UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
OFFICE OF NEW REACTORS
WASHINGTON, DC 20555-0001

October 3, 2013

NRC INFORMATION NOTICE 2013-20: STEAM GENERATOR CHANNEL HEAD AND TUBESHEET DEGRADATION

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power reactor under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

All holders of or applicants for an early site permit, standard design certification, standard design approval, manufacturing license, or combined license under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of instances of steam generator channel head and tubesheet degradation. Although the operating experience discussed is related to steam generators, the findings may relate to other structures, systems, and components. The NRC expects that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to ensure that regulatory requirements are met. Suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

The primary side of a recirculating steam generator consists of several components, including the channel head, divider plate, tubesheet, and tubes (refer to Figure 1). The channel head is hemispherically shaped and is divided into two chambers by a divider plate. One chamber receives the primary coolant from the reactor through the primary inlet (hot-leg) nozzle, and the divider plate channels this coolant through the tubes. After exiting the tubes, the primary coolant enters the other chamber of the channel head and exits the steam generator through the primary coolant outlet (cold-leg) nozzle(s) so that it can be pumped back into the reactor.

The steam generator channel head is typically made of carbon or low-alloy steel base material and is clad on the interior surface with a corrosion-resistant material such as stainless steel to protect the channel head's base material. Some steam generator designs have a drain line that is centered under a semicircular cutout region of the divider plate (frequently referred to as a mouse hole) in the bottom center of the channel head. The drain line facilitates removal of water from the steam generator for maintenance and permits draining of both the hot- and cold-leg sides of the channel head. The tubesheet is a thick plate, typically made from low-alloy

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steel that contains thousands of holes for the steam generator tubes. The primary side (underside) of the tubesheet is clad with a corrosion-resistant material and each tube is welded to the tubesheet's primary face.

As discussed below, recent operating experience has revealed degradation of the steam generator channel head and tubesheet.

Foreign Operating Experience

In 2011, a foreign utility identified apparent defects in the steam generator channel head in one of its three steam generators at one of its nuclear power plants. The steam generators were placed into operation in 1987. The inspections showed indications of degradation in the cladding and/or divider plate-to-channel head weld resulting in exposure and corrosion of the channel head base material. The visually observed degradation is located on the cold leg side of the channel head in the vicinity of the drain line. The largest observed defect in the cladding measured 7.5 mm (0.3 in.) by 14.4 mm (0.6 in.) by ultrasonic examination. There were five other smaller defects in the cladding in the region of the drain line. The degradation in the channel head base material is volumetric in the form of one large cavity which extends to a maximum depth of 28 mm (1.1 in.). The area of the degradation in the base material is irregular in shape and extends a maximum of 75 mm (3.0 in.) from the edge of the drain line with a maximum azimuthal extent of 285 degrees about the central drain. The cause of the cladding degradation is not currently known.

In January 2012, Westinghouse issued a Nuclear Safety Advisory Letter (NSAL) informing their customers of the operating experience and providing recommendations for inspections. The Electric Power Research Institute's Steam Generator Management Program shared this information with all member utilities that operate steam generators. The recommendations in the NSAL included performing a visual inspection of the steam generator's channel head area under dry conditions the next time the primary side of the steam generator is open, with the intent of identifying gross defects. The inspections are to include the channel head's cladding, the weld connecting the divider plate to the channel head, and, when it is accessible, the weld at the top of the channel head's bowl drain tube. The inspections could be limited to a circle with a 914-mm (36-in.) radius centered on the very bottom of the channel head's bowl. If no degradation is detected during the initial visual inspection, the inspection results should be documented and visual inspections should be performed each time the primary steam generator manway is open. If degradation is detected, the NSAL recommended performing dye penetrant testing if the inside surface of the channel head has been machined smooth to establish the extent of the cladding degradation, using ultrasonic testing from outside of the steam generator to determine whether any corrosion of the channel head's base material has occurred, and performing an engineering assessment of the findings. An assessment of the foreign operating experience by the domestic nuclear industry concluded that the most likely failure mode was gross defects in the stainless steel cladding that resulted in exposure of the base material to water with high concentrations of dissolved oxygen and boric acid.

