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SAXTON PLUTONIUM PROJECT
QUARTERLY PROGRESS REPORT FOR THE PERIOD
ENDING SEPT. 30, 1973

MASTER

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Prepared for the Chicago Operations Office
U. S. Atomic Energy Commission
Under AEC Contract No. AT(11-1)-3044
Previously Contract No. AT(30-1)-3385

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 SCOPE

This quarterly report covers work completed on the Saxton Plutonium Project during the period July through September 1973.

1.2 OBJECTIVES

The overall objective of the Saxton Plutonium Project is to develop information concerning the utilization of plutonium enriched fuels in pressurized water reactor systems. The program includes design, fabrication, operation, and post-irradiation examination of a partial plutonium core. The in-pile performance of the fuel will be evaluated and compared with analytical predictions.

1.3 PROJECT ADMINISTRATION

The quarterly report for the period ending June 30, 1973 was issued.

1.4 SUMMARY OF PROGRESS DURING THE PERIOD

Remaining mass spectrometric analyses for isotopic compositions and burnup determinations of Core III end-of-life fuel were completed. All of the mass spectrometric data were reduced, evaluated, and compared with predictions.

SECTION 2

ISOTOPIC COMPOSITIONS AND BURNUP ANALYSES OF CORE III FUEL

(W. R. Smalley, E. Iwinski, T. E. Caye,
R. L. Stover, H. H. Crain, J. A. Corbett)

2.1 MASS SPECTROMETRIC ANALYSES

Mass spectrometric data used for determining burnups were obtained for each of the following:

- a) full cross-section samples from near the peak burnup position of each of the eight rods in the core III end-of-life sampling plan, and
- b) ten radial drill samples, adjacent to the full cross-section sample, from one of the highest burnup rods (IM).

The full cross-section isotopic data were reported previously.^[1] However, because of inconsistencies revealed during reduction of the data on samples from rods BE and JX, an additional aliquot of each was analyzed by mass spectrometric methods. These corrected values are presented in Table 2-1, along with the previously reported isotopic data for the other six samples. The isotopic data obtained on the radial drill samples from rod IM (16.3 inches from the bottom) are summarized in Table 2-2. Sample 12-5 was apparently contaminated with enriched uranium from an unknown source. A reanalysis of the aliquot gave similar results.

2.2 BURNUP ANALYSES

The heavy element isotopic and Nd-148 data were reduced with the REBUF code^[2,3] to obtain burnup for both the full cross-section samples and the radial drill samples. Unit cell calculations (based on a modified LEOPARD code and similar to calculations used for Saxton Core II fuel analyses) and core-wide calculations (based on the PDQ code^[4]) were made to predict burnups.

Table 2-1
Isotopic Compositions of Saxton Core III
End-of-Life Burnup Samples⁽¹⁾

Fuel Rods From Which Burnup Samples Were Taken	Sample Midpoint Location, inches From Bottom of Rod ⁽²⁾	Isotopic Compositions, a/o											Date of Analysis
		U-234	U-235	U-236	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Pu-239/U-238 (10 ⁻²)	Nd-148/U-238 (10 ⁻⁴)	
FI	16.5	0.005	0.403	0.065	99.527	0.712	52.125	34.274	10.117	2.772	2.319	7.286	1/3/73
LS	16.5	0.005	0.415	0.063	99.517	0.737	50.388	35.471	10.379	3.028	2.182	7.795	1/2/73
GM	16.5	0.005	0.428	0.061	99.506	0.656	53.761	33.761	9.885	2.534	2.393	7.403	1/5/73
BE	16.5	0.005	0.411	0.060	99.524	0.669	50.660	36.259	9.704	2.708	2.201	7.543	10/25/73 ⁽³⁾
BX	16.5	0.005	0.399	0.065	99.531	0.703	48.352	37.506	10.327	3.112	2.657	7.868	4/16/73
JX	16.5	0.005	0.401	0.064	99.531	0.734	49.237	36.878	10.215	2.936	2.088	7.856	10/26/73 ⁽³⁾⁽⁴⁾
IM	17.0	0.005	0.360	0.073	99.562	1.020	43.847	38.898	11.979	4.256	1.157	8.973	5/14/73
PF	16.5	0.005	0.357	0.071	99.567	0.984	44.492	38.477	11.936	4.111	1.852	9.281	5/15/73

(1) End of irradiation for these rods was May 1, 1972.

