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A REVIEW OF METALLURGICAL FACTORS IN DEVELOPMENT OF THE  
WARHEAD MK 19 MOD 0 FOR ASM-N-7A BULLPUP GUIDED MISSILE

S. F. Magle

NOX



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Date: 12 December 1960

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U. S. Naval Weapons Laboratory  
Dahlgren, Virginia

A Review of Metallurgical Factors in Development of the  
Warhead Mk 19 Mod O for ASM-N-7a BULLPUP Guided Missile

by

S. F. Magis  
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NWL REPORT NO. 1728

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ABSTRACT

This report reviews metallurgical data and characteristics pertinent to the development of the Mk 19 Mod 0 (EX 29 Mod 3) warhead for use in the ASM-N-7a BULLPUP guided missile. Warhead bodies of AISI 4340 standard basic electric furnace steel with proper heat treatment were found to be of suitable metallurgical quality. In comparison with AISI 4340 warhead bodies the AISI 4140 bodies were inferior metallurgically. The mechanical property specifications established during the development of the EX 29 warhead were substantiated and deemed suitable for use in quantity production of Mk 19 type warheads.

FOREWORD

This report issued by the Naval Weapons Laboratory, Dahlgren, covers the metallurgical studies conducted during development of the Warhead, Mk 19 Mod 0 (EX 29 Mod 3).

The work on the project reported herein was conducted during the period of December 1958 to February 1960 and relates to references (a), (b) and (c).

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INTRODUCTION

This report presents metallurgical data and summarizes metallurgical characteristics deemed pertinent to the design and development of the Mk 19 Mod 0 (EX 29) warhead. The final prototype Warhead (EX 29 Mod 3) described herein is essentially the same design as the production quality warhead designated the Mk 19 Mod 0, and was used for final evaluation of the warhead design. The final evaluation tests demonstrated that the warhead, when explosive loaded and mounted in the BULLPUP guided missile as shown in Figure 1, is rugged enough to withstand impact on and penetration of light steel and reinforced concrete targets at striking velocities up to 1800 ft/sec and to remain in an effective bursting condition. The metallurgical characteristics of the EX 29 Mod 3 warhead are an integral part of the warhead design and considered to have contributed materially to the satisfactory penetration performance exhibited by this warhead in its final evaluation impact tests conducted in actual BULLPUP missiles (from a track) at NOTS, China Lake, California.

DESCRIPTION OF MATERIAL

The EX 29 warhead (empty) is a three component assembly, shown in Figure 2, consisting of a body of one piece forged construction, a base plug, and a fuze cavity liner. The preliminary prototype warheads EX 29 Mods 0 and 1 and the final prototype EX 29 Mod 3 warhead, treated in this report, were nearly identical in configuration and differed only in the steel composition used in the body and base plug components. AISI 4340 steel was used for the body and base plug on the EX 29 Mods 0 and 3 warheads and has been specified for the corresponding components of the Mk 19 Mod 0 warhead. AISI 4140 steel was used for the body and base plug on the EX 29 Mod 1 warhead for the purpose of determining the effect of a lower alloy content than AISI 4340 on warhead performance and problems associated with procurement, fabrication and inspection insofar as practicable consistent with performance requirements. The steel used for the fuze cavity liner on all warheads was AISI 4130. In general, standard basic electric furnace quality steel was used for the body component. The design of the body component of the EX 29 Mod 3 warhead is shown in Figure 3. The results of experimental work with

3.2 inch reduced scale model warheads were used to establish the metallurgical characteristics and design of the EX 29 warhead. In this earlier warhead development work the mechanical properties listed in Table 1(A) were evolved, utilized, and found to be suitable for use in a penetrating type of warhead. Such mechanical properties assured a good combination of strength, toughness and ductility, permitted machining, and were capable of use in a specification for production warheads. As a result, the heat treatment of EX 29 warheads given in Table 2 was aimed to provide mechanical properties shown in Table 1(A).

#### PROCEDURE

A metallurgical evaluation was conducted of representative EX 29 warheads as received from the contractor in the final heat treated condition. The warhead body component was tested as follows:

- a. A check chemical analysis was made on a sample from the body wall.
- b. Rockwell C hardness tests were taken on a longitudinal cross section. Tests included at least 14 Rockwell C hardness determinations in the heavy ogive section.
- c. A macroscopic examination or macro-etch test was made of a longitudinal cross section.
- d. Tensile tests were conducted on two specimens taken from the ogive section in a near longitudinal direction as shown in Figure 4.
- e. Charpy impact tests were made on V-notch specimens taken from the ogive section in a near longitudinal direction as shown in Figure 4. The notch of the specimen was approximately perpendicular to the outside surface of the body. At least two specimens were tested at 0°C and in some cases specimens were tested at various other temperatures to determine the transition temperature from ductile to brittle failure. Here the percent of granular fracture was determined from the fracture appearance of the impact specimen and plotted vs testing temperature. A curve was drawn and the temperature for a point on the

curve at which fracture was fifty percent granular and fifty percent fibrous was determined. This temperature was considered to be the transition temperature. On some warhead bodies Charpy V-notch specimens were taken also from the heavy nose section transverse to the longitudinal axis of the body and tested at 0°C.

f. The depth of decarburization on the outside and cavity surfaces was determined from microscopic examination of metallographic specimens taken in the longitudinal direction.

g. Grain size measurements were made by microscopic examination of specimens taken in a transverse direction.

h. A metallographic examination was made of the entire central longitudinal section for microstructure, banding, and inclusions. Photomicrographs were taken at locations shown in Figure 5 to show the microstructure, inclusions, and banding.

The base plug and cavity liner components were tested only for Rockwell C hardness and chemical composition.

### RESULTS AND DISCUSSION

Check chemical analyses and Rockwell C hardness tests showed representative base plugs and cavity liners of EX 29 warheads to be within the check analysis limits for the particular AISI steel and the hardness limits given in Table 1(A). The results of metallurgical tests on the EX 29 warhead bodies illustrated in Figures 6 through 40 and Tables 1(B) and 1(C) are discussed in the following paragraphs.

a. Chemical Composition - The chemical compositions of the EX 29 warhead bodies given in Table 1(B) are within the check analysis tolerances for either AISI 4140 or AISI 4340 steel.

b. Tensile Properties - The tensile test results in Table 1(C) show that all warhead bodies, with the exception of No. 3, exceed the yield strength and reduction of area minimums given in Table 1(A). The yield strength of warhead

body No. 3 was only 700 psi under the minimum requirement. Elongation and reduction of area were slightly higher for the AISI 4340 bodies than for the AISI 4140 bodies.

c. Charpy Impact Properties - The Charpy impact test results in Table 1(C) made at 0°C on specimens from the location shown in Figure 4 show that all warhead bodies with the exception of AISI 4140 warhead body No. 1a exceed the impact strength minimum of 40 ft-lbs specified in Table 1(A). The AISI 4140 warhead body No. 1a with the lowest impact strength had the highest yield and tensile strength and AISI 4340 warhead body No. 3 with the highest impact strength had the lowest yield and tensile strength. Table 1(C) shows the AISI 4340 bodies to be superior to the AISI 4140 bodies in impact strength determined with specimens taken either in the near longitudinal direction as shown in Figure 4 or in a transverse direction from the heavy ogive section. This superiority is more pronounced on comparing the transition temperatures in Table 1(C). Here the AISI 4340 bodies gave much lower transition temperatures than the AISI 4140 bodies. These results demonstrate that the AISI 4340 bodies are somewhat tougher than AISI 4140 bodies.

d. Grain Size - The grain sizes of the warhead bodies are tabulated in Table 1(C). In general, the warhead bodies have a slightly finer grain size than the ASTM 7 to 8 range expected in commercial grades of AISI 4140 and 4340 steels. The wide grain size range (6-9) in body No. 3 did not affect quality adversely as illustrated by high impact strength and low transition temperature.

e. Decarburization - The depths of decarburization on the outside and cavity surfaces of the warhead bodies are given in Table 1(C). On all bodies decarburization is greater on the cavity surface than on the outside surface. Warhead body No. 1a shows the most decarburization, probably as a result of reheat treatment.

f. Hardness - The results of Rockwell C hardness tests of warhead bodies are given in the hardness distributions in Figures 6 through 12. A grouping of hardness values according to warhead number, nose section, and wall section is tabulated as follows:

| Figure Number | Warhead Number | AISI Composition | Rockwell C Hardness Range |              | Total No. of Hardness Readings | Hardness Readings Within Specification in Table 1(A) |         |
|---------------|----------------|------------------|---------------------------|--------------|--------------------------------|------------------------------------------------------|---------|
|               |                |                  | Heavy Nose Section        | Wall Section |                                | Number                                               | Percent |
| 6             | 1              | 4140             | 27-35                     | 30-52        | 101                            | 15                                                   | 15      |
| 7             | 2              | 4340             | 35.5-37                   | 35.5-38      | 92                             | 92                                                   | 100     |
| 8             | 1a             | 4140             | 33-40                     | 38.5-41      | 132                            | 107                                                  | 81      |
| 9             | 3              | 4340             | 33-35                     | 34-36        | 77                             | 40                                                   | 52      |
| 10            | 4              | 4140             | 31-36                     | 35-39        | 76                             | 67                                                   | 88      |
| 11            | 5              | 4340             | 34-36                     | 35-37        | 76                             | 75                                                   | 99      |
| 12            | 6              | 4340             | 35-36                     | 35-36        | 76                             | 76                                                   | 100     |

Warhead body No. 1 represents the first lot of warheads received at a time when the contractor's heat treating practice was under development. The wide variation in hardness of body No. 1, shown above and in Figure 6, indicated that heat treatment was not optimum and necessitated reheat treatment of this lot of EX 29 Mod 1 bodies. For this reason the hardness test results of body No. 1 are not used in any subsequent hardness comparisons. Warhead body No. 1a represents the reheat treated warheads. In general the hardness of the warhead bodies is higher in the wall section than in the nose section as expected from the shape of the body. The overall hardness of the AISI 4340 bodies No. 2, 5 and 6 is within the aim 35 to 40 Rockwell C range listed in Table 1(A) with the exception of one value of 34 in the nose section of body No. 5. The AISI 4140 bodies No. 1a and 4 show a wider variation in hardness than the AISI 4340 bodies No. 2, 3, 5 and 6, particularly in the heavy nose section.

g. Macro-etch Test - Figures 13 through 19 show a large view of the ogive sections of the warhead bodies after macro-etching. The flow lines in the AISI 4140 bodies (Figures 13, 15 and 17) are more prominent than in the AISI 4340 bodies (Figures 14, 16, 18 and 19). Warhead body No. 2 as shown in Figure 14 represents the first lot of AISI 4340 warhead bodies to be received. The pitted condition in the heavy nose section just forward of the cavity is evidence of faulty forging practice. A study indicated that too rapid extrusion of the material at the forward end of the coining punch caused the material to leave the punch and resulted in the voided condition.

Slight changes to forging tools and rearrangement of forging passes successfully eliminated this pitted condition in later bodies No. 3, 5 and 6 shown in Figures 16, 18 and 19. Except for the pitted condition in body No. 2, Figure 14, the results of macro-etch test (Figures 13 through 19) show all warhead bodies to be of satisfactory quality.

h. Microstructure - The microstructures of the warhead bodies at locations A, B, C and D of Figure 5 are shown in Figures 20 through 26. The reheat treatment of AISI 4140 warheads represented by body No. 1 is substantiated by the microstructures shown in Figure 20. The excessive free ferrite at locations A, B and C and the marked decomposition of martensite at locations A and B resulted from nonuniformity of heat treatment. In heavy nose section locations A and B the representative AISI 4140 warheads show free ferrite in bodies No. 1a and 4 (Figures 22 and 24) whereas the AISI 4340 warheads show no free ferrite in bodies No. 2 and 6 (Figures 21 and 26) and very little free ferrite in bodies No. 3 and 5 (Figures 23 and 25).

i. Inclusions - The inclusions in the warhead bodies at locations A and D of Figure 5 are shown in Figures 27 through 33. The drawn out nature of the inclusions at location D gives an indication of the degree and direction of the forging and drawing of the steel at this location. The ASTM standard rating of the inclusions in the warhead bodies (Figures 27 through 33) is less than three and indicates satisfactory material.

j. Banding - Typical examples of the banding present in the warhead bodies are given in Figures 34 through 40. Banding was not excessive in any of the warhead bodies. AISI 4140 body No. 1a (Figure 36) shows the least banding and AISI 4340 bodies No. 3 (Figure 37) and No. 5 (Figure 39) show the most banding. A comparison of Figure 34 and Figure 36 indicates the reduction in banding obtained by reheat treatment.

#### Metallurgical Defects in Production Quality EX 29 Mod 3 Warheads

As the only practical means of meeting an early requirement for warheads for fleet use, a limited quantity of final prototype EX 29 Mod 3 warheads was produced using

controls, inspection and acceptance procedures normally involved in procurement and acceptance of production items. A large number of EX 29 Mod 3 warheads met the prescribed requirements but a few warheads failed the acceptance tests. Some metallurgical data and defects observed in the failed warheads are reviewed here.

The results of a metallographic examination of inclusions in two warhead bodies representing different production lots of EX 29 Mod 3 warheads are illustrated in Figure 41. Both warhead bodies were processed from the same heat of steel and had chemical compositions within the range shown in Table 1(B) for the AISI 4340 warhead bodies. The manufacturer reported the mechanical properties of both bodies to be in accordance with the requirements of Table 1(A). The warhead body with inclusions as shown in Figure 41(A) passed the required ballistic penetration test while the warhead body with inclusions as shown in Figure 41(B) failed the ballistic penetration test by circumferential rupture near the base end of the cylindrical section. In comparison with the inclusions in development quality bodies in Figures 27 through 33 the inclusions in the body which passed ballistic test (Figure 41(A)) are somewhat heavier, whereas the inclusions in the body which failed the ballistic test Figure 41(B) are considerably heavier.

Figures 42 and 43 show an EX 29 Mod 3 pilot lot warhead body after failure in the ballistic penetration test. The chemical composition of the steel used in this warhead body was as follows:

|          |           |          |          |           |           |           |           |           |
|----------|-----------|----------|----------|-----------|-----------|-----------|-----------|-----------|
| <u>C</u> | <u>Mn</u> | <u>P</u> | <u>S</u> | <u>Si</u> | <u>Ni</u> | <u>Cr</u> | <u>Mo</u> | <u>Cu</u> |
| .38      | .75       | .024     | .031     | .29       | 1.76      | .77       | .24       | .12       |

Although the chemical composition is within the limits specified for AISI 4340 steel of the open hearth grade the phosphorus and sulfur contents are more than double those shown in Table 1(B) and are much higher amounts than normally obtained with standard basic electric furnace practice. The manufacturer reported that the steel was made in an electric furnace using a single slag practice and conditions similar to open hearth practice. Such practice could account for the high phosphorus and sulfur content. Tests conducted on a sample warhead body representative of the failed pilot lot warhead body included: Rockwell C hardness,

tensile, Charpy V-notch impact, macroscopic examination, and microscopic examination for structure, inclusions, banding and grain size. The hardness distribution representative of this pilot lot warhead body shown in Figure 44 ranges from 32 to 36 Rockwell C with the low hardnesses obtained mainly in the ogive section. The tensile properties met the requirements of Table 1(A). The Charpy V-notch impact strength was 34.5 to 38.5 ft-lbs at 0°C and the transition temperature was -40°C. Such impact properties are lower than the 40 ft-lb minimum strength specified in Table 1(A) and significantly inferior compared with the impact properties listed in Table 1(C) for AISI 4340 development quality warhead bodies. The macroetch section in Figure 45 shows heavier flow lines than any of the test sections from development quality warhead bodies shown in Figures 13 through 19. The microstructure in Figure 46 is as uniform as the microstructure of the better AISI 4340 warhead bodies No. 2 and 6 (Figures 21 and 26) indicating satisfactory heat treating practice. The inclusions in Figure 47 are mainly sulfides and are more abundant than the inclusions in development quality bodies in Figures 27 through 33. The banding in Figure 48 is considered normal. The grain size was 8-9 (ASTM No.).

### CONCLUSIONS

Based on the results of metallurgical tests conducted during development of the Mk 19 Mod 0 (EX 29) warhead and covered herein, it was concluded that:

- a. The warhead bodies of AISI 4340 standard basic electric furnace steel with proper heat treatment were of suitable metallurgical quality.
- b. In comparison with AISI 4340 warhead bodies the AISI 4140 warhead bodies were inferior metallurgically as revealed by lower impact strength, higher transition temperature, and wider variation in hardness and microstructure.
- c. The mechanical property specifications given in Table 1(A) were acceptable for use in design of the Warhead Mk 19 Mod 0.

REFERENCES

- (a) BUORD Conf Task Assignment All Ser 019177 of  
16 Jul 1959 (Task No. NA-000-136-61017-90064)
- (b) BUORD Conf Task Assignment All Ser 019176 of  
16 Jul 1959 (Task No. NA-000-136-61017-91064)
- (c) BUWEPS Conf Task Assignment RMMO-5 RFH Ser 037960 of  
7 Sep 1960 (WEPTASK No. 000-136-61017-91064 Amendment  
No. 3)

## APPENDIX A

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TABLE I

DATA ON PROTOTYPE WARHEADS, EX 29 MODS 0, 1 AND 3

(A) Mechanical Property Specifications

| Warhead Component    | Yield Strength<br>0.2% Offset | Reduction<br>of Area | Hardness Limits<br>Rockwell C |      | Charpy V-notch<br>Impact Strength<br>at 0°C |
|----------------------|-------------------------------|----------------------|-------------------------------|------|---------------------------------------------|
|                      | Min.<br>(psi)                 | Min.<br>(%)          | Min.                          | Max. | Min.<br>(ft. - lbs.)                        |
| Body                 | 145,000                       | 45                   | 35                            | 40   | 40                                          |
| Base Plug            |                               |                      | 35                            | 40   |                                             |
| Fuze Cavity<br>Liner |                               |                      | 25                            | 30   |                                             |

(B) Identification and Chemical Composition of Prototype Warhead Body Samples

| Sample<br>Warhead<br>Number | No. of<br>Warheads<br>in Lot<br>Represented | Date<br>Received | Mod | AISI<br>Composition | Chemical Composition |     |      |      |     |      |     |     |     |
|-----------------------------|---------------------------------------------|------------------|-----|---------------------|----------------------|-----|------|------|-----|------|-----|-----|-----|
|                             |                                             |                  |     |                     | C                    | Mn  | P    | S    | Si  | NI   | Cr  | Mo  | Cu  |
| 1                           | 10                                          | 12-8-58          | 1   | 4140                | .40                  | .89 | .008 | .011 | .28 | .09  | .94 | .20 | .06 |
| 2                           | 10                                          | 12-24-58         | 0   | 4340                | .41                  | .76 | .010 | .015 | .29 | 1.70 | .83 | .25 | .07 |
| 1a *                        | 10                                          | 1-20-59          | 1   | 4140                | .36                  | .80 | .009 | .011 | .25 | .10  | .96 | .20 | .06 |
| 3                           | 12                                          | 2-13-59          | 0   | 4340                | .38                  | .75 | .011 | .013 | .25 | 1.65 | .68 | .24 | .06 |
| 4                           | 11                                          | 3-6-59           | 1   | 4140                | .36                  | .95 | .011 | .011 | .28 | .07  | .89 | .16 | .06 |
| 5                           | 45                                          | 5-1-59           | 3   | 4340                | .37                  | .76 | .008 | .013 | .28 | 1.85 | .92 | .27 | .07 |
| 6                           | 35                                          | 5-20-59          | 3   | 4340                | .37                  | .78 | .007 | .013 | .33 | 1.76 | .84 | .28 | .08 |

(C) Tensile and Impact Properties, Grain Size and Decarburization of Prototype Warhead Body Samples

| Sample<br>Warhead<br>Number | AISI<br>Compo-<br>sition | Ultimate<br>Tensile<br>Strength<br>(psi) | Yield<br>Strength<br>0.2%<br>Offset<br>(psi) | Elonga-<br>tion<br>(%) | Reduc-<br>tion<br>of<br>Area<br>(%) | ASTM<br>Grain<br>Size<br>No. | Charpy V-notch<br>Impact Strength<br>at 0°C<br>(ft. - lbs.) |                          | Transi-<br>tion<br>Tempo-<br>rature<br>0°C | Depth of Decarburization (Inches) |         |      |      |
|-----------------------------|--------------------------|------------------------------------------|----------------------------------------------|------------------------|-------------------------------------|------------------------------|-------------------------------------------------------------|--------------------------|--------------------------------------------|-----------------------------------|---------|------|------|
|                             |                          |                                          |                                              |                        |                                     |                              | Location<br>in<br>Figure 4                                  | Heavy<br>Hose<br>Section |                                            | Cavity                            | Outside |      |      |
|                             |                          |                                          |                                              |                        |                                     |                              |                                                             |                          |                                            |                                   | Min.    | Max. | Min. |
| 1                           | 4140                     |                                          |                                              |                        |                                     |                              |                                                             |                          |                                            | .017                              | .038    | .005 | .007 |
| 2                           | 4340                     | 167,000                                  | 157,050                                      | 14.8                   | 50.1                                | 8-9                          | 49.0-50.5                                                   | 29.5                     | -90                                        | .001                              | .035    | .002 | .004 |
| 1a *                        | 4140                     | 183,550                                  | 173,200                                      | 13.6                   | 48.7                                | 8-10                         | 36.0-37.5                                                   | 21.5                     | -30                                        | .000                              | .004    | .000 | .015 |
| 3                           | 4340                     | 157,800                                  | 144,300                                      | 15.5                   | 52.0                                | 6-9                          | 54.5-56.0                                                   |                          | -100                                       | .002                              | .013    | .001 | .004 |
| 4                           | 4140                     | 167,950                                  | 154,600                                      | 12.9                   | 50.5                                | 8-9                          | 42.0-44.5                                                   |                          | -30                                        | .002                              | .020    | .001 | .004 |
| 5                           | 4340                     | 163,500                                  | 152,900                                      | 14.7                   | 53.1                                | 8-9                          | 47.0-49.0                                                   | 38.0                     | -90                                        | .006                              | .009    | .001 | .002 |
| 6                           | 4340                     | 162,000                                  | 156,150                                      | 15.4                   | 53.5                                | 7-9                          | 48.0-48.5                                                   |                          |                                            | .000                              | .022    | .000 | .010 |

