REPORT NO. 710/418

CONFIDENTIAL

HELMETS

METALLURGICAL EXAMINATION OF HELMETS FROM GERMANY, THE NETHERLANDS, FRANCE, AND THE IRISH FREE STATE

by

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March 26, 1942

WATERTOWN ARSENAL
WATERTOWN, MASS.

Report No. 710/418
Watertown Arsenal
Confidential
(Ex.O. 51-A33)

March 26, 1942

HELMETS

Metallurgical Examination of Helmets from Germany, the Netherlands, France, and the Irish Free State

The object of this 1942 report was

OBJECT

To determine the ballistic and metallurgical characteristics of four foreign helmets.

REFERENCES

Letter O.O. 421/707 R.I.A. 421/738 W.A. 421/252

1st Ind., " " "

Correspondence pertaining to this report are contained in Appendix A.

SUMMARY OF RESULTS

1. Ballistic tests performed against the sides of the crowns of the helmets gave the following results:

Helmet Designation	Ballistic Limit Cal. .45 Pistol Ball	Average Thickness of Impacted Area
German	893 f/s	0.040"
Dutch	914 f/s	0.042"
French	745 f/s	0.030"
Irish	803 f/s	0.033"

2. Chemical analyses of the helmets are as follows:

Helmet	C	Mn	Si	S	P	Ni	Cr	Cu	Mo	V
German	.36	.77	.75	.017	.026	trace	1.19	.05	nil	nil
Dutch	.36	.50	1.70	.014	.010	2.05	.33	.25	nil	nil
French	.98	11.66	.11	.012	.037	.28	.18	.35	nil	nil
Ventilator Cover of French Helmet	.07	.23	trace	.026	.007	nil	.06	-	nil	nil
Irish	.85	13.82	.27	.013	.042	trace	.10	.25	nil	nil

The French and Irish helmets are made of nonmagnetic high manganese steels, while the German and Dutch helmets are made of heat-treated alloy steels.

3. Hardness surveys on cross-sections of the helmets gave the following results:

	Hardness Range		
Helmet	Rockwell C	Rockwell B	Equivalent Brinell
German	48-53.5	-	477-540
Dutch	49-53.5	-	486-540
French	-	81-101	149-251
Irish	-	73-85	123-163

4. The thicknesses of the German and Dutch helmets are very uniform throughout the cross-section; the German helmet having a maximum variation in gauge of 0.004" and the Dutch 0.003". The French helmet showed a maximum variation in gauge of 0.013" and the Irish helmet 0.014". (See Figures 9, 10, 11, and 12.)

5. Rivet holes, such as in the German and Irish helmets are detrimental to best ballistic performance, causing tears in the metal when impacts occur near them. (See Figures 1 and 4.)

6. A good correlation was found between the ballistic limits and the thicknesses of the impacted areas of the helmets, the thickest helmet having the highest ballistic limit. (See Figure 13.)

7. Austenitic steels are very much more deformed by partial penetrations caused by lead ball impacts than are heat-treated magnetic steels. Complete penetrations in austenitic steels result from the tearing open of the metal, whereas in hardened magnetic

steels of the type studied, complete penetrations result from the blowing out of pieces of metal under the impact that are much larger than the diameter of the bullet.

E. L. Reed.

E. L. Reed,
Research Metallurgist.

A. Hurlich

A. Hurlich,
Jr. Metallurgist.

APPROVED:

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

INTRODUCTION

Four foreign helmets were forwarded to this Arsenal from Rock Island Arsenal to study their ballistic and metallurgical characteristics.

TEST PROCEDURE

The four helmets were subjected to ballistic tests, chemical and spectrographic analyses, microscopic examination, and hardness surveys. The helmets were weighed as received, and also after the linings were stripped from the metal shells.

RESULTS

1. Chemical Analysis

The chemical analyses of the four helmets are as previously listed.

2. Microscopic Examination

a. German Helmet

The microstructure of the German helmet consists of martensite which has apparently been tempered at a relatively low temperature. (See Figure 6B.) The high hardness (48-53.5 Rc) of the German helmet in conjunction with its carbon content of 0.36% would indicate a low tempering temperature. Very fine stringers of nonmetallic inclusions were found throughout the cross-section of the German helmet. (See Figure 6A.) These elongated nonmetallics are too fine to be visible at lower magnification. (See Figure 5A.)

b. Dutch Helmet

The microstructure of the Dutch helmet contains a fine grained tempered martensite in which fine globular carbides are uniformly dispersed. (See Figure 6D.) There is evidence of granular attack for a distance of about 0.0005" from both surfaces of the metal. (See Figure 6C.) The steel is quite clean, containing well distributed nonmetallics. (See Figure 5B.)

c. French Helmet

The microstructure of the French helmet consists of austenite having an A.S.T.M. grain size of No. 7. (See Figures 7A, X100, and 8A, X250.) No free carbides are present in the microstructure.

Elongated nonmetallic stringers are found throughout the cross-section. (See Figures 5C and 7A.) Slip lines resulting from cold-working are in evidence.

The ventilator cover of the French helmet, see Figure 3, is made of a very low carbon deep-drawing steel.

d. Irish Free State Helmet

The microstructure of the Irish helmet consists of austenite having an A.S.T.M. grain size of #2. (See Figures 7B, X100, and 8B, X250.) No free carbides are present. The steel is relatively clean, containing well dispersed fine inclusions. (See Figure 5D.)

3. Hardness Surveys

Hardness surveys and thickness measurements were made along strips cut through the middle of the helmets. The results are tabulated in Figures 9 through 12.

4. Weight Measurements

	Weight as Received		Weight of Stripped Metal Sh	
Helmet	Grams	Ounces	Grams	Ounces
German	1176	41.4	1082	38.2
Dutch	1167	41.1	1000	35.3
French	976	34.4	877	30.9
Irish	1140	40.2	1043	36.8

5. Markings Found on Helmets

The following markings were found on the helmets:

German - BD546 (Inside of crown) [illegible]66 (Inside of crown)
Dutch - $\frac{32}{K}$ (Inside of crown)
French - C. JAPY (Painted in 5/8" letters on inside of crown)
Irish - V. $\frac{LTD}{H407/'27}$ H2324 (Inside of rim)

6. Ballistic Tests

Photographs of the helmets before and after ballistic tests are shown in Figures 1 through 4. Ballistic tests were conducted using preloaded cal. .45 lead balls fired from a cal. .45 revolver at a range

of 25 feet. Striking velocities were recorded by means of an Aberdeen chronograph. Detailed results of the ballistic tests are given below:

a. German Helmet

Round No.	Velocity F/S	Penetration	Remarks
1	887	Partial	Bulge 3½" in diameter. Helmet indented 3/4".
2	899	Complete	Piece 1-1/4"x1" blown out on impact and tears about 1" long made on impacted face. Bullet passed through helmet and hit 1/4" from a rivet hole on rear side of helmet, producing three tears from 1-1/4" to 2" long radiating out from the rivet hole.

