Entergy

Entergy Operations, Inc.
1448 S R. 333
Russellville, AR 72802
Tel 501 858 5000

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Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
ANO-1 OTSG Reroll Amendment Supplemental Information

Gentlemen:

On September 28, 2000 Entergy submitted a license amendment request (1CAN090008) to the Arkansas Nuclear One Unit 1 (ANO-1) Technical Specifications (TSs) for NRC review and approval. The proposed request modifies the existing reroll repair process used to repair tubes with eddy-current indications within the tubesheet region of the ANO-1 Once-Through Steam Generators (OTSGs). The basis for this change is a report prepared for Arkansas Nuclear One by Framatome Technologies, Inc. (FTI); Topical Report BAW-2303P, Revision 4, *"OTSG Repair Roll Qualification Report."* This report supports the application of the reroll repair process to the upper and lower tubesheet regions, removal of the limitation of only one reroll per OTSG tube, and permits the installation of overlapping reroll repairs.

During a meeting conducted with the NRC Staff on January 23, 2001, NRC questions were discussed regarding the application of reroll repairs on ANO-1. Responses to these questions are contained in Attachment 1 to this letter. Attachment 2 provides a summary of the root cause of the reroll repair transition cracking identified in 1R15. Per NRC request, a change is being made to the proposed Technical Specifications (specification 4.18.5.a.4) which was proposed in our September 28, 2000 submittal to add Revision 4 on the reference to Topical Report BAW-2303P. In addition, the Bases have been expanded to more clearly define the pressure boundary for rerolled joints. The no significant hazards considerations contained in our September 28, 2000 letter are unchanged as a result of this proposed modification to the TSs.

We request to have the repair option proposed by this amendment request available for the upcoming 1R16 refueling outage currently scheduled to begin on March 16, 2001.

A001

I declare under penalty of perjury that the foregoing is true and correct.

Executed on February 19, 2001.

Very truly yours,

Jimmy D. Vandergrift
Director, Nuclear Safety Assurance

JDV/sab
Attachments

cc: Mr. Ellis W. Merschoff
Regional Administrator
U. S. Nuclear Regulatory Commission
Region IV
611 Ryan Plaza Drive, Suite 400
Arlington, TX 76011-8064

NRC Senior Resident Inspector
Arkansas Nuclear One
P.O. Box 310
London, AR 72847

Mr. William Reckley
NRR Project Manager Region IV/ANO-1
U. S. Nuclear Regulatory Commission
NRR Mail Stop O-7 D1
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

Responses to NRC Request for Additional Information
Alternate Repair Criteria for Steam Generator Tubes
Arkansas Nuclear One, Unit 1 (ANO-1)

By letter dated September 28, 2000, Entergy submitted for staff review and approval a proposed amendment to the ANO-1 Technical Specifications (TS), section 4.18. The proposed amendment would modify the existing reroll repair process for degraded tubes within the tubesheet region of the ANO-1 steam generators. To complete our review, the staff requests the following information:

SPECIFIC QUESTIONS FOR ANO-1

NRC Question 1.

In a letter to Duke Energy Corporation dated December 15, 2000, the NRC staff approved a reroll amendment for the Oconee Units 1, 2, and 3 steam generators. Several issues were raised in the review of the Oconee reroll amendment. The reroll design is affected by design basis conditions (e.g., small break LOCA and MSLB transients) which were analyzed in BAW-2374, "Justification for Not Including Postulated Breaks in Large-Bore Reactor Coolant System Piping in the Licensing Basis for Existing and Replacement Once-Through Steam Generators." In addition, the NRC staff was concerned about potential circumferential indications in the tubesheet expansion transition regions. The NRC staff imposed certain license conditions on the Oconee reroll amendment related to assuring that adequate safety margins continue to be satisfied as discussed in the December 15, 2000 letter. The license conditions are intended to ensure that an evaluation will be performed to demonstrate that gross structural failure and leakage of the roll expansion joints will not occur in the event of a large break LOCA. In light of these license conditions, the NRC staff requests Entergy to provide the same commitments for this amendment.

Entergy Response:

Recognizing that the NRC Staff Review is still ongoing with regards to the long term acceptability of eliminating large break loss of coolant accidents (LBLOCAs) from the design basis of B&W steam generators, ANO commits, in the interim, to perform the following:

1. Following each inservice inspection of steam generator tubes but prior to returning the ANO-1 steam generators to service, Entergy will verbally notify the NRC of the following:
   a. Indication of circumferential cracking inboard of the roll repair.
   b. Indication of circumferential cracking in the original roll or heat affected zone adjacent to the tube-to-tubesheet seal weld if no reroll is present.

c. Determination of the best-estimate total leakage that would result from an analysis of the limiting LBLOCA based on circumferential cracking in the original tube-to-tubesheet rolls, tube-to-tubesheet reroll repairs, and heat affected zones of seal welds as found during each inspection. [Commitment]

2. Demonstrate that the primary-to-secondary leakage following a LBLOCA, as described in Appendix A to BAW-2374, is acceptable, based on the as-found condition of the SGs. This is required to demonstrate that adequate margin and defense-in-depth are maintained. For the purpose of this evaluation, acceptable means a best estimate of the leakage expected in the event of a LBLOCA that would not result in a significant increase of radionuclide release (e.g., in excess of 10 CFR 100 limits). A summary of this evaluation shall be provided to the NRC within 3 months following completion of steam generator tube inservice inspection with the report required by Technical Specification 4.18.6. [Commitment]

Entergy also recognizes that further NRC review of BAW-2374 may necessitate modification to this commitment and may involve additional action on Entergy's part to comply with final NRC conclusions on this matter.

