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Saxton Plutonium Program
 Semi-Annual Progress Report
 For the Period Ending
 June 30, 1969

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Prepared for the New York Operations Office
 U. S. Atomic Energy Commission
 Under AEC Contract AT(30-1)-3385

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 SCOPE

This semi-annual report covers work completed during the first half of calendar year 1969.

1.2 OBJECTIVES

The purpose of the Saxton Plutonium Project is to develop information concerning the utilization of plutonium-enriched fuel in pressurized water reactor systems through design, fabrication, and operation of a partial core of PuO_2 - UO_2 in the Saxton reactor. In-pile performance of this fuel will be evaluated and post-irradiation examination of fuel samples will be made. Performance will be analyzed and compared with analytical predictions.

1.3 PROJECT ADMINISTRATION (R. S. Miller, J. B. Roll, W. R. Smalley)

The Semi-Annual Report for the period ending December 31, 1969 was written, reviewed, and issued. Revision No. 7 of the work program was issued.

Because of budget limitations, the complete Core II post-irradiation examination program was reviewed to identify work which could be deferred and/or reduced in scope. As a result, the majority of the destructive examinations were deferred to the second half of 1969, and to be consistent with license requirements and the reactor operating schedule, nuclear operations efforts (both Core II and III) were reduced in scope.

1.4 SUMMARY OF PROGRESS DURING THE PERIOD

Nuclear data from the Saxton Core II overpower and end-of-life experiments were reduced and evaluated. Predictions of fission gas release were made for all 18 fuel rods in the PIE program. A new sampling plan was specified for the removal of burnup, metallographic, clad hydrogen, mechanical test, and flux dosimetry specimens.

Thirteen additional fuel rods were transferred to the WPIF Hot Laboratory, and all non-destructive examinations on these rods and the five transferred earlier were completed. These examinations included visual, dimensional (length and diameter), and gamma scanning. All 18 rods were punctured to determine fission gas release and then sectioned to provide samples for destructive examination. Four burnup samples were dissolved and analyzed for heavy element isotopic content and Nd^{148} . Metallographic examination of all samples in the Overpower Test program and eight samples from high burnup rods was completed. Four ring sections of clad from one of the highest burnup rods were analyzed for hydrogen content, and two sections from the same rod were analyzed for fast flux exposure.

During the period, a decision was made to defer the majority of the destructive examinations until the second half of 1969. The deferred work included essentially all of the burnup analyses (including those on radial drill samples), approximately two thirds of the metallography, eight hydrogen samples, six fast flux dosimetry samples, and all mechanical testing of clad. However, the sectioning of rods, mounting of metallographic samples, and removal of fuel from mechanical test specimens was completed before the end of the report period.

Final design changes in the Core III Loose Lattice fuel assemblies were made. Fuel rods for these re-constituted assemblies were removed from Core II assemblies, inspected, loaded into seven new Loose Lattice skeletons, and shipped to the Saxton reactor site.

SECTION 2

NUCLEAR ANALYSIS OF CORE II

(F. L. Langford, D. Dabby)

Nuclear data and flux maps from the end-of-life experiments were analyzed and the moderator temperature coefficient was re-evaluated with the aid of a revised version of LEOPARD. A summary of the re-evaluated moderator temperature coefficient as a function of burnup is shown in Table 2-1. Note that the calculated values compare favorably with measured values. The results were included in a Summary Report on Saxton Core II Nuclear Operations, which was written during the period and will be issued as WCAP-3385-55 (EURAEC-2108).

TABLE 2-1
CALCULATED VERSUS MEASURED MODERATOR TEMPERATURE
COEFFICIENT AS A FUNCTION OF BURNUP

Core Average BU $\left(\frac{\text{MWD}}{\text{MTM}}\right)$	Moderator Temp. (°F)	Boron Conc. (PPM)	$\frac{\partial \rho}{\partial T} \Big _{\text{calc.}}$	$\frac{\partial \rho}{\partial T} \Big _{\text{meas.}}$
0	530	2260	-2.22×10^{-4}	-2.36×10^{-4}
5715	515	1240	-2.56×10^{-4}	-2.61×10^{-4}
10196	530	620	-3.34×10^{-4}	-3.30×10^{-4}

SECTION 3

POST-IRRADIATION EXAMINATION OF $\text{PuO}_2\text{-UO}_2$ FUEL RODS FROM CORE II

(Examinations: D. T. Galm, E. S. Schwartz, J. A. Corbett, J. T. Barnes
Evaluations: K. R. Jordan, R. S. Miller, J. F. Mellor, W. R. Smalley
E. J. O'Neil, R. J. Nodvik)

3.1 NON-DESTRUCTIVE EXAMINATIONS

3.1.1 Visual

Thirteen fuel rods were examined on the stereo-viewer to determine their overall surface condition. The examination showed that most of the surfaces were covered by a thin dark gray, non-lustrous film, presumably corrosion product deposits ("crud"). These deposits appeared to be heavier and more patchy in the high power locations, generally in the center 20 inches of each rod. An example of this patchy-type crud on Rod TT is shown in Figure 3-1. The thickness of the crud film near the center of Rod TT, as determined by Filar eyepiece measurements, was in the range of 0.2 to 0.6 mil. Crud thicknesses in other areas of Rod TT and on other rods were estimated to be less than 0.5 mil in all cases.

The rods exhibited many handling scratches and axial score marks, the latter resulting from removal of the rods past the grid contact points. In the areas of the scratches, it was evident that most of the crud film was soft and non-adherent. The axial score marks varied in width and were intermittently bright, indicating varying frictional forces during removal of the rods past the grid contacts.

PHOTO 4150

~ 4X

Figure 3-1. Example of Patchy-type Crud near Center of Rod TI

All fuel rods were examined closely for crud patterns, excessive wear, and fretting, particularly at grid locations. Generally, the crud patterns were altered in the areas of grid contact, indicating a change in coolant flow around the grids. Figure 3-2 illustrates typical crud patterns near grids; note the apparent reduction in crud immediately adjacent to the grid contact points. Although the grid-to-clad contact areas were obvious on all rods, there was no evidence of significant fretting except at a bottom grid location on one Vipac fuel rod. In this instance, the deepest of the fretted areas, shown in Figure 3-3, was measured as 0.110" long x 0.085" wide x 0.015" deep. A one-inch long section containing the major fretted areas was removed from the rod for subsequent metallographic study. The results will be presented in the next semi-annual report. More typical grid-clad contact areas, which exhibited no significant wear or fretting, are shown in Figure 3-2 and Figure 3-4.

The visual examinations showed no evidence of clad cracks, swelling, hydride blisters, ridging, white corrosion products, or other defects.

3.1.2 Dimensional

Length measurements were performed by placing each fuel rod in a special fixture and observing the deflection on a dial indicator compared with that for a rod of calibrated length. As shown in Table 3-1, all rods increased in length by 0.14 to 0.22%, with pellet rods showing slightly higher increases. The data also suggest a trend toward greater increases with higher burnup.

