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Light Weight Radioisotopic Heater Unit (LWRHU) Production for the Galileo Mission

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LIGHT WEIGHT RADIOISOTOPIC HEATER UNIT (LWRHU) PRODUCTION FOR THE GALILEO MISSION

by

G. H. Rinehart

ABSTRACT

The Light Weight Radioisotopic Heater Unit (LWRHU) is a $^{238}PuO_2$-fueled heat source designed to provide a thermal watt of power for space missions. The LWRHU will be used to maintain the temperature of various components on the spacecraft at the required level. The heat source consists of a $^{238}PuO_2$ fuel pellet, a Pt-30Rh capsule, a pyrolytic graphite insulator, and a woven graphite aeroshell assembly. Los Alamos National Laboratory (LANL) has fabricated 134 heater units which will be used on the Galileo Mission. This report summarizes the specifications, fabrication processes, and production data for the heat sources fabricated at LANL.

I. INTRODUCTION

The Light Weight Radioisotopic Heater Unit (LWRHU) is a $^{238}PuO_2$-fueled heat source designed to provide one thermal watt to various locations on a spacecraft. The heat sources are required to maintain the temperature of specific components within normal operating ranges. The first application of the LWRHU's will be on the Galileo Mission. Los Alamos National Laboratory (LANL) was responsible for the design, fabrication, and safety testing of the LWRHU. The heat source consists of a hot-pressed $^{238}PuO_2$ fuel pellet, a Pt-30Rh vented capsule, a pyrolytic graphite insulator, and a FINE-WEAVE-PIERCED^{TM} Fabric (FWPF) graphite aeroshell assembly. The heat source assembly is shown in Fig. 1. The design of the LWRHU has been described by Tate (Ref. 1). The LWRHU specifications and construction drawings are presented in Appendices I and II, respectively. This report describes the fabrication and the production data for the 134 heat sources that were delivered to the Jet Propulsion Laboratory. The production effort included processing the raw PuO_2 feed material from the Savannah River Plant (SRP), hot pressing the fuel pellets, encapsulating the pellets in a Pt-30Rh alloy, placing the capsules in the aeroshell assemblies, and performing all the associated nondestructive testing (NDT) activities.

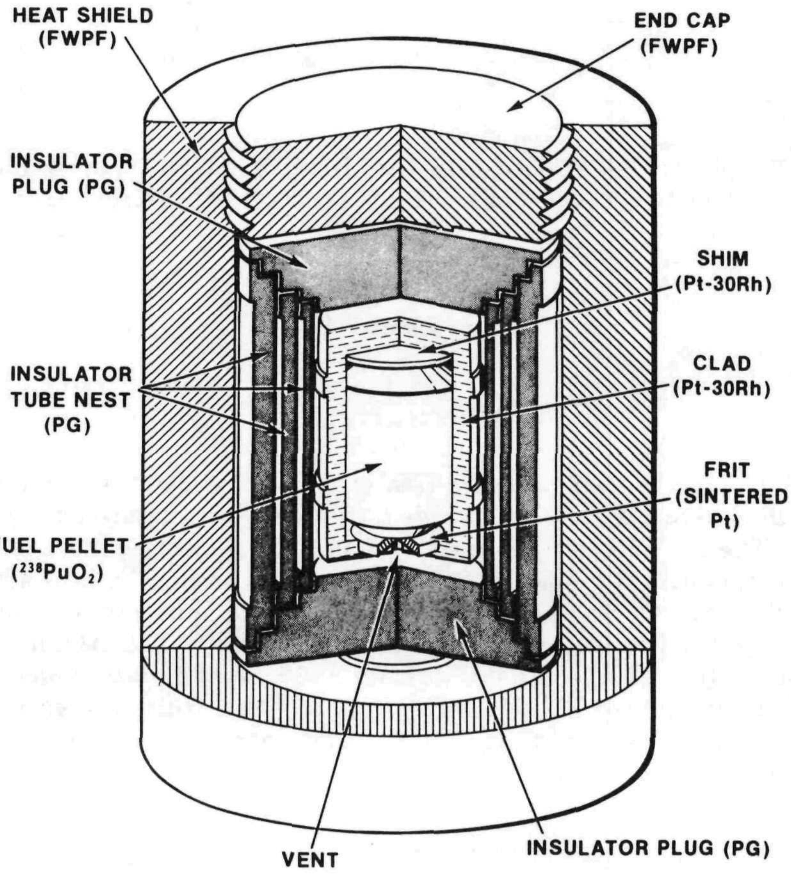

Fig. 1. Light Weight Radioisotopic Heater Unit.

II. FUEL PROCESSING AND CHARACTERIZATION

A. Fuel Processing

The LWRHU fuel processing flowsheet is shown in Fig. 2. The details of the fuel processing steps have been described by Kent (Ref. 2). Four lots of feed powder (915 g) from SRP were processed for the LWRHU production effort. The processing yielded 850 g of seasoned granules.

B. Fuel Characterization

1. Neutron Emission Data. Neutron emission rate data for the feed lots are listed in Table I. The as-received SRP feed powder had an average neutron emission rate of 18 970 ± 1 860 $ns^{-1}g^{-1}(^{238}Pu)$. After O-16 exchange and other processing, the average neutron emission rate of the fuel granules was 6 510 ± 1 740 $ns^{-1}g^{-1}(^{238}Pu)$. Fuel lots 38 and 39 did not meet the specification of $\leq$6 000 $ns^{-1}g^{-1}(^{238}Pu)$ after processing, but the neutron emission rate was expected to drop significantly during pellet fabrication.

2. Spectrochemical Data. The spectrochemical results for the four as-received SRP feed lots are compared to the impurity levels in the processed fuel granules in Tables II and III. Spectrochemical samples were not obtained for processed lots 38 and 39, although spectrochemical samples were taken from pellet lots fabricated from these two fuel lots.

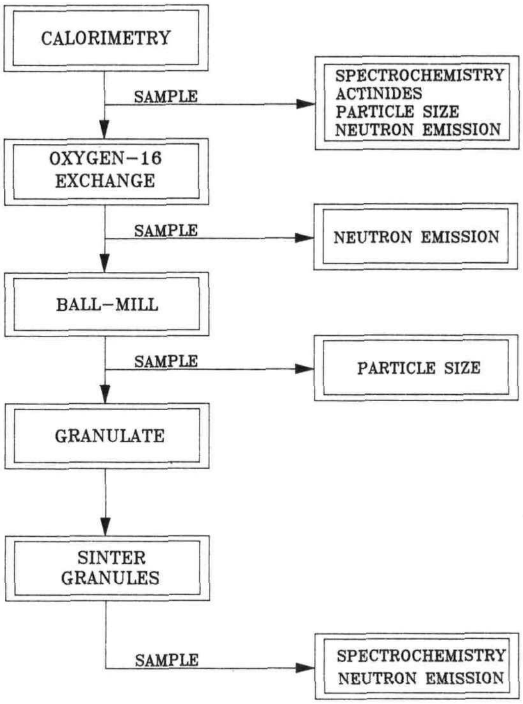

Fig. 2. LWRHU Fuel Processing Flowsheet.

3. Isotopic Data. The plutonium isotopic data for the fuel lots are listed in Table IV. The SRP isotopic data in the Table have been decayed to the same dates as the LANL analysis. There is excellent agreement between the SRP and LANL results.

4. Actinide Data. The ^{232}Th, ^{234}U, ^{236}Pu, ^{237}Np, and ^{241}Am contents of the four as-received SRP feed lots, back-decayed to the date of precipitation at SRP, are listed in Table V. The actinide levels of all lots were well within specification.

5. Particle-Size Data. Particle-size data for both as-received SRP feed powder and ball-milled powder are listed in Table VI. Ball-milling the feed powder for 44 h reduces the mass median diameter of the particles from an average of 3.4 microns to 1.2 microns as preparation for forming the <125-micron fuel granules.

III. HOT PRESSING AND FUEL PELLET CHARACTERIZATION

A. Hot Pressing

The fuel used to fabricate the LWRHU fuel pellets was obtained by mixing the <125-micron granules seasoned at 1100°C (60 wt%) and 1600°C (40 wt%). The mixing was accomplished by placing the granules in a ball-mill jar and rolling it for 15 to 30 min at 27 rpm. No balls were used during the mixing process. The jar was charged with 43.72 g of granules. After mixing was completed, the hot-press graphite die was loaded with 16 fuel charges, each weighing 2.670 g.

The die assembly is shown on drawing 26Y-79818 in Appendix II. It consisted of a cylindrical insert, susceptor, locking pin, 32 punches, and 2 endcaps. The pellets were formed in 16 holes bored through the insert. The susceptor was sized to both the insert and the induction coil to maximize heating efficiency. Seven black-body holes in the susceptor served as targets for an optical pyrometer. The insert and susceptor were positioned relative to one another by means of the locking pin. Sixteen punches were introduced into one end of the insert, the charges were loaded, and then sixteen punches were introduced into the other end of the insert.

The LANL hot-press system consisted of a Materials Test System's hydraulic system, a vacuum system, and an induction heating system. The hydraulic system powered two main pressing servorams and three actuators. The servorams were mounted vertically and extended into the vacuum system through the axis of the induction coil. The actuators were used to raise and lower the vacuum chamber so that the die assembly could be introduced into the vacuum system. Each of the main servorams was provided with a water-cooled load cell. The pressing cycle was controlled by a Data Trak programmer and the signal from the load cell located in the master servoram. The system was capable of producing a maximum force of 111.9 kN.

The heating system consisted of a 100-kVA motor generator and associated controls. With a Micro Optical Pyrometer, temperatures were measured by sighting through a quartz optical window into one of the black-body holes in the susceptor.

The vacuum system consisted of a Varian 102-mm-diam Model M4 diffusion pump backed by a Welch Model 1397B mechanical pump. Convoil 20 oil was used in both pumps. The vacuum chamber pressure was measured by a thermocouple gauge and a Bayard-Alpert ion gauge.

After the graphite die was loaded with the charges, it was positioned in the center of the induction coil, the vacuum chamber was lowered, and the system was evacuated. When the vacuum chamber reached a pressure of 1.3×10^{-4} Pa, a slight preload, 0.5 kN, was applied to the die. The timer was then started and the motor generator power was increased to 67.5% of full power. Five min into the run, when the temperature reached 1300°C, the programmed load cycle was initiated. Six and one half min into the run, when the susceptor temperature reached 1530°C, the motor generator power was reduced to about 50% of full power to maintain a temperature of 1530°C for the remainder of the run. The full programmed load, 9.6 kN, was attained 10-11 min into the run. The die was held at 1530°C under full load for 15 min, although punch closure usually occurred about 5 min after the full load had been applied. At the end of the pressing cycle, the motor generator was turned off and the load was removed from the die assembly. After a suitable cooling period, the vacuum system was backfilled with argon and the die assembly was removed.

