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WCAP-3385-31

SAXTON PLUTONIUM PROJECT
QUARTERLY PROGRESS REPORT FOR
THE PERIOD ENDING MARCH 31, 1972

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November 1972

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 SCOPE

This quarterly report covers work completed on the Saxton Plutonium Project during the period January through March, 1972.

1.2 OBJECTIVES

The overall objective of the Saxton Plutonium Project is to develop information concerning the utilization of plutionium 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 October through December, 1971 (WCAP-3385-30) period was written, reviewed, and prepared for publication.

The topical report "Saxton Core II Fuel Performance Evaluation, Part I, Materials," WCAP-3385-56 was published.

1.4 SUMMARY OF PROGRESS DURING THE PERIOD

The reactor operated in the load follow mode for 26 days during the months of January and February and was shut down for 34 days. The shutdown time was a result of plant maintenance and high primary coolant activities. The reactor operated at reduced steady state power levels (approximately 15 MW) for the entire month of March. The cumulative energy generated as of March 31, 1972 was 5352 megawatt days with a total of 631 load cycles. The peak burnups in the loose lattice region were:

1. For peak power rod — 26,400 MWD/MTM
2. For highest burnup rod — 49,200 MWD/MTM

Unfinished examinations on rods removed at middle-of-life were completed. Data reduction and evaluation continued throughout the quarter.

Significant effort was expended to develop a fuel reprocessing contract.

SECTION 2

CORE III OPERATIONS

(C. E. PALMER, R. L. STOVER, AND T. E. CAYE)

The reactor operated for 13 days during the month of January. The beginning-of-month 100 percent power was defined as 24.9 MW and was later reduced to 24.4 MW based on incore flux maps obtained during the month. The reactor was shut down on January 14 for planned maintenance activities. Although the shutdown was scheduled for 4 days, containment vessel activity levels caused delays resulting in an extension of the shutdown through the end of the month. All planned maintenance was completed and the reactor was hot and pressurized by January 31. A total of 241 megawatt days of operation and 82 load follow cycles were achieved in January.

The reactor was taken to power on February 1, 1972 and operated in the load cycle mode until an unscheduled shutdown on February 12, 1972. The shutdown was due to high primary coolant activities resulting from a possible fuel failure on February 11, 1972. Shutdown occurred when the estimated primary coolant activity approached the Technical Specification limit. The shutdown continued until February 29 while required maintenance functions were performed. Startup was initiated on February 29 and at the end of the month the reactor was operating at 10 megawatts. During February the reactor operated for 12 days and was shut down for 17 days. A total of 209 megawatt days of operation and 46 load cycles were achieved during the month.

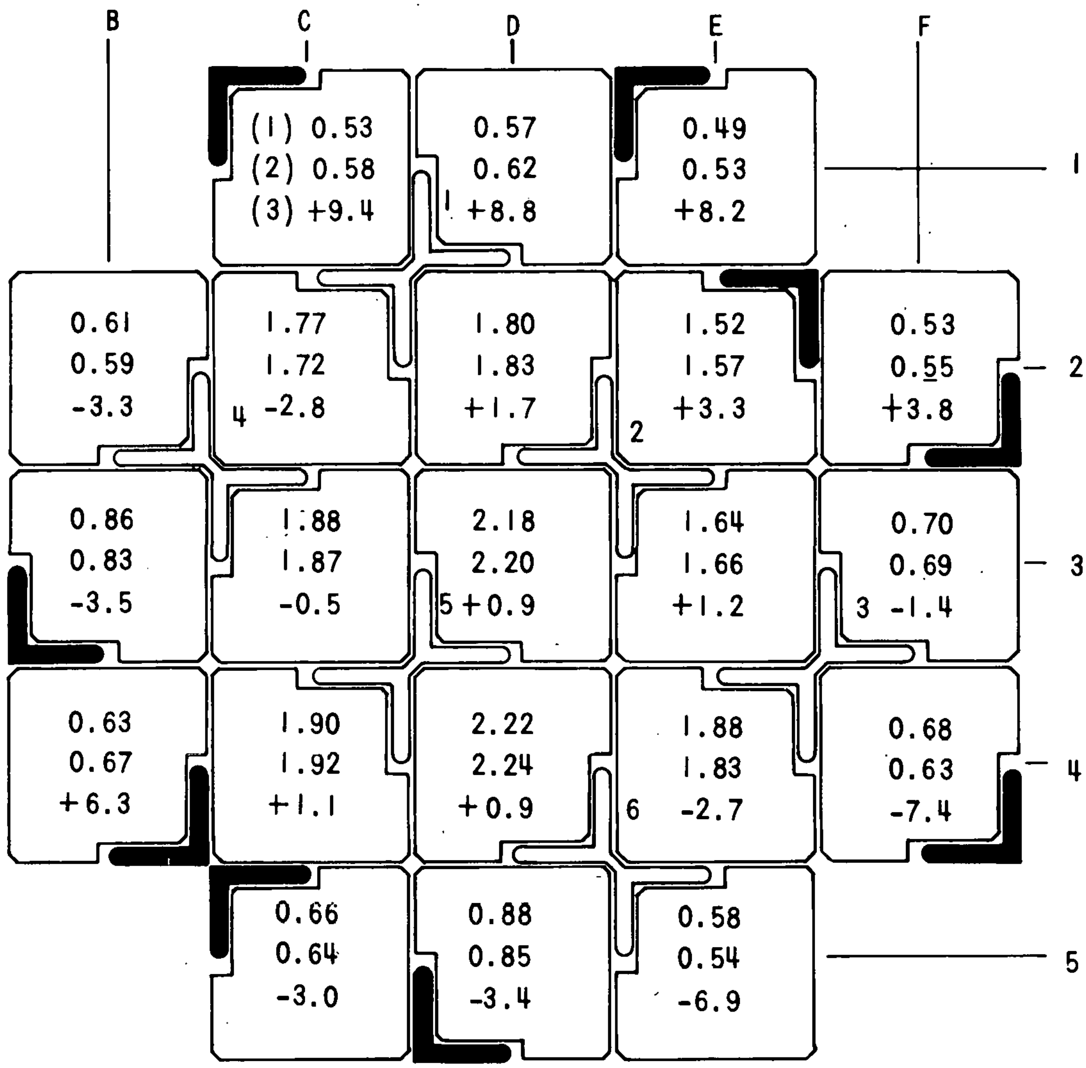
The reactor operated the entire month of March at reduced power levels due to high primary coolant activities. Reactor power through March 15 was maintained at 15 MW. During this period the primary coolant activity was stabilized at less than 50 percent of the Technical Specification limit. As a result, power was increased to 16.5 MW on March 15 and the reactor operated at this power level through the end of March. A total of 483 megawatt days of operation was achieved in March. The high primary coolant activity prevented load cycling during the month.

As of March 31, 1972, the cumulative energy generated in Core III was 5352 megawatt days, with a first quarter 1972 total of 933 megawatt days. An additional 128 load follow cycles were achieved resulting in a total of 631 since the beginning of core III.

Flux map data were analyzed to provide relative assembly and rod powers representative of the Core III January-March 1972 operating period. Figure 2-1 shows a comparison of predicted and measured relative assembly powers during this quarter. Peak pellet powers and burnups through March 31, 1972 are shown in Table 2-1. Peak pellet burnup is 49,200 MWD/MTM in center 3 x 3 rod PF.

Figure 2-2 shows the boron follow curve to 5,300 EFPH. The data extrapolate to 5,900 EFPH.

Several meetings were held with reprocessing company representatives in an effort to develop a fuel reprocessing contract.



KEY
(1) PREDICTED
(2) MEASURED
(3) $\frac{2-1}{1}$ X 100

DATE: 2-7-72
POWER: 24.2 MW
BURNUP: 4898 EFPH

Figure 2-1 Saxton Core III Flux Map

TABLE 2-1

SUMMARY OF SAXTON CORE III OPERATING HISTORY
THROUGH MARCH 31, 1972

	Through DEC 31, 1971	During JAN FEB & MAR 1972	Cumulative to MAR 31, 1972
Energy Generated, MWD	4,419	933	5,352
Number of Load Cycles	503	128	631
Peak Linear Power, Kw/ft[1]			
1. Peak Power Rod	21.2	21.2	---
2. Peak Burnup Rod (in center 3 x 3)	14.2	14.2	---
3. Peak Burnup Rod (outside center 3 x 3)	12.1	12.1	---
Peak Pellet Burnup, MWD/MTM[2]			
1. Peak Power Rod	21,100	5,300	26,400
2. Peak Burnup Rod (in center 3 x 3)	45,700	3,500	49,200
3. Peak Burnup Rod (outside center 3 x 3)	42,500	3,100	45,600

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

(2) Best estimate, fission basis.

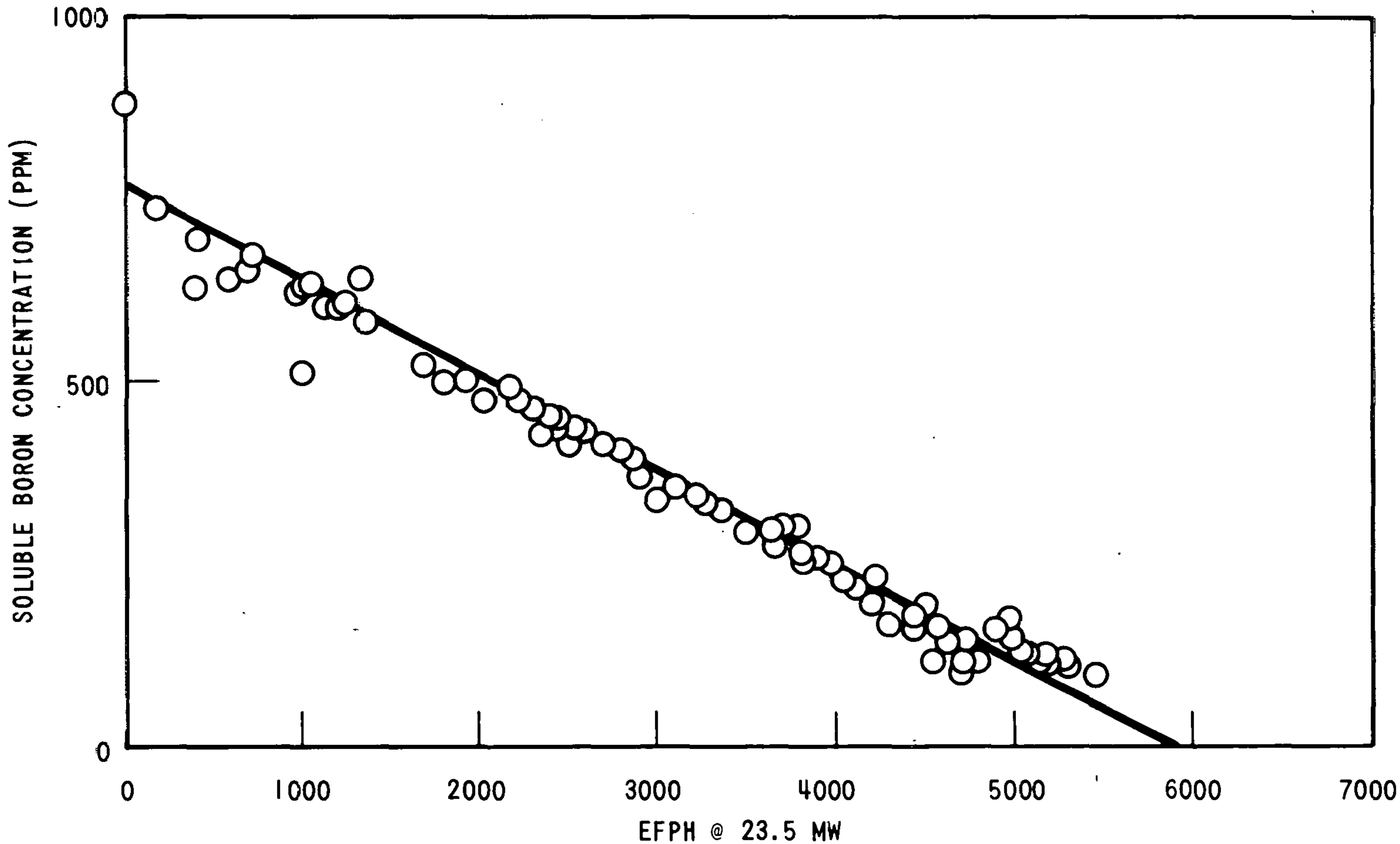


Figure 2-2 Saxton Core III Boron Curve

SECTION 3

EVALUATION OF CORE III FUEL*

(M. G. BALFOUR, N. R. METCALF, G. W. PARRY, A. C. HOTT, AND T. E. CAYE)

3.1 NONDESTRUCTIVE EXAMINATIONS OF MIDLIFE RODS

3.1.1 Profilometry Measurements

Figures 3-1 through 3-7 summarize the measured clad diametral data on the loose lattice rods profiled at midlife. Included are mean diameters and maximum and minimum diameters taken at axial locations representative of the entire fuel rod. The estimated precision on mean diameters is plus or minus 0.0002 inch (2σ). The profilometry was performed in the Battelle hot cells, using a 1/8 inch travel per revolution helical trace profilometer. No data are available on selected regions of the rods because of prior nickel electroplating for metallography.

