UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D.C. 20555-0001

July 10, 1997

NRC INFORMATION NOTICE 97-49: B&W ONCE-THROUGH STEAM GENERATOR TUBE INSPECTION FINDINGS

Addressees

All holders of operating licenses or construction permits for nuclear power reactors.

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice to present the findings from the examination of tubes in Babcock and Wilcox (B&W) once-through steam generators (OTSGs). It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice are not NRC requirements; therefore, no specific action or written response is required.

Description of Circumstances

Licensees using B&W OTSGs have historically observed very little service-induced degradation in steam generator tubes. During the last few years, however, more degradation has been observed and this degradation has been seen at a variety of locations, such as dented (dinged) areas, the expansion transition region, the freespan region, the sludge pile region, and the sleeve joints. Pertinent inspection findings from steam generator tubes at several plants with OTSGs are discussed.

Degradation at Dented Locations

Indications of degradation associated with dented (dinged) areas have been found at several plants--Arkansas Nuclear One, Unit 1 (ANO-1), Oconee Unit 1, and Crystal River Unit 3. These indications have been axial, circumferential, or volumetric in nature. At ANO-1 (in 1993), two volumetric indications with circumferentially oriented cracklike indications were found at dents on the secondary face of the upper tubesheet (UTS). These indications were initially found with a bobbin coil probe and were confirmed to be present with a rotating pancake coil eddy current inspection probe. At ANO-1 (in 1996), two axially oriented eddy current indications associated with dented areas in the tube's freespan region were observed. Similar to the 1993 indications, these indications were also initially found with a bobbin coil probe. Rotating pancake coil probe inspection of one of these indications confirmed that the indication initiated from the outside diameter of the tube and that the indication was offset relative to the tube axis by approximately 35 degrees. At Oconee Unit 1 (in 1995), a volumetric and a circumferential indication were detected at dents located at the 15th tube

support plate. At Crystal River Unit 3 (in 1996), a volumetric eddy current indication was found at a dented area. This indication was detected with the bobbin coil and confirmed with a pancake and plus-point coil.

Degradation at the Expansion Transition Region

The expansion transition region of the tubes in B&W OTSGs were heat treated to reduce residual stresses from tube fabrication and installation, and to increase resistance to primary water stress corrosion cracking (PWSCC). This heat treatment resulted from a full furnace stress relief of the entire tube bundle. During the manufacturing process, however, several tubes were re-rolled into the tubesheet following the full furnace stress relief to temporarily seal the tube during the shop hydrostatic tests. As a result, a limited population of tubes was not stress relieved at the expansion transition region (i.e., fewer than 200 tubes are known to have not been stress relieved). Axial indications associated with the expansion transitions of both stress-relieved and nonstress-relieved transitions were recently noted in several B&W units (Davis-Besse, Crystal River 3, ANO-1, and Oconee 3). The inspection findings at these plants are discussed below.

At Davis-Besse (in the spring of 1996), an axially oriented indication was detected during the examination of what was believed to be a nonstress-relieved roll transition. This indication was in the roll transition in the UTS (i.e., the hot leg). Subsequent review of shop records showed that the expansion transition had not been re-rolled and was, therefore, stress relieved. The licensee removed the roll transition portion of this tube for destructive examination. The destructive examination showed that the indication was caused by PWSCC. To ascertain whether the tube had been stress relieved, the licensee performed additional analyses and testing. As a result of this testing, the licensee concluded that the roll transition was not stress relieved (i.e., it had been re-rolled following the full bundle stress relief process).

At Crystal River 3 (in the spring of 1996), a single axial indication was detected in the roll transition in a tube that had been re-rolled following the full bundle stress relief (i.e., a nonstress-relieved transition), and a multiple axial indication was detected in the tube end, above the shop re-roll in the same tube. These indications were located in the roll transition in the UTS (i.e., the hot leg). The eddy current data clearly indicated that the tube had been rolled multiple times. The licensee attributed the indication to PWSCC.

