XI.M12 THERMAL AGING EMBRITTLEMENT OF CAST AUSTENITIC STAINLESS STEEL (CASS)

Program Description

The reactor coolant system components are inspected in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI. This inspection is augmented to detect the effects of loss of fracture toughness due to thermal aging embrittlement of cast austenitic stainless steel (CASS) piping components except for pump casings and valve bodies. This aging management program (AMP) includes determination of the susceptibility of CASS components to thermal aging embrittlement based on casting method, molybdenum (Mo) content, and percent ferrite. For "potentially susceptible" components, as defined below, aging management is accomplished through either (a) qualified visual inspections, such as enhanced visual examination (EVT-1); (b) a qualified ultrasonic testing (UT) methodology; or (c) a component-specific flaw tolerance evaluation in accordance with the ASME Code, Section XI, 2004 edition.[10] Additional inspection or evaluations to demonstrate that the material has adequate fracture toughness are not required for components that are not susceptible to thermal aging embrittlement.

For pump casings and valve bodies, based on the results of the assessment documented in the letter dated May 19, 2000, from Christopher Grimes, Nuclear Regulatory Commission (NRC), to Douglas Walters, Nuclear Energy Institute (NEI) (May 19, 2000 NRC letter), screening for susceptibility to thermal aging embrittlement is not required. The existing ASME Code, Section XI inspection requirements, including the alternative requirements of ASME Code Case N-481 for pump casings, are adequate for all pump casings and valve bodies.

Aging management of CASS reactor internal components of pressurized water reactors (PWRs) are discussed in AMP XI.M16A and of CASS reactor internal components of boiling water reactors (BWRs) in AMP XI.M9.

Evaluation and Technical Basis

1. ***Scope of Program:*** This program manages loss of fracture toughness in potentially susceptible ASME Code Class 1 piping components made from CASS. The program includes screening criteria to determine which CASS components are potentially susceptible to thermal aging embrittlement and require augmented inspection. The screening criteria are applicable to all primary pressure boundary components constructed from cast austenitic stainless steel with service conditions above 250°C (482°F). The screening criteria for susceptibility to thermal aging embrittlement are not applicable to niobium-containing steels; such steels require evaluation on a case-by-case basis.

   Based on the criteria set forth in the May 19, 2000, NRC letter, the susceptibility to thermal aging embrittlement of CASS materials is determined in terms of casting method, molybdenum content, and ferrite content. For low-molybdenum content steels (SA-351 Grades CF3, CF3A, CF8, CF8A or other steels with ≤ 0.5 weight percent [wt.%] Mo), only static-cast steels with >20% ferrite are potentially susceptible to thermal embrittlement. Static-cast low-molybdenum steels with ≤20% ferrite and all centrifugal-cast low-molybdenum steels are not susceptible. For high-molybdenum content steels (SA-351 Grades CF3M, CF3MA, and CF8M or other steels with 2.0 to 3.0 wt.% Mo), static-cast

[10] Refer to the GALL Report, Chapter I, for applicability of other editions of ASME Code, Section XI.

steels with >14% ferrite and centrifugal-cast steels with >20% ferrite are potentially susceptible to thermal embrittlement. Static-cast high-molybdenum steels with ≤14% ferrite and centrifugal-cast high-molybdenum steels with ≤20% ferrite are not susceptible. In the susceptibility screening method, ferrite content is calculated by using the Hull's equivalent factors (described in NUREG/CR-4513, Rev. 1) or a staff-approved method for calculating delta ferrite in CASS materials. A fracture toughness value of 255 kilojoules per square meter (kJ/m^2) (1,450 inches-pounds per square inch) at a crack depth of 2.5 millimeters (0.1 inch) is used to differentiate between CASS materials that are not susceptible and those that are potentially susceptible to thermal aging embrittlement. Extensive research data indicate that for CASS materials not susceptible to thermal aging embrittlement, the saturated lower-bound fracture toughness is greater than 255 kJ/m^2 (NUREG/CR-4513, Rev. 1).

For pump casings and valve bodies, screening for susceptibility to thermal aging embrittlement is not needed (and thus there are no aging management review line items). For all pump casings and valve bodies greater than a nominal pipe size (NPS) of 4 inches, the existing ASME Code, Section XI inspection requirements, including the alternative requirements of ASME Code Case N-481 for pump casings, are adequate. ASME Code, Section XI, Subsection IWB requires only surface examination of valve bodies less than a NPS of 4 inches. For these valve bodies less than a NPS of 4 inches, the adequacy of inservice inspection (ISI) according to ASME Code, Section XI has been demonstrated by an NRC-performed bounding integrity analysis (May 19, 2000 letter).

2. ***Preventive Actions:*** This program is a condition monitoring program and does not mitigate thermal aging embrittlement.

3. ***Parameters Monitored/Inspected:*** The program monitors the effects of loss of fracture toughness on the intended function of the component by identifying the CASS materials that are susceptible to thermal aging embrittlement.

   The program does not directly monitor for loss of fracture toughness that is induced by thermal aging; instead, the impact of loss of fracture toughness on component integrity is indirectly managed by using visual or volumetric examination techniques to monitor for cracking in the components.

