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*Space Nuclear Safety and
Fuels Program*
June 1981

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Los Alamos, New Mexico 87545

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S. E. Bronisz

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SPACE NUCLEAR SAFETY AND FUELS PROGRAM

June 1981

Compiled by

S. E. Bronisz

ABSTRACT

This technical monthly report covers studies related to the use of $^{238}\text{PuO}_2$ in radioisotope power systems carried out for the Office of Coordination and Special Projects of the US Department of Energy by Los Alamos National Laboratory.

Most of the studies discussed here are ongoing. Results and conclusions described may change as the work continues. Published reference of the results cited in this report should not be made without the explicit permission of the person in charge of the work.

I. GENERAL-PURPOSE HEAT SOURCE

The General-Purpose Heat Source (GPHS), a 250-W modular heat source fueled with ^{238}Pu , was developed by Los Alamos National Laboratory for the US Department of Energy. The final Los Alamos design was turned over to the Department in the Fall of 1979. Since that time, the Laboratory has tested the design modifications introduced by the production agencies and has provided aid to the agencies during the start of production.

In June the post-mortem examinations of the iridium clads and the fuel from the first Design Iteration Test (DIT-1) were carried out. All four fueled clads were cracked by the impact. The microstructures of the capsule welds were similar, as were the microstructures of the fuel pellets.

A. Impact Results (R. W. Zocher)

The measured strains in the fueled clads used in the DIT-1 impact assembly were reported last month. The locations of these strains are shown in Fig. 1. The secondary design features that might have influenced the deformation (flight control bevels, impact-shell closures, aeroshell closures, and lock member recesses) did not do so (Fig. 1). The two design features that did affect the deformation were the low-density insulation and the central window. The former provided no support and allowed the impact shell to intrude into the effective void. By providing even less support on the inboard side, the latter allowed the deformation to proceed asymmetrically in that direction.

Fig. 1. The diametral height strains (in per cent) that resulted from the DIT-1 impact are shown on the fueled clads. The view is from the gun's breech to the catch tube.

B. Capsule Disassembly (F. W. Schonfeld)

After external examinations and measurements, the iridium capsules were removed from the fuel. In each case a circumferential cut was made 6 mm above the weld in the cup containing the vent. The cut was made by notching the iridium wall with a narrow abrasive wheel and then cracking the notch open by prying with a small screwdriver. Capsules 101, 103, and 104 were opened in a metallographic sample preparation box. Capsule 102 was opened underwater in the particle sizing box to retain the fine particles for analysis.

The empty capsule pieces were sampled to provide sections required for metallographic and chemical analyses. The metallographic samples of the welds were taken according to the standard Savannah River Plant (SRP) procedure.¹ A section through each vent was also removed for metallographic preparation. After the capsules were open, cracks were detected on the inside surfaces in the reverse-bend regions of all four capsules, so metallographic sections were taken through them, too.

A sample was removed from each cup (well away from the weld) for a bulk chemical analysis. Samples to be analyzed by Auger Electron Spectroscopy (AES)

were cut from the base metal of each cup of each capsule and from the weld region. The weld samples were taken so one could be fractured across and the other along the weld for the Auger examination. The locations of these samples are shown in Fig. 2.

The fuel pellets were sampled for ceramography and chemical analysis. Two ceramographic samples, one from the outer edge and one from the center, were taken from each pellet. Two chemical analysis samples, one for spectroscopy and one for a phosphorus determination, were also taken from each fuel pellet.

The example-weld capsules, IRG-105 and IRG-106, were sampled similarly. Additional samples from the region of the weld crack were taken from IRG-106. The fuel pellet used in the example welds was not examined.

C. Weld Examinations (F. W. Schonfeld)

The microstructures of the welds in the impacted capsules are reasonably uniform and of good quality. The minor microstructural variations did not result in any significant differences in the capsules' responses to the impacts. Figure 3 shows the weld-overlap region of the four welds, and Fig. 4 shows the single-pass region of the weld in each capsule.

