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FABRICATION OF ALUMINUM-PLUTONIUM ALLOY FUEL ELEMENTS BY COEXTRUSION

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ABSTRACT

This report describes the development of the fabrication process and preparation of 144 coextruded fuel elements for the Trans-Plutonium Program. The fuel elements were requested by the Savannah River Laboratory (SRL) and were in the form of coextruded rods, 0.94 inches in diameter and 60 inches in length. The cladding was aluminum (X-8001 alloy) and was 0.040-0.120 inches thick. The fuel cores were aluminum-7.35 weight percent plutonium alloy. The fuel elements were coextruded in an extrusion press which was mounted in a plutonium-contaminated glove box. The extruded elements were easily decontaminated The cast fuel cores for the coextrusion billets were machined only on one end. The fuel elements were fabricated during February thru July, 1959, and all are currently under irradiation.

INTRODUCTION

In February, 1959, the Plutonium Metallurgy Operation received authorization to fabricate 144 aluminum-plutonium alloy fuel elements (Figures 1 and 2) for the Trans-Plutonium Program.[1, 2, 3] The Savannah River Laboratory (SRL) initiated the fabrication request. The fabrication of elements was completed during July, 1959.[4, 5, 6] The fuel elements were in the form of rods and were clad with aluminum (X-8001 alloy) and had fuel cores of aluminum-7.35 weight percent plutonium alloy. The coextruded fuel rods were 0.94 inches in diameter, 60 inches in length, and contained 83.3 ± 4.2 grams of plutonium. The cladding thickness was 0.040-0.120 inches. Completed fuel rods were autoclaved at the Savannah River Laboratory. Four aluminum-7.35 w/o uranium alloy fuel elements for ex-reactor evaluation were prepared and shipped.

SUMMARY AND CONCLUSIONS

The required 144 coextruded fuel elements with aluminum-7.35 w/o plutonium alloy cores clad with aluminum (X-8001 alloy) were fabricated and shipped. A total of 12 kilograms of plutonium was involved. All 144 fuel elements are being irradiated at SRL. Analyses on all of the fuel element cores were within five per cent of the nominal composition.

All fuel rods were coextruded in an extrusion press which was mounted in a plutonium-contaminated glove box or hood. The extruded rods were easily decontaminated to low levels (smearable plutonium contamination, less than 500 disintegrations per minute). In the majority of the cases no smearable contamination was detected. Plug and socket type end fittings were machined on all of the coextruded fuel rods. No radioactive contamination on the machined surfaces was detected.

It was demonstrated that the fuel element fabrication process which was developed is capable of producing metallurgically bonded fuel elements. The use of essentially as-cast fuel cores in the coextrusion billets substantially reduced the amount of core machining required and fuel alloy chips generated.

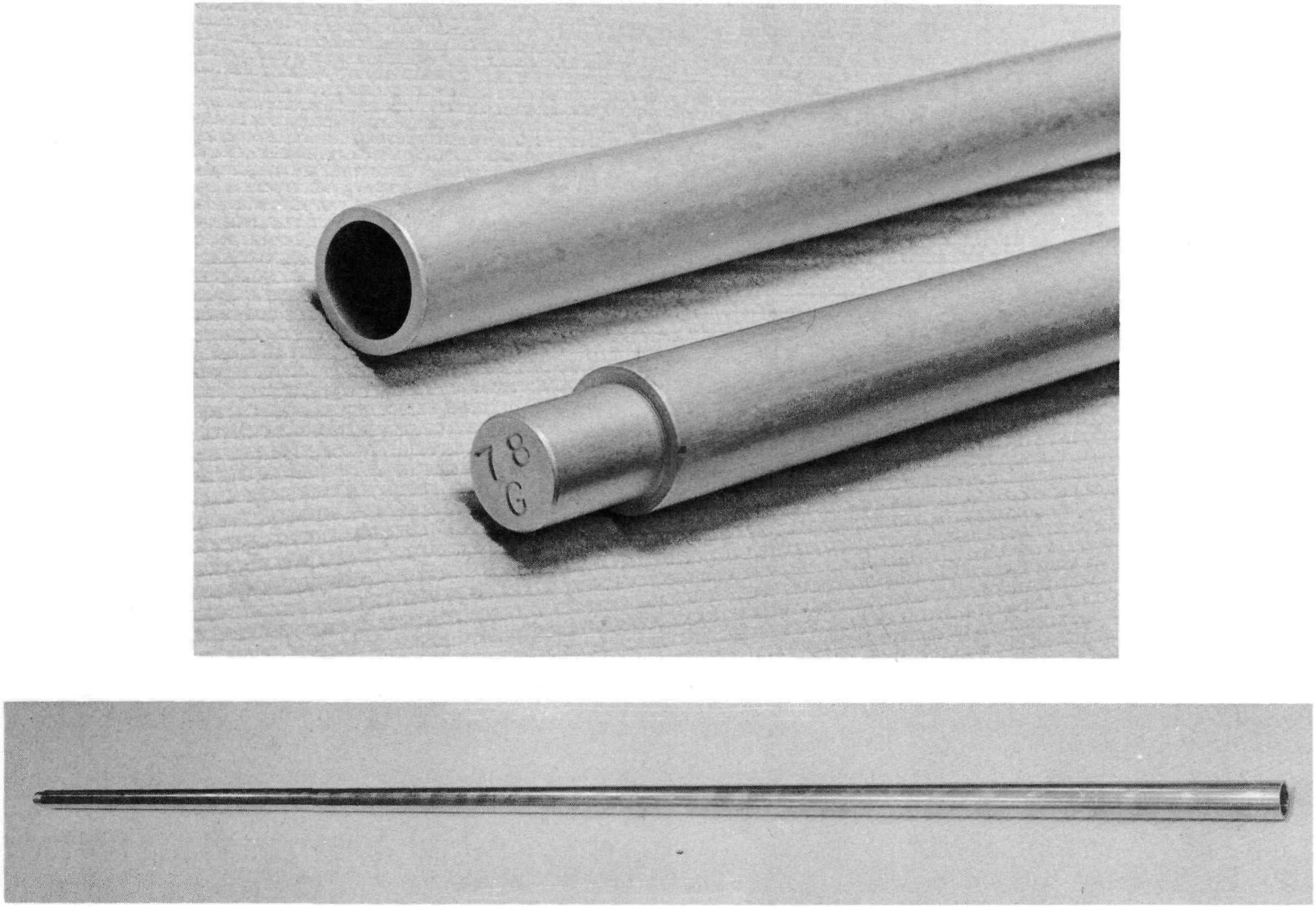

FIGURE 1

Coextruded, Aluminum-Clad, Aluminum-7.35 w/o Plutonium Alloy Fuel Element
Note End Fittings in Close-up of Etched, Finished Fuel Rods

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(1)

(2)

(3)

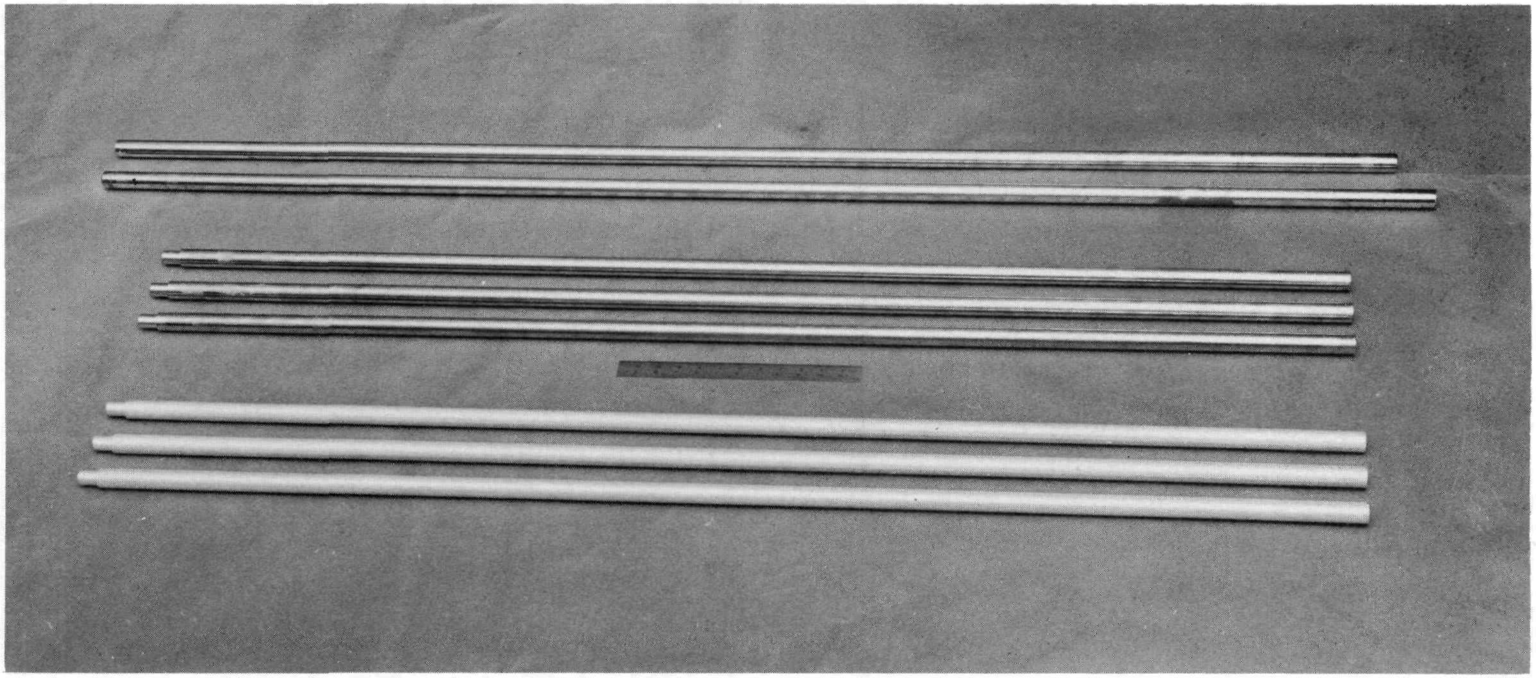


FIGURE 2

Coextruded Aluminum-Plutonium Alloy Fuel Elements at Various Stages: (1) Extruded and Straightened, (2) Machined, and (3) Etched and Inspected

