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LA-10630-PR
Progress Report

I-25606

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PR-1631-4

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Space Nuclear Safety Program

September 1984

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The four most recent reports in this series, unclassified, are LA-10536-PR, LA-10557-PR, LA-10563-PR, and LA-10571-PR.

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

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**LA-10630-PR
Progress Report**

**UC-33A
Issued: February 1986**

**Space Nuclear Safety Program
September 1984**

Compiled by
T. G. George



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SPACE NUCLEAR SAFETY PROGRAM

September 1984

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ABSTRACT

This technical monthly report covers studies related to the use of $^{238}\text{PuO}_2$ in radioisotope power systems conducted for the Office of Special Nuclear Projects of the US Department of Energy by Los Alamos National Laboratory. Most of the studies discussed are ongoing; the results and conclusions described may change as the work progresses.

I. GENERAL-PURPOSE HEAT SOURCE (GPHS)/SAFETY VERIFICATION TEST (SVT) SERIES

A. SVT-10 Postmortem Examination (T. George)

On August 30, 1984, a fully loaded GPHS module was impacted at 54.3 m/s and 975°C. The module orientation was $\alpha = 30^\circ$, $\beta = 0^\circ$, $\gamma = 0^\circ$ (Fig. 1). Before impact, the test assembly was subjected to a simulated reentry temperature of 1375°C; in addition, the fueled clads were

aged for 91.5 days at 1287°C. Encapsulation details for the SVT-10 fueled clads are given in Table I; data describing the fuel pellets are presented in Table II. After the test, a sealed catch tube containing the impacted module was transferred to Wing 2 of the CMR building. Postmortem examination of the module began immediately.

The catch tube was placed in an open-fronted hood and the pump-out plug was removed. A swab was inserted into the pump-out hole and a count taken; only low levels of activity were detected. The end of the catch

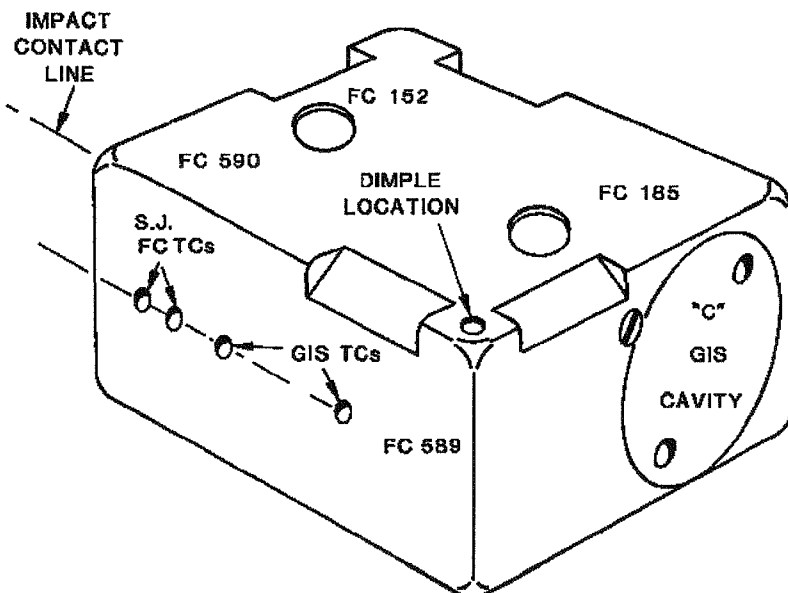


Fig. 1. SVT-10 impact assembly.

TABLE I. Encapsulation Details for the SVT-10 Clads

Capsule	SRP/NDE Crack Indication	Iridium Cups		Fuel Pellet
		Vent	Weld Shield	
FC-152	11.0	N512-5	N516-1	8107HF152
FC-185	1.5	PR714-3	PR716-3	8109HF185
FC-589	1.7	T115-2	T113-2	8301HF589
FC-590	3.7	V203-5	V202-3	8301HF590

tube was removed, and the inner nickel can (a thermal radiation shield) was extracted with tongs. The impact assembly and loose components were then extracted and placed on a bed of solid CO₂ (Fig. 2). As in previous SVT impacts, a significant amount of debris remained in the catch tube (Fig. 3). The largest pieces of graphite were removed from the catch tube; the remaining debris was washed down and packaged for ²³⁸Pu analysis.

The SVT-10 aeroshell was completely destroyed by the impact (Fig. 4). The aeroshell walls fractured along the axial contact lines of the impact shells. Both graphite impact shells (GISs) were released into the catch tube.

Impact shell damage was moderate (Figs. 5 and 6). Thin longitudinal cracks ran the length of the prime GIS impact face, and a wide axial crack extended over 75% of the impact face on the secondary GIS. The cap of the secondary GIS was removed, and FC-152 was released into the catch tube.

The fuel capsules were extracted from the GISs, photographed, and measured. Side and end views of each capsule are shown in Fig. 7. Capsule dimensions and calculated gross strains are listed in Tables III and IV.

Macroscopic examination of the SVT-10 capsules did not reveal any exterior cracks or other defects. The clad

deformations were relatively small. Although capsule FC-152 was released into the catch tube, it did not appear to be significantly more deformed than capsule FC-185 (which remained in the GIS). A sharp crease on the FC-152 impact face (Fig. 8) was apparently caused by the random breakup and the subsequent displacement of a large fuel fragment.

