BACKGROUNDER

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Steam Generator Tube Issues

Background

Pressurized water reactors (PWRs) use steam generators, large components that convert water into steam using heat produced in the reactor core. These devices can measure up to 70 feet in height and weigh as much as 800 tons. Inside the steam generators, hot radioactive water is pumped through thousands of feet of tubing – each steam generator can contain anywhere from 3,000 to 16,000 tubes, each about three-quarters of an inch in diameter – under high pressure to prevent it from boiling. That water flowing through the inside of the tubes then heats non-radioactive water on the outside of the tubes. This produces steam that turns the blades of turbines to make electricity. The steam is subsequently condensed into water and returned to the steam generator to be heated once again.

These tubes have an important safety role because they constitute one of the primary barriers between the radioactive and non-radioactive sides of the plant. For this reason, the integrity of the tubing is essential in minimizing the leakage of water between the two "sides" of the plant. There is the potential that if a tube bursts while a plant is operating, radioactivity from the primary coolant system – the system that pumps water through the reactor core – could escape directly to the atmosphere in the form of steam.

NRC Regulations

The NRC places a high priority on ensuring that possible steam generator tube degradation is carefully addressed through inspections, strict repair criteria and the monitoring of water chemistry to detect radiation leaking from the primary to the secondary side of the plant. In addition, NRC regulations establish requirements for steam generator tube integrity. Tubes must have an extremely low probability of abnormal leakage and must be periodically inspected and tested.

To obtain an operating license, applicants must show that the consequences of a steam generator tube rupture would not exceed the NRC's conservative limits for radiation doses offsite or outside the plant (described in the agency's regulations in Title 10 of the Code of Federal Regulations, Part 100). Plant operators also are required to have emergency procedures for mitigating steam generator tube ruptures and leaks.

Once a plant is in service, its operator is required to inspect its steam generators and repair or remove from use any tubes found to contain flaws exceeding certain limits. Each plant's technical specifications describe the frequency and scope of these inspections and tube repair limits. There are also operational leakage limits to ensure that if the tubes leak beyond these limits, the plant will be shut down quickly. Existing regulations in conjunction with industry guidance and NRC review have been effective in providing reasonable assurance for protecting public health and safety.

Tube Materials

Two of the most important factors affecting a tube’s vulnerability to degradation are the tube material and the tube’s heat treatment. The two types of tube material being used in the U.S. are Alloy 600 and Alloy 690. The two types of heat treatment applied to these materials for improving their mechanical and corrosion properties are mill annealing and thermal treatment. In the U.S., steam generator tubes are either mill-annealed Alloy 600, thermally treated Alloy 600, or thermally treated Alloy 690. At a given plant, typically all of the tubes are fabricated from the same material/heat treatment. Of the 69 plants with steam generators, 10 (14 percent) have steam generators with mill-annealed Alloy 600 tubes, 17 (25 percent) have steam generators with thermally treated Alloy 600 tubes, and 42 (61 percent) have steam generators with thermally treated Alloy 690 tubes.

Tube Degradation

During the early-to-mid 1970s all plants, except one, had mill-annealed Alloy 600 steam generator tubes. The dominant cause of tube degradation was thinning of the mill-annealed Alloy 600 steam generator tube walls due to the chemistry of the water flowing around them. However, all plants have changed their water chemistry control programs since then, virtually eliminating the problem with tube thinning.

After tube thinning, tube denting became a primary concern in the mid to late-1970s. Denting results from the corrosion of the carbon steel support plates and the buildup of corrosion product in the crevices between tubes and the tube support plates. Measures have been taken to control denting, including changes in the chemistry of the secondary (i.e., non-radioactive) side of the plant. But other phenomena continue to cause tube cracking in plants with mill-annealed Alloy 600 tubes.

The extensive tube degradation at PWRs with mill-annealed Alloy 600 steam generator tubes has resulted in tube leaks, tube ruptures, and midcycle steam generator tube inspections. This degradation also led to the replacement of mill-annealed Alloy 600 steam generators at a number of plants and contributed to the permanent shutdown of other plants.

As mill-annealed Alloy 600 steam generator tubes began exhibiting degradation in the early 1970s, the industry pursued improvements in the design of future steam generators to reduce the likelihood of corrosion. In the late 1970s, Alloy 600 tubes were subjected to a high-temperature treatment to improve the tubes’ resistance to corrosion. This thermal treatment process was first used on tubes installed in replacement steam generators put into service in the early 1980s. Although no significant degradation problems have been observed in plants with thermally treated Alloy 600 steam generator tubes, plants which replaced their steam generators since 1989 have primarily used tubes fabricated from thermally treated Alloy 690, which is believed to be even more corrosion resistant than thermally treated Alloy 600.

