ANL-6659
Metals, Ceramics,
and Materials
(TID-4500, 24th Ed.)
AEC Research and
Development Report

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BREEDING-GAIN SPECIMENS FOR EBR-I CORE IV

by

A. B. Shuck, A. G. Hins, W. R. Burt,
and R. A. Beatty

Parts of this information have been presented
in the following reports:

ANL-6516, Metallurgy Division Annual Report for 1961, p. 64, 65

ANL-6677, Metallurgy Division Annual Report for 1962, pp. 57 to 63

Metallurgy Division
Program 7.2.23

September 1963

Operated by The University of Chicago
under
Contract W-31-109-eng-38
with the
U. S. Atomic Energy Commission

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INTRODUCTION

A large number of jacketed plutonium, enriched uranium and depleted uranium foils are required for breeding-gain studies with the plutonium Core IV in EBR-I. These specimens will be irradiated in special fuel rods and in carrier tubes termed "baskets." Jacketed plutonium or depleted uranium slugs will be between the foils so that the test assemblies have nuclear similarity to standard fuel rods. Blind tubes, termed "thimbles," are provided such that they have the same outside diameter as a fuel or blanket rod. These will be assembled in the EBR-I fuel rod clusters and will extend to the top of the reactor. The thimbles will form wells into which the baskets, loaded with the test foils and slugs, will be lowered.

The purposes of Program 7.2.23 were (1) to fabricate the plutonium and uranium specimens, and spacer slugs, and (2) to furnish the thimbles, baskets, and other materials required for the experiments. Stainless steel tubing, uranium foils, and uranium slugs were furnished by the Foundry and Fabrication Group. The fabrication of plutonium specimens, final machining, assembly and welding of thimbles and baskets, and the assembly of the special fuel and thermocouple rods were done by the Plutonium Fabrication Group.

A total of 240 aluminum-clad plutonium foils and 102 aluminum-jacketed plutonium slugs were made. Care was taken to prevent external alpha contamination of these specimens, so that they could be used without glovebox protection. Nine hundred (93.5%) enriched uranium foils and the same number of (0.22% U^{235}) depleted uranium foils were prepared. A total of 441 depleted uranium blanket slugs were furnished. The compositions, quantities required, and dimensions of plutonium and uranium breeding-gain specimens are shown in Table I.

The Experimental Breeder Reactor I, Mark IV, is loaded with two types of blanket rods. The outer sections use rods from the Mark-III loading, each rod having a jacket diameter of 0.413 in. The inner rods are of the same diameter, 0.297 in., as the Core-IV fuel rods. Two sizes of baskets and thimbles were therefore required. Nine 0.413-in.-diameter x 10-ft-long thimbles and eighteen 0.334-in.-diameter x 2-ft-long baskets were supplied for the outer blanket positions. Twenty 0.297-in.-diameter x 10-ft-long thimbles and thirty-four 0.237-in.-diameter x 24-in.-long baskets were made for the core and inner blanket positions. The dimensions and construction of

the specimens, thimbles and baskets are shown in Figure 1. The basket plugs were secured by a bead which was rolled into the tubes by a tool modified from a tubing cutter. This tool was furnished to allow reuse of the baskets.

Table I

PLUTONIUM AND URANIUM BREEDING-GAIN SPECIMENS

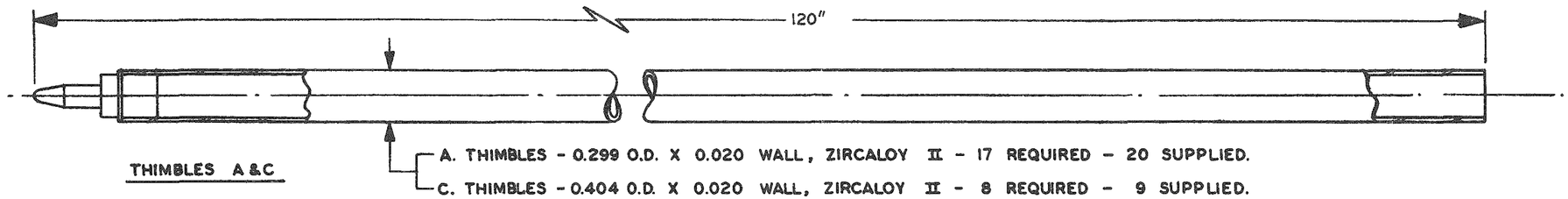
Item		Drawing No.	No.	Core or Spec Composition	Nominal Size, in.		Desired Weight, g	
					Core Dia x Length	Jacket Dia x Length	Core	SF Wt
A	Al-clad Pu Slugs							
1		PF1427	77	Pu-1.25 w/o Al	0.164 x 0.900	0.199 x 0.990	4.20-4.40	4.20-4.35
2		PF1427	11	Pu-1.25 w/o Al	0.164 x 0.900	0.199 x 0.980	4.20-4.40	4.20-4.35
3		PF1427	11	Pu-1.25 w/o Al	0.164 x 0.384	0.199 x 0.464	1.70-1.80	1.70-1.76
B	Al-clad Pu Foils	PF1418	220	Pu-1.25 w/o Al	0.150 x 0.003	0.200 x 0.009	0.0125-0.0135	0.0123-0.0133
C	Enriched U Foils	PF1414	900	93.5 w/o U^{235}	0.200 x 0.005	-	0.05	0.046 U^{235}
D	Depleted U Foils	PF1415	900	0.22 w/o U^{235}	0.200 x 0.005	-	0.05	-
E	Depleted U Slugs							
1		EB5581A	144	0.22 w/o U^{235}	0.306 x 0.995	-	22.55	-
2		EB5582A	8	0.22 w/o U^{235}	0.306 x 0.735	-	16.65	-
3		EB5583A	8	0.22 w/o U^{235}	0.306 x 0.484	-	10.97	-
4		EB5584A	8	0.22 w/o U^{235}	0.306 x 0.292	-	6.62	-
5		EB5585A	6	0.22 w/o U^{235}	0.196 x 0.995	-	9.25	-
6		EB5586A	17	0.22 w/o U^{235}	0.196 x 0.735	-	6.83	-
7		EB5587A	17	0.22 w/o U^{235}	0.196 x 0.484	-	4.49	-
8		EB5588A	218	0.22 w/o U^{235}	0.196 x 0.292	-	2.71	-

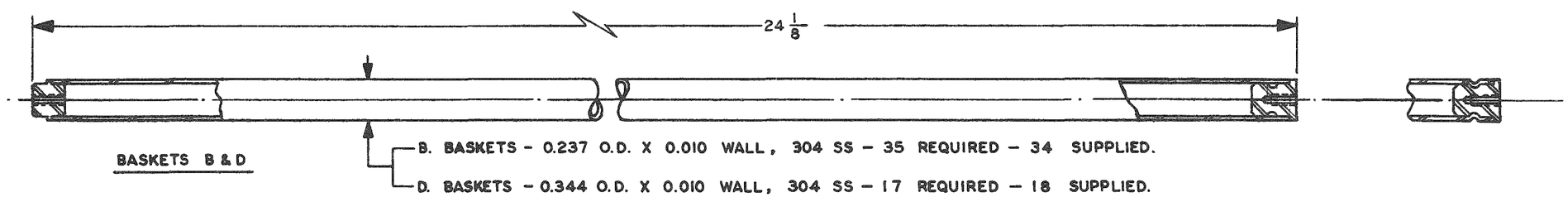
Four Core-IV-type fuel jackets and two Core-III-type fuel jackets were loaded with special low-generation-time plutonium capsules supplied. The loading plan for these special rods is shown in Figure 2. The elements were NaK filled and welded by standard methods developed for EBR-I Core-IV fuel rods.

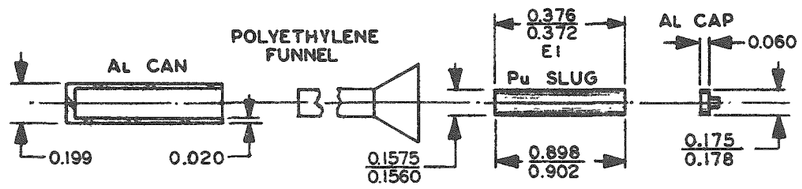
PLUTONIUM SPECIMENS

Each plutonium specimen was sealed in a close-fitting metal jacket to prevent oxidation of the specimen and to allow handling without contamination of the surroundings. Tight mechanical contact between the specimens and jackets was required for heat transfer. Both aluminum and zirconium were judged suitable for the jacketing material. Zirconium was stronger and provided greater protection, and aluminum facilitated the radiochemical steps in the breeding-gain experiment. Both jacketing materials were tried. Aluminum was chosen because it was more easily fabricated and welded.

All specimens were weighed with extreme care before jacketing. The slug specimens were weighed on a Mettler Type-B5 balance to the nearest milligram. The foil specimens were weighed on a Mettler Type-S6 microbalance to the nearest 0.005 mg. Each balance was frequently zeroed and checked against calibration weights in the mass range of the samples weighed.



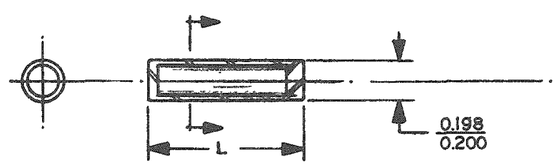




Pu FUEL SPECIMEN COMPONENTS

E. Pu FUEL SPECIMENS

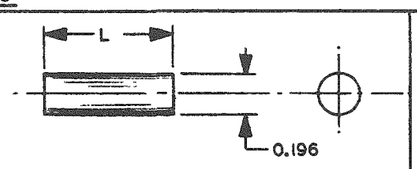
	DIM. L	NO. REQ'D	NO. SUPPLIED
E1	0.464	11	13
E2	0.980	11	11
E3	0.990	77	78

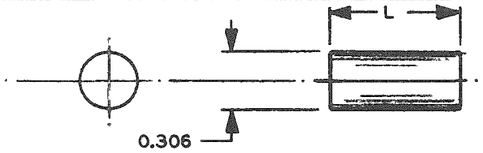


COMPLETED Pu FUEL SPECIMEN

F. MARK IV UNALLOYED DEPLETED U BLANKET SPECIMENS

	DIM L	NO. REQ'D	NO. SUPPLIED
F1	0.484	6	7
F2	0.292	17	20
F3	0.735	17	18
F4	0.995	210	218

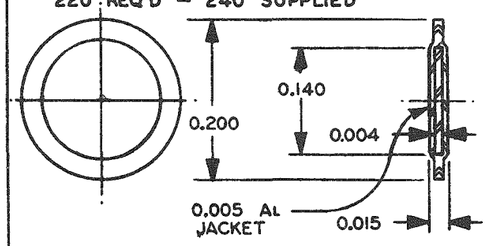




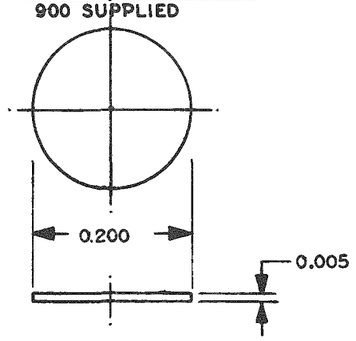
G. MARK III NATURAL U-2 % Zr BLANKET SPECIMENS

	DIM. L	NO. REQ'D	NO. SUPPLIED
G1	0.484	8	8
G2	0.292	8	8
G3	0.735	8	8
G4	0.995	140	146

H. CLAD Pu - 1.25 % AL FOILS
220 REQ'D - 240 SUPPLIED



I. 93 % U - 235 FOILS
900 SUPPLIED



J. DEPLETED URANIUM FOILS
900 SUPPLIED

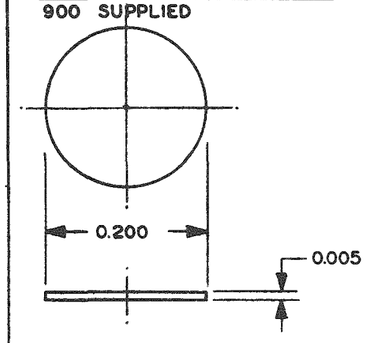


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Figure 1. Schematic Summary of Materials Required for EBR-I Mark IV Breeding-gain Studies