COOLANT FLOW
DIRECTION

PHOTO 4182
TOP GRID LOCATION, ROD PO

~4X

COOLANT FLOW
DIRECTION

PHOTO 4173
SECOND-FROM-BOTTOM GRID, ROD S1

~4X

Figure 3-2. Typical Crud Patterns at Grid Contacts

PHOTO 4194

~ 4X

Figure 3-3. Significant Fretting at Bottom Grid Location of Vipac Rod K4

PHOTO 4206
TOP GRID LOCATION, ROD TE

~ 4X

PHOTO 4180
SECOND-FROM-BOTTOM GRID, ROD PO

~ 4X

Figure 3-4. Typical Grid-to-Cladding Contact Areas

TABLE 3-1

SAXTON CORE II FUEL ROD LENGTH CHANGES

<u>Rod Number</u>	<u>Fuel Type</u>	<u>Rod^a Location</u>	<u>Calculated Rod Average Burnup, MWD/MTM</u>	<u>Final Length, In.</u>	<u>Original Length, In.</u>	<u>Length Increase, In.</u>	<u>Length Increase, %</u>
TI	Pellet	D3-A1	22,400	39.139	39.074	0.065	0.17
EC	Pellet	D3-A4	23,300	39.152	39.080	0.072	0.18
TP	Pellet	D3-D1	22,600	39.155	30.075	0.080	0.20
TT	Pellet	D3-A6	21,900	39.133	39.066	0.065	0.17
QE	Pellet	C3-A1	22,900	39.150	30.067	0.083	0.21
TE	Pellet	C3-D1	22,700	39.143	39.069	0.074	0.19
LA	Pellet	E2-A1	21,700	39.134	39.065	0.069	0.18
MY	Pellet	C3-D5	15,700	39.144	39.058	0.086	0.22
RI	Pellet	C3-E4	16,000	39.128	39.065	0.063	0.16
JF	Pellet	C3-E5	15,400	39.145	39.069	0.074	0.19
K4	Vipac	D4-A1	23,400	39.087	39.020	0.067	0.17
N3	Vipac	D4-A2	23,400	39.089	39.028	0.061	0.16
N1	Vipac	D4-A4	23,300	39.089	39.024	0.065	0.17
S1	Vipac	D4-D5	16,900	39.075	39.020	0.055	0.14
P0	Vipac	D4-E5	16,300	39.083	39.024	0.059	0.15

^aRod locations are described in Appendix A.

Each fuel rod was scanned with an in-cell profilometer, which provided a spiral trace of diameter as a function of axial position. A portion of a typical profilometer trace is shown in Figure 3-5. The results were as follows:

1. When compared with diameters near top and bottom, diameters were less over the center 30 in. of each rod. The differences between minimum and end-of-rod diameters ranged between 0.001 and 0.0025 in., which represents about a 0.2 percent to 0.6 percent diameter decrease. These reductions in fuel rod diameter are qualitatively consistent with original design predictions⁽¹⁾.
2. Ovality was typically about 0.001 in., but locally as high as 0.0035 inch. Vibratory-compacted fuel rods generally showed less ovality.
3. Mean diameter ranged from 0.3939 to 0.3888 in. as compared with preirradiation diameters of 0.392 ± 0.002 in.
4. There was no evidence of gross fuel rod swelling, local hydride blisters, or longitudinal ridging.
5. Several high burnup pellet rods showed evidence of slight clad ridging at pellet interfaces. The extent of this ridging was typically 0.0005 in. and never greater than 0.001 inch.

Figures 3-6, 3-7, and 3-8 summarize the variation in mean diameters as a function of axial position for three groups of rods: (1) high burnup pellet rods, (2) intermediate burnup pellet rods, and (3) high burnup Vipac rods. Note that the mean diameters of the three high burnup Vipac rods were greater than those of the pellet rods along their entire length. Moreover, the

Figure 3-5. Typical Portion of Spiral Profilometer Trace, Rod TP

Figure 3-6. Summary of Profilometer Data for High Burnup Pellet Rods

Figure 3-7. Summary of Profilometer Data for Intermediate Burn-up Pellet Rods

Figure 3-8. Summary of Profilometer Data for High Burnup Vipac Rods

diameters near the center of the Vipac rods were approximately the same as end-of-rod diameters, reflecting the support provided by the Vipac fuel throughout operation. The two intermediate burnup Vipac rods exhibited widely differing diameters. The reason for the large differences is not known. However, it may be attributed, in part, to differences in pre-irradiation (after pickling) tubing diameters. The results of the in-cell profilometry for all rods scanned in this program are presented in Appendix B. The data are plotted to show mean diameter and ovality at one inch intervals along the length of each rod.

3.1.3 Gamma Scans

Nineteen fuel rods were scanned with a sodium-iodide scintillation crystal detector. The gross gamma activity data, consisting of 10 second counts at quarter-inch intervals, are summarized in Table 3-2. These data indicate relative rod average burnups and help establish locations for burnup and metallographic samples.

Fuel rods A and B were irradiated for approximately 6670 hours in assemblies E4 (rod position A5) and C2 (rod position E1), respectively, then removed from the core for a period of time, and subsequently inserted in the 2 x 2 subassembly contained in assembly D3 for an additional 1050 hours of irradiation. Fuel rod D was irradiated for approximately 6670 hours. The remaining rods, listed in Table 3-2, were irradiated without relocation for all of Core II operation (approximately 9740 hours). No valid comparisons of gamma activities can be made between fuel rods which were exposed to different irradiation histories.

TABLE 3-2

SUMMARY OF SINGLE-CHANNEL GAMMA SCAN DATA

<u>Rod No.</u>	<u>Fuel Type</u>	<u>Irrad. Time (Days)</u>	<u>Cooling Time (Days)</u>	<u>Peak-to-Ave. Ratio</u>	<u>Relative Activity</u>
JF	Pellet	406	102	1.287	1.000
RI	Pellet	406	102	1.300	1.001
MY	Pellet	406	103	1.309	1.001
QE	Pellet	406	112	1.272	1.322
TE	Pellet	406	115	1.278	1.323
TI	Pellet	406	82	1.401	1.136
EC	Pellet	406	82	1.327	1.235
TT	Pellet	406	82	1.321	1.278
TP	Pellet	406	102	1.342	1.263
CH	Pellet	406	115	1.279	1.314
LA	Pellet	406	115	1.408	1.146
S1	Vipac	406	102	1.282	1.062
P0	Vipac	406	102	1.273	1.023
K4	Vipac	406	102	1.267	1.309
N1	Vipac	406	103	1.274	1.322
N3	Vipac	406	103	1.280	1.247
A	Pellet	322	60	1.272	1.325
B	Pellet	322	60	1.260	1.322
D	Pellet	278	492	1.423	0.760

3.2 SAMPLING PLAN FOR POST-IRRADIATION EXAMINATIONS

The sampling plan for removal of burnup and materials specimens was revised and is summarized in Table 3-3. The nondestructive examination sampling information also is summarized in this table.

3.3 DESTRUCTIVE EXAMINATIONS

3.3.1 Fission Gas Release Measurements

All 18 fuel rods listed in the sampling plan were punctured in a calibrated vacuum system to collect and sample internal gases. In addition, each rod was helium leak tested after puncturing, but no leaks were detected. Samples of the released gases were analyzed by mass spectrometry. The results of fission gas analyses are given in Table 3-4. Predicted and measured fractional release values are included in the table based on calculated rod average burnup. Generally, there is reasonable agreement between predicted and measured releases, despite the fairly wide scatter in experimental data. The predictions for the two medium-burnup Vipac rods appear to be conservatively high, while releases for overpower test rods A and B were underestimated slightly. All fission gas release data will be re-evaluated after measured values of burnup are available so that more significant comparisons of predicted and measured releases can be made.

