REPORT NO. 314/61

GUN STEEL - CENTRIFUGAL CASTINGS

Evaluation of the Normalize Treatment

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December 17, 1942

WATERTOWN ARSENAL
WATERTOWN, MASS.

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12/23/42

Report No. 314/61
Watertown Arsenal
XO-1108 A-41

December 29. 1942

GUN STEEL - CENTRIFUGAL CASTINGS

Evaluation of the Normalize (Homogenize) Treatment.

OBJECT

To evaluate the influence of high temperature normalizing (homogenizing) on the characteristics of centrifugally cast gun tubes as produced at Watertown Arsenal.

REFERENCE

W.A. Report No. 314/50

CONCLUSIONS

1. The physical properties (strength, ductility hardness and impact) of standard centrifugal castings of Watertown Arsenal gun composition are not influenced materially by long-time high temperature normalizing.

2. Normalizing, as evidenced by macro and micro examination, does tend to break down the "as cast" structure and to destroy evidences of dendritism.

3. Standard castings with four times the regular normalize treatment failed to show any beneficial effects of normalizing in processing; comparison was based on machining and cold working.

4. Based upon the results obtained in this limited investigation, standard castings without the high-temperature treatment can be processed satisfactorily into cold worked guns that meet the requirements of the specifications up to proof-firing. Proof-firing has not yet been attempted.

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INTRODUCTION

Watertown Arsenal Report No. 314/50* concludes, "There is apparently no change in the heat treated physical properties as measured by the tensile and tensile impact tests when the normalizing** treatment is omitted on centrifugally cast Watertown Arsenal gun steel". This conclusion was reached from treating and testing adjacent pieces (10 inches long) from three 40 mm. gun tubes.

To evaluate the normalize treatment on full size castings, there was authorized the processing for cold work of two production 105 mm. Howitzers with complete omission of the standard high temperature normalize (16 hours at 2200°F and air cool). For comparison, there was authorized also the concurrent processing of two companion castings with four times the usual normalize treatment (64 hours at 2200°F and air cool).

Four guns were selected from routine production for similarity of ladle chemistry and cast hole size. (A fifth gun had been selected but was later rejected. It failed to meet the physical properties because of low muzzle carbon content. See Appendix A). With the exception of the normalize treatment, each gun tube was processed and cold worked in accordance with routine shop practice. The guns, however, represented extremes of heat treatment which bracketed the regular production standard. An exhaustive study of the comparative processing data; and macro, micro, and physical properties of these castings is presented herein.

RESULTS AND DISCUSSION

1. Processing.

(a) Heat Treating

Two castings, 2L-1125 and 2N-1431, were water quenched (from 1650°F) and drawn (1320°F) directly from the "as cast" condition; the total furnace time was 16 hours. Two similar castings 2N-1268 and 2N-1271

* "A comparison of Normalized and Not Normalized Centrifugal castings of Watertown Arsenal Gun Composition" 11/16/42.

** At Watertown Arsenal, the term "Normalize" refers to a high temperature homogenizing treatment.

were treated at 2200°F for 64 hours and air cooled (normalized) prior to the standard quench and draw as above; the total furnace time was 88 hours. The furnace time for regular production treatments of normalize (16 hours at 2200°F) and quench and draw totals 40 hours. The 64 hour normalize guns had nine-sixteenth inch thick scale on the outside due to normalizing while regular production guns (16 hour normalize) have four-sixteenth inch thick scale. Most of the scale produced during normalizing is knocked off before quench and draw. The two guns without normalize developed only a paper-thin scale from quench and draw.

(b) <u>Machining</u>

All four guns were straightened, turned and bored in regular production at normal feeds and speeds. In each case the operator was questioned afterwards for comments as to the relative machinability, hard spots, etc. The only exceptional circumstance was the frequent replacement of opening cutters during rough boring of the normalized guns since the cast hole had been practically sealed shut by oxidation. The gun tubes without normalizing machined without this difficulty.

(c) <u>Cold Working</u>

All four guns were cold worked under the personal supervision of the head of the cold work section. Boroscoping before and after cold-working failed to disclose any defects. Normalized guns were star-gauged (bore) and measured (outside) at 12" intervals to determine the extent of autofrettage; guns without normalize were measured at 4" intervals to detect any localized non-uniformities. Details are summarized in Table I. The behavior of all guns during cold-working was normal and satisfactory. Casting 2N-1271 (64 hr. normalize) showed a small surface crack at 13" from the breech and was turned undersize and wire wrapped prior to cold work. Casting 2L-1125 (no normalize) showed a surface crack about 3/8" long at 75" from the breech after cold work and was turned to remove the defect after soak.* All castings were soaked, checked for straightness and concentricity, and were ready to ship October 20, 1942.

* 3 hours heating to 570°F, 5 hour hold at 570°F and air cool.

2. Testing

(a) Chemical Analyses

Ladle and actual gun analyses are listed in Table II. Each gun tube showed a definite drop in carbon from breech to muzzle. This is the usual rather than the exceptional occurance in centrifugally cast gun tubes.

(b) Physical Properties

Table III lists the heat treatments and physical properties of these gun tubes. Table III can be summarized in a single statement; it is evident that gun castings can be quenched and drawn from the "as cast" condition to have acceptable physical properties equal to those of normalized, quenched and drawn material.

(c) Macro-Examination

Breech and muzzle discs of all four guns were submitted "as cast" for standard etch and examination. Macro photographs of these discs are given as Figures 1 to 8. The macros are significant only in that they indicate the guns to be comparable, and typical of normal melting and casting practice. The "as cast" structure is radial and columnar, most discs show segregation of impurities at the bore. The muzzle disc of 2N-1268 (Figure 6) shows the occurrence of a "carbon ring" which is not infrequent in production castings.

After quench and draw, the guns were cut in the routine practice (2" discard) and sample discs were again submitted to standard macro-examination. Photographs are attached (Figures 9 to 16). The two castings which were normalized 64 hours show a "flat" etch devoid of anything which might be termed radial or columnar. (It is interesting to note that the "carbon ring" is still evident, Figure 14, after 64 hours at 2200°F). On the other hand, the castings without the normalize have an etched structure quite comparable in appearance to that of the original "as cast" tube. An exception is the muzzle of 2L-1125 (Figure 10) which, for some reason, has the flat appearance of normalized, quenched, and drawn material. This type of comparison has been used as evidence that a high temperature treatment will break down the "as cast" structure into complete uniformity.

It has been the experience of the Laboratory that internal strains apparently increase the etching rate, and that heat treatment, perhaps conversely, inhibits the reaction. For this reason, "as cast" discs are etched 40 minutes to bring out what is believed to be a satisfactory indication of structure, while heat treated discs are etched 80 minutes to approximate the same degree of attack. It is also the experience of the Laboratory that columnar (dendritic) structure can be developed in routine gun discs (normalized 16 hours) merely by increasing the time of etching. That columnar structure can be developed even in 64 hour normalize material has been demonstrated by etching 2N-1268 for 500 minutes. (Figure 17) From a comparison of Figures 13 and 17, the same disc etched for 80 and 500 minutes, respectively; it may be concluded that even 64 hours at 2200°F does not result in thoroughly homogenized, non-dendritic material.

As a matter of interest, the breech disc of 2L-1125 was likewise over-etched. Figures 9 and 18 show the same disc etched for 80 minutes and 500 minutes, respectively. The most striking contrast is, of course, the layering near the outside and the abrupt line of demarcation near the midwall. These same features are observed with less contrast on long etching of the normalized material (Figure 17). Further study of this apparent line of demarcation near the midwall does not bear directly on the evaluation of normalizing and is covered in Appendix B.

(d) Micro Examination

Guns 2L-1125 and 2N-1268 were selected for systematic comparison of micro-structure because their respective physical properties were quite comparable despite the differences in heat treatment. All samples were taken at the midwall of the cast dimensions, since heat treatment (including quench and draw) of all guns regularly routed to cold work is completed prior to any machining. "As cast" samples were cut from discs after 2" end discards were taken. Samples after heat treatment were cut 7" from the ends of each gun to eliminate the influence of end cooling during quench. All samples were examined carefully to insure that the photographs submitted are representative of the material.

Figures 19 and 20 demonstrate typical "as cast" micro-structures of breech and muzzle sections of the two castings; they confirm the macro evidence that these particular castings are typical of normal production and that they are comparable. The Widmanstatten pattern noted in the muzzle of 2L-1125 (Figure 19) is fairly common in Arsenal gun castings; it is believed the consequence of a particular cooling rate and is not significant to this investigation.

Figures 21 and 22 demonstrate the final micro-structure of castings quenched and drawn without and with a 64 hour normalize, respectively. At 100 magnification (top photographs) there are several differences to be noted; first, is the amount, shape, and size of the ferrite. The amount of ferrite is a function of chemical analysis, section thickness and quenching rate. As may be anticipated, the muzzle (thinnest section) of each gun shows less and finer ferrite than the breech. Further, the normalized sections show less ferrite than the sections without normalize. While other variables as chemistry and quench water temperature must be considered, it is possible that the excessive scaling of the bore and outside of the normalized gun, 2N-1268, resulted in less effective quenching (and so more ferrite rejection) than for 2L-1125 which was charged for quenching in the "as cast" condition.

A second difference (Figures 21-22) is the presence of dark areas (apparently interdendritic) in the material without normalize. These are evident especially in the muzzle and can be distinguished in the breech. There is no trace of them in the 64 hour material, although they can be demonstrated usually by suitable etching of regular (16 hour) gun production. Dendritic material is commonly associated (in forgings) with brittle structure as measured by low impact, elongation and reduction in area.