Following macroscopic examination, the fueled clads were defueled and then sectioned to provide specimens for metallography. An abrasive cutting wheel was used to make a small circumferential slit 8-10 mm above the weld (blind cup) on capsules FC-185 and FC-589. The capsules were pried open with a small screwdriver and the patterns of fuel fracture were photographed (Figs. 9 and 10).

To determine the quantity of respirable fuel particles produced by the impact, we selected FC-152 and FC-590 for particle size analyses. The capsules were transferred to a glovebox train used for fines analysis and were opened underwater (to prevent the loss of small fuel fragments). The patterns of fuel breakup (Figs. 11 and 12) were similar to those observed in the other clads. The fuel in capsule FC-152 was particularly interesting because it fractured along a plane 45° to the impact face (Fig. 11).

TABLE II. Data for the SVT-10 Fuel Pellets

Pellet	Diameter (mm)	Length (mm)	Weight (g)	Processing Atmosphere
8107HF152	27.49	27.74	148.9	Ar/O
8109HF185	27.51	27.61	148.7	Ar/O
8301HF589	—not available—		150.1	Ar
8301HF590	27.51	28.17	150.4	Ar

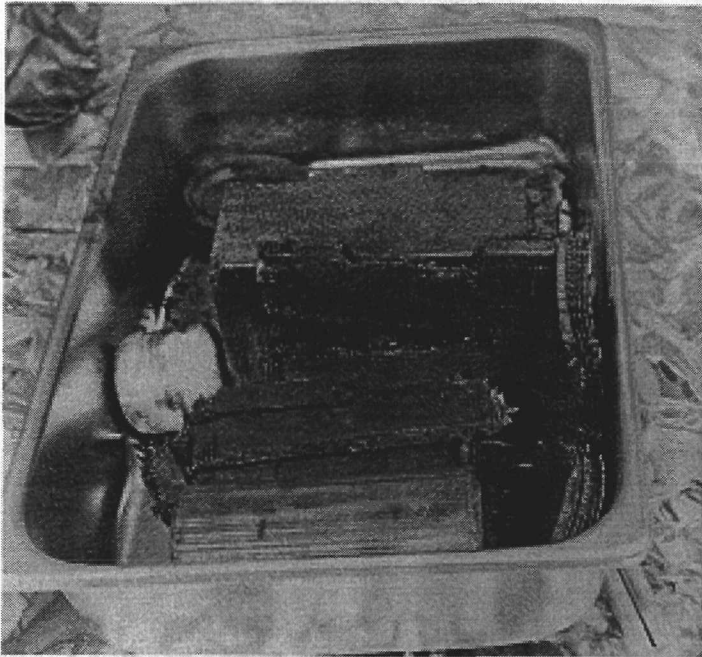


Fig. 2. The SVT-10 test assembly was badly broken up.

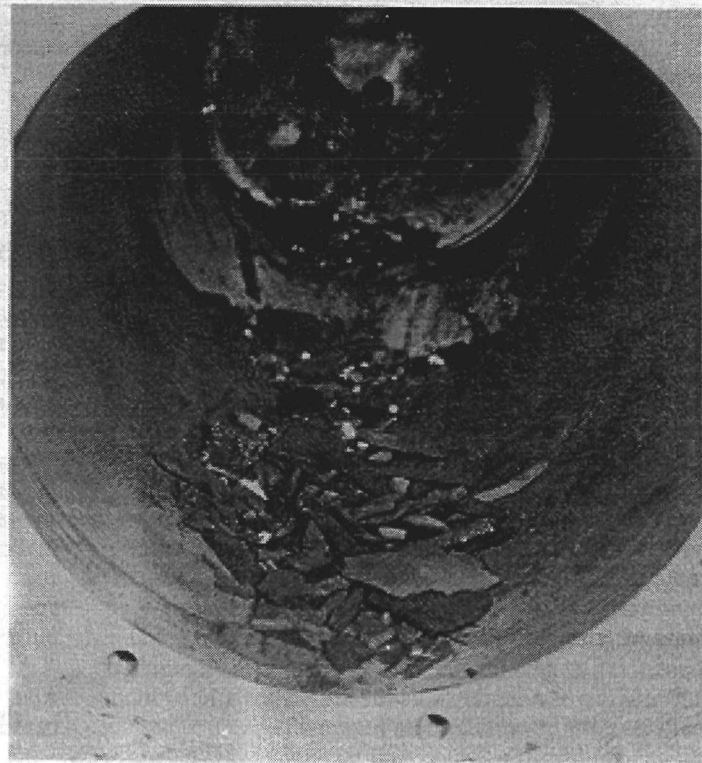


Fig. 3. A significant amount of debris remained in the SVT-10 catch tube after the impact assembly was removed.



Fig. 4. The SVT-10 aeroshell was completely destroyed.