Ballistic Limit - 893 F/S
Average Thickness of Impacted Area - 0.040"

b. Dutch Helmet

Round No.	Velocity F/S	Penetration	Remarks
1	773	Partial	Bulge 2-3/4" in diameter. Helmet indented 7/16".
2	905	Partial	Bulge 3½" in diameter. Helmet indented 5/8".
3	922	Complete	Piece 1-7/8"x1-1/2" blown out. Helmet indented 1/8".

Ballistic Limit - 914 F/S
Average Thickness of Impacted Area - 0.042"

c. French Helmet

Round No.	Velocity F/S	Penetration	Remarks
1	777	Complete	Hit junction of rim and crown. Bullet failed to pass through. Tear in metal approximately 2" long.

Round No.	Velocity F/S	Penetration	Remarks
2	702	Partial	Bulge 4½" in diameter. Helmet indented 1½".
3	797	Complete	Bulge 4½" in diameter. Helmet indented 1-5/8". Hole in helmet 3/4" in diameter.
4	693	Partial	Bulge 3½" in diameter. Helmet indented 15/16".
5	712	Partial	Bulge 4" in diameter. Helmet indented 1-3/8".

The ventilator cover was blown off on impact of round no. 5.
Ballistic Limit - 745 F/S
Average Thickness of Impacted Area - 0.030"

d. Irish Free State Helmet

Round No.	Velocity F/S	Penetration	Remarks
1	801	Partial	Bulge 3½" in diameter. Helmet indented 1".
2	800(estimated)	Complete	Hit 1½" above rim and ½" from rivet. No bulge. Tear 1-3/8" across made through rivet hole. Bullet passed through.
3	800(estimated)	Partial	Hit 1½" above rim. Bulge 2½" in diameter. Helmet indented 11/16
4	800(estimated)	Complete	Hit high up in thin section of crown and passed completely thr both back and front of helmet. Bulge 2-1/4" in diameter. Helm indented ½". Exit hole 5/8" in diameter.
5	805	Complete	Bulge 2" in diameter. Helmet in dented 3/4". Bullet failed to thru helmet. Tear 1-1/4" long roughly parallel to rim.

Ballistic Limit - 803 F/S
Average Thickness of Impacted Area - 0.033"

DISCUSSION

In this study it seems that large variations in the hardness of helmet steel do not seem to have anywhere near as great an influence upon the ballistic limit as do small variations in thickness. The French and Irish Free State helmets ranged from 123 to 251 Brinell and the German and Dutch helmets ranged from 477 to 540 Brinell and yet the correlation between thickness and ballistic limit was very good, and seemed to indicate the existence of a direct proportionality between ballistic limit and thickness in the light gauges of sheet used for helmets. (See Figure 13.)

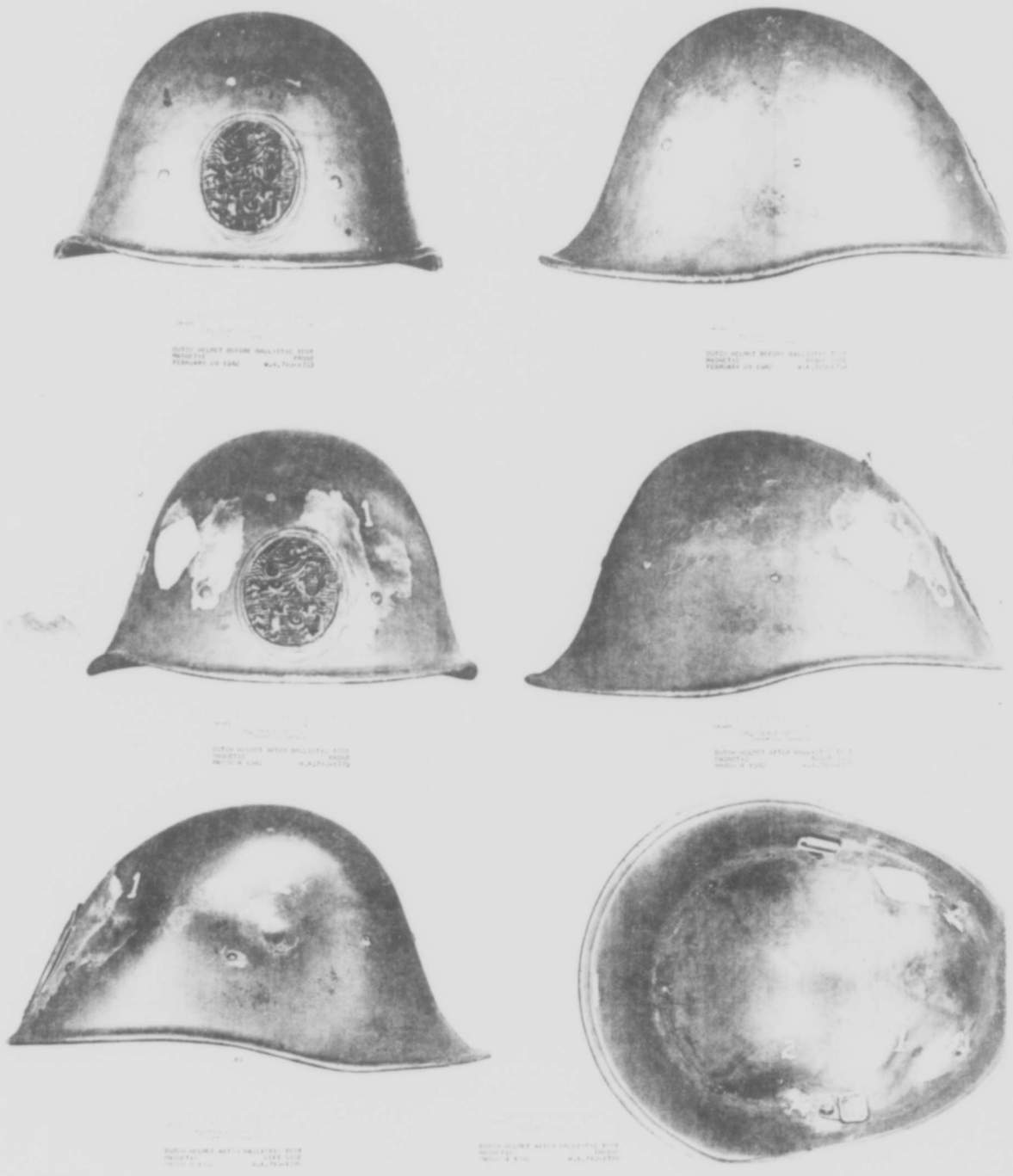
The presence of free carbides in the Dutch helmet does not seem to materially change its ballistic performance from that displayed by the German helmet, which had about the same hardness.

