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KNOLLS ATOMIC POWER LABORATORY

SCHENECTADY, NEW YORK

AEC RESEARCH AND DEVELOPMENT REPORT

ALUMINUM CANNING OF NICKEL-PLATED, HANFORD FOUR-INCH URANIUM FUEL SLUGS BY HOT-PRESSING

H. T. Sumsion
C. J. Beck
L. S. DeLuca

May 17, 1955

OPERATED FOR THE

U.S. ATOMIC ENERGY COMMISSION

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Metallurgy and Ceramics
(M-3679, 16th ed)

General Electric Company
KNOLLS ATOMIC POWER LABORATORY
Schenectady, New York

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ABSTRACT

Conditions of time, temperature, and pressure for hot-press bonding of aluminum/nickel and uranium/nickel disks were determined experimentally. A process for jacketing Hanford four-inch slugs, coated with nonporous nickel electroplates, in aluminum cans by cold-sizing and hot-pressing was developed and conditions of time, temperature, and pressure required for the actual canning process were determined.

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ALUMINUM CANNING OF NICKEL-PLATED HANFORD FOUR-INCH URANIUM FUEL SLUGS BY HOT-PRESSING

H. T. Sumsion, C. J. Beck, L. S. DeLuca

INTRODUCTION

Standard fuel slugs used at Hanford are made up of a natural uranium core bonded by an aluminum-silicon alloy to an enveloping aluminum can and cap. Because of production loss due to slug failures in reactor operations, the Hanford Works initiated a program of fuel slug improvement. As part of this program KAPL was requested to investigate the application and bonding of thin corrosion-resistant coatings between the aluminum can or jacket and the uranium core. The function of the intermediate coating would be to replace the aluminum-silicon alloy in bonding the aluminum and uranium together, to act as a diffusion barrier, and to form a secondary protective coating for the uranium should the aluminum can be penetrated by the cooling water.

The objective of this part of the investigation was to develop a method or methods of surrounding the coated uranium slug with an aluminum jacket that would result in a durable thermal bond between the aluminum (the protective metal coating) and the uranium slug core.

Several methods for coating uranium employing a variety of metals were investigated at KAPL[1,2,3,4]. Electrodeposition of nickel[4] appeared to be the method and metal of greatest interest, and as a result efforts in the canning phase of the program for the most part were restricted to electrodeposited nickel coatings on uranium, and more particularly to the nonporous, smooth-interfaced type of nickel plate developed at KAPL by Beard and Crooks[4].

Of the several methods (hot-pressing, drawing, swaging, and coextrusion) considered for applying the aluminum jacket to the coated uranium fuel element, hot-pressing appeared to offer the greatest possibilities in simplicity of application, minimum damage to the nickel coat, and control of aluminum jacket thickness. A production technique of jacketing uranium fuel slugs that would not require the process to be carried out under vacuum or other protective atmosphere would be highly desirable. Cold-sizing and hot-pressing of the aluminum jacket on fuel slugs dipped in aluminum-silicon alloy had been successful experimentally at Hanford, and the process appeared to be directly applicable to nickel-plated fuel elements.

PRELIMINARY EXPERIMENTS

The effects of pressure, temperature, and time at temperature on the bonding of aluminum/nickel and uranium/nickel by hot-pressing were investigated by a method of producing sandwich-type couples which approximated the above conditions of cold-sizing and hot-press canning of fuel slugs.

Procedure

The bonding technique consisted of placing cleaned and abraded 1/16-inch thick, 1-inch diameter disks, of the couple metals (nickel/2S aluminum, nickel/uranium, or 2S aluminum/nickel/uranium) in a hard steel die and press assembly. The assembly was surrounded with a resistance heating coil, and pressure was applied to the disks by a hand-operated hydraulic press prior to and during heating. Contact of the bonding surfaces with the atmosphere was prevented by this technique which prevented oxide formation and made hot-press bonding possible without using vacuum or inert atmosphere. Approximately two hours were required to heat a specimen to 600°C and cool to 100°C, with proportionately shorter times required for lower temperatures.

The evaluation of the hot-pressed disk specimens was made by metallographic examination and bond strength tests. Metallographic examination showed bond continuity and extent of diffusion as indicated by the extent of intermetallic compound formation. Bond strength was determined by a modified Ollard test[5]. Figure 1121346 shows a cross-sectional view of the bond strength test assembly with a specimen in place for testing. A compressive load which subjected the test area to tensile force was applied in a Baldwin-Southwark testing machine. The applied load was read to the nearest one-half pound. The area under test in the specimens was 0.0511 square inch.

Results

Aluminum/Nickel Couples

Aluminum/nickel disks were hot-pressed at temperatures from 325 to 600°C under pressures of 1 to 30 tsi. The bond strength results are shown graphically in Figure KS-4895 with bond strength plotted against temperature of pressing. Pressure in tons per square inch is shown within or at the side of each datum circle. Specimens which failed during machining are shown between arrows indicating bond strength above zero but less than the lowest tested specimen. No appreciable bonding was obtained at temperatures below 500°C, partial bonding occurred at this temperature, and apparently optimum bond strengths were obtained at 550 and 600°C. Metallographic examination of specimens showed that at 500°C the diffusion zone has just begun to form, at 550°C it has increased to an appreciable extent (Figure 1121348 A and B), while at 600°C it has again increased several times (Figure 1121347 B) to approximately 0.0005 inch.

Pressure, within the range investigated of 1 to 30 tsi, appeared to have very little effect upon the bond strength developed. At 550 and 600°C optimum bond strengths of 8,000 to 11,000 psi, compared to 13,000 psi nominal tensile strength of 2S aluminum, were obtained at all pressures used from 1 to 30 tsi. There was, however, one exception to the general observation that bond strength is relatively unaffected by pressure; with 30-tsi pressure, optimum bond strength was developed at 500°C, 50° lower than for all other pressures. Metallographic examination showed no discernible effect of pressure on the extent of intermetallic compound formation. Figure 1121347 A and B shows the same amount of diffusion at 600°C with 1-tsi as with 12-tsi pressure. Figure KS-4896 A and B shows photomicrographs at 1000 diameters of the diffusion or bond zone of aluminum/nickel couples hot-pressed at 550°C at pressures of 12 and 44 tsi.

The effect of time on aluminum/nickel bonding was investigated briefly by holding couples at temperature for periods up to one-half hour. At temperatures of 550°C and above, no increase in bond strength was observed; this behavior was expected since optimum strength had been obtained without the increased time periods. At 475 and 500°C holding at temperature increased the bond strengths, but periods up to one-half hour did not produce the optimum values obtained at 550°C and above.

Uranium/Nickel Couples

Investigation of the conditions required to give satisfactory bonding between uranium and nickel disks was made similar to the investigation made for aluminum/nickel. No uranium/nickel bonding was obtained at a temperature of 500°C or lower. At 550 and 600°C visually good bonding between nickel and uranium disks was obtained at pressures of 1 to 15 tsi. However, because of the brittleness of the uranium/nickel bond all of these specimens broke in attempting to machine the tensile bond specimens.

Uranium/Nickel/Aluminum Couples

Hot-pressing of premachined tensile specimens was tried by pressing the cup part of the specimen (Figure 1121346) machined from nickel onto the flat washer-type part made of uranium. This was not completely satisfactory because the cup part flattened under pressure. However, two out of three of these specimens which were heated to 550°C under 15 tsi pressure were suitable for testing and gave bond strengths of 6250 and 6700 psi. Three uranium disks plated with approximately 0.002 inch of nickel were hot-pressed under 12 tsi, one each at 500, 550, and 600°C. The 500°C specimen showed some bonding but failed in machining; tensile specimens were successfully produced from the other two. The 600°C couple gave a bond strength of only 3600 psi, the 550°C a strength of 7100 psi.

Figure 1121920 A is a photomicrograph of the 600°C specimen. Good diffusion bonding was obtained between nickel and uranium and also between nickel and aluminum. It is evident that machining of the tensile specimen weakened the bond strength by multiple cracking of the nickel-rich phase of the nickel/aluminum diffusion zone. Also there has been an initial separation between uranium and the uranium/nickel diffusion zone as indicated by the wedge-shaped intrusion. The dark line which appears to be an extension of the intrusion is a preferential etch effect upon the uranium/nickel diffusion zone; prior to etching, continuous bonding is evident across the diffusion zones from aluminum to uranium. Failure in testing characteristically occurred in both the uranium/nickel and the aluminum/nickel diffusion zones as shown by Figure 1121920 B. Uranium/nickel/aluminum bonding in the couple hot-pressed at 550°C is shown in Figure 1121921. Here the nickel-rich nickel/aluminum diffusion zone is much thinner than in the 600°C specimen, resulting in less tendency to crack during machining of a tensile specimen and undoubtedly accounting for the higher bond strength of the former.

APPLICATION TO HANFORD FUEL ELEMENTS

Bond strengths, uranium/nickel and aluminum/nickel, in excess of the yield strength of 2S aluminum (approximately 5000 psi), were considered sufficiently high to make nickel-plated uranium fuel slugs acceptable for aluminum canning. On the basis of the experimental data obtained from hot-pressing of the disk couples, it appeared that acceptable bond strengths could be obtained by hot-pressing at nominal temperatures of 550 to 600°C; temperatures dropped 25 to 35°C during pressing for a four-minute pressing period. Pressure and time of pressing appeared not to be critical, although there was some indication that higher pressures would be somewhat advantageous. A pressure of 12 tsi was selected for initial hot-press canning of nickel-coated Hanford fuel slugs. This pressure appeared to be sufficiently high to give optimum bonding strengths well within high-temperature limitations of tool steels for hot-press die fabrication. A hot-pressing time of four minutes was selected arbitrarily for initial experiments.