B. Post-Press Sintering and Dimensioning of Fuel Pellets

During hot pressing, the plutonia was reduced by the graphite die. Twenty-four hours after the hot pressing, the plutonia stoichiometry was about $PuO_{1.93}$. To oxidize the pellets to a stoichiometry of PuO_2 and increase their density, the pellets were sintered in flowing $Ar\text{-}H_2{}^{16}O$ for 6 h at 1000°C followed by 6 h at 1527°C. Heating and cooling rates were 150°C/h. The pellets were sintered in a platinum boat filled with high-fired thoria powder to prevent stress points that could occur if the pellets were in direct contact with the platinum boat. The use of $Ar\text{-}H_2{}^{16}O$ flow gas during this process decreased the neutron emission rate of the pellets.

After sintering, each pellet was weighed and the length and diameter were measured. Table VII lists the mass, length, diameter, and percent of theoretical density of each pellet. The mass of each pellet met the specification of 2.664 ± 0.010 g. The reference design length and diameter of the pellets were 9.37 and 6.25 mm, respectively.

C. Analytical Chemistry of Pellet Lots

One pellet from each hot-press run was submitted for spectrochemical analysis, actinide analysis, isotopic content, and neutron emission rate.

1. Spectrochemical Analysis. The nonactinide cationic impurity levels for the pellet lots are listed in Table VIII. The pellet lots in Table VIII were fabricated from fuel lots 38 and 39.

Pellet lots RU03, RU07, and RU10 exceeded the silicon impurity specification of 200 ppm, but were accepted for flight use by the Materials Review Board. The pellet lots in Table VIII (Lot 12-17) were fabricated from fuel lots 69 and 74 and met the impurity specifications.

2. Neutron Emission Rate. The neutron emission rates for the pellet lots are listed in Table IX. All pellet lots met the specification of $<6\,000$ $ns^{-1}g^{-1}(^{238}Pu)$.

3. Isotopic Composition. The isotopic composition data for the pellets are listed in Table X.

4. Actinide Data. The actinide data for the pellet lots are listed in Table XI.

IV. WELDING AND NDT OF HEAT SOURCE CAPSULES

A. Welding

1. Hardware. All components of the capsule, except for the frit vent, were fabricated from Pt-30Rh tube, sheet, and foil. The frit vent was a pressed and sintered disk of pure platinum powder. Details of the capsule design are shown in the drawings in Appendix II. Monsanto Research Corporation, Mound Facility (MF) fabricated the components and electron beam welded the frit vent and vent end cap into place before shipping the hardware to LANL. Each piece of hardware was visually inspected at LANL before it was released for production. After the hardware was released for production, it was cleaned with absolute ethanol in an ultrasonic cleaner and then baked at 100°C in a vacuum oven.

2. Equipment. The welding was performed in a helium-atmosphere glovebox. A gas purifying system was plumbed to the glovebox in a closed loop to maintain the atmosphere purity at less than 25 ppm oxygen and less than 60 ppm moisture. A Teledyne Analytical Instruments Model 317X oxygen monitor and an Ondyne Model 355 moisture monitor were used to analyze the glovebox atmosphere. Helium entered the glovebox on a demand basis to maintain a pressure approximately 0.4-0.8 in. of water, negative with respect to the room atmospheric pressure.

The Gas Tungsten Arc (GTA) welding power supply was a 300-ampere DC Hobart Cyber-Tig Model CT-300 with a Series 600 programmer. A remote pendant contained the controls to start, downslope, and stop the welding current; set the weld current level; and set the fixture rotational direction and speed. The welding fixture consisted of a vertical spindle which penetrated the floor of the box. The drive was an Electrocraft E-550 motor/tachometer; a Model 007-1628-2 gearbox provided a 100:1 speed reduction. The gearbox was coupled to the spindle via sprockets and a roller chain which provided an additional 2:1 speed reduction. The motor power supply was a rack-mounted Electrocraft Model E-550-M controller. A size 5C collet was attached to the top end of the spindle. The collet was bored to accept the diameter of the capsule and to allow 6.7 mm of the capsule to protrude from the collet. The welding torch was a Weldcraft Model WP-20P-12 pencil-type, water-cooled GTA torch. The cooling water was recirculated in a closed loop with a LANL Model 107A limited-volume, chilled-water system. The torch gas was a 75% helium: 25% argon mixture.

A Gould-Brush Model 2007-6304-00 three channel recorder with three Model 13-4615-10 amplifiers was used to record the arc voltage, current, and fixture rotational speed. The voltage signal was measured at the welding cable feedthroughs on top of the glovebox. The current signal was measured at a current shunt near the weld power supply. The fixture speed signal was received from the drive motor/tachometer. A Hewlett-Packard Model 6111A DC Power Supply and Model 3465A Digital Multimeter were used to calibrate the recorder.

3. Welding Procedure. The welding procedure, equipment, and operator were qualified by consecutively welding three LWRHU capsules, sectioning them, and performing a metallographic examination. An example weld was performed before the daily production run and after every 12 production welds. The example welds were sectioned and examined before the production welds were performed. Photomicrographs of two example welds (CB373 and CB379) are shown in Figs. 3 and 4. After the capsules were welded, they were visually inspected, decontaminated to zero alpha swipe in a nitric acid/hydrofluoric acid solution, and then submitted for NDT.

B. Nondestructive Testing

The welded capsules were submitted to the following tests: helium leak check; flourescent dye penetrant inspection of weld for evidence of cracks; radiography of weld area to ensure 100% weld penetration; measurement of the height, diameter, and weld stand-off height; neutron emission rate; thermal power; and measurement of the gamma and neutron dose rate at a distance of 20 cm for one capsule from each pellet lot.

1. Helium Leak Check. A Veeco Model MS-18AB helium leak detector was used to check the GTA welds. The detector had a sensitivity of 2×10^{-11} atm cm^3/sec for helium and was calibrated with a certified standard helium leak. The test fixture was a water-cooled copper unit that could contain a maximum of seven LWRHU assemblies. All assemblies had leak rates $<1 \times 10^{-9}$ atm cm^3/sec, which were well within the maximum helium leak rate specification of 1×10^{-6} atm cm^3/sec.

2. Thermal Power and Neutron Emission Rates. The thermal power of each capsule was measured in one of three MF-designed twin bridge calorimeters. The calorimeters were calibrated with a certified thermal standard each day that measurements were performed. At the one watt level, the calorimeters had a precision of ±0.001 W and an accuracy of ±0.004 W. A LANL-designed thermal neutron counter was used to measure the neutron emission rate of each capsule. The instrument was calibrated with a certified neutron source each day that measurements were performed. The neutron counter had a precision of ±0.1% and an accuracy of ±3%. The thermal power and neutron emission rate of each capsule are summarized in Table XII.

3. Gamma and Neutron Dose Rates. The gamma and neutron dose rates at 20 cm were measured on one capsule from each pellet lot. A Victoreen Model 440 Low Energy Survey Meter was used to measure the gamma dose rate and an Eberline Model PRS-2 Portable Rate Meter-Scaler was used to measure the neutron dose rate. Both instruments were calibrated against standards traceable to the National Bureau of Standards (NBS). The gamma and neutron dose rates are summarized in Table XIII.

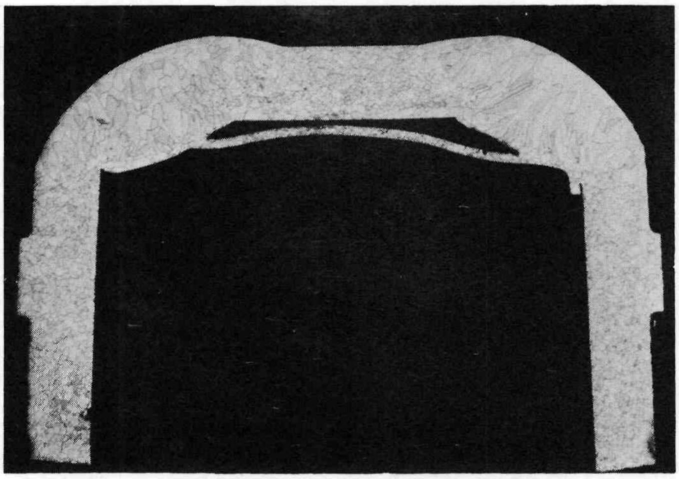

Fig. 3. Example Weld, CB373.

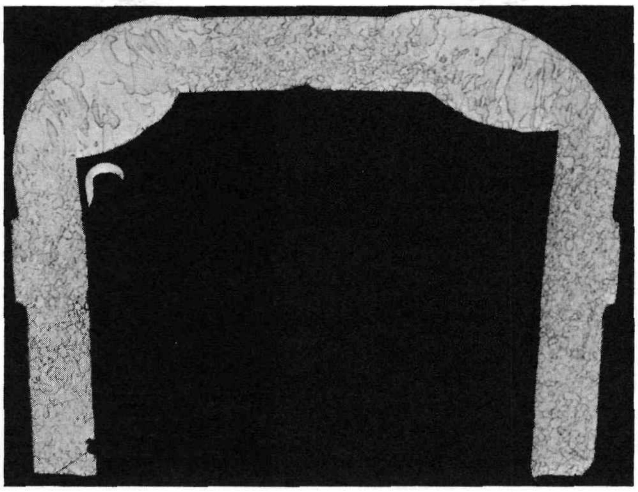

Fig. 4. Example Weld, CB379.

V. FINAL ASSEMBLY

After the LWRHU capsule had passed the NDT, it was submitted for final assembly. The pressed and sintered platinum powder frit vent was activated by cutting into the vented end (electron-beam-welded end) of the capsule at the center line with a 0.635 ± 0.050-mm-diam endmill to a depth of 0.279 to 0.406 mm. The capsule was then examined under a microscope to ensure that the frit was visible through the milled hole. After a swipe check for loose alpha contamination (<220 dpm), the capsule was placed into the graphite aeroshell (vent end down) and the graphite lid was glued in place. The graphite aeroshell was then heat treated at 100 ± 5°C for a period of 4.0 ± 0.5 h followed by heating at 130 ± 10°C for 16 ± 1 h to cure the cement. The assembled heater was swipe checked to ensure surface contamination was <220 dpm; then its dimensions and mass were measured.

A. Equipment

The vent activation was performed with a Servo Products Company Model 7230 vertical micromilling machine. The milling machine was equipped with a Sony Model SR-745 6/150 Digital Position Readout System and Sony Magnescale LF-200-22 Digital Display. The endmill had a diameter of 0.635 mm and was obtained from the Spiral Step Tool Company.

The graphite cement was Union Carbide Corporation UCAR C-34, which consisted of a graphite powder and a molasses-colored liquid. The cement was prepared by mixing 100 parts (by weight) of powder with 35.3 parts (by weight) of liquid.

B. LWRHU Final Assembly Data and Record of Assembly

The mass, height, diameter, and thermal power (decayed to January 1, 1985) of the final assemblies are summarized in Table XIV. The record of assembly for each heat source is listed in Table XV.