The austenitic helmets (French and Irish Free State) showed more deformation, i.e. larger bulges and deeper indentations, under lead ball impacts than did the heat treated magnetic steels. This greater deformation is probably due to both the greater ductility and lower hardness of the austenitic steels as well as the lesser thicknesses of these helmets as compared to the German and Dutch helmets.

WATERTOWN ARSENAL

GERMAN HELMETS BEFORE AND AFTER BALLISTIC TEST
MARCH 20 1942 W.A.710-1792-C

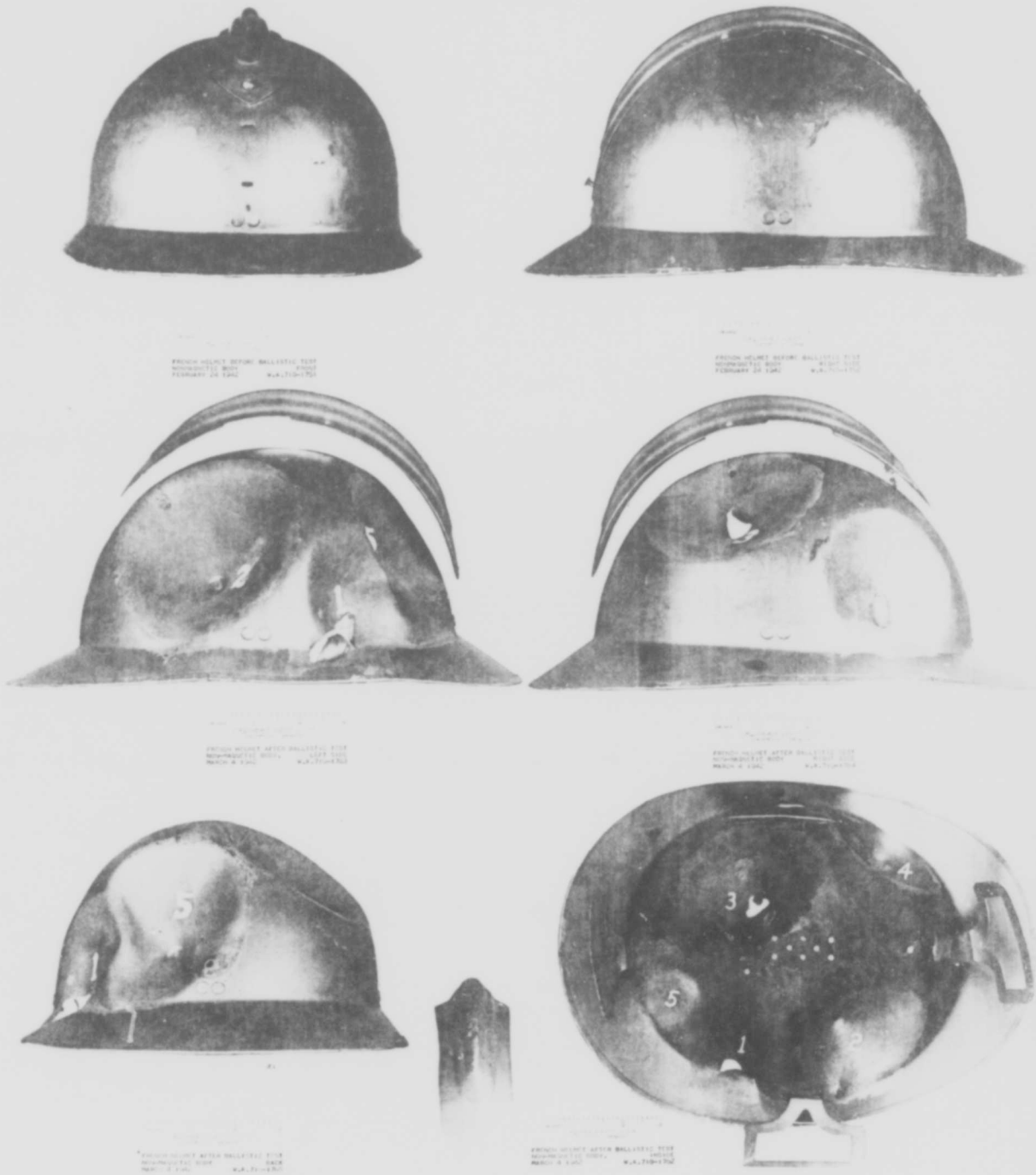
FIGURE 1.



WATERTOWN ARSENAL

DUTCH HELMETS BEFORE AND AFTER BALLISTIC TEST
MARCH 20 1942 W.A.710-1790-C

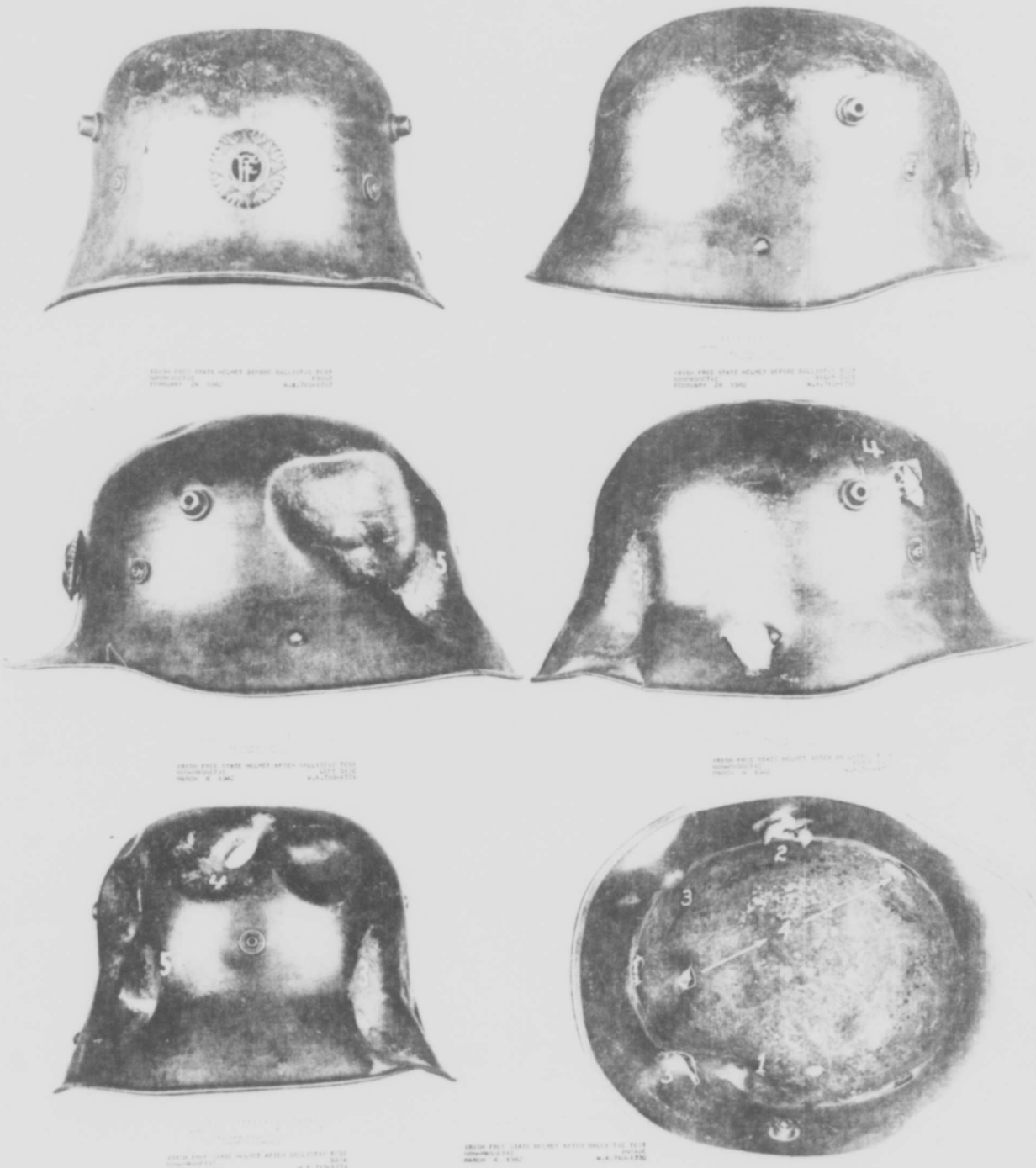
FIGURE 2.



