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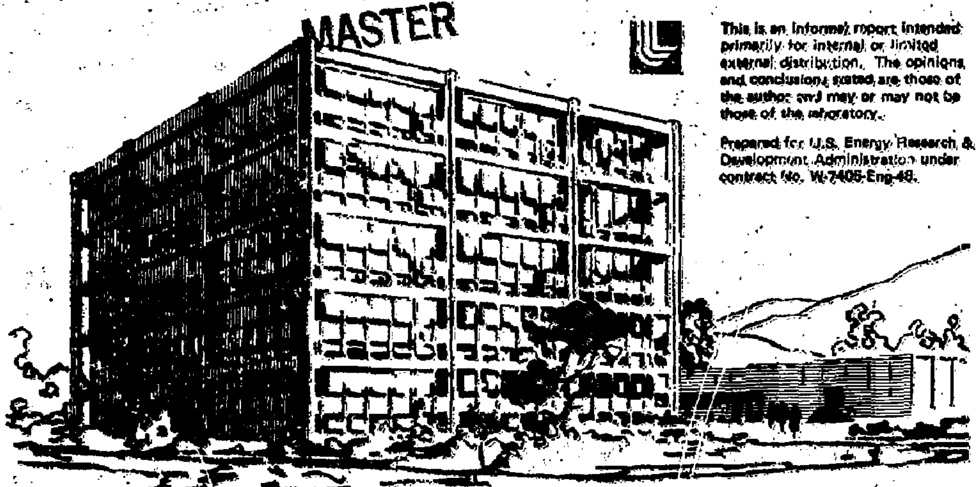
FABRICATION OF A LARGE PLUTONIUM SPHERE FOR USE IN LLL PULSED-SPHERE EXPERIMENTS

Robert L. Rose

June 17, 1977

MASTER



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ABSTRACT

Two plutonium-alloy hemispheres were cast, machined, and canned for use in pulsed-sphere experiments. LLL physicists will use the data from these experiments to improve physics codes. The total mass of Pu-1.0 wt% Ga was 9.3 kg. The hemispherical shapes had a radius of 53.7 mm. Both hemispheres were cast with hollow polar cones. In one casting the cone was plugged; in the other casting the cone was left to allow fitting to the neutron generator. The hemispheres were electron beam welded into close-fitting stainless steel cans so they could be used in a non-plutonium area. This report describes the fabrication of the device, which is expected to have long-term research utility.

INTRODUCTION

In an effort to improve physics codes,[1] LLL physicists designed a ^{239}Pu-1.0 wt% Ga alloy* sphere for pulsed-sphere experiments. A 14-MeV neutron generator will be fitted to the 9.3-kg plutonium sphere to inititate fission reactions; time of flight and cross-section characteristics will be studied. The device (see Figs. 1-3) was fabricated in the LLL Plutonium Facility.

Safety restrictions dictated that this sphere be assembled into its largest mass configuration only in a specially designated place at the site of the experiment. Because the experiment was to be done using a 14-MeV neutron generator in a radioactively cold area (ICT facility), the parts had to be encapsulated in a strong, clean container with minimum neutron interference.

The sphere was made in two hemispherical parts. The parts were covered with cadmium and placed in stainless steel cans, which were electron beam (EB) welded closed. The purpose of the cadmium layer is to absorb reflected neutrons if the sphere were accidentally immersed in water.

A container (Fig. 4) was specially made to allow safe assembly of the two hemispheres at the work site. MORSE C calculations[2-4] revealed a maximum neutron multiplication of 0.869 ± 0.006 for the entire research assembly.

