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AD 14698

AL 762/589 (c)

# WATERTOWN ARSENAL LABORATORY

## REPORT

NO. WAL 762/589(c)  
O. O. PROJECT NUMBER: TB3-0035

METALLURGICAL EXAMINATION  
OF  
SOVIET 76MM APHE PROJECTILE MOD. BR-354B, FMAM 2267

BY

C. A. RIDDLE  
PHYSICAL SCIENCE AIDE

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28 October 2005

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1. Reference: Watertown Arsenal Laboratory Report No. 762/589,  
"Metallurgical Examination of Soviet 76MM APHE Projectile Mod.  
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TITLE

METALLURGICAL EXAMINATION  
OF  
SOVIET 76MM APHE PROJECTILE MOD. BR-354B, FMAM 2267

Report Number: WAL 762/589(c)

O. O. PROJECT NUMBER: TB3-0035

C. A. RIDDLE  
PHYSICAL SCIENCE AIDE

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Authorized by: ORDTB  
O. O. Project Number: TB3-0035  
Report Number: WAL 762/589(c)  
Priority: 2A  
Title of O. O. Project: Evaluation of Foreign Materiel  
Filing Title: Projectile, Armor Piercing, Foreign

TITLE

METALLURGICAL EXAMINATION OF SOVIET 76MM APHE PROJECTILE,  
MOD. BR-354B, FMAM 2267

OBJECT

To conduct a metallurgical examination of the subject projectile and to evaluate its design, method of manufacture, and performance characteristics.

SUMMARY

A dimensioned drawing of the projectile was prepared and the chemical compositions, hardness, macroscopic, and microscopic structures of all projectile components were determined. The shot body was machined from medium carbon silicon-chromium steel bar stock of a type which has been previously observed in Soviet shot, and was decrementally hardened from Rockwell C 45 at the nose to Rockwell C 17 at the base. Two deep circumferential notches were machined into the shot body above the bourrelet. The shot was blunt nosed, having an approximately 1" diameter flat machined on the front. A deep drawn low carbon steel windshield was crimped into two circumferential grooves machined into the shoulder below the flat nose. A single copper rotating band was fitted into an undercut band seat. The explosive cavity was small, consisting of a cylindrical hole approximately 1" in diameter and 3-1/2" deep.

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## CONCLUSIONS

1. The subject 76MM APHE shot is similar in general design to Soviet shot of other calibers which have been previously examined, reference Watertown Arsenal Laboratory Report No. WAL 762/582(c) "Metallurgical Examination of Soviet 45MM, 57MM, and 85MM APHE Projectiles, FMAM 1121, 1935, and 2175."

2. The steel employed for the 76MM shot body differs radically in composition from shot steels employed in this country. The low carbon content (0.34%) results in a relatively low hardness (Rockwell C 45 in the nose). American shot generally contain from 0.50 to 0.60% carbon and are hardened to approximately Rockwell C 60 in the nose. In addition, the high silicon content (1.54%), which is typical of Soviet projectile and armor steels, indicates the use of this element as a deliberate alloying agent whereas it is usually present in only residual quantities in domestic alloy steels employed for projectiles.

3. The silicon-chromium steel has insufficient hardenability to completely quench harden to martensite in a 76MM shot as indicated by the large amount of rejected ferrite observed in the nose of the shot. In addition, the heat treatment employed in hardening the shot resulted in the base having a very considerable amount of ferrite and pearlite, and probably involved quenching only the forward part of the shot with the base being air cooled from an elevated temperature. As a consequence of the above, the shot would probably tend to fracture in a brittle manner upon impact against moderately severe targets.

4. The notable features of the subject shot, flat nose and circumferential notches above the bourrelet, indicate that the shot was probably designed to be effective in defeating moderately thin (up to 2" thick) armor under conditions of attack involving moderate to high obliquities of impact.

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5. As observed in most Soviet ordnance materiel, fine machine finishes are reserved for critical bearing surfaces such as the bourrelet regions of shot, mating surfaces, etc. while all other surfaces show evidence of coarse machining and no attempt to meet close tolerances. The method of manufacture stresses simplicity and economy in production practices.

*C. A. Riddle*

C. A. RIDDLE

Physical Science Aide

APPROVED: .

*J. L. Martin*  
J. L. MARTIN

Director of Laboratory

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OCTI-200-1-51 and Change 2 thereto dated 16 Sept. 1952.