Examination at 1500 magnification (lower photographs Figures 19 - 22) resolves the structure but does not yield anything additional. It may be concluded from the micro-examination that neither gun was fully hardened in the quench, that normalizing <u>does</u> tend to "break down the "as cast" structure", but that, apart from the evidence of dendritism, there is no choice in micro-structure. If anything, the gun without normalize is more uniformly sorbitic.

Further proof of residual dendritism in the gun without normalize was developed when breech samples of 2L-1125 and 2N-1268 were etched to show the presence of dendrites. The photographs of Figure 23 are striking evidence that high temperature normalizing tends to destroy dendritism in cast material.

3. General Considerations

In brief summary, the data of this report lead to several implications which are of immediate concern to the Production Departments of this Arsenal. Within the limits of random selection in choosing castings for test, there has been shown the probability that high temperature normalizing may be omitted from standard processing without apparent influence on quality of product and with significant savings in time, materials and labor. Within the scope of these tests there has been demonstrated that castings without the normalize treatment will meet Ordnance Department specifications of manufacture (i.e.- physical properties, machinability and cold working). While supplementary information from macro and micro examination show a greater degree of residual dendritism in the gun without normalize, it must be concluded from processing comparisons and from physical tests that this condition is not detrimental to quality.

There remains the possibility that proof firing of these guns will disclose some unevaluated merit of normalizing which may result in the failure of castings not so treated. However, in view of the successful cold working of the guns without normalize, it is believed that failure in the field is extremely unlikely.

TABLE I

COLD WORK DATA

	GUN NUMBERS			
	Without Normalize		64 hour Normalize	
	2L-1125	2N-1431	2N-1268	2N-1271
Average for Breech and Muzzle (P.S.I.)				
Yield Strength (.01% offset)	64,125	67,375	67,750	74,375
Calculated pressure to Cold Work*	81,000	86,400	85,800	95,000
Average for Breech Only (P.S.I.)				
Yield Strength	67,500	74,200	68,500	74,000
Calculated pressure to Cold Work*	86,800	95,400	88,000	95,200
Actual Pressure to Cold Work (P.S.I.)				
Start (Muzzle)	81,000	95,000	87,000	86,000
Complete (Breech)	90,000	100,000	93,000	94,300
Percent Cold Working of Bore				
Range	5.8-6.6	5.3-6.0	5.6-6.6	5.6-6.5

Note:* An estimate of the pressure necessary for 6% cold-working of the bore is obtained by multiplying the yield strength by a pressure factor governed by the wall ratio of the tube. The P.F. for the breech of a 105 mm. Howitzer is 1.285.

P.S.I. = Pounds per square inch.

TABLE II

CHEMICAL ANALYSES

Gun Number	Location of Test	C	Mn	Si	P	S	Cr	Mo	V
2L-1125	Ladle	.19	.67	.33	-	-	.99	.51	.10
	Breech 12 o'clock	.20	.54	.33	.008	.020	1.00	.52	.13
	Breech 6 o'clock	.18	.63	-	-	-	-	-	-
	Muzzle Tensile	.14	.62	-	-	-	-	-	-
2N-1431	Ladle	.19	.75	.29	-	-	1.10	.51	.10
	Breech Tensile	.20	.69	.30	.007	.023	1.06	.49	.11
	Muzzle Tensile	.14	.72	-	-	-	-	-	-
2N-1268	Ladle	.19	.65	.33	-	-	1.05	.50	.12
	Breech Tensile	.20	.56	.26	.011	.023	.98	.52	.12
	Muzzle Tensile	.17	.49	-	-	-	-	-	-
2N-1271	Ladle	.20	.63	.33	-	-	1.10	.53	.10
	Breech Tensile	.21	.57	-	-	-	-	-	-
	Muzzle Tensile	.18	.52	-	-	-	-	-	-

TABLE III

PHYSICAL PROPERTIES

HEAT TREATMENT

PHYSICAL PROPERTIES

Gun Number	Normalize Time	Normalize Temp. of	Water Quench from	Draw 6 hrs. at	Location	Y.S. PSI	T.S. PSI	Elong %
REQUIRED						60,000 / 85,000		
2L-1125			1650°F	1320°F	Breech	67,500	92,500	24.0
			.	.	Muzzle	60,700	87,200	26.0
		(Longitudinal)			Breech	65,700	91,500	18.6
		(Longitudinal)			Muzzle	61,500	86,000	25.3
2N-1431	-	-	1650°F	1320°F	Breech	74,200	100,900	20.3
			.	.	Muzzle	60,500	85,700	26.4
2N-1268	64 hrs	2200	1650°F	1305°F	Breech	68,500	90,000	23.6
			.	.	Muzzle	67,000	86,900	25.0
2N-1271	64 hrs	2200	1650°F	1305°F	Breech	74,000	95,200	20.7
			.	.	Muzzle	69,700	88,800	25.3

Note: All tests, except those marked longitudinal (3" discard), are after 2" disc[...] value, except impact, represents the average of two tests tangent to the fir[...]

y.s. = yield strength (.01% offset method)
t.s. = Tensile Strength
P.S.I. = Pounds per Square Inch.
Impact = Charpy Tensile
Brinell = 3000 Kg. Load.

C = Cupped
P = Pitted
G.C = Gas Cavities
SLC = Small Lustrous Cavities
Ir.Br. = Irregular Break.

TABLE III

AL PROPERTIES

AL PROPERTIES

T.S. PSI	Elong %	R.A. %	Fracture	Impact Ft-lbs	BRINELL HARDNESS Distance from Cast Hole, Inches .75	1.5	2.25	3.0	3.75	4.5
		45% MIN								
					197	187	187	187	179	18
92,500	24.0	50.0	Ir.Br-P-G.C.	42/51						
87,200	26.0	70.0	C-P							
91,500	18.6	46.1	Ir.Br-P-G.C.	-						
86,000	25.3	73.7	C-P	-						
100,900	20.3	55.7	C-P-SLC	-						
85,700	26.4	74.4	C-P	-						
					187	187	197	197	207	19
90,000	23.6	68.3	C-P	-						
86,900	25.0	71.8	C-P	47/46						
95,200	20.7	56.2	C-P-SLC	-						
88,800	25.3	70.7	C-P	-						

, are after 2" discard. Each
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Cavities
ll Lustrous Cavities.
egular Break.

APPENDIX A

Subject: 2N-1173

Gun tube casting 2N-1173 was originally selected for processing with complete omission of the normalizing treatment. It was later rejected when it failed to meet the required physical properties because of low muzzle carbon content. The results obtained on this tube are in agreement with the other data submitted herein, and are given below merely as additional information, and without comment.

CHEMICAL ANALYSIS

Test Location	C	Mn	Si	Cr	Mo	V
Ladle	.20	.67	.30	1.02	.51	.10
Breech Tensile	.18	.62	-	-	-	-
Muzzle Tensile	.15	.60	-	-	-	-

PHYSICAL PROPERTIES

Test Location	Y.S. PSI	T.S. PSI	Elong. %	R.A. %	Fracture	Impact Ft-lbs.
(After 1650° Water Quench - 6 hour draw at 1320°F - No Normalize)						
Breech	66,500	91,000	18.2	36.9	Ir-P-GC	36/44
Muzzle	55,200	82,600	27.8	72.9	C-P	
(After retreat - 1650°F Quench - 6 hour draw at 1305°F)						
Breech	68,000	89,800	21.0	49.6	C-P	
Muzzle	58,600	78,300	26.4	71.3	C-P	

Y.S. = Yield Strength (.01% offset method)
T.S. = Tensile Strength
P.S.I. = Pounds per Square Inch.
Impact = Charpy Tensile

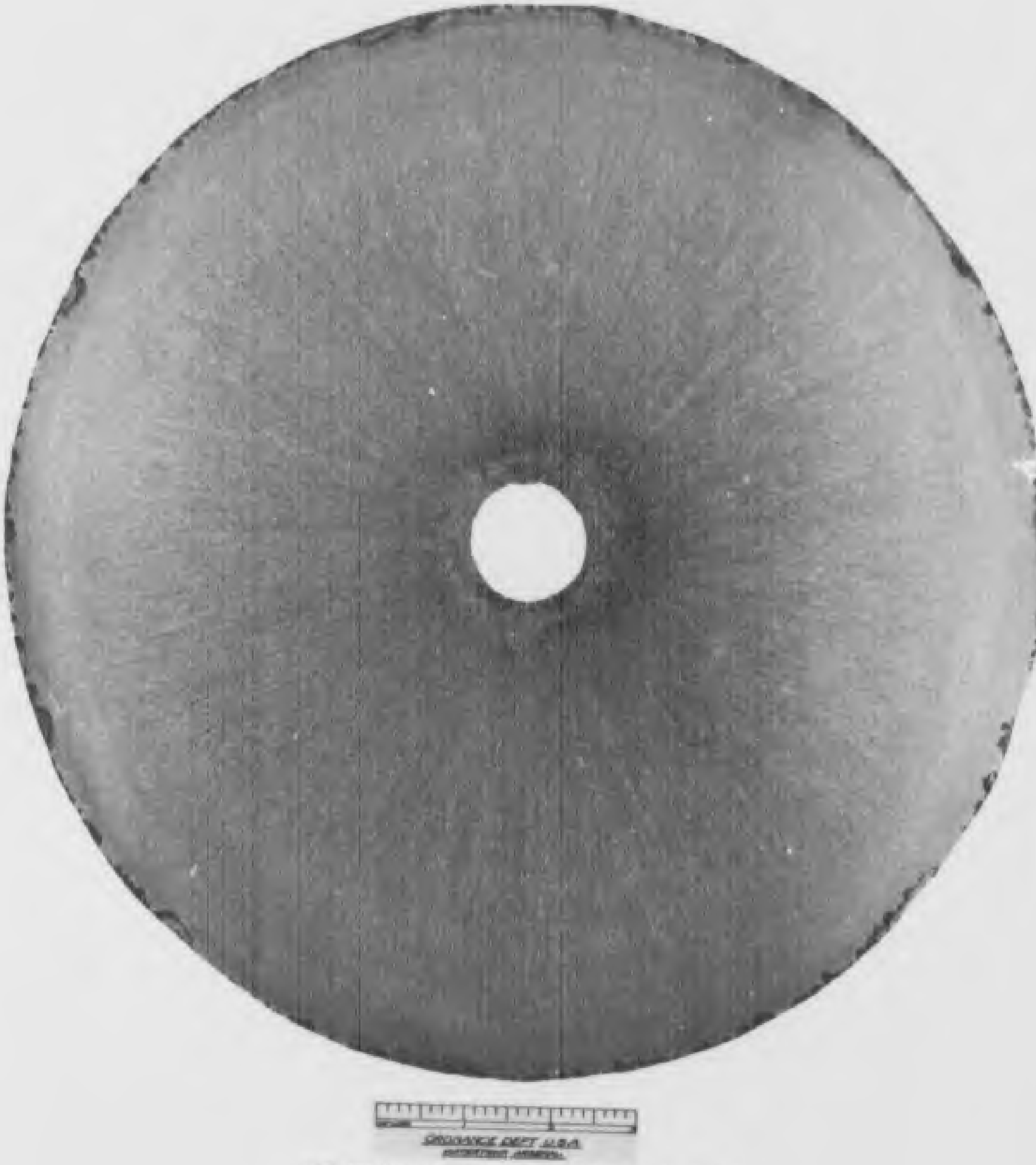
C = Cupped
P = Pitted
Ir.B = Irregular Break.
GC = Gas Cavity