Comparison with rod profilometry data taken during Core III acceptance examinations(1) shows that the highest burnup rod LZ (17.3 Kw/ft, 44,200 MWD/MTM) had negligible change in mean diameter during Core III. However, rod BO (21 Kw/ft, 34,800 MWD/MTM) showed a maximum diametral increase of 1.2 mils. The profilometry did not reveal any clad anomalies such as blisters, ridges, local depressions, swelling, fretting, and the like.

3.1.2 Gamma Scans

All seven rods in the sampling plan were scanned using a sodium iodide detector measuring gross gamma activity with energies greater than 0.5 Mev. The data collected were full length scans using a constant traverse rate of 2 inches per minute, a detection slit width of 0.050 inch and a counting interval of 1 second. The system is capable of detecting gaps in the fuel column of the order of 0.1 inch. The data reflect the relative power/burnup during Core III

* Hot cell operation conducted by BMI, Columbus, under contract to Westinghouse Nuclear Fuels Division.

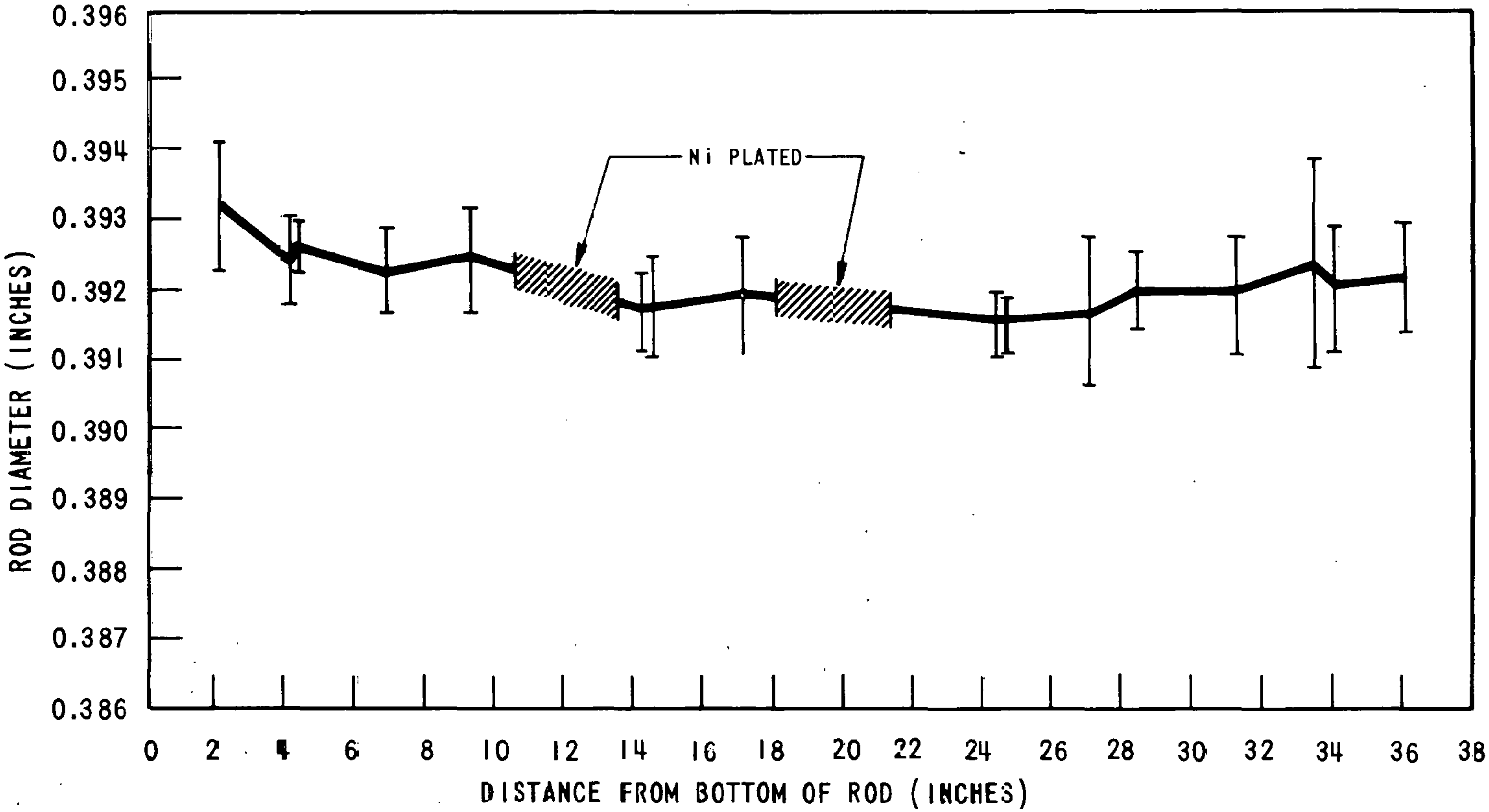


Figure 3-1 Profilometer Data for Saxton Fuel Rod LZ

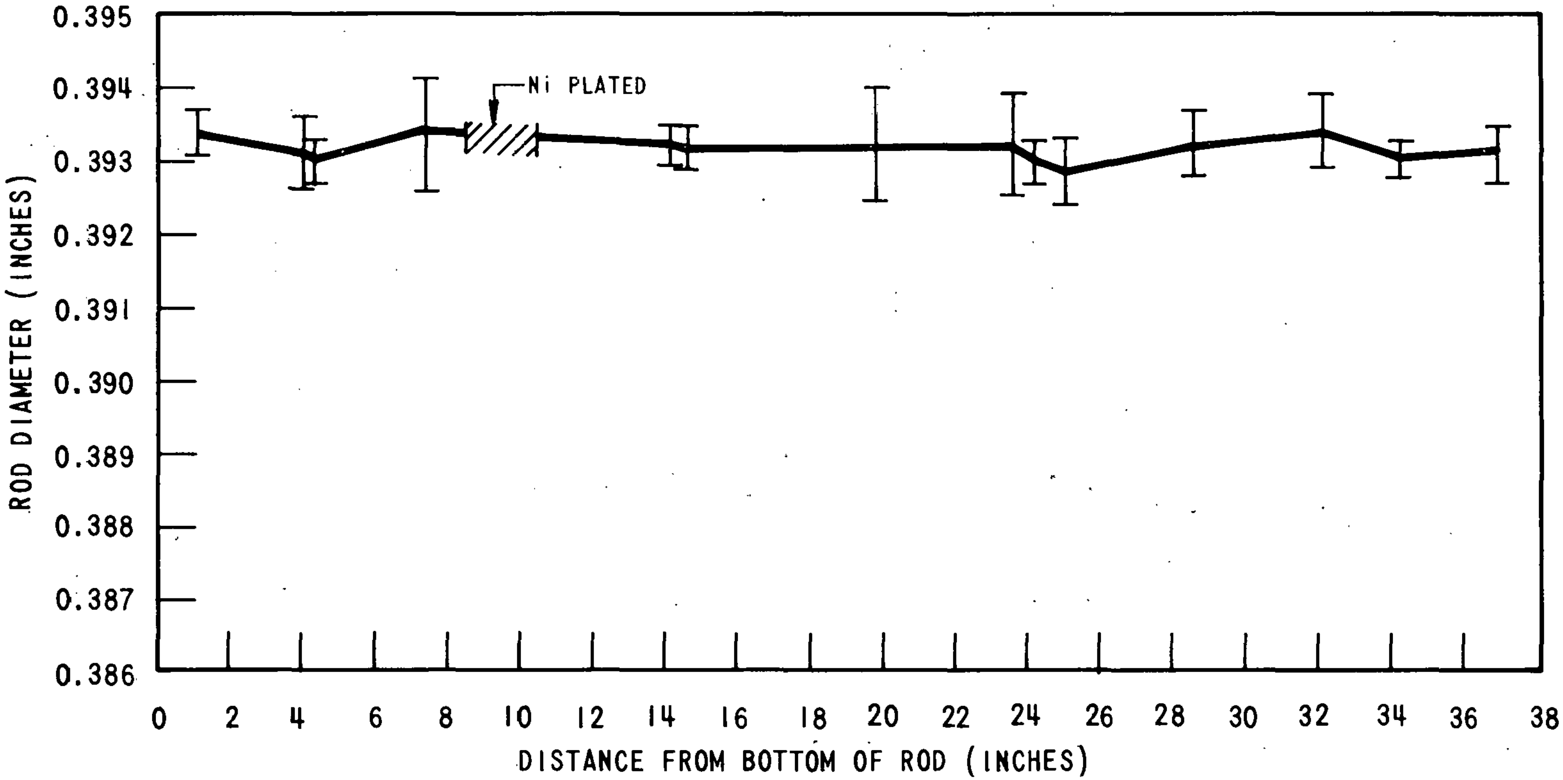


Figure 3-2 Profilometer Data for Saxton Fuel Rod BO

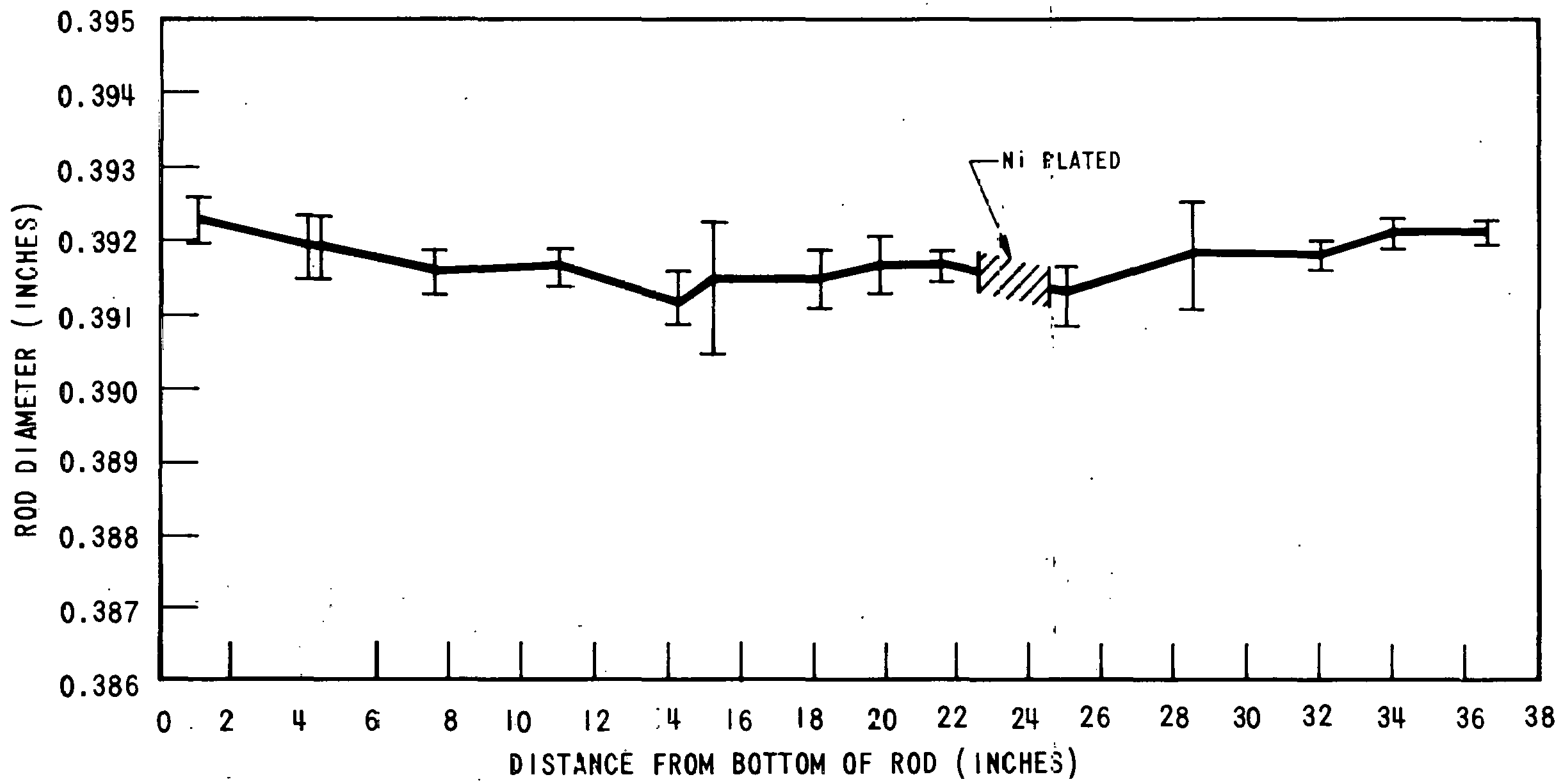


Figure 3-3 Profilometer Data for Saxton Fuel Rod FS

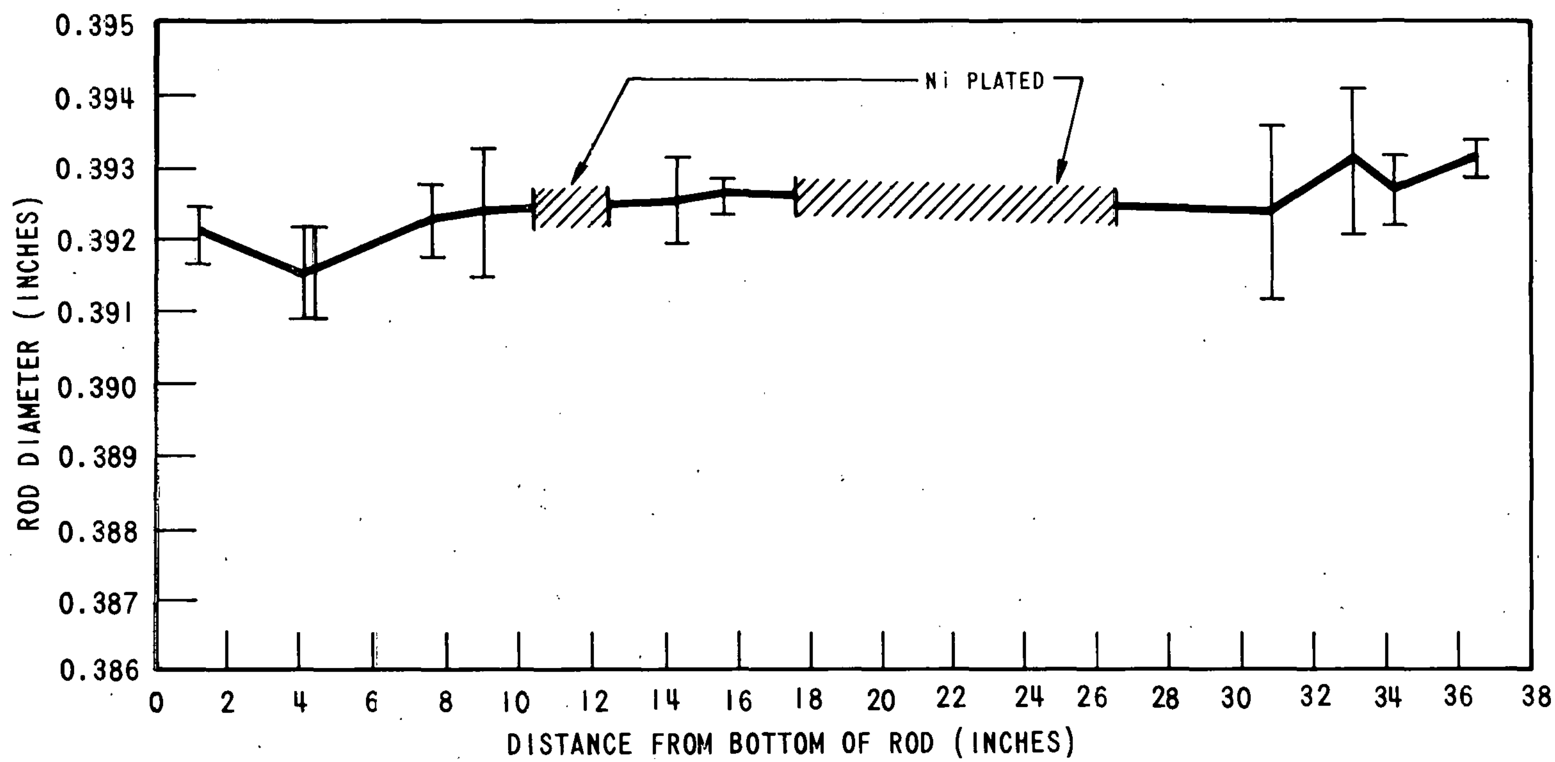


Figure 3-4 Profilometer Data for Saxton Fuel Rod GL

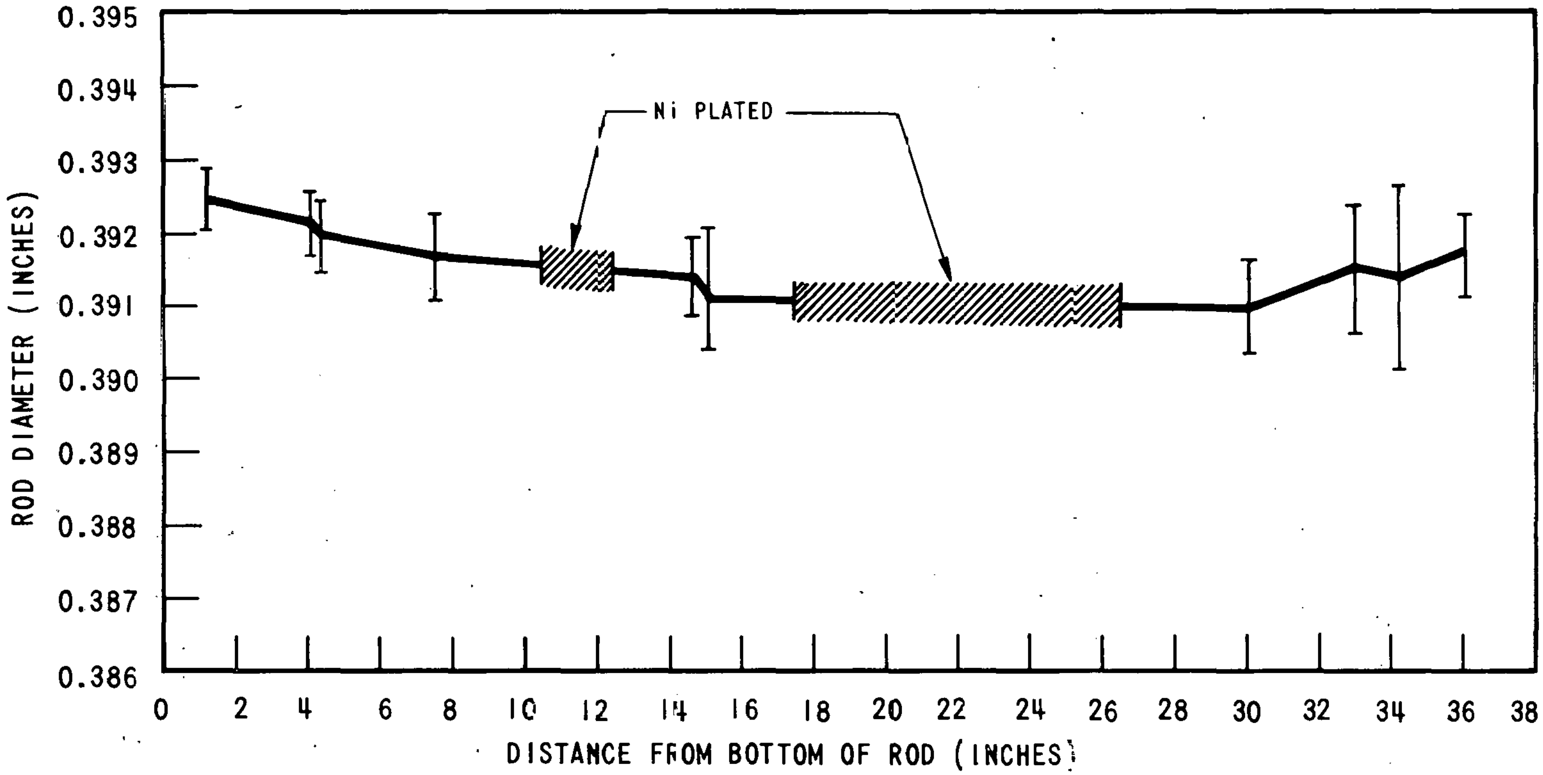


Figure 3-5 Profilometer Data for Saxton Fuel Rod MQ

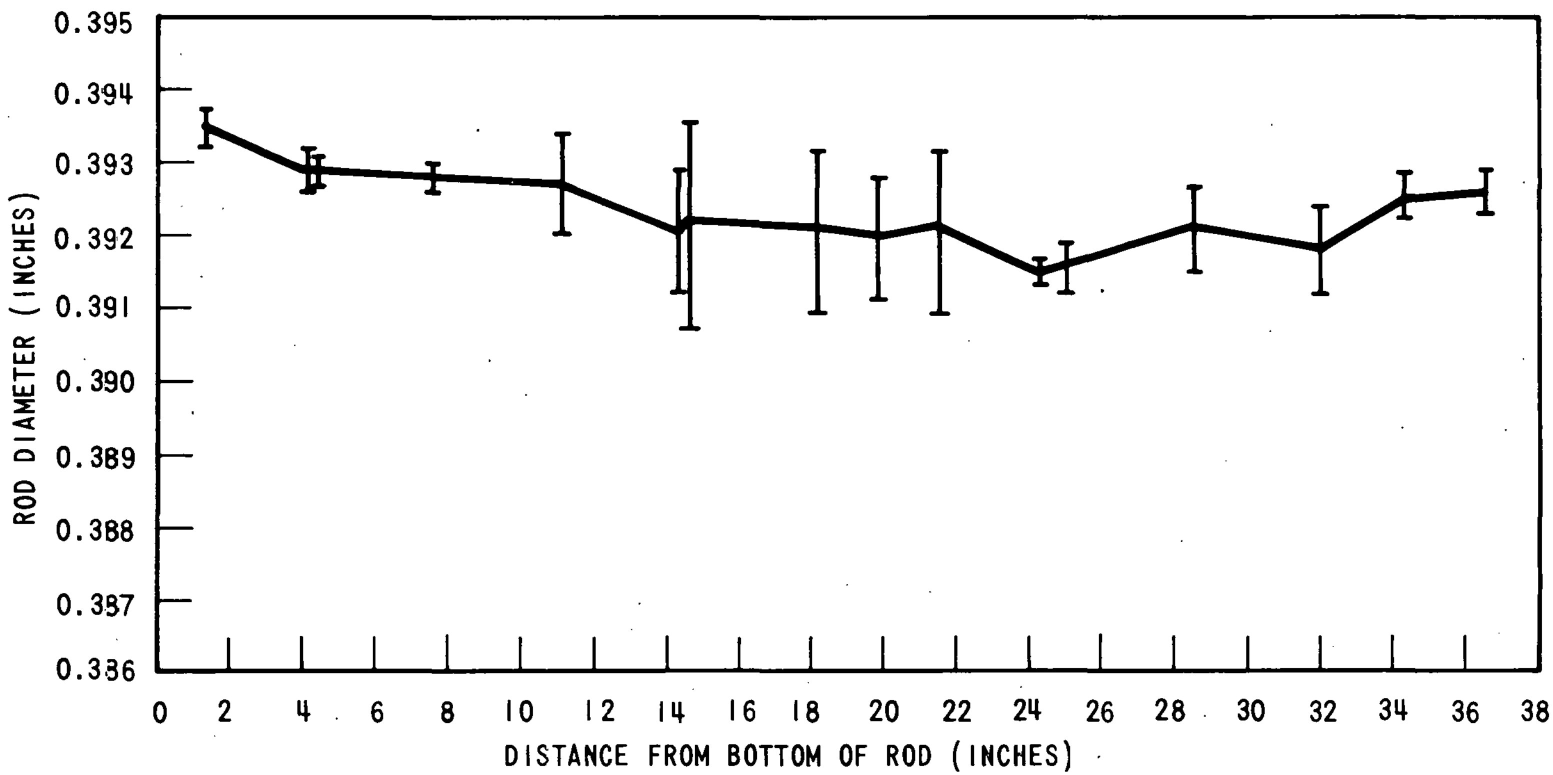


Figure 3-6 Profilometer Data for Saxton Fuel Rod NI

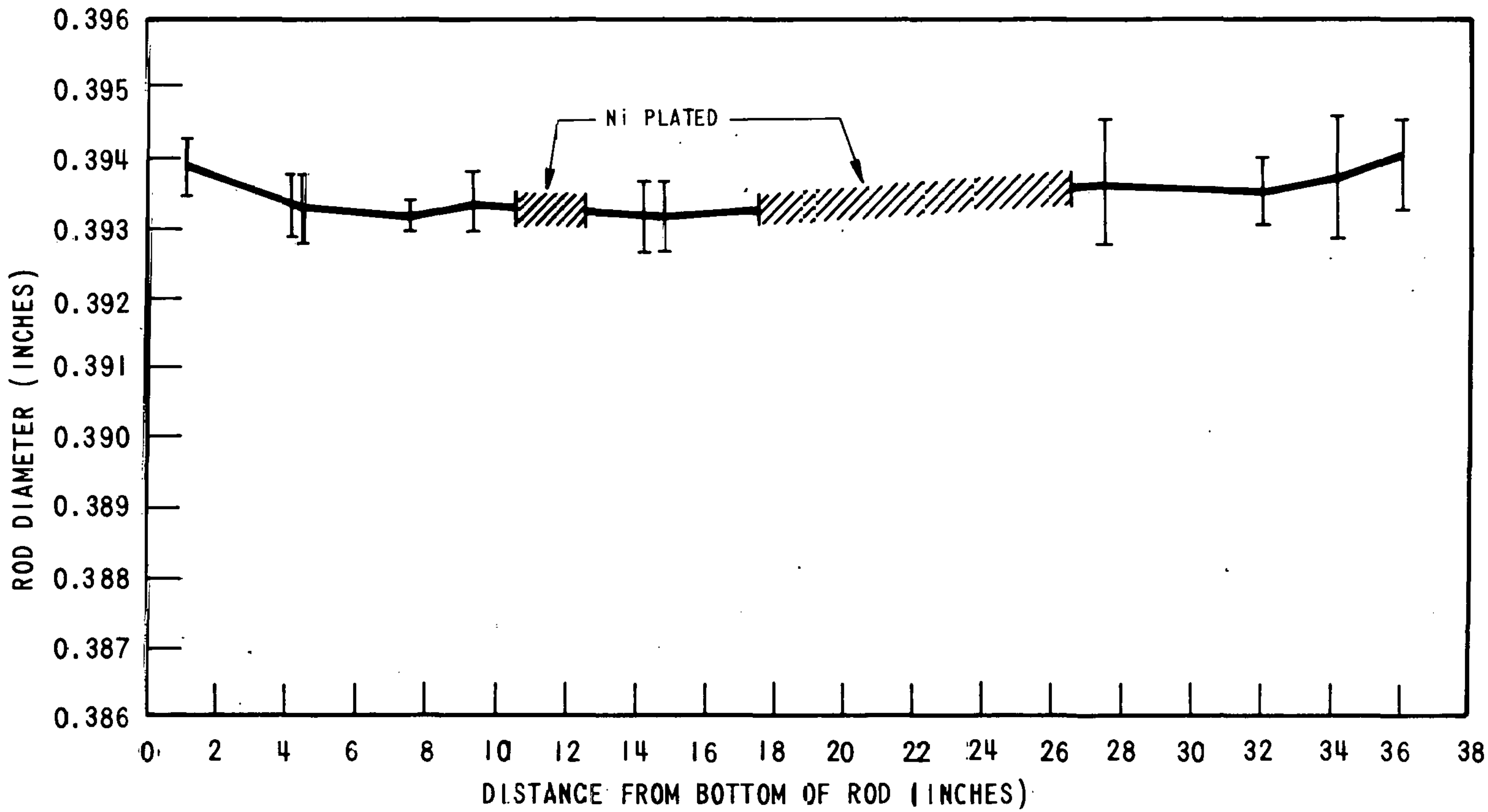


Figure 3-7 Profilometer Data for Saxton Fuel Rod RD

operation and provide a semiquantitative indication of axial fuel distribution.