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## INTRODUCTION

At the request of the Office, Chief of Ordnance a Soviet 76MM APHE, projectile was submitted to this Arsenal by Picatinny Arsenal for metallurgical examination. The shot was identified as follows:

76MM, APHE, Mod. UBR-354-B FMAM 2267

The shot was received at Watertown Arsenal inerted and without fuze.

## TEST PROCEDURE

The projectile was examined to determine significant design features and all markings were recorded. The projectile was photographed and measurements obtained for the preparation of a dimensioned drawing.

A longitudinal slice cut through the center of the shot was surface ground for hardness and macroetch testing. Specimens for chemical analysis and microscopic examination were obtained from all projectile components.

## DATA AND DISCUSSION

### A. Visual Observations

The general appearance of the shot is shown in Figure 1. The shot was unpainted and showed no evidence of having a protective coating of any type. Coarse machining marks were visible over the entire projectile with the exception of the bourrelet which had a finely ground finish.

The following markings were observed stamped into the projectile:

96 B -3  
Between Bourrelet and Rotating Band  
K 2 4 6 M  
On Rotating Band  
96  
On Base

It is apparent that the shot was made with a minimum amount of time being spent to obtain fine finishes and close control of dimensional tolerances. The appearance of the explosive cavity, which is a simple drilled hole, is consistent with the above observations, no unnecessary effort being spent in obtaining a smooth contour for the cavity. The identification and inspection markings were crudely stamped into the surfaces of the shot.

The total projectile weight was 13.95 lbs.

1. Letter file ORDBB-T 386.3/6-27, WTN 386.3/562, see Appendix A

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## B. Design Features

### 1. Windshields

The windshield was crimped into a double cannellure between knurled ridges at the forward end of the shot, see Figure 2. This simple but efficient method of attachment gives a secure joint, particularly with blunt nosed projectiles of the subject type.

### 2. Shot Body

Blunt nosed projectiles are especially effective against under-matching<sup>2</sup> armor at all obliquities of attack, particularly when fired from guns designed for low muzzle velocities, (the subject projectile has a reported muzzle velocity of 1995 ft/sec. ). The penetration of armor by blunt nosed projectiles is achieved by the plugging mechanism, wherein a disc of armor is displaced ahead of the shot. Sharp pointed, ogival nosed projectiles tend, on the other hand, to ricochet off the face of highly sloped armor and are consequently less effective against such targets than are blunt nosed shot. Against overmatching armor and at low obliquities, blunt nosed shot become inefficient and are much less effective than sharp nosed shot.

Many Soviet armor piercing shot<sup>3</sup> which have been examined to date have circumferential grooves machined some distance below their noses; some have one and some have two grooves, sometimes located forward of the bourrelet and sometimes below the bourrelet. The wide variation in number, location, depth, and contour of these grooves demonstrates lack of a standardized design procedure and leads one to conclude that this feature is still the subject of considerable experimentation.

It is more understandable when notches are observed in the bodies of ogival nosed shot, since the notches serve to break off the shot nose when striking armor at high obliquities. Since highly sloped armor is more

2. Undermatching armor is plate which is thinner than the diameter of the attacking projectile.
3. For example see Watertown Arsenal Laboratory Report No. WAL 762/582(c), "Metallurgical Examination of Soviet 45MM, 57MM, and 85MM APHE Projectiles, FMAM 1121, 1935, and 2175."

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effectively coped with by blunt nosed shot, the notches thus serve to convert the shot, by deliberately fracturing it, into a shot of more efficient design. The presence of notches in blunt nosed shot is more difficult to explain since such shots are already properly designed to cope with high obliquity armor. They may serve, however, to localize fracture, when it does occur, to the solid portion of the shot nose and thus keep the explosive cavity intact to insure a high order detonation after perforation of the armor.

Tests which have been conducted with notched shot in this country have not demonstrated them to have any particular overall superiority in armor penetration performance to warrant the adoption of this practice.

### 3. Rotating Band

The rotating band was well seated as demonstrated by the deep and uniform imprint of the band seat knurling into the band, see Figure 5, as well as by the difficulty with which the band was removed.

Detailed dimension of the band and the band seat are shown in Figure 2. The band seat scoring consisted of two parallel series of "V" indentations produced by knurling the flat surface of the band seat.