REFERENCES

1. R. E. Tate, "The Light Weight Radioisotope Heater Unit (LWRHU): A Technical Description of the Reference Design," Los Alamos National Laboratory report LA-9078-MS (January 1982).

2. R. A. Kent, "LASL Fabrication Flow Sheet for GPHS Fuel Pellets," Los Alamos Scientific Laboratory report LA-7972-MS (September 1979).

TABLE I. Neutron Emission Rate Data for Feed Lots

ID Numbers			Neutron Emission Rate $ns^{-1}g^{-1}(^{238}Pu)$	
LANL	SRP		As	
Lot	Lot	Run	Received	Processed
38	440	906923	18 070	8 430
39	440	906922	18 470	7 340
69	482	009150	17 730	5 810
74	499	101215	21 630	4 450
			18 970	6 510
			±1 860	±1 740

TABLE II. Spectrochemical Data for Feed Lots As-Received from SRP (LANL Analysis)

		LANL Lot ID			
Species	Specification	38	39	69	74
Al	---	85	70	15	170
B	---	<1	<1	<1	<1
Ca	---	130	130	750	750
Cd	---	<10	<10	<10	<10
Cr	---	70	130	40	60
Cu	---	15	15	1	<1
Fe	800	240	300	95	150
Mg	---	10	10	10	<1
Mn	---	10	10	4	3
Mo	---	5	10	3	3
Na	---	2	3	<2	4
Ni	---	45	75	35	30
Pb	---	15	5	10	25
Si	200	210	120	25	20
Sn	---	5	5	5	<5
Zn	---	20	15	5	<5

TABLE III. Spectrochemical Data for Processed Fuel Lots

		LANL Lot ID			
Species	Specification	38	39	69	74
Al	---	---	---	9	15
B	---	---	---	<1	<1
Ca	---	---	---	3	800
Cd	---	---	---	<10	<10
Cr	---	---	---	40	60
Cu	---	---	---	<1	1
Fe	800	---	---	140	160
Mg	---	---	---	1	1
Mn	---	---	---	4	5
Mo	---	---	---	<3	15
Na	---	---	---	2	8
Ni	---	---	---	7	30
Pb	---	---	---	<5	10
Si	200	---	---	90	120
Sn	---	---	---	5	<5
Zn	---	---	---	<5	<5

TABLE IV. Isotopic Data for Feed Lots

Feed		Plutonium Isotope (Weight Percent)				
Lot	Laboratory	238	239	240	241	242
38	SRP	83.57	13.88	1.96	0.46	0.12
	LANL	---	---	---	---	---
39	SRP	83.55	13.91	1.96	0.45	0.12
	LANL	83.49	13.95	1.97	0.46	0.13
69	SRP	82.80	14.57	2.07	0.42	0.14
	LANL	83.18	14.24	2.02	0.41	0.14
74	SRP	83.42	14.04	2.00	0.39	0.14
	LANL	83.38	14.08	2.01	0.40	0.14
SRP Average		83.34	14.10	2.00	0.43	0.13
		±0.36	±0.32	±0.05	±0.03	±0.01
LANL Average		83.35	14.09	2.00	0.42	0.14
		±0.16	±0.15	±0.03	±0.03	±0.01

TABLE V. Actinide Data for As-Received Fuel Lots (LANL Analysis)

Isotope (ppm)*	LANL Lot ID 38	39	69	74
^{232}Th	510	470	540	1200
^{234}U	230	330	150	<100
^{236}Pu	0.66	0.79	0.50	0.36
^{237}Np	210	190	890	2480
^{241}Am	60	60	<10	<10

*Back-decayed to date of SRP precipitation.

TABLE VI. Particle-Size Data for Feed Lots

Lot	Mass Median Diameter (microns) As Received	Ball-Milled
38	---	---
39	---	---
69	3.8	1.0
74	3.0	1.3

TABLE VII. Sintered Pellet Dimensions

Pellet ID	Mass (g)	Length (mm)	Diameter (mm)	% Theoretical Density
RU03-08	2.665	9.225	6.246	84.4
RU03-09	2.663	9.345	6.248	83.1
RU03-10	2.665	9.314	6.248	83.5
RU03-11	2.664	9.274	6.243	84.0
RU03-12	2.656	9.251	6.253	83.6
RU03-13	2.663	9.274	6.246	83.9
RU03-14	2.662	9.266	6.259	83.5
RU03-15	2.662	9.266	6.261	83.5
RU03-16	2.661	9.271	6.253	83.6
RU04-03	2.656	9.317	6.226	83.8
RU04-04	2.670	9.324	6.243	83.7
RU04-05	2.663	9.294	6.246	83.7
RU04-06	2.666	9.271	6.248	83.9
RU04-07	2.666	9.271	6.241	84.1
RU04-08	2.668	9.253	6.231	84.6
RU04-09	2.663	9.246	6.228	84.6
RU04-10	2.667	9.253	6.233	84.5
RU04-11	2.666	9.248	6.246	84.2
RU04-12	2.666	9.276	6.220	84.6
RU04-13	2.671	9.309	6.215	84.6
RU04-14	2.668	9.319	6.241	83.7
RU04-15	2.669	9.322	6.243	83.7
RU04-16	2.666	9.332	6.223	84.0
RU05-03	2.666	9.294	6.243	83.8
RU05-04	2.669	9.347	6.243	83.5
RU05-05	2.670	9.276	6.246	84.0
RU05-06	2.666	9.304	6.243	83.7
RU05-07	2.669	9.352	6.248	83.3
RU05-08	2.668	9.368	6.243	83.2
RU05-09	2.668	9.347	6.248	83.3
RU05-10	2.668	9.360	6.233	83.6
RU05-11	2.671	9.324	6.236	83.9
RU05-12	2.668	9.352	6.241	83.4
RU05-13	2.668	9.322	6.226	84.1
RU05-15	2.668	9.340	6.243	83.5
RU05-16	2.658	9.304	6.231	83.8
RU06-08	2.667	9.474	6.233	82.5
RU06-09	2.667	9.462	6.233	82.6
RU06-10	2.665	9.390	6.241	83.0
RU06-11	2.667	9.421	6.228	83.1
RU07-02	2.660	9.555	6.231	81.7
RU07-03	2.665	9.525	6.218	82.4
RU07-06	2.665	9.456	6.226	82.8
RU07-07	2.664	9.530	6.228	82.0
RU07-08	2.663	9.472	6.223	82.6
RU07-09	2.663	9.418	6.231	82.9
RU07-10	2.662	9.462	6.238	82.3

TABLE VII. (Continued)

Pellet ID	Mass (g)	Length (mm)	Diameter (mm)	% Theoretical Density
RU07-11	2.662	9.469	6.238	82.3
RU07-12	2.662	9.423	6.246	82.4
RU07-13	2.661	9.517	6.226	82.1
RU07-14	2.657	9.525	6.246	81.4
RU07-15	2.661	9.500	6.243	81.8
RU07-16	2.659	9.515	6.231	82.0
RU09-14	2.660	9.383	6.233	83.1
RU09-15	2.664	9.380	6.231	83.3
RU09-16	2.665	9.378	6.231	83.4
RU10-01	2.661	9.365	6.231	83.3
RU10-02	2.660	9.322	6.231	83.7
RU10-03	2.660	9.368	6.228	83.4
RU10-04	2.660	9.329	6.231	83.7
RU10-05	2.663	9.368	6.228	83.5
RU10-06	2.663	9.428	6.223	83.1
RU10-07	2.662	9.456	6.226	82.7
RU10-08	2.661	9.428	6.236	82.7
RU10-13	2.662	9.469	6.210	83.0
RU10-14	2.660	9.451	6.218	82.9
RU10-16	2.668	9.370	6.223	83.7
RU12-01	2.669	9.365	6.203	84.4
RU12-02	2.667	9.413	6.200	84.0
RU12-03	2.669	9.373	6.208	84.2
RU12-04	2.669	9.375	6.200	84.4
RU12-05	2.670	9.383	6.203	84.3
RU12-08	2.670	9.347	6.208	84.4
RU12-09	2.669	9.337	6.205	84.6
RU12-10	2.669	9.335	6.213	84.4
RU12-11	2.669	9.332	6.213	84.4
RU12-12	2.668	9.352	6.208	84.3
RU12-13	2.669	9.362	6.215	84.0
RU12-14	2.670	9.403	6.210	83.9
RU12-15	2.669	9.408	6.215	83.6
RU13-01	2.660	9.375	6.226	83.4
RU13-02	2.671	9.355	6.228	83.9
RU13-03	2.658	9.342	6.223	83.7
RU13-04	2.659	9.327	6.218	84.0
RU13-09	2.668	9.324	6.218	84.4
RU13-10	2.668	9.329	6.213	84.4
RU13-13	2.667	9.357	6.220	84.0
RU13-14	2.668	9.395	6.226	83.5
RU13-15	2.669	9.370	6.226	83.7
RU13-16	2.668	9.393	6.223	83.6
RU14-05	2.666	9.449	6.228	82.9
RU14-06	2.663	9.472	6.241	82.2
RU14-07	2.666	9.492	6.226	82.5
RU14-08	2.665	9.444	6.231	82.8

TABLE VII. (Continued)

Pellet ID	Mass (g)	Length (mm)	Diameter (mm)	% Theoretical Density
RU14-09	2.665	9.474	6.228	82.6
RU14-10	2.665	9.416	6.233	83.0
RU14-11	2.666	9.423	6.231	83.0
RU14-12	2.666	9.423	6.233	83.0
RU14-13	2.664	9.456	6.226	82.8
RU14-14	2.667	9.454	6.226	82.9
RU14-15	2.664	9.464	6.246	82.2
RU14-16	2.665	9.469	6.243	82.2
RU15-07	2.668	9.411	6.218	83.5
RU15-08	2.667	9.401	6.213	83.8
RU15-09	2.667	9.362	6.205	84.3
RU15-10	2.668	9.378	6.208	84.1
RU15-11	2.668	9.416	6.218	83.5
RU15-12	2.667	9.411	6.218	83.5
RU15-13	2.667	9.426	6.215	83.4
RU15-14	2.666	9.413	6.208	83.8
RU15-16	2.666	9.497	6.215	82.8
RU16-01	2.668	9.428	6.208	83.7
RU16-02	2.668	9.368	6.210	84.1
RU16-04	2.667	9.436	6.208	83.6
RU16-05	2.668	9.456	6.215	83.2
RU16-06	2.668	9.456	6.213	83.3
RU16-07	2.668	9.454	6.215	83.2
RU16-08	2.669	9.390	6.218	83.8
RU16-09	2.669	9.370	6.215	84.0
RU16-10	2.668	9.378	6.208	84.1
RU16-11	2.668	9.375	6.205	84.2
RU16-12	2.668	9.329	6.213	84.4
RU16-13	2.669	9.335	6.208	84.6
RU16-14	2.669	9.380	6.213	84.0
RU16-16	2.666	9.431	6.205	83.7
RU17-03	2.667	9.365	6.200	84.4
RU17-04	2.669	9.327	6.203	84.8
RU17-05	2.669	9.368	6.200	84.5
RU17-06	2.669	9.347	6.198	84.7
RU17-08	2.671	9.322	6.205	84.8
RU17-09	2.670	9.317	6.203	84.9
RU17-10	2.668	9.301	6.205	84.9
RU17-12	2.667	9.291	6.215	84.7
RU17-16	2.665	9.332	6.208	84.4