B. Bullet/Fragment Test 3—Postmortem Examination (T. George)

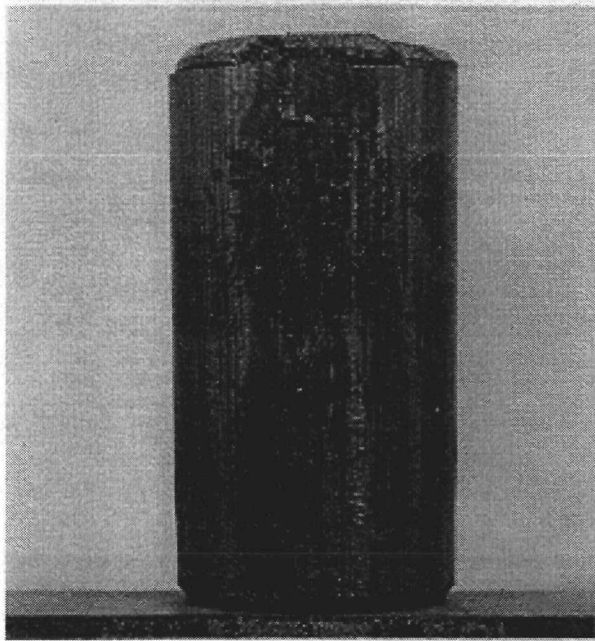
Details of the test conditions and initial macroscopic examination were given in previous monthly reports. In this month we continued with the postmortem examination. Specimens of an apparent Ir/Al intermetallic compound were removed from the exterior of capsule SC-130 and prepared for metallography. The deposit of intermetallic compound that remained attached to the aluminum bullet (Fig. 13) was also sampled to provide specimens for optical metallography, SEM examination, and microprobe analysis.

Metallographic examination of a section removed from the intermetallic compound attached to the aluminum bullet revealed a number of interesting features. At least five phases appear to be present on the deposit cross section (Fig. 14). After metallographic examination, the section was submitted for microprobe analysis of the apparent phase regions.

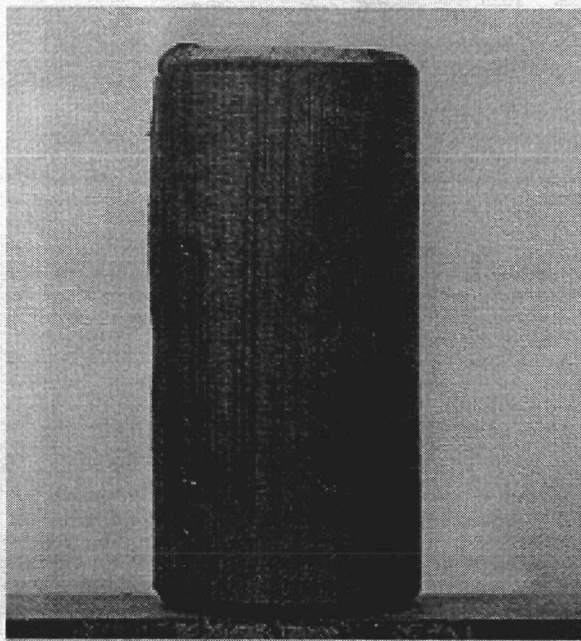
C. Overpressure Tests

1. Bare Module Test 3—Postmortem Examination (T. Cull and T. George). On March 8, 1983, the third bare module overpressure test was conducted on the Coyote Test Site at Sandia National Laboratory. In the test, a bare GPHS module, containing four simulant-fueled (UO_2) iridium clads, was exposed to an overpressure of 1070 psi. Module temperature at impact was 1095°C ; the static impulse was $3.75 (\pm 0.5)$ psi/s. The overpressure disrupted the GPHS module, fragmented the graphite components, and drove the fuel capsules 3.05 m into a vermiculite-filled catch tube. Three of the fuel capsules stopped within the vermiculite; the fourth continued on, penetrated a 0.5-in. plywood bulkhead, and came to rest in the dirt fill 100 mm behind the bulkhead. None of the capsules breached.

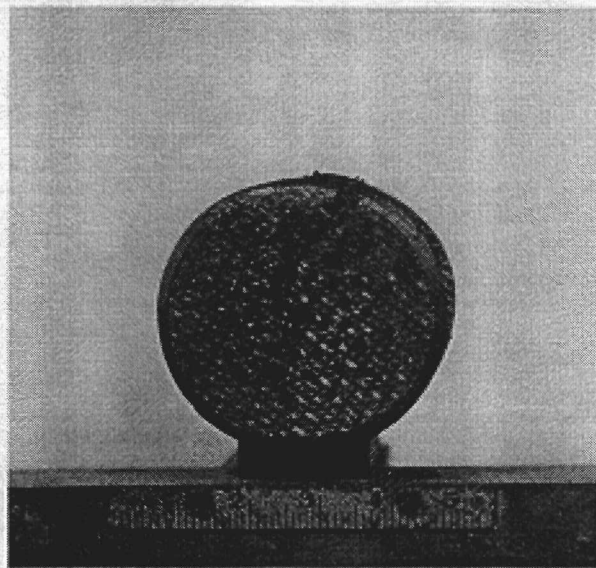
After the test, the capsules were returned to Los Alamos for examination. The surface condition of the capsules did not permit precise identification so they



(a)