### 4. Explosive Cavity

The explosive cavity was apparently designed so as to detract as little as possible from the strength of the shot body, presumably to avoid fracture of the shot thru the explosive cavity during the penetration of armor. The cavity was produced by drilling a hole approximately 1" in diameter and 3-1/2" deep into the base of the shot. As seen in Figure 3, the surface of the cavity is indicative of very rough machining. The walls of the shot around the cavity are quite substantial and strong, being at least 1" in thickness.

## C. Metallurgical Characteristics

### 1. Shot Bodies

#### a. Chemical Composition

The body was made from a medium carbon, silicon-chromium steel having a composition similar to that of previously examined Soviet

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APHE projectiles.<sup>3</sup> It was previously observed that no apparent selection of alloy content consistent with hardenability requirements to harden through varying section sizes had been attempted; in fact, the steel of higher carbon and total alloy content was employed for the smallest caliber of shot examined. The subject shot is consistent with the above observation in that the carbon and alloy content fall midway between the compositions of the smallest and largest caliber that were previously examined, specifically 45MM and 85MM. In domestic practice higher alloy contents are employed for larger caliber shot in order to obtain full hardening of the heavier sections. It is also American practice to employ alloy steels having carbon contents of 0.50-0.60% in order to obtain hardnesses of Rockwell C 60 upon quenching. The subject shot, with 0.34% carbon, should harden to Rockwell C 52-55 upon complete transformation to martensite. The chemical composition of the subject 76MM shot is such, however, that it cannot be fully hardened to martensite by quenching.

#### b. Hardness Tests

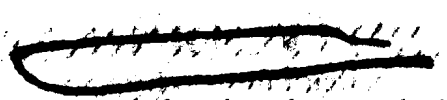
A Rockwell C hardness survey was conducted on a surface ground longitudinal cross section cut from the center of the shot, and the results are shown in Figure 6. The shot was decrementally hardened, averaging Rockwell C 42 from the nose to the rotating band, from which area the hardness decreased rapidly to Rockwell C 16.5 at the base. As would be expected from the low carbon and alloy content, and therefore relatively low hardenability of the steel, the hardness decreased from the surface to center of the body, dropping from Rockwell C 47 at the outer surface to Rockwell C 37.5 at the center of the section.

Domestic AP shot are heat treated to Rockwell C 60, or higher, and then differentially base tempered to obtain hardnesses of approximately Rockwell C 59 at the bourrelet, gradually decreasing to Rockwell C 45 at the base. Hardnesses lower than Rockwell C 60 at the nose result in greater shattering of the shot against armor, as well as reduction in the velocity of impact at which shatter initiates.

#### c. Macroetch Test

A longitudinal cross section of the shot was hot acid etched in a solution of 50% concentrated hydrochloric acid and 50% water. A steel bar stock of moderately poor quality was employed for the shot as demonstrated by the heavy concentrations of long stringers shown in Figure 3. The

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transverse line across the nose of the shot forward of the grooves represents a saw-cut that started to deviate from the longitudinal axis of the shot and is not a feature of the macrostructure of the shot body.

#### d. Microscopic Examination

Specimens obtained from the locations shown in Figure 6 were polished, etched, and examined microscopically.

No section of the projectile was completely transformed to martensite although the nose area is more fully hardened than the rest of the shot. The microstructure from the nose to the explosive cavity is uniform containing large amounts of bainite and ferrite in addition to martensite, see Figure 4C and 4D, this microstructure is indicative of inadequate quenching or insufficient alloy content to completely harden through the cross section. The shot was differentially quenched, probably by immersing the nose section in the quenching medium and permitting the base to cool in air, as evidenced by the ferritic and pearlitic microstructure and the low hardness of the base.

The brittle, though soft, condition of the base obtained by this method of producing a differential hardness pattern makes this manner of decrementally hardening shot the least desirable. The optimum method of obtaining a differential hardness pattern is to completely transform the shot to a martensitic structure, and then differentially temper the base section to soften this region without decreasing the hardness of the nose. This method of heat treatment produces a shot that becomes progressively softer and tougher towards the base and insures that the body and base section remain intact during armor penetration.

## 2. Windshield

### a. Chemical Composition

The windshield was made from a low carbon unalloyed steel of the composition shown in Table I. This analysis is typical of rimmed steel employed in this country and abroad for deep drawn objects.