DISCUSSION

Coextrusion was selected as the most promising method of fabricating the required metallurgically-bonded fuel elements shown in Figures 1 and 2. The 280-ton horizontal extrusion press (Figure 3) to be employed was a hooded unit and was contaminated with plutonium. Development work was initiated to determine a satisfactory fabrication technique. Aluminum-uranium alloy billet cores were cast and machined and placed in machined aluminum (1100 alloy) jackets for cursory extrusion experiments to establish the approximate billet core end configurations which would produce acceptable extruded fuel core contours and yet maintain adequate cladding thickness (Figure 4). The lead end of the coextruded rod presented more of a problem than the trailing end. Using the experimentally determined billet core shapes, aluminum-plutonium alloy cores and aluminum (X-8001 alloy, see Appendix) containers were prepared and additional coextrusion experiments conducted. The aluminum-plutonium alloy billet cores were machined on a tracer lathe. The billet core configuration was modified and tested until satisfactory results were consistently obtained. The ideal billet core configuration for square core ends on the extruded rod was found to be a spherical end of 0.840-inch radius connected to the billet core cylindrical surface by a cone with an apex angle of 60 degrees. However, a "dogbone" or an enlargement of the lead and trailing ends of the extruded core was observed (Figure 4) when this contour was employed. The enlargement was severe enough to decrease the cladding thickness on the first and last two inches of core to less than the minimum allowed (0.040 inches). By making the design modifications shown in Figure 4, the core end enlargement was reduced, although the squareness of the core ends was sacrificed to a degree. The entire fabrication process is shown in flow chart form in Figure 5.

Briefly, the process consists of alloying aluminum (1245 alloy, see Appendix) with plutonium, either in the form of metal or aluminum-plutonium alloy, at 850-950 C in an air melting induction furnace. Melt temperature was controlled by thermocouples located in the crucible wall. The alloy was held at temperature for 10-20 minutes. Induction and manual stirring of the

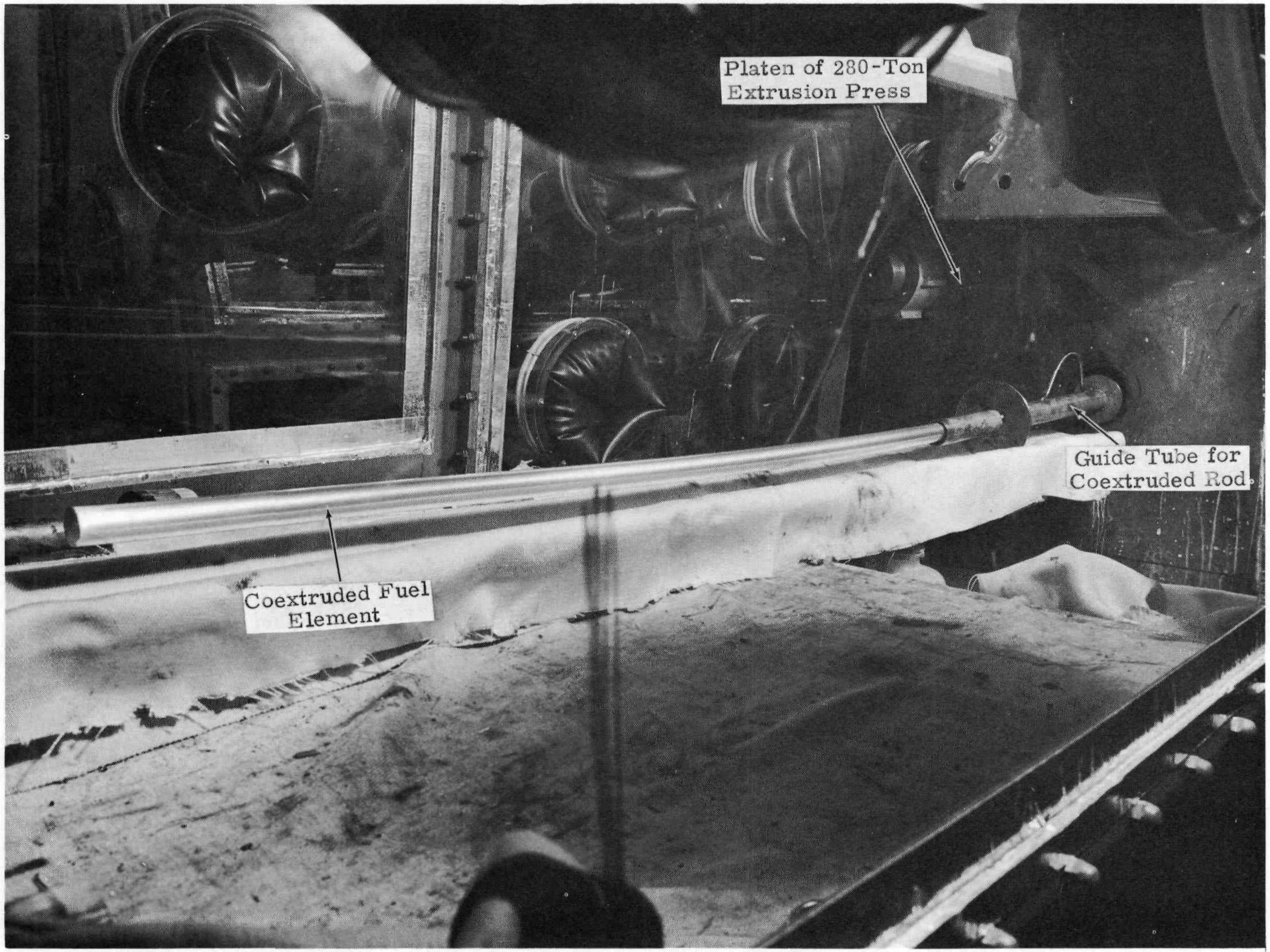


FIGURE 3

View of Al-Clad, Al-Pu Alloy Fuel Element During Coextrusion Operation in Hooded Extrusion Press