\* First Lot (Sample Warhead Number 1) Reheat Treated

TABLE 2MANUFACTURER'S HEAT TREATMENT OF WARHEAD BODIES

| <u>Sample<br/>Warhead No.</u> | <u>Heat Treatment</u>                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                             | Anneal: 1525°F 3 hours, gas fired furnace, furnace cool for 14 hours<br>Preheat: 1250°F 50 mins., salt bath<br>High heat: 1525°F 50 mins., salt bath, 30 secs. transfer time to quench<br>Quench: 600°F 15 mins., salt bath, air cool to less than 200°F, wash out salt by immersion in hot water<br>Draw: 600°F 3 hours, gas fired furnace, air cool to room temperature |
| 1a and 4                      | Preheat: 1250°F 50 mins., salt bath<br>High heat: 1575°F 50 mins., salt bath<br>Quench: 200°F circulated oil<br>Draw: 1050°F 3 hours, gas fired furnace, air cool to room temperature                                                                                                                                                                                     |
| 2 and 3                       | Preheat: 1250°F 50 mins., salt bath<br>High heat: 1525°F 50 mins., salt bath<br>Quench: 200°F circulated oil<br>Draw: 1050°F 3 hours, gas fired furnace, air cool to room temperature                                                                                                                                                                                     |
| 5 and 6                       | Heat: 1525°F 2 hours, gas fired furnace<br>Quench: 110°F 8 mins. circulated oil on inside and outside surface, warhead nose up<br>Draw: 1025°F 3 hours, gas fired furnace, warheads rolled through furnace, air cool to room temperature                                                                                                                                  |

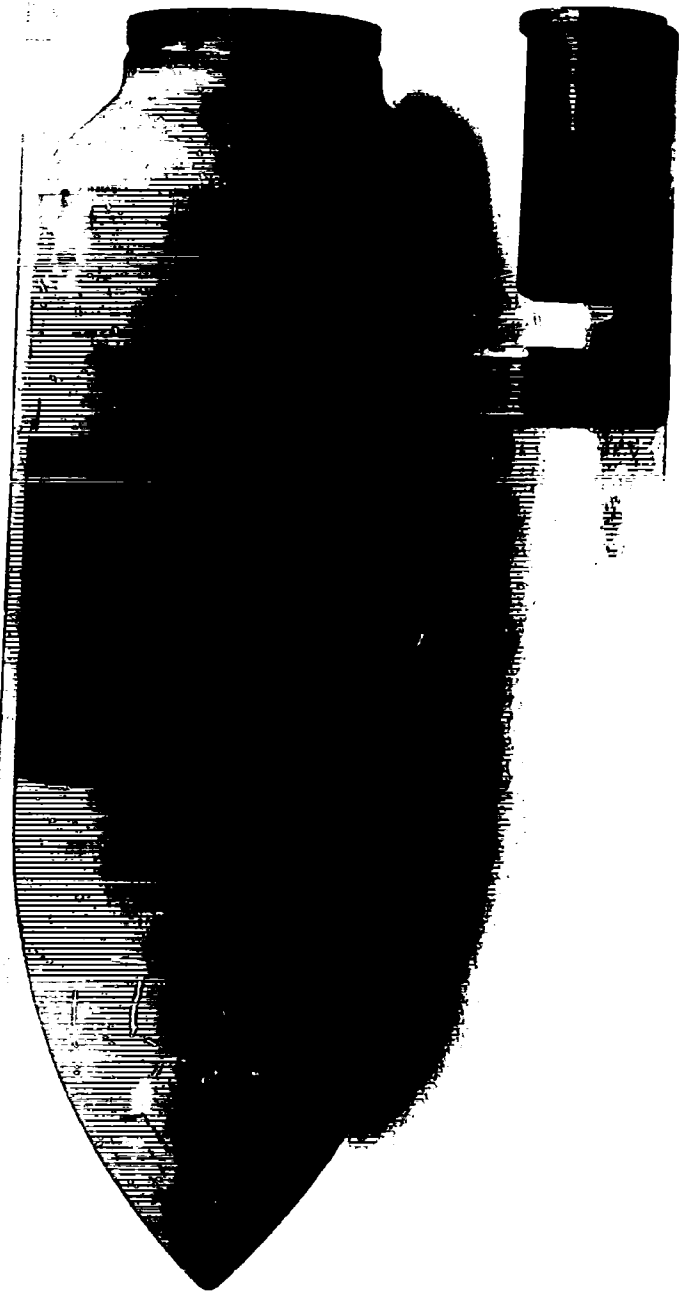


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FIGURE 1

PHOTOGRAPH OF SULLFUP GUIDED MISSILE YAS-1-7 (PROTOTYPE AS-1-7a) SHOWING A PRACTICAL VIEW  
OF THE WARHEAD EX 29 MOD 3 (PROTOTYPE .K 19 MOD 0)

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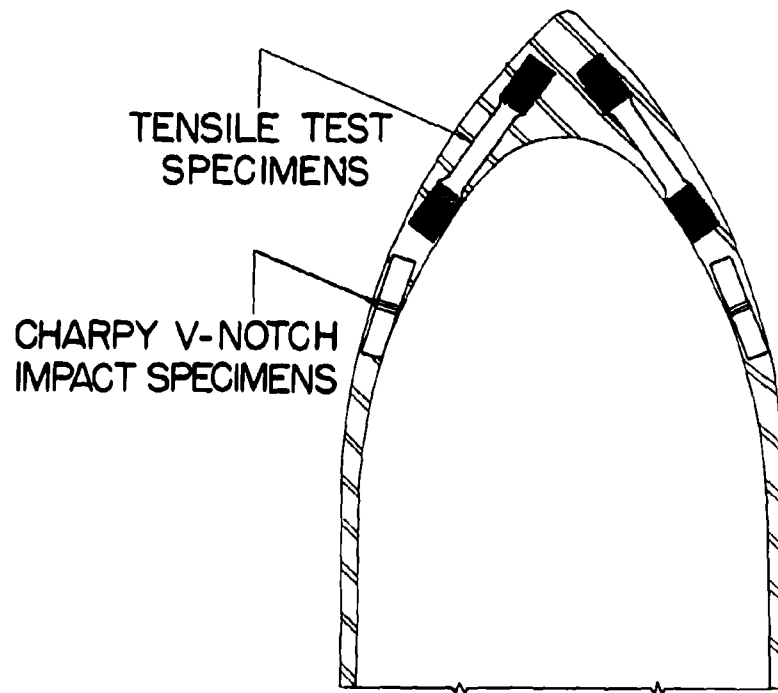
FIGURE 2

GUIDED MISSILE WARHEAD EX 29 MOD 3

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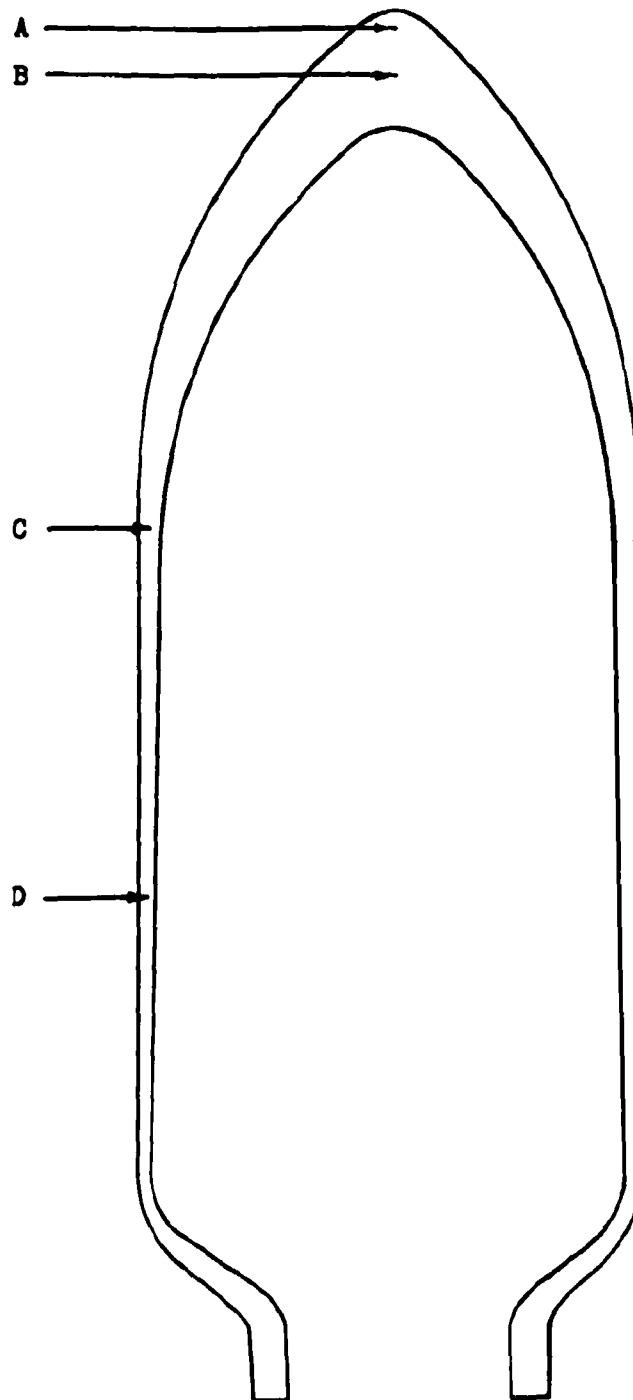


LOCATION OF  
TENSILE AND CHARPY IMPACT SPECIMENS

PHD 55555

FIGURE 4

CONFIDENTIAL

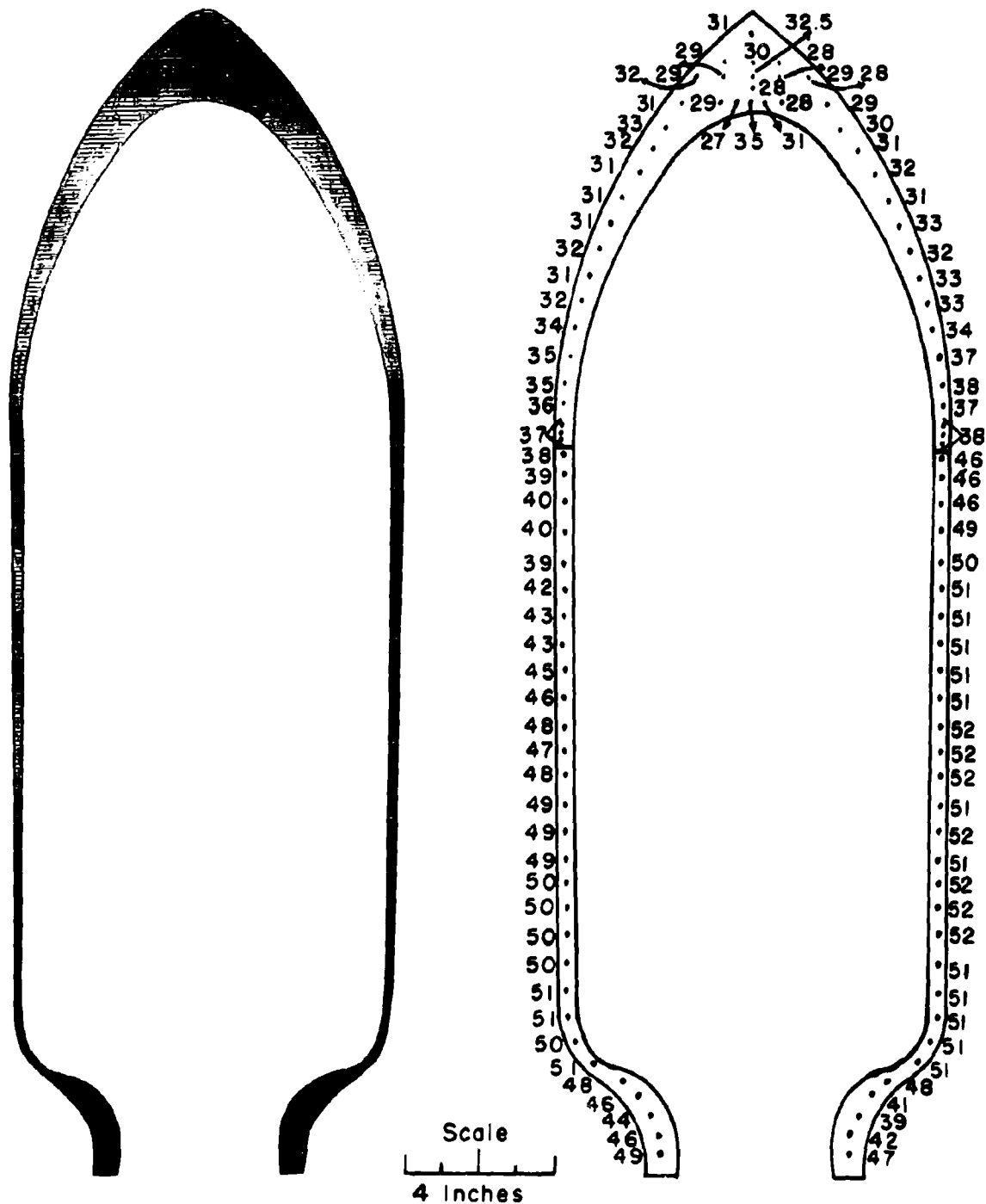


PHD-55552

FIGURE 5

LOCATIONS AT WHICH PHOTOMICROGRAPHS WERE TAKEN FROM WARHEAD BODY.

CONFIDENTIAL



PHD-55222

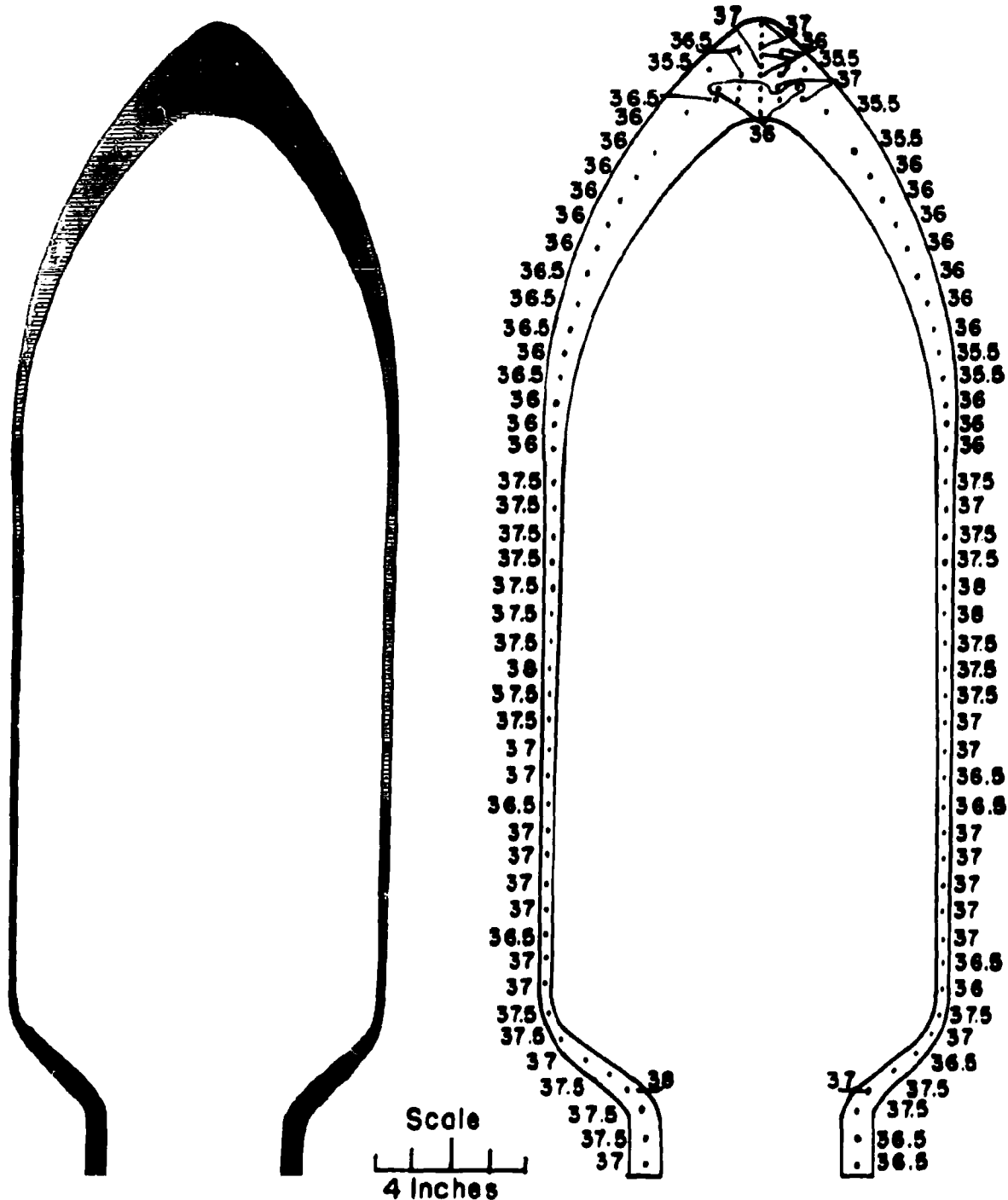
FIGURE 6

December 1958

SAMPLE WARHEAD NO. 1  
HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
EX 29 MOD 1 AISI 4140

Hardness Values: Rockwell C Scale  
Etch: 50% Hydrochloric Acid

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PHD-55239

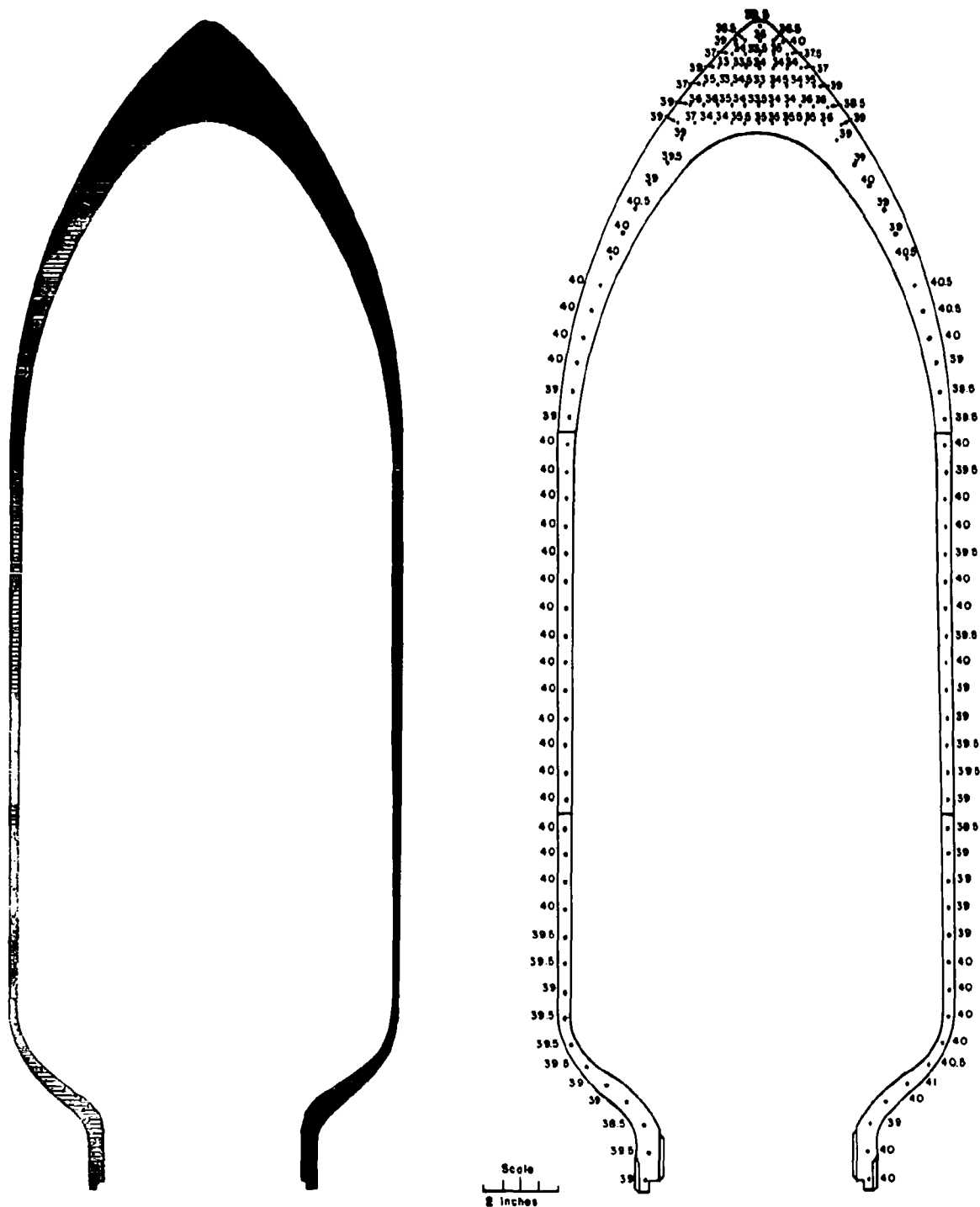
FIGURE 7

January 1959

SAMPLE WARHEAD NO. 2  
HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
EX 29 MOD 0 AISI 4340

