ST. LUCIE UNIT 2

FUEL ROD AXIAL GROWTH EVALUATION

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I. INTRODUCTION

This report summarizes the analytical methods and measurements performed to demonstrate that adequate distance exists between the top of the fuel rods and the bottom of the upper end fitting (shoulder gap clearance) for all the fuel assemblies loaded into the St. Lucie Unit 2 Cycle 2 core.

The general approach taken was:

a) obtain minimum shoulder gap measurements for ten pre-selected assemblies at the End-of-Cycle 1 (EOC-1);

b) use the measured data to statistically verify the predetermined remaining shoulder gap model;

c) use this qualified model to predict remaining shoulder gap at EOC-2; and

d) determine the need for Batch B assembly modifications prior to Cycle 2 startup.

II. CONCLUSION

The minimum shoulder gap measurements demonstrate that the methodology used for projecting the remaining shoulder gap at EOC-2 is valid and is a conservative representation of the actual shoulder gap changes. Based upon the results of the analysis, all Batch B assemblies show a large margin when compared to predicted minimum shoulder gap required for operation through EOC-2. Therefore, no assembly modifications were required.

Also, all modified Batch B, C and D assemblies have been determined to have adequate shoulder gaps through EOC-2 operation, and should have adequate shoulder gap during their expected core life. This is based on a) the observed axial growth rates at EOC 1, b) the projected EOC-2 fluences for these assemblies and c) the increased initial shoulder gap of these assemblies relative to the unmodified Batch B assemblies measured.

III. BACKGROUND

The St. Lucie 2 license condition on axial growth states that "Prior to startup following the first refueling outage, the licensee shall provide an analysis and/or make hardware modifications to assure that shoulder gap clearance between fuel rods and fuel assembly end fittings is adequate."

As a result of the fuel assembly shoulder gap clearances observed at ANO-2 throughout their first three cycles of operations, the NRC has imposed license conditions on CE plants with 16X16 fuel designs.

Although the St. Lucie Unit 2 16X16 fuel design is similar to the ANO-2 16X16 fuel design, there are some differences that influence shoulder gap clearance throughout the life of the fuel assembly. These were presented to the NRC at the March 3, 1983 meeting regarding axial growth and high burnup fission gas release. The most important parameters which influence the remaining gap are the cold-worked, stress relieved annealed guide tubes and the initial holddown force. Both items contribute to a slower shoulder gap closure as a function of fluence.

St. Lucie Unit 2 completed Cycle 1 operation on October 13, 1984. The Cycle 2 reload consists of 73 Batch B, 64 Batch C and 80 Batch D fresh fuel assemblies.

Due to observed decreases in shoulder gaps for ANO-2 fuel, hardware modifications were performed prior to Cycle 1 startup to most assemblies scheduled for Cycle 2 operation. Sixteen Batch B and all Batch C assemblies were shimmed to increase the initial shoulder gap clearance from 0.997 in. to 1.447 in. (Reference 1). Increased concern over observed axial growth rates at ANO-2 led to the implementation of a more conservative Batch D fuel design that would assure adequate shoulder gap clearance for the life of the fuel. The Batch D design was modified to yield an initial shoulder gap clearance of 2.147 in. This was achieved by reducing the fuel rod length by 0.3 in and increasing the guide tube length by 0.4 in. The guide tube material was changed from cold worked to annealed due to the slower irradiation induced growth rates of the latter material (Reference 2).

Shoulder gap analysis performed by CE has concluded that all modified Batch B and C assemblies and the fresh Batch D fuel assemblies have adequate shoulder gap clearance for Cycle 2 operation. The observed ANO-2 fuel pin and guide tube growth rates were conservatively incorporated into the analysis which led to this conclusion. Therefore, the shoulder gap analysis and measurements during the EOC-1 outage addressed the ability of the 57 Batch B unshimmed assemblies to undergo Cycle 2 operation without hardware modifications.

IV. RESULTS

Table 1 and Figure 1 provide a summary of the model predicted and measured minimum gaps at EOC-1 for the ten pre-selected assemblies. The measured minimum gaps for the Batch B assemblies show a large margin when compared to the EOC-1 predictions. The maximum shoulder gap decrease at EOC-1 for the worst rod was 0.185 in. (Assembly B048, south quadrant), leaving a 0.812 in. shoulder gap clearance to accommodate any axial growth during Cycle 2 operation.