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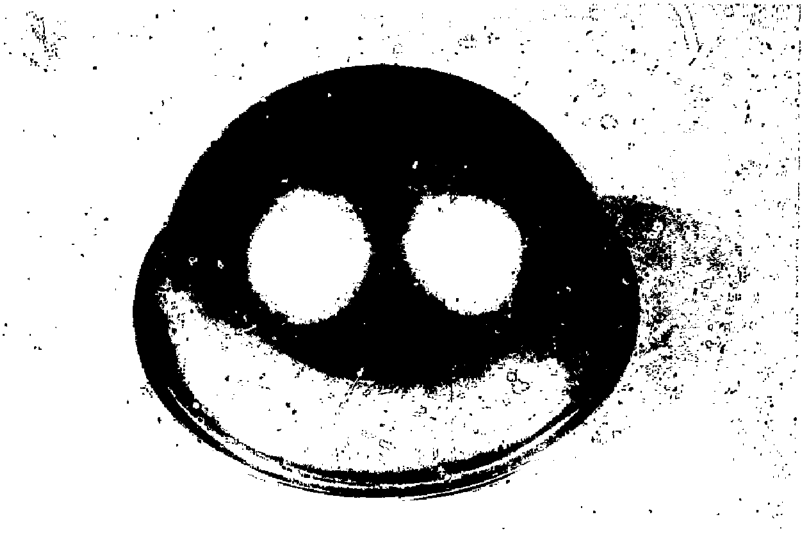
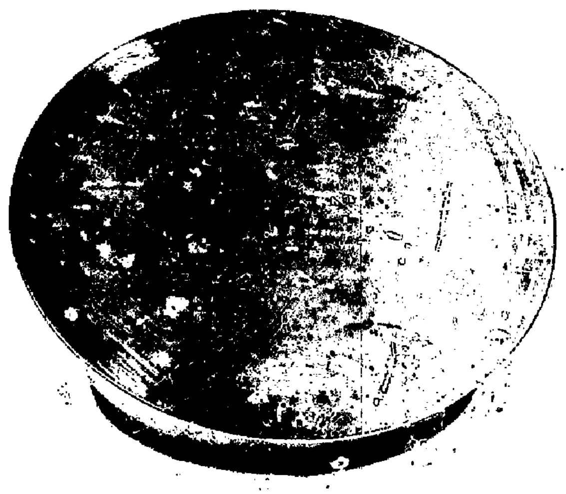
*Designated Pu-1Ga.



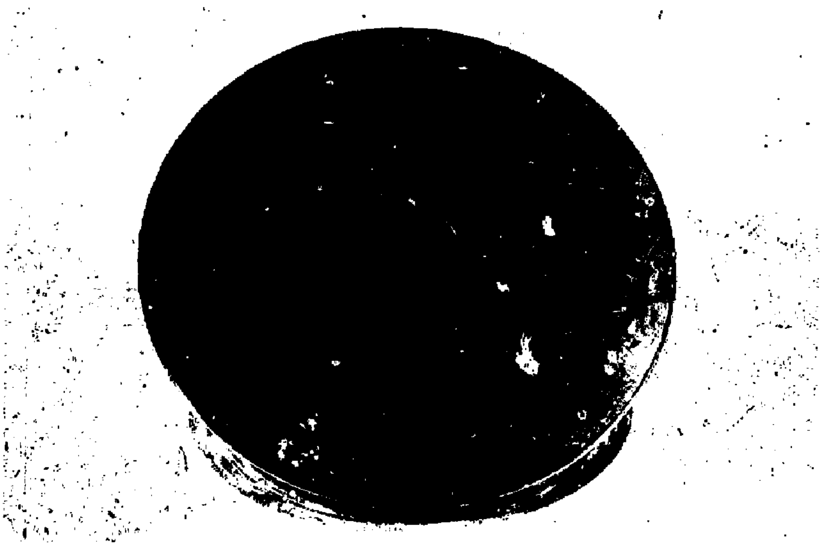
Polar view



Waist view

Fig. 1. The finished solid Pu-1Ga hemisphere. This part was cast, machined, and canned in the LLL Plutonium Facility.

Polar view



Waist view

Fig. 2. The hollow Pu-1Ga hemisphere for the pulsed sphere.

