CEN-309(A)-NP

ARKANSAS NUCLEAR ONE, UNIT 2
CYCLE 5 SHOULDER GAP EVALUATION

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I. Introduction

Arkansas Nuclear One, Unit 2 (ANO-2) completed Cycle 4 operation on March 16, 1985. During the refueling outage, measurements of the shoulder gaps (distance between the top of the fuel rods and the bottom of the upper end fitting) and fuel assembly guide tube lengths were taken in 14 fuel assemblies. These measurements were taken as part of the inspection program identified in Reference (1). This report summarizes those inspections and describes the shoulder gap analyses performed that justify the fuel assemblies being operated for their third or fourth cycle in Cycle 5.

Shoulder gaps change with residence time in the reactor due to differential growth between the fuel rods and the fuel assembly structure (guide tubes). Measurements of shoulder gap changes have now been made at ANO-2 on selected fuel assemblies after each cycle of operation.

Measurements taken after Cycle 2 revealed shoulder gaps less than those predicted for some Batch C fuel assemblies. Mechanical modifications, namely, the installation of guide tube shims, were made to selected Batch C fuel assemblies to ensure that adequate shoulder gap was available for the third cycle of operation for those assemblies (Reference (2) and (3)).

Shoulder gap measurements taken after Cycle 3 provided the justification to conclude that none of the lead batch (Batch D) assemblies required modification for purposes of operation in Cycle 4 (Reference (4)). However, one Batch D assembly (AKD040) was modified during the Cycle 3 outage in order to prepare it for a potential fourth cycle of operation in Cycle 5. The design modification incorporated guide tube shims that were essentially the same as those used in the Cycle 2 outage, except for a slightly shorter length.

The inspection program during the Cycle 4 outage at ANO-2 was designed to provide data for justification of the third cycle fuel (Batch E) and the fourth cycle assembly (AKD040) being loaded for operation in Cycle 5. In addition, the results of all the above inspections were used to obtain a conservative fluence bound applicable to fuel that will experience its third cycle of operation during Cycles 6 and 7 (Batches F and G, respectively).

II. Shoulder Gap and Guide Tube Length Measurements

The fuel inspection program which provided the data for the evaluation of Cycle 5 shoulder gap adequacy consisted of shoulder gap and guide tube length measurements on a total of 14 fuel assemblies; 5 Batch D and 9 Batch E. Shoulder gap measurements were made on all peripheral fuel rods on the four faces of each assembly while guide tube measurements were made on each of the four outer guide tubes. The shoulder gap change data are shown in Figures 1 and 3 while the guide tube length change data are shown in Figures 2 and 4.

Five Batch D fuel assemblies were inspected. These included 4 fuel assemblies that had been inspected after both their first and second cycle of operation and 1 fuel assembly that had been inspected only after its second cycle of operation. Important conclusions from the Batch D inspections are summarized below:

a. The shoulder gap change of the Batch D fuel rods continued to be less than the limiting shoulder gap change rates of the Batch C fuel, as shown in Figure 1.

b. The limiting shoulder gap change rates of the Batch D fuel rods are continuing to decrease with additional exposure, indicating that linear extrapolation of shoulder gap change is conservative for Batch D fuel.

c. The length change data of the annealed guide tubes of the Batch D fuel assemblies showed essentially no net change in length, which agrees with the analytical method described in Reference (5). (See Figure 2).

A total of 9 Batch E fuel assemblies were inspected, including 4 fuel assemblies that had been inspected after their first cycle of operation. The selection of the other 5 fuel assemblies was biased to include a large representation of those assemblies which will have accumulated high exposures after three cycles. Important conclusions from the Batch E inspections are summarized below:

a. The Batch E shoulder gap change data are shown in Figure 3 along with the limiting gap change prediction which combines the Batch C fuel rod growth rate with the lower 95% guide tube length change prediction (see item b below). Figure 3 shows that the Batch E shoulder gap change data are well below (~60%) of the limiting prediction.

b. The guide tube length change data of the cold-worked guide tubes of the Batch E fuel assemblies are shown in Figure 4 along with the length changes predicted by using the method described in Reference (5). Figure 4 shows that the data are close to the best estimate prediction and well within the upper and lower 95% predictions.

c. The combination of these two observations leads to the conclusion that the length changes of the Batch E fuel rods are significantly less than the limiting growth associated with the Batch C fuel rods.

III. Shoulder Gap Criterion and Evaluation

The criterion used to evaluate the adequacy of the shoulder gaps at end of Cycle 5 is as follows:

> At a 95% probability, the worst rod in the assembly will not have shoulder gap closure at the end of Cycle 5.