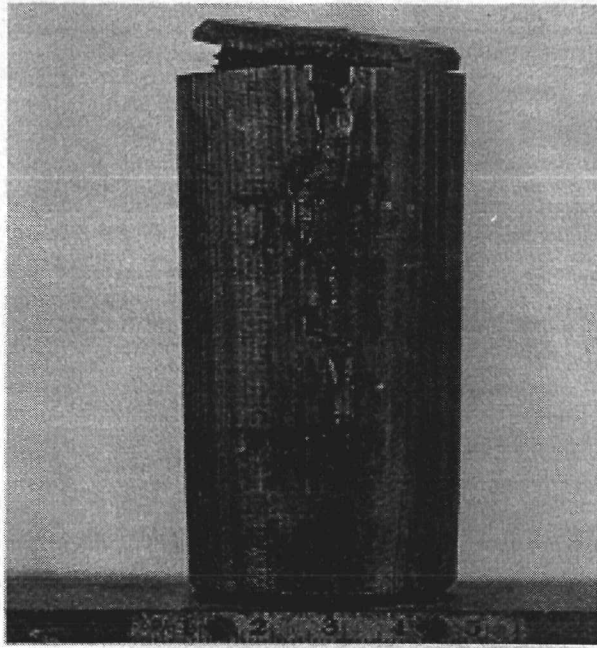


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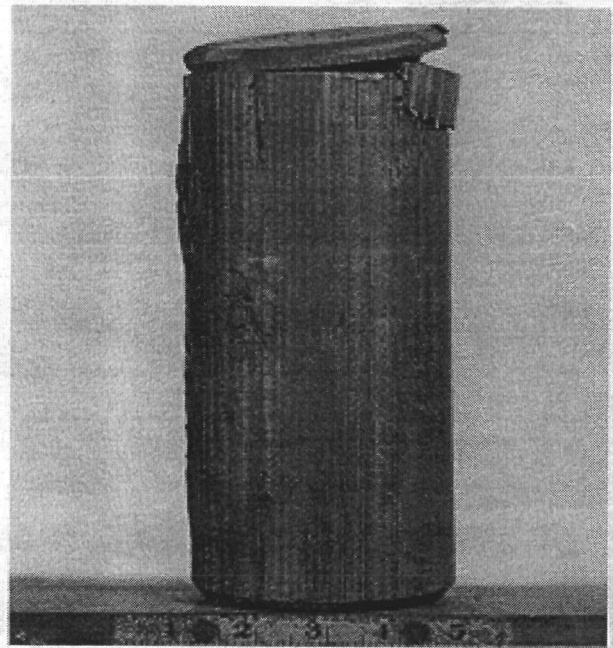


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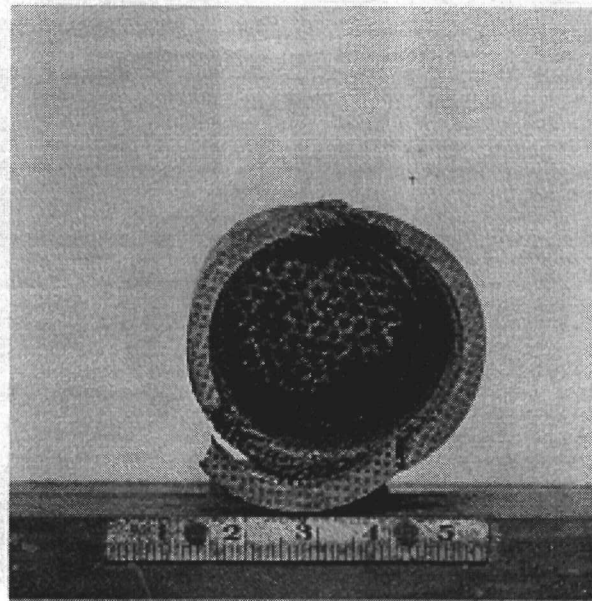
Fig. 5. The primary GIS sustained only minor damage. (a) Impact face, (b) profile, and (c) closure end; all at 1X.



(a)

