LA-9918-PR
Progress Report

UC-33a
Issued: October 1983

Space Nuclear Safety Program

May 1983

Compiled by
S. E. Bronisz

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

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SPACE NUCLEAR SAFETY PROGRAM
May 1983

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 Special Nuclear 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.

I. GENERAL-PURPOSE HEAT SOURCE

A. Early Compatibility Test II (D. Pavone)

The second test assembly (ECT-2), which consisted of two General-Purpose Heat Source (GPHS) fueled clads, a standard graphite impact shell, and a set of CBCF insulators contained in an ATJ graphite furnace fixture, was aged for 90 days at a clad temperature of 1310°C and subjected to post-mortem examination without impact testing. Initial observations of the visual appearance and iridium metallography were reported in LA-9906-PR, "Space Nuclear Safety Program, April 1983," (October 1983). Additional analytical results were obtained this month.

Results of Auger Electron Spectroscopy (AES) analysis of the grain boundary chemistry are given in Table I. All samples examined exhibited a duplex microstructure, with larger grains at the interior edge occupying approximately one-third of the wall thickness. Thorium depletion, varying from moderate to severe, was observed in all samples, consistent with the microstructural observations and with past experience. Oxygen was detected at nearly all locations of both cups of fueled clad HF-8 and carbon was detected in both samples of its vent cup (LR236-6). No carbon was detected in the HF-8 shield cup (LR234-2). Relatively high concentrations of both

oxygen and carbon were found in cups of fueled clad HF-9 (vent cup LR237 1, shield cup LR234-4). Neither the significance of nor the reason for the differences in carbon and oxygen levels in the two fueled clads has been established.

The results of emission spectrographic analysis of the four iridium cups are shown in Table II; only the elements present in quantities exceeding the detection limit are listed. The compositions of these cups are in the range of previous observations. Silicon (detection limit 10 ppm) was not detected in any of these iridium samples.

The phosphorus content of each plutonia pellet, determined by a colorimetric procedure, was 3 ppm, which is consistent with the absence of phosphorus in the iridium AES analyses.

The absence of vent effusates and the relatively small quantities of vent deposits present in the two capsules suggested that the plutonia pellets would be of comparatively high purity. However, the results of the emission spectrographic analyses conflicted with this assumption (Table III). Pellet HF-8 did not have unusually high concentrations of impurity elements, except for tantalum, but pellet HF-9 contained more impurities, which were inhomogeneously distributed. One HF-9 sample had high concentrations of calcium and silicon with nearly normal concentrations of other impurities.

Table I. The Auger Intensities Found on the Grain Boundaries of the Iridium Cups Used in the ECT-2 Exposure

Specimen	Location	Th ₆₅	C ₂₇₀	O ₅₁₀	S ₁₅₀	B or Cl ₁₈₀
		Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉
HF-8						
Vent Cup (LR236)						
Sample 1	Inner Edge	0.26	0.52	0.77	---	---
	Center	0.58	---	0.55	---	---
	Outer Edge	0.54	0.30	0.83	---	---
	Average	0.46	0.27	0.72	---	---
Sample 2	Inner Edge	0.09	---	0.49	---	---
	Center	0.42	---	---	---	---
	Outer Edge	0.62	0.45	0.81	---	---
	Average	0.38	0.15	0.43	---	---
Shield Cup (LR234)						
Sample 1	Inner Edge	0.38	---	0.36	---	---
	Center	0.68	---	---	---	---
	Outer Edge	0.68	---	0.34	---	---
	Average	0.38	---	0.43	---	---
Sample 2	Inner Edge	0.34	---	---	---	---
	Center	0.82	---	0.30	---	---
	Outer Edge	0.60	---	0.35	---	---
	Average	0.59	---	0.22	---	---
HF-9						
Vent Cup (LR237)						
Sample 1	Inner Edge	0.26	0.86	0.86	0.05	---
	Center	0.40	0.37	0.79	---	0.11
	Outer Edge	0.34	0.49	0.70	---	---
	Average	0.33	0.57	0.78	0.02	0.04
Sample 2	Inner Edge	0.28	0.37	0.68	0.02	---
	Center	0.54	0.30	0.46	0.07	---
	Outer Edge	0.42	0.45	0.93	0.21	---
	Average	0.41	0.37	0.69	0.10	---
Shield Cup (LR234)						
Sample 1	Inner Edge	Trace	0.35	0.45	---	---
	Center	0.46	0.60	0.76	---	0.07
	Outer Edge	0.72	0.34	0.70	---	0.06
	Average	0.39	0.43	0.64	---	0.04
Sample 2	Inner Edge	0.12	1.00	0.60	---	---
	Center	0.60	1.06	1.18	---	---
	Outer Edge	0.50	1.34	1.05	---	---
	Average	0.41	1.13	0.94	---	---

