ATTACHMENT (3)

CALVERT CLIFFS LEAD FUEL ASSEMBLY THIRD CYCLE PIE REPORT – NON-PROPRIETARY

Calvert Cliffs Nuclear Power Plant, LLC
July 27, 2011

ANP-3020(NP)
Revision 000

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Nature of Changes

Item	Page	Description and Justification
1.	All	Initial release.

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1.0 Purpose

The purpose of this report is to document the post irradiation examinations (PIE) that were conducted on two Lead Fuel Assemblies (LFAs) from Calvert Cliffs Nuclear Power Station after three cycles of irradiation. This report evaluates the overall condition, fuel assembly growth, fuel rod growth, and fuel rod oxide layer thickness of these two LFAs per the PIE campaign engineering scope.

2.0 Methodology / Approach

The engineering requirements for the PIE campaign are found in the campaign engineering scope and the raw data collected during the examinations are found in data transmittal request. The raw data and video recordings include 4 face fuel assembly visual inspections, dipstick fuel assembly length measurements, shoulder gap visuals, and fuel rod oxide measurements and visuals. The raw data collected are used to determine the fuel assembly growth, fuel rod growth, and shoulder gap closure within this report.

The assembly length measurements are compared to pre-characterized length measurements to evaluate percent growth of the fuel assembly. Shoulder gap length measurements are derived from still images of the shoulder gap during assembly visual exams. The fuel rod length data are determined by subtracting the shoulder gap measurements from the irradiated tie plate to tie plate length, and then compared to pre-characterization measurements or design values to evaluate percentage growth of fuel rods. Fuel rod oxide thickness data was determined by using an eddy current contact probe which measures the distance from the outer surface (including crud and oxide build-up) to the metal surface of the fuel rod cladding.

3.0 Key Assumptions

1) There are no significant assumptions requiring verification. Minor assumptions may be identified through-out this report where necessary.

2) Fuel Assembly and Fuel Rod nomenclature will follow AREVA NP standard practices with regard to rod locations (See Figure F-1 in Appendix F). Cardinal directions are included in the figure to provide Fuel Assembly orientation in the spent fuel pool during exams.

4.0 PIE scope and Calculations

3.1 *Fuel Design and History*

The Calvert Cliffs LFA design is an AREVA NP, Inc. design for a Combustion Engineering (CE) 14x14 assembly arrangement. It is a 14x14 lattice with nine Zircaloy-4 High Thermal Performance (HTP) spacers, a FUELGUARD^{TM} lower tie plate (LTP), a reconstitutable upper tie plate (UTP), and five Zircaloy-4 guide tubes (one being an instrument tube). The fuel rods contain 96 % theoretical density (TD) uranium dioxide (UO_2) pellets clad in M5 tubes).

Previous PIE campaigns for first and second cycles of irradiation have been performed on the LFAs resulting in positive performance. Two of the LFAs were selected for a 3rd cycle of irradiation which required a modified upper tie plate (UTP) to support fuel bundle growth criteria consistent with a peak rod exposure of 70 MWd/mtU. The modified UTP length was reduced from [ ] to meet the engagement and growth design criteria using approved correlations. This reduction of [ ] of bundle length is accounted for when determining calculated results from PIE data in this report.

3.2 *Pre-Irradiation Characterization Data*

Pre-irradiation characterization values for the guide tube lengths of the assemblies were obtained for later use in the fuel assembly growth calculations (see Appendix G for pre-characterized guide tube measurements). These as-built guide tube assembly dimensions were used to calculate fuel assembly length as described later in Section 4.4.2.

3.3 *Visual Inspections*

Both LFAs were visually inspected to determine the condition of the peripheral rods and structural components (e.g., oxide color, crud patterns, general rod and assembly straightness), and to identify areas needing further examination (e.g., damaged components, evidence of debris).