Table 2 is a summary of the model predicted minimum gap required (for the assemblies measured) to assure with a 95% probability there will be no shoulder gap closure at EOC-2 for the worst rod in that assembly. A comparison of the predicted minimum gap required at EOC-1 to the measured minimum gap at EOC-1 determined there was no need for fuel assembly modifications.

V. MINIMUM GAP MEASUREMENT PROGRAM

The objective of the minimum gap measurement program was to obtain sufficient data over the maximum spread of fluence available to accomplish the following:

a) determine minimum shoulder gap for the selected assemblies;

b) verify the methodology assumed to project remaining shoulder gaps as a function of fluence; and

c) determine need of hardware modification for the Batch B assemblies in question.

The measurement program consisted of minimum shoulder gap measurements for ten pre-selected assemblies, nine Batch B assemblies and one Batch A assembly. Batch B assemblies were selected based upon the predicted EOC-1 fluences to provide maximum variation. The Batch A (A047) assembly had the minimum projected fluence at EOC-1.

Table 1 summarizes the results of the minimum gap measurements. The predicted minimum gap value quoted is the EOC-1 minimum gap at a statistical 99% confidence level.

Minimum gap measurements were performed using an adjustable "feeler" gauge with electronic readout (LVDT). The gauge consisted of two adjustable plates which covered several rod locations simultaneously and determined minimum gap in the group. Measurements were taken by assembly quadrants, and the minimum gap observed was the value used for the entire assembly. The true minimum shoulder gap for each quadrant was obtained from the differences between the LVDT readings with a correction for fixture calibration;

$$\text{Corrected Minimum Gap} = \text{LVDT} + 0.25 - \text{Measurement Uncertainty}$$

where, 0.25 in. is the thickness of the adjustable plates.

After obtaining the measured data, verification of the pre-campaign gap closure model was successfully completed as described in Section VI.B of this report.

The following evaluation technique was used to determine the acceptability of the unmodified Batch B assemblies for use during St. Lucie Unit 2 Cycle 2 operation. The criterion applied was that at a 95 percent probability, the worst fuel rod in each Batch B assembly would not contact the flow plate during Cycle 2.

Using the pre-campaign gap closure model for St. Lucie Unit 2, the shimming criteria for the Batch B assemblies was established as shown previously on Table 2. The following method was used to determine the minimum gap size allowable prior to requiring the assembly be shimmed.

1. The minimum individual pin fluence from each assembly under consideration was determined after one cycle of operation.

2. The maximum individual pin fluence was determined after two cycles of operation.

3. The difference in fluence between the values from steps 1 and 2 defined the Cycle 1 to Cycle 2 fluence (Fluence) regardless of the actual pins from which the value is taken.

   Fluence (Assyi) = Min. Pin Fluence EOC-1 (Assyi)-
   Max. Pin Fluence EOC-2 (Assyi)

4. The Fluence was then multiplied by the slope of the 5% confidence limit line (as determined by the Monte Carlo simulations), to establish the maximum gap closure during Cycle 2 (GC_{max}).

   Gap Closure (Cycle 2) = Fluence (Assyi) * Slope
   of the 5% Model Line

5. The $GC_{max.}$ value was corrected for in-core to ex-core effects and the margin used in the in-core model (i.e. .085 inches approximately .050 inches of which is margin).

   Min. Allowable Gap = Gap Closure (Cycle 2) + .085

6. The minimum allowed gap was compared to the actual minimum gap for each measured assembly to determine if shimming was required.

VI METHODOLOGY

A. Pre-Campaign Model

In order to assess the adequacy of shoulder gap clearances for the fuel assemblies to be used during Cycle 2 operation, a remaining gap vs fluence model was developed. This model, referred to as the "pre-campaign" model, is composed of three submodels:

1) Initial shoulder gap model
2) Fuel pin growth model
3) Guide tube growth model

The fuel pin growth model used is the EPRI pin growth correlation explained in detail in Reference 3.

$$\Delta L/L = 2.41 \times 10^{-21} (\phi t)^{0.845}$$

where, ϕt = fluence in n/cm^2, $E > 1$ MeV.

