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LA--10190-PR

DE84 016973

Space Nuclear Safety Program

February 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. Impact Test (D. Pavone)

The fifth safety verification impact test, SVT-5, was completed; none of the fueled clads failed in the 975°C, 54 ms⁻¹, side-on impact.

No abnormalities were observed when the module was removed from the shipping can and disassembled. The impact assemblies were aged simultaneously in a graphite furnace fixture for 90 days at a clad temperature of 1287°C and in a vacuum below 1×10^{-6} torr, then subjected to a simulated reentry temperature pulse to 1375°C. The components of the SVT-5 module are listed in Table I.

Radiographic inspection of the impact assemblies after aging revealed that all of the plutonia pellets were cracked both axially and transversely near midlength. The cracks in the pellets of the prime impact assembly appeared to have greater separation than those in the secondary pellets.

Figure 1 shows the impacted module in the catch tube before recovery and the aeroshell after the impact assemblies were removed. The impact face of the aeroshell (Fig. 1b) was separated from the body along fractures parallel to the axis of the lead impact assembly. The aeroshell closure cap of the lead impact assembly was not retained, and a circular disk was torn from the

opposite end, leaving the lead impact assembly free to be ejected from the aeroshell. The closure cap of the lead impact shell was not retained in the body, and one of the fueled clads was partially out of the impact shell (Fig. 1a).

The lead impact shell had a central crack nearly the full length of its impact face and cracks on the side about midway between the impact face and the centerline

TABLE I. GPHS SVT-5 Test Assembly Components

Component	Identification
Aeroshell	PAT-1008
Prime impact assembly	
Impact shell	PGT-1027
Fueled clads	FC-260 and FC-267
Fuel pellets	HF-260 and HF-267
Insulation sleeve	C41-3
Insulation disks	P11-2-12:P11-2-20
Secondary impact assembly	
Impact shell	PGT-1029
Fueled clads	FC-415 and FC-426
Fuel pellets	HF-415 and HF-426
Insulation sleeve	C34-2
Insulation disks	P11-2-18:P11-2-29

(Figs. 2a and 2b). The profile view showed depressions at the location of the floating membrane and on each end. The secondary impact shell had a typical irregular crack on the impact face and a transverse crack on the back side ~8 mm from the closure end (Figs. 2c and 2d).

The prime fueled clads from the leading impact assembly are shown in Fig. 3, and the secondary fueled clads from the trailing impact assembly are shown in Fig. 4. There were no failures. In all fueled clads, the localized iridium deformation was mild to moderate, occurring principally on the impact face, and the overall deformation was, in general, symmetric. The gross deformations of the fueled clads are listed in Table II. The height deformation of lead fueled clad FC-260 exceeded those observed in previous tests, but the diametral deformation was about average. As expected, the overall deformations of the fueled clads in the trailing impact assembly were much less than those of the lead impact assembly.

Because of the absence of failures and the absence of alpha activity in the catch-tube debris, only the graphite impact shells were analyzed for plutonium. The total plutonium released from the fueled clads was 2 mg. This amount represents only effusion through the vents and is considered to be of <10- μ m particle size. A summary of the plutonium released in the five SVT impact tests is presented in Table III.

The fractured plutonia pellets are shown in Fig. 5. The fracture patterns of pellets HF-260 and HF-267, from the lead impact assembly, were similar, having small, columnar, radially oriented fragments. The fragments in HF-415 and HF-426 were generally larger with less well developed radial columnar structures.

Sections through the regions of severest deformation in the prime fueled clads are shown in Figs. 6-8. The greatest local deformation in FC-260 occurred on the back side in the shield cup (Fig. 6). The iridium was deformed against the edge of a fuel fragment, but it did