APPENDIX B

Subject: Apparent radial differences in Structure
Figures 17 and 18.

For valid micro comparison of normalized and not normalized material, it was suggested that the samples should be selected definitely from either the light or dark etching portions of the discs shown in the subject photographs. Inasmuch as the occurrence of the line on both discs would indicate inherent radial differences in structure, both discs were sectioned for micro samples at the line of demarcation. Etched with Nital, the difference in microstructure of the light and dark etching, portions was not discernible. For detailed examination, panoramic photographs (not submitted with this report) across the boundary confirmed the differences in microstructure between normalized and not normalized guns (Figures 21 and 22), but failed to disclose any difference within the sample. Etched to show dendrites (Figure 23), however, the line of demarcation can be noted in the casting without normalize but still cannot be distinguished in the normalized material.

From close examination of the dendrite pattern, it is believed that the boundary is not an inherent radial difference in the casting; it may represent the "striking power" of the chill mold. Up to the boundary line, solidification has been progressing at a rapid rate; dendrites are columnar. The boundary may occur when the chill mold has absorbed sufficient heat to be in equilibrium with the surface of the casting; at this time the rate of solidification is appreciably decreased and dendrites become shorter and stubbier with more pronounced non-homogeniety. This more pronounced segregation may be the cause for even 64 hour (normalized) material to appear columnar at the center after long macroetching. Other theories may be advanced to explain this demarcation line.

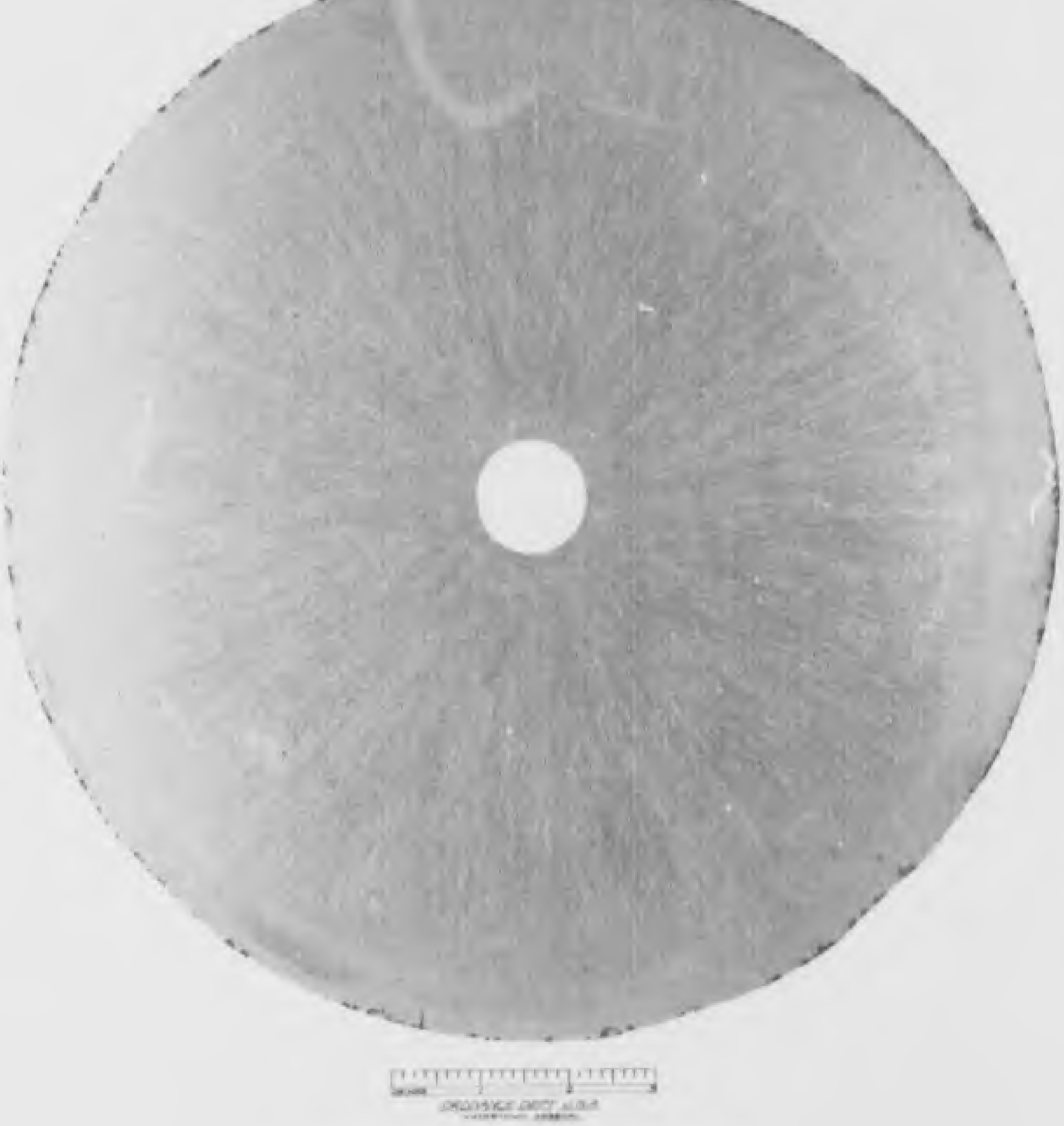


105 MM HOWITZER # 2L-1125 - AS CAST
OCTOBER 12 1942 BREECH WTN.223-2542

FIG. 1

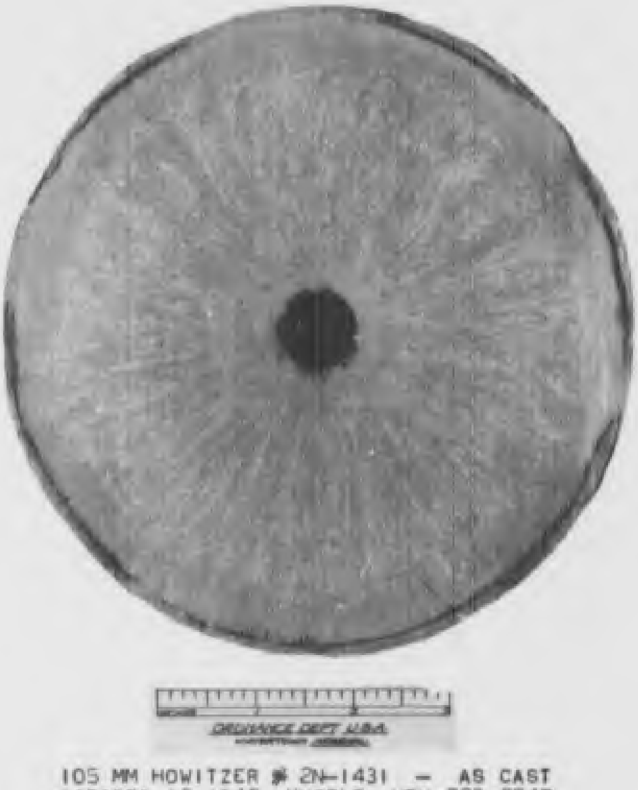
105 MM HOWITZER # 2L-1125 - AS CAST
OCTOBER 12 1942 MUZZLE WTN.223-7543

