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SUBJECT: Provides response to GL 95-03 re circumferential cracking of SG tubes.

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June 13, 1995
OG-95-1519

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Subject: B&W Owners Group Generic Response to GL 95-03

Gentlemen:

The B&W Owners Group (BWOG) has reviewed NRC Generic Letter 95-03 regarding circumferential cracking of steam generator tubes and is submitting the attached generic response for all utilities with operating B&W Once-Through Steam Generators (OTSG). This generic BWOG response will be referenced and incorporated in each Utility's individual response to GL 95-03.

The circumferential cracking issue addressed in GL 95-03 has some applicability to the B&W OTSG's. However, by virtue of the OTSG design and tubing material, the tubes have not been susceptible to many of the cracking mechanisms known to exist in other steam generator designs. Preventive sleeving has minimized the occurrence of circumferential fatigue failures. Past tube inspections have concentrated on susceptible areas and circumferential cracking has not been identified as a significant degradation mechanism at B&W plants. The next inspection of OTSG's will continue to concentrate on these areas. As required by Generic Letter 95-03, the attached information provides the justification for continued operation of the B&W plants to their next scheduled steam generator inspection outage.

Very truly yours,

John A Selva

John A. Selva
B&W Owners Group
Steering Committee Chairman

c: J.D. Woodward (SGMP)
T.E. Tipton (NEI)
C. Welty (EPRI)

June 13, 1995

Generic Response to GL 95-03 for B&W OTSG Relative to Circumferential Cracking of Steam Generator Tubes

I Applicability of B&W OTSGs to Circumferential Cracking Issue

1.0 Introduction

NRC Generic Letter 95-03 "Circumferential Cracking of Steam Generator Tubes" dated April 28, 1995 addressed circumferential cracking of steam generator tubes. It notified all holders of PWR operating licenses of recent steam generator tube inspection findings at Maine Yankee and the safety significance of these findings. The letter also requested a review of recent operating experience at each plant with respect to the detection and sizing of circumferential indications, in addition to a safety assessment to justify continued operation until the next scheduled steam generator tube inspection.

This document is a generic safety assessment which applies to the licensees whose plants use once-through steam generators (OTSGs).

2.0 OTSG Background Information

The OTSG is a vertical once-through steam generator containing typically 15,531 5/8-inch diameter Alloy 600 straight tubes, each over 56-feet long (see attached Figure 1). The tubes are aligned and supported by 15 carbon steel tube support plates (TSP) which have broached holes to provide three-point support and a space for axial flow around each tube. During manufacture each tube was roller expanded 1-inch deep at each primary face of the 24-inch thick tubesheets for tube-to-tubesheet welding. Each fully assembled steam generator underwent a furnace stress relief heat treatment process at 1100 to 1150 degrees for 12 hours.

At full power, the primary coolant enters the upper head at about 604 degrees F and exits the lower head at about 554 degrees F, while approximately 450 degree F feedwater is preheated in an annulus around the tube bundle and then boils and superheats as it flows axially up around the tubes. Superheated steam leaves the OTSG at about 570 degrees F.

The first OTSG went into operation at Oconee 1 in 1974, and the 14 now in operation have accumulated EFPYs ranging from 9 to 16 years. All OTSGs started up using AVT water treatment and full-flow condensate polishing, and the feedwater chemistry has generally been maintained well below the maximum EPRI guideline values.

3.0 Susceptible Circumferential Crack Locations

The areas of the OTSG tubes which may be susceptible to circumferential cracking are (1) those which may be subjected to high-cycle fatigue, and (2) those roll transitions which have residual tensile stresses which are primarily in an axial orientation. These criteria indicate four regions which may be susceptible. However, it should be noted that service-induced circumferential cracking has been observed only in region (a) below.

a. The uppermost span of tubes in the lane/wedge region,
b. Tube-to-tubesheet expansion transitions, including 189 total tubes which have not been stress-relieved and are therefore expected to be more susceptible to cracking,
c. Tube kinetic expansion transitions, which have not been stress relieved (TMI-1 UTS only), and
d. Tube/sleeve expansions at sleeve roll transitions.

