests on the Breeze plates consisted of two bursts of 5 rounds each, while shock tests on the Disston and Diebold plates consisted of but one burst of 5 rounds.

The locations and positions of the tipping screens used in producing the yawed impacts of caliber .50 A.P. bullets are shown in Figure 9. Bullets traveling toward the plate were yawed or tipped in passing through the first screen, and were stabilized in their yawed or "sidewise" flight by passing through the second screen so that they struck the plate flat rather than with their points forward.

2. Metallurgical Examination

After completion of the ballistic tests, the plates were sectioned for a metallurgical study which included a layer carbon analysis through the hyper-eutectoid case on seven typical plates, a macroscopic examination, microscopic examination, fracture grain size determination on the case and core, Brinell hardness on face and back, Vickers hardness surveys taken at intervals of .020" across the thickness of the plate and modified Izod impact tests made only on plates carburized by Breeze.

Since it was desired to have the notch of the Izod specimens extend below the case of the face hardened plate samples, the case depth was measured microscopically to determine the notch depth necessary. The test bars were ground on the face to make them .365" square then notched through the case to a depth of .095". A diagram of the test specimen is shown in Figure 10.

The chemical analyses were taken from the test coupons cast from the seven heats investigated.

RESULTS AND DISCUSSION

1. Ballistic Tests

A summary of the ballistic tests is given in Table II and examples of satisfactory and poor armor plate subjected to yawed impact tests are shown in Figures 1-8 inclusive. Detailed firing records are contained in Appendix C.

a. Results of Ballistic Tests on Plates Subjected to the Standard Penetration and Shock Tests

The ballistic limits of all plates were between 75 f/s and 346 f/s in excess of the ballistic limit specified for 3/8" face hardened armor. However, several of the plates containing no nickel and one plate containing 2% nickel failed to pass the specifications for face hardened armor because of poor resistance to shock. This group of poor quality plates included the non-nickel bearing steels carburized by Breeze which exhibited undesirable face spalling, namely, Plates 564-1-2 (Cr-Mo), 566-1-2 (Cr-Mo-V), 567-1-2 (Cr-Mo-Zr), 569-1-2 (Mn-Mo), and also a series of plates carburized by Disston which spalled on the face and on the back, Plate 566 (Cr-Mo-V), and 567 (Cr-Mo-Zr). One of the nickel bearing steels carburized by Disston, Plate 571 (Ni-Mo-V) spalled on the back under the shock test.

The plates containing nickel carburized by Breeze and Diebold and the four plates 564 (Cr-Mo), 569 (Mn-Mo), 565 (Ni-Cr-Mo), and 570 (Ni-Mo) carburized by Disston passed satisfactorily the requirements of Specification AXS-490* for 3/8" face hardened armor.

b. Results of Ballistic Tests on Plates Subjected to the Yawed Impacts of Caliber .50 AP M2 Projectiles

Armor plate made from Heats 565 (Ni-Cr-Mo), 566 (Cr-Mo-V), 570 (Ni-Mo), and 571 (Ni-Mo-V) exhibited properties far superior to those plates from other Heats 564 (Cr-Mo), 567 (Cr-Mo-Zr), and 569 (Mn-Mo). The ballistic limits of these satisfactory plates were from 300 f/s to 780 f/s higher than those of the poor plates, whereas the exit diameters were generally much smaller than those observed in the poor quality plates. There were a few exceptions, for some undesirably large exit diameters were observed in Plates 566, 570, and 571, carburized and heat treated by Disston. It may be significant that two of these plates, Nos. 570 and 571, had been water quenched.

2. Metallurgical Examination

a. Chemical Analyses

Chemical analyses taken from test coupons cast from the seven heats investigated are given in Table III.

*AXS-490 - Specification for 1/4" to 1-1/8" Rolled Face Hardened Armor Plate, September 27, 1940.

b. Carbon Distribution in the Carburized Case

The carbon distribution through the cases of the seven plates, selected as representative from sixteen plates tested and examined, is given in Table IV.

Results of carbon analyses indicate that the carbon content near the face is much greater in the plates carburized by Breeze than in those carburized by Diebold or Disston. Plate 565-1 carburized by Diebold had a very shallow depth of case. This was confirmed by the Vickers hardness survey as shown in Figure 16.

c. Macrostructure

A study of the macro-etched sections indicates that Plates 569 and 569-1-2 (Mn-Mo) showed evidence of a pronounced segregation of elongated nonmetallic inclusions while the remaining series of plates were relatively free from segregated nonmetallics, see Figure 11. All plates have been thoroughly cross rolled as shown in Figure 11 which reveals the similar etching characteristics in both the longitudinal and transverse directions, indicating the degree of cross rolling.

d. Microstructure

The results of the microscopic examination of the case and core, depth of case, and amount of decarburization are summarized in Table V. Typical photomicrographs of plates carburized by the three fabricators, Disston, Diebold, and Breeze, taken at .010", and .025" from the face and one from the core are shown in Figures 13, 14, and 15. Although not all photomicrographs are described in detail, they were included in order to make the study complete.

With the exception of plates made from Heat 569 (Mn-Mo) which contained undesirable stringers of nonmetallic inclusions, the balance of the heats, Nos. 564 (Cr-Mo), 565 (Ni-Cr-Mo), 566 (Cr-Mo-V), 567 (Cr-Mo-Zr), 570 (Ni-Mo), and 571 (Ni-Mo-V) were relatively free from elongated nonmetallic inclusions, see Figure 12.

There is no correlation between the ballistic performance of the plates and the small amount of retained austenite in the carburized cases. Austenite is revealed as a white constitutent present as shown in the photomicrographs taken at .010" and .025" from the surface of the carburized plates, see Figures 13, 14, and 15.

There were many more undissolved carbides in the carburized cases of the plates face hardened by the Breeze Corporations than in the plates face hardened by the Henry Disston and Sons, Inc. See Figures 13A, D, G, J, and 15A, E, H, and K. This may be accounted for by the fact that the plates carburized by Disston are rolled and annealed after carburizing, thus causing a diffusion of carbon from the surface layers of the plate. It is believed that a diffusion or case migration treatment given to the plates carburized by Breeze would have eliminated this excessive undissolved carbide condition and hence would have reduced the brittleness in the carburized faces which resulted in face spalling, especially in those plates containing no nickel.

In Figure 15C is shown the hard light-etching martensitic structure found at .040" beneath the surface of the plates carburized by Breeze. This formation of an outer case .030" deep was more or less prominent in all the plates carburized by Breeze.

The two Diebold Plates 565-1 (Ni-Cr-Mo) and 570-1 (Ni-Mo) had a relatively shallow case as a result of the short carburizing cycle employed, but the ballistic properties of these two plates were very satisfactory. In the sixteen plates examined the case depth varied from 15% to 32% of the plate thickness, indicating that face hardened armor may have wide variations in case depth and still possess acceptable ballistic properties.

The microstructure of the core of the plates 565, 565-1, and 565-1-2 (Ni-Cr-Mo) and 570-1 and 570-1-2 (Ni-Mo) containing 3% nickel which exhibited superior resistance to the yawed impacts consisted of a uniform tempered martensitic structure with no evidence of ferrite present. (See Figures 13-O, 14C, F, and 15P, S.) The plates containing 2% nickel, Nos. 571, 571-1-2, and one plate (No. 566-1-2) from the Cr-Mo-V heat had fairly good ballistic properties under yawed impacts although there was some free ferrite present in the core. (See Figures 13U, 15V, and 15G.) Plates from the remaining three heats (Cr-Mo), (Cr-Mo-Zr), and (Mn-Mo) which were unsatisfactory when subjected to yawed impacts contained much more ferrite in the core and by the same token were relatively lower in hardness. (See Figures 13C, I, L, 15D, J, and M.) On this basis, however, the ballistic properties of the unsatisfactory plate No. 570 (3% Ni-Mo) could not be readily explained since it contained a uniform martensitic structure in the core accompanied by a fairly high core hardness, see Figure 13R. In this connection it was observed that the Disston water quenched plates were more brittle than the oil quenched plates.

e. Shepherd Fracture Grain Size

The results of a comparison between the fracture grain size of the case and core of plates in the heat treated condition with the Shepherd Fracture Grain Size Standards* are given in Table V.

The fracture grain size of the armor plate having satisfactory ballistic properties varied from 6-9 in the core whereas a grain size of 4-7 was observed in the core of the plates having poor resistance to yawed impacts. The carburized cases of all plates exhibited a fine grain structure.

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*Metals Handbook, 1939 edition, pages 652-654.

f. Mechanical Tests

(1) Brinell Hardness

Brinell hardness tests were made by the fabricators and by Watertown Arsenal on both the face and back of the plates studied. Low hardness values reported by the fabricating companies probably resulted from their failure to remove the decarburization. Decarburization was especially pronounced in most of the plates treated by Disston. A comparison of the Brinell hardness values reported by the fabricators and those determined at Watertown Arsenal is given in Table V.

(2) Vickers Hardness Surveys

Vickers hardness surveys taken across sections through the plate shown in Figure 16, indicate the case depth, the maximum case hardness, and the core hardness. Plates carburized by Diebold had a relatively shallow case without adversely affecting the ballistics. The core hardnesses in the nickel steels are consistently higher than in the non-nickel steels.

(3) Impact Tests

The results of the impact tests which are in Table V indicate that the Izod impact values of the nickel bearing steels are somewhat higher than those of the non-nickel bearing steels. It should be noted also that the hardness of the nickel bearing steels is relatively higher than that of the non-nickel bearing steels.

There is some question as to the significance of these impact data since the "V" notches of certain test specimens do not extend entirely through the hardened case into the core of the plate as had been planned. Notch depths had been specified on the basis of a microscopic determination of case depth. Subsequent Vickers hardness surveys indicated the case hardening to extend beyond the depth shown microscopically and, in some cases, beyond the vertices of the "V" notches. It is possible that this condition would influence the impact energies reported.

TABLE I

Schedule of the Experimental Plates Tested and Examined

at Watertown Arsenal

STEEL		Serial Numbers of 3/8" Face Hardened Test Plates		
W.A. Heat No.	Type	Carburized and Heat Treated by Henry Disston & Sons, Inc.	Carburized and Heat Treated by Diebold Safe and Lock Co.	Carburized and Heat Treated by Breeze Corp.
564	Cr-Mo	564		564-1-2
565	Ni-Cr-Mo	565	565-1	565-1-2
566	Cr-Mo-V	566		566-1-2
567	Cr-Mo-Zr	567		567-1-2
569	Mn-Mo	569		569-1-2
570	Ni-Mo	570	570-1	570-1-2
571	Ni-Mo-V	571		571-1-2

TABLE II

Summary of Ballistic Tests of 3/8" Low Alloy Experimental Armor Pla

Detailed Firing Records - See Appendix C

Plate #	Type	Thickness Inches Nom.	Thickness Inches Act.	Reported Brinell Hardness Face	Reported Brinell Hardness Back	Ballistic Limit F/S Normal Cal..30 APM2	Specified Ballistic Limit F/S for Thickness Specified	Shock Test MG Fire* Cal..30 APM2 Striking Velocity Service Max. Exit Diameter	Yawed Impacts Cal. .50 AP M2 Ballistic Limit F/S	Yawed Impacts Cal. .50 AP M2 Striking Velocity F/S
564 Disston	Cr-Mo	.375	.370	601	321	2540 2564 2552Av. No Spalls	2238 +314	7/16x7/16" No Spalls	1566	-
564-1-2 Breeze	Cr-Mo	.375	.382	627	277	2585 2432 2509Av. 1"x7/8" Face Spall	2267 +242	1/2"x3/8" No Spalls	-	2204, CP, PT 1-1/2x2-5/8" back spall. 2197, CP, PT Exit diamete 1-7/8x1-7/8" 2211, CP -PT
565 Disston	Ni-Cr-Mo	.375	.368	601	415/429	2325 2296 2311Av.	2234 + 77	1/2"x1/2" Slight Back Spalls	2286	-
565-1 Diebold	Ni-Cr-Mo	.375	.387	601/627	415/444	2495 2565 2530Av. No Spalls	2279 +251	7/16"x3/8" No Spalls	2380	-
565-1-2 Breeze	Ni-Cr-Mo	.375	.389	555	429	2358 2358 2358Av. No Spalls	2284 + 74	9/16x7/16" No Spalls	Approx. 2203	2209 PP 2203 CP
566 Disston	Cr-Mo-V	.375	.378	627	285/293	2536 2549 2543Av. 3/4x3/4"Face Spall	2257 +286	1/2x3/8" 1/2x5/8" Back Spall	1911	-
566-1-2 Breeze	Cr-Mo-V	.375	.40[illegible]	653	363	2502 2647 2575Av. 1-3/4x1-3/4" Face Spalls	2302 +273	9/16x1/2" 1-1/2"x1-5/16" Face Spall	2199	2208 3-3/4"dia. Concentric face crack
567 Disston	Cr-Mo-Zr	.375	.367	627	255/277	2375 2350 2363Av. No Spalls	2231 +132	1/2x3/8" Large Back Spall Starting	1600	-
567-1-2 Breeze	Cr-Mo Zr	.375	.379	601	277	2462 2419 2441Av. 1"x1" Face Spall	2260 +181	7/8x1/2" No Spalls	-	2211 CP, PT 2203 CP, PT 2-1/8x2"exi diameter. 2197 CP, PT 1-3/4x1-7/8 exit diamet
569 Disston	Mn-Mo	.375	.372	601	302/321	2445 2312 2379Av. No Spalls	2243 +136	3/8x7/16" No Spalls	1503	-
570						2450 2507	2267	1/2"x1/2"		[illegible] CP, PT 2196 CP - 1 3/16" exit

