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SAXTON PLUTONIUM PROJECT
QUARTERLY PROGRESS REPORT FOR THE PERIOD
ENDING SEPTEMBER 30, 1972

by

R. C. Goodspeed
Project Engineer

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TABLE OF CONTENTS

Section	Title	Page
1	INTRODUCTION AND SUMMARY	1-1
	1.1 Scope	1-1
	1.2 Objectives	1-1
	1.3 Project Administration	1-1
	1.4 Summary of Progress During the Period	1-1
2	CORE III NUCLEAR OPERATIONS SUMMARY	2-1
	2.1 Introduction	2-1
	2.2 Core III Operations	2-1
	2.3 Physics Measurements	2-4
	2.4 Core Burnup	2-7
	2.5 Core Power Distributions	2-7
	2.6 Conclusions	2-7
3	EVALUATION OF CORE III FUEL	3-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
2-1	Saxton Core III Fuel Loading at BOL	2-2
2-2	Saxton Core III Boron Curve	2-8
2-3	Saxton Core III Flux Map at OEFPH (BOL)	2-14
2-4	Saxton Core III Flux Map at 1721 EFPH (70-I)	2-15
2-5	Saxton Core III Flux Map at 3714 EFPH (MOL)	2-16
2-6	Saxton Core III Flux Map at 5943 EFPH (EOL)	2-17

LIST OF TABLES

Table	Title	Page
2-1	Saxton Core III Power History	2-3
2-2	Saxton Core III Reactor Parameters - 0 EFPH (BOL)	2-5
2-3	Saxton Core III Reactor Parameters - 3714 EFPH (MOL)	2-6
2-4	Summary of Saxton Core III Operating History through End-of-Life	2-9
2-5	Saxton Core III Calculated Burnup at 0 EFPH (BOL)	2-10
2-6	Saxton Core III Calculated Burnup at 1721 EFPH (70-I)	2-11
2-7	Saxton Core III Calculated Burnup at 3714 EFPH (MOL)	2-12
2-8	Saxton Core III Calculated Burnup at 5943 EFPH (EOL)	2-13
3-1	Saxton Plutonium Program Core III End-of-Life Post-Irradiation Sampling Plan	3-2

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 1972.

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, 1972, underwent patent review and management approval. Both this report and the quarterly report for the period ending March 31, 1972 are being prepared for submittal to the AEC for patent review.

Discussions with the AEC resulted in agreement that reprocessing of Saxton Core III spent fuel will be performed by the AEC at the Savannah River Plant. Final contract agreement is expected by November 15, 1972.

1.4 SUMMARY OF PROGRESS DURING THE PERIOD

A Core III end-of-life post irradiation examination (PIE) sampling plan was internally approved and transmitted to the AEC for review.

Fuel shipments to the Battelle Memorial Institute (BMI) hot cell facility required for the end-of-life PIE program were completed. Shipments included five assemblies and four subassemblies. The balance of mixed oxide fuel has been shipped to the Waltz Mills fuel handling pool for future shipment to Savannah River for reprocessing when final contract agreement has been reached.

Hot cell equipment set up and qualification continued at BMI in preparation for the PIE task.

A Saxton Core III nuclear operations summary emphasizing pre- and post-midlife shutdown core physics measurements was prepared since insufficient post-midlife core depletion was achieved to warrant execution and evaluation of end-of-life physics tests. This nuclear operations summary is included in Section 2 of this report.

SECTION 2

CORE III NUCLEAR OPERATIONS SUMMARY

(R. L. Stover)

2.1 INTRODUCTION

The Saxton Reactor was designed to investigate areas of interest in the development of pressurized water reactors. Core I was composed of 21 UO_2 fuel assemblies with an enrichment of 5.7 w/o U-235 and operated from November, 1962, to October, 1965; it accumulated a core average burnup of 9,700 MWD/MTU. Core II contained 12 uranium assemblies of 5.7 w/o UO_2 and 9 plutonium assemblies of 6.6 w/o PuO_2 in natural UO_2 . It operated until October, 1968, with a cycle burnup of 10,900 MWD/MTM.