Procedure

Canning

Development of a process for applying aluminum jackets to nickel-plated Hanford uranium fuel slugs within the limitations of the above conditions was based upon a cold-sizing and hot-pressing technique which was then under investigation by Hanford for jacketing aluminum-silicon-dipped fuel slugs[6]. In the process, as developed at KAPL for nickel-coated slugs, a fuel slug plated with approximately 0.002 inch of nickel and an aluminum end cap are inserted into a chemically cleaned aluminum can, and the assembly is pressed through a die which effectively extrudes the can over the slug. This operation forces all air out of the container and ensures intimate contact between component parts of the slug and jacket assembly. After sizing, the jacketed slug is placed in the pressing container, which consists of a 1.440-inch diameter split liner held together by a retaining sleeve with punches at each end extending beyond the liner. The slug assembly is cold-pressed to upset the end cap to bring it into tight mechanical contact with the end of the slug and with the aluminum side wall. Prepressing also serves to position punches so that equal pressure is applied to both punches by the single-acting press. The container and slug are placed in a furnace and heated to temperature, requiring one-half to one hour to heat to 550 to 600°C. After heating, the slug is pressed for four minutes or longer in a single-action hydraulic press. A thermocouple placed in a well in the liner is used to obtain desired temperatures. The hot-pressing assembly is shown schematically in Figure KS-4897.

Several slugs were pressed before temperature conditions, sizing tolerances, and pressing times were brought under control and a slug with a bonded can was realized. From this work the apparently optimum canning conditions of 12-tsi pressure, four minutes pressing time, and 550 to 600°C temperature were determined. If the pressing temperature was greater than 600°C the aluminum could be bonded to the steel die, while if the temperature was under 550°C the bonding between the aluminum and nickel, and between the nickel and uranium was mechanically inadequate - in accordance with the results of the preliminary experiments. It was found that the cold-sizing die should be of such a size that the can wall is reduced by at least 0.001 inch in order to achieve adequate removal of air from the slug assembly.

Initially powdered graphite or molybdenum disulphide was used as a lubricant or parting agent to prevent bonding between the steel die and the aluminum cans. Corrosion tests indicated that particles embedded in aluminum increased its susceptibility to corrosion. Anodization of the outer surface of the can was found to prevent bonding effectively between aluminum and steel, and this treatment was adopted as standard procedure. The complete procedure as finally developed for hot-pressing nickel-plated Hanford four-inch uranium fuel slugs is described in detail in Appendix I.

Evaluation

Evaluation of the hot-pressed slugs by means other than visual examination to detect blistering of the aluminum can was necessarily performed by destructive testing. Slices approximately 1/4 to 1/2-inch thick were cut off each end of the jacketed slug and out of the center. These slices were sectioned and at least one specimen from each of the three positions was examined metallographically for microscopic observation of uranium/nickel/aluminum bonding. The remaining sections of each slice were "peel tested" or "chisel tested" for bond adhesion by attempting to separate the aluminum can wall from the uranium manually with pliers and/or chisel.

For each jacketed slug from which metallographic and "peel" test specimens were cut as described above, there remained two sections 1 1/2 to 2-inches long between the center slice and the two end slices. In an attempt to obtain quantitative values of aluminum/nickel/uranium bond strengths of the canned slugs, segments were cut from these center sections and machined into tensile specimens as indicated in Figure KS-4898. When these specimens are subjected to tension, the area between the two cuts is placed in shear while the aluminum across the width where the uranium has been removed is placed in tension. The ratio of the two areas had to be made in such a manner that a load which approximated the maximum strength of the aluminum in tension also approximated the maximum strength of the aluminum in shear.

A limited number of the jacketed slugs were corrosion-tested in boiling water for a minimum period of 200 hours to check the effectiveness of the pressure weld seal between the aluminum end cap and the can sidewall. One canned slug had several small (approximately 1/8-inch diameter) holes drilled through aluminum and nickel coats into the uranium. The slug was then corrosion-tested in boiling water as a rough test on the effectiveness of the uranium/nickel diffusion layer in preventing undercutting of the nickel in event of porosity penetration of aluminum and nickel surrounding the uranium. One hole was carefully drilled and chemically etched with caustic through the aluminum just to the nickel coating. This gave a similar rough check in the above corrosion test of the effectiveness of the aluminum/nickel diffusion layer in preventing undercutting of the aluminum can.

Results

Temperature

After hot-pressing the initial slugs to check the applicability of the pressing conditions as indicated in the preliminary experiments, a series of eight slugs was pressed to determine more closely the pressing temperature, and also to determine whether a bonding heat-treatment immediately following nickel-plating was desirable. This heat-treatment consists of one-half hour in vacuum at 600°C and had been found previously to result in good mechanical adherence of the nickel to the uranium. All eight slugs, four heat-treated and four as-plated, were pressed at 12-tsi pressure for four minutes. Duplicate slugs of each type were pressed at 550 and at 600°C nominal temperatures. One set was sectioned for metallographic examination and the other set was corrosion-tested in boiling water for a minimum of 200 hours. None of these showed any indication of water leakage through the pressure-welded seal between the cap and the can wall. The soundness of these welds is illustrated by the macrographs shown in Figure 1132294.

Figure 1132290 and 1132291 are illustrative photomicrographs of the fuel slugs which were not heat-treated after nickel plating. The increase in thickness of the diffusion layers at 600°C can be seen in Figure 1132290 (Slug 115) when compared with Figure 1132291 (Slug 140) hot-pressed at 549°C. The same effect is apparent in comparing the slugs which had been heat-treated after nickel plating; Figure 1132292 consists of photomicrographs of Slug 145, hot-pressed at 600°C, and Figure 1132293, (Slug 146), hot-pressed at 566°C. Cracking of the extremely brittle nickel-rich nickel/aluminum diffusion compound is apparent in Figure 1132290 C and 1132292 D.

Because of the brittle nature of the uranium/nickel and aluminum/nickel diffusion products, it appeared desirable to limit as much as possible the amount of diffusion taking place after complete bonding has been obtained between component elements; for this reason 600°C pressing temperature appeared to be excessive. In some cases incomplete bonding was observed at 550°C, and consequently the nominal pressing temperature for subsequent hot-pressing was placed at 575°C; with this starting temperature there was a drop to 535°C at the end of the four-minute pressing period. The average pressing temperature for this period agrees closely with the 550°C minimum temperature established by the preliminary experiments for optimum bonding. The annealing heat-treatment of the nickel-plated slugs prior to hot-pressing was found to be detrimental because the nickel/uranium diffusion product was subject to cracking in the cold-sizing operation and prevented formation of a sound bond in hot-pressing, and also if cracking did not occur during cold-sizing, excessive uranium/nickel diffusion occurred with hot-pressing.

Unequal diffusion product formation was noted in these first pressings with wider diffusion bands occurring at the sides rather than at the top or bottom. This nonuniformity was attributed to excessive heat loss by conduction in pressing with the end punches in contact with the cold platens of the press and was subsequently minimized by the use of thermal insulators between end punches and press platens.

Pressure

To investigate the possible advantage of increased pressure, four slugs which had unsatisfactory nickel coatings, principally because of blistering, were hot-press canned at 575°C for four minutes, two under 12 and two under 24 tsi. Poorly plated slugs were used to see if greater pressure would give better bonding than the standardized 12 tsi. Although metallographic examination indicated that good bonding and diffusion zones of approximately equal thickness were obtained under the two different pressures (Figure KS-628 A and B), "peel tests" of the sectioned slugs showed that the two pressed at 12 tsi had very poor adherence while the two pressed at 24 tsi were well bonded.

Twenty-five nickel-plated uranium fuel slugs were jacketed by cold-sizing and hot-pressing at a nominal temperature of 575°C and held four minutes under pressure. Seventeen were pressed at 12-tsi and eight at 24-tsi pressure. Five of the 12-tsi and two of the 24-tsi slugs were sectioned for evaluation by metallographic examination and adhesion "peel testing". All five slugs pressed at 12 tsi showed good metallurgical bonding when examined metallographically. However, only two showed good bond strength in the "peel test". Specimens from top, center, and bottom sections of the other three slugs showed very poor adhesion and "peeled" with comparative ease. The two which showed good adhesion were among the first of the group to be processed. In all cases where separation of the aluminum from the uranium occurred, it occurred between the diffusion product and the nickel on the uranium side.

The two slugs pressed at 24 tsi which were sectioned showed good metallurgical bonding, similar metallographically to those canned at 12 tsi. However, the 24-tsi specimens exhibited strength superior to the 12-tsi specimens. The aluminum could be stripped from the sectioned pieces only in occasional spots and with great difficulty. When separation did occur, it was not consistently between nickel and uranium as with the 12-tsi slugs but was in either the uranium/nickel or the aluminum/nickel zone, or occasionally in both.

Time of Pressing

Six additional fuel slugs were hot-press canned at 575°C nominal temperature, three at 12-tsi and three at 24-tsi pressure; all were held sixteen minutes under pressure instead of four minutes. One slug at each pressure was sectioned and examined. Each showed slightly greater diffusion zones than comparable slugs hot-pressed for four minutes. In the "peel test" the 24-tsi slug showed adhesion comparable to the ones hot-pressed for four minutes while the 12-tsi slug exhibited definitely improved bond strength over that of slugs hot-pressed for four minutes. On the basis of these two specimens, it would appear that improvement in strength of bonds might be obtainable at lower pressures by increased time of pressing. However, this is at best but a superficial evaluation of the effect of time since it is based on only one pressing at two pressures, and also because without means of heating the hot-pressing assembly while pressing, the temperature of the slug was dropping constantly while under pressure. For only about 10 of the 16 minutes of the pressing period, the slug and assembly were above 475°C, a temperature below which no appreciable diffusion bonding was observed in the preliminary experiments.