TABLE VIII. Spectrochemical Data for Pellet Lots

Species	Specification	Pellet Lot ID 03	04	05	06	07	09	10
Al	---	250	50	30	35	360	290	15
B	---	5	<1	2	1	<1	<1	<1
Ca	---	10	10	8	50	130	50	50
Cd	---	<10	<10	<10	<10	<10	<10	<10
Cr	---	45	220	260	130	140	85	85
Cu	---	5	1	<1	<1	2	<1	<1
Fe	800	280	430	390	190	290	160	180
Mg	---	100	300	300	200	75	200	200
Mn	---	15	5	4	7	4	5	10
Mo	---	3	4	4	4	<3	4	<3
Na	---	2	3	2	4	<2	4	10
Ni	---	30	20	30	15	35	6	20
Pb	---	5	<5	<5	<5	<5	<5	<5
Si	200	290	180	150	150	230	140	220
Sn	---	7	5	5	5	<5	<5	<5
Zn	---	10	20	10	15	10	15	20

TABLE VIII. (Continued)

Species	Specification	Pellet Lot ID 12	13	14	15	16	17
Al	---	10	55	30	65	50	45
B	---	<1	<1	<1	<1	<1	<1
Ca	---	1000	100	100	300	200	300
Cd	---	<10	<10	<10	<10	<10	<10
Cr	---	40	35	25	60	35	35
Cu	---	10	<1	<1	2	1	<1
Fe	800	120	110	85	190	140	130
Mg	---	5	1	2	4	4	2
Mn	---	2	2	1	25	5	1
Mo	---	4	3	4	3	3	3
Na	---	7	3	2	3	4	2
Ni	---	8	<5	<5	10	10	8
Pb	---	<5	<5	<5	5	<5	<5
Si	200	55	50	65	200	130	130
Sn	---	<5	<5	<5	<5	<5	<5
Zn	---	<5	<5	<5	<5	<5	<5

TABLE IX. Neutron Emission Rates for Pellet Lots

Pellet Lot	$ns^{-1}g^{-1}(^{238}Pu)$
RU03	5 270
RU04	4 790
RU05	4 510
RU06	4 190
RU07	4 430
RU09	5 660
RU10	4 890
RU12	4 100
RU13	3 670
RU14	3 520
RU15	3 800
RU16	4 430

TABLE X. Isotopic Data for Pellet Lots

Pellet Lot	Analysis Date	Plutonium Isotope (Weight Percent)				
		238	239	240	241	242
RU03	09/11/80	83.41	14.04	1.98	0.44	0.13
RU04	09/11/80	83.49	13.97	1.98	0.43	0.13
RU05	09/11/80	83.46	14.00	1.98	0.44	0.13
RU06	07/29/80	83.53	13.99	1.94	0.38	0.15
RU07	09/11/80	83.44	14.01	1.98	0.43	0.13
RU09	05/13/80	83.43	14.01	1.98	0.45	0.13
RU10	09/11/80	83.43	14.02	1.98	0.44	0.13
RU12	04/26/82	83.24	14.20	2.03	0.39	0.14
RU13	10/12/82	83.24	14.21	2.03	0.38	0.14
RU14	10/12/82	83.22	14.23	2.03	0.38	0.14
RU15	10/12/82	83.22	14.22	2.03	0.38	0.14
RU16	10/13/82	83.22	14.23	2.03	0.38	0.14
RU17	10/13/82	83.21	14.23	2.03	0.38	0.14

TABLE XI. Actinide Data for Pellet Lots

Pellet Lot	Isotope (ppm) of Total Pu*				
	^{232}Th	^{234}U	^{236}Pu	^{237}Np	^{241}Am
RU03	290	130	---	235	60
RU04	330	290	---	225	70
RU05	325	300	---	230	80
RU06	310	100	---	230	50
RU07	295	<100	---	235	75
RU09	250	<100	---	235	50
RU10	225	<100	---	230	55
RU12	755	<100	0.48	1950	55
RU13	705	<100	0.38	1885	<10
RU14	955	<100	0.47	1895	<10
RU15	880	<100	0.56	1850	<10
RU16	770	<100	0.45	1905	<10
RU17	930	<100	0.40	1950	<10

*Back-decayed to date of SRP precipitation.

TABLE XII. Thermal Power and Neutron Emission Rates for LWRHU Capsules

Capsule ID	Thermal Power (W)	Measurement Date	Neutron Emission Rate ns^{-1}
021	1.116	1/28/81	10 220
022	1.113	1/28/81	11 540
024	1.116	1/29/81	11 000
029	1.111	1/26/81	11 370
031	1.114	1/29/81	10 950
032	1.117	1/30/81	10 700
033	1.114	1/30/81	10 850
042	1.116	2/01/81	10 860
045	1.115	2/01/81	10 360
048	1.111	2/03/81	9 330
049	1.118	2/04/81	9 510
051	1.115	2/04/81	9 370
053	1.097	6/18/81	8 420
054	1.118	2/05/81	9 660
055	1.117	2/06/81	9 790
056	1.117	2/06/81	9 710
059	1.116	2/09/81	9 080
060	1.118	2/09/81	9 060
061	1.116	2/10/81	9 290
062	1.116	2/10/81	9 270
063	1.118	2/11/81	9 220
064	1.095	6/18/81	8 770
065	1.117	2/12/81	9 350
066	1.118	2/12/81	9 390
067	1.116	2/13/81	9 360
068	1.115	2/17/81	9 070
069	1.112	2/17/81	9 090
070	1.119	2/18/81	9 180
071	1.119	2/18/81	9 260
073	1.116	2/19/81	9 300
075	1.117	2/19/81	9 170
076	1.119	2/20/81	8 420
077	1.095	6/19/81	8 100
078	1.117	2/23/81	8 360
079	1.118	2/23/81	8 600
084	1.117	2/24/81	8 630
085	1.099	6/19/81	8 300
089	1.117	2/24/81	8 540
091	1.118	2/25/81	8 820
093	1.113	2/26/81	8 720
094	1.116	2/26/81	8 320
095	1.115	2/27/81	8 310
097	1.114	3/02/81	8 880

TABLE XII. (Continued)

Capsule ID	Thermal Power (W)	Measurement Date	Neutron Emission Rate ns^{-1}
098	1.116	3/03/81	8 800
099	1.114	3/03/81	8 750
100	1.116	3/04/81	8 480
101	1.115	3/04/81	8 510
102	1.114	3/05/81	8 640
103	1.116	3/05/81	8 810
105	1.113	3/06/81	8 800
107	1.116	3/06/81	8 570
108	1.119	3/09/81	8 590
109	1.120	3/10/81	8 820
110	1.121	3/11/81	9 240
112	1.120	3/11/81	9 170
113	1.097	6/19/81	8 220
114	1.120	3/12/81	9 620
115	1.120	3/12/81	9 860
116	1.119	3/13/81	9 680
117	1.120	3/13/81	9 630
118	1.118	3/16/81	9 750
121	1.099	6/18/81	8 920
122	1.096	6/18/81	9 520
301	1.086	1/05/83	8 520
302	1.085	1/05/83	8 020
303	1.085	1/05/83	8 060
304	1.086	1/05/83	8 290
305	1.094	1/05/83	7 360
307	1.095	1/05/83	7 320
308	1.093	1/05/83	7 370
309	1.085	3/16/84	8 220
310	1.094	1/05/83	7 350
313	1.084	3/16/84	8 340
315	1.094	1/05/83	7 310
316	1.090	1/10/83	7 230
321	1.089	1/10/83	7 240
322	1.089	1/10/83	7 200
323	1.087	1/10/83	7 190
324	1.095	1/10/83	7 260
327	1.094	1/10/83	7 180
328	1.093	1/10/83	7 220
330	1.082	3/16/84	7 500
331	1.092	1/10/83	7 150
332	1.093	1/10/83	7 140
333	1.080	3/16/84	7 550
334	1.082	3/16/84	7 610
335	1.082	3/16/84	7 540
336	1.094	1/10/83	7 180
338	1.080	3/16/84	7 730

TABLE XII. (Continued)

Capsule ID	Thermal Power (W)	Measurement Date	Neutron Emission Rate ns^{-1}
339	1.081	3/16/84	7 780
344	1.083	3/19/84	7 860
345	1.094	1/12/83	7 220
346	1.093	1/12/83	7 430
347	1.093	1/12/83	7 430
348	1.093	1/12/83	7 510
349	1.083	3/19/84	7 910
350	1.093	1/12/83	7 470
351	1.093	1/12/83	7 550
352	1.083	3/19/84	8 110
353	1.084	3/19/84	7 850
354	1.082	3/19/84	7 850
356	1.084	3/19/84	8 110
357	1.083	3/19/84	8 140
360	1.083	3/19/84	7 650
361	1.084	3/19/84	7 610
362	1.084	3/19/84	7 580
364	1.082	3/22/84	7 600
365	1.082	3/22/84	7 700
368	1.082	3/22/84	7 740
369	1.083	3/22/84	8 010
375	1.082	3/20/84	8 040
376	1.083	3/20/84	8 090
380	1.083	3/20/84	8 010
381	1.084	3/20/84	8 130
382	1.084	3/20/84	8 210
383	1.084	3/20/84	7 920
384	1.084	3/20/84	7 920
385	1.083	3/20/84	7 860
386	1.083	3/20/84	7 990
387	1.084	3/20/84	8 020
388	1.084	3/20/84	7 910
389	1.083	3/20/84	7 970
391	1.083	3/21/84	7 710
392	1.082	3/21/84	7 840
395	1.083	3/21/84	7 810
396	1.083	3/21/84	7 830
398	1.084	3/21/84	7 870
399	1.083	3/21/84	8 110
400	1.083	3/21/84	8 100
402	1.083	3/21/84	8 100
405	1.082	3/20/84	8 090
502	1.082	3/16/84	7 820
506	1.083	3/19/84	7 650
507	1.083	3/22/84	7 920

TABLE XIII. Gamma and Neutron Dose Rates of Capsules at 20 cm

Capsule ID	Pellet Lot	Gamma Dose (mR h)	Neutron Dose (mRem h)
033	RU03	0.2	<0.1
068	RU05	0.2	<0.1
304	RU06	0.3	0.1
105	RU07	0.2	<0.1
113	RU09	0.2	<0.1
112	RU10	0.3	<0.1
347	RU12	0.2	<0.1
322	RU13	0.2	<0.1
330	RU14	0.3	0.2
362	RU15	0.2	<0.1
384	RU16	0.1	<0.1
396	RU17	0.2	<0.1