Core III consisted of 11 uranium assemblies from Core I, 7 loose lattice plutonium assemblies reconstituted from Core II, and 3 fresh uranium assemblies (see Figure 2-1). Shutdown took place on May 1, 1972, with a cycle burnup of 8082 MWD/MTM.

Objectives of the Core III irradiation program were to:

- 1) demonstrate performance of Zircaloy clad mixed oxide fuel, and
- 2) obtain depletion characteristics of mixed oxide fuel at high burnup.

2.2 CORE III OPERATIONS

Beginning-of-life (BOL) for Core III was January 11, 1969, when power operation commenced. There were two major shutdowns for fuel changes, the first, 70-I shutdown, occurring in mid 1970, and the second, middle-of-life shutdown (MOL), occurring in March, 1971. End-of-life (EOL) was May 1, 1972, when the core was shut down, since the major program objectives had been achieved and operation at maximum power was restricted by coolant activity waste handling limitations.

For calculational convenience Core III operation was divided into 6 periods as shown in Table 2-1. Cycle burnup was 8082 MWD/MTM or 5943 effective full power hours at 23.5 MWt.

Figure 2-1. Saxton Core III Fuel Loading at BOL

TABLE 2-1

SAXTON CORE III POWER HISTORY

<u>Period</u>	<u>Calendar Time</u>	<u>Eff. Full Power Hrs. @ 23.5 MW</u>		<u>Core Energy Production</u>	<u>Core Burnup</u>
		<u>Step</u>	<u>Accumulative</u>	<u>MWD</u>	<u>MWD/MTM</u>
1	(BOL) 12/11/69 to 2/12/70	700	700	685	952
2	2/13/70 to 5/14/70 (70-I)	1021	1721	1685	2340
3	8/24/70 to 11/17/70	1000	2721	2664	3700
4	11/18/70 to 3/12/71 (MOL)	993	3714	3637	5051
5	11/10/71 to 1/31/72	1045	4759	4660	6472
6	2/ 1/72 to 5/ 1/72 (EOL)	1184	5943	5819	8082

Normal, full power operation varied between 20 and 25 MWt depending upon the lead rod power level and burnup. 100 percent core power was then determined from weekly flux maps by using the fuel center-line-melt criteria as contained in the Saxton Core III Technical Specification. The limit on mixed oxide fuel at 0 MWD/MTM was 24.0 kw/ft (design) or 21.2 kw/ft (best estimate).

During the week, the core was normally cycled 6 times daily between 100 percent and 40 percent power. On weekends, operation was steady state at 100 percent power. For the power changes, control rod #2 was moved ~ 3 inches from its normal steady state position of 17 inches (36.6 inches = out). A total of 631 load follow cycles was achieved.

During the last two months of operation, the core was operated at a steady state reduced power level of 15 to 16.5 MWt due to the high coolant activity waste handling limitations.

2.3 PHYSICS MEASUREMENTS

Reactivity coefficients and rod worths were measured at BOL and MOL shutdowns.^[1] Measured and calculated values are shown in Tables 2-2 and 2-3 for 0 and 3714 EFPH, respectively. Agreement is good between calculation and measurement except for the moderator temperature coefficients which were overpredicted by up to 5 pcm/°F. This discrepancy is attributed to the actual moderator temperature being slightly lower than assumed in calculating the predicted values.

The increasing value of moderator temperature coefficient and boron worth with decreasing boron concentration, however, was confirmed as well as the smaller power defect with higher burnup. The pressure coefficient and xenon defect were unchanged by burnup as expected while the control rod 2 worth decreased as the fresh fuel around it was depleted.

¹The planned end-of-life physics test were not conducted because there was insufficient incremental depletion since the mid-life physics tests to merit them. Differences in measurements would be of the same order of magnitude as the uncertainties associated with the measurements. Also, reduction in power due to coolant activity precluded full power measurements.