FIG. 2



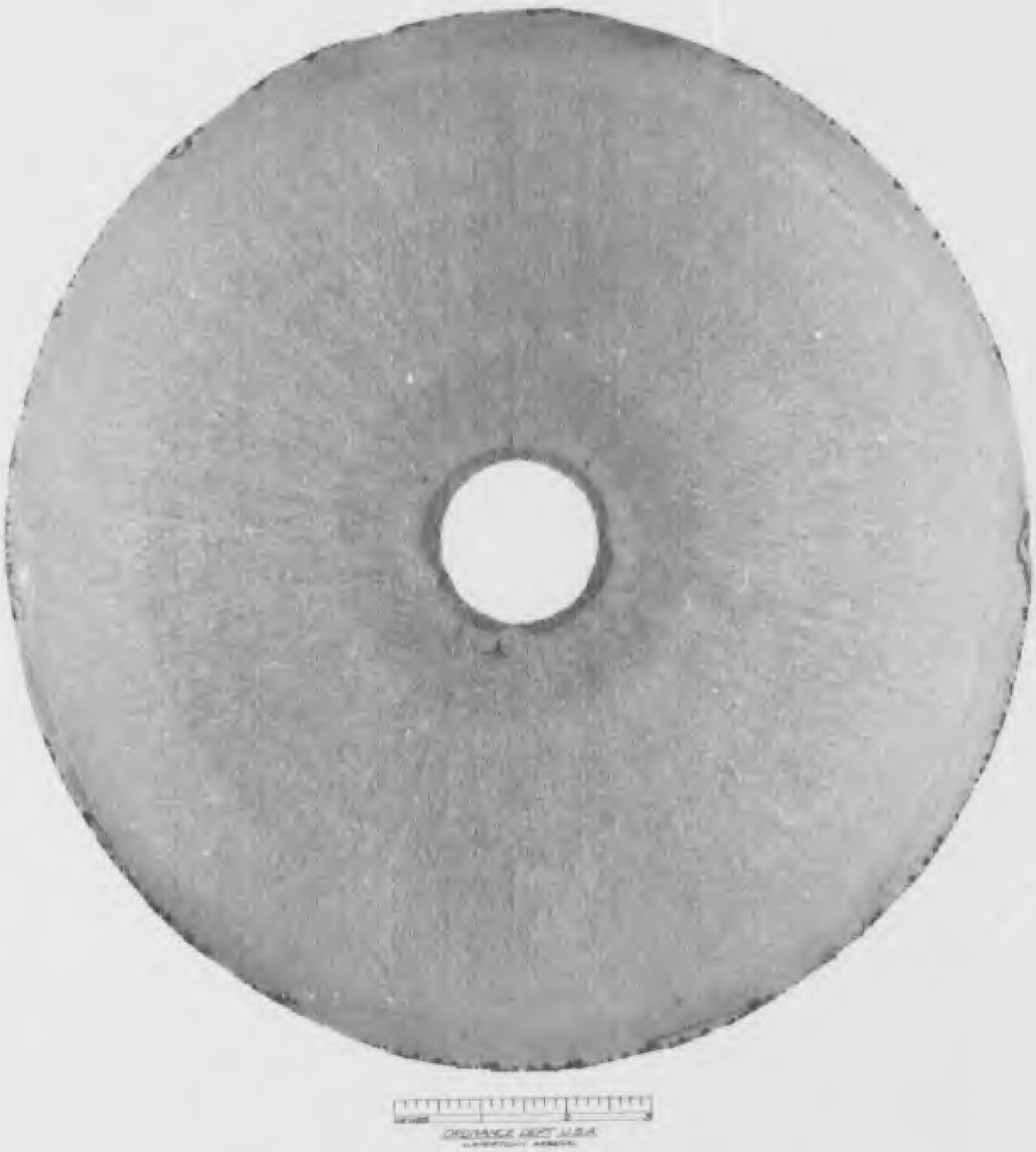
105 MM HOWITZER # 2N-1431 - AS CAST
OCTOBER 17 1942 BREECH WTV.223-2546

FIG. 3



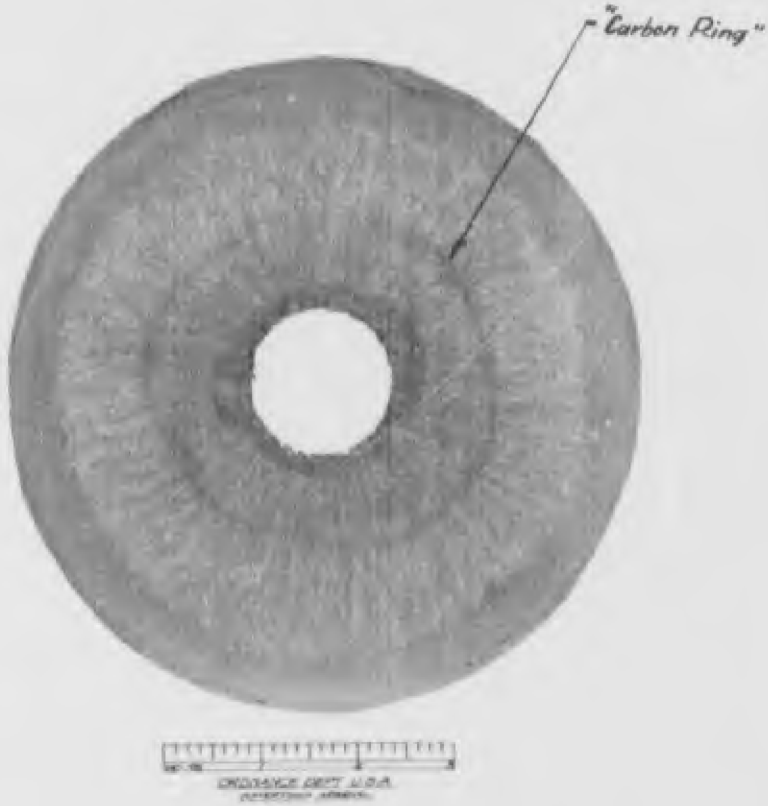
105 MM HOWITZER # 2N-1431 - AS CAST
OCTOBER 12 1942 MUZZLE WTN.223-2547

FIG. 4



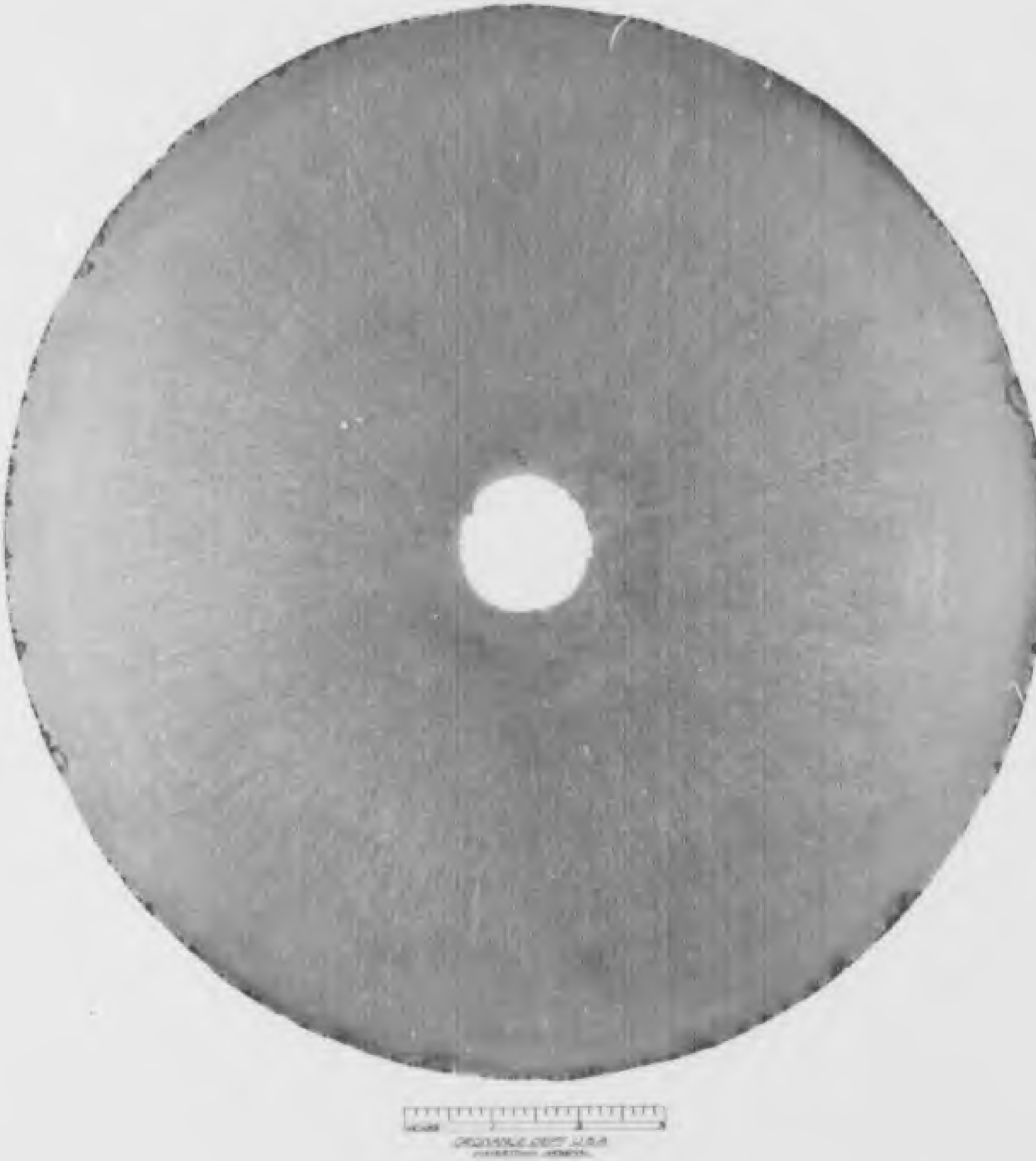
105 MM HOWITZER # 2N-1260 - AS CAST
OCTOBER 12 1942 BREECH WTN.223-2544

