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LA-9450-PR
Progress Report

I-4834

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MASTER

Flight-Systems Safety Program

March 1982

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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This work was supported by the US Department of Energy, Office of Coordination and Special Projects.

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LA-9450-PR
Progress Report

UC-33^A

Issued: July 1982

LA--9450-PR

DE82 019490

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S. E. Bronisz

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FLIGHT SYSTEMS SAFETY PROGRAM

March 1982

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 (GPHS)

A. Design Iteration Test Summary (F. W. Schonfeld)

The impact response of the GPHS module used in the second design iteration test (DIT-2) was quite similar to that obtained in the first test (DIT-1). The small variations observed illustrate again that the net reaction is the sum of individual reactions that cannot be defined precisely because the materials cannot be reproduced precisely.

DIT-2 results supplement those of DIT-1. All eight capsules showed significant cracking that might have propagated to failure had there been a small increase in stress, a slight increase in strain, or a reduction in temperature. The microstructures and chemical analyses of the iridium alloy cups and welds and the fuel pellets showed that these components were very much like those previously tested. Because no structural or chemical anomalies were found, the test results must be considered typical of a GPHS module after moderate aging.

The small decrease in impact temperature from 965°C , used in the verification tests, to 930°C , used for the iteration tests, seems to have increased the strain-

hardening capacity of the iridium alloy. Tests at the higher temperature did not show significant hardening of the deformed material, whereas deformation at the lower test temperature increased the iridium hardness as much as 100 DPHN.

Deformation and cracking patterns observed in the iridium alloys after impact show that bending stresses effectively produce and propagate cracks under the test conditions. Because of the semibrittle nature of iridium and the temperature dependence of notch sensitivity, any decrease in test temperature will tend to increase the iridium's sensitivity to bending. The cracks in the bending regions were in the welds and walls and across the interface between weld and wall, indicating no great difference in susceptibility to cracking between the capsule and its weld. More cracks occurred in the weld bead, but this seems likely to be a result of the larger grain size in the weld bead.

The mechanical integrity of the vent structures in both DIT assemblies was satisfactory, although no accurate estimate of their long-term performance can be made on the basis of the short-term exposures used in the two tests.

B. Early Compatibility Test

This test assembly consists of two GPHS-fueled clads, an impact shell, and a set of insulation contained in an ATJ graphite heat-treating fixture. The test temperature is 1310°C, measured by sighting on the end of the top fueled clad through small holes in the furnace fixture, insulation, and the impact shell.

As of April 1, 1982, the accumulated exposure time was 816 h. Continuous monitoring of the helium released from the assembly indicated a decline of the helium signal after 633 h exposure. A sharp drop to approximately 50% of the generation rate followed at 782 h. A large burst of helium occurred 41 h later, and the helium pressure rapidly decayed to a level equal to the generation rate from two fuel pellets. These observations indicate that one of the two vents remained open throughout the exposure and one vent slowly plugged over a 150-h period, remained plugged for 41 h, and then reopened completely.

C. Impact Tests

Plans for the third design iteration test, DIT-3, are not completed. The test, designed to determine the effects of a nonflat impact and the presence of weld cracks on impact response, will be performed on a full module. The graphite components are complete and ready for the test, as is the angled sample holder for the gun. The fueled clads and their preimpact treatment still must be determined.

DIT-1 and DIT-2, with which DIT-3 will be compared, used iridium clads that had been given a grain-size heat treatment before being welded over fuel pellets. The iridium clads to be used in DIT-3 did not receive the grain-size treatment, so it will be necessary to age them as fueled clads to achieve the same iridium grain size.

D. Fragment Testing (C. M. Seabourn, R. W. Zocher)

The three-phase fragment impact tests of the GPHS modules were started.

(1) Impact a fine-weave pierced fabric (FWPF) on a flat plate equal in thickness to the thinnest region of the GPHS module side wall (4.86 mm) with an 18-g 0.50 caliber aluminum alloy bullet at 365, 729, and 1094 m/s (1000, 2000, and 3000 ft/s).

(2) Impact four partial modules with the same bullet at several velocities to span the clad failure threshold.

(3) Impact two full-size modules with the same bullet at the threshold velocity.

Results of the first phase, completed this month, are shown in Table I. The damage caused to the FWPF by the 1076-m/s bullet is shown in Fig. 1. For comparison, we also show photographs of one of the bulk-graphite plates used in the test-development experiments. The ability of the composite FWPF to limit collateral damage is strikingly evident.