In addition, Entergy has performed a review to assure that the ANO-1 plant-specific EOPs are consistent with the descriptions in BAW-2374 in regard to the key operator actions for mitigation of the accident sequence of concern. The key operator actions are the transfer of the ECCS suction from the refueling water storage tank to the containment sump, and the isolation of the secondary system to minimize any primary-to-secondary leakage. Entergy has also confirmed that the ANO-1 EOPs are consistent with the B&W Owners Group's November 27, 2000, letter with respect to compliance with 10 CFR 50.46.

NRC Question 2.

In a letter to the NRC dated January 3, 2000, Entergy submitted the steam generator inservice inspection report for the inspection conducted in 1999 for refueling outage 1R15 (cycle 15). The licensee identified flaws in rerolled joints which were installed in 1R14. The flaws were identified as volumetric and axial/mixed mode. (a) In the report, the licensee stated that a root cause was being performed at the time. Discuss the findings in the root cause study, including corrective actions taken to prevent or minimize future flaws in rerolled joints. (b) Provide information since the issuance of the report on the detected indications in the upper and lower tubesheets including crack orientation (axial or circumferential), crack location relative to the reroll, degradation mechanism (PWSCC, ODSCC, crack-like, or volumetric), and estimated crack size (length, average depth, maximum depth, percentage degraded area). In the discussion, include data from pulled tubes, as applicable. (c) On Page 18 of the report, Entergy reported that its preliminary study indicates that the tooling and rolling process may have contributed to the detected flaws in the rerolled joints. Discuss any changes that have been made or are anticipated in the reroll installation process that deviate from the process specified in BAW-2303P, Revision 4. Discuss the impact of these changes on the applicability of the tests supporting the reroll design in BAW-2303P, Revision 4.

Entergy Response:

A total of 3118 re-rolls (1963 in the "A" SG and 1155 in the "B" SG) were installed in the ANO-1 SGs during 1R14 (Spring of 1998) and a total of 111 re-rolls (78 in "A" and 33 in "B") were installed during 1R15 (Fall of 1999). Re-rolling has only been performed in the upper tubesheet. During the 1R15 refueling outage at Arkansas Nuclear One Unit 1 (ANO-1), axial indications were detected in some of the heel transitions of the repair rolls installed in the OTSG upper tubesheet during 1R14. A review of other B&W facilities (Davis Besse, Oconee Units 1, 2, or 3) where reroll repairs have been installed in a similar time frame did not show cracking in the heel transition after one cycle operation.

An OTSG Repair Roll Cracking root cause report was developed by the B&W Owners Group and concluded that the re-roll process did not cause the premature occurrence of the degradation of the re-roll joint. A comparative review of material properties, RCS chemistry data, and installation parameters was accomplished and no measurable variations were found that could explain the apparent differences in susceptibility to cracking. Results of the stress corrosion cracking tests suggest that increasing the installation of the repair roll depth from 3.25 inches to 3.75 inches may potentially lengthen the repair life. Entergy plans to install future re-rolls at the deeper elevation.

Another possible factor identified in the BWOG report is the final mill annealing temperature for the ANO-1 tubing may have been lower. The higher the annealing temperature, the more resistant to PWSCC the tubing material becomes. In general, those tubes re-rolled during the ANO-1 1R14 outage are from Sawhill. The Oconee tubing, which did not experience the re-roll cracking, was from Pacific Tube Company. A review of the certified material test reports indicates that the tubing at both plants was annealed a temperature in excess of 1600° F (tubing specification). However the actual mill annealing temperature for the ANO-1 tubes was considered proprietary by the tube vendors and therefore the actual final annealing temperature could not be verified.

The cracking in the re-roll joint has been classified as PWSCC. All cracking is occurring at the heel transition of the re-roll. The majority of the cracking is axial and volumetric indications with some circumferential indications. The circumferential and axial extent of the individual flaws are generally less than 0.30 inches. A few tubes also contained multiple indications having minor circumferential extent. ANO has not identified a need to pull any tubes due to reroll cracking, to date. Four re-roll cracks were in-situ pressure tested during 1R15 with no leakage (pressurized to 2850 lbs). Since the heel transition is not part of the qualified repair roll; cracking in the heel transition does not affect the structural integrity or leak-limiting capability of the repair roll as long as the 1-inch repair roll and the toe transition remain free of indications.

A more detailed explanation of the root cause investigation of the reroll transition cracking is provided in Attachment 2 of this report.

NRC Question 3:

The current TS 4.18.3.b specifies that all tubes which have been repaired using the reroll process will have the new roll area inspected during the inservice inspection. The inspection plan is discussed in Section 8.0 of BAW-2303P, but in general terms.

(a) Discuss the inspection scope, inspection expansion criteria, and inspection technique for the reroll at ANO-1 for pre-service inspection and inservice inspection.

(b) Discuss the acceptance criteria for reroll joints for pre-service inspection (during the installation process) and inservice inspection.

(c) Discuss disposition of the reroll joint that does not satisfy the acceptance criteria during pre-service inspection and inservice inspection.

Entergy Response:

A 100% Motorized Rotating Pancake Coil (Plus Point coil) and 100% bobbin exam of all re-rolls is accomplished post installation and during each refueling outage following installation. No indication of degradation is allowed in the 1-inch effective roll. All re-rolls that have an indication in the 1-inch effective rolls have been plugged, to date. With the acceptance of this amendment request, future degradation in the 1-inch roll joint will be candidates for further rerolling. As discussed above, the transition cracking found in the heel of the reroll (not extending into the 1-inch reroll) does not affect the pressure boundary and can remain in service based on the inservice inspections. Each re-roll with an indication of cracking in the 1-inch effective roll is screened for in-situ pressure testing and then repaired.