WATERTOWN ARSENAL

FRENCH HELMETS BEFORE AND AFTER BALLISTIC TEST
MARCH 20 1942 W.A.710-1791-C

FIGURE 3.



WATERTOWN ARSENAL

IRISH FREE STATE HELMETS BEFORE AND AFTER BALLISTIC TEST. MARCH 20 1942 W.A.710-1793-C

FIGURE 4.

Figure 5

Distribution of Nonmetallics in Helmets

A. German Helmet

Clean steel with well distributed nonmetallics.

X100 Unetched NA-4090

B. Dutch Helmet

Clean steel with well distributed nonmetallics.

X100 Unetched NA-4091

C. French Helmet

Well distributed fine nonmetallics with occasional stringers.

X100 Unetched NA-4089

D. Irish Free State Helmet

Well distributed fine nonmetallics.

X100 Unetched NA-4088

FIGURE 5.

A.

B.

C.

D.

Figure 6

Microstructure of Helmets

A. **German Helmet**

Very thin elongated nonmetallic stringers found throughout cross-section of helmet.

X1000 Picral Etch MA-4081

B. **German Helmet**

Fine martensite. Occasional small carbides out of solution.

X1000 Picral Etch MA-4082

C. **Dutch Helmet**

Edge of cross-section showing granular attack to about 0.0005" below surface.

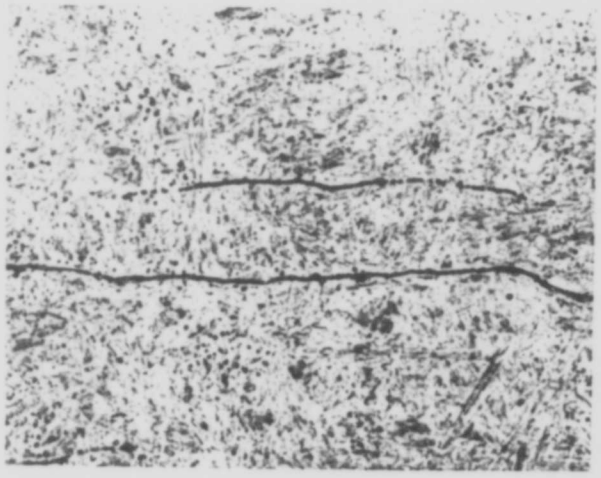
X1000 Picral Etch MA-4085

D. **Dutch Helmet**

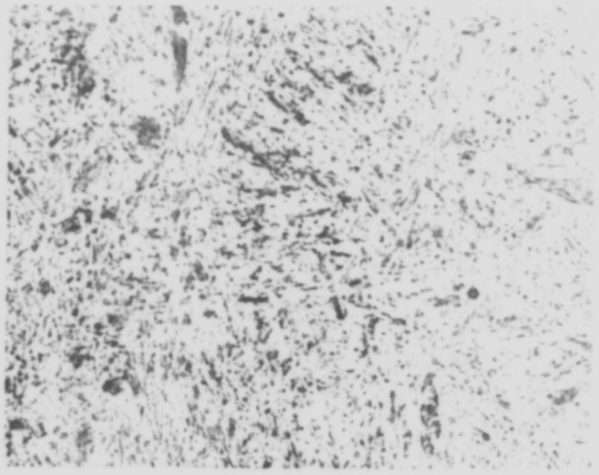
Fine martensite containing well distributed globular carbides.

X1000 Picral Etch MA-4084

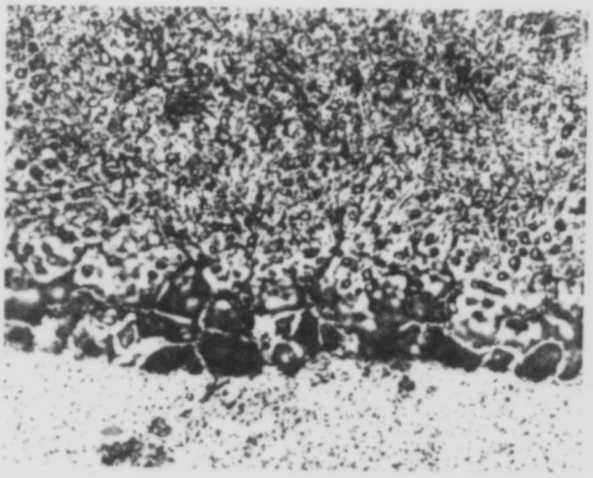
FIGURE 6.



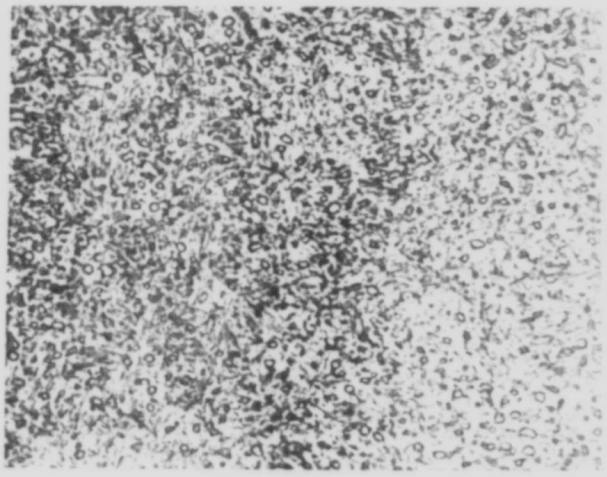
A.



