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THE MANUFACTURE OF GLASS-BONDED FUELS FOR DOPPLER COEFFICIENT MEASUREMENT

by

J. E. Ayer, A. G. Hins,
D. E. White, D. C. Carpenter
and C. F. Konicek

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THE MANUFACTURE OF GLASS-BONDED FUELS FOR DOPPLER COEFFICIENT MEASUREMENT

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ABSTRACT

This report describes procedures used to manufacture and assemble glass-bonded, plutonium-containing fuels for Doppler coefficient measurement. Seventeen acceptable fuel rods containing (U-Pu)O₂ or PuO₂ pellets were made. The pellets, which were required to have low (about 70% theoretical) density, were held together by a silicate bond. The pellets were made by milling the oxide; compacting, granulating, and sintering the milled product; pressing pellets from "fired" granules treated with Na₂SiO₃; and sintering the pellets. The pellets were loaded into capsules, the capsules were decontaminated, welded closed, leak tested at room temperature and at 1000°C, and radiographed. The acceptable fuel rods were shipped to the ANL Idaho Division for the determination of Doppler coefficient in ZPR-III.

INTRODUCTION

One of the criteria to assure safety in the operation of fast breeder reactors is a prompt negative power coefficient of sufficient magnitude to, at least, limit the effects of excursion. In metallic fuel systems this is achieved through the expansion, and resulting decrease in fuel density, with increasing temperature. Fuel systems that exhibit small changes in density with temperature may rely on the Doppler effect to provide a decrease in reactivity with increasing temperature.⁽¹⁾

For reactors the Doppler effect, in its simplest terms, is the change in reactivity resulting from temperature-induced variations of effective capture and fission cross sections of the materials of the reactor.

The determination of the magnitude of the Doppler effect is, by definition, relevant to the study of reactor systems, and such investigations are under way at ANL.^(2,3) The fabrication of fuel specimens upon which measurements of the Doppler effect were made is the subject of this report.

FUEL ELEMENT DESCRIPTION

The Doppler element consisted of two fuel rods, containing fuel pellets, and assembled end-to-end as shown in Figure 1. Two lots of elements were manufactured: one contained pellets made of depleted $\text{UO}_2\text{-12.5w/oPuO}_2$; the second contained PuO_2 pellets. The fuel body consisted of a stack of twelve right circular cylindrical pellets and two quartz spacers held in contact by the ends of the fuel rod.

The fuel was required to be a low-density pellet. This requirement was met through the use of glass-bonded fuel bodies.⁽⁴⁾ Figure 2 shows an assembled Doppler rod and the components from which the rods were made.

The cored fuel pellets had an OD of 1.250 ± 0.005 cm and a length of 1.270 ± 0.015 cm. The axial hole, through which a thermocouple-protection tube was inserted, was specified at a nominal 3.7-mm diameter. A pellet density of 70 percent of theoretical and 67 percent of theoretical was desired for the mixed oxide and plutonium oxide, respectively. Weight specification was impressed, not upon individual pellets, but upon the loaded fuel rod, for which a constant weight ± 0.5 percent was required.

The capsules which contained the fuel pellets were supplied by the Reactor Physics Division. The capsule had a mineral-insulated, Inconel-sheathed, heating element wound spirally and brazed along its length. The heating element was used to control the temperature of the fuel body during experiment. The temperature of the fuel body was sensed through a coaxial thermocouple-protection tube which extended from one end of the capsule to within 1.7 cm of the opposite end. After being loaded with pellets and quartz spacers, the container was pressurized to about 0.22 kg/cm² with helium and sealed.

The rods were considered to be ready for leak testing if, after assembly and welding, they were free of alpha-active materials. A rod was considered sufficiently clean when it showed less than 400 dpm direct count and zero wipe count. An acceptable rod was one that showed a leak rate less than 2×10^{-6} std cc/sec after helium mass spectrometer leak detection at 1000°C with a pressure less than 0.1 mm Hg on the rod exterior.

PELLET MANUFACTURING PROCEDURE

The manufacture of pellets and the jacketing, welding, and decontamination of the Doppler specimens were carried out in the helium-atmosphere gloveboxes of the ANL Plutonium Fabrication Facility. The $\text{UO}_2\text{-12.5w/oPuO}_2$ specimens were fabricated and cleared from the gloveboxes before the PuO_2 -containing rods were started. The mixed oxide pellets were made in the following manner:

350-727

Fig. 1. Doppler Element Assembly

350-682

Fig. 2. Assembled Doppler Rod and Exploded View of Components

Milling, which was required to provide a uniform starting substance free of agglomerated material or chunks, was accomplished by placing 250 g of PuO_2 in a 5-liter grinding jar with 1750 g of depleted UO_2 , 2 liters of ethyl alcohol, and approximately 50 alumina balls of various diameters. The jar was placed on a roll rack, and the charge was milled overnight. When milling was complete, the jar was opened and allowed to stand while the solids settled. After the supernatant liquid was siphoned off, the jar and its sedimented content were placed in a vacuum chamber. The sediment was evaporated to dryness by vacuum distillation of the remaining alcohol.