(2) Burnup samples had nominal lengths of 0.5 inch.

(3) Date of reanalysis

(4) Plutonium isotopic abundances determined on 7-11-73.

Table 2-2

Isotopic Compositions of Saxton Core III End-Of-Life Radial
Drill Burnup Samples from Rod IM⁽¹⁾

Sample Identity	Effective O.D. of Annulus, In.	Isotopic Compositions, Atom Percent									Pu^{239}/U^{238} (10^{-2})	Nd^{148}/U^{238} (10^{-4})	Date of Analysis
		U-234	U-235	U-236	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242			
IM12-1	.104	.004	.426	.070	99.500	.709	47.561	39.412	9.536	2.762	2.028	7.723	5/03/73
IM12-2	.164	.005	.399	.069	99.527	.755	46.657	39.934	9.758	2.896	1.919	7.951	5/29/73
IM12-3	.193	.005	.410	.071	99.514	.813	45.792	40.219	10.046	3.130	1.858	7.939	7/16/73
IM12-4	.240	.004	.387	.071	99.538	.912	44.331	40.698	10.630	3.429	1.757	8.198	7/17/73
IM12-5	.243	.008	1.132	.110	98.750	.805	46.745	39.563	9.870	3.017	1.765	8.478	7/26/73
IM12-6	.275	.005	.356	.072	99.565	1.023	42.517	40.540	11.813	4.107	1.646	9.286	7/27/73
IM12-7	.296	.005	.342	.074	99.579	1.167	41.357	39.489	13.158	4.829	1.603	9.172	7/27/73
IM12-8	.311	.005	.341	.075	99.579	1.313	41.252	37.780	14.122	5.493	1.551	9.564	7/30/73
IM12-9	.331	.005	.330	.076	99.589	1.526	42.272	33.568	16.000	6.633	1.649	10.407	8/06/73
IM12-10	.337	.005	.332	.079	99.584	1.582	46.993	27.461	16.788	7.175	2.255	12.365	8/06/73

(1) Samples were from 15.75 - 16.75" from bottom end of rod

2.2.1 Full Cross Section Samples

The measured burnups, as determined by both heavy element and Nd-148 methods, for the full cross-section samples are given in Table 2-3. In addition, the predicted burnups are presented and compared with the Nd-148 measured values. Generally, there was good agreement between the heavy element and Nd-148 measured burnups. With the exception of one sample (from rod IM), the heavy element and Nd-148 results were within $\sim 4\%$ of one another. This level of agreement is consistent with previous burnup comparisons of plutonium fuel from Saxton.^[3,5] Furthermore, the measured Nd-148 burnups agreed well with the predicted values; on the average the measured values were about one percent below the predicted values. The maximum difference was a 3.6% overprediction for the sample from rod BE. Again, the agreement is about the same as that previously experienced.^[3]

The full cross section sample from rod IM showed a 41 percent difference between heavy element and Nd burnups ($\sim 30,000$ MWD/MTM for heavy element and 50,900 MWD/MTM for Nd-148). A review of the isotopic composition, atom ratios and reduced data indicates an inconsistency in the value for Pu-239/U-238. As shown in the last column of Table 2-3, there was excellent agreement between the Nd-148 measured burnup and its predicted value. Moreover, the Nd burnup agreed reasonably well with the measured volume average burnup of adjacent radial drill samples (see Table 2-4). In view of the above, it is concluded that the burnup inferred from the Nd-148 measurement is the valid one.