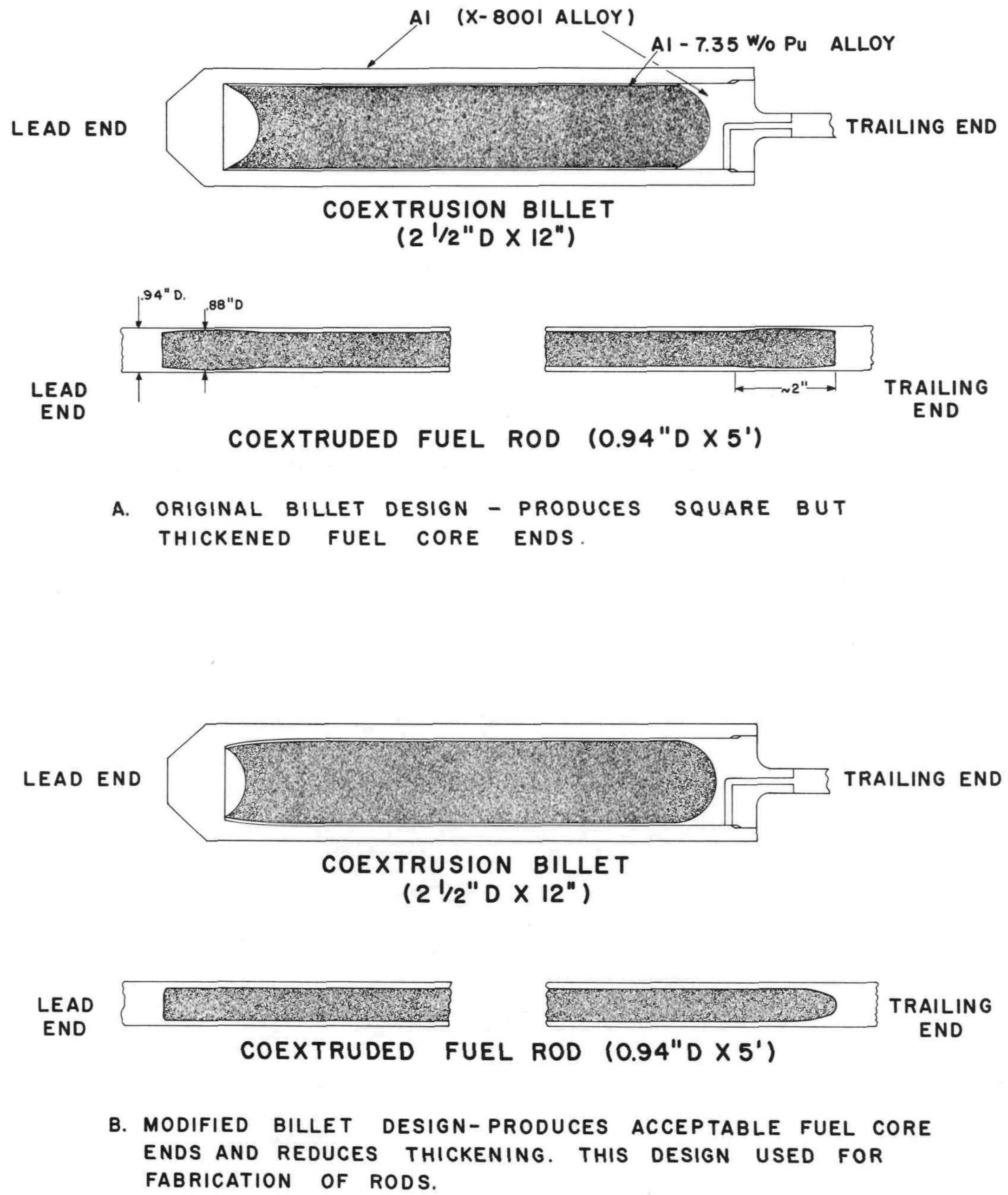


FIGURE 4

Development of Al-7.35 w/o Pu Alloy Coextrusion Billet

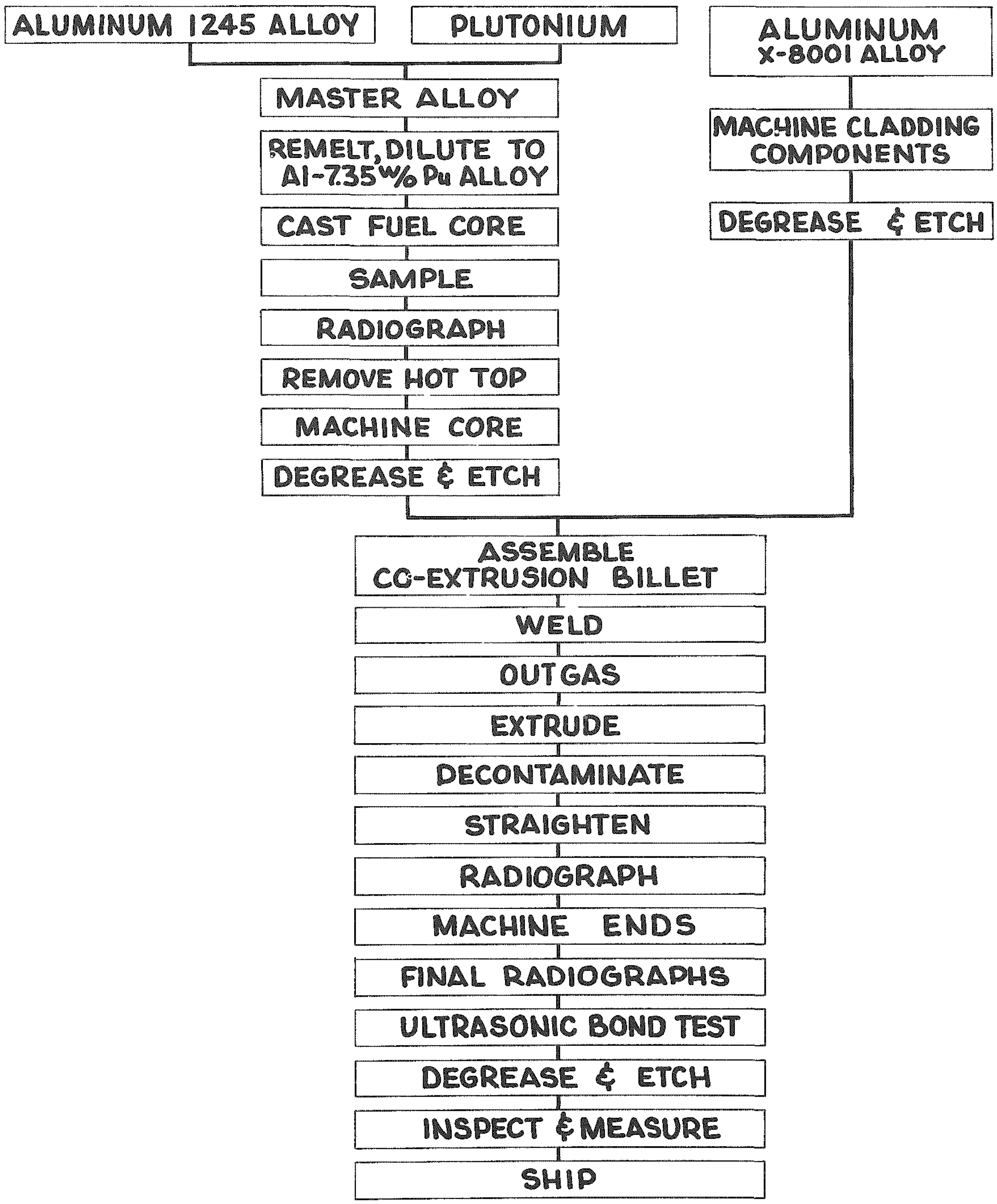


FIGURE 5

Fabrication of Coextruded Aluminum-Plutonium Fuel Elements melt was employed. The melt temperature was reduced to 775 C and the billet cores were individually cast by pouring the melt into one-piece, hot (about 300 C) graphite molds. Depending on amount of scrap available for recycle, 8-14 billet cores were produced per melt. An analytical sample was taken from the first and last billet core of each melt. One historical sample from every billet core was retained. A hot top was provided on the mold to feed the solidification shrinkage. The mold stood vertically and was filled rapidly in order to obtain a good surface on the billets. The billet cores shown in Figure 6 are cast to the correct diameter and with one end configuration to eliminate as much machining as possible. Radiation level for one billet core was about 160 milliroentgens per hour (direct contact, within two inches of the piece). The nominal plutonium concentration of the alloy is 7.35 w/o. The analyses on all of the cast billet cores were within five per cent of the nominal composition. The billet quality was spot checked by radiography. The hot top was removed from each billet core by a cut-off saw. Cropped billets cores were machined in a lathe with a pair of form cutters which produced the concave-convex end on the billet core (Figure 4). A machined billet core weighed 1100-1150 grams.

The machined billet cores and billet cladding components (Figure 7) were cleaned and assembled. The cladding components were machined from extruded aluminum (X-8001 alloy) bar stock. All coextrusion billet parts were degreased with trichlorethylene, etched in sodium hydroxide, and etched in nitric-hydrofluoric acid. See Appendix for details. The coextrusion billet was assembled and fusion welded. The trailing-end plug was joined to the container and an aluminum (3003 alloy, see Appendix) tube, about 12 inches long, was welded to the trailing-end plug protrusion. The welded coextrusion billets were outgassed for at least 12 hours at 590 C. The pressure obtained was 4 to 7 x 10^{-5} millimeters of mercury as measured at the manifold to which the billet outgassing tubes are connected. The outgassed billets were sealed by pressure welding in the tube section and placed in the extrusion press billet furnace which was operated at 545 C. The pressure weld was effected by crimping the tube with a pair of modified

FIGURE 6

Aluminum-7.35 w/o Plutonium Alloy Fuel Core Castings (1/2X)