TABLE II

tic Tests of 3/8" Low Alloy Experimental Armor Plate

ailed Firing Records - See Appendix C

pecified allistic imit F/S for hickness pecified	Shock Test MG Fire* Cal..30 APM2 Striking Velocity Service Max. Exit Diameter	Yawed Impacts Cal. .50 AP M2 Ballistic Limit F/S	Striking Velocity F/S	Maximum Exit Diameter Yawed Impacts	Remarks
2238 +314	7/16x7/16" No Spalls	1566	-	2"x1-3/4" 1/2"crack	Unsatisfactory - Yawed impact, Cal..50 APM2. Satisfactory under standard ballistic test.
2267 +242	1/2"x3/8" No Spalls	-	2204, CP, PTP. 1-1/2x2-5/8" back spall. 2197, CP, PTP. Exit diameter 1-7/8x1-7/8". 2211, CP -PTP.	2-7/8x2"	Unsatisfactory under yawed impact Cal..50APM2 Unsatisfactory under standard ballistic test.
2234 + 77	1/2"x1/2" Slight Back Spalls	2286	-	1-1/8"x3/8" 3/4"x2"cracks	Satisfactory under yawed impacts Cal..50 APM2. Satisfactory under standard ballistic test.
2279 +251	7/16"x3/8" No Spalls	2380	-	1-1/2&2" cracks CP - LB	Satisfactory under yawed impacts, Cal..50 APM2. Satisfactory under standard ballistic test.
2284 + 74	9/16x7/16" No Spalls	Approx. 2203	2209 PP 2203 CP	$1\frac{1}{2}$"x$1\frac{1}{2}$"	Satisfactory under yawed impacts Cal..50 APM2. Satisfactory under standard ballistic test.
2257 +286	1/2x3/8" 1/2x5/8" Back Spall	1911	-	$2\frac{1}{2}$x2" 2" cracks	Unsatisfactory under yawed impactsCal..50APM2. Unsatisfactory under standard ballistic test.
2302 +273	9/16x1/2" 1-1/2"x1-5/16" Face Spall	2199	2208 3-3/4"dia. Concentric face cracks.	$1\frac{1}{2}$x$1\frac{1}{2}$"	Satisfactory under yawed impacts Cal..50 AP M2. Unsatisfactory under standard ballistic test.
2231 +132	1/2x3/8" Large Back Spall Starting	1600	-	3-1/2x2-1/2" 1-1/4" crack thru plate.	Unsatisfactory under yawed impacts Cal..50APM2 Unsatisfactory under standard ballistic test.
2260 +181	7/8x1/2" No Spalls	-	2211 CP, PTP. 2203 CP, PTP. 2-1/8x2"exit diameter. 2197 CP, PTP. 1-3/4x1-7/8" exit diameter.	2-3/4x1-5/8" Excessive Back Spalls	Unsatisfactory under yawed impactsCal..50APM2. Unsatisfactory under standard ballistic test.
2243 +136	3/8x7/16" No Spalls	1503	-	2-1/8x1-1/4" 2"Crack	Unsatisfactory under yawed impactsCal..50APM2. Satisfactory under standard ballistic test.
2267 +212	1/2"x1/2" No Spalls	-	2209 CP, PTP. 2196 CP - 1"x 3/16" exit diameter. 2205CP	3"x3-1/2"	Unsatisfactory under yawed impactsCal..50APM2. Unsatisfactory under

						Face Spalls				face cracks
567 Disston	Cr-Mo-Zr	.375	.367	627	255/277	2375 2350 2363Av. No Spalls	2231 +132	1/2x3/8" Large Back Spall Starting	1600	-
567-1-2 Breeze	Cr-Mo Zr	.375	.379	601	277	2462 2419 2441Av. 1"x1" Face Spall	2260 +181	7/8x1/2" No Spalls	-	2211 CP, PTP 2203 CP, PTP 2-1/8x2"exit diameter. 2197 CP, PTP 1-3/4x1-7/8" exit diamete
569 Disston	Mn-Mo	.375	.372	601	302/321	2445 2312 2379Av. No Spalls	2243 +136	3/8x7/16" No Spalls	1503	-
570 Disston	Mn-Mo	.375	.382	601	375	2450 2507 2479 Av. 1"x1-1/8" Face Spall	2267 +212	1/2"x1/2" No Spalls	-	2209 CP, PTP 2196 CP - 1" 3/16" exit di- ameter. 2205 PTP. 2-7/8x1-
570 Disston	Ni-Mo	.375	.390	601/627	401/415	2449 2409 2429Av. No Spalls	2286 +143	7/16x3/8" No Spalls	2036	-
570-1 Diebold	Ni-Mo	.375	.380	578/627	363/401	2275 2496 2386Av. No Spalls	2262 +124	9/16x3/8" No Spalls	2175 2183	-
570-1-2 Breeze	Ni-Mo	.375	.384	601	415	2442 2441 2442Av. No Spalls	2272 +170	1/2"x3/8" No Spalls	-	2204 CP, PTP Back spall 1-1/8x3/4". 2197 CP, PTP 2-3/4"diamete Concentric cracks.
571 Disston	Ni-Mo-V	.375	.370	627	331/341	2545 2623 2584Av. No Spalls	2238 +346	1-3/8"x1" Face Spall	1930	-
571-1-2 Breeze	Ni-Mo-V	.375	.380	601	321	2508 2447 2478Av. No Spalls	2262 +216	1/2x7/16" No Spalls	Approx. 2199	2199 CP, LB. $1\frac{1}{2}$" crack. 2205 CP, LB. 3/4"crack in rear.

NOTE: CP - Complete Penetration
PTP - Projectile through Plate
LB - Large Bulge

NOTE: Plates considered unsatisfactory under yawe
exceeds 1-1/2"x1-1/4".

*The Disston and Diebold plates were subject
The Breeze plates were subjected to 10 rour

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Face Spall		[illegible] face cracks.		standard ballistic test.
1/2x3/8" [La]rge Back Spall Starting	1600	–	3-1/2x2-1/2" 1-1/4" crack thru plate.	Unsatisfactory under yawed impacts Cal..50APM2 Unsatisfactory under standard ballistic test.
7/8x1/2" No Spalls	–	2211 CP, PTP. 2203 CP, PTP. 2-1/8x2"exit diameter. 2197 CP, PTP. 1-3/4x1-7/8" exit diameter.	2-3/4x1-5/8" Excessive Back Spalls	Unsatisfactory under yawed impactsCal..50APM2. Unsatisfactory under standard ballistic test.
3/8x7/16" No Spalls	1503	–	2-1/8x1-1/4" 2"Crack	Unsatisfactory under yawed impactsCal..50APM2. Satisfactory under standard ballistic test.
1/2"x1/2" No Spalls	–	2209 CP, PTP. 2196 CP - 1"x 3/16" exit diameter. 2205CP PTP. 2-7/8x1-5/8" [illegible]	3"x3-1/2"	Unsatisfactory under yawed impactsCal..50APM2. Unsatisfactory under standard ballistic test.
7/16x3/8" No Spalls.	2036	–	2-3/4x2-1/8"	Unsatisfactory under yawed impacts,Cal..50AP M2. Satisfactory under standard ballistic test.
9/16x3/8" No Spalls	2175 2183	–	1-1/2x1-1/4" 2" crack	Satisfactory under yawed impacts,Cal..50APM2. Satisfactory under standard ballistic test.
1/2"x3/8" No Spalls	–	2204 CP, PTP Back spall 1-1/8x3/4". 2197 CP, PTP. 2-3/4"diameter. Concentric cracks.	2"x1/2"	Satisfactory under yawed impacts, Cal..50 AP M2. Satisfactory under standard ballistic test.
1-3/8"x1" Face Spall	1930	–	2-1/8x1-1/4" 1" crack thru plate	Unsatisfactory under yawed impacts,Cal..50AP M2. Unsatisfactory under standard ballistic test.
1/2x7/16" No Spalls	Approx. 2199	2199 CP, LB. 1½" crack. 2205 CP, LB. 3/4"crack in rear.	2-1/4"diam. Concentric face cracks.	Satisfactory under yawed impacts, Cal..50 AP M2. Satisfactory under standard ballistic test.

[Pl]ates considered unsatisfactory under yawed impact when maximum exit diameter [ex]ceeds 1-1/2"x1-1/4".

[Th]e Disston and Diebold plates were subjected to 5 rounds, Cal..30 APM2 MG Fire.
[Th]e Breeze plates were subjected to 10 rounds of Cal..30 AP M2 MG Fire.

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TABLE III

Chemical Compositions of the Seven Experimental Armor Plate Heats

Heat No.	Type	C	Mn	P	S	Si	Ni	Cr	Mo	V	Zr
564	Cr-Mo	.23	.41	.009	.022	.22	---	.76	.34	---	-
565	Ni-Cr-Mo	.23	.53	.010	.019	.23	3.05	1.36	.36	---	-
566	Cr-Mo-V	.24	.45	.013	.021	.24	---	1.27	.56	.17	-
567	Cr-Mo-Zr	.22	.83	.014	.025	.88	---	.69	.17	---	.18
569	Mn-Mo	.22	1.38	.025	.033	.27	---	---	.425	---	-
570	Ni-Mo	.23	.49	.010	.023	.21	3.33	---	.45	---	-
571	Ni-Mo-V	.22	.51	.007	.018	.31	2.09	---	.29	.115	-

TABLE IV

Layer Carbon Analyses tc a Depth of 3/32" through

Carburized Cases of Seven Test Plates

Plate #	Type	Distance below Surface: 1st Cut 1/64"	2nd Cut 1/32"	3rd Cut 3/64"	4th Cut 1/16"	5th Cut 5/64"	6th Cut 3/32"	Ballistic Behavior under Cal. .50 A.P. M2 Yawed Impacts
564 Disston	Cr-Mo	.73	.62	.53	.42	.33	.30	Unsatisfactory
564-1-2 Breeze	Cr-Mo	.92	.87	.77	.50	.42	.40	Unsatisfactory
565 Disston	Ni-Cr-Mo	.60	.50	.42	.39	.36	.40	Satisfactory
565-1 Diebold	Ni-Cr-Mo	.71	.60	.47	.29	.27	.26	Satisfactory
565-1-2 Breeze	Ni-Cr-Mo	.89	.82	.58	.46	.35	.29	Satisfactory
569-1-2 Breeze	Mn-Mo	.91	.87	.75	.55	.39	.32	Unsatisfactory
571 Disston	Ni-Mo-V	.62	.66	.62	.49	.37	.29	Unsatisfactory

TABLE V

Summary of Metallurgical and Physical Properties of

3/8" Low Alloy Experimental Armor Plate

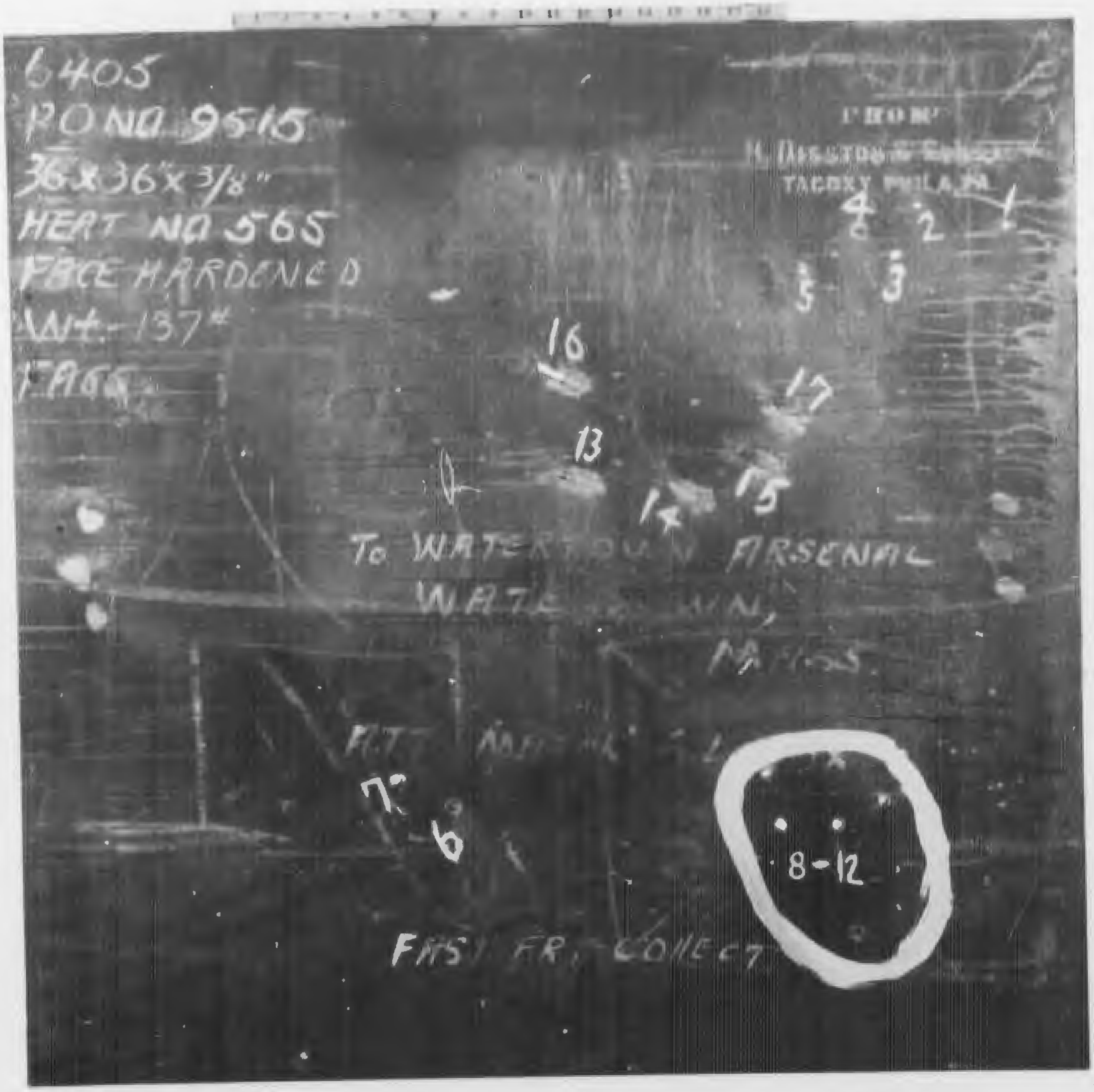
Plate #	Type	METALLURGICAL PROPERTIES							PHYSICAL		
		Structure of Case	Structure of Core	Depth of Case		Total Depth of Decarburization	Shepherd Fracture Grain Size		Brinell Hardness		
				From Hardness Survey	From Micro Survey		Case	Core	Case		Co
									Reported	W.A.	Reported
564 Disston	Cr-Mo	Martensite, some carbides and austenite.	Low carbon martensite with some ferrite.	.110"	.100"	.060"	8	6	601	653	321
564-1-2 Breeze	Cr-Mo	Martensite and excess carbides.	Low carbon martensite and some ferrite.	.100"	.095"	very little	8	4-5	627	653	277
565 Disston	Ni-Cr-Mo	Martensite, some carbides, and austenite.	Low carbon martensite.	.125"	.090"	very little	9	8	601	601	415/429
565-1 Diebold	Ni-Cr-Mo	Martensite and a few carbides.	Low carbon martensite.	.075"	.060"	very little	8	7	601/627	601	415/444
565-1-2 Breeze	Ni-Cr-Mo	Martensite and some carbides.	Low carbon martensite.	.125"	.075"	very little	9	9	555	653	429
566 Disston	Cr-Mo-V	Martensite and a few carbides.	Low carbon martensite and little ferrite.	.115"	.100"	.025"	8	7	627	601	285/293
566-1-2 Breeze	Cr-Mo-V	Martensite and excess carbides.	Low carbon martensite and some ferrite.	.105"	.085"	.010"	9	7	653	712	363
567 Disston	Cr-Mo-Zr	Martensite, some carbides and austenite.	Low carbon martensite and ferrite.	.100"	.085"	.070"	8	5&7	627	653	255/277
567-1-2 Breeze	Cr-Mo-Zr	Martensite and excess carbides.	Low carbon martensite and ferrite.	.100"	.085"	.030"	7	4&7	601	653	277
569 Disston	Mn-Mo	Martensite and some carbides.	Low carbon martensite and much ferrite.	.115"	.105"	.040"	8	5&6	601	627	302/321
569-1-2 Breeze	Mn-Mo	Martensite, some carbides, and austenite.	Low carbon martensite and some ferrite.	.115"	.095"	very little	8	7	601	653	375
570 Disston	Ni-Mo	Martensite, carbides, and some austenite.	Low carbon martensite.	.120"	.085"	.010"	8	8	601/627	601	401/415
570-1 Diebold	Ni-Mo	Martensite and some carbides.	Low carbon martensite.	.055"	.050"	very little	8	8	578/627	601	363/401
570-1-2 Breeze	Ni-Mo	Martensite, some carbides, and austenite.	Low carbon martensite	.110"	.075"	very little	8	8	601	601	415
571 Disston	Ni-Mo-V	Martensite and some carbides.	Low carbon martensite with a little ferrite.	.120"	.090"	.030"	8	8	627	653	331/341
571-1-2 Breeze	Ni-Mo-V	Martensite, some carbides, and austenite.	Low carbon martensite with some ferrite.	.100"	.085"	very little	8	6	601	682	321