As expected, the rods with higher heat ratings (higher burn-ups) showed greater gas release. The volume of gas collected from each of the two high-burnup Vipac rods was greater than for any pellet rod. This observation is also in qualitative agreement with predictions. Part of the difference between pellet and Vipac rods is due to the significant nitrogen released from the

TABLE 3-3

Saxon Plutonium Program - Post-Irradiation Examination

Rod No.	Assm. Loc.	Rod Loc.	Calculated Peak Burnup, SWD/MTM	Type/Purpose	Met.	Tensile	Burst	Mn-54	Clad H	HE	Nd-148	Am-241,243 Np-237	Pu-236, -238	Cs-137	α Auto.	β - γ Auto.
QE	C3	A1	30.1	P/M	5			4	4	1	1				1	1
TI	D3	A1	33.1	P/M	2	2	2		2	1	1				1	1
TP	D3	D1	32.0	P/M	2	1	1			1	1					
LA	E2	A1	32.3	P/M	2	1	1	2	2	1	1					
TE	C3	D1	30.6	P/M,P	2	1	1		2	3	3					
TT	D3	A6	30.3	P/M	2	2	2	2		1	1					
RI	C3	E4	21.5	P/P,R						18	18	3	3	10		
MY	C3	D5	21.2	P/P		1	1			3	3	3	3			
JF	C3	E5	20.8	P/P						3	3		3			
K4	D4	A1	30.8	V/M	5	1	1		4	1	1				1	1
N1	D4	A4	30.9	V/M	2	1	1			1	1					
N3	D4	A2	30.8	V/M	2	1	1			1	1					
S1	D4	D5	22.3	V/P						5	5		3			
PO	D4	E5	21.6	V/P						4	4		3			
A	2x2	2x2	24.6	P/OP	2				2	1	1				1	1
B	2x2	2x2	24.5	P/OP	2				2	1	1				1	1
D	Out	Out	17.6	P/OP/ref	2				2	1	1					
CH	D3	D9	31.1	P/OP/ref	2				2	1	1					

Notes: 1. Type: P - pellet fuel, Zircaloy clad
V - Vipac fuel, Zircaloy clad

2. Purpose: M - materials performance evaluation
P - physics performance evaluation
R - radial sample
OP - overpower test rod
ref - overpower reference rod (D has similar burnup w/o high kw/ft; CH has similar kw/ft with high burnup)

3. All rods receive: visual exam., with photos as needed; profilometer and length measurements; fission gas sampling and analysis; single-channel γ -scan.

4. Rod RI receives multi-channel γ -scan with and without cladding.

5. Radial sample includes 10 samples drilled from different radii with analyses for Cs-137, HE, and Nd-148. In addition, α and β - γ autoradiographs and metallurgical mounts will be prepared.

6. "HE" includes U-234, -235, -236 and -238; Pu-239, -240, -241, and -242; and Pu-239/U-238. In addition to samples indicated, five archive samples will be analyzed.

TABLE 3-4

FISSION GAS RELEASE DATA, SAXTON PLUTONIUM FUEL RODS

Rod No.	Rod Location ^a	Calculated Rod Average Burnup MWD/MTM	Volume of Gas Released ^b , cm ³	Gas Composition, Mole %					Fractional Release, %	
				He	N ₂	Ar	Kr	Xe	Measured	Predicted ^c
TI	D3-A1	22,400	79.4	8.4	0.1	0.1	5.6	85.8	24	27
IP	D3-D1	22,600	85.6	8.3	0.1	0.4	5.4	85.8	26	25
TT	D3-A6	21,900	91.5	6.1	0.1	0.4	5.5	87.7	29	22
QE	C3-A1	22,900	74.4	9.6	0.1	0.5	5.3	84.5	22	22
TE	C3-D1	22,700	87.4	8.6	0.1	0.4	5.3	85.6	26	23
LA	E2-A1	21,700	55.1	10.0	0.2	0.6	5.3	83.8	17	25
MY	C3-D5	15,700	28.6	15.2	0.1	1.0	5.1	78.6	11	6
RI	C3-E4	16,000	14.3	22.6	0.5	3.9	4.6	68.2	5	6
JF	C3-E5	15,400	13.0	39.7	0.2	3.4	3.6	53.1	4	6
K4	D4-A1	23,400	114.2	8.7	5.6	0.1	4.5	81.0	32	36
N1	D4-A4	23,300	115.6	8.6	7.0	<0.1	4.4	79.7	32	36
N3	D4-A2	23,400	[Sample lost during puncturing]							
S1	D4-D5	16,900	30.1	22.4	0.1	<0.1	4.5	73.0	11	19
P0	D4-E5	16,300	27.1	28.0	0.2	<0.1	4.5	67.3	9	18
A	O/P 2x2	17,800	82.5	8.3	1.4	0.5	5.1	84.7	30	24
B	O/P 2x2	18,400	81.9	7.4	1.4	0.5	5.2	85.4	30	24
D	E3-E1	13,100	34.0	26.0	14.0	4.8	3.1	50.8	11	9
CH	D3-D9	23,300	82.4	9.1	0.3	0.6	5.1	84.9	22	25

^aSee Appendix A for Rod Location nomenclature^bCorrected to STF^cBased on Nominal Power, Nominal Dimensions

highest temperatures regions of the Vipac fuel, the source of the nitrogen being the atmosphere in which the arc-fused UO_2 was prepared. All rods showed significant helium in the collected gases. The principal source of the helium is the original backfill atmosphere although some is produced by ternary fission. The presence of argon in the pellet rods is attributed to the in-box welding atmosphere (10 percent argon-90 percent helium).

3.3.2 Metallography

3.3.2.1 General

During the report period, 24 samples were removed from fuel rods and mounted for metallographic examination. Of these, five samples from Rod QE and one each from Rods TI, TE, and TP were examined. These examinations established the extent of oxidation and hydriding of the Zircaloy-4 clad, microstructural changes in the PuO_2 - UO_2 fuel, and evidence of fuel-clad interaction.

Four of the five samples from Rod QE were transverse sections representing power levels ranging from peak to ~45% of peak and were removed from the following axial positions:

<u>Sample Number</u>	<u>Power Relative to Peak</u>	<u>Dist. From Bottom End of Rod, Inches</u>
1	1.00	17.8
2	0.93	25.0
3	0.75	30.0
4	0.45	35.0

The other sample was a longitudinal one of the top end closure area, including the end plug, seal weld, and adjacent clad. Two of the other samples, those from Rods TE and TP, were also longitudinal and were selected primarily to evaluate corrosion and possible fretting of the Zircaloy clad in grid

contact areas. The remaining sample (Rod TI) was a transverse section representing the highest burnup (as-calculated) region of any Saxton Core II fuel rod.