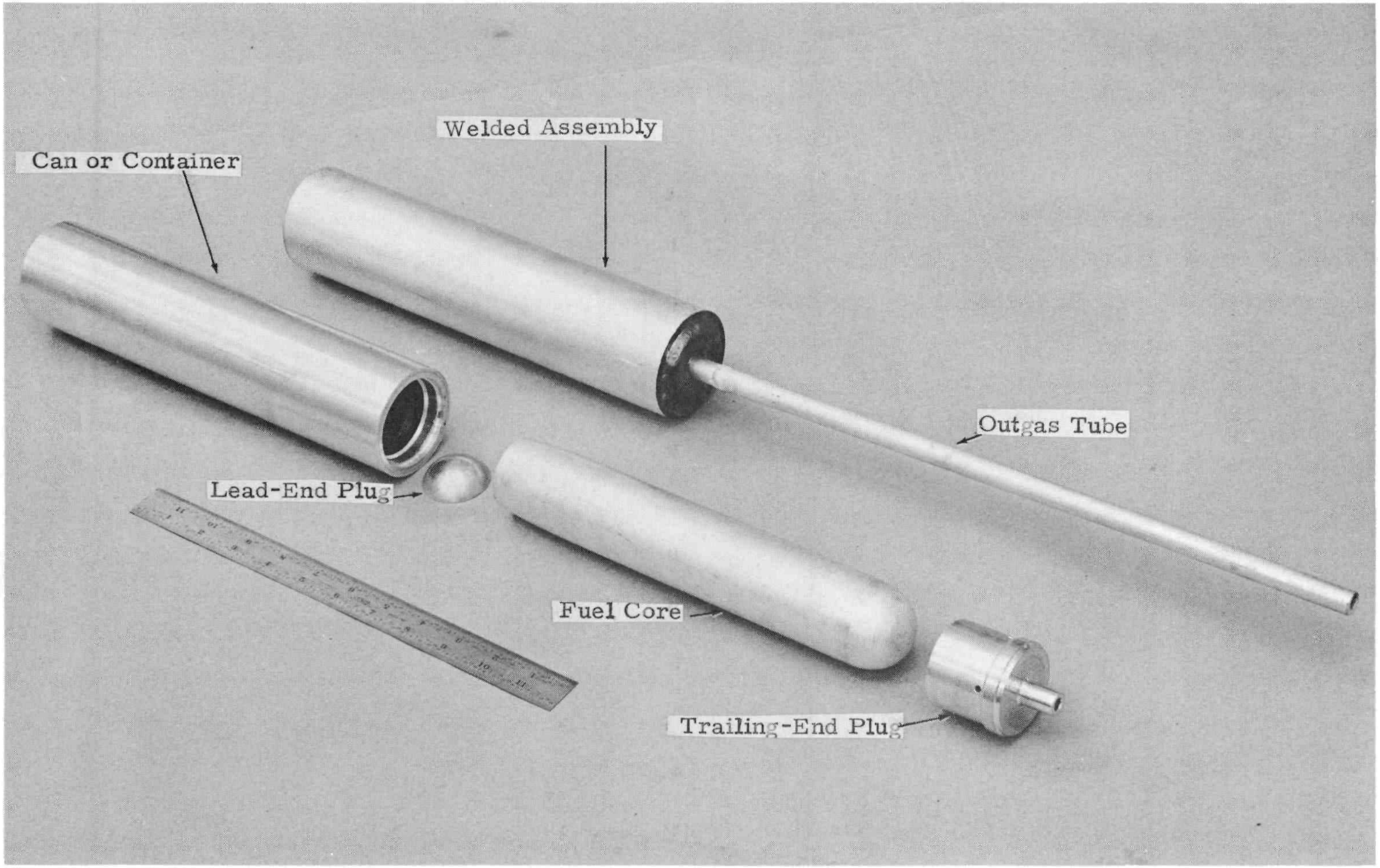


FIGURE 7

Coextrusion Billet Components and Welded Assembly bolt cutters. The coextrusion billet was 2.5 inches in diameter and about 12 inches long. The billet core was 1.80 inches in diameter and the container wall was 0.350 inches thick. The die and the preheated billet were lubricated with a graphite-oil dispersion. The average extrusion pressure was 64,200 pounds per square inch. The extrusion die container was operated at 525 C and the extrusion die at about 100 C. The ram speed was about 20 inches per minute. A streamline-flow type die with a 90 degree entrance angle was used. The extruded rod was approximately 70 inches long, had a fuel core length of 55-57 inches, had an outside diameter of 0.94 inches and had a cladding thickness of about 0.10 inches. The over-all reduction in area was 6.7 to 1, however, since the core was harder than the cladding, a difference in relative reduction was obtained. The former had a reduction in area of 5.9 to 1 and the latter, about 11 to 1. The extruded rods were trimmed to 64 inches in length in length to facilitate subsequent handling and fabrication steps. A single coextruded rod exhibited a radiation level of about 26 milliroentgens per hour (direct contact, within two inches of piece). During the fabrication effort, the average production rate of rods at the extrusion step was 12 per eight-hour shift. Billet heating time and billet-furnace capacity were the limiting factors on the extrusion operation.

Since the extrusion step was performed in a plutonium-contaminated hood and since unclad aluminum-plutonium alloy billets for a different fabrication program were also periodically extruded from the same extrusion press container, the coextruded fuel rods had to be decontaminated. The rods were decontaminated by etching in sodium hydroxide and in nitric-hydrofluoric acid. See Appendix for detailed information on solutions used. The rods were surveyed for possible remaining contamination and if any were present, the treatment was repeated. The level of smearable contamination on the processed rods had to be less than 500 disintegrations per minute. Most of the processed rods had no detectable smearable contamination after one pass through the decontamination operation. The few exceptions were rods which had marred surfaces, caused by handling or galling of the pieces in the extrusion operation.

Surface condition of the extrusions was improved by minimizing the amount of lubricant (oil-graphite dispersion) used on the extrusion die, however, this led to considerable galling and necessitated cleaning of the die in a caustic solution after one to three extrusions.

The decontaminated rods were processed through a rod straightener in order to meet the specified tolerance of 0.010 inch maximum bow per foot of length and to produce a uniform diameter with a smooth finish (Figures 1 and 2). By employing a guide tube on the extrusion press (Figure 3), relatively straight rods were extruded. This significantly reduced the number of straightener passes to yield satisfactory rods. In general, two or three passes were normally required for the straightening step. Kerosene was used as a lubricant. A rod increased 0.05 inches in length after three passes and one end of the rod rotated about ten degrees with respect to the other end. Radiographs of the straightened rods were examined to estimate thickness of cladding, for presence of inclusions or voids, and to note location and appearance of the core ends.

The rods were radiographed to determine fuel core integrity and size and were cut to length. Plug and socket type end fittings, 1.00 inches long and 0.73 inches in diameter, were machined on each rod (Figure 1). Care was taken to center the fuel core with respect to the rod ends. Normally the fuel core end was 0.5-1.5 inches away from the nearest portion of the rod end fitting. A minimum of 1/8-inch of cladding was required. The machining step was performed in an open-front type hood. No contamination problems were encountered during this operation.

Final radiographic inspection of machined rods consisted of two full-length exposures (90 degrees apart) for cladding thickness measurements. The cladding thickness was visually measured on the radiographs with the aid of a scale-equipped magnifier.

Ultrasonic testing equipment was used to detect fuel rod discontinuities, the most important of which were non-bond areas. The specification states that the maximum allowable single non-bonded area on a rod, as measured on the surface of the rod and by ultrasonic transmission, is 1/8 of a square inch. The total non-bonded area on a rod must not exceed 3/8 of a square inch.

The core-clad interface on a well-bonded fuel element is shown in Figure 8. A fuel element with a nonbond area, detected by the ultrasonic tester, is shown in Figure 9. The testing equipment was also capable of detecting fuel core flaws of the type shown in Figure 10. Details of the ultrasonic testing unit and its operation may be found in the Appendix.

The rods were etched in sodium hydroxide and in nitric-chromic-hydrofluoric acid for a final cleaning treatment. See Appendix for details. The cleaned rods were measured and were visually inspected for cladding surface defects greater than 0.010 inches deep. Typical defects were inclusions, laps or seams, and galled areas. The specifications for the finished rods were: diameter, 0.933 to 0.943 inches; length, 59.875 to 60.125 inches; and straightness, maximum of 0.010 inches of bow per foot of length.

Detailed information on all fuel elements shipped to SRL is presented in the Appendix. Isotopic concentration of plutonium in the fuel elements may be found in HW-61439[7] and HW-61567[8].

The significant fabrication problems encountered were high boron content in some of the billet core castings, blisters on extruded rods, and metallic inclusions on straightened rods. A boron pickup of up to 100 parts per million was detected spectrographically in some of the billet cores. The boron pickup coincided with the use of clay-graphite crucibles (Figure 11) for melting. Previously, machined graphite crucibles were used. Samples of the crucible material were analyzed. Only the glaze, normally sprayed on the exterior of the crucible before firing, was found to contain a sufficient amount of boron to have caused the amount of boron detected in the alloy. The boron pickup disappeared in later alloys made in the same and similar crucibles. It is suspected that some of the glaze was inadvertently sprayed into the interior of the crucible and was ultimately consumed. Since SRL indicated that 100 parts per million boron could be tolerated in the alloy, no rejects resulted from this problem.

