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Westinghouse Atomic Power Divisions

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SAXTON PLUTONIUM PROJECT
QUARTERLY PROGRESS REPORT

FOR THE PERIOD ENDING

MARCH 31, 1970

MASTER

by

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 SCOPE

This quarterly report covers work completed during the first quarter of the calendar year 1970..

1.2 OBJECTIVES

The purpose of the Saxton Plutonium Program is the development of information concerning the utilization of plutonium-enriched fuel in pressurized water reactor (PWR) systems through design, fabrication, and operation of a partial core of $\text{PuO}_2\text{-UO}_2$ 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 evaluated and compared with analytical predictions.

1.3 PROJECT ADMINISTRATION

The semi-annual report for the period ending December 31, 1969, was written, reviewed and issued. Progress and expenditures on the various tasks of the program were reviewed regularly throughout the quarter.

1.4 SUMMARY OF PROGRESS DURING THE PERIOD

During the period, all laboratory work involving Saxton Core II fuel rods was completed. This work included:

1. Further metallographic examination of selected fuel rod sections with relatively thick, porous oxide layers.
2. Metallographic examination of locally hydrided cladding, primarily on rod ML.
3. Characterization of fuel and cladding in archive rod MZ to determine whether initial hydrogen or moisture could have contributed to local

hydriding of Zircaloy clad.

4. Metallographic determination of failure strains of selected cladding burst samples and evaluation of anomalous burst pressures.
5. Burnup analyses of 10 radial drill samples from rod RI.
6. Cesium-137 analyses of seven axial burnup samples and the above 10 radial drill samples.
7. Additional analyses to determine the reason for unexpectedly low Pu-239/U-238 ratios in archive fuel samples.

The major portion of burnup and isotopic data was reduced and evaluated. In addition, the analysis of all data on oxidation films and hydrogen uptake was completed. The evaluation of local hydriding in rod ML and suspect areas on several other rods was also completed.

Core III achieved full power late in December, and the at-power physics program was completed in January. The entire on-site system for reducing flux data was completed and is now functional. Since the beginning of full power operation, Core III has accumulated 1,098 megawatt-days of operation, with a total of 36 load follow cycles. As of March 31, the calculated peak burnup in the loose lattice region of Core III is 32,500 MWd/MTM.

SECTION 2

POST-IRRADIATION EXAMINATION OF CORE II FUEL RODS

(Examinations: D. T. Galm, E. S. Schwartz, J. A. Corbett, J. T. Barnes

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2.1 METALLOGRAPHY

2.1.1 General

As noted in the previous Semi-Annual report^[1], metallographic examination had revealed abnormally thick oxide films on the outer surfaces of several high power rods. In many locations, the oxide thickness varied widely, and the oxide appeared non-adherent and porous. The condition was studied further during the current period.

During the reconstitution program [2, 3], dimensional inspection had identified several rods with anomalous diameters. These rods were not used in the Core III loose lattice assemblies but were held for possible further study later in the program. Subsequently, this group of rods was transferred to the Hot Laboratory to determine the correlation of dimensional anomalies with fuel and clad microstructure. The results of these studies are described in section 2.1.3 below.

2.1.2 Evaluation of Corrosion Films

Additional sections of high power fuel rods were examined metallographically to define further the nature and location of abnormally thick oxidation films. The major objective of this additional work was to determine the relationship between the surface appearance of the rod and nature of the oxide layer (and crud, if present).

Five sections from rod CH were studied, primarily because this rod had exhibited numerous patchy, stain-like areas and apparent residual crud during visual examination. Sections from near the peak power sections of rods QE and TE also were examined. Prior to mounting, each of the sections was photographed to document surface features as related to circumferential orientation marks. An example of the stain-like patches on rod CH is shown in Figure 2-1.