Full length scans for six of the rods included in the MOL sampling plan are given in Figures 3-8 through 3-13. The gamma scan for the peak power rod BO was reported last quarter. The positions of the burnup samples are indicated on the gamma scans. The gamma activity intensities are dominated by Core II burnup. Activity peaks, however, are located at the Core II peak burnup elevation and the lower Core III peak power elevation.

The only anomaly observed was evidence of a gap in the fuel column of rod NI. As shown in Figure 3-11, the trace contained evidence of ~ 0.1 inch gap in the fuel column 21 inches from the bottom of the rod.

3.2 DESTRUCTIVE EXAMINATIONS OF MIDLIFE RODS

3.2.1 Fission Gas Release Measurements

All seven fuel rods included in the middle-of-life sampling plan were punctured in a calibrated vacuum system to collect and sample internal gases. Samples of the released gases were analyzed by mass spectrometry. Elemental and isotopic results are reported in Tables 3-1 and 3-2, respectively. Measured fractional release values are included in Table 3-1. The gas release calculations were based on calculated rod average burnups normalized to the Nd-148 measured burnup.

The data presented in Table 3-1 indicate a trend of increasing gas release with Core III peak rod power. A comparison of measured percent gas release for center 3x3 rods LZ and RR indicates little change as a result of incremental burnup and load cycling operation. These two rods had essentially identical power burnup histories in Core II and Core III to the point when rod RR was removed during the 1970 interim shutdown. Rod RR, removed after 138 load cycles, showed 32 percent gas release while rod LZ, removed after 464 load cycles, showed a 31.3 percent gas release.

The measured gas release for Core III middle of life rods (Table 3-1) is slightly higher than observed in pellet fuel during the Core II end-of-life examinations.[1]