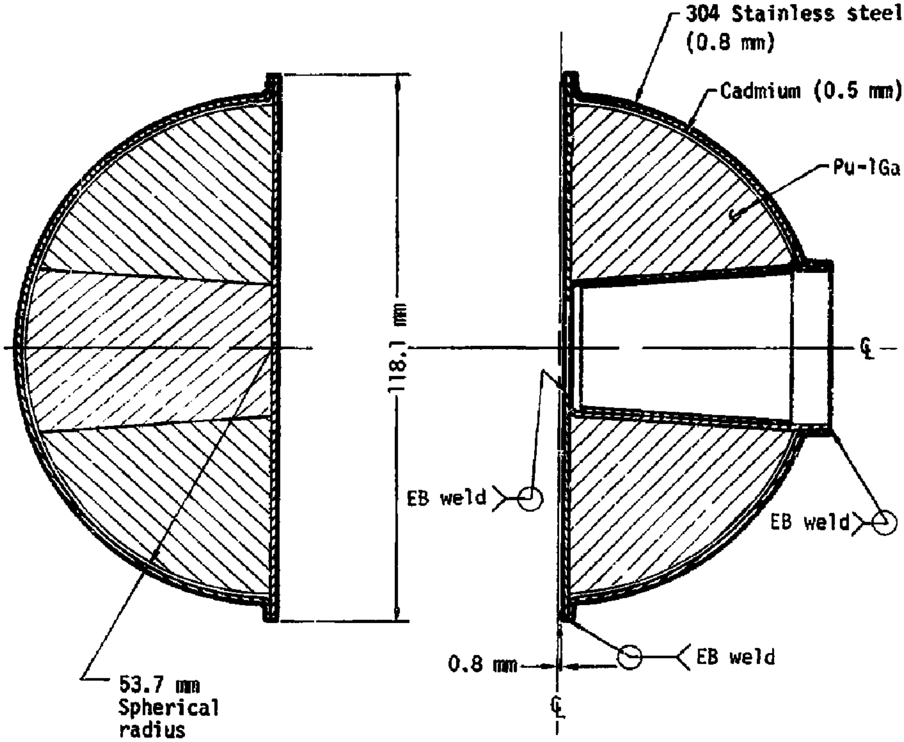


Fig. 3. The pulsed-sphere assembly.

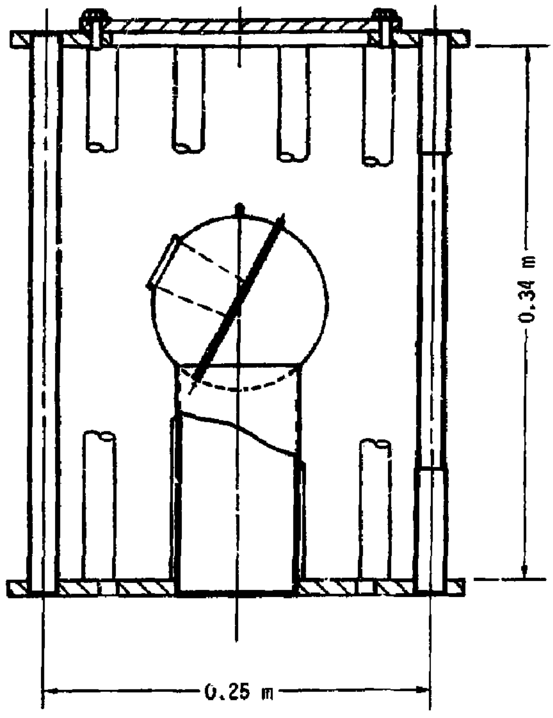


Fig. 4. Special birdcage container that was made to allow safe assembly of the pulsed sphere. (Taken from LLL drawing AAA 76-118148-0B).

The practical way to make these parts was to cast close to size and machine to finish. A solid hemisphere would have had to be cast much larger (5.1 kg) than the finished part to insure proper cleanup of the casting. This would have put the part weight above the allowable plutonium mass at available fabrication sites. The engineers also considered making the hemispherical parts of nested hemispherical shells. The exacting machine tolerances and extensive fabrication made this method expensive.

The decision was made to do the job at LLL and cut costs by using the following method:

1. Make two hollow castings of the same size and shape (i.e., cone center).

2. Plug one casting near its finished size and machine it to finish tolerance.

This method required a single mold design for both parts. The method also allowed us the latitude of selecting the best casting (surface perfection) for the largest part.