The solid product from the evaporation step was divided into 10-g lots, loaded into a 2.5-cm-diameter, cylindrical pressing die and compacted at 9,000 kg total force with a Carver press. The resultant wafers were crushed through a 50-mesh sieve with a porcelain pestle. The 50-mesh sieve* was nested with a 70-mesh sieve. Fines that passed through the 70-mesh sieve were recycled to the compacting operation.

*Note: All sieve sizes are U. S. Sieve Sizes.

Granules were made to achieve low density in the final fuel pellet; the grain size was chosen for ease of coating with sodium silicate.

An alumina crucible containing a charge of granules was covered and placed in a carbon-element, resistance-heated furnace. The mixed oxide grains were raised to about 1600°C and held at that temperature for one hour in a helium atmosphere of about one kg/cm² pressure. The granules, which tended to fuse, were separated by light crushing and divided into lots, each weighing 11 g.

The 11-g charges of fired oxide granules, weighed to the nearest 0.1 g, were mixed with five drops (approximately 1.1 g) of 40% Na₂SiO₃-60% H₂O water glass. Figure 3 shows a charge of granules and a cored pellet which was made from such a charge. The mixture was packed into a 1.27-cm-diameter die with a 3.61-mm-diameter core rod. The oxide mixture was pressed into an annular shape of 1.27-cm controlled length. The pressing of a fixed weight of oxide granules to controlled length in a die resulted in controlled pellet density. In this manner, the required pellet density of 70% theoretical was realized. Figure 4 is a view of the component parts of the die used to manufacture the oxide pellets.

Fig. 3

Mixed Oxide Granules and
Cored Pellet

350-689

Fig. 4

Die Assembly Used
to Make Cored Oxide
Pellets

350-677

Each "green" pellet was allowed to dry for about 16 hr before being stacked in an alumina crucible. The crucible charge of "green" pellets was then heated to 1200°C and held for about one hour at about one kg/cm² helium pressure. The purposes of this firing were to drive the water from the Na₂SiO₃ and to disperse the oxides of uranium and plutonium into the silicate. The resulting dispersion caused the oxide granules to bond to each other through the silicate-oxide layer.

Each pellet, after firing, was measured for length and diameter to the nearest 0.03 mm. The weight of every pellet was taken to the nearest milligram. Each pellet was placed in an individually numbered compartment of a plastic tray, and the compartment number was logged against the weight, diameter, and length. Selection of pellets to be loaded into a capsule was made from the compartmented tray.

Chemical analyses were made on samples selected from a number of process points. In particular, analyses were made of process materials as follows: Sintered granules were analyzed by X-ray fluoroscopy for uranium and/or plutonium content, and by gas-analysis techniques for oxygen. The finished oxide pellets were sampled and analyzed for silicon by aqueous techniques and by spectrochemical methods for elements not absorbed from HCl media by anion-exchange resin.

At the request of the experimental physicist one finished pellet was analyzed to determine change in density with diameter. The determination was made by successively opening the axial hole, reweighing the pellet, and calculating the density of the remaining shell. The hole in the pellet under study was enlarged from 3.71 to 6.67 mm in eleven steps. The density changed uniformly from 8.03 g/cc to 7.87 g/cc in the above interval.

The procedure for making plutonium oxide pellets was modified slightly from that used for manufacture of the mixed oxide specimen. The plutonium oxide required no mixing with a second material and was quite finely divided; therefore, no milling was necessary. The compacting and granulating step was identical for both materials.

In the sintering operation an unusual condition, not related to the influence of PuO₂, occurred. An alumina crucible containing a charge of granules was "fired" at 1600°C for about one hour. Although the procedure was identical with that imposed on the mixed oxide granules, a small area of the alumina crucible was dissolved away by the charge. A sample of the granules submitted for spectrochemical analysis showed sodium content, from an unknown source, of the order of 0.5 percent. Re-analysis confirmed the presence of sodium in excessive amount and fixed the concentration at about 0.2 w/o. We believe that at 1600°C the sodium, which no doubt occurred as an oxide, dissolved the alumina to form a glassy liquid phase that

flowed outward from the area of attack. The presence of sodium in such concentrations was not objectionable from a practical standpoint, so all future heating of PuO_2 was carried on in a tungsten crucible, which resisted the attack.

The pellet-forming procedure was identical for both compositions. However, it was found that a thin coating of Na_2SiO_3 on the outside of a PuO_2 pellet was extremely helpful in minimizing contamination of the capsule. The silicate coating was applied to a "fired" pellet by dipping it in a 15% water glass solution. The pellets were air dried after dipping and re-fired to insure evaporation of all constituents volatile at testing temperature. The contamination and cleanup problem relative to the loading of PuO_2 pellets will be discussed in the Capsule Decontamination section of this report.