Hardness Values: Rockwell C Scale  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



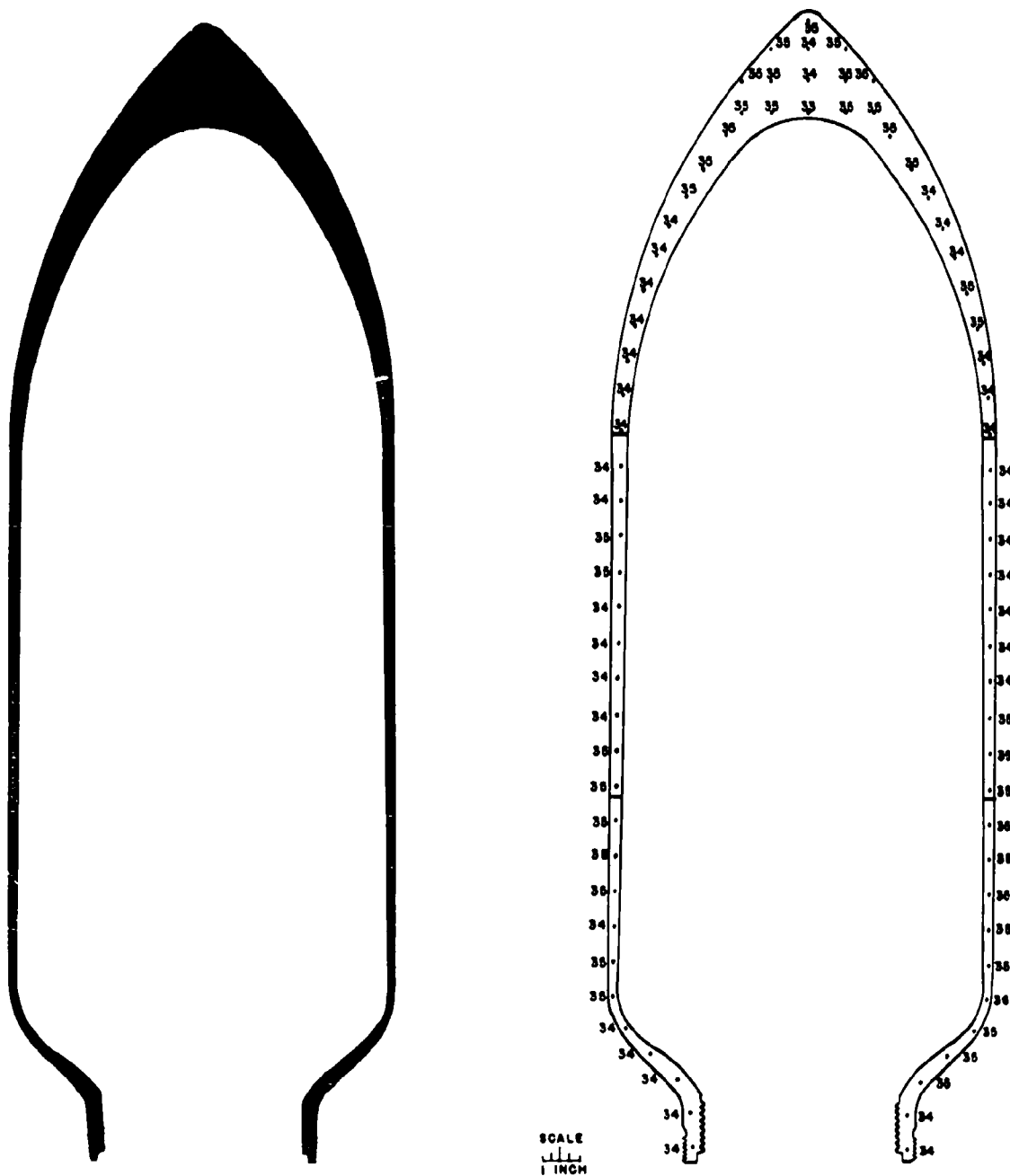
PHD-55298

FIGURE 8

February 1959

SAMPLE WARHEAD NO. 1a  
 HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
 EX 29 MOD 1 AISI 4140 REHEAT-TREATED  
 Hardness Values: Rockwell C Scale  
 Etch: 50% Hydrochloric Acid

CONFIDENTIAL



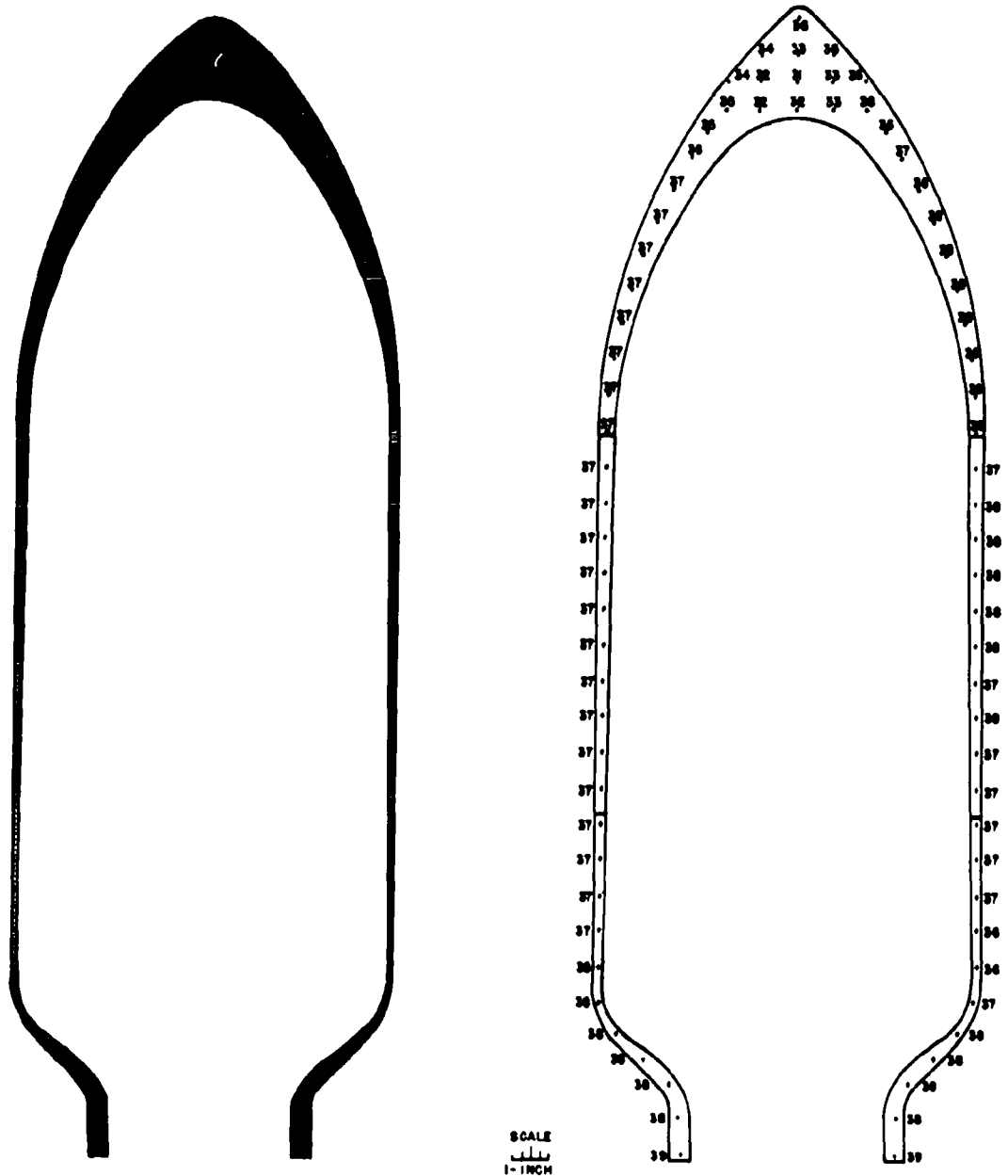
PHD-55557

FIGURE 9

March 1959

SAMPLE WARHEAD NO. 3  
 HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
 EX 29 MOD 0 AISI 4340  
 Hardness Values: Rockwell C Scale  
 Etch: 50% Hydrochloric Acid

CONFIDENTIAL



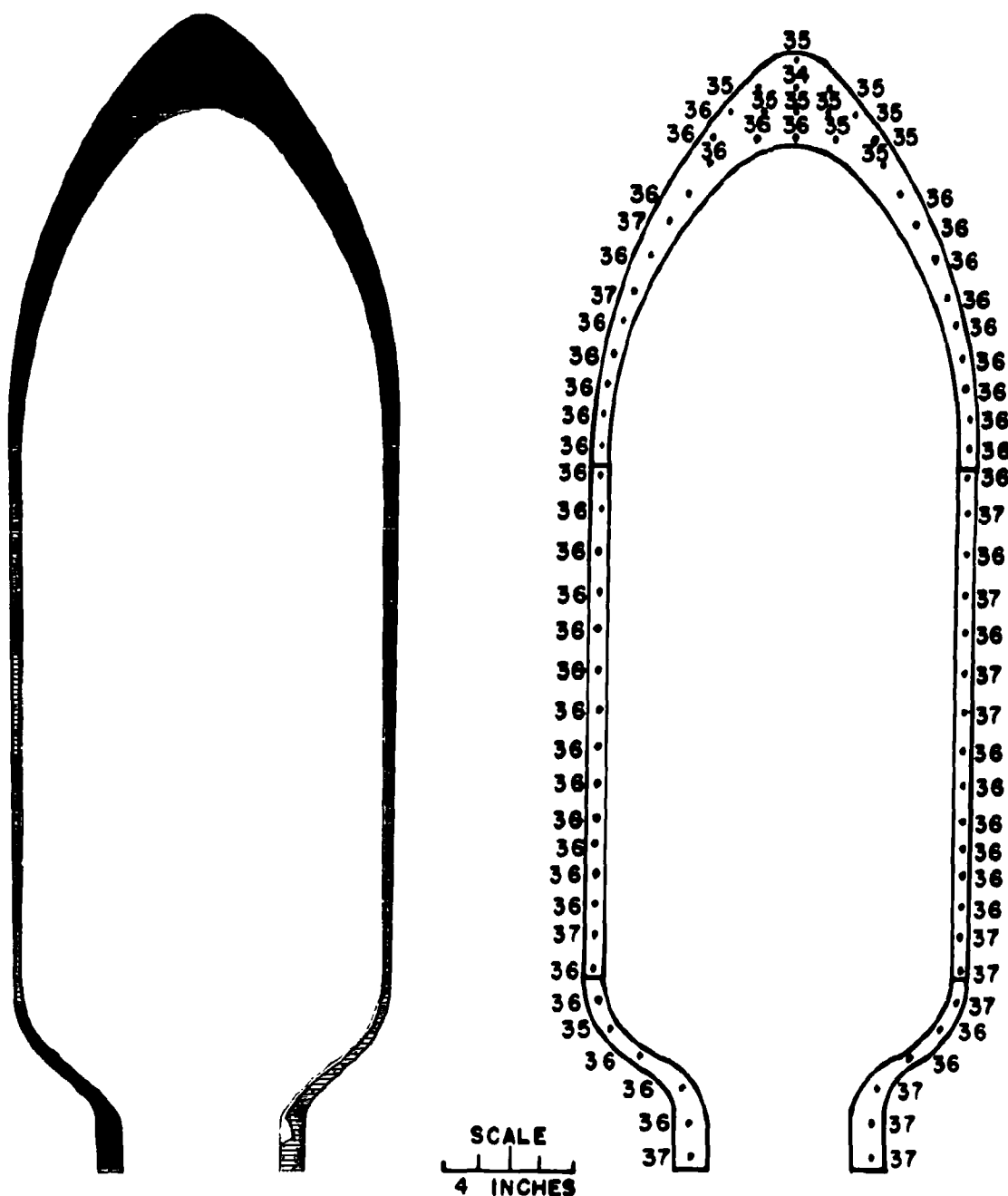
PHD-55558

FIGURE 10

April 1959

SAMPLE WARHEAD NO. 4  
 HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
 EX 29 MOD 1 AISI 4140  
 Hardness Values: Rockwell C Scale  
 Etch: 50% Hydrochloric Acid

CONFIDENTIAL



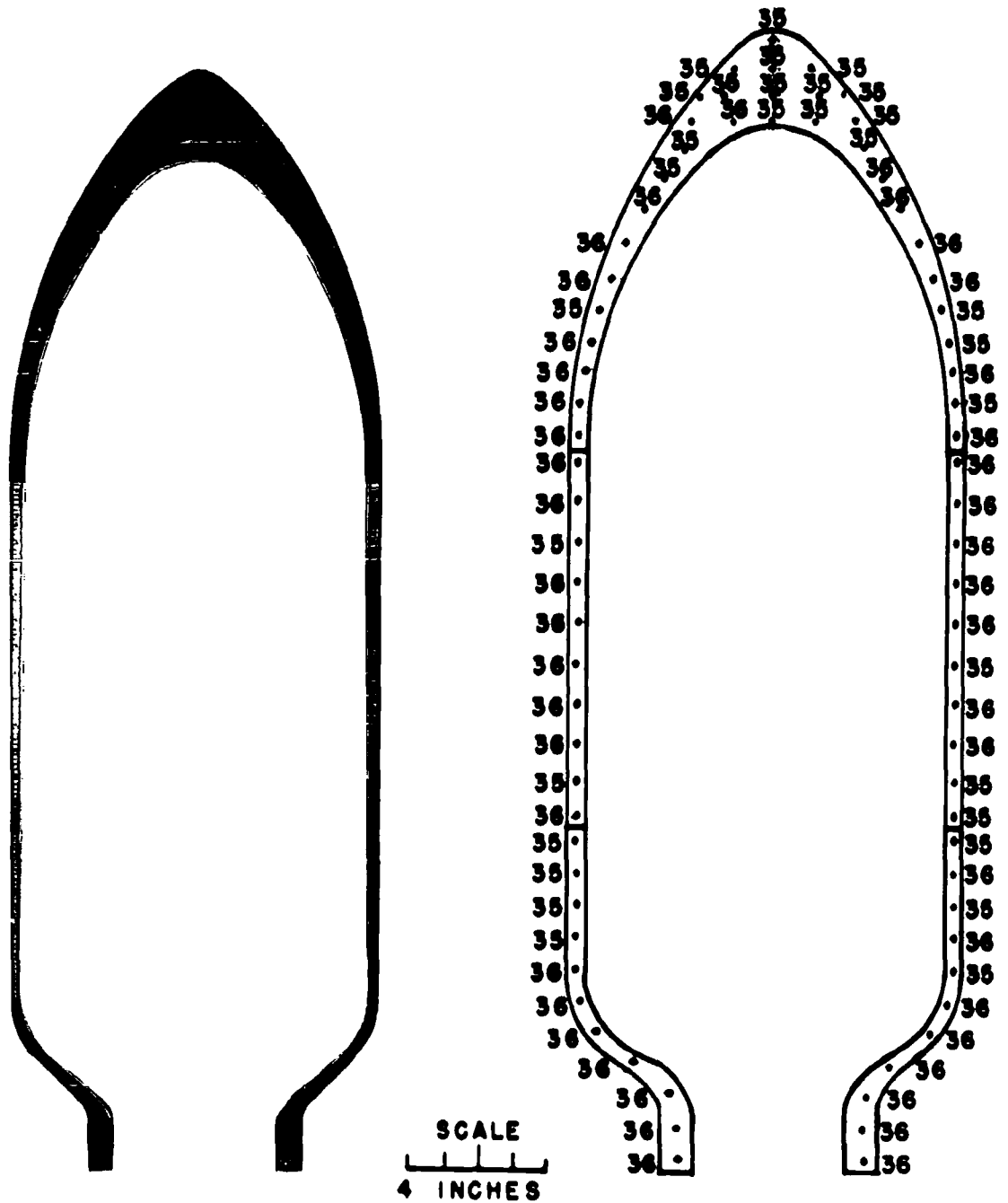
PHD-55559

FIGURE 11

June 1959

SAMPLE WARHEAD NO. 5  
 HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
 EX 29 MOD 3 AISI 4340  
 Hardness Values: Rockwell C Scale  
 Etch: 50% Hydrochloric Acid

CONFIDENTIAL



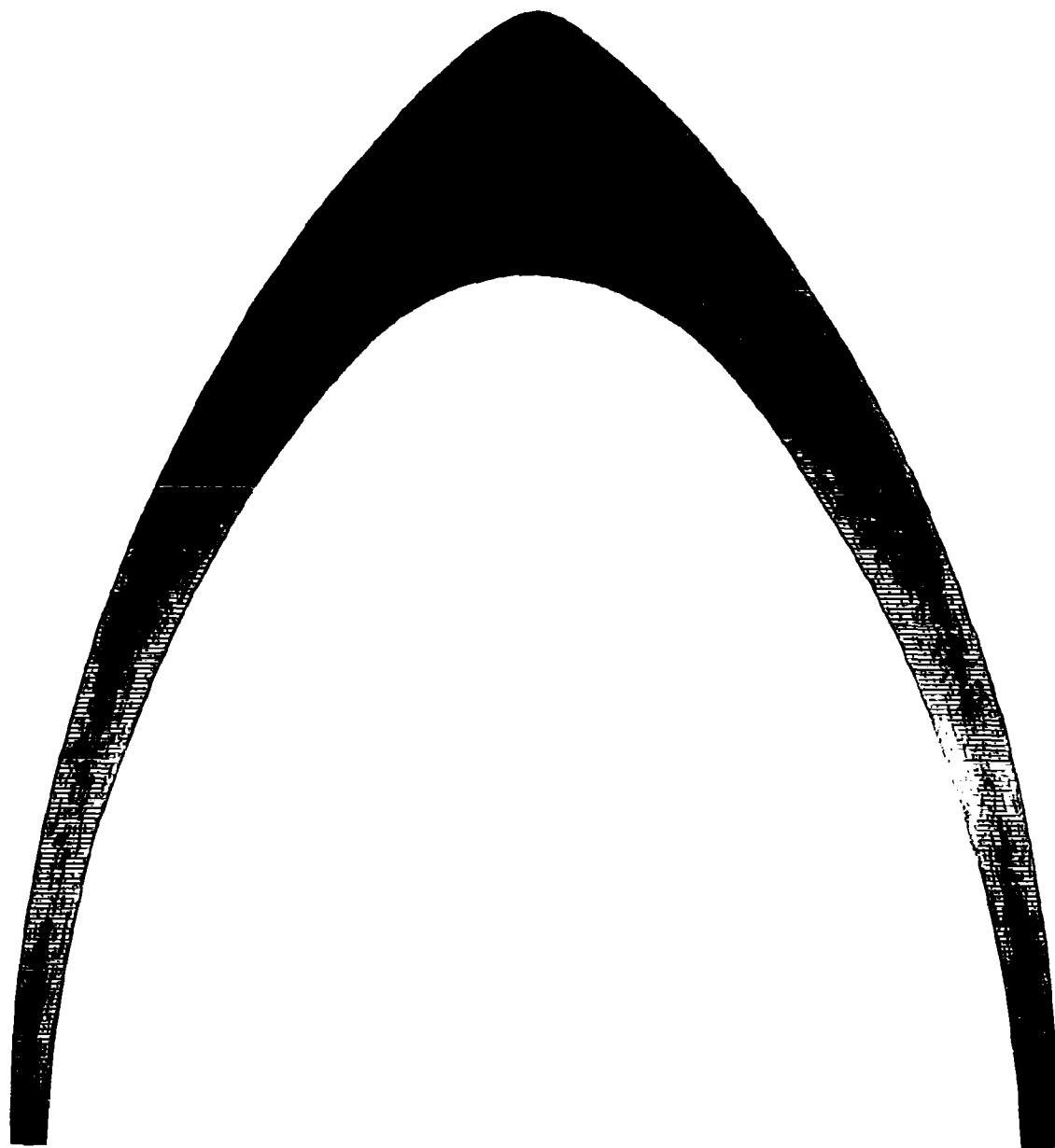
PHD-55560

FIGURE 12

June 1959

SAMPLE WARHEAD NO. 6  
 HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
 EX 29 MOD 3 AISI 4340  
 Hardness Values: Rockwell C Scale  
 Etch: 50% Hydrochloric Acid