2.2.2 Radial Drill Samples from Rod IM

The measured burnups, as determined by both heavy element and Nd-148 methods, for the radial drill samples from rod IM are given in Table 2-4. The agreement between burnups determined by heavy element and Nd-148 methods for any one sample was within about 7%, which is generally consistent with results obtained previously on radial drill samples.^[3,5]

The predicted burnups for the entire cross-section from which the radial drill specimens were obtained was 50,100 MWD/MTM. This value was within 3 percent of the Nd-148 value of the composite or volume averaged burnup of

Table 2-3

Burnup Results of Full Cross Section Samples from
Saxton Core III End-Of-Life Fuel Rods

Fuel Rod No.	Sample Midpoint Location, In.(1)	Measured Burnups, MWD/MTM		% Difference(3)	Predicted Burnup MWD/MTM	% Difference Predicted vs. Measured(4)
		H.E.(2) Method	Nd-148 Method			
FI	16.5	41,650	39,980	+ 4.2	40,760	+ 1.9
LS	16.3	42,680	42,850	- 0.4	41,630	- 2.9
GM	16.5	39,660	40,740	- 2.6	41,360	+ 1.5
IM	17.0	29,970	50,860	-41.1	50,510	- 0.7
PF	16.5	49,870	50,950	- 2.1	51,010	+ 0.1
BE	16.5	41,680	41,490	+ 0.5	43,000	+ 3.6
BK	16.3	43,880	43,260	+ 1.4	44,510	+ 2.9
JX	16.8	42,870	43,180	- 0.7	43,960	+ 1.8

(1) Distance from bottom end of rod

(2) Heavy Element

(3) $\frac{\text{Measured (by H.E.)} - \text{Measured (by Nd)}}{\text{Measured (by Nd)}}$

(4) $\frac{\text{Predicted-Measured (by Nd)}}{\text{Measured (by Nd)}} \times 100$

Table 2-4

Burnup Results on Radial Drill Sections
from Saxton Core III End-Of-Life Fuel Rod IM(1)

Sample Identity	Effective O.D. of Annulus, In.	Measured Burnups, MWD/MTM		% Difference(3)
		H.E. Method(2)	Nd-148 Method	
IM12-1	0.104	42,790	42,520	+ 0.6
IM12-2	0.164	42,550	43,880	- 3.0
IM12-3	0.193	43,350	43,770	- 1.0
IM12-4	0.240	44,580	45,210	- 1.4
IM12-5	0.243	(4)	(4)	--
IM12-6	0.275	47,490	51,250	- 7.3
IM12-7	0.296	51,190	50,340	+ 1.7
IM12-8	0.311	51,920	52,520	- 1.2
IM12-9	0.331	57,800	56,790	+ 1.8
IM12-10	0.337	70,210	66,410	+ 5.7
IM12 Composite - (Volume Averaged)		48,100	48,700	- 1.2

(1) Axial position was 15.75 to 16.75 inches from bottom of rod

(2) Heavy Element

(3)
$$\frac{\text{Measured (by H.E.)} - \text{Measured (by Nd)}}{\text{Measured (by Nd)}}$$

(4) Not possible to compute burnups due to anomalous isotopic data;
suspect sample contamination

the entire cross-section. Because sample 12-5 was apparently contaminated with enriched uranium, a linear average of samples 12-4 and 12-6 was used in its place for calculating the composite burnup.

SECTION 3

COMPARISON OF CALCULATED AND MEASURED ISOTOPIC BUILDUPS AND DEPLETIONS IN FULL CROSS-SECTION SAMPLES

(E. Iwinski, R. L. Stover)

3.1 MAIN CHAIN URANIUM AND PLUTONIUM ISOTOPES

Atom percent abundances for main chain uranium and plutonium isotopes and Pu-239/U-238 atom ratios were measured and reported for each of eight transverse pellet sections removed at Core III end-of-life (EOL) (see Table 2.1) and seven sections removed at middle-of-life (MOL).^[5] The results are shown with corresponding prediction curves as a function of burnup in Figures 3-1, 3-2, and 3-3 for uranium isotopes, plutonium isotopes, and Pu-239/U-238 atom ratio, respectively. Samples LS, BK, IM and PF were measured for special isotopes and are specifically identified in Figure 3-3, while the remaining samples plotted are identified only as MOL or EOL samples. The percent differences between predictions and measurements are presented in Table 3-1.

Each atom percent isotopic abundance measurement was decay corrected to MOL (3-21-71) or EOL (5-1-72), respectively, and then plotted against the Nd-148 measured burnup for that pellet (see Section 2.2.1). The prediction curves were obtained from unit cell calculations performed with a modified version of the LEOPARD code and are consistent with the analytical methods described in (3).