The visual inspections indicate that the fuel assemblies appear to have performed normally (see Appendix A). The peripheral fuel rods were fully seated on the LTP, had consistent growth at the top of the bundle, and a positive upper shoulder gap was present. Sample still images that were captured from the inspection videos are included in Appendix A (Figs. A-1 through A-4) and Appendix G. Typical surface markings of M5 clad fuel rods were present on the rods seen in Figure A-2. The spacer grids were intact and show no signs of damage, wear, or unusual corrosion (Figure A-3). There was no significant rod bow observed. A thin layer of loose crud was observed on the rods and grids which is acceptable for the associated bundle burn-ups.

3.4 *Fuel Assembly Growth*

4.4.1 Fuel Assembly Growth Due to Irradiation

The overall growth of a fuel assembly is almost entirely due to growth of the fuel assembly guide tubes. Minimal growth is observed in the upper and lower tie plates of the assembly. Therefore, growth measurements are limited to the guide tube lengths or the measured distance from the top surface of the lower tie plate to the bottom surface of the upper tie plate. For CE fuel designs, the growth correlations define fuel assembly growth ($\%\Delta L/L$) as the post-irradiation guide tube length minus the as-built guide tube length divided by the active fuel column length. The Calvert Cliffs LFAs have Zircaloy-4 guide tubes. The LFAs were operated for three cycles and were discharged at an average assembly burn-up of 62.24 GWd/mtU.

The length of the guide tubes measured is the sum of the standard length adjusted to the local fuel assembly temperature and the dial indicator readings. Note that the guide tube length is adjusted to eliminate the effects of thermal expansion:

$$GT_{irr} = SL_{Tmeas} + DI_{Tmeas} - \Delta L_{\text{thermal expansion}}$$

Where:

GT_{irr} is the irradiated guide tube length adjusted to the reference temperature,

SL_{Tmeas} is the standard length at the measurement temperature,

DI_{Tmeas} is the dial indicator reading at the measurement temperature,

$\Delta L_{\text{thermal expansion}}$ is the thermal expansion of the guide tube at the reference temperature, defined by:

$$\Delta L_{\text{thermal expansion}} = SL_{Tmeas} \times \alpha_{GT} \times (T_{meas} - T_{ref})$$

Where:

α_{GT} is the coefficient of thermal expansion for Zirc-4 guide tubes ($2.99 \times 10^{-6}\ {}^{0}F^{-1}$),

T_{meas} is the temperatures measured at the four corners of the fuel assembly, and

T_{ref} is the adjusted temperature of the design guide tube.

4.4.2 Dipstick Assembly Length Measurements

The pool side guide tube length, from the top surface of the guide tube locking nut to the top of the guide tube lower end fitting, was measured using a dipstick measurement tool. The tool used an M5 measurement standard FO-0864 calibrated with standard plug FO-0867 (see Appendix B for calibration reports). The pool side fuel assembly measurements utilizing the dipstick method are found in the data transmittal record.

4.4.2.1 Standard Length Adjustment

The standard length (SL_{Tmeas}) at the measurement temperatures is:

$$SL_{Tmeas} = 153.543(1 + \alpha_{ST} \times (T_{s,\,meas} - T_{s,\,ref}))$$

Where:

α_{ST} is the coefficient of thermal expansion for M5 standard ([ ]),

$T_{s,\,meas}$ is the measurement temperature of the standard,

$T_{s,\,ref}$ is the reference temperature of the standard,

153.543 is the length of the standard minus the standard plug as reported in the calibration reports in Appendix B (156.0415 – 2.4981 = 153.543").

4.4.2.2 Fuel Assembly Length Adjustment

The design guide tube assembly length from upper tie plate to lower tie plate is not referenced to the same surfaces that are measured using the dipstick method in the spent fuel pool. Therefore, the design guide tube length adjusted to pool side measurement surfaces (L_{FA}) is converted from the as-built guide tube assembly length (L_{GT}) using the formula:

$$L_{FA} = L_{GT} - L_{EC} + L_{RS} + L_{nut}$$

[ ]

Where:

L_{FA} is the design guide tube assembly length adjusted to the pool side measurement surfaces

L_{GT} is the pre-characterized guide tube assembly length (Appendix E),

L_{EC} is the guide tube lower end fitting length,

L_{RS} is the design length of the retaining sleeve, and

L_{nut} is the design length of the locking nut (Note: [ ] shorter due to modified UTP)