B.



C.



D.

Figure 7

Microstructure of Helmets

A. French Helmet

Austenite with A.S.T.M. grain size No. 7. Elongated stringers of nonmetallics typical of those found throughout section.

X100 MA-4076

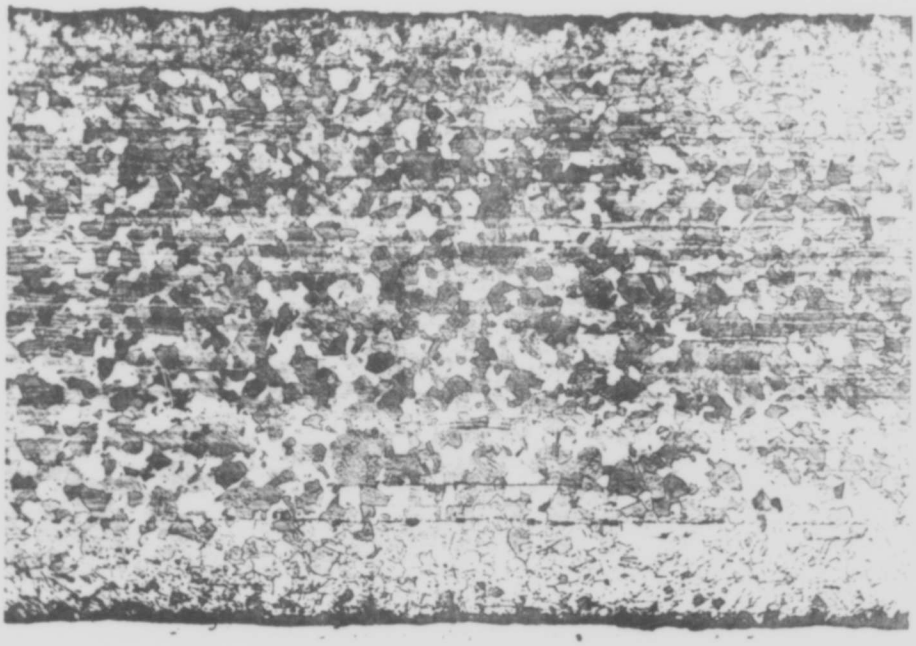
B. Irish Free State Helmet

Austenite with A.S.T.M. grain size No. 2. Slip lines evident.

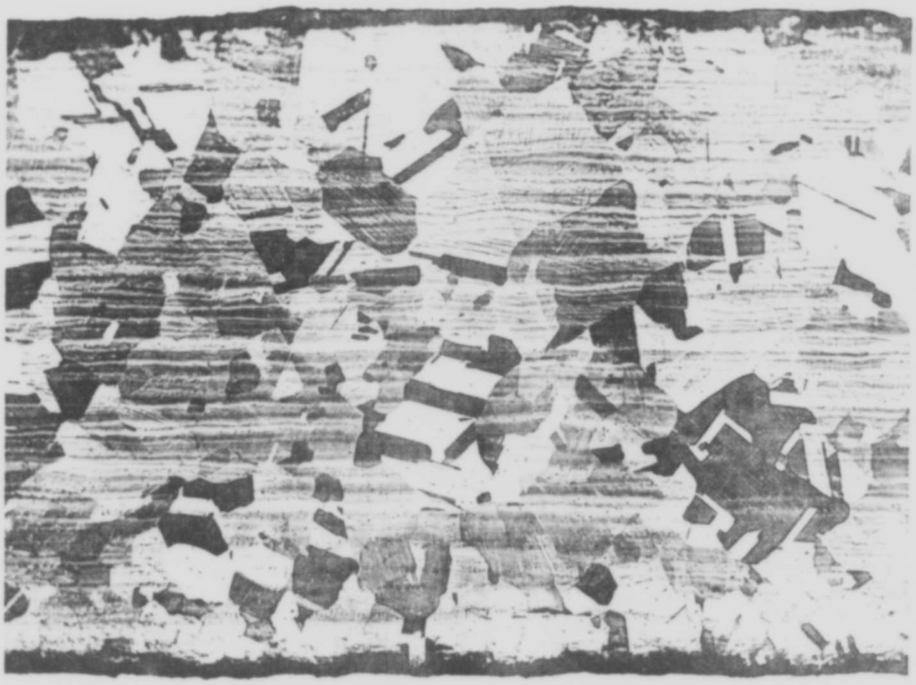
X100 MA-4078

Above specimens etched alternately in nital, picral, and Vilella's reagent, repolished, and re-etched in above solutions.

FIGURE 7.



A.



B.

Figure 8

Microstructure of Helmets

A. French Helmet

Same as Figure 7A.

X250 Ma-4087

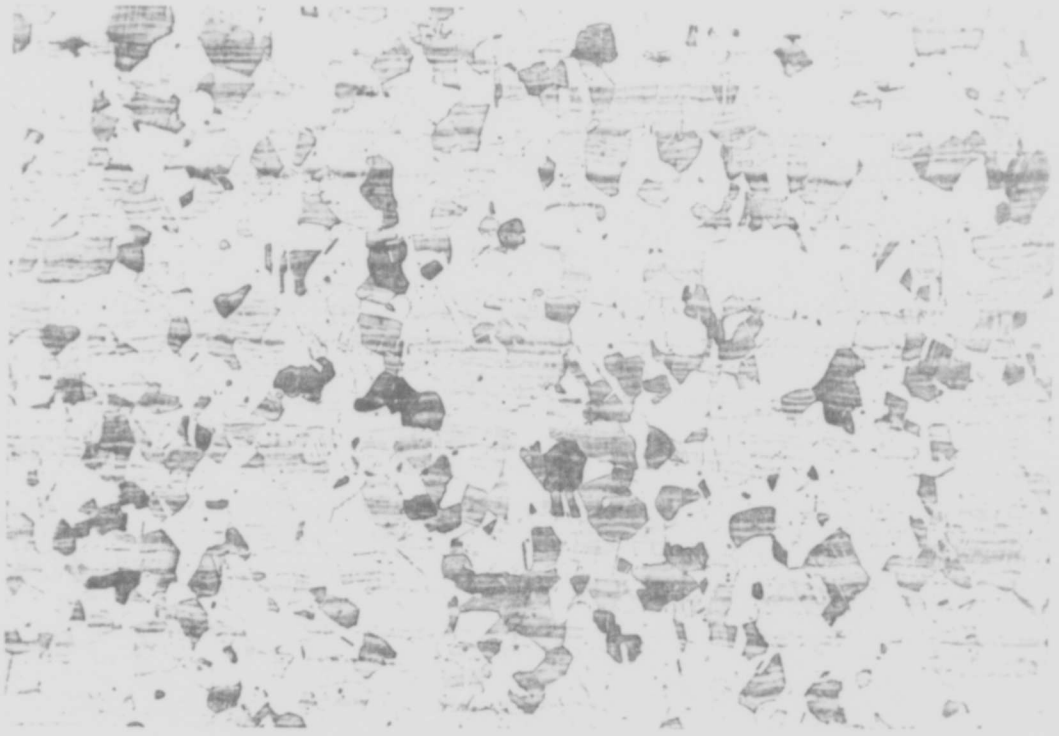
B. Irish Helmet

Same as Figure 7B. Note banding.