2

TABLE V

Metallurgical and Physical Properties of
Low Alloy Experimental Armor Plate

PERTIES				PHYSICAL PROPERTIES						
Case From Micro Survey	Total Depth of Decarburization	Shepherd Fracture Grain Size		Brinell Hardness				Izod Impact Using Modified Notched Bar		Ballistics Cal..50 AP M2 Yawed Impacts
				Case		Core		Longitudinal Ft/Lbs.	Transverse Ft/Lbs.	
		Case	Core	Reported	W.A.	Reported	W.A.			
.100"	.060"	8	6	601	653	321	363	-	-	Poor
.095"	very little	8	4-5	627	653	277	269	9.9	9.9,9.6	Poor
.090"	very little	9	8	601	601	415/429	429	-	-	O.K.
.060"	very little	8	7	601/627	601	415/444	444	-	-	O.K.
.075"	very little	9	9	555	653	429	401	15.0	14.9 11.9	O.K.
.100"	.025"	8	7	627	601	285/293	321	-	-	Poor
.085"	.010"	9	7	653	712	363	388	13.0,11.3	5.8	O.K.
.085"	.070"	8	5&7	627	653	255/277	269	-	-	Poor
.085"	.030"	7	4&7	601	653	277	277	11.0,9.7	9.0	Poor
.105"	.040"	8	5&6	601	627	302/321	341	-	-	Poor
.095"	very little	8	7	601	653	375	415	16.0	8.0,4.0	Poor
.085"	.010"	8	8	601/627	601	401/415	429	-	-	Poor
.050"	very little	8	8	578/627	601	363/401	415	-	-	O.K.
.075"	very little	8	8	601	601	415	415	18.9,18.9	18.5,11..	O.K.
.090"	.030"	8	8	627	653	331/341	331	-	-	Poor
.085"	very little	8	6	601	682	321	341	15.5,21.9	15.5,17.8	O.K.



WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED NI-CR-MO ARMOR PLATE
NOTE; YAWED IMPACT SHOTS 13,14,15,16 AND 17.
JULY 7 1942 PLATE #565 - FRONT WTN.710-1906

FIGURE 1

WATERTOWN ARSENAL

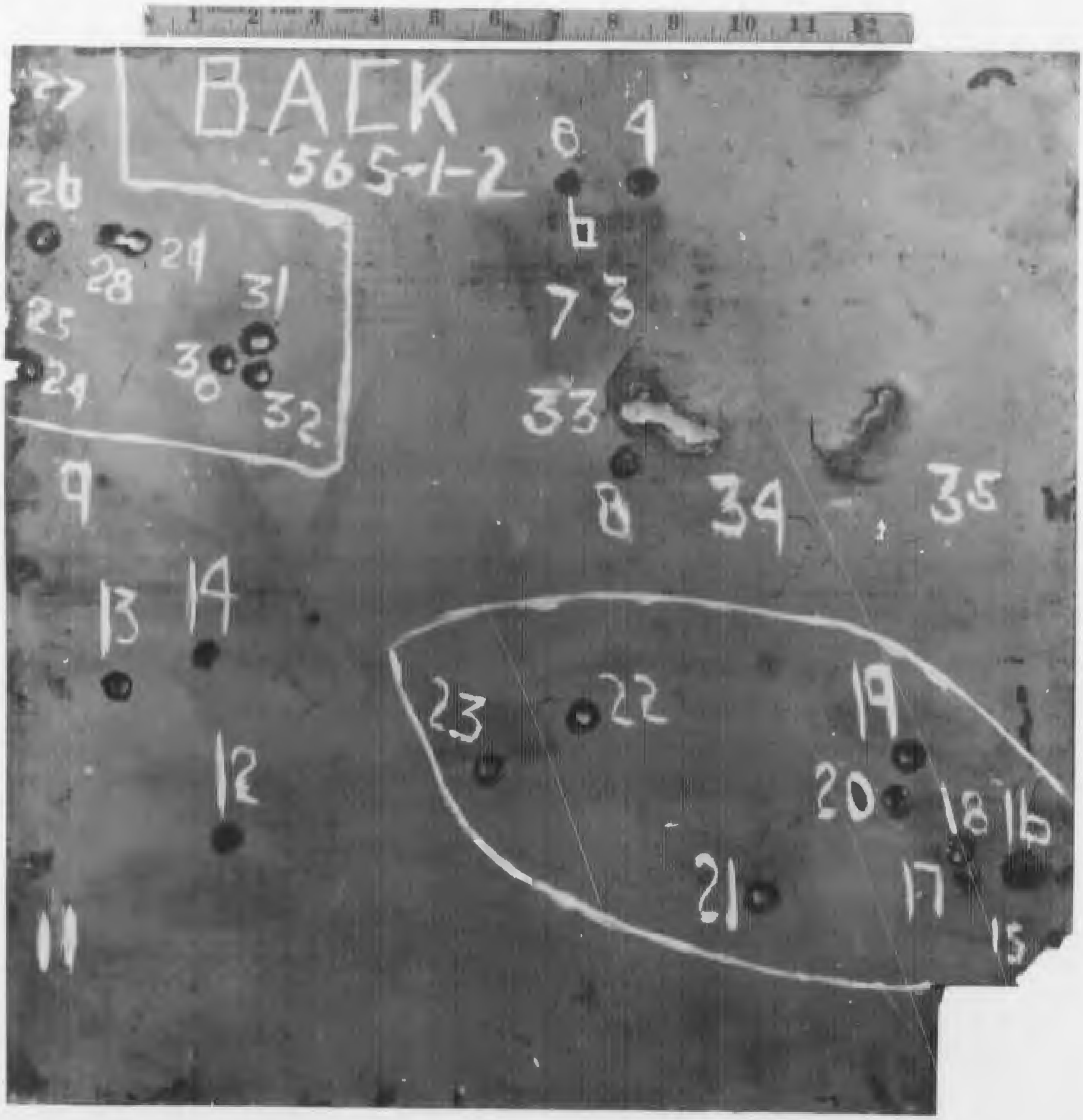
EXPERIMENTAL 3.8" FACE HARDENED NI-CR-MO ARMOR PLATE
NOTE : YAWED IMPACT SHOTS 13,14,15,16 AND 17.
JULY 7 1942 PLATE #565 - BACK WTN.710-1907

FIGURE 2

WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED NI-CR-MO ARMOR PLATE
CARBURIZED BY BREEZE CORPORATION — PLATE #565-1-2
NOTE: YAWED IMPACT SHOTS 33,34 AND 35.
JULY 9 1942 FACE WTN.710-1910

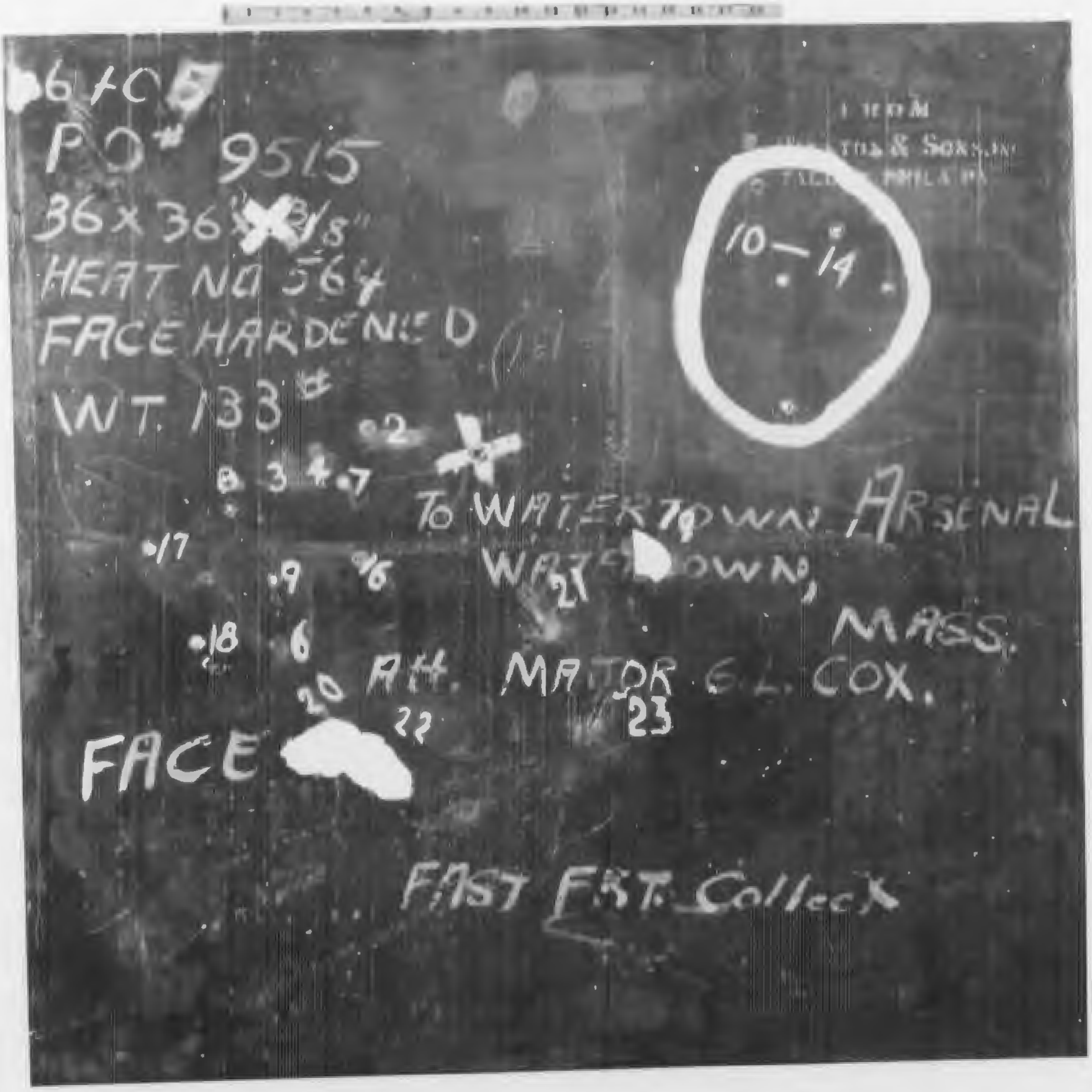
FIGURE 3



WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED NI-CR-MO ARMOR PLATE
CARBURIZED BY BREEZE CORPORATION - PLATE #565-1-2
NOTE: YAWED IMPACT SHOTS 33,34 AND 35.
JULY 9 1942 BACK WTN.710-1911

FIGURE 4



WATERTOWN ARSENAL

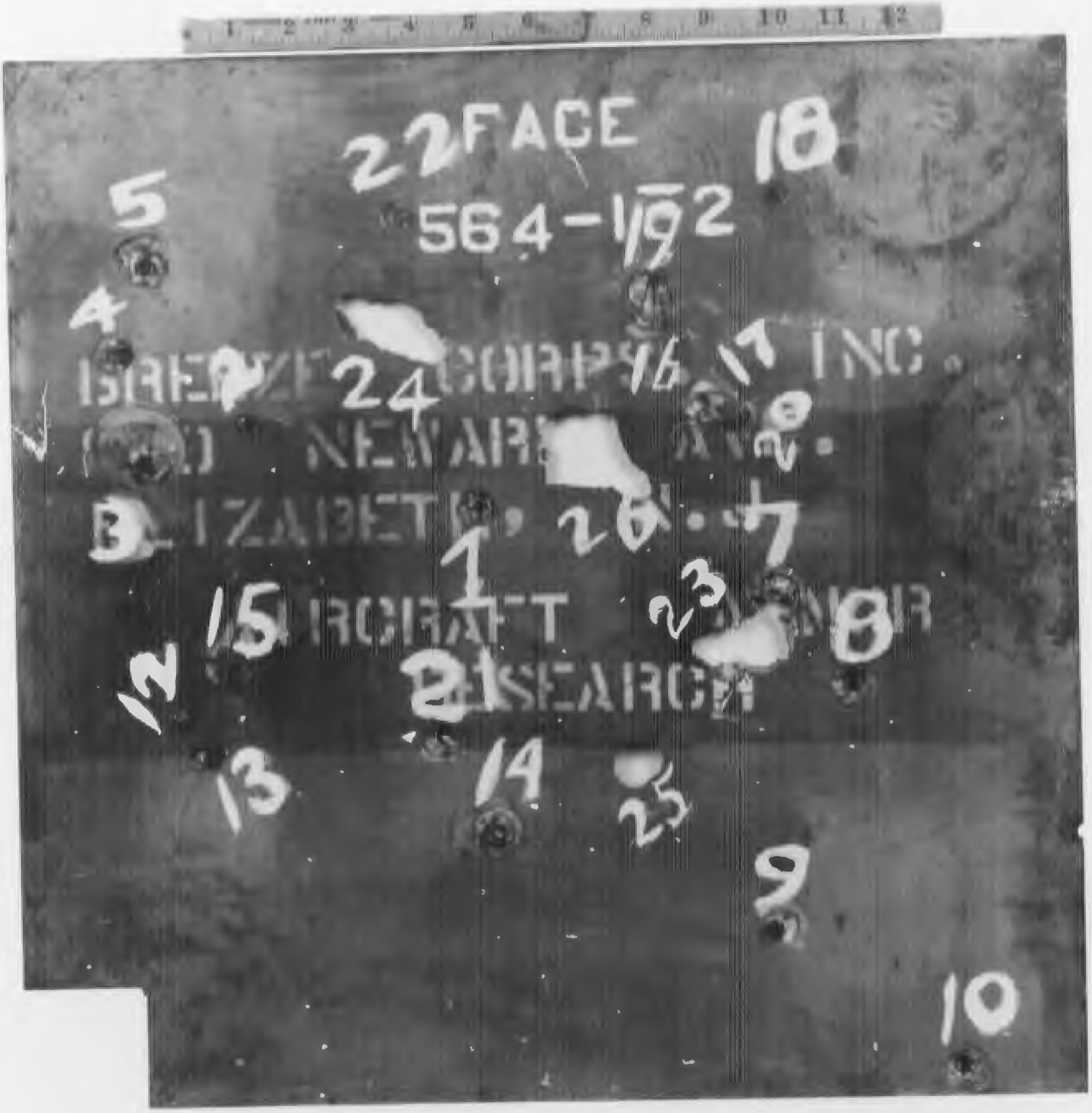
EXPERIMENTAL 3/8" FACE HARDENED CR - MO ARMOR PLATE
NOTE: YAWED IMPACT SHOTS 19,20,21,22 AND 23.
JULY 7 1942 PLATE #564 - FACE WTN.710-1904