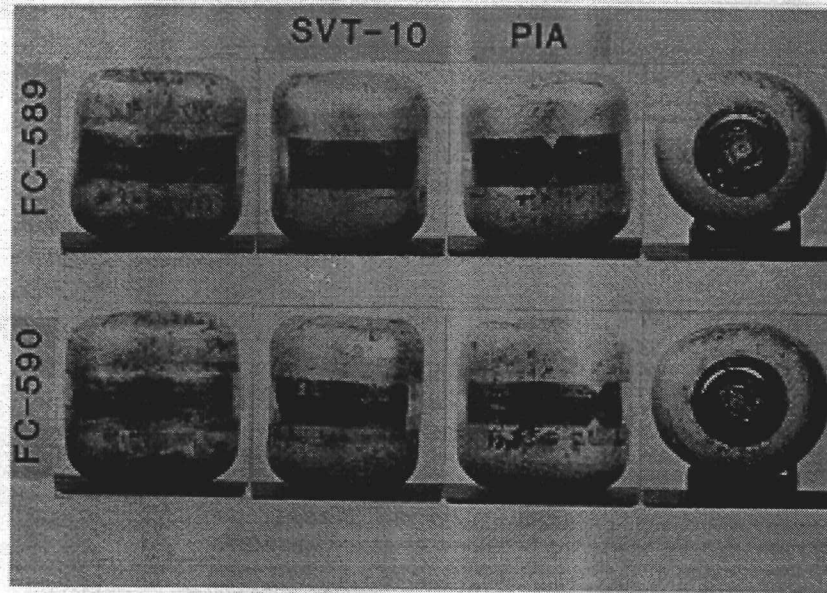


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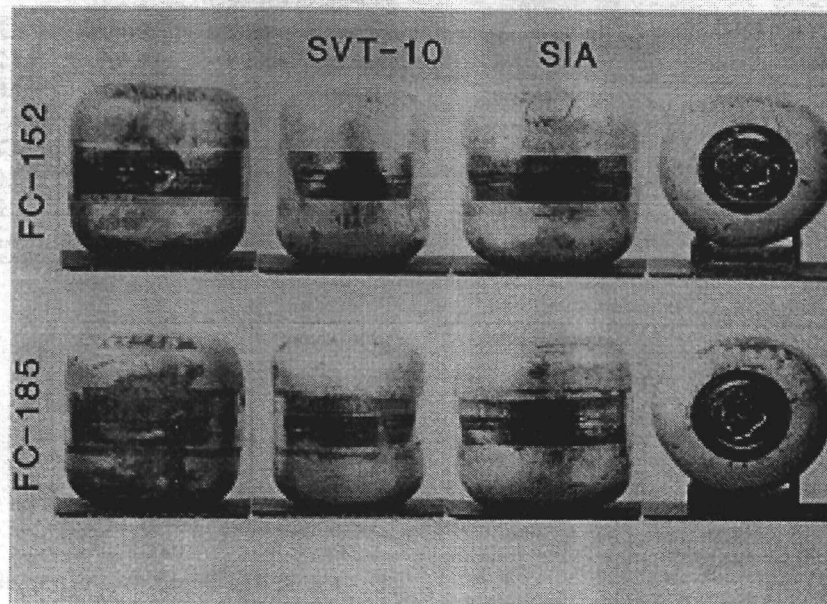


(c)

Fig. 6. The secondary GIS sustained moderate damage. (a) Impact face, (b) profile, and (c) closure end; all at 1X.



(a)



(b)

Fig. 7. The SVT-10 capsule deformations were minor. (a) Clads contained within the primary GIS, and (b) clads contained in the secondary GIS.

TABLE III. Dimensions of the SVT-10 Fueled Clads

Preimpact		FC-152	FC-185	FC-589	FC-590
Diameter (mm)		29.76	29.76	29.74	29.74
Length (mm)		29.97	29.97	29.97	29.97
Postimpact					
Diameter (mm)					
Vent cup	min	27.42	28.08	28.91	27.90
	max	31.33	31.56	31.00	30.89
Weld	min	27.69	27.49	28.88	27.98
	max	32.51	32.20	31.16	31.92
Blind cup	min	27.86	27.70	28.34	27.49
	max	31.56	31.32	30.80	31.26
Length (mm)	min	30.96	30.68	30.34	31.05
	max	31.25	31.30	31.24	31.81

TABLE IV. Postimpact Strains in the SVT-10 Fueled Clads

Diameter		FC-152	FC-185	FC-589	FC-590
Vent cup	min	-7.86%	-5.65%	-2.79%	-6.19%
	max	+5.27	+6.05	+4.24	+3.87
Weld	min	-6.96	-7.63	-2.89	-5.92
	max	+9.24	+8.20	+4.77	+7.33
Blind cup	min	-6.38	-6.92	-4.70	-7.57
	max	+6.05	+5.24	+3.56	+5.11
Length	min	+3.30	+2.37	+1.23	+3.60
	max	+4.27	+4.44	+4.24	+6.14

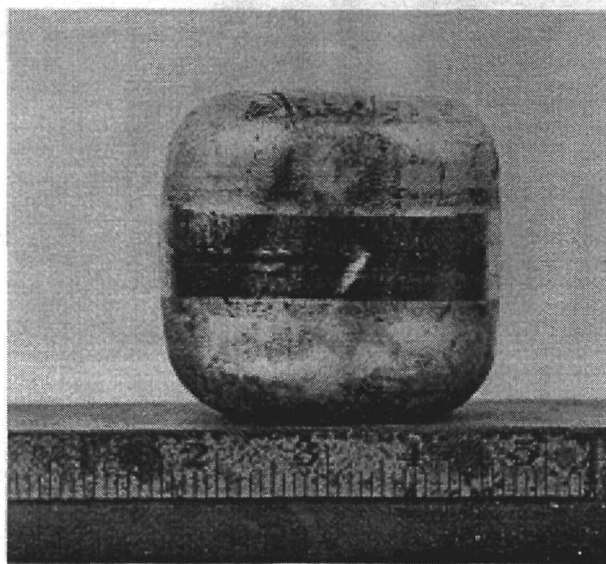


Fig. 8. The impact face of capsule FC-152 contained a deep crease; 1.5X.

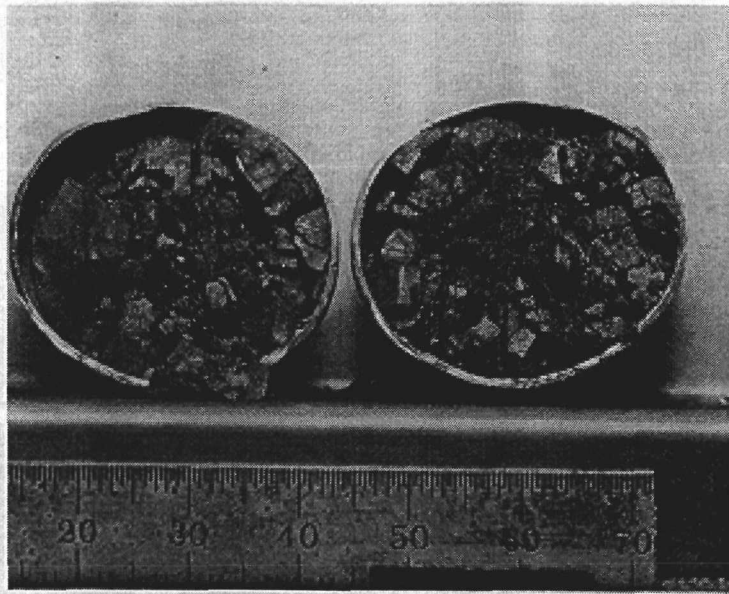


Fig. 9. The fuel in capsule FC-185 fractured in a brittle manner; 1.5X.