Each of these regions is discussed separately.

3.1 The Uppermost Span of Tubes in the Lane/wedge Region

This region consists of tubes in the lane/wedge region at elevations between the upper tubesheet secondary face (UTSF) and the uppermost tube support plate (15th TSP). The inspection lane is an un-tubed channel which extends from the periphery to the center of the tube bundle along Row 76 of the tube layout. The lane/wedge region has been defined as a region of tubes which abuts the outer half of this lane and then flares out into a wedge shape near the periphery of the tube bundle, per the attached Figure 2.

The steam flow in the uppermost tube span is primarily across the tubes as it turns to exit the bundle. The open lane is a cooler area of the generator which in turn lets wet steam deposit contaminants higher in the bundle, contributing to local degradation. The lower flow resistance of the lane/wedge region results in higher crossflow velocities, and this high velocity steam may cause flow-induced vibration of these tubes. This vibration could result in high cycle fatigue failure (Reference NRC Information Notice 91-43).

3.2 Tube-to-Tubesheet Expansion Transitions

During manufacture of the OTSGs each tube was roller expanded 1-inch deep at the primary face of both tubesheets in preparation for the tube-to-tubesheet welds. This roller expansion process produces a diameter change in the tube and leaves the transition area with residual stresses which are primarily tensile on the OD surface. These cold-worked areas are expected to be more susceptible to cracking than the balance of the tube which has not been cold-worked. Later the entire assembled OTSG was subjected to a furnace stress relief process, which reduced the residual stresses in the transitions and thermally treated the tubes.

However, a few tubes in each plant were re-expanded during the shop hydrostatic tests as a temporary seal until the leaking tube could be rewelded. These deeper expansions did not have a post-roll stress relief, which makes them more likely candidates for cracking. There are a total of 189 known non-stress relieved transitions existing in all the OTSGs according to manufacturing records, including 47 in the UTS (hot leg upper tubesheet) and 142 in the LTS (cold leg lower tubesheet). Most of these expansions are in the Oconee-1 plant, including 29 located in the UTS.

Stress relief of Alloy 600 is neither required nor prohibited by ASME Section III Code. However, this 12-hour furnace stress relief at 1100 to 1150 F constitutes a thermal treatment which both reduces the residual stresses and enhances the resistance of Alloy 600 to caustic corrosion. Therefore the roll transition joints which did not get the standard treatment are likely to be the location of the first tube transition failures in the OTSGs. Unlike an RSG, the tubes are normally in compression during operation, which reduces the likelihood of circumferential cracking in the transitions.

Three tubes in the Oconee-3 B-OTSG were explosively expanded full length in both upper and lower tubesheets. It could not be determined from available records whether the expansions were performed before or after the full bundle stress relief.

3.3 Tube Kinetic Expansion Transitions (TMI-1 UTS only)

During an extended cold shutdown period, the tubes of the TMI-1 steam generators were found to have many ID-initiated IGA assisted cracks near the top of the upper tubesheet (Reference NRC Information Notices 82-14 and 84-18). This was a singular event due to a reduced sulphur excursion during the shutdown. Some tubes were plugged, and all tubes remaining in service were kinetically expanded part-length through the upper tubesheet to create a new load-carrying and essentially leak-tight joint. The lower transition of the new expanded length has not been subjected to a stress relief process. These kinetic expansion transitions are similar to the rolled tube transitions discussed above, and could be considered to be potential sites for circumferential cracking.

3.4 Tube/Sleeve Expansions at Sleeve Roll Transitions

Mechanical sleeves have been installed in all operating B&W plants in order to mitigate tube leaks due to high cycle fatigue and to repair tubes with other UTS or 15th TSP degradation. Sleeves are in service that are fabricated from both Alloy 600TT and Alloy 690TT material. The mechanical sleeve has roller expanded joints at each end to seal it into the parent tube. These tube expansion transitions have had no stress relief process. Thus, consistent with earlier discussions, this is a potential site for circumferential cracking. However, the orientation of the crack can not be reliably predicted because the resultant of the residual and operational stresses may vary.

