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

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NRC INFORMATION NOTICE 2011-04: CONTAMINANTS AND STAGNANT CONDITIONS AFFECTING STRESS CORROSION CRACKING IN STAINLESS STEEL PIPING IN PRESSURIZED WATER REACTORS

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power pressurized water reactor (PWR) issued 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 PWR standard design certification, standard design approval, manufacturing license, or combined license issued 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 the effects of contaminants and stagnant conditions on the potential for stress corrosion cracking (SCC) in stainless steel piping in PWRs. The NRC expects recipients to review the information for applicability to their facilities and consider taking action, as appropriate, to avoid similar problems. The suggestions that appear in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

Callaway Plant

In September 2008, Callaway Plant (Callaway) personnel detected a small leak from a through-wall flaw in the 2-inch diameter, Schedule 160, American Society of Mechanical Engineers (ASME) Class 2, Type 304 stainless steel pressurizer auxiliary spray pipe. The flaw was axially oriented and was located beneath a pipe support clamp. Subsequently, the licensee detected a second pipe support clamp with corrosion on the same piping, although no leak was observed. The licensee replaced the degraded section of pipe. Based on a failure analysis of the pipe specimen, the licensee attributed the flaws to transgranular stress corrosion cracking (TGSCC) originating at the outside surface. The licensee also observed pitting corrosion on the outside surface of the pipe under pipe support clamps. Pitting and TGSCC of austenitic stainless steels are caused by exposure to chlorides. The licensee performed a chemical

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analysis of the pipe surface before performing penetrant testing and detected chlorides on the outside surface of the pipe.

The pressurizer auxiliary spray line is used during normal shutdown operation. During normal plant operation, the coolant in the line is stagnant, but pressurized by the normal charging system. A control valve in the line is normally closed and the line is insulated. The temperature of the line is the surrounding ambient temperature during normal operation. During periods of warm weather, the moisture content in the containment building is elevated. The licensee believes that, under these circumstances, it is likely that condensation will form in the crevice between the pipe clamp and pipe outside surface. According to the licensee, the line operates between 120 – 212 ºF during lower energy operations. The location of cracking is not close to any pipe welds.

Wolf Creek Generating Station, Unit 1

In October 2009, as a result of the Callaway findings, Wolf Creek Generating Station (Wolf Creek) personnel conducted liquid-penetrant testing on similar piping and detected several axial indications beneath the pipe support clamps of the pressurizer auxiliary spray line. On one of the clamps, a small quantity of boron crystals was observed, indicating a through-wall flaw in the pipe. The through-wall flaw was not located near any pipe welds. The licensee attributed cracking to SCC originating at the outside diameter. Based on a review of relevant operating experience, the licensee concluded that the outside diameter-initiated SCC (ODSCC) was most likely TGSCC due to the presence of chlorides. As a result of the through-wall flaw, the licensee inspected other safety piping systems potentially susceptible to TGSCC to determine the extent of the condition. In this expanded inspection, the licensee performed visual examinations of potentially susceptible piping (i.e., chemical and volume control, accumulator safety injection, and high pressure coolant injection piping) to identify boric acid deposits or potential leaks in the proximity of pipe supports or elements that contact the outside surface of the pipe. The licensee did not find any boron crystal deposits or leakage in the expanded inspection. Wolf Creek and Callaway are sister plants. The above degradation, environment, and operating conditions in the pressurizer auxiliary spray line at Callaway apply to Wolf Creek.

San Onofre Nuclear Generating Station, Units 2 and 3

From 2009 to 2010, personnel at San Onofre Nuclear Generation Station (SONGS) detected three leaks at Unit 2 and five leaks at Unit 3 in various ASME Class 2 stainless steel pipes. The affected systems include refueling water storage tank (RWST) gravity feed line to charging pump, RWST line to the emergency core cooling system (ECCS) suction line, ECCS minimum return line to the RWST, and containment emergency sump to the charging pump. The following are details of three representative degradation incidents at SONGS.

At SONGS Unit 2, the licensee identified boric acid residue on the 6-inch diameter, Schedule 10 (0.134-inch nominal wall thickness), Type 304 stainless steel RWST gravity feed line to charging pump suctions. The boric acid residue was found at the toe of a pipe weld joint. The pipe was located in a tunnel, not insulated, and exposed to a marine atmosphere environment. The coolant in the line is stagnant during normal operation and is under static head pressure of the gravity feed pipe. The Unit 2 pipe had a circumferential flaw approximately 0.5-inches long on the inside surface and 0.1-inch on the outside surface of the pipe. The licensee performed destructive examinations on the affected area of the Unit 2 pipe. The licensee has not completed the failure analysis but its preliminary assessment found that the circumferential flaw was initiated from the inside surface of the pipe and was located within the heat-affected zone of a pipe weld. The licensee observed excessive heat tinting on the inside surface and pitting on the outside surface of the pipe. The preliminary assessment showed that the heat-affected zone may be sensitized.