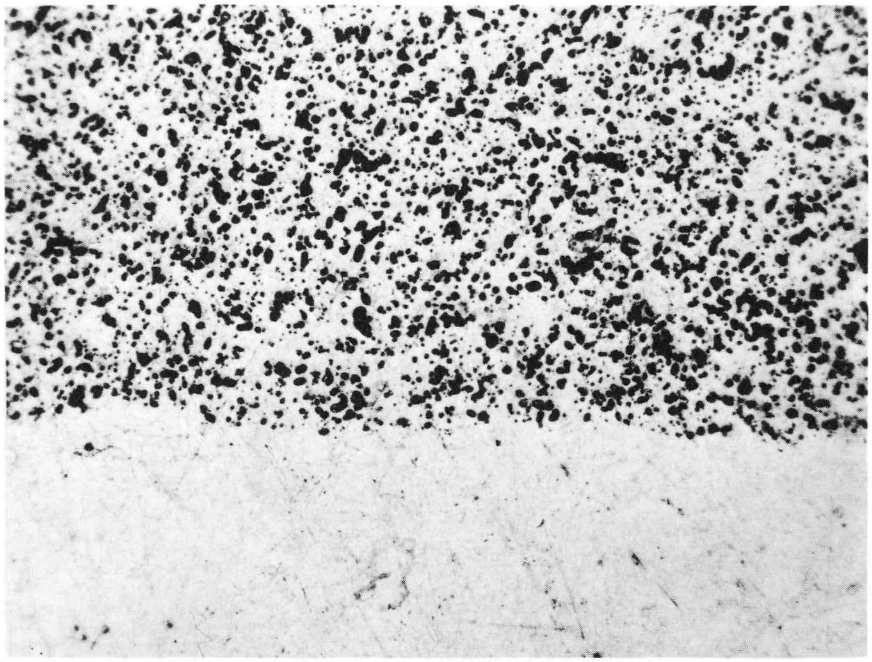


FIGURE 8

Photomicrograph of Tranverse Section at Bond Interface of Coextruded Al-7.35 w/o Pu Alloy Fuel Element (250X)

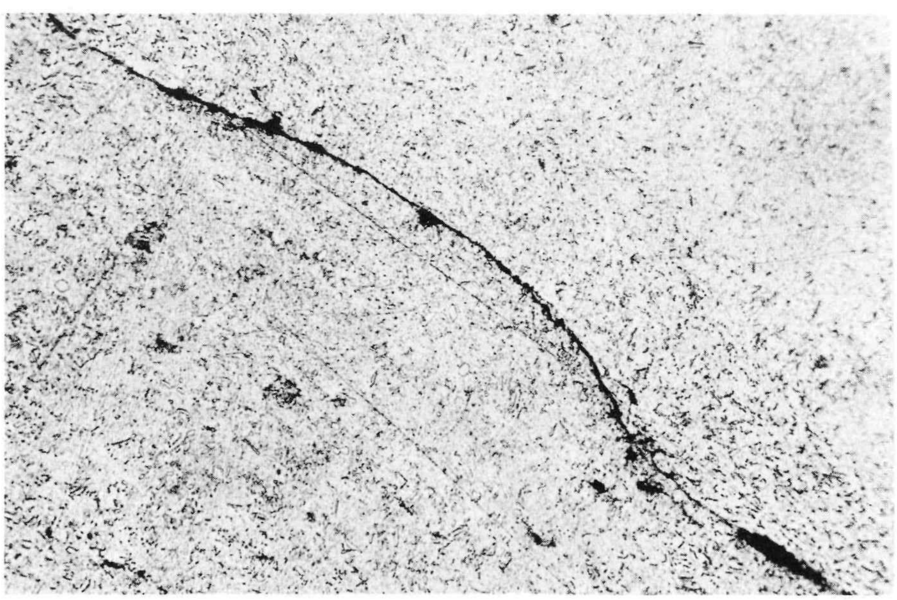


FIGURE 9

Photomicrograph of Transverse Section of Ultrasonically Detected Non-Bond Area on Coextruded Al-7.35 w/o Pu Alloy Fuel Element (250X)

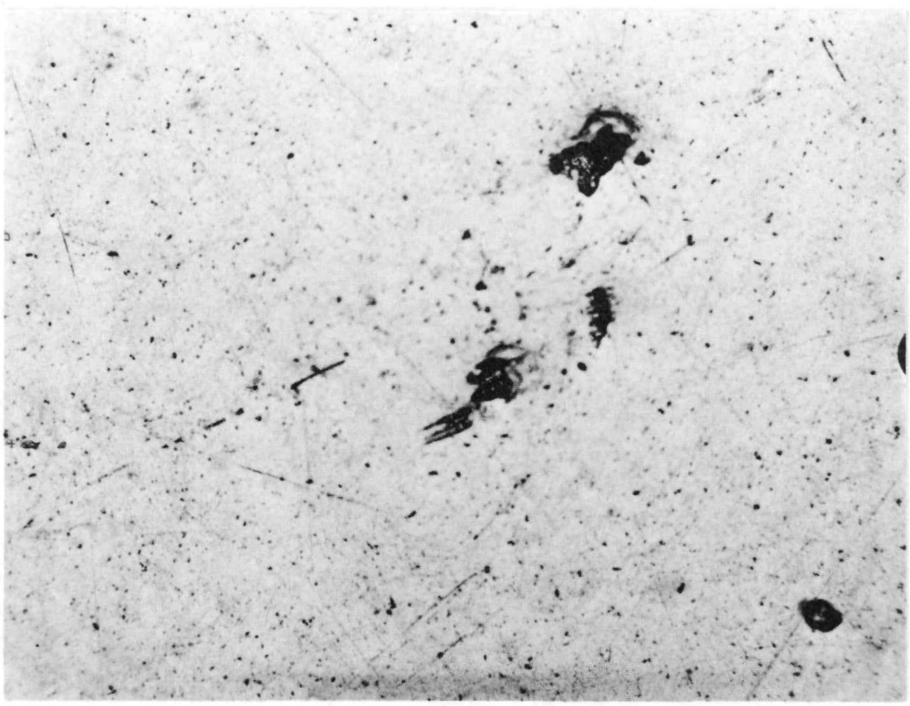
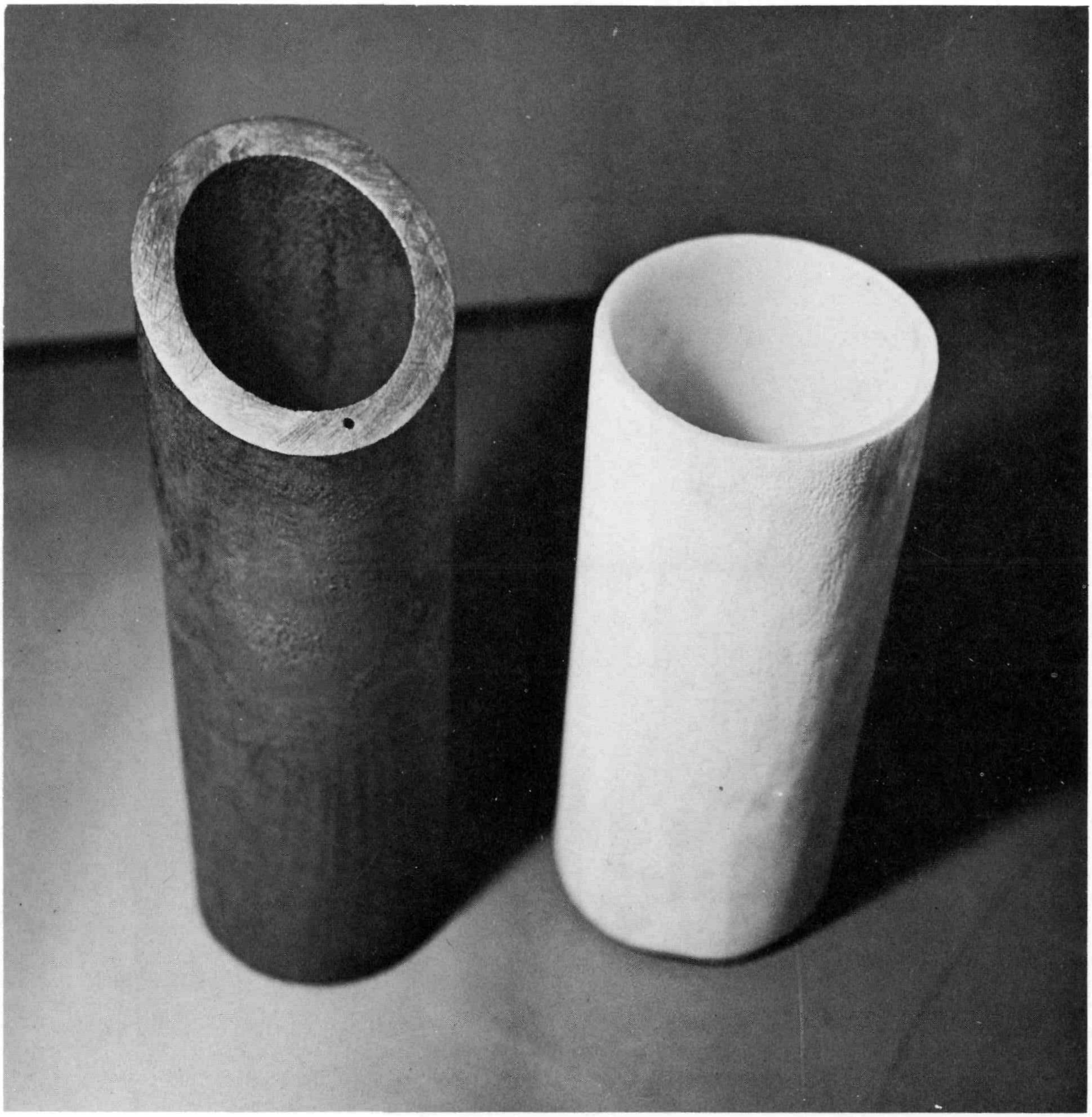


FIGURE 10

Photomicrograph of Transverse Section of Ultrasonically Detected Core Defects on Coextruded Al-7.35 w/o Pu Alloy Fuel Element (250X)



Clay-Graphite Crucible

SiO_2 Crucible

FIGURE 11

Crucibles for Use in Air-Melting Induction Furnace. Clay-Graphite Crucible is Placed in SiO_2 Crucible and Annular Gap Filled with Loose-Pack Bubbled Alumina. Thermocouples are Placed in the Single Hole in the Clay-Graphite Crucible Wall.