The single- and double-pass regions of IRG-105, the first example-weld capsule, were morphologically very

similar to the same regions in the four test capsules (Fig. 5). The single-pass region of IRG-106, the second example-weld capsule, just ahead of the overlap contained a wider central band of fine grains [Fig. 6(a)], whereas the single-pass region well away from the overlap was characterized by a somewhat coarser grain structure without a marked central band [Fig. 6(b)].

The first submergence region of the weld overlap in capsule IRG-106 was cracked. A scanning electron micrograph of the crack shows the place where the weld stopped penetrating fully at the left of Fig. 7. A section through the main part of the crack is shown in Fig. 8.

The characteristic dimensions of the overlap regions in the four test and two example-weld capsules were measured. Figure 9 is a schematic cross section of the weld-closure region that identifies the locations of these measurements (Table I). The welds were made with the Los Alamos procedure at 8 rpm.²

The fuel that remained in the capsule pieces after they were sectioned is shown in Figs. 10-13. The microstructures of the four fuel pellets were quite homogeneous and were identical, for all practical purposes. The photomicrographs in Fig. 14 show that the structure of pellet SRP-27 (capsule 101) was the same near the surface as in the interior. This was true of the other three pellets. The etched microstructures of the exterior and interior samples from SRP-27 are shown in Fig. 15.

The uniformity of structure among the four fuel pellets echoes the uniformity of their impact responses (Fig. 1). These uniformities show that the test was valid and that the results can be used to evaluate the design. This evaluation must conclude that the current GPHS design is deficient in impact protection.

II. SYSTEMS SUPPORT (D. Pavone)

Results of the AES analyses of fracture surfaces of iridium containment shell samples of spheres MHFT-74 and MHFT-75 are tabulated in Table II. A moderate tendency for thorium depletion was observed at the inside surfaces of both of these test assemblies. Phosphorus was detected in modest quantities at some locations of the samples of MHFT-74 but was not detected in the samples from MHFT-75. Small quantities of sulfur and either boron or chlorine were observed sporadically in these samples, as in previously examined iridium containment shells aged in contact with $^{238}\text{PuO}_2$.

Fig. 2. The samples for Auger analysis were taken from the weld region (A-1, across the weld and A-2, along the weld) and from each of the cups (A-3 and A-4).

(a)

(b)

(c)

(d)

Fig. 3. The microstructures of the weld-overlap regions in all four DIT-1 iridium capsules were similar. (1) 101, 50X; (b) 102, 50X; (c) 103, 40X; (d) 104, 40X.

(a)

(b)

(c)

(d)

Fig. 4. The microstructures of the single-pass regions of the weld were very similar in all four iridium capsules from the DIT-1 assembly, (a) 101, 50X; (b) 102, 50X; (c) 103, 40X; (d) 104, 40X.

(a)

(b)

Fig. 5. The weld microstructures of capsule 105 (the first example of the weld for the DIT-1 capsules) were very similar to those of the test capsules. (a) overlap region, 40X; (b) single-pass region, 50X.

(a)

(b)

Fig. 6. The character of the single-pass weld region in capsule 106 varied with location; (a) just ahead of weld overlap, 50X; (b) away from weld overlap, 50X.

Fig. 7. The crack on the inside surface of the taper-down portion of the weld overlap in capsule 106, 35X.

Fig. 8. The microstructure of the weld near the crack in capsule 106 was significantly different from those of the other weld sections, 100X.

Fig. 9. The characteristics of the GPHS closure weld are (a) overrun length, (b) downramp, and (c) total double-pass length.

TABLE I. Characteristic Dimensions of the Los Alamos Welds on the DIT-1 Impact Capsules

Capsule No.	Dimensions (mm)		
	Overrun	Downramp	Double-pass
101	7.1	3.6	10.2
102	3.4	5.3	9.1
103	7.1	3.8	9.6
104	7.4	3.8	---
105	7.1	3.6	8.9
106	5.3	3.2	9.1

Fig. 10. The impacted fuel from DIT-1, capsule 101; fuel pellet SRP-27.