At SONGS Unit 2 the licensee found two leaks on the 24-inch, Schedule 10, RWST to train A ECCS suction piping. The pipe is at ambient temperature and is exposed to a marine atmosphere environment. The coolant inside the pipe is stagnant during normal operation. The licensee's preliminary laboratory results show that the degradation on this piping has similar aspects to the degradation observed on the 6-inch RWST gravity feed pipe. Specifically, the boric acid residue was found at the toe of a butt weld in the 24-inch pipe, outside surface pitting was present, and linear indications were found by penetrant testing. The cause of the leakage has not yet been determined.

For SONGS Unit 3, the licensee found different flaw characteristics on the 24-inch, Schedule 10, RWST line to the train A ECCS suction line. The licensee detected three indications at the north-side pipe support lug and two indications at the south-side pipe support lug (the lugs were welded to the pipe). The most significant indication was a 100 percent through-wall flaw 1.875-inches long. The failure mechanism for the cracking in the vicinity of the lug has not yet been determined. The licensee removed the affected section of the pipe during a refueling outage and will analyze it in the near future.

BACKGROUND

In 10 CFR 50.55a(a)(1), the NRC requires that structures, systems, and components must be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed. The regulation in 10 CFR 50.55a(a)(2) requires that systems and components in boiling and pressurized water-cooled nuclear power reactors must meet American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Sections III and XI.

ASME Code Sections III and XI contain requirements for the construction of piping and mechanical components of nuclear power plants, and for the inspection and testing of piping and mechanical components of nuclear power plants, respectively. Therefore, the structural integrity of the piping discussed above is governed and monitored by ASME Code Sections III and XI, in accordance with 10 CFR 50.55a, "Codes and Standards."

Related Generic Communications

- NRC Circular 76-06, "Stress Corrosion Cracks in Stagnant Low Pressure Stainless Piping Containing Boric Acid Solution at PWR's"

- Bulletin 79-17, "Pipe Cracks in Stagnant Borated Water Systems at PWR Plants"

- IN 79-19, "Pipe Cracks in Stagnant Borated Water systems at PWR Plants"
- IN 85-34, "Heat Tracing Contributes to Corrosion Failure of Stainless Steel Piping"
- IN 91-05, "Intergranular Stress Corrosion Cracking in Pressurized Water Reactor Safety Injection Accumulator Nozzles"
- IN 97-19, "Safety Injection System Weld Flaw at Sequoyah Nuclear Power Plant, Unit 2"

DISCUSSION

The operating experience described above shows that, as nuclear plants age, SCC can potentially become an emergent degradation mechanism in PWRs for environments that contain chlorides or stagnant flow conditions. Licensees should be aware of the potential for SCC to occur in stainless steel in PWR applications.

Material

There have been cases of intergranular stress corrosion cracking (IGSCC) of austenitic stainless steels in PWRs. NRC IN 91-05 and IN 97-19 discuss cases of IGSCC in PWRs due to furnace sensitized materials being exposed to an oxygenated environment. IGSCC in austenitic stainless steels is usually attributed to sensitization of the material by excessive exposure of the material to temperatures between approximately 800 – 1,500 ^{o}F, usually during fabrication. Particular care is needed when welding thin-walled components, which are more prone to sensitization because the thin sections limit the ability of welding heat to dissipate into surrounding material.

ODSCC can sometimes be attributed to intergranular cracking in the heat-affected zones of welds if the base material becomes sensitized by improperly controlled welding, heat treatment, or other fabrication or service conditions that result in temperatures above approximately 800 ^{o}F. Pitting at the outside surface of the pipe due to the presence of chlorides may also contribute to ODSCC because the local chemistry in a pit is conducive to cracking and the pit is a stress concentration location.

Austenitic stainless steels are subject to TGSCC in the presence of chlorides when the temperature exceeds approximately 140 ^{o}F, although some occurrences have been reported to occur at lower ambient temperatures. Some of the observed cracking has been transgranular.

Environment

TGSCC of austenitic stainless steels requires the presence of water and an environmental condition conducive to TGSCC such as a sufficient level of oxygen dissolved in the water and a sufficient level of chlorides. The SCC is more severe with increasing temperature and chloride concentration. For the TGSCC at Callaway, the licensee's preliminary study showed that the probable cause was chloride contamination on the pipe trapped in a crevice environment between the pipe and the clamps. The temperature swings in the containment could permit condensation to accumulate in the interface between the pipe clamps and the outside surface of the pipe. The condensation may dissolve residual chlorides resulting in a corrosive environment.

