Prairie Island High Burnup LTA Inspection Report

October 2004

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Executive Summary

Assembly T81R was placed in the center core position in Unit 1 Cycle 21 for its third cycle of irradiation. It achieved an assembly-average burnup of [ ]^{a,b,c} MWD/MTU.

An assembly visual inspection of T81R showed [

]^{a,b,c}.

Assembly growth measurements showed the assembly length increased [ ]^{a,b,c} inches from its nominal dimension. The assembly grew [
]^{a,b,c}. The absolute growth corresponds to [
]^{a,b,c}. This fits the expected growth rate for Zirlo fuel assemblies.

The average fuel rod growth from rod to nozzle gap measurements was [ ]^{a,b,c}. This rod growth is consistent with Zirlo rod growth database. [

]^{a,b,c}.

Peripheral fuel rod corrosion measurements resulted in peak oxide thickness that ranged from [

]^{a,b,c}.

Grid corrosion measurements showed oxide thickness ranging from [ ]^{a,b,c} microns. The lowest corrosion was at Grid 2 and the highest at Grid 6. The grid material was Zr-4. This material is more susceptible to corrosion than the Zirlo material. Therefore, it is not unexpected to find higher levels of corrosion on the grid straps compared to the fuel rods, even though the grids are non-heat producing surfaces.

1.0 Introduction/Background

Fuel inspections were performed on fuel assembly T81R as part of a high burnup test program. Assembly T81R was originally supplied to Prairie Island as part of Region 18, the feed region of Unit 2 Cycle 16. It was irradiated for two cycles in Cycles 16 and 17, and then was inspected as part of the IRI (Incomplete Rod Insertion) inspection program conducted in June 1997. These inspections included measurements of peripheral fuel rod oxide thickness, guide thimble oxide thickness, RCCA drag tests, fuel assembly growth, fuel rod growth, and instrument tube growth.

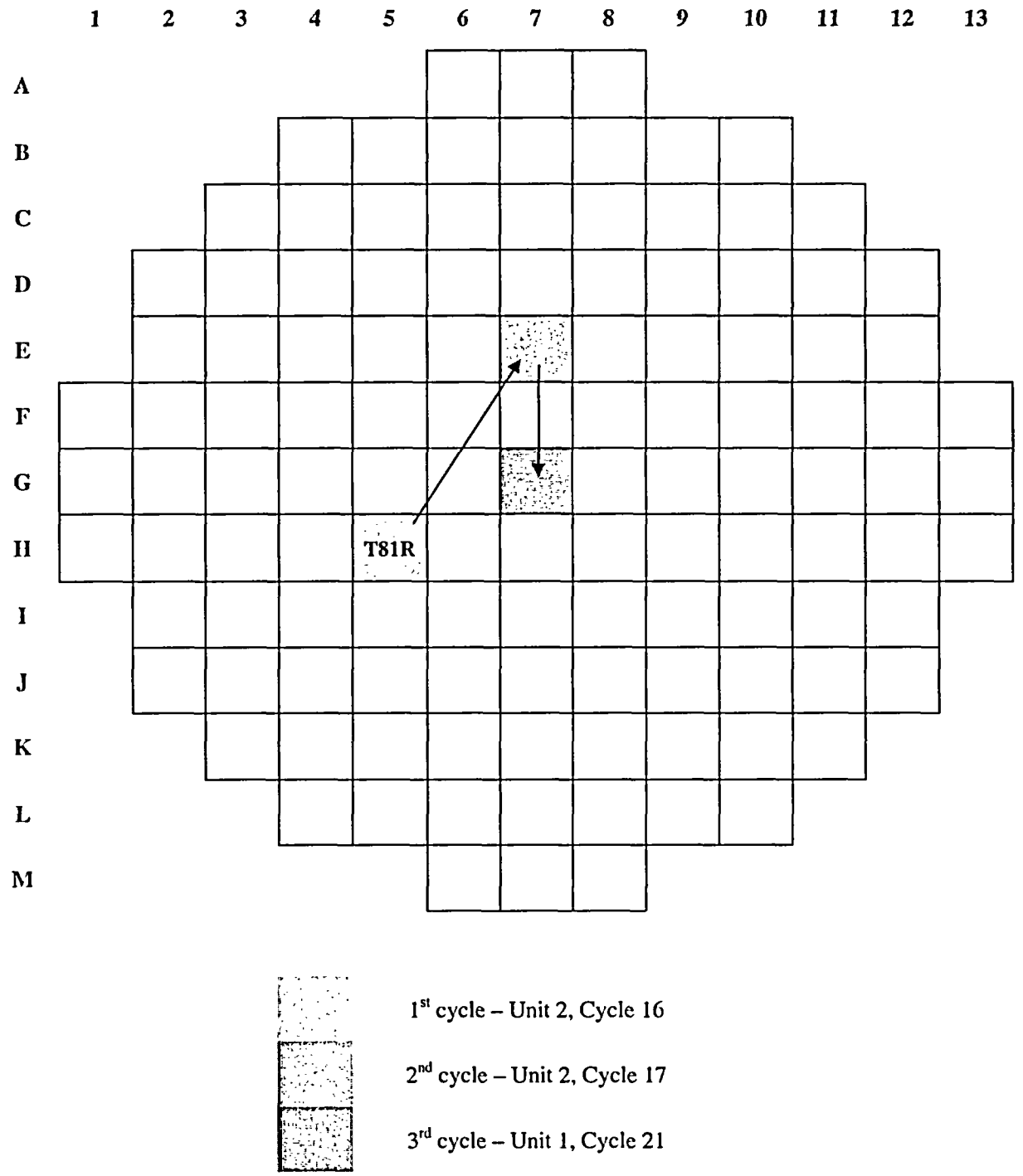
Later, assembly T81R was chosen to be a test assembly to collect high burnup fuel performance data. It was re-inserted into Unit 1 Cycle 21 at the center core location. The assembly was discharged at the EOC-21 in October 2002 after achieving an assembly-average burnup of [ ]$^{a, b, c}$ MWD/MTU. A fuel inspection was performed in June 2004 to obtain the high burnup performance data. The inspections included measurements of assembly growth, fuel rod growth, peripheral fuel rod oxide thickness, and grid oxide thickness.