Fig. 11. The impacted fuel in DIT-1, capsule 102 after it was cleaned ultrasonically; fuel pellet SRP-48.

Fig. 12. The impacted fuel in DIT-1, capsule 103; fuel pellet SRP-6.

Fig. 13. The impacted fuel in one section of DIT-1, capsule 104; face pellet SRP-7.

(a)

(b)

Fig. 14. The structures of (a) the exterior and (b) the interior of fuel pellet SRP-27 that was impacted in DIT-1, capsule 10-, were identical; 20X.

(a)

(b)

Fig. 15. The microstructures of (a) the exterior and (b) the interior regions of fuel pellet SRP-27 that were impacted in DIT-1, capsule 101 were very similar; 250X.

TABLE II. AES Results of MHW and Phosphorus-doped DOP-26 Iridium Auger Intensity Ratios

Specimen	Treatment	Location	Th ₆₅ /Ir ₂₂₉	P ₁₂₀ /Ir ₂₂₉	C ₂₇₀ /Ir ₂₂₉	O ₅₁₀ /Ir ₂₂₉	S ₁₅₀ /Ir ₂₂₉	B or Cl ₁₈₀ /Ir ₂₂₉	Th ₆₅ /Ir ₅₄
MHFT-74-A1	720 h	Inside edge	0.24	---	1.08	0.80	0.13	0.09	0.04
	@ 1210°C	Center	0.43	---	1.06	1.09	0.04	0.06	0.07
	GIS	Outside edge	0.39	---	2.98	0.99	0.09	0.06	0.06
MHFT-74-A2	720 h	Inside edge	0.07	---	0.30	0.60	---	---	0.01
	@ 1210°C	Center	0.29	0.13	0.34	0.50	---	---	0.04
	GIS	Outside edge	0.44	---	0.46	0.52	---	---	0.07
MHFT-74-B1	720 h	Inside edge	0.38	---	0.25	0.51	---	---	0.05
	@ 1210°C	Center	0.14	0.10	0.35	0.53	---	---	0.02
	GIS	Outside edge	0.49	0.24	0.44	0.65	---	---	0.08
MHFT-74-B2	720 h	Inside edge	0.23	---	0.32	0.60	---	---	0.03
	@ 1210°C	Center	0.44	0.27	0.76	0.73	---	---	0.07
	GIS	Outside edge	0.33	0.24	0.85	0.69	0.03	0.03	0.05
MHFT-75-A1	720 h	Inside edge	0.28	---	0.62	0.81	0.03	---	0.04
	@ 1210°C	Center	0.30	---	0.69	0.98	0.03	---	0.04
	GIS	Outside edge	0.34	---	0.66	0.93	---	---	0.05
MHFT-75-A2	720 h	Inside edge	0.08	---	0.19	0.43	---	---	0.01
	@ 1210°C	Center	0.68	---	0.08	0.14	---	---	0.09
	GIS	Outside edge	0.42	---	0.63	0.79	0.06	---	0.06
MHFT-75-B1	720 h	Inside edge	0.26	---	0.15	0.24	---	---	0.03
	@ 1210°C	Center	0.38	---	0.11	0.15	---	---	0.08
	GIS	Outside edge	0.32	---	0.29	0.50	---	---	0.05
MHFT-75-B2	720 h at	Inside edge	0.44	---	0.58	0.75	---	0.04	0.06
	1210°C	Center	0.30	---	0.37	0.73	---	---	0.04
	GIS	Outside edge	0.32	---	0.92	0.75	0.10	0.04	0.05

III. LIGHT-WEIGHT RADIOISOTOPE HEATER UNIT (C. Seabourn, M. Christian)

Nine calibration tests were completed to prepare for the explosion overpressure tests of the heater unit. The nominal launchpad explosion overpressure has been specified as 13.8 MPa (2000 psi) with an impulse of 37.2 Pa·s (5.4 psi·s). The overpressure was attained easily, but the impulse is proving to be much more difficult to reach. The 37.2 KPa·s impulse is quite long compared to the impulses in overpressure tests of previous heat sources. The longest impulse we have achieved is 18.6 KPa·s (2.7 psi·s), using SF₆ in the shock tube.