FIGURE 5

WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED CR - MO ARMOR PLATE
NOTE : YAWED IMPACT SHOTS 19,20,21,22 AND 23.
JULY 7 1942 PLATE #564 - BACK W.A.710-1905

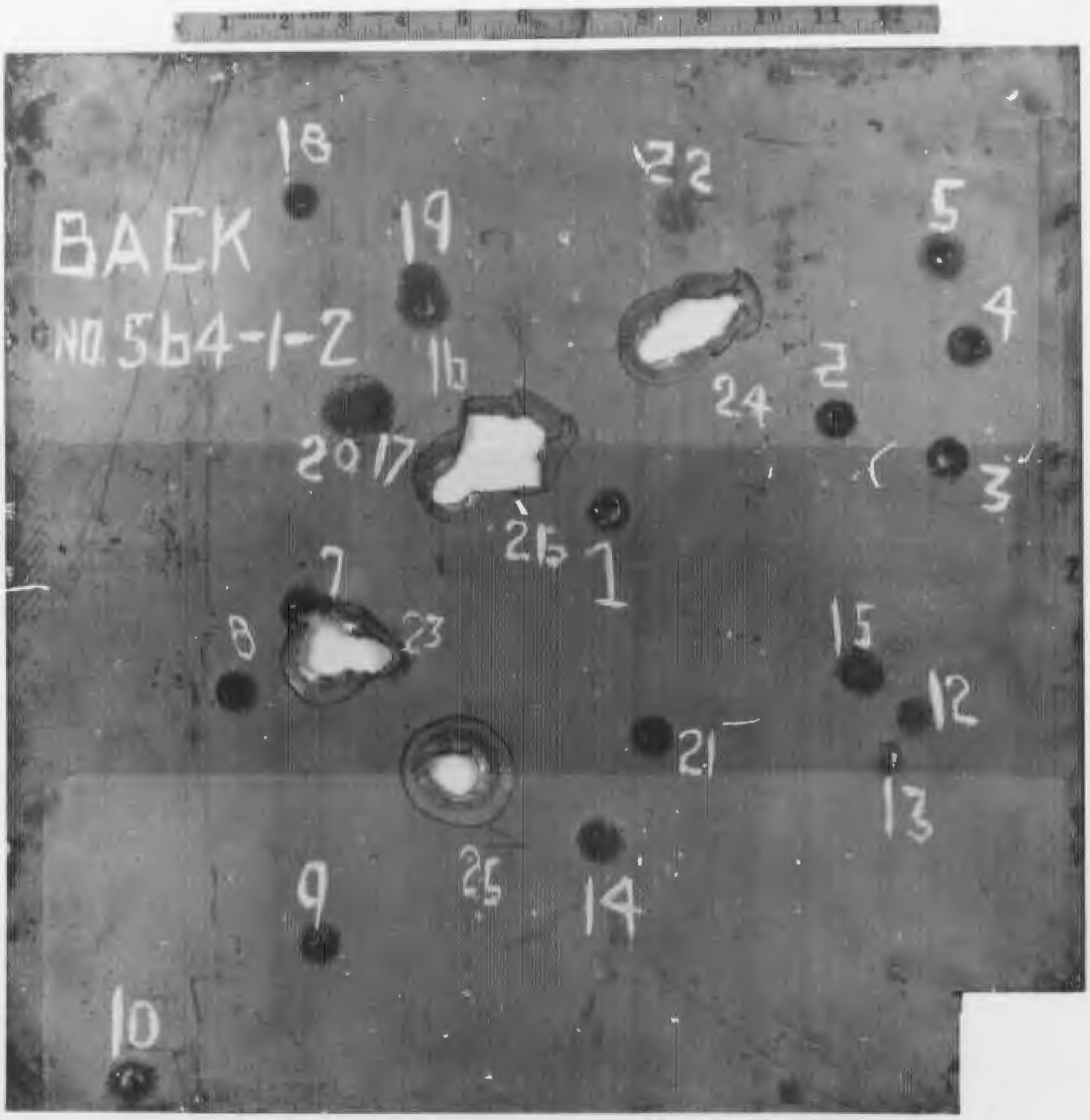
FIGURE 6



WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED CR – MO ARMOR PLATE
CARBURIZED BY BREEZE CORPORATION – PLATE #564-1-2
NOTE: YAWED IMPACT SHOTS 23,24,25 AND 26.
JULY 9 1942 FACE WTN.710-1908

FIGURE 7



WATERTOWN ARSENAL

EXPERIMENTAL 3/8" FACE HARDENED CR – MO ARMOR PLATE
CARBURIZED BY BREEZE CORPORATION – PLATE #564-1-2
NOTE YAWED IMPACT SHOTS 23,24,25 AND 26
JULY 9 1942 BACK WTN.710-1909

FIGURE 8

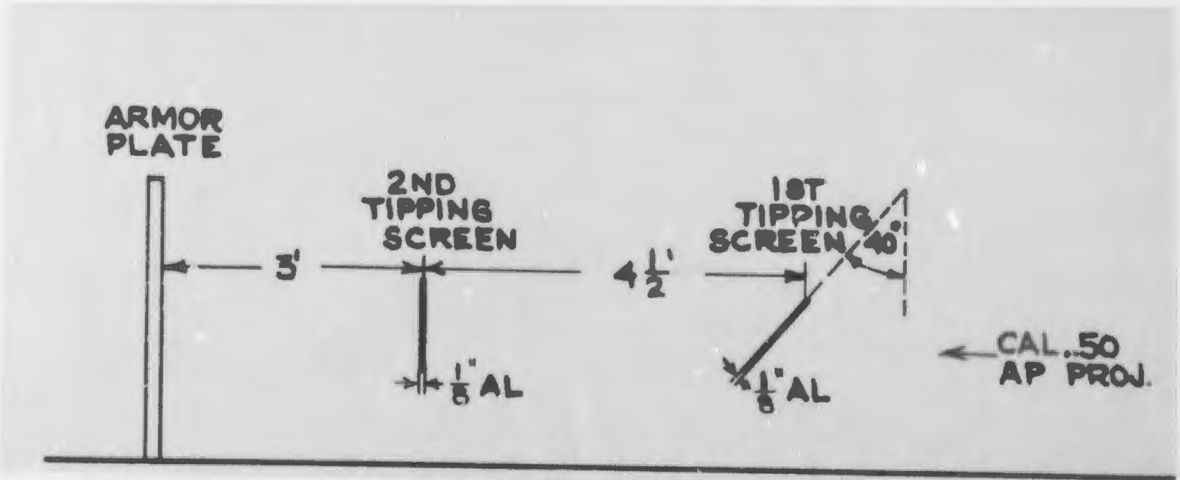


Figure 9
Schematic Diagram of the Tipping Screens

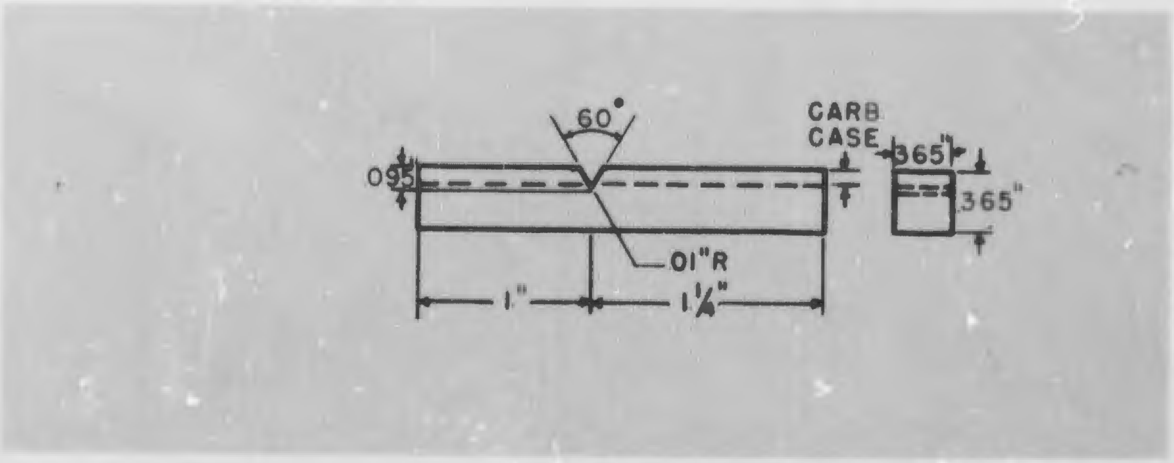
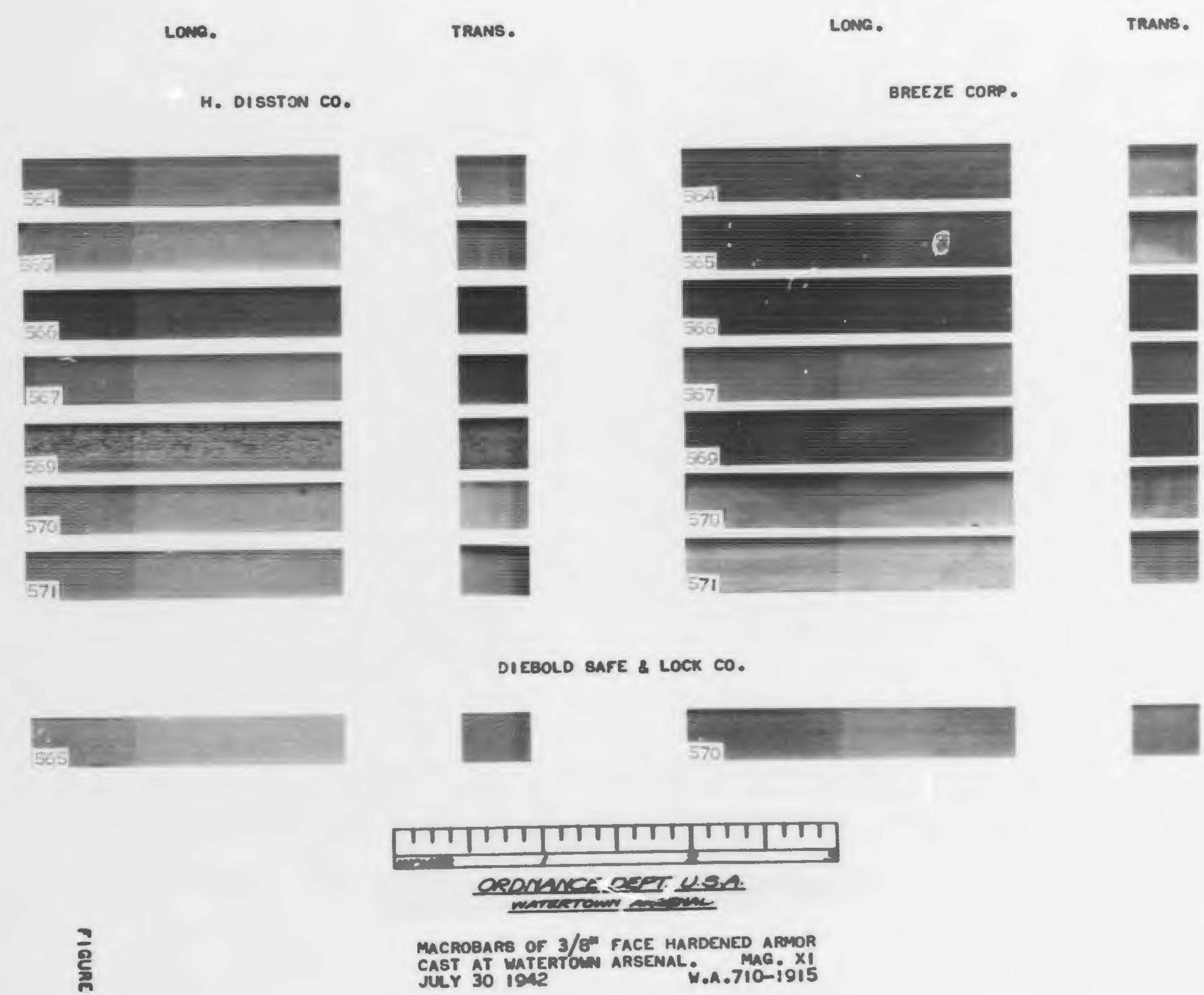


Figure 10
Izod Impact Test Specimen



LONG.
TRANS.
LONG.
TRANS.
H. DISSTON CO.
BREEZE CORP.
564
565
566
567
569
570
571
564
565
566
567
569
570
571
DIEBOLD SAFE & LOCK CO.
565
570
ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL
MACROBARS OF 3/8" FACE HARDENED ARMOR
CAST AT WATERTOWN ARSENAL. MAG. X1
JULY 30 1942 W.A.710-1915

FIGURE 11

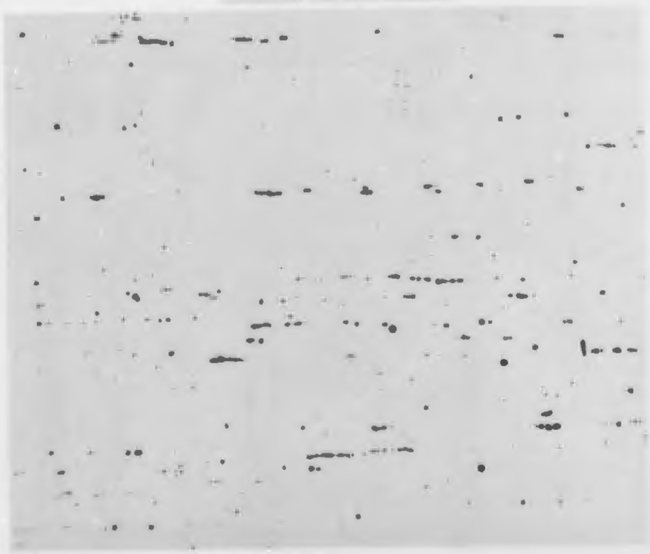
DISTRIBUTION OF NONMETALLICS
IN THE PLATES INVESTIGATED

PLATE 565-1-2

X100 —A— UNETCHED

TYPICAL DISTRIBUTION OF NONMETALLICS IN HEATS 564, 565, 566, 567, 570, 571

PLATE 569-1-2



X100 —B— UNETCHED

TYPICAL DISTRIBUTION OF STRINGERS IN LONGITUDINAL SECTION OF PLATES ROLLED FROM HEAT 569.