MACRO 4801 ~4X
~8.5 IN. FROM BOTTOM OF ROD

MACRO 4807 ~4X
~29 IN. FROM BOTTOM OF ROD

Figure 2-1. Dark, Non-Lustrous Patchy Areas on Outer Surface of Rod CH

The comparison of surface features and structure of oxide layers indicated that there is no direct correlation between the two. When black, non-lustrous patches were observed, however, they usually were associated with thick oxide layers (>0.4 mil). On the other hand, some samples showed thick oxide in areas of normal surface appearance, i.e., free of dark, stain-like patches. Furthermore, there were many locations where surface features varied considerably, but where the oxide thickness remained uniform. In addition, residual crud up to 0.4 mil frequently was observed in areas of thick oxide (and dark, patchy surface appearance) and also occasionally where oxide layers were thin. The presence of residual crud, however, could not be correlated consistently with the appearance of fuel rod surface. Figures 2-2 and 2-3 show several of the conditions discussed above.

The additional metallographic studies of samples from rods CH, QE, and TE confirmed the significant local variability in oxide thicknesses, noted previously^[1]. The thickest oxide layers observed were in the range of 0.5 to 0.8 mil, which were essentially the same as those of other sections of the same rods. Although the oxide thicknesses tended to be greater in the areas of highest heat flux and on the highest power rods, the reason for local variability of oxide layers is still not apparent. There was no evidence of an associated increase in hydrogen absorption on samples which exhibited accelerated oxidation.

2.1.3 Investigation of Local Hydriding

Rod ML was held for further study because of anomalous dimensions observed during the reconstitution program. Profilometer measurements had shown localized diameter variations which were 0.003 to 0.004 in. greater than nominal in an area 10 to 12 inches from the bottom of the rod. Subsequent puncturing of the rod for fission gas collection and analysis indicated that the rod had not failed, i.e., there was no evidence of leaks, and the quantity and composition of the collected gas were normal for a rod of this burnup. Metallographic examination in this region revealed local hydriding near the outer surface and an associated thick oxide layer (~ 1.0 mil). Metallographic examination of adjacent sections also showed extensive hydriding near the outer surfaces (solid hydride in several locations) and relatively thick oxide where the hydriding was heavy. In several cross sections, cracking of the clad was

Figure 2-2. Thick Oxide Layer Associated with Dark Non-Lustrous Surface, 28.5 Inches from Bottom of Rod CH

Figure 2-3. Intermittent Oxide Film in Area of Uniformly Dark, Non-Lustrous Surface, 27.3 Inches from Bottom of Rod CH

observed, with the cracks originating at the inner surface and extending to a maximum of about 70 percent of the wall thickness. Figures 2-4 and 2-5 show typical areas of this portion of the rod. Examinations of a longitudinal section after several incremental grinding steps showed small amounts of solid hydride at the inner surface of the clad, suggestive of internal contamination. As shown in Figure 2-6, a transverse section at the peak heat flux region, about 19 inches from the bottom of the rod, also revealed surface hydriding and cracks in the cladding from the inner surface to about 25 percent of the wall thickness.

The investigation of hydriding in rod ML indicates an internal source of hydrogen, i.e., the inner portion of the clad was hydrided first, became embrittled, and cracked. In time, most of the excess hydrogen diffused down the thermal gradient toward the cooler outer surface where it precipitated.

Three fuel rods which were adjacent to rod ML in Core II were examined closely for unusual surface features, especially at the axial position (10-12 in.) where ML exhibited hydriding. None of these rods exhibited any abnormal surface conditions.

Metallographic sections were removed from areas of four other rods which had anomalous dimensions (LI, MG, RA, and TM). Of these, only one section -- 13.6 inches from the bottom of rod MG -- showed evidence of significant hydriding. On this sample, there was one small area of solid hydride near the outer surface but no cracks in the cladding and no evidence of thick oxide film in the hydrided zone.

A review of fabrication records showed that the two hydrided rods (ML and MG) contained fuel from pellet batch #3. Therefore, two additional rods (MO and MY) containing fuel from this batch were examined metallographically. No heavily hydrided regions were observed in any of the seven sections from these two rods. However, several sections exhibited higher-than-normal hydrogen concentrations near the outer surface. One of these is shown in Figure 2-7.

Because of the suspect nature of fuel from pellet batch #3, archive rod MZ (which also contained batch #3 pellets) was characterized for internal gas content, moisture in the fuel, and hydrogen in both fuel and cladding. The rod was first punctured and the fill gas collected, the analysis of which revealed

786.5

100X

Figure 2-4. Transverse Section Showing Local Hydriding of Rod ML,
10.8 Inches from Bottom of Rod

Figure 2-5. Longitudinal Section of Rod ML at ~11.5 Inches from Bottom of Rod. (note: solid hydride and thick oxide near outer surface and cracks near inner surface)

791.6

100X

Figure 2-6. Transverse Section of Rod ML near Peak Heat Flux Region. (Note: solid hydride near outer surface and cracks near inner surface of cladding.)