The majority of the blisters on the rods extruded during the early stages of the fabrication effort were caused by blockage of the outgassing tube during the fusion welding step. The cladding components were modified to reduce the possibility of passageway restriction and the blister reject rate was sharply reduced.

During final inspection of the rods a number of metallic inclusions were observed. The inclusion material was analyzed and found to contain mainly tin with some lead and copper. It was determined that the rod straightener guides were edged with this material and that the metal was scraped off of the guides by rods which had slightly rough or bent ends and was imbedded in the cladding during subsequent straightening operations. Normally the as-extruded rods (Figure 3) were fairly straight (less than about one inch bow over the entire length) but occasionally rods would be produced which had rather severe bends within the first six inches of the lead end of the extrusion. A nitric-chromic-hydrofluoric acid etch solution was employed to selectively remove the inclusions. See Appendix for details. Even with the chromic acid inhibitor present, the base metal was etched at a rate of 0.004 inches per hour. The maximum etch time for acceptable rods was set at 15 minutes.

ACKNOWLEDGEMENT

We would like to thank the following people for their splendid cooperation and assistance: G. E. Wilbur and R. L. Scott (Radiography); D. C. Worlton and F. R. Busch (Ultrasonic Bond Testing); L. C. Lemon (Welding); W. B. Weihermiller and L. C. Cox (Tool Design and Machining). The aid and the team spirit of the engineering assistants of the Plutonium Metallurgy Operation and the guidance and suggestions furnished by I. D. Thomas and O. J. Wick contributed very significantly to the success of the fabrication effort.

APPENDIX

I. ETCHING PROCEDURES

A. Coextrusion Billet Cladding and Core Cleaning

1. Degrease: Trichlorethylene
   Cladding - vapor
   Core - liquid (20 C)
2. Etch: Sodium Hydroxide
   Concentration - 10 w/o
   Temperature - 20 C
   Time - 5 minutes
3. Rinse: Running water (20 C)
4. Etch: Nitric-Hydrofluoric Acid
   Concentration - 10 volume percent HNO_3
   1 volume percent HF
   Temperature - 20 C
   Time - 30 seconds
5. Rinse: Running water (50-60 C)
6. Dry: Warm air

B. Decontamination of Extruded Rods

1. Etch: Sodium Hydroxide
   Concentration - 10 w/o
   Temperature - 40 C
   Time - 5 minutes
2. Rinse: Running water (50-60 C)
3. Etch: Nitric-Hydrofluoric Acid
   Concentration - 10 volume percent HNO_3
   1 volume percent HF
   Temperature - 20 C
   Time - 20 seconds
4. Rinse: Running water (50-60 C)
5. Dry: Warm air
6. Survey: Scan for alpha contamination

APPENDIX (contd.)

C. Final Cleaning of Fuel Rods

1. Degrease: Trichlorethylene (liquid, 20 C)
2. Etch: Sodium Hydroxide
   Concentration - 10 w/o
   Temperature - 20 C
   Time - 4 minutes
3. Rinse: Running water (20 C)
4. Etch: Nitric-Chromic-Hydrofluoric acid
   Concentration - 10 volume percent HNO_3
   10 volume percent H_2CrO_4
   2 volume percent HF
   Temperature - 20 C
   Time - 30 seconds (normal)
   15 minutes (maximum)
5. Rinse: Running water (20 C)
6. Dry: Wipe
7. Survey: Scan for alpha contamination

II. ULTRASONIC TESTING OF FUEL ELEMENTS

A. Equipment Details

1. Transducer - Lithium sulfate crystal, 3/4 inch diameter, focused to 1 8 inch diameter on the fuel rod surface
2. Frequency - 10 megacycles
3. Fuel Rod Rotation - 150 revolutions per minute
4. Fuel Rod Translation - 16 inches per minute
5. Surface Scanned - 100 per cent of fuel rod cylindrical surface is examined

   Rod is fully immersed in water during examination

APPENDIX (contd.)

6. Measurement Method - Manual observation of oscilloscope (Figure 12). Operator outlines on fuel rod surface the reject areas and records the defect type, size, and location

B. Experiments with Al-7.35 U Alloy Fuel Rods

Initial experiments with the ultrasonic testing equipment were performed on aluminum-7.35 w/o uranium alloy coextruded fuel rods. The equipment was capable of easily determining whether a fuel rod was well bonded (Figure 13), had nonbond areas (Figure 14), or had core defects (Figure 15).

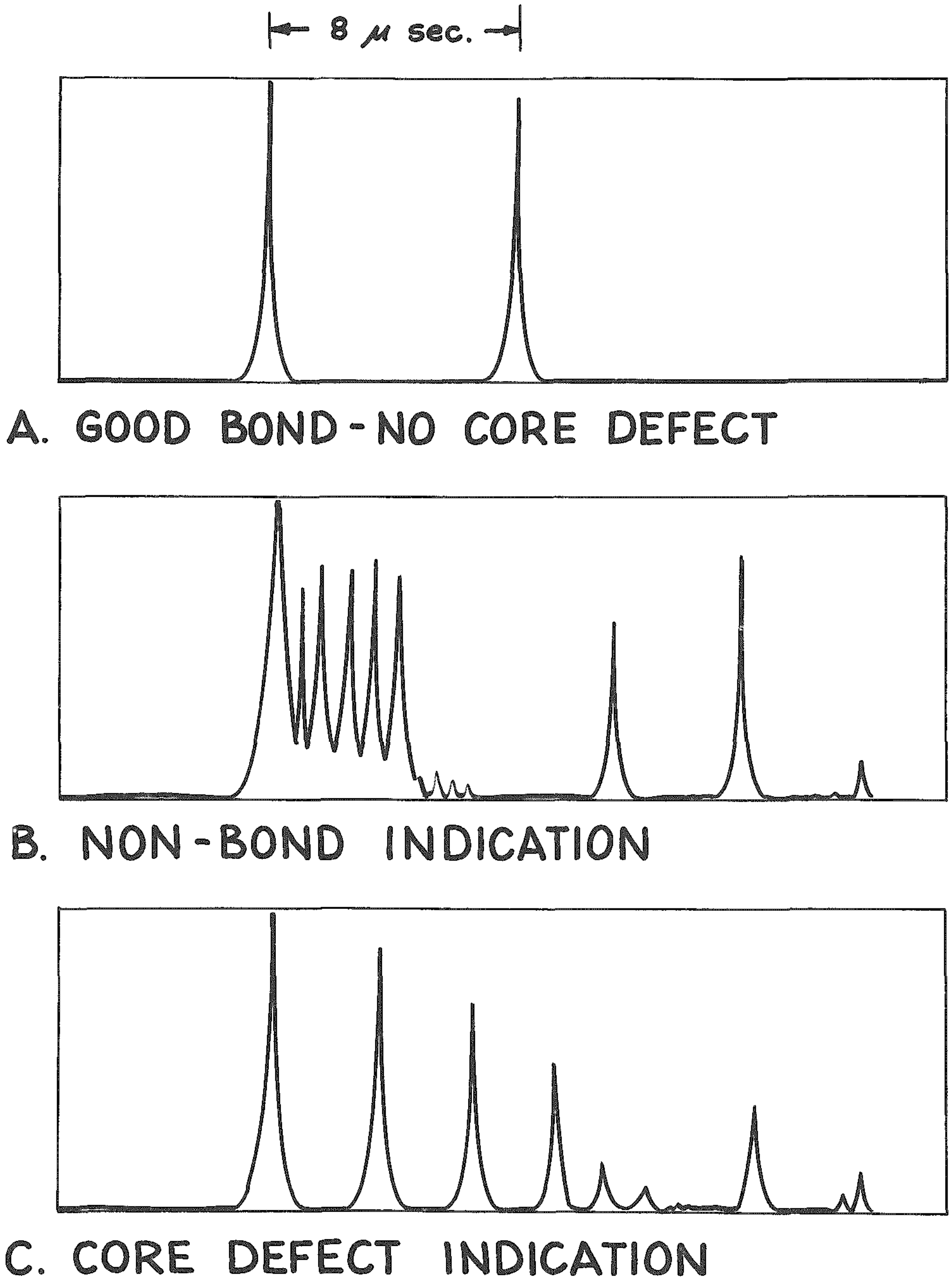
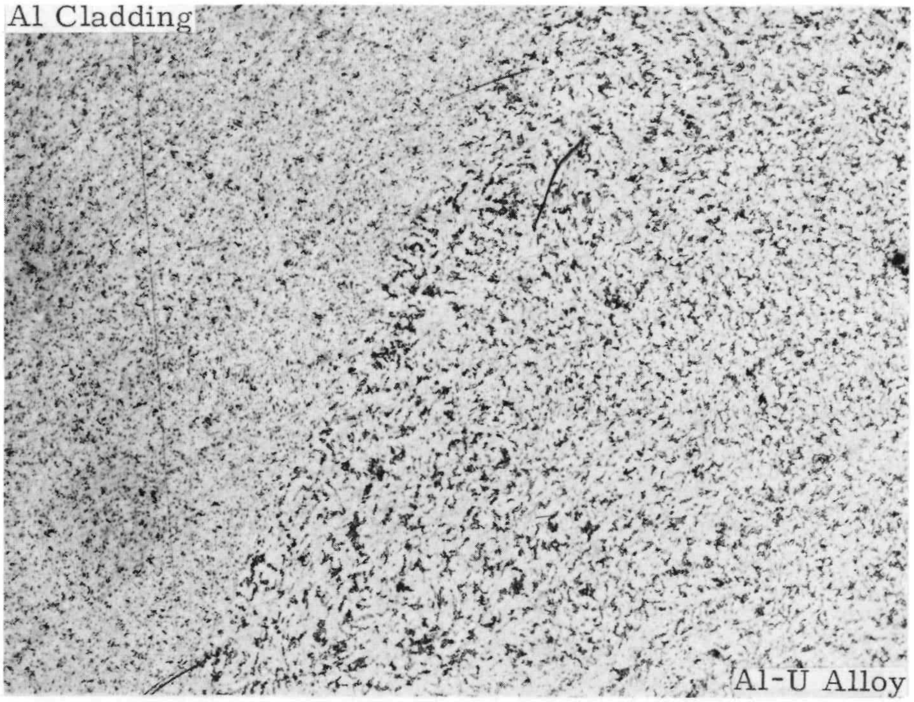
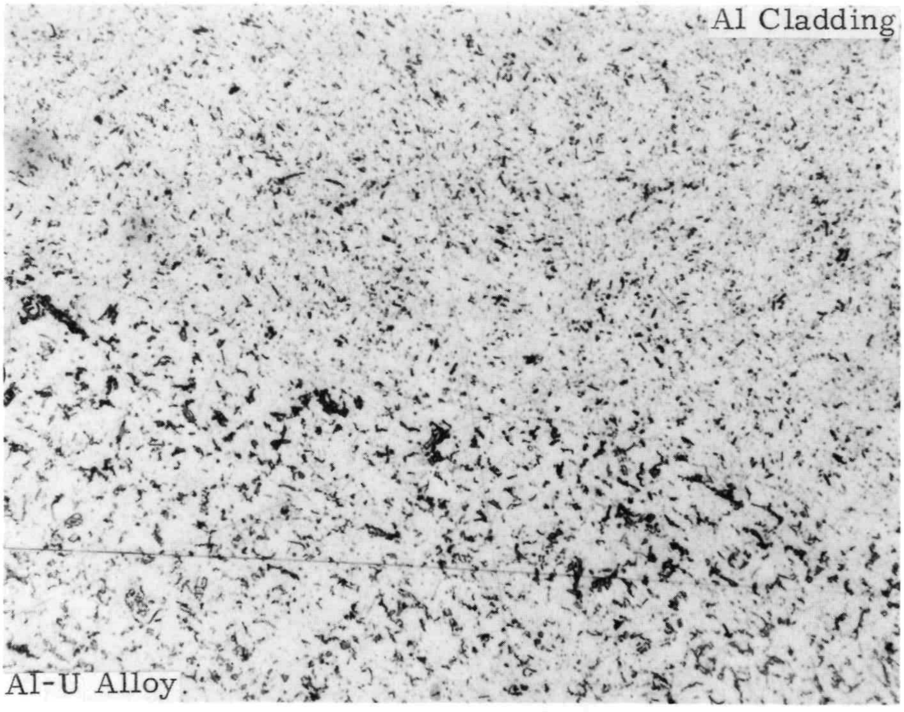