Bond Strength Tests

In the attempt to obtain quantitative values of aluminum/nickel/uranium bond strengths, specimens (Figure KS-4898) were cut in duplicate from 14 jacketed fuel slugs and tested. Two specimens from different slugs failed partially in the aluminum/nickel bond, and partially in the aluminum, which indicates that the bond strength in shear was approximately that of the shear strength of 2S aluminum, 9500 psi. All other specimens failed in the aluminum, either in shear or tension, indicating a bond strength in shear greater than 9500 psi. The slugs tested included an approximately equal number canned at 12 tsi and at 24 tsi. The two specimens which showed a bond strength not in excess but equal to that of aluminum were canned at 12 tsi. All specimens were cut from slugs which had been previously tested for adhesion by the "peel test". Several of the slugs canned at 12 tsi had shown poor bonding by this "peel test", but these tensile tests indicate that all the canned slugs had an aluminum/nickel/uranium bond strength in shear equal to or greater than that of aluminum.

Corrosion Undercutting Tests

Resistance of the aluminum/nickel/uranium diffusion zones to undercutting of the aluminum can wall and the nickel coat, respectively, was surveyed on the one canned slug with multiple 1/8-inch holes drilled through aluminum and nickel coatings into the uranium, and one hole drilled and etched through the aluminum can wall to the nickel. This slug was placed in boiling water for 70 hours, then sectioned along a plane through the drilled holes and examined metallographically. Figure KS-629 A is a low-magnification photomicrograph of the hole made just to the nickel coating. It can be noted that the nickel offers complete protection to the uranium and that there is but limited undercutting of the aluminum along the nickel/aluminum interface after the 70-hour exposure to boiling water. Figure KS-630 A is a photomicrograph at 250X of this area. Such undercutting as is indicated could have been caused principally or in part by NaOH prior to exposure to the boiling water. Figure KS-629 B shows one of the holes drilled through aluminum and nickel into the uranium. Figure KS-630 B is a high magnification (250X) photograph of the aluminum/nickel/uranium diffusion area of one of the holes. It can be seen that aluminum/nickel diffusion product shows little susceptibility to boiling water corrosion; even areas where the aluminum/nickel diffusion product was badly cracked by the drilling of the hole show negligible undercutting of the aluminum.

Hanford Tests

Twenty-two nickel-coated uranium fuel slugs hot-press jacketed in aluminum cans were shipped to Hanford for evaluation. Eleven of the seventeen slugs which were tested for bonding had areas which were not bonded according to procedures used[7]. Almost complete lack of bonding between nickel and aluminum existed for two slugs that had been among the last to be hot-pressed. In adhesion "peel tests" at KAPL poor aluminum/nickel bonding had been observed also for some of the slugs canned toward the end of a run. In the hot-pressing procedure, a commercial deoxidizing or cleansing solution was used in the final treatment of the aluminum can prior to insertion of the uranium slug. This cleansing solution was in short supply and was apparently used beyond the point where it was effective in cleaning and deoxidizing the aluminum.

Designation of areas of separation between nickel and aluminum which occur during "chisel testing" as unbonded does not appear to be justified if it is evident that metallurgical bonding has existed. Separation results simply because the stress applied at that point exceeds the strength of the diffusion product or the bond strength between the diffusion product and one of the two interfaces. The fuel slugs plated at KAPL have a nonporous, smooth nickel plate deposited upon a smooth uranium surface obtained by vapor blasting and cathodic pretreatment of the fuel slug. A bond at such a smooth interface would not appear as strong when evaluated by a "chisel" or "peel test" as would a plate with a rough interface such as exists on anodically pretreated slugs where mechanical interlocking is present. Results of the bond strength tests on specimens machined from hot-pressed fuel slugs appear to be sufficiently conclusive to indicate that in general adequate bonding is obtained which has strength equal to or exceeding that of aluminum.

In corrosion tests consisting of exposure to 170°C deionized water, Hanford found that the undercutting resistance of the slugs tested was generally good and that they showed secondary corrosion resistance.

CONCLUSIONS

Uranium fuel slugs coated with nonporous nickel electroplate can be jacketed in capped aluminum cans by a process of cold-sizing and hot-pressing in accordance with conditions of time, temperature, and pressure as established experimentally. By the use of careful laboratory technique, a satisfactory bonding of the aluminum can to the uranium fuel slug is obtainable. However, in order to adapt this process to production conditions and to assure consistently satisfactory results, further development of this technique would be necessary.

APPENDIX

Procedure for Canning Nickel-Plated Uranium Slugs in Aluminum

I. Machine unfinished end from end cap to obtain a clean flat surface having a good finish.

II. Anneal the machined end caps and aluminum cans 15 minutes at 550°C (air).

III. Expand the aluminum can.

(a) Pour a 50% H_2O - Johnson Wax mixture into a clean can, empty the can, and allow it to dry thoroughly.

(b) Start the expansion mandrel into the lubricated can with a hammer.

(c) Use the arbor press in the machine shop to force the mandrel to the bottom of the can.

(d) Remove the mandrel from the can and clean the can with hot water and Bab-O. It is important that the wax lubricant be completely removed from the interior of the can.

IV. Deoxidize the can in Diversey solution.

(a) Clean a large stainless steel beaker and fill it with Diversey solution.

(b) Immerse the aluminum can and end cap in the Diversey solution for six minutes.

(c) Rinse the can and end cap in clean water and allow it to dry. Do not touch the end cap or interior of the can with hands, dirty rag or gloves. If possible use clean nylon gloves for handling clean cans, end caps, and nickel-plated uranium slugs.

V. Cold-Sizing Can over Slug

(a) Have the outer surface of the can anodized electrolytically with cores.

(b) Insert a nickel-plated uranium slug and end cap into a can.

(c) Coat the exterior of the can with the 50% H_2O - Johnson Wax lubricant. Be careful not to get lubricant near the open end of the can. Allow the lubricant to dry.

(d) Cold-size the slug through a die of such diameter to give 0.002-inch to 0.003-inch reduction of the can walls after the walls are known to be in contact with the slug. Sizing should be done on the Watson-Stillman press. The slug is pressed through the die with the end cap up. Use a punch slightly smaller in diameter than the end cap. Put a cloth under the die to cushion the fall of the slug when it falls free of the die.

(e) Use a tube cutter to trim the excess can length exactly even with the top of the end cap.

(f) Clean the lubricant from the slug with a wet rag.

VI. Hot-pressing the slug

(a) Thoroughly clean the split liner in the pressing container.

(b) Put the slug and punches in the liner and the liner into the container. Be certain that the liner halves are in the container so that their tops are flush with each other. Apply about 10-ton pressure to the liner halves and check to see that the punches are free to move.

(c) Apply 20-ton pressure to the punches.

(d) Put the assembly into a furnace operating at 575°C, using the container cradle furnished. Use thermocouple and potentiometer to determine the temperature of the assembly.

(e) When the assembly is 575°C, quickly remove it from the furnace and apply 20-ton pressure. Hold pressure four minutes. Remove slug from container being careful not to damage the surface of the aluminum which is very soft at this temperature.

REFERENCES

1. KAPL-952, "Research on Corrosion Resistant Coatings for Uranium", by C. E. Lacy, et al., February 1952 to February 1953.

2. KAPL-876, "Iodide Decomposition Process for Coating Uranium with Zirconium", by W. L. Robb and F. J. Shipko, February 24, 1953.

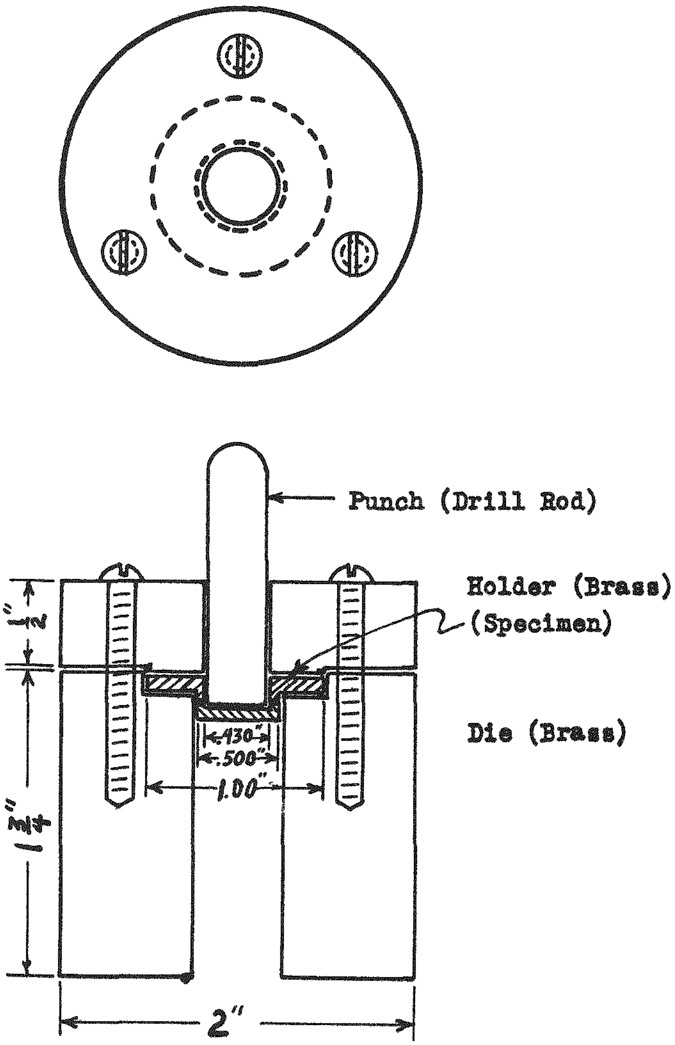
3. KAPL-1100, "Metallic Coatings on Uranium by Sputtering and Evaporation", by W. D. Davis, April 1, 1954.