Six tubes were sleeved at Oconee-1 in 1979 on a test basis with hydraulically expanded sleeves. Four of these had short sleeves at both UTSF and 15th TSP, and the other two were sleeved only at UTSF. The four sleeved tubes in the lane region have subsequently been plugged for reasons unrelated to the sleeves, but two of the double-sleeved tubes remain in service. These hydraulic expansions are also potential sites for circumferential cracking.

4.0 Scope of Past Tube Inspections

Past tube inspections have concentrated upon the susceptible regions described above. The susceptible regions have been inspected as follows:

4.1 The upper span of any unsleeved tubes in the lane/wedge region has been examined by MRPC at the UTSF and 15th TSP.

4.2 Duke Power has inspected all the non-stress relieved UTS roll transitions in the Oconee-1 plant during the most recent inspection outages using MRPC.

4.3 Kinetic transitions in the lane/wedge region at TMI-1 have been frequently examined using an 8x1 array pancake coil probe.

4.4 All plants have examined a portion of their in-service tube sleeves using both standard and crosswound bobbin coils at each scheduled inspection. In addition, some sites have recently used rotating plus point and rotating crosswound techniques for examination of sleeve rolled joints. During the Spring 1995 outage ANO-1 used the plus point probe to inspect the rolled joints of approximately 222 Alloy 600 sleeves, which included the 50 sleeves which have the longest service life of any rolled sleeves in an operating B&W OTSG. Ten of these sleeves have now seen over 6 EFPY of operation.

5.0 <u>Past Tube Inspection Results</u>

The results of past tube inspections related to circumferential cracking are listed for the four susceptible locations described above:

5.1 Uppermost Span of Tubes in the Lane/wedge Region

There have been 41 OTSG tube leaks which have been attributed to circumferential cracks caused by high cycle fatigue in the lane/wedge region. These cracks generally occur where the bending is restrained at the upper edge of the 15th TSP and at the secondary face of the upper tube sheet, initiating in any local discontinuities. Tube failure due to high cycle fatigue usually progresses rapidly after crack initiation, with primary to secondary leakage typically occurring within a period of hours.

The OTSG plant licensees have relied upon the installation of preventative sleeves in the top span of these tubes to minimize tube failures. The 80-inch mechanical sleeve stiffens the tube and provides an inner pressure boundary. All OTSG plants now have completed sleeving tubes in their defined lane/wedge regions. The annual rate of OTSG tube leaks decreased as the preventive sleeving program neared completion, confirming the effectiveness of this program. Note that sleeving mitigates the consequences of fatigue failures, and it is not dependent upon inspection by non-destructive examination.

5.2 Tube Roller Expansion Transitions

None of the rolled tube transitions have leaked or shown service-induced eddy current indications to date, whether stress relieved or not.

5.3 Tube Kinetic Expansion Transitions

There have been no confirmed service-induced tube cracks or leaks found in the TMI-1 kinetic expansions to date.

5.4 Tube/sleeve Expansions at Sleeve Roll Transitions

To date, no sleeved tubes have been removed from service due to service-induced degradation in the sleeved area of the parent tube or sleeve.

II. <u>Justification for Continued Operation</u>

The B&W plants by virtue of their design and tubing material have not been susceptible to many of the circumferential cracking mechanisms known to exist in other plants. The OTSG plants have not identified any service-induced circumferential cracking in the tubes or sleeves other than fatigue-induced cracks in the upper span of the lane/wedge region. Degradation in this region has been adequately addressed by preventative sleeving, as discussed in Section I. Inspections of the other susceptible regions have not identified circumferential cracks.

The inspection techniques used at B&W plants are capable of reliable detection of circumferential cracking. These techniques have been shown to prevent uncontrolled tube degradation.

If a tube should develop a circumferential crack and sever at a rolled or kinetic expansion transition, the consequences of this failure are minimized because the severed ends of the tube would be captured within the tubesheet. In a similar manner, the sleeve prolongation beyond the rolled joint would keep the ends of the tube from separating if a tube should sever at a rolled sleeve transition. The consequences of a circumferential crack which severs a tube are minimized by these design features.

