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PNEUMATIC INJECTION CASTING OF ALUMINUM-PLUTONIUM FUEL ELEMENTS

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INTRODUCTION

This program was undertaken at Hanford to determine the feasibility of fabricating injection-cast, aluminum-plutonium alloy fuel rods in support of the Plutonium Recycle Program. Spike enrichment plutonium fuel elements will be used for initial loadings of the Plutonium Recycle Test Reactor (PRTR) and the injection-casting process appeared to offer less fabrication expense.

This report summarizes only that portion of the injection-casting experiments in which the castings were made with air pressure.

SUMMARY AND CONCLUSIONS

A process was developed for the injection casting of 96-inch long, plutonium alloy fuel rods within a glove box. Cast-bonded, Al-2 w/o Pu-2 w/o Ni alloy, 1/2-inch diameter rods with 0.035-inch Zircaloy cladding were made with densities over 95 per cent of wrought density. Core-to-clad bond shear strengths of 3000-4500 psi were measured, and ultrasonic testing of a seven-rod irradiation cluster showed good bond uniformity.

It was demonstrated on a laboratory scale that aluminum-plutonium fuel elements can be fabricated by pneumatic injection casting. No conclusions can be drawn concerning the unit cost of injection-cast fuel elements as compared with extruded-core elements, since the prototypic equipment was not operated long enough to establish bases for such data.

Difficulty was encountered in meeting the specifications pertaining to plutonium distribution. This problem was in part due to equipment limitations and was not completely resolved. A study of the ternary system in the high aluminum range would help account for some of the anomalies found in the Al-2 w/o Pu-2 w/o Ni alloy castings.

DISCUSSION

The general principle of the process is illustrated in Figure 1.* Cored billets (Part 22, Figure 2) with axial holes for a dip tube and graphite-sheathed dip thermocouple were prepared in an induction-melting facility.(1) The cored billets were loaded in the clay graphite crucible; the furnace chamber was closed with the hydraulic cylinder and was secured with six locking bolts.

Expendable Zircaloy dip tubes (Part 19, Figure 2) were oxidized in air to form a blue-black coating that resisted attack by molten aluminum. A modified tubing union (Part 4, Figure 2) sealed together the flanged ends of the dip tubes and casting tubes. The 90-degree flanges were formed with a spinning tool on a lathe.

A 3/4-inch stainless steel shroud tube was welded to the top half of the tubing union and made it possible to evacuate both the interior and exterior of the Zircaloy tubing before casting. No discernible surface oxide formed on the cladding of the fuel rods made within the shroud tube.

After a billet was loaded, the furnace chamber was closed and the shrould tube assembly was fastened in place. The top of the shroud tube was connected to the 5/8-inch copper line (Part 8, Figure 3). The system was evacuated and approximately one hour was required for melting the billet. The flanged tubing joint was heated with two 500-watt electric heating cartridges. The temperature was controlled during solidification of the casting.

When the desired casting temperature and vacuum were attained, the two valves (Parts 7 and 9, Figure 1) were closed and the air-operated valve (Part 10, Figure 1) was opened. Air from the storage tank (Part 12, Figure 1) then passed through a throttled globe valve into the furnace chamber, forcing the aluminum fuel alloy into the Zircaloy tubing. The length of the castings was determined by the placement of slotted aluminum freeze plugs, which were secured by constrictions in the tubing (Part 16, Figure 3).

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*Table I lists the parts designated by number in Figures 1, 2, and 3.