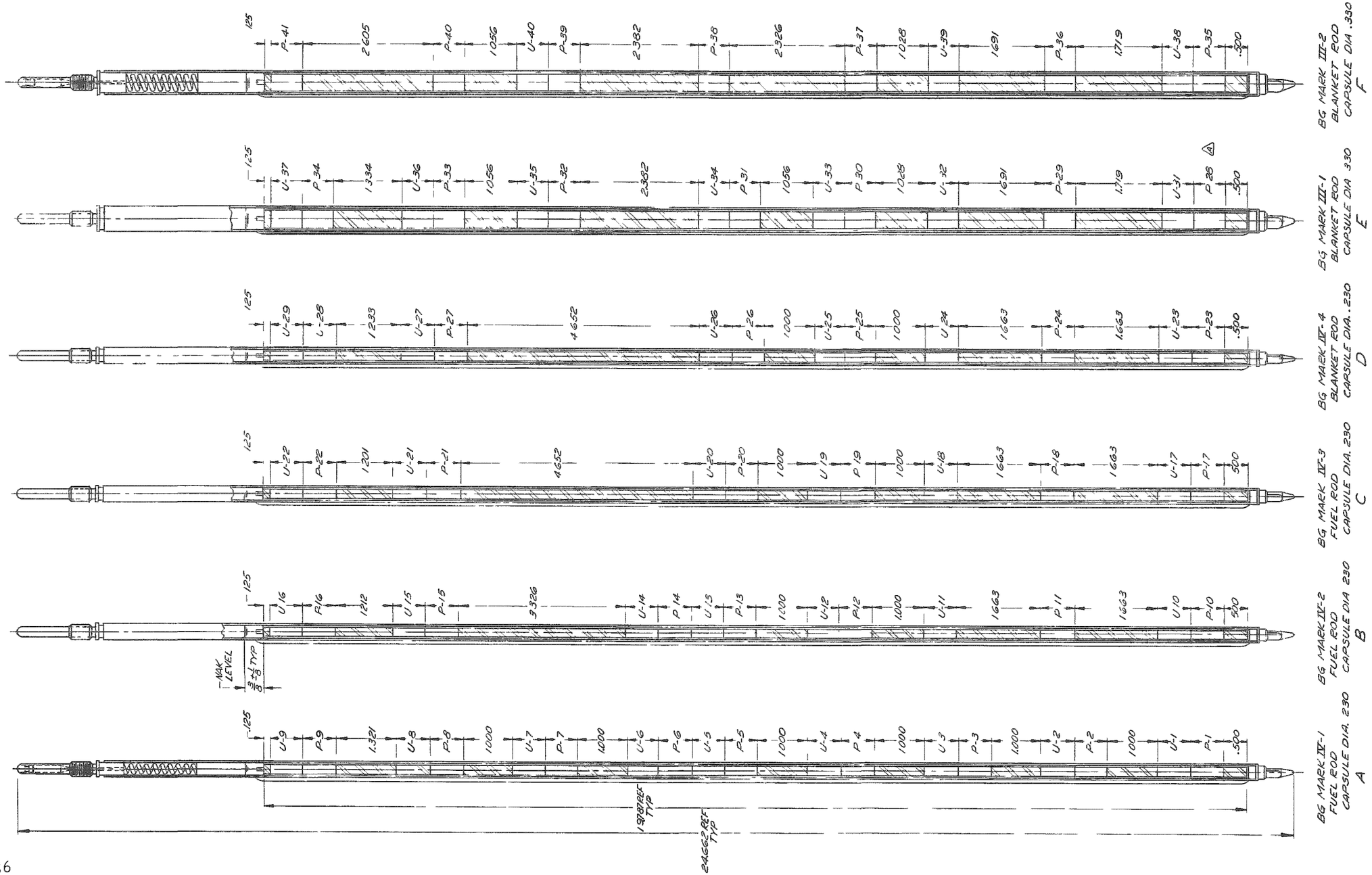

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Figure 2. Loading Plan for Special Breeding-gain Rods

Slug Specimens

All breeding-gain slugs were machined from a single batch of injection-cast EBR-I Core-IV stock. The technique of injection casting the Core-IV fuel is described in ANL-6622.[1] The materials used, the charge calculation, and the analysis of this batch are shown in Table II. The castings produced were nominally 0.235 in. in diameter by 17 in. long. They were inspected for surface defects and cleaned of yttrium oxide. The rods were then parted into lengths $\frac{1}{16}$ in. longer than their as-machined length.

Table II

CHARGE CALCULATION FOR INJECTION-CAST EBR-I CORE-IV BREEDING-GAIN SLUGS

Batch No. 3-775
Melt No. R-74
Date: 12-21-61

Item No.	Material	Batch No.	Weight (g)	Source and Fissionable Elements				Alloying Elements	
				Pu	Pu^{239}	Pu^{240}	Pu^{241}	Al	Impurities
1	Pu-1.25 w/o Al M46 Remelt	423-751	22.11	98.60 21.80	94.82 20.67	4.68 1.02	0.50 0.11	1.25 0.28	0.15 0.03
2	Pu-1.25 w/o Al R53 Remelt	423-753	60.85	98.60 60.00	94.82 56.89	4.68 2.81	0.50 0.30	1.25 0.76	0.15 0.09
3	Pu-1.25 w/o Al R53 Remelt	423-753/1	489.16	98.60 482.32	94.82 457.34	4.68 22.57	0.50 2.41	1.25 6.11	0.15 0.73
4	Pu-1.25 w/o Al R55 Remelt	423-755	775.91	98.62 765.21	94.83 725.64	4.71 36.04	0.46 3.52	1.23 9.54	0.15 1.16
5	Plutonium	423-634/6	918.28	99.85 916.90	94.79 869.13	4.68 42.91	0.53 4.86	- -	0.15 1.38
6	Aluminum	Reagent Grade	11.62	- -	- -	- -	- -	99.70 11.59	0.30 0.03
Total Weights (g)			2277.93	2246.23	2129.67	105.35	11.20	28.28	3.42
Calculated Composition			w/o	98.61	94.81	4.69	0.50	1.24	0.15
Composition by Analysis					94.82	4.71	0.451 +0.019% Pu^{242}	1.15 ± 0.11	

Spectrochemical Analysis - Minor Constituents

Ag <5	Al	As	B <10	Ba <5	Be <0.02	Bi <5	Ca <10	Cd <10	Co <5	Cr 50	Cu 200	Fe 200	Hg	K <5	Li <0.05	Mg <5	Mn 8	Mo 50	Na <5
Ni 400	Hf <5	P	Pb S	Sb <20	Si	Sn <20	Ti <5	Sr <0.05	V <5	Zn <20	Zr <5	Eu <2	La <1	Ga 150	Rb <10	Rh <10	Ru <10	W <20	Y 30

The breeding-gain slugs were machined in a modified Hardinge Type-HVL lathe to a nominal diameter of 0.156 in. Owing to flexibility of the stock, most of the slugs showed a taper of about 0.0010 in. It was possible to hold the slug diameter range to $0.156^{-0.0000}_{+0.0015}$ in. An attempt was made to face the slugs to length by means of a collet stop and a fixed-position facing tool. The 0.005-in. variation in length produced by this method was unacceptable. A length variation within ±0.001 in. was achieved by facing the slugs about 0.010 in. too long by the above method. They were then measured with a dial comparator, and the precise amount was faced off to normalize the length.

Jacketing plutonium specimens without contaminating the exterior of the jacket or weld zone is a principal problem in producing such specimens. An attempt was made to jacket the plutonium slugs in Zircaloy-2 by means of tungsten-inert-gas shielded (TIG) arc welds and capacitor-discharge arc welds. Both methods have given difficulty in producing contamination-free welds. Aluminum jackets sealed by a pressure weld technique were then developed. Because these methods did not employ heat, contamination was more easily controlled.

The pressure weld method was developed with Aluminum Alloy Number 1061-T4 slugs in place of plutonium slugs. The aluminum alloy slugs had approximately the same hardness as the plutonium-1.25 w/o aluminum alloy. The slug jackets and caps were machined from Type 1100 aluminum alloy. The jacketing operations and dimension of the components before jacketing are shown in Figure 3. The jacket parts were slightly etched in a ten per cent nitric acid solution containing ten drops of hydrofluoric acid per 50 cc. They were neutralized in a ten per cent ammonium hydroxide solution, rinsed through distilled water, alcohol and acetone, and then oven-dried at 80°C for 15 min to one-half hour. The jackets were placed hot in a desiccator. The desiccator was evacuated and transferred to the helium atmosphere glovebox. Only the number of jackets which could be used the same day were prepared at a time.

The plutonium-aluminum alloy slugs were loaded into freshly cleaned jackets through a 0.002-in.-thick polyethylene funnel to prevent contamination of the jacket lip. This operation is shown in Figure 4. The plug caps were placed on the top of the plutonium slugs and the assembly forced through a nylon die to draw the jacket tightly onto the plutonium slug and cap. An ammunition-loading toggle press, modified as shown in Figure 5, was used for this operation.

The drawn assembly was placed in a split coining die and pressed at 130,000 to 140,000 psi between two plungers. The top plunger was shaped to roll the jacket rim down tightly onto the cap and, as the pressure was increased, to extrude the jacket material up around the projection on the cap. A holddown pin in the center of the top plunger prevented the extrusion of the projection. The movement and shearing forces between the extruded jacket material and the projection on the top of the cap caused a friction weld to be made. The split coining die was then inverted and pressed from its tapered container. The slugs were knocked out and the extrusion inspected.

After inspection, the specimens were replaced in the die and were coined between flat plungers at a pressure of 175,000 to 185,000 psi. (The final pressing operation is shown in Figure 6.) This produced the right-cylindrical specimens in their final form. An assembled specimen, two of the extrusion-welded specimens, and two coined specimens are shown in Figure 7.

