LA-10511-PR
Progress Report

UC-33A
Issued: August 1985

LA--10511-PR

DE86 003278

Space Nuclear Safety Program

March 1984

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SPACE NUCLEAR SAFETY PROGRAM
March 1984

Compiled by

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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 (GPHS)

A. Safety-Verification Tests (SVTs) (D. Pavone)

1. Postmortem Examination of SVT-1 Through SVT-5. Metallographic cross sections through the vent assemblies of the SVT-1 through SVT-5 prime fueled clads are shown in Figs. 1-10. The quantities of vapor-transported plutonia and impurity phases at the vent entrances were generally low, and there were no deposits in the vent holes or on the clad exteriors. The vent-assembly welds were sound; however, some of the welds showed large grain sizes in the parent metal. It is not known whether these large grains occurred in areas of the weld overlap that experienced extensive heating or were related to a final forming and sizing step in the clad-cup manufacture. No failures were associated with the vent assembly and decontamination cover welds. However, clad impact deformations were typically small in the vent region.

2. SVT-6 (C. Frantz). The capsules of SVT-6 were subjected to a simulated orbital-decay thermal reentry. The module was impacted at a 90°C orientation, at 54.64 ± 0.18 m/s, and at a clad temperature of 975°C . The centerlines of the graphite impact shells (GISs) were parallel to the impact surface. The clad temperature was measured by a split-junction thermocouple in contact with the clad.

II. LIGHT-WEIGHT RADIOISOTOPE HEATER UNIT (LWRHU) (C. Land)

A. Impact Tests

1. RHU-09-9. This aged unit, impacted side-on last month, was sectioned circumferentially and the fuel removed for fines analysis. Both halves of the capsule were sectioned longitudinally, metallographically prepared, and examined. Macros of the fritted end and the closure end are shown in Figs. 11 and 12. The weld sections in both capsule halves showed full penetration. The sections shown appear to be typical of weld character and do not demonstrate any weld defect (Figs. 13 and 14). The capsule was only slightly deformed along the impact face (right-hand side of Figs. 11 and 12).

2. RHU-10-12. This aged LWRHU fueled clad, which was impacted 135° to the vent end last month, was sectioned circumferentially at about the waistline of the capsule, and the fuel was removed for fines analysis. Both resulting halves of the capsule were then sectioned longitudinally for metallographic examination. Photomicrographs were taken of the capsule-frit vent end and of the clad closure-weld end (Figs. 15 and 16). Figure 15 is a photomicrograph of a section through the major diameter of the capsule and would, in a flight-quality fueled clad, expose the fritted vent. This test

capsule did not contain a vent frit. Apparently, MRC-Mound (Monsanto Research Corporation) personnel drilled a starter hole for the frit within the end disk and then inverted the disk at the assembly weld. There was an intergranular crack in the weld opposite to the impact corner (see Figs. 16, 17, and 18). This crack started on the inside of the capsule and extended across ~90% of the weld thickness. The crack probably occurred during solidification after welding. Microprobe examination of this area failed to reveal any contaminating agent, although the platinum and rhodium content in some areas was slightly lowered. Despite the extensive depth, the crack apparently did not penetrate the weld and no plutonia release was detected. The weld shim was incorporated into the other weld section (see Fig. 19). Particles identified by microprobe as PuO_2 appear to have been trapped during welding (see Figs. 20 and 21).

A large blow hole was present in the weld, and an intergranular crack originated at the blow hole (see Figs. 20 and 21). It is suggestive but not conclusive that plutonium is picked up during the welding process and is deposited along the grain boundaries during solidification. Some of the gas bubble formation encountered during welding of the RHUs may also be directly attributable to pickup of PuO_2 .

B. Example Welds

Four example welds were sectioned through the minimum push-through and 180° to it. The weld specimens were then examined metallographically. The minimum push-through typically occurs at the end of the overlap zone.

1. CB-505. A photomacrograph of the section examined is shown in Fig. 22. Photomicrographs for the two weld sections are shown as Figs. 23 and 24. Full weld penetration was achieved in both sections. No porosity was detected in either weld. Near the start of the weld the molten zone was centered about the cap and body, but 180° from the start, the molten zone was shifted off-center toward the cap. This shift implies that the torch initially was 45° to the workpiece but shifted position during welding.

2. CB-058. A photomacrograph of the weld section is shown in Fig. 25. Photomicrographs from the two weld sections are shown in Figs. 26 and 27. Full weld penetration was achieved in both sections; no porosity was detected in either weld. The torch was located 45° to the capsule at the start of the weld but had changed to $\sim 60^\circ$ by the time the clad had rotated 180° .

