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

July 17, 2002

NRC INFORMATION NOTICE 2002-02, Supplement 1: RECENT EXPERIENCE WITH PLUGGED STEAM GENERATOR TUBES

Addressees

All holders of operating licenses for pressurized-water reactors (PWRs), except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor.

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of findings from recent inspections and examinations of steam generator tubes at Oconee Nuclear Station Unit 1 (ONS-1). The NRC anticipates that recipients will review the information for applicability to their facilities and consider taking actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice do not constitute NRC requirements; therefore, no specific action or written response is required.

Background

Potential severance of plugged steam generator tubes was discussed in IN 2002-02, "Recent Experience With Plugged Steam Generator Tubes," (ML013480327) as a result of inspection findings at Three Mile Island Unit 1 (TMI-1) during the fall 2001 refueling outage. At TMI-1, a plugged tube, located on the periphery of the tube bundle, severed near the secondary side of the upper tubesheet and damaged four adjacent in-service (i.e., nonplugged) tubes. The preliminary laboratory investigation of the severed tube found signs of high cycle fatigue, ductile failure, and outside-diameter-initiated intergranular attack (IGA). In addition, the tube diameter was greater than the nominal tube diameter, indicating that the severed tube had swollen. The licensee determined that the most likely cause of failure was fatigue caused by flow-induced vibration of the swollen and restrained tube. The licensee attributed the swelling to water leaking into the tube around the plugs while the unit was shut down. As the tube heated during plant startup, the water in the tube expanded faster than it could escape past the tube plugs, thereby resulting in a pressure buildup and subsequent swelling of the tube. The effect is called the "diode effect." The swelling caused the tube to become clamped at the drilled hole in the 15th tube support plate and at the upper tubesheet. Under the high-flow conditions that existed in the area of the upper tubesheet, this clamping made the restrained tube more susceptible to fatigue caused by flow-induced vibration. The licensee also concluded that the

IGA on the outside of the tube might have made it more susceptible to severing and that the plug type was probably a factor in the diode effect. In addition, the industry concluded that it was unlikely the once-through steam generator tubes would sever in the lower tubesheet region.

Description of Circumstances

On March 25, 2002, ONS-1 was shut down for a refueling outage. In addition to the standard steam generator tube inspections, the licensee performed supplemental inspections of plugged tubes in both steam generators. These supplemental inspections were performed to address the TMI-1 plugged tube severance event (discussed in Information Notice 2002-02). During the supplemental inspections the licensee removed a number of plugs, dewatered the tube, and examined the tubes with eddy current, including tube diameter measurements to determine if the tube was swollen. No tubes deplugged as a result of this inspection showed any evidence of swelling or tube severance at the upper or lower tubesheet. The tubes were replugged prior to plant restart.

While inspecting a deplugged tube in the B steam generator, row 77 tube 123 (B77-123), the licensee identified signs of wear on the outside tube surface near the secondary face of the lower tubesheet. The wear scar on the tube began at the lower tubesheet secondary face and extended up approximately 6.4 inches and was approximately 28 percent through wall. This wear scar was not detected when the tube was plugged in 1991. An explosive plug in the lower tubesheet of Tube B78-124, which is adjacent to Tube B77-123 (see Figure 1), could not be removed. Therefore, in accordance with the inspection program, the lower tubesheet explosive plug was inspected. It was found to have defects and, per the program, the tube was required to be captured/caged (i.e., surrounded by tubes that were plugged and stabilized). Since previously plugged tube B78-123 was required to be a capture location for tube B78-124, it was deplugged and inspected with eddy current probes. This tube also showed wear in the span near the lower tubesheet area. Tube B78-123 had been plugged in 1999 for volumetric indications in the lower span which could be traced back to 1995. The licensee compared the 2002 inspection data to the 1999 data. The indications appeared to be similar in size. The licensee now believes the volumetric indications were wear indications due to impact from an adjacent tube.

The circumferential location of the wear on these two tubes indicated that the wear was most likely due to impact from an adjacent tube, B78-124. Subsequent visual inspection from the secondary side of the steam generator indicated that tube B78-124 was completely severed at the secondary side (i.e., top) of the lower tubesheet. Based on the flow direction and velocity in the lower tubesheet region, the severed tube would be expected to impact three tubes (B77-123, B78-123, and B79-127). Tube B79-127 was visually inspected from the secondary side and a small wear mark was visible. Based on the location and preliminary characterization of the severed tube's degradation, the licensee concluded it potentially represented a new damage mechanism for once-through steam generators. The NRC obtained this information from the licensee via several conference calls, summaries of which are being prepared and will be made available on the docket.

The licensee removed several tubes, including the upper half of the fracture surface of the severed tube, to assess the root cause of the failure. The preliminary laboratory investigation of the severed tube indicated inside diameter IGA through the entire thickness of the tube wall. There were no indications of fatigue or significant ductile tearing. There were three areas of

smeared metal from rubbing against the three adjacent worn tubes. After removing the upper half of the fracture surface of the severed tube, the licensee examined the remaining section of tube B78-124 with a bobbin coil probe and a rotating probe. The licensee determined that slight tube swelling had occurred between the 12th and 15th support plates, but no swelling was observed near the point of severance. This was very different than the experience at TMI-1.