FIG. 5



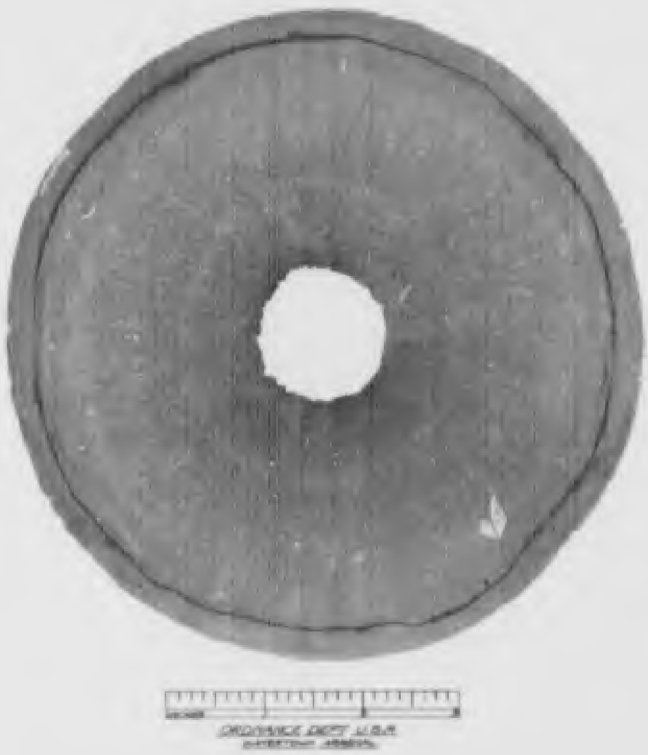
105 MM HOWITZER # 2N-1268 - AS CAST
OCTOBER 12 1942 MUZZLE WTN.223-2546

FIG. 6



105 MM HOWITZER # 2N-1271 - AS CAST
OCTOBER 12 1942 BREECH WTN.223-2540

FIG. 7



105 MM HOWITZER # 2L-1271 - AS CAST
OCTOBER 12 1942 MUZZLE WTN.223-2540

FIG. 8

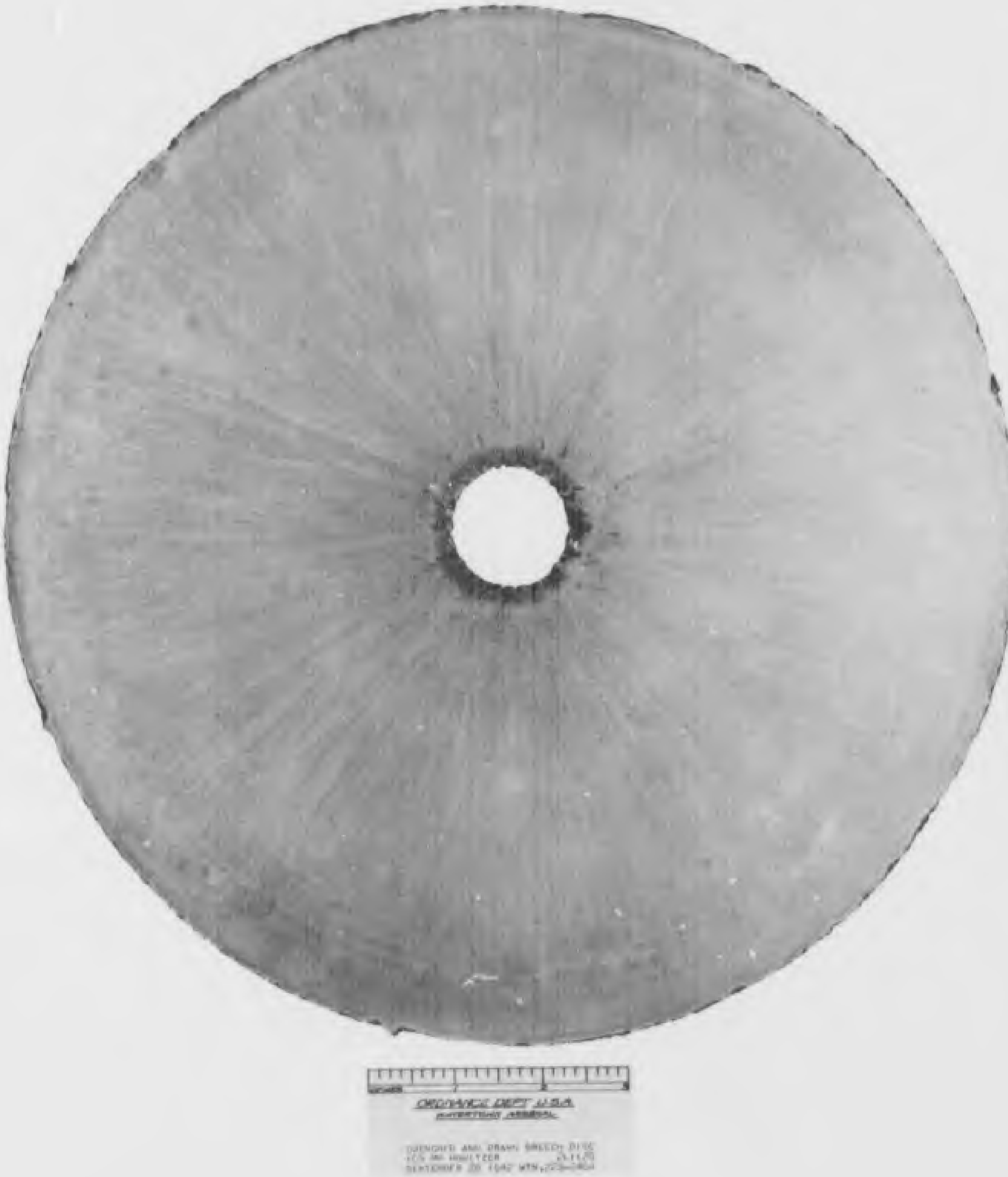
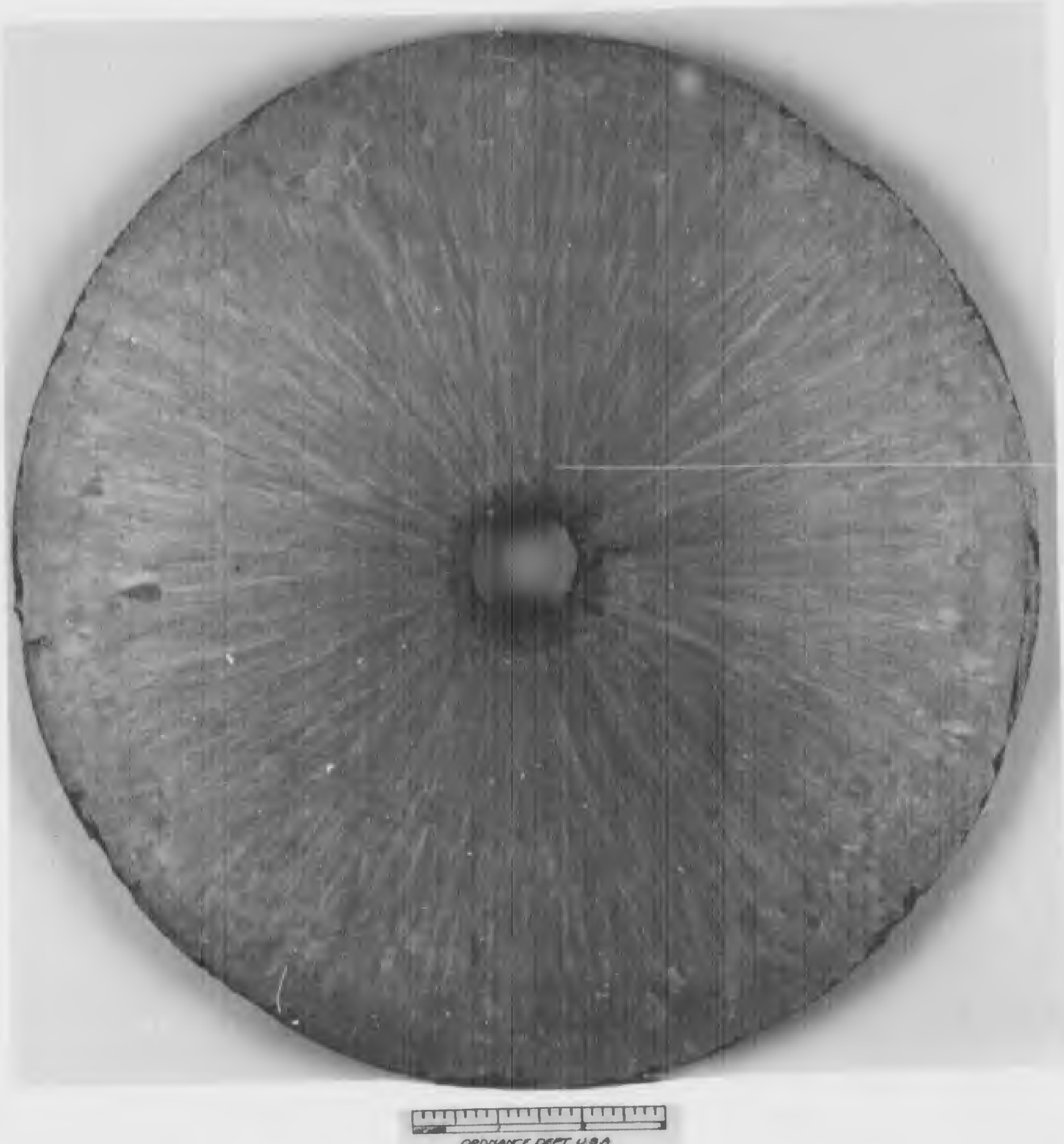

