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Progress Report

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Flight-Systems Safety Program

September 1982

Los Alamos

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Los Alamos, New Mexico 87545

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Photocomposition by Jo Ann Painter

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Compiled by
S. E. Bronisz

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FLIGHT SYSTEMS SAFETY PROGRAM

September 1982

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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 Space 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. DIT-3 Impact (F. W. Schonfeld)

The examination of the third design iteration test (DIT-3), a General-Purpose Heat Source (GPHS) module that had been impacted at 930°C and 58 m/s at an incident angle of 30°, was completed. In general, the response of DIT-3 to the impact was very similar to the responses of the two prior tests in the series, DIT-1 and DIT-2, when the differing impact attitude and resulting fuel fracture are considered.

1. Vent Structure. The vents of the four fueled clads were all similar. They were clean, and only minor amounts of vapor-deposited fuel and glassy mixed oxides were observed, as would be expected after the relatively short aging time. Their appearance is typified by the vent from capsule SRP-127, shown in Fig. 1. The responses of the vents to aging and impact have been very similar throughout the DIT series, indicating that the design and fabrication produce vents of adequate mechanical strength and that, at least for the short term, the vents reasonably contain fuel off-gassing products.

2. Fuel Structure. The impacted fuel pellets are shown in Fig. 2 as they appeared when the capsules were cut

open. Only in SRP-251, Fig. 2(c), is there a clearly evident fracture plane that matches an area of high local shear strain. The fuel fracture patterns vary within fairly narrow limits, but those limits are sufficiently wide to affect overall impact response.

The microstructures of the four fuel pellets were all similar, as typified by pellet SRP-127 (Fig. 3). The grains were equiaxed and all within the same size population.

3. Capsule Deformation. Capsules SRP-127 and SRP-140, which occupied the trailing positions in the DIT-3 impact test, were only lightly deformed, as shown in Fig. 4. The leading capsules in the DIT-3 module, SRP-251 and SRP-317, were deformed somewhat more (Fig. 5). The maximum strains in SRP-251 were 0.09 in the vent end and 0.07 in the shield end, whereas those in SRP-317 were 0.055 in the vent end and 0.05 in the shield end.

Although the local strain levels produced in the DIT-3 capsules are not very different from those observed in DIT-1 and DIT-2, we must keep in mind that these strains are largely determined by the extent and character of the fuel breakup and that two quite different detrimental stress systems are at work—sometimes independently, sometimes simultaneously. The capsule walls are subjected to shear stresses if the fuel breaks with large, sharp-edged pieces that can move with

respect to one another, whereas, if the fuel shatters into many small pieces that move cooperatively (pseudoviscous flow) rather than independently, bending and hoop stresses will be produced. Because the fuel pellet is a nonuniform, porous, brittle solid of low thermal conductivity, it begins to accumulate defects, large and small, during cooling from the hot-pressing operation. Also, because of its high activity, the fuel pellet is further damaged by alpha bombardment and helium precipitation and bubble growth. All of these factors suggest that fracture behavior might be variable and unpredictable, as observation has indicated.

Further, impact attitude and the characteristics of the resisting medium (in this case the FWPF* impact shell) are important variables. Early in the development program, we found that attitude strongly influenced the fragmentation of the fuel pellet in tests that impacted encapsulated (in Pt-3008) fuel pellets directly against hardened steel or granite. When the capsule hit the target flat-end-on, we saw little tendency for shear (push-through) on the impact face because the abrupt and uniform deceleration essentially pulverized that portion of the fuel pellet that was near the area of contact. Side-on impact, in which first contact is line contact, produced more evidence of shear, and corner-on impact produced still more. The interposition of graphite between capsule and target (impact shell, insulator, and aeroshell in the DIT series) dampens and causes overlap of these orientation effects to a large degree, but seems not to eliminate them. The deformations of the two leading capsules (SRP-251 and SRP-317) of DIT-3, as shown in Fig. 5, are largely the result of shear produced by differing movements of large blocks of fuel, illustrating that orientation remains an important variable.