804.1

100X

Figure 2-7. Transverse Section of Rod MO, 17.9 Inches from Bottom of Rod, Showing Heavier-than-Normal Hydriding

no evidence of hydrogenous contamination or other anomalous conditions. Moisture contents of individual pellets from the rod were determined with a CEC moisture analyzer. The results indicated an average of 2 ppm. Hydrogen analyses of archive cladding samples, both with and without autoclaving, assuming uniform and complete internal hydrogen pickup during autoclaving, showed that the initial moisture content of pellets in MZ was 12 ppm. Individual pellets also were analyzed for gaseous content. Because of low releases of volatiles, the hydrogen content of the pellets could not be measured directly. However, on the assumption that all gas evolved (after trapping the CO_2 and H_2O) is hydrogen, the equivalent average moisture content from this source is 3 ppm. Thus, pellet batch contamination by moisture or other hydrogenous impurity, as suggested by earlier observations (rods ML, MG, and MO), does not appear likely. The most probable cause of the observed hydriding is stray hydrogenous contamination introduced during fabrication.

2.2 MECHANICAL TESTING

The anomalous burst test data reported previously^[1] were evaluated further. Microhardness readings were taken on selected samples in areas adjacent to the bulge and in the failed region. These measurements did not show evidence of significant annealing in the failed regions of the anomalous test samples. However, several instances of mechanical damage to the cladding (reduced wall thickness) were noted. The damage, which occurred during removal of fuel from the samples, could have reduced burst pressures.

2.3 BURNUP AND ISOTOPIC ANALYSES

2.3.1 General

During the period all data on non-irradiated fuel -- test reports from fuel suppliers and that recently obtained on archive samples -- were evaluated to establish the beginning-of-life isotopic compositions for both pellet and Vipac fuel. In addition, the reduction and re-evaluation of all burnup data obtained in the program were completed. Data from the special isotopic analyses (Pu-236, Pu-238, etc.) also were reduced and converted to a form suitable for comparison with predicted values.

2.3.2 Beginning-of-Life Isotopic Composition

Because of the importance of pre-irradiation composition in calculating isotopic depletions, all "beginning-of-life" (BOL) data on Saxton plutonium fuel were closely reviewed. The data included isotopic composition, plutonium assays, and Pu/U ratios from suppliers' test reports and the more recently obtained isotopic data on archive retainer samples.

The values of initial plutonium isotopic composition and Pu/U ratios previously used in the program were obtained from fuel supplier test reports and design data. These values were given in Reference 4 and are essentially the same as those used as a basis for the heavy element burnup determination in the last Semi-Annual Progress Report.^[1]

Recent mass spectrographic measurements were made on non-irradiated archive samples at the Westinghouse Advanced Reactors Division (WARD). The results for pellet fuel, when corrected for Pu-241 decay, showed good agreement with the supplier data for isotopic composition. However, the values for Pu-239-to-U-238 ratio in the pellet samples were about 3 percent lower than those calculated from supplier Pu/U data. A bias of 3 percent in initial Pu/U could result in erroneous conclusions in comparing calculated vs measured Pu-239 depletions. Such a bias would also lead to inconsistencies in burnups inferred from heavy element isotopic balance as compared with Nd-148/U-238 atom ratio.

Because of the potential consequences of a 3 percent bias in the original Pu/U ratio, tests were initiated to determine the source of the discrepancy. A statistical evaluation of data from the fuel manufacturer and the WARD Analytical Laboratories showed that the differences in Pu/U ratio were significant, i.e. not merely random. As a result, additional archive fuel was dissolved and analyzed at the Westinghouse Plutonium Fuel Development Laboratory for Pu content by coulometric titration, a procedure known to provide accuracies within ± 0.4 percent relative. These Pu values were converted to Pu/U ratios and gave essentially the same values as reported by the fuel supplier.

The two most likely reasons for the discrepancy were inaccuracy of the mass spectrometric spike calibration and incomplete dissolution of plutonium from the archive pellets.