NRC Question 4:

For completeness, the revision number, 4, must be included in the reference of the topical report, BAW-2303P, in the proposed TS section 4.18.5.a.4. The NRC staff has required licensees to include the revision number of technical reports that are referenced in the TS.

Entergy Response:

The proposed TS 4.18.5.a.4 (TS page 110m) has been modified to add Revision 4 to the reference of BAW-2303P and is enclosed.

NRC Question 5:

The licensee proposed that in TS Section 4.18.5.a.9, the portion of the tube outboard of the new roll can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed. Provide a clear definition of the word "outboard" in this TS section. Also, discuss this inspection requirement as it relates to the information needed to satisfy the license conditions discussed in Question 1 above.

Entergy Response:

The portion of the tube that is outboard of the repair roll is the portion of the tube closest to the primary side of the tubesheet and includes tubing from the tube end up to and including the heel expansion transition. The 1-inch repair roll is considered to be within the pressure boundary. If more than one repair roll is present, the outboard portion includes tubing from the tube end to the heel transition and the beginning of the 1-inch repair roll that is farthest from the primary side of the tubesheet. The section of tubing inboard of the re-roll will continue to be analyzed and any newly identified crack indications will be included in the leakage calculation.

The Bases for TS 4.18.5.4 (TS page 110n) has been expanded to more clearly define that the outboard roll expansion transition is not part of the pressure boundary. The outboard portion of the tubing from the re-roll will continue to be eddy current tested and analyzed but the qualification of the re-roll process was accomplished assuming that the tube was severed at the outboard section of the heel transition. See enclosed TS Bases page.

GENERIC QUESTIONS ON BAW-2303P, REVISION 4.

NRC Generic Question Statement:

The NRC staff forwarded the following questions to Duke Power Company as a part of the NRC staff review of the reroll license amendment for steam generator tubes at Oconee Units 1, 2, and 3. Duke Power has responded to the following questions satisfactorily in various supplements to the NRC staff (in letters dated September 12, October 4, October 26, November 10, and December 8, 2000). These questions are generic and are applicable to proposed ANO-1 reroll amendment. Entergy needs to respond to the following questions by either confirming that Duke Power's responses to these questions are applicable to the ANO-1 reroll amendment or providing additional information if Duke Power's responses are not applicable to ANO-1. These questions do not include the NRC staff's questions related to thermal hydraulics and structural analysis in BAW-2303P, Revision 4.

Entergy Response:

The responses to questions 1 through 6 below for Oconee are also applicable to ANO-1. However, for completeness, Entergy is providing a short response to each of these questions. The response to question 7 for ANO-1 below is different than that for the Oconee units due to different heatup processes.

NRC Generic Question 1:

On page 1-2, Framatome states that volumetric indications attributed to Intergranular Attack (IGA) have been identified in the unexpanded portion of the tube within the tubesheet crevice. Discuss the impact of IGA on the rerolling operation and exclusion zones.

Entergy Response:

The presence of IGA in a tube does not exclude the tube from being repaired by re-roll. Re-roll repair can be implemented provided the re-roll is not installed in an exclusion zone and the re-roll itself is free of indications. The selected re-roll area is verified to be free of indications by post installation eddy current testing.

In addition, ANO sponsored tests with Babcock & Wilcox in 1985 to evaluate the effects of roller expanded sleeving as a means of repair on tubes having ODIGA corrosion. This process uses a roller expander process similar to that used for rerolled joints. The objective of the program was to determine whether the roller expansion process causes propagation of existing IGA damage present on the tubes and to determine the effects of corrosion on these joints. The OTSG tubes tested were ANO-1 tubes. The corrosion tests were performed at conditions more severe than actually exist in the SG chemistry. The results of mechanical test due to the roller expanding process only showed that the existing grain boundaries of IGA opened in the circumferential direction relative to the hoop strain but showed no change in IGA depth. The results of the corrosion test indicated that there was little or no additional grain boundary attack other than that which existed in the control specimen. Therefore, it was demonstrated that expanding tubes on IGA does not result in degradation of the tube beyond that of the normal expansion process in normal steam generator tubing. A bobbin and plus-point exam of the re-rolled joint will continue to be accomplished each outage to verify that no in-service cracking is occurring.

NRC Generic Question 2:

On page 2-1, Framatome states that: "There are three overlapping roll configurations that may be installed. The compressive load is minimized by installing an inboard roll followed by an overlapping outboard roll for a total addition compressive load of 21 lbs. Installing an outboard roll, followed by an overlapping inboard roll results in a total additional compressive load of 50 lbs." Provide an explanation as to why the sequence of rolling, i.e., inboard roll followed by overlapping outboard roll vis-a-vis outboard roll followed by overlapping inboard roll, could result in doubling the compressive load from 21 to 50 lbs.

Entergy Response:

If the inboard repair roll is installed first, the tube is "locked" into place resulting in a 21 lb. compressive load over the length of the tube; thus the second, outboard repair roll does not impart any additional compressive load. If the outboard repair roll is installed first, 21 lbs of compressive load results, then the second, inboard roll imparts an additional 29 lbs of compressive load over the length of the tube due to material pushed out beyond the toe transition of the second roll. The compressive loads that result from installation of the repair rolls was based on test measurements of tube elongation resulting from repair roll installation for the configurations noted above.

NRC Generic Question 3:

Comparing Table 3-1 "B&W OTSG Performance Characteristics" in BAW-2303P, Rev. 4 with Table 4.1 "B&W OTSG Performance Characteristics" in BAW-2303P, Rev. 3, discuss the deletion of 25 psia secondary side pressure for main steam line break (MSLB) and 15 psia for primary side pressure for small break LOCA (SBLOCA).