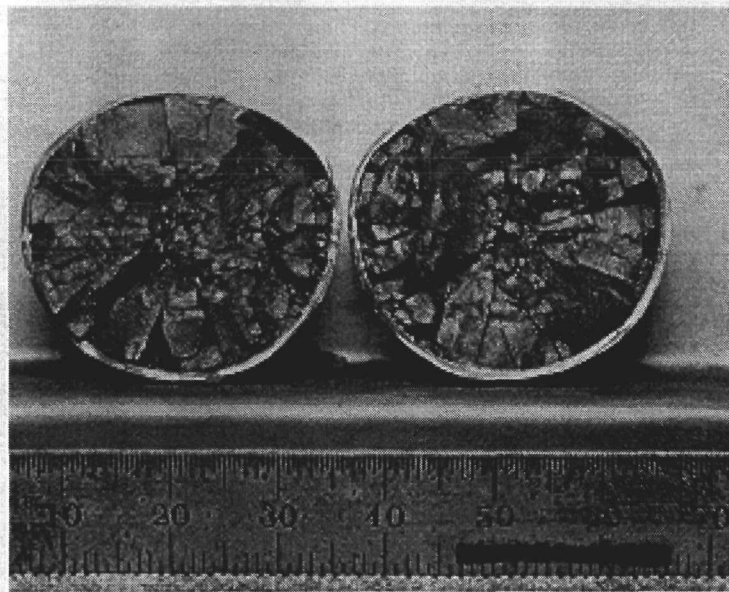


Fig. 10. Capsule FC-589 as-opened; 1.5X.

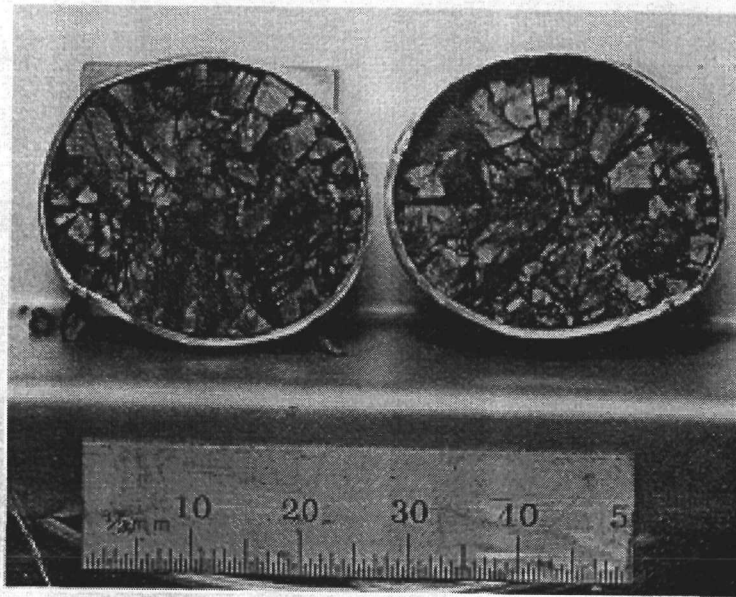


Fig. 11. The fuel in capsule FC-152 fractured in an unusual manner, with a well-defined shear plane running 45° to the impact face; 1.5X.

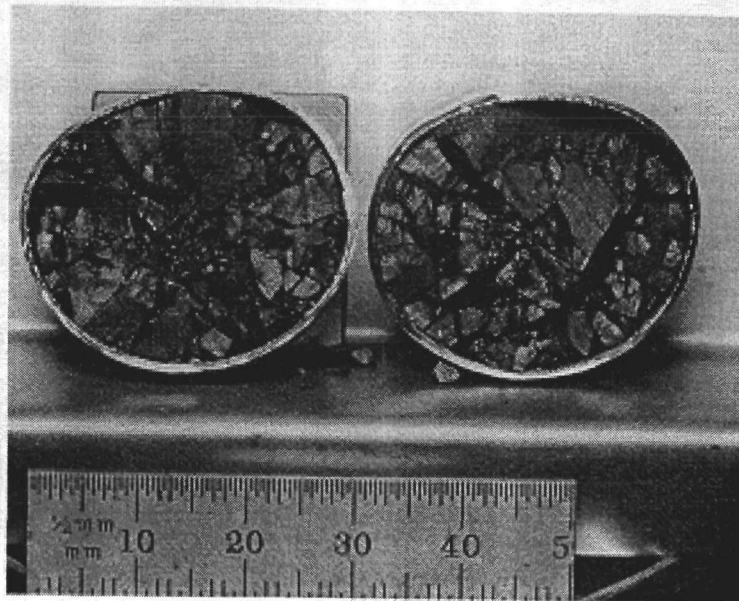


Fig. 12. The fuel in capsule FC-590 fractured in a much more random manner; 1.5X.