### b. Hardness Tests

The hardness of the windshield was measured with the Rockwell Superficial Hardness Tester using the "15-T" scale. The following re-

  
sults were obtained:

Rockwell 15-T  
Hardness

Brinell  
Hardness (converted)

91.0, 91.5, 91.0

205

c. Microscopic Examination

The microstructure of the windshield consisted of moderately fine grained ferrite with scattered spheroidized carbides, see Figures 4A and 4B. The absence of evidence of cold working indicates the windshield was process annealed after the cold drawing operations.

3. Rotating Band

a. Chemical Composition

The rotating band was made from a high purity copper, the analysis of which is shown in Table I.

b. Hardness Tests

The hardness of the rotating band was obtained with the Rockwell Superficial Hardness Tester using the "15-T" scale with the following results:

Rockwell 15-T  
Hardness

Brinell Hardness  
(converted)

83.5, 84.0, 84.0,  
83.5, 84.0, 83.5

127

c. Microscopic Examination

The microstructure of the rotating band is typical of cold worked copper, showing evidence of twinning, see Figure 4F.

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GENERAL CONSIDERATIONS

The subject Soviet shot was produced from a medium carbon silicon-chromium steel similar in composition to that of previously examined AP shot ranging in caliber from 45 to 85MM.<sup>3</sup> The low carbon content and reduced hardenability of the steel as well as the poor heat treatment practice employed in hardening the shot resulted in a low hardness in the nose of the shot and brittle microconstituents, particularly in the base of the shot.

The design of the shot indicates that it was probably intended for the defeat of highly sloping armor up to approximately 2" in thickness. The low muzzle velocity reported for the gun from which the subject shot is fired makes it unlikely that it can defeat any target heavier than 2", although the design of the shot is such that it can defeat highly sloped 3" thick armor if fired at higher muzzle velocities (3000-3200 f/s).

The subject 76MM shot does not possess any single feature of metallurgy, design, or manufacture which has not been previously observed in other Soviet shot which have been returned to this country for examination.

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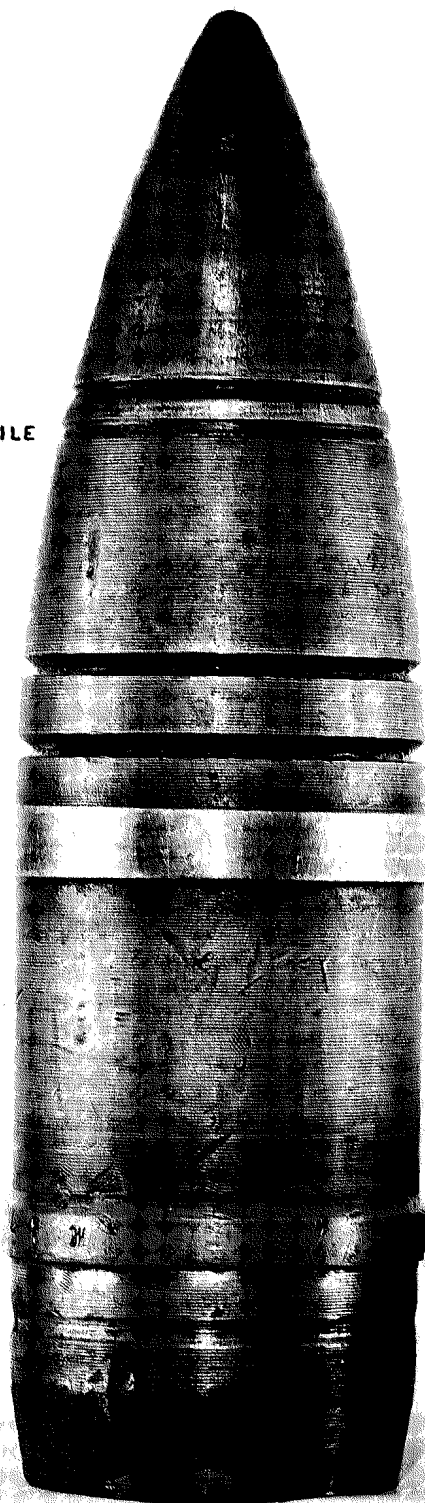
TABLE I