4. KAPL-1181, "Electrodeposition of Nickel on Uranium", by A. P. Beard and D. D. Crooks, August 31, 1954.

5. Knapp, B. B., "Adhesion of Hard Nickel to High Strength Aluminum Alloy", Metal Finishing 12, 42 (1949).

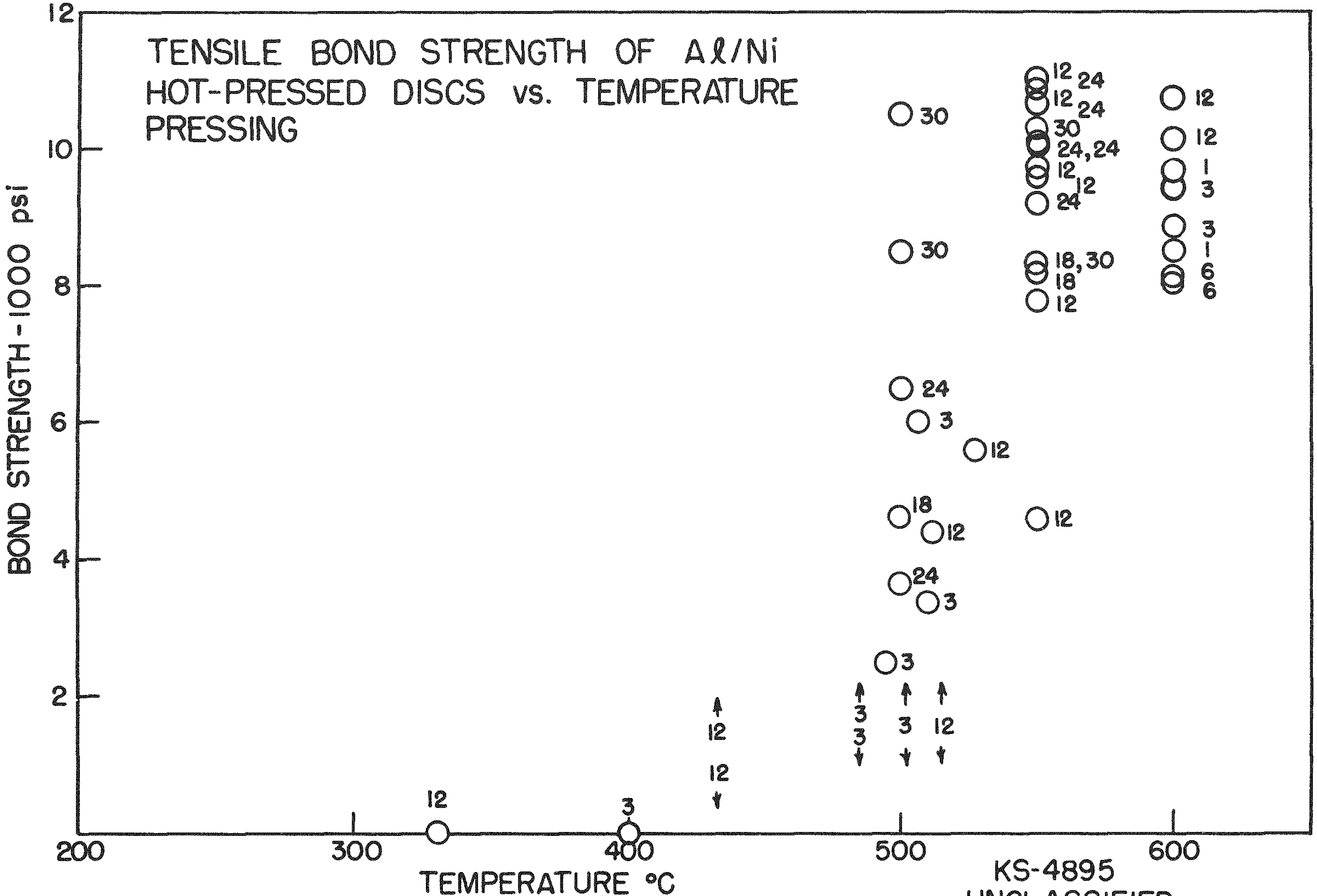
6. HW-25392, "Technical Activities Report - New Canning", Edited by E. A. Eschback, August 1952.

7. HW-35486, "Evaluation of KAPL Nickel-Plated, Hot-Pressed, Four-Inch Slugs", by E. A. Evans, February 24, 1955.



BOND STRENGTH TEST ASSEMBLY

UNCLASSIFIED



KS-4895
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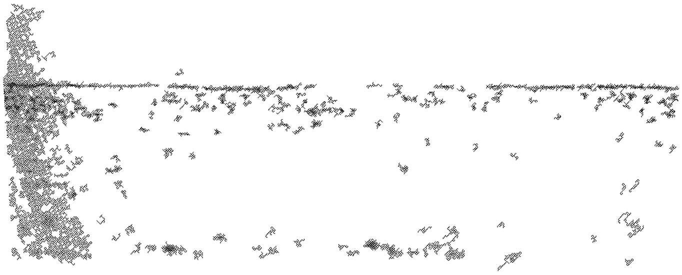
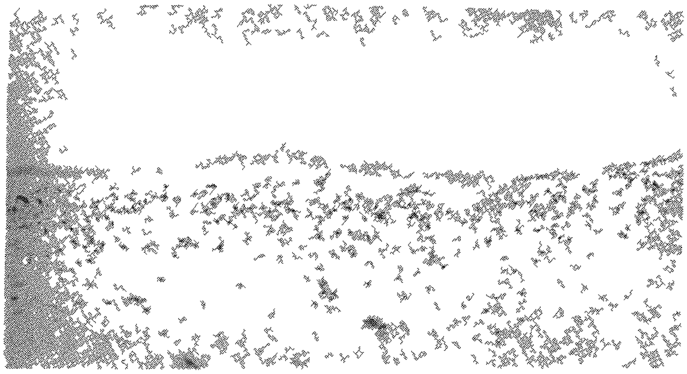
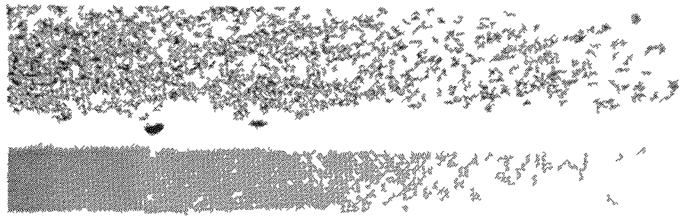


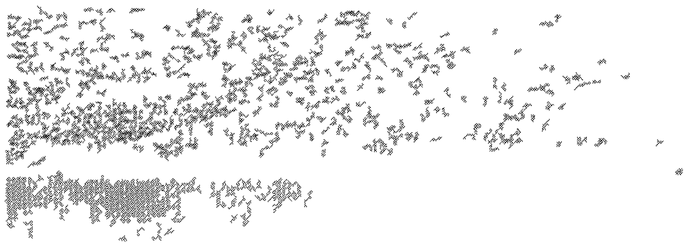
(A) Al/Ni HOT-PRESSED COUPLE. 12-tsi pressure, 500°C, HF etch-polish. 1000X.



(B) Al/Ni HOT-PRESSED COUPLE. 12-tsi pressure, 550°C, HF etch-polish. 1000X.

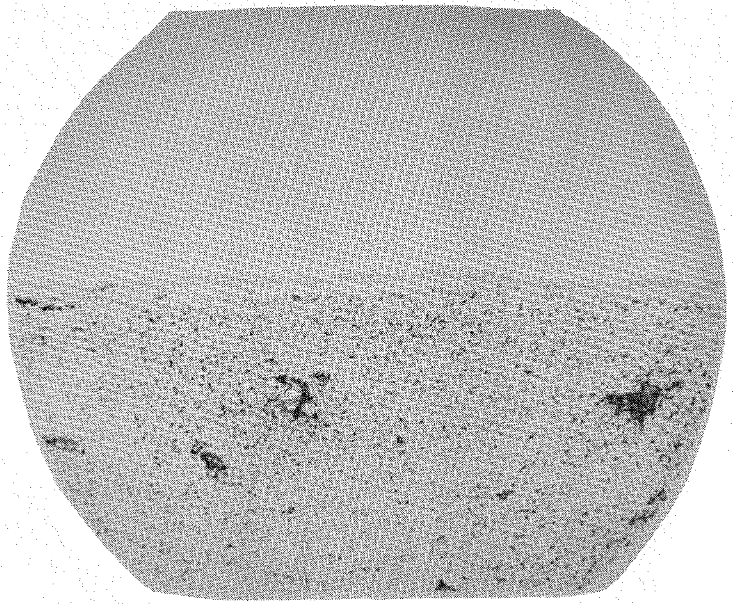


(A) Al/Ni HOT-PRESSED COUPLE. 1-tsi pressure, 600°C, HF etch-polish. 1000X.



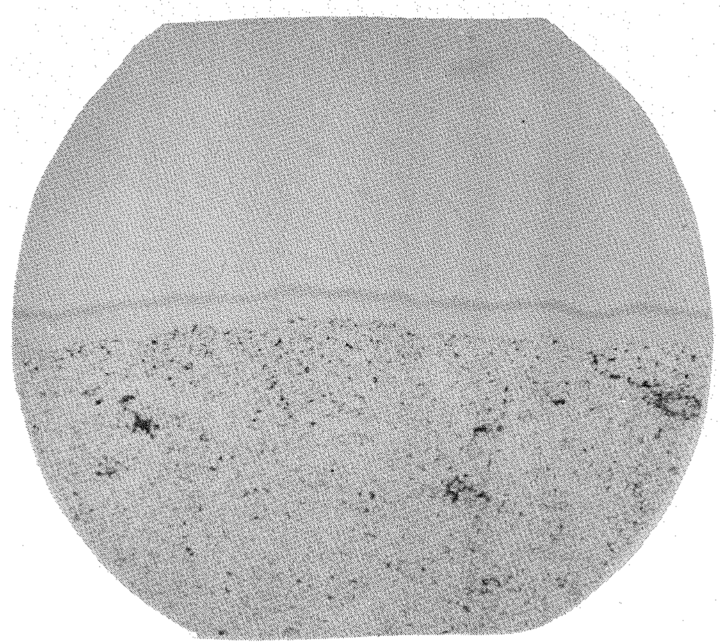
(B) Al/Ni HOT-PRESSED COUPLE. 12-tsi pressure, 600°C, HF etch-polish. 1000X.