Identified circumferential cracking has been successfully repaired at B&W plants. The inspection techniques which have been used will reliably detect the onset of circumferential cracking where it is known to occur. The potential for the rupture of a tube is very low, and the consequences of a severed tube are mitigated by the capture provisions of the design. Therefore, based upon the demonstrated success of preventative sleeving and the lack of observed failures in other areas believed to be most susceptible to circumferential cracking, there is no known risk incurred by continuing to operate the OTSG plants. Continued operation of the OTSG plants until the next scheduled tube inspection is safe and is therefore justified.

III. Plans for the Next Inspection for Circumferential Cracking

1.0 Scope of the Inspections

The specific locations considered to be most susceptible to circumferential cracking in B&W OTSGs will be inspected at the next scheduled tube inspection outage as follows:

1.1 The Uppermost Span of Tubes in the Lane/Wedge Region

Tubes in the lane/wedge region have been preventively sleeved in the uppermost span to mitigate the consequences of fatigue failures. A one-tube wide border of un-sleeved tubes in service around the lane/wedge region of sleeved tubes will be examined to confirm that the sleeved region is still adequately bounded. This examination will consist of inspection of the 15th TSP and UTSF areas of each tube. Examination of sleeved tubes is addressed in item III.1.4 below.

If cracking is confirmed in the uppermost span of the border tubes surrounding the sleeved lane/wedge region, the inspection scope will be expanded until the area of cracking is demonstrated to be bounded.

1.2 Tube-to-Tubesheet Expansion Transitions

Each of the rolled tube transitions which has not been stress relieved will be examined if it has not been sleeved or plugged . This includes transitions within both UTS and LTS. Note that these transitions in OTSG tubes are deep within the tubesheet where the signals are not distorted by dents or the face of the tubesheet.

If cracking is confirmed in the rolled expansion transitions which have not been stress relieved, sample expansion into the stress relieved transitions will be evaluated.

1.3 Tube Kinetic Expansion Transitions

The examination of unsleeved tubes in the lane region at TMI-1 will include inspection of the kinetic expansion transitions for those tubes (approximately 280 tubes per OTSG). Indications of circumferential cracking in the kinetic expansion transitions will be cause for additional examinations as necessary to bound that occurrence.

Leak testing by bubble test is scheduled for both TMI-1 OTSGs during the next refueling outage; such leak testing is capable of identifying upper tubesheet kinetic expansion transition crack leaks for follow-up eddy current examination and repairs as required. Note that previous leak tests since 1985 have consistently found that there were no leaking kinetic expansion transitions.

1.4 Tube/sleeve Expansions at Sleeve Roll Transitions.

A 20 percent random sample of all sleeved tubes will be selected for examination. This examination will include tubesheet and freespan expansions in the pressure boundary portions of the sleeve and parent tube.

If cracking is found in the sleeved tubes, the sample will be expanded to 100% of the installed sleeves or until the expanded inspection scope demonstrates that the cracking is localized to a specific area or population of tubes.

2.0 Inspection Methods and Equipment

The technique to be used for the detection of circumferential cracking in OTSG tubes and sleeves will use a probe which has been qualified for detection of circumferential cracks per Appendix H of EPRI Report NP-6201 "PWR Steam Generator Examination Guidelines", or other site-specific qualification.

The analysts will be qualified to SNT-TC-1A Level II or higher, as well as to site-specific guidelines with respect to detection of circumferential cracking.

IV Conclusion

The circumferential cracking issue is applicable to the B&W OTSGs. By virtue of the design and the tubing material, the tubes have not been susceptible to many of the cracking mechanisms known to exist in other steam generator designs. Preventive sleeving has minimized the occurrence of fatigue failures. Past tube inspections have concentrated upon certain areas of the tubes which may be susceptible, and circumferential cracking has not been identified as a significant degradation mechanism at B&W plants.

The inspection techniques which have been used are capable of reliable detection of circumferential cracking. The potential for the rupture of a tube remains acceptably low and the consequences of a rupture are mitigated by the design features. The next inspections of OTSGs will continue to concentrate upon areas which may be susceptible to circumferential cracking. Thus, as required by Generic Letter 95-03, it is concluded that continued operation of the OTSG plants until the next scheduled tube inspection is justified.

