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Steam Generator Tube Issues

Background

There are two primary types of nuclear reactors, which use slightly different approaches to generating electricity. Pressurized water reactors use steam generators to convert water into steam using the reactor core's heat. Boiling water reactors don't use steam generators.

Steam generators are significant pieces of equipment. They can be up to 70 feet tall and weigh as much as 800 tons. Hot radioactive water from the reactor enters the generator, pumped through thousands of feet of tubing under high pressure to prevent it from boiling. Steam generators hold from 3,000 to 16,000 tubes, each about three-quarters of an inch in diameter. The water inside the tubes heats non-radioactive water on the outside, which makes steam. This non-radioactive steam turns a turbine to make electricity. The steam is then condensed back into water for another trip through the steam generator.

Steam generator tubes help protect the public. They are one of a PWR's many barriers between the radioactive nuclear fuel and the environment. A plant can release the non-radioactive steam to the atmosphere in some situations. This means it's important the tubes remain intact and prevent radioactivity from the reactor core from reaching the atmosphere in the released steam.

NRC Regulations

Before the NRC allows a PWR to operate, the plant owner must show the plant can keep the public safe even if a very unlikely tube rupture happens. The plant must show radiation doses beyond the plant's fence would stay below the NRC's conservative limits (described in Title 10 of the Code of Federal Regulations, Part 100). Plant operators must also have emergency procedures for safely dealing with steam generator tube ruptures and leaks.

The NRC requires PWRs to regularly inspect steam generator tubes and detect possible damage before anything happens. Agency rules also require plants to monitor water chemistry to detect radiation from any tube leakage. These requirements work together to ensure an extremely low chance of tube leakage that could affect the environment.

Tubes with flaws beyond a certain limit must be repaired or removed from use. Detailed specifications for each PWR describe the inspection frequency and scope, as well as tube repair limits. Other leakage limits – if reached – would force a plant to shut down quickly.

Tube Materials

The nickel-chromium-steel alloys and construction methods used to build steam generators affect a tube's ability to resist wear and corrosion. U.S. steam generators use Alloy 600 and Alloy 690, with 690 having more chromium to better resist corrosion. Heating these alloys after the tubes are formed further improves their resistance to mechanical failure and corrosion. Heating methods for steam generators are called mill annealing and thermal treatment. The majority of PWRs in the U.S. (69 percent) have steam generators with thermally treated Alloy 690 tubes.

Tube Degradation

During the early-to-mid 1970s, all but one PWR had mill-annealed Alloy 600 steam generator tubes. Research showed the tube walls in these generators were thinning due to the chemistry of the water flowing around them. PWRs have changed their water chemistry control programs since then, virtually eliminating that source of tube thinning.

Tube denting became a primary concern in the mid-to-late 1970s. Denting is caused by corrosion on carbon steel support plates in the generators and in the crevices between tubes and the tube support plates. Plants control denting through changes in water chemistry on the non-radioactive side of the generator. However, there were other causes for tube cracking, leaks and ruptures in plants with mill-annealed Alloy 600 tubes.

These problems forced plants to shut down more often for additional tube inspections. Many plants replaced their mill-annealed Alloy 600 steam generators and a few PWRs permanently shut down because of the issue.

The nuclear power industry worked to reduce steam generator tube corrosion in the early 1970s. In the late 1970s, the thermal treatment process was developed to improve Alloy 600 tubes' resistance to corrosion. Thermally treated replacement steam generators were first used in the early 1980s. These replacements have avoided significant degradation problems. Replacement steam generators built after 1989 have primarily used thermally treated Alloy 690, which is even better at resisting corrosion.

Makers of most newer steam generators, including all replacement steam generators, have taken other steps to reduce corrosion-related damage. Stainless steel tube support plates help minimize denting and new fabrication techniques minimize mechanical stress that can lead to damage later on.

Some tubes, mostly mill-annealed Alloy 600, have cracked from a combination of stress and corrosion. A small number of thermally treated Alloy 600 tubes have also cracked this way. Thermally treated Alloy 690 tubes have yet to demonstrate this stress corrosion cracking. The NRC and the industry continue researching causes of corrosion and cracking in reactor materials.