Assembly T81R is a 14x14 rod array design with the following features:

a) Zirlo fuel rod cladding with Zr-4 end plugs
b) Zirlo guide thimbles and instrument tube
c) Improved Zr-4 middle grids
d) Inconel 718 top and bottom anti-snag grids
e) Removable top nozzle
f) Debris filter bottom nozzle
g) 167 fuel rods with 4.95% U-235 fuel and 4.95% U-235 annular axial blanket
h) 12 fuel rods with 6% Gd_2O_3 and 2.97% U-235 fuel, and 3.95% U-235 solid axial blanket

The nominal, non-irradiated assembly length is [ ]$^{a, b, c}$ inches and the nominal, non-irradiated fuel rod length is [ ]$^{a, b, c}$ inches. The skeleton consists of 16 guide thimbles, 1 instrument tube, and 7 grids.

Figure 1-1 Location of Assembly T81R during its Three Cycles of Operation



2.0 Objectives/Work Scope

Fuel inspections at Prairie Island were limited to the post-characterization requirements of the NRC. Prairie Island is a relatively low-duty plant. High burnup inspections at another plant with high fuel duty will provide an upper bound for corrosion, growth, and hydrogen pickup behavior due to the more aggressive environment.

2.1 Assembly visual

An assembly visual inspection was performed to assess the overall condition of the fuel assembly and observe the levels of crud deposition and corrosion. The spaces between the top nozzle and fuel rod top and the bottom nozzle and fuel rod bottom were observed to allow subsequent measurement for determination of fuel rod growth.

The camera was mounted on a pole and hung from the wall of the spent fuel pool. The camera was positioned just above the spent fuel racks and the view was maintained in a horizontal position parallel to the top of the racks. The fuel assembly was brought to an open water area and lowered and raised in front of the camera. All four faces were viewed in this fashion. Effort was made to minimize use of camera tilt (up and down motion), but some left and right panning was required to obtain complete views of the rod-to-nozzle gaps at the necessary magnification.