PROCEDURE FOR FUEL ROD ASSEMBLY

Techniques for capsule assembly previously developed in the Plutonium Fabrication Facility were modified to meet the requirements of production of the Doppler rods. Leak-tight, α -contamination-free capsules with a minimal clearance (0.3 mm axial and radial) between fuel and capsule wall were desired. The steps described below were taken to assemble the capsules:

The Inconel capsules, of 12.8-cm ID x 0.50-mm wall thickness x 187 mm long (see Figure 2), were inspected visually and by helium mass spectrometer leak detector for soundness.

Leaks were found in some capsules; other capsules contained deep pits in the capsule wall. All capsules with less than 0.38-mm wall thickness were considered unsuitable.

Hardware, pellets, and quartz spacers were selected to provide minimum clearance between the core stack and the capsule end caps. The internal dimensions of capsules were determined by use of a comparator gauge. Pellets were selected on the basis of length and calculated density in order to meet standard requirements. Pellets were stacked in a column as shown in Figure 5; the stack length was measured with a height gauge. Individual pellets were exchanged in the column until the desired length was achieved. In some cases it was necessary to add a stainless steel shim disk to the column to obtain the required length.

Fuel pellets and spacer components were loaded into the capsule by a technique previously described. The capsule was attached to a glovebox by a flexible PVC pouch. A 0.13-mm-thick acetate funnel was inserted into the capsule mouth to protect against contamination. Light brushing of the

pellets before loading removed loose particles adhering to the surface. Single pellets were removed from the pellet stack and inserted through the funnel into the capsule. After completion of loading, the pouch mouth was dielectrically sealed, the capsule portion was severed, and the assembly was transferred to a contamination-free glovebox.

Fig. 5

PuO₂ Pellets Stacked
for Measurement of
Column Length

350-679

Capsules were decontaminated before closure welding to prevent plutonium from alloying into the molten weldbead and permanently contaminating the surface. The ends of most of the mixed-oxide capsules were α -contaminated to 5,000-10,000 dpm upon removal of the plastic loading fitting. Decontamination was accomplished by alternating wipes with dry tissues and swabs moistened in ethyl alcohol. Excess alcohol was wrung from the swab to prevent it from seeping into the capsule or wetting the pellets. A background level of 400 dpm in the glovebox was achieved on the capsule exterior surfaces and on the interior to a depth of 6 mm inside the capsule mouth.

Decontamination of capsules loaded with uncoated PuO₂ pellets was a monumental task. The capsules were contaminated beyond the sensitivity of the measuring instruments. In addition, the general glovebox area became contaminated to a level above 1,000,000 dpm. The subsequent

application of a silicate coating on the pellets reduced the contamination to levels comparable with those found on the mixed-oxide capsules.

Before the end cap was inserted, the length of the pellet stack was checked by inserting a dial depth gauge into the capsule mouth. In cases for which the stack length was different after pellet loading, the length of the end cap was adjusted to provide proper fit.

Two welds were made to seal the capsule. The end cap was joined to the capsule by a TIG girth weld, made by rotating the capsule under a welding electrode. A spring-loaded split copper block provided chilling for the weld. A close-up of the arrangement for making the girth weld is shown in Figure 6. After the girth weld was made the capsule was evacuated, then pressurized to about 0.22 kg/cm^2 with tank helium. The tube in the end cap was then pinched closed and trimmed. The final seal was made by a capacitor discharge weld on the trimmed tip of the tube.

Fig. 6

Chucking Arrangement for Making
Girth Weld on Doppler Rod

ASSEMBLY EVALUATION

The following quality-control procedures were used for the assembled capsules:

Completed capsules were transferred to an air glovebox where they were surveyed for alpha contamination with a gas proportional counter. Some capsule surfaces were contaminated to 1200 dpm. Wiping with dry tissue and scrubbing with a fiber glass brush reduced the contamination levels to less than 400 dpm in all cases.

A room-temperature helium mass spectrometer leak test was made on all capsules. The test was inconclusive in most cases because helium had been adsorbed by the porous heater wire braze and mineral insulation while in the helium system. The resulting high background reduced the sensitivity of the test beyond practical limits.

The capsules were radiographed to show the condition of the pellets and to inspect the welds for soundness. No fractured pellets were found. A gap in the pellet stack of capsule #20 caused its rejection. It was subsequently found that during loading a portion of the acetate loading funnel had been broken off and had wedged in the pellet stack. All girth welds and seal welds were of satisfactory soundness.

Each Doppler rod was leak detected at 1000°C before final acceptance. The rod was placed in a chamber which was fitted with feedthroughs to allow heater and thermocouple wires to penetrate its surface. The chamber was connected to a vacuum pump which maintained a vacuum around the fuel rod exterior. The capsule was heated to 1000°C by its attached helically wound heater. During heating the line between the chamber and the vacuum pump was continually sampled by a helium mass spectrometer leak detector. Heater current, fuel rod temperature, and helium mass-spectrometer signal were monitored and recorded during each test.

All acceptable capsules showed leak rates less than 2×10^{-6} std cc/sec. As in the cold leak test, hot leak testing was complicated by the fact that the rods were assembled in a helium atmosphere which permeated such regions as pores, crevices, and the mineral-insulated heater wire. The outgassing helium tended to give signals in bursts during the heating of the specimen. In most cases the helium signal diminished to an acceptably low value at 1000°C. A specimen was considered leak tight if the helium signal at 1000°C indicated leakage less than 2×10^{-6} std cc/sec and if the integrated helium loss during testing was much less than the amount of helium originally present in the fuel rod.