Visual inspections of the steam generator's channel head region have been performed at many domestic utilities with none reporting similar degradation. Although no similar degradation has been found domestically, one utility did identify some base material corrosion in its steam generator channel head in 2013 as discussed below.

Wolf Creek Generating Station

Wolf Creek Generating Station (Wolf Creek) has four Westinghouse Model F steam generators. In spring 2013, Wolf Creek Nuclear Operating Corporation (the licensee) conducted visual inspections of the steam generator's channel head region in response to the foreign operating experience discussed above. During these inspections, the licensee did not identify any degradation in the region where degradation was observed in the steam generator at the foreign unit; however, a rust-colored spot was identified approximately 152 mm (6 in.) below the primary face of the tubesheet along the weld connecting the divider plate to the channel head.

The divider-plate-to-channel-head weld is made with weld material of the Alloy 600 type. The cladding on the channel head is primarily stainless steel; however, the cladding near the rust-colored spot may be either stainless steel or Alloy 182 (an Alloy 600 type material) depending on the actual fabrication process. Visual inspections revealed a flaw in the divider-plate-to-channel-head fillet weld, which was attributed to a fabrication defect. An ultrasonic test indicated the flaw in the channel head's base material was approximately 2.5 mm (0.1 in.) deep and approximately 51 mm (2 in.) long. The width of the flaw could not be determined because the ultrasonic testing equipment could not be placed at the appropriate location on the outside surface of the channel head due to access limitations.

The flaw at the edge of the divider-plate-to-channel-head weld was evaluated in accordance with Subparagraph IWB-3510.1 and Table IWB-3510-1 of Section XI of the American Society of Mechanical Engineers *Boiler and Pressure Vessel Code*. The flaw in the base material was treated as a planar flaw. The evaluation considered flaw growth in the future. The licensee concluded that it was acceptable to operate the steam generator through the operating cycle. During the cycle, the licensee planned to perform a detailed fracture mechanics analysis of the flaw to determine the long-term corrective action required.

Based on the corrosion properties of the stainless steel cladding and Alloy 600 weld material, and because the primary chemistry is usually maintained in a condition that scavenges oxygen, the licensee concluded that the flaw in the divider-plate-to-channel-head weld was only able to grow when there were oxidizing conditions in the primary coolant (i.e., for a short period before each shutdown as a result of peroxide addition during the shutdown process) and when the steam generator was open for inspection. Based on this estimated exposure period and boric acid corrosion rates in literature, the licensee predicted that the flaw in the base material would be approximately 2.5 mm (0.1 in.) deep, assuming that the base material corrosion started at the beginning of plant operation. This matches the actual extent of degradation observed in the channel head base material, as determined from the ultrasonic examination. Using a flaw growth rate of approximately 0.1 mm (0.005 in.) per operating cycle, the licensee concluded the flaw in the channel head base material would be approximately 2.7 mm (0.105 in.) deep at the next refueling outage.

The licensee performed a review of historical steam generator channel head visual inspections and noted that the rust spot was not visible during the 2011 inspections, but was visible during all prior outages in which visual inspections of this region were performed (i.e., in 2009, 2006, 2000, and 1994). The 1994 video is the earliest video recording of this area and is a black-and-white recording.

Because structural interferences prevent a zero-degree ultrasonic examination of the divider-plate-to-channel-head weld flaw, the licensee could not confirm that there is no delamination between the stainless steel cladding and the channel head's base material in the

area directly under the flaw. The licensee has confirmed that there are no delaminations between the cladding and the channel head in those areas around the divider-plate-to-channel-head weld flaw, where there is access for a zero-degree ultrasonic examination.

The licensee has no direct evidence that the flaw at the rust spot's location was not caused by stress corrosion cracking (SCC) or fatigue. However, the licensee has indirect evidence to support the conclusion that the flaw was not caused by SCC or fatigue. The licensee's evidence includes the fact that SCC is highly unlikely in stainless steel or carbon steel on the primary side of a steam generator, and the existence of the rust stain is evidence that the carbon steel channel head is corroding. The rust spot is around a black spot that the licensee has stated appears to be either a weld crater pit or weld porosity. The rust spot appears to be about 21.8 mm (0.86 in.) long and 6.4 mm (0.25 in.) wide. Also, a fatigue stress analysis performed by the industry and cited by the licensee showed that the fatigue stresses in this location of the steam generator are very low. The licensee indicated there could be additional paths of SCC in the weld, but that there was currently no evidence of these additional paths. The licensee concluded that the black spot is a fabrication defect in the weld material and that a breach through the cladding was probably created as a result of the high tensile stresses from the weld geometry.