CASTING

Weapons grade Pu-1Ga was obtained from Rockwell International, Rocky Flats Division. We received ingots in tree form (i.e., all ingots of a given heat in one piece connected with runners). Each segment of each heat was separated from the ingot and cast into feed slugs.[5] The composition of each heat is shown in Table 1. Table 2 shows the isotopic composition of the castings. Table 3 shows the material balance for all the Pu-1Ga that went into the products.

The molds are shown in Fig. 5. The molds were made of A.T.J. carbon,[6] spray coated with Y_2O_3.[7] The casting was done using the bottom-pour vacuum-induction method.[5] No homogenization of the castings was contemplated, so we attempted to control coring[8] by casting at a melt temperature (850°C) low enough to preclude cold shuts, but allow the heat capacity of the mold to bring the casting temperature rapidly through the two-phase ϵ-δ region. The cooling rate for the casting through the ϵ-δ region was 10 to 12°C/minute.

Table 1. Compositions of ingots.

Ingot heat No.	Spectroscopic, ppm														Chemical			Atomic absorption, ppm	
	Al	P	Be	Ca	Cr	Cu	K	Mg	Mn	Mo	Pb	Si	Sn	Ti	C, ppm	U, ppm	Ga, wt%	Ni	Fe
18014	59	<10	.1	<5	62	44	<5	<5	18	5	30	68	30	10	198	264	1.00	120	275
18023	28	<10	<.1	<5	33	25	<5	<5	13	6	9	34	16	<5	160	200	0.98	119	240

Table 2. Isotopic composition of castings.

Casting No.	Wt% of Ingot 18014	Wt% of Ingot 18023	Gamma spectrometric isotopic analysis of each casting				
			^{239}Pu, wt%	^{240}Pu, wt%	^{241}Pu, wt%	^{238}Pu, Mg/g of Pu	^{241}Am, Mg/g of Pu (2-17-77)
RR-1348A	100.0	----	93.79 ±0.03%	5.834 ±0.53%	0.347 ±0.27%	0.104 ±2.4%	0.383 ±0.19%
RR-1348D	38.3	61.7	98.80 ±0.02%	5.810 ±0.39%	0.352 ±0.20%	0.103 ±1.8%	0.365 ±0.14%
RR-1348E	22.2	77.8	93.77 ±0.03%	5.839 ±0.50%	0.358 ±0.25%	0.104 ±2.3%	0.363 ±0.18%

Table 3. Material balance.

Solid hemisphere

	Charge w, g	Casting w, g
Hemi-casting (RR-1348D)	5232.4	5122.6
Plug (RR-1348A)	1865.6	1822.6

Total Pu assembly wt (RR-1348AD) = 5112.8 g (calc. ρ = 15.80 Mg/m^3)

Stainless steel and Cd can parts = 257.52 g

Total canned solid hemisphere wt = 5369.58 g* ρ

Hollow hemisphere

	Charge w, g	Casting w, g
Hemi-casting	5371.3	5297.3

Total Pu assembly wt (RR-1348E) = 4222.5 g (immersion ρ = 15.88 Mg/m^3)

Stainless steel and Cd can parts = 277.20 g

Cd cone = 25.80 g

Total canned hemisphere = 4524.90 g

*Component wts/finished parts wts — error within accuracy of balance.

MACHINING

Figure 6 shows the machining specification. Machining was done on a Model E.E. Monarch lathe with a tracer attachment. Figure 7 shows the hemisphere and the plug. The polar radius of the plug was cut ~3.1 mm long. A level projection ~19 mm o.d. was cut at the minimal plug taper for future machine use.

The hemispherical casting was roughed 0.13 mm oversize on the spherical radius and 0.38 mm on the waist flat. The part was held by a projection on the waist surface (sprue casting). The hole taper was cut to match the plug taper ±0.01 mm.