TABLE II. Results of the Spectrographic Analysis of the Iridium Cups Used in ECT-2

Element	Elemental Content (ppm)			
	HF-8		HF-9	
	Vent Cup (LR236)	Shield Cup (LR234)	Vent Cup (LR237)	Shield Cup (LR234)
Chromium	15	30	15	20
Nickel	70	50	50	40
Aluminum	40	40	40	40
Copper	10	15	15	15
Iron	200	100	150	100
Rhodium	40	nd ^a	30	30

^aNot detected.

and a second sample contained the expected levels of calcium and silicon, but a high concentration of iron. These analytical data reinforce the observation that individual samples of the fuel cannot be relied upon to indicate the quantity of impurities present in a particular pellet.

TABLE III. Emission Spectrograph Analysis Results of the Second Early Compatibility Test Fuel Pellets (ppm)

Element	Fuel Pellet		
	HF-8	HF-9	
		Sample #1	Sample #2
Silver	25	25	3
Manganese	1	15	20
Strontium	nd	5	nd
Aluminum	70	80	40
Calcium	100	750-7500	130
Tantalum	800	400	100
Sodium	5	2	nd
Titanium	20	100	7
Barium	3	10	nd
Iron	70	240	900
Silicon	90	890	25
Magnesium	nd	10	nd
Tungsten	nd	200	nd
Chromium	7	nd	nd

The graphite impact shell, which contained the fueled clads during the aging treatment, was analyzed for plutonia by combustion and radiochemical analysis of the resulting ash and found to contain 32 g of plutonium.

B. Safety-Verification Tests

1. Direct Course (C. Seabourn). Los Alamos will supply four UO₂-containing iridium clads for the GPHS module to be used in the DIRECT COURSE explosion test at White Sands Missile Range this fall. As an aid to recovery of the objects, the clads will be activated in the Laboratory's Omega West Reactor. The ²⁹²Ir level, after the first calibration exposure, was about half that necessary to produce the desired 10 mr/h at 100 mm on the September 14 test date.

A second calibration exposure will be counted as soon as the highly radioactive, short-half-life components decay. The correct exposure will then be given to the four test capsules.

2. Reentry (C. Frantz). The electron-beam furnace that will be used to expose the GPHS impact assemblies to the required heating regimens was tested. The tests were successful, but the high-voltage power supply had little reserve power at the highest temperature. It will be tuned prior to use.

3. Samples (R. Zocher). The final four aeroshell assemblies were machined to simulate the ablation that would occur during an orbital-decay reentry. Inspection

revealed that all were within tolerance dimensionally and free of other discrepancies.

II. LIGHT-WEIGHT RADIOISOTOPE HEATER UNITS (LWRHU)

A. Overpressure Test (C. Land and C. Seabourn)

The post-mortem examinations of the two simulant-loaded LWRHUs that had been exposed to an overpressure of 13.8 MPa (2000 psi) and 38.6 KPa-s (5.6 psi-s) in Sandia National Laboratories' 305-mm-diam, 16.76-m-long shock tube were completed. Although initial visual inspections of the recovered capsules detected no failure, detailed examinations revealed that one capsule had failed. A third LWRHU assembly, also exposed in this test, was not recovered.

1. LRF-003. The capsule (RHU-030), recovered after the test and shown in Fig. 1, is deformed severely and the deformed side is scarred from being impacted by solid particles. The capsule was sectioned longitudinally (Fig. 1c), which revealed the failure visible on the upper corner of the left-hand piece. This failure is shown in more detail in Fig. 2. The pressure wave deformed the side of the capsule facing the blast, tore the weld, and sheared through the weld shim.

When the section was etched and examined at higher magnification (Fig. 3), we could see that the capsule wall had plastically deformed only in the outer half of its thickness. This indicates that the weld quality was probably similar to that of the diametrically opposite, unfailed side of the capsule (Fig. 2).

2. LRF-006. The capsule from this test assembly (RHU-044) is shown in Fig. 4 as recovered and after sectioning. The side toward the blast was deformed more symmetrically than that of capsule RHU-030, presumably because the closure weld did not fail in this capsule. At higher magnification (Fig. 5), the lack of complete weld penetration can be detected. The horizontal part of the joint was not fused on the side of the capsule facing the blast (Fig. 5b), and the horizontal joint and part of the vertical joint were unfused on the side away from the blast (Fig. 5c).