3.3.2.2 Macroexamination

Examination of the mounted samples at low magnification revealed the usual crack patterns in the fuel, typical of oxide fuel which had operated at linear heat ratings of ~7-15 kw/ft. The cracks were predominantly radial in the lowest power section from QE; however, both radial and circumferential cracks were clearly evident in the peak and near-peak power sections, as shown in Figure 3-9. This observation is consistent with those made in previous CVTR and Yankee fuel examinations^(2,3,4). The macrographs also showed no central void or evidence of columnar grain growth. In light of the power history of these rods, neither would be expected. Another feature of the macrographs of samples from Rod QE was the larger apparent fuel-to-clad gap in the low power section as compared with those of high power. This observation is consistent with the profilometer measurements, which showed at least partial closing of the gap at the higher power positions. None of the macrographs revealed any evidence of clad defects.

3.3.2.3 Autoradiography

Autoradiographs, both alpha and beta-gamma, of the peak power section of Rod QE (Sample #1) showed homogenization of the center area of the fuel out to ~1/3 radius (Figure 3-10). Such homogenization is consistent with expectations for mixed oxide fuel of moderate power rating and has been observed previously^(5,6). The higher alpha activity near the periphery of the fuel,

4232
35 IN. FROM BOTTOM, 0.45 OF PEAK POWER

4233
30 IN. FROM BOTTOM, 0.75 OF PEAK POWER

4334
25 IN. FROM BOTTOM,
0.93 OF PEAK POWER

4335
17.8 IN. FROM BOTTOM,
~PEAK POWER POSITION

Figure 3-9. Photomicrographs of Four Transverse Sections from Rod QE

ALPHA ~8X
(WHITE AREAS REPRESENT HIGH α ACTIVITY)

BETA-GAMMA ~8X
(DARK AREAS REPRESENT HIGH β - γ ACTIVITY)

Figure 3-10. Autoradiographs of Peak Power Section of Rod QE

due to the greater plutonium higher isotope production in this region, is shown clearly in the α -autoradiograph.

3.3.2.4 Clad Microstructure

None of the metallographic samples showed evidence of cracks, accelerated oxidation, local hydriding, or other clad defects. Although oxide film thicknesses on the outer surfaces varied considerably, they were generally in reasonable agreement with predictions. Although more detailed analysis of these data is required, there appears to be no significant acceleration of corrosion due to irradiation. Also, they showed the expected trend of decreasing thickness with reduced power level, as indicated in the following table:

<u>Sample Number</u>	<u>Relative Power</u>	<u>Dist. from Bottom End of Rod, Inches</u>	<u>Typical Range of Oxide Thickness, Mils</u>
QE-1	1.00	17.8	0.10 - 0.25
QE-2	0.93	25.0	0.07 - 0.20
QE-3	0.75	30.0	0.03 - 0.20
QE-4	0.45	35.0	0.04 - 0.12
QE-5	---	Top End	≤ 0.04
TI-1	1.00	17.8	0.06 - 0.20

Figure 3-11 shows the typical appearance of the oxide film on the outer surface and illustrates the large variation in thickness within a short circumferential span.

Hydrides in the clad microstructure appeared to be uniformly distributed, with random to circumferential orientation. Occasionally, the hydrides clustered in a star-pattern near the center of the clad cross-section, but in no case was there evidence of massive hydriding or local radial hydriding. Furthermore, none of the samples showed any indication of stress re-orientation of hydrides. The hydrogen content, as estimated from micrographs of samples

Figure 3-11. Typical Appearance of Oxide Film on Outer Surface of Rod QE at Peak Power Position

from QE, was in the range of 80 to 100 ppm. These estimates were confirmed by subsequent hydrogen analyses of ring samples cut from locations immediately adjacent to the metallography specimens. The results were as follows:

<u>Sample Number</u>	<u>Dist. from Bottom End of Rod, Inches</u>	<u>Hydrogen*, ppm</u>
QE-1	17.6	93
QE-2	25.1	88
QE-3	30.1	71
QE-4	35.1	78

*Based on average of two determinations per ring sample.

The above hydrogen analyses also agree well with the original predicted end-of-life hydrogen content of 71 ppm, based on peak burnups of 25,000 MWD/MTM⁽⁷⁾. Extrapolation of the 71 ppm value for the higher peak burnups actually experienced in Saxton Core II would increase this to 80 to 85 ppm, which is close to the observed values.

Photomicrographs illustrating the nature of hydrides in clad samples from Rod QE are shown in Figure 3-12.

The hydrogen content of the top end closure weld area appeared to be significantly lower than that of any clad samples. In addition, the hydrides were smaller and more uniformly distributed in the weld area, the heat affected zone, and the end plug itself than in the clad.

3.3.2.5 Clad-Fuel Interaction

All of the fuel bearing sections exhibited an oxide-type layer on the inner surface of the clad. The typical appearance of this layer is shown

MICRO 670.12
35 IN. FROM BOTTOM, 0.45 PEAK POWER

500X

MICRO 673.12
17.8 IN. FROM BOTTOM, PEAK POWER POSITION

500X

Figure 3-12. Cross-Section of Fuel Cladding from Rod QE Showing Typical Concentration and Orientation of Hydrides

in Figure 3-13. The layer was more pronounced at the higher power positions. Metallographically, the layer was similar to the ZrO_2 film on the outer surface; however, it was more variable in thickness. Formation of an apparent zirconium oxide film on the clad inner surface was observed previously in the lower burnup Vipac fuel⁽⁸⁾. Further evaluation of this oxide layer will be made when data on both Vipac and intermediate burnup pellet fuel have been obtained.

The micrographs also reveal numerous areas where small pieces of fuel appeared to be bonded to the inner surface of the clad, suggesting that the fuel was in contact with the clad at least during some portion of operation. In most of these instances, the fuel particles were attached to the inner oxide layer, with an intermediate gray phase of unknown composition observed intermittently between the fuel and oxide layer. The typical appearance of this multiple interaction zone is shown in Figure 3-14.

3.3.2.6 Fuel Microstructure

The main features of the transverse fuel microstructures were (1) equiaxed grain growth in the center region, (2) small, metallic precipitates in the area of grain growth, and (3) clusters of gas bubbles around the original PuO_2 particles near the periphery of the fuel. These are illustrated in Figures 3-15 and 3-16, which are montages of two of the transverse sections from Rod QE. The extent of grain growth in these samples was greater than in the pellet fuel samples examined previously⁽⁸⁾, indicating higher power densities and higher center temperatures. However, as with the earlier studies, none of the recent samples have shown any central void or columnar growth. Center fuel temperature, although higher than that of previously examined Saxton $\text{PuO}_2\text{-UO}_2$ fuel, probably

Figure 3-13. Typical Appearance of Reaction Layer on Inner Surface of Cladding

Figure 3-14. Examples of Fuel-Clad Interaction Showing Intermediate Gray Phase Between Fuel and Inner Surface Oxide Layer

FIG. 3-15 FUEL MICROSTRUCTURE OF TRANSVERSE SECTION 30 IN. FROM BOTTOM OF ROD QE, 0.75 PEAK POWER (AS POLISHED)

FIG. 3-16 FUEL MICROSTRUCTURE OF PEAK POWER
SECTION FROM ROD QE (AS POLISHED)

did not exceed 1700°C in Rod QE. The metallic precipitates in the regions of grain growth have been noted in numerous other post-irradiation studies and are believed to be fission products. These fuel microstructures will be further evaluated when metallographic examination of the remaining rods has been completed.