B. DIT-4 Impact (F. W. Schonfeld)

The fourth design iteration test, DIT-4, was intended to provide information regarding the possible effects on impact behavior of changing the procedure used at the Mound Facility to remove surface defects from drawn cups. The change involved only a shift from a strictly manual abrasion technique to use of a small, motor-driven, rubber-bonded abrasive wheel, a change that we would consider to be trivial for most materials. However, the behaviors of iridium-rich alloys have not always

*Fineweave-Pierced Fabric 3-D carbon/carbon composite, a product of AVCO Systems Division, 201 Lowell St., Wilmington, MA 01887.

corresponded to the expected, so a test of this kind was appropriate.

Two fueled clads, SRP-394 (manual abrasive cleaning) and SRP-398 (motor-driven abrasive cleaning), were radiographed, aged for 30 days at 1310°C in an impact assembly, radiographed, assembled into an ablated partial aeroshell, and impacted at 58 m/s and 930°C in the flat-on orientation. Neither capsule failed, but both contained the interior cracks in the reverse-bend region that are characteristic of this design in this orientation.

Figure 6 shows the before and after radiographs of the fueled clads. The two cannot be compared directly because the capsules were loaded into graphite jigs for the heat treatment in a geometric relationship that differed from that in the shipping container (in other words, they were loaded to simulate the operational arrangement during the heat treatment). The radiographs indicated that the aging treatment caused little or no degradation of the fuel pellets.

The arrangement of the partial module used for the impact test is shown in Fig. 7. Fueled clad SRP-394 was in the blind end of the impact shell, and SRP-398 was in the closure end of the impact shell.

The as-recovered impacted sample is shown in Fig. 8. The impact fractured the aeroshell and removed the impact shell's cap, allowing fueled clad SRP-398 to come out. The other fueled clad remained in the blind end of the impact shell.

The impact shell, with SRP-394 still inside, is shown in Fig. 9. A crack in the shell extended the length of the impact surface and for 25% of the length on the back surface. The impact shell has the same type of permanent bending seen in DIT-1 and DIT-2.

The fueled clads are shown in Fig. 10. Again, the strains (Table I) and the asymmetrical appearances are quite similar to those observed after the DIT-1 and DIT-2 impacts.

TABLE I. DIT-4 Impact Strains

	Capsule 394		Capsule 398	
	Negative	Positive	Negative	Positive
Diametral				
Vent cup	0.103	0.089	0.116	0.097
Weld	0.095	0.124	0.104	0.124
Shield cup	0.100	0.079	0.074	0.067
Length	0.028	0.050	0.034	0.040
Diagonal	0.052	0.027	0.035	0.029

C. Early Compatibility Test (D. Pavone)

The early compatibility test (ECT) assembly was aged for 6 months in vacuum at an iridium-clad temperature of 1310°C. The aging assembly consisted of two GPHS fueled clads, identified as HF2 and HF5; a FWPF graphite impact shell; and a set of carbon-bonded, carbon fiber insulation held in a ATJ furnace fixture. The impact test simulated the temperature (930°C) and velocity (59.3 m/s) of an orbital-decay reentry, but no reentry temperature pulse was applied to the assembly. The FWPF aeroshell used in this partial module test had been machined to simulate reentry ablation and was identical to the one used in the DIT-4 impact.

During the first heat-up period of the impact test, the test assembly was accidentally immersed in water when a seal in the bullet assembly failed. Following immersion, the assembly was vacuum dried for 3 days and radiographed to determine the effect of the immersion on the plutonia pellets. As shown in Fig. 11, additional cracking of the pellet of fueled clad HF2 (FC-HF2) had occurred, but little or no additional cracking occurred in the pellet of fueled clad HF5 (FC-HF5). The assembly was reinstalled in the gun, heated, and impacted.

On recovery, the aeroshell was found to have been broken into three pieces along longitudinal cracks through the thinnest regions of the impact face and side walls. The impact shell had the typical bowed shape and was split longitudinally along the center of the impact face.