Most of the newer steam generators, including all of the replacement steam generators, have features which make the tubes less susceptible to corrosion-related damage. These include using stainless steel tube support plates to minimize the likelihood of denting and new fabrication techniques to minimize mechanical stress on tubes.

Tube Repair Criteria

Traditional tube repair criteria are based on a minimum wall thickness requirement. Typically, the tube wall thickness may be degraded by up to 40 percent of the initial wall thickness before the tube must be repaired. This allows an adequate margin against leakage and bursting. This criteria can be overly conservative for localized flaws such as short stress corrosion cracks. As a result, use of the 40-percent through-wall repair criteria may result in tubes being unnecessarily removed from service even though they would continue to satisfy the existing regulatory guidance for adequate structural and leakage integrity.

In 1995, NRC issued Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking." This report describes the methodology to be used to ensure adequate structural and leakage integrity of the steam generator tubing throughout the plant's operating cycle without taking credit for the presence of tube support plates. These plates minimize the likelihood of tube burst or tube leakage under postulated accident conditions. The alternate repair criteria specified in the generic letter differ from the minimum wall thickness requirements in that tube integrity is ensured through the application of voltage-based (via electrical testing) rather than depth-based repair limits. This repair criteria can be used, after NRC approval, at certain plants with mill annealed Alloy 600 steam generator tubes.

Corrosion cracking has primarily occurred at plants with mill-annealed Alloy 600 steam generator tubes. A few plants with thermally treated Alloy 600 tubes have observed corrosion cracking; however, this cracking has only affected a small number of tubes at this time. No plants with thermally treated Alloy 690 tubes have observed corrosion cracking at this time.

Inspection Issues

In-service inspections are critical in maintaining steam generator tube integrity. The scope and frequency of these inspections vary from plant to plant based on each facility's operating experience. For plants with extensive tube degradation (e.g., plants with mill-annealed Alloy 600), all tubes are typically inspected at every outage.

Since traditional inspection techniques only partially identified and precisely measured the size of cracks, the NRC issued Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes" in 1995, alerting plant operators about the importance of performing comprehensive tube examinations of tubes using appropriate inspection techniques and equipment capable of reliably detecting degradation. The industry has since developed better methods of detecting cracks before tube integrity is potentially impaired. However, there continue to be challenges including precisely measuring crack size.

In December 1997, NRC issued Generic Letter 97-05, "Steam Generator Tube Inspection Techniques," to address measuring the size of steam generator tube flaws and Generic Letter 97-06, "Degradation of Steam Generator Internals," which emphasizes the importance of performing comprehensive examinations of steam generator internals to ensure that tube structural integrity is maintained in accordance with 10 CFR 50, Appendix B. The second letter was issued as a result of foreign and U.S. operating experience indicating the potential for degradation to damage tube supports and tube bundle wrappers.

In November 2000, NRC issued Regulatory Issue Summary (RIS) 00-022, "Issues Stemming from NRC Staff Review of Recent Difficulties Experienced in Maintaining Steam Generator Tube Integrity." This RIS summarized 10 issues arising from the NRC's review of tube integrity at several facilities.

In August 2004, NRC issued Generic Letter 2004-01, "Requirements for Steam Generator Tube Inspections," to address the requirements related to the solution of inspection problems.

Revisions to NRC's Regulatory Framework and Impact of Industry Initiative

In late 1997, the industry, through the Nuclear Energy Institute (NEI), adopted an initiative entitled NEI 97-06, "Steam Generator Program Guidelines," to improve both the quality and consistency of steam generator programs. The initiative calls for licensees to evaluate their existing steam generator programs and, where necessary, revise or strengthen program attributes to meet the intent of the NEI guidelines.

In October 1998, the NRC staff informed the Commission of its intent to delay the issuance of a proposed generic letter while working with the industry to resolve NRC concerns about the industry initiative and changes necessary to the regulatory framework to implement this initiative. On Feb. 4, 2000, NEI submitted a generic license change package (GLCP), which proposed new steam generator tube surveillance requirements intended to facilitate full implementation of the programmatic strategy of NEI 97-06. The proposed technical specifications would require tube condition monitoring at each steam generator tube inspection to verify that specific performance criteria were met.