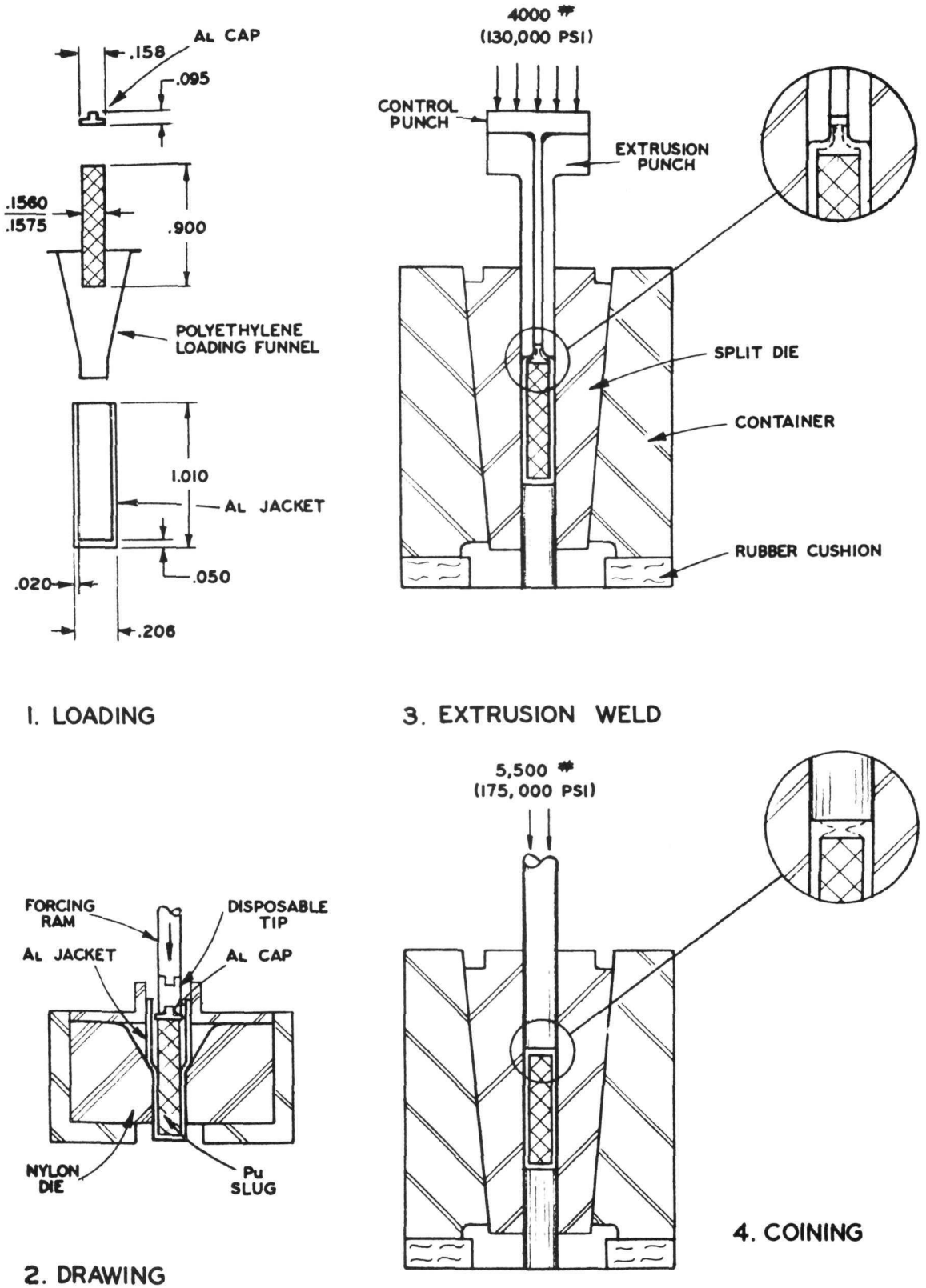

Figure 3. Jacketing Operations for Pu-1.25 w/o Al Breeding-gain Slugs

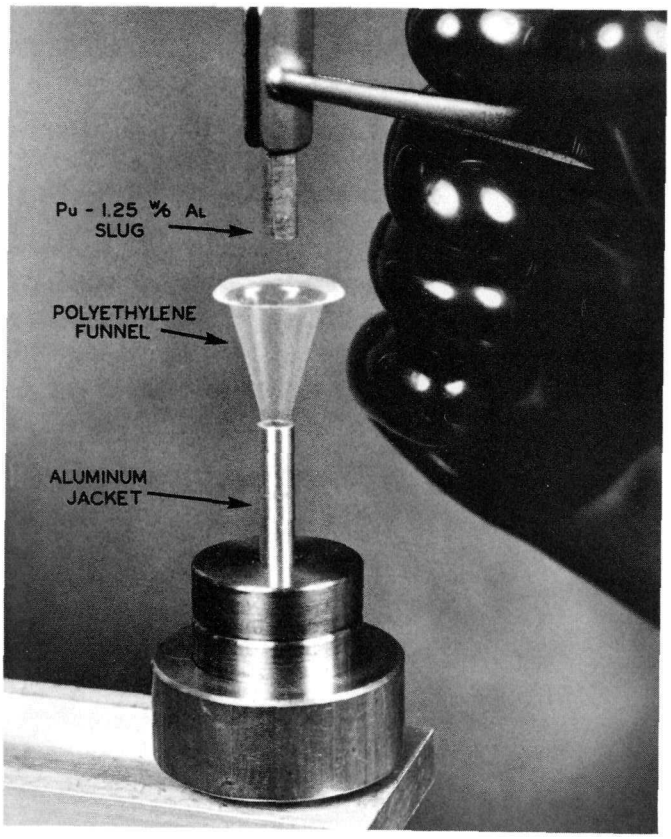

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Figure 4

Loading Plutonium Slugs into Aluminum Jackets

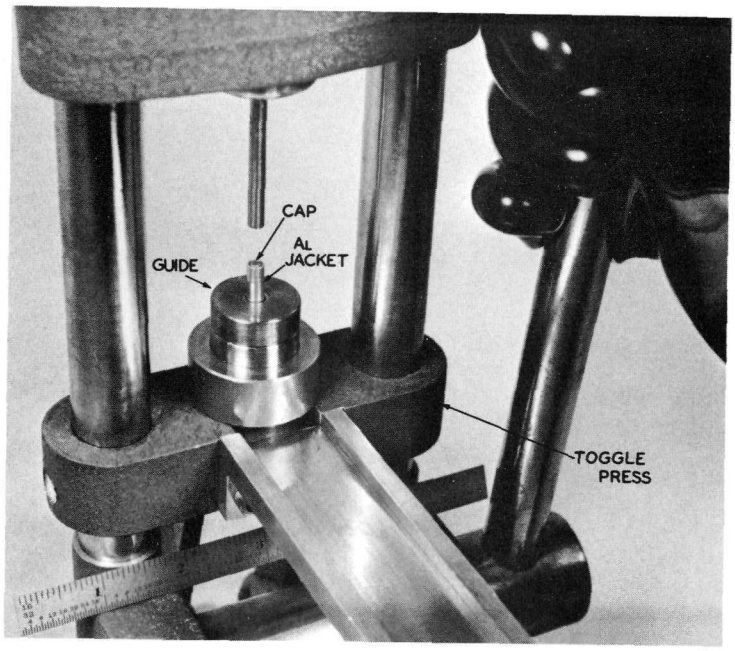

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Figure 5. Drawing Jacket onto Slug through Nylon Die

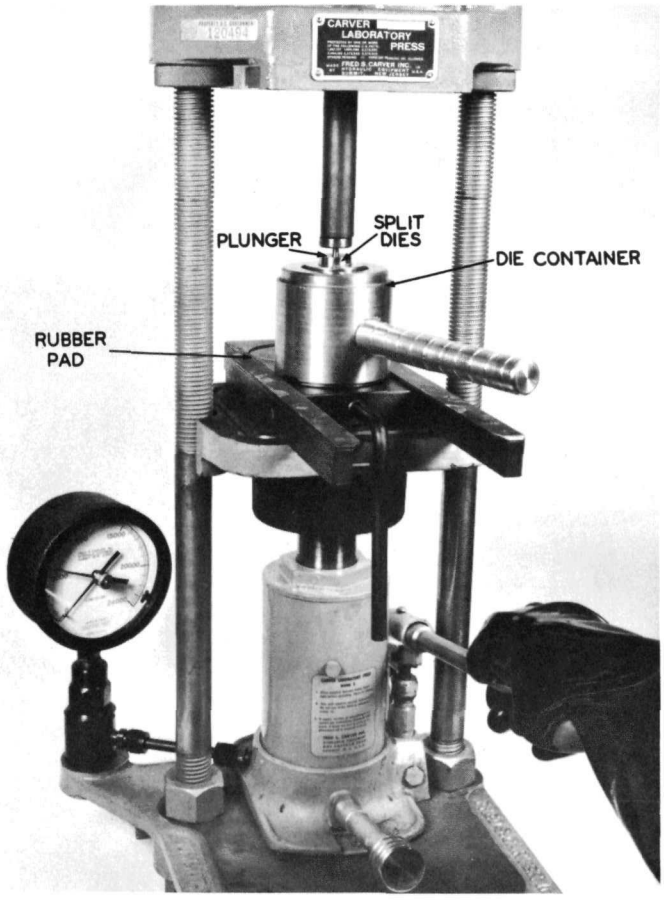

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Figure 6

Coining Jacketed Slugs to Finished Size

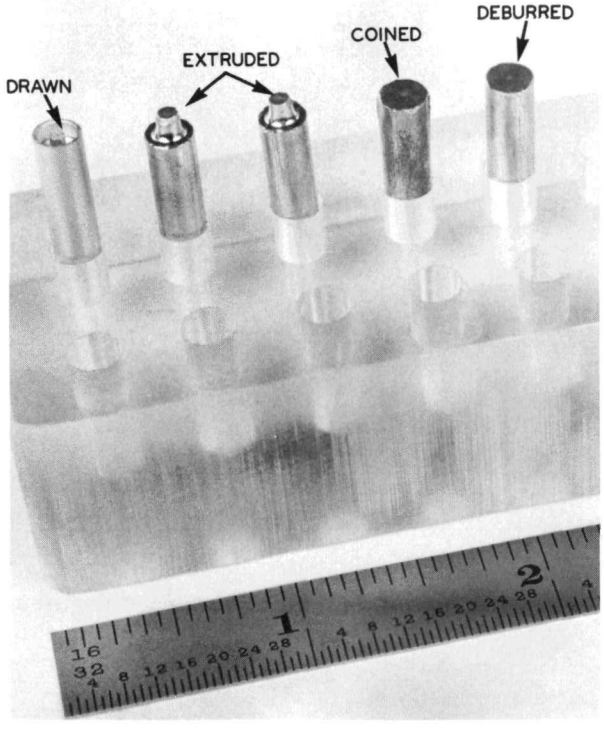

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Figure 7

Breeding-gain Slugs after Drawing, Extruding, Coining, and Trimming

Approximately 300 aluminum alloy slugs were jacketed and destructively tested before jacketing the plutonium slugs. Many of these were tested by cutting the bottom from the jacket, extracting the slug, and vacuum leak detecting with a mass spectrometer leak detector. A number of specimens were sectioned and examined metallographically. Figures 8 and 9 show typical photomacrographs of pressure welds after extrusion and after coining. During the jacketing and welding of the plutonium slug specimens, aluminum control specimens were periodically jacketed, sectioned, and leak detected.

The correct contour of the extrusion die and absolute cleanliness of the components were found to be critical in making pressure welds. Once cleaned and etched, it was necessary to handle jackets with clean stainless-steel tongs. Separate tongs were used for handling the plutonium slugs. A fingerprint or contact with a slightly oily surface would nearly always cause a leaky weld. Several extrusion punches were made, and although these gaged to be identical, only two of them consistently produced good welds.

The tools used for upsetting and handling the jackets were wiped after every fifth specimen was jacketed. The wipes were removed from the glovebox with the specimens and were carefully counted for alpha contamination. If surface contamination was found on the specimens, the tools, dies, and punches were checked for contamination. If contamination was found, the tools were replaced or decontaminated.

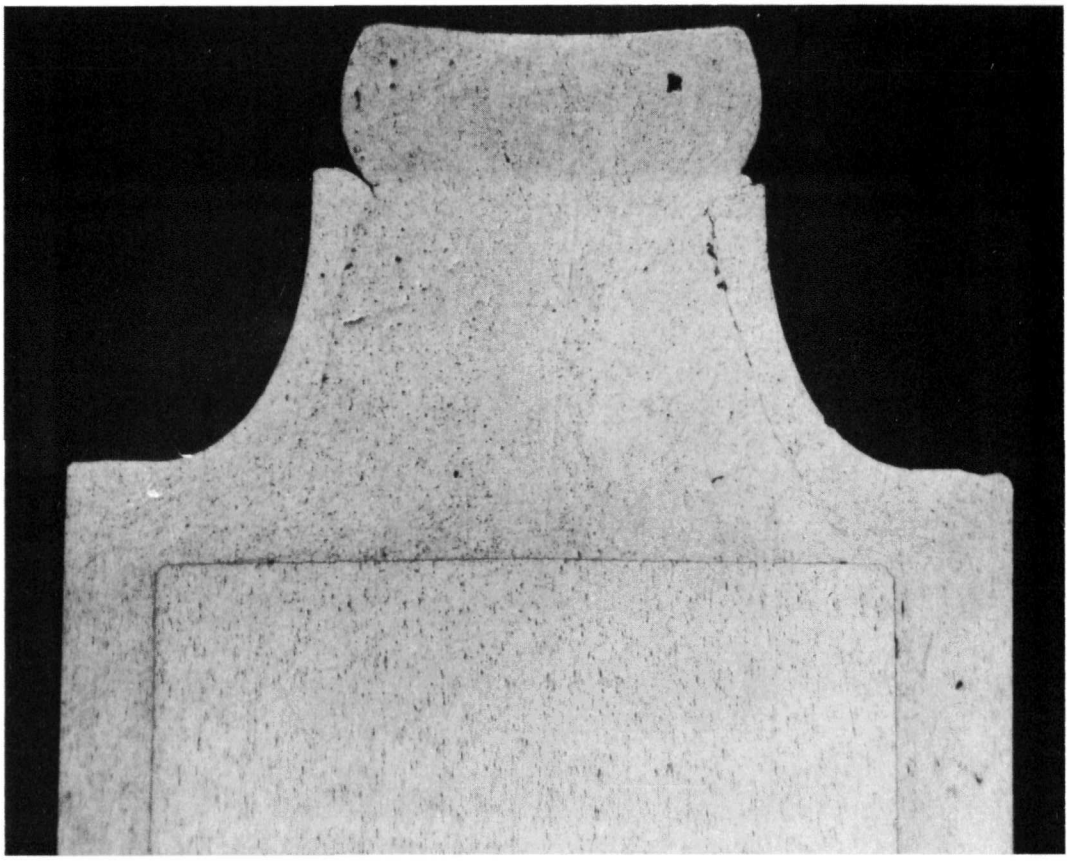
The jacketed plutonium slugs were visually inspected and measured to the nearest 0.001 in. They were then electroetched with an identity number and placed in plastic holders for storage and shipment. The dimensions, weights, and calculated isotopic contents are listed in Appendix A of this report.