ORDNANCE DEPT U.S.A.
QUENCHED AND DRAWN BREECH DISC
105 MM HOWITZER

FIG. 9

FIG. 10

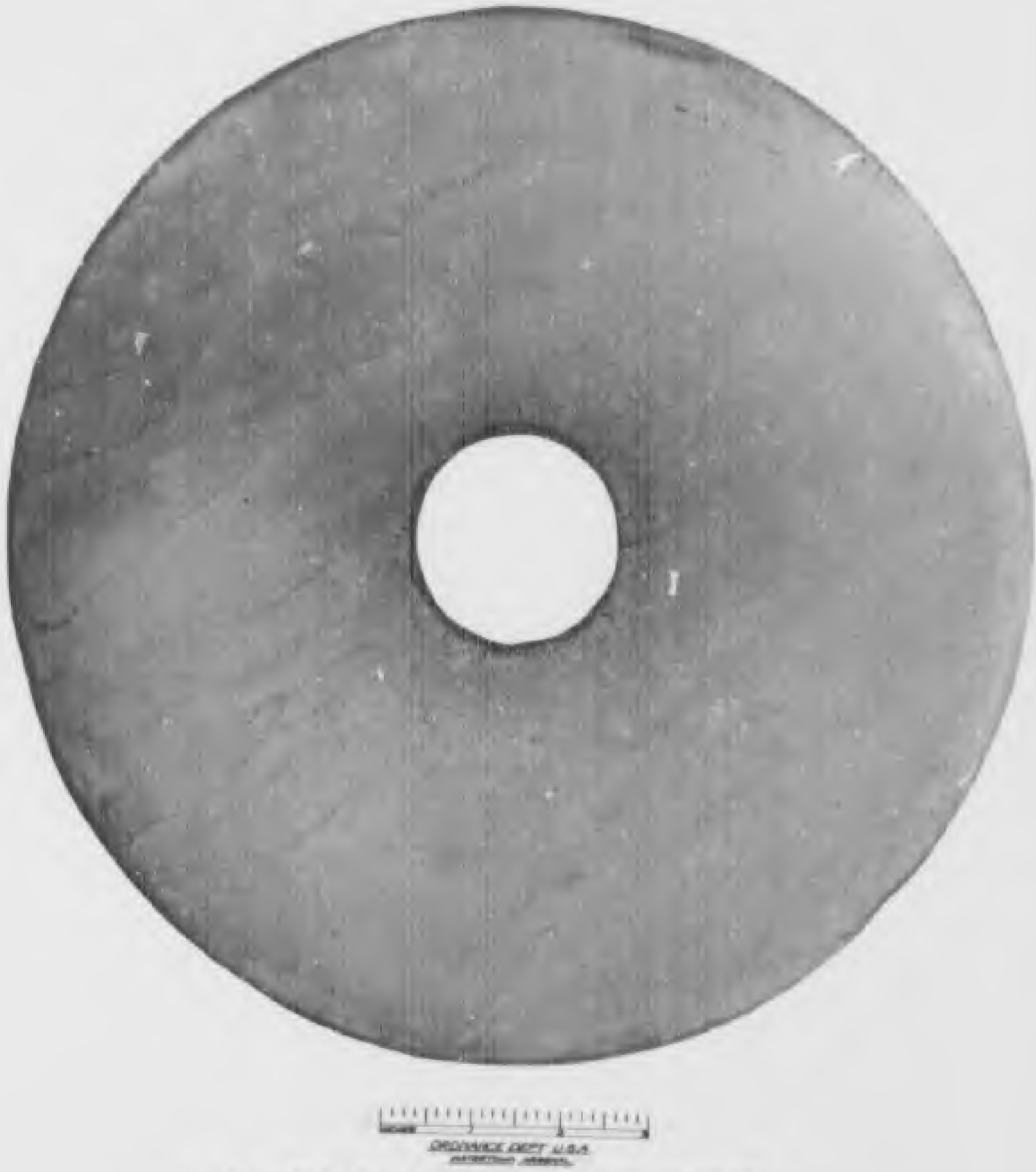


NO. 2N-1431 - QUENCHED AND DRAWN FROM AS-CAST CONDITION
OCTOBER 14 1942 BREECH WTN.223-2550

FIG. 11

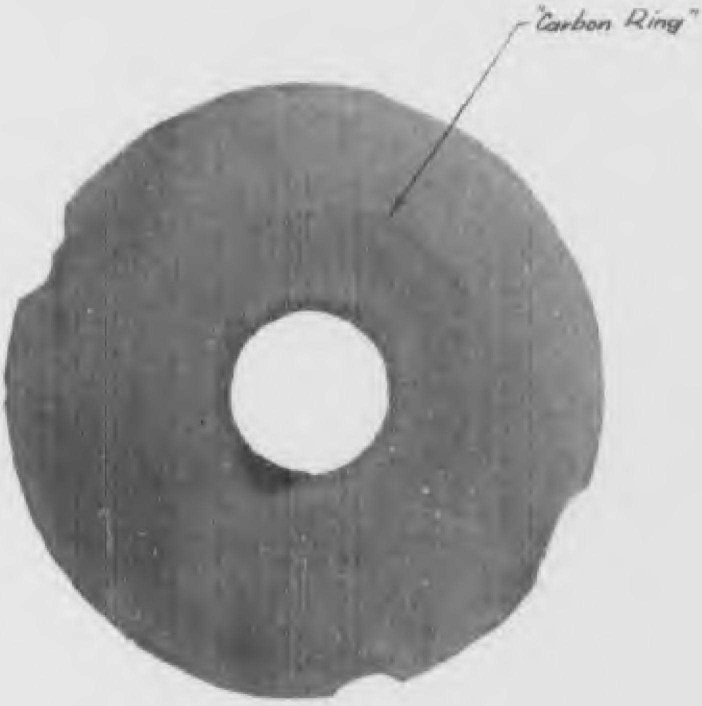
NO. 2N-1431 - QUENCHED AND DRAWN FROM AS-CAST CONDITION
OCTOBER 14 194[illegible] MUZZLE WTN.223-2551

FIG. 12



NO. 2N-1268 - NORMALIZED 64 HOURS AT 2200°F
QUENCHED AND DRAWN IN ROUTINE PRACTICE.
OCTOBER 12 1942 BREECH WTN.223-2538

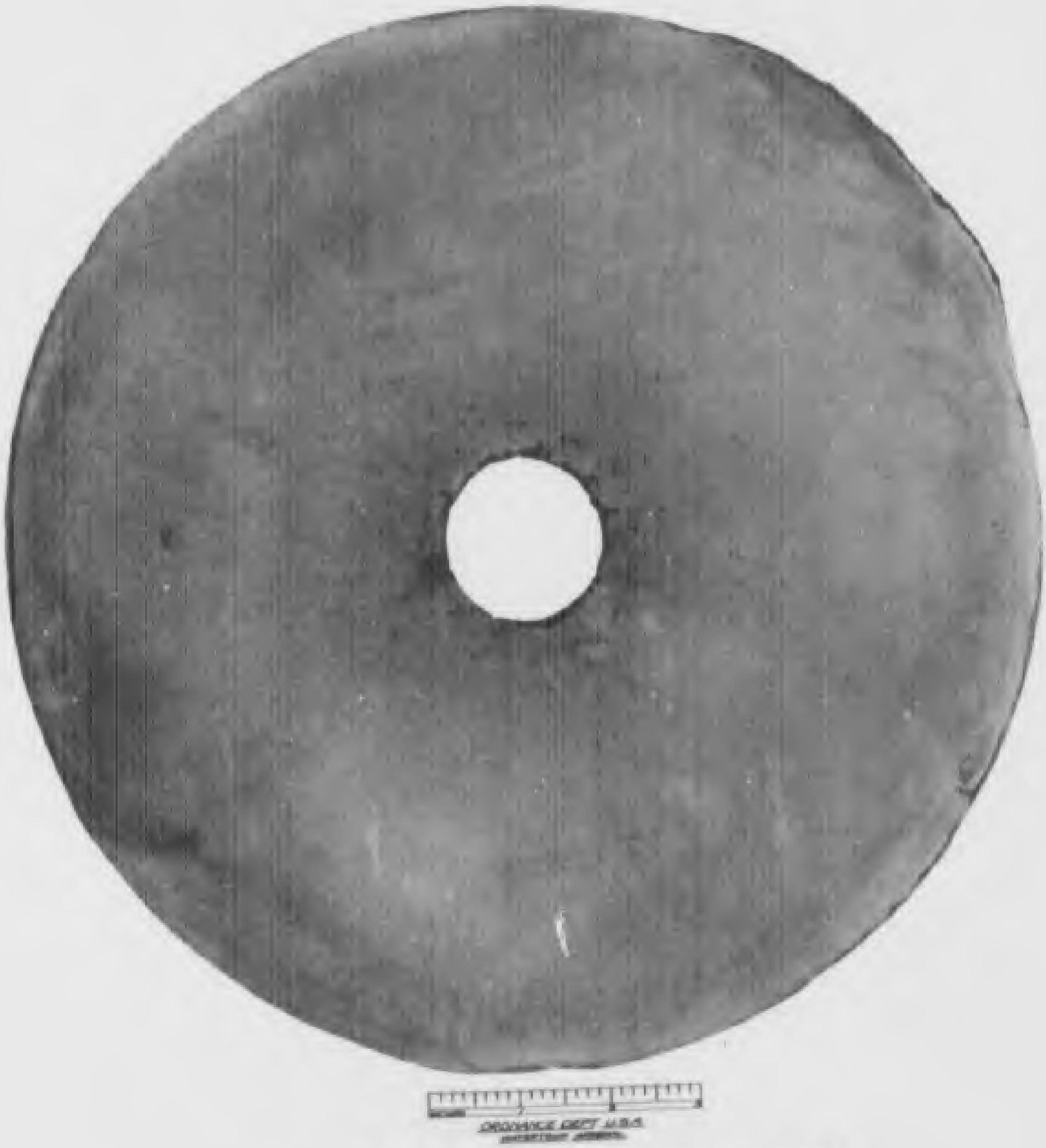
FIG. 13



ORDNANCE DEPT U.S.A.