Main chain uranium isotopic measurements show good agreement in general when compared with the predictions. The average percent differences between predictions and measurements are within +2 percent except for U-236, which was overpredicted by about 8 percent. For the plutonium isotopes, the average percent differences between predictions and measurements are within +9 percent except for Pu-238, which is consistently underpredicted by approximately 50 percent. The Pu-238/U-238 atom ratios in Figure 3-3 are overpredicted by an average of +7.7 percent. These results are consistent with those previously reported.^[3]

Figure 3-1. Calculated and Measured Uranium Isotopic Abundance versus Burnup in Saxon Core III Mixed Oxide Fuel

Figure 3-2. Calculated and Measured Plutonium Isotopic Abundance versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-3. Calculated and Measured Pu-239/U-238 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Table 3-1

Saxton Core III Fuel Analyses Results - Comparison of
Prediction and Measurement for Uranium and Plutonium Isotopes

<u>Isotope</u>	<u>Average⁽¹⁾ of $\left(\frac{\text{Pred.}-\text{Meas.}}{\text{Meas.}} \times 100\right), \%$</u>	<u>Range⁽¹⁾ of Data Averaged, %</u>
U-234	+ 0.1	- 9.4 to +11.2
U-235	- 1.4	- 6.4 to + 5.7
U-236	+ 8.2	- 0.5 to +13.2
U-238	0.0	0.0
Pu-238	-52.3	-62.4 to -43.4
Pu-239	+ 4.0	- 1.85 to + 7.5
Pu-240	-8.4	-15.0 to - 3.1
Pu-241	+ 6.0	+ 0.8 to + 9.8
Pu-242	+ 3.8	- 8.8 to +17.4
<u>Atom Ratio</u>		
Pu-239/U-238	+ 7.7	-14.8 to +46.1

(1) Average and range includes data from 15 rod samples

3.2 SPECIAL ISOTOPE OF Pu, Np, Am, Cm

Special isotopic analyses were performed on four selected mixed-oxide fuel rods, LS, BK, PF, and IM, which were removed from Core III at EOL. Pu-236, Pu-238, Am-241, Am-243, Cm-242, and Cm-244 were measured by alpha spectrometry as atom ratios relative to Pu-239, and Np-237 was measured by radiochemical analysis as a mass ratio relative to uranium. These measured data were reported previously.^[1]

The measured atom ratios^[1] were decay corrected to May 1, 1972 (EOL) then plotted with corresponding prediction curves as a function of Nd-148 burnup in the attached figures. The prediction curves were generated from unit cell calculations as described in Section 2.2.1.

The atom ratio Np-237/U-238 is compared in Figure 3-4 with the prediction curve. Pu-236, Pu-238, Am-241, Am-243, Cm-242 and Cm-244 atom ratios relative to Pu-239 are shown with corresponding prediction curves in Figures 3-5 through 3-10.

Discontinuities in the predicted curves for Np-237, Pu-236, Pu-238, Am-241, and Cm-244 reflect the effects of long shutdown periods in Saxton Core II through Core III. Reactor power histories for Cores II and III are given in reference 3 and Table 3-2, respectively. Thus, individual plots were provided for each data point representing different power history of each rod. Am-243 and Cm-244 are not sensitive to power history, and thus, the data points are compared to the same prediction line.

For the special isotope analyses at EOL, the Pu-236/Pu-239 atom ratio was underpredicted by 4.7 percent with all samples falling within the uncertainties of the measurements. Discrepancies were observed for the remaining isotopes. Calculations underpredicted Np-237, Pu-238, Am-241, and Cm-242 by an average of 12.0, 56.8, 14.7, and 6.6 percent, respectively. Am-243 and Cm-244 were overpredicted by an average of 78.3 and 12.2 percent, respectively. Table 3-3 gives ranges for these averages.