Plutonium Foil Specimens

The desired plutonium foils were 0.140 in. in diameter and 0.004 in. thick. The jackets were 0.200 in. in diameter and 0.015 in. thick. Five-mil material was used for the cover foils, and only 0.030 in. was allowed for edge welding or mislocation of the plutonium foil.

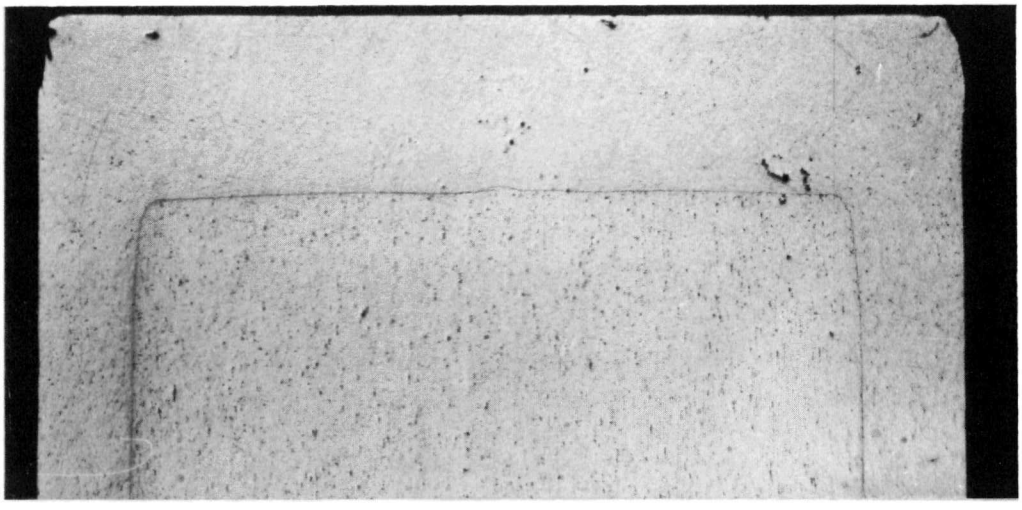
A 206-g plutonium-1.25 w/o aluminum melt was made and cast into a top-pour yttrium oxide-coated carbon book mold. The charge calculations and analyses for this melt are shown in Table III. EBR-I remelt stock was used, and the charge was double melted to obtain maximum homogeneity.

A $\frac{1}{8}$ x $1\frac{1}{16}$ x 3-in. casting was parted from the sprue. The edges of this casting were trimmed and the flat surfaces scalped by facing in a lathe. The resulting $\frac{3}{32}$ x $\frac{15}{16}$ x $2\frac{15}{16}$-in. slab was cold-rolled into six pieces



350M100 5% NaOH Etch 25x

Figure 8. Extruded Jacket Closure Section



350M101 5% NaOH Etch 25x

Figure 9. Coined Jacket Closure Section

measuring approximately 4 x 1 x 0.010 in. These pieces were vacuum annealed at 450°C for one hour and were then flattened by rolling to 0.008 in. and sandwiched between polished 0.020-in.-thick hot-rolled steel strips. The resulting packs were rolled from 0.070-in. to 0.030-in. thickness. The packs were sheared open and the 0.0040-in. to 0.0044-in. by $1\frac{1}{8}$-in. plutonium foils were removed. Ends and edges were sheared to remove thinned areas. Twelve pieces measuring 1 in. wide and 4 to 5 in. long were recovered which had a thickness variation of less than ±0.0002 in.

Table III

CHARGE CALCULATION FOR PLUTONIUM-1.25 w/o ALUMINUM ALLOY FOR BREEDING-GAIN FOILS

Batch No. 3-769
Melt No. R-66
Date: 11-30-61

Item No.	Material	Batch No.	Weight (g)	Source and Fissionable Elements				Alloying Elements	
				Pu	Pu^{239}	Pu^{240}	Pu^{241}	Al	Impurities
1	Pu-1.25 w/o Al M46 Remelt	423-751	59.16	98.60 58.33	94.82 55.31	4.68 2.73	0.50 0.29	1.25 0.74	0.15 0.09
2	Pu-1.25 w/o Al R57 Remelt	3-759	90.56	98.60 89.29	94.82 84.66	4.68 4.18	0.50 0.45	1.25 1.13	0.15 0.14
3	Pu R64 Remelt[a]	3-767	59.29	99.85 59.20	95.16 56.33	4.41 2.61	0.42 0.25	- -	0.15 0.09
4	Aluminum	Reagent Grade	0.75	- -	- -	- -	- -	99.70 0.75	0.30 ~
Total Weights (g)			209.76	206.82	196.30	9.52	0.99	2.62	0.32
Calculated Composition[a] w/o				98.60	94.91	4.60	0.48	1.25	0.15
Composition by Analysis[b] w/o								1.06	

Spectrochemical Analysis - Minor Constituents

Ag <5	Al -	As -	B <10	Ba <5	Be <0.02	Bi -	Ca <10	Co <5	Cr 30	Cu 100	Fe 350	Hg -	K <5	Li <0.05	Mg <5
Mn 8	Mo 30	Na <5	Ni 200	P -	Pb 8	Sb <20	Si -	Sn <20	Sr <0.05	Ti <5	V -	Zn <20	Zr -	Ga 70	W <20

Remarks: [a] Plus 0.01% Pu^{238}

[b] Six foil samples, one from each segment, were submitted for analysis. The results were as follows: 1.03 w/o, 1.07 w/o, 1.04 w/o, 1.05 w/o, 1.07 w/o, and 1.06 w/o.

A 0.140-in.-diameter punch and die were used in a hand-operated press to punch out approximately 450 disks. These were washed through absolute alcohol and acetone, and were dried and carefully inspected. Some disks were rejected for rough or burred edges. The remainder were transferred to the microbalance glovebox. A total of 250 disks weighing between 0.01200 and 0.01400 g were selected. Weights are reported to the nearest 0.05 mg in Appendix B. Each weighed foil was placed in a separate compartment in a numbered tray.

Foil Jacketing

Both Zircaloy 2 and aluminum were investigated for jacketing. Dies were made for an ammunition-loading press which simultaneously punched a disk and formed a depression to hold the plutonium foil (see Figure 10).

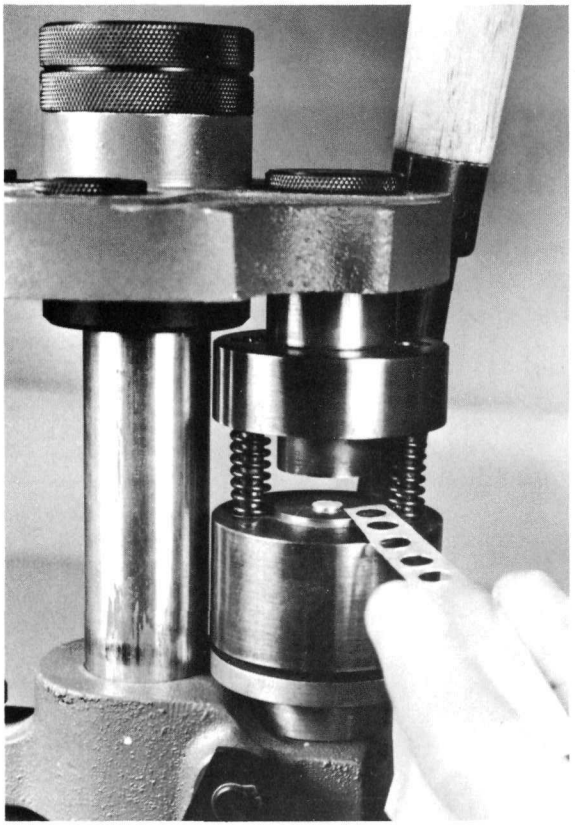


Figure 10

Punching and Forming 0.005-in.-thick Foil Covers

350-289

An effort was made to use Zircaloy-2 jackets because of their greater strength. The 0.140-in.-diameter plutonium foils were sandwiched between 0.005-in.-thick Zircaloy-2 foils held between copper chill pads in a vertical-axis lathe. A sliding gage ring was used to center the sandwich before clamping. The overhanging edges were then sealed by means of a tungsten-inert-gas shielded (TIG) arc weld.

Figure 11 shows an acceptable TIG edge-welded cross section. A variation of more than $\frac{1}{2}$ amp produced undesirable effects. When too much welding current was used, the weld tended to bunch up in droplets spaced at more or less regular intervals around the edge of the specimen. When welding current was $\frac{1}{2}$ amp too low, fusion was incomplete. Plutonium contamination of the TIG weld presented a serious problem. Although the method was demonstrated to be feasible, it was more difficult than the aluminum pressure weld technique described below.

Pressure-welded Aluminum-clad Specimens

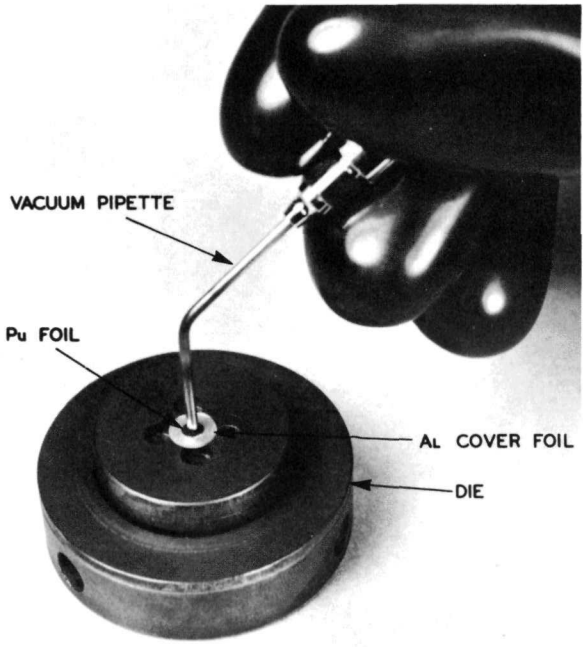
Five-mil aluminum foil was prepared by cleaning with ethyl alcohol and acetone. One side was then thoroughly abraded with a wire brush. The foil was cut into strips and disks were punched out.

33938 HF-$AgNO_3$ Etch 250x

Figure 11. TIG Edge-welded Zircaloy-2 Foil (Section)

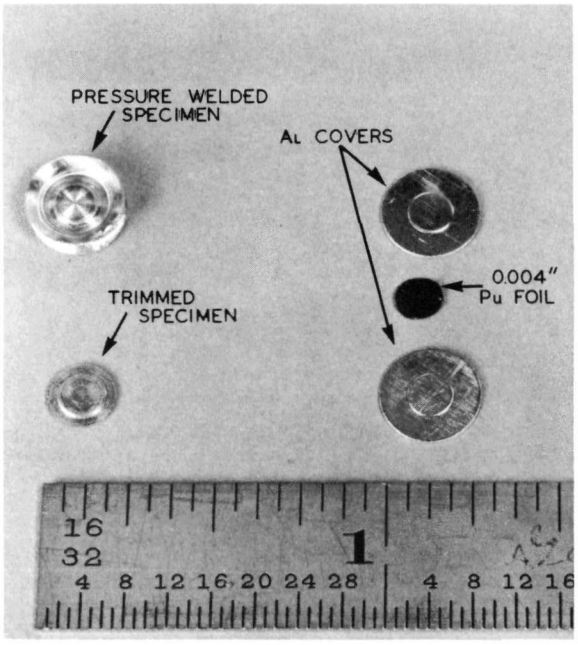
A combination edge welding and trimming die was made which was used in a hand-operated laboratory hydraulic press. The lower foil with the abraded side up was placed on the lower die. The 140-mil-diameter plutonium disk was then placed in the depression on the exact center of the lower foil. A vacuum pipette was used to handle the foils, as shown in Figure 12. The top foil was positioned. The upper one-half of the die was placed and the assembly inserted between the press platens. The press was closed to 6000-lb load. The die was designed to reduce a

0.020-in.-wide edge from a 0.010-in. combined thickness to 0.004-in. thickness. A shear ring mounted on a threaded collar was then actuated which trimmed off the flash, leaving a jacketed specimen of 0.200-in. diameter. The foil and covers before assembly, after pressure welding, and after trimming are shown in Figure 13.