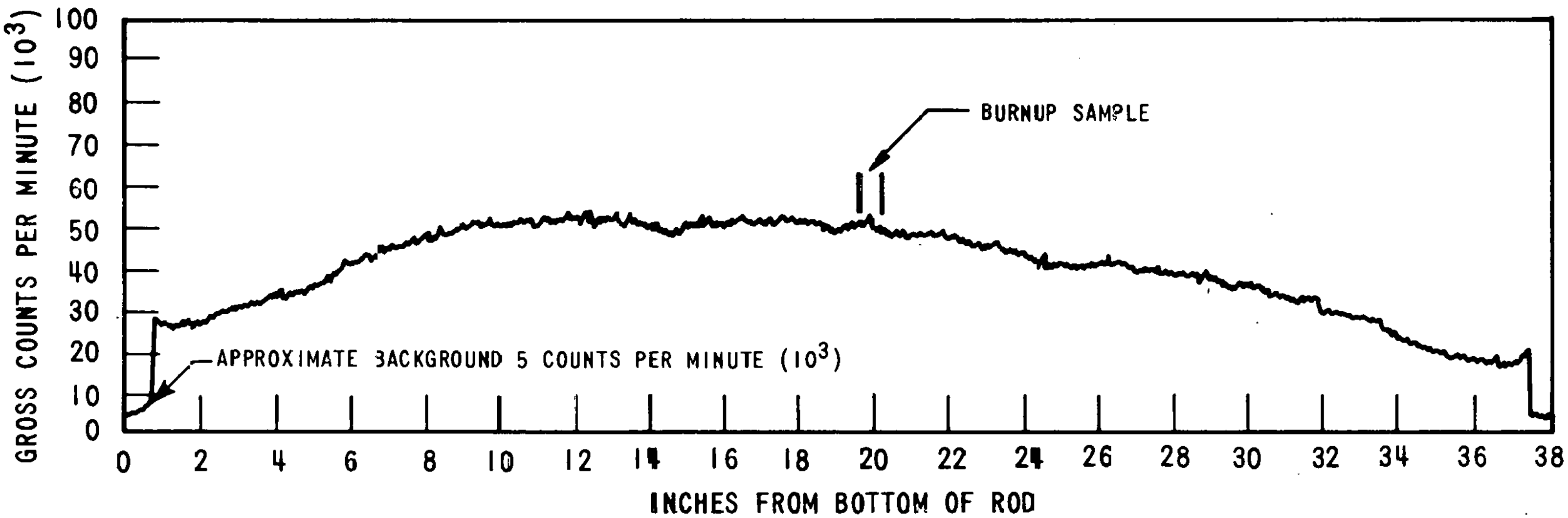


Figure 3-8. Rod LZ Gamma Scan Data Plot

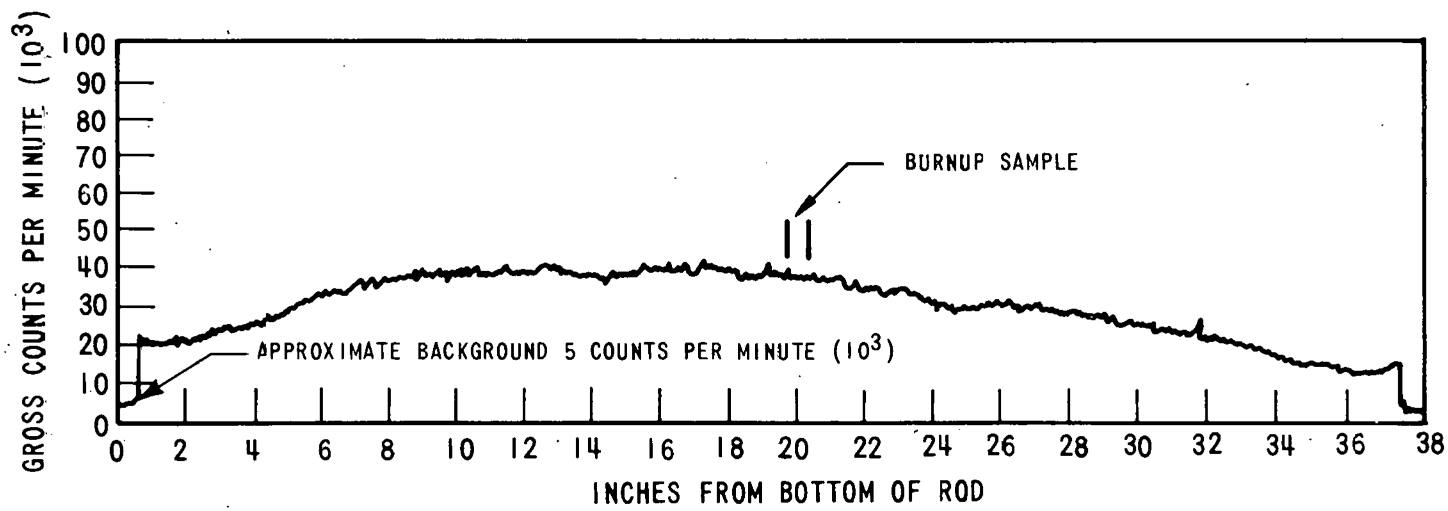


Figure 3-9. Rod RD Gamma Scan Data Plot

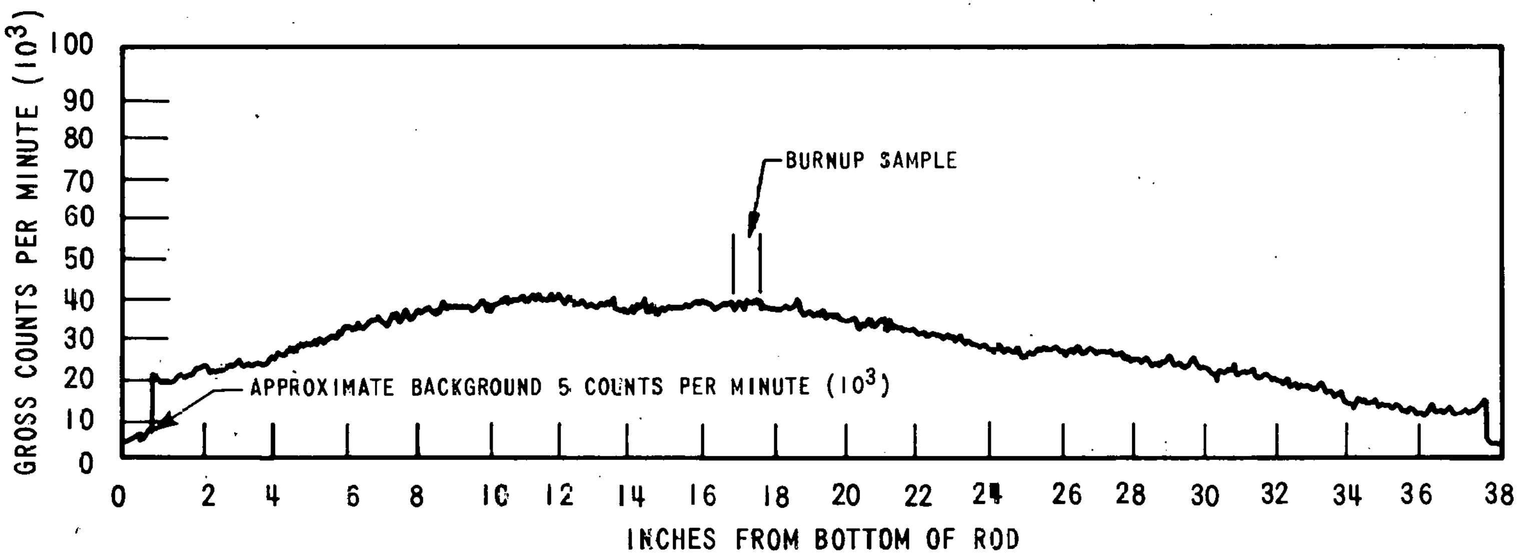


Figure 3-10. Rod GL Gamma Scan Data Plot

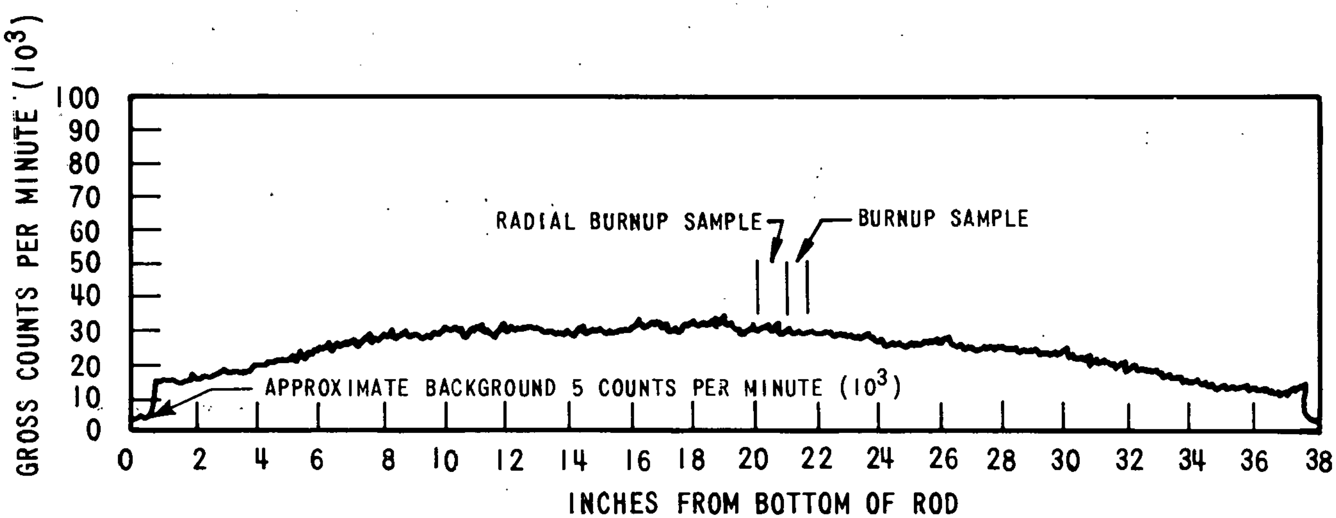


Figure 3-11. Rod MQ Gamma Scan Data Plot

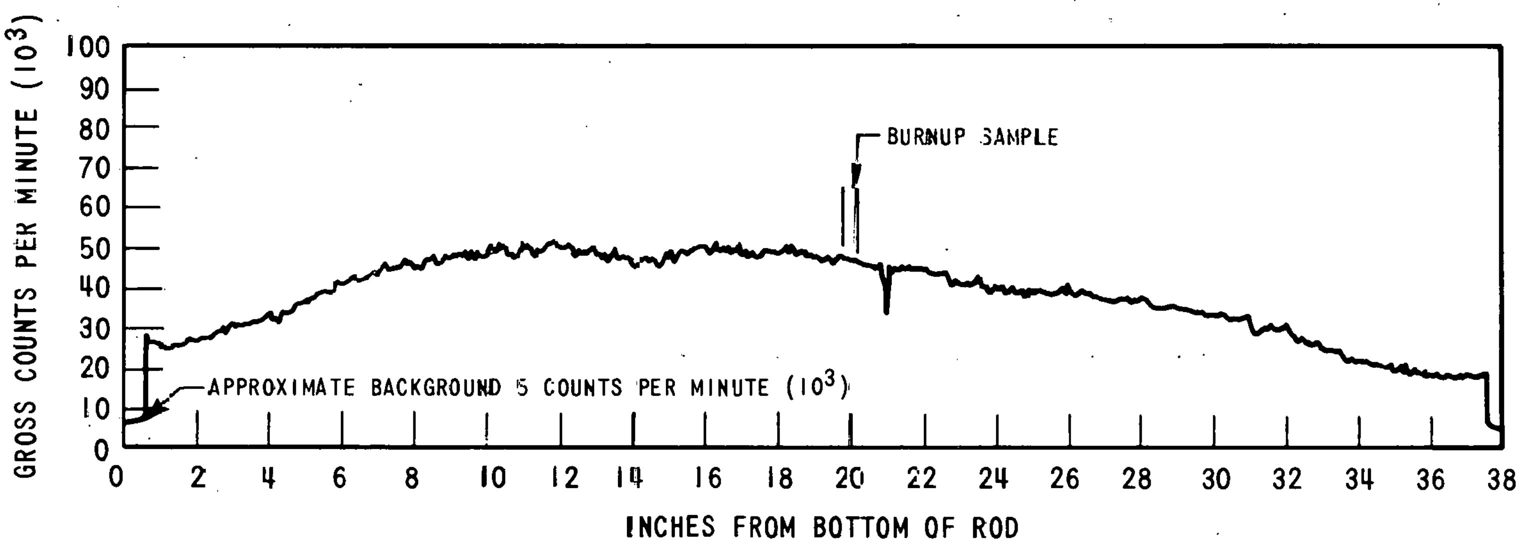


Figure 3-12. Rod NI Gamma Scan Data Plot

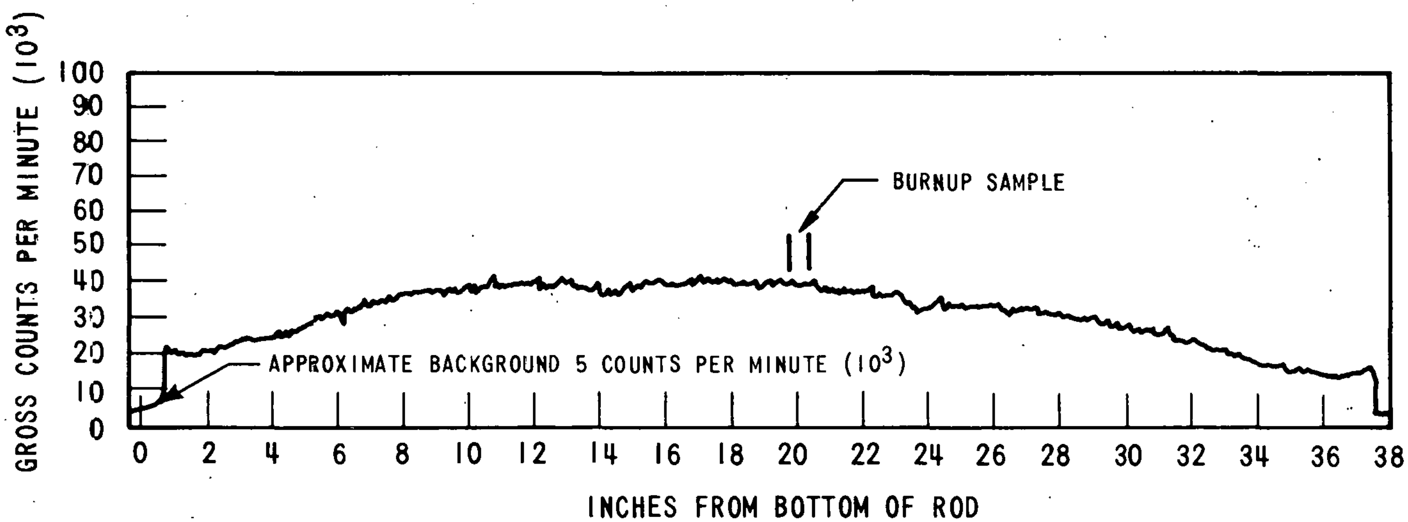


Figure 3-13. Rod FS Gamma Scan Data Plot

TABLE 3-1

FISSION GAS RELEASE DATA

Rod I.D. Number	Rod Average Burnup (MWD/MTM) (1)	Total Vol. of Gas Released (cm^3) (S.T.P.)	Gas Composition, Vol. % He	N_2	Ar	Kr	Xe	O_2	CO_2	H_2O	H_2	Measured Fractional Release %
LZ	33,700	162	7.84	1.81	.18	5.24	84.4	.33	<.01	.07	.07	31.3
			7.98	1.87	.18	5.36	84.4	.23	<.01	.02	<.01	--
MQ (2)	28,800	9.7	2.84	79.80	.96	.63	15.3	.12	<.01	.2	.08	--
			2.52	79.05	.88	.40	17.0	.03	---	---	.10	
BO	25,800	146	6.80	7.52	.37	4.89	78.7	1.65	<.01	<.01	.08	34.5
			6.70	7.26	.36	4.85	78.9	1.89	<.01	.06	.06	
NI	27,000	130	8.68	.03	.19	6.00	84.4	<.01	<.01	.04	.25	31.5
FS	25,500	98	10.4	.20	.39	5.25	83.7	.03	<.01	<.01	.07	24.9
GL	26,500	109	10.6	1.38	.44	5.30	82.1	.04	---	.05	.10	26.1
RD	26,100	120	8.66	.04	.31	5.32	85.5	<.01	---	.02	.17	30.4
RR (3)	25,100	123	3.94	.78	.27	5.99	83.9	.01	---	---	.15	32.0

(1) Calculated rod average values normalized to measured Nd-148 burnup

(2) Backup analysis performed at Waltz Mill

(3) Data previously reported in the quarterly progress report for October-December 1970 (WCAP-3385-26)

TABLE 3-2

SAXTON MIDDLE-OF-LIFE FISSION GAS ISOTOPIC DATA

Rod I.D.	Krypton Composition, a/o				Xenon Composition, a/o			
Number	83	84	85	86	131	132	134	136
LZ	16.6	30.6	6.1	46.7	12.1	20.9	27.5	39.5
LZ	16.3	30.6	6.0	47.1	12.0	20.9	27.6	39.5
MQ	16.6	30.7	5.85	46.8	12.4	21.4	28.0	38.2
BO	16.7	30.0	6.3	47.0	13.0	20.4	27.8	38.8
BO	16.8	29.8	6.2	47.2	13.0	20.3	27.9	38.8
NI	16.9	30.1	6.1	46.9	12.8	20.9	28.0	38.3