NO. 2N-1268 – NORMALIZED 64 HOURS AT 2200°F
QUENCHED AND DRAWN IN ROUTING PRACTICE.
OCTOBER 12 1942 MUZZLE WTN.223-2539

FIG. 14



NO. 2N-1271 – NORMALIZED 64 HOURS AT 2200°F
QUENCHED AND DRAWN IN ROUTINE PRACTICE.
OCTOBER 12 1942 BREECH WTN.223-2540

FIG. 15

NO. 2N-1271 – NORMALIZED 64 HOURS AT 2200°F
QUENCHED AND DRAWN IN ROUTINE PRACTICE.
OCTOBER 12 1942 MUZZLE WTN.223-2541

FIG 16

BREECH 105 MM HOWITZER #2N-1268, QUENCHED AND DRAWN
AFTER NOWMALIZE 64 HOURS AT 2200°F.
OCTOBER 14 1942 WTN.223-2532

FIG. 17

ORDNANCE DEPT U.S.A.
WATERTOWN ARSENAL

WATERTOWN ARSENAL

BREECH IC5 MM HOWITZER # 2L-1125
QUENCHED AND DRAWN FROM AS-CAST CONDITION
NOVEMBER 5 1942 WTN.223-2569

FIG. 18

105MM HOWITZER [illegible] — 11[illegible] — AS CAST

BREECH MIDWALL

MUZZLE MIDWALL

MC 670 100X NITAL

FERRITE (WHITE) WITH PEARLITE UNRESOLVED (DARK)

MC 671 100X NITAL

FERRITE (WHITE) WITH PEARLITE UNRESOLVED (DARK) AND WIDMANSTATTEN PATTERN

WTN.639-4681

MC 674 1500X NITAL

FERRITE AND PEARLITE

MC 675 [illegible] NITAL

FERRITE AND PEARLITE PARTIALLY IN WIDMANSTATTEN PATTERN.

FIG. 19

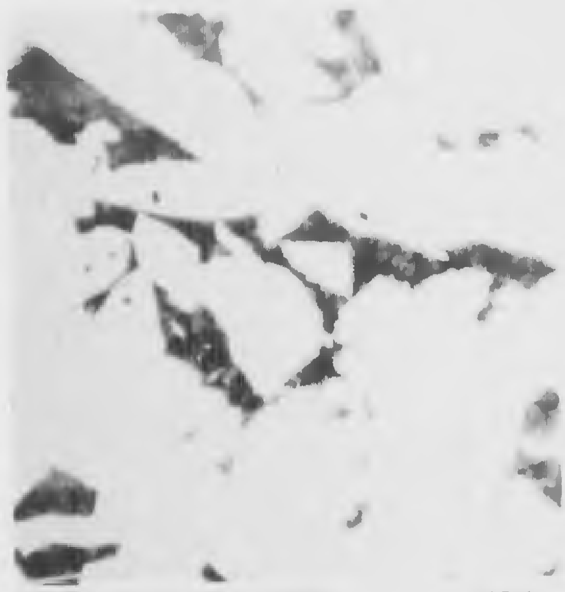
105MM HOWITZER #2N — 1760 — AS CAST

BREECH MIDWALL

MC 668 100X NITAL

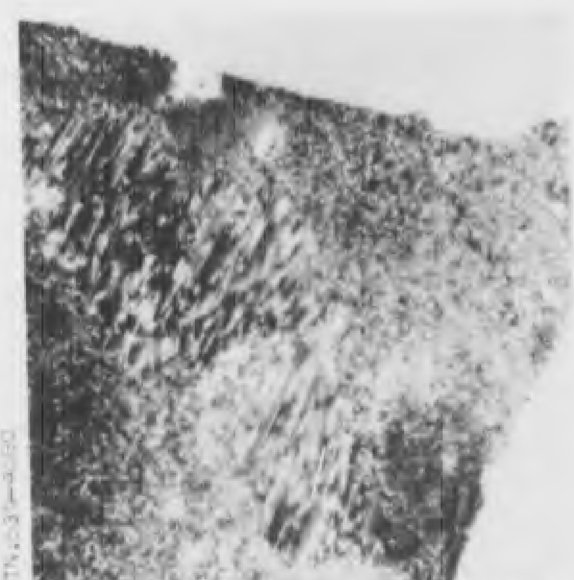
FERRITE (WHITE) WITH PEARLITE UNRESOLVED (DARK)

MUZZLE MIDWALL



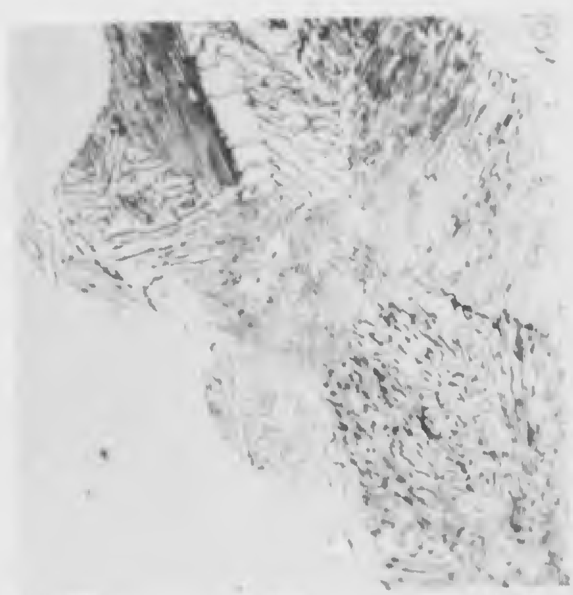
MC 669 100X NITAL

FERRITE (WHITE) WITH PEARLITE UNRESOLVED (DARK)



MC 672 1500X NITAL

FERRITE AND PEARLITE



MC 673 1500X NITAL

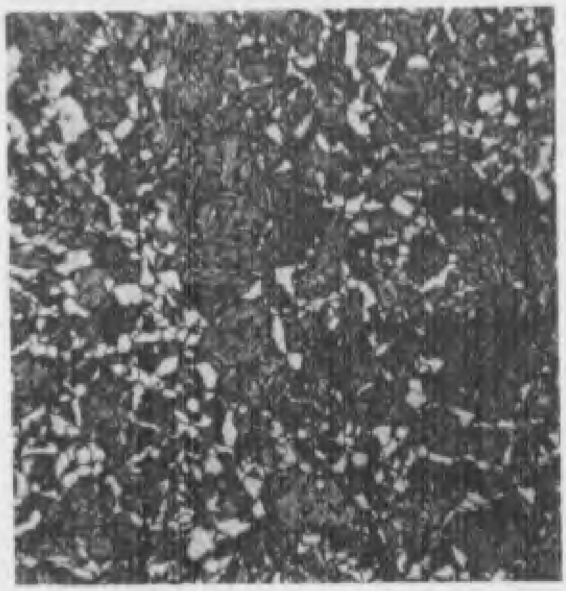
FERRITE AND PEARLITE

FIG. 20

105MM HOWITZER #2L — 1125 — QUENCHED AND DRAWN
FROM AS CAST CONDITION

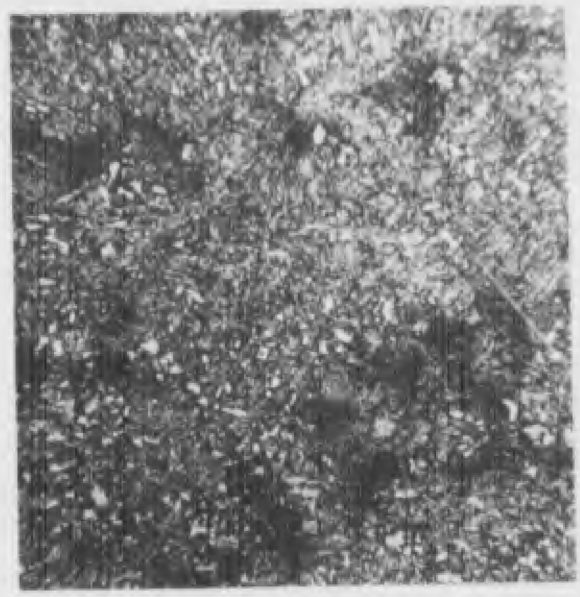
BREECH MIDWALL

MUZZLE MIDWALL



MR 130 100X NITAL

FERRITE (WHITE) AND SORBITE (DARK)