2.2 Assembly growth

The length of fuel assembly T81R was measured to determine the growth of the assembly after three cycles of irradiation. The assembly had previously been measured after two cycles of irradiation. Length measurement was performed in accordance with Westinghouse field procedure SAE-RRS-FP-115(84) Rev 6. A description of the tool may be found in this procedure.

A measurement cell in the spent fuel storage racks, U18, was selected for performance of the length measurement. An adjacent cell, V18, was selected as a reference cell. A length standard was placed in the measurement cell and the length of the standard was measured three times. The pool temperature was recorded prior to the length measurements. The length standard was removed from U18 and placed in the reference cell. The standard was measured three times in the reference cell. Assembly T81R was placed in U18 and measured three times. The pool temperature was recorded again at this time. The length standard was again measured three times in the reference cell and compared to previous measurements to ensure consistency (all measurements within +/- 0.003 inch). Assembly T81R was then returned to its storage location and the length standard was placed in the measurement cell, U18. The length standard was measured a final three times in this location to verify calibration of length measurements (all standard measurements in this location within +/- 0.003 inch). A final measurement of pool temperature was recorded at this time.

2.3 Rod growth

The lengths of peripheral fuel rods in T81R were measured to determine the fuel rods' growth after three cycles of irradiation. Fuel rod length is determined by measuring the spaces between the fuel rods and the top and bottom nozzles. These spaces are known as top and bottom shoulder gaps, respectively. The total shoulder gap is subtracted from the distance between the top and bottom nozzles to determine rod length. The distance between the nozzles is adjusted for assembly growth as determined by the assembly length measurement.

2.4 Peripheral rod oxide

Fuel clad corrosion was measured on selected peripheral rods from all four faces of assembly T81R. Fuel rods 1, 5 through 10, and 14 (numbered from left to right when viewing the face) were measured on each face. Therefore, corner rods (1 and 14) were measured twice at 90° apart. Measurements were performed on the outer face of each rod over the 6 spans between the outer grid straps.

Twenty-five data points per inch are acquired. The data points are averaged over the inch interval and the resulting value is reported at the center of that interval. The acquisition system is calibrated using oxide references ranging from 6 to 95 microns of thickness. Qualified data must be obtained between two successful calibration checks, requiring measurement of the oxide references to be within +/- 3 microns.

The two highest duty faces, 1 and 4, were brushed with Scotch-brite pads after the initial measurement and measured again after brushing. This provides some information about the effect crud may be having on the oxide thickness measurements.

2.5 Grid oxide

Grid corrosion was measured on the outer straps of the 5 middle grids on each face. These measurements provide corrosion performance data for non-heat source structural material. Measurements are made by using a surface-riding eddy current probe that measures lift-off distance from the base metal. The probe was set up to scan across the outer strap from the right edge to the left edge. Initial measurements were tested at several positions on the grid. The best data was obtained with the probe positioned near the top of the grid, above the spring slots but below the grid tabs. This includes the area of the strap welds, but spikes in the data caused by the weld surfaces were removed.

Twenty-five data points per inch are acquired. A running average of the 25 data points is calculated at each data point (using the given data point plus 12 backward and 12 forward data points). The acquisition system is calibrated using oxide references ranging from 10 to 76 microns of thickness. Qualified data must be obtained between two successful calibrations checks, requiring measurement of the oxide references to be within +/- 3 microns.

3.0 Inspection Results

3.1 Assembly Visual

The assembly visual showed that assembly T81R was [

]^{a,b,c}.

[

]^{a,b,c}.

3.2 Assembly Growth

Measured data and the growth calculation are shown in Table 3.2-1. A standard of known length and the fuel assembly are measured using an LVDT. The difference between the two measurements is applied to the temperature corrected length of the standard. This is the length of the fuel assembly at pool temperature. The length is corrected to a room temperature length and compared to the nominal assembly length. The final assembly length indicates that assembly T81R experienced growth of [ ]^{a,b,c} inches after three cycles of irradiation. This correlates to [ ]^{a,b,c}. A normalized growth of [ ]^{a,b,c}.