3.3.3 Fast Flux Dosimetry

Two ring samples were cut from Rod QE and analyzed for Mn^{54} activity and iron content to determine fast flux exposure by the $\text{Fe}^{54} (n, p) \text{Mn}^{54}$ reaction.

Evaluation of the data showed the results to be anomalous. Additional samples from the same rod will be analyzed along with ring samples from other rods during the next period.

3.3.4 Burnup Analysis

Five fuel samples (four from the Overpower Test program, one regular) were prepared for burnup analysis. Dissolution was accomplished with a multi-reagent technique using 12N HNO_3 -0.1N HF, aqua regia, and HBr. Dilute aliquots were made of each solution and transferred to the Analytical Laboratories. Results of mass spectrometric analysis of these first five burnup samples have been processed with the REBUF⁽⁹⁾ data-reducing code. The REBUF code, developed to process data for UO_2 fuel, has been modified for UO_2 - PuO_2 fuel. The nuclear parameters and constants used in these preliminary evaluations were obtained from References 10 through 15.

Values of burnup determined from heavy element materials balance (HE burnup) and from the concentration of the fission product Nd-148 (Nd burnup) are given in Table 3-5. The mass spectrometric data from WARD are not internally self-

consistent for fuel rods CH, B, and D. The major cause of these inconsistencies was tentatively identified as incomplete isotopic exchange between the Pu spike and the Pu in the sample. An additional reduction-oxidation cycle was introduced into the separation procedure to alleviate this condition. Further work is planned to resolve the problem, so that the remaining burnup samples will be analyzed and evaluated during the next reporting period.

TABLE 3-5

FUEL PELLET BURNUP (PRELIMINARY)

Fuel Rod	Fuel Sample Axial Location (Inches From Bottom of Rod)	Mass Spectrometric Laboratory	Date of Analysis	Burnup (MWD/MTM)		Single-Channel Gamma Activity, c/10-second (x 10 ⁻⁵)
				HE	Nd-148	
QE	18.75-19.75	WARD	May 5, 1969	26,200	28,000	9.746
QE		GE-Vallecitos ^(a)	May 29, 1969	26,400	27,300	
CH	18.5 -19.5	WARD	April 29, 1969	21,000	28,700	9.724
CH		GE-Vallecitos ^(a)	May 29, 1969	27,400	27,800	
A	19.0 -20.0	WARD	May 2, 1969	21,500	21,900	9.806
B	19.0 -20.0	WARD	May 12, 1969	10,600	22,000	9.695
B		WARD ^(b)	May 27, 1969	12,100	20,800	9.925 ^(c)
D	19.0 -20.0	WARD	May 13, 1969	12,100	14,400	6.108

Notes: (a) Results from cross-check sample submitted to General Electric-Vallecitos.
 (b) Re-analysis
 (c) Re-analysis by repeat gamma scan.

SECTION 4

OVERPOWER TEST EVALUATION

4.1 PROGRAM OBJECTIVE (R. S. Miller, E. J. O'Neil)

This phase of the program is designed to demonstrate that mixed oxide fuel can withstand short duration overpower conditions after operation to moderately high burnup. The scope of this program was published in a previous progress report⁽¹⁶⁾.

4.2 METALLOGRAPHIC EXAMINATIONS

The metallographic examinations of all sections from Rods A, B, and reference rods CH and D were completed during the report period. Sections from the peak heat flux regions of rods A and B exhibited limited columnar grain growth and formation of an incipient central void, illustrated in Figure 4-1 and Figure 4-2. Fission product precipitates also are visible in the high temperature central regions. A section from the peak heat flux region of rod CH is shown in Figure 4-3. In contrast to the sections from rods A and B, only equiaxed grain growth was observed. Small fission product precipitates were noted throughout the fuel at grain boundaries.

The α -autoradiographs in the peak sections of rods A and B, (Figures 4-4 and 4-5) indicate significant homogenization of the PuO_2 to about 50 percent of the pellet radius. The extent of homogenization agrees well with the limit of small columnar grain growth. The β - γ autoradiographs of rods A and B exhibit

FIG. 4-1 EDGE-TO-CENTER COMPOSITE OF PEAK SECTION OF ROD A (150 x, ETCHED)

PELLET
SURFACE

GEOMETRIC
CENTER
OF FUEL

FIG. 4-2 EDGE-TO-CENTER COMPOSITE OF PEAK
SECTION OF ROD B (150 x , ETCHED)

FIG. 4-3 EDGE-TO-CENTER COMPOSITE OF PEAK SECTION OF ROD CH (150 x, ETCHED)

PHOTOMACROGRAPH

β - γ AUTORADIOGRAPH
(DARK AREAS REPRESENT
HIGH β - γ ACTIVITY)

α -AUTORADIOGRAPH
(WHITE AREAS REPRESENT
HIGH α ACTIVITY)

Figure 4-4. Peak Heat Flux Region - Rod A

PHOTOMACROGRAPH

α -AUTORADIOGRAPH
(WHITE AREAS REPRESENT
HIGH α ACTIVITY)

β - γ AUTORADIOGRAPH
(DARK AREAS REPRESENT
HIGH β - γ ACTIVITY)

Figure 4-5. Peak Heat Flux Region - Rod B

typical features for fuel which has experienced columnar grain growth, including bands of high fission product activity and adjacent areas of low activity. Radiographs of the peak section of rod CH are shown in Figure 4-6. In comparison with rods A and B, these radiographs indicate a lower fuel center temperature by the absence of bands of activity. This observation is consistent with the (~ 14 kw/ft) peak power level for this fuel rod.

The observed fuel microstructures (absence of significant columnar grain growth or well-defined central void) in rods A and B are not consistent with operation at 21.5 kw/ft. In light of the inconsistencies revealed, a complete review of the nuclear operating data, design data, temperature calculation methods, and metallography was initiated. Completion of the above analyses and final resolution of the operating powers and temperatures are expected during the next report period.

PHOTOMACROGRAPH

α -AUTORADIOGRAPH
(WHITE AREAS REPRESENT
HIGH α ACTIVITY)

β - γ AUTORADIOGRAPH
(DARK AREAS REPRESENT
HIGH β - γ ACTIVITY)

Figure 4-6. Peak Heat Flux Region - Rod CH

SECTION 5

SAXTON CORE III LOOSE LATTICE PROGRAM

5.1 OBJECTIVES AND SUMMARY

The objectives of the Saxton Core III Loose Lattice Program (extended burnup test) are to:

1. Demonstrate performance capability of Zircaloy clad mixed oxide fuel elements over a broad spectrum of burnups and power levels;
2. Obtain depletion characteristics and transuranic isotope generation data for high burnup, mixed oxide fuel.

During this period, final design changes were made, the Saxton Core III Safety Analysis report was written, and the seven Core III loose lattice assemblies were reconstituted at WPIF and shipped to the Saxton Reactor site.

5.2 DESIGN CHANGES

5.2.1 Mechanical Design (E. A. Bassler, R. N. Stansfield)

As noted in the previous semi-annual report, the loose lattice assemblies were to be modified to prevent buckling by increasing the stiffness of the enclosure and re-setting the grid springfingers to reduce axial friction loads between the grids and fuel rods. The fuel assemblies were strengthened by replacing six Zircaloy water tubes with six stainless steel tubes and spot welding 0.028 in. thick stainless steel angles between the enclosure and the tubes. The

one-inch long clips which previously fastened the two halves of the enclosure were replaced by full length clips in the spans between grids. A cross-section of the repaired loose lattice assembly is shown in Figure 5-1.