The lack of weld penetration in these simulant-loaded capsules has not been observed in $^{238}\text{PuO}_2$ -fueled LWRHU capsules. It is apparent that capsule RHU-030 failed because of poor welding. If the vertical joint had

Fig. 1. Capsule RHU-030 was deformed in the overpressure test: (a) deformed face, (b) side view showing extent of deformation, (c) sectioned capsule (2X).

been fused, the failure would not have occurred. We believe that the fueled capsules would have survived the 13.8-MPa (2000-psi) overpressure without failure.

B. Impact Test (C. Seabourn)

Fueled LWRHU-9-03 containing capsule RHU-133 was impacted at ambient temperature at 48 mps on a hardened steel target. The LWRHU was oriented with its axis at 45° to the target so that the impact would occur

Fig. 2. The polished section of capsule RHU-030 shows that the overpressure caused the capsule to fail by acting against the side wall (8X).

Fig. 3. The failed wall of capsule RHU-030 showed evidence of plastic deformation in only its outer half (100X).

(a)

(b)

Fig. 4. Capsule RHU-044 was deformed in the overpressure test: (a) as-recovered, (b) after sectioning (2X).

(a)

(b)

(c)

Fig. 5. The weld joints in capsule RHU-044 were incompletely fused but the capsule did not fail in the blast; (a) as-polished section (8X), (b) closure weld facing the blast (100X), (c) closure weld away from the blast (100X).

on the closure end of the aeroshell (the nonvented end of the capsule).

The recovered assembly, Fig. 6, shows that the impact fractured the corner of the aeroshell and split off the diametrically opposite piece. The remaining sides held the closure cap in place. The pyrolytic-graphite insulation was essentially intact.

The capsule appeared undamaged by the impact (Fig. 7). Unlike the simulant-loaded capsules (above), the welds were completely fused (Fig. 8). The impact at 110% of the terminal velocity is not a severe environment for the LWRHU because the capsule was designed to withstand an impact of 128 mps without the graphite.

C. Fragment Impact (C. Land)

The post-mortem examination of two LWRHUs that had been impacted with the standard 50-caliber bullet made from the same aluminum alloy as the Space Shuttle's external tank (2219-T87) were completed. Neither capsule failed.

1. RHU-125. This assembly was impacted at 305 mps (1000 fps) at ambient temperature. The bullet destroyed the graphite and hit the capsule near the nonvented end. The capsule was deformed but intact (Fig. 9). The corner of the bullet apparently hit close to the end of the capsule.

The fracture pattern of the fuel simulant suggests that the pellet was in two pieces before impact (Fig. 10), so that relatively little impact energy was transferred to the

Fig. 6. The 45° corner-on impact fractured the corner of the aeroshell of LWRHU-9-03 but the closure plug was retained (1.8X).

Fig. 7. Capsule RHU-133 was undamaged by the impact (1.8X).

two-thirds of the pellet next to the vented end. The fuel was removed from the other capsule section, which was then polished (Fig. 11). This section clearly shows where the inner surfaces of the capsule walls were embossed by the edges of the transversely cracked UO_2 pellet. The weld penetration at the impact point was complete but the horizontal joint opposite was not.

2. RHU-038. This assembly was impacted at ambient temperature at 661 mps (2170 fps). The bullet destroyed the graphite but did not break the capsule (Fig. 12). The impact point was toward the vented end, but not as close to the end as it was in capsule RHU-125. The capsule

Fig. 8. The closure weld in capsule RHU-133 was completely fused (50X).

(a)

(b)

Fig. 9. The 305-mps bullet deformed capsule RHU-125 but did not cause it to fail: (a) impacted face, (b) side view (2X).

Fig. 10. The UO_2 simulant in capsule RHU-125 was in two pieces before the bullet impact. The smaller piece nearer the impact point sustained more damage (8X).

Fig. 11. The capsule walls of capsule RHU-125 were embossed by the corners of the separated fuel pieces (8X).

(a)

(b)

Fig. 12. The 661-mps bullet deformed capsule RHU-038 but did not cause it to fail: (a) impact face, (b) side view (2X).

was sectioned and ground (Fig. 13). Although the fuel-simulant pellet is not present, the offsets on the inside surfaces of the capsule walls suggest that it also was split into two pieces, one about twice the length of the other.