The guide tube growth model used was developed using the approach suggested in TREE-NUREG 1180:

$$\left(\frac{\Delta L}{L}\right) = 3.715\ \phi t \times 10^{-25}$$

The initial gap size model was developed to statistically account for the initial gap uncertainty for the St. Lucie Unit 2 fuel.

The objective was to develop a model which can predict with a 95 percent probability, that none of the individual fuel rods in the Batch B assemblies will contact the flow plate during Cycle 2 operation.

The "pre-campaign" model previously described combines the three basic models and accounts for uncertainties related to:

- projected EOC-1 and EOC-2 fluence values
- "as built" shoulder gap
- active fuel length
- hold down force
- "as built" guide tube length
- specific models,

to come up with a remaining gap for a particular fluence. Monte Carlo simulations combined these uncertainties to produce the predicted remaining gaps at a particular fluence within a 95 percent probability.

Figure 1 summarizes the pre-campaign model predictions over the fluence values expected at EOC-1. Model nominal, 95%, 97% and 99% probability lines are included (labeled nominal, 5%, 3%, 1% respectively).

B. Model Qualification

Validation of the "pre-campaign" model was executed using the measured minimum gap data for the 10 assemblies as listed in Table 1.

Two methods were used in the verification process; 1) graphical qualification and 2) statistical tests.

1) Graphical Qualification - The purpose of this method was to provide a quick and simple way of evaluating the measured data against the model predictions. This test was not intended to serve as a stand alone verification of the model, but rather a pictorial presentation of the measurements vs the predictions.

   Graphical qualification was initially executed by plotting the measured gap vs the quadrant average fluence for each assembly. Figure 1 includes the predicted model curves and the measured data points. The measured data shows that the "pre-campaign" model conservatively predicts the remaining shoulder gap for the fluence values in question.

2) Statistical Tests - Two statistical tests were used for model verification. The purpose of the tests was to determine how well the measured data compared to model predictions. The paired difference test and the frequency test were applied to the measured data to determine the degree of conservatism of the model relative to the measured data. Both tests indicated that the model is conservative relative to the measured data and is valid for predicting remaining shoulder gap for all Batch B assemblies through EOC-2 operation.

TABLE 1

PREDICTED VS ACTUAL MINIMUM GAP DATA AT EOC-1

ASSEMBLY NO.	QUADRANT	PREDICTED MINIMUM GAP (1%)	MEASURED MINIMUM GAP*
B011	N	.628	.883
	E	.616	.876
	S	.621	.885
	W	.634	.884
B018	N	.608	.857
	E	.605	.878
	S	.615	.872
	W	.609	.863
B024	N	.619	.868
	E	.618	.854
	S	.613	.877
	W	.620	.866
B030	N	.599	.876
	E	.608	.847
	S	.606	.850
	W	.614	.881
B037	N	.613	.842
	E	.611	.860
	S	.607	.854
	W	.603	.835
B048	N	.617	.870
	E	.614	.846
	S	.624	.812
	W	.626	.830
B054	N	.600	.872
	E	.603	.843
	S	.603	.841
	W	.610	.862
B057	N	.628	.866
	E	.625	.815
	S	.619	.828
	W	.613	.860
B067	N	.620	.847
	E	.612	.851
	S	.622	.914
	W	.619	.850

TABLE 1 (CONTINUED)

PREDICTED VS ACTUAL MINIMUM GAP DATA AT EOC-1

ASSEMBLY NO.	QUADRANT	PREDICTED MINIMUM GAP (1%)	MEASURED MINIMUM GAP*
A047	N	.651	.836
	E	.679	.895
	S	.673	.904
	W	.659	.848

*Measured Minimum Gap = Corrected Minimum Gap - Measurement Uncertainty

Measurement Uncertainty = 0.010 in.