If we do not achieve the desired impulse by the end of August, we will start testing with the longest impulse we can produce.

IV. SAFETY TECHNOLOGY

A. Iridium Grain Growth (D. Pavone)

The average grain size of a sample of DOP-26 iridium (lot L-267-4), which had been phosphorus-doped and aged 957 h at 1330°C, was 11.8 grains across a nominal 640-μm thickness. This grain size is somewhat smaller than predicted by previous work. The results of the AES examinations of this sample and a companion aged for 500 h are given in Table III. The phosphorous concentrations were substantial in both cases.

TABLE III. Grain-Boundary Analyses of Phosphorus-Doped Iridium Samples, Lot L-267-4

Specimen	Treatment	Location	Th ₆₅ /Ir ₂₂₉	P ₁₂₀ /Ir ₂₂₉	C ₂₇₉ /Ir ₂₂₉	O ₅₁₀ /Ir ₂₂₉	Th ₆₅ /Ir ₅₄
L-267-4-1	500 h @ 1300°C with P ₂ O ₅	Edge	0.54	0.71	0.16	0.22	0.07
		Center	0.74	0.77	0.11	0.13	0.09
		Edge	0.42	0.57	0.25	0.35	0.05
L-267-4-2	957 h @ 1330°C with P ₂ O ₅	Edge	0.60	0.78	0.14	0.23	0.08
		Center	0.68	0.68	Trace	0.10	0.08
		Edge	0.52	0.66	0.22	0.36	0.07

B. Helium Release (D. Peterson, J. Starzynski, J. Early)

Thirteen samples were selected from GPHS ²³⁸PuO₂ fuel pellet GP-19 produced at Los Alamos. This pellet had been subjected to a reentry simulation approximately 6 months ago. The samples selected were exposed to one of five temperature/time profiles, and the helium released was measured during the heating.³ The total helium released as a function of the heating mode, the sample mass, and the percentage of helium inventory released during each treatment are given in Table IV. The total helium released apparently does not depend on sample mass or size. Note that sample 5T showed a significantly lower percentage of helium released than did the other samples. Because this sample was subjected to the steepest temperature pulse, one can posit that helium was trapped in grain-boundary bubbles from which it was more difficult to remove. Variations in the helium released from the other samples may be explained by microstructural differences in the samples. These hypotheses are being tested by correlating the helium release and sample microstructure with the temperature pulse.

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TABLE IV. Total Helium Released From ²³⁸PuO₂^a

Sample	Mass (g)	Heat Mode ^b	Total Helium (scc/g)	Percentage of Inventory
17661-5Y	0.075	1	0.228	93
-5C	0.894	2	0.136	52
-5C	---	3	0.102	38
-5A	0.300	5	0.253	88
-5G	0.231	5	0.248	86
-5P	0.255	5	0.251	88
-5Q	0.236	5	0.249	87
-5R	0.200	5	0.275	98
-5S	0.169	5	0.242	85
-5T	0.103	4	0.225	81
-5U	0.116	5	2.263	89
-5V	0.116	5	0.271	92
-5W	0.118	5	0.255	88

^aSamples given selected temperature exposures.^bHeat Mode Key:

- (1) Ambient to 1600°C in 180 s, hold until helium decreases to background.
- (2) Ramp 472 to 1130°C in 4 h, then hold 44 h.
- (3) Hold at 1600°C until helium decreases to background.
- (4) Ramp 450 to 1510°C in 140 s, then hold at 1600°C until helium decreases to background.
- (5) Ramp 450 to 1510°C in 280 s, then hold at 1600°C until helium decreases to background.

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