TABLE 2-2

SAXTON CORE III REACTOR PARAMETERS - 0 EFPH (BOL)

<u>Item</u>	<u>Conditions</u>	<u>Calculated</u>	<u>Measured</u>	<u>Units</u>
1. Critical boron	HZP, ARO	1132	1082	ppm
	HFP, ARO, Eq. Xe	810	750	ppm
2. Moderator temperature coefficient	HZP, ARO, 1052 ppm	-13.0	-8.2	pcm/°F
	HZP, Rod 2 In, 788 ppm	--	-14.2	pcm/°F
	HFP, ARO, 744 ppm	-13.7	-14.5	pcm/°F
	HFP, ARO, 670 ppm	-15.0	-15.8	pcm/°F
	HFP, ARO, 540 ppm	-16.0	-17.6	pcm/°F
3. Boron worth	HZP, ARO, 920 ppm	-8.9	-9.9	pcm/ppm
	HFP, ARO, 613 ppm	-10.3	-12.1	pcm/ppm
4. Pressure coefficient	HFP, 2117	+0.21	+0.20	pcm/psi
5. Control rod 2 worth	HZP	3.67	3.17	%Δk/k
	HFP	3.60	3.42	%Δk/k
6. Power defect	0 to 25 MWt	1.24	1.28	%Δk/k
7. Xenon defect	0 to 21 MWt	2.66	2.38	%Δk/k
	0 to 11 MWt	2.00	1.80	%Δk/k

HZP Hot Zero Power

HFP Hot Full Power

ARO All Rods Out

TABLE 2-3

SAXTON CORE III REACTOR PARAMETERS - 3714 EFPE (MOL)

<u>Item</u>	<u>Conditions</u>	<u>Calculated</u>	<u>Measured</u>	<u>Units</u>
1. Critical boron	HZP, ARO	630	591	ppm
	HFP, ARO, Eq. Xe,	280	323	ppm
2. Moderator temperature coefficient	HZP, ARO	-13.0	-11.5	pcm/°F
	HZP, Rod 2 in	-19.0	-16.3	pcm/°F
	HFP, ARO	-17.0	-14.0	pcm/°F
	HFP, Rod 2 in	-23.0	-18.0	pcm/°F
3. Boron worth	HZP, 466 ppm	-10.3	-11.5	pcm/ppm
	HFP, 282 ppm	-12.5	-9.9	pcm/ppm
4. Pressure coefficient	HZP, 2245 psia	+0.25	+0.17	pcm/psi
5. Control rod 2 worth	HZP	3.20	2.96	%Δk/k
	HFP	--	2.62	%Δk/k
6. Power defect	C to 25 MWt	1.28	1.16	%Δk/k
7. Xenon defect	C to 23 MWt	2.50	2.20	%Δk/k

HZP Hot Zero Power

HFP Hot Full Power

ARO All Rods Out

2.4 CORE BURNUP

Critical boron concentration was measured frequently during Core III operation and compared to the calculated values. Figure 2-2 shows the comparison between calculated and measured boron values, both corrected to 23.5 MWt, $T_{\text{mod}} = 485^{\circ}\text{F}$, and all rods out. The measured boron data extrapolates to 6100 EFPH; shutdown actually occurred at 5943 EFPH due to coolant activity waste handling limitations.

Lead rod powers and burnups at EOL for the plutonium, loose lattice rods are listed in Table 2-4. Maximum rod power obtained during Core III operation was 21.2 kw/ft (best estimate) and peak burnup was 51,000 MWD/MTM (best estimate).

Calculated burnups for each assembly and the center subassembly are listed in Tables 2-5 through 2-8 at each of the major shutdowns (BOL, 70-I, MOL and EOL). At MOL, the assemblies in positions C3 and E3 were interchanged and a 5 w/o PuO_2 assembly inserted into position D5 replacing a 5.7 w/o UO_2 assembly. Burnups include irradiation accrued in Cores I or II, where applicable.

2.5 CORE POWER DISTRIBUTIONS

Using miniature fission detectors, flux maps were taken weekly throughout core life. Four maps representative of Core III operating history are shown in Figures 2-3 through 2-6. Calculated values obtained were generally within ± 5 percent of the measured values. One less flux thimble was operable in the core after midlife. Therefore, somewhat larger discrepancies occurred in three of the assemblies located near this thimble position. Control rod 2 is inserted approximately 50 percent for these flux maps.