350-290

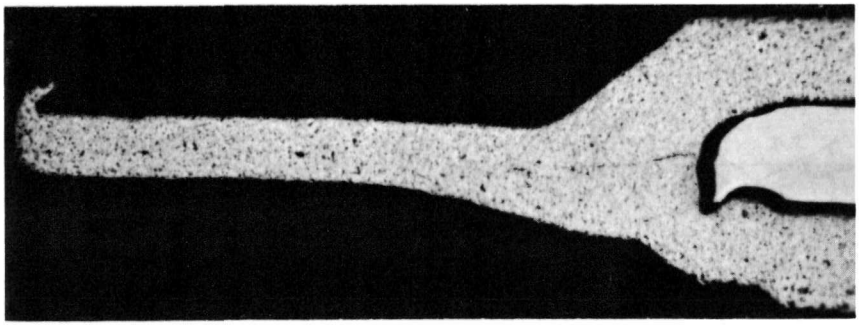
Figure 12. Placing Plutonium Foils with Vacuum Pipette



350-353

Figure 13. Plutonium Foils before Assembly, Pressure Welded, and Trimmed

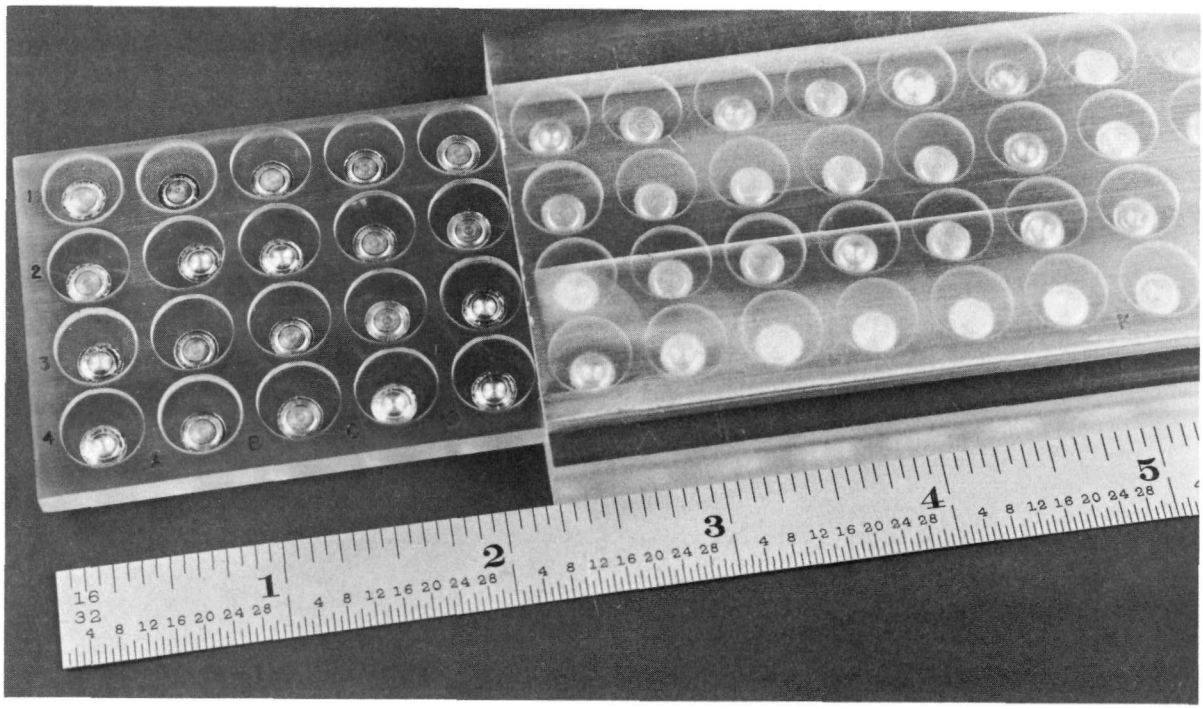
The welds produced in this manner were inspected by several means. Die penetrant was injected into the cavity. Many welds were sectioned and examined metallographically. A typical weld cross section is shown in Figure 14. Some of the welds were subjected to a tear test which, when the weld was properly made, invariably tore outside the weld. Similar welds were leak detected. After consultation with the EBR-I representatives the method was judged acceptable.



34781 2% NaOH Etch 100x

Figure 14. Pressure-welded Aluminum Foil Section

The 250 foils were jacketed between 5-mil aluminum foils as described above. Only three showed external contamination. Approximately seven more were rejected by microscopic inspection for edge weld irregularities. A total of 240 foils were packed in plastic trays, as shown in Figure 15, numbered and were shipped. The weights and compositional data for these foils are given in Appendix B, attached.



350-303

Figure 15. Tray of Jacketed Pu-1.25 w/o Al Foils

SPECIAL EBR-I CORE-IV FUEL, BLANKET, AND THERMOCOUPLE ROD JACKET ASSEMBLIES

The special jackets were similar in design and construction to their EBR-I Core-IV counterparts. Materials required for the six assemblies were available as excess stock from the previous production run. Procurement, processing, and inspection data for this material supplied earlier will be reported in ANL-6621[2] and not be treated in detail here.

304 Stainless Steel and Uranium Requirements

Table IV outlines the stainless tubing requirements. All tubing was commercially procured. Upon receipt the material was inspected

visually and dimensionally. Items 1, 3, and 5 (see Table IV) were eddy-current inspected. Of 560 ft of tubing so inspected, 468 ft (84 per cent) were free of fissures deeper than 0.0015 in. This material of better quality was assured by a more stringent specification (see Appendix C). The basket tubing did not require leak-tight integrity and, accordingly, the specifications were less restrictive (see Appendix D). Reports on Tubing Items 1, 3, and 5, provided by the vendors (see Table V), gave the chemical analysis of the ingots from which the tubing was made. They also included certification by the vendors that the tubing conformed to the specifications.

Table IV

TYPE 304 STAINLESS STEEL TUBING

Item	Quantity	OD, in.	Wall, in.	Length, ft	Type	Use
1	8	0.413	0.016	10	Core III	Thimble
2	16	0.344	0.010	2	Core III	Basket
3	17	0.297	0.017	10	Core IV	Thimble
4	34	0.237	0.010	2	Core IV	Basket
5	2	0.404	0.021	2	Core III	Special Blanket Rod Jacket

Table V

INGOT ANALYSIS OF STAINLESS STEEL TUBING (%)

	C	Mn	P	S	Si	Ni	Cr	Cu	Mo
Item 1 (0.413-in.-OD x 0.016-in. wall)	0.050	1.40	0.025	0.030	0.58	10.50	18.47	0.24	0.20
Item 3 (0.297-in.-OD x 0.017-in. wall)	0.058	1.68	0.019	0.016	0.51	9.50	18.10	0.22	0.32
Item 5 (0.404-in.-OD x 0.021-in. wall) (Same ingot as Item 1)	0.050	1.40	0.025	0.030	0.58	10.50	18.47	0.24	0.20

INSPECTION CERTIFICATION

Item No.	Hydrostatic Test	Flange, Flare, and Flattening Tests	Eddy-current Test	Hardness R_B	Report No.	Date
1	OK	OK	OK	58/64	6550	4-18-62
3	OK	OK	OK	60/65	6551	4-18-62
5	OK	OK	OK	67/72	6673	5-14-62

After inspection and acceptance, Items 1 through 4 were delivered to Building 350 for further processing, in the lengths indicated in Table IV.

The blanket rod jacket tubing (Item 5) was further processed before delivery. The jacket tubes were combined with rib spacer wires and stainless steel tips to form jacket assemblies by equipment and methods common

to the earlier EBR-I Core-IV production and described in ANL-6621.[2] Commercial Type 308L stainless steel wire of $\frac{1}{16}$-in. diameter was used for the spacer ribs that were located parallel to the tube axis, 120° apart. Before welding, the rib-wire stock was vacuum annealed for 15 min at 930°C. The tips were machined from Type 304 stainless-steel stock on hand. Welded jacket assemblies were machined to final size, inspected, and delivered to Building 350.

The uranium components provided by the Foundry and Fabrication Group are outlined in Table VI.

Table VI

URANIUM COMPONENTS

Item	Quantity	Dia, in.	Length or Thickness, in.	Type	Use
6	8	0.306	0.292	Core III	Breeding-gain Sample Slugs
7	8	0.306	0.484	Core III	Breeding-gain Sample Slugs
8	8	0.306	0.735	Core III	Breeding-gain Sample Slugs
9	144	0.306	0.995	Core III	Breeding-gain Sample Slugs
10	6	0.196	0.484	Core IV	Breeding-gain Sample Slugs
11	17	0.196	0.292	Core IV	Breeding-gain Sample Slugs
12	17	0.196	0.735	Core IV	Breeding-gain Sample Slugs
13	218	0.196	0.995	Core IV	Breeding-gain Sample Slugs
14	900	0.200	0.005	Enriched U	Breeding-gain Sample Foil
15	900	0.200	0.005	Depleted U	Breeding-gain Sample Foil

The Core-III and Core-IV depleted uranium slugs (Items 6-13 in Table VI) were machined from previously beta-treated 0.316- and 0.235-in.-diameter stock, respectively. The material was free of porosity and of uniform grain size as determined by ANL nondestructive testing methods described in ANL-6632.[3]

To provide stock for the enriched foil disks, 0.010-in.-thick material was cold rolled to 0.0075 in. For the depleted disks, 0.200-in.-thick material was rolled in a steel jacket at 600°C to the same thickness. Both materials were annealed followed by cold rolling to the 0.005-in. final thickness. The 900 disks, of each type, were punched from the cold-worked foil to the specified size.

ASSEMBLY OF SPECIAL FUEL, BLANKET, AND THERMOCOUPLE RODS

Thirty-nine high-grade U^{235} and 41 low-generation-time plutonium samples in aluminum capsules were furnished by the Idaho Division. These

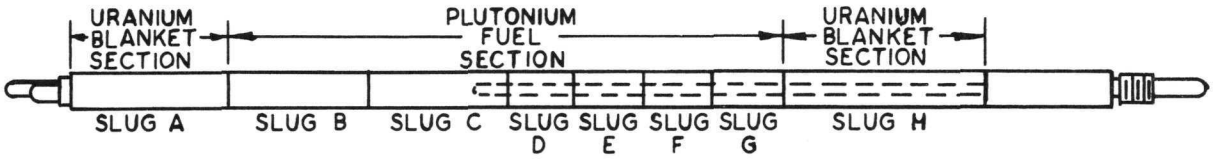
were loaded with Type 304 stainless steel spacers into special fuel and blanket rods by the loading scheme shown in Figure 2. These rods were NaK filled to specification by procedures described in Report ANL-6622.[1] The advisability of NaK bonding aluminum specimens was questioned. The rod will operate below 450°C and, since there is precedent for NaK bonding aluminum capsules in EBR-I jackets, it was felt that there was little risk.

One special thermocouple rod was loaded as shown in Table VII. This rod was not NaK bonded. Its purpose is to monitor the analogous temperature of fuel slugs and specimens in the Core-IV thimbles.

Table VII

EBR-I CORE-IV THERMOCOUPLE FUEL ELEMENT

BG PT-669



Slug No.		A	B	C	D	E	F	G	H	Total
Slug Type		Blkt.	Fuel	Fuel	Fuel	Fuel	Fuel	Fuel	Blkt.	
SPM Batch No. for Pu: 423-701/		6-7							6-7	
Slug Met. No.		-	R74-1	R74-2	R74-3	R74-4	R74-5	R74-6	-	
Alloy Content, w/o	Pu	-	98.61	98.61	98.61	98.61	98.61	98.61	-	
	Al	-	1.24	1.24	1.24	1.24	1.24	1.24	-	
	Imp	-	0.15	0.15	0.15	0.15	0.15	0.15	-	
Pu Isotopic Content, %	Pu^{239}	-	94.81	94.81	94.81	94.81	94.81	94.81	-	
	Pu^{240}	-	4.69	4.69	4.69	4.69	4.69	4.69	-	
	Pu^{241}	-	0.50	0.50	0.50	0.50	0.50	0.50	-	
	Pu^{242}	-	-	-	-	-	-	-	-	
Blanket Slug Weight, g	Gross	47.7	-	-	-	-	-	-	82.3	130.0
	U^{235}	0.10	-	-	-	-	-	-	0.18	0.28
Fuel Slug Weight, g	Gross	-	22.43	21.93	9.52	9.58	9.56	9.45	-	82.47
	Pu	-	22.12	21.63	9.39	9.45	9.43	9.32	-	81.34
	Pu^{239}	-	20.97	20.50	8.90	8.96	8.94	8.83	-	77.10
	Pu^{240}	-	1.04	1.01	0.44	0.44	0.44	0.44	-	3.81
	Pu^{241}	-	0.11	0.11	0.05	0.05	0.05	0.05	-	0.42
	Pu^{242}	-	-	-	-	-	-	-	-	-
Dimensions, in.	Avg. Body Dia.	Nom. 0.235	0.232	0.233	0.232	0.232	0.232	0.232	Nom. 0.235	
	Avg. Ribbed Dia.	Nom. 0.245	0.243	0.243	0.241	0.244	0.242	0.243	Nom. 0.245	
	Length	Nom. 3.552	2.122	2.122	1.061	1.060	1.060	1.059	Nom. 7.745	

Remarks: 1. NaK Level: no NaK in this rod.