W.A.639-4474
FIGURE 12

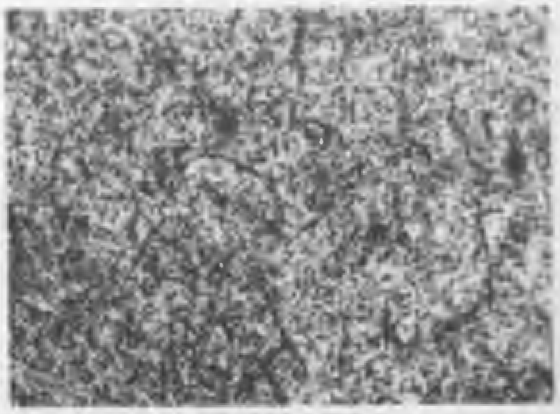
1

X1000 —A— .010 FROM FACE

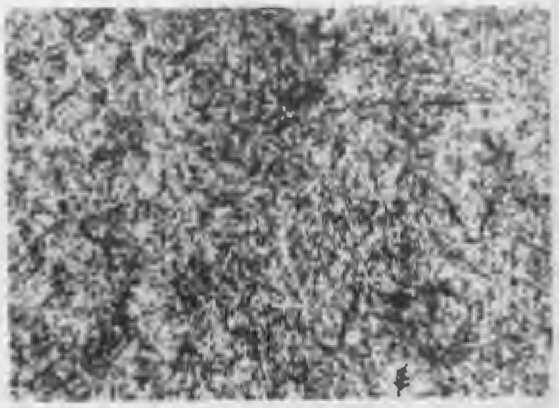
X1000 —B— .025 FROM FACE

X1000 —C— CORE

PLATE 564 TYPE CR—MO



X1000 —D— .010 FROM FACE



X1000 —E— .025 FROM FACE

X1000 —F— CORE

PLATE 566 TYPE CR—MO—V

ETCHED IN 1% NITAL

W.A.639—4480

MICROSTRUCTURE

X1000 —G—

X1000 —H—

X1000 —I—

PLATE 567

MICROSTRUCTURE OF PLATES CARBURIZED BY DI

X1000 —G— .010 FROM FACE

X1000 —J— .010 FROM FACE

X1000 —H— .025 FROM FACE

X1000 —K— .025 FROM FACE

X1000 —I— CORE

PLATE 567 TYPE CR—MO—ZR

X1000 —L— CORE

PLATE 569 TYPE MN—MO

W.A.639-4481

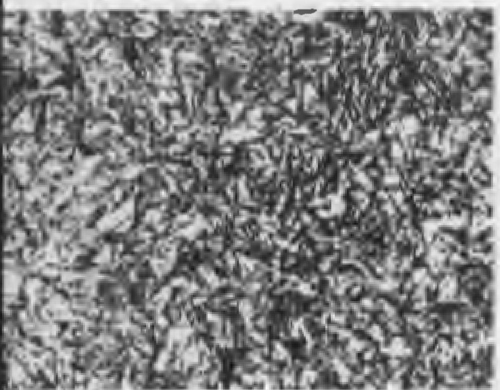
X1000 —M— .010 FR

X1000 —N— .025 FR

X1000 —O—

PLATE 565 TYPE NI

000 —M— .010 FROM FACE

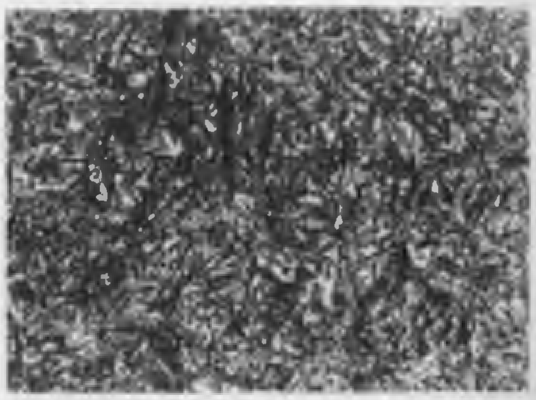


000 —N— .025 FROM FACE

000 —O— CORE

TE 565 TYPE NI—CR—MO

X1000 —P— .010 FROM FACE



X1000 —Q— .025 FROM FACE

X1000 —R— CORE

PLATE 570 TYPE NI—MO

W.A.639—4482

1000 —S— .010 FROM FACE

X1000 —T— .025 FROM FACE

X1000 —U— CORE

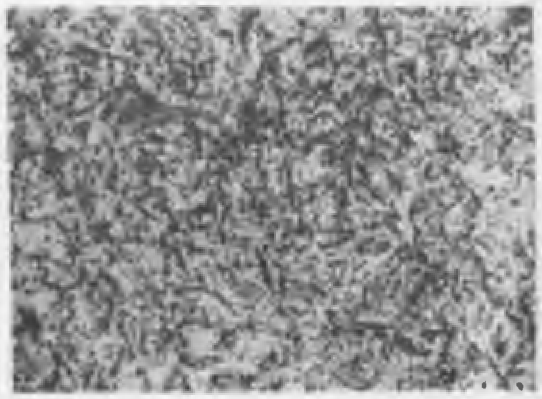
PLATE 571 TYPE NI—MO—V

W.A.639—4483

FIGURE 13

MICROSTRUCTURE OF PLATES CARBURIZED BY DIEBOLD

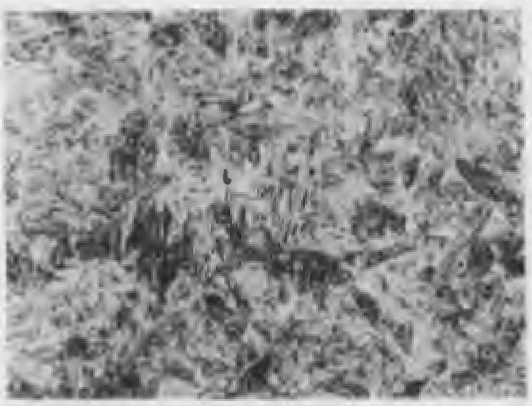
X1000 —A— .010 FROM FACE



X1000 —D— .010 FROM FACE

X1000 —B— .025 FROM FACE

X1000 —E— .025 FROM FACE



X1000 —C— CORE

PLATE 565-1 TYPE NI-CR-MO

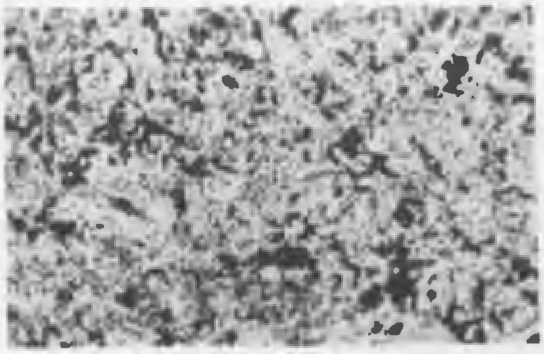
X1000 —F— CORE

PLATE 570-1 TYPE NI-MO

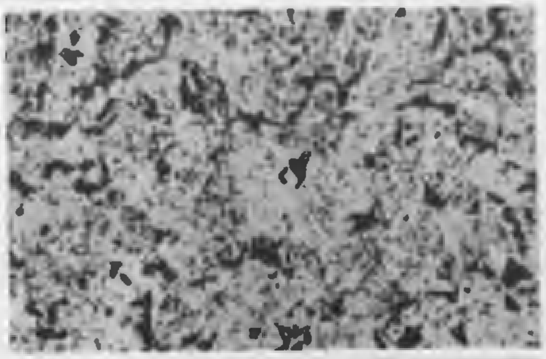
ETCHED IN 1% NITAL

W.A.[illegible]

FIGURE 14



X1000 —A— .010 FROM FACE



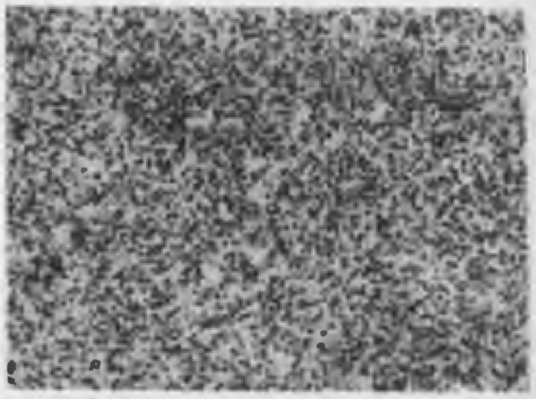
X1000 —B— .025 FROM FACE

X1000 —C— .040 FROM FACE

X1000 —D— CORE

PLATE 564-1-2 TYPE CR-MO

X1000 —E— .010 FROM FACE



X1000 —F— .025 FROM FACE

X1000 —G— CORE

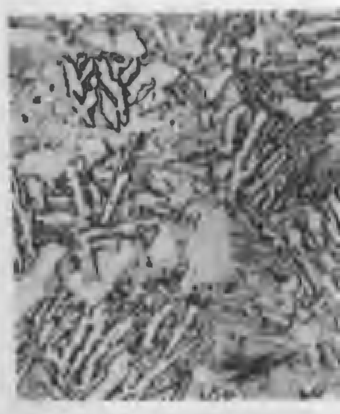
PLATE 566-1-2 TYPE CR-MO-V
ETCHED IN 1% NITAL

W.A.639-4475

MICROSTRUCTURE

X1000 —H—

X1000 —I—

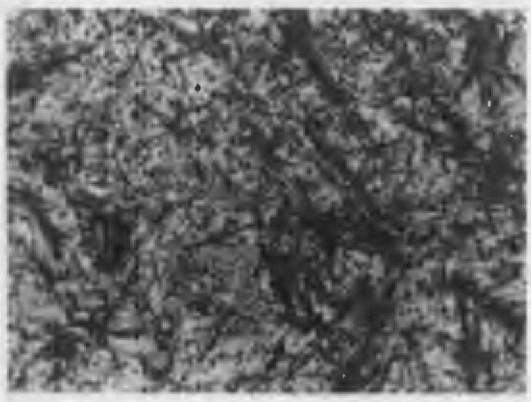


X1000 —J—

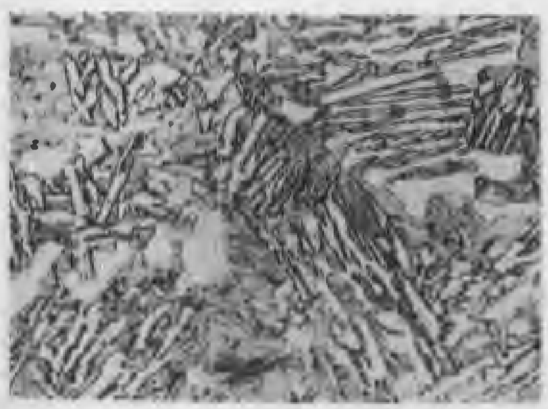
PLATE 567-1-2

MICROSTRUCTURE OF PLATES CARBURIZED BY [illegible]