Based on NRC feedback on legal, technical, and administrative issues, NEI revised its GLCP approach for addressing the steam generator tube integrity surveillance requirements. The industry submitted proposed technical specifications revisions through both a plant-specific (i.e., lead plant) and generic process. The staff received the lead-plant submittal on Feb. 25, 2003, and the generic submittal on March 14, 2003. The generic submittal followed a process established by the Technical Specification Task Force (TSTF) for proposing changes to the standard technical specifications. This process is described in RIS 2000-06, "Consolidated Line Item Improvement Process for Adopting Standard Technical Specification Changes for Power Reactors."

The staff reviewed both the plant-specific amendment request and the TSTF changes. The plant-specific submittal served as the staff's vehicle for addressing any remaining technical issues identified during the review of the GLCP.

In response to NRC comments, the lead plant submittal and the TSTF were revised by letters dated Sept. 13, 2004, and Oct. 7, 2004, respectively. While these two items were being revised, another plant requested a similar technical specification amendment which addressed the NRC's comments. The revised technical specifications for this plant were approved on Sept. 10, 2004.

NRC will continue to review any additional industry submittals in an open forum. The approach outlined above makes the best use of industry and NRC resources, gives appropriate credit to the industry initiative, and provides opportunity for participation by all the interested stakeholders.

The new framework (or technical specifications) enhances safety by replacing prescriptive criteria focused on wall thinning as the dominant degradation mechanism with a performance-based framework that focuses on the goals of a steam generator tube integrity program: maintaining tube integrity between inspections.

The new framework also improves regulatory effectiveness and efficiency primarily because the new framework reflects the performance of improved tube materials (e.g., thermally treated Alloy 600 and Alloy 690). Plants with the new materials will not need to request approval for extending the operating interval between inspections. As a result, the staff will no longer be required to review many of these requests. The new framework also improves effectiveness and efficiency by defining the goals of the inspection program rather than providing prescriptive requirements which would be based on a specific set of assumptions and conditions, which may change with time.

Steam Generator Tube Integrity Issues

To track the efforts associated with revising the steam generator regulatory framework, the NRC developed a Steam Generator Action Plan in the early 1990s. This plan was significantly upgraded in November 2000 following a steam generator tube leakage event at Indian Point 2 to include other activities related to steam generators. In May 2001, this plan was further revised to address a differing professional opinion on steam generator tube integrity. The differing opinion related to the approach and methodology the NRC has taken on steam generator repair criteria. Conclusions and recommendations stemming from the review of the differing professional opinion are documented in NUREG-1740, "Voltage Based Repair Criteria," dated Feb. 2001.

The action plan milestones are tracked and status is updated on a quarterly basis. This plan is just one facet of NRC's overall strategy to maintain safe operation of nuclear power plant steam generators, increase public confidence in agency regulatory actions, and improve effective and efficient use of NRC's resources. The plan is publicly available and also appears on the NRC web site at: http://www.nrc.gov/reactors/operating/ops-experience/steam-generator-tube.html.

The NRC communicates significant steam generator operating experience through the issuance of generic communications. These generic communications are publicly available and also appear on the NRC web site at: http://www.nrc.gov/reading-rm/doc-collections/gen-comm/index.html.

Generic Communications Related to Steam Generator Tube Integrity

Information Notice 2003-13, "Steam Generator Tube Degradation at Diablo Canyon," dated Aug. 28, 2003.

Information Notice 2003-05, "Failure to Detect Freespan Cracks in PWR Steam Generator Tubes," dated June 5, 2003.

Information Notice 2002-021, Supplement 1: "Axial Outside-Diameter Cracking Affecting Thermally Treated Alloy 600 Steam Generator Tubing," dated April 1, 2003.

Information Notice 2002-002, Supplement 1: "Recent Experience with Plugged Steam Generator Tubes," dated July 17, 2002.

Information Notice 2002-021: "Axial Outside-Diameter Cracking Affecting Thermally Treated Alloy 600 Steam Generator Tubing," dated June 25, 2002.

Information Notice 2002-002: "Recent Experience with Plugged Steam Generator Tubes," dated Jan. 8, 2002.

Information Notice 2001-016: "Recent Foreign and Domestic Experience with Degradation of Steam Generator Tubes and Internals," dated Oct. 31, 2001.

Regulatory Issue Summary 2000-022, “Issues Stemming from NRC Staff Review of Recent Difficulties Experienced in Maintaining Steam Generator Tube Integrity,” dated Nov. 3, 2000.

Information Notice 2000-009: “Steam Generator Tube Failure at Indian Point Unit 2,” dated June 28, 2000.

Information Notice 1998-027: “Steam Generator Tube End Cracking,” dated July 24, 1998.

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