In general, the prediction versus measurement comparison for all special isotopes is better for rods LS and BK with approximately 43,000 MWD/MTM burnup than for PF and IM with approximately 51,000 MWD/MTM burnup. The

Figure 3-4. Calculated and Measured Np-237/U-238 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-5. Calculated and Measured Pu-236/Pu-239 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-6. Calculated and Measured Pu-238/Pu-239 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-7. Calculated and Measured Am-241/Pu-239 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-8. Calculated and Measured Am-243/Pu-239 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-9. Calculated and Measured Cm-242/Pu-239 Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Figure 3-10. Calculated and Measured $\text{Cm-244}/\text{Pu-239}$ Atom Ratio versus Burnup in SAXTON Core III Mixed Oxide Fuel

Table 3-2
Saxton Core III
Reactor Power History

Time Interval	Number of Days	MWT
12/12/69 to 1/20/70	40	16.3
1/21/70 to 2/10/70	21	0
2/11/70 to 2/26/70	15	18.3
2/27/70 to 3/01/70	3	0
3/02/70 to 3/09/70	7	19.7
3/10/70 to 4/08/70	29	0
4/09/70 to 4/17/70	8	21.8
4/18/70 to 4/21/70	3	0
4/22/70 to 5/14/70	22	17.9
5/15/70 to 8/23/70	101	0
8/24/70 to 9/07/70	14	21.3
9/08/70 to 9/09/70	1	0
9/10/70 to 9/18/70	8	16.9
9/19/70 to 10/08/70	20	0
10/09/70 to 11/07/70	29	18.6
11/08/70 to 11/15/70	7	0
11/16/70 to 11/23/70	7	16.5
11/24/70 to 12/20/70	26	0
12/21/70 to 1/28/71	38	19.1
1/21/71 to 1/31/71	3	0
2/01/71 to 2/05/71	4	16.0
2/06/71 to 3/10/71	33	0
3/11/71 to 3/12/71	1	13.5
11/19/71 to 11/21/71	3	8.9
11/22/71 to 11/30/71	9	19.4
12/01/71 to 12/06/71	6	21.8
12/07/71 to 12/09/71	3	0
12/10/71 to 12/20/71	11	22.3
12/21/71 to 12/25/71	5	23.0
12/26/71 to 12/27/71	2	0
12/28/71 to 1/14/72	18	24.0
1/15/72 to 2/01/72	18	0
2/02/72 to 2/11/72	10	23.2
2/12/72 to 2/29/72	18	0
3/01/72 to 3/15/72	15	14.3
3/16/72 to 4/05/72	21	16.1
4/06/72 to 4/12/72	7	15.3
4/13/72 to 5/01/72	19	14.5

Table 3-3

Saxton Core III Fuel Analyses Results - Comparison of
Prediction and Measurement for Special Isotopes

<u>Isotope</u>	Average ⁽¹⁾ of $\left(\frac{\text{Pred.} - \text{Meas.}}{\text{Meas.}} \times 100 \right), \%$	Range ⁽¹⁾ of <u>Data Averaged, %</u>
Pu-236	- 4.7	-17.6 to + 11.7
Pu-238	-56.8	-65.9 to - 44.0
Np-237	-12.0	-31.1 to + 10.5
Am-241	-14.7	-20.7 to - 5.0
Am-243	+78.3	+43.6 to +119.4
Cm-242	- 6.6	-16.7 to + 16.7
Cm-244	+12.2	- 6.1 to + 22.6

(1) Average and range include data from 4 samples.

results of the special isotope analyses at EOL follow trends established in the Core II fuel performance evaluation^[3], except for Am-243 and Cm-244, which are overpredicted for Core III as compared to the closer agreement found in the Core II evaluation.^[3]

SECTION 4

COMPARISON OF CALCULATED AND MEASURED ISOTOPIC BUILDUPS AND DEPLETIONS IN RADIAL DRILL SAMPLES

(C. S. Rim, G. W. Hopkins)

Radial drill data from Saxton 6.6 w/o $\text{PuO}_2\text{-UO}_2$ fuel rods were analyzed using the LASER code^[6] in order to validate the LASER predictions on the variation of radial power distribution and fuel isotopics with burnup. Data on uranium and plutonium isotopic abundances, Pu-239/U-238 atom ratios, and burnups obtained from 10 radial drill samples from Saxton Core III end-of-life rod IM are presented in Tables 2-2 and 2-4. These samples were taken at an axial location approximately 16.3 inches from the bottom of the rod. Similar measurements were previously obtained for a Saxton Core III middle-of-life mixed-oxide fuel sample from rod MQ.^[5]

In addition to the data obtained from Core III fuel samples, similar measurements were also taken from Core II mixed-oxide fuel rod RI.^[3] For these samples, the Nd-148 measurements resulted in radial volume average burnups of 48,700, 36,670, and 20,450 MWD/MTM for rods IM, MQ and RI, respectively.