Comparison of growth after two and three cycles is shown in Table 3.2-2. After two cycles and [ ]^{a,b,c} MWD/MTU burnup, assembly T81R experienced [ ]^{a,b,c} normalized growth. After three cycles and [ ]^{a,b,c} MWD/MTU burnup, the assembly showed [ ]^{a,b,c} normalized growth.

Figure 3.2-1 compares normalized assembly T81R growth to other assemblies with Zirlo™ alloy skeletons. The plot shows that T81R growth matches well with growth from other Zirlo fuel assemblies. The growth at high burnup does not indicate an excessive increase in the growth rate.

3.3 Rod Growth

Table 3.3-1 shows rod growth data for assembly T81R after two and three cycles of irradiation. There were no gaps present between the rod bottoms and the bottom nozzle. The gaps measured between the tops of the rods and the top nozzle indicated that the minimum growth was [ ]^{a,b,c} and the maximum growth was [ ]^{a,b,c}. The average rod growth was [ ]^{a,b,c}.

Figure 3.3-1 shows the average rod growth from assembly T81R compared to other assemblies with Zr-4-clad and Zirlo-clad fuel rods. Growth from T81R and other Prairie Island assemblies is at the low end of the Zirlo database. Fuel rod growth at high burnup still appears well within the expected growth rate.

3.4 Peripheral Rod Oxide

Results from peripheral fuel rod corrosion measurements are shown in Table 3.4-1. The peak corrosion thickness and the elevation of occurrence are listed for each rod measured. The same information is given for Faces 1 and 4 after brushing. The peak oxide thickness ranged from [ ]^{a,b,c} microns. The peak rod thickness after brushing ranged from [ ]^{a,b,c} microns. Plots of the data before brushing are shown in Figures 3.4-1 to 3.4-4. Data tables showing averaged data are provided in Appendix A.

Table 3.4-2 shows a comparison of the two measurements made on each corner fuel rod. Peak measurements were all within 3 microns. Table 3.4-3 shows a comparison between the two-cycle and three-cycle data from assembly T81R. Peak oxide thickness increased [ ]^{a,b,c} microns on Face 1 as a result of its third cycle of operation.

Figure 3.4-5 shows the measured data from assembly T81R compared to the rest of the Zirlo alloy database. It shows that the corrosion on T81R is well within the experience base, even at high burnup. Peak oxide values for T81R are lower than corrosion thickness for other Zirlo assemblies at a comparable burnup.

Figures 3.4-6 and 3.4-7 compare measurements before and after brushing of Faces 1 and 4. The plots show that brushing did not have a significant impact on the results. The average difference between values on Face 1 was less than 1 micron, with some individual differences as high as 4 microns. The average difference for Face 4 was between 1-2 microns, with two individual differences as high as 7 microns. Data tables showing averaged data are provided in Appendix B.

3.5 Grid Oxide

Grid corrosion results are shown in Table 3.5-1. The grid oxide thickness ranges from [ ]^{a,b,c} microns. The highest thickness occurred on Face 1, the highest power face of the assembly. The grid material is Zr-4. This material is more susceptible to corrosion than the Zirlo material used for the fuel rod cladding. Therefore, it is expected that corrosion levels are higher on the grids compared to the fuel rods. Data tables showing averaged data are provided in Appendix C.

The Zr-4 material also biases data acquired by the oxide measurement system. The system uses Zirlo material references to calibrate the system. This difference in calibration material versus measuring surface material causes the results to be biased higher than actual. A correction factor of -6 microns was applied to all grid oxide thickness data.

Table 3.2-1 Assembly Growth Summary Data

F/A ID	Fuel Type *	Measurement #1 (in)	Measurement #2 (in)	Measurement #3 (in)	Average (in)	Pool Temp. (F)	F/A Length (in)	Corrected F/A Length (in)	Pre-Irradiated F/A Length (in)	Delta Length (in)	Percent F/A Growth ** (%)	F/A Burnup (MWD/MTU)	F/A Fluence (x E21)
Standard	-												
Standard	-												
Avg. Std.	-												
T81R	14OFA												

a, b, c

**Percent growth is normalized to [ ]a, b, c

Table 3.2-2 Two and Three-Cycle Growth Data for Assembly T81R

Inspection	Date	F/A ID	Cycles	Burnup	Delta Length	% Growth	Normalized % Growth
1	July 1997	T81R	2	[ ]a, b, c	[ ]a, b, c	[ ]a, b, c	[ ]a, b, c
2	June 2004	T81R	3	[ ]a, b, c	[ ]a, b, c	[ ]a, b, c	[ ]a, b, c