The licensee plans to re-inspect this area during the next refueling outage to monitor/confirm the flaw's growth rate.

<u>Surry Power Station Unit 2</u>

Surry Power Station Unit 2 has three Westinghouse Model 51F steam generators. During a refueling outage in 2006, Virginia Electric and Power Company, the licensee, performed a visual inspection of the plugs inserted into some of the tubes on the hot-leg side of the steam generator's channel head. During these visual inspections, a yellow stain was noted in the tube end of one of the tubes and on a portion of the channel head near this tube location. Upon further investigation, it was determined that the affected tube was inadvertently plugged in 1986. When this plug was removed by drilling in 1991, the tube appeared to have been drilled off-center longitudinally from the tube end for a distance of approximately 44 mm (1.75 in.). This resulted in perforating the tube wall over a circumferential distance of approximately 23 mm (0.9 in.). As a result, this damaged tube end was in service from 1991 until 2006 when the yellow stain was noticed. The yellow stain was attributed to the corrosion of the tubesheet material. Although the damage to the tube end was substantial, the licensee concluded that the as-found condition did not compromise tube integrity given that the tube damage was near the primary face of the tubesheet.

Given the damage to the tube near the tube-end, a special plug was used on the hot-leg side of the tube. The plug's structural joint was above the damaged region. Two other joints, including one below the damaged region, were made. The lowest joint was expected to form a tortuous leakage path and allow little or no primary coolant to contact the tubesheet material. However, to the extent that the lower joint does not isolate the carbon steel, it was assumed that corrosion of the tubesheet material could occur. The rate of carbon steel corrosion during operation with very low oxygen in the primary coolant is much lower than that during shutdown when the material could be exposed to air. The licensee performed an assessment assuming corrosion would occur and concluded that the corrosion would not impact the structural integrity of the tubesheet. This tube was plugged at both ends during the 2006 outage. The licensee plans to

visually inspect this region during future inspections of the tubes in the affected steam generator.