Several factors support the validity of the spike calibration; these include:

1. Good agreement among results of cross check mixed oxide samples analyzed by Idaho Nuclear Corp., General Electric Vallecitos Nuclear Center, and WARD.
2. Close agreement of WARD analytical results on the Yankee Monitor sample over a long period of time with those of Idaho Nuclear, General Electric and Tracerlab West.
3. Verification of the original spike calibration in most recent checks made during the last three months.

The most probable reason for the 3 percent discrepancy appears to be incomplete dissolution of the plutonium in the archive pellets. Experience at several other laboratories also indicates that unirradiated PuO_2 is difficult to dissolve completely.

In the case of the Vipac fuel, the Pu/U ratio determined from the archive samples agrees with that obtained from the manufacturer's records. However, the isotopic abundances of the archive fuel appear to be distinctly different from those shown in supplier test reports. The reason for these differences is not known.

No measurements were made on Saxton fuel for impurities such as Th-232, Pa-231, Pu-236, U-232, and Am-241 at the time of manufacture. Therefore, the concentrations of these isotopes had to be either estimated or determined by alpha spectrometry on archive samples. The BOL concentrations of Th-232 and Pa-231 were estimated from data on non-irradiated Yankee Core I fuel. The initial Pu-236/Pu-239 and Pu-238/Pu-239 atom ratios were established from alpha spectrometric measurements. Uranium-232 contents at BOL were estimated from the results of alpha spectrometry of Pu-236 and were based on the assumption that the plutonium separation took place during May 1964. The Am-241 was estimated from the results of mass spectrometric analyses for the Pu isotopic abundances in the archive samples. Again, the estimate assumed a Pu separation date of May 1964.

A summary of the initial composition for both pellet and Vipac fuel is given in Tables 2-1 and 2-2. The main U and Pu isotopic abundances from manufacturer's reports and from analyses of archive samples are compared in Table 2-1. The entire fuel composition, including concentrations of the special isotopes,

is summarized in Table 2-2. [In this Table, the values for main chain U and Pu isotopes are based on the average results of pellet and Vipac archive samples.]

2.3.3 Burnup Analyses of Fuel Pellet Samples

All results of mass spectrometric and radiochemical analyses have been processed with the REBUF data reducing code.^[5] The nuclear parameters and constants used in the reduction of the data are listed in Appendix A. Since the fission yield values and initial isotopic composition are slightly different than those used previously, the burnup values reported in the last progress report^[1] were recomputed; these are listed in Table 2-3. In addition, burnups for the remaining seven axial samples from Vipac rods P0 and S1 were determined and are shown in Table 2-4. The burnup values determined by three different methods (Nd-148, heavy element, and Cs-137) for seven samples from rod R1, are compared in Table 2-5. The results indicate consistency among the three methods and suggest little, if any, axial migration of cesium within the fuel rod.

2.3.4 Rod Average Burnups

The burnup and gamma activity measured at various positions along each rod are listed in Tables 2-3 and 2-4. As shown in Figure 2-8, these values were correlated to re-estimate the average burnup for each fuel rod. The results are summarized in Table 2-6.

TABLE 2-1

SUMMARY OF INITIAL ISOTOPIC COMPOSITION OF SAXTON CORE II FUEL^(a)

	Archive Samples ^(b)		Manufacturer's Records ^(c)	
	Pellet	Vipac	Pellet	Vipac
U-234	5.48×10^{-3}	5.27×10^{-3}	5.71×10^{-3}	5.71×10^{-3}
U-235	0.729	0.728	0.720	0.720
U-236	---- (d)	---- (d)	0	0
U-238	99.265	99.267	99.274	99.274
Pu-238	0.016	0.015	0.016 ^(e)	0.015 ^(e)
Pu-239	90.472	90.454	90.531	90.316
Pu-240	8.593	8.608	8.559	8.572
Pu-241	0.875	0.877	0.847	1.030
Pu-242	0.044	0.046	0.047	0.068
Pu/U Mass Ratio	0.0683	0.0695	0.0705	0.069

- (a) All data in atom percent and referenced to Saxton Core II beginning-of-life on December 28, 1965.
- (b) From WARD mass spectrometric analysis of unirradiated samples of archive fuel. (Three samples each of pellet and Vipac fuel)
- (c) Uranium isotopic analysis not reported in manufacturer's records; nominal values for natural uranium shown here. Plutonium abundance data from mass spectrometric analysis; Pu/U data from chemical Pu assay -(Reference 6)
- (d) Not detectable
- (e) Manufacturer's records do not include analysis for Pu-238; values for Pu-238 shown here are from mass spectrometric analysis of unirradiated archive samples.