CHEMICAL COMPOSITIONS OF SOVIET 76MM APHE PROJECTILE, FMAM 2267

BODY									
C	Mn	Si	S	P	Ni	Cr	Mo	Va	
.34	.84	1.54	.015	.013	.25	1.23	.06	Nil	
WINDSHIELD									
C	Mn	Si	S	P	Ni	Cr	Mo	Va	
.085	.39	.003	.037	.013	Trace	.05	.05	Nil	
ROTATING BAND									
Cu	Mn	Sn	Pb	Fe	Al	Ni	P	Zn	
99.87	Nil	Nil	Nil	Trace	Nil	Trace	Nil	Trace	

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PROJECTILE



BASE VIEW



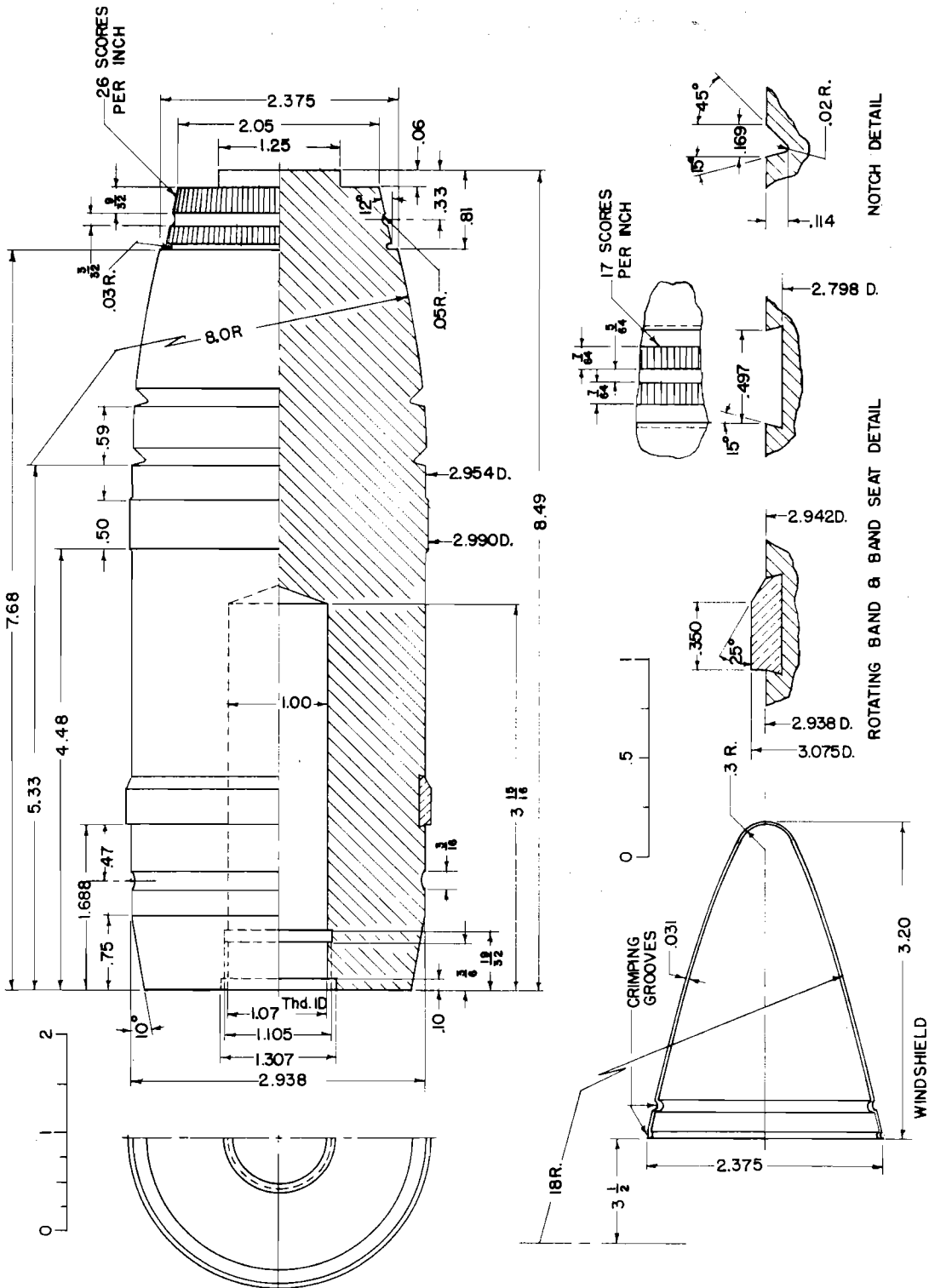
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FIGURE 1