X1000 —H— .010 FROM FACE



X1000 —I— .025 FROM FACE



X1000 —J— CORE

PLATE 567-1-2 TYPE CR-MO-ZR

X1000 —K— .010 FROM FACE

X1000 —L— .025 FROM FACE

X1000 —M— CORE

PLATE 569-1-2 TYPE MN MO

X1000 —N— .010 FROM FACE

X1000 —O— .025 FROM FACE

X1000 —P— CORE

PLATE 565-1-2 TYPE NI-CR-

W.A.639-4476

1

-N- .010 FROM FACE

X1000 -Q- .010 FROM FACE

X1000 -T- .010 FROM FACE

-O- .025 FROM FACE

X1000 -R- .025 FROM FACE

X1000 -U- .025 FROM FACE

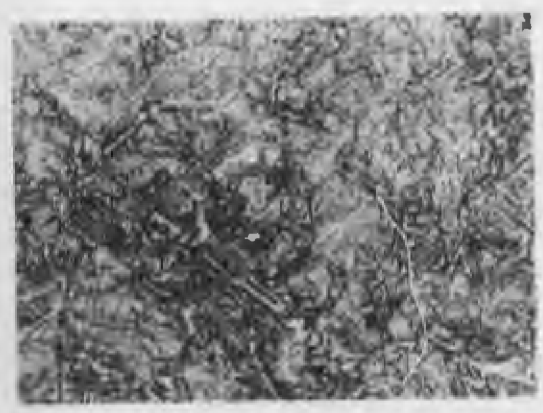
-P- CORE

565-1-2 TYPE NI-CR-MO

X1000 -S- CORE

PLATE 570-1-2 TYPE NI-MO

W.A.639-4477

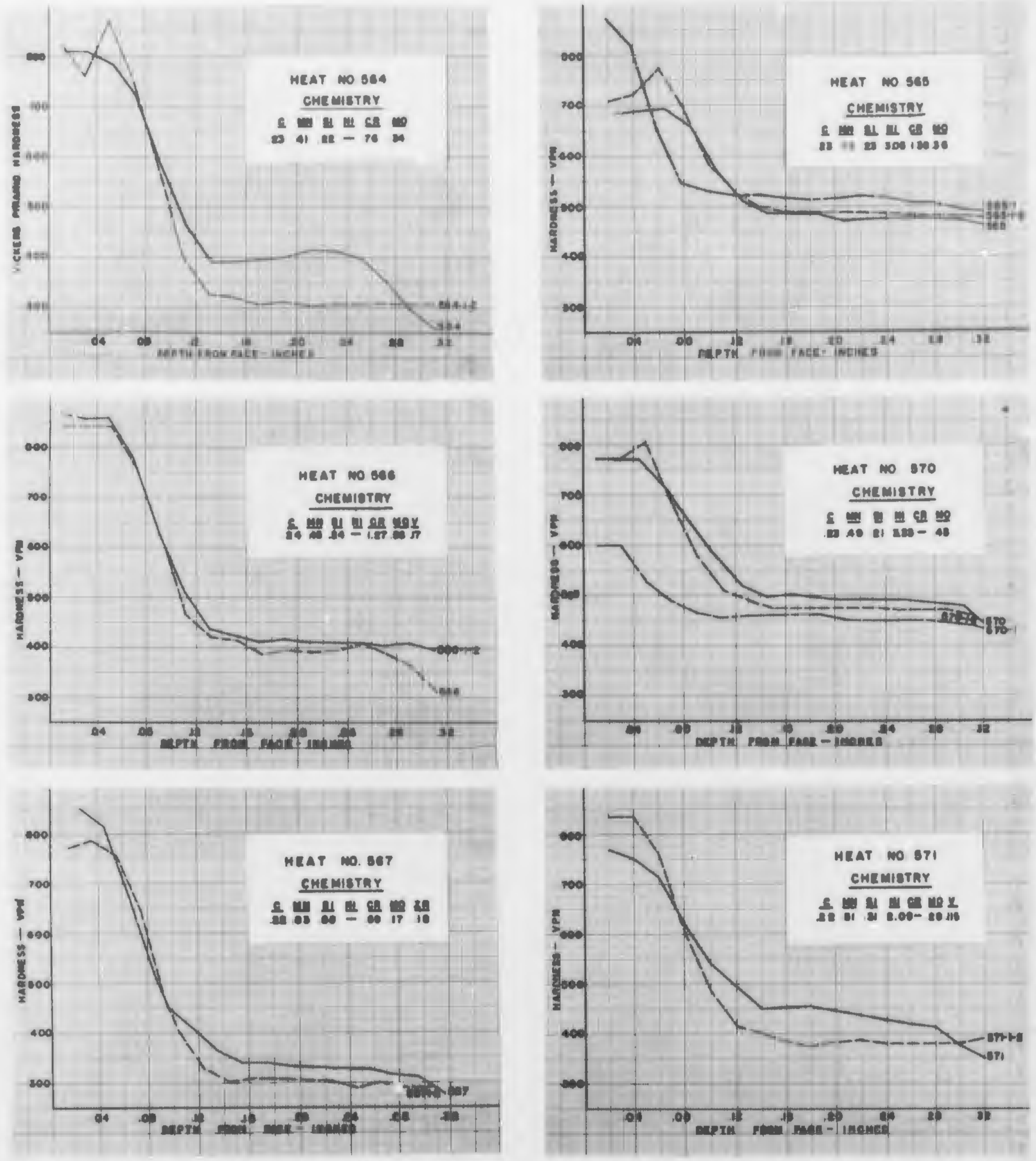


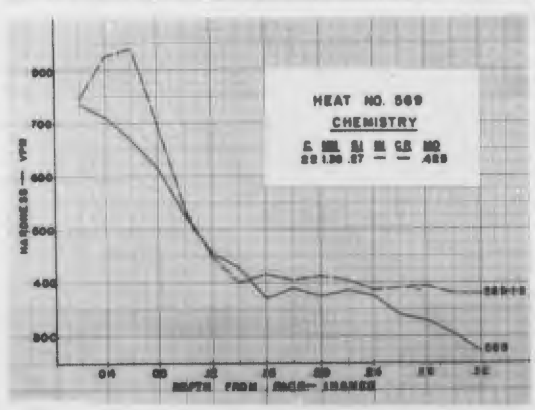
X1000 -V- CORE

PLATES 571-1-2 TYPE NI-MO-V

W.A.639-4478

FIGURE 15





HARDESS SURVEYS THROUGH CASES OF
3/8" FACE HARDENED ARMOR
CAST BY WATERTOWN ARSENAL
ROLLED AND CARBURIZED BY
COMMERCIAL HEAT TREATERS

LEGEND

SERIES —-1 DIEBOLD
SERIES —-1-2 BREEZE
SERIES — H.DISSTON

W.A.639-4468

FIGURE 16

INCLOSURE A

Fabrication of the Experimental Armor Plates

1. Steel Making Practice

The seven experimental heats were made at Watertown Arsenal in an induction acid-lines furnace and cast in the form of 800-lb. ingots measuring 6"x12"x36" not including the hot top. The heats were aluminum-silicon killed (aluminum 1#/ton).

2. Rolling Practice

The ingots were first homogenized at 2000°F for 10 hours, cooled in air, and shot blasted. They were then sent to the plant of Henry Disston & Sons, Inc., for rolling into plate according to the procedure shown in Table I.

TABLE I

Disston Rolling Practice

Showing Initial Rolling Temperature

(Degrees Fahrenheit)

W.A. Heat No.	Type	Hammer Cogging Cog Rolling to 1" thick Plates	Cross-Rolling to Plate: Reducing 1" Face-Carburized Slabs to 3/8" Plate	Cross-Rolling to Plate: Reducing 1" Untreated Slabs to 3/8" Plate for Carburization by Diebold and Breeze
564	Cr-Mo	2130	2150	2175
565	Ni-Cr-Mo	2275	2185	2300
566	Cr-Mo-V	2175	2150	2220
567	Cr-Mo-Zr	2170	2150	2210
569	Mn-Mo	2180	2120	2240
570	Ni-Mo	2200	2160	2280
571	Ni-Mo-V	2250	2130	2270

NOTE: The 1" thick cog rolled plates were not annealed after rolling. The 3/8" thick carburized plates were subsequently annealed at 1200°F for 10 hours. The 3/8" thick plates sent to Diebold and Breeze were annealed at 1200°F for 10 hours.

3. Carburizing Practice

a. Henry Disston and Sons, Inc.

One inch thick slabs of each composition were heated in solid carburizer to 1750°F in 24 hours and held at temperature for 90 hours. The slabs were subsequently rolled into 3/8" plate as outlined above in the Rolling Practice.

b. Diebold Safe and Lock Company

The 36"x36"x3/8" plates were heated in solid carburizer to 1680-1700°F in 4-6 hours and held at temperature for 36-38 hours and box cooled.

c. Breeze Corporations

The 36"x36"x3/8" plates were heated in liquid carburizer at 1750°F for about 14 hours and air cooled.

4. Heat Treatment

Heat treatments as reported by the manufacturers are given below in a. Table II, b, and c Table III.

a. The heat treating cycles given the plates by the Henry Disston and Sons, Inc. are given in Table II.

TABLE II

Experimental 3/8" Low Alloy Face Hardened Plates Heat Treated by the Henry Disston and Sons, Inc.

		Heating and Quenching				Tempering (Held at temp. for 2hrs.)		
		Quench Temp. °F	Coolant	Brinell After Quench		Draw Temp.	Brinell After Draw	
Plate#	Type			Face	Back		Face	Back
564	Cr-Mo	1500	water	495	321/331	300°F	601	321
565	Ni-Cr-Mo	1550	oil	601	415	300°F	601	415/429
566	Cr-Mo-V	1550	oil	555	321	300°F	627	285/293
567	Cr-Mo-Zr	1550	oil	601/627	341/363	300°F	627	255/277
569	Mn-Mo	1550	oil	601	331/363	500°F	601	302/321
570	Ni-Mo	1425	water	601/627	388	300°F	601/627	401/415
571	Ni-Mo-V	1450	water	627	331/341	300°F	627	331/341

b. The heating treating cycles given the plates by Diebold Safe and Lock Company are as follows:

Plates 565-1 (Ni-Cr-Mo) and 570-1 (Ni-Mo) were normalized at 1680-1700°F for one hour, air cooled, and annealed at 1180°F.

Plates were then reheated to 1500°F in 1/4 hour, held at temperature for 3/4 hour, and full oil quenched. The temperature of the quenching oil was 90-110°F. The plates were then drawn at 325°F for 1/4 hour.

c. The heating treating cycles given the plates by Breeze Corporations, Inc. are given in Table III.

TABLE III

Experimental 3/8" Low Alloy Face Hardened Plates

Heat Treated by the Breeze Corporations

		Quenching Practice			Brinell Hardness	
Plate#	Type	Time of 1st Immersion in Oil	Time in Air	Time of 2nd Immersion in Oil	Face	Back
564-1-2	Cr-Mo	50 sec.	1 min.	4 min.	627	277
565-1-2	Ni-Cr-Mo	50 sec.	1-3/4 min.	4 min.	555	429
566-1-2	Cr-Mo-V	60 sec.	2 min.	4 min.	653	363
567-1-2	Cr-Mo-Zr	50 sec.	3 min.	4 min.	601	277
569-1-2	Mn-Mo	50 sec.	5 min.	4 min.	601	375
570-1-2	Ni-Mo	50 sec.	1-3/4 min.	4 min.	601	415
571-1-2	Ni-Mo-V	50 sec.	1-1/2 min.	4 min.	601	321

NOTE: Plates were heated at 1550°F for 20 minutes in a salt bath furnace for quenching.

APPENDIX A

HENRY DISSTON & SONS, INC.

PHILADELPHIA, U.S.A.

April 15, 1942

The Commanding Officer,
Watertown Arsenal,
Watertown, Mass.

Attention: Laboratory (Major G. L. Cox)

Gentlemen:

We are shipping today the last item covered by your Purchase Order #9515. This consists of seven targets 36" x 36" x 3/8" carburized and heat treated by us. These plates 'epresent the following heat numbers: 564, 565, 566, 567, 69, 570 and 571.

The following is a tabulation of the process information on the various heat numbers which you requested.

Heat No.	Rolled to	Final Rolling Temperature	
538	1 1/2"	2250° F.	Finished at I 1/2" for Homo Armor.
539	"	2220° F.	
540	"	2210° F.	
541	"	2240° F.	
542	"	2310° F.	
543	"	2250° F.	
544	"	2210° F.	
545	"	2240° F.	
556	"	2210° F.	
557	"	2280° F.	
588	"	2300° F.	
564	1"	2130° F.	Rolled to 1" for carburizing.
565	"	2275° F.	
566	"	2175° F.	
567	"	2170° F.	
569	"	2180° F.	
570	"	2200° F.	
571	"	2250° F.	

W.A. 470.5/4380

Heat No.	Rolled to	Final Rolling Temperature	
564	3/8"	2150° F.)	Rerolled to 3/8" after carburizing
565	"	2185° F.)	
566	"	2150° F.)	
567	"	2150° F.)	
569	"	2120° F.)	
570	"	2160° F.)	
571	"	2130° F.)	

Attention Major G. L. Cox.

Heat No.	Rolled to	Final Rolling Temperature	
564	3/8"	2175° F.)	Finished at 3/8" for shipment to Diebold and Breeze Not carburized. Two targets (Nos. 1&2) trimmed from each.
565	"	2300° F.)	
566	"	2220° F.)	
567	"	2210° F.)	
569	"	2240° F.)	
570	"	2280° F.)	
571	"	2270° F.)	

The annealing cycle was the same for all plates regardless of gage and consisted in heating to 1200°F. and holding at temperature for 10 hours. The time necessary for the plates to come to heat would, of course, vary with the gage of the plate.

The carburizing cycle for the seven targets carburized at DISSTON (carburized at 1" and rerolled to 3/8") consisted in heating the plates with solid carburizer to 1750°F. in 24 hours and holding at temperature for 90 hours.

W.A. 470.5/4380

The seven targets carburized at DISSTON were rerolled to 3/8" and heat treated according to the following schedule:

Heat No.	Type	Quench Temp.	Quench Media	Brinell A H Face	Brinell A H Back	Temper	Brinell A T Face	Brinell A T Back
564	Cr-Mo	1550°F.	Oil	514-555	255-269			
564	Cr-Mo	1600°F.	Oil	477-514	235-241			
564	Cr-Mo	1500°F.	Water	495	321-331	300°F.-2 hrs.	601	321
565	Ni-Cr-Mo	1550°F.	Oil	601	415	300°F.-2 "	601	415-429
566	Cr-Mo-V	1550°F.	Oil	555	321	300°F.-2 "	627	285-293
567	Cr-Mo-Zr	1550°F.	Oil	601-627	341-363	300°F.-2 "	627	255-277
569	Mn-Mo	1550°F.	Oil	601	331-363	500°F.-2 "	601	302-321
570	Ni-Mo	1425°F.	Water	601-627	338	300°F.-2 "	601-627	401-415
571	Ni-Mo-V	1425°F.	Water	627-653	321-341			
571	Ni-Mo-V	1450°F.	Water	627	331-341	300°F.-2 "	627	331-341

We hope this information will be sufficient for your purpose. If there is anything further which you require, please let us know.

Yours very truly,

E. K. SPRING
CHIEF METALLURGIST

b

c.c. R.S.

W.A. 470.5/4380

BREEZE CORPORATIONS

INCORPORATED

24 SOUTH SIXTH STREET

NEWARK, NEW JERSEY

July 6, 1942

Waverly Plant,
829 Newark Ave.,
Elizabeth, N. J.

The Commanding Officer,
Watertown Arsenal,
Watertown, Massachusetts.

Attention: Colonel H. H. Zornig, Ord. Dept.
Director of Laboratory.

Laboratory - ELR

Reference: Col. H. H. Zornig letter dated July 3. 1942.

Dear Sir:

Quenching procedures for seven Disston plates (3/8 - x 18 x 18) processed in our plant are given in Table I.

The 36 x 36 plates shipped by Disston were quartered (18x18) stamped with additional identification Number (-1, -2, -3 and -4), all carburized in the same furnace, and the -2 sections quenched and shipped to your Laboratory. The -3 and -4 sections were quenched and tested in our own range. The results of these tests appear in Table II.

In my opinion the only conclusions that may be formed from results shown in Table II are:

1. Straight quench produces a plate with maximum resistance to penetration.

2. Delay quench produces a plate with less resistance to penetration but with better shock properties than #1.

3. Delay quench lessens tendency to face-spall.

Very truly yours,

BREEZE CORPORATIONS, INC.

L. Hrusovsky,
Chief Chemist-Metallurgist
Armor Division

JM

W.A. 470.5/4751

TABLE I

THERMAL BALLISTIC TREATMENT OF DISSTION PLATES (3/8 x 18 x 18)

All plates reheated 20 minutes at 1550°F. in salt bath furnace and quenched in oil at 100°F.

PLATE NO.	DELAY QUENCH Oil	Air	Oil	B.H.N. Face	Back
564-1-2	50 sec.	1 min.	4 min.	627	277
565-1-2	50 sec.	1 3/4 min.	"	555	429
566-1-2	60 sec.	2 min.	"	653	363
567-1-2	50 sec.	3 min.	"	601	277
569-1-2	50 sec.	5 min.	"	601	375
570-1-2	50 sec.	1 3/4 min.	"	601	415
571-1-2	50 sec.	1½ min.	"	601	321

TABLE II

DISSTON PLATES SHOT AT BREEZE RANGE

Quench: All plates reheated 20 minutes at 1550°F. in salt bath furnace and quenched in oil at 100°F.