4.4.3 Summary of LFA Growth

Table C-1 in Appendix C provides a summary of the raw data reported and the calculations completed to determine the overall fuel assembly growth. The active fuel column length of 136.7" was used to calculate the percent change in length. The maximum measured assembly growth of the two assemblies was [ ] %ΔL/L at an average assembly burnup of 62.24 GWd/mtU. If an uncertainty of ±[ ] (equal to three times the average standard deviation of guide tube measurements) is applied to the irradiated length of the assembly, the bounding range of assembly growth is [ ]%ΔL/L. Thus, the overall average measured fuel assembly growth was [ ] %ΔL/L at an average assembly burnup of 62.24 GWd/mtU (1.13E+22 n/cm^2).

The Calvert Cliffs LFAs demonstrated fuel assembly growth well below the expected growth model for CE fuel designs with Zirc-4 guide tubes for fluences greater than 8.0E21 n/cm^2 (45.8 MWd/mtU). Based on the approved growth correlations, the percent growth of the LFAs should have been between [ ] %ΔL/L and [ ] %ΔL/L. Since high burn-up data for CE fuel assembly designs with Zirc-4 guide tubes was not available, the growth model conservatively assumed that guide tubes grow at the same rate as fuel rod cladding for fluences greater than 8.0E21 n/cm^2. Therefore, the LFAs irradiated growth is acceptable since comparable burn-up data does not exist, the percent growth is bounded by the approved growth model, and a positive upper shoulder gap exists. A plot of the growth data compared with other CE fuel with Zirc-4 guide tubes is displayed in Appendix C, Figure C-1.

3.5 *Shoulder Gap*

The upper shoulder gap is defined as the distance from the upper surface of the fuel rod to the lower surface of the upper tie plate. Complete seating of the peripheral rods on the lower tie plate where observed (Appendix A, Figure A-4), therefore only the upper shoulder gap is measured. The shoulder gap accommodates the differential fuel rod to fuel assembly thermal expansion and irradiation growth and must remain positive through-out the life of the fuel. Figure A-1 in Appendix A displays a positive shoulder gap for both assemblies.

Upper shoulder gap measurements were taken for each peripheral fuel rod on both LFAs per Figures F-1 and F-2 in Appendix F. Still images taken from video inspection of the upper shoulder gap including the upper tie plate face were used to determine the shoulder gap. These images where used to count the number of pixels between the top of the upper end cap and the bottom of the upper tie plate and then scaled against the pixel length of a known component dimension (UTP face of [ ]). An example of this method is displayed in Figure D-1 in Appendix D.

The shoulder gap videos were taken while the assemblies were hanging in the spent fuel pool, therefore the guide tube elongation of [ ] due to the assemblies free-hanging weight ([ ] lbs) is subtracted from the shoulder gap measurements. The adjustment is calculated assuming that the grids and fuel rods do not contribute to the fuel assembly stiffness:

$$HangingWeightCorrection = \frac{\frac{WT_{FA\_Wet}}{QTY_{GT}}(L_{FA\_Assy})}{\frac{\pi}{4}(OD_{GT}^{2} - ID_{GT}^{2})(G_{Zirc-4})}$$

Where:

WT_{FA_Wet} = [ ]lbs,

QTY_{GT} = 4,

L_{FA_Assy} = [ ],

OD_{GT} = 1.115",

ID_{GT} = 1.035",

G_{Zirc-4} = 14.35E+06 psi, therefore

Hanging Weight Correction = [ ]

Tables D-1 and D-2 in Appendix D provides a summary of the shoulder gap measurements adjusted for temperature and elongation. The minimum and average observed shoulder gap for LFA 2TF01 is [ ]% closure) and [ ]% closure), respectively. The minimum and average observed shoulder gap for LFA 2TF03 is [ ]% closure) and [ ]% closure), respectively.

Corner rods in each assembly are measured twice, allowing for an estimation of the uncertainty in the shoulder gap measurements. The average standard deviation of these duplicate measurements is ~0.01 inches, and thus a tolerance of ± 0.03 inches can be used to provide a bounding rod growth estimate.