9. Thermocouple Well Tube: number unknown.

10. Connector-Sleeve Weld: welded twice, acceptable.

ACKNOWLEDGMENTS

The following persons directly assisted in the preparation of the specimens described in this report: Tool design, R. Frank; preparation of plutonium alloys, T. Bright; foil rolling, A. Carr and L. Kocenko; component machining, B. Mikolajeski, G. Flanigan, and J. Tamayo; encapsuling and welding, J. Summers and D. Carpenter; NaK bonding, F. Mallie; evaluation, X rays and macrophotography, S. Smith.

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2. Beatty, R. A., McCuaig, F. D., and Bean, C. H., Procurement and Processing of EBR-I Core IV and Breeding Gain Hardware. ANL-6621 (to be published).

3. Selner, R. H., Perry, R. B., Balaramamoorthy, K. R., and Renken, C. J., Nondestructive Tests Performed on Components for Mark-IV Loading of EBR-I, ANL-6632 (to be published).

APPENDIX A

Clad Pu-Al Breeding-gain Slugs

Ident. Holder/ Capsule No.	Dimensions		Slug Weight (g)	Calculated Composition					
	Capsule Length (in.)	Capsule Mean Diameter (in.)		Pu (98.61 w/o of Slug Wt) (g)	Pu^{239} (94.81% of Pu Wt) (g)	Pu^{240} (4.69% of Pu Wt) (g)	Pu^{241} (0.50% of Pu Wt) (g)	Al (1.24 w/o of Slug Wt) (g)	Impurities (0.15 w/o of Slug Wt) (g)
Nominal Length: 0.990 in.									
1	0.993	0.199	4.288	4.228	4.009	0.197	0.021	0.053	0.006
2	0.994	0.199	4.308	4.248	4.028	0.199	0.021	0.053	0.006
3	0.994	0.198	4.328	4.268	4.046	0.200	0.021	0.054	0.006
4	0.994	0.198	4.287	4.227	4.008	0.198	0.021	0.053	0.006
5	0.994	0.198	4.281	4.221	4.002	0.198	0.021	0.053	0.006
6	0.993	0.198	4.288	4.228	4.009	0.198	0.021	0.053	0.006
7	0.994	0.199	4.335	4.275	4.053	0.200	0.021	0.054	0.007
8	0.991	0.198	4.277	4.218	3.999	0.198	0.021	0.053	0.006
9	0.992	0.199	4.282	4.222	4.003	0.198	0.021	0.053	0.006
10	0.992	0.198	4.292	4.232	4.012	0.198	0.021	0.053	0.006
11	0.994	0.200	4.316	4.256	4.035	0.200	0.021	0.054	0.006
12	0.993	0.198	4.292	4.232	4.012	0.198	0.021	0.053	0.006
13	0.992	0.198	4.296	4.236	4.016	0.199	0.021	0.053	0.006
14	0.993	0.198	4.305	4.245	4.025	0.199	0.021	0.053	0.006
15	0.987	0.198	4.294	4.234	4.014	0.199	0.021	0.053	0.006
16	0.991	0.198	4.260	4.201	3.983	0.197	0.021	0.053	0.006
18	0.991	0.199	4.312	4.252	4.031	0.199	0.021	0.053	0.006
19	0.994	0.199	4.255	4.196	3.978	0.197	0.021	0.053	0.006
21	0.992	0.198	4.298	4.238	4.018	0.199	0.021	0.053	0.006
22	0.994	0.200	4.304	4.244	4.024	0.200	0.021	0.053	0.006
23	0.986	0.199	4.242	4.183	3.966	0.196	0.021	0.053	0.006
25	0.993	0.199	4.258	4.199	3.981	0.197	0.021	0.053	0.006
26	0.994	0.199	4.308	4.248	4.028	0.199	0.021	0.053	0.006
27	0.987	0.199	4.292	4.232	4.012	0.198	0.021	0.053	0.006
28	0.985	0.196	4.307	4.247	4.027	0.199	0.021	0.053	0.006
29	0.993	0.200	4.298	4.238	4.018	0.199	0.021	0.053	0.006
30	0.994	0.199	4.328	4.268	4.046	0.200	0.021	0.054	0.006
33	0.993	0.200	4.302	4.242	4.022	0.199	0.021	0.053	0.006
34	0.994	0.198	4.331	4.271	4.049	0.200	0.021	0.054	0.006
36	0.994	0.198	4.290	4.230	4.010	0.198	0.021	0.053	0.006
37	0.993	0.200	4.321	4.261	4.040	0.200	0.021	0.054	0.006
38	0.994	0.199	4.335	4.275	4.053	0.200	0.021	0.054	0.007
39	0.987	0.198	4.21	4.15	3.93	0.19	0.02	0.05	0.01
40	0.987	0.198	4.330	4.270	4.048	0.200	0.021	0.054	0.006
41	0.993	0.199	4.308	4.248	4.028	0.199	0.021	0.053	0.006
42	0.994	0.200	4.256	4.197	3.979	0.197	0.021	0.053	0.006
43	0.994	0.198	4.298	4.238	4.018	0.199	0.021	0.053	0.006
44	0.986	0.198	4.305	4.245	4.025	0.199	0.021	0.053	0.006
45	0.991	0.198	4.273	4.214	3.995	0.198	0.021	0.053	0.006
46	0.991	0.198	4.272	4.213	3.994	0.198	0.021	0.053	0.006
52	0.987	0.200	4.297	4.237	4.017	0.199	0.021	0.053	0.006
56	0.985	0.198	4.314	4.254	4.033	0.200	0.021	0.053	0.006
57	0.987	0.199	4.312	4.252	4.031	0.199	0.021	0.053	0.006
59	0.985	0.198	4.327	4.267	4.046	0.200	0.021	0.054	0.006
61	0.994	0.200	4.268	4.209	3.991	0.197	0.021	0.053	0.006
62	0.994	0.199	4.305	4.245	4.025	0.199	0.021	0.053	0.006
63	0.994	0.199	4.307	4.247	4.027	0.199	0.021	0.053	0.006
65	0.994	0.198	4.303	4.243	4.023	0.199	0.021	0.053	0.006
66	0.994	0.199	4.303	4.243	4.023	0.199	0.021	0.053	0.006
67	0.994	0.198	4.335	4.275	4.053	0.200	0.021	0.054	0.006
68	0.994	0.200	4.295	4.235	4.015	0.199	0.021	0.053	0.006
69	0.994	0.200	4.268	4.209	3.991	0.197	0.021	0.053	0.006

Ident. Holder/ Capsule No.	Dimensions		Slug Weight (g)	Calculated Composition					
	Capsule Length (in.)	Capsule Mean Diameter (in.)		Pu (98.61 w/o of Slug Wt) (g)	Pu^{239} (94.81% of Pu Wt) (g)	Pu^{240} (4.69% of Pu Wt) (g)	Pu^{241} (0.50% of Pu Wt) (g)	Al (1.24 w/o of Slug Wt) (g)	Impurities (0.15 w/o of Slug Wt) (g)
Nominal Length: 0.990 in. (Contd.)									
72	0.988	0.198	4.318	4.258	4.037	0.200	0.021	0.054	0.006
73	0.989	0.198	4.278	4.219	4.000	0.198	0.021	0.053	0.006
75	0.993	0.198	4.313	4.253	4.032	0.199	0.021	0.053	0.006
76	0.994	0.199	4.260	4.201	3.983	0.197	0.021	0.053	0.006
77	0.994	0.200	4.287	4.227	4.008	0.198	0.021	0.053	0.006
78	0.991	0.198	4.290	4.230	4.010	0.198	0.021	0.053	0.006
79	0.993	0.199	4.316	4.256	4.035	0.200	0.021	0.054	0.006
81	0.993	0.198	4.309	4.249	4.028	0.200	0.021	0.053	0.006
82	0.992	0.200	4.324	4.264	4.043	0.200	0.021	0.054	0.006
83	0.993	0.199	4.278	4.219	4.000	0.198	0.021	0.053	0.006
84	0.992	0.199	4.308	4.248	4.028	0.199	0.021	0.053	0.006
85	0.993	0.198	4.271	4.212	3.993	0.198	0.021	0.053	0.006
86	0.994	0.199	4.245	4.186	3.969	0.196	0.021	0.053	0.006
87	0.994	0.198	4.293	4.233	4.013	0.199	0.021	0.053	0.006
88	0.985	0.198	4.299	4.239	4.019	0.199	0.021	0.053	0.006
89	0.987	0.198	4.314	4.254	4.033	0.200	0.021	0.053	0.006
90	0.993	0.198	4.285	4.225	4.006	0.198	0.021	0.053	0.006
91	0.989	0.198	4.321	4.261	4.040	0.200	0.021	0.054	0.006
92	0.994	0.197	4.306	4.246	4.026	0.199	0.021	0.053	0.006
94	0.994	0.198	4.280	4.221	4.002	0.198	0.021	0.053	0.006
95	0.987	0.198	4.313	4.253	4.032	0.199	0.021	0.053	0.006
96	0.991	0.198	4.290	4.230	4.010	0.198	0.021	0.053	0.006
97	0.987	0.198	4.330	4.270	4.048	0.200	0.021	0.054	0.006
98	0.994	0.198	4.310	4.250	4.029	0.199	0.021	0.053	0.006
99	0.994	0.198	4.289	4.229	4.010	0.198	0.021	0.053	0.006
100	0.987	0.198	4.342	4.282	4.060	0.201	0.021	0.054	0.006
Nominal Length: 0.980 in.									
20	0.981	0.198	4.313	4.253	4.032	0.199	0.021	0.053	0.006
24	0.981	0.196	4.277	4.218	3.999	0.198	0.021	0.052	0.006
35	0.976	0.196	4.278	4.219	4.000	0.198	0.021	0.052	0.006
47	0.980	0.196	4.286	4.226	4.007	0.198	0.021	0.052	0.006
49	0.980	0.198	4.275	4.216	3.997	0.198	0.021	0.052	0.006
50	0.979	0.198	4.320	4.260	4.039	0.200	0.021	0.053	0.006
53	0.976	0.200	4.290	4.230	4.010	0.198	0.021	0.052	0.006
60	0.976	0.196	4.307	4.247	4.027	0.199	0.021	0.053	0.006
70	0.979	0.198	4.304	4.244	4.024	0.199	0.021	0.053	0.006
71	0.977	0.198	4.281	4.221	4.002	0.198	0.021	0.052	0.006
93	0.976	0.197	4.306	4.246	4.026	0.199	0.021	0.053	0.006
Nominal Length: 0.464 in.									
101	0.469	0.198	1.768	1.743	1.653	0.082	0.009	0.022	0.003
102	0.466	0.200	1.771	1.746	1.655	0.082	0.009	0.022	0.003
103	0.469	0.198	1.770	1.745	1.654	0.082	0.009	0.022	0.003
106	0.469	0.200	1.758	1.734	1.644	0.081	0.009	0.022	0.003
107	0.469	0.200	1.770	1.745	1.654	0.082	0.009	0.022	0.003
108	0.462	0.198	1.768	1.743	1.653	0.082	0.009	0.022	0.003
110	0.469	0.198	1.745	1.721	1.632	0.081	0.009	0.022	0.003
112	0.469	0.198	1.773	1.748	1.657	0.082	0.009	0.022	0.003
113	0.465	0.198	1.772	1.747	1.656	0.082	0.009	0.022	0.003
115	0.468	0.199	1.771	1.746	1.655	0.082	0.009	0.022	0.003
116	0.469	0.198	1.760	1.736	1.646	0.081	0.009	0.022	0.003
119	0.469	0.198	1.786	1.761	1.670	0.083	0.009	0.022	0.003
120	0.468	0.198	1.756	1.732	1.642	0.081	0.009	0.022	0.003