TABLE 2-2

SUMMARY OF SAXTON CORE II INITIAL FUEL COMPOSITION

Isotope	Atom Percent, In Element	Atom Percent, In Metal
Th-232		8.2×10^{-6}
Pa-231		1.1×10^{-9}
U-232	6.32×10^{-9}	5.91×10^{-9}
U-234	5.37×10^{-3}	5.02×10^{-3}
U-235	0.729	0.682
U-236	----	----
U-238	99.266	99.892
Pu-236	1.93×10^{-7}	1.24×10^{-8}
Pu-238	0.015	9.64×10^{-4}
Pu-239	90.463	5.805
Pu-240	8.600	0.5519
Pu-241	0.876	0.0562
Pu-242	0.045	0.0029
Am-241		4.84×10^{-3}
Total U		93.579
Total Pu		6.417
Total Metal		100.000

TABLE 2-3

SUMMARY OF SAXTON CORE II BURNUP ANALYSES

Rod Number	Fuel Type (a)	Spectrum Type (b)	Sample Location (Inches from Bottom of Rod)	Burnup (MWd/MTM)		Gross Activity c/sec x 10 ⁻⁴
				Nd-148	Heavy Element	
TI	P	WS	18.8-19.8	26,320	26,350	9.110
TP	P	WS	18.8-19.8	27,220	27,360	9.743
TT	P	WS	18.8-19.8	27,410	28,010	9.707
LA	P	WS	18.8-19.8	24,500	24,670	9.199
TE	P	WS	8.8-9.8	24,830	25,070	8.981
TE	P	WS	18.8-19.8	27,910	28,420	9.697
TE	P	WS	28.8-29.8	20,520	21,090	7.478
JF	P	ASYM	8.8-9.8	18,040	18,280	6.744
JF	P	ASYM	17.8-18.8	20,580	20,860	7.524
MY	P	ASYM	8.8-9.8	17,090	18,120	6.652
MY	P	ASYM	18.8-19.8	20,690	20,940	7.535
MY	P	ASYM	28.8-29.8	14,910	15,160	5.812
RI	P	ASYM	2.0-2.8	9,470	9,810	4.136
RI	P	ASYM	8.8-9.8	18,010	18,480	6.766
RI	P	ASYM	16.8-17.8	21,020	21,370	7.661
RI	P	ASYM	18.8-19.8	20,910	21,270	7.554
RI	P	ASYM	20.8-21.8	20,130	20,410	7.374
RI	P	ASYM	23.8-24.8	17,160	17,600	6.483
RI	P	ASYM	25.8-29.8	14,860	15,140	5.779
RI	P	ASYM	35.3-36.0	7,320	7,450	3.078
K4	V	WS	18.8-19.8	27,900	28,360	9.679
N1	V	WS	18.8-19.8	29,690	27,870	9.874
N3	V	WS	18.8-19.8	26,380	26,820	9.279
PO	V	ASYM	18.8-19.8	21,280	21,310	7.657
S1	V	ASYM	18.8-19.8	21,660	22,080	7.830
S1	V	ASYM	35.3-36.0	7,600	7,450	3.259

a. P: Pellet, V: Vipac

b. WS: Rod location adjacent to water slot in perturbed neutron spectrum
 ASYM: Rod located in inner region of fuel assembly in asymptotic neutron spectrum

TABLE 2-4

SUMMARY OF BURNUP ANALYSES ON VIPAC RODS PO AND S1

Rod No.	Spectrum Type	Sample Location, In. from Bottom of Rod	Burnup (MWd/MTM)		Gross Activity, 10^{-4} c/sec
			Nd-148	Heavy Element	
PO	ASYM	8.8-9.8	18,620	19,050	6.772
PO	ASYM	16.8-17.8	21,600	21,840	7.657
PO	ASYM	18.8-19.8 *	21,280	21,310	7.634
PO	ASYM	28.8-29.8	15,630	15,980	5.913
S1	ASYM	2.0-2.8	10,000	10,220	4.016
S1	ASYM	8.8-9.8	19,140	19,320	7.030
S1	ASYM	18.8-19.8 *	21,660	22,080	7.830
S1	ASYM	28.8-29.8	15,120	15,200	6.030
S1	ASYM	35.3-36.0 *	7,600	7,450	3.259

* Data on these samples are repeated from Table 2-3 for comparison with other samples of same rod.