Photographs of impacted FC-HF2, which was located in the closed end of the graphite impact shell (GIS), are shown in Fig. 12. A large amount of vent effusate was apparent on the end surface of the vent cup. A major failure occurred on the back of the fueled clad and extended down the end surface of the vent cup nearly parallel to the impact direction. The maximum width of the fracture was about 1.5 mm and the length was about 30 mm. Three additional cracks occurred on the vent-end face, and a small crack appeared in the center of the impact face on the vent cup.

Two cracks were observed in the impacted FC-HF5, a 7- by 0.5-mm crack on the vent-end face and a very small crack (which may not have penetrated the iridium) on the corner of the impact face. This capsule was located in the closure end of the GIS. Figure 13 shows photographs of the impacted FC-HF5. A large quantity of vent effusate was also apparent on the vent-end face of this capsule. A distinct pattern of dots in a hexagonal array suggests that the deposits may have been trans-

ported from FC-HF2 through holes in the floating membrane.

The maximum overall capsule strains are tabulated below:

	FC-HF2 (%)	FC-HF5 (%)
Diametral strain	+10.9	+8.8
Height strain	-12.9	-7.9
Length strain	+4.9	+5.1

The deformation of FC-HF2 was greater than that of FC-HF5 even though it was located in the closed end of the GIS. Subjectively, it appeared that the plutonia pellet of FC-HF2 was more severely fractured than that of FC-HF5. The greater deformation of FC-HF2 may reflect this difference in plutonia response. Sieve analyses of the impacted plutonia pellets are being performed to determine if this subjective observation is, indeed, a fact.

Samples from the surface and core regions of each of the plutonia pellets were examined ceramographically. The microstructures of all samples were typical of plutonia fabricated at Savannah River Plant (SRP); that is, they were small, had uniformly distributed porosity, and generally had a uniform grain size. However, the edge of the surface sample of pellet HF2 showed two impurity phases, as illustrated in Fig. 14. Electron microprobe analysis indicated the dark gray material contained high concentrations of aluminum, silicon, calcium, and oxygen with a low concentration of plutonium. The medium gray material contained high concentrations of aluminum, chromium, iron, and oxygen with lower concentrations of magnesium, nickel, and plutonium.

To retain the relative positions of the edges of the major crack and the impact-face crack, a nearly complete transverse cross section of the vent cup of FC-HF2 was mounted for metallographic examination. The fracture at both failures was brittle, intergranular, and showed no evidence of reduced thickness of the capsule wall. The microstructures at both failures consisted of very large iridium grains, approaching one grain across the thickness, as shown in Fig. 15. However, the microstructures at the other locations, principally the sides of the impacted clad, were extremely variable. Figure 15(c) shows an area in which a duplex microstructure of large grains on the interior portion of the wall and fine grains on the exterior portion occurred. Such a microstructure is similar to that observed in other test assemblies aged for extended periods at operating

temperatures. Figure 15(d) illustrates a location in which the grain size is larger on the exterior portion of the wall than on the interior portion, and Fig. 15(e) shows a location in which a sharp transition in microstructure occurs.

Metallographic examination of axial and transverse cross sections of the shield cup of FC-HF2 revealed the expected duplex microstructure of large grains on the interior portion of the wall and fine grains on the exterior portion (Fig. 16). This microstructure was generally uniform around the circumference of the capsule.

The variable microstructure observed in the vent cup of FC-HF2 is an unexpected and disturbing development. The uniform microstructure of the shield cup of this assembly suggests that the grain growth characteristics were an inherent property of the iridium sheet from which the cup was fabricated and not an abnormality introduced by the accidental immersion in water. However, we cannot dismiss the possibility that the iridium was contaminated by elements contained in the material that vaporized through the vents. Additional metallographic data from FC-HF5 and the chemical analyses will help to explain the observations.

D. Phosphorus Effects Experiment (D. Pavone)

As of October 8, 1982, the accumulated exposure times were 2521 h for the fueled assemblies and 1505 h for the archive-ring control samples.