The second phase of the GPHS fragment test will use the test assembly shown in Fig. 2. The bullet will be fired into a partial GPHS module, consisting of a single impact assembly (UO₂-loaded) in a modified aeroshell. The partial module will be backed with a bulk-graphite block containing a tantalum mass simulant and bracketed with module-sized bulk-graphite blocks, each containing a mass simulant. The test stack will not be clamped, but GPHS interlock members will be used between the components.

E. Insulation Properties (R. E. Tate)

We designed an experiment to evaluate the uniformity of thermal conductivity of the insulation sleeves used in the GPHS module. This experiment, shown

TABLE I. Velocity Decrements in FWPF
Fragment Tests, 18-g Aluminum
Alloy Bullet, 4.86-mm-Thick
FWPF Plate

Bullet Velocity (m/s)		Velocity Decrement	
Initial	Exit	(m/s)	(%)
1076.1	995.9	80.2	7.45
756.8	694.1	62.7	8.28
382.8	344.1	38.7	10.1

(a)

(b)

Fig. 1. The effects of a 1076 m/s 0.50 caliber bullet are much less severe in the FWPf composite (a) than in bulk graphite (b). The entrance holes are on the left and the exit holes are on the right.

Fig. 2. The second phase of the GPHS fragment impact test program will use a single partial aeroshell in a simulated stacked array.

Fig. 3. The uniformity of the GPHS insulation sleeves will be determined with an infrared sensing system.

schematically in Fig. 3, uses an infrared camera to detect nonuniform temperatures in the camera's field of view. The necessary hardware has been fabricated.

F. Publication

One topical report was issued.

D. E. Peterson and C. E. Frantz, "Reentry Thermal Testing of a General Purpose Heat Source Fueled Clad," Los Alamos National Laboratory report LA-9227, March 1982.

II. LIGHT-WEIGHT RADIOISOTOPE HEATER UNIT (LWRHU)

A. Safety Tests (C. M. Seabourn)

We completed the first fragment impact test. The side of a single LWRHU in its aluminum housing was impacted with an 18-g 0.50 caliber aluminum alloy bullet at 1094 m/s. The UO_2 -fueled capsule was not recovered, although fragments of the other components were. We will analyze the recovered pieces for UO_2 in an attempt to determine whether the fueled clad was breached.

B. Publications

Two topical reports were issued.

(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) D. E. Peterson and J. S. Starzynski, "Reentry Thermal Testing of Light-Weight Radioisotope Heater Units," Los Alamos National Laboratory report LA-9226, March 1982.

III. MULTI-HUNDRED WATT (D. Pavone)

Test assembly MHFT-73 was aged 8820 h in vacuum at 1210°C on the graphite impact shell and impacted after a simulated orbital-decay reentry. The results of the initial post-mortem examination are summarized in Table II.

Metallographic examination of a cross section through the reentrant fold on the impact face, which included a

crack along the centerline of the weld, revealed that grain growth had eliminated the original microstructure of the weld (Fig. 4). The two edges shown in the photomicrograph are not exact matches because the sample fractured during preparation. The exterior surface of the clad showed evidence of compressive upset at the root of the reentrant fold, indicating that the impact crack formed after the fold. Before sectioning, the crack was not observed on the interior surface; the appearance of the fracture edges suggests that the impact crack did not penetrate the iridium clad.

Iridium grain size was nonuniform, with a strong tendency toward larger grains on the interior and smaller grains on the exterior portions of the clad in some locations but not in other locations. Photomicrographs illustrating the variation are shown in Fig. 5. The average grain sizes were 5.1 and 5.5 grains/thickness, consistent with those observed in other test assemblies (MHFT-61 and MHFT-71) that had been aged for 1 yr.

Examination of the metallographic cross section through the large push-through failure confirmed the visual observation that the fracture mode at this location was ductile shear (Fig. 6). The width of the fracture, scaled from the photomicrograph of Fig. 6, is 3 mm.

Table III lists those elements that exceeded the emission-spectrographic detection limits in each MHFT-73 hemisphere.

Results of Auger electron spectroscopy (AES) analysis are presented in Table IV and summarized in Table V. Spectra obtained on the outside edge of one sample (MHFT-73-B1) showed gross contamination by both carbon and oxygen that nearly masked the iridium spectrum and made determination of the thorium-iridium intensity ratio impossible. This spectrum showed a strong S_{150} indication as well. Subsequent sputtering of the sample eliminated the oxygen and sulfur peaks and markedly reduced the carbon peak. The results of the analysis show thorium depletion, moderate amounts of phosphorus at four locations, and sulfur at two locations.