FIGURE 12

In (A), Peak at left Represents Signal from Initial Water-Rod Interface and Peak at right is response from Diametrically Opposite Water-Rod Interface. Note Distortion Produced by Defects in (B) and (C).



(a) 100X

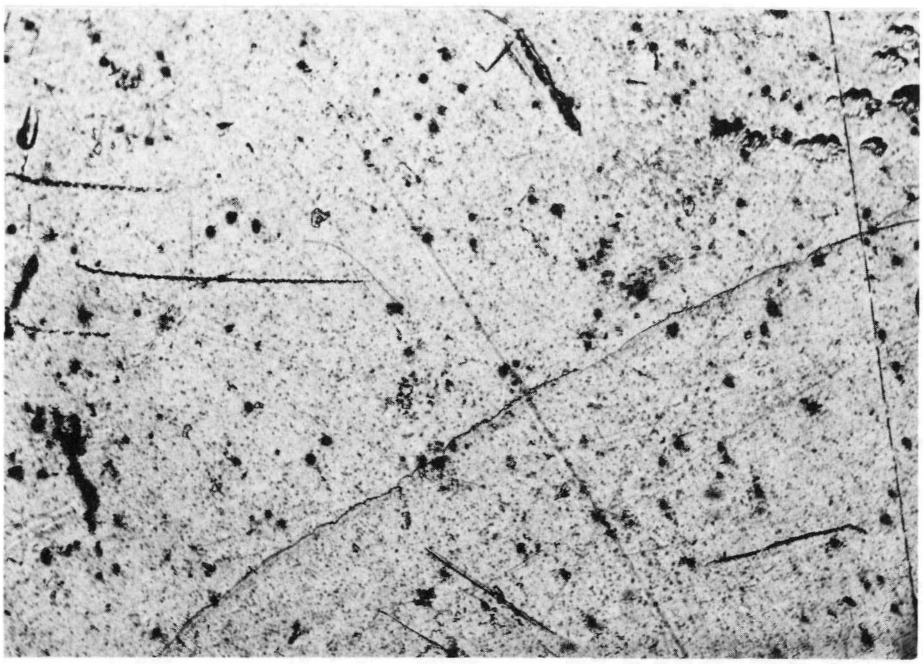


(b) 250X

FIGURE 13

Photomicrographs of Transverse Section of Al-Clad, Al-7.35 w/o U Alloy Coextruded Fuel Element. Ultrasonic Test Indicated Good Bonding Present

Cladding



Fuel Core

FIGURE 14

Photomicrograph of Ultrasonically Detected Non-Bond Area on Transverse Section of Coextruded Al-7.35 w/o U Alloy Fuel Rod (50X)

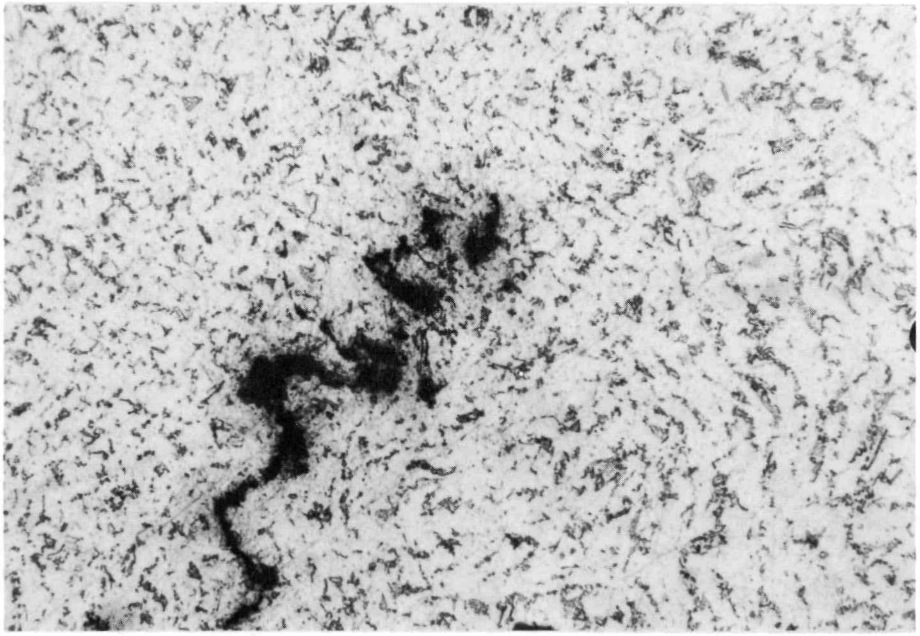


FIGURE 15

Photomicrograph of Transverse Section of Al-Clad, Al-7.35 w/o U Alloy Coextruded Fuel Element. Ultrasonic Test Indicated Core Defect Present (250X)

III. FUEL ELEMENT DATA

A detailed listing of all elements requested by the Savannah River Laboratory, including special and end-reactor evaluation elements, is located in HW-67651.[3] The 144 fuel elements for irradiation are listed below:[9, 10]