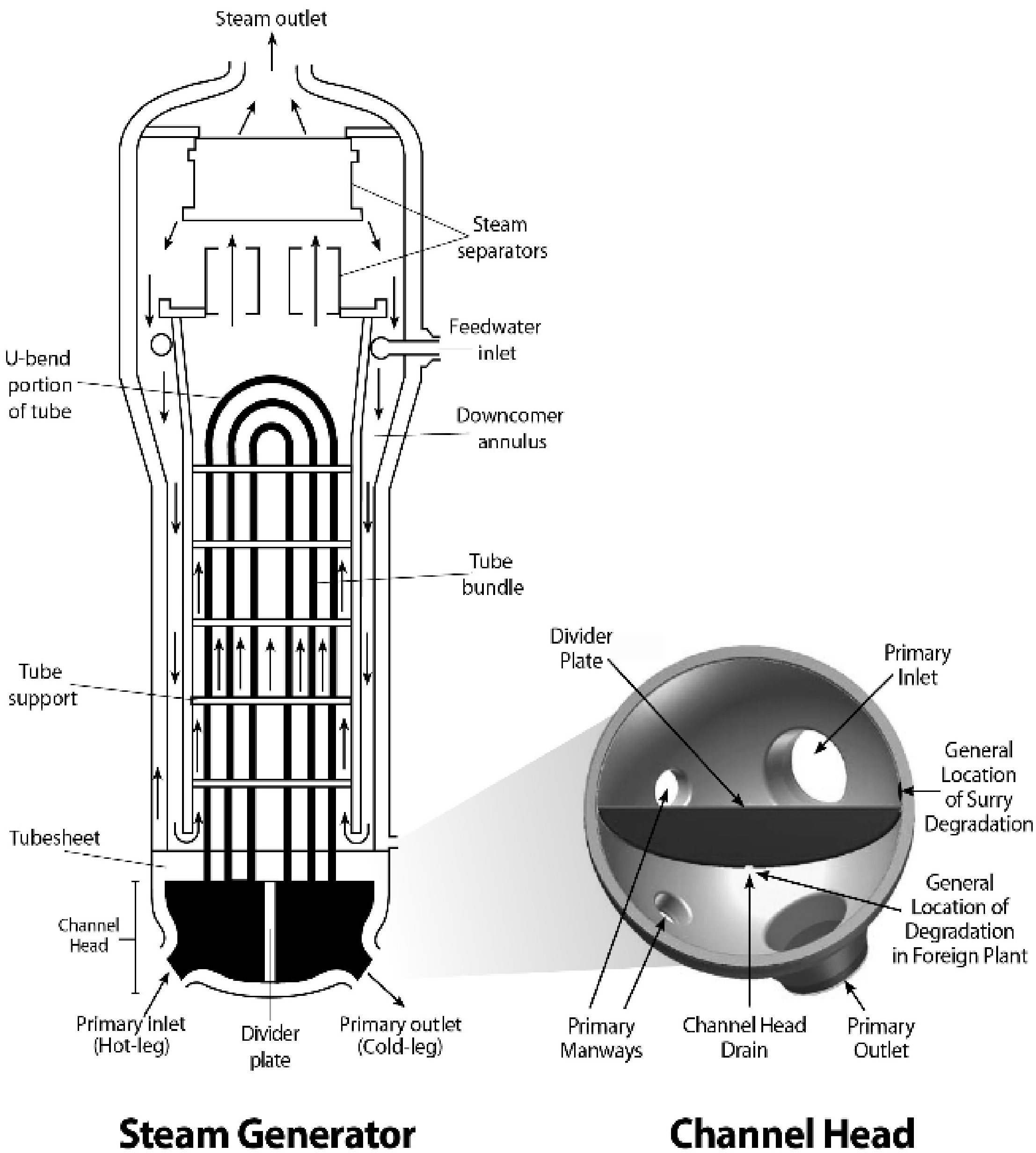
The channel head degradation was characterized and evaluated by the licensee. Ultrasonic examination of the tubesheet-to-channel-head transition region confirmed that no degradation extended into the base material. The licensee performed an evaluation of potential carbon steel corrosion rates and concluded that the condition was acceptable for continued service without repair for the remaining licensed life of the unit. During an outage in 2012, the licensee visually inspected this region and there was no change in the indication/degradation.

During the 2006 outage at Surry 2, a visual examination of the hot-leg primary manway flange face was performed. This inspection revealed a localized region of corrosion between the gasket seating surface and the bolt circle. During 2012, this area was re-examined and there was no advancement of the degradation. The licensee concluded that the degradation was caused by gasket leakage at some point prior to 2006.

DISCUSSION

The steam generator is an integral part of the reactor coolant pressure boundary, and its integrity is important to the safe operation of the plant. Carbon and low-alloy steel portions of the steam generator are typically isolated from the primary coolant to prevent their corrosion. In several instances it appears that defects in the cladding have resulted in exposing the underlying carbon and low-alloy steels, resulting in their corrosion. Although the most probable cause of the cladding defects identified at Surry were mechanical activities and not original fabrication, it is not conclusively known whether the other cladding/weld defects discussed above were service-induced (e.g., as a result of cracking) or whether they were present since fabrication. Nonetheless, the operating experience indicates the importance of monitoring clad regions to ensure the integrity of the cladding and for ensuring that maintenance activities (e.g., tube inspections and repairs) do not result in exposing the underlying carbon or low-alloy steels. If the carbon or low-alloy steels are exposed, it is important to determine the extent of any corrosion of the base material to ensure the component can still perform its intended safety function until the next inspection or until the component can be replaced or repaired.

Figure 1:
Steam Generator Channel Head Assembly



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This IN requires no specific action or written response. Please direct any questions about this matter to the technical contact listed below or to the appropriate NRC project manager.

/RA/

Lawrence E. Kokajko, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA/

Michael C. Cheok, Acting Director
Division of Construction Inspections
and Operational Programs
Office of New Reactors

Technical Contacts: Kenneth J. Karwoski, NRR
301-415-2752
E-mail: kenneth.karwoski@nrc.gov

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