FS(1)	16.6	30.4	6.1	46.9	12.8	20.9	28.0	38.2
GL(2)	16.9	30.1	5.8	47.2	12.8	21.1	28.2	37.8
RD(3)	16.8	30.1	6.1	47.0	12.8	20.5	28.0	38.6

(1) Xe-129 = .02, Xe-130 = .08
(2) Xe-129 = .02, Xe-130 = .10
(3) Xe-129 = .03, Xe-130 = .09

The total volume of gas released from each rod listed in Table 3-1 varies slightly from the preliminary values reported in the last quarterly report.[2] These values are based on more precise pressure and temperature measurements. Only rod BO shows a significant change (∿6 percent) from the previously reported values.

Reference was made in the last quarterly report to minor inconsistencies in the mass spectrometry data. The data in question were the volume percent nitrogen levels reported for rods BO and LZ. Although the levels appeared high relative to levels observed in the other MOL rods, a reanalysis of backup gas samples gave comparable data. Both the nitrogen to oxygen ratio and the presence of a significant quantity of oxygen suggest that these constituents resulted from air leakage into the sampling system.

As discussed in the last quarterly report, the gas data for rod MQ is strongly indicative of a failed rod. All nondestructive and destructive P.I.E. data were reviewed in an attempt to clarify the condition of the rod when it was removed from the reactor. Although no evidence of failure (other than missing fission gas) was observed, clad metallography did reveal extensive hydriding in localized areas. In the absence of further data, rod MQ must be identified as a suspect failure.

3.2.2 Metallography

A. Clad Metallography

The major part of the metallographic effort during the last quarter was spent in data reduction and compilation. Table 3-3 summarizes the external clad corrosion measurements taken at axial locations corresponding to the peak Core II and III heat flux locations. The Nd-148 burnups for each section are also listed in Table 3-3. The oxide thicknesses are within predicted maximum levels.

