

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

December 23, 1994

NRC INFORMATION NOTICE 94-88: INSERVICE INSPECTION DEFICIENCIES RESULT IN SEVERELY DEGRADED STEAM GENERATOR TUBES

## Addressees

All holders of operating licenses or construction permits for pressurized- water reactors.

## Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to alert addressees to recent findings from steam generator (SG) tube inspections and investigations at Maine Yankee Atomic Power Station (Maine Yankee). A number of tubes were degraded to the point where they potentially no longer retained adequate structural margins to sustain the full range of normal operating, transient, and postulated accident conditions without rupture. This occurrence is the result of inservice inspection deficiencies during past inspections. On December 7, 1992, NRC informed addressees of a similar problem at Arkansas Nuclear One, Unit 2 (ANO 2), by issuing NRC IN 92-80, "Operation With Steam Generator Tubes Seriously Degraded." 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

On July 15, 1994, Maine Yankee Atomic Power Company, the licensee for Maine Yankee, shut down the plant when the measured primary-to-secondary leak rate approached 189 liters [50 gallons] per day. The technical specification limit is 818 liters [216 gallons] per day. Beginning at a low rate before the last refueling outage, this leakage had slowly increased during the operating cycle, which began in October 1993.

After shutting down the plant, the licensee tested for leaks and found four leaking tubes. The licensee conducted an eddy current test (ECT) inspection of the leaking tubes using a motorized rotating pancake coil (MRPC) probe and found circumferential cracks, initiating from the tube inner diameter surface, at the hot leg expansion transition location, which is near the top of the tubesheet. One of these tubes contained a circumferential indication with an average depth of 94% and extending 360 degrees around the tube circumference. Inner diameter circumferential cracking at the tube expansion transition location had been observed previously in other tubes at Maine Yankee during inspections dating back to 1990.

Reanalysis of previous inspection data for the leaking tubes, performed with the benefit of "hindsight," indicated that circumferential indications were present in these tubes since at least 1990 when MRPC inspections were first performed at Maine Yankee. These indications had not been previously reported due to the difficulty of discriminating the flaw indication from the interference signal associated with probe "liftoff" effects caused by the transition geometry and denting. This problem was intensified by the fact that cracks initiating from the inner diameter surface produce a signal with a phase angle rotation that is small in comparison to the geometry- and denting induced interference signal such that the composite signal was

interpreted as a normal, non-flawed indication. However, terrain plots of these signals, generated as part of the data reanalysis, revealed the presence of the circumferential crack indications. These terrain plots had not been generated as part of the original field analysis for these tubes.

The licensee performed a 100% MRPC inspection of all expansion transition locations on the hot leg side of each steam generator. The licensee employed a 3-coil MRPC consisting of a 2.9-mm [0.115-inch] diameter pancake coil which is sensitive to both axial and circumferential cracks, an "axial" coil which is primarily sensitive to axial cracks, and a "circumferential" coil which is primarily sensitive to circumferential cracks. The licensee reported that improved signal-to-noise performance was achieved through the use of the larger 2.9-mm [0.115-inch] diameter pancake coil in lieu of the previously used 2.0-mm [0.080-inch] diameter coil together with the use of larger diameter copper cables ("low loss cables") for the MRPC probe.

The licensee also employed improved data analysis procedures to reflect information learned from the reanalysis of the previous inspection data for the leaking tubes and from recent experience at ANO-2. All primary and secondary analysts were trained and tested on the 1992 and 1993 data for the Maine Yankee tubes that leaked in 1994. The primary and secondary analysts were required to generate a pancake coil terrain plot for each tube at the expansion transition. Any circumferential indication from the terrain plot was to be recorded as a possible crack. Level III resolution analysts reviewed all indications of possible cracks using voltage ratios from the axial and circumferential coils to assist in interpretation of the pancake coil signals. The voltage ratio criterion is based on the premise that pancake coil indications caused by geometry or dents are likely to produce a response on both the axial and circumferential coils whereas circumferential crack indications are likely to produce a significant response only on the circumferential coil. The licensee considered a voltage ratio of 2.0 (circumferential coil response divided by the axial coil response) to indicate a circumferential crack. The licensee stated that it would likely have found the cracks in previous inspections and plugged the tubes if it had used these data analysis methods.