TABLE I

PARTS LIST FOR FIGURES 1, 2, AND 3

1.	Glove Box
2	Shroud Tube
3	Casting Tube
4.	Tubing Union
5.	Furnace Chamber
6.	Hydraulic Cylinder
7.	Manual Vacuum Valve
8.	Copper Tubing (5/8-inch)
9 & 10.	Solenoid-Actuated, Air-Operated, One-Inch Vacuum Valve
11.	Mechanical Vacuum Pump
12.	Air Storage Tank
13.	Air Compressor
14.	Glove Box Inlet Filter
15.	Vacuum Hose
16.	Freeze Plug
17.	Heating Cartridges
18.	Air and Vacuum Line
19.	Dip Tube
20.	Dip Thermocouple
21.	Resistance Furnace (1.7 kw)
22.	Cored Billet
23.	Clay Graphite Crucible
24.	Ceramic Insulator
25	Stainless Steel Heat Shield

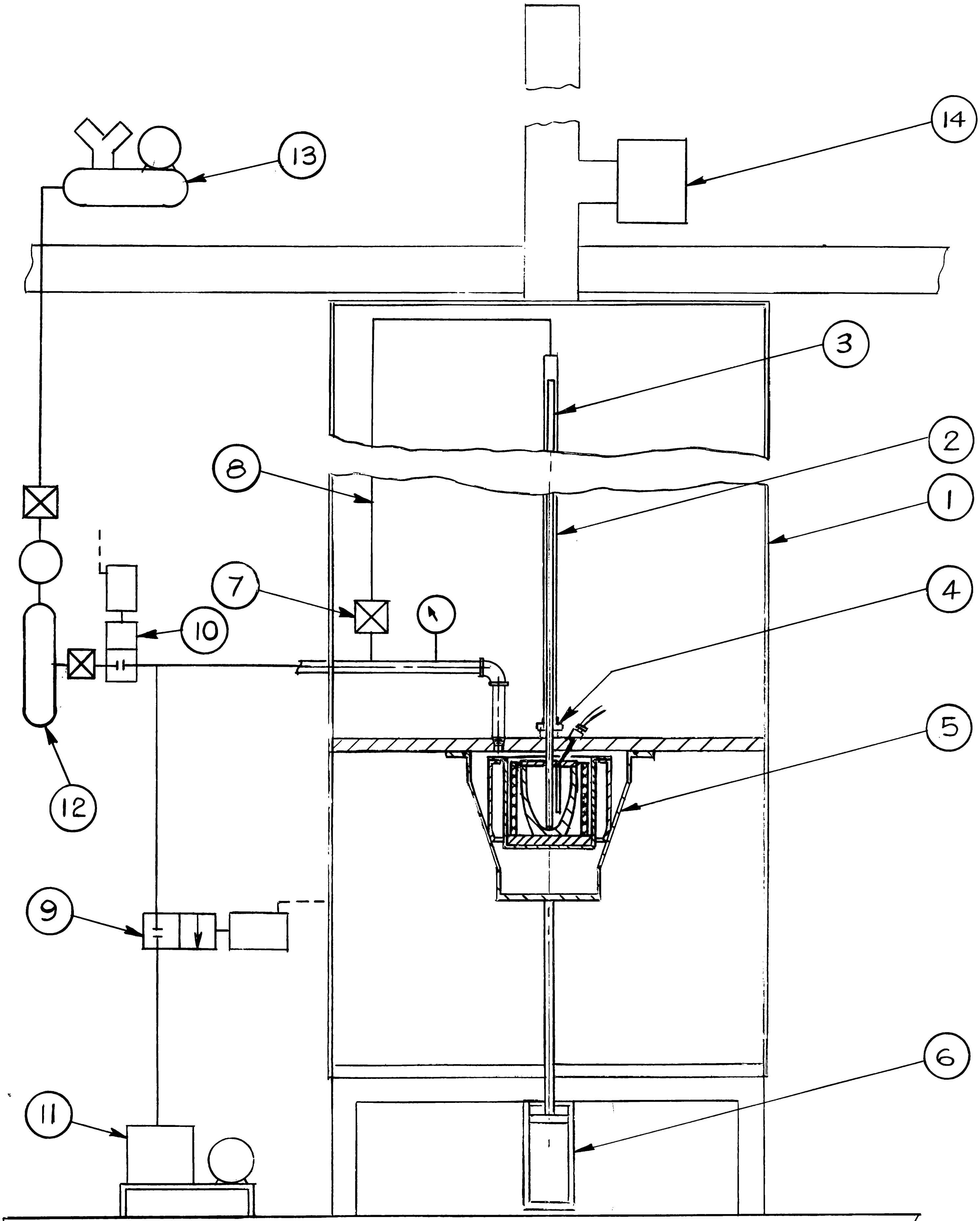

FIGURE 1

Injection-Casting Apparatus

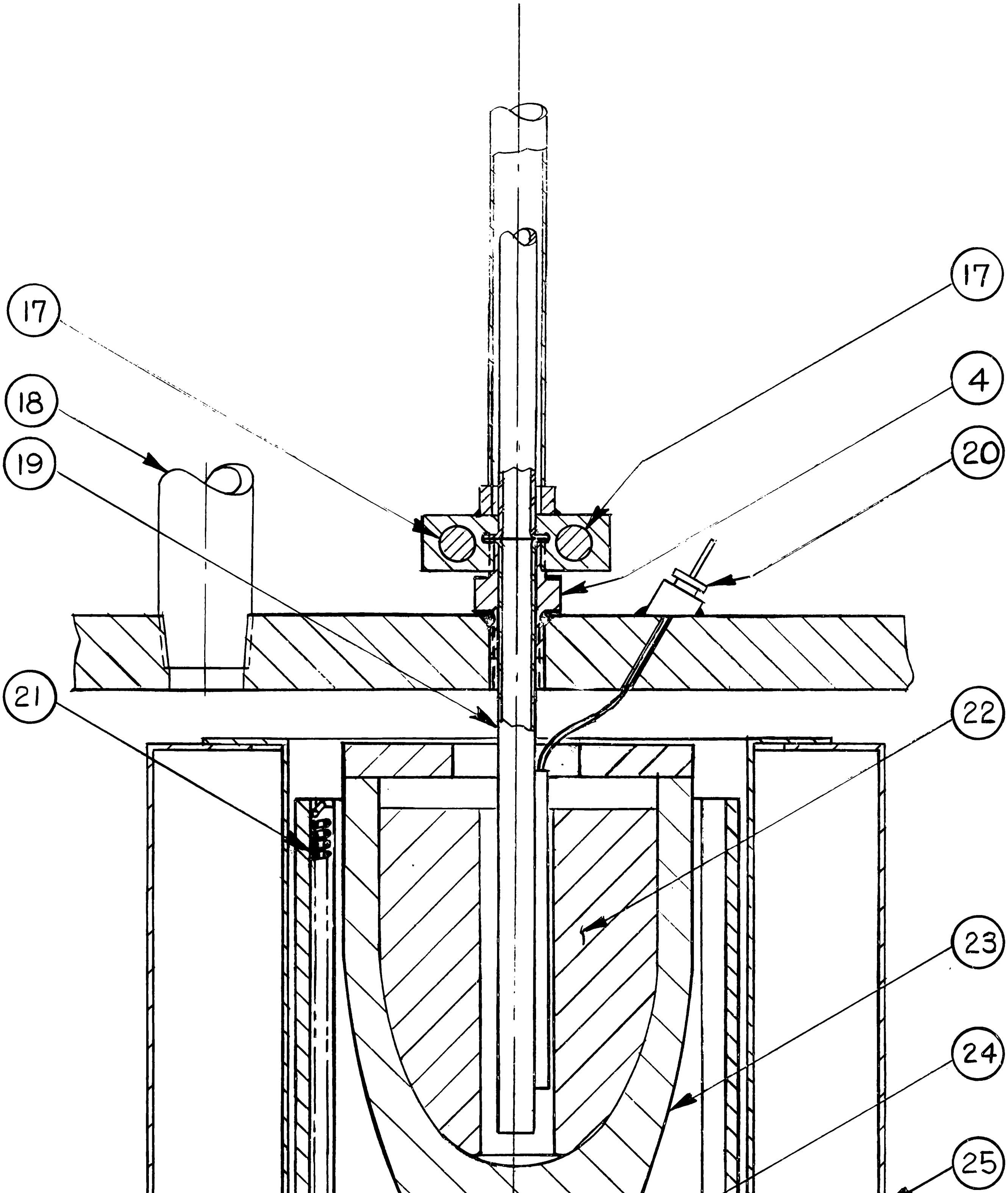

FIGURE 2

Furnace and Dip Tube Assembly

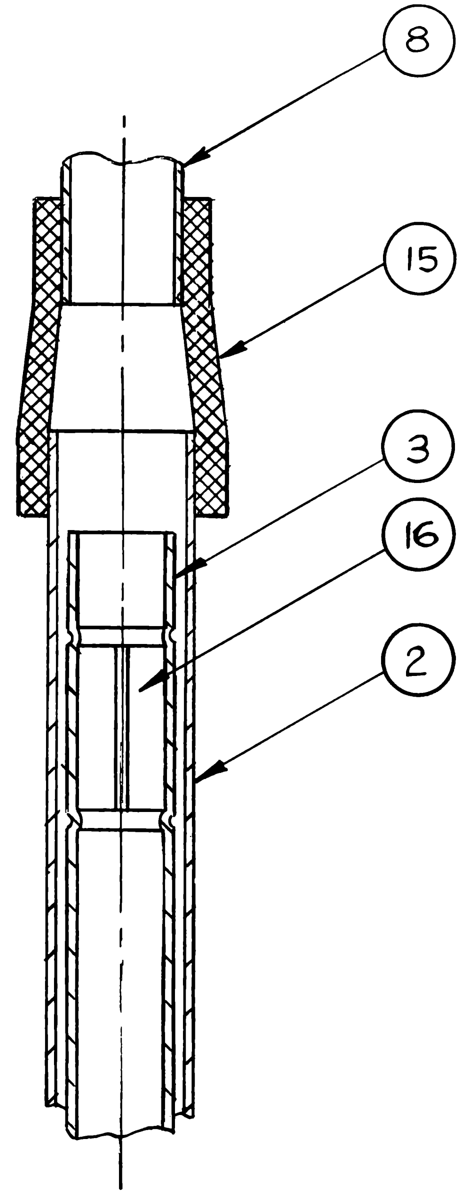

FIGURE 3