3.6 *Estimated Fuel Rod Growth*

The nominal fuel rod irradiation growth is estimated by taking the measured fuel assembly length (Table C-1), correcting it to the distance between upper and lower tie plates, and then subtracting the shoulder gap length (Tables D-1 and D-2). Tables D-1 and D-2 provides a summary of the fuel rod growth based on the shoulder gap calculations and Figure D-2 in Appendix D displays a comparison of rod growth for other fuel designs that use M5 cladding. The M5 fuel rod growth correlation is also plotted in Figure D-2 for comparison. The maximum observed fuel rod irradiation growth is [ ] % at a rod burn-up of 63.84 GWd/mtU (2TF03, Rod D-14). The calculated average fuel rod growth for 2TF01 and 2TF03 is [ ] % and [ ]%, respectively. Fuel rod growth is as expected.

The measurement uncertainty quantified in Section 4.5 also applies to the fuel rod measured length, as the shoulder gap is used to calculate fuel rod length. If the [ ]%) assembly length measurement uncertainty (see Section 4.4.2.2) is used in conjunction with the bounding uncertainty of 0.03" ([ ]%) identified for the shoulder gap measurements (Section 4.5), the bounding conservative estimate for fuel rod growth is [ ]% at a rod burn-up of 63.84 GWd/mtU, which lies below the 95/95 UTL M5 fuel rod growth correlation (Figure D-2). Figure D-3 in Appendix D is a bundle map representation of the maximum and minimum rod growth locations per LFA.

3.7 *Oxide Measurements*

Selected fuel rod oxide measurements were taken on both LFAs per Figures F-1 and F-2 in Appendix F. Each identified fuel rod was removed from the fuel assembly and inserted into the Individual Rod Inspection Station (IRIS) to determine the oxide thickness across the entire span of the fuel rod. For periphery fuel rods, the outside (0 degree face) and the inside (180 degree face) surfaces were measured. For interior fuel rods, each 90 degree face was measured (e.g., the 0°, 90°, 180°, and 270° faces were measured in a clock-wise direction). The raw oxide thickness data was processed by Field Fuel Services and is graphically summarized for each measured fuel rod face, an example of the oxide data for an individual fuel rod face is displayed in Figure E-1 in Appendix E.

Tables E-1and E-2 in Appendix E summarize the average, minimum, and maximum oxide layer thickness. The rods with the maximum oxide thickness for each of the LFAs are highlighted in Figure D-3. The maximum assembly average fuel rod oxide layer thickness is well below the licensing limit of [ ] microns at [ ] microns for fuel assembly 2TF01 at the average assembly burn-up of 62.24 GWd/mtU. The maximum average oxide layer thickness for a single rod is [ ] microns at a peak rod burn-up of 64.76 GWd/mtU, also in assembly 2TF01. Figure E-2 in Appendix E demonstrates how the Calvert Cliffs oxide measurements compare favorably with the M5 Fuel Rod Corrosion database. To display the oxide resistance benefits of M5 cladding, Figure E-3 displays the oxide database for fuel rods with Zirc-4 cladding.

5.0 Summary / Conclusion

Summary of the Post-Irradiation Examinations of the Calvert Cliff LFAs

- Visual inspections indicate that the fuel assemblies appear to have performed normally at an average assembly burn-up of 62.24 GWd/mtU. The peripheral fuel rods were fully seated on the LTP, had consistent growth at the top of the bundle, and a positive upper shoulder gap was present. Typical surface markings of M5 clad fuel rods were present on the rods. The spacer grids were intact and show no signs of damage, wear, or unusual corrosion. No significant rod bow observed and a thin layer of loose crud was observed on the rods and grids which is acceptable for the associated bundle burn-ups.