The combined effect of the above changes provides a safety factor of 1.5 between friction forces generated by the grids and the buckling strength of the cans. Furthermore, the design modifications will not compromise the thermal-hydraulic performance in Core III. The minimum DNB ratio still will be above the limit of 1.30 specified in the operating license for the Saxton reactor.

5.2.2 Nuclear Design (F. L. Langford, D. Dabby)

The major aspects of the nuclear design for the loose lattice assemblies were presented in the previous semi-annual report. Additional calculations were made to provide moderator temperature coefficients over an increased range of temperatures and boron concentrations for both zero power and full power conditions. The results are summarized in Figures 5-2 and 5-3.

Steam break calculations and minimum boron requirements were evaluated further. The study showed that adequate boron concentration will be maintained to insure at least a one percent shutdown by rods for the worst primary system cooldown that would result from a steam break. Hence, the core will not return to critical as a result of this type of accident. Minimum allowable boron concentrations were calculated as a function of core lifetime and are listed in Table 5-1, along with installed reactivity for various Saxton Core III conditions.

- $\text{PuO}_2 - \text{UO}_2$ FUEL ROD
- ZIRCALOY WATER TUBE
- STAINLESS STEEL WATER ROD

Figure 5-1. Cross-Section of Repaired Loose Lattice Assembly

Figure 5-2. Saxton Core III Zero Power Temperature Coefficient (Beginning of Life) as a Function of Boron Concentration

Figure 5-3. Saxton Core III Temperature Coefficient at Full Power as a Function of Boron Concentration

5.3 LICENSING (D. J. Paul)

During the period, the following reports were completed, reviewed by the Saxton Safety Committee, and approved for transmittal to the AEC:

1. Answers to AEC Formal Core III Questions
2. Summary Report on Buckling of Saxton Core II Fuel Assemblies and Prevention of Buckling in Core III
3. Re-evaluation of Saxton Core III Loss-of-Coolant Accident
4. An Addendum to the Core III Safeguards Report, titled Small Break Heat Rejection Capability

In addition, the following drafts were prepared and reviewed by Westinghouse and the Saxton Nuclear Experimental Corporation:

1. Change Request 32 to allow loading of Core III.
2. Change Request 33 to allow 1 MWt reactor operation until the 28 MWt license is granted.
3. Miscellaneous reports clarifying design of loop seals and amplifying answers to formal questions.
4. Preparation of the Saxton Core III Final Safeguards Analysis Report was initiated.

TABLE 5-1

INSTALLED REACTIVITY AND MINIMUM BORON REQUIREMENTS FOR CORE III

Core Condition	Installed Reactivity, % $\Delta K/K$	Worth of Control Bank With Rod Stuck, % $\Delta K/K$	Uncontrolled Reactivity $K_{eff} = 0.99$ % $\Delta K/K$	Maximum Reactivity Addition on Cooldown (at 0 ppm), % $\Delta K/K$	Minimum Boron Concentration Requirement for:	
					Stuck Rod	Stuck Rod Steam Break
Hot Zero Power (BOL)	11.3	12.0	.3	3.0	30	330
Hot Full Power (BOL) Equilibrium Xe	7.3	12.0	-3.7	4.2	0	50
Hot Zero Power 5000 Hrs	1.3	12.0	-9.7	3.5	0	0

5.4 RECONSTITUTION (D. R. McClintock, E. Llewellyn, W. Kotsenas,
R. S. Miller, W. R. Smalley)

5.4.1 Operator Training and Equipment Checkout

Operator training and checkout of all handling, cleaning, and inspection equipment were completed. In particular, a modified LVDT-type profilometer, underwater rod length measuring device, and crud sampling apparatus were checked out as inspection devices to supplement data obtained from the Mobile Fuel Evaluation System (MFES).

5.4.2 Removal of Rods From Core II Assemblies

The top plates and nozzles were removed from the remaining four fuel assemblies, and the following number of rods were extracted and cleaned:

<u>Assembly</u>		<u>Number of Rods Removed</u>	<u>Number of Rods Cleaned</u>
<u>Serial Number</u>	<u>Core II Location</u>		
503-12-4	E2	55	50
503-12-2	C2	57	54
503-12-7	C4	57	54
503-12-8	E4	43	40

5.4.3 Inspection of Fuel Rods Used in Reconstitution

5.4.3.1 General

The inspection of fuel rods for the reconstitution program consisted of the following:

1. Examination of most rods in the MFES, i.e. 3-TV camera visual, diameter scans with Hydrojet gaging system, and gamma scans with an ionization chamber.

2. Visual examination of 38 selected rods with the underwater periscope and single TV camera to evaluate crud deposits; crud sampling on two of these rods.
3. Length measurements on 183 rods with an extended depth micrometer.
4. Supplemental diametral scans on approximately half the rods with a portable LVDT-type profilometer.

The major purpose of these examinations was to qualify rods for use in Core III, and to document the beginning-of-Core III-life conditions, particularly surface features, dimensions, and burnup distribution.

5.4.3.2 Visual Examinations

As part of a program to assess crud behavior, 14 rods were examined with the periscope and single TV camera. Generally, crud deposits were present on all rods but were much more prominent on the higher burnup rods. There was evidence of only thin, ($< .001$ in.), soot-like deposits on the low burnup rods. These visual examinations served as a basis for subsequent crud sampling of two of the fuel rods, which appeared to have had sufficiently heavy deposits for meaningful thickness measurements and chemical analysis. Subsequent thickness measurements and sampling for density measurement were abortive because of equipment limitations. Radiochemical analyses show that the crud is similar to that found on stainless steel clad rods.

Six removable rods from 9 x 9 assemblies were examined to observe the nature and extent of crud deposits on low and intermediate burnup rods. Although in many areas the deposits appeared to have been rubbed or flaked off during

handling operations, all of these rods exhibited light to moderate soot-like deposits. On two of the rods, about half of the crud was missing; on the other rods, the crud was intact except for axial scratches and appeared to cover the rods uniformly from top to bottom.

Later in the reconstitution program, 24 uncleaned rods were inspected to document their surface condition, especially crud deposits, prior to their insertion into loose lattice assemblies. These 24 rods represented all burnup groups and, therefore, should have exhibited a wide range of surface conditions.

Generally, the crud deposits were heavier on the Group V and VI rods (rod average burnups of 15,500 to 21,000 MWD/MTM), as expected. These rods exhibited a variety of crud conditions, ranging from fairly thick (up to ~2 mils), patchy areas over the center 10 in. to a uniform brownish-gray, semi-lustrous surface. Frequently, there was evidence that crud was being scraped loose by the edge of the handling tool. In the areas near grid contacts, crud patterns were generally altered and often appeared to be related to the perturbed flow. Near the ends (within ~3 in.) of the higher burnup rods, the surfaces appeared to be covered with a thin, grainy, nonlustrous dark gray film. Figure 5-4 shows the general appearance of the crud deposits in grid contact areas of a Group V fuel rod. It also illustrates the thin, non-lustrous film near the top end of the rod. The estimated crud thicknesses were less than 0.002 in., even in the areas with relatively heavy, patchy crud. Over the major fraction of the rod surfaces, the crud was probably less than 0.001 in. thick.