The solid hemisphere was made by driving the plug into the cone of the hemisphere with a soft hammer. The solid roughed assembly was then gripped in the lathe chuck by the plug projection (waist) and the spherical radius was finish cut. A vacuum pot chuck was made to hold the part for final waist cutting to finish size (Fig. 8). The hollow hemispherical casting was machined in the same way, except finishing was completed in one operation (Fig. 9).

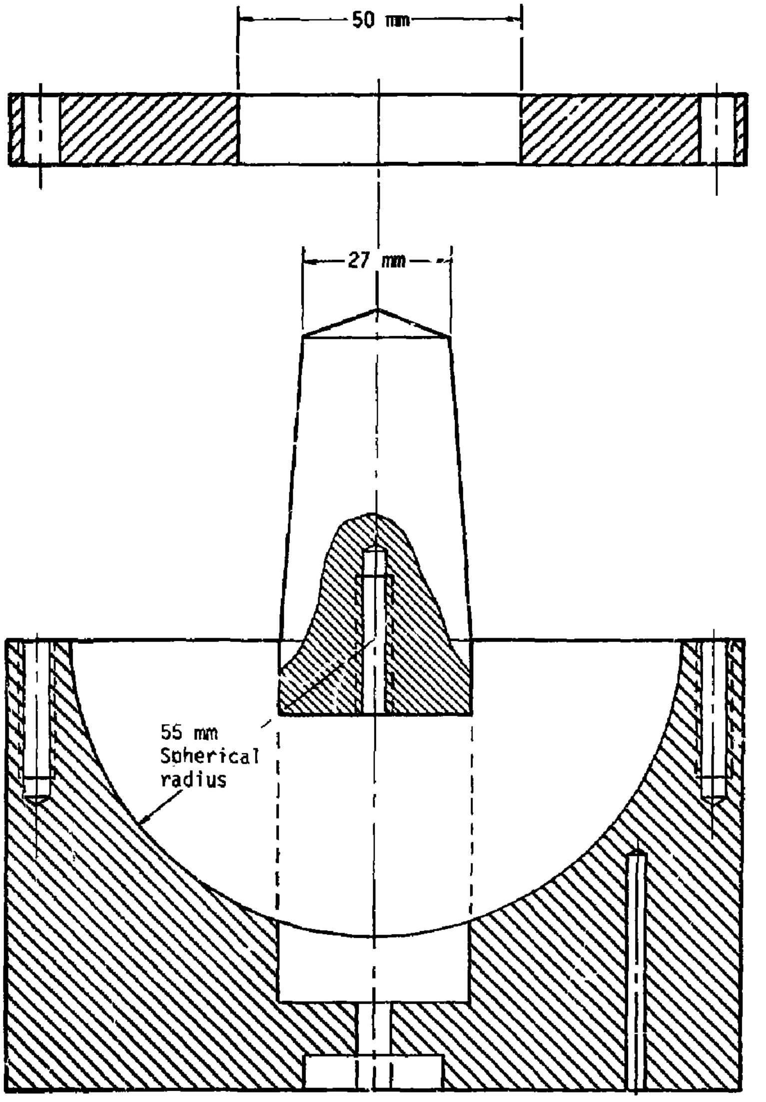


Fig. 5. Mold for casting the Pu-1Ga hemispheres. (Taken from LLL drawings AAA 76-115142-00, 76-115140-00, and 76-115141-00).