- The overall average measured fuel assembly growth was [ ] %ΔL/L. The Calvert Cliffs LFAs demonstrated fuel assembly growth well below the expected growth model for CE fuel designs with Zirc-4 guide tubes for fluences greater than 8.0E21 n/cm^2 (45.8 MWd/mtU). Since high burn-up data for CE fuel assembly designs with Zirc-4 guide tubes was not available, the growth model conservatively assumed that guide tubes grow at the same rate as fuel rod cladding for fluences greater than 8.0E21 n/cm^2. Therefore, the LFAs irradiated growth is acceptable since comparable burn-up data does not exist, the percent growth is bounded by the approved growth model, and a positive upper shoulder gap exists.

- The minimum and average observed shoulder gap for LFA 2TF01 is [ ]% closure) and [ ]% closure), respectively. The minimum and average observed shoulder gap for LFA 2TF03 is [ ]% closure) and [ ]% closure), respectively.

- The maximum observed fuel rod irradiation growth is [ ] % at a rod burn-up of 63.84 GWd/mtU (2TF03, Rod D-14). The calculated average fuel rod growth for 2TF01 and 2TF03 is [ ] % and [ ] %, respectively. Fuel rod growth is as expected.

- The maximum average oxide layer thickness for a single rod is [ ] microns. The average fuel rod oxide thickness is well below the licensed limit.

Appendix A : Visual Inspection Results

A.1 Shoulder Gap

[ ]

Figure A-1: Shoulder Gap Visuals

A.2 Rod Face Visuals

[ ]

Figure A-2: Face Visuals

A.3 Spacer Grids

[ ]

Figure A-3: Spacer Grid Visuals

A.4 Rods Seated on LTP

[ ]

Figure A-4: Rod Seating Visuals

Appendix B : Calibration reports

B.1 Dipstick Standard

B.2 Dipstick Calibration Standard "+1"

Appendix C : LFA Irradiation growth data

C.1 Fuel Assembly Growth

Table C-1: Calvert Cliffs LFA Average Assembly Growth

Figure C-5: Assembly Growth for CE Zirc-4 Guide Tube Fuel Designs

Appendix D : Shoulder Gap and Rod Growth

Table D-2: Shoulder Gap and Fuel Rod Growth for LFA 2TF01

Table D-3: Shoulder Gap and Fuel Rod Growth for LFA 2TF03

[ ]

