

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
WASHINGTON, DC 20555-0001

November 14, 2012

NRC INFORMATION NOTICE 2012-20: POTENTIAL CHLORIDE-INDUCED STRESS
CORROSION CRACKING OF AUSTENITIC
STAINLESS STEEL AND MAINTENANCE OF
DRY CASK STORAGE SYSTEM CANISTERS

ADDRESSEES

All holders of and applicants for an independent spent fuel storage installation (ISFSI) license or Certificate of Compliance (CoC) under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of recent issues and technical information concerning the potential for chloride-induced stress corrosion cracking (SCC) of austenitic stainless steel dry cask storage system canisters. Significant SCC could affect the ability of the spent fuel storage canisters to perform their confinement function during the initial license or license renewal storage period(s).

The NRC expects that recipients will review this information to determine how it applies to their designs and facilities and consider actions, as appropriate, to avoid these potential problems. However, suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

Several instances of chloride-induced SCC have occurred in austenitic stainless steel components that were exposed to atmospheric conditions near salt-water bodies. The summaries below describe relevant examples:

In the fall of 2009, three examples of chloride-induced SCC which extended through-wall were discovered at the San Onofre Nuclear Generating Station (SONGS) in the weld heat-affected zone (HAZ) of Type 304 stainless steel piping. The piping included 24-inch, Schedule 10 emergency core cooling system (ECCS) suction piping; 6-inch, Schedule 10 alternate boration gravity feed to charging line piping; and an ECCS mini flow return to refueling water storage tank. While the through-wall failures were attributed to chloride-induced SCC, surface pitting was also observed on the surface of the pipes, with a greater concentration in the weld HAZ. All

three pipes were exposed to the outside ambient marine atmosphere. Through-wall cracks developed after an estimated 25 years of service.¹

Chloride-induced SCC was identified on the weld HAZ of Type 304 stainless steel ECCS suction piping at the St. Lucie Nuclear Power Plant in 1999. The 24-inch, Schedule 10 piping was exposed to the outside ambient environment for an estimated 16 years of service before discovery of through-wall cracks. Susceptible regions of the pipe were subject to residual tensile stresses resulting from fabrication and field welds, in addition to the normal operating conditions of approximately 207 kPag (30 psig) at 49 degrees Celsius (C) (120 degrees Fahrenheit (F)). Investigators found more severe indications at field welds than at axial fabrication welds that were solution annealed.^{1,2}

In 2005, at the Turkey Point Nuclear Generating Station, a through-wall crack in a Type 304 stainless steel spent fuel pool cooling line was detected and attributed to chloride-induced SCC. The 8-inch, Schedule 10S, seamless pipe was located in a room with a grating steel door that exposed the piping to atmospheric conditions. The crack initiated on the outer diameter at the base of a pit located on the bottom side of the pipe, approximately 0.5-inches downstream from a flange butt weld. The design temperature and pressure for this pipe was 100 degrees C (212 degrees F) and 1.03 MPag (150 psig), respectively.³

In 2001, through-wall cracks were discovered at the Koeberg Nuclear Power Station in Type 304L stainless steel reactor cavity and spent fuel cooling system tanks and attributed to chloride-induced SCC. The tanks that were fabricated to American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Subsection NC, maintained water between 7 and 40 degrees C (45 and 104 degrees F) and were open to the atmosphere. The cracks showed up primarily in areas adjacent to welds. Through-wall cracks developed after an estimated 16–25 years of exposure to the marine atmosphere.^{4,5}

BACKGROUND

SCC is induced from the combination of tensile stress and a specific corrosive environment. Austenitic stainless steels under tensile stress are known to be susceptible to SCC when exposed to chlorides in the environment. A literature survey has revealed failures attributed to chloride-induced SCC in the types of austenitic stainless steels typically used in dry cask storage system canisters when these materials are exposed to atmospheric conditions near salt-water bodies. This phenomenon is of concern at temperature and relative humidity combinations that allow the chloride compounds to deliquesce. It is thought that airborne salts could deposit on the material surface, then form chloride-rich deliquescent brines in conditions

¹ Letter from the Pressurized Water Reactor Owners Group to the NRC, dated October 14, 2010, "PWR Owners Group, for Information Only – Outside Diameter Initiated Stress Corrosion Cracking Revised Final White Paper, PA-MSC-0474," ADAMS Accession No. ML110400241.