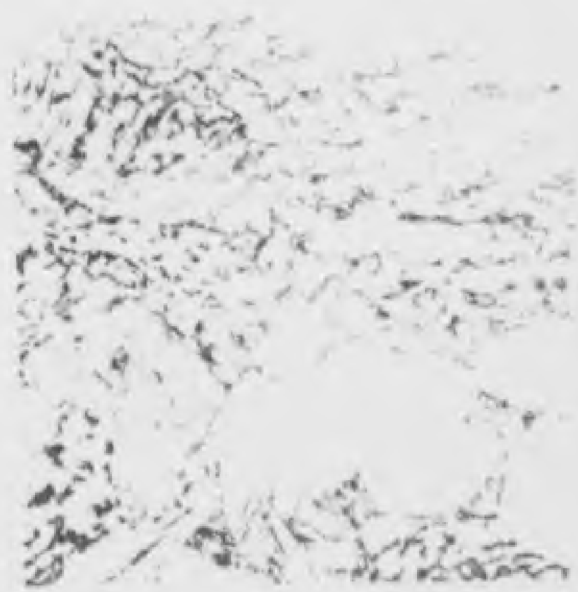


MR 131 100X NITAL

FERRITE (WHITE) AND SORBITE (DARK)
NOTE DARK INTERDENDRITIC AREAS

MR 132 [illegible] NITAL

FERRITE AND SORBITE



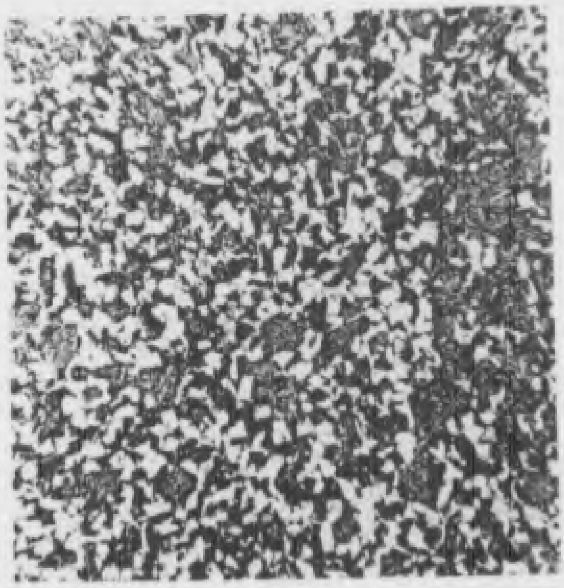
MR [illegible] [illegible]

FERRITE AND [illegible]

FIG. 21

105 MM HOWITZER #[illegible] — 1200 — [illegible]
AFTER NORMALIZE FOR [illegible] HOURS.

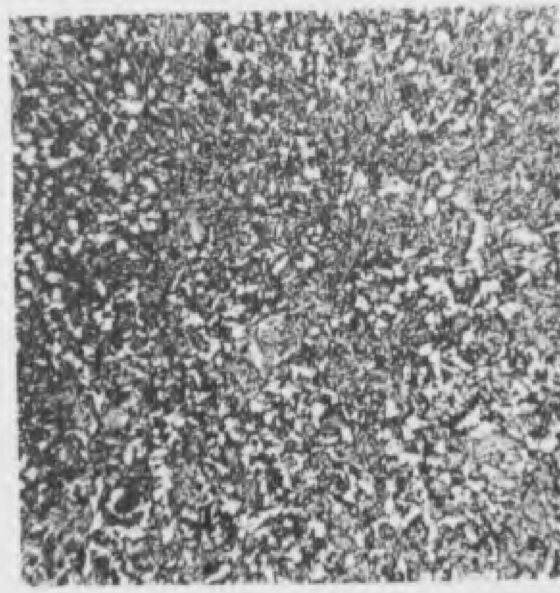
BREECH MIDWALL



MC 665 100X NITAL

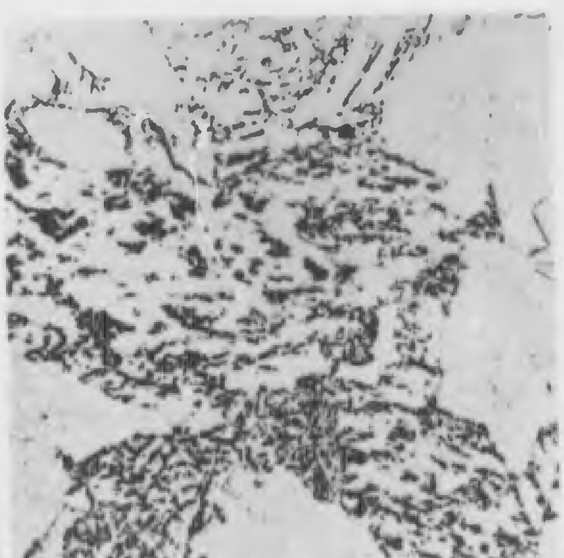
FERRITE (WHITE) AND SORBITE (DARK)

MUZZLE MIDWALL



MC — 100X NITAL

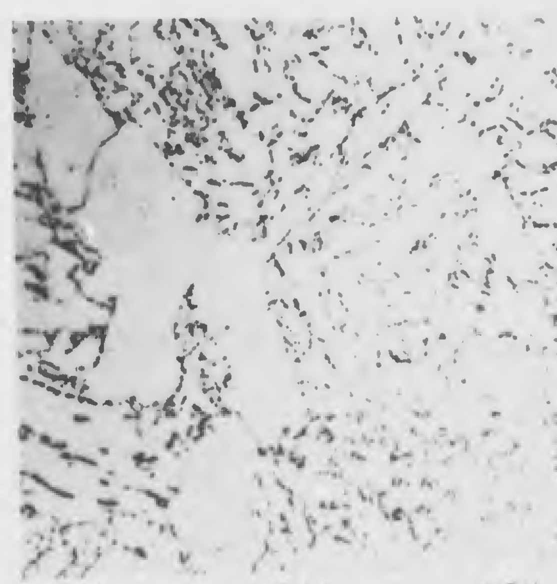
FERRITE (WHITE) AND SORBITE (DARK)



WTN.639-4679

MC 667 1500X NITAL

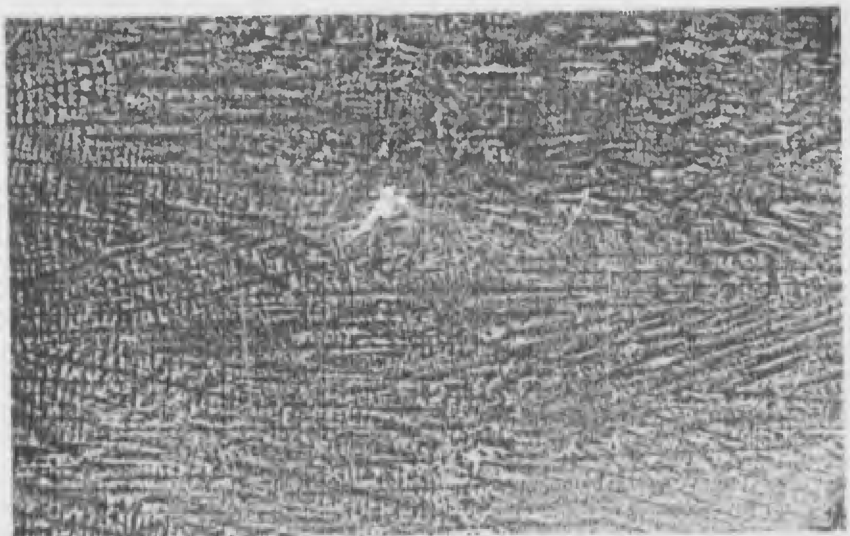
FERRITE AND SORBITE



MC 666 1500X NITAL

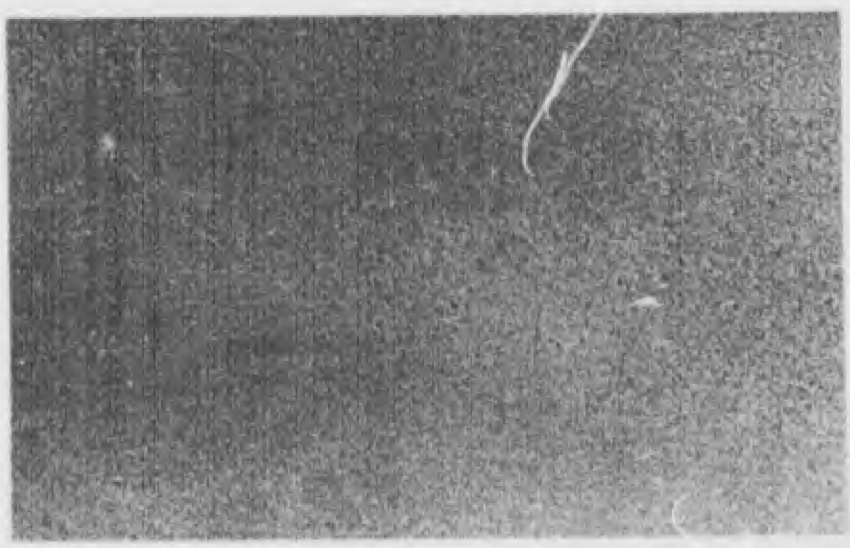
FERRITE AND SORBITE

FIG 22



MC-716 5X OBERHOFFER'S ETCH

BREECH #L-1125, QUENCHED AND DRAWN FROM AS-CAST CONDITION. REFER TO WTN.[illegible]



MC-717 5X OBERHOFFER'S ETCH

BREECH #N-1708, QUENCHED AND DRAWN AFTER NORMALIZE 64 HOURS AT 2200°F. REFER TO WTN.[illegible]-2532.
NOTE: THE DEEP-ETCH LINE OF DEMARCATION PASSES VERTICALLY THROUGH THE CENTER OF THE ABOVE PHOTOGRAPHS. THE MATERIAL ON THE LEFT WAS DARK-ETCHING (I.E.-NEAREST THE BORE) WHILE THE MATERIAL ON THE RIGHT ETCHED LIGHT.

FIG. 23