2.6 CONCLUSIONS

1. The reactor operation phase of the Saxton Core III program was successfully completed with the achievement of peak pellet burnups exceeding 50,000 MWD/MTM. Upon final reduction of data, the program will have provided depletion

Figure 2-2. Saxton Core III Boron Curve

TABLE 2-4

SUMMARY OF SAXTON CORE III OPERATING
HISTORY THROUGH END-OF-LIFE

	<u>Through March 31, 1971</u>	<u>During April-May 1972</u>	<u>End-of-Life</u>
Energy Generated, MWD	5352	467	5819
Number of load cycles	631	0	631
Peak Linear power, kw/ft ^(a)			
1. Peak power rod	21.2	14.7	---
2. Peak burnup rod (in center 3x3)	14.2	9.9	---
3. Peak burnup rod (outside center 3x3)	12.1	8.4	---
Peak Pellet Burnup, MWD/MTM ^(b)			
1. Peak power rod	26,400	2700	29,100
2. Peak burnup rod (in center 3x3)	49,200	1800	51,000
3. Peak burnup rod (outside center 3x3)	45,600	1500	47,100

(a) Best estimate, thermal basis (thermal = 0.974 of fission).

(b) Best estimate, fission basis.

TABLE 2-5

SAXTON CORE III CALCULATED BURNUP AT 0 EFPH (BOL)

<u>Core Location</u>	<u>Assembly Serial No.</u>	<u>Number of Rods</u>	<u>Initial MTM</u>	<u>Average Burnup MWD/MTM</u>
C1	503-1-12	71	0.03780	6,800
D1	503-1-16	71	0.03780	8,200
E1	503-2-6	61	0.03248	7,200
B2	503-10-7	68	0.03235	0
C2	503-17-8	36	0.01734	16,400
D2	503-17-2	35	0.01686	14,600
E2	503-17-3	36	0.01734	16,000
F2	503-1-9	72	0.03833	7,200
B3	503-2-4	61	0.03248	9,000
C3	503-18-1	60	0.02700	0
D3	503-17-4	32	0.01542	12,400
E3	503-18-3	60	0.02700	0
F3	503-1-17	71	0.03780	7,300
B4	503-1-8	71	0.03780	6,800
C4	503-17-5	36	0.01734	16,600
D4	503-17-6	34	0.01638	14,000
E4	503-17-9	36	0.01734	16,500
F4	503-2-5	61	0.03248	5,700
C5	503-2-2	61	0.03248	5,100
D5	503-1-11	70	0.03727	5,400
E5	503-1-5	72	0.03833	6,800
D3 (subassembly)	503-4-31	4	0.00193	20,500

TABLE 2-6

SAXTON CORE III CALCULATED BURNUP AT 1721 EFPH (70-I)

<u>Core Location</u>	<u>Assembly Serial No.</u>	<u>Number of Rods</u>	<u>Initial MTM</u>	<u>Average Burnup MWD/MTM</u>
C1	503-1-12	71	0.03780	7,900
D1	503-1-16	71	0.03780	9,500
E1	503-2-6	61	0.03248	8,300
B2	503-10-7	68	0.03235	1,400
C2	503-17-8	36	0.01734	21,000
D2	503-17-2	35	0.01686	19,400
E2	503-17-3	36	0.01734	20,100
F2	503-1-9	72	0.03833	8,400
B3	503-2-4	61	0.03248	10,900
C3	503-18-1	60	0.02700	5,100
D3	503-17-4	32	0.01542	18,600
E3	503-18-3	60	0.02700	4,400
F3	503-1-17	71	0.03780	8,900
B4	503-1-8	71	0.03780	8,200
C4	503-17-5	36	0.01734	21,700
D4	503-17-6	34	0.01638	20,100
E4	503-17-9	36	0.01734	21,400
F4	503-2-5	61	0.03248	7,200
C5	503-2-2	61	0.03248	6,500
D5	503-1-11	70	0.03727	7,200
E5	503-1-5	72	0.03833	8,000
D3 (subassembly)	503-4-31	4	0.00193	24,200