² LER 1999-003-00, dated May 6, 1999, "ECCS Suction Header Leaks Result in Both ECCS Trains Inoperable and TS 3.0.3 Entry," ADAMS Legacy Library Accession No. 9905130085.

³ L-2005-168: "10 CFR 50.55a Request for Temporary Non-Code Repair," ADAMS Accession No. ML052780060.

⁴ RFI No. NUC110801/WB, Appendix 6.1, Ref. DSG-310-301, "Technical Specification for Replacement PTR Tanks for Koeberg Nuclear Power Station," 2011.

⁵ Alexander, D. and P. Doubell, and C. Wicker, "Degradation of Safety Injection System and Containment Spray Piping and Tank Fracture Toughness Analysis," September 30, 2010.

of high relative humidity. Laboratory data suggests that chloride-induced SCC is of particular concern as the canister surface temperature decreases to the level where salt will deliquesce.⁶

Researchers do not yet fully understand the relationship between the proximity to a salt-water body and the potential for chloride deposition on a dry cask storage system canister. However, it should be noted that many ISFSIs are located near salt-water bodies or other sources of chlorides, such as salted roads or condensed cooling tower water. These canisters may have high tensile residual stresses from welding or other fabrication processes.

Canisters serve as the confinement system in many licensed dry cask storage systems. Under normal conditions of storage, the confinement system integrity must be maintained over the duration of the storage license, including the initial licensing period (40-year maximum) and any subsequent license renewal periods (increments of up to 40 additional years). A breach in the confinement system could cause a safety concern and result in noncompliance with several regulations, including, but not limited to the following:

- 10 CFR 72.120(d), which requires, in part, that the ISFSI be designed, made of materials, and constructed to ensure that there will be no significant chemical, galvanic, or other reactions between or among the storage components.
- 10 CFR 72.122(b)(1), which requires, in part, that the structures, systems, and components (SSCs) important to safety be designed to accommodate the effects of site characteristics and environmental conditions associated with normal operation and maintenance.
- 10 CFR 72.122(h)(1), which requires, in part, that the spent fuel cladding must be protected during storage against degradation that leads to gross ruptures. The spent fuel cladding is typically protected by an inert environment within the confinement system.
- 10 CFR 72.122(h)(4), which requires, in part, that the dry spent fuel storage confinement systems have the capability for periodic monitoring in a manner such that the licensee will be able to determine when corrective action needs to be taken to maintain safe storage conditions.
- 10 CFR 72.122(l), which requires, in part, that the storage systems must be designed to allow ready retrieval of spent fuel.
- 10 CFR 72.236(d), which requires that the radiation shielding and confinement features are sufficient to meet the requirements of 10 CFR 72.104, "Criteria for Radioactive Materials in Effluents and Direct Radiation from an ISFSI or MRS [Monitored Retrievable Storage]," and 72.106, "Controlled Area of an ISFSI or MRS."
- 10 CFR 72.236(l), which requires, in part, that the spent fuel storage cask and its systems important to safety be evaluated to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

The NRC is currently evaluating data to determine the level of susceptibility and potential safety significance for existing licenses and certificates. The NRC has engaged the Nuclear Energy Institute (NEI) to describe information related to structures, systems, and components important

⁶ Mintz, T. and L. Caseres, X He, J. Dante, G. Oberson, D Dunn, and T. Ahn, "Atmospheric Salt Fog Testing To Evaluate Chloride-Induced Stress Corrosion Cracking of Type 304 Stainless Steel," *Corrosion* 2012, March 11–15, 2012, Salt Lake City, UT, Agencywide Documents Access and Management System (ADAMS) Accession No. ML120720549.

to safety and to understand industry plans for generically addressing this issue.^{7,8,9,10} The NRC also has communicated concerns and technical information regarding this topic at several stakeholder meetings.^{11,12,13,14,15} At this point, no immediate safety concern has been identified with currently approved licenses that would warrant a backfit analysis under 10 CFR 72.62, "Backfitting." However, maintenance and surveillance programs during initial license periods and aging management programs (AMPs) during license renewal periods are required to address aging effects, such as chloride-induced SCC, as appropriate for the relevant canister design(s), operating conditions, specific site environmental conditions, and proposed license or license renewal period(s).