Figure 3.2-1 Plot of Assembly Growth for ZIRLO Skeleton Fuel Assemblies

[a, b, c]

Table 3.3-1 Peripheral Fuel Rod Growth for Assembly T81R

SUMMARY OF PRAIRIE ISLAND LTA ASSEMBLY-WISE ROD GROWTH									
ASSEMBLY NO	FUEL TYPE	ASSY BURNUP	FLUENCE ($1x10^{21}$ nvt)	ROD GROWTH %			SHIP DATE	NO OF CYCLES	CLADDING TYPE
				MAX	AVG	MIN			
T81R	14x14 OFA	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	2	ZIRLO
T81R	14x14 OFA	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	3	ZIRLO

Figure 3.3-1 Comparison of Prairie Island Fuel Rod Growth to ZIRLO Database

[] a, b, c

Table 3.4-1 Peripheral Fuel Rod Oxide Data Summary for Assembly T81R

a, b, c

Table 3.4-2 Comparison of Corner Rod Data for Assembly T81R

Rod ID	Faces	Peak Oxide	Elevation
A1	4, 1	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
A14	1, 2	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
N14	2, 3	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
N1	3, 4	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$

Table 3.4-3 Two and Three-Cycle Peak Oxide Data for Assembly T81R

			Two-Cycle Data Assembly Burnup = [ ]$^{a, b, c}$ MWD/MTU		Three-Cycle Data Assembly Burnup = [ ]$^{a, b, c}$ MWD/MTU	
Face	Rod #	Rod ID	Peak Oxide	Elevation	Peak Oxide	Elevation
1	5	A10	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
	6	A9	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
	7	A8	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
	8	A7	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
	9	A6	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$
	10	A5	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$	[ ]$^{a, b, c}$

Figure 3.4-1 Peripheral Fuel Rod Oxide Data – Face 1

a, b, c

[ ]

Figure 3.4-2 Peripheral Fuel Rod Oxide Data – Face 2

a, b, c

[ ]

Figure 3.4-3 Peripheral Fuel Rod Oxide Data – Face 3

a, b, c

[ ]

Figure 3.4-4 Peripheral Fuel Rod Oxide Data

[a, b, c

]

Figure 3.4-5 Assembly T81R Corrosion Compared to ZIRLO Database

a, b, c

Figure 3.4-6 Comparison of Brushed versus Non-Brushed Oxide Measurements, Assembly T81R, Face 1

a, b, c

Figure 3.4-7 Comparison of Brushed versus Non-Brushed Oxide Measurements, Assembly T81R, Face 4

a, b, c

Figure 3.5-1 Grid Strap Corrosion Data Summary

	Peak Oxide Thickness (microns)			
Grid	Face 1	Face 2	Face 3	Face 4
6	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}
5	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}
4	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}
3	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}
2	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}	[ ]^{a,b,c}

4.0 Summary

Assembly T81R was placed in the center core position in Unit 1 Cycle 21 for its third cycle of irradiation. It achieved an assembly-average burnup of approximately [ ]^{a,b,c} MWD/MTU.

An assembly visual inspection of T81R showed [

]^{a,b,c}.

Assembly growth measurements showed the assembly length increased [ ]^{a,b,c} inches from its nominal dimension. The assembly grew [
]^{a,b,c}. The absolute growth corresponds to [ ]^{a,b,c} normalized growth. This fits the expected growth rate for Zirlo fuel assemblies.

The average fuel rod growth from rod to nozzle gap measurements was [ ]^{a,b,c}. This rod growth is consistent with Zirlo rod growth database. [

]^{a,b,c}.

Peripheral fuel rod corrosion measurements resulted in peak oxide thickness that ranged from [

]^{a,b,c}.