TABLE 2-7

SAXTON CORE III CALCULATED BURNUP AT 3714 EFPH (MOL)

<u>Core Location</u>	<u>Assembly Serial No.</u>	<u>Number of Rods</u>	<u>Initial MTM</u>	<u>Average Burnup MWD/MTM</u>
C1	503-1-12	71	0.03780	9,400
D1	503-1-16	71	0.03780	11,100
E1	503-2-6	61	0.03248	9,700
B2	503-10-7	68	0.03235	3,200
C2	503-17-8	36	0.01734	26,200
D2	503-17-2	35	0.01686	24,800
E2	503-17-3	36	0.01734	24,600
F2	503-1-9	72	0.03833	9,800
B3	503-2-4	61	0.03248	13,100
C3	503-18-3	60	0.02700	9,400 ⁽¹⁾
D3	503-17-4	32	0.01542	25,400
E3	503-18-1	60	0.02700	10,800 ⁽¹⁾
F3	503-1-17	71	0.03780	10,700
B4	503-1-8	71	0.03780	9,800
C4	503-17-5	36	0.01734	27,500
D4	503-17-6	34	0.01638	26,900
E4	503-17-9	35	0.01686	27,000
F4	503-2-5	61	0.03248	9,000
C5	503-2-2	61	0.03248	8,200
D5	503-10-8	68	0.03150	0 ⁽²⁾
E5	503-1-5	72	0.03833	9,300
D3 (subassembly)	503-4-31	4	0.00193	28,500

(1) Assemblies interchanged at MOL shutdown.

(2) Assembly 503-1-11 removed at MOL shutdown with discharge burnup of 9,200 MWD/MTM, and replaced with assembly 503-10-8.

TABLE 2-8

SAXTON CORE III CALCULATED BURNUP AT 5943 EFPH (EOL)

<u>Core Location</u>	<u>Assembly Serial No.</u>	<u>Number of Rods</u>	<u>Initial MTM</u>	<u>Average Burnup MWD/MTM</u>
C1	503-1-12	71	0.03780	11,100
D1	503-1-16	71	0.03780	12,900
E1	503-2-6	61	0.03248	11,200
B2	503-10-7	68	0.03235	5,100
C2	503-17-8	36	0.01734	31,800
D2	503-17-2	35	0.01686	30,800
E2	503-17-3	36	0.01734	29,900
F2	503-1-9	72	0.03833	11,400
B3	503-2-4	61	0.03248	15,600
C3	503-18-3	60	0.02700	15,300
D3	503-17-4	32	0.01542	32,600
E3	503-18-1	60	0.02700	16,800
F3	503-1-17	71	0.03780	12,800
B4	503-1-8	71	0.03780	11,800
C4	503-17-5	36	0.01734	33,800
D4	503-17-6	34	0.01638	34,300
E4	503-17-9	35	0.01686	33,100
F4	503-2-5	61	0.03248	10,900
C5	503-2-2	61	0.03248	10,100
D5	503-10-8	68	0.03150	2,800
E5	503-1-5	72	0.03833	10,900
D3 (subassembly)	503-4-31	4	0.00193	35,000

KEY:

(1) PREDICTED

(2) MEASURED

(3) $\frac{2-1}{1} \times 100$

INCORE MAP: 310.2.18.1

CORE POWER: 20.5 MWt

ROD 2: 17.0 INCHES (36.6 INCHES OUT)

Figure 2-3. Saxton Core III Flux Map at 0 EFPH (BOL)

KEY

(1) PREDICTED

(2) MEASURED

(3) $\frac{2-1}{1} \times 100$

INCORE MAP: 310.3.38

CORE POWER: 23.5 MWt

ROD 2: 17.0 INCHES (36.6 INCHES OUT)

Figure 2-4. Saxton Core III Flux Map at 1721 EFPH (70-1)

KEY:

(1) PREDICTED

(2) MEASURED

(3) $\frac{2-1}{1} \times 100$

INCORE MAP: 310.6.9

CORE POWER: 23.1 MWt

ROD 2: 18.1 INCHES (36.6 INCHES OUT)

Figure 2-5. Saxton Core III Flux Map at 3714 EFPH (MOL)

KEY:

(1) PREDICTED

(2) MEASURED

(3) $\frac{2-1}{1} \times 100$

INCORE MAP: 310.6.15

CORE POWER: 14.7 MWt

ROD 2: 17.4 INCHES (36.6 INCHES OUT)

Figure 2-6. Saxton Core III Flux Map at 5943 EFPH (EOL)

characteristics of mixed oxide fuel at higher burnups and information concerning Zircaloy clad mixed oxide fuel performance limits.