Fig. 13. The intermetallic compound that remained attached to the aluminum bullet was sectioned for metallography; 1.5X.

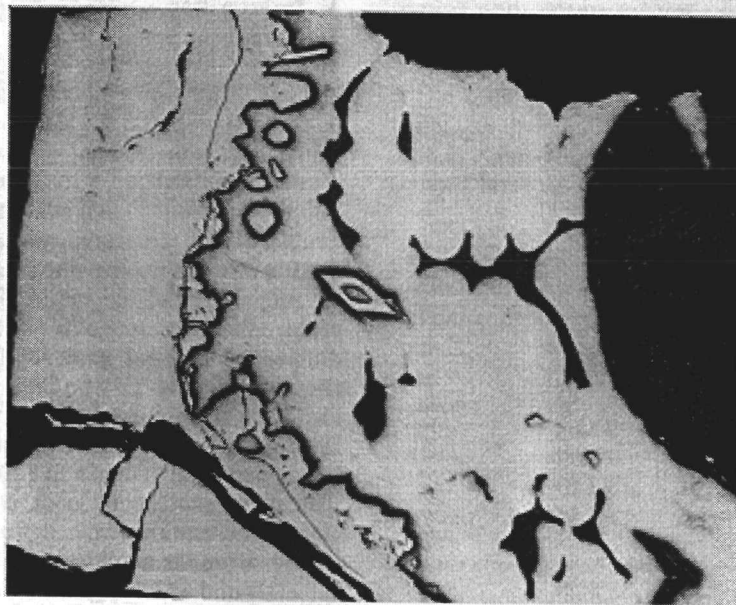


Fig. 14. Several phases appeared to be present in the intermetallic deposit; 40X.

were designated A, B, C, and D (capsule D had penetrated the plywood). The most deformed clad (capsule C) was sectioned to determine if any cracking was present on the interior surface; none was observed.

To provide a reference point for the converter segment (CST) overpressure tests now being planned, we retrieved the three intact capsules from storage and determined the capsule strains; these strains are listed in Table V.

2. CST Test Series (T. Cull). Most of September was spent preparing for the CST overpressure test series. For these tests, a simulated radioisotope thermoelectric generator (RTG) housing will be positioned within a shock tube, 38 mm upstream of a module stack. The first test (CST-1) will be done at an overpressure of 735 psi, with a static impulse of 3.2 psi/s; this test will provide a direct comparison with a previous 735-psi bare module test.

In preparation for the CST test series, two 5-ft shock tube sections were transported to Los Alamos from the Coyote Test Site at Sandia National Laboratory. These sections will be modified to accommodate the CST test machinery and will be shipped back to the test site. Los Alamos engineering has designed a winch assembly to close a sliding door over the cavity (Fig. 15) into which the furnace (used to heat the module stack) drops. Los Alamos has also designed a holding frame, which will attach the RTG housing simulant to the sliding door, allowing it to move into position 38 mm upstream of the module stack when the door closes.

The RTG housing simulant that will be used in the CST test series is a flat, circular plate with an actual RTG housing segment attached. The 5-in. \times 8.8-in. RTG segment, to be manufactured by General Electric

Company, will be positioned directly upstream from the center module of the three-module stack. In order for the entire housing simulant to move evenly when the shock wave hits, the simulant housing plate must be the same weight per unit area as the RTG housing segment. The weight per unit area of the RTG housing segment was approximated using the component weights listed in the December 1983 GE Technical Progress Report. The calculated weight per unit area is 3.74 lb/ft² for the 3-in. \times 6.8-in. part of the RTG segment containing the insulation and thermocouples. An appropriate simulant housing plate (same weight per unit area) can be made from 0.25-in.-thick 2024-T3 aluminum lined with 0.25-in.-thick carbon felt insulation. The calculated weight per unit area of this simulant housing plate, with carbon felt insulation, is 3.73 lb/ft². The actual RTG segments will be weighed when they arrive so that the design of the simulant housing plate can be adjusted if necessary.

A preliminary shock tube test is being set up to show the movement of the simulant housing and the action of the holding frame when subjected to a shock wave. This test will be done at Sandia-Coyote Test Site in the existing shock tube during the week of October 8th.

II. SAFETY TECHNOLOGY PROGRAM

A. Investigation of Ir/Al Properties (L. Foltyn and T. George)

X-ray diffraction of an arc-melted Ir/Al mixture (50% Ir, 50% Al) prepared last month revealed a single-phase compound with a slight excess of iridium (probably caused by vaporization of aluminum by the arc). The diffraction results indicate that the Ir/Al compound has a cubic, Pm3m structure, with $a_0 = 2.9884 \pm 0.0002 \text{ \AA}$.