CONFIDENTIAL



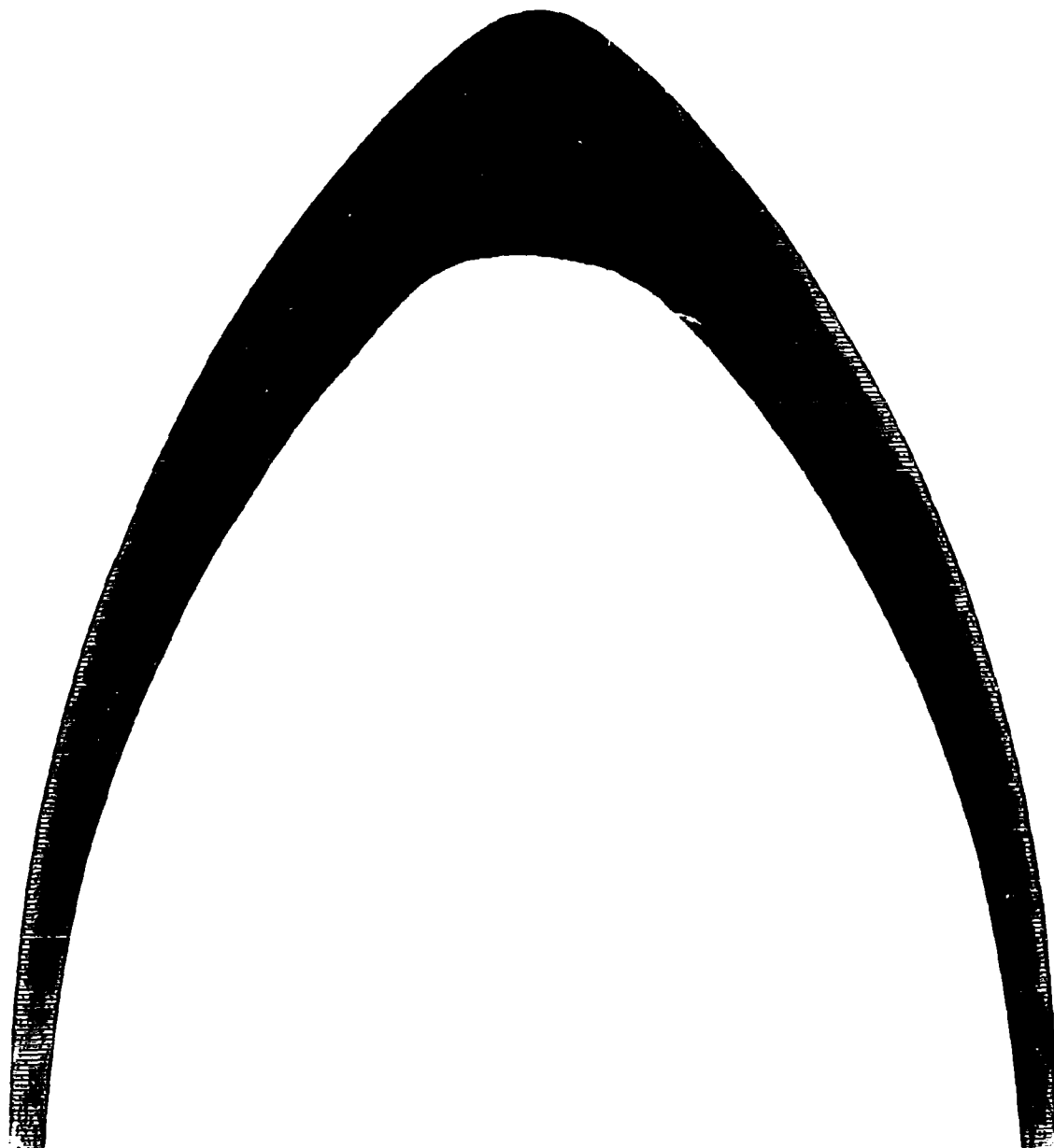
PHD-55561

FIGURE 13

December 1958

SAMPLE WARHEAD NO. 1  
MACROSECTION OF OGIVE FROM: BULLPUP WARHEAD EX 29 MOD 1 AISI 4140  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



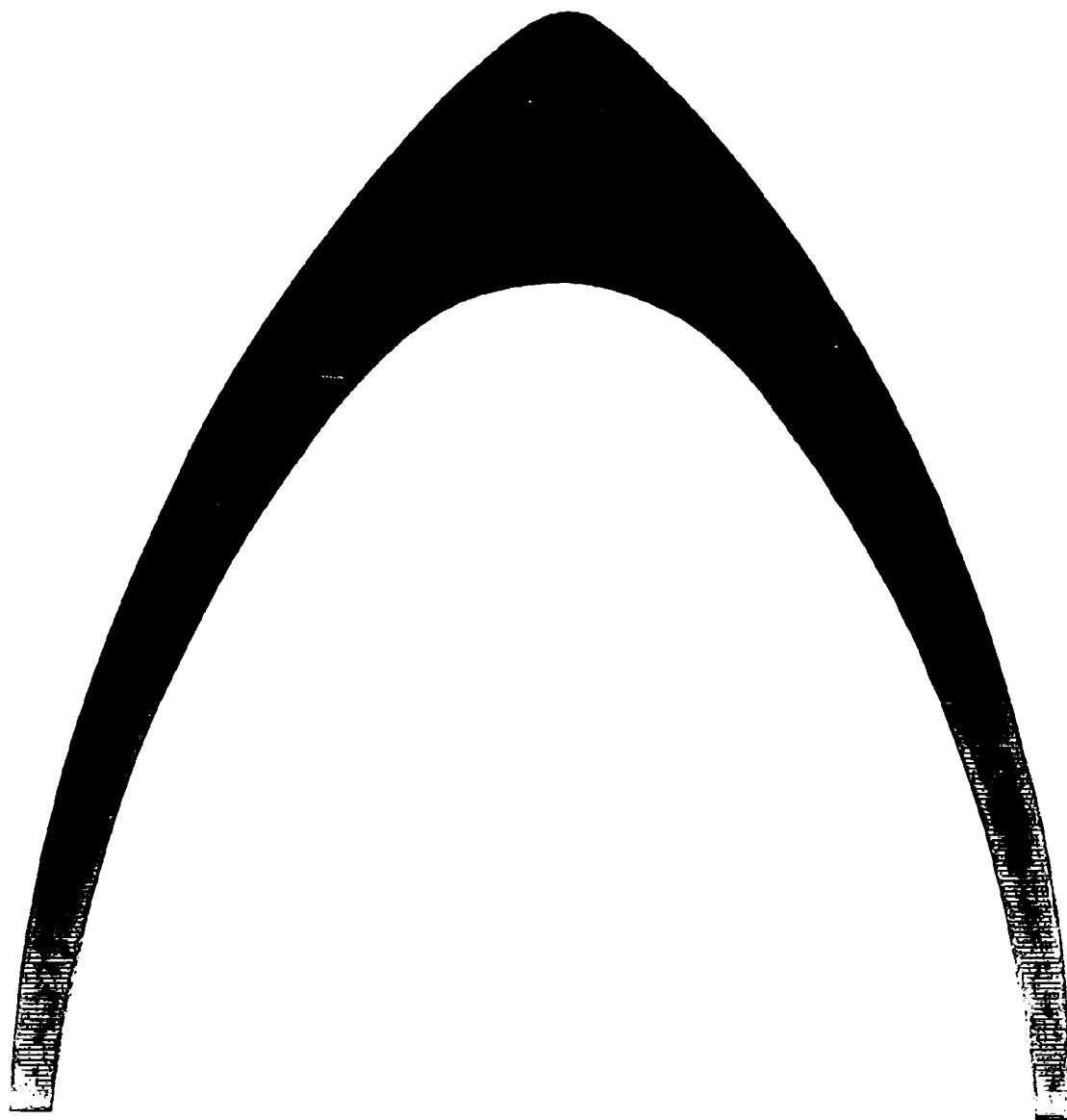
PHD-55562

FIGURE 14

January 1959

SAMPLE WARHEAD NO. 2  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD EX 29 MOD 0 AISI 4340  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



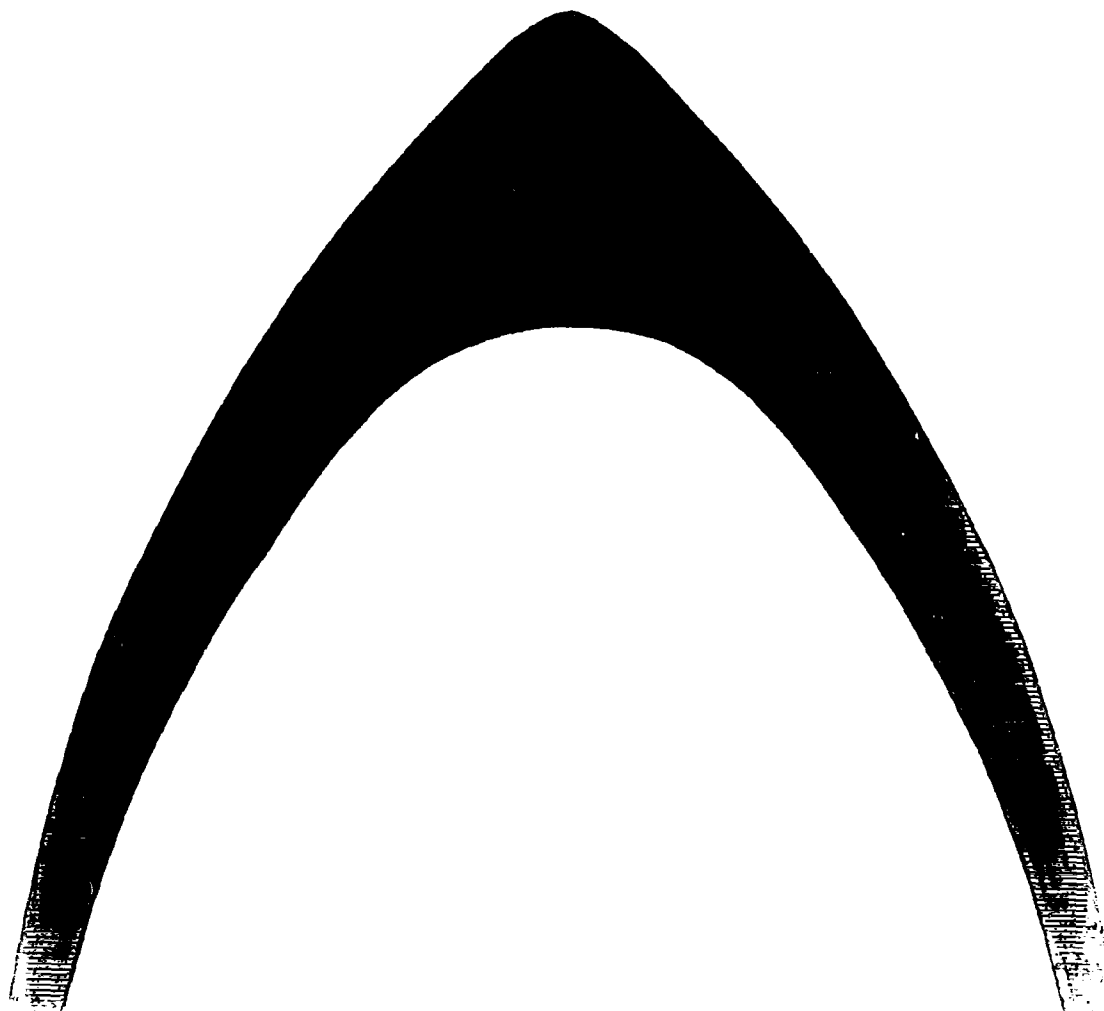
PHD-55563

FIGURE 15

February 1959

SAMPLE WARHEAD NO. 1a  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD  
EX 29 MOD 1 AISI 4140 REHEAT-TREATED  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



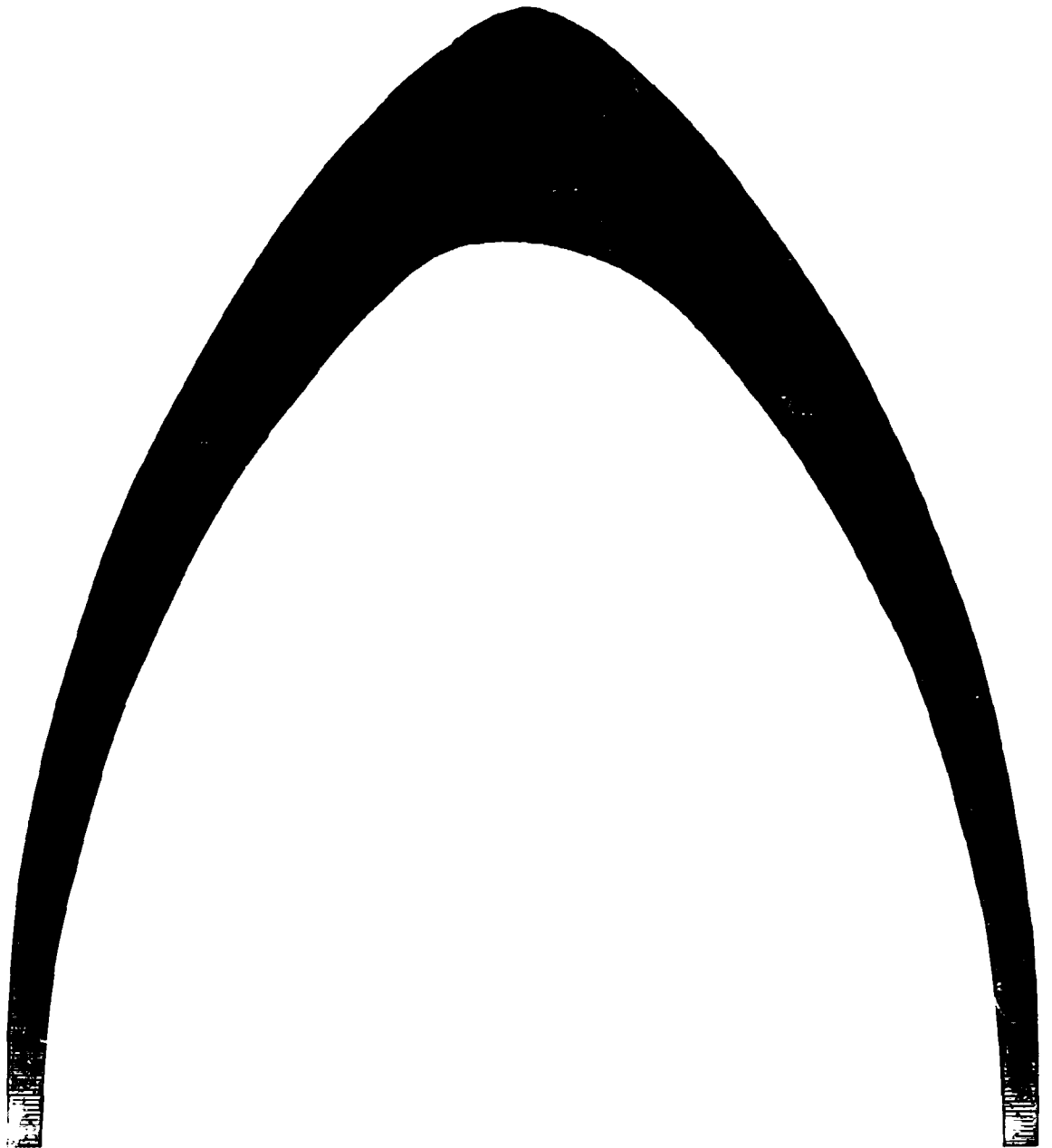
PHD-55564

FIGURE 16

March 1959

SAMPLE WARHEAD NO. 3  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD EX 29 MOD 0 AISI 4340  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



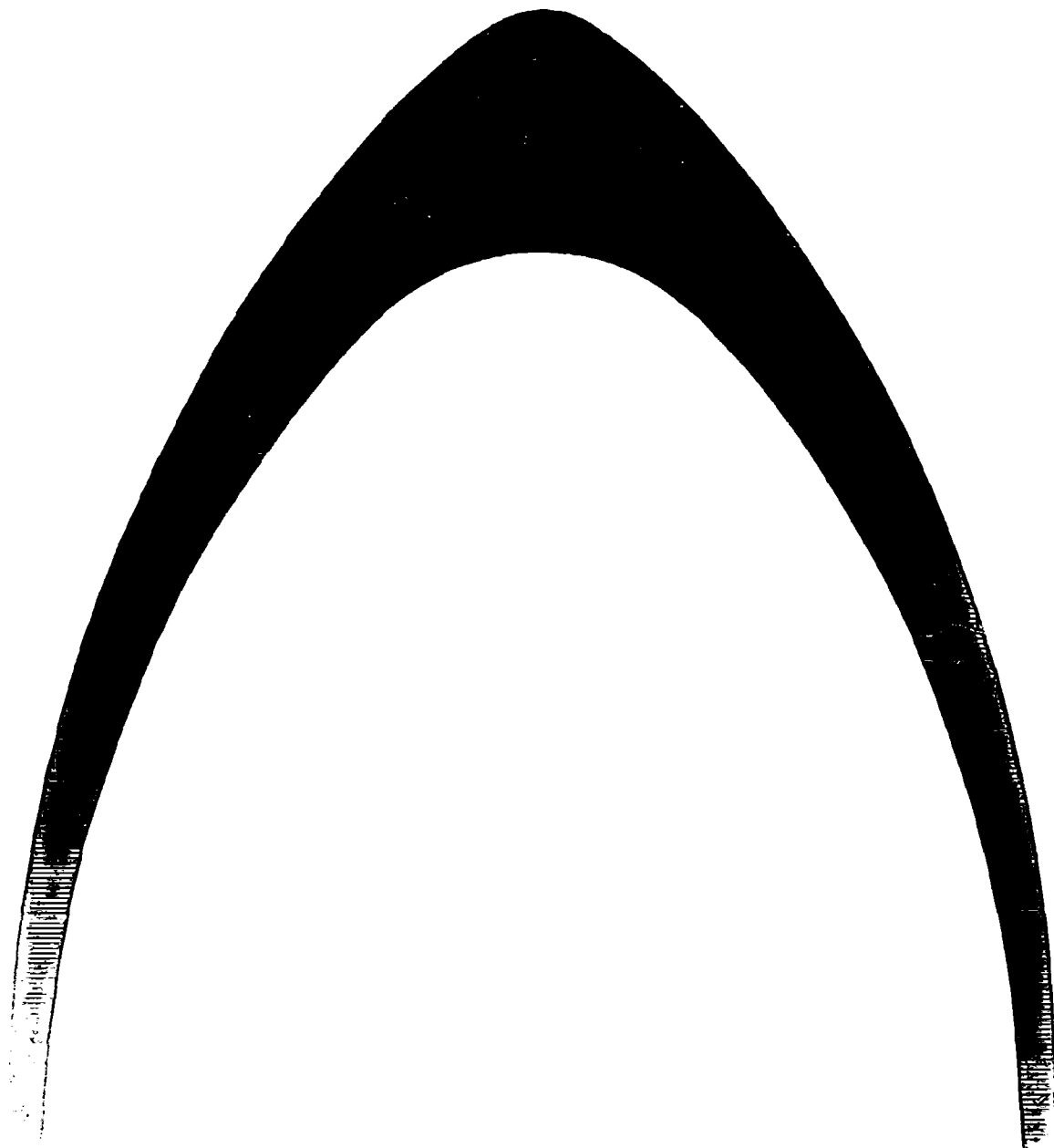
PHD-55565

FIGURE 17

April 1959

SAMPLE WARHEAD NO. 4  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD EX 29 MOD 1 AISI 4140  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