TABLE XIV. Final Assembly Data				
Graphite Aeroshell ID	Mass (g)	Height (mm)	Diameter (mm)	Thermal Power (W) (1/1/85)
LRF-028	40.09	31.974	25.966	1.082
LRF-029	40.08	32.029	25.979	1.079
LRF-030	40.06	32.024	25.977	1.082
LRF-031	40.03	32.022	25.979	1.077
LRF-032	40.13	32.029	25.984	1.080
LRF-033	40.07	32.024	25.987	1.083
LRF-034	40.12	31.999	25.977	1.080
LRF-035	40.17	32.022	25.984	1.082
LRF-036	40.10	32.022	25.972	1.081
LRF-037	40.10	31.991	25.977	1.077
LRF-038	40.15	31.989	25.974	1.084
LRF-039	40.15	31.979	25.977	1.081
LRF-040	40.12	32.002	25.974	1.067
LRF-041	40.12	31.986	25.964	1.084
LRF-042	40.07	31.994	25.977	1.083
LRF-043	40.10	31.991	25.977	1.083
LRF-044	40.10	32.014	25.977	1.082
LRF-045	40.09	32.019	25.974	1.084
LRF-046	40.05	31.979	25.977	1.082
LRF-047	40.12	31.976	25.974	1.082
LRF-048	40.03	32.022	25.961	1.084
LRF-049	40.07	31.979	25.979	1.065
LRF-050	40.08	31.981	25.964	1.083
LRF-051	40.03	31.984	25.969	1.084
LRF-052	40.09	31.996	25.974	1.082
LRF-053	39.99	32.002	25.982	1.081
LRF-054	40.03	31.999	25.972	1.079
LRF-055	40.04	31.999	25.972	1.085
LRF-056	39.99	32.012	25.966	1.085
LRF-057	39.95	31.979	25.954	1.082
LRF-058	40.09	32.004	25.966	1.083
LRF-059	40.01	32.012	25.977	1.085
LRF-060	40.10	32.017	25.977	1.065
LRF-061	40.01	31.996	25.966	1.084
LRF-062	40.13	32.024	25.972	1.084
LRF-063	40.11	32.002	25.979	1.084
LRF-064	39.99	31.987	25.964	1.069
LRF-065	39.93	31.983	25.947	1.084
LRF-066	39.96	31.968	25.952	1.085
LRF-067	40.05	31.982	25.965	1.080
LRF-068	40.06	31.972	25.951	1.083
LRF-069	40.09	31.993	25.954	1.082
LRF-070	40.07	31.968	25.947	1.081
LRF-071	40.11	31.992	25.966	1.083
LRF-072	40.10	31.982	25.968	1.081
LRF-073	40.12	31.968	25.971	1.083

TABLE XIV. (Continued)

Graphite Aeroshell ID	Mass (g)	Height (mm)	Diameter (mm)	Thermal Power (W) (1/1/85)
LRF-074	40.09	31.987	25.980	1.082
LRF-075	40.19	31.972	25.958	1.081
LRF-076	40.10	31.996	25.957	1.083
LRF-077	40.03	31.983	25.956	1.080
LRF-078	40.09	31.983	25.961	1.083
LRF-079	40.13	31.990	25.968	1.086
LRF-080	40.01	31.974	25.962	1.087
LRF-081	40.10	31.986	25.976	1.088
LRF-082	40.07	31.974	25.961	1.087
LRF-083	40.16	31.964	25.973	1.067
LRF-084	40.15	31.959	25.975	1.087
LRF-085	40.11	31.972	25.957	1.087
LRF-086	40.14	31.965	25.969	1.086
LRF-087	40.09	31.968	25.965	1.087
LRF-088	40.17	31.976	25.968	1.085
LRF-089	40.08	31.972	25.951	1.069
LRF-101	39.70	31.994	25.972	1.066
LRF-102	39.54	31.993	25.952	1.069
LRF-103	39.62	31.995	25.966	1.068
LRF-104	39.68	31.988	25.954	1.068
LRF-105	39.48	31.991	25.957	1.069
LRF-107	39.56	31.990	25.957	1.077
LRF-109	39.52	31.994	25.969	1.078
LRF-110	39.62	31.997	25.954	1.076
LRF-111	39.56	31.984	25.963	1.078
LRF-112	39.53	31.979	25.944	1.077
LRF-113	39.49	31.982	25.944	1.077
LRF-114	39.55	31.986	25.954	1.077
LRF-115	39.62	31.990	25.962	1.073
LRF-116	39.54	31.981	25.956	1.072
LRF-117	39.58	31.984	25.955	1.072
LRF-118	39.49	31.982	25.951	1.070
LRF-119	39.72	31.994	25.972	1.078
LRF-120	39.65	31.984	25.967	1.077
LRF-121	39.64	31.985	25.961	1.076
LRF-122	39.49	31.995	25.950	1.075
LRF-123	39.56	31.982	25.955	1.075
LRF-124	39.57	31.980	25.962	1.076
LRF-125	39.55	31.986	25.966	1.073
LRF-126	39.52	31.982	25.969	1.075
LRF-128	39.63	31.995	25.962	1.075
LRF-129	39.57	31.993	25.967	1.077
LRF-130	39.61	31.982	25.954	1.073
LRF-134	39.56	31.980	25.962	1.074
LRF-135	39.58	31.975	25.945	1.076
LRF-136	39.63	31.982	25.958	1.077
LRF-137	39.54	31.994	25.956	1.076

TABLE XIV. (Continued)

Graphite Aeroshell ID	Mass (g)	Height (mm)	Diameter (mm)	Thermal Power (W) (1/1/85)
LRF-138	39.53	31.980	25.965	1.076
LRF-139	39.49	31.996	25.945	1.076
LRF-140	39.49	31.984	25.957	1.076
LRF-141	39.50	31.981	25.955	1.076
LRF-142	39.55	31.983	25.970	1.076
LRF-143	39.62	31.978	25.966	1.076
LRF-144	39.55	31.980	25.962	1.077
LRF-145	39.59	31.989	25.966	1.075
LRF-146	39.64	31.984	25.952	1.077
LRF-147	39.61	31.980	25.950	1.076
LRF-148	39.60	31.984	25.947	1.076
LRF-149	39.58	31.982	25.940	1.077
LRF-150	39.50	31.976	25.954	1.077
LRF-151	39.58	31.984	25.960	1.075
LRF-152	39.64	31.988	25.967	1.075
LRF-154	39.55	31.980	25.959	1.075
LRF-155	39.68	31.980	25.965	1.076
LRF-156	39.66	31.980	25.961	1.075
LRF-157	39.62	31.987	25.961	1.076
LRF-158	39.66	31.990	25.947	1.076
LRF-159	39.62	31.986	25.951	1.077
LRF-160	39.58	31.988	25.950	1.077
LRF-161	39.57	31.987	25.962	1.077
LRF-162	39.51	31.986	25.951	1.077
LRF-164	39.56	31.981	25.949	1.076
LRF-166	39.58	31.976	25.960	1.076
LRF-168	39.66	31.988	25.951	1.077
LRF-170	39.56	31.977	25.956	1.077
LRF-171	39.73	31.980	25.961	1.076
LRF-172	39.84	31.993	25.947	1.076
LRF-173	39.83	31.986	25.949	1.075
LRF-175	39.82	31.991	25.966	1.076
LRF-176	39.83	31.983	25.961	1.076
LRF-178	39.90	31.975	25.951	1.077
LRF-179	39.90	31.994	25.959	1.076
LRF-180	39.86	31.975	25.955	1.076
LRF-181	39.85	31.975	25.949	1.076
LRF-182	39.84	31.974	25.965	1.075
LRF-183	39.89	31.978	25.951	1.075
LRF-184	39.87	31.981	25.936	1.076
LRF-186	39.97	31.978	25.951	1.076

TABLE XV. Record of Assembly

Graphite Aeroshell ID	Capsule ID	Pellet ID	LANL Fuel Lot(s)	SRP Fuel Lot(s)
LRF-028	021	RU03-08	L38	440906923
LRF-029	022	RU03-09	L38	440906923
LRF-030	024	RU03-10	L38	440906923
LRF-031	029	RU03-11	L38	440906923
LRF-032	031	RU03-12	L38	440906923
LRF-033	032	RU03-13	L38	440906923
LRF-034	033	RU03-14	L38	440906923
LRF-035	042	RU03-15	L38	440906923
LRF-036	045	RU03-16	L38	440906923
LRF-037	048	RU04-03	L39	440906922
LRF-038	049	RU04-04	L39	440906922
LRF-039	051	RU04-05	L39	440906922
LRF-040	053	RU10-13	L38	440906923
LRF-041	054	RU04-06	L39	440906922
LRF-042	055	RU04-07	L39	440906922
LRF-043	056	RU04-08	L39	440906922
LRF-044	059	RU04-09	L39	440906922
LRF-045	060	RU04-10	L39	440906922
LRF-046	061	RU04-11	L39	440906922
LRF-047	062	RU04-12	L39	440906922
LRF-048	063	RU04-13	L39	440906922
LRF-049	064	RU10-14	L38	440906923
LRF-050	065	RU04-14	L39	440906922
LRF-051	066	RU04-15	L39	440906922
LRF-052	067	RU04-16	L39	440906922
LRF-053	068	RU05-03	L39	440906922
LRF-054	069	RU05-04	L39	440906922
LRF-055	070	RU05-05	L39	440906922
LRF-056	071	RU05-06	L39	440906922
LRF-057	073	RU05-07	L39	440906922
LRF-058	075	RU05-08	L39	440906922
LRF-059	076	RU05-09	L39	440906922
LRF-060	077	RU09-14	L38/L39	440906923/440906922
LRF-061	078	RU05-10	L39	440906922
LRF-062	079	RU05-11	L39	440906922
LRF-063	084	RU05-12	L39	440906922
LRF-064	085	RU09-15	L38/L39	440906923/440906922
LRF-065	089	RU05-13	L39	440906922
LRF-066	091	RU05-15	L39	440906922
LRF-067	093	RU05-16	L39	440906922
LRF-068	094	RU07-02	L38/L39	440906923/440906922
LRF-069	095	RU07-03	L38/L39	440906923/440906922
LRF-070	097	RU07-06	L38/L39	440906923/440906922
LRF-071	098	RU07-07	L38/L39	440906923/440906922
LRF-072	099	RU07-08	L38/L39	440906923/440906922
LRF-073	100	RU07-09	L38/L39	440906923/440906922

TABLE XV. (Continued)