SOVIET 76MM APHE MOD. UBR-354-B PROJECTILE

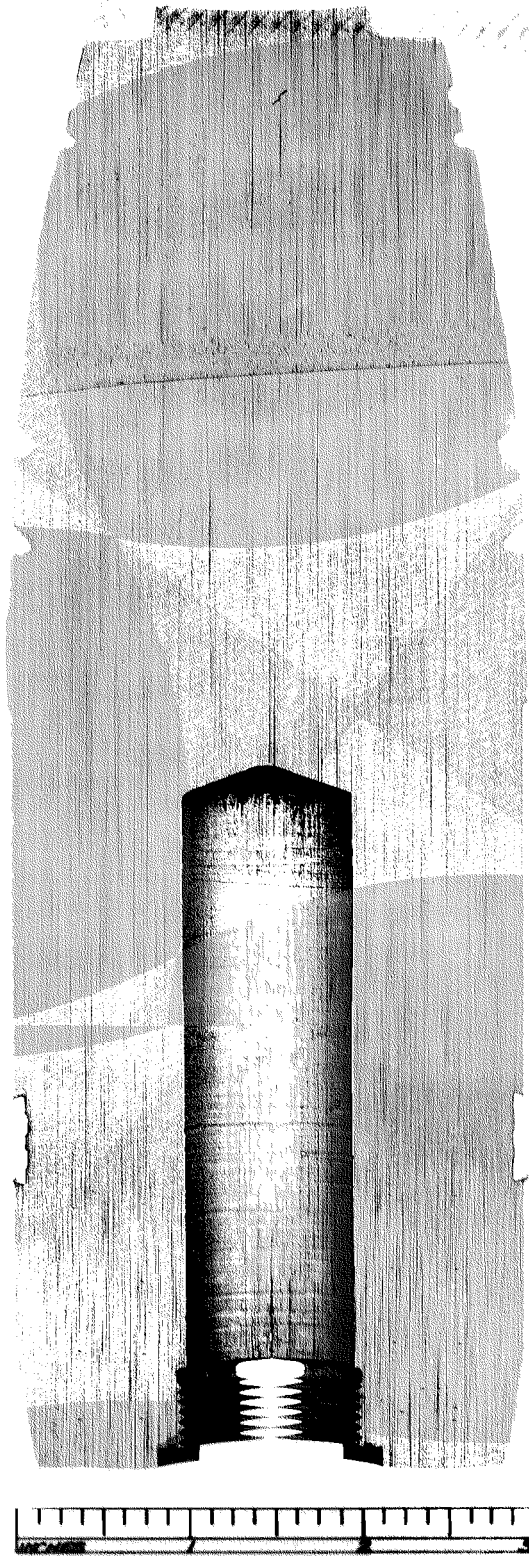
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MACROETCHED STRUCTURE OF SOVIET 76MM APHE, MOD. UBR-254B PROJECTILE, FMAM 2267  
WTN.751-2051

FIGURE 3

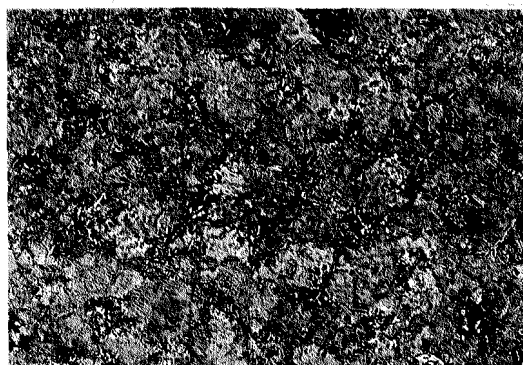
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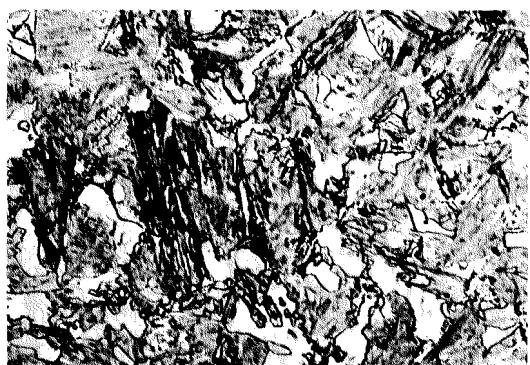
X100 -A- PICRAL  
WINDSHIELD- HOT ROLLED LOW CARBON  
SHEET STEEL.