E. Explosion Test (R. E. Tate)

The test objects for the pre-DIRECT-COURSE explosion test, now scheduled for early October at the

White Sands Missile Range, were completed. In this test, which is a precursor to the 1983 DIRECT COURSE explosion, a GPHS module that contains lead mass simulants and is sandwiched between aeroshell-sized graphite blocks will be exposed to a 13.8-MPa (2000-psi) overpressure. The event will be photographed and the ground will be searched for the test objects or pieces of them. To facilitate the search, the aeroshells have been painted bright green and the internal components have been painted bright orange.

II. HELIUM RELEASE FROM PLUTONIA

(D. Peterson, J. Early)

The extensive files of helium-release data were re-organized on the computer disks in preparation for conversion from the PDP-11 to the HP-87 system. Further tests of the theoretical model being developed on the HP-87 computer were performed this month. The release data are currently being analyzed and correlated with previous results.

III. PUBLICATIONS

A presentation entitled "Thermodynamics of Plutonium-Nobel Metal Compounds" was made by D. Peterson at the Workshop on Alloy Theory and Development, held in Los Alamos, New Mexico, September 8-10, 1982, and at the National American Chemical Society Conference, Kansas City, Missouri, September 13-14, 1982. The invited paper is to be published in the American Chemical Society's symposium series.

(a)
A diametral section of the complete vent, 10X

(b)
The central exit 40X

(c)
The vent edge and entrance, 40X

Fig 1 The vent from capsule SRP 127 was deformed by impact but remained intact

(a)
SRP-127

(b)
SRP-140

(c)
SRP-251

(d)
SRP-317

Fig. 2. The fuel pellets used in the DIT-3 impact were fragmented.

(a)
Edge, 10X.

(b)
Center, 10X.

(c)
Edge, 250X.

(d)
Center, 250X.

Fig. 3. The microstructures of pellet SRP-127 are typical of all the fuel pellets used in the DIT-3 impact.

(a)
SRP 127 vent end

(a)
SRP 251 vent end

(b)
SRP 127 shield end

(b)
SRP 251 shield end

(c)
SRP 140 vent end

(c)
SRP 317 vent end

(d)
SRP 140 shield end

(d)
SRP 317 shield end

Fig 4 The trailing capsules in the DIT 3 impact were lightly deformed

Fig 5 The leading capsules were deformed by the DIT 3 impact

Fig. 6. The aging caused little or no additional degradation of the fuel pellets used in the DIT 4 impact

Fig. 7. The partial module used in the DIT 4 impact test contained a single impact assembly

Fig. 8. The impact of DIT 4 released fueled clad SRP 398. Fueled clad SRP 394 remained in the impact shell

(a)
Impact surface.

(b)
Side view with thermocouple penetrations.

(c)
End view into impact shell.

Fig. 9. The DIT 4 impact shell was cracked and bent by the impact.

Fig. 10. The deformations of the two fueled clads in the DIT-4 impact were similar to those observed in the DIT-1 and DIT-2 impacts.

Fig. 11. Radiographs illustrating cracking of the plutonia pellets in the ECTs.

(a)
Impact face.

(b)
Side view.

(c)
Back side.

(d)
Vent end.

Fig. 12. Photographs of the impacted FC-HF2.

(a)
Impact face

(b)
Side view

(c)
Back side.

(d)
Vent end

Fig. 13. Photographs of the impacted FC HF5 All views ~1.5X

(a)

(b)

Fig. 14. Photographs of the plutonia pellet HF2 illustrating the presence of impurity phases at the surface. The dark gray material consists of aluminum, calcium, silicon, and oxygen with a small concentration of plutonium. The medium gray phase consists primarily of aluminum, chromium, iron, and oxygen with lower concentrations of magnesium, nickel, and plutonium. 250X, as polished.

(a)

(b)

(c)

(d)

(e)

Fig. 15. Photomicrographs illustrating the variable microstructures observed in the vent cup of FC-HF2. All views 50X.

(a)
Transverse cross section, 50X.

(b)
Axial cross section, 50X.

Fig. 16. Typical microstructures of the shield cup of assembly FC-HF2.

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