RESULTS

Thirty-seven capsules were used to make seventeen acceptable Doppler rods by the methods described. The two-to-one ratio of capsules used to rods completed will be discussed in this section of the report. The loading data for each capsule is contained in the Appendix.

Table I is a list of capsule numbers versus the weight of contained fuel and the results of rod evaluation for mixed oxide rods.

Table I
RESULTS OF MIXED OXIDE ROD ASSEMBLY

Capsule No.	Weight (U-Pu)O ₂ , g	Evaluation	Capsule No.	Weight (U-Pu)O ₂ , g	Evaluation
1	131.02	Acceptable	9	130.91	Reject B*
2	130.98	Acceptable	10	131.12	Reject A
3	130.59	Reject A*	11	131.06	Acceptable
4	130.87	Reject A	12	131.06	Acceptable
5	131.10	Reject A	13	131.06	Reject B
6	130.83	Acceptable	14	130.91	Acceptable
7	130.95	Acceptable	15	130.97	Acceptable
8	131.05	Reject A	16	130.61	Acceptable

*Note: Reject A denotes a leaking capsule; Reject B denotes a component failure, such as leakage current, broken lead wire, and shorted lead wire.

The average weight of pellets in a capsule was 130.94 g. A measure of the control of fuel charged to a capsule is the deviation of any fuel weight from this norm. This measure is represented by the standard deviation for the sixteen-rod population which was 0.15 g or 0.11% of the average fuel charge.

The high reject rate (44%) can be broken down to show that 12.5% of the rods were rejected for failure of a capsule component, primarily due to difficulties encountered with the heater, and 31.3% for unsound welds. Our experience has shown that 90% of the type of welds made on these rods should be acceptable. Because the rate of rejection for unsound welds was over three times that expected, a policy of close inspection of capsules before loading was established. The intent of inspection was to reject unsound capsules before they were loaded and assembled.

Table II lists capsule numbers versus the weight of contained fuel and the results of rod evaluation for plutonium oxide rods.

Table II
RESULTS OF PLUTONIUM OXIDE ROD ASSEMBLY

Capsule No.	Weight (U-Pu)O ₂ , g	Evaluation	Capsule No.	Weight (U-Pu)O ₂ , g	Evaluation
17	132.29	Reject A	25	132.14	Reject C
18	132.10	Acceptable	26	132.05	Acceptable
19	131.99	Reject B	27	132.03	Acceptable
20	131.75	Reject C*	28	132.06	Acceptable
21	131.38	Reject B	29	132.09	Acceptable
22	131.77	Acceptable	30	132.15	Not Tested
23	131.70	Reject C	31	131.43	Acceptable
24	131.78	Acceptable	32	131.61	Reject C

*Note: Reject C denotes a rod that was rejected for some deficiency developed on loading, such as excessive contamination or unacceptable condition found in radiography.

The average weight of pellets in a capsule was 131.90 g and the standard deviation for a twelve-rod population was 0.26 g or 0.20% of the average fuel charge. Although the control of weight of fuel in the rod was acceptable, it was not as consistent as for the mixed oxide loading.

The inspection of capsules before loading resulted in the rejection of five capsules: two for leaks determined by helium mass spectrometer, and three for pits in the tube wall that were deep enough to cause concern. Sixteen capsules, numbered 17 through 32, which passed the capsule inspection were charged to the process. Two of the sixteen were contaminated to excessive levels during the insertion of PuO₂ pellets. A protective coating of Na₂SiO₃ was applied to all pellets before loading subsequent capsules; however, the two contaminated capsules were irrecoverable.

Acetate loading funnels were used in the loading operation. The funnels become very stiff and brittle when exposed for long times to the very dry (about 40 ppm water vapor) helium atmosphere of the glovebox. The loss of plasticity accounted for the rejection of two Doppler rods when the loading funnels tore and entered the capsule with the fuel pellet. In one case the failure of the funnel was noted when the PVC pouch was removed from the capsule before welding. Presence of the missing funnel portion in that Doppler rod was confirmed by radiography.

If the four rods rejected for contamination and the presence of a foreign object are discounted (conditions that are controllable by routine process changes), 14.3% of the PuO_2 Doppler rods were rejected because of failure of a capsule component. Only one rod (8.3%) was rejected for unsound welds. We believe that the decreased rejection rate for unsound welds is entirely due to the preliminary inspection of capsule hardware.

RECOMMENDATIONS

The fabrication procedure for the manufacture of pellets was, in general, highly successful for a small number of batches. If, however, more than a few batches were required, mechanization of the compacting and pellet-forming steps would be advisable.

In order to avoid contamination of capsule hardware, application of a coating to the plutonium oxide pellets is recommended. An investigation into the consequences of loading coated fuel pellets directly into capsules should be made. One of the fuel rods containing coated PuO_2 pellets was successfully loaded without the use of a funnel. When and if funnels are found necessary, they should be made of polyethylene or some other more elastic material than acetate.