After a strong exothermic reaction was observed during preparation of the sample for x-ray diffraction, we prepared a 1:1 mixture of Ir and Al powders to run in the differential thermal analyzer (DTA). Three separate aliquots, ranging in size from 3.5 to 10.9 mg, were loaded into alumina liners. Two were covered with Al₂O₃ powder as an inert diluent, the third was not. Upon heating at 10°/min to 1200°C, all showed a single very sharp exothermic peak between 635 and 675°C. Onset temperatures ranged from 651 to 655°C. Heat releases from the two aliquots covered with Al₂O₃ were 169 cal/g and 173 cal/g, versus 133 cal/g for the sample with no diluent. Similar runs on high-purity metal standards have shown that the magnitude of heat released varies with the presence or absence of diluent, which apparently affects the radiation of heat from the sample. Since the two runs with alumina powder more closely followed conditions of the standard runs which were used for calibration, those values (169 and 173 cal/g) for the heat of reaction are probably more accurate.

TABLE V. Bare Module Test 3—Capsule Strains

	Strain (%)	
	Min	Max
Capsule A		
Vent cup	-2.90	+1.62
Weld	-1.11	+1.97
Shield cup	-1.45	+0.85
Length	-0.84	+0.51
Capsule B		
Vent cup	-2.31	+0.09
Weld	-0.85	+1.11
Shield cup	-2.14	0
Length	-1.09	0
Capsule D		
Vent cup	-1.45	+0.85
Weld	-0.34	+1.19
Shield cup	-1.79	+0.26
Length	-0.08	+0.17

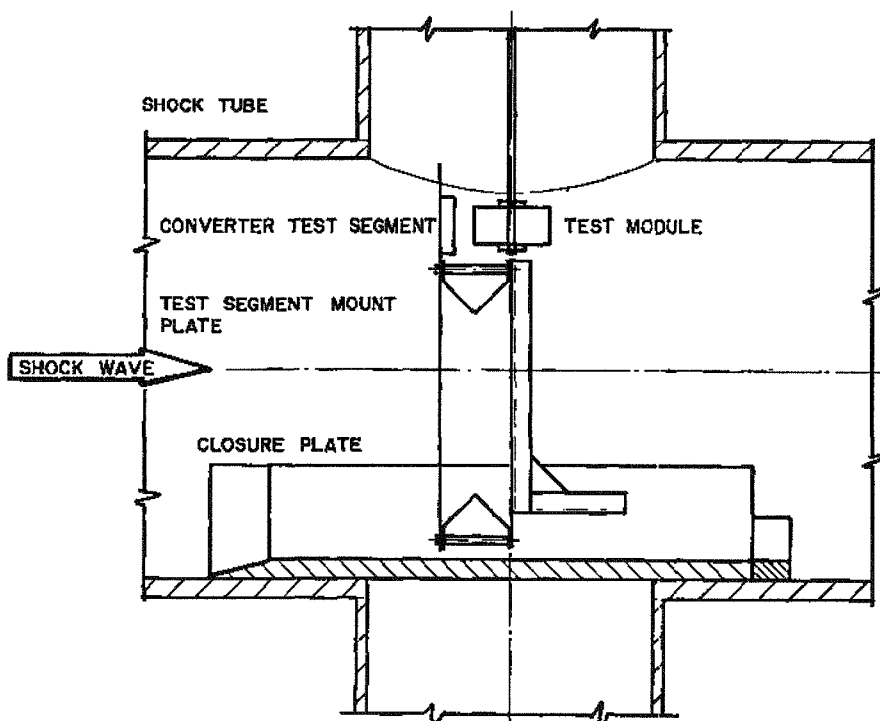


Fig. 15. CST shock tube.

A DTA run was also made on 8.8 mg of the pharmaceutical-grade aluminum powder used in making the mixture above. The sample melted in the range 645-685°C, consuming 104 cal/g. This is approximately the same temperature range as the Al/Ir reaction; its effect on the measured heat of reaction is unknown.

B. Characterization of the Ir/Al Binary System (K. Axler)

After the recent test in which an aluminum alloy bullet was fired into and reacted with an iridium-clad heat source, we initiated an in-depth study of the Ir/Al binary system.

A comprehensive literature search is under way as well as experimentation to characterize IrAl phases and define the binary phase diagram. Specimens of the IrAl phase (1:1) were produced in the arc melter, and we are now experimenting to produce arc-melted samples of other Ir/Al ratios. An arc-melted sample was prepared comprising the 2:3 Ir/Al ratio. The experiment produced IrAl and IrAl₃, with no evidence of an Ir₂Al₃ compound. IrAl₃ is a new phase; no reference to it appears in the literature. The IrAl₃ produced was

10-20% ordered. Pieces of the sample were annealed at 800°C in vacuum for approximately 2 weeks. An x-ray diffraction analysis will be done on the annealed material to determine if any change occurred in the degree of order.

C. Investigation of Ir/Th/P Compounds (K. Axler)

We began characterization of a ternary ThIrP(1:1:1) phase by growing single crystals from a copper melt. The sample was slowly cooled from 1150 to 700°C over an 11-day period. Numerous crystals were obtained by dissolving the copper solvent in hot nitric acid. The metal solvent technique uses the low-melting Cu-P eutectic (15.9 at.%, 714°C) to achieve a large liquid range. The most thermodynamically stable ThIrP phase should form as the copper flux cools. This approach allows us to prepare significant amounts of the ThIrP phase most likely responsible for phosphorus retention along the iridium grain boundaries. This phase could also be a factor in the thorium loss mechanism. We have not been successful at preparing a ThIrC ternary by arc-melting or by reaction in a graphite cell heated to 1900°C.

Printed in the United States of America
 Available from
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