3. CB-510. A photomacrograph of the weld section is shown in Fig. 28. Photomicrographs from the two weld sections are shown in Figs. 29 and 30. There was a definite weld underbead in both weld sections, and some porosity was also present. The weld torch was located $\sim 60^\circ$ to the capsule at the start of the weld and $\sim 90^\circ$ by the time the clad had been rotated 180° .

4. CB-508. A photomacrograph of the weld section is shown in Fig. 31. Photomicrographs from the weld sections are shown in Figs. 32 and 33. There was a slight weld underbead in both weld sections and some fine porosity, plus one large pore (10 mils in diameter) located at the edge of the weld near the cap center. This pore was $\sim 25\%$ of the cap thickness. The weld torch was set at $\sim 80^\circ$ at the start but had shifted to $\sim 95^\circ$ by the time the clad had rotated 180° .

5. CB-509. This weld was sectioned through the minimum push-through and at 90° intervals thereafter. Photomacrographs of the four weld sections, starting with the minimum push-through and going around in order, are shown in Figs. 34-37.

A crack present near the center of the weld in the first section began on the inside and traveled at a 45° angle outward to approximately one-third the weld thickness (see Figs. 38 and 39). Microprobe analysis did not identify any contaminants in the cracks. A line of porosity running parallel to the cap was located along the cap/body weld step and probably resulted from impurities picked up by the mating parts. These parts were stored in a contaminated box for several months and were not cleaned before being welded. No defects were seen in the section at 90° to the weld start (Fig. 40).

Porosity stringers (see Fig. 41) lay along the cap/body weld step in the section at 180° to the start. Microprobe analysis identified minute amounts of plutonium in the stringers.

Some fine porosity can be seen (Fig. 42) in the section at 270° to the start.

C. LWRHU Documentation (R. E. Tate)

The final versions of the Los Alamos documentation on Light-Weight Radioisotope Heater Unit production items were forwarded to the Office of Special Nuclear Projects in Germantown, Maryland. The six documents/drawings included were

- LWRHU Product Specification, 26Y-318189;
- LWRHU Product Index, 26Y-318194;
- LWRHU Material Specification for Plutonium-238 Dioxide Fuel Granules, 26Y-318193;
- LWRHU Fuel Pellet, 26Y-318192, Rev. B;
- LWRHU Fueled Capsule, 26Y-318191, Rev. B;
- LWRHU Assembly, 26Y-318190, Rev. B.

Two Materials Review Board actions proposed by Mound Facility (MRB 043 and 044 RHU 83 MD) were reviewed and approved. In these actions, slight length discrepancies in inner and outer insulator bodies are acceptable when selectively assembled.

III. SAFETY TECHNOLOGY PROGRAM

A. Iridium Biaxial Testing (T. George)

Five DOP-26 iridium disks were impacted; test parameters for each of these disks and for two disks tested previously are listed in Table I. A modified test matrix is now 75% complete (we did not receive enough disks to satisfy the original test matrix). When all of the disks in the modified test matrix have been impacted, we will use the results to determine the direction of further testing.

A summary of the results obtained from iridium disks with an average of 25 grains/0.635-mm thickness impacted at 1440°, 1000°, 800°, and 600°C is presented in Table II. Although we had initially intended to test one disk at 400°C, the marginal ductility at 600° suggested that the alloy would be completely brittle at a lower temperature.

Metallographic examination of a cross section removed from disk VR227-6 (tested at 1440°C, 45 m/s, 25 grains/thickness) revealed that the iridium had necked to a razor edge (Fig. 43). Calculation of the major strain at the fracture site (made by determining sheet thickness from the micrograph, using the known lateral strain, and assuming conservation of material) gives a value of 2796.0%.

B. Iridium Chemistry (K. Axler)

We began experimentation to form a ternary compound with thorium, iridium, and carbon.

The reactants were combined in a ratio to accommodate the ThIr_3C stoichiometry. The sample was heated at 1200°C for 3 h under vacuum. The product was analyzed and ThIr_2 , with lesser amounts of ThC_2 and ThO_2 , was present. An identical reactant mixture was induction-heated for 1 h at 1500°C. The mixture was analyzed and ThIr_2 was the only product species present.

We used the arc melter in an attempt to form a thorium carbide; this carbide will be used in later experiments on the formation of ternary compounds. The product has been submitted for analysis.