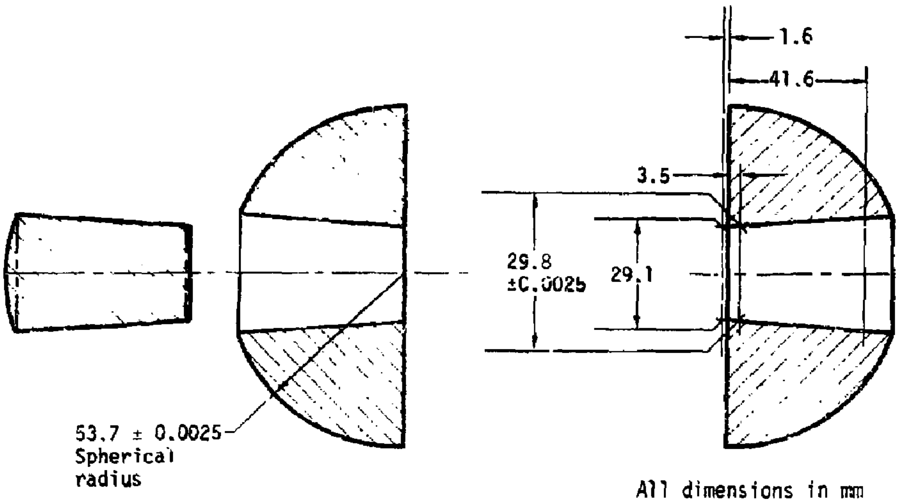


Fig. 6. Machining specifications for the plutonium sphere. The finish was 63FAO unless otherwise specified. (Taken from LLL drawings AAA 76-115268-00, 76-115276-00, and 76-113295-0B).

Components of solid part

Plug driven into cone

Fig. 7. The solid hemisphere before and after the conical plug was driven into the hollow hemisphere.

Fig. 8. The solid hemisphere in the measuring chuck.

Fig. 9. The hollow hemisphere in the lathe chuck.

CANNING

Plutonium hemispheres were canned in 304 stainless steel containers made in the LLL shops. The cans were hydroformed from sheet, finish machined on edges and weldment areas, and lined with cadmium. Cadmium was verified by x-ray spectrometry.[9] The finished plutonium castings had to be placed in cans and held in place for EB welding without contaminating the exterior surfaces of the cans. Fixturing was made for both the solid part (Figs. 10 and 11) and the hollow part (Figs. 12 and 13).

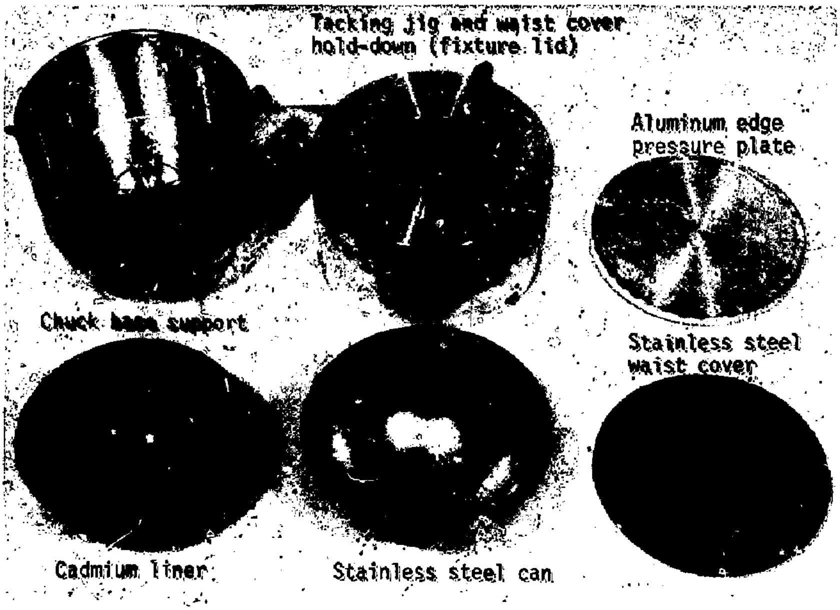
The plutonium hemisphere was placed pole up on a down-draft table (i.e., a Pu assembly area in which Pu can be handled in the open). The cadmium liner was placed over the plutonium then the stainless steel can was placed over the cadmium. The plutonium was then held securely in place from underneath and the assembly inverted and nested into the EB chuck base support (Fig. 10). The stainless steel lid was positioned over the flat face of the plutonium.

An aluminum edge pressure plate was placed over the stainless steel. The fixture lid was emplaced and the part within adjusted to the circumferential tacking holes (see Fig. 11). The lid was EB tack welded through the holes until a tack was completed behind each hole. The fixture lid was removed and a continuous weld was made over the tacks. After removal from the EB vacuum chamber no signs of external plutonium contamination could be found on the part.