Entergy Response:

In Revision 04 of the repair roll topical report, the maximum pressure of either the primary or secondary side is conservatively taken as the primary-to-secondary pressure difference; thereby, maximizing the pressure difference. The MSLB secondary pressure of 25 psia and SBLOCA primary side pressure of 15 psia were conservatively ignored when establishing the design pressure differences.

NRC Generic Question 4:

On page 4-13, Framatome states: "Differential dilation is a term that is used to refer to the interface between the tube OD and the tubesheet bore diameter, which allows a comparison of the relative interface of the joint for any transient condition. The differential dilation is equal to the tubesheet bore dilation (due to tubesheet bowing and free thermal growth) minus the tube dilation (due to internal pressure and free thermal growth). A positive value indicates that the increase in bore diameter is greater than the increase in the tube OD with a reduced interference within the rolled joint. A negative value indicates that the tube free expansion would be greater than the bore expansion resulting in an increase in the interference pressure of the rolled joint. The differential dilations are expressed as diametrical changes along two perpendicular axes. "Radial" refers to the dilation along the radius from OTSG center to the tube centerline and "circumferential" refers to the dilation perpendicular to the radial dilation."

In Tables 5-3 to 5-8, clarify the physical representation of both the major and minor differential dilations having positive values. Clarify if there is a reduced (or no) contact between the tube and tubesheet. Clarify the relationship between the "major and minor" differential dilations (Tables 5-1, 5-2, 5-3, 5-4, 5-6) and "radial and circumferential" differential dilations (Tables 4-1 and 4-2).

Entergy Response:

Positive differential dilations in both directions indicate the contact is reduced in both directions. "Major" and "minor" are related to the magnitude of the dilations with the larger dilation (larger reduction in contact) referred to as the major dilation. "Radial" and "circumferential" relate to the direction of the dilation in the generator. "Radial" dilation refers to the dilation along the radius from the SG center to the tube centerline. The "circumferential" dilation refers to the direction perpendicular to the radial dilation. The major dilation may be in either the radial or circumferential direction depending on the location of the tube in the SG. Regarding qualification of the repair roll, the magnitude of the dilations is evaluated (referenced as major and minor) and the direction of the dilation has no impact on the results.

NRC Generic Question 5:

On page 5-1, Framatome states that: "However, the lower tubesheet crevice is known to contain solid particles in the sludge that collect in this region. Previous testing had demonstrated that leak rates are much higher for repair rolls without crevice deposits. Therefore, leak tests performed without crevice deposits provided conservative leak rates for upper tubesheet and lower tubesheet repair rolls. In addition, previous testing has shown that the joint strength is higher for rolled joints with deposits. Therefore, testing without crevice deposits is conservative for both leakage and structural integrity." This license amendment request seeks to remove the restriction on lower tube sheet area rerolling. The operating experience with rerolled tubes in some PWRs indicates that crevice deposits may be a significant contributor to a reduction in the leakage integrity of rerolled tubes. Discuss the basis for the assumption of superior leakage integrity and joint strength for repair rolls with crevice deposits. Provide the results of the previous testing cited in the above discussion.

Entergy Response:

See response for question #6 below.

NRC Generic Question 6:

On page 5-1, Framatome states that: "Previous testing has shown that cyclic loading associated with normal operating and steam generator transient conditions does not degrade the integrity of the repair roll. Cyclic loading has been shown to result in higher joint strength for both high yield and low yield tubing. Previous repair roll leak test resulted in higher leakage for test samples without deposits that were not subjected to cyclic loading prior to testing than for sample with deposits that were subjected to cyclic loading prior to testing. Therefore, all leak and load testing to support this qualification of the repair was conservatively performed on samples that were not subjected to cyclic loading." Discuss the basis for the assumption of superior leakage integrity and joint strength for repair rolls subjected to cyclic loading. Provide the results of previous testing cited in the above discussion.

Entergy Response:

The test configuration was selected based on leak and load tests performed using the same roll installation process as that currently used for the OTSGs.

Leak test data from testing conducted in 1999 was evaluated that included samples with and without crevice deposits, pre-fatigue and post-fatigue. The test results clearly show that for the OTSG installation process, a clean crevice leaks more than a packed crevice, both in the pre-fatigue and post-fatigue cases. The resulting leak rate from the clean crevice, pre-fatigue samples was 11 times greater than the leak rate from the packed crevice samples (with or without fatigue). The decreased leakage for the packed crevice is attributed to sludge providing a partial seal between the tube and tubesheet that would be an open flow path in a clean crevice.

Framatome Tube Hole Dilation Leak Test Summary (MSLB 2580 psi)

Dilation Pressure (psi)	Average Leak Rate Without Crevice Deposits in^3/hr		Average Leak Rate With Crevice Deposits in^3/hr	
	Pre-Fatigue	Post-Fatigue	Pre-Fatigue	Post-Fatigue
6000	0.3152	0.0851	0.0094	0.0288

An evaluation of joint strength test data from 1999 from testing performed on clean crevice samples for pre-fatigue and post-fatigue conditions and packed crevice samples for post-fatigue conditions showed a maximum of 10% difference in joint strength for the tested conditions. For the configurations tested, the results showed that the pre-fatigue, clean crevice sample resulted in the minimum joint strength.