TABLE II. Impact Summary, GPHS SVT Series

Test No.	Clad No.	Deformation (%)		Failures ^a	
		Diametral	Axial	Number	Area (mm ²)
SVT-1 Prime assembly	FC-232	+13.5, -11.1	+5.8	0	25.4
	FC-238	+9.6, -7.3	+3.8	0	
	Secondary assembly	FC-261	+11.7, -11.1	+5.6	2
		FC-410	+9.8, -9.6	+1.4	1
SVT-2 Prime assembly	FC-355	+10.0, -10.4	+4.1	0	8.4
	FC-369	+9.1, -9.3	+4.1	0	
	Secondary assembly	FC-449	+12.5, -10.3	+5.6	3
		FC-273	+10.3, -10.5	+4.4	0
SVT-3 Prime assembly	FC-343	+12.3, -9.0	+5.7	0	0.4
	FC-350	+10.0, -8.5	+2.6	0	
	Secondary assembly	FC-457	+10.8, -7.2	+5.6	0
		FC-454	+9.5, -6.4	+2.9	1
SVT-4 Prime assembly	FC-348	+11.5, -11.3	+6.4	1	1.8
	FC-354	+8.5, -8.2	+4.0	0	
	Secondary assembly	FC-139	+12.5, -8.5	+5.1	0
		FC-162	+10.3, -9.3	+3.4	0
SVT-5 Prime assembly (leading)	FC-260	+10.9, -13.7	+4.1	0	0
	FC-267	+10.4, -9.1	+5.5	0	
	Secondary assembly (trailing)	FC-415	+5.5, -4.5	+1.2	0
		FC-426	+5.0, -6.9	nil	0

^aThe number of failures in each fueled clad and the sum of the areas of all cracks in the four clads in an impacted module.

TABLE III. GPHS SVT Fuel Release

Module	Component ^a	Pu Content (g)		
		<10 μm	>10 μm	Total
SVT-1	GIS, intact ^b	0.0010	0.0034	0.0044
	GIS, failed ^c	0.0074	0.0710	0.0784
	A/S, insul.	0.0039	0.0196	0.0235
	C.T. debris	0.0005	0.0032	0.0037
	Totals	0.0128	0.1072	0.1100
SVT-2	GIS, intact	0.0001	0.0000	0.0001
	GIS, failed	0.0029	0.0197	0.0226
	A/S, insul.	0.0010 ^d	0.0049	0.0059
	C.T. debris	0.0001	0.0002	0.0003
	Totals	0.0041	0.248	0.0289
SVT-3	GIS, intact	0.006	0.004	0.0010
	GIS, failed			
	and A/S	0.0018 ^d	0.0090	0.0108
	C.T. debris	0.0027	0.0032	0.0059
	Totals	0.0051	0.0126	0.0177
SVT-4	GIS, intact	0.0045	0.0000	0.0045
	GIS, failed	0.0005	0.0160	0.0165
	A/S, C.T. debris	0.0026	0.0021	0.0047
	Totals	0.0076	0.0181	0.0257
SVT-5	GIS, intact (combined)	0.0020	0.0000	0.0020

^aGIS—graphite impact shell; A/S—aeroshell; C.T.—catch tube.

^bContained fueled clads without failures.

^cContained fueled clads with failures.

^dEstimated value, sample lost during dissolution.

not crack. A similar but somewhat more severe local deformation occurred in the shield cup of the other prime clad, FC-267 (Fig. 7). In this case, shallow cracks formed on both the inner and outer surfaces. Fuel-fragment indentations were also present on the impact face FC-267 (Fig. 8); no cracks were associated with them.

Typical transverse microstructures of the cups of the prime iridium clads are shown in Fig. 9. The grain size in the interior portion of the wall was somewhat greater than in the outer portion. This is consistent with observation of corresponding components of tests SVT-3 and SVT-4, which had similar thermal histories. The average grain sizes of the cups are tabulated in Table IV.

Axial cross sections through the capsule welds indicated that the welds were free of porosity, had penetrated the wall completely, and possessed desirable, though somewhat different, microstructure (Fig. 10).

Results of Auger electron spectroscopy analysis of the grain-boundary chemistry of the iridium cups are shown in Table V. Thorium concentrations at the interior edge are low in a few of the samples, and consistent with previous observations, carbon and oxygen occur in widely varying concentrations. The shield cup of FC-267 showed a low concentration of sulfur in one sample and a very high concentration at the exterior edge of the other sample. Low concentrations of chlorine were also observed in this sample.