APPENDIX B

Clad Pu-Al Breeding-gain Foils

Identification		Foil Wt (g)	Calculated Composition						
Holder/ Col./ Row	Foil No.		Pu (98.60 w/o of Foil Wt) (g)	Pu^{238} (0.01% of Pu Wt) (g) 1.0×10^{-6}	Pu^{239} (94.91% of Pu Wt) (g)	Pu^{240} (4.60% of Pu Wt) (g) 1.0×10^{-6}	Pu^{241} (0.48% of Pu Wt) (g) 1.0×10^{-6}	Al (1.25 w/o of Foil Wt) (g) 1.0×10^{-6}	Impurities (0.15 w/o of Foil Wt) (g) 1.0×10^{-6}
1 A 1	1	0.012770	0.012591	1	0.011950	579	60	160	19
1 A 2	2	0.012930	0.012749	1	0.012100	586	61	162	19
1 A 3	3	0.012940	0.012759	1	0.012110	587	61	162	19
1 A 4	No Foil								
1 B 1	4	0.012325	0.012152	1	0.011533	559	58	154	18
1 B 2	5	0.012915	0.012734	1	0.012086	586	61	161	19
1 B 3	6	0.012875	0.012695	1	0.012049	584	61	161	19
1 B 4	7	0.012600	0.012424	1	0.011792	572	60	157	19
1 C 1	8	0.012565	0.012389	1	0.011758	570	59	157	19
1 C 2	9	0.012685	0.012507	1	0.011870	575	60	159	19
1 C 3	10	0.012625	0.012448	1	0.011814	573	60	158	19
1 C 4	11	0.012790	0.012611	1	0.011969	580	60	160	19
1 D 1	12	0.013050	0.012867	1	0.012212	592	62	163	20
1 D 2	13	0.012670	0.012493	1	0.011857	575	60	158	19
1 D 3	14	0.012290	0.012118	1	0.011501	557	58	154	18
1 D 4	15	0.013150	0.012966	1	0.012306	596	62	164	20
1 E 1	16	0.012640	0.012463	1	0.011829	573	60	158	19
1 E 2	17	0.012785	0.012606	1	0.011964	580	61	160	19
1 E 3	18	0.012555	0.012379	1	0.011749	569	59	157	19
1 E 4	19	0.012975	0.012793	1	0.012142	588	61	162	19
1 F 1	20	0.012760	0.012581	1	0.011941	579	60	159	19
1 F 2	21	0.012675	0.012498	1	0.011862	575	60	158	19
1 F 3	22	0.012735	0.012557	1	0.011918	578	60	159	19
1 F 4	23	0.012965	0.012783	1	0.012132	588	61	162	19
1 G 1	24	0.012000	0.011832	1	0.011230	544	57	150	18
1 G 2	25	0.012560	0.012384	1	0.011754	570	59	157	19
1 G 3	26	0.013005	0.012823	1	0.012170	590	62	163	20
1 G 4	27	0.012335	0.012162	1	0.011543	559	58	154	19
1 H 1	28	0.013185	0.013000	1	0.012338	598	62	165	20
1 H 2	29	0.012045	0.011876	1	0.011272	546	57	151	18
1 H 3	30	0.012745	0.012567	1	0.011927	578	60	159	19
1 H 4	31	0.012790	0.012611	1	0.011969	580	61	160	19
1 I 1	32	0.012540	0.012364	1	0.011735	569	59	157	19
1 I 2	33	0.012645	0.012468	1	0.011833	574	60	158	19
1 I 3	34	0.012730	0.012552	1	0.011913	577	60	159	19
1 I 4	35	0.013710	0.013518	1	0.012829	622	65	171	21
1 J 1	36	0.013860	0.013666	1	0.012970	629	66	173	21
1 J 2	37	0.013200	0.013015	1	0.012353	599	62	165	20
1 J 3	38	0.012975	0.012793	1	0.012142	588	61	162	19
1 J 4	39	0.012785	0.012606	1	0.011964	580	61	160	19
1 K 1	40	0.012685	0.012507	1	0.011870	575	60	159	19
1 K 2	41	0.013820	0.013627	1	0.012933	627	65	173	21
1 K 3	42	0.013150	0.012966	1	0.012306	596	62	164	20
1 K 4	43	0.013105	0.012922	1	0.012264	594	62	164	20
1 L 1	44	0.013080	0.012897	1	0.012241	593	62	163	20
1 L 2	45	0.012970	0.012788	1	0.012137	588	61	162	19
1 L 3	46	0.012835	0.012655	1	0.012011	582	61	160	19
1 L 4	47	0.013220	0.013035	1	0.012372	600	63	165	20
1 M 1	48	0.013325	0.013138	1	0.012469	604	63	167	20
1 M 2	49	0.013560	0.013370	1	0.012689	615	64	169	20
2 A 1	50	0.012820	0.012641	1	0.011998	581	61	160	19

Identification		Foil Wt (g)	Calculated Composition						
Holder/ Col./ Row	Foil No.		Pu (98.60 w/o of Foil Wt) (g)	Pu^{238} (0.01% of Pu Wt) (g) 1.0×10^{-6}	Pu^{239} (94.91% of Pu Wt) (g)	Pu^{240} (4.60% of Pu Wt) (g) 1.0×10^{-6}	Pu^{241} (0.48% of Pu Wt) (g) 1.0×10^{-6}	Al (1.25 w/o of Foil Wt) (g) 1.0×10^{-6}	Impurities (0.15 w/o of Foil Wt) (g) 1.0×10^{-6}
2 A 2	51	0.012460	0.012286	1	0.011661	565	59	156	19
2 A 3	52	0.011905	0.011738	1	0.011141	540	56	149	18
2 A 4	53	0.013055	0.012872	1	0.012217	592	62	163	20
2 B 1	54	0.013670	0.013479	1	0.012793	620	65	171	21
2 B 2	55	0.013710	0.013518	1	0.012830	622	65	171	21
2 B 3	56	0.013890	0.013696	1	0.012999	630	66	174	21
2 B 4	57	0.013445	0.013257	1	0.012582	610	64	168	20
2 C 1	58	0.013365	0.013178	1	0.012507	606	63	167	20
2 C 2	59	0.013235	0.013050	1	0.012386	612	63	165	20
2 C 3	60	0.013490	0.013301	1	0.012624	584	64	169	20
2 C 4	61	0.012865	0.012685	1	0.012039	582	61	161	19
2 D 1	62	0.013230	0.013045	1	0.012381	600	63	165	20
2 D 2	63	0.013070	0.012887	1	0.012231	593	62	163	20
2 D 3	64	0.013125	0.012941	1	0.012282	595	62	164	20
2 D 4	65	0.013570	0.013380	1	0.012699	615	64	170	20
2 E 1	66	0.013675	0.013484	1	0.012798	620	65	171	21
2 E 2	67	0.013195	0.013010	1	0.012348	598	62	165	20
2 E 3	68	0.012935	0.012754	1	0.012105	587	61	162	19
2 E 4	69	0.013205	0.013020	1	0.012357	599	62	165	20
2 F 1	70	0.013090	0.012907	1	0.012250	594	62	164	20
2 F 2	71	0.013535	0.013346	1	0.012667	614	64	169	20
2 F 3	72	0.012710	0.012532	1	0.011894	576	60	159	19
2 F 4	73	0.013510	0.013321	1	0.012643	613	64	169	20
2 G 1	74	0.013310	0.013124	1	0.012456	604	63	166	20
2 G 2	75	0.012410	0.012236	1	0.011613	563	59	155	19
2 G 3	76	0.013275	0.013089	1	0.012423	602	63	166	20
2 G 4	77	0.013320	0.013134	1	0.012465	604	63	166	20
2 H 1	78	0.012660	0.012483	1	0.011848	574	60	158	19
2 H 2	79	0.013730	0.013538	1	0.012849	623	65	172	21
2 H 3	80	0.013900	0.013705	1	0.013007	630	66	174	21
2 H 4	81	0.011940	0.011773	1	0.011174	542	57	149	18
2 I 1	82	0.013390	0.013203	1	0.012531	607	63	167	20
2 I 2	83	0.013340	0.013153	1	0.012484	605	63	167	20
2 I 3	84	0.013155	0.012971	1	0.012311	597	62	164	20
2 I 4	85	0.013320	0.013134	1	0.012465	604	63	166	20
2 J 1	86	0.013430	0.013242	1	0.012568	609	64	168	20
2 J 2	87	0.013520	0.013331	1	0.012652	613	64	169	20
2 J 3	88	0.013430	0.013242	1	0.012568	609	64	168	20
2 J 4	89	0.013840	0.013646	1	0.012951	628	66	173	21
2 K 1	90	0.013860	0.013666	1	0.012970	629	66	173	21
2 K 2	91	0.013960	0.013765	1	0.013064	633	66	174	21
2 K 3	92	0.013355	0.013168	1	0.012498	606	63	167	20
2 K 4	93	0.013575	0.013385	1	0.012704	616	64	170	20
2 L 1	94	0.013710	0.013518	1	0.012830	622	65	171	21
2 L 2	95	0.013685	0.013493	1	0.012806	621	65	171	21
2 L 3	96	0.013995	0.013799	1	0.013097	635	66	175	21
2 L 4	97	0.013725	0.013533	1	0.012844	623	65	172	21
2 M 1	98	0.013890	0.013696	1	0.012999	630	66	174	21
2 M 2	99	0.013720	0.013528	1	0.012839	622	65	171	21
3 A 1	100	0.013765	0.013572	1	0.012881	624	65	172	21
3 A 2	101	0.013200	0.013015	1	0.012353	599	62	165	20
3 A 3	102	0.012560	0.012384	1	0.011754	570	59	157	19
3 A 4	103	0.012905	0.012724	1	0.012076	585	61	161	19
3 B 1	104	0.012675	0.012498	1	0.011862	575	60	158	19
3 B 2	105	0.013240	0.013055	1	0.012391	601	63	165	20

Identification		Foil Wt (g)	Calculated Composition						
Holder/ Col./ Row	Foil No.		Pu (98.60 w/o of Foil Wt) (g)	Pu^{238} (0.01% of Pu Wt) (g) 1.0×10^{-6}	Pu^{239} (94.91% of Pu Wt) (g)	Pu^{240} (4.60% of Pu Wt) (g) 1.0×10^{-6}	Pu^{241} (0.48% of Pu Wt) (g) 1.0×10^{-6}	Al (1.25 w/o of Foil Wt) (g) 1.0×10^{-6}	Impurities (0.15 w/o of Foil Wt) (g) 1.0×10^{-6}
3 B 3	106	0.013125	0.012941	1	0.012282	595	62	164	20
3 B 4	107	0.012605	0.012429	1	0.011796	572	60	158	19
3 C 1	108	0.012670	0.012493	1	0.011857	575	60	158	19
3 C 2	109	0.013135	0.012951	1	0.012292	596	62	164	20
3 C 3	110	0.012830	0.012650	1	0.012006	582	61	160	19
3 C 4	111	0.012930	0.012749	1	0.012100	586	61	162	19
3 D 1	112	0.012675	0.012498	1	0.011862	575	60	158	19
3 D 2	113	0.012775	0.012596	1	0.011955	579	60	160	19
3 D 3	114	0.012685	0.012507	1	0.011870	575	60	159	19
3 D 4	115	0.012700	0.012522	1	0.011885	576	60	159	19
3 E 1	116	0.012640	0.012463	1	0.011829	573	60	158	19
3 E 2	117	0.012760	0.012581	1	0.011941	579	60	159	19
3 E 3	118	0.013065	0.012882	1	0.012226	593	62	163	20
3 E 4	119	0.012580	0.012404	1	0.011773	571	60	157	19
3 F 1	120	0.012715	0.012537	1	0.011899	577	60	159	19
3 F 2	121	0.012725	0.012547	1	0.011908	577	60	159	19
3 F 3	122	0.012745	0.012567	1	0.011927	578	60	159	19
3 F 4	123	0.012635	0.012458	1	0.011824	573	60	158	19
3 G 1	124	0.012645	0.012468	1	0.011833	574	60	158	19
3 G 2	125	0.013190	0.013005	1	0.012343	598	62	165	20
3 G 3	126	0.012740	0.012562	1	0.011923	578	60	159	20
3 G 4	127	0.013410	0.013222	1	0.012549	608	63	168	20
3 H 1	128	0.013310	0.013124	1	0.012456	604	63	166	20
3 H 2	129	0.013490	0.013301	1	0.012624	612	64	169	20
3 H 3	130	0.013635	0.013444	1	0.012760	618	65	170	20
3 H 4	131	0.013730	0.013538	1	0.012859	623	65	172	21
3 I 1	132	0.013060	0.012877	1	0.012222	592	62	163	20
3 I 2	133	0.013250	0.013064	1	0.012399	601	63	166	20
3 I 3	134	0.013320	0.013134	1	0.012465	604	63	166	20
3 I 4	135	0.013070	0.012887	1	0.012231	593	62	163	20
3 J 1	136	0.013440	0.013252	1	0.012577	610	64	168	20
3 J 2	137	0.013410	0.013222	1	0.012549	608	63	168	20
3 J 3	138	0.013490	0.013301	1	0.012624	612	64	169	20
3 J 4	139	0.013740	0.013548	1	0.012858	623	65	172	21
3 K 1	140	0.013510	0.013321	1	0.012643	613	64	169	20
3 K 2	141	0.013160	0.012976	1	0.012316	597	62	164	20
3 K 3	142	0.013145	0.012161	1	0.012301	596	62	164	20
3 K 4	143	0.013260	0.013074	1	0.012409	601	63	166	20
3 L 1	144	0.013305	0.013119	1	0.012451	603	63	166	20
3 L 2	145	0.013360	0.013173	1	0.012502	606	63	167	20
3 L 3	146	0.013410	0.013222	1	0.012549	608	63	168	20
3 L 4	147	0.013345	0.013158	1	0.012488	605	63	167	20
3 M 1	148	0.013045	0.012862	1	0.012207	592	62	163	20
3 M 2	149	0.013510	0.013321	1	0.012643	613	64	169	20
4 A 1	150	0.012565	0.012389	1	0.011758	570	59	157	19
4 A 2	151	0.013440	0.013252	1	0.012577	610	64	168	20
4 A 3	152	0.013510	0.013321	1	0.012643	613	64	169	20
4 A 4	153	0.013215	0.013030	1	0.012367	599	63	165	20
4 B 1	154	0.013705	0.013513	1	0.012825	622	65	171	21
4 B 2	155	0.013620	0.013429	1	0.012745	618	64	170	20
4 B 3	156	0.013500	0.013311	1	0.012633	612	64	169	20
4 B 4	157	0.013330	0.013143	1	0.012474	605	63	167	20
4 C 1	158	0.013750	0.013557	1	0.012867	624	65	172	21
4 C 2	159	0.013460	0.013272	1	0.012596	611	64	168	20
4 C 3	160	0.013630	0.013439	1	0.012755	618	65	170	20