Framatome ANP Summary of Average Repair Roll Joint Strength

Condition	Average Joint Strength (lbs) (Tube Yield Strength 41.5 ksi)
Post-Fatigue, Dilated, Without Deposits	4785
Post-Fatigue, Dilated, With Deposits	4408
Pre-Fatigue, No Dilations, Without Deposits	4296

Since the current qualification allows the joint to slip, qualification of the repair roll is based primarily on leakage, with joint strength as a secondary factor. Therefore, the test configuration (clean crevice, pre-fatigue) was selected that resulted in the highest leakage. The test configuration results in conservative leak rates for the LTS and bounding leak rates for the UTS. The leak rates are applied very conservatively by assuming a 360°, 100% TW circumferential crack at the heel transition of every repair roll and taking no credit for the seal weld. Additional conservatism results from applying the leak rate to repair rolls in the generator in the broken loop and in the unbroken loop.

NRC Generic Question 7:

On page 9-1, Framatome states that: "Two single 1-inch repair rolls or any overlapping repair roll that results in a maximum of 50 lbs additional compressive load may be installed at a qualified location in any one tube. Additional repair rolls may be installed on a case-by-case basis by evaluating for acceptable compressive tube loads." The license amendment request seeks to remove the limitation of only one reroll per SG tube. Discuss how to evaluate acceptable maximum compressive tube loads to determine how many additional repair rolls may be installed in a single tube. It should be noted that Oconee has committed to a maximum of 50 pounds additional compressive load per tube as a result of the reroll process.

Entergy Response:

The topical report for qualification of the repair roll allows 50 lbs additional compression load for the repair rolls. The maximum predicted compressive loads in the OTSGs occur during the design heatup transient for the Oconee plants, which is a 100°/hr heatup with the secondary side at a minimum level. The low secondary side level limits the heat transfer from the tubes to the shell; therefore, increasing the tube-to-shell temperature difference. This particular heatup applies only to the Oconee plants. The low level heatup specified for the Oconee plants is not used at ANO-1. The normal heatup at ANO-1 occurs with the secondary at the mid-level of the steam generator. The mid-level heatup improves the heat transfer from the tubes to the shell; therefore, the resulting tube compressive loads are bound by the minimum level heatup. Both of the transients are conservative relative to actual procedures. An additional 50 lbs is a negligible increase to the maximum compressive load due to the heatup. The compressive loads vary as a function of radial position in the tubesheet with the maximum loads occuring in the periphery. Therefore, additional repair rolls could be installed at locations within the tube bundle without causing the compressive load at that location to exceed the maximum allowed load for the worst-case tube. Additional repair rolls would be subject to review on a case-by-case basis, with the number of repair rolls and the configuration of the repair rolls limited to the maximum compressive load for the applicable design heatup plus an additional 50 lbs compression from the repair rolls.

OTSG Repair Roll Cracking Root Cause Summary

Background

During the 1R15 refueling outage at Arkansas Nuclear One Unit 1 (ANO-1), axial indications were detected in the heel transitions of the repair rolls installed in the OTSG upper tubesheet during the previous outage. During the development of the OTSG repair rolls it was realized that the product could not be qualified for a 40-year repair life. Based on industry experience, it was anticipated that PWSCC would develop in the non-stress relieved re-roll repair transitions. However, it was expected that the repair would last at least a few cycles before a significant quantity of re-roll cracks would occur. Axial indications in the heel of the roll transitions after one cycle have not been experienced at Davis Besse, Oconee Nuclear Station Units 1, 2, or 3 (Oconee-1, Oconee-2, and Oconee-3). For these reasons, an investigation into causal factors was performed to determine a root cause for the reduction in repair life at ANO-1.

Scope

The scope of this investigation included the following activities:

1) A review of OTSG repair roll installations performed and inspected to date. This includes a review of the installation records for ANO-1, Davis Besse, Oconee-1, Oconee-2, and Oconee-3.
2) A review of equipment and procedures used by FTI for the OTSG repair roll installations (i.e., ANO-1, Davis Besse, and the Oconee units).
3) A review of the material properties of a sample of re-rolled tubes at ANO-1 and Oconee-2 was performed to determine whether a difference exists between the ANO-1 tubing and the Oconee-2 tubing that may explain the apparent difference in susceptibility to cracking.
4) A historical review of FTI repair rolls for RSG installations was performed to determine if the re-roll repairs have experienced degradation in the roll transitions.
5) A historical review of FTI repair products that include mechanical roller expansions (e.g., rolled plugs and sleeves).
6) A comparative review of ANO-1 and Oconee-2 reactor coolant system (RCS) chemistry data was performed to determine if the chemistry was a contributing factor in the difference in performance of the repair rolls at the two plants.
7) A review of EPRI documents in regards to degradation of roll transitions in Alloy 600 tubing.
8) Testing of OTSG tubing material with various mechanical roll expansion parameters in order to determine the relative difference in stress corrosion cracking (SCC) susceptibility.

REVIEWS PERFORMED

Eddy Current Bobbin Profilometry Review

The eddy current bobbin profiles were surveyed against the end of cycle ECT data for the OTSG repair roll installations (i.e., ANO-1, Davis Besse-1, and the Oconee units) in order to determine if roller mandrel "walk out" (the affect from mandrel retraction that applies additional cold work at the heel of the reroll) is strongly correlated to the premature occurrence of the expected degradation at ANO-1.

Based on the survey of the bobbin profiles against the end of cycle ECT data for the OTSG repair roll installations, the following observations have been made:

- The ANO-1 1R14 re-roll installations that possess axial indications in the heel transition after the first cycle of operation are not limited to profiles that indicate tool "walk out."
- Not all profiles that indicate tool "walk out" during the roll process for all OTSGs possess axial indications in the heel transition after the first cycle of operation.

In summary, based on the review of the bobbin profiles for the OTSG repair roll installations, roller mandrel "walk out" is not correlated to the indications of PWSCC at ANO-1.