ACKNOWLEDGMENTS

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APPENDIX

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.35	12.83	12.65	12.65	12.65	12.65	12.70	12.67	12.64	12.65	12.71	12.61	12.60	9.38
Dia, mm		12.47	12.48	12.50	12.48	12.47	12.50	12.50	12.50	12.48	12.50	12.47	12.50	
Weight, g		11.09	10.92	10.91	10.92	10.79	10.99	10.94	10.93	10.92	10.93	10.82	10.88	
Pellet No.		B 1	H 1	H 2	H 3	I 1	I 2	I 3	J 1	J 2	J 3	M 1	S 3	

Capsule Number 1Pellet Material UO₂-PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.75	12.71	12.71	12.69	12.74	12.65	12.69	12.67	12.69	12.65	12.70	12.61	9.50
Dia, mm		12.48	12.50	12.48	12.48	12.47	12.48	12.48	12.48	12.50	12.47	12.48	12.48	
Weight, g		11.04	10.89	10.93	10.93	10.94	10.86	10.89	10.91	10.92	10.90	10.93	10.85	
Pellet No.		T 3	U 1	W 3	Z 1	Z 3	d 1	d 2	d 3	e 1	e 2	e 3	i 2	

Capsule Number 2

Pellet Material UO₂-PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.65	12.65	12.64	12.62	12.62	12.62	12.70	12.60	12.65	12.61	12.67	12.64	9.53
Dia, mm		12.50	12.50	12.50	12.48	12.51	12.48	12.50	12.50	12.50	12.48	12.50	12.50	
Weight, g		10.87	10.92	10.84	10.90	10.84	10.92	10.87	10.79	10.96	10.91	10.85	10.94	
Pellet No.		N 4	P 6	R 5	Q 5	P 5	R 4	Q 6	C 9	B 8	D 4	R 6	F 7	

Capsule Number 3Pellet Material UO₂-PuO₂

*0.76 mm shim added

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.50	12.73	12.70	12.70	12.69	12.69	12.66	12.66	12.62	12.69	12.65	12.75	12.75	9.53
Dia, mm		12.50	12.48	12.50	12.50	12.48	12.50	12.47	12.47	12.50	12.48	12.48	12.50	
Weight, g		10.95	10.87	10.88	10.92	10.91	10.88	10.95	10.91	10.90	10.84	10.92	10.94	
Pellet No.		F 2	M 3	P 1	X 2	X 3	b 1	b 2	c 1	c 2	c 3	f 3	g 3	

Capsule Number 4

Pellet Material UO₂-PuO₂

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.65	12.65	12.64	12.62	12.62	12.62	12.70	12.60	12.65	12.61	12.67	12.64	9.53
Dia, mm		12.48	12.50	12.50	12.50	12.48	12.50	12.50	12.50	12.48	12.51	12.48	12.50	
Weight, g		10.93	10.87	10.88	10.82	10.94	10.92	10.99	10.97	10.97	10.87	10.94	10.90	
Pellet No.		A 7	F 9	A 8	B 9	F 8	H 8	D 7	L 8	G 7	B 8	S 6	G 9	

Capsule Number 5Pellet Material UO₂-PuO₂

*0.51 mm shim added

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.65	12.65	12.64	12.62	12.65	12.70	12.70	12.59	12.62	12.59	12.67	12.56	9.53
Dia, mm		12.51	12.50	12.48	12.50	12.50	12.50	12.50	12.48	12.50	12.47	12.50	12.48	
Weight, g		10.96	10.88	10.95	10.97	10.93	10.88	10.97	10.81	10.92	10.81	10.93	10.82	
Pellet No.		K 9	J 9	N 7	J 8	M 9	I 8	A 9	O 6	D 6	S 5	H 7	E 8	

Capsule Number 6

Pellet Material UO₂-PuO₂

*0.64 mm shim added

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.75	12.70	12.61	12.65	12.66	12.69	12.66	12.69	12.64	12.76	12.75	12.64	9.50
Dia, mm		12.48	12.50	12.47	12.48	12.48	12.51	12.48	12.50	12.50	12.48	12.48	12.47	
Weight, g		10.92	10.94	10.88	10.81	10.92	10.95	10.89	10.91	10.94	10.93	10.90	10.95	
Pellet No.		Y 3	a 1	a 2	f 1	f 2	g 2	h 1	h 2	i 3	E 6	G 4	j 3	

Capsule Number 7Pellet Material UO₂-PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.70	12.60	12.62	12.62	12.62	12.67	12.62	12.61	12.66	12.57	12.69	12.71	9.53
Dia, mm		12.50	12.50	12.48	12.48	12.48	12.50	12.48	12.50	12.48	12.50	12.48	12.50	
Weight, g		10.90	10.91	10.97	10.88	10.87	10.99	10.91	10.85	10.91	10.95	10.95	10.96	
Pellet No.		C 7	O 9	P 8	I 5	E 7	E 9	P 7	L 7	N 6	J 7	S 4	M 4	