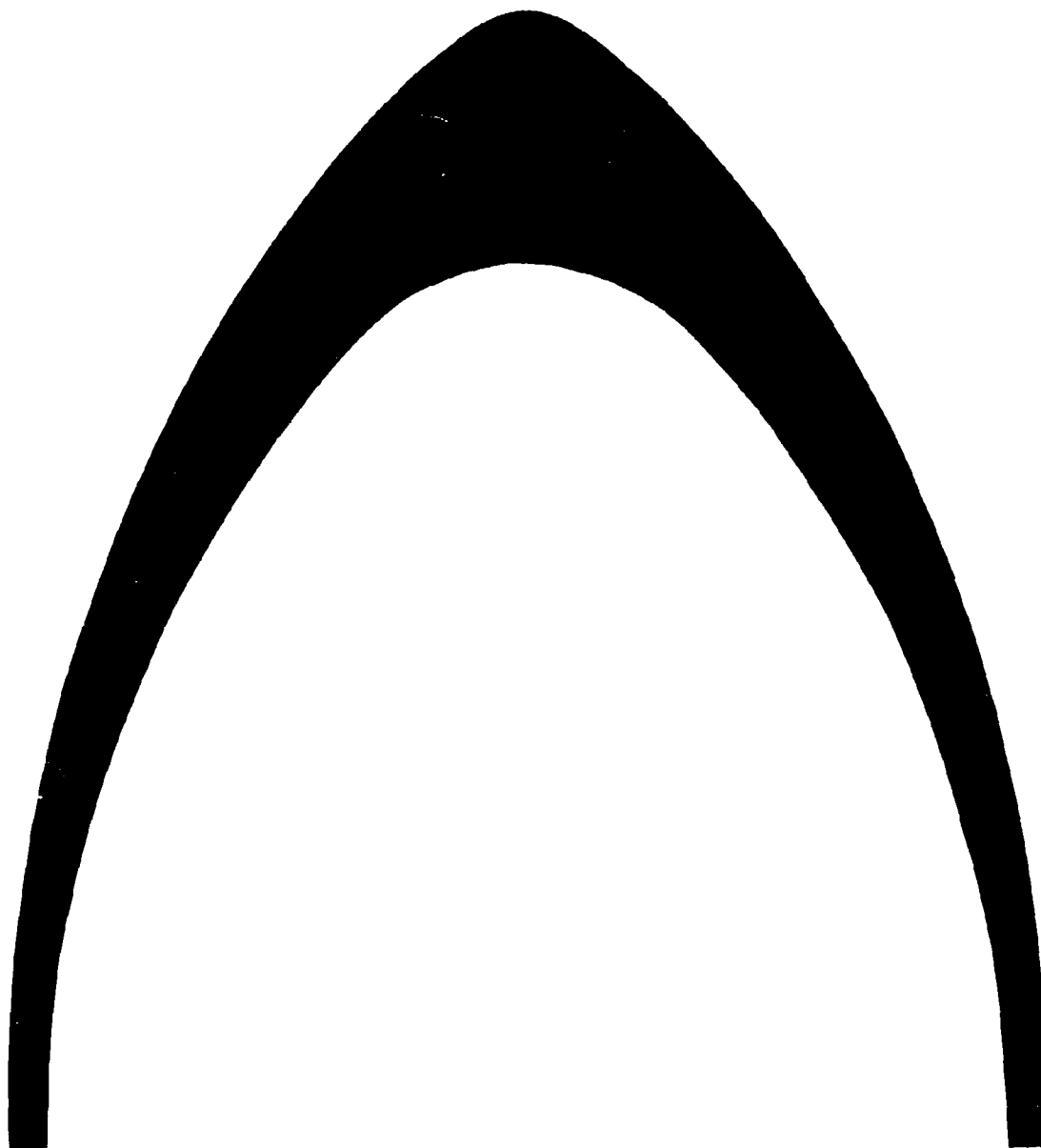
PHD-55566

FIGURE 18

June 1959

SAMPLE WARHEAD NO. 5  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD EX 29 MOD 3 AISI 4340  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



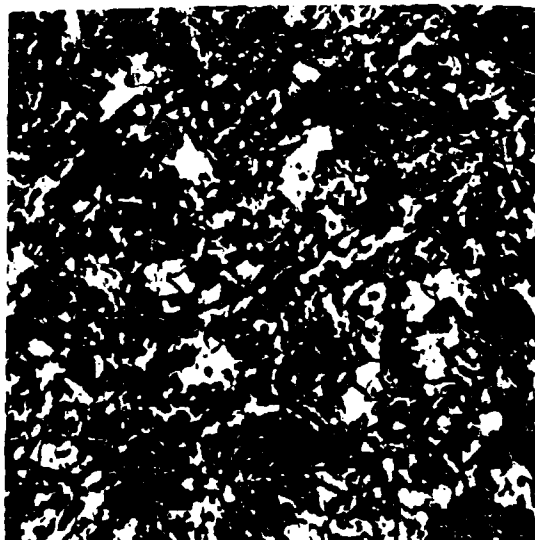
PHD-55567

FIGURE 19

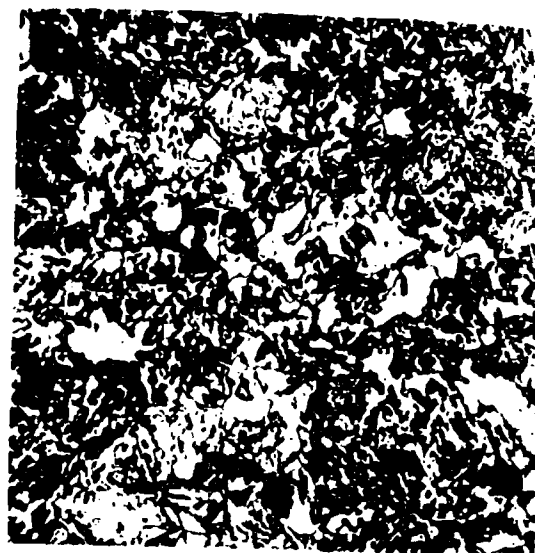
June 1959

SAMPLE WARHEAD NO. 6  
MACROSECTION OF OGIVE FROM BULLPUP WARHEAD EX 29 MOD 3 AISI 4340  
Etch: 50% Hydrochloric Acid

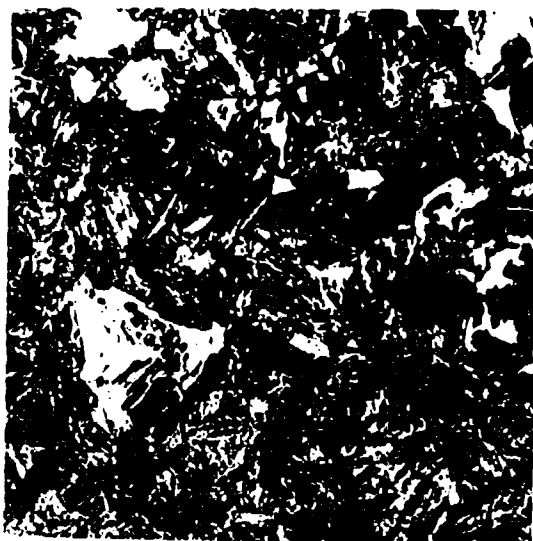
CONFIDENTIAL



A



B



C



D

PL 1000

FIGURE 10

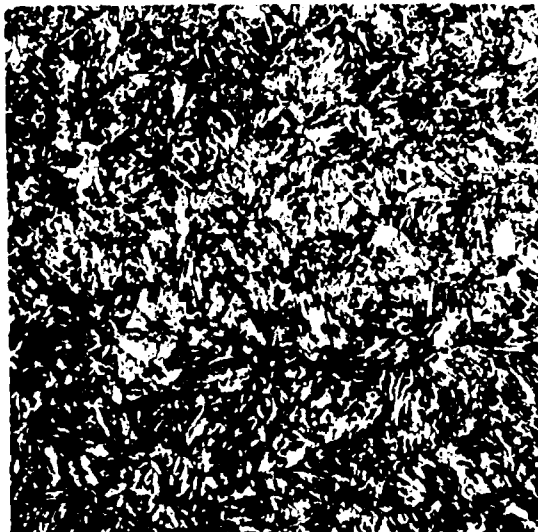
SAMPLE AREA NO. 1  
PHOTO MICROGRAPHS OF BULLY AREA NO. 1000

LOCATIONS A, B, C AND D IN FIGURE 5

tech: Vital

magnification: 1000x

CD. FIBER LAB



A

B

100-54507

FIGURE 21

SAMPLE CARTRIDGE NO. 2  
PHOTOGRAPHIC OF BULLETPH CARTRIDGE IN 29 LOD O AISI 4340

LOCATIONS A, B, C AND D IN FIGURE 5

Etch: Nital

Magnification: 1000X

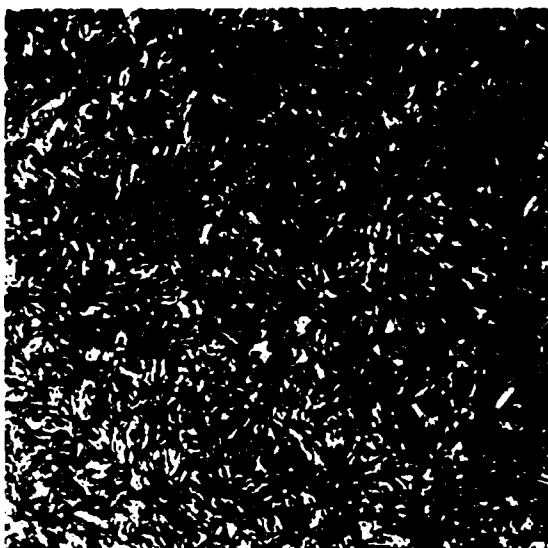
CONFIDENTIAL



A



B



C



D

FND-55570

FIGURE 22

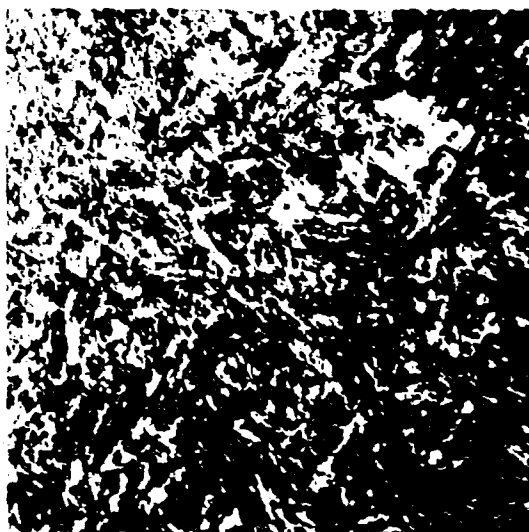
Sample Warhead No. 1a  
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140 REHEAT-  
TREATED

Locations A, B, C and D in Figure 5

Etch. Nital

Magnification: 1000X

CONFIDENTIAL



A



B



C



D

PHD-55571

FIGURE 23

SAMPLE WARHEAD NO. 3

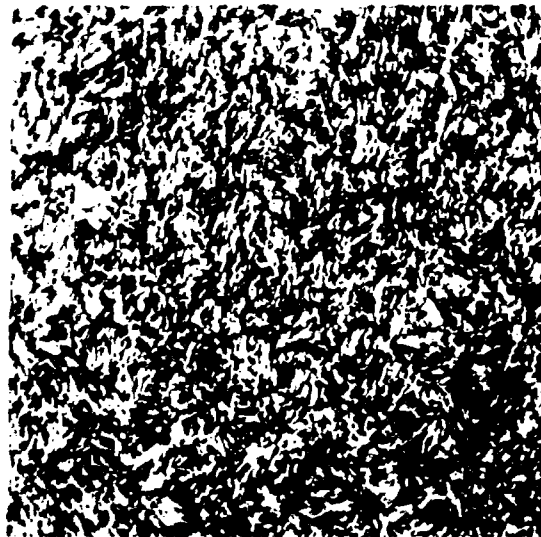
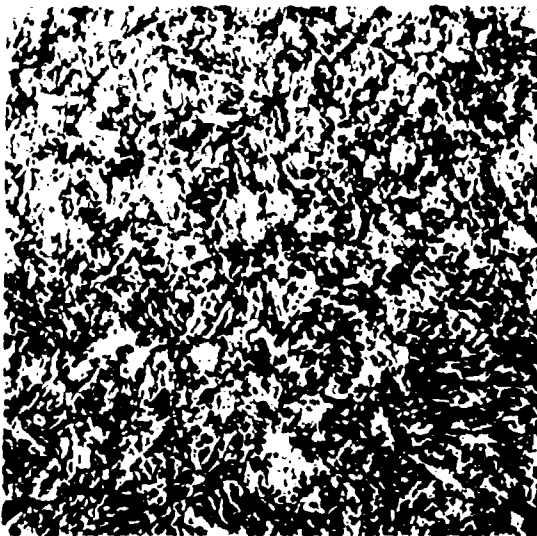
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 0 AISI 4340

LOCATIONS A, B, C AND D IN FIGURE 5

Etch: Nital

Magnification: 1000X

CONFIDENTIAL



C

D

PHD-55572

FIGURE 24

SAMPLE WARHEAD NO. 4  
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140

LOCATIONS A, B, C AND D IN FIGURE 5

Etch: Nital

Magnification: 1000X

CONFIDENTIAL



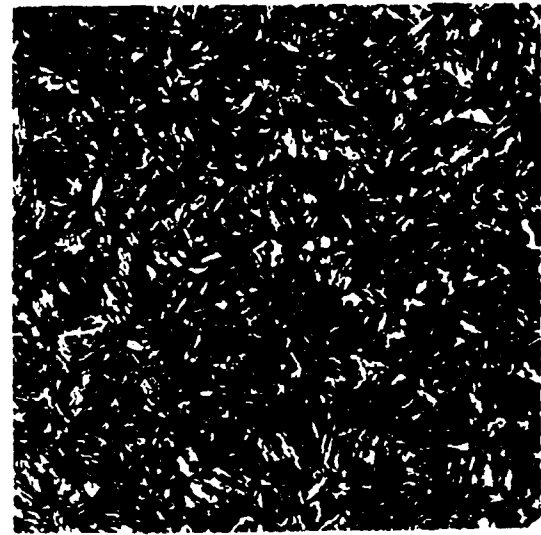
A



B



C



D

FND-55573

FIGURE 25

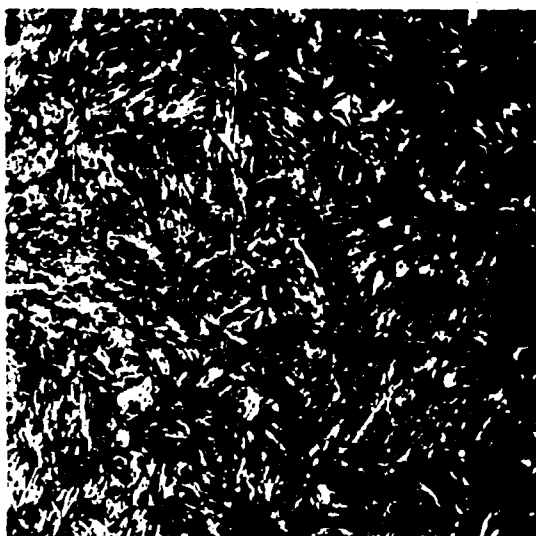
SAMPLE WARHEAD NO. 5  
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

LOCATIONS A, B, C AND D IN FIGURE 5

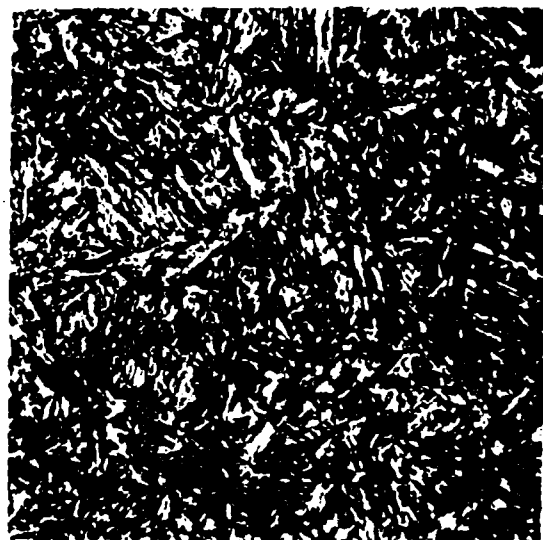
Etch: Nitral

Magnification: 1000X

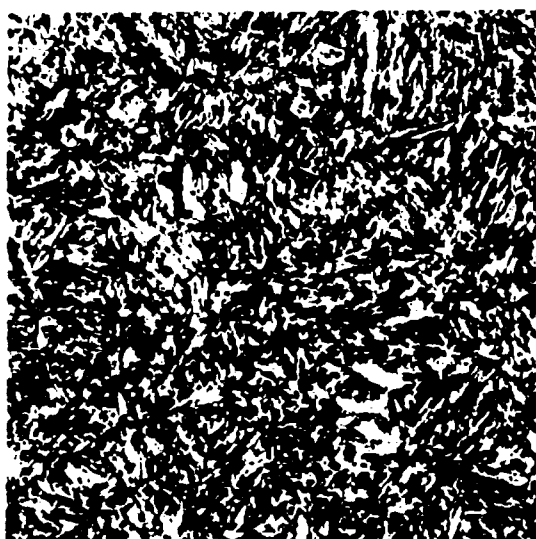
CONFIDENTIAL



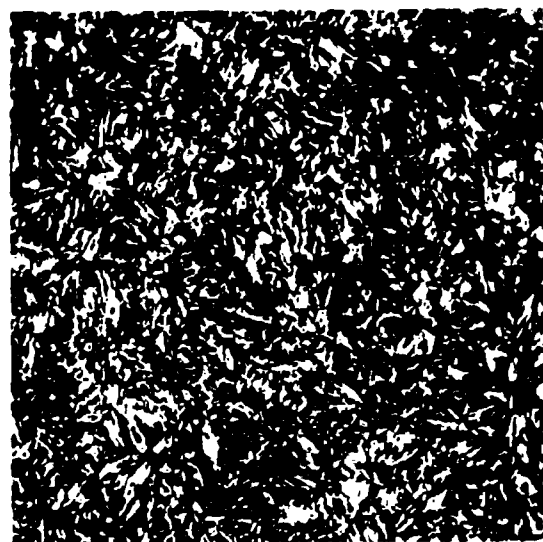
A



B



C



D

W-55574

FIGURE 26

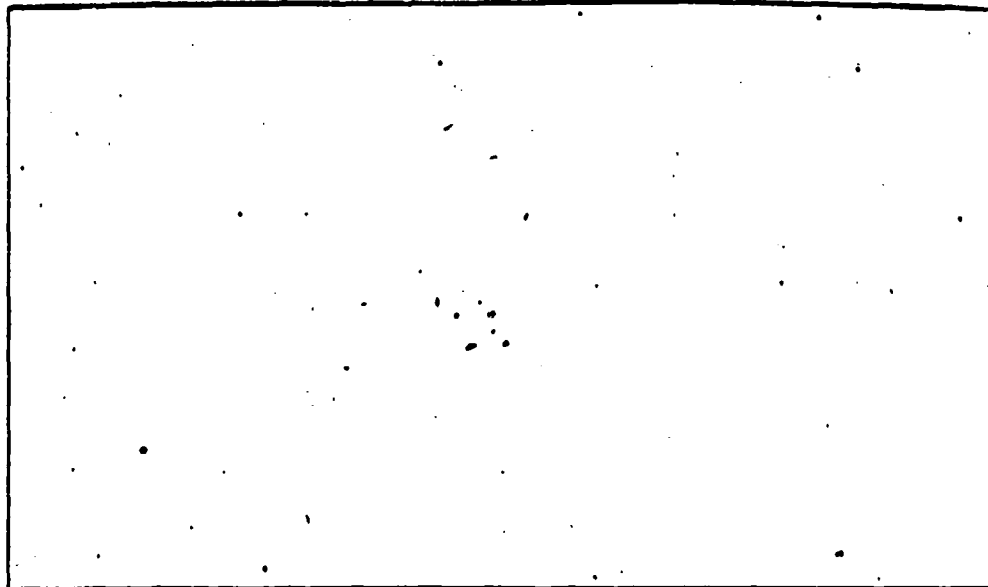
SAMPLE NUMBER: 1000  
PHOTOGRAPHED BY: TULLPUP WAREHEAD: 29 JOB 3 KISI 4310

LOCATION: A, B, C AND D IN FIGURE 5

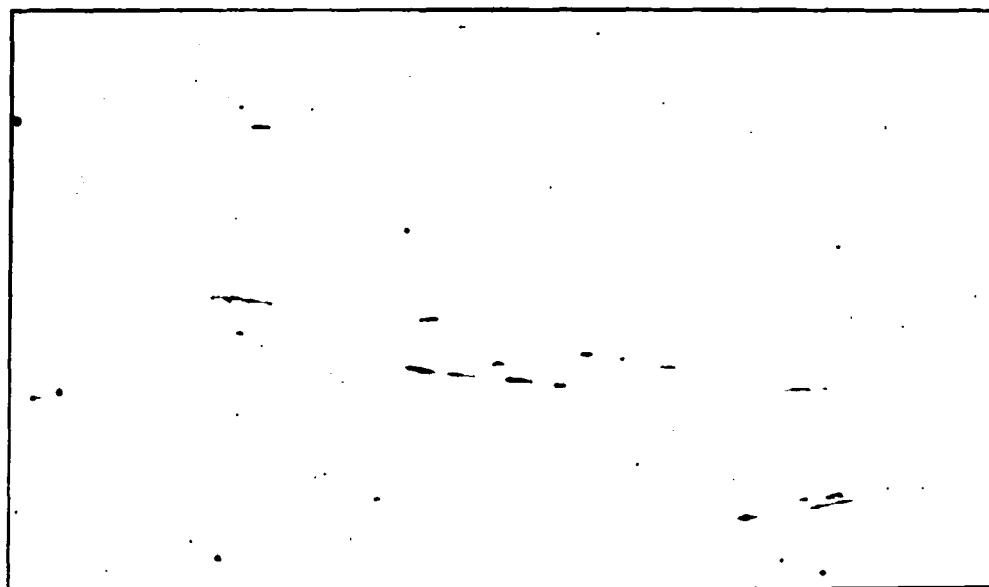
Etch: Hival

Magnification: 1000X

CONFIDENTIAL



A



D

PHD-55575

FIGURE 27

Sample Warhead No. 1

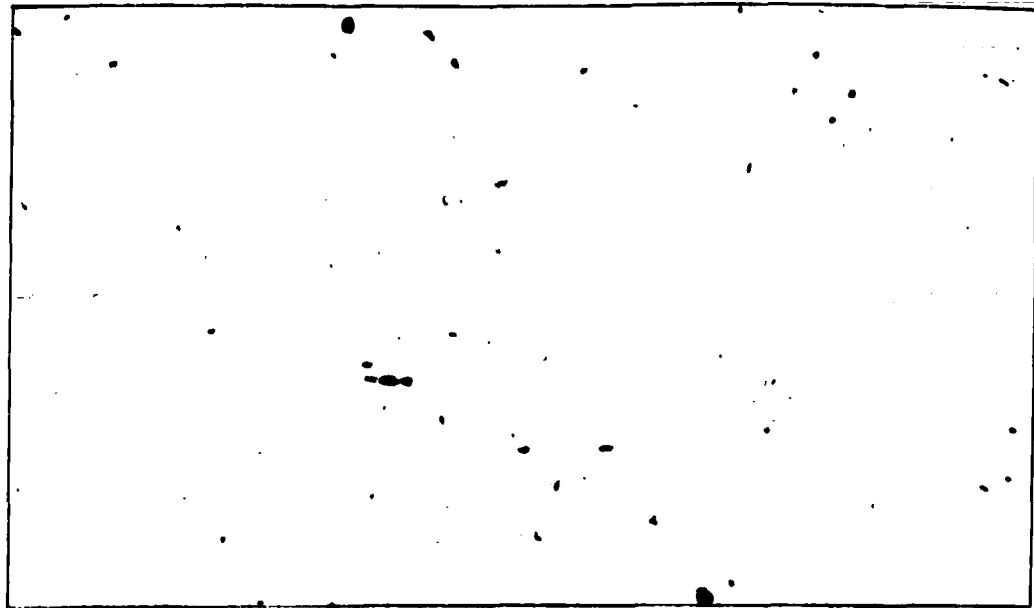
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140