The lower burnup rods (Groups II, III, and IV) exhibited no patchy crud but showed the same grainy type surface near the top and bottom ends as the high burnup rods. Near the grid contact area, the surfaces were usually a non-

↑ TOP OF ROD

TOP GRID CONTACT AREA OF ROD CI-8

↑ TOP OF ROD

CONTACT AREA NEAR SECOND-FROM-BOTTOM GRID OF ROD CI-8

Figure 5-4. Typical Appearance of Crud Deposits in Grid Contact Areas

lustrous, dark gray with similar swirl patterns as noted for Group V and VI rods. The thicknesses of the crud on the lower burnup rods were estimated to be <0.001 inch.

The visual inspections of the crud evaluation rods also revealed the absence of clad cracks, swelling, hydride blisters, severe wear, and other defects.

To minimize disturbance of the crud deposits, these rods were not characterized for dimensions prior to insertion into Core III assemblies. However, rods of equivalent power history were profilometer-scanned to help document the "beginning-of-Core III life" dimensions of each rod group.

The visual inspections in the MFES also revealed the expected axial scratches, about 90° apart, associated with removal of rods past the grids. Moreover, there was evidence of other bright scratches, which exposed base metal. These are attributed to the multiple handling operations experienced by many of the rods. With the exception of the crud and axial score marks, the rods appeared uniformly black and lustrous, typical of Zircaloy-clad rods which had operated in a PWR environment. Furthermore, none of the MFES visual examinations revealed any evidence of cracks, swelling, blisters, ridges, white corrosion products, or other obvious defects.

5.4.3.3 Dimensional Measurements

5.4.3.3.1 Length Changes

From measurements made on 183 fuel rods, all Zircaloy-clad rods increased in length by 0.13 to 0.24 percent. Table 5-2 summarizes the length change data taken on Zircaloy-clad rods during the reconstitution program. These data represent a sampling of measurements on at least seven rods from each

burnup group. The results show a trend of greater length increases for the higher burnup rods; they also indicate less change in Vipac rods than for pellet rods of comparable burnup. These length changes are consistent with the fast flux-related increases observed in zircaloy tubing at other laboratories (17, 18).

TABLE 5-2
SUMMARY OF LENGTH CHANGE DATA
FROM SAXTON RECONSTITUTION PROGRAM

<u>Burnup Group No.</u>	<u>Type Fuel</u>	<u>Calculated Rod Average Burnup, MWD/MTM</u>	<u>Average Length Increase, %</u>	<u>Range of Length Increase, %</u>
II	Pellet	12,100	0.16	0.14-0.19
III	Pellet	13,100	0.18	0.17-0.19
IV	Pellet	14,400	0.18	0.15-0.23
V	Pellet	16,400	0.18	0.15-0.22
V	Vipac	16,300	0.15	0.13-0.17
VI	Pellet	19,500	0.21	0.19-0.23
I	Pellet	22,200	0.21	0.19-0.23

5.4.3.3.2 Diameter Measurements

The diametral scans with both the MFES and profilometer systems showed the following results:

1. Decreased rod diameters over most (approximately the center 30 in.) of the length of each rod as compared with diameters near top and bottom.
2. Mean diameters, as measured to the nearest 0.001 in., ranged from 0.388 to 0.393 in., as compared with pre-irradiation diameters of $0.392 \pm .002$ in.

3. In general, ovality was 0.001 to 0.002 in. but in isolated instances was as high as 0.006 in.
4. There was no evidence of gross fuel rod swelling or local blisters.
5. There was occasional evidence of local clad ridging, up to ~0.0025 in., especially in higher burnup rods.

These results are generally consistent with the in-cell profilometry discussed in Section 3.1.2

Early comparisons of Hydrojet and profilometer data on the same fuel rods indicated that the two systems revealed similar trends, e.g. large ovalities or 1.5 to 2.5 mil ridge-type indications would appear at the same axial location on the charts of both systems. Qualitatively, the comparisons were favorable; the quantitative comparisons, however, showed many inconsistencies. From a series of comparative scans on calibrated step standards and a pre-measured drill rod, it was concluded that the portable profilometer provided better accuracy for the purposes of the reconstitution program and, therefore, was used as the primary means for measuring beginning-of-Core-III-life diameters of the loose lattice rods. The Hydrojet inspection performed a screening function, to help identify rods with local diameter variations. Such rods required specific analysis by the more accurate profilometer to assure compliance with acceptance criteria.

The major criteria for rejecting rods for use in the reconstituted assemblies were:

1. Cracks

2. Local collapse of clad in unsupported region
3. Longitudinal wrinkling
4. Blisters
5. Evidence of leaks

The visual and dimensional inspections showed that none of the rods were rejectable on the basis of any of the criteria. The Hydrojet data, however, identified several rods with anomalous dimensions, mainly ridge-type indications. The location and extent of these anomalous areas were confirmed by the portable profilometer.

5.4.3.4 Gamma Scanning

The gamma scans provided data on relative gamma activity, from which the end-of-Core-II-life burnup distribution could be calculated. The results of the gamma scans also showed the burnup depressions associated with grid locations, particularly for the two center grids. Several rods exhibited apparent gaps in the fuel column. Three fuel rods which exhibited more prominent gap indications were not used in the loose lattice assemblies since there was no means of quantitatively determining the actual pellet separation from the gamma scan trace.

5.4.4 Loading Plan for Loose Lattice Assemblies

The fuel rods accepted for reconstitution were loaded into the new loose lattice enclosures in accordance with the loading plan shown in Appendix C. The previous location of each rod in Core II is indicated by an alpha-numeric designation (rod position within the assembly followed by last digit of assembly

serial number). Also shown is the two-letter identification stamped on the top end of each rod.

5.5 FUEL SHIPMENT (B. James)

Prior to shipment of the reconstituted fuel assemblies, fuel rod stresses and behavior of cask drain and vent valve systems under hypothetical accident conditions were analyzed. This information was submitted to the AEC Division of Material Licensing for evaluation under Federal Regulation 10 CFR 71, "Packaging of Radioactive Material for Transport". A special permit to use Westinghouse cask model EX16-10 was granted by the Department of Transportation during the period. Hold-down springs to fit into the fuel assembly nozzles and subassembly fingers were designed, built, and tested. These springs helped assure limited movement of the assemblies during shipment to the Saxton site. Shipment of the reconstituted loose lattice assemblies to Saxton was completed on March 25, 1969.