2. Movable in-core detectors with the aid of off-site data reduction codes were able to accurately monitor the lead rod power and burnups. Results from Core II and Core III flux maps indicated that no significant problems are to be expected in predicting power distributions in cores with uranium and mixed-oxide fuel assemblies.

3. Good agreement has been obtained between predicted and destructively measured burnups in mixed oxide pellets.

4. Predicted values of reactivity coefficients and control rod worths also agreed well with measured values, thus verifying the design methods and codes used during the program.

SECTION 3

EVALUATION OF CORE III FUEL*

(M. G. Balfour, N. R. Metcalf, W. R. Smalley, and T. E. Caye)

A core III end-of-life post irradiation examination sampling plan was prepared and transmitted to the AEC for review. Rod selections and the proposed program scope are summarized in Table 3-1. All rods included in this plan previously were subjected to diameter profile measurement during either the reconstitution of Core III or the middle-of-life examination program. The plan provides a pair of rods from each of four different Core III power/Core II burnup categories. The distribution within these categories is similar to the middle-of-life sampling plan and will permit a comparison of fuel performance at varying Core III burnup levels. The two rods which achieved the highest peak pellet burnup (center 3 x 3 rods IM and PF) are included in the program. These two rods will be compared with rods previously removed at midlife (rod LZ) and the 1970 interim shutdown (rod RR).

Fuel shipments from the Saxton reactor site to the hot cell facility were completed. The four loose lattice rods were removed from the center 3 x 3 subassembly. A cursory residual examination of these rods revealed no evidence of surface anomalies. Non-destructive examinations of all eight loose lattice rods included in the sampling plan will be completed during the next quarter and destructive examinations will be initiated.

*Hot cell operations conducted by BMI, Columbus, under contract to Westinghouse Nuclear Fuel Division.

TABLE 3-1

SAXTON PLUTONIUM PROGRAM CORE III END-OF-LIFE POST-IRRADIATION SAMPLING PLAN⁽¹⁾

Rod ID	Assembly Location	Rod Location	Estimated Rod Peak Burnup (MWD/MTM)	Met.	Tensile	Burst	Mn-54	Clad H ₂	c Autoradiog.	β-γ Autoradiog.	Nd-148 Burnup	H.E. (2) Burnup	Special (3) Isotopes
IM	D3	D5	50500	2	1	1	1	1	1	1	2 ⁽⁴⁾	2 ⁽⁴⁾	1
PF	D3	E6	51000	2	1	1	1	1	1	1	1	1	1
BE	D3	F1	43000	2	1	1	1	1	-	-	1	1	-
BK	E4	A8	44900	2	1	1	1	1	1	1	1	1	1
GM	E4	A2	41500	2	1	1	1	1	-	-	1	1	-
QL	D2	B2	42000	2	1	1	1	1	-	-	1	1	-
LS	E4	H3	42000	2	1	1	1	1	-	-	1	1	1
FI	E4	F1	40900	2	1	1	1	1	1	1	1	1	-

- NOTES:
1. All rods receive: visual examination with photos as needed; profilometry and length measurements; fission gas sampling and analysis; single-channel gamma scan.
 2. HE package includes U-234, -235, -236 and -238; Pu-239, -240, -241, and -242; and Pu-239/U-238.
 3. Special isotopes package includes Pu-236 and -238; Np-237; Am-241 and -243; and Cm-242 and -244.
 4. One of the burnup samples on rod IM is a radial sample including 10 samples drilled from different radii with analyses for HE and ND-148. In addition α and β-γ autoradiographs and a metallurgical mount will be prepared before drilling.