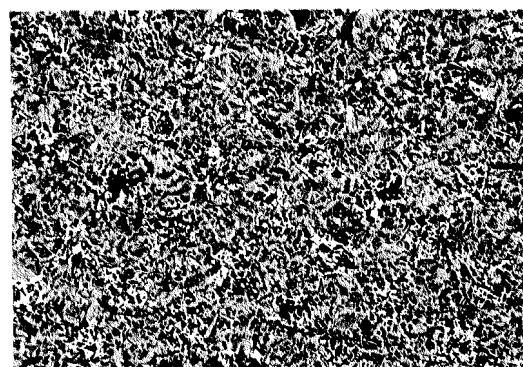
X1000 -B- PICRAL  
WINDSHIELD- SAME AREA AS A. LARGE  
CARBIDES AT GRAIN BOUNDARIES.



X100 -C- PICRAL  
BODY- NOSE SECTION.



X1000 -D- PICRAL  
SAME AREA AS C. INCOMPLETELY QUENCH  
HARDENED STRUCTURE. FERRITE AND  
BAINITE IN MARTENSITIC MATRIX.



X100 -E- PICRAL  
BODY-BASE SECTION- MIXED FERRITE AND  
PEARLITE TYPICAL OF HOT ROLLED STEEL.

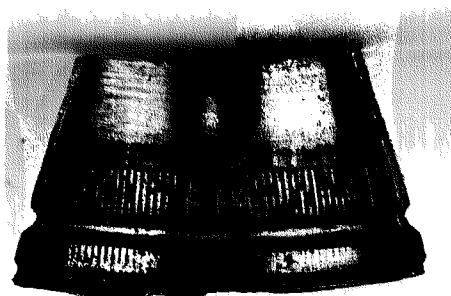


X100 -F-  $\text{NH}_4\text{OH}, \text{H}_2\text{O}_2$   
ROTATING BAND- COLD WORKED COPPER.

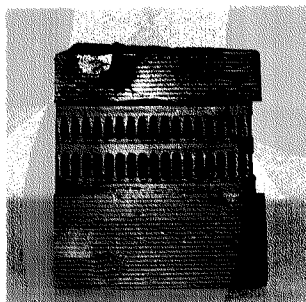
MICROSTRUCTURE OF COMPONENTS OF SOVIET 76MM APHE PROJECTILE  
MOD BR-354-B, FMAM 2267.

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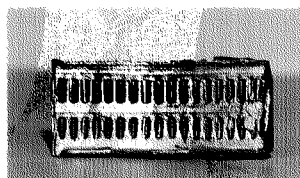
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WINDSHIELD