Graphite Aeroshell ID	Capsule ID	Pellet ID	LANL Fuel Lot(s)	SRP Fuel Lot(s)
LRF-074	101	RU07-10	L38/L39	440906923/440906922
LRF-075	102	RU07-11	L38/L39	440906923/440906922
LRF-076	103	RU07-12	L38/L39	440906923/440906922
LRF-077	105	RU07-13	L38/L39	440906923/440906922
LRF-078	107	RU07-14	L38/L39	440906923/440906922
LRF-079	108	RU07-15	L38/L39	440906923/440906922
LRF-080	109	RU07-16	L38/L39	440906923/440906922
LRF-081	110	RU10-01	L38	440906923
LRF-082	112	RU10-02	L38	440906923
LRF-083	113	RU09-16	L38/L39	440906923/440906922
LRF-084	114	RU10-03	L38	440906923
LRF-085	115	RU10-04	L38	440906923
LRF-086	116	RU10-05	L38	440906923
LRF-087	117	RU10-06	L38	440906923
LRF-088	118	RU10-07	L38	440906923
LRF-089	121	RU10-16	L38	440906923
LRF-101	122	RU10-08	L38	440906923
LRF-102	301	RU06-08	L39	440906922
LRF-103	302	RU06-09	L39	440906922
LRF-104	303	RU06-10	L39	440906922
LRF-105	304	RU06-11	L39	440906922
LRF-107	305	RU13-01	L69/L74	482009150/499101215
LRF-109	307	RU13-02	L69/L74	482009150/499101215
LRF-110	308	RU13-03	L69/L74	482009150/499101215
LRF-111	309	RU12-14	L69/L74	482009150/499101215
LRF-112	310	RU13-04	L69/L74	482009150/499101215
LRF-113	313	RU12-15	L69/L74	482009150/499101215
LRF-114	315	RU13-09	L69/L74	482009150/499101215
LRF-115	316	RU13-10	L69/L74	482009150/499101215
LRF-116	321	RU13-13	L69/L74	482009150/499101215
LRF-117	322	RU13-14	L69/L74	482009150/499101215
LRF-118	323	RU13-15	L69/L74	482009150/499101215
LRF-119	324	RU13-16	L69/L74	482009150/499101215
LRF-120	327	RU12-01	L69/L74	482009150/499101215
LRF-121	328	RU12-02	L69/L74	482009150/499101215
LRF-122	330	RU14-05	L69/L74	482009150/499101215
LRF-123	331	RU12-03	L69/L74	482009150/499101215
LRF-124	332	RU12-04	L69/L74	482009150/499101215
LRF-125	333	RU14-06	L69/L74	482009150/499101215
LRF-126	334	RU14-07	L69/L74	482009150/499101215
LRF-128	335	RU14-08	L69/L74	482009150/499101215
LRF-129	336	RU12-05	L69/L74	482009150/499101215
LRF-130	338	RU14-09	L69/L74	482009150/499101215
LRF-134	339	RU14-10	L69/L74	482009150/499101215
LRF-135	344	RU14-12	L69/L74	482009150/499101215
LRF-136	345	RU12-08	L69/L74	482009150/499101215
LRF-137	346	RU12-09	L69/L74	482009150/499101215

TABLE XV. (Continued)

Graphite Aeroshell ID	Capsule ID	Pellet ID	LANL Fuel Lot(s)	SRP Fuel Lot(s)
LRF-138	347	RU12-10	L69/L74	482009150/499101215
LRF-139	348	RU12-11	L69/L74	482009150/499101215
LRF-140	349	RU14-13	L69/L74	482009150/499101215
LRF-141	350	RU12-12	L69/L74	482009150/499101215
LRF-142	351	RU12-13	L69/L74	482009150/499101215
LRF-143	352	RU14-14	L69/L74	482009150/499101215
LRF-144	353	RU14-15	L69/L74	482009150/499101215
LRF-145	354	RU14-16	L69/L74	482009150/499101215
LRF-146	356	RU15-07	L69/L74	482009150/499101215
LRF-147	357	RU15-08	L69/L74	482009150/499101215
LRF-148	360	RU15-09	L69/L74	482009150/499101215
LRF-149	361	RU15-10	L69/L74	482009150/499101215
LRF-150	362	RU15-11	L69/L74	482009150/499101215
LRF-151	364	RU15-13	L69/L74	482009150/499101215
LRF-152	365	RU15-14	L69/L74	482009150/499101215
LRF-154	368	RU15-16	L69/L74	482009150/499101215
LRF-155	369	RU16-01	L69/L74	482009150/499101215
LRF-156	375	RU16-04	L69/L74	482009150/499101215
LRF-157	376	RU16-05	L69/L74	482009150/499101215
LRF-158	380	RU16-06	L69/L74	482009150/499101215
LRF-159	381	RU16-07	L69/L74	482009150/499101215
LRF-160	382	RU16-08	L69/L74	482009150/499101215
LRF-161	383	RU16-09	L69/L74	482009150/499101215
LRF-162	384	RU16-10	L69/L74	482009150/499101215
LRF-164	385	RU16-11	L69/L74	482009150/499101215
LRF-166	386	RU16-12	L69/L74	482009150/499101215
LRF-168	387	RU16-13	L69/L74	482009150/499101215
LRF-170	388	RU16-14	L69/L74	482009150/499101215
LRF-171	389	RU16-16	L69/L74	482009150/499101215
LRF-172	391	RU17-03	L69/L74	482009150/499101215
LRF-173	392	RU17-04	L69/L74	482009150/499101215
LRF-175	395	RU17-05	L69/L74	482009150/499101215
LRF-176	396	RU17-06	L69/L74	482009150/499101215
LRF-178	398	RU17-08	L69/L74	482009150/499101215
LRF-179	399	RU17-09	L69/L74	482009150/499101215
LRF-180	400	RU17-10	L69/L74	482009150/499101215
LRF-181	402	RU17-12	L69/L74	482009150/499101215
LRF-182	405	RU17-16	L69/L74	482009150/499101215
LRF-183	502	RU14-11	L69/L74	482009150/499101215
LRF-184	506	RU15-12	L69/L74	482009150/499101215
LRF-186	507	RU16-02	L69/L74	482009150/499101215

APPENDIX I

LWRHU SPECIFICATIONS

The LWRHU specifications define the chemical and physical requirements for the $^{238}PuO_2$ fuel and hot-pressed pellets. The specifications also define the encapsulation of the pellets into the Pt-30Rh capsules, the thermal power of the unit, the neutron emission rate, the activation of the vents, assembly of the graphite aeroshell, and physical requirements for the completed assembly.

I. DOCUMENTS

A. LANL Documents

1. RHU-MST11-PD-2. Fabrication, Inspection, and Test Plan for the LWRHU.

2. HS-QA-PD-1. Heat Source Quality Assurance (QA) Program Plan.

3. 26Y-318194. Light Weight Radioisotopic Heater Unit (LWRHU) Product Index.

B. DOE Documents

1. ERDAM-0529. Packaging and Shipping Requirements.

2. QC-1. Energy Research Development Administration-Albuquerque Operations Office (ERDA-ALO) Quality Control Policy QC-1.

II. SPECIFICATION FOR PLUTONIUM-238 DIOXIDE FUEL GRANULES (DRAWING 26Y-318193).

A. Feed Material

1. Plutonium-238 Content. The ^{238}Pu content shall be 83.5 ± 1.0 at.% of the total plutonium content at the date of analysis at SRP.

2. Plutonium-236 Content. The ^{236}Pu shall not exceed 1 ppm of the total plutonium content, back-decayed to the date of fuel precipitation.

3. Actinide Impurities. The total actinide impurities, ^{241}Am, ^{237}Np, ^{234}U, and Th, shall not exceed 1% of the total plutonium content when back-decayed to the date of precipitation. On the same basis, no individual actinide impurity shall exceed 0.5%.

B. Oxygen-16 Exchanged Sintered Powder Feed

1. Nonactinide Cationic Impurities. The total of all nonactinide cationic impurities shall not exceed 2 550 ppm. Iron and silicon shall not exceed 800 ppm and 200 ppm, respectively (by weight). Other individual elements listed below shall be reported in the summary package.

Element							
Al	B	Ca	Cd	Cr	Cu	Fe	Mg
Mn	Mo	Na	Ni	Pb	Si	Sn	Zn

2. Granule Size. Both prior to and after seasoning, the granules shall pass through a U. S. Standard Sieve, American Society for Testing Machine (ASTM) No. 120 (124 microns).

3. Granule Seasoning. Approximately 60% of a fuel lot shall be material seasoned at 1100 ± 10°C in flowing $Ar\text{-}H_2{}^{16}O$, and the remainder shall be seasoned at 1600 ± 15°C in flowing $Ar\text{-}H_2{}^{16}O$.

4. Neutron Emission Rate. The specific neutron emission rate shall not exceed 6 000 neutron $ns^{-1}g^{-1}(^{238}Pu)$ on the seasoned fuel lot.

III. LWRHU PRODUCT SPECIFICATIONS (DRAWING 26Y-318189).

A. Fuel

1. Granule Mixture. The fuel granules loaded into the hot press die shall consist of 60 ± 0.2 wt% of granules seasoned at 1100°C, and the remaining granules seasoned at 1600°C.

2. Graphite Die Assembly. Latest revision of LANL drawing 26Y-79818.

3. Hot-Press Parameters. The pellets shall be hot-pressed 16 at a time in vacuum at 2 825 ± 50 psi for 15 ± 2 min at 1530 ± 30°C. The vacuum shall be 1×10^{-6} torr or better at the start of the run.

4. Post-Press Sintering. After hot pressing, the pellets shall be sintered in flowing $Ar\text{-}H_2{}^{16}O$ (2-4 cfh) for 360 ± 5 min at 1000 ± 10°C, followed by 360 ± 5 min at 1527 ± 10°C.

B. Pellets

1. Dimensions for Sintered Pellets. The reference diameter of the sintered pellets shall be 6.25 mm. The reference length shall be 9.37 mm. The weight shall be 2.664 ± 0.010 g. All dimensions shall be determined within 1 week after the pellets are sintered.

2. Analyses. One pellet from each pressed lot shall be submitted for three chemical analyses: spectrochemical, actinide, and isotopic. Neutron emission rate measurements shall be made on the spectrochemical sample. Material exceeding fuel specification shall be deemed nonconforming.

3. Nonintegral Pellets. Any pellet that is nonintegral after sintering shall be used for analyses or discarded. No nonintegral pellets shall be loaded for flight use.

4. Thermal Inventory. The fuel pellets shall have a thermal inventory of 1.10 ± 0.03 W back-decayed to the time of pressing.

C. Hardware, Welding, and Testing

1. Hardware.

a. Platinum-30 Rhodium Capsules. DOE-accepted capsules furnished to LANL by MF. (See Appendix II for the appropriate MF drawings).

b. Graphite Aeroshell and Insulator. DOE-accepted assemblies furnished to LANL by MF. (See Appendix II for the appropriate MF drawings).