TABLE 2-5

COMPARISON OF BURNUP VALUES DETERMINED BY
THREE DIFFERENT METHODS
ON SEVEN SAMPLES FROM FUEL ROD RI

Sample Location, In. from Bottom of Rod	Burnup (MWd/MTM)		
	Nd-148	HE	Cs-137
2.0-2.8	9,470	9,810	9,980
8.8-9.8	18,010	18,480	18,320
16.8-17.8	21,020	21,370	20,850
18.8-19.8	20,910	21,270	21,410
23.8-24.8	17,160	17,600	18,000
28.8-29.8	14,860	15,140	15,280
35.3-36.0	7,320	7,450	7,450

Figure 2-8. Correlation of Burnup and Gamma Activity in Saxton Core II Fuel

TABLE 2-6

ROD AVERAGE BURNUPS OF SAXTON CORE II FUEL RODS

<u>Rod Number</u>	<u>Lattice Position Assembly - Rod</u>	<u>Rod Average Burnup MWd/MTM</u>
JF	C3-E5	15,010
RI	C3-E4	15,140
MY	C3-D5	15,130
QE	C3-A1	21,010
TE	C3-D1	21,020
TI	D3-A1	17,700
TP	D3-D1	19,990
TT	D3-A6	20,360
CH	D3-D9	20,860
EC	D3-A4	19,440
LA	E2-A1	18,060
PO	D4-E5	15,530
S1	D4-D5	15,970
K4	D4-A1	20,760
N1	D4-A4	21,010
N3	D4-A2	19,600
A	O/P 2 x 2	15,650
B	O/P 2 x 2	15,660
D	E3-E1	9,450

SECTION 3

SAXTON CORE III OPERATIONS

(D. R. McClintock, D. M. Woodall)

3.1 CORE III OPERATING HISTORY

Full power was achieved in the reactor in late December, at which time a series of at-power physics tests were initiated. These tests, which were performed at reactor power levels of 10 MW and 18 MW, were completed on January 16 and provided a basis for further operation of Core III. In addition to the at-power physics tests, three cycles of load follow operation were completed in January to obtain nuclear data on axial xenon variation. Late in January the reactor was shut down for maintenance and repairs of plant components.

On February 11, load follow operation resumed and continued until February 26, when problems with the flux mapping system necessitated a hot shutdown for repairs. After repair of the system, the reactor was returned to full power on March 2. It operated until March 9, when an unscheduled scram necessitated another shutdown. The cause of the condition leading to the scram is currently being investigated. Since the March 9 shutdown, further repairs were made to the in-core flux detectors, and the reactor has been utilized for operator training.

As of March 31, a total of 36 load follow cycles and 1,098 megawatt-days of operation have been accumulated. A summary of the incremental and cumulative burnups achieved in the loose lattice region of Core III is given in Section 3.2.

3.2 PHYSICS TESTING

The first phase of the at-power physics tests determined essential nuclear parameters, which served as a basis for further operation of Core III. These parameters are shown in Table 3-1.

The physics tests also provided power distributions as measured with an in-core flux mapping system. The resulting power distributions indicate that the

TABLE 3-1

NUCLEAR PARAMETERS FROM AT-POWER PHYSICS TESTS

Temperature Coefficient @485°F T (average)	-14.5 pcm/°F at 744 ppm Boron -15.8 pcm/°F at 670 ppm Boron -17.6 pcm/°F at 540 ppm Boron
Pressure Coefficient @2117 psia	$+2.1 \times 10^{-6} \Delta k/k/psi$
Boron Worth @613 ppm Average Boron Concentration	-12.1 pcm/ppm
All Rods Out Boron Concentration (Hot Full Power, no Xenon)	948 ppm
Integral Equilibrium Xenon Worth, $\Delta k/k$	2.38%
Integral Rod 2 Worth, $\Delta k/k$	3.42%
Power Defect (at 25 MWt), $\Delta k/k$	1.28%

power levels of the loose lattice fuel are 5 to 10 percent lower than predicted. The results show that the best estimate for maximum power density attainable in the loose lattice region will be 20.0 kw/ft.