At ANO-1 (in the fall of 1996), 24 axially oriented and volumetric indications were detected in stress-relieved roll transitions in the UTS (i.e., the hot leg). The licensee attributed the axial indications to inside diameter-initiated stress corrosion cracking (i.e., PWSCC). The volumetric indications had been initiated on the outside diameter, pointing perhaps to

intergranular attack (IGA) or to closely spaced cracks. To further characterize the nature and cause for the upper roll transition indications (and other indications), the licensee for ANO-1 removed several tube sections for destructive examination. The destructive examination findings from the one roll transition indication that was removed confirmed that the indication was attributable to PWSCC. This transition had been stress relieved.

At Oconee Unit 3 (in the fall of 1996), 19 tubes were identified by eddy current testing as having PWSCC at the roll transition region in the UTS. Of the 19 indications, 15 were axial indications in the roll transition region, 3 were axial indications in the rolled area , and 1 was a volumetric indication at the roll transition region. One tube was removed for laboratory analysis of the indication at the upper roll transition region. The laboratory destructive examination findings were not available at the time this notice was prepared.

Degradation at Freespan Locations

Axially oriented degradation in the freespan region has been observed in several B&W OTSGs (Oconee 1, Oconee 2, Oconee 3, and ANO-1). Freespan degradation is degradation observed above the sludge pile region and not located at any support structure (e.g., tube support plates). A freespan axial indication was first identified at Oconee 1 in May 1994. This indication was identified with a bobbin coil and confirmed to be present with a rotating pancake coil probe. This tube along with six others were removed for destructive examination. The destructive examination confirmed the presence of freespan axially oriented IGA in all seven tubes. The tube with the indication detected with a bobbin coil was the most significant with a through-wall depth of 47 percent and a burst pressure of 7400 pounds per square inch (psi), well above the structural criteria specified in Regulatory Guide 1.121. The IGA in the remaining tubes ranged from 5 percent to 28 percent through-wall.

Subsequent bobbin coil inspections at Oconee Units 1, 2, and 3 identified additional tubes with freespan axial indications. For example, 9 tubes with indications were detected at Oconee 2 in October 1994, 22 tubes with indications were detected at Oconee 3 in June 1995, 40 tubes with indications were detected at Oconee 1 in November 1995, and 173 tubes with indications were detected at Oconee 2 in April 1996. During the Oconee 2 inspection outage in April 1996, four tubes were removed for destructive examination. The selection criteria for these tubes included small and large indications, the number of indications per tube, and a sampling across the tube bundle. The burst pressures for these tubes ranged from 5700 psi to 11000 psi. In November 1996, the most recent steam generator inspection outage at an Oconee unit, 67 tubes with confirmed bobbin coil indications were identified at Oconee 3. An assessment performed by the licensee, based on previous tube pull analysis, indicated that these tubes had adequate structural integrity. All tubes with axially oriented freespan IGA, which were confirmed to be present with a rotating pancake coil probe, were removed from service upon detection. During the Oconee 3 outage in November 1996, three tubes with IGA were removed for destructive examination. The laboratory destructive examination findings were not available at the time this notice was prepared.

The root cause analysis from the Oconee 1 tube pull analysis did not identify any unique feature to this degradation mechanism that would indicate that the problem was limited to the Oconee Units. That is, the base material properties met specific values, no high residual stresses were measured, and no detrimental environmental or chemical species were identified. These results indicate that all B&W OTSGs are potentially susceptible to this mechanism. In September/October 1996, the licensee for ANO-1 detected freespan axial indications similar to those observed at the three Oconee units. Approximately 13 tubes with freespan axial indications were identified and plugged at ANO-1 during this outage. These indications were initially detected with a bobbin coil probe. In-situ pressure testing of two of the more severe indications (as identified by nondestructive examination) indicated burst pressures for these freespan axial indications in excess of 4550 and 5750 psi. No leakage was observed from either of these two indications during the in-situ test. Each of the Oconee units and ANO-1 inspected 100 percent of the inservice tubes with a bobbin coil during their last inspection outage.