DISCUSSION

Several failures in austenitic stainless steels have been attributed to chloride-induced SCC. The components that have failed because of this failure mechanism at nuclear power plants, as discussed above, are made from the same types of austenitic stainless steels typically used to fabricate dry cask storage system canisters. As discussed above, empirical data has demonstrated that this failure mechanism is reproducible in Type 304 and 304L stainless steel as well as in Type 316L stainless steel.^{16,17,18,19,20} Accordingly, the NRC expects that all types of austenitic stainless steels typically used to fabricate dry cask storage system canisters (304, 304L, 316, and 316L) are susceptible to this failure mechanism.

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- 7 Ruffin, Steve, NRC, letter to Doug Weaver, May 4, 2012, "Summary of April 12, 2012, Meeting with the NEI and Industry Regarding Marine Atmosphere SCC," ADAMS Accession No. ML12128A134.
 - 8 Staab, Chris, NRC, letter to Doug Weaver, NRC, August 26, 2010, "Summary of August 20, 2010, Meeting with NEI and Industry Regarding Issue Resolution Protocol and Pilot Issue," ADAMS Accession No. ML102420183.
 - 9 Staab, Chris, NRC, letter to Doug Weaver, March 29, 2011, "Summary of March 14, 2011, Meeting with NEI and Industry Regarding Issue Resolution Protocol and Pilot Issue," ADAMS Accession No. ML110910063.
 - 10 Ruffin, Steve, NRC, letter to Michael Waters, March 13, 2012, "Summary of February 14, 2012, Meeting with the Nuclear Energy Institute and Industry Regarding Top Nozzle and Marine Atmosphere Stress Corrosion Cracking," ADAMS Accession No. ML12074A012.
 - 11 DePaula, S., "Stress Corrosion Cracking (SCC): Considerations for Dry Cask Storage System Canisters Exposed to a Marine Atmosphere," NEI Used Fuel Management Conference, May 2011.
 - 12 DePaula, S., and J. Plotter, "Lessons Learned from the Regulatory Issue Resolution Protocol (RIRP) Pilots," SFST Regulatory Conference, November 3, 2011, ADAMS Accession No. ML113130533.
 - 13 Ahn, T. and S. DePaula, J. Solis, T. Mintz, H. Jung, R. Pabalan, K. Lee, and R. Einziger, "An Evaluation of Stress Corrosion Cracking (SCC) of Stainless Steel Canister in Marine Environment for Long-term Dry Storage of Spent Nuclear Fuel," Extended Storage Collaboration Program Meeting, December 2011, ADAMS Accession No. ML113350299.
 - 14 Gordon, M. and S. DePaula, G. Oberson, R. Einziger, "Marine Atmosphere Stress Corrosion Cracking (SCC)," NEI Used Fuel Management Conference, May 2012, ADAMS Accession No. ML12136A024.
 - 15 DePaula, S., M. Gordon, R. Einziger, "Cladding Failure Resulting from Chloride-Induced Stress Corrosion Cracking in Dry Cask Storage System Canisters," ANS Annual Meeting, June 2012, ADAMS ML120170379.
 - 16 Money, K. and W. Kirk, "Stress Corrosion Cracking Behavior of Wrought Fe-Cr-Ni Alloys in Marine Atmosphere," Materials Performance, July 1978.
 - 17 Yajima, M. and M. Arai, "Chloride Stress Corrosion Cracking of AISI 304 Stainless Steel in Air," Materials Performance, December 1980.
 - 18 NUREG/CR-7030, "Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Cask Storage Containers Exposed to Marine Environments," October 2010.
 - 19 Shirai, K. and J. Tani, T. Awai, M. Wataru, H. Takeda, and T. Saegusa, "SCC Evaluation of a Multi-Purpose Canister," IHLRWMC 2011, April 2011.
 - 20 Albores-Silva, O.E. and E.A. Charles and C. Padovani, "Effect of Chloride Deposition on Stress Corrosion Cracking of 316L Stainless Steel Used for Intermediate Level Radioactive Waste Containers," Corrosion Engineering, Science, and Technology, Volume 46, pages 124-128, 2011.