Location A and D in Figure 5

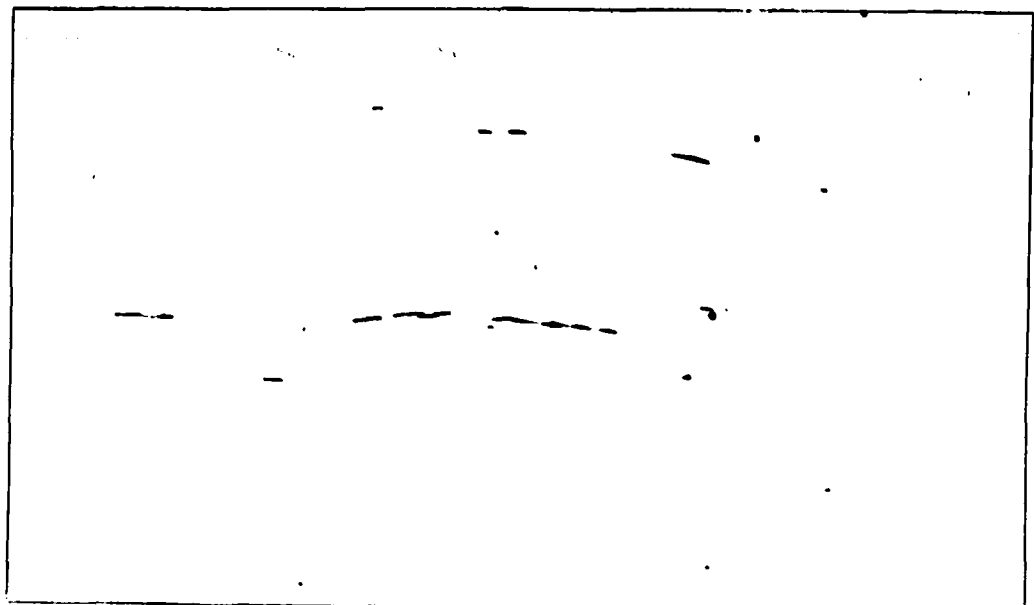
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55576

FIGURE 28

Sample Warhead No. 2

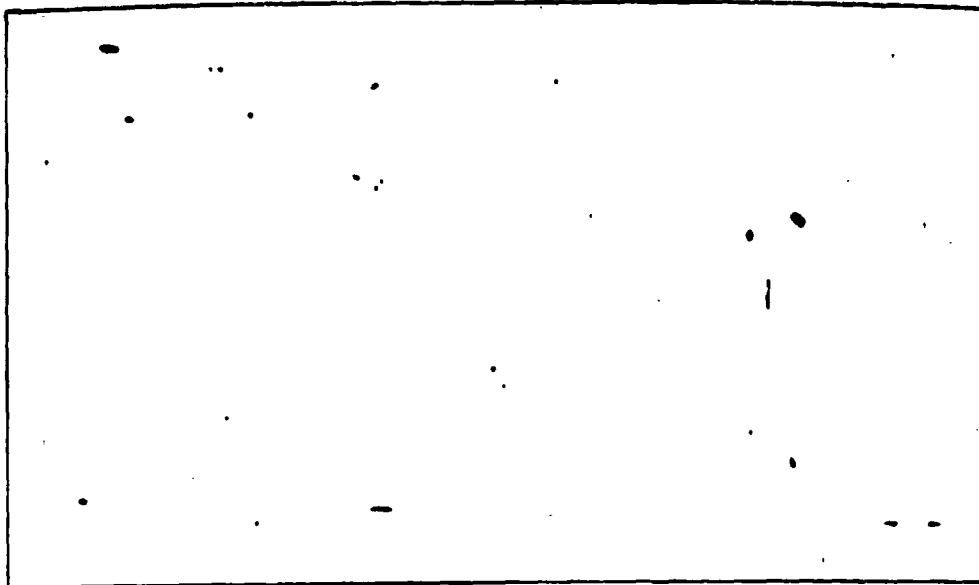
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD C AISI 4340

Locations A and D in Figure 5

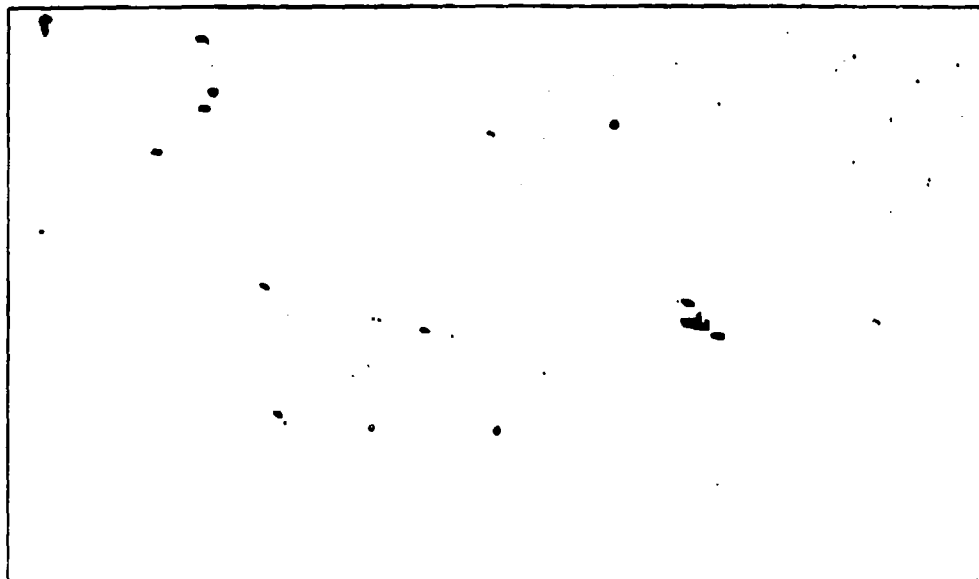
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55577

FIGURE 29

Sample Warhead No. 1a

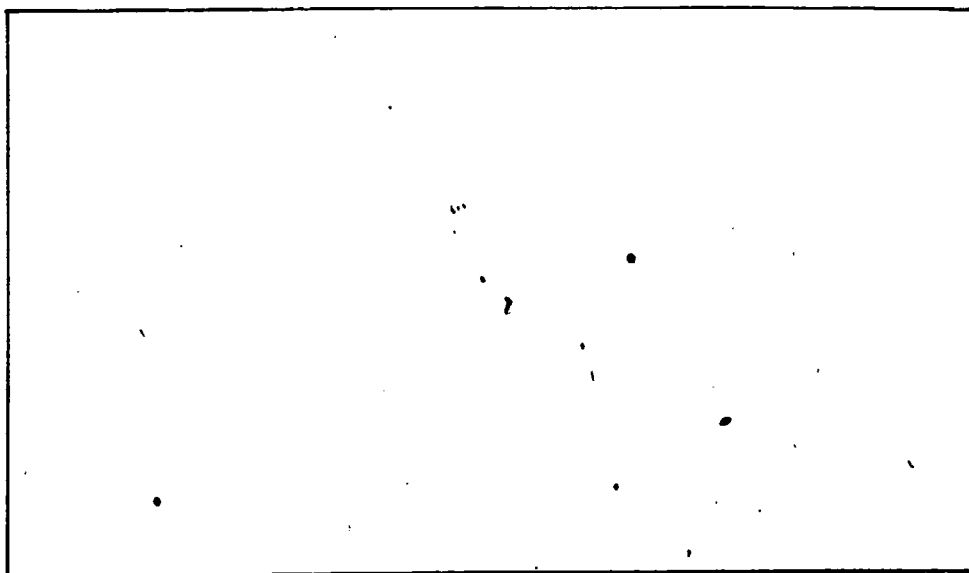
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140 REHEAT TREATED

Locations A and D in Figure 5

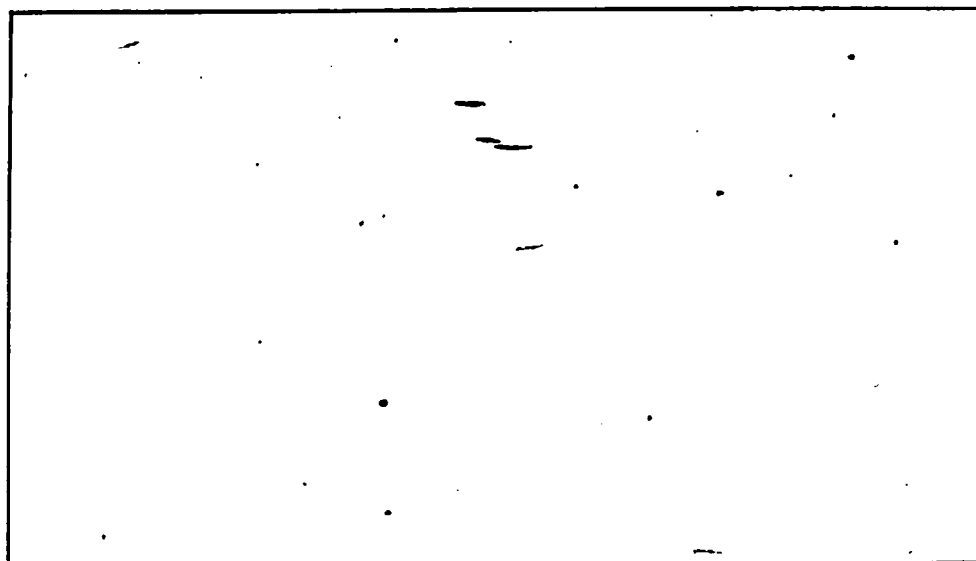
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55578

FIGURE 30

Sample Warhead No. 3

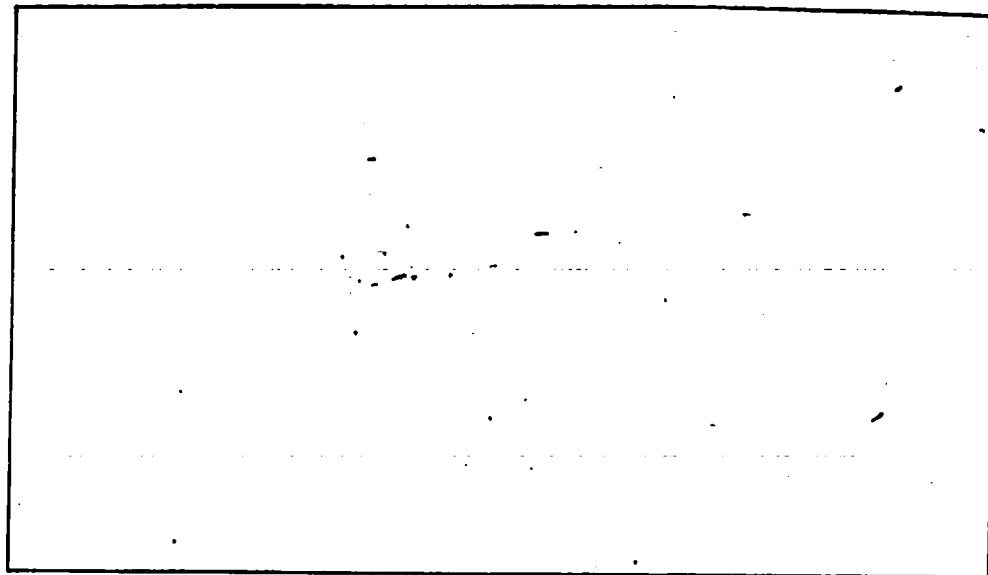
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 0 AISI 4340

Location A and D in Figure 5

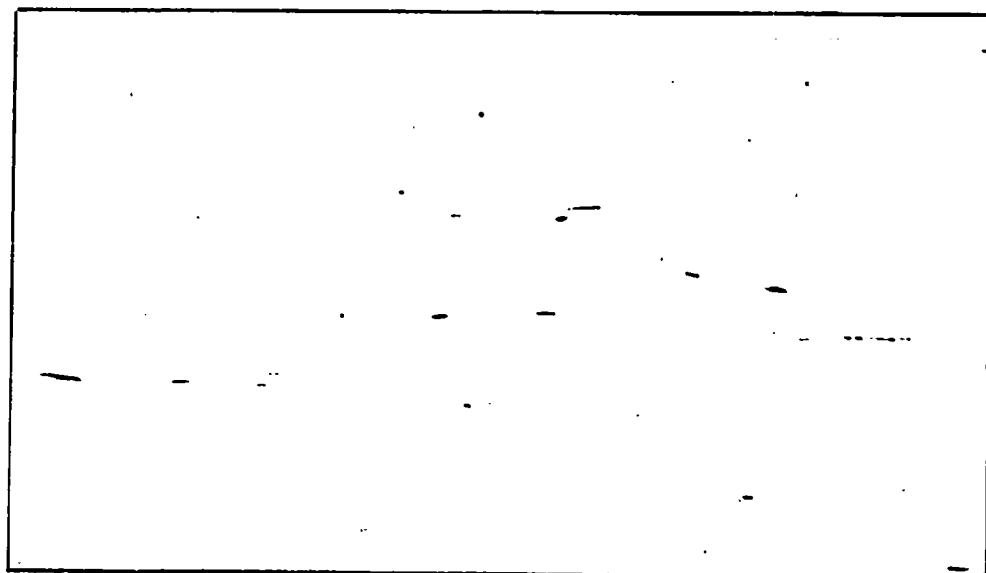
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55579

FIGURE 31

Sample Warhead No. 4

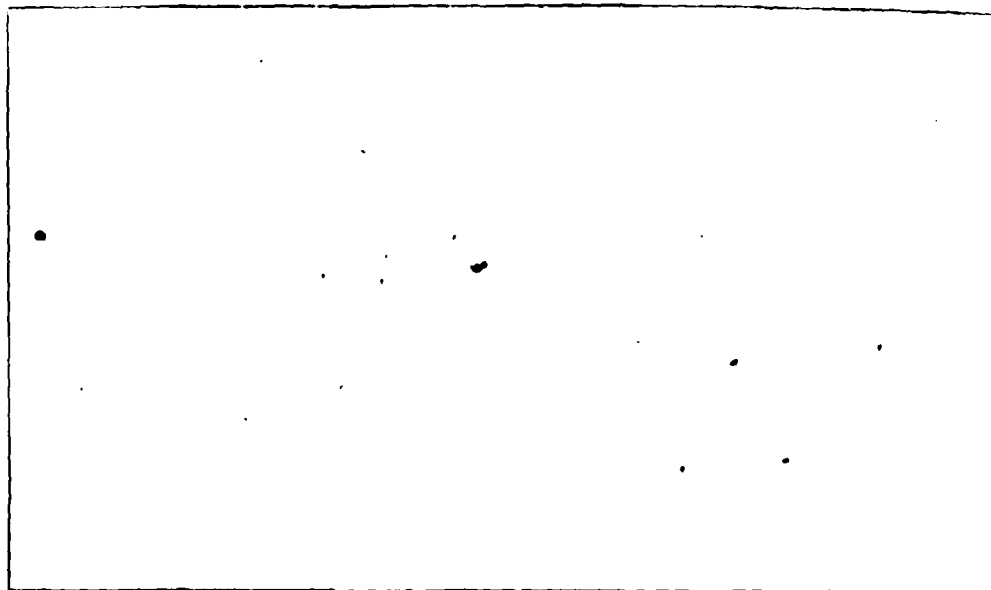
PHOTOMICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140

Location A and D in Figure 5

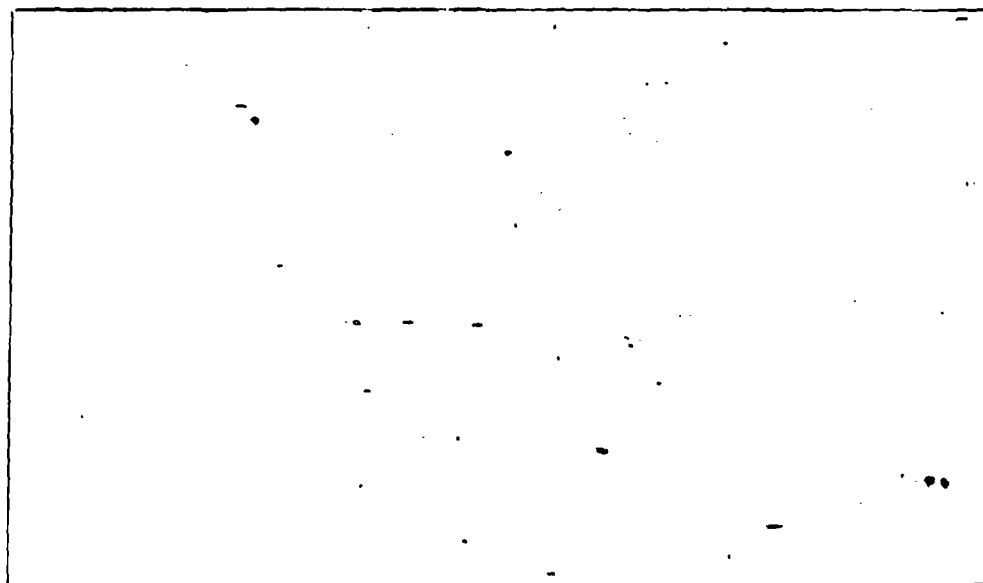
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55580

FIGURE 32

Sample warhead No. 5

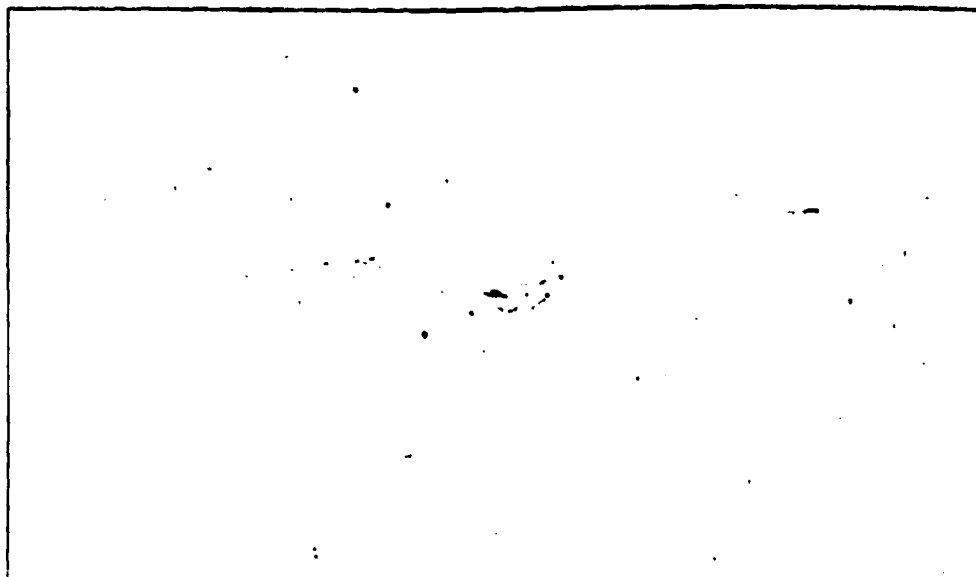
PHOTO MICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