Capsule Number 8

Pellet Material UO₂-PuO₂

*0.76 mm shim added

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.60	12.64	12.65	12.56	12.67	12.67	12.69	12.69	12.67	12.67	12.66	12.73	9.50
Dia, mm		12.47	12.50	12.50	12.48	12.48	12.48	12.50	12.50	12.51	12.48	12.50	12.50	
Weight, g		10.87	10.89	10.97	10.96	10.86	10.91	10.89	10.85	10.89	10.94	10.92	10.95	
Pellet No.		j 1	B 4	C 6	D 5	E 4	F 4	F 5	F 6	H 4	H 5	G 5	G 6	

Capsule Number 9Pellet Material UO₂-PuO₂

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.50	12.59	12.78	12.73	12.62	12.67	12.64	12.67	12.65	12.65	12.62	12.67	12.70	9.53
Dia, mm		12.47	12.47	12.47	12.47	12.50	12.48	12.50	12.50	12.48	12.47	12.50	12.47	
Weight, g		10.92	11.01	11.03	10.94	10.91	10.84	10.84	10.94	10.95	10.91	10.90	10.92	
Pellet No.		A 1	A 3	C 1	C 3	E 3	F 1	F 3	G 1	G 2	L 2	N 3	O 1	

Capsule Number 10

Pellet Material UO₂-PuO₂

Conditioned Acceptance

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.64	12.66	12.62	12.66	12.64	12.66	12.71	12.66	12.67	12.62	12.69	12.65	9.53
Dia, mm		12.48	12.48	12.50	12.48	12.50	12.48	12.50	12.47	12.50	12.48	12.48	12.48	
Weight, g		10.87	10.96	10.87	10.93	10.93	10.98	10.96	10.87	10.94	10.91	10.89	10.94	
Pellet No.		j 2	A 5	B 6	H 6	I 4	I 6	J 4	J 5	K 4	K 5	K 6	L 6	

Capsule Number 11Pellet Material UO₂-PuO₂

*0.51 mm shim added

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.50	12.80	12.70	12.67	12.67	12.65	12.67	12.67	12.61	12.65	12.67	12.64	12.62	9.53
Dia, mm		12.47	12.50	12.50	12.50	12.48	12.48	12.50	12.50	12.48	12.47	12.47	12.47	
Weight, g		10.97	10.97	10.91	10.99	10.87	10.91	10.89	10.88	10.96	10.83	10.93	10.95	
Pellet No.		B 3	E 2	N 1	N 2	R 3	S 1	S 2	T 1	T 2	U 2	W 2	Y 2	

Capsule Number 12

Pellet Material UO₂-PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.50	12.73	12.70	12.75	12.66	12.66	12.67	12.67	12.67	12.59	12.67	12.64	12.65	9.53
Dia, mm		12.47	12.47	12.50	12.48	12.47	12.48	12.50	12.48	12.47	12.47	12.47	12.48	
Weight, g		11.03	11.02	10.97	10.88	10.84	10.91	10.97	10.91	10.83	10.90	10.84	10.96	
Pellet No.		C 2	D 2	E 1	O 2	U 3	V 1	V 2	V 3	W 1	Y 1	Z 2	a 3	

Capsule Number 13Pellet Material UO₂-PuO₂

Not Tested

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.50	12.78	12.65	12.67	12.67	12.66	12.70	12.62	12.67	12.67	12.67	12.57	12.64	9.53
Dia, mm		12.47	12.48	12.48	12.48	12.50	12.48	12.47	12.48	12.47	12.50	12.48	12.47	
Weight, g		11.06	10.85	10.92	10.93	10.93	10.98	10.95	10.88	10.93	10.85	10.74	10.91	
Pellet No.		B 2	K 1	K 2	K 3	L 1	L 3	O 3	P 2	Q 2	Q 3	R 1	R 2	

Capsule Number 14

Pellet Material UO₂-PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.65	12.65	12.64	12.62	12.62	12.62	12.70	12.59	12.66	12.61	12.67	12.64	9.53
Dia, mm		12.48	12.50	12.50	12.50	12.48	12.50	12.50	12.48	12.50	12.48	12.50	12.48	
Weight, g		10.90	10.91	10.86	10.96	10.93	10.92	10.98	10.87	10.88	10.80	10.98	10.97	
Pellet No.		H 9	I 9	M 7	L 9	N 8	O 8	K 7	L 5	N 9	Q 4	D 8	G 8	

Capsule Number 15Pellet Material UO₂-PuO₂

*0.76 mm shim added

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.53	12.65	12.61	12.62	12.62	12.62	12.67	12.65	12.64	12.64	12.65	12.70	12.60	9.53
Dia, mm		12.48	12.47	12.50	12.48	12.47	12.48	12.47	12.48	12.48	12.50	12.50	12.48	
Weight, g		10.82	10.88	10.91	10.83	10.83	10.90	10.92	10.84	10.90	10.90	10.94	10.93	
Pellet No.		P 3	A 4	C 4	C 5	E 5	L 4	M 5	O 4	P 4	N 5	O 5	C 8	