X250 Ma-4086

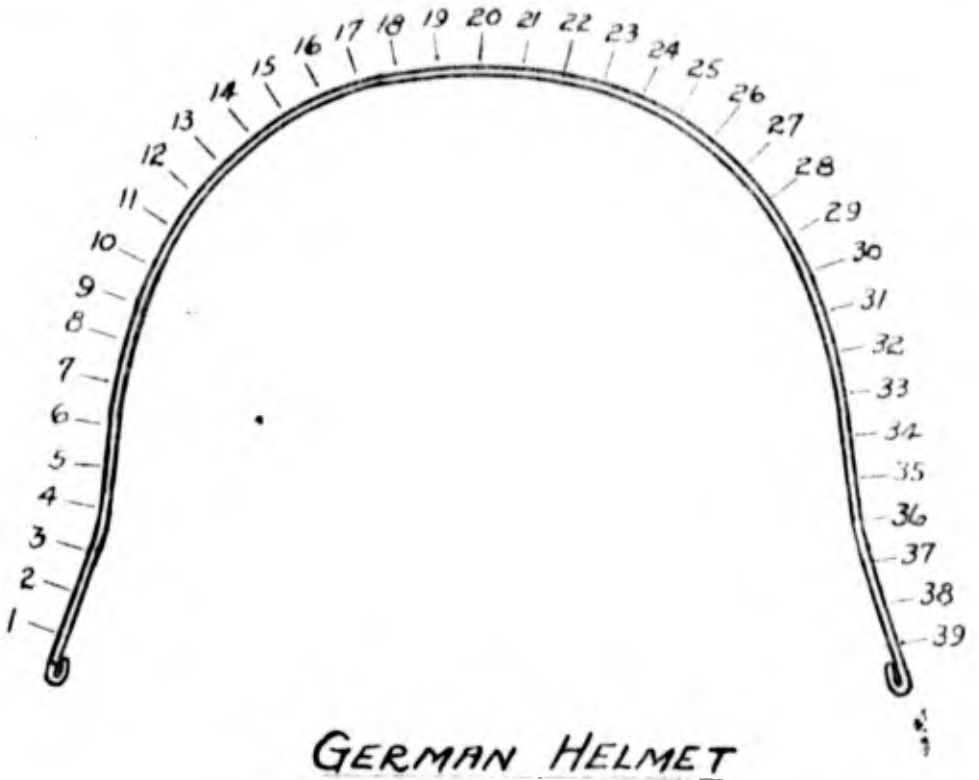
Above specimens etched alternately in nital, picral, and Vilella's reagent, repolished and re-etched with above solutions.

FIGURE 8.



A.

B.



GERMAN HELMET

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13
THICKNESS	.038	.039	.041	.040	.041	.040	.040	.039	.040	.039	.040	.040	.038
HARDNESS	53	50	53	48	50	51	50	52	49	52.5	53	50	50

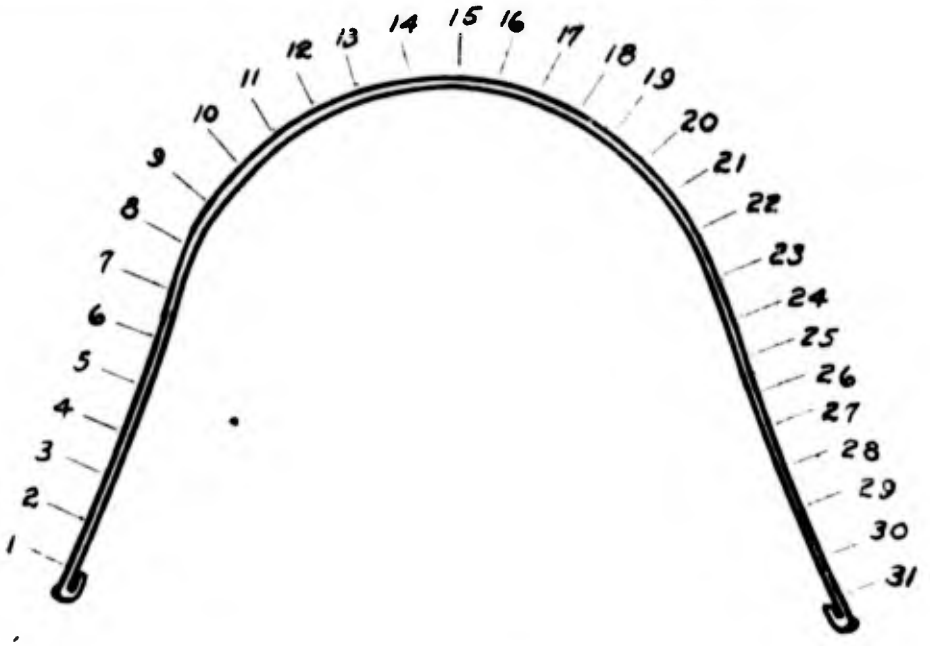
STATION	14	15	16	17	18	19	20	21	22	23	24	25	26
THICKNESS	.037	.038	.038	.037	.037	.037	.037	.037	.037	.037	.038	.038	.038
HARDNESS	51	52	50	49	49	50	51	53	51	52.5	52	53	52

STATION	27	28	29	30	31	32	33	34	35	36	37	38	39
THICKNESS	.039	.040	.040	.040	.040	.041	.040	.040	.041	.040	.040	.038	.037
HARDNESS	53	52	53	52.5	52	52	51.5	52.5	51.5	52	53.5	53	53.5

ROCKWELL 'C' HARDNESS SURVEY
AND
THICKNESS MEASUREMENT
OF CROSS-SECTION OF GERMAN HELMET.
READINGS TAKEN EVERY HALF INCH.

FIGURE 9.