Delay: 50 seconds oil, 1-3/4 minute air, 5 minutes oil.

Straight(ST) - 5 minutes in oil.

PLATE NO.	QUENCH	B.L. f/s	P.P.	C.P.	SHOCK Remarks	
564-1-3	Delay	2322	0	12	1-1" semi circular F.S.	NG
564-1-4	ST.	2453	0	12	1 3/4"F. Spalls -4	NG
565-1-3	Delay	2327	0	12	Extremely small F.S.	OK
565-1-4	ST.	2374	0	12	2- 3/8" x 1/4" face spalls	-
566-1-3	Delay	2565	8	2	F.S. 2-1 3/4"x1" 2-½"x3/8"	NG
566-1-4	ST.	2640	14	1	F.S. 6-1 3/4"x1½"	NG
567-1-3	Delay	2454	0	15	F.S. 1-1/2" Dia.	NG
567-1-4	ST.	2527	0	12	F.S. 1" dia.	NG
569-1-3	Delay	2441	0	12	F.S. 1 - 3/8" dia.	-
569-1-4	ST.	2520	0	12	F.S. 1 - 3/8" dia.	-
570-1-3	Delay	2365	0	12	Extremely small F.S.	O[illegible]
570-1-4	ST.	2438	0	12	" " "	O[illegible]
571-1-3	Delay	2432	0	13	F.S. 2-1/4" dia. OtherFS. O[illegible]	
571-1-4	ST.	2489	0	14	F.S. 2-1-3/8" dia. Smaller	

APPENDIX B.

RESTRICTED

SUMMARY OF THE FIRST
MEETING OF THE RESEARCH SUB-GROUP
FOR LIGHT AIRCRAFT ARMOR

The meeting was held at the Penn Athletic Club, December 3rd, 1941.

The following members were in attendance:

Lt. N. A. Matthews:-Watertown Arsenal
Dr. E. L. Reed :-Watertown Arsenal
Captain C. Mc Innes:-Wright Field
Mr. J. B. Lewarre :-Wright Field
Mr. A. B. Cooper :-Jessop Steel Company
Mr. H. E. Doughtey :-Jesson Steel Company
Mr. Braender:-Carnegie Illinois Steel Co.
Mr. John Hodge:-Carnegie Illinois Steel Co.
Lt. J. J. Flynn:-Navy Dept., Bureau of Ord.
Dr. Igor Zavarine:-Navy Dept., Bureau of Aeronautics
Mr. W. Miller:-Diebold Safe & Lock Co.
Mr. Abbott : " " " " "
Mr. Clark : " " " " "
Major J. L. Atkins:-Office of Chief of Ord. Ind. Reasearch
Lt. G. W. Reitwiesner: Aberdeen Proving Ground
Dr. H. B. Allen: Franklin Institute
Mr. Robert Sibley:-Henry Disston & Sons, Inc.
Major H. A. Quinn:-Office of Chief of Ord. Ind. Research

The following also attended:

Mr. Ensign)
Mr. Steinmeier) American Car & Foundry Co.
Mr. George Miller)

A program for investigating yawed impacts induced by tipping screens on various grades of armor plate was initiated.

The following types of plate are to be used in this investigation.

All Test Plates to be 36 x 36 x 3/8"

1. Standard face hardened plate
2. Lightly carburized face hardened plate
3. Hard homogeneous plate
4. Homogeneous plate to conform with Specification-AXS-495.
5. Nitrided Plate

(Con't on next page)
RESTRICTED

It was decided that the Diebold Safe & Lock Company and American Car & Foundry Company would undertake the manufacture and investigation of Item #1 and #2; that the Carnegie Illinois Steel Company and Jessop Steel Company would undertake the manufacture and investigation of Item #3 and #4; Henry Disston & Sons would furnish the nitrided plate.

Aberdeen Proving Grounds are to institute immediately, under the direction of Lt. G. W. Reitwiesner, experiments to establish a uniform test procedure to be used in the investigation of this plate.

It was also decided that samples from the plate tested will be sent to Watertown Arsenal for microscopic investigation.

Agreement was reached that all information gained from the investigation is to become the common property of the committee members. It was the opinion of the Chairman and the majority of the members that there was nothing in the offing to produce any great improvement in ballistics over the material and alloys already in current use.

Dr. Reed of Watertown Arsenal was requested to incorporate in these investigations any of the low alloy armor analyses found to be promising for Rolled Armor. It was agreed in the discussion with Captain Mc Innes of Wright Field and with other service representatives that the best tipping screen for inducting yaw appeared to be 1/8" duraluminum. It was tentatively agreed that the preliminary investigation would be made using 1/8" dural screen, set 60° from the vertical and at a distance of 5'6" from the target.

A proposal by Major H. A. Quinn that all armor 3/8" and over used inside an airplane be made homogeneous, in accordance with specificationAXS-495. It was the decision of the group that before final adoption of this proposal the committee should consider the information and data to be gained from the test program already outlined.

Any test plates showing promise ballistically shall be submitted to the Committee For Resistance Welding.

It was decided that another meeting should be held as soon as results had been attained.

APPENDIX C

FIRING RECORDS

BALLISTIC DATA SHEET # 1

Plate 564 - Henry Disston & Sons, Inc., treatment

Face Hardened Cr-Mo ------- .364" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results		
Cal. .30 AP M2 firings					
1	36.0	Lost	PP	NB	shattered
2	37.0	2192	PP	NB	"
3	39.0	2169	PP	NB	"
4	40.0	2259	PP	NB	"
5	42.0	2412	PP	NB	"
6	44.0	2553a	PP	NB	"
7	54.0	2678	CP	PTP	3/8"x3/8" Pun. S.
8	53.0	2652	CP	PTP	7/16"x7/16" Pun.S.
9	51.0	2575a	CP	FPTP	1/4"x3/8" Shattered
10 to 14	5 rd. m.g. burst cal. .30 APM2 service velocity		4CP-PTP Max. exit 7/16"x7/16" 1CP-FPTP-CIP-BD		
15	44.0	2555	Miss		
16	44 0	2522b	PP	NB	shattered
17	45.0	2590	CP	PTP	
18	44.5	2557b	CP	PTP	

Cal. .50 APM2 firings.

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

19	140.0	1919	CP	PTP	2" x 1 3/4"
20	120.0	1665	CP	PTP	1 3/4" x 1 1/2"
21	105.0	1448	PP	SB	
22	110.0	1574*	CP	PTP	1 1/2" x 1"
23	107.0	1557*	PP	MB	1/2" Crack

a,b. Ballistic limits in diagonally opposite areas of plate 2564 F/S, 2540 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 1566 F/S.

BALLISTIC DATA SHEET #2

Plate #565 - Henry Disston & Sons, Inc., treatment

Face Hardened Ni-Cr-Mo -------- .368" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. .30 AP M2 firings:			
1	44.0	2544	CP Backed by support
2	42.0	2413	CP FPTP 1/4"x1/4" Exit shattered
3	41.0	2397	CP PTP 1/4"x3/8" Exit
4	40.0	2302a	PP NB
5	40.5	2348a	CP PTP 1/4"x5/16" Exit
6	40.0	2286b	PP NB Shattered
7	40.5	2306b	CP PTP 1/4"x5/16" Exit
8 to 12	5 rds. m.g. burst cal. .30 AP M2 Service velocity		4 CP PTP Max. exit diam. 1/2"x1/2". 1 CP CIP backed by support. Slight back spalls.

Cal. .50 AP M2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen at 0°, 3' in front of plate.

Plate Rd. No.	Powder Charge	Str. Vel.	Results
13	150.0	2040	PP SB No cracks
14	160.0	2164	PP MB 2" crack on back
15	165.0	2229	PP MB 1½" " " "
16	170.0	2308*	CP FPTP 1 1/8" x 3/8" Exit
17	167.5	2263*	PP SB 3/4" cracks

a.b. Ballistic limits in diagonally opposite areas in plate 2325 F/S, 2296 F/S.

* Ballistic limit (cal. .50 AP M2 projectiles yawed) 2286 F/S.

BALLISTIC DATA SHEET #3

Plate 566 - Henry Disston & Sons, Inc., treatment

Face Hardened Cr-Mo-V ----------- .378"x36"x36".

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. 30 APM2 firings:			
1	40.0	2330	PP-No buldge Shattered
2	41.0	2338	PP-SB Shattered
3	42.0	2418	PP-SB Shattered
4	43.0	2502	PP-MB-CIP BD FS 1/2"x1/4"
5	43.5	2519	PP-MB-CIP BD
6	43.8	2522a	PP-CIP-Pun. S. BD
7	44.0	2550a	CP-PTP Exit 1/4"x1/4"
8	44.0	2534b	PP-CIP-SB Shattered
9	44.1	2532	PP-SB-CIP Shattered
10	44.4	2563b	CP-PTP Exit 5/16"x5/16" FS 3/4"x3/4"
11 to 15	5 rds. Cal..30 APMG Service velocity.		1CP-CIP-BD 2CP-PTP 2CP-Backed by support. Max. exit diam. ½"x5/8" Exit diam.
16 to 20	5 rds. m.g. burst Cal. 30 APM2 Service velocity.		5 CP-PTP one BS 1/4"x1/8"

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

21	165.0	2233	CP-PTP 2"x1 1/4" Exit Diam.
22	160.0	2168	CP-PTP 2 1/8"x3/4" " "
23	155.0	2130	CP-PTP 2"x3/16" " "
24	150.0	2065	CP-PTP 2"x3/4" " "
25	145.0	2018	CP-proj. rejected 1"x3/4"
26	142.0	1981	CP-PTP 2 3/4"x1 1/4"
27	140.0	1915	Hit Shot 21
28	140.0	1932*	CP-PTP 2½"x2"
29	130.0	1890*	PP-SB 2 - 2" cracks

a.b. Ballistic limits in diagonally opposite areas on plate 2536 F/S, 2549 F/S.

* Ballistic Limit (Cal. .50 APM2 projectile yawed) 1911 F/S.

BALLISTIC DATA SHEET #4

Plate 567 - Henry Disston & Sons, Inc., treatment

Face Hardened Cr-Mo-Zr. ------- .367" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. .30 APM2 firings:			
1	40.0	2330a	PP-SB-CIP Shattered
2	41.0	2369a	CP-PTP Exit 1/4" x 7/16"
3	40.0	2355b	PP-MB-CIP Shattered
4	41.0	2395b	CP-PTP Exit 5/16" x 5/16"
5 to 9	5 rd. m.g. burst Cal. .30 APM2 Service velocity		5 CP-PTP Max. exit 3/8"x½" Large BS starting

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

Plate Rd. No.	Powder Charge	Str. Vel.	Results
10	150.0	2051	CP-PTP 2 1/4" x 3/4" exit
11	140.0	1943	CP-PTP 2" x 1" exit
12	135.0	1872	CP-PTP Hit shot #10
13	130.0	1843	CP-PTP 2 1/4" x 3/4" exit
14	125.0	1722	CP-PTP
15	122.0	1714	CP-PTP 1 7/8" x 1 1/8" exit
16	118.0	lost	CP-FPTP 1 1/4" crack thru plate
17	115.0	1610	Hit shot #13 CP-PTP
18	115.0	1617*	CP 3 1/2" x 2 1/2" opening
19	110.0	1582*	PP-SB no cracks

a.b. Ballistic limits in diagonally opposite areas in plate 2350 F/S, 2375 F/S.

* Ballistic limit (Cal. .50 APM2 projectiles yawed) 1600 F/S

BALLISTIC DATA SHEET #5

Plate 569 - Henry Disston & Sons, Inc., treatment

Face Hardened Mn-Mo ------- .372" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results	
Cal. .30 APM2 firings:				
1	42.0	2422a	PP-CIP-F.S.	7/8"x½" Shattered
2	43.0	2468a	CP-CIP	Shattered
3	42.0	2400	CP-PTP	
4	41.0	2335b	CP-PTP	
5	40.0	2289b	PP-CIP-MB-BD	
6 to 10	5 rd. m.g. burst cal. .30 APM2		5 CP-PTP max. exit 7/16" x 7/16"	

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

11	150.0	2076	CP-PTP	2 1/8"x1"
12	135.0	1892	CP-PTP	1 3/4"x1"
13	120.0	1660	CP-PTP	2 1/8"x1 1/4"
14	110.0	1559	CP-FPTP	2" crack
15	107.0	1528*	CP-FPTP	2" crack
16	105.0	1478*	PP-SB	

a.b. Ballistic limits in diagonally porosity areas on plate 2445 F/S, 2312 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 1503 F/S.

BALLISTIC DATA SHEET #6

Plate 570 - Henry Disston & Sons, Inc., treatment

Face Hardened Ni-Mo -------- .390" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results	
Cal. .30 APM2 firings:				
1	43.0	2469a	CP-PTP	
2	41.0	2315	PP-No bulge	Shattered
3	42.3	2398	PP-No bulge	Shattered
4	42.7	2428a	PP-No bulge	Shattered
5	43.0	2485	CP-PTP	
6	42.5	2418b	CP-PTP	
7	42.0	2400b	PP-SB	
8 to 13	6 rd. m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP Max. exit 7/16" x 3/8"	

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

14	160.0	2167	CP-PTP 2"x3/4" Pun.
15	155.0	2105	CP-PTP 2 1/8"x1 1/8" Pun.
16	150.0	2056*	CP-PTP 2 3/4"x2 1/8"
17	145.0	2046	Hit Shot #15
18	145.0	2061	PP-No bulge struck screen frame.
19	140.0	1921	PP-SB 1" BC
20	143.0	1964	PP no bulge
21	145.0	1967	PP-SB 1/4" back crack
22	148.0	2040	Hit shot #19 CP-PTP
23	147.0	1998	PP backed by support
24	147.0	2016*	PP-M.B. 1" BC on bulge.

a,b. Ballistic Limits in diagonally opposite areas in plate 2449 F/S, 2409 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 2036 F/S.

BALLISTIC DATA SHEET # 7

Plate 571 - Henry Disston & Sons, Inc., treatment

Face Hardened Ni-Mo-V ------ .370"x36"x36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results	
Cal. .30 APM2 firings:				
1	43.0	2472	PP-CIP-BD	
2	44.0	2522a	PP-SB	Shattered
3	44.5	2568a	CP-PTP	
4	44.5	2549	PP-SB-CIP	Punching started
5	45.0	2600b	PP-MB	Punch S.
6	45.2	2646b	CP-CIP	Punching
7 to 11	5 rds. m.g. burst cal. .30 APM2 Service velocity		2 CP-PTP FS 1 3/8"x1" 2 CP-CIP 1 PP-SB	

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

12	160.0	2196	CP-PTP 2 1/8"x1 1/4"
13	140.0	1951*	CP-FPTP 1" crack
14	137.0	1909*	P.P.

a.b. Ballistic limits in diagonally opposite areas of plate 2545 F/S, 2623 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 1930 F/S.