Figure D-6: Shoulder Gap Determination

Figure D-7: M5 Fuel Rod Growth Growth vs. Burnup

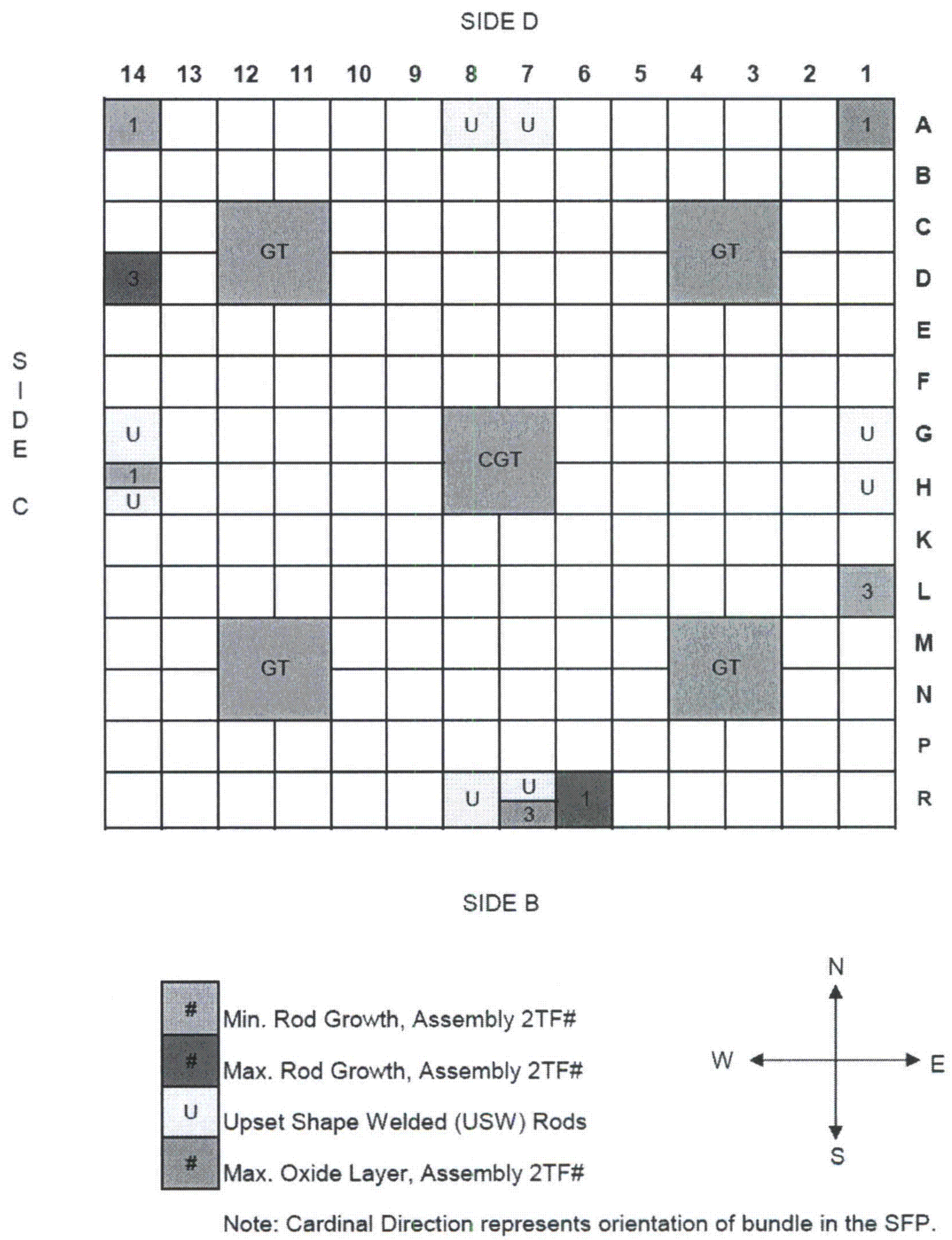


Figure D-8: Fuel Rod Locations for Growth and Oxide Thickness

Appendix E : Fuel rod oxide thickness

Figure E-9: Sample Oxide Thickness Data (2TF01, Rod E4, 0^0 Face)