Steam generator tubes have also been damaged by mechanical wear. In January 2012, the San Onofre Unit 3 reactor experienced a small reactor coolant leak from one of its steam generators to the atmosphere. The utility licensed to operate the plant, Southern California Edison, reviewed information from the event and estimated the leak could have led to a member of the public receiving a radiation dose thousands of times lower than the NRC's strict limits. During follow-up tube inspections in Unit 3

and Unit 2, SCE discovered unexpected mechanical wear in both units' generators. San Onofre was permanently shut down in 2013.

Tube Repair Criteria

One way to see if tubes need repair is to require a minimum tube wall thickness to protect against leakage and bursting. Typically, if inspections show a tube has at least 60 percent of its original wall thickness, no repairs are needed. Applying the 60-percent wall thickness requirement can, however, prematurely remove tubes from service. This meant plants could benefit from tube repair limits other than the 60-percent wall thickness requirement.

In 1995, the NRC approved an electrical testing method to determine if mill-annealed Alloy 600 tubes need repairs. Generic Letter 95-05 describes this method, where a trained technician passes an electric probe through the tubes, and the probe's results can demonstrate the tubes' adequate structural and leakage integrity.

Inspection Issues

Inspections are critical in maintaining steam generator tube integrity. The details and schedule for these inspections depend on each plant's operating experience. For example, plants with mill-annealed Alloy 600 tubes typically inspect all tubes during every scheduled shutdown.

In December 1997, the NRC gave PWRs more guidance on properly maintaining their tubes. Generic Letter 97-05 discusses measuring tube flaw size, while Generic Letter 97-06 emphasizes the importance of properly examining the rest of the steam generator's internal parts. The NRC issued the second letter based on foreign and U.S. operating experience with degradation and damage to tube supports and tube bundle wrappers.

The NRC provided another update in November 2000. Regulatory Issue Summary 00-022 covers 10 issues the NRC encountered in reviewing tube integrity at several facilities. Additional updates are listed at the end of this document.

NRC's Steam Generator Regulatory Framework

In late 1997, the Nuclear Energy Institute coordinated the industry's effort to improve both the quality and consistency of steam generator programs. This led to all U.S. PWRs adopting NEI 97-06, "Steam Generator Program Guidelines."

In 2005, a task force of industry specialists published new steam generator requirements that the NRC approved in 2005. In January 2006, the NRC discussed the new requirements and plant implementation of NEI 97-06 in Generic Letter 2006-01. All U.S. PWRs responded to the letter by adopting the task force requirements.

The NRC twice clarified some of the requirements as plants were implementing the task force's work. Regulatory Issue Summary 2007-20 clarified the NRC position on leakage performance criteria. Regulatory Issue Summary 2009-04 clarified the NRC position on inspection requirements.

The task force learned from the plants' experience with those requirements. The task force revised both inspection schedules and the ways plants select tubes for inspection in a March 2010 document. The revision's editorial corrections, changes, and clarifications better aligned with other industry guidance documents. The NRC approved these additional revisions in October 2011 and many U.S. plants have modified their technical specifications accordingly.

Generic Communications Related to Steam Generator Tube Integrity

The NRC continues to monitor industry experience with steam generator tubes. The agency issues "generic communications" to share that information with U.S. plants. These documents appear on the NRC website. Some steam generator generic communications include:

Regulatory Issue Summary 16-02, "Design Basis Issues Related to Tube-to-Tubesheet Joints in Pressurized-Water Reactor Steam Generators," dated March 23, 2016

Information Notice 2013-20, "Steam Generator Channel Head and Tubesheet Degradation," dated Oct. 3, 2013.

Information Notice 2012-07, "Tube-To-Tube Contact Resulting in Wear in Once-Through Steam Generators," dated July 17, 2012.

Information Notice 2010-21, "Crack-Like Indication in the U-Bend Region of a Thermally Treated Alloy 600 Steam Generator Tube," dated Oct. 6, 2010.

Information Notice 2010-07, "Welding Defects in Replacement Steam Generators," dated April 5, 2010.

Information Notice 2010-05, "Management of Steam Generator Loose Parts and Automated Eddy Current Data Analysis," dated Feb. 3, 2010.

Information Notice 2008-07, "Cracking Indications in Thermally Treated Alloy 600 Steam Generator Tubes," dated April 24, 2008.

Information Notice 2007-37, "Buildup of Deposits in Steam Generators," dated Nov. 23, 2007.

Information Notice 2005-29, "Steam Generator Tube and Support Configuration," dated Oct. 27, 2005.

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