The radial isotopic and burnup distribution data obtained from these three fuel samples have been compared with predictions made by the LASER code. These LASER calculations included the effect of the difference in fuel rod lattice spacing between Cores II and III (at the end of Saxton Core II operation, the regular tight lattice was converted to the "loose" lattice for the purpose of increasing the core reactivity lifetime). The increased lattice spacing resulted in a softer neutron spectrum during Core III operation. The isotopic composition at the beginning of reactor irradiation as used in the LASER calculations is:

Uranium isotopic abundances:	0.0055 a/o U-234
	0.729 a/o U-235
	99.265 a/o U-238

Plutonium isotopic abundances:	0.016 a/o Pu-238
	90.47 a/o Pu-239
	8.59 a/o Pu-240
	0.88 a/o Pu-241
	0.044 a/o Pu-242

Plutonium/Uranium mass ratio:	0.0706
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The above values were obtained from mass spectrometric measurements and appropriate corrections have been made to account for the effect of Pu-241 decay (half life of 13 years) in obtaining plutonium isotopic abundances at the beginning of reactor irradiation.

Figure 4-1 illustrates the comparison between the LASER predictions and the measured data of radial burnup distributions for the fuel samples obtained from rods RI, MQ and IM. LASER calculations were normalized to measured volume average burnups. The LASER predicted radial burnup distributions are in good agreement with measured data at all burnup levels. Since the radial burnup distribution is the time integrated effect of the radial power distribution, the agreement supports the use of LASER predicted radial power distributions.

The data and predictions for Pu-239/initial U-238 atom ratio are shown in Figure 4-2. The measured Pu-239/initial U-238 ratios were obtained by combining measured values of Pu-239/U-238 ratio at discharge and final-to-initial U-238 ratio. The LASER calculations show good agreement with the measurements except near the pellet surface at high burnup. Both data and LASER calculations show an upturn in the radial distribution at the pellet surface indicating the buildup of Pu-239 converted from U-238. The LASER predicted buildup at the surface, though, is not as great as that suggested by the data. This could be due to the radial U-238 capture rate distribution used as an input to the LASER code; the radial U-238 capture rate distribution used in the present analysis of $\text{PuO}_2\text{-UO}_2$ lattice is that obtained from previous Monte Carlo calculations for a UO_2 lattice.^[7]

Figures 4-3, 4-4 and 4-5 show the radial distributions of uranium isotopic abundances. The LASER predictions compare well with the data, especially for the low burnup fuel samples. The measured U-235 and U-238 abundances for the high burnup sample from rod IM display considerable scatter near

Figure 4-1. Calculated and Measured Radial Burnup Distribution in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-2. Calculated and Measured Radial Distribution of Pu-239 Concentration in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-3. Calculated and Measured Radial Distribution of U-235 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-4. Calculated and Measured Radial Distribution of U-236 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-5. Calculated and Measured Radial Distribution of U-238 Abundance in SAXTON Mixed-Oxide Fuel Pellets

the center of the pellet. The LASER code underestimates the U-235 abundance and overestimates the U-238 abundance at the center of this high burnup pellet. Figure 4-6 shows the radial distribution of the final-to-initial U-238 atom ratio. Both predictions and data show an enhanced U-238 depletion at the pellet surface.