Ceramographic examination of samples of the plutonia sphere taken from the impact face (exterior surface) and from the core indicated that the microstructure was typical of plutonia fuel fabricated at the Savannah River Plant. No impurities were detected.

IV. HELIUM RELEASE (D. Peterson and J. Starzynski)

Seven additional samples from the GPHS pellet GP-19 were exposed to thermal ramps, and the helium

TABLE II. Impact Test Summary — Galileo MHW-Fueled Sphere Assemblies

Assembly Id.	Aging Time (h)	Impact Test Conditions	Post-Impact Dimensions			Failure Type				Iridium Type
	1210°C-GIS ^a Vacuum	(Reentry T/Impact T Velocity)	Height (mm)	Diam (mm)	% Strain ^b Height/Diam	Hoop	Fingerprint ^c	Fuel Push-through	Other	
MHFT-61	8834	1550°C/1440°C 74 m/s	31.09	43.46	-23.5/+6.9		No Failures			DOP-26
MHFT-62	720	1550°C/1440°C 85 m/s	30.38	45.34	-25.6/+12.4	---	---	X	Weld bead back side	HDR
MHFT-64	720	1475°C/1300°C 85 m/s	29.03	45.11	-28.7/+10.8		(X)	---	---	DOP-26
MHFT-65	4320	1550°C/1440°C 85 m/s	28.55	43.84	-28.7/+8.0		(X)	X	If crack ex- tends hoop area	DOP-26
MHFT-66	720	1550°C/1440°C 85 m/s	30.68	43.64	-23.8/+6.9	---	X	---	---	HD
MHFT-67	100	1500°C/1430°C 74 m/s	29.64	43.66	-27.1/+7.4		No Failures			DOP-26
MHFT-68	110	1792°C/1579°C 82 m/s	30.07	43.66	-27.6/+7.4		No Failures			DOP-26
MHFT-69	100	---/1037°C 82 m/s	30.99	43.71	-23.8/+7.6	---	(X)	---	Weld bead crack-IF	DOP-26
MHFT-70	720	1500°C/1430°C 82 m/s	29.16	43.26	-28.3/+6.4	---	X	X	---	DOP-26
MHFT-72	720	1500°C/1430°C 82 m/s	30.43	43.76	-25.1/+7.6		No Failures			DOP-26
MHFT-74	720	1500°C/1430°C 81 m/s	29.74	43.54	-26.8/+7.1		No Failures			DOP-26
MHFT-75	720	1500°C/1430°C 81 m/s	30.07	43.23 44.07	-26.0/+6.6-8.3		No Failures			DOP-26
MHFT-71	9215	1550°C/1430°C 82 m/s	29.79	42.98	-26.7/+5.8	---	X	---	---	DOP-26
MHFT-73	8820	1500°C/1430°C 82 m/s	30.05	43.97	-26.1/+8.2	X	---	X	Reentrant Fold	DOP-26
MHFT-76	8820	1500°C/1430°C 82 m/s	30.84	43.61	-24.8/+7.3	X	---	---	---	DOP-26

^aGraphic impact shell (GIS) surface.^bBased upon nominal 40.64-mm diam except MHFT-62 through -66 based upon Mound Facility gaging.^cParentheses indicate penetration confirmed metallographically.

Fig. 4. Microstructure of the iridium clad weld of MHFT 73 at the impact face reentrant fold. 50X.

release rates were measured. In runs 54 and 55, the temperature was raised from ambient to 1400°C at a rate of $120^{\circ}/\text{min}$, held at about 1400°C for 3 h, and then raised and held at 1600°C until the helium signal fell to background. Sample 53 was heated at $240^{\circ}/\text{min}$ to 1170°C , where the temperature was maintained for 3 h. Samples 56 and 57 were heated to 1400°C at $240^{\circ}/\text{min}$ and held there for 3 h.

The temperature dependence of the diffusion constant was determined from analysis of the measured helium release rates using a simple diffusion model. The diffusion constant logarithm is plotted vs the reciprocal temperature for runs 51 through 57 in Fig. 7. Runs 51 and 52, ramped at $120^{\circ}/\text{min}$ and described last month, are shown for comparison. D' at a constant temperature

of 1170°C in run 55 showed no change in average value over the 3-h heating period. An average D' of -6.40 was measured, which correlates well with the final D' value measured during this ramp. A similar constant D' was also found in the analyses of the other ramps.