Table E-4: Fuel Rod Oxide Thickness Summary – FA: 2TF01

Table E-5: Fuel Rod Oxide Thickness Summary – FA: 2TF03

[

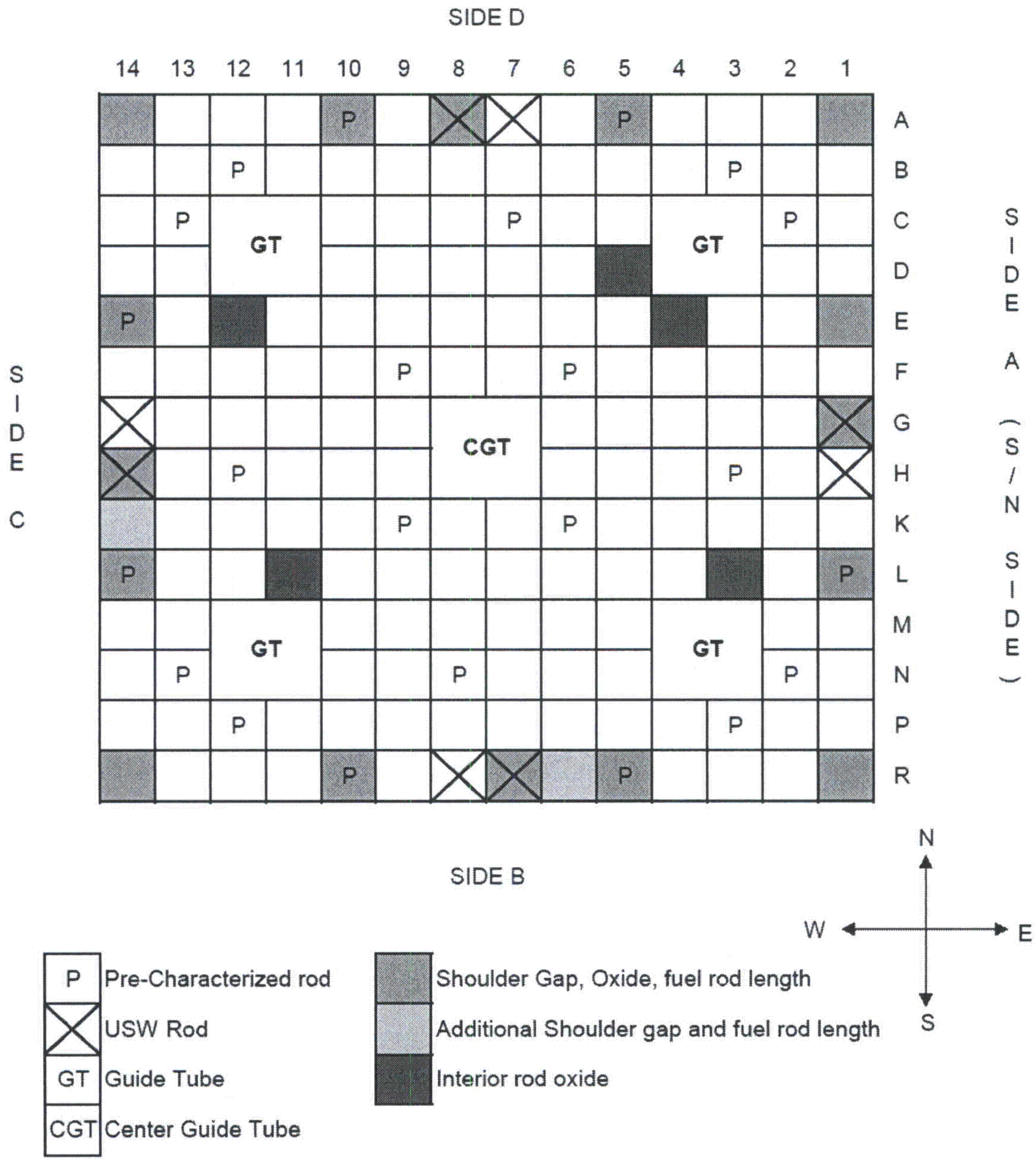
]

Figure E-10: Calvert Cliffs Maximum Measured Oxide Thickness compared to M5 Oxide Database

Figure E-11: Zirc-4 Fuel Rod Oxide Thickness Database

Appendix F : bundle maps for fuel rod measurements

F.1 Fuel Rod Measurement Locations and Bundle Maps



Note: Cardinal Direction represents orientation of bundle in the SFP.