Clad hydride precipitation of the loose lattice rods was generally light to moderate. The peak burnup rod LZ has previously been reported[2]; typical hydride precipitate levels for rod BO (high Core III power level) and FS (intermediate Core III power level) are shown in Figures 3-14 and 3-15. The only anomalous hydride precipitation was observed in low-power rod MQ, in which the 18.75-inch

TABLE 3-3

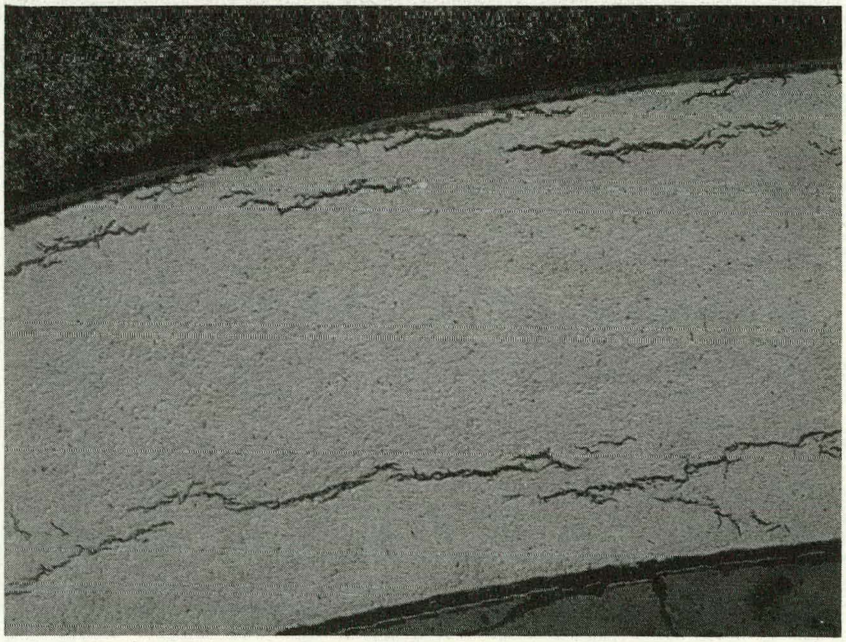
SUMMARY OF SAXTON LOOSE LATTICE CORROSION DATA (MOL)

Rod ID	Burnup MWD/MTM	Power Level Kw/ft	Section Location In. From Bottom	Oxide Thickness Range, mils
LZ	40,700	13.2	20.75	1.13 - 1.40
	43,500	17.2	12	0.34 - 1.16
BO	34,200	18.8	18	0.50 - 0.63
	33,900	20.8	11	0.34 - 0.61
FS	33,100	14.5	18	0.26 - 0.84
	32,800	15.3	12	0.25 - 0.88
GL	31,900	10.2	18.75	0.35 - 0.58
	35,700	15.1	12	0.28 - 0.62
MQ	37,200	10.1	18.75	0.33 - 1.18
	36,700	10.5	12	0.39 - 1.14
NI	34,800	15.7	18	0.30 - 0.54
	35,600	18.3	12	0.39 - 0.61
RD	33,400	13.8	18	0.36 - 0.64
	34,800	17.1	12	0.34 - 0.70

NOTES:

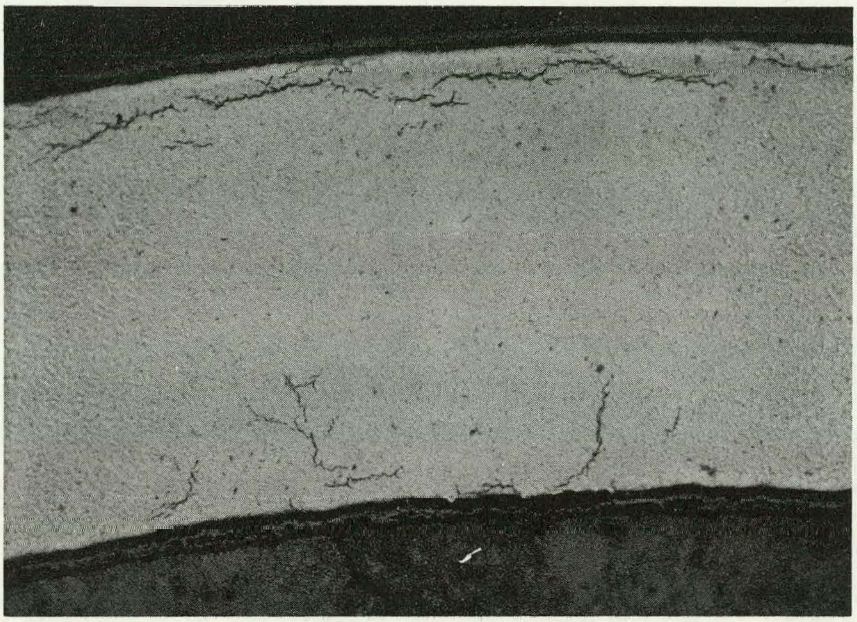
(1) Power levels are best estimate thermal at 23.5 MWt reactor power; burnups are from Nd-148 analyses.

(2) Power levels are estimates for the specific axial location from which the metallographic sections were removed.



BO-11-11 100X

Figure 3-14. Typical Clad Hydride Precipitate Level, Rod BO, 11 Inches from Bottom



FS-12-29 100X

Figure 3-15. Typical Clad Hydride Precipitate Level, Rod FS, 12 Inches from Bottom section exhibited extensive (virtually solid) OD hydriding, locally occurring over a 45° arc of the clad (see Figure 3-16). The 12-inch section appeared normal, with moderate hydride precipitates. This anomaly may be related to previously observed hydriding in several Core II fuel rods[3], since rod MQ contained fuel from the same pellet lot as these rods.

B. Fuel Metallography

A total of 14 transverse sections were mounted and examined for fuel behavior studies, 2 from each of the 7 rods. The sections were selected to examine the Core III peak power region of the rod and the the peak burnup positions.

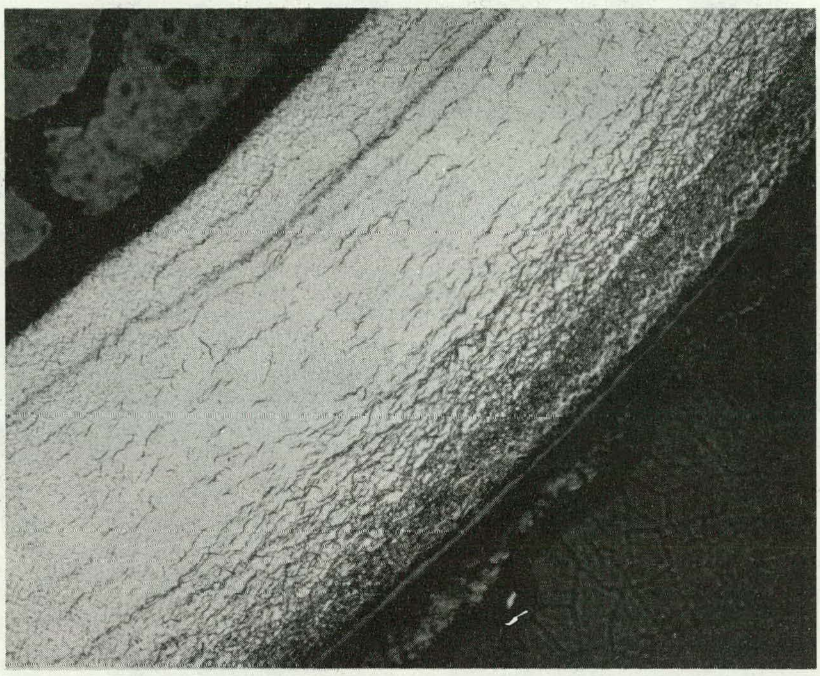
Macroexamination

All sections examined displayed typical pellet cracking. The lower powered sections exhibited a well developed pattern of radial cracks and less well defined circumferential cracks. The sections from rods which operated at powers greater than 13 Kw/ft (all rods except MQ) exhibited a well defined circumferential cracking pattern also.

Large pores or gas bubbles were visible in the peripheral region of the fuel outside the radius of grain growth. Columnar grain growth was obvious in the sections from rods NI, RD, and BO. A typical example is shown in Figure 3-17. The sections from LZ contain a series of radially oriented pores in the central region which gave the appearance of columnar grains.

Microstructure

The major microstructural features of note were: gas bubbles associated with PuO_2 particles, a region of low porosity, equiaxed grain growth, columnar grain growth, central void formation, and the distribution of metallic precipitates. These features are illustrated in Figures 3-18 through 3-21. A systematic progression of microstructures at the pellet centers were observed. The microstructure



MQ-18.75-30 100X

Figure 3-16. Heavy O.D. Hydride Precipitation, Rod MQ, 18.75 Inches from Bottom, 225°, Transverse Section

ZERO DEGREE

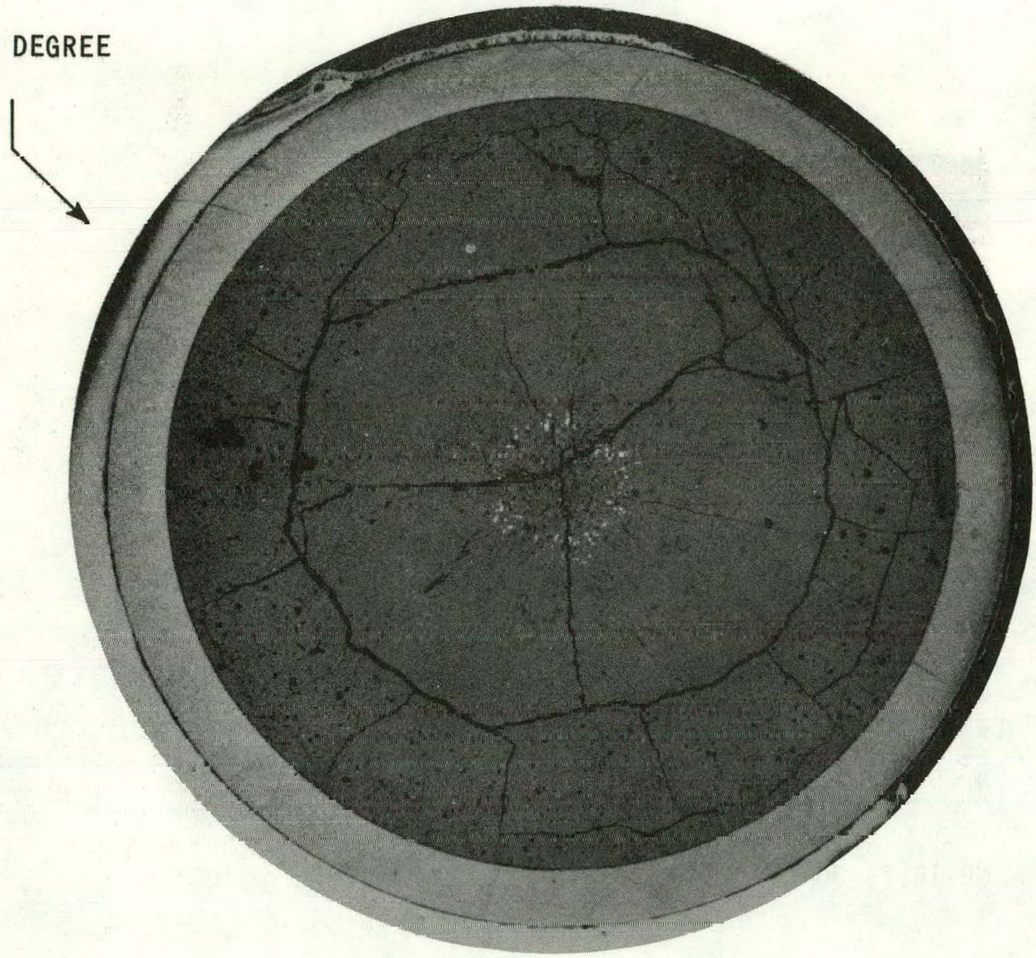
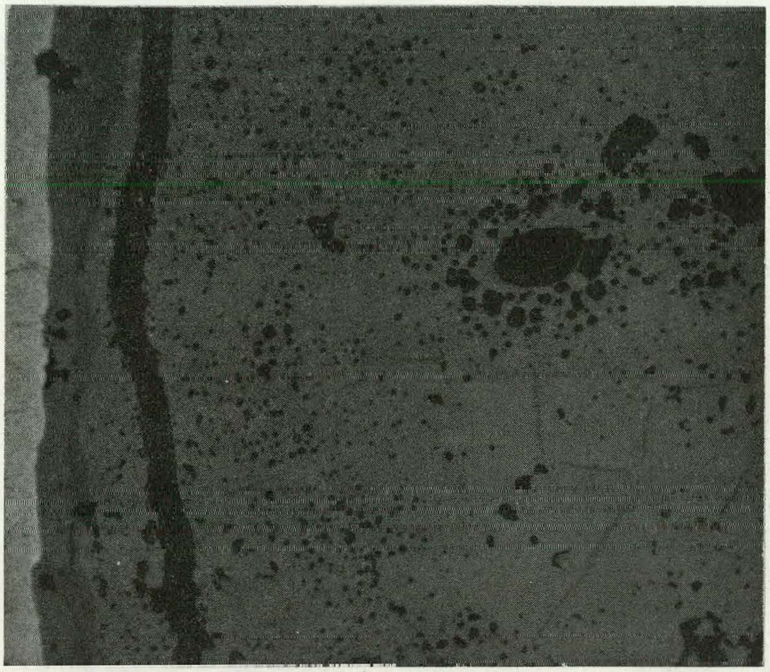
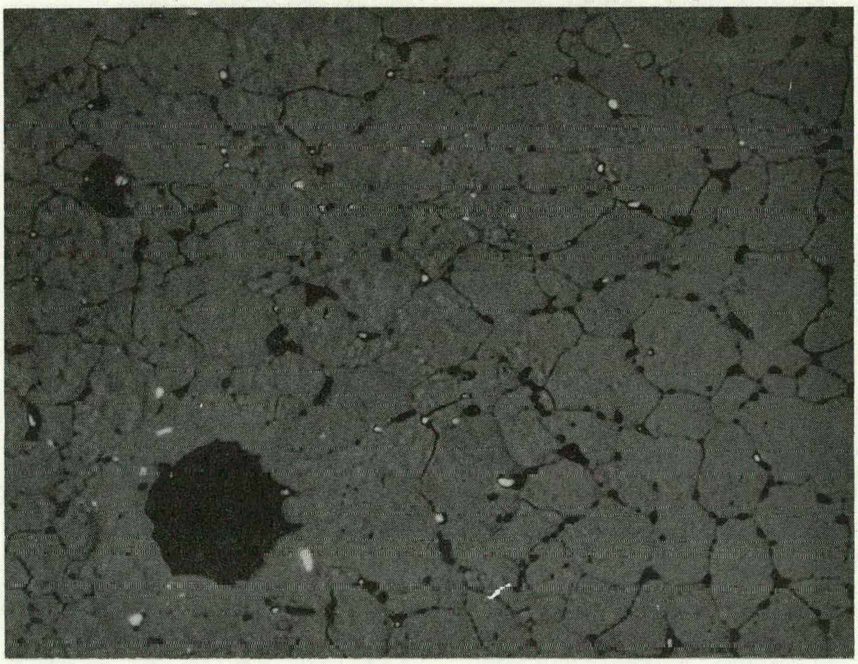