It is apparent that the diffusion constants converged at high temperatures. The E_a and $\log D_0$ values calculated from the least squares analysis of the $\log D'$ vs $1/T$ plot are given in Table VI. It appears that the slower ramp ($120^{\circ}/\text{min}$) has lower E_a values but higher D' values at low temperatures.

It is encouraging that the helium release rates can indeed be satisfactorily modeled using Fick's laws of simple diffusion. The observed constancy of the D' value at a given temperature is also interesting.

(a)

(b)

(c)

Fig 5 Metallographic cross section through the push through failure of the iridium clad of MHFT 73. The fracture mode was ductile shear (a) 7X, (b) and (c) 100X

(a)

(b)

(c)

Fig. 6. Microstructures observed in the iridium clad of MHFT-73. The grain size was nonuniform. The interior surface is at the bottom of the photomicrographs. All 100X.

TABLE III. Impurities Found in the MHFT-73 Iridium Hemispheres

Element	Hemisphere A	Hemisphere B
	(ppm)	(ppm)
Magnesium	5	5
Aluminum	70	70
Silicon	20	30
Calcium	3	3
Chromium	10	15
Iron	400	400
Nickle	200	200
Copper	40	30
Rhodium	40	100
Plutonium	100	100

TABLE IV. AES Analysis of MHW Iridium

Specimen	Treatment	Location	Auger Intensity Ratios						
			Th ₆₅ /Ir ₂₂₉	P ₁₂₀ /Ir ₂₂₉	C ₂₀₇ /Ir ₂₂₉	O ₅₁₀ /Ir ₂₂₉	Si ₉₂ /Ir ₂₂₉	S ₁₅₀ /Ir ₂₂₉	Th ₆₅ /Ir ₅₄
MHFT-73-B1	8820 h, 1210°C, GIS, vacuum	Edge	0.16	---	0.90	0.74	---	---	0.02
		Inside							
		Center	0.59	0.19	0.53	1.17	---	---	0.08
MHFT-73-B2	8820 h, 1210°C, GIS, vacuum	Edge							
		Inside	0.17	---	---	---	---	---	0.02
		Center	0.77	0.23	---	---	---	---	0.09
		Edge	0.49	0.35	---	---	---	---	0.06
MHFT-73-A1	8820 h, 1210°C, GIS, vacuum	Outside							
		Edge	0.04	---	0.17	0.21	---	---	Trace
		Inside							
		Center	0.80	0.24	---	---	---	---	0.09
MHFT-73-A2	8820 h, 1210°C, GIS, vacuum	Edge	0.57	---	0.31	0.53	---	---	0.07
		Outside							
		Edge	0.38	---	2.15	0.68	---	0.18	0.06
		Inside							
MHFT-73-A2	8820 h, 1210°C, GIS, vacuum	Center	0.39	--	1.21	0.81	---	---	0.06
		Edge	0.46	---	1.25	0.84	---	0.16	0.07
		Outside							

TABLE V. Summary of AES Intensity Ratios from MHFT-73

Location	TH ₆₅ / Ir ₂₂₉	P ₁₂₀ / Ir ₂₂₉	C ₂₇₀ / Ir ₂₂₉	O ₅₁₀ / Ir ₂₂₉	S ₁₅₀ / Ir ₂₂₉	TH ₆₅ / Ir ₂₂₉
Edge	0.15	---	0.81	0.41	0.05	0.03
Inside						
Center	0.64	0.17	0.44	0.50	---	0.08
Edge	0.51	0.12	0.52	0.46	0.04	0.07
Outside						
Average	0.43	0.10	0.59	0.46	0.01	0.06

TABLE VI. Activation Energy E_a and Logarithm of the Constant of Diffusion D'_0 , Determined from Helium Release Measurements on $^{238}\text{PuO}_2$

Run No.	Thermal Pulse	E_a (kcal/mol)	Log D'_0 (s ⁻¹)
51	Ambient to 1400°C	40.9 ± 0.4	-0.108 ± 0.083
52	at (120°/min)	41.6 ± 0.3	0.254 ± 0.065
54		45.5 ± 0.4	0.746 ± 0.068
55		39.4 ± 0.4	0.012 ± 0.075
53	Ambient to 1200°C	55.6 ± 0.8	2.254 ± 0.142
56	Ambient to 1400°C	50.6 ± 0.8	1.621 ± 0.105
57	at (240°/min)	50.1 ± 0.6	1.430 ± 0.110

Fig. 7. Temperature dependence of diffusion constant for helium in plutonia.

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