Freeze Plug Assembly

The casting pressure was maintained for five minutes and then released. When the casting was cool enough to handle with hood gloves, the dip tube was cut off and the rod was removed from the hood and radiographed. After radiography, wafers for plutonium analysis were cut from the ends of the lengths required for fuel rods.

End closures, similar to those required for extruded-core plutonium spike fuel elements,(2) were made after the rods were counterbored (Figure 4).

RESULTS

A plutonium composition tolerance of ± 5 per cent of the nominal composition was difficult to achieve in this direct-casting fuel fabrication process because porosity and casting defects such as hot tears magnified the effect of the segregation that occurred with slow remelting of the Aluminum-Plutonium-Nickel fuel alloy.

Core densities over 95 per cent of wrought density were achieved after the optimum combination of process variables was determined experimentally.

The tubing union temperature was controlled at 700 C during solidification of the casting. The temperature gradient thus established in the casting facilitated feeding the solidification shrinkage.

As aluminum was injected into one tube an electronic timer measured the interval during which contact was made between two sensing probes located at opposite ends of an 89-inch long, 9/16-inch diameter Zircaloy tube. At the maximum rate of pressurization of the furnace chamber, the tube filled in 0. 36 seconds. This measurement was made with commercially pure aluminum before the equipment was sealed for operation with plutonium alloys.