Table I. Biaxial Punch Tests Completed by 3/31/84

Disk	Tested	Average No. of Grains/Thickness	Strain State	Velocity (m/s)	Temperature (°C)
VR227-6	1/6/84	25	+0	45	1440
ZR566-3	2/3/84	25	+0	45	1440
ZR579R-5	3/1/84	25	+0	45	1000
ZR576-5	3/2/84	25	+0	45	1000
ZR567-5	3/6/84	25	+0	45	800
ZR567-3	3/7/84	25	+0	45	600
ZR567-1	3/22/84	15	+0	45	1440

Table II. Results of DOP-26 Iridium Biaxial Testing^a (+0 strain state, 25 grains/thickness, 45 m/s)

Test Temperature (°C)	Approximate Strain at Onset of Localized Necking	Maximum Strain at Fracture
1440	50%	120%
1000	30%	?
800	15%	15%
600	5%	5%

^aAll values are engineering strain, as measured from the deformation of 1.27-mm (0.050-in.) grit-blasted circles.

(a)

(b)

(c)

Fig. 1. Microstructures of the vent assembly of FC-232: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 2. Microstructures of the vent assembly of FC-238: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 3. Microstructures of the vent assembly of FC-355: (a) vent entrance, 100X; (b) vent hole, 50X (damaged while cutting sample); (c) vent weld, 50X.

Fig. 4. Microstructures of the vent assembly of FC-369: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 5. Microstructures of the vent assembly of FC-348: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 6. Microstructures of the vent assembly of FC-354: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 7. Microstructures of the vent assembly of FC-343: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 8. Microstructures of the vent assembly of FC-350: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 9. Microstructures of the vent assembly of FC-267: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

(a)

(b)

(c)

Fig. 10. Microstructures of the vent assembly of FC-260: (a) vent entrance, 100X; (b) vent hole, 50X; (c) vent weld, 50X.

Fig. 11. RHU-09-09: Longitudinal section of vent end after aging and impact, as polished, 10X.

Fig. 12. RHU-09-09: Longitudinal section of closure end after aging and impact, as polished, 10X.

Fig. 13. RHU-09-09: Nonimpacted weld section, as etched, 50X.

Fig. 14. RHU-09-09: Impacted weld section, as etched, 50X.

Fig. 15. RHU-10-12: Longitudinal section of vent end after aging and impact, as polished, 10X.

Fig. 16. RHU-10-12: Longitudinal section of closure end after aging and impact, as polished, 10X.

Fig. 17. RHU-10-12: Nonimpact weld section, as etched, 50X.

Fig. 18. RHU-10-12: Nonimpacted weld section, as polished, 100X.

Fig. 19. RHU-10-12: Impacted weld section, as etched, 50X.

Fig. 20. RHU-10-12: Impacted weld section, as polished, 250X.

Fig. 21. RHU-10-12: Impacted weld section, as polished, 500X.

Fig. 22. CB-505: Longitudinal section of example weld, as polished, 10X.

Fig. 23. CB-505: Area of minimum push-through in example weld, as etched, 50X.

Fig. 24. CB-505: Area 180° to minimum push-through in example weld, as etched, 50X.

Fig. 25. CB-058: Longitudinal section of example weld, as polished, 10X.

Fig. 26. CB-058: Area of minimum push-through in example weld, as etched, 50X.

Fig. 27. CB-058: Area 180° to minimum push-through in example weld, as etched, 50X.

Fig. 28. CB-510: Longitudinal section of example weld, as polished, 10X.

Fig. 29. CB-510: Area of minimum push-through in example weld, as etched, 50X.

Fig. 30. CB-510: Area 180° to minimum push-through in example weld, as etched, 50X.

Fig. 31. CB-508: Longitudinal section of example weld, as polished, 10X.

Fig. 32. CB-508: Area of minimum push-through in example weld, as etched, 50X.

Fig. 33. CB-508: Area 180° to minimum push-through in example weld, as etched, 50X.

Fig. 34. CB-509: Area of minimum push-through in example weld, as polished, 10X.

Fig. 35. CB-509: Area 90° to minimum push-through in example weld, as polished, 9X.

Fig. 36. CB-509: Area 180° to minimum push-through in example weld, as polished, 10X.

Fig. 37. CB-509: Area 270° to minimum push-through in example weld, as polished, 10X.

Fig. 38. CB-509: Crack and porosity along cap/body join showing minimum push-through, as polished, 50X.

Fig. 39. CB-509: Crack and porosity along cap/body join in weld section showing minimum push-through, as etched, 50X.

Fig. 40. CB-509: Weld section in area 90° to minimum push-through, as etched, 50X.

Fig. 41. CB-509: Porosity stringers along cap/body join in weld section 180° to minimum push-through, as etched, 50X.

Fig. 42. CB-509: Weld section in area 270° to minimum push-through, as etched, 50X.

Fig. 43. Disk VR227-6 necked to a razor edge; as polished, 50X.

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