Grid corrosion measurements showed oxide thickness ranging from [ ]^{a,b,c} microns. The lowest corrosion was at Grid 2 and the highest at Grid 6. The grid material was Zr-4. This material is more susceptible to corrosion than the Zirlo material. Therefore, it is not unexpected to find higher levels of corrosion on the grid straps compared to the fuel rods, even though the grids are non-heat producing surfaces.

5.0 References

1. [
]^{a,b,c}.

2. [
]^{a,b,c}.

Appendix A

Table A-1: Peripheral Fuel Rod Oxide Data – Face 1

Peripheral Oxide — *All elevations are in inches and all oxide measurements are in microns.*

Utility:	Prairie Island
Assembly:	T81R
Face:	1
Date:	14-Jun-2004

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Table A-2: Peripheral Fuel Rod Oxide Data – Face 2

Peripheral Oxide — All elevations are in inches and all oxide measurements are in microns.

Utility:	Prairie Island
Assembly:	T81R
Face:	2
Date:	15-Jun-2004

Elevation	R01	R05	R06	R07	R08	R09	R10	R14

a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Table A-3: Peripheral Fuel Rod Oxide Data – Face 3

Peripheral Oxide — All elevations are in inches and all oxide measurements are in microns.

Utility:	Prairie Island
Assembly:	T81R
Face:	3
Date:	15-Jun-2004

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Table A-4: Peripheral Fuel Rod Oxide Data – Face 4

Peripheral Oxide — All elevations are in inches and all oxide measurements are in microns.

Utility:	Prairie Island
Assembly:	T81R
Face:	4
Date:	14-Jun-2004

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

[redacted]

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Elevation	R01	R05	R06	R07	R08	R09	R10	R14
[								] a, b, c

Appendix B

Brushed Peripheral Rod Oxide Data

Table B-1: Brushed Peripheral Fuel Rod Oxide Data – Face 1

Peripheral Oxide All elevations are in inches and all oxide measurements are in microns.
Utility: Prairie Island Brushed
Assembly: T81R
Face: 1
Date: 14-Jun-2004

Elevation	R01 Clean	R05 Clean	R06 Clean	R07 Clean	R08 Clean	R09 Clean	R10 Clean	R14 Clean

a, b, c

Elevation	R01 Clean	R05 Clean	R06 Clean	R07 Clean	R08 Clean	R09 Clean	R10 Clean	R14 Clean	a, b, c
[									]

Table B-2: Brushed Peripheral Fuel Rod Oxide Data – Face 4

Peripheral Oxide All elevations are in inches and all oxide measurements are in microns.
Utility: Prairie Island Brushed
Assembly: T81R
Face: 4
Date: 14-Jun-2004

Elevation	R01 Clean	R05 Clean	R06 Clean	R07 Clean	R08 Clean	R09 Clean	R10 Clean	R14 Clean
[								] a, b, c

Elevation	R01 Clean	R05 Clean	R06 Clean	R07 Clean	R08 Clean	R09 Clean	R10 Clean	R14 Clean
[								] a, b, c

Appendix C

Grid Oxide Data

Table C-1: Grid Oxide Data – Face 1

The position is the lateral measurement on the grid face in inches and all oxide measurements are in microns.

Grid Oxide
Utility: Prairie Island Grid
Assembly: T81R
Face: 1
Date: 17-Jun-2004

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
a, b, c					

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Table C-2: Grid Oxide Data – Face 2

The position is the lateral measurement on the grid face in inches and all oxide measurements are in microns.

Grid Oxide Utility: Prairie Island Grid
Assembly: T81R
Face: 2
Date: 17-Jun-2004

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
a, b, c					

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
a, b, c					

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	a, b, c

Table C-3: Grid Oxide Data – Face 3

The position is the lateral measurement on the grid face in inches and all oxide measurements are in microns.

Grid Oxide Utility: Prairie Island Grid
Assembly: T81R
Face: 3
Date: 17-Jun-2004

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6

a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
a, b, c					

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	a, b, c

Table C-4: Grid Oxide Data – Face 4

Grid Oxide	The position is the lateral measurement on the grid face in inches and all oxide measurements are in microns.
Utility:	Prairie Island Grid
Assembly:	T81R
Face:	4
Date:	17-Jun-2004

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6

a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
[					] a, b, c

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
a, b, c					

Position	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	a, b, c