TABLE IV. Iridium Grain Size, GPHS SVT Series

Test No.	Clad No.	Cup No. ^a	Grain Size		Comments
			Intercept Diam (μm)	Nominal ^c	
SVT-1	232	LR313-1(v)	25.7	25	Uniform
	232	LR316-1(s)	30.7	21	Uniform except for tab weld
	238	LR315-2(v)	32.3	20	Uniform
	238	LR318-6(s)	23.3	28	Uniform
	261	P709-6(v)	29.1	22	Uniform
	261	Q804-1(s)	29.8	22	Uniform
	410	S2-5(s)	31.6	20	Uniform
SVT-2	355	Q806-2(v)	30.4	21	Uniform
	355	Q806-5(s)	25.8	25	Uniform except for tab weld
	369	NR528-2(v)	29.7	22	Uniform
	369	NR528-3(s)	23.2	28	Uniform except for tab weld
	449	S27-2(v)	28.5	23	Uniform
	449	S25-3(s)	28.1	23	Uniform
SVT-3	343	PR718-5(v)	32.7	20	Lg. int. grains, 20-25% of thk.
	343	PR719-5(s)	38.9	16	Lg. int. grains, 20-25% of thk.
	350	R904-7(v)	35.7	18	Lg. int. grains, 20-25% of thk.
	350	R904-5(s)	36.4	18	Lg. int. grains, 20-25% of thk. and tab weld
	454	S39-5(s)	42.3	15	Lg. int. grains, 20-25% of thk. + isolated lg. ext. grains
SVT-4	348	QR820-1(v)	35.8	18	Lg. int. grains, 20-25% of thk.
	348	QR820-6(s)	43.5	15	Lg. int. grains, 20% of thk. + tab weld
	354	QR820-3(v)	34.1	19	Lg. int. grains, 20% of thk.
	354	QR820-4(s)	36.8	17	Lg. int. grains, 20% of thk.
SVT-5	267	P701-5(V)	46.3	14	Lg. int. grains, 30-35% of thk.
	267	P708-5(s)	39.2	16	Lg. int. grains, 20-25% of thk. and tab weld
	260	PR717-3(v)	44.0	15	Lg. int. grains + isolated lg. ext. grains
	260	PR717-4(s)	39.9	16	Lg. int. grains, 20-25% of thk.

^a(v)—vent cup; (s)—shell cup.

^bThe intercept size is the average diameter determined by the boundary-intercept method.

^cThe nominal size is the number of grains across a 640- μm thickness.

TABLE V. Results of Auger Electron Spectroscopy Analysis of the Iridium Clads of GPHS Test SVT-5

Specimen	Location	Th ₄₅	C ₂₇₀	O ₅₁₀	S ₁₅₀	Cl ₁₈₀
		Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉	Ir ₂₂₉
FC 260	Int. edge	0.20	0.64	0.73	nd ^a	
Vent cup-1	Center	0.56	0.38	0.73	nd	
	Ext. edge	0.38	0.35	0.69	nd	
	Average	0.39	0.46	0.71	nd	
FC 260	Int. edge	0.36	0.18	0.21	nd	
Vent cup-2	Center	0.77	nd	nd	0.02	
	Ext. edge	0.49	0.19	0.54	0.04	
	Average	0.54	0.12	0.25	0.02	
FC 260	Int. edge	0.35	0.21	0.32	nd	
Shield cup-1	Center	0.36	0.24	0.46	nd	
	Ext. edge	0.52	0.18	0.49	nd	
	Average	0.43	0.21	0.43	nd	
FC 260	Int. edge	0.05	0.96	0.84	nd	
Shield cup-2	Center	0.37	0.68	1.18	nd	
	Ext. edge	0.42	0.75	1.18	nd	
	Average	0.28	0.79	1.07	nd	
FC 267	Int. edge	0.21	nd	0.36	nd	
Vent cup-1	Center	0.76	nd	nd	nd	
	Ext. edge	0.81	nd	0.31	nd	
	Average	0.59	nd	0.22	nd	
FC 267	Int. edge	0.38	nd	nd	nd	
Vent cup-2	Center	0.97	nd	nd	nd	
	Ext. edge	0.96	nd	nd	nd	
	Average	0.77	nd	nd	nd	
FC 267	Int. edge	0.34	0.81	1.10	0.03	
Shield cup-1	Center	0.35	0.75	0.97	0.08	
	Ext. edge	0.53	0.67	1.17	0.04	
	Average	0.41	0.74	1.08	0.05	
FC 267	Int. edge	0.19	1.02	0.87	0.17	0.04
Shield cup-2	Center	0.22	0.71	0.93	0.09	0.05
	Ext. edge	0.46	0.99	1.50	0.61	0.06
	Average	0.29	0.91	1.10	0.29	0.05

^and—not detected.