SECTION 6

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APPENDIX A

NOMENCLATURE FOR ROD AND ASSEMBLY LOCATIONS

ASSEMBLY LOCATIONS IN CORE

Figure A-1. Nomenclature for Rod and Assembly Locations
Saxton Plutonium Program

APPENDIX B
PROFILOMETER DATA

Fig. B-1. Profilometer Data for Saxton Fuel Rod TI

Figure B-2. Profilometer Data for Saxton Fuel Rod TP

Figure B-3. Profilometer Data for Saxton Fuel Rod TT

Figure B-4. Profilometer Data for Saxton Fuel Rod QE

Figure B-5. Profilometer Data for Saxton Fuel Rod TE

Figure B-6. Profilometer Data for Saxton Fuel Rod LA

Figure B-7. Profilometer Data for Saxton Fuel Rod MY

Figure B-8. Profilometer Data for Saxton Fuel Rod RI

Figure B-9. Profilometer Data for Saxton Fuel Rod JF

Figure B-10. Profilometer Data for Saxton Fuel Rod K4

Figure B-11. Profilometer Data for Saxton Fuel Rod N1

Figure B-12. Profilometer Data for Saxton Fuel Rod N3

Figure B-13. Profilometer Data for Saxton Fuel Rod SI

Figure B-14. Profilometer Data for Saxton Fuel Rod P0

APPENDIX C

LOADING DIAGRAMS FOR CORE III LOOSE LATTICE ASSEMBLIES

	1	2	3	4	5	6	7	8	9
A		G4-1 Q4		A9-3 PM		B5-9 SA		A8-1 RO	
B	A6-4 QR		H7-2 KQ		H5-3 CP		G8-9 JM		H7-9 OE
C		E3-2 NA		H1-4 LH		A4-4 DO		H1-9 EW	
D	D9-2 IL		C4-4 DV		C3-3 JK		J3-3 SE		D2-9 NH
E		F3-4 DA		F5-3 QW		A9-4 FK		J1-4 CJ	
F	F6-2 IG		D4-4 DT		D4-3 CM		B4-3 IU		
G		D4-2 KZ		B6-4 BD		G2-2 DZ		G1-2 BZ	
H	E5-4 JZ		C3-2 HH		E3-4 BW		J2-4 FM		
J		B4-2 JT		E8-2 OY					

Figure C-1. Loading Diagram of Core III Assembly C2 No. 17-8
(Previously Designated 17-1)

	1	2	3	4	5	6	7	8	9
A	F5-1 L5		A7-3 NX				C7-8 HD		B5-8 HS
B		B9-7 QL		A8-3 TN		H6-2 MJ		C1-8 HK	
C	C4-8 AR		E6-8 OK		E6-7 AI		G4-7 IQ		H2-7 MI
D		G7-2 QH		G3-7 HJ		F5-2 IP		D7-7 GL	
E	E1-2 I		C6-4 PJ		A4-7 QM		F6-8 KB		
F		F3-7 ES		B3-2 JR		H1-8 BP		C2-8 SI	
G	A7-2 LC		A8-2 RD		F4-8 CN		G5-8 SG		
H		C4-2 NI		E7-2 LX		D5-7 BF		D3-8 AZ	
J	G7-4 BO		F6-4 NE						

Figure C-2. Loading Diagram of Core III Assembly D2 No. 17-2

	1	2	3	4	5	6	7	8	9
A		D2-8 FQ		E4-8 TH		B8-7 HT		G8-3 KM	
B	A3-7 BT		F5-8 JV		E4-4 IN		E7-7 IT		A9-7 RT
C		G1-8 GX		E4-2 MF		A1-7 EJ		C8-8 OT	
D	F4-4 IC		B5-4 NV		E2-7 DU		B3-3 IH		A4-8 EH
E		G2-7 AY		D5-8 AH		A8-7 DC		G8-7 BB	
F	H2-4 FG		F7-8 MV		G8-8 HO		F8-7 IF		
G		B3-8 AG		B6-3 G5		H1-7 GY		G1-9 QI	
H	F7-7 LK		H5-2 FZ		H6-3 DR		C5-9 GB		
J		G1-7 BJ		E8-8 PP					

Figure C-3. Loading Diagram of Core 111 Assembly E2 No. 17-3

	1	2	3	4	5	6	7	8	9
A		F2-8 OS		G3-8 AK		G6-4 EZ		D5-2 MP	
B	D7-2 MA		E7-4 NF		C2-7 FC		G4-8 NS		B7-2 ER
C		H7-4 DK		G2-8 CF		H3-8 PS		G5-4 PC	
D	C3-7 KN		H2-8 FH		H8-9 LZ		D8-2 JX		B8-2 CG
E		F7-4 QX		B1-9 PF		A9-9 RR		H4-8 RS	
F	B2-7 BE		B3-7 DM		B1-3 IM		D3-7 PO		
G		C4-7 DL		G8-4 EK		H8-4 QU		E2-8 PL	
H	B6-2 OL		D6-2 EU		E6-4 GH		E3-8 KM		
J		B5-7 HN		H6-4 MM					

Figure C-4. Loading Diagram of Core III Assembly D3 No. 17-4

	1	2	3	4	5	6	7	8	9
A		H6-9 FX		C7-9 LD		H8-3 NN		G3-1 SS	
B	A7-1 A2		D3-9 FR		A6-3 LE		B3-4 NY		C4-3 KR
C		C3-9 PQ		A2-2 NB		C2-4 OX		H3-2 MC	
D	F7-9 GD		F2-2 NC		E6-1 QO		H4-2 EQ		A9-2 NJ
E		C9-3 SN		E4-1 R3		A7-4 BR		J4-4 QD	
F	D1-2 GZ		D2-4 LU		G5-2 JC		D2-2 MU		
G		G1-4 OJ		F4-2 SM		A4-2 GE		C2-2 OO	
H	H8-2 SQ		D9-4 BG		F8-2 IV		G6-2 PR		
J		E8-3 DX		D3-2 SR					

Figure C-5. Loading Diagram of Core III Assembly C4 No. 17-5

	1	2	3	4	5	6	7	8	9
A	D4-7 QF		B5-2 PI				C8-2 AD		C7-2 LL
B		F8-4 EG		C6-2 BC		B4-7 AB		C5-2 RM	
C	C9-2 LR		G4-4 CO		C5-7 CA		B9-2 KL		E8-4 LY
D		C6-7 BU		C7-4 EN		D6-4 CU		G3-4 KJ	
E			H3-4 HV		F7-2 CS		B8-4 RV		
F		E4-7 LO		F4-7 DD		B2-2 TG		H3-7 CQ	
G	A6-2 QG		F2-7 RX		F5-7 DS		A6-7 HI		
H		C5-3 DQ		C9-7 LT		G5-1 I9		H5-7 RE	
J	E8-7 KG		G6-1 DO						

Fig. C-6. Loading Diagram of Core III Assembly
D4 No. 17-6

	1	2	3	4	5	6	7	8	9
A		G7-7 GM		C8-7 DR		J2-8 QV		F5-4 BK	
B	C1-2 DY		F8-3 DJ		C5-8 MH		B7-7 FF		E3-7 BY
C		E2-4 VW		F6-7 HF		C3-8 BI		E5-2 OA	
D	F1-2 SF		D9-7 GO		H6-8 FS		C5-4 RK		C1-7 HP
E		D9-3 BN		F4-3 JQ		G7-8 KD		B7-4 GK	
F	D7-9 FI		B8-8 AF		F4-1 G4		H7-3 CW		
G		G5-9 MQ		B7-8 GV		H8-8 BM		B6-8 FE	
H	J2-9 MS		G6-9 LS		F1-7 JU		B1-2 OP		
J		B6-9 FP		B4-9 ST					

Figure C-7. Loading Diagram of Core III Assembly E4 No. 17-7