BALLISTIC DATA SHEET #8

Plate 565-1 - Diebold Safe & Lock Co. treatment

Face Hardened Ni-Cr-MO --------- .387" x 36" x 36"

Plate Rd. No.	Powder Charge	Str. Vel.	Results	
Cal. .30 APM2 firings:				
1	44.0	2562	CP-PTP	
2	42.0	2402	PP-CIP	BD
3	43.0	2480a	PP-CIP	BD
4	43.5	2509a	CP-PTP	
5	43.0	2499	PP-SB	Shattered
6	43.5	2503	PP-LB-Pun. S.	Shattered
7	43.8	2537	PP-CIP-MB	BD
8	44.0	2555b	PP-CIP-MB	BD
9	44.3	2572b	CP-PTP	
10 to 14	5 rd. m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP Max. exit diam. 7/16"x3/8"	

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

15	170.0	2286	CP-Nose forced through plate, shattered, unyawed.	
16	170.0	2313	PP-LB 1½" BC	Shattered
17	175.0	2493	CP-PTP	Unyawed
18	175.0	2356*	PP-LB	
19	178.0	2404*	CP-LB 2" BC	

a.b. Ballistic limits in diagonally opposite areas in plate 2495/ F/S, 2565 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 2380 F/S.

BALLISTIC DATA SHEET #9

Plate 570-1 - Diebold Safe & Lock treatment

Face Hardened Ni-Mo ---------- .380 x 36" x 36"

Plate Rd. No.	Powder Charge	St. Vel.	Results	
Cal. .30 APM2 firings:				
1	44.0	lost	PP-no bulge	Shattered
2	44.0	2559	CP-PTP	
3	43.0	2487	CP-PTP	
4	42.0	2425	CP-PTP	
5	40.0	2278a	CP-CIP-Pun. S.	Shattered
6	39.5	2272a	PP-SB	Shattered
7	40.3	2312	PP-MB-CIP	Shattered
8	40.7	2402	PP-CIP	Shattered
9	41.0	2393	PP-CIP	Shattered
10	41.2	2380	PP-CIP	Shattered
11	41.5	2462	PP-CIP-SB	Shattered
12	42.0	2470	PP-CIP-MB	Shattered
13	42.5	lost	PP-CIP-MB	Shattered
14	43.0	2490b	PP-CIP-Pun. S.	Shattered
15	43.3	2502b	CP-CIP-Pun. S.	
16 to 20	5 rds. m.g. Cal. .30 APM2 Service velocity		5 CP-PTP Max. exit diam. 7/16"x3/8"	

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plates, then through second screen at 0°, 3' in front of plate.

21	145.0	2055	PP-SB Shattered
22	155.0	2115	PP-MB-Pun. S.
23	160.0	2168	CP-Hit other impact
24	160.0	2194	Not yawed CP-PTP
25	160.0	2186	CP-PTP-Yaw. 60°
26	160.0	2176	CP-PTP-Yaw. 75°
27	160.0	2183	CP-shattered-Yaw. 75°
28	160.0	2173a	PP-Shattered yawed
29	180.0	2330	CP-PTP Yawed opening 1 7/8"x3/4"
30	170.0	2278	CP-PTP-Yawed
31	165.0	2239	CP-PTP-Yawed
32	162.0	2193a	CP-PTP Yawed
33	165.0	2253	CP-PTP Not fully yawed
34	165.0	2237	CP-PTP 1 ½"x1 1/4"
35	160.0	2187b	CP-LB-2" crack
36	158.0	2156	Hit previous impact

(cont.) 1

BALLISTIC DATA SHEET #9 (cont.) 2

Plate Rd. No.	Powder Charge	Str. Vel.	Results
37	158.0	2163b	PP-MB-No crack on back

a.b. Ballistic limits in diagonally opposite areas in plate 2275 F/S, 2496 F/S.

a.b. Ballistic limit (Cal. .50 APM2 projectile yawed) 2183 F/S, 2175 F/S.

BALLISTIC DATA SHEET #10

Plate 564-1-2 - Breeze Corporations treatment

Face Hardened Cr-Mo ---------- .383" x 18" x 18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
1 to 11	11 rds. m.g. burst cal. .30 APM2 Service Velocity		5 CP-PTP punchings max. exit ½" x 3/8", 5 CP-PTP full petalling max. exit 3/8"x3/8". 1 rd. missed.
Cal. .30 APM2 firings:			
12	43	2432	PP Pun. S. CIP- BD
13	43.5	2460	PP-MB-CIP BD
14	44	2522	PP-LB-CIP BD
15	45	2582a	PP-CIP intact Pun. S.
16	44	2532	CP-Punching Exit ¼"x5/16" FS 1"x7/8"
17	43.5	2492	CP-Punch 3/8"x3/8" FS 1"x7/8"
18	43	2442b	CP-Punching 1/4"x1/4"
19	42.5	2402	CP-hit shot #16
20	42.5	2402	PP-too close to shot #17
*21	53(lot6.5 HU)	2587a	CP-Pun. 5/16"x7/16"
22	42.5	2422b	PP-MB

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

23	165	2209	CP-Struck Rds. 6 & 7
24	165	2204	CP-PTP B.S.-1½" x 2 5/8"
25	165	2197	CP-PTP Exit 1 7/8" x 1 7/8"
26	165	2211	CP-PTP Exit 2 7/8" x 2"

a.b. Ballistic limits in diagonally opposite areas of plate--2585 F/S, 2432 F/S.

* Shot 21 in first B.L. test using high Vel. powder

BALLISTIC DATA SHEET #11

Plate #565-1-2 - Breeze Corporations treatment
Face Hardened Ni-Cr-Mo -------- .389" x 18" x 18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. .30 APM2 firings:			
1	38.0	2274	PP-NB
2	39.5	2350	Yawed impact
3	39.0	2313	PP-SB-CIP
4	40.0	2373a	CP-PTP punching 3/8"x5/16"
5	39.5	2304	PP-SB-CIP
6	39.7	2363	CP-PTP punching 3/8"x5/16" too close to rd. #5.
7	39.7	2300	PP-SB
8	39.7	2343a	PP-CIP-Pun. S. B.D.
9	40.0	2264	PP-SB
10	40.0	2254	PP-SB-CIP-BD
11	41.0	2343b	PP-NB-CIP-BD
12	42.0	2432	CP-PTP 3/8"x3/16" punching
13	41.5	2402	CP-PTP 7/16"x¼" punching
14	41.3	2373b	CP-PTP 3/8"x3/8" punching
15 to 19	5 rds m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP punchings max. exit 9/16"x7/16"
20 to 24	5 rd. m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP punchings max. exit 7/16"x½"

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

25	165	2209*	PP
26	165	2197	Struck Rd. #1 CP-PTP
27	165	2203*	CP-CL Exit 1½"x½"

a.b. Ballistic limits in diagonally opposite areas of plate - 2358 F/S, 2358 F/S.

* Ballistic limit (cal. .50 APM2 projectile yawed) about 2203.

BALLISTIC DATA SHEET #12

Plate 566-1-2 - Breeze Corporations treatment
Face Hardened Cr-Mo-V --------- .401"x 18" x18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
1 to 5	5 rd. m.g. burst cal. .30 APM2 Service velocity		3 CP-PTP punching 9/16"x½" 2 PP
6 to 10	5 rd. m.g. burst cal. .30 APM2 Service velocity		4 PP Pun. S. 1 CP Punching 3/8"x3/8" Face spalls 1 3/8"x2", 1½"x1 5/16".

Cal. .30 APM2 firings:

Plate Rd. No.	Powder Charge	Str. Vel.	Results
11	43.0	2477a	PP-NB
12	44.0	2557	CP Punching 7/16"x3/8"
13	43.5	2527a	CP Punching ¼"x7/16"
14	44.0	2512	PP-NB
15	44.5	2552	PP-NB
16	45.0	2592	PP-SB
17	54.0(Hi Vel)	2662b	CP-CIP Pun. S. B.D.
18	53.5(Hi. Vel.)	2632b	PP Star crack F.S. 1"x3/4"
19	65.0	3094	CP Punching 7/16"x½" hit #15
20	63.0	3052	CP-PTP Punching 5/8"x5/8" hit #17
21	60.0	2923	CP-PTP Punching 3/8"x½" FS 1"x1 1/8"
22	60.0	2917	CP-PTP Punching ½"x½"
23	60.0	2942	CP-PTP Punching 9/16"x½"

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through a second screen set at 0°, 3' in front of plate.

Plate Rd. No.	Powder Charge	Str. Vel.	Results
24	165.0	2196*	PP-MB
25	165.0	2201*	CP-FPTP exit 5/8"x5/8"
26	165.0	2208	CP-FPTP Punching 1"x½"

a.b. Ballistic limits on diagonally opposite areas of plate 2502 F/S, 2647 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 2199 F/S.

BALLISTIC DATA SHEET #13

Plate 567-1-2 - Breeze Corporations treatment

Face Hardened Cr-Mo-Zr ------------ .379"x18"x18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. .30 APM2 firings:			
1	54	2672	CP-PTP Pun. 7/16" x ½"
2	53.0	2637	CP-PTP Pun. 5/16"x3/8"
3	52.0	2592	CP-PTP Pun. 3/8"x½"
4	51.0	2537	CP-PTP Pun. 3/8"x7/16"
5	50.0	2472a	CP-PTP Pun. 3/8"x3/8"
6	48.0	2392	PP-MB-CIP-BD
7	49.0	2452a	PP-MB-CIP-BD
8	49.0	2437b	CP-PTP Pun. 3/8"x3/8"
9	48.0	2401b	PP Pun. S.
10 to 19	10 rd. m.g. burst cal. .30 APM2 Service velocity		2 rds. tangent 7/8"x½" 3 rds. CP-PTP pun. ½"x½" 5 rds. CP-PTP pun. 7/16"-x 3/8".

Cal. .50 APM2 firings;

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

20	165	2211	CP-PTP exit 1 5/8"x2 3/4"
21	165	2203	CP-PTP exit 2 1/8"x2"
22	165	2197	CP-PTP exit 1 3/4"x1 7/8"

a.b. Ballistic limits in diagonally opposite areas of plate 2462 F/S, 2419 F/S.

BALLISTIC DATA SHEET #14

Plate 569-1-2 - Breeze Corporations treatment

Face Hardened Mn-Mo ------ .382"x18"x18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
Cal. .30 APM2 firings:			
1	43.0	2467a	CP-PTP pun. 3/8"x½"
2	42.0	2392	PP-NB
3	42.5	2432a	PP-NB
4	43.0	2437	PP-NB
5	43.5	2502b	PP-Pun. S.
6	51.0(Hi. Vel.)	2512b	CP-PTP Pun. 3/8"x7/16"
7 to 16	10 rd. m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP punchings. Max. exit ½"x½" 3 CP-PTP punchings Max. exit ½"x7/16" 2 PP-Pun. S.

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

17	165.0	2209	CP-PTP exit 3"x3½"
18	165.0	2196	CP-exit 1"x3/16" backed by support.
19	165.0	2205	CP-PTP exit 2 7/8"x1 5/8" struck shot #12 and #14.

a.b. Ballistic limits in diagonally opposite areas of plate 2450 F/S, 2507 F/S,

BALLISTIC DATA SHEET #15

Plate 570-1-2 - Breeze Corporations treatment

Face Hardened Ni-Mo ---------- .384"x18"x18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
1 to 10	10 rd. m.g. burst cal. .30 APM2 Service velocity		5 CP-PTP Max. exit ½"x3/8" 3 CP-PTP Max. exit 7/16"x3/8" 2 yawed impacts

Cal. .30 APM2 firings:

11	43.0	2412	PP-SB-CIP-BD
12	44.0	2552	CP-PTP pun. ½"x5/16"
13	43.5	2500	CP-PTP pun. 3/8"x7/16"
14	43.0	2422a	PP-CIP-BD
15	43.2	2462a	CP-PTP pun. 5/16"x3/8"
16	43.0	2449b	CP-PTP pun. 3/8"x3/8"
17	42.5	2432b	PP-SB-CIP-BD

Cal. .50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

18	165	2204	CP-PTP B.S. 1 1/8"x3/4"
19	165	2197	CP-PTP max. exit ½"x2"

a.b. Ballistic limits in diagonally opposite areas of plate 2442 F/S, 2441 F/S.

BALLISTIC DATA SHEET #16

Plate 571-1-2 - Breeze Corporations treatment

Face Hardened Ni-Mo-V -------- .380"x18"x18"

Plate Rd. No.	Powder Charge	Str. Vel.	Results
1 to 10	10 rd. m.g. burst cal. .30 APM2 Service velocity		5CP-PTP pun. 3/8"x3/8" 5CP-PTP 3 pun. ½"x7/16" 2 petalling

Cal. .30 APM2 firings:

11	42	2442	PP-MB-CIP-BD
12	42.5	2462	PP-MB-CIP-BD
13	43.0	2484a	PP-MB-CIP-BD
14	44.0	2532a	CP-PTP pun. ½"x5/16"
15	44.0	2572	CP-PTP pun. 3/8"x7/16"
16	43.0	2472b	CP-PTP pun. 3/8"x3/8"
17	42.0	2373	PP-SB-CIP
18	42.5	2422b	PP-MB-BD

Cal..50 APM2 firings:

Projectiles tipped through 1/8" aluminum screen set at 40°, 7'6" in front of plate, then through second screen set at 0°, 3' in front of plate.

19	165	2201	CP-proj. failed to yaw.
20	165	2199*	CP-L.B. 1½" BC
21	165	2217	CP-proj. failed to yaw.
22	165	2205*	P.P.-LB 3/4" BC

a.b. Ballistic limits in diagonally opposite areas of the plate 2508 F/S, 2447 F/S.

* Ballistic limit (cal. .50 APM2 projectiles yawed) 2199 F/S.

KEY TO ABBREVIATIONS

Effects on Plate

CP	–	Complete penetration
PP	–	Partial penetration
CIP	–	Core in plate
Pun S	–	Punching started
SB	–	Slight bulge on back
LB	–	Large bulge on back
MB	–	Medium bulge on back
NB	–	No bulge on back
BS	–	Back spall
FS	–	Face spall
FP	–	Face petalling
BP	–	Back petalling
Inc.	–	Incomplete
SC	–	Star crack
BC	–	Back crack

Effects on Projectile

PTP	–	Passed thru plate
FPTP	–	Failed to pass thru plate
ND	–	Nose destroyed
BD	–	Base destroyed
Ni	–	Nose intact
BI	–	Base intact

Note: Unless otherwise specified, the powder charge was measured in grains.