Repair Roll Installation Data Review

The review of repair roll installation data for ANO-1, Davis Besse, and the Oconee units included a survey of the re-roll graphs and data sheets from the field procedure. The re-roll graphs, which provide roll torques and diameters, were surveyed for the OTSG installations in an attempt to identify any potential anomalies with the repair roll process. The completed data sheets which provide installation depths, were surveyed for the OTSG installations in order to determine if there are any significant variations that would explain the apparent difference in susceptibility to cracking.

The roll torques and diameters were determined to be within the qualification ranges provided in the field procedure for OTSG tube reroll. A comparative review of the data shows that there is little if any difference in the roll torques and diameters for the repair roll installations at ANO-1, Davis Besse, and the Oconee units.

A review of the completed data sheets from the field procedure for OTSG tube re-roll was performed for roll position. Based on the review of the data against the end of cycle ECT data for the ANO-1 1R14 repair roll installations, the following observations were made:

1. The ANO-1 1R14 repair rolls installed at a depth of 11 inches did not experience axial/mixed mode degradation in the heel transition.

2. Re-roll depths of 3.125 and 3.75 inches from the primary face of the UTS were used in the ANO-1 1R14 re-roll installations. Some rolls at each depth had axial indications in the heel transition after the first cycle of operation.
3. Re-roll depths of 3.125 and 3.75 inches from the primary face of the UTS were also used in the ANO-1 1R14 re-roll installations that had no detectable axial/mixed mode degradation in the heel transition after the first cycle of operation.
4. Re-roll depths of 3.75 and deeper were used in the Davis Besse and Oconee re-roll installations where roll transition cracking did not occur after one cycle of operation.

Based on the above, the comparative review of the installation depths used for the ANO-1, Oconee, and Davis Besse repair roll installations does not show any significant differences that would explain the apparent difference in susceptibility to cracking.

Equipment and Procedures

A review of the equipment and procedures used by FTI for the OTSG repair roll installations was performed to determine whether a difference exists between the ANO-1 installations and the other OTSG installations (i.e., Davis Besse and the Oconee units). A review of the FTI field installation documents for ANO-1, Davis Besse, and the Oconee units indicates that the roller and cage design were the same for these OTSG installations as well as the lubricant. The survey of the field installation documents also revealed that the FTI roll procedure used at ANO-1 is the same roll procedure that was used at Davis Besse and the Oconee units. Based on the above discussion, no differences exist between the ANO-1 repair roll installations and the other OTSG repair roll installations with respect to equipment and procedures used by FTI.

Material Properties Review

A comparative review of the material properties (i.e., mechanical and chemical composition) of a sample of re-rolled tubes at ANO-1 and Oconee-2 was performed to determine whether a difference exists between the ANO-1 tubing and the Oconee-2 tubing that would explain the apparent difference in susceptibility to cracking. The material properties of the re-rolled tubes at ANO-1 and Oconee-2 were obtained by reviewing the certified material test reports (CMTRs). The CMTRs that correspond to the heats of material used in the fabrication of the re-rolled tubes were located by first reviewing the shop records for the applicable tube locations to identify heat numbers.

As part of this investigation, the material properties of a sample of re-rolled tubes at ANO-1 and Oconee-2 were examined to determine whether a difference exists between the ANO-1 tubing and the Oconee-2 tubing that would explain the apparent difference in susceptibility to cracking. The comparative review of the material property data for a sample of re-rolled tubes at ANO-1 and Oconee-2 does not show any differences that would explain the apparent difference in susceptibility to cracking.

The amount of tube expansion could have an influence on the residual tensile stress in the roll transition region. For example, larger tube expansions impart more strain in the roll transitions. As part of this investigation, an examination of the roll diameters was performed for the repair roll installations at ANO-1, Davis Besse, and the Oconee units. A comparative review of the installation data shows there is little if any difference in the roll diameters for the OTSG repair roll installations. In addition, an examination of the ANO-1 1R14 installation data shows that the roll diameters are similar for two groups of re-rolled tubes: (1) those re-rolled tubes with axial/mixed mode indications in the heel transition after one cycle of operation, and (2) those re-rolled tubes that had no detectable axial/mixed mode degradation in the heel transition after one cycle of operation. Based on the above, the amount of expansion in the ANO-1 re-rolled tubes is not connected to the premature occurrence of the expected degradation at ANO-1.

The equipment and procedures used during rolling operations could have an influence on the residual tensile stress in the roll transition region. A review of the equipment and procedures used by FTI for the OTSG repair roll installations was performed to determine whether a difference exists between the ANO-1 installations and the other OTSG installations. As a result, no real differences exist between the ANO-1 repair roll installations and the other OTSG repair roll installations with respect to equipment and procedures used by FTI. Therefore, the equipment and procedure that was used for the ANO-1 1R14 repair roll installations is not considered a contributor to the premature occurrence of the expected degradation at ANO-1.

The average hot leg temperature at ANO-1 was compared to the hot leg temperature at Oconee-2. The higher the temperature the less time it takes for roll transitions to develop PWSCC. The average hot leg temperatures varied by less than one degree and therefore, hot leg side temperature was not connected to the premature occurrence of the expected degradation at ANO-1.

The higher final annealing temperature used during tube manufacturer the more resistant to PWSCC the tubing material becomes. A review of the CMTRs that correspond to the heats of material used in the fabrication of the re-rolled tubes at ANO-1 and Oconee-2 was performed. The review indicates that the tubing at both plants was annealed at a temperature in excess of 1600°F. Because the final annealing temperatures are not exactly known for the ANO-1 and Oconee-2 tubing, a comparison of the final annealing temperatures could not be made. The final annealing temperature was considered proprietary by the tubing vendors. It is possible that the ANO-1 tubing was annealed at a lower temperature than the Oconee-2 tubing. In general, those tubes that were re-rolled during the ANO-1 1R14 outage are from Sawhill. The Oconee-2 tubing, which did not experience axial/mixed mode indications in the heel transitions after one cycle, was from Pacific Tube Company. This connects the tube annealing process used by the mill as a potential factor contributing to increased susceptibility. Based on the above, it is uncertain if the final annealing temperature used during tube manufacturing is linked to the premature occurrence of the expected degradation at ANO.