2. Welding.

a. Glovebox Atmosphere. The atmosphere of the glovebox used for welding shall be monitored before and during welding. The oxygen content shall be <25 ppm and the moisture content shall be <60 ppm.

b. Torch Gas. The Gas Tungsten Arc (GTA) welds shall be performed with commercial welding-grade gas that is nominally 25% Ar: 75% He.

c. Example Welds. One GTA example weld shall be made as the initial weld for each production run. (A production run is one work period during which welding is performed by the operators with the same equipment on one capsule design.) Example weld hardware shall be representative of the production hardware.

d. Examination of Example Weld. The weld shall be examined visually at 30X for defects, such as cracks, pores, and discoloration. The presence of any irregularities shall be cause to reject the weld and postpone production welding. The example weld capsule shall be opened and defueled. The interior of the weld shall be examined visually for defects. If none is found, production welding may start. A diametral section through the weld shall be prepared metallographically and examined at 30X. Evidence of any unwelded region in the vertical part of the joint, any pore or pores whose aggregate diameter is greater than 0.25 mm, or any crack in the weld bead longer than 0.1 mm shall cause the production capsules welded in the run to require formal acceptance by the Materials Review Board.

e. Production Welds. When visual inspection indicates that the example weld is satisfactory, the production run may be welded. Welding parameters for the production run will be the same as for the example weld. Each production weld shall be examined at 30X for defects, such as cracks, pores, and discoloration. Any physical irregularities detected shall be referred to the Materials Review Board for evaluation.

f. Decontamination. The production capsules shall be decontaminated by successive immersions in a reagent-grade acid solution (5:2:2 of H_2O:HF:HNO_3), distilled water, and absolute ethanol. The decontamination shall be considered complete when a swipe count taken at least 24 h after the final ethanol rinse is <220 dpm.

3. Nondestructive Testing.

a. Helium Leak Test. Each welded capsule shall have a leak rate not to exceed 1×10^{-6} cm^3/s (STP) helium as determined by a mass spectrometer-type helium leak detector.

b. Radiography. Each welded capsule shall be radiographed to verify that the weld exhibits complete penetration of the vertical part of the joint and is free of cracks.

c. Neutron Emission Rate Measurement. The neutron emission rate shall be measured for each welded capsule. The rate shall be <6 000 $ns^{-1}g^{-1}(^{238}Pu)$. The beta-gamma dose rate at 20 cm will be measured for 1 capsule from each lot.

d. Calorimetry. The thermal inventory of each welded capsule shall be measured. The thermal output shall be 1.10 ± 0.03 W, back-decayed to the time of pellet pressing.

D. Final Assembly

1. Vent Activation. The frit vent shall be activated immediately prior to the capsule being placed into the graphite shell. This shall be accomplished by cutting into the vented end of the capsule at the center line with a 0.025 ± 0.002 in-diam endmill. The capsule shall be visually examined to ensure that the frit is visible through the drilled hole.

2. Assembly into Graphite. After a swipe check <220 dpm, the capsule with the activated vent shall then be placed into the graphite shell and the graphite lid shall be glued into place. The glue will be the same as previously used by MF and will be supplied to LANL by MF. The graphite shell shall then be heat treated at 100 ± 5°C for a period of 4.0 ± 0.5 h, followed by heating at 130 ± 10°C for 16.0 ± 1.0 h to cure the cement.

3. Surface Contamination. The assembled heater unit shall be checked by swipe. The graphite shell shall be free of any surface contamination greater than that allowed by Department of Transportation (DOT) regulations: 220 dpm.

E. Additional Testing

LANL shall perform any additional operations or tests which are considered necessary by LANL or Department of Energy (DOE) to ensure the quality of the completed product. Such work will be documented and available for review at LANL.

F. Retention of Records

Appropriate QA records and documentation shall be retained to confirm that all specifications have been met. For each heater unit shipped, records shall be maintained for at least 5 years past mission launch date. These records shall be available for inspection when desired by DOE and/or Sandia National Laboratories, Albuquerque (SNLA).

G. Packaging and Shipping

The fueled heater units shall be packaged and shipped according to LANL procedure RHU-MST11-PP-5 and applicable DOT and DOE regulations.

H. Summary Data Package

1. Summary Data Package Inclusions. The summary data package shall include a compilation of the processing and fabrication parameters and analytical results as listed below, together with identification of the contents of the shipping container and the appropriate sign-offs by LANL QA.

2. Plutonium-238 Dioxide Fuel.

a. Fuel Lot ID. The fuel lot ID, traceable to the original SRP lot ID, will be listed for each encapsulated pellet.

b. Parameters and Dimensions. The feed processing and pellet fabrication parameters, together with the sintered pellet dimensions, will be listed for each pellet lot included in the shipment.

c. Analytical Data. Spectrochemical, actinide content, and isotopic composition data shall be summarized for those pellets included in the shipment that were fabricated from each feed lot employed.

3. Welding.

a. Identification. The pellet ID numbers will be listed and related to the capsule ID numbers.

b. Welding Parameters. The welding times and currents will be listed, together with the oxygen and moisture contents of the glovebox at the time of welding.

c. Photomicrographs of Example Welds. Photomicrographs of selected example weld capsules will be included in the data package.

4. Nondestructive Testing.

a. Swipe Count. The surface contamination will be listed for each capsule.

b. Radiography. Radiographs will be included for each lot of welded capsules.

c. Calorimetry. The thermal inventory for each capsule will be listed as of the date of measurement together with the value calculated for the shipping date.

d. Leak Check. The helium leak rate shall be listed for each capsule.

e. Neutron Emission Rate. The neutron emission rate shall be listed for each capsule.

5. Graphite Assembly.

a. Identification. The capsule ID numbers will be listed and related to the graphite shell ID numbers.

b. Bake-Out Profile. The time-temperature profile will be listed for each glued assembly.

I. Materials Review Board

A Materials Review Board shall be appointed by the Project Leader to review all deviant production items and to determine the disposition of these items. When this board decides that an item is acceptable for flight use, its action and the reasons for it shall be documented and made part of the data package submitted for DOE acceptance. The Board's members shall include a representative from the Los Alamos Materials Science and Technology Division's Quality Assurance Group.

APPENDIX II

CONSTRUCTION DRAWINGS

This appendix consists of copies of the LANL construction drawings for the LWRHU.

1. 26Y-79818 Die Assymetrical, Radioisotopic Heater Unit
2. 26Y-318190 LWRHU Assembly
3. 26Y-318191 LWRHU Fueled Capsule
4. 26Y-318192 LWRHU Fuel Pellet

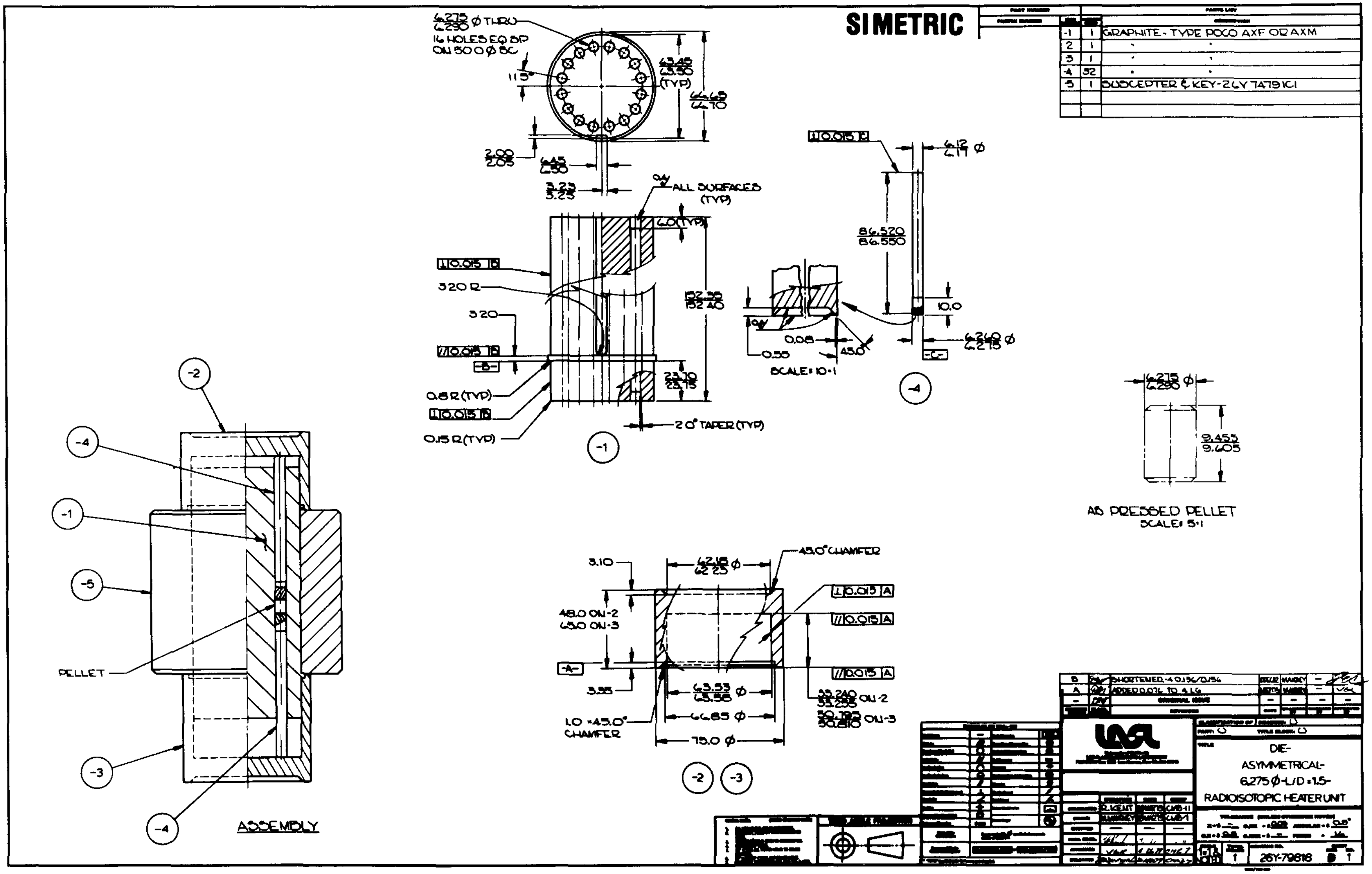

Fig. II-1. 26Y-79818 Die Assymetrical, Radioisotopic Heater Unit.