(A)



Al/Ni HOT-PRESSED COUPLE.
12-tsi pressure, 550°C,
HF etch-polish 1000X

(B)



Al/Ni HOT-PRESSED COUPLE.
44-tsi pressure, 550°C,
HF etch-polish 1000X

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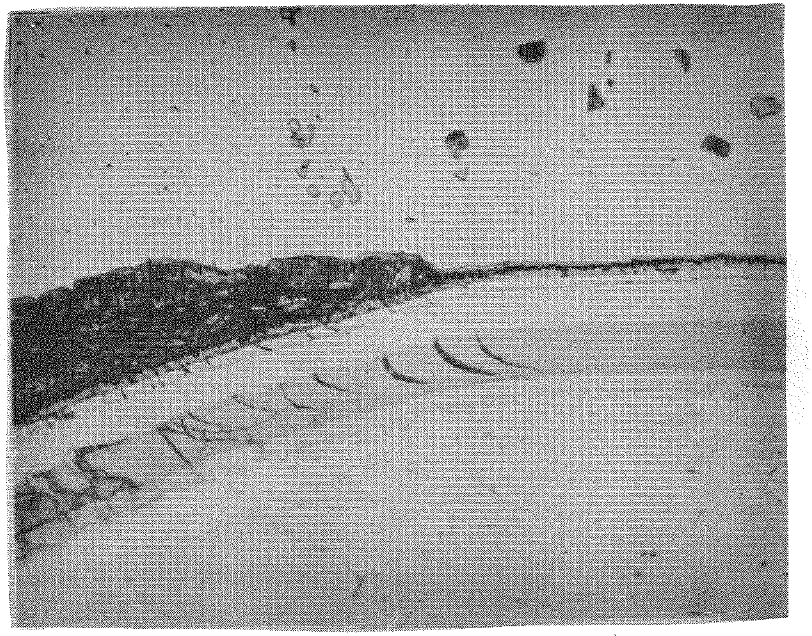
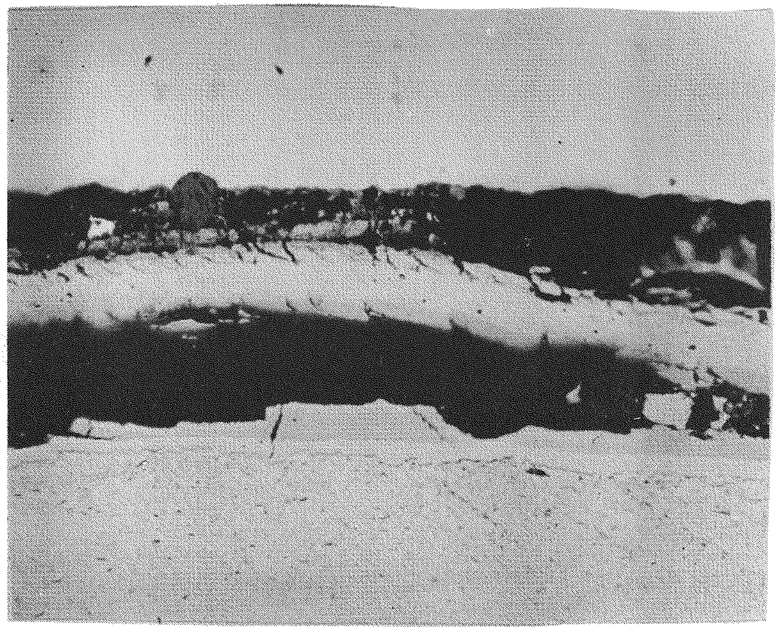


Al/Ni/U HOT-PRESSED COUPLE, 12 tsi, 600°C



Al/Ni/U HOT-PRESSED COUPLE TESTED TO FAILURE

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1121920

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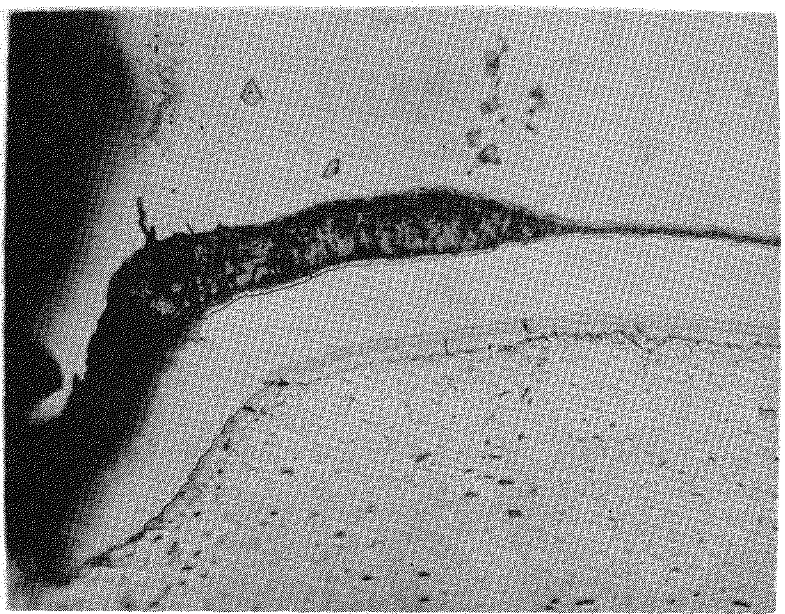

Al/Ni/U HOT-PRESSED COUPLE, 12 tsi, 550°C

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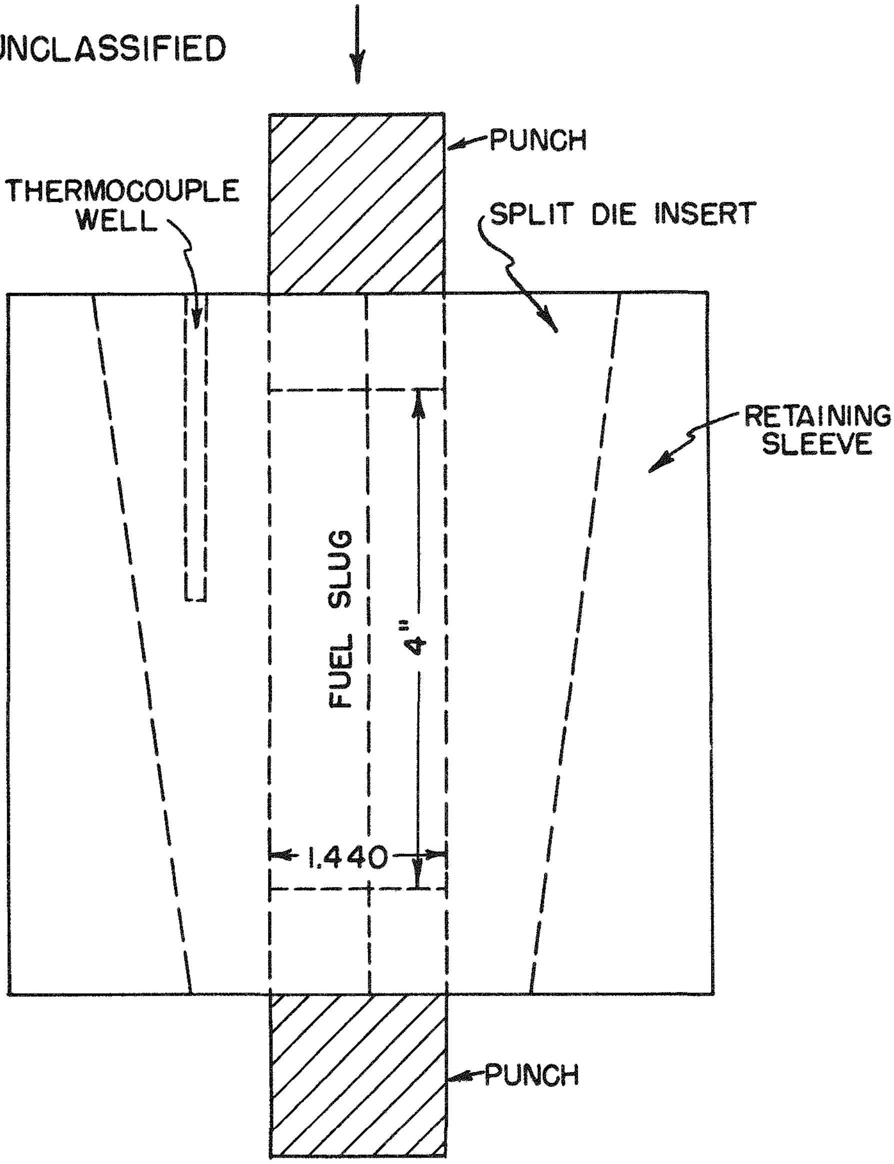