The rate of pressurization was varied by throttling the air flow through a hand-operated globe valve, which is shown between Parts 10 and 12 in Figure 1. The most effective pressurization rate was the minimum rate at which the tube completely filled.

QTY.				PT. NO.	DESCRIPTION	
			X	1	ASSEMBLY	
		X	3	2	FUEL TUBE ASSY CW WIRE WRAP	
	X		3	3	↓ CCW WIRE	
X			1	4	↓ CENTER	
			1	5	END BRACKET TOP	SK-3-9018 P1
			1	6	↓ BOTTOM	↓ P2
	1	1		7	END CAP TOP	H-3-13635
	1	1		8	BOTTOM	H-3-13634
1				9	↓ CENTER	H-3-13636 P2
			2	10	NUT	H-3-13641 P8
			6	11	PIN $\frac{.125}{.124}$ DIA × .438 LG	304 L SST
			AR	12	BAND $\frac{3}{16}$ WIDE × .010 THK	↓
			2	13	CLIP	
1	1	1		14	FUEL TUBE	
	1	1		15	WIRE .072 DIA LENGTH AS REQD	ZIRCALOY-2

GENERAL NOTES

ALL PARTS (UNLESS OTHERWISE NOTED) SHALL CONFORM TO THE FOLLOWING:

1. TOLERANCES: FRACTIONAL ± $\frac{1}{64}$ DECIMAL ± .005 ANGULAR ± 0°30'
2. PARTS TO SHOW GOOD WORKMANSHIP, FREE FROM BURRS, UNMARRED AND CLEAN.
3. BREAK ALL CORNERS.
4. ALL MACHINED SURFACES $\overset{63}{\surd}$ (ASA B46.1 - 1955)
5. ALL MATERIAL TO BE AS SPECIFIED, OR EQUAL QUALITY.