Table VI contains the results of emission spectrographic analysis of the iridium cups. Iron was the principal impurity detected but was present in amounts generally less than those observed in the previous tests. It is interesting to note the consistency of the concentration of aluminum that has been observed thus far in the test series.

Impurity elements detected in the plutonia pellets by emission spectrographic analysis are listed in Table VII. Comparatively high concentrations of phosphorus were

found in pellets HF-260 and HF-267, 40 and 55 ppm, respectively. However, no phosphorus was detected in the grain boundaries of any of the iridium cups. The observations are not consistent, but the reason for the inconsistency is not apparent. Pellet HF-260 also had a high concentration of aluminum, 320 ppm. This level of aluminum far exceeds that contained in other pellets of the SVT test series and exceeds the Savannah River Plant guideline of 150 ppm as well.

TABLE VI. Results of Spectrographic Analysis of GPHS Iridium

FC No.	Cup No.	Selected Elements*(ppm)								
		Cu	Mg	Ca	Al	Si	Cr	Fe	Ni	Pt
SVT-1										
232	LR313-1	3	nd	nd	40	nd	nd	80	10	nd
	LR316-1	20	7	5	50	25	30	150	40	nd
238	LR315-2	15	10	20	50	25	nd	120	40	nd
	LR318-6	15	7	15	50	10	10	120	45	nd
261	P709-6	15	15	20	50	50	nd	150	45	50
	Q804-1	15	15	25	50	30	nd	150	35	150
410	S2-4	3	15	20	50	100	nd	150	50	nd
	S2-5	5	20	30	50	140	nd	120	20	100
SVT-2										
355	Q806-2	nd	3	nd	50	nd	nd	200	30	nd
	Q806-5	10	5	3	60	150	15	200	40	nd
369	NR528-2	3	nd	nd	40	nd	nd	100	nd	nd
	NR528-3	nd	nd	nd	50	nd	nd	150	10	nd
449	S27-2	20	nd	nd	40	nd	10	200	30	nd
	S25-2	10	nd	nd	50	nd	15	200	30	nd
SVT-3										
343	PR718-5	40	nd	nd	40	nd	nd	150	30	nd
	P719-5	20	nd	nd	50	nd	15	200	60	nd
350	R904-7	6	nd	nd	60	nd	15	300	50	nd
	R904-5	6	nd	nd	60	nd	15	300	40	nd
SVT-4										
348	QR820-1	5	nd	nd	50	nd	10	200	40	nd
	QR820-6	nd	nd	nd	50	nd	10	200	30	nd
354	QR820-3	15	nd	nd	40	10	15	150	30	nd
	QR820-2	40	nd	3	60	10	50	400	80	30
SVT-5										
267	P701-5	15	7	4	50	50	nd	150	60	nd
	P708-5	15	nd	3	60	nd	10	150	50	nd
250	PR717-3	20	nd	nd	60	nd	10	120	50	nd
	PR717-4	20	nd	nd	70	nd	nd	120	50	nd

*Elements present in excess of the detection limit; nd—not detected.

TABLE VII. Plutonium Analyses, GPHS SVT Series

Pellet No.	Selected elements (ppm)								
	P ^a	Mg	Ca	Al	Si	Fe	Cr	Ni	Ti
SVT-1									
HF-232	5	1	130	20	15	60	15	nd	5
HF-238	5	1	200	25	70	70	15	5	5
HF-261	5	nd	200	20	25	85	40	nd	7
HF-410	2	3	400	25	45	110	35	5	7
SVT-2									
HF-355	4	2	40	25	30	65	30	nd	10
HF-369	3	2	30	15	15	45	10	nd	5
HF-273	3	2	40	25	70	55	25	7	5
HF-449	2	2	40	35	50	80	30	nd	10
SVT-3									
HF-350	3	nd	200	35	20	35	10	nd	20
HF-343	5	10	100	35	30	20	10	nd	15
HF-454	2	nd	200	60	50	70	60	nd	20
HF-457	3	nd	150	35	10	20	15	nd	3
SVT-4									
HF-348	4	3	40	40	10	30	15	nd	7
HF-354	3	3	50	40	15	35	25	nd	7
HF-139	3	2	30	25	8	20	25	nd	10
HF-162	2	2	30	20	8	25	9	nd	5
SVT-5									
HF-260	40	nd	30	320	15	20	5	nd	15
HF-267	55	2	40	75	35	30	6	nd	15
HF-415	6	nd	20	40	8	7	nd	nd	15
HF-426	6	nd	30	60	10	10	15	nd	20