Location A and D in Figure 5

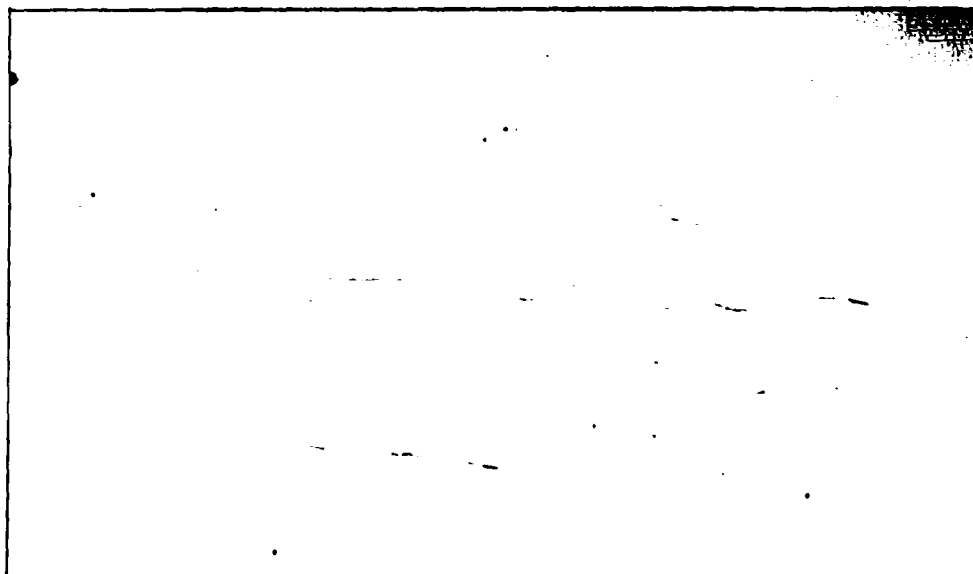
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55561

FIGURE 33

Sample Warhead No. 6

PHOTO: MICROGRAPHS OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

Location A and D in Figure 5

As Polished

Magnification: 100X

CONFIDENTIAL



PHD-55592

FIGURE 34

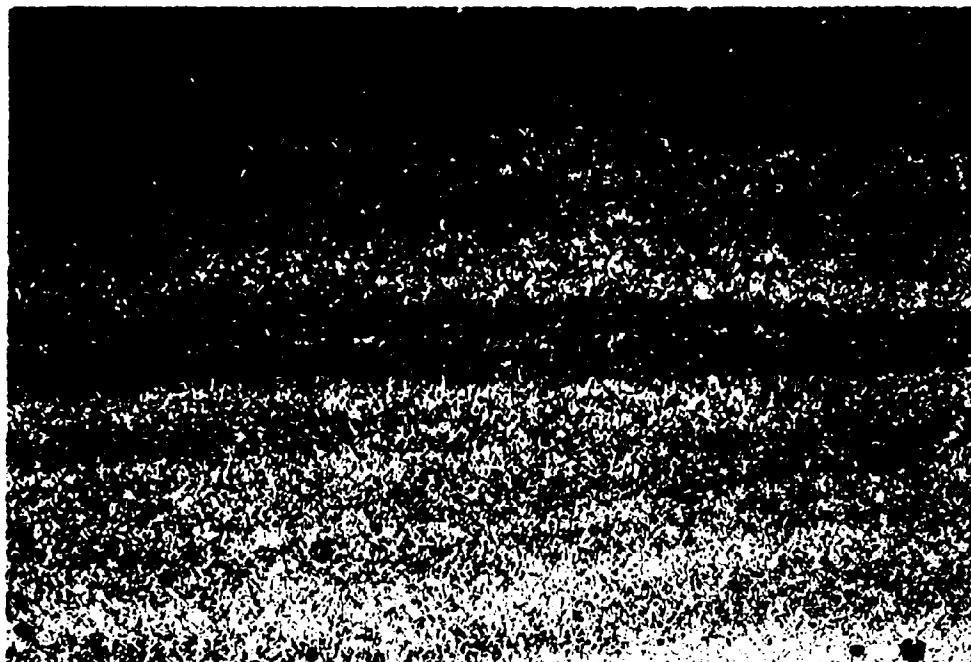
Sample Warhead No. 1  
PHOTOMICROGRAPH OF BULLPUP WARHEAD EX 29 MOD 1 AISI 4140

Location C in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



PHD-55593

FIGURE 35

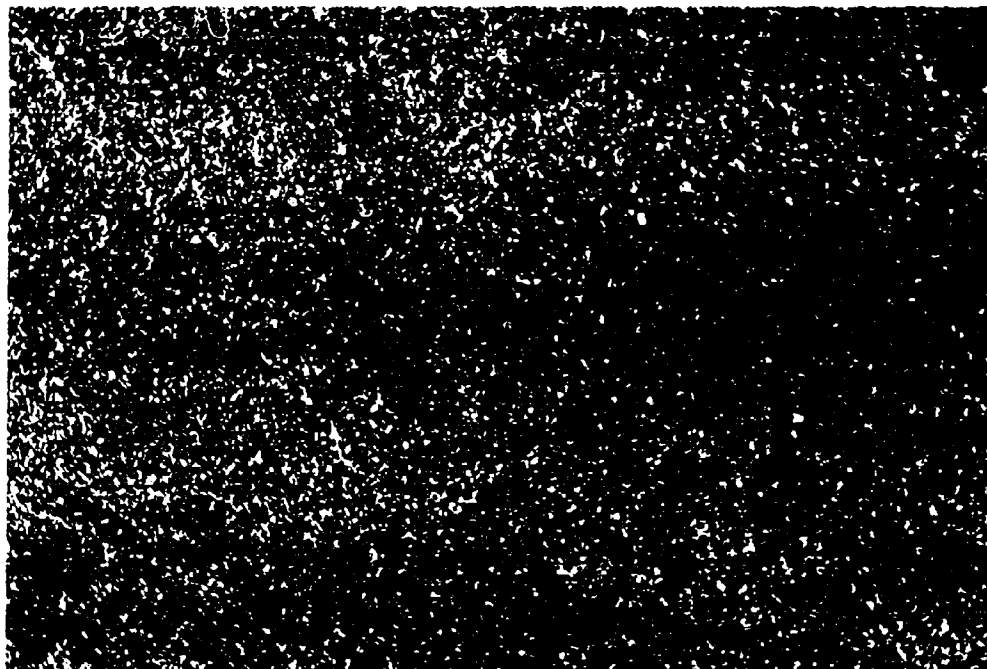
Sample Warhead No. 2  
PHOTOMICROGRAPH OF BULLPUP WARHEAD EX 29 MOD 0 AISI 4340

Location C in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



PHD-55594

FIGURE 36

Sample Warhead No. 1a

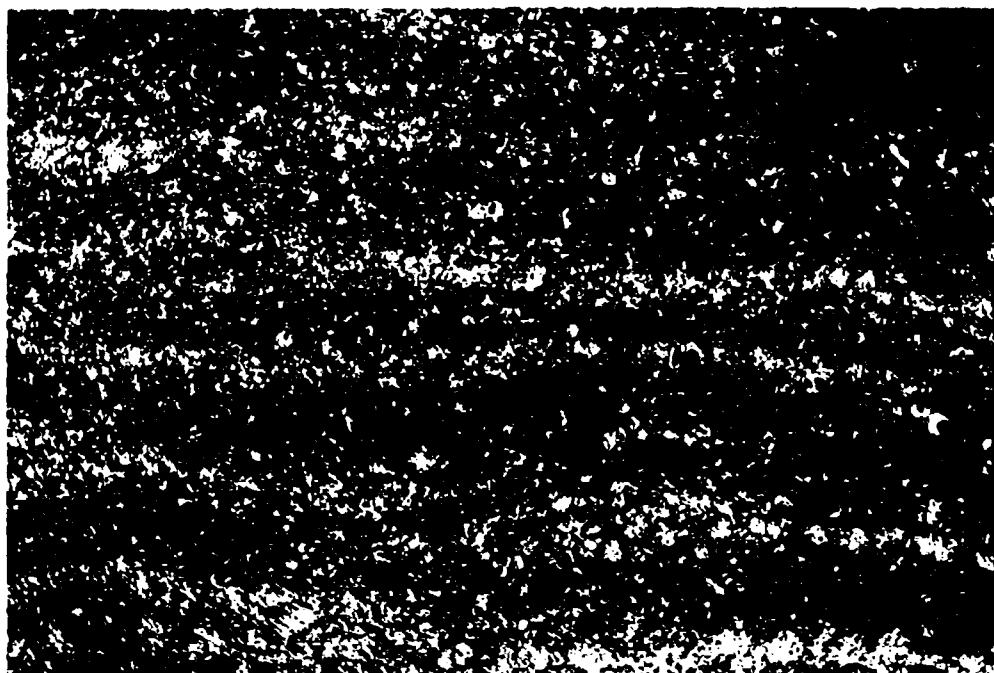
PHOTOMICROGRAPH OF BULLETPROOF WARHEAD EX 29 MOD 1 AISI 4140 RELAT-TREATED

Location C in Figure 5

Stain: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



PHD-55595

FIGURE 37

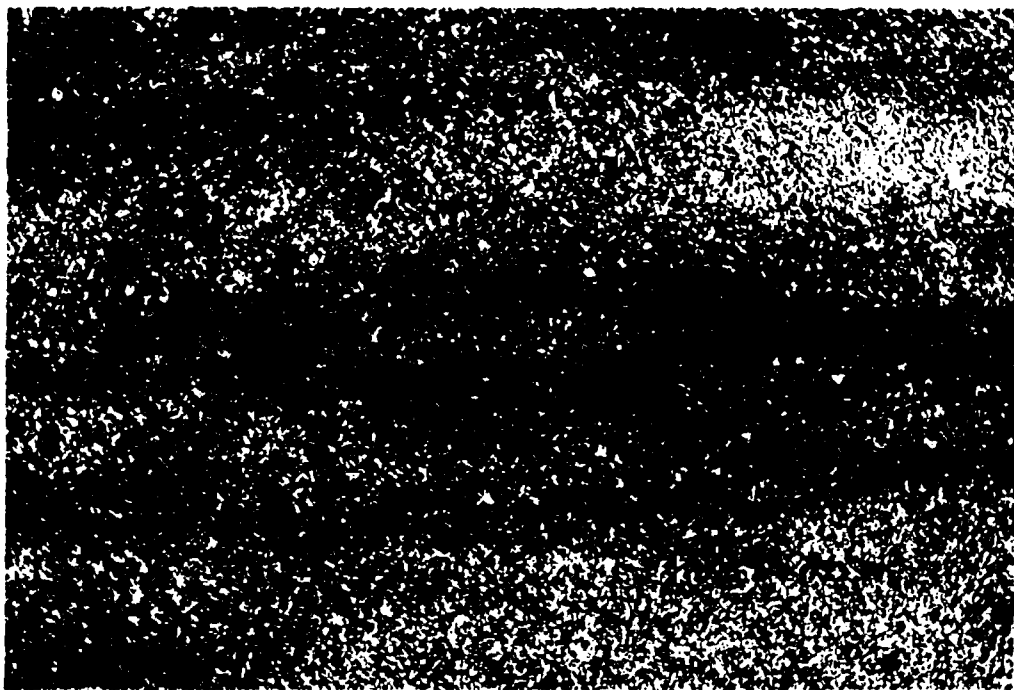
Sample Warhead No. 3  
PHOTOMICROGRAPH OF BULLPUP WARHEAD EX 29 MOD O AISI 4340

Location C in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



AFD-55596

FIGURE 38

Sample Warhead No. 4

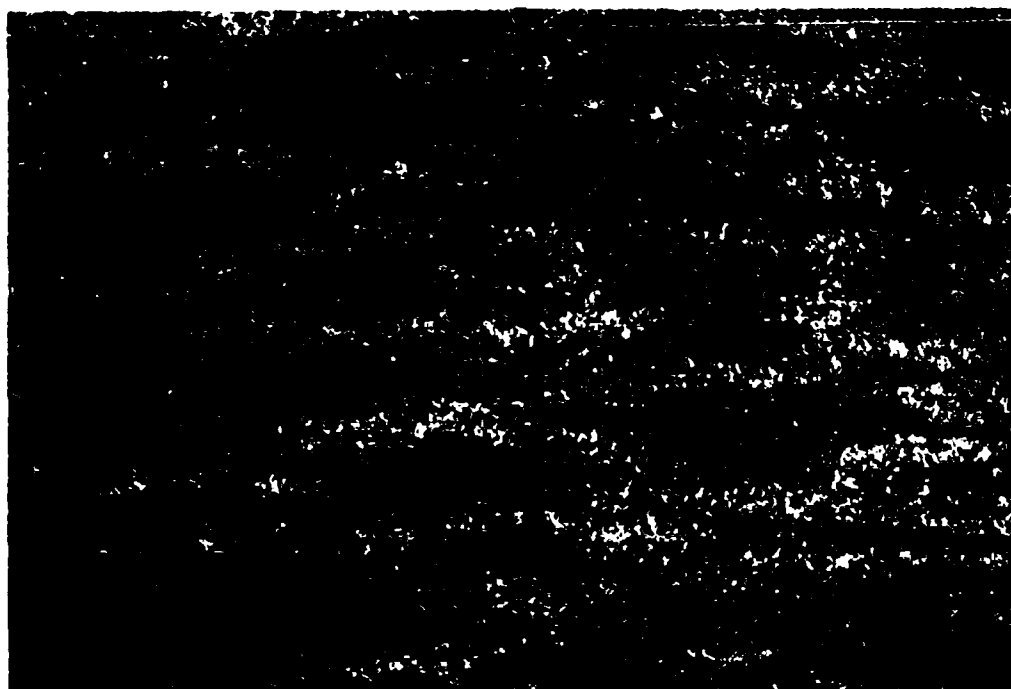
PHOTOMICROGRAPH OF BULLPUP WARHEAD EX 29 LOC 1 AIBI 4140

Location C in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



PHD-55597

FIGURE 39

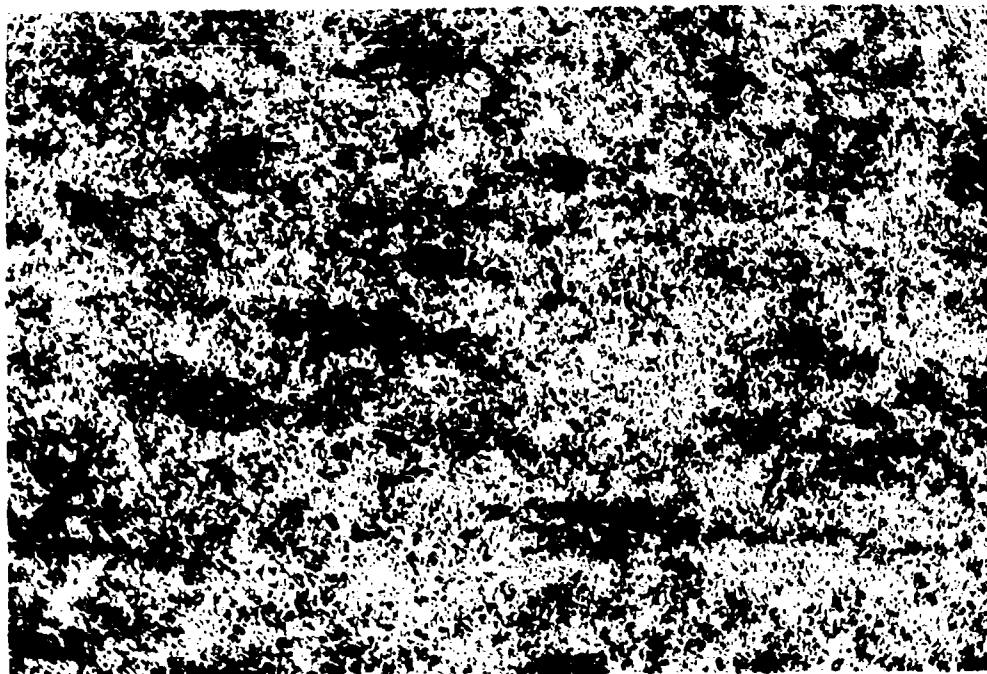
Sample Warhead No. 5  
PHOTOMICROGRAPH OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