KS-4897
UNCLASSIFIED

HOT PRESSING ASSEMBLY

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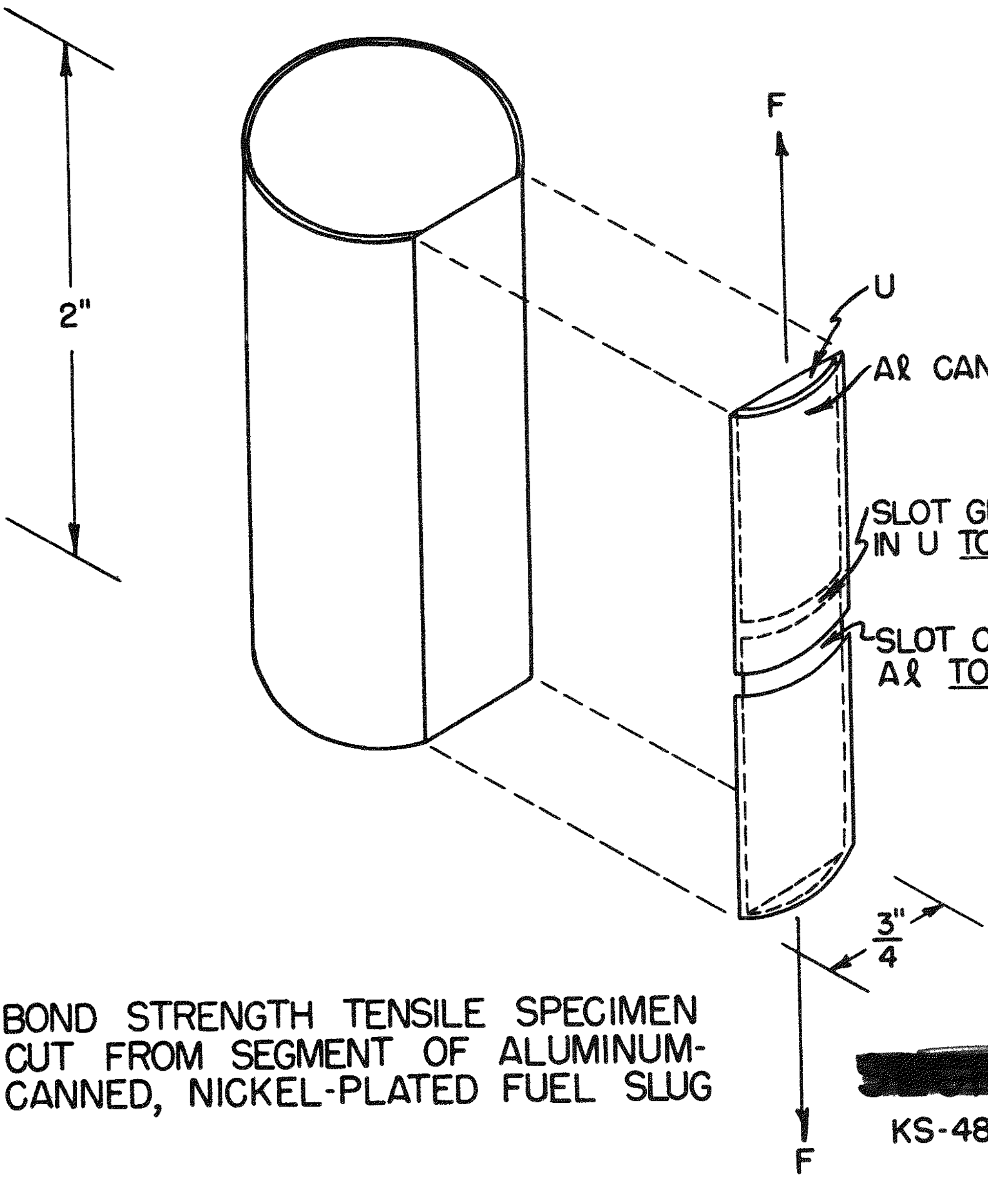

BOND STRENGTH TENSILE SPECIMEN
CUT FROM SEGMENT OF ALUMINUM-
CANNED, NICKEL-PLATED FUEL SLUG

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KS-4898

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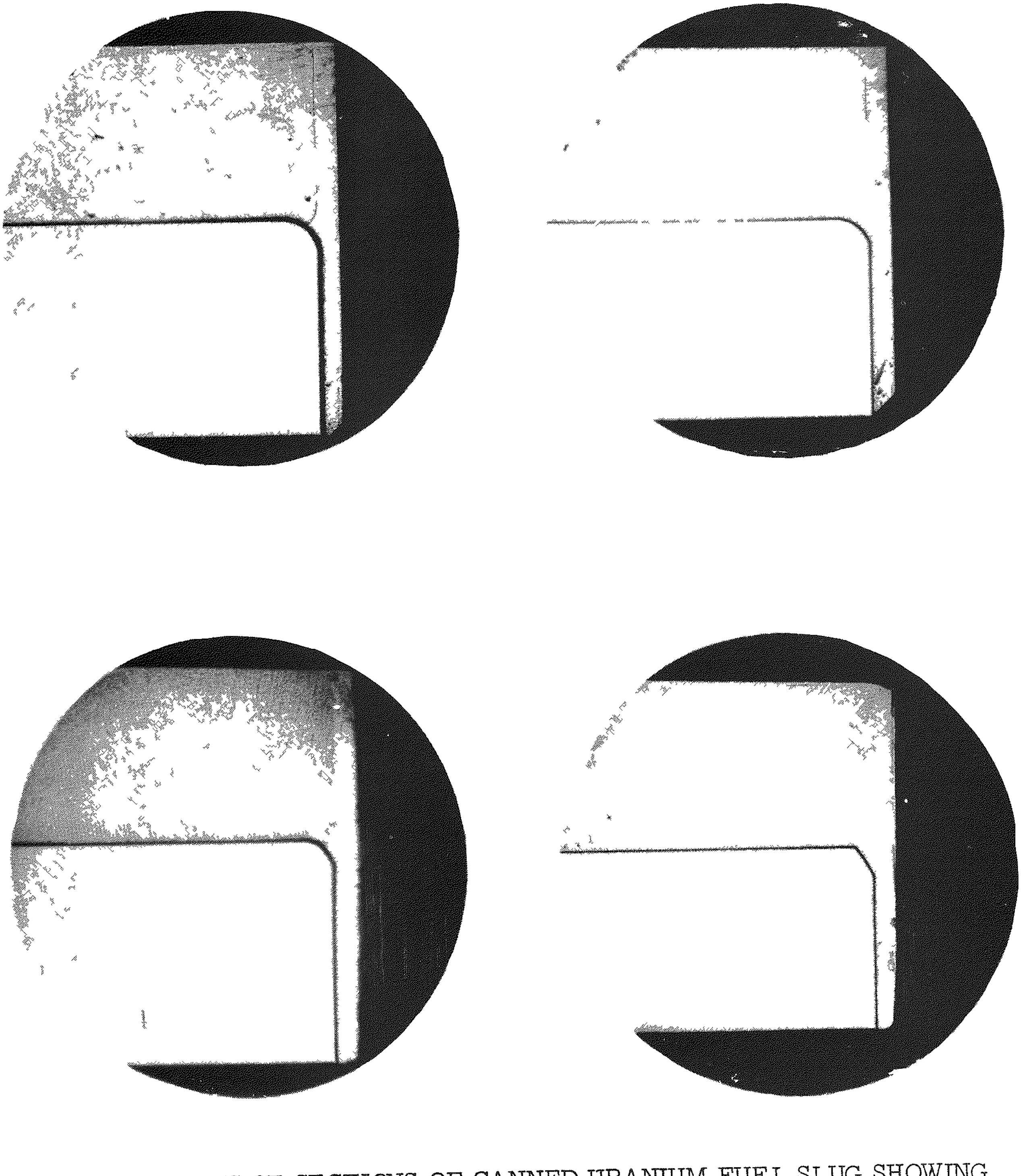

MACROGRAPHS OF SECTIONS OF CANNED URANIUM FUEL SLUG SHOWING CAN WALL - FUEL SLUG - END CAP JUNCTIONS

1132294

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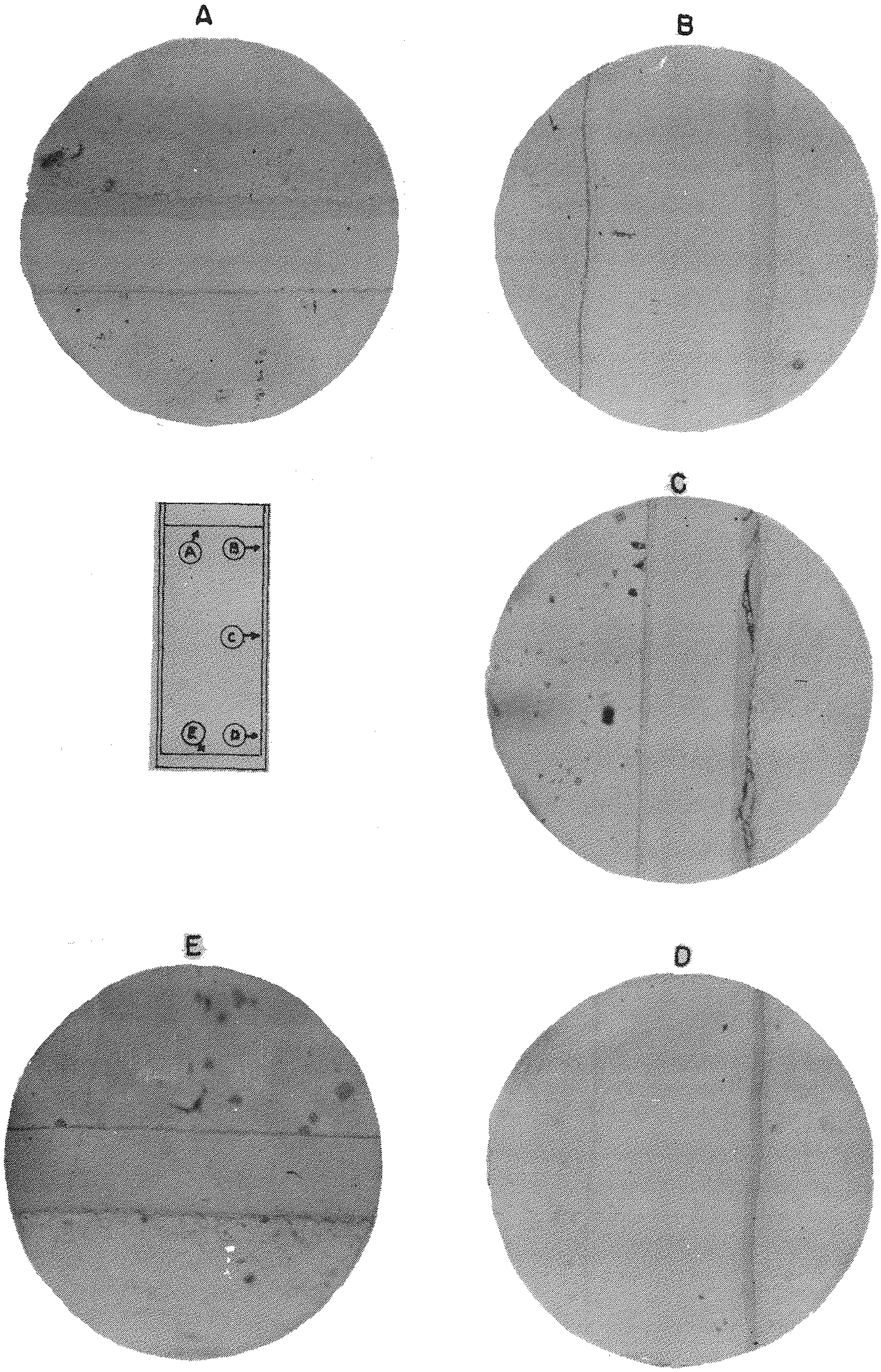