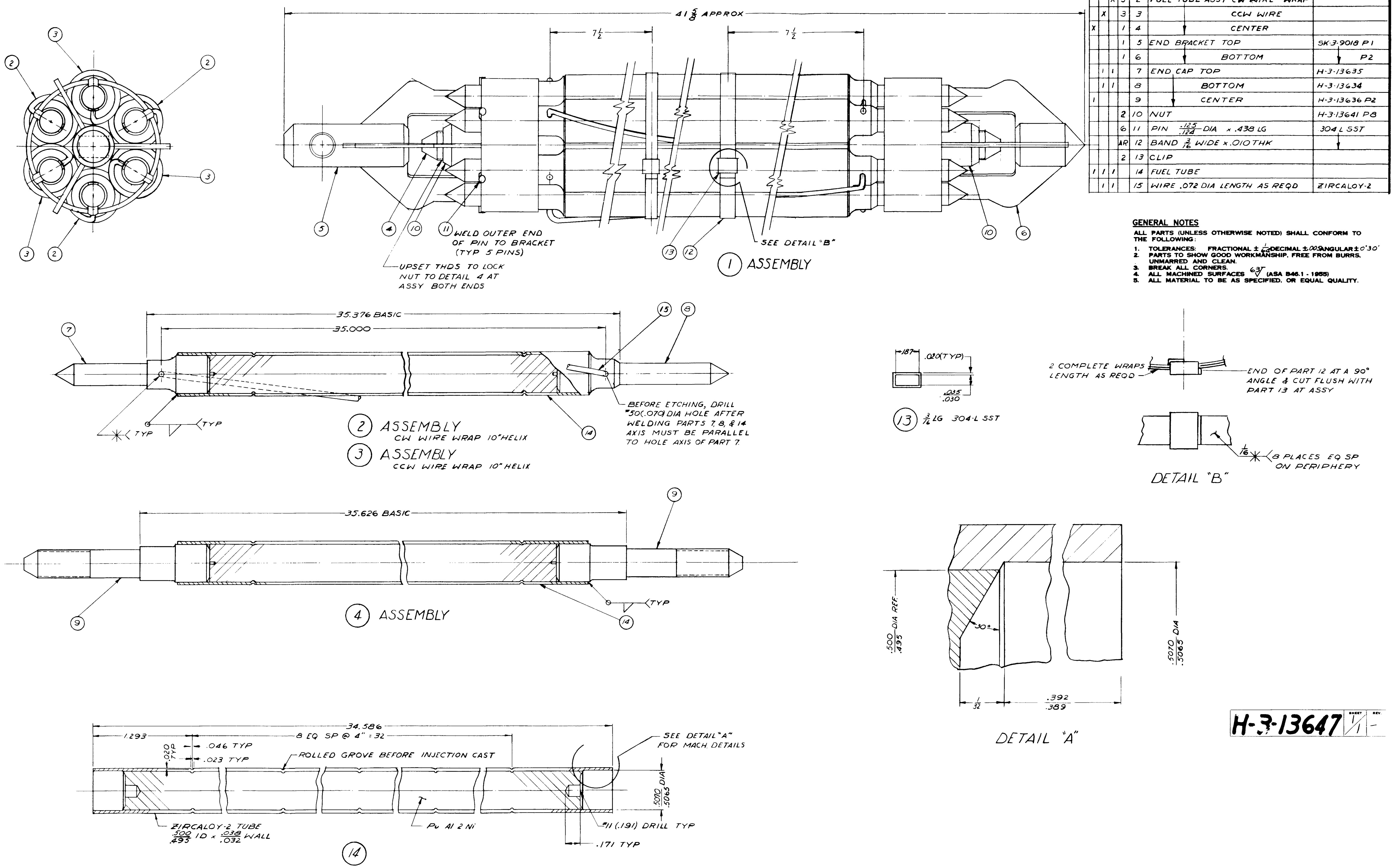

FIGURE 4

Fuel Tube Assembly Mark 1-K Seven-Rod Cluster Engineering Test Reactor Test Element

BONDING

Core-to-clad bonded fuel elements were obtained when castings were made with immersion-etched tubing. The fabrication process imposes a shear stress on the bond through the differential contraction that occurs as the castings cool. Precursory tensile-machine tests of the shear strength of the Aluminum-Plutonium-Nickel to Zircaloy bond showed a range of 3000-4500 psi. The metallurgical bond was reinforced by forming constrictions in the tubing (Figure 4) before casting. When the castings were made at injection temperatures only a few degrees above the melting range of the alloy, the upper six inches of the castings frequently were unbonded; therefore, it was necessary to compromise the injection temperature for maximum density with that which produced a reaction layer for the full length of the casting.

SEGREGATION

A 2 w/o Ni alloy was chosen for the spike loading of the PRTR.(3) The plutonium phase segregated in injection castings of this alloy. Figure 5 is a plot of the plutonium content of the bottom, center, and top of 90-inch long castings of a nominal 2.5 Pu-2 Ni-Al alloy. The segregation in the rods is reversed from that in the crucible because of feeding from the bottom of the crucible. Plutonium uniformity for the right hand group of three castings was improved by increasing the soak temperature prior to casting. The segregation in the crucible apparently occurred during the 15-minute period from start to completion of melting. The seven rods, for which the plutonium analysis is plotted in Figure 5, were all cast from billets which were made in one batch in the induction-melting facility. Approximately one-third of the billet remained in the crucible after casting. It was determined that this heel was depleted in plutonium for those runs which were segregated badly.