Capsule Number 16

Pellet Material UO₂-PuO₂

*0.76 mm shim added

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.67	12.65	12.78	12.79	12.73	12.79	12.75	12.64	12.67	12.70	12.70	12.70	9.58
Dia, mm		12.51	12.50	12.52	12.51	12.50	12.51	12.52	12.50	12.51	12.50	12.51	12.50	
Weight, g		10.94	11.03	11.00	11.14	10.95	11.08	11.09	11.01	10.95	11.06	11.03	11.01	
Pellet No.		3 K	1 F	3 R	3 V	2 L	3 U	2 T	2 F	2 M	1 G	3 H	3 S	

Capsule Number 17Pellet Material PuO₂

Rejected - Leak

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.66	12.69	12.62	12.71	12.74	12.69	12.75	12.74	12.69	12.74	12.71	12.70	9.58
Dia, mm		12.51	12.50	12.50	12.50	12.52	12.51	12.50	12.50	12.51	12.50	12.51	12.50	
Weight, g		11.00	11.04	10.86	11.03	11.07	11.02	11.06	11.05	10.99	10.99	10.99	10.99	
Pellet No.		1 T	3 F	3 g	2 g	1 b	3 e	1 a	3 E	2 G	1 C	2 E	1 A	

Capsule Number 18

Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.60	12.71	12.75	12.71	12.74	12.76	12.75	12.74	12.67	12.70	12.70	12.73	9.58
Dia, mm		12.51	12.50	12.50	12.50	12.50	12.50	12.51	12.50	12.50	12.50	12.50	12.50	
Weight, g		10.87	10.98	11.09	11.01	10.91	11.03	11.10	11.03	10.82	11.13	11.02	11.00	
Pellet No.		3 M	3 b	3 T	1 W	2 Q	1 N	3 L	1 L	2 H	2 V	3 Y	2 C	

Capsule Number 19Pellet Material PuO₂

Component Failure

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.69	12.66	12.65	12.75	12.71	12.74	12.73	12.69	12.70	12.71	12.69	12.71	9.58
Dia, mm		12.51	12.51	12.52	12.51	12.51	12.51	12.50	12.51	12.51	12.51	12.50	12.51	
Weight, g		11.01	11.02	11.00	10.99	11.02	10.98	11.00	10.87	11.06	10.79	11.00	11.01	
Pellet No.		4 g	6 U	6 h	4 Q	4 f	4 W	5 X	5 B	6 e	6 Q	6 M	6 b	

Capsule Number 20

Pellet Material PuO₂

Note: Piece of plastic funnel wedged in pellet stack!!
Rejected

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.76	12.73	12.64	12.75	12.50	12.74	12.55	12.74	12.75	12.75	12.59	12.70	9.58
Dia, mm		12.55	12.51	12.52	12.51	12.51	12.51	12.52	12.51	12.52	12.50	12.51	12.52	
Weight, g		11.11	10.99	11.00	11.05	10.72	11.06	10.84	10.89	11.06	10.77	10.82	11.06	
Pellet No.		5 H	4 c	4 h	6 R	4 i	4 Z	5 V	6 C	6 E	4 B	6 A	6 Y	

Capsule Number 21Pellet Material PuO₂

Component Failure

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.73	12.74	12.71	12.73	12.62	12.69	12.73	12.69	12.70	12.70	12.70	12.70	9.58
Dia, mm		12.51	12.51	12.52	12.53	12.55	12.51	12.51	12.53	12.51	12.51	12.52	12.51	
Weight, g		11.01	10.87	11.01	10.88	10.86	10.97	10.85	11.07	11.05	11.03	11.11	11.04	
Pellet No.		4 S	6 c	4 T	5 d	6 i	4 R	5 D	5 C	6 W	6 A	5 I	4 V	

Capsule Number 22

Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm		12.71	12.74	12.73	12.75	12.69	12.71	12.70	12.65	12.70	12.67	12.70	12.69	
Dia, mm		12.51	12.53	12.52	12.50	12.50	12.51	12.52	12.52	12.50	12.53	12.52	12.51	
Weight, g		11.01	10.98	10.75	11.07	11.00	11.06	10.86	11.07	10.79	11.11	10.90	11.10	
Pellet No.		6 b	6 T	5 P	5 J	6 M	6 J	5 a	5 N	4 I	4 D	6 H	5 e	

Capsule Number 23Pellet Material PuO₂

Rejected

Note: Not welded closed due to excessive contamination of capsule.