Similar comparisons of the radial distributions of the plutonium isotopic abundances are shown in Figures 4-7 through 4-10. Figures 4-7 and 4-8 show excellent agreement between the calculations and experimental data on Pu-239 and Pu-240 abundances. Figure 4-8 illustrates that with increasing burnup both calculations and measurements show lower Pu-240 concentrations at the pellet surface than at the center. The LASER code predicts that at low burnups (up to $\sim 10,000$ MWD/MTM) Pu-240 builds up more at the surface of the pellet than at the center because of the higher Pu-239 capture rates at the surface. With increasing burnup and Pu-240 buildup, though, the spatial self-shielding of the large Pu-240 resonance becomes important and results in more depletion at the surface. The effects of the change in radial Pu-240 distribution with burnup should be considered in the accurate calculation of Doppler coefficients. Figures 4-9 and 4-10 show very good agreement between LASER predictions and data for Pu-241 and Pu-242 radial distributions.

Figure 4-11 shows the radial distribution of total plutonium as a function of burnup. This figure was generated by combining Figure 4-2 and Figure 4-7. Good agreement is shown between measurements and LASER predictions. Figure 4-11 also shows no evidence of plutonium migration up the temperature gradient because the LASER code does not account for this phenomenon and the calculated plutonium distributions agree well with the measured distributions. These rods were irradiated at high power levels; peak power of ~ 10 kw/ft for rod RI, ~ 10 kw/ft for rod MQ and ~ 16 kw/ft for rod IM.

Figures 4-12 and 4-13 show the distributions of U-234 and Pu-238 abundances. The U-234 abundance data from rods RI and MQ are shown in Figure 4-11. Data from rod IM indicated U-234 abundances in the range of 0.004 to 0.005 atom percent. These data show a considerable amount of scatter and exhibit no definite trend with burnup. The LASER code does not calculate the radial

Figure 4-6. Calculated and Measured Radial Distribution of U-238 Concentration in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-7. Calculated and Measured Radial Distribution of Pu-239 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-8. Calculated and Measured Radial Distribution of Pu-240 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-9. Calculated and Measured Radial Distribution of Pu-241 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-10. Calculated and Measured Radial Distribution of Pu-242 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-11. Calculated and Measured Radial Distribution of Plutonium Concentration in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-12. Calculated and Measured Radial Distribution of U-234 Abundance in SAXTON Mixed-Oxide Fuel Pellets

Figure 4-13. Calculated and Measured Radial Distribution of Pu-238 Abundance in SAXTON Mixed-Oxide Fuel Pellets

distribution of U-234 depletion and Pu-238 buildup; only the average concentrations are determined when the higher isotope calculation is made. The resulting LASER average abundances for U-234 and Pu-238 are also shown in Figures 4-12 and 4-13. Figure 4-12 shows that the predicted values generally fall within the range of the scattered data on U-234 abundance. Figure 4-13 shows that the LASER code underpredicts Pu-238 abundance.

In summary, analysis of radial drill data from Saxton mixed $\text{PuO}_2\text{-UO}_2$ rods after burnups of $\sim 20,000$ to $\sim 50,000$ MWD/MTM indicates:

- 1) good agreement between measurements and LASER predictions on radial distributions of burnup (power) and isotopics; and
- 2) no evidence of plutonium migration up the temperature gradient.

SECTION 5

REFERENCES

1. R. C. Goodspeed, "Saxton Plutonium Project Quarterly Progress Report for the Period Ending June 30, 1973," WCAP-3385-36, July 1973.
2. R. J. Nodvik, "Evaluation of Mass Spectrometric and Radiochemical Analyses of Yankee Core I Spent Fuel," WCAP-6068, March 1966.
3. R. J. Nodvik, "Saxton Core II Fuel Performance Evaluation, Part II: Evaluation of Mass Spectrometric and Radiochemical Analysis of Irradiated Saxton Plutonium Fuel," WCAP-3385-56 Part II, July 1970.
4. W. R. Cadwell, "PDQ-07 Reference Manual," WAPD-TM-678, January 1967.
5. T. E. Caye, "Saxton Plutonium Project Quarterly Progress Report for the Period Ending March 31, 1972," WCAP-3385-31, November 1972.
6. C. G. Poncelet, "LASER-A Depletion Program for Lattice Calculations Based on MUFT and Thermos," WCAP-6073, April 1966.
7. C. G. Poncelet, "Burnup Physics of Heterogeneous Reactor Lattices," WCAP-6069, June 1965.