In this case, however, the larger piece bore the brunt of the impact. Despite the higher velocity used for RHU-038, local damage was less than that for RHU-125 because of the combination of impact point and the size of the more affected pellet piece.

Fig. 13 The offset steps in the capsule walls of RHU-038 indicate that the UO_2 pellet was broken into two pieces before the 661-mps bullet impact (8X).

ADDITIONAL DISTRIBUTION

B. J. Rock, Dept. of Energy/OSNP, Washington, DC
 G. L. Bennett, Dept. of Energy/OSNP, Washington, DC
 J. J. Lombardo, Dept. of Energy/OSNP, Washington, DC
 R. B. Morrow, Dept. of Energy/OSNP, Washington, DC
 R. Brouns, Dept. of Energy/OSNP, Washington, DC
 J. Griffo, Dept. of Energy/OSNP, Washington, DC
 D. K. Stevens, Dept. of Energy/BES, Washington, DC
 M. Norin, Dept. of Energy, Washington, DC
 G. Ogburn, Dept. of Energy, Washington, DC
 J. A. Yoder, Dept. of Energy, Washington, DC
 C. Osterberg, Dept. of Energy, Washington, DC
 I. Van Der Hoven, Dept. of Energy, Washington, DC
 R. L. Clark, Dept. of Energy/ALO, Albuquerque, NM
 J. P. Crane, Dept. of Energy, Albuquerque, NM
 K. Elliot, Dept. of Energy, Albuquerque, NM
 D. L. Krenz, Dept. of Energy, Albuquerque, NM
 J. R. Roeder, Dept. of Energy, Albuquerque, NM
 R. B. Crouch, Dept. of Energy, Albuquerque, NM
 J. N. Bailey, Dept. of Energy, Albuquerque, NM
 H. N. Hill, Dept. of Energy/DOA, Miamisburg, OH
 L. C. Sjostrom, Dept. of Energy, Aiken, SC
 R. J. Hart, Dept. of Energy/ORO, Oak Ridge, TN
 J. Pidkowitz, Dept. of Energy, Oak Ridge, TN
 W. L. Von Flue, Dept. of Energy, SFOO, Oakland, CA
 T. B. Kerr, NASA, Washington, DC
 F. R. Schmidt, NASA, Washington, DC
 E. Gabris, NASA, Washington, DC
 N. Sculze, NASA, Washington, DC
 B. R. McCullar, NASA, Washington, DC
 Operations and Systems Requirements, NASA, Washington, DC
 A. V. Diaz, NASA, Washington, DC
 R. G. Ivanoff, NASA/JPL, Pasadena, CA
 R. Campbell, NASA/JPL, Pasadena, CA
 L. T. Shaw, JPL, Pasadena, CA
 R. J. Spehalski, JPL, Pasadena, CA
 AFISC/SNS, Attn: Col. J. A. Richardson, Kirtland AFB, NM
 AFISC/NTYNS, Attn: Capt. D. K. Zimmerman, Kirtland AFB, NM
 AFWL/NTYNS, Attn: Maj. J. D. Martens, Kirtland AFB, NM
 Lt. Col. James H. Lee, Jr., AFWL/NTYN, Kirtland AFB, NM
 Capt. Michael K. Seaton, AFWL/NTYNP, Kirtland AFB, NM
 Maj. Ray Baca, HQ AFSC/IGF, Andrews AFB, Washington, DC
 Col. William Licht, ATSD/AE, Washington, DC
 Lt. John Erb, ESMC/SGPH, Patrick AFB, FL
 L. J. Ullian, ESMC/SE, Patrick AFB, FL
 D. W. Keesler, AFML/MPE, Wright-Patterson AFB, OH
 Lt. Col. Mel Nosal, AFISC/SES, Norton AFB, CA
 Lt. Col. Ken Morrison, AFISC/SES, Norton AFB, CA
 Maj. Walt Wilson, AFISC/SEM, Norton AFB, CA
 John Marshall, AFRPL/LKC, Edwards AFB, CA
 Lt. Col. Williams B. Moyer, AFMSC/SGPZ, Brooks AFB, TX
 W. Riley, WSMC/SE, Vandenberg AFB, CA
 Capt. Charles Snow, SAMSO/SE, Los Angeles, CA
 HQ Space Div./YLVS, Attn: Lt. Col. Needham, Los Angeles, CA
 R. L. Folger, SRL, Aiken, SC
 J. Howell, SRL, Aiken, SC
 J. B. Mellen, SRP, Aiken, SC
 G. L. Albert, SRP, Aiken, SC
 B. Roberts, SRP, Aiken, SC
 J. R. McClain, MRC, Miamisburg, OH
 W. T. Cave, MRC, Miamisburg, OH
 W. Amos, MRC, Miamisburg, OH