The evaluation approach for ANO-2 Cycle 5 parallels the method used for ANO-2 Cycle 4 (Reference (4)), i.e., required shoulder gap predictions for operation in Cycle 5 without modification were based on the minimum available shoulder gap at the beginning of life, a conservatively low guide tube growth prediction, and a conservatively high fuel rod growth prediction. These parameters are discussed in more detail below:

a. The minimum available shoulder gap at the beginning of life accounted for component dimensional tolerances, elastic compression of the guide tubes, and differential thermal expansion between the fuel rods and the guide tubes. The end result was to reduce the nominal initial shoulder gap (cold) by 0.143 inches (hot).

b. There was no credit taken for guide tube growth in the evaluation of the Batch D assembly (AKD040) since the assembly has annealed guide tubes. The evaluation of the Batch E assemblies (all with cold-worked guide tubes) utilized the lower 95% predictions using the method described in Reference (5) which, as stated above, has been shown to be conservatively low for the Batch E fuel.

c. The limiting Batch C fuel rod growth data is used as a conservatively high fuel rod growth prediction for Assembly AKD040 and the Batch E fuel through Cycle 5. The growth of the Batch D fuel rods has been shown to be less than the limiting growth of Batch C fuel rods (Figure 1), and the limiting Batch D rods exhibit a decreasing growth rate with increased exposure. The use of Batch C fuel rod growth data is, therefore, conservative to extrapolate fuel rod growth of Batch D fuel. Likewise, the Batch E fuel has been shown to behave more favorably than the limiting Batch C fuel.

Implementation of this approach showed that Assembly AKD040 and all 9 of the measured Batch E fuel assemblies were predicted to satisfy the shoulder gap criterion at end of Cycle 5. It was concluded that the remaining (unmeasured) Batch E fuel assemblies were also acceptable, based on the margin associated with the 9 measured assemblies and the fact that the selection of the 9 measured assemblies had been biased to include mostly fuel assemblies with high exposure at end of Cycle 5.

A similar evaluation was performed for Batch F and G fuel assemblies to determine a conservative lower bound of the fluence capability of their design with regard to shoulder gap. The design of the Batch F and G fuel is the same as the Batch E design except that their initial shoulder gap is 0.7 inches larger than for Batch E. As before, the limiting Batch C fuel rod growth data was used as a conservative upper bound on fuel rod growth. For this evaluation, the limiting Batch E guide tube growth thru two cycles of operation was used as a conservative estimate of the Batch F and G guide tube growth through three cycles of operation. The resulting conservative lower bound fluence for shoulder gap closure of the Batch F and G design is 11.6×10^{21} nvt (E > .821 MeV). As an indication of the magnitude of the conservatism associated with this value, a minimum remaining shoulder gap of approximately 0.6 inches would be predicted at a fluence of 11.6×10^{21} nvt if, as is expected, the Batch F and G fuel rods behave like ANO-2 Batch D or Batch E fuel rods.

IV. Conclusions

1. The fuel assemblies with annealed guide tubes (Batch D) have had essentially no net length change (Figure 2) whereas the fuel assemblies with cold-worked guide tubes (Batch E) have grown enough to significantly reduce the shoulder gap changes.

2. The fuel rod growth for both Batch D and Batch E has been shown to be less than the limiting fuel rod growth associated with Batch C fuel.

3. The use of conservative estimates of initial shoulder gap, guide tube growth, and fuel rod growth has resulted in the conclusion that Assembly AKD040 and all the Batch E fuel satisfy the shoulder gap criterion for Cycle 5 without requiring increases in their shoulder gaps. The minimum predicted shoulder gaps at the end of Cycle 5 for Assembly AKD040 and the Batch E fuel are 0.118 inches and 0.182 inches, respectively.

4. The use of conservative estimates of initial shoulder gap, guide tube growth, and fuel rod growth has resulted in the conclusion that Batch F and G fuel assemblies will satisfy the shoulder gap criterion for fluences up to 11.6×10^{21} nvt (E > 0.821 MeV). This fluence corresponds to a fuel rod burnup of approximately 56,000 MWD/MTU.

V. References

1. J. Ted Enos to James R. Miller, Docket No. 50-368, Letter #2CAN018501, 1/4/85.

2. J. R. Marshall to Robert A. Clark, Docket No. 50-368, Letter #2CAN128207, 12/10/82.

3. J. R. Marshall to Robert A. Clark, Docket No. 50-368, Letter #2CAN038307, 3/10/82.

4. CEN-261 (A), "Arkansas Nuclear One, Unit 2 Cycle 4 Shoulder Gap Evaluation", issued November, 1983.

5. CENPD-198-P, "Zircaloy Growth In-Reactor Dimensional Changes in Zircaloy-4 Fuel Assemblies", December, 1975, including Supplement 1, December, 1977, and Supplement 2, November, 1978.

FIGURE 1. ANO-2 BATCH D SHOULDER GAP CHANGE DATA

Shoulder Gap Decrease (in.)

Fuel Rod Fluence (nvt x 10^{-21})

FIGURE 2. ANO-2 BATCH D GUIDE TUBE LENGTH CHANGE DATA

△ Assembly Average
Guide Tube Growth

Guide
Tube
Length
Change
(in.)

Guide Tube Fluence (nvt x 10^{-21})

FIGURE 3. ANO-2 BATCH E SHOULDER GAP CHANGE DATA

Shoulder
Gap
Decrease
(in.)

Fuel Rod Fluence (nvt x 10^{-21})

FIGURE 4. ANO-2 BATCH E GUIDE TUBE LENGTH CHANGE DATA

△ Assembly Average
Guide Tube Growth

Guide
Tube
Length
Increase
(in.)

Guide Tube Fluence (nvt x 10^{-21})

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