4. ***Detection of Aging Effects:*** For pump casings, valve bodies, and other "not susceptible" CASS piping components, no additional inspection or evaluations are needed to demonstrate that the material has adequate fracture toughness.

   For "potentially susceptible" piping components, the AMP provides for qualified inspections of the base metal, such as enhanced visual examination (EVT-1) or a qualified UT methodology, with the scope of the inspection covering the portions determined to be limiting from the standpoint of applied stress, operating time, and environmental considerations. Examination methods that meet the criteria of the ASME Code, Section XI, Appendix VIII are acceptable. Alternatively, a plant-specific or component-specific flaw tolerance evaluation, using specific geometry, stress information, material properties, and ASME Code, Section XI can be used to demonstrate that the thermally-embrittled material has adequate toughness. Current UT methodology cannot detect and size cracks; thus, EVT-1 is used until qualified UT methodology for CASS can be established. A description of EVT-1 is found in Boiling Water Reactor Vessel and Internals Project (BWRVIP)-03 (Revision 6) and Materials Reliability Program (MRP)-228 for PWRs.

5. ***Monitoring and Trending:*** Inspection schedules in accordance with ASME Code, Section XI, IWB-2400 or IWC-2400, reliable examination methods, and qualified inspection personnel provide timely and reliable detection of cracks. If flaws are detected, the period of acceptability is determined from analysis of the flaw, depending on the crack growth rate and mechanism.

6. ***Acceptance Criteria:*** Flaws detected in CASS components are evaluated in accordance with the applicable procedures of ASME Code, Section XI, IWB-3500 or ASME Code, Section XI, IWC-3500. Flaw tolerance evaluation for components with ferrite content up to 25% is performed according to the principles associated with ASME Code, Section XI, IWB-3640 procedures for SAWs, disregarding the ASME Code restriction of 20% ferrite. Extensive research data indicates that the lower-bound fracture toughness of thermally aged CASS materials with up to 25% ferrite is similar to that for SAWs with up to 20% ferrite (Lee et al., 1997). Flaw tolerance evaluation for piping with >25% ferrite is performed on a case-by-case basis by using the applicant's fracture toughness data.

7. ***Corrective Actions:*** Repair and replacement are performed in accordance with ASME Code, Section XI, IWA-4000. As discussed in the Appendix for GALL, the staff finds the requirements of 10 CFR Part 50, Appendix B acceptable to address the corrective actions.

8. ***Confirmation Process:*** Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the requirements of 10 CFR Part 50, Appendix B. As discussed in the Appendix for GALL, the staff finds the requirements of 10 CFR Part 50, Appendix B acceptable to address the confirmation process and administrative controls.

9. ***Administrative Controls:*** The administrative controls for this program provide for a formal review and approval of corrective actions. The administrative controls for this program are implemented through the site's QA program in accordance with the requirements of 10 CFR Part 50, Appendix B.

10. ***Operating Experience:*** The AMP was developed by using research data obtained on both laboratory-aged and service-aged materials. Based on this information, the effects of thermal aging embrittlement on the intended function of CASS components will be effectively managed.

References

10 CFR Part 50, Appendix B, *Quality Assurance Criteria for Nuclear Power Plants*, Office of the Federal Register, National Archives and Records Administration, 2009.

10 CFR Part 50.55a, *Codes and Standards*, Office of the Federal Register, National Archives and Records Administration, 2009.

ASME Section XI, *Rules for Inservice Inspection of Nuclear Power Plant Components*, The ASME Boiler and Pressure Vessel Code, 2004 edition as approved in 10 CFR 50.55a, The American Society of Mechanical Engineers, New York, NY.

ASME Code Case N-481, *Alternative Examination Requirements for Cast Austenitic Pump Casings*, Section XI, Division 1.

BWRVIP-03, Rev. 6, *BWR Vessel and Internals Project: Reactor Pressure Vessel and Internals Examination Guidelines* (EPRI TR-105696).

Lee, S., Kuo, P. T., Wichman, K., and Chopra, O., *Flaw Evaluation of Thermally-Aged Cast Stainless Steel in Light-Water Reactor Applications*, Int. J. Pres. Vessel and Piping, pp 37-44, 1997.

Letter from Christopher I. Grimes, U.S. Nuclear Regulatory Commission, License Renewal and Standardization Branch, to Douglas J. Walters, Nuclear Energy Institute, License Renewal Issue No. 98-0030, *Thermal Aging Embrittlement of Cast Stainless Steel Components*, May 19, 2000. (ADAMS Accession No. ML003717179)

Letter from Mark J. Maxin, to Rick Libra (BWRVIP Chairman), Safety Evaluation for Electric Power Research Institute (EPRI) Boiling Water Reactor Vessel and Internals project (BWRVIP) Report TR-105696-R6 (BWRVIP-03), Revision 6, BWR Vessel and Internals Examination Guidelines (TAC No MC2293)," June 30, 2008 (ADAMS Accession No ML081500814)

MRP-228, *Materials Reliability Program: Inspection Standard for PWR Internals,* 2009.

NUREG/CR-4513, Rev. 1, *Estimation of Fracture Toughness of Cast Stainless Steels During Thermal Aging in LWR Systems*, U.S. Nuclear Regulatory Commission, August 1994.