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.69	12.67	12.65	12.75	12.71	12.74	12.73	12.69	12.71	12.70	12.70	12.70	9.58
Dia, mm		12.51	12.51	12.51	12.55	12.52	12.52	12.51	12.50	12.53	12.51	12.56	12.51	
Weight, g		10.97	11.01	10.95	11.06	10.95	11.05	10.86	10.90	10.97	11.03	11.00	11.04	
Pellet No.		6 j	4 L	5 i	5 Q	6 d	6 P	5 A	5 F	5 R	5 g	5 j	5 f	

Capsule Number 24

Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.66	12.69	12.62	12.71	12.74	12.76	12.75	12.74	12.69	12.74	12.71	12.70	9.58
Dia, mm		12.51	12.50	12.50	12.50	12.52	12.51	12.50	12.50	12.51	12.50	12.51	12.50	
Weight, g		11.00	11.04	10.86	11.03	11.07	11.08	11.06	11.05	10.99	10.99	10.99	10.98	
Pellet No.		1 T	3 F	3 g	2 g	1 b	3 e	1 a	3 E	2 G	1 C	2 E	1 A	

Capsule Number 25Pellet Material PuO₂

Rejected

Note: Not welded closed due to excessive contamination of capsule.

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.65	12.65	12.78	12.70	12.74	12.76	12.70	12.74	12.67	12.75	12.70	12.70	9.58
Dia, mm		12.51	12.50	12.51	12.50	12.50	12.51	12.50	12.51	12.50	12.50	12.51	12.50	
Weight, g		10.88	11.04	11.15	10.96	11.02	11.01	11.11	11.08	10.98	10.92	11.05	10.85	
Pellet No.		2 b	1 Q	2 S	3 B	1 U	2 R	3 G	2 W	3 C	1 S	2 Z	2 a	

Capsule Number 26

Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.70	12.66	12.70	12.73	12.74	12.76	12.75	12.74	12.67	12.73	12.70	12.70	9.58
Dia, mm		12.50	12.50	12.50	12.51	12.50	12.50	12.50	12.51	12.50	12.51	12.50	12.50	
Weight, g		10.86	11.00	10.98	11.00	11.06	11.00	11.10	11.01	11.03	11.04	11.01	10.94	
Pellet No.		3 Z	3 X	2 X	1 d	1 f	1 J	1 e	2 e	1 g	3 c	1 B	3 A	

Capsule Number 27Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.62	12.69	12.75	12.71	12.74	12.76	12.75	12.73	12.67	12.73	12.74	12.70	9.58
Dia, mm		12.50	12.51	12.51	12.50	12.50	12.50	12.51	12.51	12.51	12.50	12.51	12.50	
Weight, g		10.79	11.02	11.08	10.97	11.04	10.99	11.04	11.07	10.95	11.05	11.01	11.04	
Pellet No.		1 R	3 a	1 H	2 I	3 O	2 O	2 K	1 c	3 W	2 P	3 N	1 M	

Capsule Number 28

Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.60	12.69	12.78	12.71	12.74	12.76	12.75	12.74	12.67	12.73	12.70	12.70	9.58
Dia, mm		12.50	12.51	12.51	12.51	12.50	12.50	12.51	12.50	12.50	12.51	12.50	12.50	
Weight, g		10.86	11.07	11.13	11.02	10.92	11.09	11.02	11.05	11.02	10.97	10.98	10.96	
Pellet No.		2 A	2 Y	3 d	2 h	1 h	3 I	1 P	3 P	2 J	2 f	1 X	1 Y	

Capsule Number 29Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.67	12.74	12.75	12.71	12.69	12.70	12.75	12.74	12.76	12.70	12.73	12.70	9.58
Dia, mm		12.50	12.50	12.50	12.50	12.50	12.50	12.51	12.50	12.51	12.51	12.50	12.50	
Weight, g		11.07	10.96	11.06	10.90	10.95	10.99	11.07	11.07	11.03	11.01	11.02	11.03	
Pellet No.		1 K	1 O	1 I	2 N	3 J	2 D	2 d	2 c	3 f	1 D	1 V	1 Z	

Capsule Number 30

Pellet Material PuO₂

Not Tested

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.74	12.67	12.62	12.71	12.71	12.74	12.73	12.69	12.71	12.75	12.70	12.70	9.58
Dia, mm		12.51	12.50	12.51	12.51	12.51	12.51	12.51	12.50	12.51	12.52	12.51	12.51	
Weight, g		11.02	10.97	10.62	11.06	11.04	10.78	11.05	11.12	10.82	10.83	11.08	11.04	
Pellet No.		6 a	6 O	5 h	6 J	6 S	6 B	6 X	4 E	4 G	4 H	4 e	6 D	

Capsule Number 31Pellet Material PuO₂

Accepted

LOADING DATA FOR OXIDE PELLETS IN DOPPLER CAPSULES

PELLET POSITION

	B	1	2	3	4	5	6	7	8	9	10	11	12	T
Length, mm	9.58	12.67	12.66	12.65	12.74	12.71	12.74	12.73	12.69	12.75	12.70	12.70	12.73	9.58
Dia, mm		12.51	12.50	12.50	12.51	12.50	12.51	12.51	12.50	12.51	12.52	12.50	12.51	
Weight, g		11.07	11.06	11.05	10.90	10.77	10.96	11.04	11.07	11.11	10.99	10.79	10.89	
Pellet No.		6 Z	4 U	4 j	5 M	6 V	5 W	4 P	6 N	4 F	5 S	4 I	4 O	

Capsule Number 32

Pellet Material PuO₂

Rejected

Note: Piece of plastic funnel wedged in pellet stack.