

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

April 1, 2003

NRC INFORMATION NOTICE 2002-21, SUPPLEMENT 1: AXIAL OUTSIDE-DIAMETER
CRACKING AFFECTING
THERMALLY TREATED ALLOY
600 STEAM GENERATOR
TUBING

Addressees

All holders of operating licenses for nuclear power reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this supplement to IN 2002-21 to inform addressees of the root cause assessment for the axially oriented outside-diameter crack indications in the thermally treated Alloy 600 steam generator (SG) tubing at Seabrook. 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.

Background

Seabrook is a four-loop Westinghouse 1198 MWe (PWR) unit. Commercial operation started in August of 1990. The unit has operated for approximately 10 effective full-power years (EFPY).

Seabrook has four Westinghouse Model F recirculating steam generators (A, B, C, D). Prior to installation, the tubes in rows 1 through 10 were stress-relieved to relieve the stresses from bending the tubes. Each steam generator contains eight stainless steel tube support plates and six antivibration bars in the U-bend region. The first tube support plate is a partial plate, consisting of only a plate ring with drilled tube holes. The remaining seven plates have quatrefoil broached tube holes.

During the eighth refueling outage, 42 eddy current indications in 15 "low row" tubes (tubes in rows 1 through 10) were identified and classified as potential axially oriented outside diameter stress corrosion cracks (ODSCC). All indications were in one steam generator and all indications were located in the region where the tube passes through a TSP (i.e., tube-to-tube-support-plate intersection). Both hot and cold leg tubes were affected. No indications were observed at the top of the tubesheet. This issue was discussed in NRC IN 2002-21, "Axial Outside-Diameter Cracking Affecting Thermally Treated Alloy 600 Steam Generator Tubing", issued June 25, 2002 (ADAMS Accession No. ML021770094).

ML030900517

Description of Circumstances

The licensee completed its root cause evaluation, including destructive examination of two pulled tubes, confirmed that the indications were axially oriented ODSCC, and also identified unusually high levels of residual stress in the straight leg sections of both the hot and cold legs. Nonoptimal tube processing during SG manufacturing was strongly suspected to be the primary cause of the high residual stresses and the principal factor increasing the susceptibility of the affected tubes to stress corrosion cracking. The precise processing steps responsible for the adverse stress state could not be conclusively determined from a review of the tube processing records.

Although an aggressive environment, locally created by concentrating chemistry effects in the crevice region between the tube and the tube support plate, is a necessary contributing factor for stress corrosion cracking, evidence of abnormal chemistry was not identified and chemistry is not believed to have been a significant factor in the early onset of stress corrosion cracking at Seabrook. Seabrook has maintained secondary chemistry in accordance with EPRI guidelines throughout plant life and has not experienced any major chemical excursions.

The Alloy 600 material in the pulled tubes complied with established chemical limits and the microstructure, although not optimal, was considered to be representative of thermally treated Alloy 600 material. Three material heats were identified as being affected (13 of the 15 cracked tubes were from one heat). Tubes from the affected heats are used throughout the four steam generators.

Prior to destructive examination, the pulled tubes were pressure-tested. One pulled tube, containing the largest flaw, was tested to 7000 pounds per square inch (psi) without signs of leakage: the tube was not tested to burst pressure in order to save the flaw for fractographic examination. Other tube portions, with and without flaws, were tested to burst pressures averaging about 11,000 psi.

During the root cause investigation, the licensee noted that the eddy current signature of the cracked tubes contained a unique offset or shift on the low-frequency (150 KHz) absolute channel between the straight leg portion of the tube and the U-bend region. This offset was attributed to changes in the residual stresses in the tube. No offset in the eddy current data was expected in the low row tubes (i.e., rows 1 through 10) because the U-bend region is stress-relieved after bending, resulting in consistently low levels of residual stress throughout the tube. Since testing of the archived material for the heats of material affected by this cracking found the expected low levels of stress, the licensee attributed the changes in residual stress levels and the resultant eddy current offset in these tubes to nonoptimal tube processing.