Continuous flux mapping was performed during the initial load follow cycling to obtain nuclear data on axial xenon variation and its effect on power in the loose lattice rods. The increase in peak power due to load follow cycling was found to be less than 5 percent. Further flux mapping will continue during load follow operation of Core III until the mid-life shutdown.

The final comparison of the two flux data reduction systems (CDC-6600 vs an on-site WANG) was completed. Since the on-site code uses approximations which are not necessary in the CDC system, it must be normalized to the CDC code by applying a correction factor. Appropriate factors were determined for each flux thimble set used to map the core. With these correction factors applied to the WANG system, the rod power predicted by the two codes showed good agreement (+ 1 percent).

The following table summarizes the peak burnups achieved in the loose lattice region of Core III as of March 31:

Type of Loose Lattice Fuel Rod	Initial Burnup, MWd/MTM	Incremental Burnup, MWd/MTM	Cumulative Burnup, MWd/MTM
Peak Power Rod	16,200	6,500	22,700
Peak Burnup Rod	27,500	5,460	32,960

SECTION 4

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APPENDIX A

PARAMETERS USED TO DETERMINE FUEL BURNUP FROM ISOTOPIC AND FISSION PRODUCT MEASUREMENT

Parameter	Burnup Indicator			Refer- ence
	Heavy (e) Element	Nd-148	Cs-137	
E ₂₅ , MeV/U-235 fission (a,b)	204	204	204	A1
E ₂₈ , MeV/U-238 fission (a,b)	202	202	202	A1
E ₄₉ , MeV/Pu-239 fission (a,b)	212	212	212	A1
E ₄₁ , MeV/Pu-241 fission (a,b)	214	214	214	A1
28, total fissions in U-238 relative to sum of total fissions in U-235, Pu-239, and Pu-241 (c)	0.051			A2
49, total captures/total fissions in Pu-239 (c)	0.503			A2
41, total captures/total fissions in Pu-241 (c)	0.369			A2
COR26, correction factor for U-236 burnout (a)	1.03			A1
COR 42, correction factor for Pu-242 burnout (a)	1.12			A1
Fission product burnout correction factor (d)		1.012	1.0	
T _{1/2} , half-life, years		(Stable)	30.5	A3
Y ₂₅ , fission yield, atoms/U-235 fission		.0169	.0628	A4, A5
Y ₂₈ , fission yield, atoms/U-238 fission		.0193	.063	
Y ₄₉ , fission yield, atoms/Pu-239 fission		.0165	.0674	
Y ₄₁ , fission yield, atoms/Pu-241 fission		.0188	.0660	

- Nominal values shown here were obtained from a LEOPARD calculation of a SAXTON 6.6 w/o UO₂-PuO₂ unit cell at 21,000 MWD/MTM burnup. Actual values used in data reduction are burnup-dependent.
- Includes kinetic energy of fission fragments and neutrons, energy of beta and gamma decay, and energy of radiative capture in fuel, cladding, and moderator.
- Nominal values shown here were obtained from a LASER^[A2] calculation of a SAXTON 6.6 w/o UO₂-PuO₂ unit cell at 21,000 MWD/MTM burnup. Actual values used in data reduction are burnup-dependent.
- Determined from LEOPARD unit cell calculation for Yankee as described in Reference A6.
- The Heavy Element method also requires the pre-irradiated isotopic distribution in the fuel. Values of initial fuel composition used in this program are 0.00537, 0.729, 0.0, and 99.266 atom percent for U-234, U-235, U-236 and U-238, respectively, and 90.463, 8.600, 0.876, and 0.0149 atom percent for Pu-239, Pu-240, Pu-241, and Pu-242, respectively; the value of Pu-239/U-238 atom ratio is 0.0625.
- Values of fission yield shown here are weighted averages.

APPENDIX A

REFERENCES

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