Figure 3-17 Photomacrograph of a Transverse Section of Fuel Rod BO, 17 Inches from Bottom



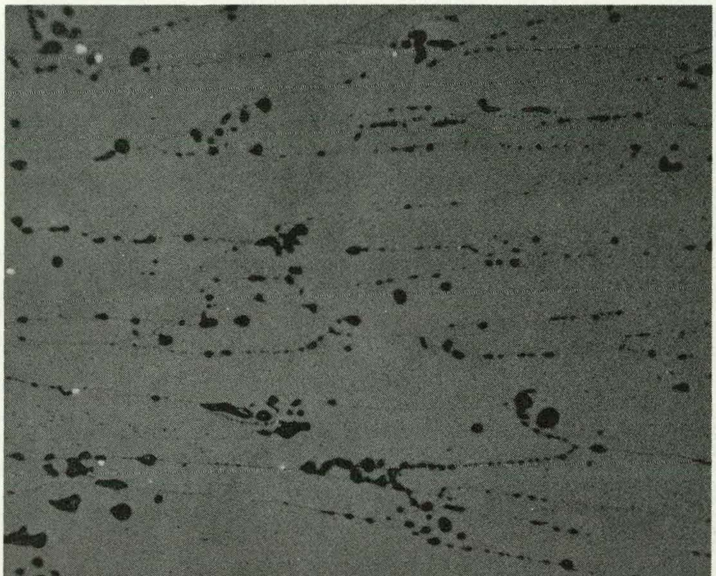
NEG. LZ-20.75-32 500X

Figure 3-18. Gas Bubble Concentration in a PuO_2 Rich Area in Rod LZ, 20.75 Inches from Bottom



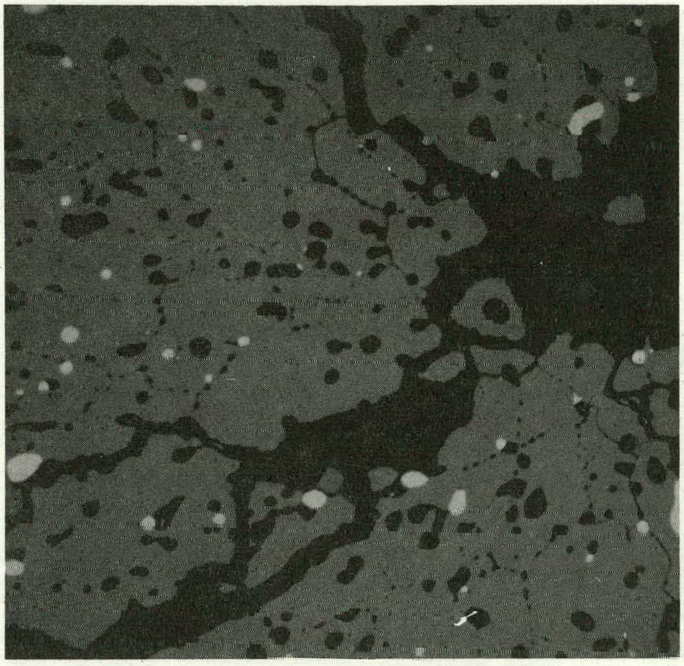
NEG. LZ-16.75-29 500X

Figure 3-19. Large Gas Bubble and Fission Products in PuO_2 Rich Area of Rod LZ, 16.75 Inches from Bottom



NEG. BO-17-20 150X

Figure 3-20. Region of Columnar Grain Growth in Rod BO,
17 Inches from Bottom



NEG. BO-17-8 150X

Figure 3-21. Central Region of Rod BO, 17 Inches from Bottom, Showing Large Precipitates, Equiaxed Grains, and Spheroidal Pores varied from one of equiaxed grain growth in the peak section of the low-powered (∿10 Kw/ft peak linear power) rod MQ to one of columnar grain growth with central void formation in the peak power region of rod BO (∿21 Kw/ft peak linear power). The microstructural variations observed were consistent with those expected based on the predicted peak powers of these rods.

Large aggregations of pores were associated with the original PuO_2 particles in the peripheral regions of the sections (Figure 3-18). This was previously reported in the sections examined at end-of-life (Core II). The volume of porosity, however, appears to have significantly increased during Core III operation. The fine fabricated pores are almost absent in a narrow zone surrounding the region which exhibited grain growth; in this zone and in the edge of the equiaxed grain growth region usually only one very large pore is associated with each original PuO_2 particle (Figure 3-19). In the region which exhibited equiaxed grain growth, the bulk of the porosity is located on grain boundaries. No large pores or pore clusters associated with the fabricated PuO_2 particles were observed in the region which exhibited equiaxed grain growth.

C. *Autoradiography*

Alpha and beta-gamma autoradiographs were prepared of the peak power sections from rods MQ, LZ, and BO. The autoradiographs indicate the degree of homogenization of PuO_2 particles, the extent of local plutonium generation, and the presence of any significant segregation of fission products. The specific rods were examined because MQ represented a high burnup at relatively constant power of ~ 10 Kw/ft, LZ was the highest burnup rod removed from Core III at midlife, and BO experienced the highest power of any rod removed. Radiographs from all three rods showed evidence of discrete PuO_2 particles in the periphery of the section and homogenization toward the center. The degree of homogenization ranged from incomplete in the MQ section to complete over two-thirds of the section radius in the BO section.

The photomacrograph, β-γ radiograph, and alpha radiograph of the section from rod BO are shown in Figures 3-17, 3-22, and 3-23. Higher alpha activity near the periphery of the fuel, due to the greater plutonium higher isotope production (higher burnup) in this region, is clearly shown in the alpha radiograph. This behavior was observed in the alpha radiographs of all three rods. The β-γ autoradiograph of rod BO exhibits typical features for fuel which has experienced columnar grain growth. The central region contains a zone of high fission product activity and an adjacent zone of low activity.

The pattern of behavior observed in the autoradiographs of these sections is consistent with those previously reported for sections of similar power histories.

3.2.3 Clad Hydrogen Analysis

Clad hydrogen analyses of quarter-inch ring samples are summarized in Table 3-4. The samples were analyzed by vacuum extraction at the Technical Service Laboratories, Waltz Mill (ARD). For comparison, the Core II analyses showed 51 - 93 ppm[4]. The MOL results in general confirm the metallography, which indicated moderate hydride precipitate levels. Rod MQ is slightly high, which is probably related to the observed locally heavy hydride precipitation (Figure 3-16).

3.2.4 Manganese-54 Fast Flux Measurements

Eight cladding samples were analyzed for manganese-54 activity and iron content. The results were used to infer the fast neutron fluence ($E > 1$ Mev). The measured Mn-54 activity and the resulting fluence are shown in Table 3-5.

3.2.5 Mechanical Property Evaluation

Tensile and burst testing of loose lattice rods was completed during the period; the results are shown in Tables 3-6 and 3-7, respectively. The tensile specimens were tested in an Instron tensile tester at a

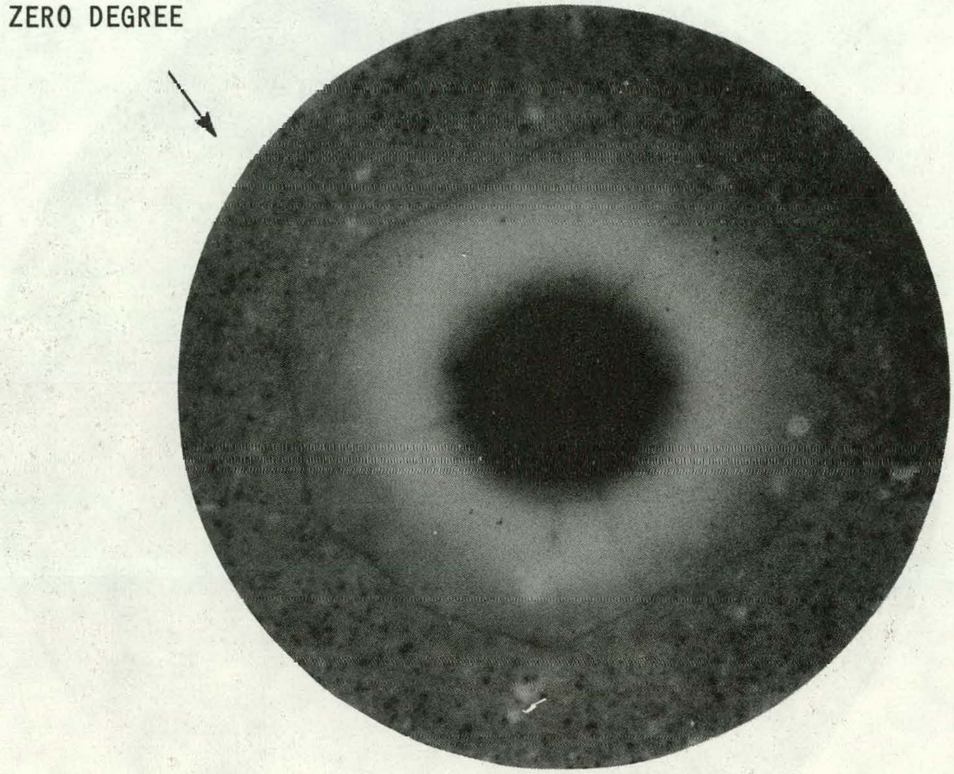


Figure 3-22. β-γ Autoradiograph of Rod BO, (Dark Spots Represent High β-γ Activity)