Figure 1

OTSG Section

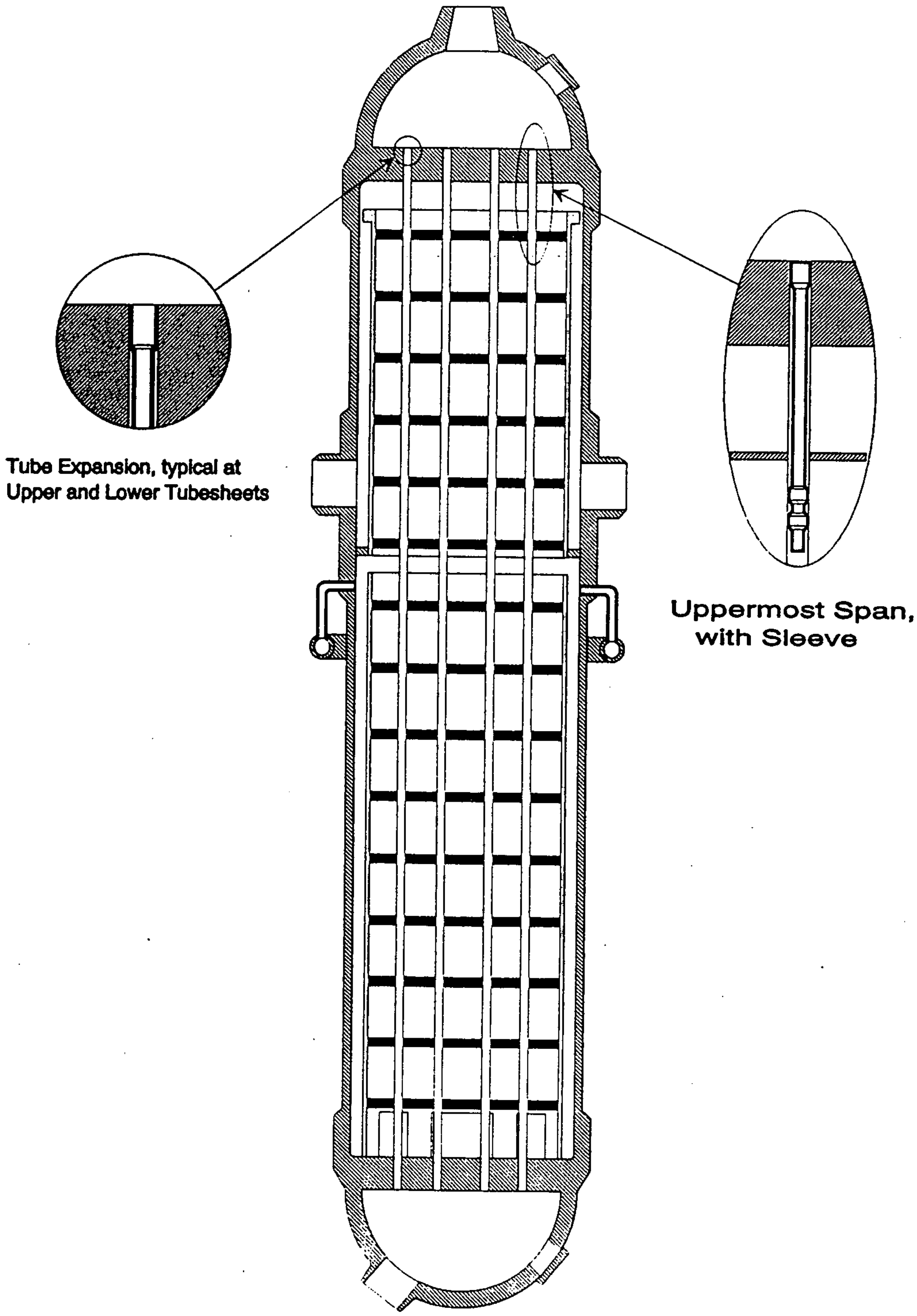

Figure 2

OTSG Lane/Wedge Region