WPAN 3-9-42



DUTCH HELMET

STATION	1	2	3	4	5	6	7	8	9	10
THICKNESS	.043	.044	.044	.043	.043	.042	042	.042	.042	.041
HARDNESS	50	50	49	51.5	49	50.5	50	50	51	51

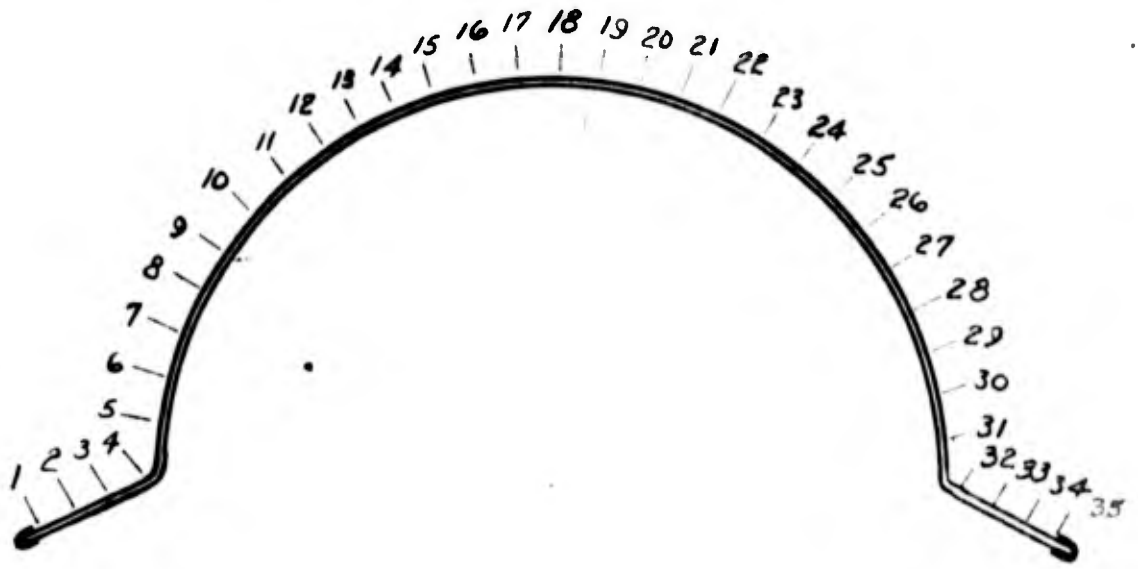
STATION	11	12	13	14	15	16	17	18	19	20
THICKNESS	.042	042	.041	042	.041	.041	.041	.041	.041	041
HARDNESS	51.5	51	52.5	53	52.5	53	51.5	53.5	53	52.5

STATION	21	22	23	24	25	26	27	28	29	30	31
THICKNESS	041	.042	.042	.042	.042	.042	041	.042	.043	.044	.044
HARDNESS	53	50	50.5	51	50	51.5	52	50	50	50	51

ROCKWELL 'C' HARDNESS SURVEY
AND
THICKNESS MEASUREMENT
OF
CROSS-SECTION OF DUTCH HELMET.
READINGS TAKEN EVERY HALF INCH.

FIGURE 10.

WAAH 3-9-42



FRENCH HELMET

STATION	1	2	3	4	5	6	7	8	9	10	11	12
THICKNESS	.037	.036	.036	.034	032	.032	.032	.030	.030	.029	.027	.026
HARDNESS	87.5	85	84.5	81	82.5	98	100	99.5	100.5	100.5	101	99

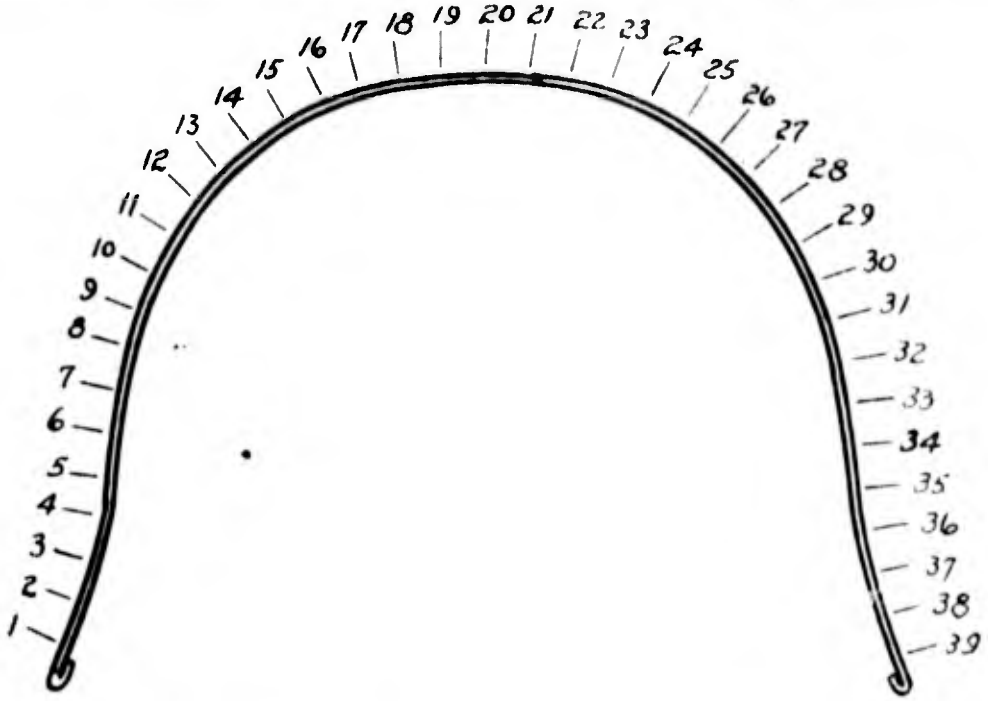
STATION	13	14	15	16	17	18	19	20	21	22	23	24
THICKNESS	.025	.026	.026	026	.027	.027	.026	.027	.027	027	.027	.026
HARDNESS	99	99	99	99	101	100.5	99	100	98.5	99	98	98.5

STATION	25	26	27	28	29	30	31	32	33	34	35
THICKNESS	.027	.028	.029	.030	.030	.033	035	.037	.037	.039	.037
HARDNESS	97	96	95.5	94	93	93.5	91	87	87	84	86

ROCKWELL 'B' HARDNESS SURVEY
AND
THICKNESS MEASUREMENT
OF
CROSS-SECTION OF FRENCH HELMET.
READINGS TAKEN EVERY HALF INCH.

FIGURE 11.