Based upon the above findings, the licensee reviewed the eddy current data from the prior outage to determine the number of tubes that may have high residual stresses (i.e., exhibit the offset). This review included not only low row tubes, where the residual stresses are expected to be consistent throughout the tube, but also the higher row tubes (i.e., those not receiving the local U-bend stress relief), where the residual stresses are expected to be higher in the U-bend region (when compared to the straight portion of the tube). Review of the eddy current data from the tubes in all four steam generators identified 21 tubes, including the 15 tubes with cracks, which exhibited the eddy current offset. The 15 degraded tubes (including the two tubes pulled for destructive examination) have been plugged. The six additional tubes identified

as having the offset showed no signs of degradation and were also located in the low row tubes (rows 1 through 10). The licensee indicated that the six tubes would be plugged during the next outage. The 21 tubes identified with the offset were all located in SG D.

A summary of the licensee's root cause analysis presentation to the staff and the root cause analysis report may be found under ADAMS Accession Nos.: ML023300457 and ML023240524.

Discussion

The indications of axially oriented ODSCC in thermally treated Alloy 600 tubing at Seabrook, reported in IN 2002-21, have been confirmed through destructive examination.

Tube cracking at Seabrook was both unexpected and unusual. Thermally treated Alloy 600 material has been successfully used for over 20 years with no prior reports of ODSCC in the United States. Seabrook has significantly less operating history, roughly 10 effective full-power years, than other plants with Model F steam generators. The first signs of cracking were observed not in the top of the tube sheet region, as would be expected, but in the region where the tubes pass through the tube support plates. Historically, cracking has been observed first at the top of the tubesheet due to increased levels of stress in the expansion transition and the buildup of contaminants that collect at the top of the tubesheet. The cracking was also identified in both the cold and hot legs, which is unexpected because the lower temperatures in the cold leg typically result in less degradation. Cracking was identified in three material heats, but the degradation mechanism does not appear to be heat dependent as these heats are used throughout the steam generators. The licensee has indicated that according to vendor records, these three heats have been used for steam generator tubes in other PWRs as well.

A unique eddy current signal offset was identified in the cracked tubes. It was reported to result from high residual stresses caused by nonoptimal tube processing. The high stresses are principally responsible for creating conditions fostering ODSCC. All tubes were screened for the signal offset; however, since the magnitude of the eddy current signal is relative, it may be difficult to adequately screen for susceptibility to ODSCC based on observing an eddy current offset. That is, tubes with consistently high residual stresses throughout their length may not display the eddy current offset, and yet these tubes may be susceptible to stress corrosion cracking.

Heat treatment and tube processing is a special process requiring in-process controls to provide reasonable assurance of end product quality. Although nonoptimal tube processing is unexpected with strict in-process controls, problems in manufacturing can occur and could generically affect mill-annealed Alloy 600, thermally treated Alloy 600, or thermally treated Alloy 690 steam generator tubes.

The unexpected nature of the Seabrook cracking, the potential applicability to other tube materials, and the ability to screen tubes which may be more susceptible to ODSCC using the eddy current offset technique illustrates the need for thorough inspections and strong inservice inspection programs which remain vigilant to the potential for stress corrosion cracking regardless of the material, location, or steam generator history. This example of unanticipated cracking should also be considered in determining appropriate frequencies for inspecting the reactor coolant pressure boundary to ensure that its integrity is maintained consistent with the plant's design and licensing basis.

This information notice requires no specific action or written response. If you have any questions about this notice, contact one of the persons listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

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ADAMS ACCESSION NUMBER: ML030900517

DOCUMENT NAME: G:\RORP\OES\Staff\Caldwell\IN 2002-21 Sup 1 Outside Diameter cracking\IN 2002-21 Sup 1 Tech Ed 1 31 03.wpd

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