Location C in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

CONFIDENTIAL



PHD-55598

FIGURE 40

Sample Warhead No. 6

PHOTOMICROGRAPH OF BULLETP WARHEAD EX 29 MOD 3 AISI 4340

Location C in Figure 5

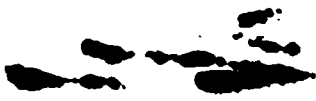
Etch: Zerkiran Chlorine

Magnification: 100X

CONFIDENTIAL



(A) Warhead Serial No. 139A From Lot 103



(B) Warhead Serial No. 103A From Lot 102

PHD-55617

FIGURE 41

PHOTOMICROGRAPHS TAKEN OF BULLPUP WARHEADS EX 29 MOD 3 FROM PRODUCTION LOTS

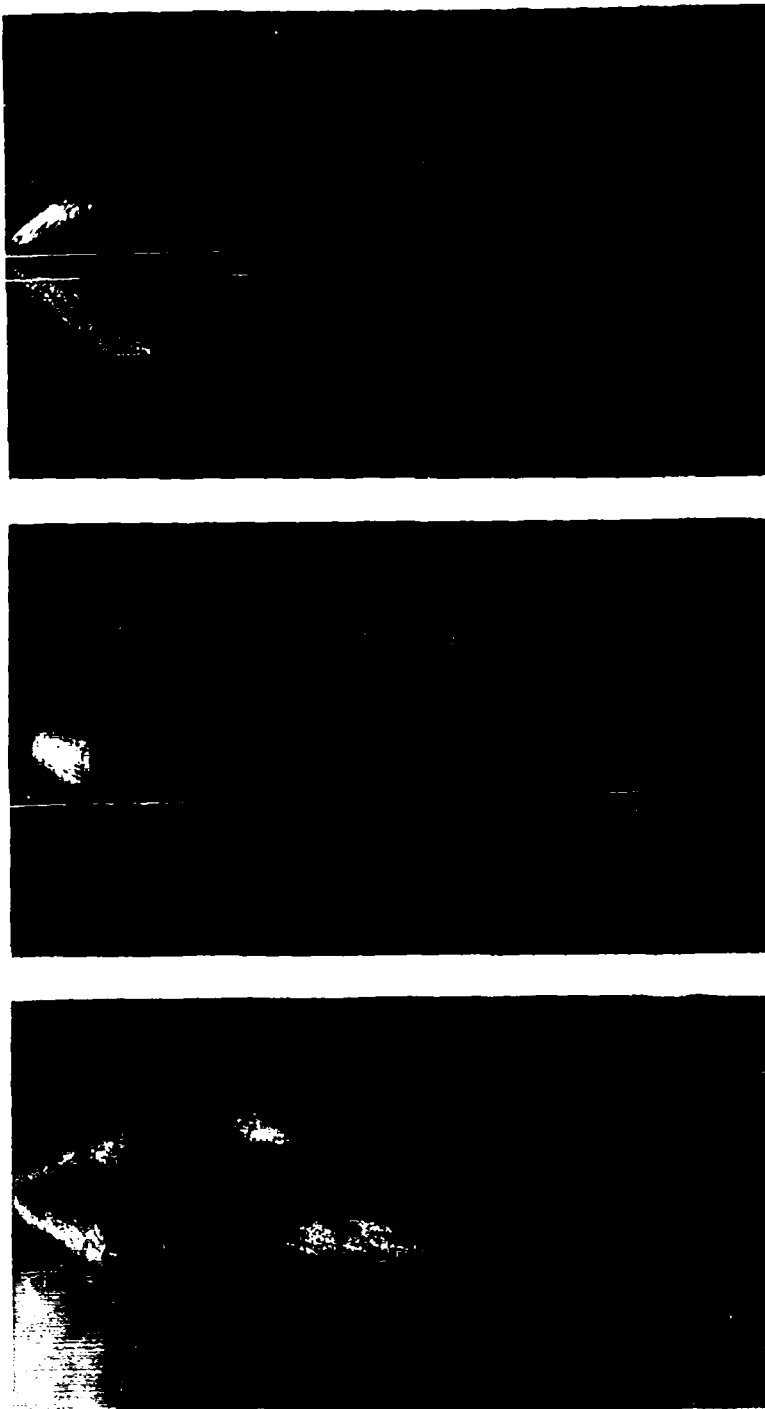
Location D in Figure 5

As Polished

AISI 4340 STEEL

Magnification: 100X

CONFIDENTIAL

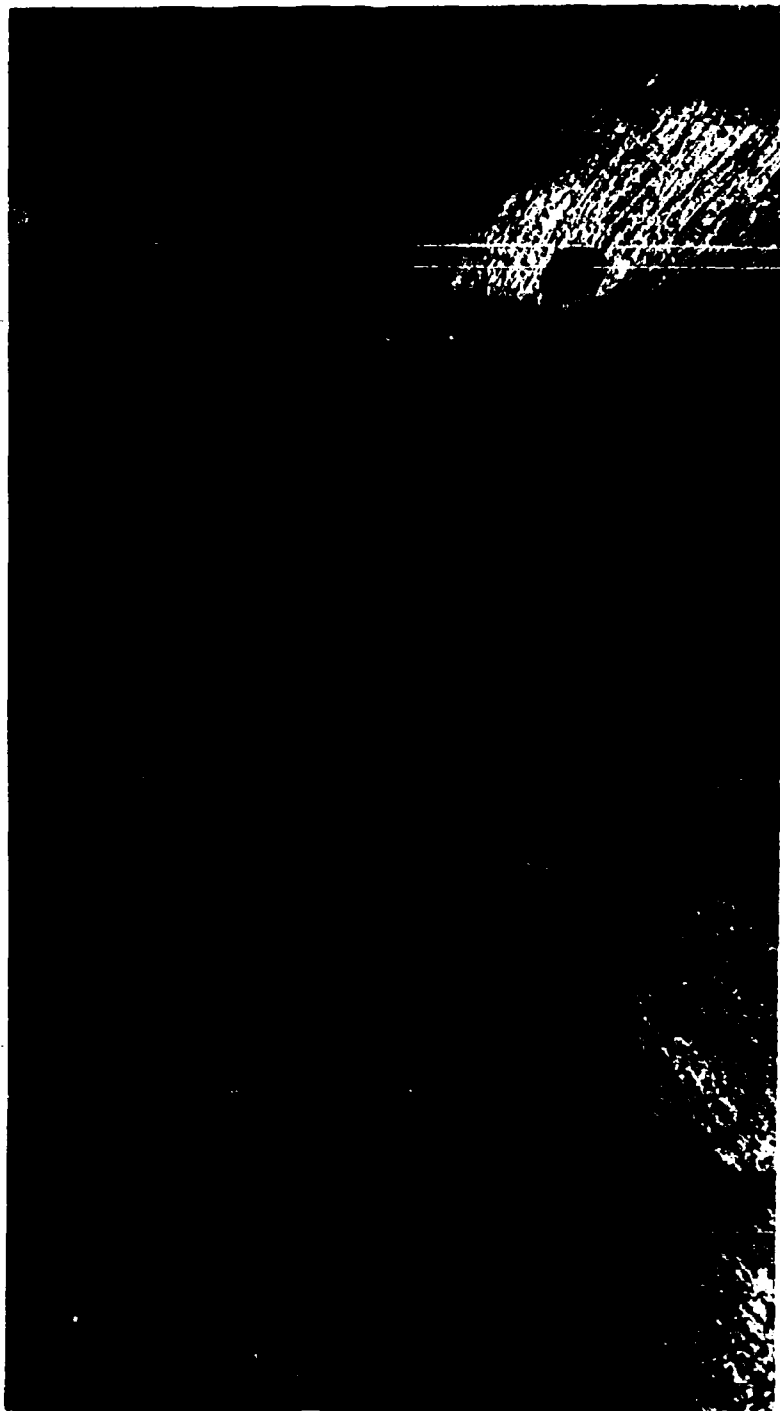


PHD-55615

FIGURE 42

INERT LOADED PILOT LOT EX 29 MOD 3 WARHEAD SERIAL NO. 6 AFTER BALLISTIC TEST AGAINST 1-1/4 INCH  
STS AT NORMAL OBLIQUITY AT STRIKING VELOCITY OF 1777 FT/SEC 3° YAW  
AISI 4340 STEEL

CONFIDENTIAL

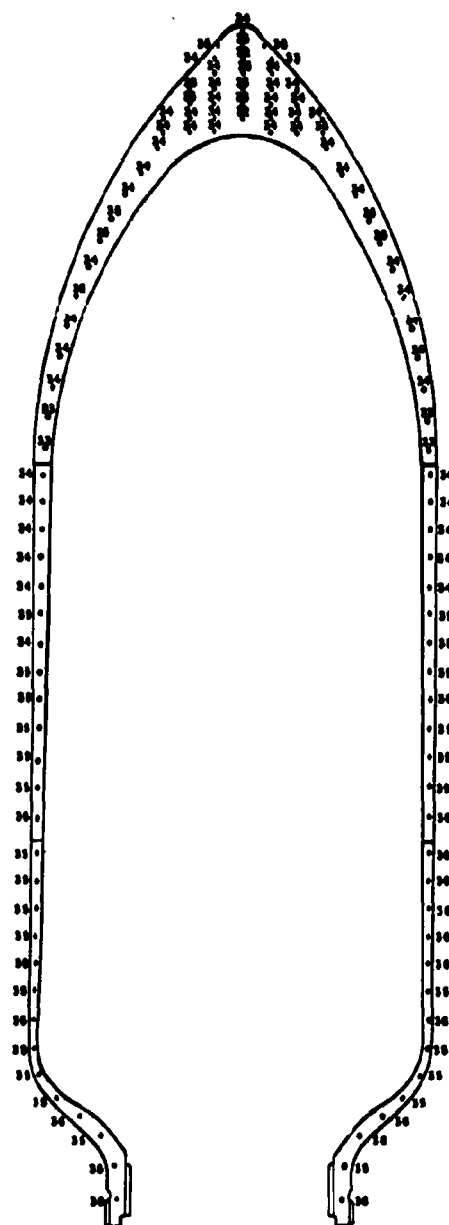
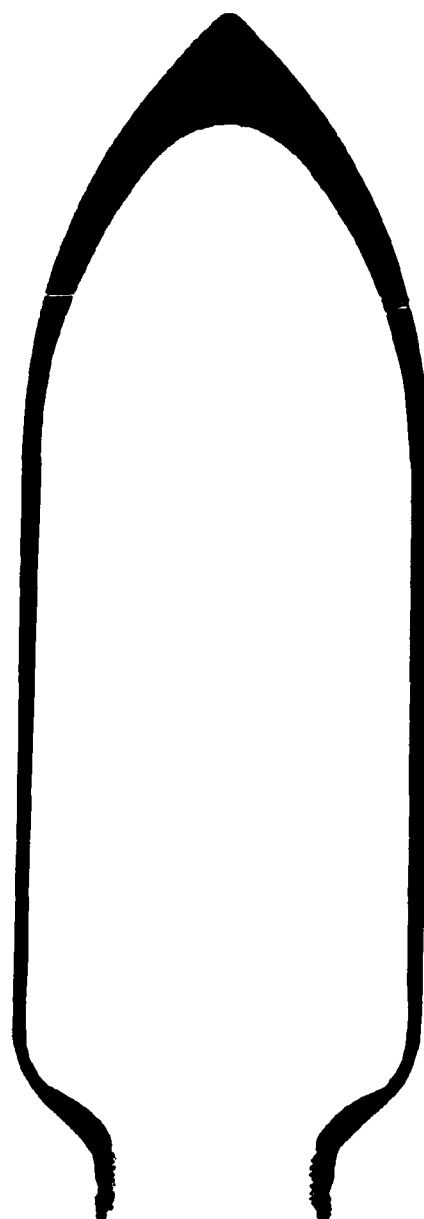


PHD-55616

FIGURE 43

TOP VIEW OF NOSE OF WARHEAD IN FIGURE 50

CONFIDENTIAL



PHD-55610

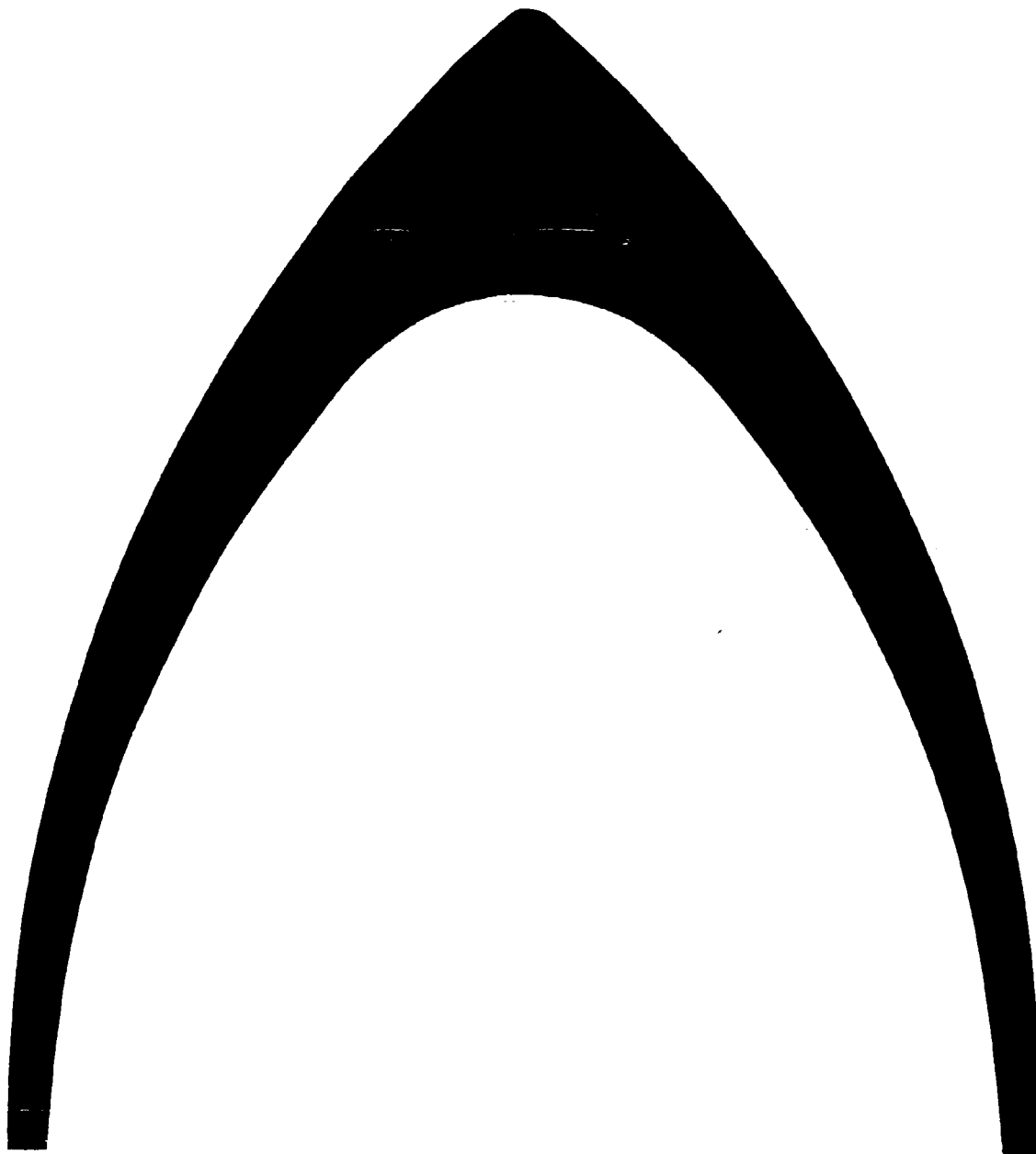
FIGURE 44

January 1960

PILOT LOT, SAMPLE WARHEAD, SERIAL NO. 4  
HARDNESS DISTRIBUTION AND MACROSECTION OF BULLPUP WARHEAD  
EX 29 MOD 3 AISI 4340

Hardness Values: Rockwell C Scale  
Etch: 50% Hydrochloric Acid

CONFIDENTIAL



PHD-55611

FIGURE 45

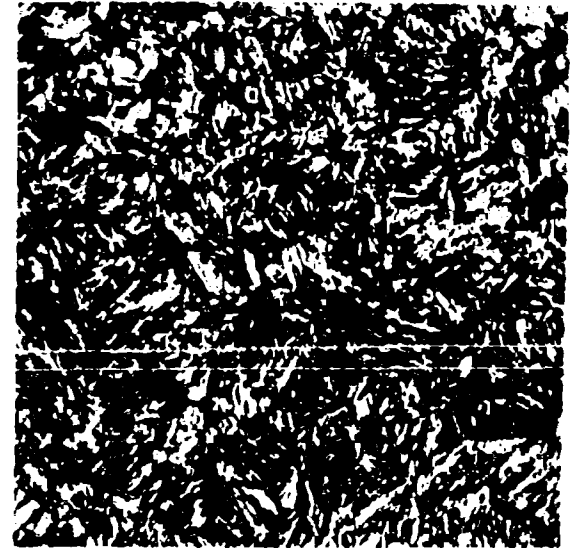
PILOT LOT SAMPLE WARHEAD, SERIAL NO. 4 MACROSECTION OF OGIVE  
FROM BULLPUP WARHEAD EX 29 MOD 3-AISI 4340

Etch: 50% Hydrochloric Acid

CONFIDENTIAL



A



B



C



D

10-30-61

FIGURE 4

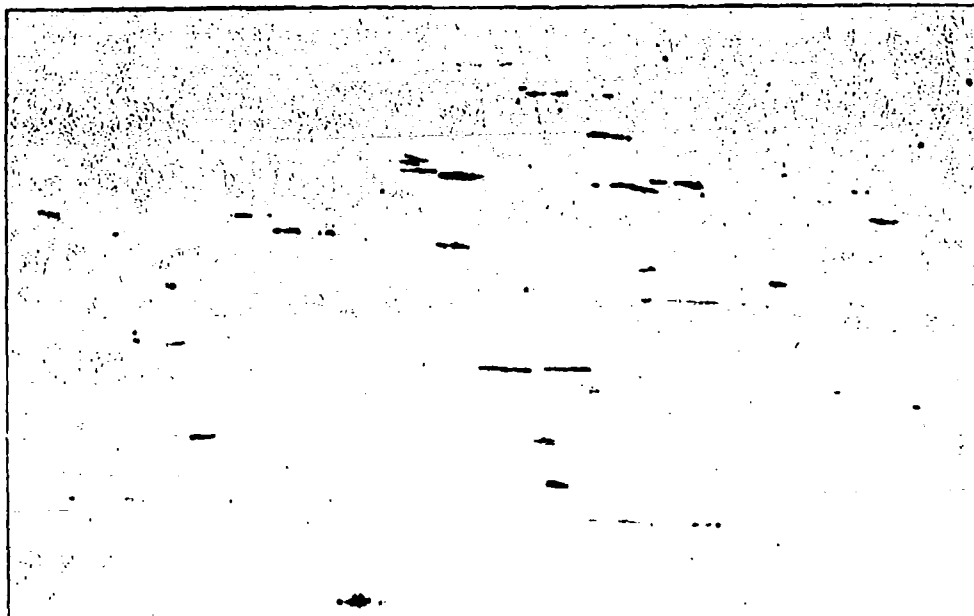
THIS IS A PHOTOGRAPH OF A SPECIMEN OF THE  
OF THE SPECIES OF THE ORDER OF THE ORDER

LOCATION: ...

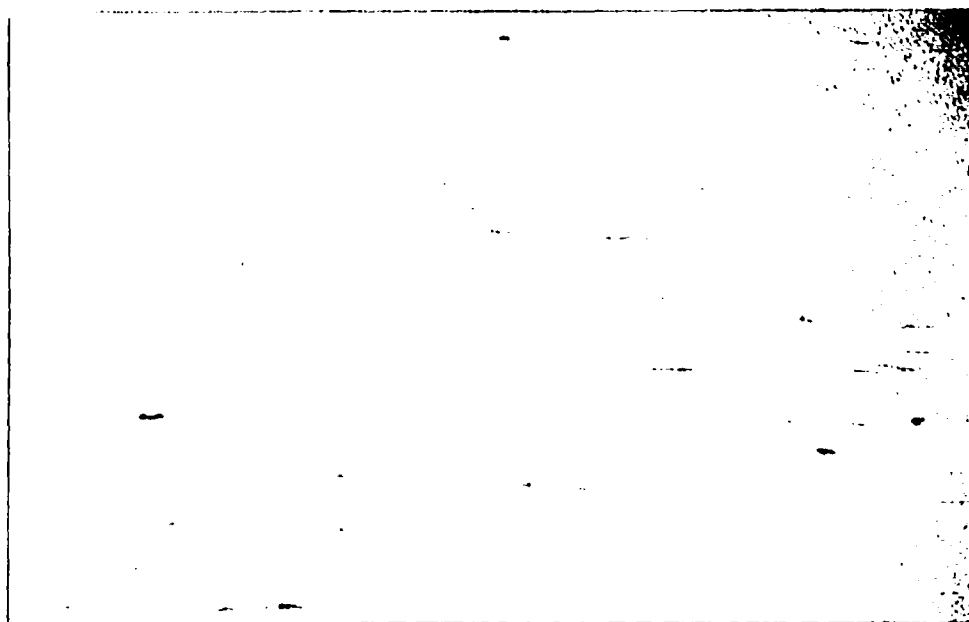
... ..

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A



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FIGURE 47

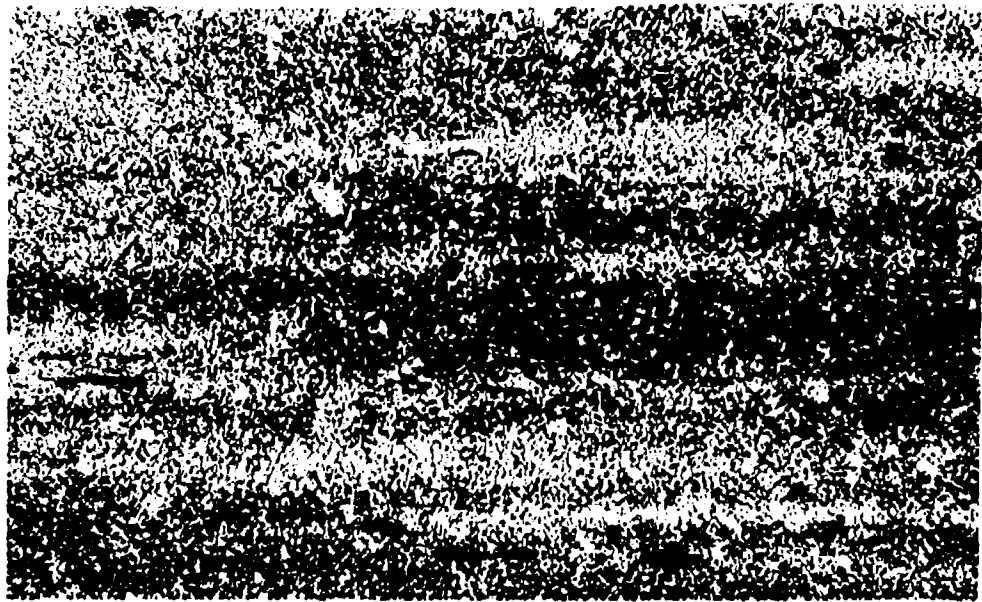
PILOT LOT SAMPLE WARHEAD, SERIAL NO. 4 PHOTOMICROGRAPHS  
OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

Location A and D in Figure 5

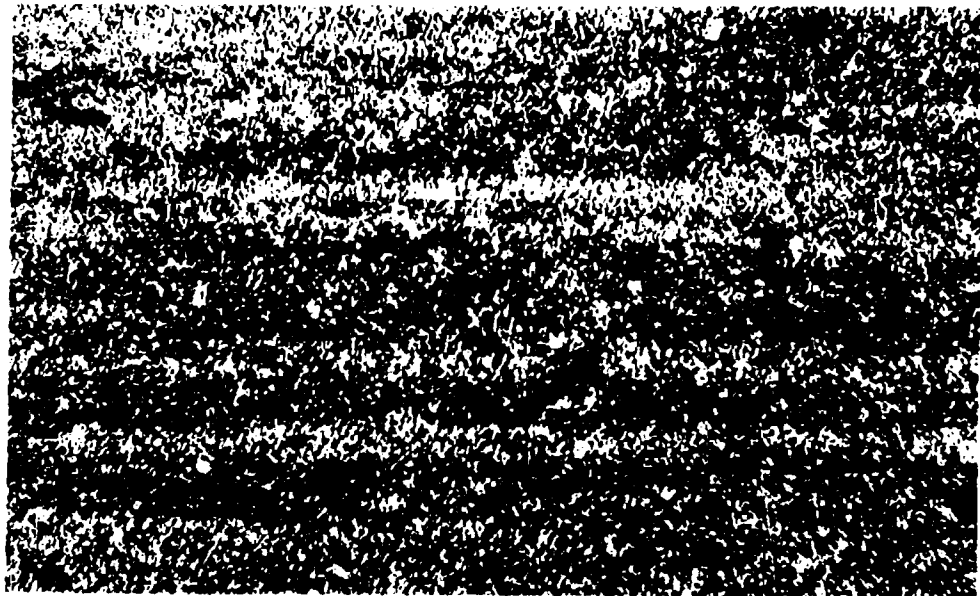
As Polished

Magnification: 100X

CONFIDENTIAL



A



D

PHD-55614

FIGURE 48

PILOT LOT SAMPLE WARHEAD, SERIAL NO. 4 PHOTOMICROGRAPHS  
OF BULLPUP WARHEAD EX 29 MOD 3 AISI 4340

Location A and D in Figure 5

Etch: Zephiran Chloride

Magnification: 100X

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