TABLE 2

SHIMMING EVALUATION

ASSEMBLY NO.	MINIMUM ALLOWABLE GAP AT EOC-1	MINIMUM MEASURED GAP AT EOC-1
B011	.348	.876
B018	.309	.857
B024	.340	.854
B030	.333	.847
B037	.333	.835
B048	.349	.812
B054	.266	.841
B057	.341	.815
B067	.340	.847

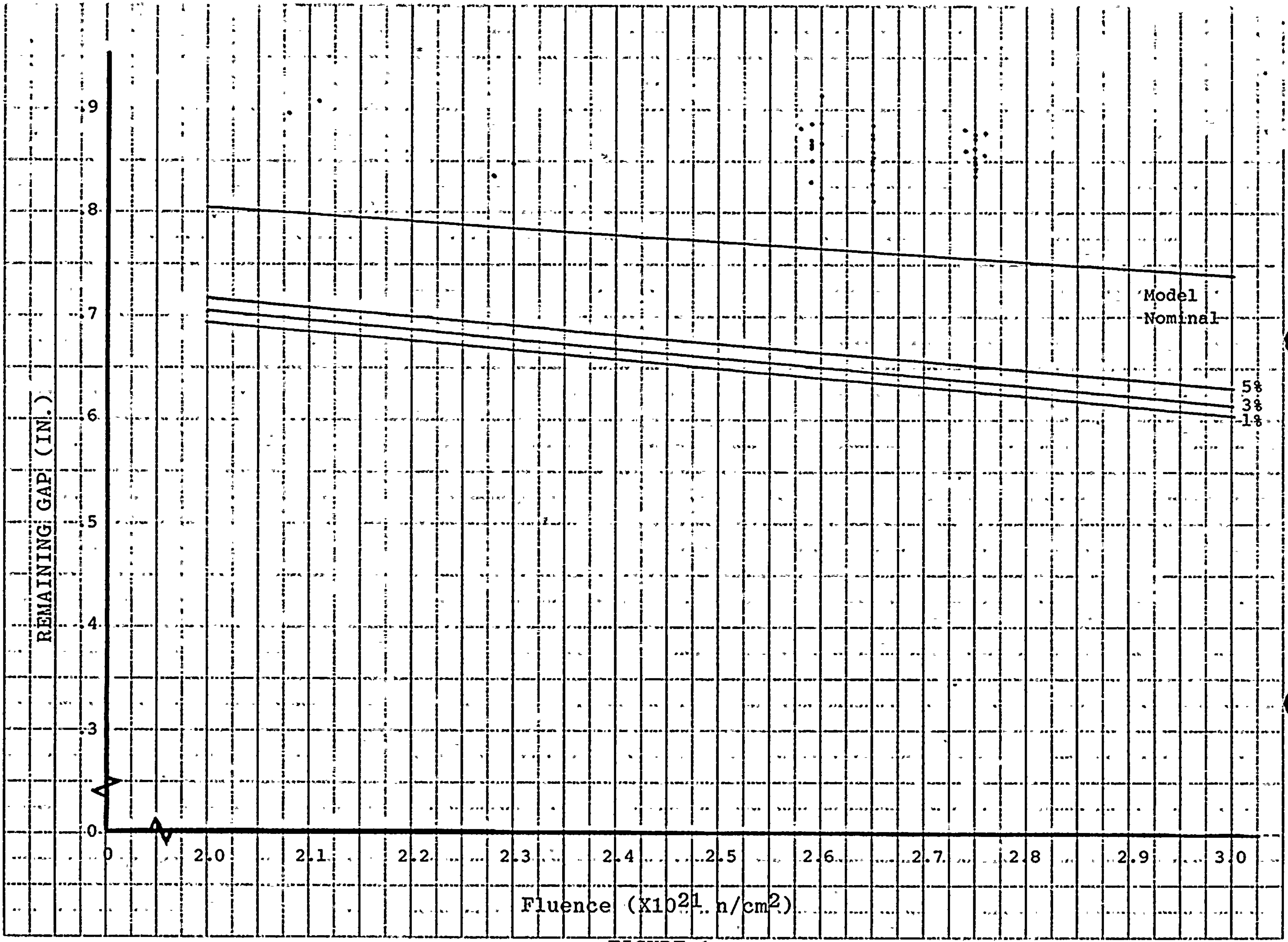

FIGURE 1

MINIMUM SHOULDER GAP MEASUREMENTS VS. MODEL PREDICTIONS

VII REFERENCES

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