Potential sources of chlorides include atmospheric chloride from sea spray or marine environments, tapes, marking fluid, threaded joint compounds, sweat, and insulation. Industry experience with ODSCC shows that austenitic stainless steels have high susceptibility to chloride-induced SCC. TGSCC can occur in either sensitized or non-sensitized material at low applied stress (when residual stress is sufficient) and even at near-ambient temperature where local effects such as heat tracing, sunlight or other sources of heat raise the local temperature near 140 ^{o}F. NRC IN 85-34 discusses the impact of heat tracing on a pipe and chlorides in the water inside the pipe that led to SCC at a nuclear plant.

Electric Power Research Institute literature indicates that even very low levels of chloride can have a detrimental influence on crack growth rates observed in the laboratory, especially at the higher oxidizing potentials associated with the presence of oxygen in solution. The nuclear power plants located close to oceans are susceptible to chloride-induced ODSCC because of the salty air. In addition, inland plants such as Wolf Creek and Callaway are also susceptible to chloride-induced degradation from other chloride sources.

Stresses

Stresses that contribute to SCC are due to operational and/or residual stresses. Higher stress increases the susceptibility for SCC. Pipe cracking can also be initiated at surface discontinuities (e.g., welded pipe support lugs, pits, rough ground areas, and crevices created by mechanical or welded joints). These areas can have higher residual stresses and altered microstructures that are susceptible to SCC (particularly in the case of the welded materials). However, these areas can also be occluded areas where the local environment can evolve into a corrosive environment and become different from the bulk environment. For pitting corrosion, such as under pipe support clamps, the stress component of ODSCC may come from stress concentration points in pits in combination with the operational stresses such as pressure and temperature.

CONCLUSION

SCC can be managed effectively to minimize the potential for catastrophic pipe failure through stainless steel piping cleanliness control and limiting the contact with fluids (including sweat from personnel) or condensation that may contain halogens (chlorides and fluorides). Water chemistry can be used to minimize the adverse effect of oxygen and chloride on SCC. When welding piping joints or attachments, appropriate procedures can be followed to minimize stainless steel sensitization. Periodic inspections of the susceptible piping systems as part of the existing boric acid corrosion control program per the April 2008 Nuclear Energy Institute report NEI 03-08, Revision 1, “Guideline for the Management of Materials Issues,” or as part of routine walkdowns have been instrumental in detecting SCC in stainless steel piping. By letter dated October 14, 2010, the PWR Owners Group issued PA-MSC-0474, “Outside Diameter Initiated Stress Corrosion Cracking Revised Final White Paper,” which provides additional information on SCC.

Austenitic stainless steel piping is susceptible to TGSCC when tensile stresses are applied in a chloride environment where local temperatures exceed approximately 140 ^{o}F. Austenitic stainless steel piping is susceptible to IGSCC when the material is sensitized. IGSCC can occur in austenitic stainless steels exposed for a sufficient time to temperatures between about 800 and 1,500 ^{o}F and subsequently exposed to tensile stress and water containing sufficient levels of oxygen (typically at least 100 parts per billion) at elevated temperatures. SCC can be initiated from the outside and inside surfaces of the pipe and can occur at the (1) location of stress concentration regions (such as at welds for pipe restraint lugs) or susceptible regions for corrosion at the interface between the pipe and support clamp and (2) sensitized heat-affected zone of a weld. Sensitization can be minimized or prevented by using the guidance in NRC Regulatory Guide 1.44, "Control of the Use of Sensitized Stainless Steel."

CONTACT

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contact listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

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Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

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Austenitic stainless steel piping is susceptible to TGSCC when tensile stresses are applied in a chloride environment where local temperatures exceed approximately 140 ^{o}F. Austenitic stainless steel piping is susceptible to IGSCC when the material is sensitized. IGSCC can occur in austenitic stainless steels exposed for a sufficient time to temperatures between about 800 and 1,500 ^{o}F and subsequently exposed to tensile stress and water containing sufficient levels of oxygen (typically at least 100 parts per billion) at elevated temperatures. SCC can be initiated from the outside and inside surfaces of the pipe and can occur at the (1) location of stress concentration regions (such as at welds for pipe restraint lugs) or susceptible regions for corrosion at the interface between the pipe and support clamp and (2) sensitized heat-affected zone of a weld. Sensitization can be minimized or prevented by using the guidance in NRC Regulatory Guide 1.44, "Control of the Use of Sensitized Stainless Steel."

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