The hollow part was canned in the same way. Additional fixturing had to be provided (Fig. 12) so the additional weld on the waist zone face could be completed. This weld was accomplished by EB tacking between the fingers of the center weld compression fixture (Fig. 13), removing the finger holder and completing a continuous EB weld. The waist perimeter was welded with the live center waist cover hold down in place. No external plutonium contamination was detected on this part after processing.

CHARACTERIZATION OF FINISHED PARTS

The machine finish on all plutonium parts exceeded the design requirements. The castings were sound and radiographic inspection showed no internal flaws. The experimenters wanted the total gap between the can and the plutonium to be as small as possible, and this depends on the aggregate part tolerances in the assembly. X-ray examination of the parts[10] showed the aggregate wall and waist gaps to be ≤ 0.08 mm.



Fi. . 10. Components of the fixture used in welding the can for the solid hemisphere.

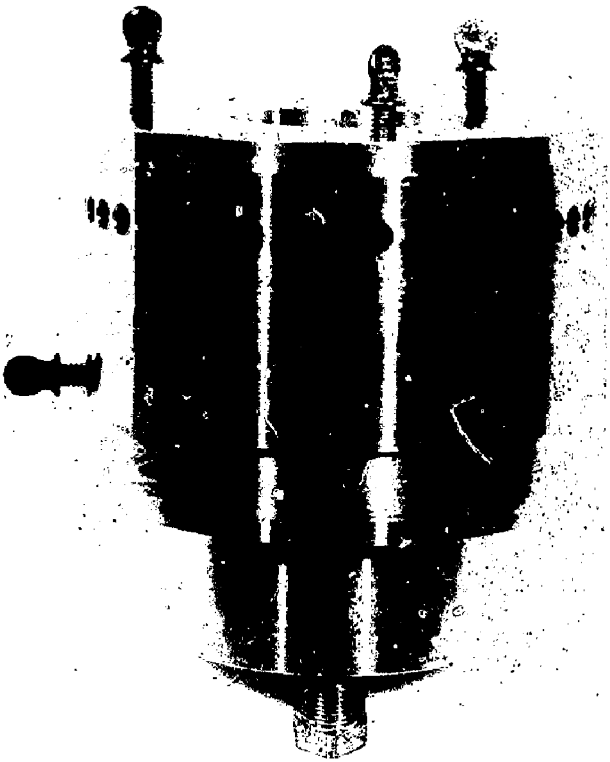


Fig. 11. Solid hemisphere in the welding fixture.