The licensee found indications of circumferential cracks in a total of 303 tubes, including the four leaking tubes. All of these tubes were plugged and staked, irrespective of the measured depth of the indications. Several of these indications were quite large, including 23 indications with average depths (over the 360-degree circumference) exceeding 79 percent of the tube wall thickness and 10 indications with average depths exceeding 89 percent of the tube wall thickness. The licensee reports that 79 percent is the allowable average crack depth, consistent with the most limiting burst pressure criterion from Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," August 1976. Analyses performed for a similar plant (ANO-2) indicate that a tube with an average crack depth exceeding 89 percent may not sustain a postulated main steam line break (MSLB) pressure of 17,340 kPa [2,500 psi]. Most of the indications found were determined to date back to at least 1990.

## Discussion

The recent eddy current test results at Maine Yankee indicate that certain tubes may have degraded to the point that they did not meet the structural margin criteria of Regulatory Guide 1.121 and that, in addition, some of these tubes may not have been capable of sustaining the differential pressures associated with a postulated MSLB. That this was, in fact, the case is not conclusive, given the large degree of uncertainty associated with eddy current depth measurements for cracks and the inability of eddy current testing to resolve small ligaments of sound material between crack segments.

The licensee performed in-situ pressure tests of ten tubes at Maine Yankee containing some of the largest indications to assess their actual burst integrity. The results of the in-situ pressure tests indicate that the eddy current test measurements for at least some of the cracks were conservative. The licensee concluded

on the basis of these tests that the majority of tubes with MRPC sized indications exceeding 79 percent average through wall had structural margins consistent with the most limiting Regulatory Guide 1.121 criterion and that all tubes were capable of sustaining an MSLB without rupture. The staff is evaluating the results of the in-situ pressure tests, but has not yet reached a conclusion regarding the validity of the tests to simulate an actual pressure transient in the steam generators.

Inadequate eddy current test procedures from 1990 or earlier appear to be the primary reason the tubes at Maine Yankee became severely degraded before their recent discovery. In INs 90-49, "Stress Corrosion Cracking in PWR Steam Generator Tubes," of August 6, 1990, and 92-80, "Operation with Steam Generator Tubes Seriously Degraded," of December 7, 1992, NRC stressed the importance of using appropriate probes such as pancake type coils when inspecting locations that are potentially subject to circumferential cracks. The Maine Yankee findings, however, indicate that use of pancake type coils is not necessarily sufficient to ensure the timely detection of circumferential cracks.

This difficulty in obtaining accurate eddy current test results also demonstrates the importance of (1) optimizing the test methods to minimize electrical noise and signal interference and to maximize flow sensitivity; (2) anticipating potential sources of interfering signals, such as from probe liftoff caused by tube transition geometry and from dents and understanding their potential effect on flaw detection; (3) developing test and analysis procedures that will allow the flaw signal to be discriminated from any unavoidable signal noise or interference; and (4) being alert to plant unique circumstances (e.g., dents, copper deposits) which may necessitate special test procedures found not to be necessary at other similarly designed steam generators or not included as part of a generic technique qualification. Recent information from ANO-2, where circumferential cracks initiated from the outer diameter surface at the expansion transition, indicates that procedures which rely on what nondestructive examination analysts refer to as "good or expected phase angle correlation" between base test frequencies can lead to missed indications. Data from pulled tube specimens are useful for developing and validating effective inspection methods for each plant. Appropriate training and performance demonstration testing of the data analysts on the test and analysis procedures are essential elements of an effective inspection program.

Circumferential cracks have been reported at the tube expansion transition locations of several Combustion Engineering (CE) designed plants (including Maine Yankee and ANO-2) and at several Westinghouse plants. Tubes in the CE steam generators and at most of the affected Westinghouse plants were explosively expanded against the tubesheet (called an "expansion" process at CE units and a "WEXTEx" process at Westinghouse units). Tubes in the remaining affected Westinghouse plants were roll expanded against the tubesheet.

The staff is continuing to evaluate the generic implications of the Maine Yankee occurrence.

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

/S/'D BY BDLIAW/FOR

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