 E. W. Johnson, MRC, Miamisburg, OH
 R. Cooper, ORNL, Oak Ridge, TN
 C. Alexander, BCL, Columbus, OH
 E. E. Rice, BCL, Columbus, OH
 J. Hagan, APL, Baltimore, MD
 B. Bartram, NUS Corporation, Gaithersburg, MD
 R. W. Englehart, NUS Corporation, Gaithersburg, MD
 H. H. Van Tuyl, PNL, Richland, WA
 A. Schock, Fairchild-Hiller Ind., Germantown, MD
 E. Skrabek, Fairchild-Hiller Ind., Germantown, MD
 C. W. Whitmore, GE, Philadelphia, PA
 C. T. Bradshaw, GE, Philadelphia, PA
 R. Kelley, GE, Philadelphia, PA
 R. Hemler, GE, Philadelphia, PA
 V. Haley, GE, Philadelphia, PA
 R. Hartman, GE, Philadelphia, PA
 W. Mecham, ANL, Argonne, IL
 D. C. Anderson, Teledyne Energy Systems, Timonium, MD
 P. Dick, Teledyne Energy Systems, Timonium, MD
 Dr. Marvin Goldman, University of California, Davis, CA
 Charles Smith, Sandia National Laboratories, Albuquerque, NM
 R. Harner, Sandia National Laboratories, Albuquerque, NM
 C. M. Barnes, L. B. Johnson Space Center, NASA SPS, Houston, TX
 R. H. Brown, L. B. Johnson Space Center, NASA FM, Houston, TX
 R. G. Rose, L. B. Johnson Space Center, NASA FA, Houston, TX
 Harold Battaglia, L. B. Johnson Space Center, NASA PF, Houston, TX
 W. H. Boggs, NASA, DE-A, J. F. Kennedy Space Center, FL
 Lloyd Parker, NASA, SF, J. F. Kennedy Space Center, FL
 George M. Marmaro, NASA, MD-ESB, J. F. Kennedy Space Center, FL
 W. A. Riehl, Marshall Space Flight Center, NASA, EH31, Marshall SFC, AL
 W. C. Pitts, NASA, STPM, Ames Research Center, Moffett Field, CA
 J. J. Givens, Ames Research Center, Moffett Field, CA
 R. Corridan, Ames Research Center-NASA, Moffett Field, CA
 J. C. Robinson, Langley Research Center, NASA, MS395, Hampton, VA
 G. J. Schaefer, Jr., Lewis Research Center, NASA, MAIC 500-120, Cleveland, OH
 R. C. Turkolu, TRW, Defense and Space Systems Group, Redondo Beach, CA
 D. Eaton, European Space Research and Technology Centre, Zwarteweg 62, Njordwijk, The Netherlands
 Dr. Ralph R. Fullwood, Science Applications, Inc., Palo Alto, CA
 Dr. William Ailor, The Aerospace Corporation, Los Angeles, CA
 T. Carter, Nuclear Regulatory Commission, Washington, DC
 C. R. Chappell, Nuclear Regulatory Commission, Washington, DC
 D. Eagan, Office of Radiation Programs, USEPA, Washington, DC
 N. Elsner, General Atomics, San Diego, CA
 Charles Salisbury, Naval Ocean Systems Center, San Diego, CA
 Dr. Herbert Weiss, Naval Ocean Systems Center, San Diego, CA
 W. J. Maraman, Los Alamos National Laboratory, Los Alamos, NM
 S. S. Hecker, Los Alamos National Laboratory, Los Alamos, NM
 R. N. R. Mulford, Los Alamos National Laboratory, Los Alamos, NM
 J. Bircly, Los Alamos National Laboratory, Los Alamos, NM
 W. F. Miller, Los Alamos National Laboratory, Los Alamos, NM
 R. J. Pryor, Los Alamos National Laboratory, Los Alamos, NM
 S. E. Bronisz, Los Alamos National Laboratory, Los Alamos, NM
 W. Stark, Los Alamos National Laboratory, Los Alamos, NM
 R. W. Zocher, Los Alamos National Laboratory, Los Alamos, NM
 J. A. Pattillo, Los Alamos National Laboratory, Los Alamos, NM
 E. M. Wewerka, Los Alamos National Laboratory, Los Alamos, NM
 T. K. Keenan, Los Alamos National Laboratory, Los Alamos, NM