Identification		Foil Wt (g)	Calculated Composition						
Holder/ Col./ Row	Foil No.		Pu (98.60 w/o of Foil Wt) (g)	Pu^{238} (0.01% of Pu Wt) (g) 1.0×10^{-6}	Pu^{239} (94.91% of Pu Wt) (g)	Pu^{240} (4.60% of Pu Wt) (g) 1.0×10^{-6}	Pu^{241} (0.48% of Pu Wt) (g) 1.0×10^{-6}	Al (1.25 w/o of Foil Wt) (g) 1.0×10^{-6}	Impurities (0.15 w/o of Foil Wt) (g) 1.0×10^{-6}
4 C 4	161	0.013670	0.013479	1	0.012793	620	65	171	21
4 D 1	162	0.013125	0.012941	1	0.012282	595	62	164	20
4 D 2	163	0.013110	0.012926	1	0.012268	595	62	164	20
4 D 3	164	0.013225	0.013040	1	0.012376	600	63	165	20
4 D 4	165	0.013230	0.013045	1	0.012381	600	63	165	20
4 E 1	166	0.013510	0.013321	1	0.012643	613	64	169	20
4 E 2	167	0.013180	0.012995	1	0.012334	598	62	165	20
4 E 3	168	0.013325	0.013138	1	0.012469	604	63	167	20
4 E 4	169	0.013390	0.013203	1	0.012531	607	63	167	20
4 F 1	170	0.013790	0.013597	1	0.012905	625	65	172	21
4 F 2	171	0.013425	0.013237	1	0.012563	609	64	168	20
4 F 3	172	0.013655	0.013464	1	0.012779	619	65	171	20
4 F 4	173	0.013610	0.013419	1	0.012736	617	64	170	20
4 G 1	174	0.013085	0.012902	1	0.012245	593	62	164	20
4 G 2	175	0.013435	0.013247	1	0.012573	609	64	168	20
4 G 3	176	0.013065	0.012882	1	0.012226	593	62	163	20
4 G 4	177	0.013675	0.013484	1	0.012798	620	65	171	21
4 H 1	178	0.013460	0.013272	1	0.012596	611	64	168	20
4 H 2	179	0.013780	0.013587	1	0.012895	625	65	172	21
4 H 3	180	0.013220	0.013035	1	0.012371	600	63	165	20
4 H 4	181	0.013195	0.013010	1	0.012348	598	62	165	20
4 I 1	182	0.013620	0.013429	1	0.012745	618	64	170	20
4 I 2	183	0.013230	0.013045	1	0.012381	600	63	165	20
4 I 3	184	0.013455	0.013267	1	0.012592	610	64	168	20
4 I 4	185	0.013230	0.013045	1	0.012381	600	63	165	20
4 J 1	186	0.013820	0.013627	1	0.012933	627	65	173	21
4 J 2	187	0.013645	0.013454	1	0.012769	619	65	171	20
4 J 3	188	0.013630	0.013439	1	0.012755	618	65	170	20
4 J 4	189	0.013570	0.013380	1	0.012699	615	64	170	20
4 K 1	190	0.013750	0.013557	1	0.012867	624	65	172	21
4 K 2	191	0.013290	0.013104	1	0.012437	603	63	166	20
4 K 3	192	0.013185	0.013000	1	0.012338	598	62	165	20
4 K 4	193	0.013640	0.013449	1	0.012764	619	65	170	20
4 L 1	194	0.013275	0.013089	1	0.012423	602	63	166	20
4 L 2	195	0.013250	0.013064	1	0.012399	601	63	166	20
4 L 3	196	0.013770	0.013577	1	0.012886	625	65	172	21
4 L 4	197	0.013460	0.013272	1	0.012596	611	64	168	20
4 M 1	198	0.013500	0.013311	1	0.012633	612	64	169	20
4 M 2	199	0.013465	0.013276	1	0.012600	611	64	168	20
5 A 1	200	0.013585	0.013395	1	0.012713	616	64	170	20
5 A 2	201	0.013180	0.012995	1	0.012334	598	62	165	20
5 A 3	202	0.013430	0.013242	1	0.012568	609	64	168	20
5 A 4	203	0.013890	0.013696	1	0.012999	630	66	174	21
5 B 1	204	0.013425	0.013237	1	0.012563	609	64	168	20
5 B 2	205	0.012500	0.012325	1	0.011698	567	59	156	19
5 B 3	206	0.013250	0.013064	1	0.012399	601	63	166	20
5 B 4	207	0.012120	0.011950	1	0.011342	550	57	151	18
5 C 1	208	0.013580	0.013390	1	0.012708	616	64	170	20
5 C 2	209	0.014065	0.013868	1	0.013162	638	67	176	21
5 C 3	210	0.014030	0.013834	1	0.013130	636	66	175	21
5 C 4	211	0.013610	0.013419	1	0.012736	617	64	170	20
5 D 1	212	0.013770	0.013577	1	0.012886	625	65	172	21
5 D 2	213	0.013950	0.013755	1	0.013055	633	66	174	21
5 D 3	214	0.013325	0.013138	1	0.012469	604	63	167	20
5 D 4	215	0.013685	0.013493	1	0.012806	621	65	171	21

Identification		Foil Wt (g)	Calculated Composition						
Holder/ Col./ Row	Foil No.		Pu (98.60 w/o of Foil Wt) (g)	Pu^{238} (0.01% of Pu Wt) (g) 1.0×10^{-6}	Pu^{239} (94.91% of Pu Wt) (g)	Pu^{240} (4.60% of Pu Wt) (g) 1.0×10^{-6}	Pu^{241} (0.48% of Pu Wt) (g) 1.0×10^{-6}	Al (1.25 w/o of Foil Wt) (g) 1.0×10^{-6}	Impurities (0.15 w/o of Foil Wt) (g) 1.0×10^{-6}
5 E 1	216	0.013150	0.012966	1	0.012306	596	62	164	20
5 E 2	217	0.013490	0.013301	1	0.012624	612	64	169	20
5 E 3	218	0.013495	0.013306	1	0.012629	612	64	169	20
5 E 4	219	0.013600	0.013410	1	0.012727	617	64	170	20
5 F 1	220	0.013895	0.013700	1	0.013003	630	66	174	21
5 F 2	221	0.013490	0.013301	1	0.012624	612	64	169	20
5 F 3	222	0.012315	0.012143	1	0.011525	559	58	154	18
5 F 4	223	0.013540	0.013350	1	0.012670	614	64	169	20
5 G 1	224	0.013180	0.012995	1	0.012334	598	62	165	20
5 G 2	225	0.013055	0.012872	1	0.012217	592	62	163	20
5 G 3	226	0.013640	0.013449	1	0.012764	619	65	170	20
5 G 4	227	0.013480	0.013291	1	0.012614	611	64	168	20
5 H 1	228	0.013160	0.012976	1	0.012316	597	62	164	20
5 H 2	229	0.013075	0.012892	1	0.012236	593	62	163	20
5 H 3	230	0.013180	0.012995	1	0.012334	598	62	165	20
5 H 4	231	0.013020	0.012838	1	0.012185	591	62	163	20
5 I 1	232	0.013215	0.013030	1	0.012367	599	63	165	20
5 I 2	233	0.013320	0.013134	1	0.012465	604	63	166	20
5 I 3	234	0.013715	0.013523	1	0.012835	622	65	171	21
5 I 4	235	0.013450	0.013262	1	0.012587	610	64	168	20
5 J 1	236	0.012470	0.012295	1	0.011669	566	59	156	19
5 J 2	237	0.012525	0.012350	1	0.011721	568	59	157	19
5 J 3	238	0.013520	0.013331	1	0.012652	613	64	169	20
5 J 4	239	0.013575	0.013385	1	0.012704	616	64	170	20
5 K 1	240	0.013465	0.013276	1	0.012600	611	64	168	20

APPENDIX C

Modified ASTM Specification A-269-60

This specification covers the manufacture of stainless steel tubing for thimbles and jackets to be used in EBR-I Core-IV breeding-gain experiments. This material shall be manufactured in accordance with ASTM specification A-269-60 with the following exceptions:

Delete items 1c and 15.

Change items 3a, 16, 17, and 18b to read as follows:

Item 3a

The tubes shall be made by the seamless process.

Item 16a

Tubes shall be free of bends or kinks, and the maximum uniform bow shall not exceed 0.010 in./ft of length up to 6 ft. Maximum uniform bow of longer lengths shall not exceed 0.020 in./ft of length. Tubes shall have smooth ends free from burrs. Tubes shall be clean and have a workmanlike finish.

Item 16b

Eddy-current examination - prior to delivery eddy-current inspection shall be performed on all tubes with equipment and techniques of sufficient sensitivity to detect any defects greater in one or more dimensions than the standard defect here defined: An empty fissure 0.002 in. in the radial direction x $\frac{1}{16}$ in. in the direction parallel to the tube axis x 0.001 in. at the widest point measured along the tube circumference.

Item 16c

Any discontinuity in the tubing which produces an indication larger than the indication produced by the standard defect shall be classified as rejected.

Item 17

The name or brand of the manufacturer, the grade (such as TP304) of material from which it is made, and the ANL purchase order number shall be legibly marked on a tag attached to the individual tube as prepared for shipment.

Item 18b

Certification - The manufacturer shall furnish a statement that material has been tested and has met the requirements of these specifications.

APPENDIX D

Modified ASTM Specification A-269-60

This specification covers the manufacture of stainless steel tubing for baskets to be used in EBR-I Core-IV breeding-gain experiments. This material shall be manufactured in accordance with ASTM specification A-269-60 with the following exceptions:

Delete items 1c and 15.

Change items 3a, 16, 17, and 18b to read as follows:

Item 3a

Tubes shall be made by the seamless process.

Item 16

Tubes shall be free of bends or kinks, and the maximum uniform bow shall not exceed 0.010 in./ft of length. Tubes shall have smooth ends free from burrs. Tubes shall be clean and have a workmanlike finish.

Item 17

The name or brand of the manufacturer, the grade (such as TP304) of material from which it is made, and the ANL purchase order number shall be legibly marked on a tag attached to the individual tube as prepared for shipment.

Item 18b

Certification - The manufacturer shall furnish a statement that material has been tested and has met the requirements of these specifications.