All of the failures discussed above occurred when the components were located near a salt-water body. At this point, however, the relationship between the proximity of the ISFSI to a salt-water body or other sources of chlorides, such as salted roads or condensed cooling tower water, and chloride-induced SCC initiation has not been defined. Licensees and CoC holders should assess the potential significance for their specific site location(s) and cask design(s), taking into account cumulative chloride exposure since fabrication. Consideration of other relevant components may be a leading indicator of the site susceptibility where comparable components exist on the site. Licensees should consider comparison of significant parameters (exposure time; component stress state; surface temperature; local relative humidity; amount, composition, and aqueous concentration of deposited salts; and type of austenitic stainless steel) between the components which may indicate site susceptibility and the dry cask storage system canisters to determine whether a valuable comparator exists.

The Pressurized Water Reactor Owners Group (PWROG) initiated a program to evaluate outside diameter SCC (ODSCC) operational events and developed an interim strategy to address such cracking, in part because of the failures mentioned above.²¹ This interim strategy relied largely on the visual, surface and volumetric inspections for cracks and active leaking of coolant and boric acid deposits. Dry cask storage system canisters are not designed to be readily accessible for visual, surface, or volumetric inspections during storage. The inert gases within the canister are not expected to leave a deposit on the canister surface if a through-wall penetration developed. Because of the high radiation field surrounding the canisters, external surface monitoring must currently be performed by remote methods, when necessary. Industry has begun to develop remote inspection techniques and has reported initial remote visual inspection results.²²

Currently, potential environmental conditions and canister characteristics conducive to SCC have been identified, but exact exposure times required to initiate SCC are not known. The resulting progression rate and associated likelihoods have not been quantified. Further research specific to the local conditions that occur at ISFSIs is needed to understand and evaluate this failure mechanism and to refine the technical understanding of the conditions and timeframes during which chloride-induced SCC is likely to initiate and propagate. However, given the examples discussed above and the safety significance of dry cask storage system canisters, licensees should consider this failure mechanism and any monitoring activities that are necessary to ensure adequate confinement integrity is maintained throughout the initial license and license renewal period(s), as appropriate. Typically, the canister condition is not monitored or periodically inspected. An effective monitoring and surveillance program for addressing this chloride-induced SCC should be established to manage the material degradation before it results in a potential safety concern. For periodic monitoring programs to be effective, consideration of expected initiation times, propagation rates and likelihoods is necessary to set useful monitoring frequencies.

²¹ Letter from PWROG to the NRC, dated February 21, 2011, "PWR Owners Group, for Information Only – PWR Owners Group Materials Subcommittee Interim Strategy for Identifying Outside Diameter Initiated Stress Corrosion Cracking (ODSCC) of Stainless Steel Systems, 51-9152699-000, PA-MS-C-0563," ADAMS Accession No. ML110820071.

²² Calvert Cliffs Nuclear Power Plant Independent Spent Fuel Storage Installation Material License No. SNM-2505, Docket No. 72-8 Response to Request for Supplemental Information, RE: Calvert Cliffs Independent Spent Fuel Storage Installation License Renewal Application (TAC No. L24475), ADAMS Accession No. ML12212A216, July 2012.

CONTACT

This IN requires no specific action or written response. Please direct any questions about this notice to the technical contact listed below or to the appropriate Office of Nuclear Material Safety and Safeguards project manager.

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