BAND SEAT



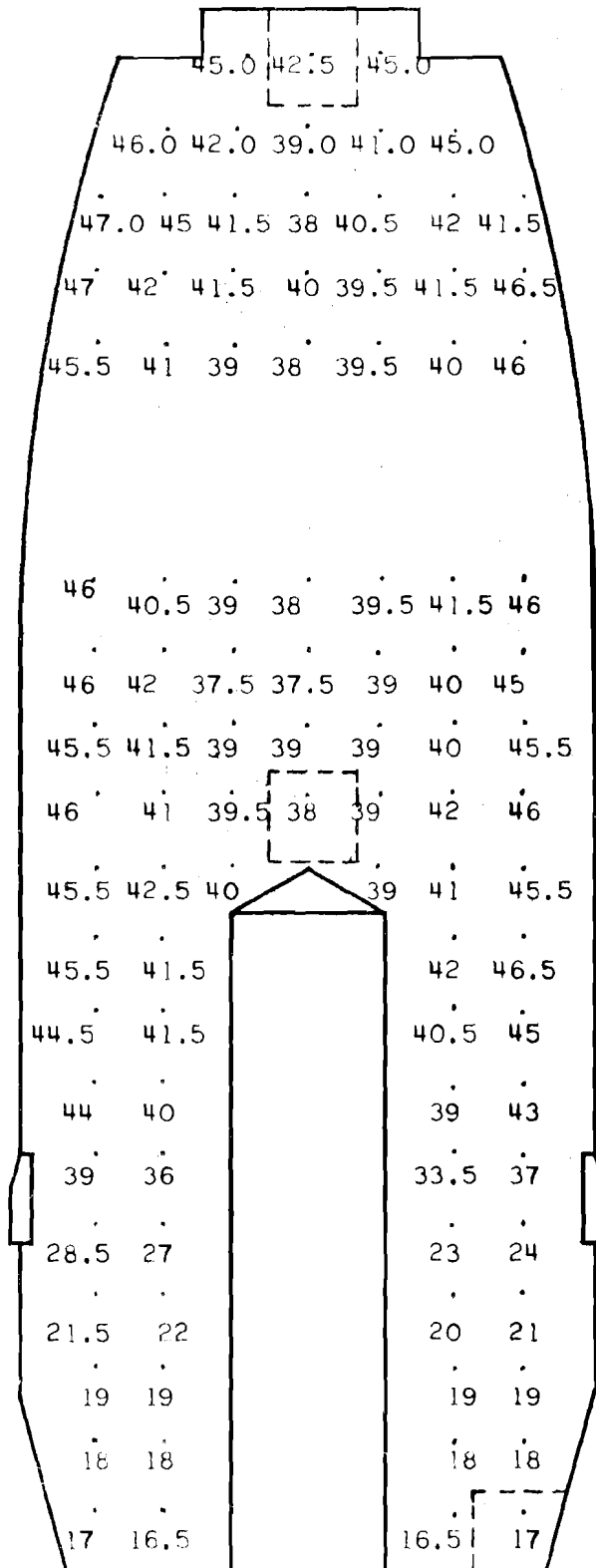
ROTATING BAND

FIGURE 5

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KNURLING DETAILS ON BAND SEAT AND INSIDE OF ROTATING BAND AND WINDSHIELD OF SOVIET  
76MM APHE MOD. UBR-354-P PROJECTILE (FMAM 2267) MAG. XI WTN.710-2049

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ROCKWELL C HARDNESS PATTERN ON BODY OF SOVIET 76MM APHE PROJECTILE MOD BR-354-B (FMAM 2267) AND LOCATION OF SPECIMENS FOR MICROSCOPIC EXAMINATION.

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APPENDIX A

Letter File ORDBB-T 386.3/6-27  
WTN 386.3/562

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RECORD

PICATINNY ARSENAL

Dover, New Jersey Mr. A. B. Schilling/kf/2193

ORDBB-T 386.3/6-27

Subject: Metallurgical Examination of Soviet Artillery Ammunition

TO: Commanding Officer  
Watertown Arsenal  
Watertown 72, Massachusetts

1. There are being forwarded, by freight, for metallurgical examination the following items of Soviet Ammunition:

1 - 76mm Projectile, APHE MOD UBR-354-B FMAM 2267

1 - 76mm Projectile, HVAP MOD UBR-354-P FMAM 2153

1 - 76mm Shell, HE, MOD UO-354 FMAM 2272

2. The flats cut on the nose of the HVAP Projectile FMAM 2153 were made locally to facilitate disassembly. The void between the two core slugs and the core cavity in the body and nose was filled with magnesium oxide to assure a tight assembly.

3. A one-half section of the HE Shell, FMAM 2272 has been retained for study of design. The principal diameter dimensions of this shell, prior to sectionalizing, are indicated on the attached photograph, M-38930.

4. It is requested that a copy of the report of the results of the examination, including a dimensional drawing, be forwarded upon completion. It is also requested that the assigned number of the report, and title, be furnished as soon as possible for incorporation as a reference in technical reports being prepared at this Arsenal on the complete round.

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ORDBB-T

SUBJECT: Metallurgical Examination of Soviet Artillery Ammunition

5. It is noted that the titles of reports WAL 762/581(c) and WAL 762/582(c) as furnished by 3rd Indorsement WTN 386.3/552R, ORDBB-T 386.3/6-21, dated 5 July 1951, do not include the "FMAM" numbers of the subject projectile. There will be other projectiles of the same caliber and type upon which examinations will be made. To assure the maintenance of the identity of all projectiles examined, it is requested that the "FMAM" number be included in the titles of the reports.

6. Return of a one-half section, if not expended in the examination, is requested upon completion of the examination. No remaining part of the HE one-half section (FMAM - 2272) is required.

7. The security classification of the reports is to be "Confidential".

FOR THE COMMANDING OFFICER:

1 Inc.

Photograph M-38930

C. R. DUTTON  
Col, Ord Corps  
Assistant

<sup>2</sup>  
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