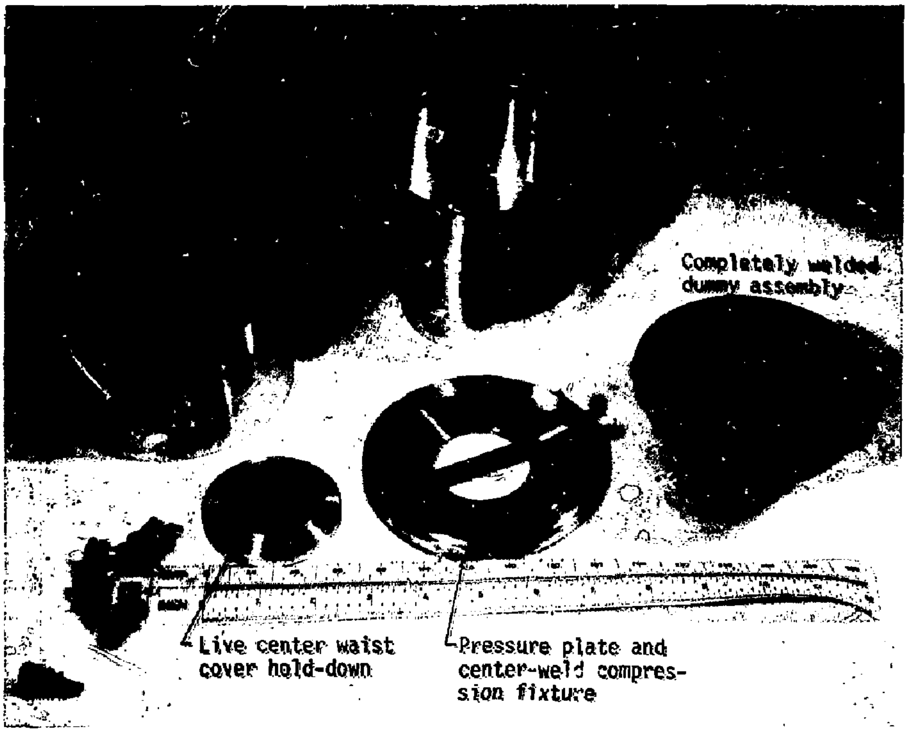


Fig. 12. Components of the fixture used in welding the can for the hollow hemisphere.

Fig. 13. Hollow hemisphere in the welding fixture.

Samples were taken of each part for analysis and the historical record. Metallographic detail was obtained on the plug, where most neutron interaction will take place. The results are shown in Fig. 14. The low-magnification picture is given to show the general cleanliness of the alloy. It looks typical for the grade of material. The high magnification picture shows the extent of coring[8] (i.e., the α-phase Pu deposition between the grains of δ-phase Pu). The average grain size and coring are typical of this alloy cooled at 10 to 12°C/minute through the two-phase δ+ε region ($\sim 50 \times 10^{-6}$m). The immersion density of this part is 15.83 Mg/m^3.

The hemispherical component of the solid plutonium part was too massive at any stage of its fabrication to allow an immersion density to be taken in the LLL facility, but a density of 15.80 Mg/m^3 was calculated from the finished part size.

An immersion density of 15.88 Mg/m^3 was obtained for the hollow part in its finished condition.

We consider the structure of all the castings to be identical.

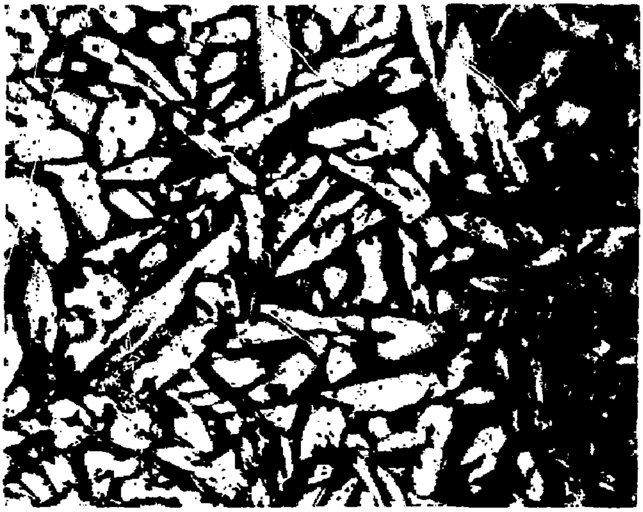
A can drop test[4] was performed to show structural strength of the finished parts. This was included in the operational safety procedures allowing this part to be used in a nonplutonium area.

The effort and cost figures for making this part are given in Table 4.

Table 4. Summary of costs for canned parts and bird cage assembly.

Man hours of effort:		
Engineering (NEED)		450
Plutonium Metallurgy		327
Shops (MFD)		613*
	Total	1390 h
Purchase fabrication costs:		
Plutonium casting molds		$390.00
Bird cage		$219.00
	Total	$609.00

*Note: Includes 270 h for can fabrication.



250 X

800 X

Fig. 14. Metallography of as-cast Pu-1Ga from the plug.

ACKNOWLEDGMENTS

The mass of the parts fabricated meant that close coordination of all efforts was essential to ensure safe working conditions. We give immense thanks to the following members of the Building 332 staff for their great teamwork in this very successful fabrication:

- Pu Foundry — B. A. Kuhn
- Machining — R. O. Willard
- Assembly & Logistics — R. A. Ramos
- Welding — R. P. Link
- Fixturing — W. L. Haugen

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