URANIUM FUEL SLUG 115

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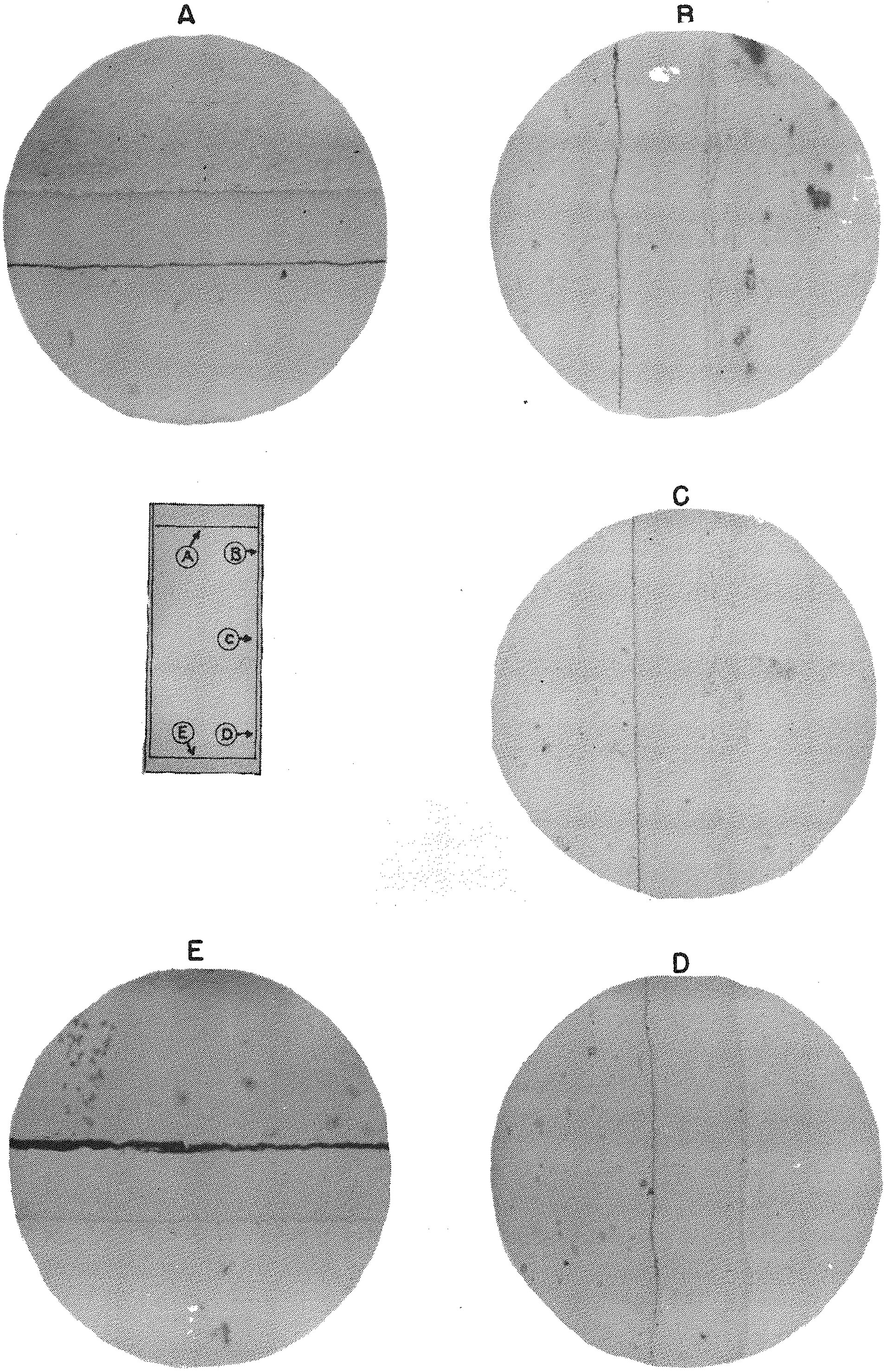

URANIUM FUEL SLUG 140

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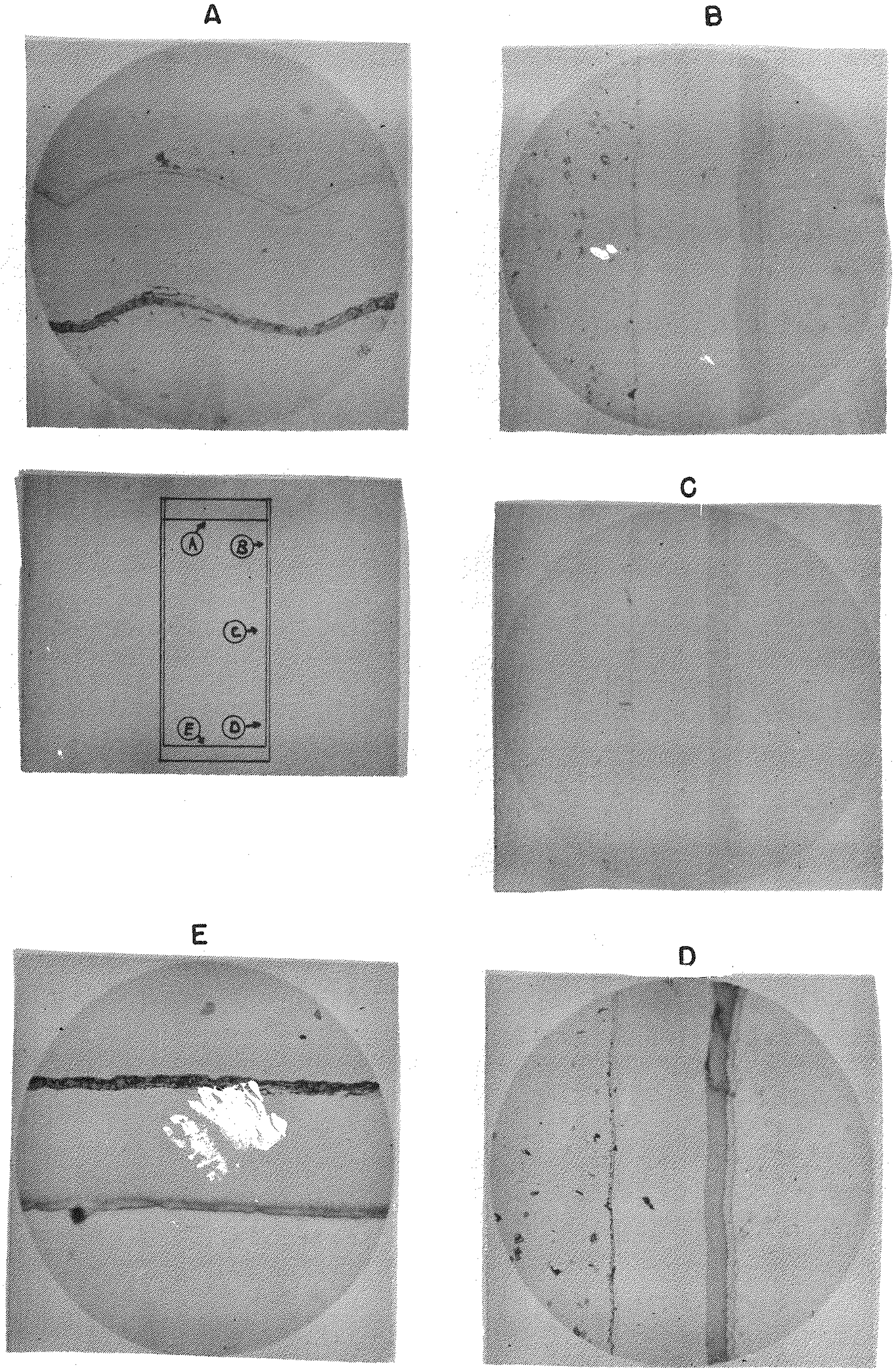