Degradation in the Sludge Pile Region

At ANO-1 (in the fall of 1996), nine axially oriented indications were observed above the lower tubesheet. These indications were in the sludge pile region, approximately 0.25-inch above the lower secondary face of the tubesheet. The indications were found with a bobbin coil and were confirmed with a motorized rotating pancake coil inspection. Two tubes were removed for laboratory examination. The laboratory destructive examination pointed to these indications being initiated from the outside diameter of the tube and were a result of axially oriented IGSCC. The licensee also observed areas of shallow intergranular corrosion initiating from the outside diameter of the tube near the fracture faces. This corrosion was three-dimensional in nature, similar to IGA regions; however, many of the affected grains were no longer present, resulting in the removal of tube material and appearance of shallow wastage. These "IGA wastage" regions were relatively shallow (less than 24-percent through-wall) and in the form of meandering grooves or gullies. The metallurgical results suggested to the licensee that the axial cracks originated at the bottom of these IGA wastage zones. On the basis of nondestructive examination, these meandering grooves appeared to be located at or near sharp edges of surface deposits.

Degradation at Sleeved Locations

B&W mechanical sleeves have been installed in all operating B&W OTSG plants in order to mitigate tube leaks caused by high-cycle fatigue and to repair tubes with other indications of degradation. The number of sleeves in service at these plants varies from a few hundred to approximately one thousand. These sleeves, fabricated from either alloy 600 or alloy 690, have three roller-expanded joints to seal them into the parent tube (one at the top of the sleeve and two at the bottom of the sleeve). These joints have not undergone any type of process to relieve stress.

Axial, circumferential, and volumetric indications were detected in the joints of B&W mechanical sleeves at ANO-1 (in 1996) although no tubes were removed to learn the nature of the degradation. The indications were found at the joints of both alloy 600 and alloy 690 sleeves with a plus-point coil. The licensee believes that 9 of the 10 indications detected are associated with the parent tube rather than with the sleeve itself. The degradation has been observed at both the upper joint (located within the UTS) and the lower joints (in the tube freespan region); 8 of the 10 indications were observed at the upper joint. One circumferential indication was detected at an alloy 600 sleeve joint at Oconee Unit 3 (in 1996) with a plus-point coil. This indication was associated with the upper of the two lower joints (i.e., the upper lower joint). The licensee for Oconee Unit 3 believes that the indication could be the result of a scratch made during the rolling process; however, this cannot be confirmed, since current technology does not permit the sleeve to be removed from the steam generator for destructive examination because of its location.

Discussion

The inspection findings from B&W OTSGs indicate that a number of locations are susceptible to degradation. In addition, studies of removed tubes have confirmed in several instances that the eddy current indications are attributable to such degradation mechanisms as IGA and stress corrosion cracking. Frequently these indications can only be reliably detected with specialized probes such as rotating probes (e.g., roll transition indications, indications in sleeve joints). In addition, the depth of many of these types of indications cannot be reliably determined.

To effectively manage the degradation mechanisms being observed, a variety of actions have been taken by licensees. These actions include inspecting locations potentially susceptible to degradation with techniques capable of reliably detecting these forms of degradation (or using the best available technique) and ensuring that the frequency and scope of inspection are sufficient at identifying and removing degradation from service to prevent the degradation from progressing to the point at which tube integrity is impaired. For example, the sleeve joints at ANO-1 and Oconee 3 were examined with a plus-point coil, and 100 percent of the tubes were examined with a bobbin coil at ANO-1 and Oconee Units 1, 2, and 3 during their last outage. Other actions taken by licensees include removing tubes from service based upon detection when the degradation cannot be reliably depth-sized (unless an alternative tube repair criterion has been approved by the NRC), and assessing significant indications in steam generator tubes to determine whether adequate structural and leakage integrity was maintained during the previous cycle. Specific actions taken by licensees to assess the structural and leakage integrity of tubes include removing tubes for destructive examination as was done at ANO-1, Davis-Besse, and Oconee 1, 2, and 3, and performing *in situ* pressure testing.

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