The licensee determined the most likely cause of failure was inside diameter IGA, which implies a corrosive environment inside the tube. This tube had a unique history. It was 1 of 12 tubes that had first-of-a-kind (FOAK) instrumentation installed in 1971 prior to commercial operation. The purpose of this instrumentation was to determine various temperature distributions in the once-through steam generator design. To conduct this testing, thermocouples were installed in 12 tubes in the B steam generator. In accordance with the FOAK instrumentation installation procedure, the tube which would eventually sever was plugged with an explosive plug in the lower tubesheet in 1971. Testing was completed during the first cycle of operation in 1974 and an explosive plug was installed in the upper tubesheet at that time. It is likely the tube was approximately 50 percent full of water when the upper plug was installed. The upper tubesheet plug was backed up by a welded plug in 1993 due to concerns about degradation of upper tubesheet explosive plugs. Based on a number of observations and hypotheses, the licensee believes the unique conditions of operation associated with FOAK instrumentation are a primary contributor to the corrosive environment and eventual tube failure. The secondary-side flow conditions at the lower tubesheet are in the radial direction toward the center of the tube bundle. The licensee's analysis of the flow conditions shows that velocities around the severed tube are large and would develop forces sufficient to pin the severed end of a tube against the adjacent tubes and cause wear.

The licensee pressure-tested tubes B77-123 and B78-123 to determine the margin to failure. Specifically, the licensee increased pressure until either the tube failed or pressure reached three times the differential pressure encountered during normal operating conditions. The maximum test pressure of three times the differential pressure encountered during normal operating conditions was reached for both tubes with no leakage or burst. Therefore, neither tube challenged the steam generator tube structural or leakage performance criteria discussed by the Nuclear Energy Institute in NEI 97-06, "Steam Generator Program Guidelines."

Except for the above findings, the supplemental tube deplugging and inspection program did not identify any other tubes with evidence of tube severance, significant degradation, or swelling at the lower or upper tubesheet. Inspection of tubes surrounding the plugged tubes found no other wear indications that suggested the presence of a severed tube. All tube locations adjacent to the 12 FOAK instrumentation tubes were plugged and stabilized at the lower tubesheet such that any FOAK instrumentation tube severance in the lower tubesheet would not result in further degradation of any adjacent in service-tubes.

Discussion

The event at ONS-1 is another example of the potential for a plugged tube to affect the integrity of adjacent tubes. Although this phenomenon does not appear to be widespread, it may become more frequent as more tubes are plugged and as the length of time plugged tubes are in service increases. Isolated occurrences of this phenomenon may be risk-significant.

Based on the TMI-1 event and earlier events (discussed in IN 2002-02), the severance of the plugged tube at ONS-1 was not expected. The industry did not expect the tube span near the lower tubesheet to be susceptible to the diode effect observed at TMI-1. The licensee for ONS-1 has pointed out that there are differences between the ONS-1 and TMI-1 event. For example: the ONS-1 tube did not swell in the region of the severance; the preliminary metallurgical examination showed no signs of high cycle fatigue and very minimal signs of ductile tearing; the wear rate on the adjacent tubes appears to have been slower than at TMI-1; and the root cause of the failure appears to be the unique history of the tube, not the diode effect seen at TMI-1. However, as the licensee has stated, its conclusions about the root cause of the event are based on circumstantial evidence drawn from several observations and hypotheses. Conclusive evidence was not available.

The events at ONS-1 illustrate a mechanism by which a plugged tube can sever and impact adjacent tubes. At ONS-1 the impacted tubes were inactive (i.e., plugged), but the severed tube could have impacted active tubes. Since the wear indications in tube B78-123 could be traced back to 1995, it appears that the wear rates at ONS-1 were relatively slow. However, this was a function of the location of the tube within the tube bundle. If the severed tube had been at a different location, the wear rates could have been higher. There was no evidence that the degradation was related to the tube's location within the tube bundle (only that it was possibly limited to tubes which in FOAK instrumentation was installed). The ONS-1 results show the importance of either evaluating plugged tubes or stabilizing the entire length of plugged tubes in all regions of the tube bundle to ensure they do not compromise the integrity of adjacent active tubes (i.e., the reactor coolant pressure boundary).

An additional issue of importance is the wear scars on tube B78-123. Tube B78-123 had been plugged in 1999 for volumetric indications in the lower span which could be traced back to 1995. The licensee now believes the volumetric indications were wear indications due to impact from an adjacent tube. The wear scars could have been considered to be a precursor to the condition discovered during the spring 2002 steam generator inspection. This highlights the importance of fully assessing tube degradation (e.g., volumetric indications) with no conclusive cause.

The NRC staff is continuing to evaluate the generic implications of the ONS-1 and TMI-1 occurrences.

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

/RA/
William D. Beckner, Program Director
Operating Reactor Improvements Program
Division of Regulatory Improvement Programs
Office of Nuclear Reactor Regulation

Technical contacts: Kenneth J. Karwoski, NRR
301-415-2752
E-mail: kjk1@nrc.gov

Jerome J. Blake, RII
404-562-4607
E-mail: jjb1@nrc.gov

Cheryl B. Khan, NRR
301-415-2751
E-mail: cdb@nrc.gov

1. Figure 1 Steam Generator B Tubesheet Pattern
2. List of Recently Issued NRC Information Notices

OCONEE NUCLEAR STATION UNIT 1
STEAM GENERATOR B TUBESHEET PATTERN
FIGURE 1