The chemistry of the re-rolled tubes at ANO-1 and Oconee-2 closely matches the EPRI material requirements for Alloy 600 SG tubing. A comparison of the data shows that the chemistry of the ANO-1 re-rolled tubes closely matches the chemical composition of the Oconee-2 tubing. Based on the above, the premature occurrence of the expected degradation at ANO-1 is not linked to the chemical composition of the re-rolled tubes.

RCS Chemistry Data Review

Framatome Technologies, Inc. performed a review of the RCS chemistry at ANO-1 and Oconee-2 for the fuel cycle during which the repair rolls were in service. The objective of the review was to determine if the chemistry was a contributing factor in the difference in performance of the repair rolls at the two plants. Results from this review are given below for each reactor coolant chemistry parameter.

- The difference between the coolant pH values at the ANO-1 and Oconee-2 plants is negligible.
- The coolant boron concentrations at ANO-1 and Oconee-2 are similar and typically decrease during the fuel cycle.
- The coolant lithium concentration at ANO-1 and Oconee-2 is similar except for early in the fuel cycles when the Oconee-2 lithium is higher for a period of about four months.
- The coolant chloride concentration at ANO-1 and Oconee-2 is similar except for the first three months in the fuel cycle when the ANO-1 chloride was slightly higher.
- The coolant fluoride concentration at Oconee-2 are higher for the fuel cycle. There is no evidence that fluoride contributes to PWSCC at the conditions at ANO-1.
- The sulfate concentration in the coolant at ANO-1 is somewhat higher than at Oconee-2.
- There is no evidence that sulfate contributes to PWSCC at the concentrations observed at ANO-1.
- The coolant hydrogen at Oconee-2 was higher for a good part of the operating cycle than the coolant hydrogen concentration at ANO-1.
- The silica concentrations at both plants tend to be high due to the presence of Boro-Flex material in the spent fuel pools but are comparable.

Based on the results above, the review indicates there are no differences that could be confirmed to account for the differences in the repair roll corrosion behavior at the two plants.

OTSG REPAIR ROLL CRACKING SUSCEPTIBILITY TESTS

Tests were performed to determine the relative difference in stress corrosion cracking (SCC) susceptibility of OTSG tubing material with various mechanical roll expansion parameters. A matrix of mockup test assemblies with various roll parameters was developed for the SCC testing. The effect of these roll parameters on the "time to failure" for the mockups was explored in the SCC test. There is a potential contribution to additional residual tensile stress (greater than in a typical roll transition) within the heel transitions from roller mandrel "walk out" during the retract step of the rolling process; therefore, roller mandrel "walk out" was also included in the matrix as a roll parameter. The roll expansion scheme presented in the matrix for the mockup assemblies covers worst case conditions to favorable conditions with respect to residual stress in the heel transition region. General test results were as follows:

- Multiple axial or single axial indications were detected in all but one of the mockups having low yield tubing. The indications are noted to be concentrated in the heel transitions, which is consistent with roll transition PWSCC in Alloy 600 that is associated with mechanical roll expander repair products.

- None of the mockups having high yield strength tubing exhibited detectable SCC after 12 hours of exposure. It is not clear why the mockup assemblies having tubing with the higher yield stress did not develop detectable eddy current indications during this test. It is possible that the higher yield stress tubing was less sensitized during the furnace heat treatment as a result of differences in carbon in solution and grain boundary microchemistry resulting from differences in the final mill anneal temperature. Because of this observed difference, comparison of "time to failure" should be restricted to the mockups within each set, or heat, of tubing only.

- Within the set of mockups having low yield strength tubing, the roller expansion placed at the greatest depth did not develop detectable SCC. Therefore, this observation suggests that increasing the installation depth of the repair roll may potentially lengthen the repair life.

- Tube yield strength or material having low yield strength tubing was dominant over the other roll parameters in influencing the residual stress in the roll transition region.

- Within the set of mockups having low yield strength tubing which did not have roller mandrel "walk out," developed detectable SCC earlier than the mockup which had roller mandrel "walk out." Therefore, roller "walk out" was not a dominant factor in influencing the residual stress in the roll transition region.

- Absence of the roller "walk out" condition did not prevent cracking in the heel transitions. It is noted that this observation is also applicable to the ANO-1 1R14 re-roll installations. Therefore, this test confirms that roller mandrel "walk out" is not correlated to the indications of PWSCC at ANO-1.

Overall Conclusions

An investigation into causal factors has been performed to determine a root cause for the reduction in repair life at ANO-1. The following conclusions are provided.

1. Based on the review and evaluation of the eddy current bobbin profiles, installation data, tooling, and procedures, it is concluded that the roll process used by FTI did not cause the premature occurrence of the expected degradation at ANO-1.
2. A comparative review of the material properties data for a sample of re-rolled tubes at ANO-1 and Oconee-2 does not show any variations that would explain the apparent difference in susceptibility to cracking.
3. Based on the comparative review of the RCS chemistry data at ANO-1 and Oconee-2 for the fuel cycle of interest, it is concluded that typical RCS chemistry over the past operational cycle did not cause the premature occurrence of the expected degradation at ANO-1. No historical RCS intrusions were reviewed.
4. The performance history of Alloy 600 rolled plugs confirms that the axial indications detected in the ANO-1 heel transitions during the 1R15 outage are consistent with roll transition PWSCC in Alloy 600 that is associated with mechanical roll expander repair products.
5. Results of the SCC tests suggest that increasing the installation depth of the repair roll may potentially lengthen the repair life.
6. Additional SCC testing may be performed to determine qualitatively the effect of roll parameters on the "time to failure" for the mockups with the higher yield stress tubing.
7. One possible factor that may explain why ANO-1 experienced PWSCC in the heel transitions earlier than the other OTSG plants is that the final mill annealing temperature for the ANO-1 tubing could have been lower, where the tubing would be less resistant to PWSCC.