^aColorimetric analysis; nd—not detected.

B. DIRECT COURSE (R. Tate)

Preparations were made to map the distribution of uranium oxide on the DIRECT COURSE test bed at White Sands Missile Range. After the DIRECT COURSE event, the activated iridium was located by its gamma radiation. At that time, no uranium was detected visually nor could any be found by the radiation detectors used to find the iridium.

Two methods will be used to determine the distribution: *in situ* gamma-ray spectral analysis, which will look for the enhancement of early daughter products of ²³⁸U, and neutron activation of recovered soil samples. The problem is complicated by the fact that the uranium oxide is probably widely scattered across the test bed, by

the presence of uranium at the parts-per-million level throughout the earth's crust, and by the low level of the gamma-ray signature.

The field measurements were made and the soil samples were collected. They will be analyzed during the next report period.

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

Four LWRHUs were examined after impact testing. None failed. The fuel from two of the impacted units and the fuel from the high-pressure seawater aging experiment were subjected to size analysis.

A. Impact Test

1. **RHU-09-02.** This LWRHU was impacted at 90° (side-on), 48 ms⁻¹, and ambient temperature. The aeroshell was cracked, but it remained together (Fig. 11). The pyrolytic-graphite sleeves were cracked, but the end caps were substantially intact (Fig. 12). The fueled clad was only slightly deformed (Fig. 13). The capsule was opened and the fuel was subjected to a size analysis (Table VIII). The assembly closure weld was sound (Fig. 14) and unaffected by the impact. There was essentially no underbead, but the weld shim was partly incorporated into the weld.

2. **RHU-09-03.** This LWRHU was impacted at 45° to its axis on the nonvented end of the capsule (the closure end of the aeroshell) at 48 ms⁻¹ and ambient temperature. The impact broke the aeroshell, freeing its cap, and broke the pyrolytic-graphite insulation sleeves (Fig. 15). The only evidence that the capsule had been impacted was the graphite smeared on its corner (Fig. 16). The closure weld was sound, but again its underbead was minimal (Fig. 17). The particle-size analysis of the impacted fuel is given in Table VIII.

3. **RHU-09-09.** This LWRHU was impacted at 90° (side-on), 49.2 ms⁻¹, and ambient temperature. The impact broke the aeroshell, released its cap, and broke the pyrolytic-graphite insulation (Fig. 18). The capsule was deformed by the impact (Fig. 19). Its major and minor diameters were 8.89 and 7.77 mm, respectively.

Table VIII. Fines Analysis

Particle Size (μm)	RHU-09-02 (Wt. Fraction)	RHU-09-03 (Wt. Fraction)	RHU-09-07 (Wt. Fraction)
+6000	0.0000	0.0000	0.7448
+2000	0.1797	0.5358	0.2363
+ 841	0.3169	0.2540	0.0000
+ 420	0.2388	0.1005	0.0049
+ 177	0.1502	0.0575	0.0022
+ 125	0.0273	0.0079	0.0008
+ 74	0.0245	0.0113	0.0012
+ 44	0.0160	0.0099	0.0014
+ 30	0.0104	0.0100	0.0007
+ 20	0.0111	0.0000	0.0023
+ 10	0.0099	0.0058	0.0022
- 10	0.0153	0.0073	0.0032

4. **RHU-10-12.** This LWRHU was impacted at 45° on the closure end of the aeroshell at 49.9 ms⁻¹ and ambient temperature. The impact crushed the impacted corner of the aeroshell, broke a section diametrically opposite the impact locus, and freed the aeroshell cap, but left the capsule undamaged (Fig. 20).