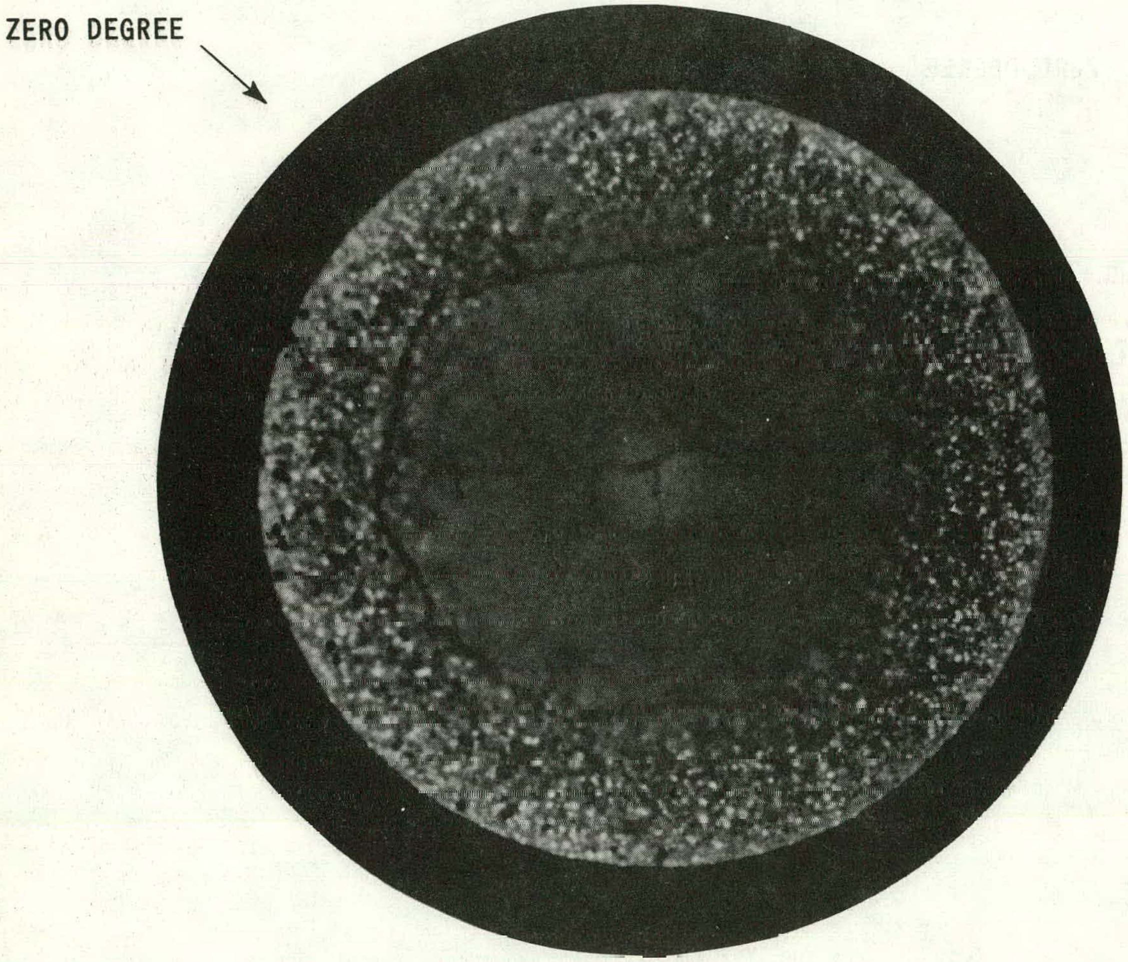


Figure 3-23. Alpha Radiograph of Rod BO, (White Areas Represent High Alpha Activity)

TABLE 3-4

CLAD HYDROGEN ANALYSIS

Rod ID	Sample Location Inches from Bottom	Average Hydrogen Concentration[1] (ppm)
LZ	20.75 - 21.0	103
BO	18.75 - 19.0	80
FS	18.75 - 19.0	70
GL	18.75 - 19.0	78
MQ[2]	18.75 - 19.0	111
NI	18.75 - 19.0	71
RD	18.75 - 19.0	66

(1) Average of two samples.

(2) Rod MQ ring sample was taken at 18.75 to 19.0 inches from the bottom of the rod. It was located immediately above the transverse met section which showed extensive hydriding (Figure 3-16).

TABLE 3-5

FLUENCE RESULTS[1]

Fuel Rods From Which Fluence Samples Were Taken	Sample Midpoint Location Inches From Bottom of Fuel Stack	Measured Mn-54[2] Activity $dpm/mg\ Fe \times 10^7$	Mn-54 Measured Fluence> 1 Mev $n/cm^2 \times 10^{21}$
LZ	20.38	5.26	3.9
NI	19.38	4.48	3.3
RD	19.38	4.25	3.2
GL	19.38	3.66	2.7
FS	11.38	3.78	2.8
FS	19.38	3.73	2.8
FS	27.38	3.03	2.3
MQ	27.13	2.81	2.1
BO	19.38	4.85	3.6

(1) End of irradiation for these rods was March 12, 1971.

(2) Mn-54 activities corrected to December 1, 1971.

TABLE 3-6

TENSILE TEST DATA

Rod ID	Location, Inches From Bottom	Testing Temp, °F	0.2% Yield Stress psi x 10^3	Ultimate Tensile Strength psi x 10^3	Uniform Strain % In 2" Gage Length	Total Strain In 2" Gage Length
BO	11 - 17	650	61.4	65.6	2.2	6.8
BO	26 - 32	650	58.1	68.9	2.4	11.3
RD	3 - 9	650	62.2	70.0	2.0	4.2
RD	12 - 18	650	60.5	65.4	1.7	5.8
MQ	12 - 18	675	70.4	77.4	1.9	6.1
MQ	28 - 34	675	66.0	75.1	1.6	6.2
FS	28 - 34	675	57.2	71.4	3.9	12.9
GL	12 - 18	675	60.5	71.5	2.4	9.3

TABLE 3-7

BURST TEST DATA AT 675°F

Rod ID	Location (inches from Bottom)	0.2% Yield Stress(1) psi x 10^3	Failure Stress(1) psi x 10^3	Failure Strain %	% Reduction In Wall Thickness
MQ	3 - 11	70.4	72.4	4.8	28
NI	3 - 11	67.7	71.7	16.1	24
NI	26 - 34	64.5	69.7	6.3	36
BO	3 - 11	67.1	70.4	19.0	24
GL	3 - 11	65.1	68.4	18.3	33
GL	28 - 36	73.0	76.3	2.6	25
FS	3 - 11	63.8	69.7	18.3	23
RD	26 - 34	63.2	71.1	4.6(2)	4

(1) Based upon thick wall formula for generalized stress.
(2) Pin hole failure.

crosshead speed of 0.02 in./min, monitored over a 2-inch gage length. The burst test specimens were run with closed ends at a hoop/axial stress ratio of 2/1 with the fuel intact. The internal pressurization rate was 2000 psi/min. Failure strains were measured from transverse metallographic sections taken at the plane of maximum deformation. The maximum test temperature for the loose lattice rods was based on post-irradiation annealing studies made at EOL Core II to provide cross comparison between Core II and Core III data. The Core II annealing studies showed that the maximum test temperature should be limited to 675°F.

The results of tensile and burst tests performed on Core II end-of-life fuel rod cladding were reported earlier[4]. Comparisons of the tensile test data indicate higher yield and ultimate strengths for the Core III samples, and lower ductility. The burst test data indicate similar yield and failure stresses for Core II and Core III; the failure strain data for Core II are too erratic for a meaningful comparison with the current results.

3.2.6 Burnup Analysis and Isotopic Compositions

Burnup data reduction and evaluation were completed. From the mass spectrometric data, burnup was determined by both the heavy element and Nd-148 methods. Burnup results for the two methods and isotopic compositions are shown in Table 3-8, for rod samples, and in Table 3-9 for the radial micro-drill samples from rod MQ. Burnup results for the two methods are comparable to within 5 percent. These results are similar to previous Saxton results.

A comparison of rod LZ measured burnup (listed in Table 3-8) to calculated burnup (43,300 MWD/MTM as reported in reference 5) shows burnup predictions are within 2 percent of the measured values. The radial drill samples on MQ show the expected effect of self-shielding within the fuel with an increasing burnup toward the O.D. of the pellet. The agreement between heavy element and Nd-148 analyses is somewhat better than the previously reported Core II results[6].

TABLE 3-8

BURNUP RESULTS AND ISOTOPIC COMPOSITIONS (1)

Fuel Rods From Which Burnup Samples Were Taken	Sample Midpoint Location, Inches From Bottom Of Fuel Stack (2)	Measured Burnup, MWD/MTM			Isotopic Compositions (3), a/o								
		Heavy Element	Nd-148	$\frac{\text{HE-Nd}}{\text{Nd}} \times 100$	U-234	U-235	U-236	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
FS	18.5	31700	32500	-2.5	.005	.488	.050	99.458	.367	60.842	29.342	7.930	1.519
NI	18.5	32400	33500	-3.2	.004	.477	.051	99.468	.388	60.337	29.580	8.073	1.620
RD	18.5	30900	31800	-2.8	.005	.487	.048	99.461	.331	60.553	29.987	7.689	1.441
BO	18.5	31900	32900	-2.9	.005	.483	.050	99.463	.365	59.753	30.408	7.897	1.576
LZ	18.75	40200	41800	-3.7	.004	.414	.061	99.520	.585	52.343	33.762	10.579	2.730
GL	18.5	30200	31500	-4.2	.005	.523	.050	99.422	.361	62.731	27.824	7.661	1.422
MQ	20.5	34800	35700	-2.5	.004	.463	.055	99.473	.445	58.571	30.234	8.842	1.908

(1) End of irradiation for these rods was March 12, 1971.

(2) Burnup samples had nominal lengths of 0.5 to 1.0 inch.

(3) Analysis were performed between 11/11/71 and 12/15/71.

TABLE 3-9

BURNUP RESULTS AND ISOTOPIC COMPOSITIONS FOR RADIAL SAMPLES IN ROD MQ[1]

Radial Drill Sample Designation	O.D. of Annular Sample, Inches	Measured Burnup, MWD/MTM			Isotopic Composition[2], a/o								
		Heavy Element	Nd-148	$\frac{HE-Nd}{Nd} \times 100$	U-234	U-235	U-236	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
RD-1	0.1088	29600	31400	-5.7	0.00444	0.483	0.0522	99.460	0.317	62.345	29.589	6.552	1.199
RD-2	0.1515	30500	32200	-5.3	0.00449	0.471	0.0535	99.471	0.355	60.322	30.760	7.171	1.392
RD-3	0.1900	31500	33000	-4.3	0.00443	0.477	0.0527	99.465	0.334	61.471	30.103	6.807	1.285
RD-4	0.2198	32800	33900	-3.1	0.00440	0.466	0.0544	99.475	0.375	59.233	31.306	7.562	1.524
RD-5	0.2328	33500	34700	-3.4	0.00445	0.463	0.0550	99.477	0.399	58.311	31.662	7.979	1.649
RD-6	0.2720	34800	36400	-4.3	0.00456	0.458	0.0616	99.476	0.474	56.882	31.925	8.797	1.922
RD-7	0.2850	36500	37700	-3.3	0.00456	0.448	0.0579	99.489	0.514	55.689	31.916	9.689	2.192
RD-8	0.2998	38400	38800	-1.1	0.00469	0.444	0.0590	99.493	0.577	54.829	31.535	10.575	2.484
RD-9	0.3330	43100	43400	+0.6	0.00479	0.437	0.0636	99.495	0.689	54.565	28.889	12.649	3.207
RD-10	0.3374	53200	50600	+5.1	0.00470	0.424	0.0629	99.508	0.770	56.655	24.523	14.248	3.804

[1] Radial drill sample located 19.25" - 20.25" from bottom of fuel stack.

[2] Analyses were performed between 12/16/71 and 1/19/72. Samples RD-2 and RD-3 appear to have been reversed.

SECTION 4

REFERENCES

1. W. R. Smalley, "Saxton Plutonium Program. Semi-Annual Progress Report for the Period Ending June 30, 1969," WCAP-3385-20, October 1969.

2. T. E. Caye, "Saxton Plutonium Program. Quarterly Progress Report for the Period Ending December 1971," WCAP-3385-30, June 1972.

3. W. R. Smalley, "Saxton Plutonium Project. Quarterly Progress Report for the Period Ending March 31, 1970," WCAP-3385-23, May 1970.

4. W. R. Smalley, "Saxton Core II Fuel Performance Evaluation Part I: Materials," WCAP-3385-56, September 1971.

5. T. E. Caye, "Saxton Plutonium Project. Quarterly Progress Report for the Period Ending September 1971," WCAP-3385-29.

6. R. J. Nodvik, "Saxton Core II Fuel Performance Evaluation Part II: Evaluation of Mass Spectrometric and Radiochemical Analyses of Irradiated Saxton Plutonium Fuel," WCAP-3385-56, July 1970.