PROPOSED TECHNICAL SPECIFICATION CHANGES

4.18.5 Acceptance Criteria

a. As used in this specification:

1. Tubing or Tube means that portion of the tube or sleeve which forms the primary system to secondary system pressure boundary.

2. Imperfection means an exception to the dimensions, finish or contour of a tube from that required by fabrication drawings or specifications. Eddy current testing indications below 20% of the nominal tube wall thickness, if detectable, may be considered as imperfections.

3. Degradation means a service-induced cracking, wastage, wear or general corrosion occurring on either the inside or outside of a tube.

4. Degraded Tube means a tube containing imperfections ≥ 20% of the nominal wall thickness caused by degradation, except where all degradation has been spanned by the installation of a sleeve or repaired by a rerolled joint.

   The reroll repair process will be used to repair tubes with defects in the upper and lower tubesheet areas as described in topical report, BAW-2303P, Revision 4.

5. % Degradation means the percentage of the tube wall thickness affected or removed by degradation.

6. Defect means an imperfection of such severity that it exceeds the plugging limit except where the imperfection has been spanned by the installation of a sleeve. A tube containing a defect in its pressure boundary is defective.

7. Plugging Limit means the imperfection depth at or beyond 40% of the nominal tube wall thickness for which the tube shall be sleeved, rerolled, or removed from service because it may become unserviceable prior to the next inspection. This does not apply during Cycle 16 to ODIGA indications within the defined region of the upper tubesheet. These indications shall be assessed for continued plant operation in accordance with topical report BAW-10235P, Revision 1.

   Axially-oriented TEC indications in the tube that do not extend beyond the adjacent cladding portion of the tube sheet into the carbon steel portion are not included in this definition. These indications shall be assessed for continued plant operation in accordance with topical report BAW-2346P, Rev. 0.

8. Unserviceable describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an Operating Basis Earthquake, a loss-of-coolant accident, or a steam line or feedwater line break as specified in Specification 4.18.4.c.

9. Tube Inspection means an inspection of the steam generator tube from the point of entry completely to the point of exit. For tubes that have been repaired by the reroll process within the upper tubesheet, that portion of the tube above the new roll can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed.

Bases

The surveillance requirements for inspection of the steam generator tubes ensure that the structural integrity of this portion of the RCS will be maintained. The program for inservice inspection of steam generator tubes is based on a modification of Regulatory Guide 1.83, Revision 1. Inservice inspection of steam generator tubing is essential in order to maintain surveillance of the conditions of the tubes in the event that there is evidence of mechanical damage or progressive degradation due to design, manufacturing errors, or inservice conditions that lead to corrosion. Inservice inspection of steam generator tubing also provides a means of characterizing the nature and cause of any tube degradation so that corrective measures can be taken.

In general, steam generator tubes that are degraded beyond the repair limit can either be plugged, sleeved, or rerolled. The steam generator (SG) tubes that are plugged are removed from service by the installation of plugs at both ends of the associated tube and thus completely removing the tube from service. When the tube end cracking (TEC) alternate repair criteria is applied, axially-oriented indications found not to extend from the tube sheet cladding region into the carbon steel region may be left in service under the guidelines of topical report BAW-2346P, Rev. 0. When the upper tubesheet outer diameter intergranular attack (ODIGA) alternate repair criteria is applied, indications found within the defined region of the upper tubesheet may be left in service under the guidelines of topical report BAW-10235P, Revision 1. The defined region begins one inch above the upper tubesheet secondary face and ends at the nearest tube roll transition. Following a SG inspection, an operational assessment is performed to ensure primary-to-secondary leak rates will be maintained within the assumptions of the accident analysis.

Degraded steam generator tubes can also be repaired by the installation of sleeves which span the area of degradation and serve as a replacement pressure boundary for the degraded portion of the tube, thus permitting the tube to remain in service.

Degraded steam generator tubes can also be repaired by the rerolling of the tube in the upper or lower tubesheet to create a new roll area and pressure boundary for the tube. The portion of the tube that is outboard of the repair roll is the portion of the tube closest to the primary side of the tubesheet and includes tubing from the tube end up to and including the heel expansion transition. The 1-inch repair roll is considered to be within the pressure boundary. If more than one repair roll is present, the outboard portion includes tubing from the tube end to the heel transition and the beginning of the 1-inch repair roll that is farthest from the primary side of the tubesheet. The rerolling repair process will be used to repair defects in the upper and lower tubesheet in accordance with BAW-2303P, Revision 4.

All tubes which have been repaired using the reroll process will have the new roll area inspected during future inservice inspections. Defective or degraded tube indications found in the new roll and any indications found in the original roll need not be included in determining the Inspection Results Category for the generator inspection.

The reroll repair process can be used to repair tubes with defects in the upper and lower tubesheet areas. Installation of multiple repair rolls in a single tube is acceptable. The new roll area must be free of detectable degradation in order for the repair to be considered acceptable. After the new roll area is initially deemed acceptable, future degradation in the new roll area will be analyzed to determine if the tube is defective and needs to be removed from service or repaired. The reroll repair process is described in the topical report, BAW-2303P, Revision 4.