URANIUM FUEL SLUG 145

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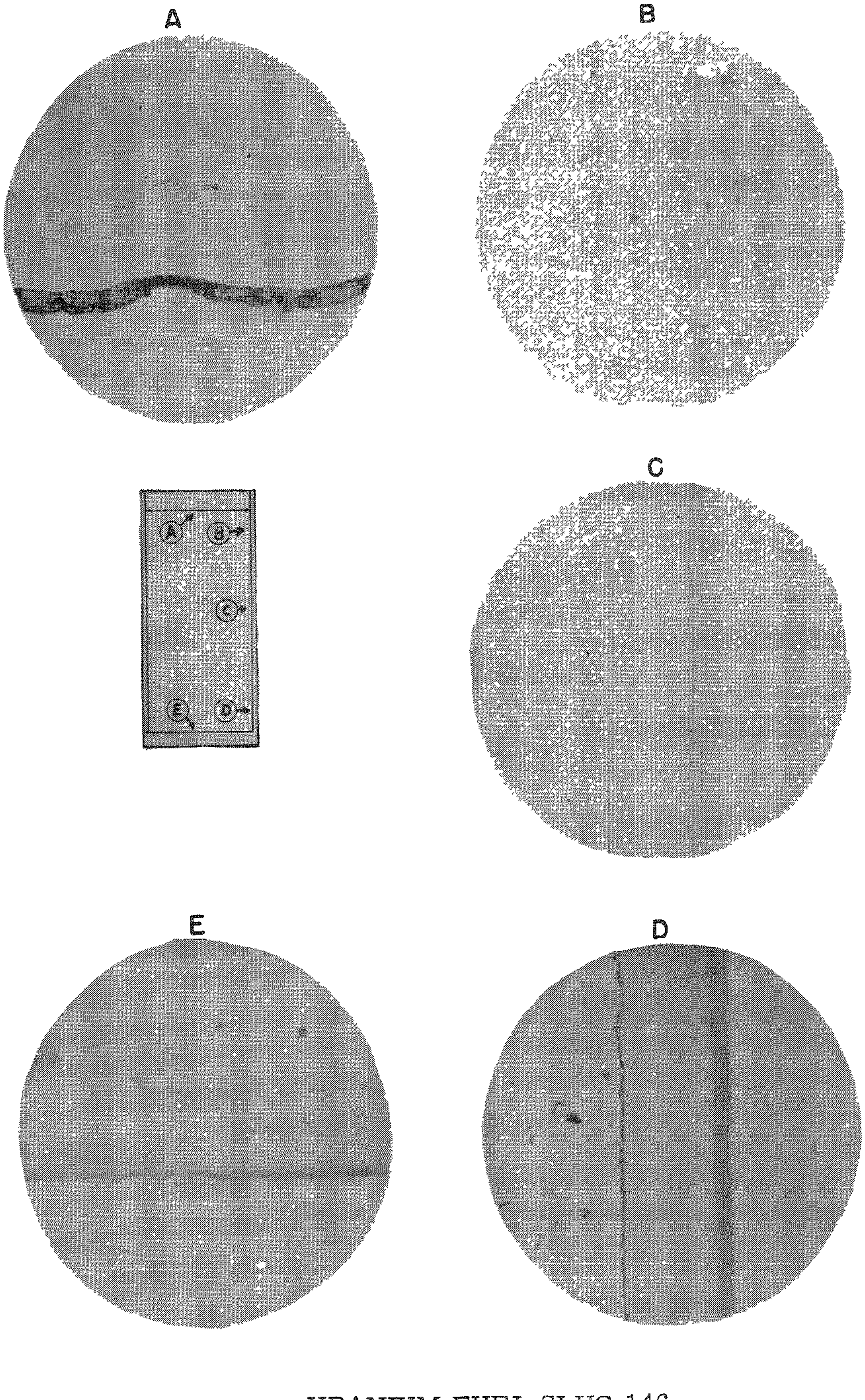

URANIUM FUEL SLUG 146

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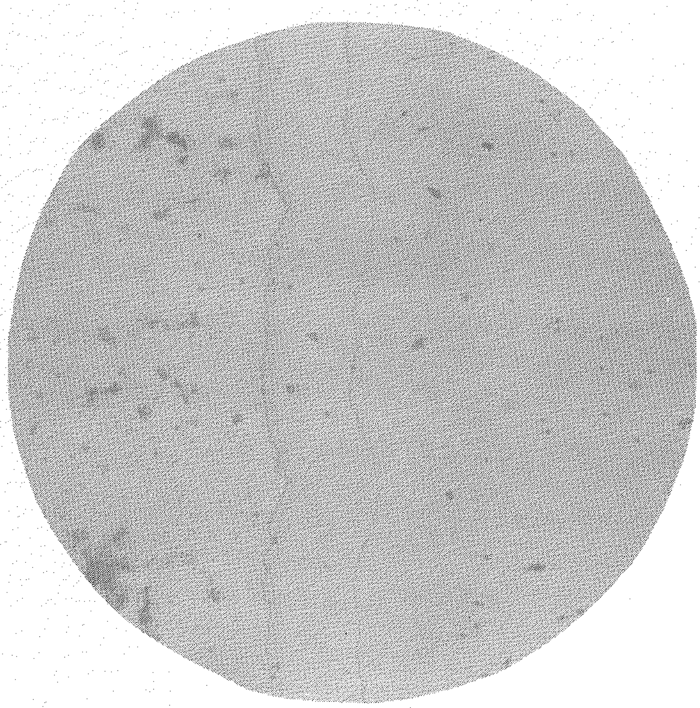
A



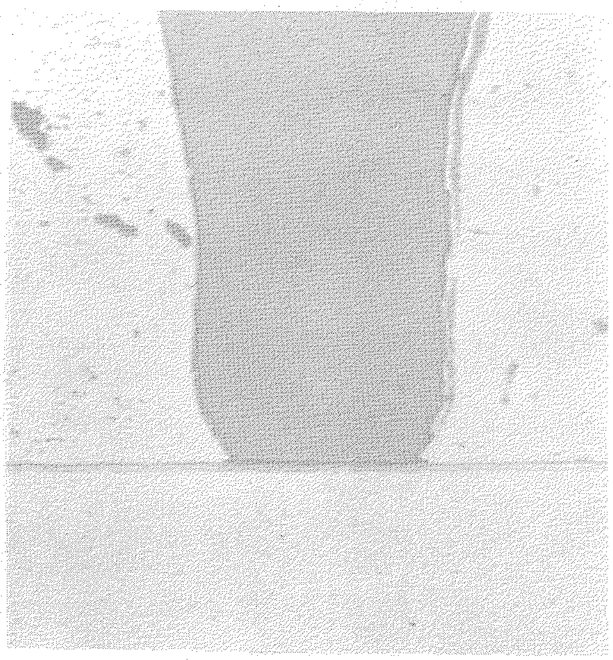
Al/Ni/U SECTION OF ONE NICKEL-COATED URANIUM FUEL SLUG CANNED IN ALUMINUM BY HOT-PRESSING FOR 4 MINUTES AT 575°C, 12 TSI.
$HF-HNO_3$ ETCH POLISH 250X

B

Al/Ni/U SECTION OF ONE NICKEL-COATED URANIUM FUEL SLUG CANNED IN ALUMINUM BY HOT-PRESSING FOR 4 MINUTES AT 575°C, 24 TSI.
$HF-HNO_3$ ETCH POLISH 250X

KS-628

A



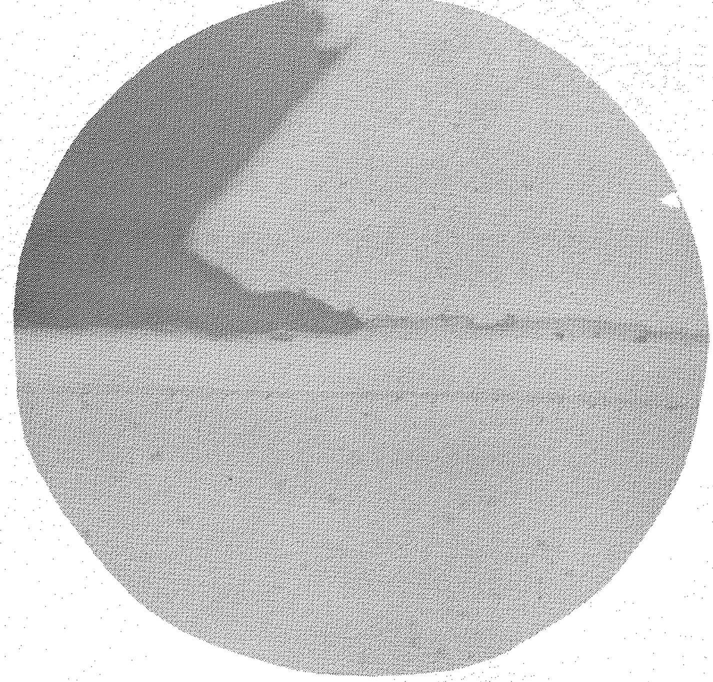
ALUMINUM-CANNED, NICKEL-COATED FUEL SLUG SHOWING HOLE DRILLED THROUGH ALUMINUM TO NICKEL. SLUG SUBJECTED TO BOILING WATER FOR 70 HOURS.
$HF-HNO_3$ ETCH POLISH 20X

B

ALUMINUM-CANNED, NICKEL-COATED FUEL SLUG SHOWING HOLE DRILLED THROUGH ALUMINUM AND NICKEL INTO URANIUM. SLUG SUBJECTED TO BOILING WATER FOR 70 HOURS.
$HF-HNO_3$ ETCH POLISH 20X

KS-629

A



ALUMINUM-CANNED, NICKEL-COATED FUEL SLUG SHOWING HOLE DRILLED THROUGH ALUMINUM TO NICKEL. SLUG SUBJECTED TO BOILING WATER FOR 70 HOURS.
$HF-HNO_3$ ETCH POLISH 250X

B

ALUMINUM-CANNED, NICKEL-COATED FUEL SLUG SHOWING HOLE DRILLED THROUGH ALUMINUM AND NICKEL INTO URANIUM. SLUG SUBJECTED TO BOILING WATER FOR 70 HOURS.
$HF-HNO_3$ ETCH POLISH 250X

KS-630