Rod number	Plutonium w/o	Plutonium (grams)	Minimum cladding thickness (mils)	Fuel core length (inches)
18A	7.37	83.10	42	56
19E	7.58	86.34	45	57-3/4
F	7.58	85.98	47	55-13/16
20B	7.34	83.40	40	55-1/2
21F	7.39	83.84	75	56-5/8
G	7.39	83.57	60	55-1/4
22C	7.49	85.33	60	57-1/8
E	7.49	84.07	45	56-1/4
I	7.49	84.64	45	55-1/4
K	7.49	85.45	55	56-1/4
23J	7.06	80.12	65	56-3/4
24D	7.24	82.07	45	54-7/8
G	7.24	82.36	50	57
I	7.24	81.88	65	55-11/16
K	7.24	82.03	45	56-9/16
L	7.24	82.50	47	56-3/4
M	7.24	81.99	50	54-1/2
25C	7.26	82.42	60	56
D	7.26	82.46	45	57-1/4
G	7.26	83.05	55	56-1/2
H	7.26	82.95	50	56-3/4
I	7.26	82.79	45	56-1/8
J	7.26	82.66	65	57
L	7.26	83.21	50	56-11/16
M	7.26	82.11	45	56
26B	7.10	81.14	50	56-1/2
E	7.10	80.86	55	56-3/4
G	7.10	80.23	40	56-7/8
I	7.10	81.17	45	57
K	7.10	80.55	45	55-1/2
27A	7.30	82.42	43	56-3/4
D	7.30	82.89	55	56-1/2
E	7.30	81.87	40	55-3/4
H	7.30	81.32	40	55-7/8
K	7.30	83.49	48	56-1/2
L	7.30	81.70	44	55-3/4
28C	7.27	82.22	45	56-5/8

III. FUEL ELEMENT DATA (contd.)

Rod number	Plutonium w/o	Plutonium (grams)	Minimum cladding thickness (mils)	Fuel core length (inches)
28D	7.27	82.27	60	56-3/8
F	7.27	81.87	45	55
29A	7.21	79.76	55	54-1/4
C	7.21	79.17	55	54-5/8
D	7.21	79.71	45	55-5/8
E	7.21	79.88	60	55-1/2
F	7.21	78.98	40	55-3/4
G	7.21	80.18	55	55-7/8
H	7.21	80.11	42	53-3/8
I	7.21	80.18	40	55
30C	7.34	81.72	40	55-7/8
E	7.34	81.92	40	55-1/2
H	7.34	81.63	44	55-7/8
I	7.34	81.69	45	55-7/8
J	7.34	81.58	50	56-1/4
L	7.34	81.61	40	54-1/8
31A	7.49	82.65	40	55-3/4
B	7.49	83.25	47	55-3/4
C	7.49	82.91	44	55-7/8
F	7.49	83.40	40	55-7/8
G	7.49	83.65	50	55-1/4
H	7.49	83.08	60	56
32A	7.36	82.18	40	55-3/8
B	7.36	81.96	40	56
C	7.36	81.80	42	55-5/8
D	7.36	81.72	40	55-5/8
F	7.36	81.85	50	55-3/8
J	7.36	81.60	40	55-1/2
33D	7.30	81.33	45	56
E	7.30	81.40	45	56
F	7.30	81.03	47	55-1/2
G	7.30	81.03	42	56-1/4
H	7.30	81.28	40	55-1/4
I	7.30	80.99	40	55
34A	7.53	83.67	45	55-7/8
B	7.53	83.85	41	56-5/8
C	7.53	83.43	40	55-1/8
D	7.53	83.70	40	55-1/2
F	7.53	83.59	42	55-5/8
H	7.53	83.51	42	55-3/4
I	7.53	84.12	40	55-1/4
J	7.53	83.85	43	55-3/4
L	7.53	83.36	45	55-1/4

III. FUEL ELEMENT DATA (contd.)

Rod number	Plutonium w/o	Plutonium (grams)	Minimum cladding thickness (mils)	Fuel core length (inches)
35B	7.49	82.02	48	55-1/8
C	7.49	82.35	50	55
36A	7.06	78.20	45	55-7/8
B	7.06	79.28	65	56-1/2
D	7.06	78.65	45	56
37A	7.11	78.78	40	55
B	7.11	78.99	52	55-3/4
G	7.11	78.42	62	55-1/8
H	7.11	78.36	45	55-7/8
I	7.11	79.23	50	55-1/4
J	7.11	79.28	45	55
L	7.11	79.38	48	55-3/4
38A	7.55	83.15	40	55-1/2
C	7.55	83.79	45	55-3/8
E	7.55	83.55	50	55-3/4
G	7.55	84.00	65	55-7/8
H	7.55	84.45	45	56
I	7.55	84.64	40	56-1/8
J	7.55	84.64	50	55-7/8
39B	7.49	83.33	60	55-1/4
C	7.49	83.30	60	54-3/4
E	7.49	83.16	60	55-1/2
F	7.49	83.24	55	55-3/4
G	7.49	83.00	45	54-7/8
I	7.49	83.59	60	55-1/2
J	7.49	83.55	55	55-5/8
40A	7.16	81.60	60	55-1/2
B	7.16	79.96	40	55-1/2
E	7.16	79.78	50	54-1/2
F	7.16	79.97	55	55-1/2
G	7.16	79.82	75	55
H	7.16	79.87	40	56
I	7.16	80.01	55	55-1/4
J	7.16	80.05	60	55-5/8
K	7.16	79.97	65	55-7/8
M	7.16	80.05	50	55-1/8
N	7.16	79.94	60	55-3/4
41A	7.29	81.47	55	55-3/8
B	7.29	81.43	65	55-1/2
D	7.29	81.17	50	55
E	7.29	81.09	50	55-3/4
F	7.29	80.94	40	55
G	7.29	81.29	50	55-7/8

III. FUEL ELEMENT DATA (contd.)

Rod number	Plutonium w/o	Plutonium (grams)	Minimum cladding thickness (mils)	Fuel core length (inches)
41I	7.29	81.43	60	55-1/8
K	7.29	81.28	60	55-1/2
43A	7.27	81.02	60	55-3/8
B	7.27	80.99	55	55-3/4
C	7.27	81.18	50	55-1/8
D	7.27	81.36	60	56-1/4
E	7.27	81.09	55	55-3/4
I	7.27	81.10	60	55-3/4
44A	7.53	84.06	60	55-1/2
B	7.53	84.11	75	55-1/4
C	7.53	83.99	55	54-3/4
D	7.53	84.15	75	55-1/2
F	7.53	84.05	60	55-3/8
G	7.53	84.26	65	55-3/8
45A	7.35	81.95	60	54-3/4
B	7.35	81.88	60	55-7/8
C	7.35	81.73	65	55-1/16
D	7.35	81.95	75	55-1/8
E	7.35	81.75	65	55-1/8
F	7.35	82.03	60	55-1/8
G	7.35	81.79	60	55

IV. ALUMINUM ALLOY COMPOSITIONS

	Per cent	Element
A. X-8001-F Alloy	0.9 - 1.3	Ni
	0.45 - 0.70	Fe
	0.17 maximum	Si
	0.15 "	Cu
	0.008 "	Li
	0.003 "	Cd
	0.001 "	Co
	0.001 "	B
	0.05 "	others, each
	0.15 "	others, total
	Remainder	Al
B. 1245 Alloy	0.70 "	Fe + Si
	0.05 "	Ti
	0.04 "	Cu
	0.03 "	Mn
	0.03 "	Cr
	0.03 "	Zn
	0.01 "	Mg
	0.01 "	Sn
	0.01 "	Pb
	0.01 "	Bi
	0.01 "	Ni
	0.008 "	Li
	0.003 "	Cd
	0.001 "	Co
	0.001 "	B
	99.30 - 99.80 "	Al
C. 3003-F Alloy	0.6	Si
	0.7	Fe
	0.20	Cu
	1.0 - 1.5	Mn
	0.10	Zn
	0.05	others, each
	0.15	others, total
	Remainder	Al

REFERENCES

1. Gifford, A. T. Letter to H. M. Parker: Fabrication of Fuel Elements for Trans-plutonic Element Irradiation Program. May 20, 1958.
2. Montenyohl, V. I. Classified Title. March 21, 1959. (SECRET).
3. Bailey, W. J., et al. Fabrication of Aluminum-Plutonium Alloy Fuel Elements by Coextrusion - Supplement to HW-63151, HW-67651. December 1, 1960. (SECRET).
4. Albaugh, F. W. Reactor and Fuels Research and Development Operation - Monthly Report - May 1959, HW-60505 A. June 15, 1959. (SECRET).
5. Albaugh, F. W. Reactor and Fuels Research and Development Operation - Monthly Report - June, 1959, HW-60846 A. July 15, 1959. (SECRET).
6. Albaugh, F. W. Reactor and Fuels Research and Development Operation - Monthly Report - July, 1959, HW-61374 A. August 15, 1959. (SECRET).
7. Shortess, C. J., Jr. Isotopic Concentration of Plutonium in Trans-plutonic Fuel Elements, HW-61439. August 6, 1959. (SECRET).
8. Shortess, C. J., Jr. Isotopic Concentration Analyses - Transplutonic Fuel Elements, HW-61567. August 14, 1959. (SECRET).
9. Eberhard, B. J. Classified Title. May 11, 1959. (SECRET).
10. Gifford, A. T. U. S. Atomic Energy Commission - Hanford Operations Office - Specifications for Pu-Al Slugs, HAN-70429. October 29, 1958. (SECRET).

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