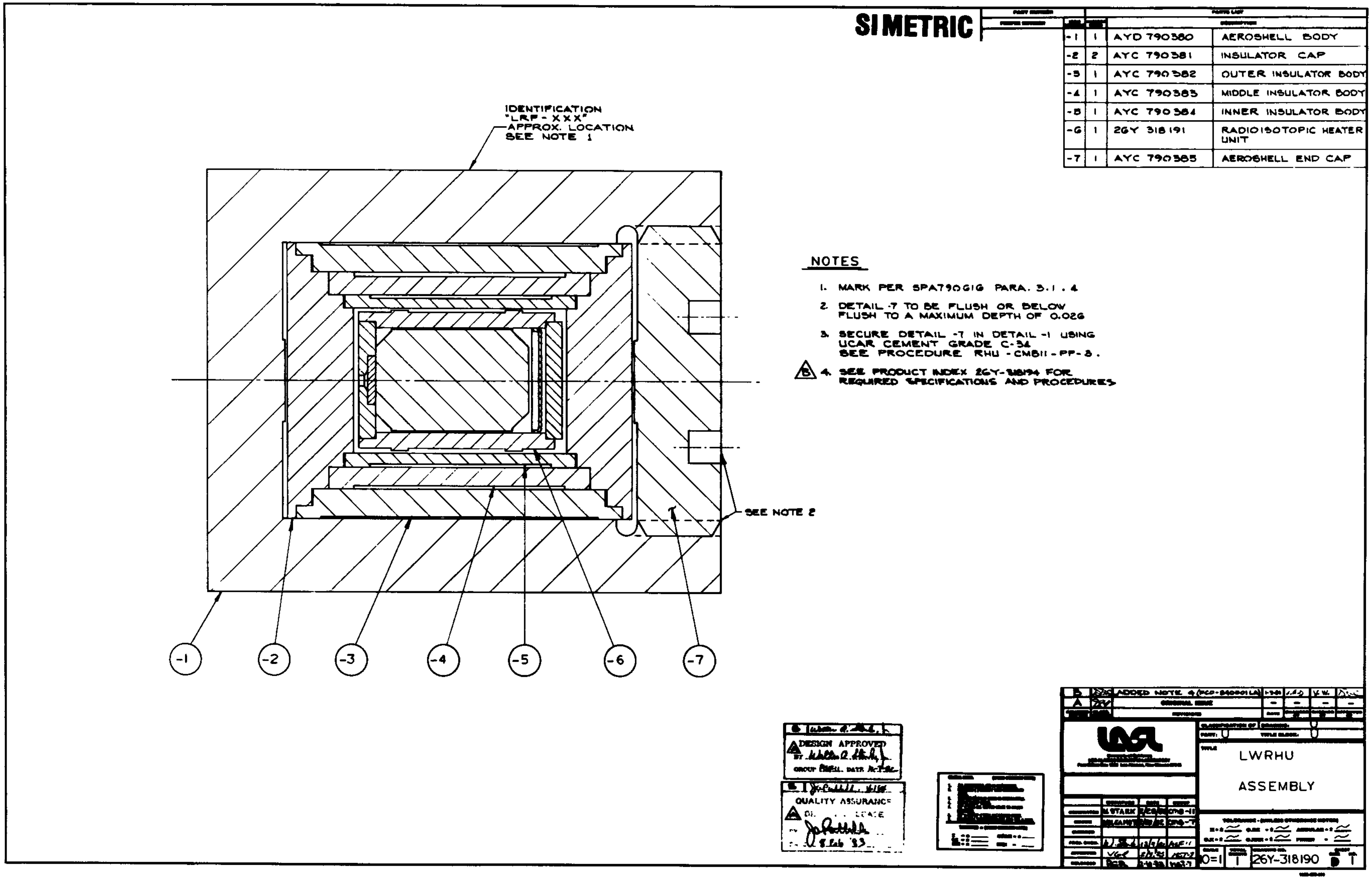

Fig. II-2. 26Y-318190. LWRHU Assembly.

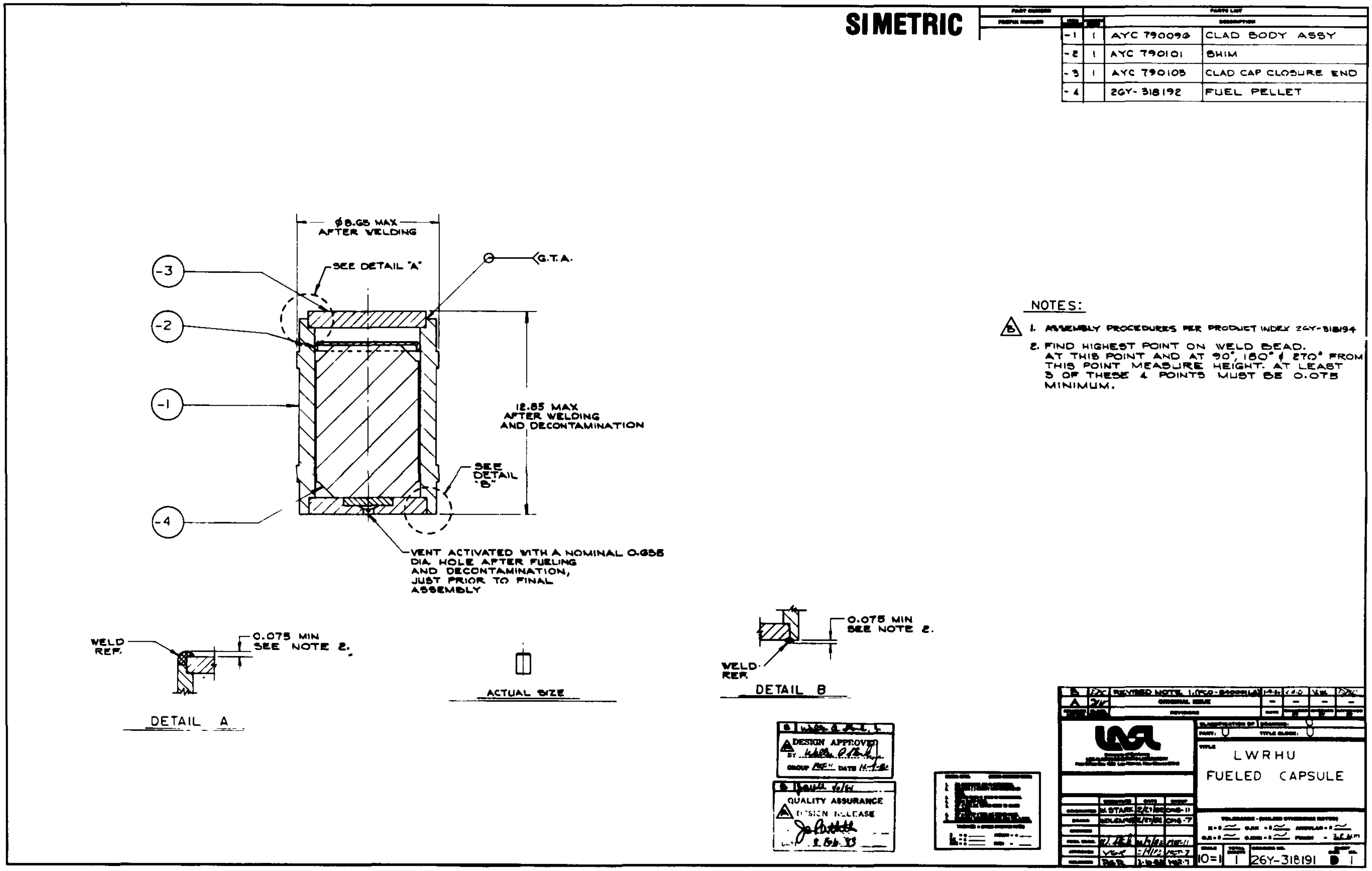

Fig. II-3. 26Y-318191. LWRHU Fueled Capsule.

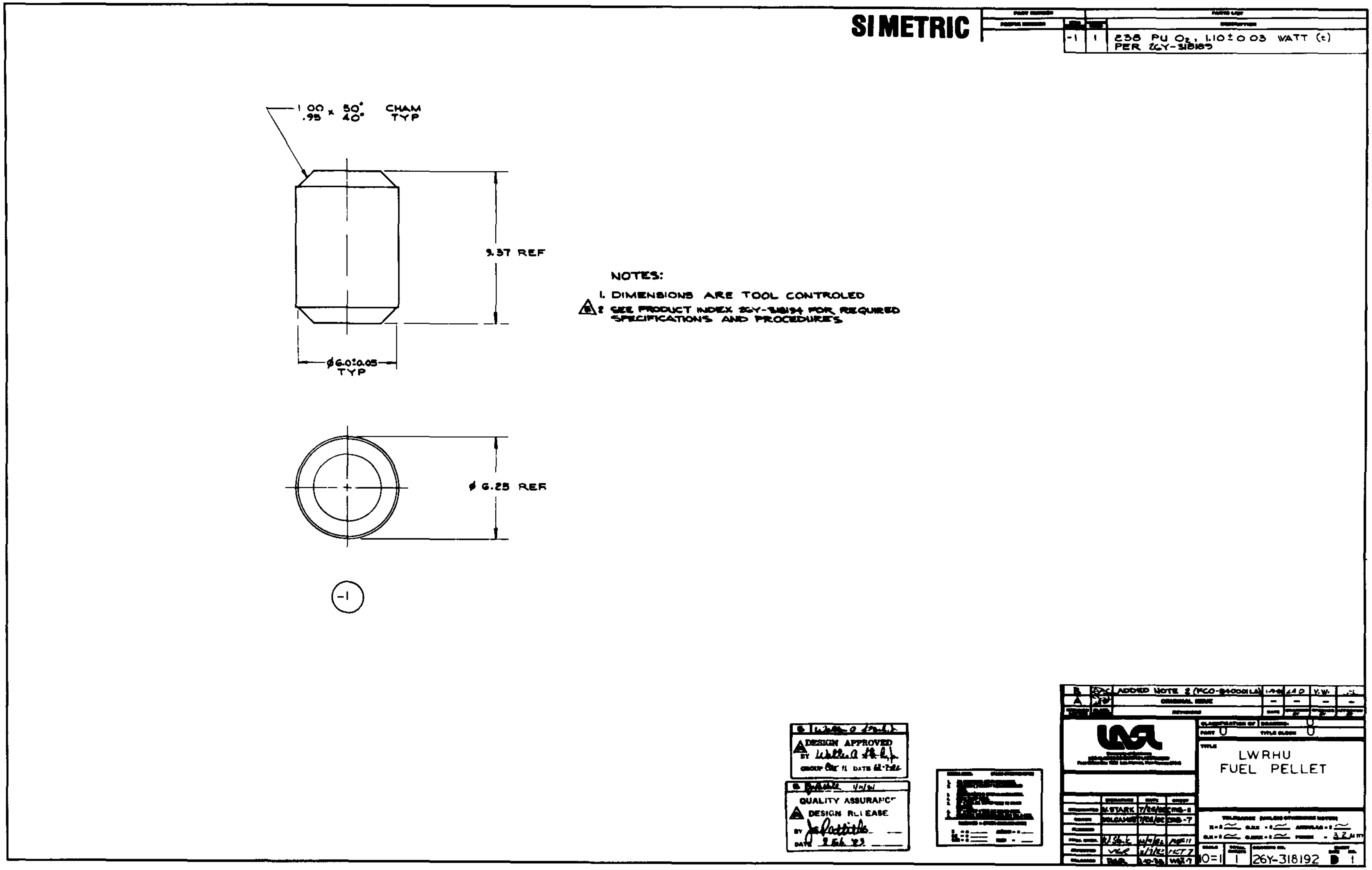

Fig. II-4. 26Y-318192. LWRHU Fuel Pellet.