W A A H 3-10-42



IRISH FREE STATE HELMET

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13
THICKNESS	.044	.044	.042	039	.036	.035	.037	.034	.033	.032	.034	032	.030
HARDNESS	84	84	83	85	83	79	82	83	78	82.5	80.5	80.5	81.5

STATION	14	15	16	17	18	19	20	21	22	23	24	25	26
THICKNESS	.032	.030	.031	.031	.033	.032	.034	.034	.034	.033	.033	.033	.031
HARDNESS	85	78	78	87	87	87	785	74	72	73	74.5	76	76

STATION	27	28	29	30	31	32	33	34	35	36	37	38	39
THICKNESS	.030	.032	.033	.033	.034	.034	.035	.036	.037	.039	.041	044	.044
HARDNESS	76	78	80.5	76	83.5	73	76	83	83.5	81.5	83	84	81.5

ROCKWELL '8' HARDNESS SURVEY
AND
THICKNESS MEASUREMENT
OF
CROSS-SECTION OF IRISH FREE STATE HELMET.
READINGS TAKEN EVERY HALF INCH

FIGURE 12.

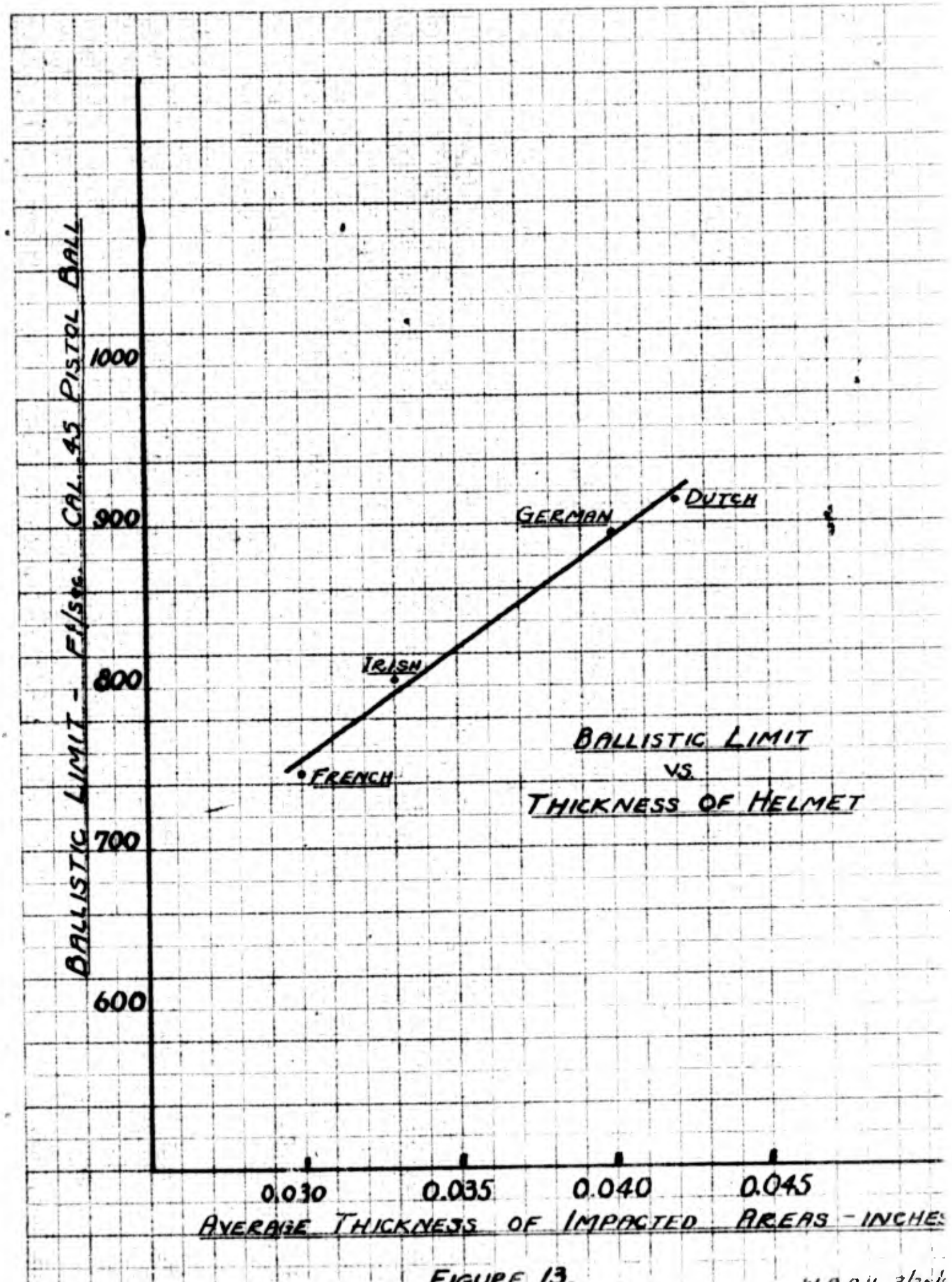


FIGURE 13.

W.A.R.H. 3/20/45

APPENDIX A

COPY

WAR DEPARTMENT

OFFICE OF THE CHIEF OF ORDNANCE

WASHINGTON White/ego

October 29, 1941

Subject: Foreign Helmets

To: The Commanding General
Rock Island Arsenal, Rock Island, Ill.

The Commanding General
Watertown Arsenal, Watertown, Mass.

IS TURN

1. There is being forwarded by express to Rock Island Arsenal and to Watertown Arsenal, in turn, one helmet from each of the following countries:

France
Netherlands
Irish Free State
Germany

2. At Rock Island Arsenal it is requested that an examination be made of the design features of these helmets and that photographs and sketches be made for a permanent record. When this study is completed they should be sent to Watertown Arsenal.

3. It is requested that the metallurgical characteristics of the helmet steels be examined at Watertown Arsenal.

4. Shipping Order S.A.D. 1658 for shipment of helmets from the Office of Chief of Ordnance to Rock Island Arsenal and Shipping Order S.A.D. 1659 for shipping helmets from Rock Island Arsenal to Watertown Arsenal are inclosed.

By order of the Chief of Ordnance:

Rene R. Studler
Lt. Col., Ord. Dept.
Assistant

6 Incls.
#1 - S.O. S.A.D. 1658 in dupl.
#2 - S.O. S.A.D. 1659 in tripl. for R.I.A.
- S.O. S.A.D. 1659 in dupl. for W.A.
4 Helmets by Express

O.O. 421/707
R.I.A. 421/738
W.A. 421/252

COPY

COPY

W.A. 421/252
O.O. 421/707

1st Ind.

CHA/gcw
RIA 421/738

Rock Island Arsenal, Illinois, February 11, 1942: To The Commanding General, Watertown Arsenal, Watertown Mass.

1. Vellum drawings have been prepared as requested and are being forwarded the Ordnance Office this date.

2. Helmets were shipped his Arsenal on February 7, 1942 with Shipping Order S.A.D. 1659 as directed in the basic letter.

Helmets w/d
(Rec. by express)

For the Commanding General:

2 Incls.
S.A.D. 1659
S.A.D. 1658

Robert T. Myers,
1st. Lt., Ord. Dept.,
Assistant.

COPY