B. Seawater Test

The particle-size distribution of the fuel from RHU-09-07, which had been held at 10°C and 69 MPa in seawater for 639 days, is given in Table VIII.

III. SAFETY TECHNOLOGY

Iridium Biaxial Tests (T. George)

The strains measured on disk VR227-6, which had been tested at 45 ms⁻¹ and 1440°C, are listed in Table IX. The maximum fracture strain measured was 118.8 × 4.6%.

The second disk in the series, ZR566-3, was tested under the same conditions. It deformed and necked but did not fail (Fig. 21). The maximum strain was ~80%.

Table IX. Fines Analysis

Strain (%)		Location
Major	Minor	
97.9	7.8	bisected by the crack
100.1	5.7	"
100.4	7.4	"
113.9	2.6	bisected by the fracture
101.3	6.0	"
108.7	3.2	"
118.8	4.6	"
9.4	9.0	disk center
9.3	7.0	"

(a)

(b)

Fig. 1. The impacted test assembly SVT-5: (a) as recovered from the catch tube (0.3X); (b) aeroshell with impact assemblies removed (0.6X).

(a)

(b)

(c)

(d)

Fig. 2. Both SVT-5 impact shells were cracked by the impact. Leading shell PGT-1027: (a) impact face, (b) side; trailing shell PGT-1029: (c) impact face, (d) side (1X).

(a)

(b)

(c)

(d)

Fig. 3. The SVT-5 prime fueled clads in the leading impact shell were deformed symmetrically: (a) FC-260 impact face; (b) FC-260 side; (c) FC-267 impact face; (d) FC-267 side (1.5X).

(a)

(b)

(c)

(d)

Fig. 4. The SVT-5 fueled clads in the trailing impact shell were only modestly deformed: (a) FC-415 impact face; (b) FC-415 side; (c) FC-426 impact face; (d) FC-426 side (1.5X).

(a)

(b)

(c)

(d)

Fig. 5. All four SVT-5 pellets were broken by the impact: (a) HF-260; (b) HF-267; (c) HF-415; (d) HF-426 (1.5X).

(a)

(b)

Fig. 6. Metallographic cross section through the region of greatest local deformation on the back side of the shield cup of FC-260: (a) photomicrograph, 7X; (b) 50X.

(a)

(b)

Fig. 7. Section through maximum local deformation on the back side of FC-267: (a) photomicrograph, 7X, (b) 50X.

(a)

(b)

(c)

Fig. 8 Metallographic cross section through the local iridium deformation on the impact face of the vent cup of FC-267: (a) photomicrograph, 7X, (b) and (c) 50X.

(a)

(b)

(c)

(d)

Fig. 9. Typical microstructures of the iridium cups of the prime fueled clads of GPHS test SVT-5: (a) vent cup—FC-260; (b) shield cup—FC-260; (c) vent cup—FC-267; (d) shield cup—FC-267 (100X).

(a)

(b)

Fig. 10. The closure welds in both prime clads were sound and satisfactory: (a) HF-260; (b) HF-267 (50X).

Fig. 11. The aeroshell of RHU-09-02 was cracked after the impact (1.9X).

Fig. 12. The impact cracked the pyrolytic-graphite insulator sleeves in RHU-09-02 (1.1X).

(a)

(b)

Fig. 13. The RHU-09-02 fueled clad was deformed slightly by the impact: (a) impact face; (b) side view (2X).

Fig. 14. The closure weld on RHU-09-02 was unaffected by the impact (10X).

Fig. 15. The impact broke the RHU-09-03 aeroshell open (2X).

Fig. 16. The RHU-09-03 capsule was not deformed by its impact (2X).

Fig. 17. The RHU-09-03 closure weld was sound (10X).

Fig. 18. The aeroshell and the insulation sleeves were broken when RHU-09-09 was impacted (2X).

(a)

(b)

Fig. 19. The impact deformed the capsule in RHU-09-09 (2X).

Fig. 20. The impact of RHU-10-12 broke the aeroshell but did not damage the capsule (2X).

Fig. 21. Iridium disk ZR566-3 deformed 80% but did not fail (1.5X).

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