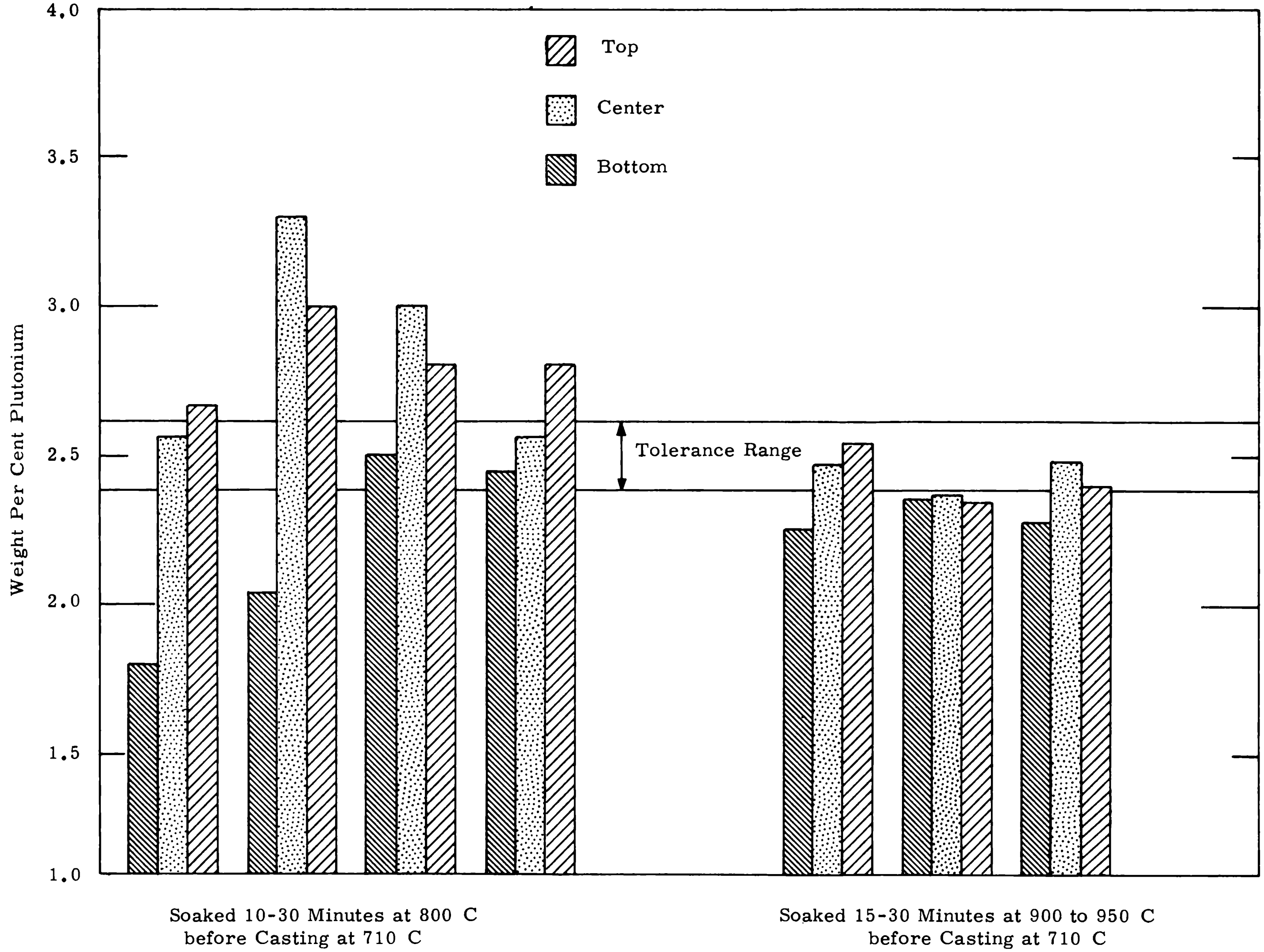

FIGURE 5

Effect of Alloy Soak Temperature on Fuel Rod Plutonium Distribution

CORROSION

Samples of injection-cast rods with the jacketing removed exhibited a corrosion resistance at 350 C in deionized water of pH 10, comparable to that of the wrought structure of extruded rods of similar alloy composition.

ACKNOWLEDGMENT

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