Figure F-12: Fuel Rod Measurement Locations for 2TF01

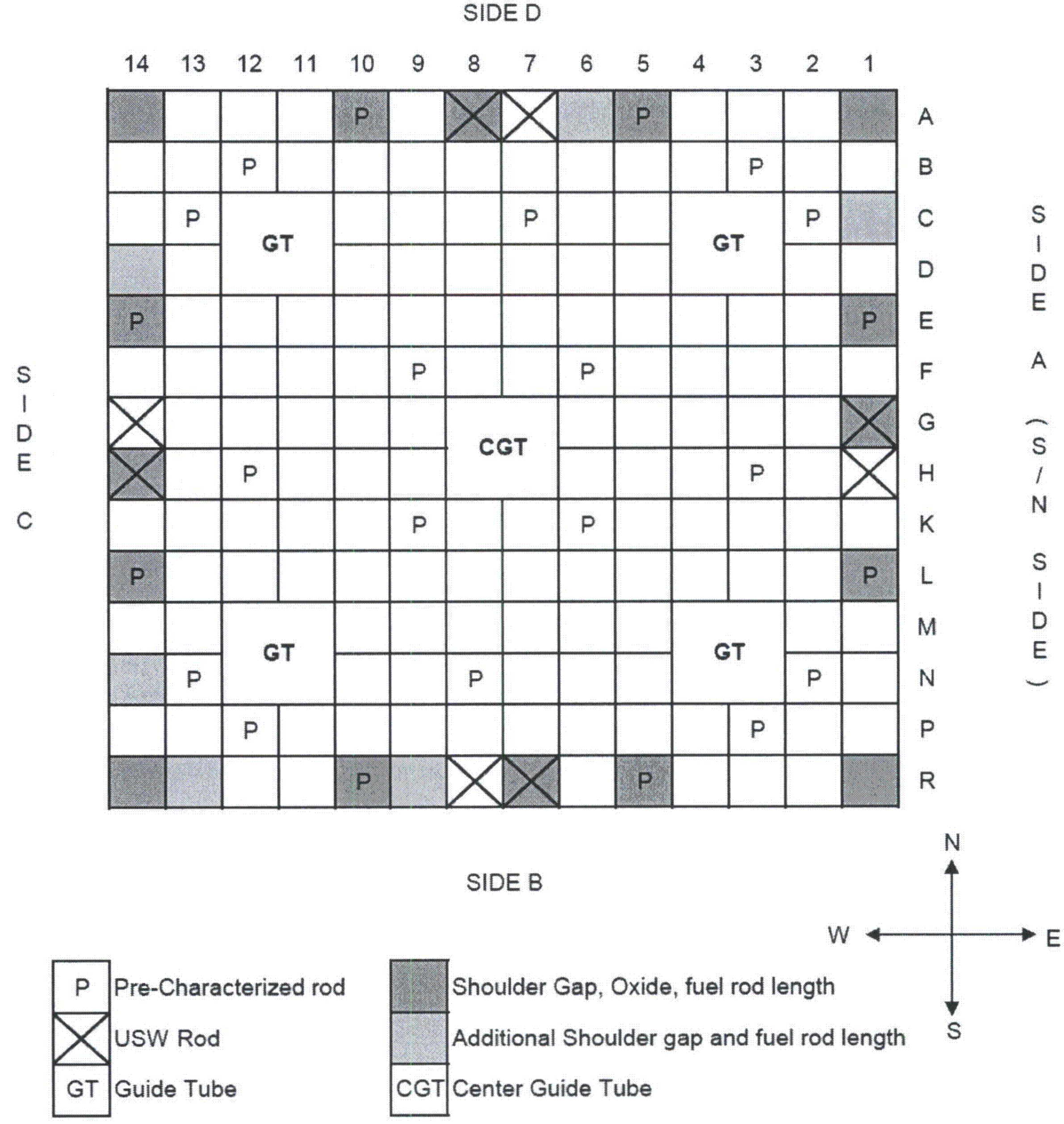


Figure F-13: Fuel Rod Measurement Locations for 2TF03

Appendix G : MISCELLANEOUS DATA

G.1 Guide Tube Pre-Characterized Measurements

G.2 Additional Visual Examination Still Images

G.2.1 2TF01 Bundle and Fuel Rod Still Images

[ ]

Figure G-14: Upper Reaction Springs – 2TF01, Face B

[ ]

Figure G-15: Upper Shoulder Gap – 2TF01, Face B

[ ]

Figure G-16: Face Visual – 2TF01, Face C

[ ]

Figure G-17: Spacer Grid – 2TF01, Face D

Figure G-18: Lower Grid and Rod Seating – 2TF01, Face A

Figure G-19: Rod A1 – 2TF01

Figure G-20: USW Upper End Cap, Rod G1 – 2TF01

Figure G-21: Rod G1 – 2TF01

Figure G-22: Rod L3 – 2TF01

Figure G-23: TIG Welded Lower End Cap, Rod R7 – 2TF01

G.2.2 2TF03 Bundle and Fuel Rod Still Images

[ ]

Figure G-24: Upper Shoulder Gap – 2TF03, Face B

[ ]

Figure G-25: Face Visual – 2TF03, Face C

[ ]

Figure G-26: Spacer Grid – 2TF03, Face D

[ ]

Figure G-27: Rod Seating Visuals – 2TF03, Face C

Figure G-28: Rod R14 – 2TF03

Figure G-29: Rod H14 – 2TF03

Figure G-30: Rod L1 – 2TF03

Figure G-31: Rod R7 – 2TF03

[ ]

Figure G-32: Rod A8 – 2TF03