United States Nuclear Regulatory Commission Official Hearing Exhibit

In the Matter of: Entergy Nuclear Operations, Inc.
(Indian Point Nuclear Generating Units 2 and 3)

ASLBP #: 07-858-03-LR-BD01
Docket #: 05000247 | 05000286
Exhibit #: NRC000201-00-BD01
Identified: 11/5/2015
Admitted: 11/5/2015
Withdrawn:
Rejected:
Stricken:
Other:

NRC position on Aging Management of CASS Reactor Vessel Internal Components

Purpose

To determine when aging management of reactor vessel internal (RVI) components manufactured from cast austenitic stainless steel (CASS) materials is needed for license renewal (LR) of light water reactors (LWRs) under 10 CFR Part 54, the NRC staff requires licensees/applicants to consider embrittlement from both thermal aging and neutron irradiation.

Thermal Embrittlement (TE) --

NUREG/CR-4513, Rev. 1 "Estimation of Fracture Toughness of Cast Stainless Steels During Thermal Aging in LWR Systems," provides a detailed analysis of CASS fracture toughness after thermal aging, by defining "lower-bound fracture toughness J-R curves" for certain categories of CASS. The analysis classified CASS into three different categories (a) low ferrite (< 10 %), (b) medium ferrite (10-15%) and high ferrite (>15%). As illustrated in NUREG-4513 for the lower-bound fracture toughness, higher toughness is associated with lower ferrite contents, lower molybdenum contents, and centrifugal casting; lower toughness correlates with higher ferrite contents, higher molybdenum contents, and static casting methods.

The component screening in the Grimes Letter (dated May 19, 2000) provides fracture toughness screening criteria for TE that were correlated with J-R curves exhibiting a minimum J value at 2.5 mm crack extension of 255 kJ/m^2, which is described as a level to differentiate non-significant and potentially significant reduction in fracture toughness for fully aged CASS materials. This fracture toughness level was associated with generic flaw tolerance analyses for CASS piping components.

Irradiation Embrittlement (IE) ---

The Grimes Letter prohibited application of the TE screening criteria described above to RVI components receiving neutron exposures greater than 0.00015 displacements per atom (dpa) [1E+17 n/cm^2 (E> 1MeV)]. For CASS components exposed to both thermal aging and neutron irradiation conditions, fracture toughness screening criteria could not be developed because there was no database of test results at the time for CASS materials with simultaneous thermal exposure and significant neutron flux. For such components, the Grimes Letter required a component-specific evaluation that could include screening based on stress or enhanced inspections.

Since the Grimes Letter was issued, fracture toughness data for CASS materials subject to both thermal aging and neutron irradiation has been published in NUREG/CR-7027, "Degradation of LWR Core Internal Materials Due to Neutron Irradiation." NUREG/CR-7027 proposed a lower bound estimate for the fracture toughness for all austenitic stainless steels subjected to irradiation. This report states that the fracture toughness for CASS materials decreased due to neutron irradiation above about 0.3 dpa. The NRC staff considers the 0.3 dpa fluence as a threshold for changes in the measured fracture toughness, but notes that the embrittlement of austenitic stainless steels becomes significant (i.e., a minimum J value at 2.5 mm crack extension of 255 kJ/m^2) at slightly higher fluence levels, 0.5 – 2 dpa, depending on the material.

NRC Staff's Position

The fracture toughness screening value of 255 kJ/m^2 specified in the Grimes Letter is based on a generic flaw tolerance evaluation for piping, and may be overly conservative for RVI CASS components that are subject to mainly compressive stresses during operation, and are part of a population of redundant components where failure of individual components can be tolerated. No comparable fracture toughness acceptance criterion for RVIs currently exists. Therefore, the staff applies the 255 kJ/m^2 value for screening purposes with the knowledge that there likely is additional conservatism present in this screening for non-pressure boundary RVI components.

Based on the data in NUREG/CR-7027, the NRC staff position is that the IE screening criterion in the Grimes Letter for CASS RVIs can be increased to 0.45 dpa from the current 0.00015 dpa. Those CASS materials with a neutron exposure less than 0.45 dpa would not require consideration of IE. Screening of CASS RVIs for TE should follow the criteria in Table 2 of the Grimes Letter, which is reproduced below as Table A.

For those CASS components with projected neutron exposure > 0.45 dpa and < 1.5 dpa, screening assessment of CASS RVIs can be based on a reduction in the delta ferrite screening level to account for the cumulative effect of neutron fluence (IE) with the concurrent TE (described as the potential synergistic effect in the Grimes Letter). For components that were statically cast, the staff considers CASS materials with a maximum ferrite level > 15% for low Mo materials and > 10% for high Mo materials to be screened in for aging management. For components that were centrifugally cast, the staff considers only high Mo materials with > 15% delta ferrite to be screened in for aging management. The staff position for screening of components with neutron exposure ≥ 0.45 dpa and ≤ 1.5 dpa is provided in Table B, which is similar in structure to Table A.

Embrittlement of CASS RVI that are not screened in for aging management due to TE can be treated as if the component is manufactured from wrought stainless steel. From the information in MRP-175 and MRP-227-A, wrought stainless steel requires aging management only when the neutron exposure exceeds 1.5 dpa.

All CASS materials with a neutron exposure > 1.5 dpa require consideration of IE. The screening of CASS RVIs with a neutron exposure > 1.5 dpa is provided in Table C.

Assessment of embrittlement susceptibility of CASS components, as described in Tables A, B, and C, is important for aging management according to MRP-227-A. Those CASS components identified as "Expansion" components in plant-specific inspection plans should include a link to a component identified as a "Primary" inspection component that is susceptible to the same aging mechanism(s).

In summary, the staff recommends the following guidelines for screening of CASS materials for loss of fracture toughness due to TE and/or IE:

1. For neutron exposures below 0.45 dpa, IE of CASS is not a significant concern. Screening for TE is still required, using the criteria of Table A, which is identical to the Grimes Letter.

2. For neutron exposures between 0.45 dpa and 1.5 dpa (inclusive), aging management of CASS due to TE and IE may be required depending on the molybdenum content, ferrite content and casting method, as detailed in Table B.

3. Above 1.5 dpa, all stainless steel and CASS RVI components are considered susceptible to loss of fracture toughness and require aging management. Components may also be susceptible to TE depending on molybdenum content, ferrite content and casting method, as detailed in Table C.

Table A Screening for Components with < 0.45 dpa neutron exposure

Molybdenum (wt. %)	Casting Method	Susceptibility	Delta ferrite %
High 2.0-3.0% (CF-8M)	static	TE	> 14%
		No	≤ 14%
	centrifugal	TE	> 20%
		No	≤ 20%
Low 0.5% max (CF-3 and CF-8)	static	TE	> 20%
		No	≤ 20%
	centrifugal	No	All

Table B Screening for Components with 0.45 dpa ≤ neutron exposure ≤ 1.5 dpa

Molybdenum (wt. %)	Casting Method	Susceptibility	Delta ferrite %
High 2.0-3.0% (CF-8M)	static	TE + IE	> 10%
		No	≤ 10%
	centrifugal	TE + IE	> 15%
		No	≤ 15%
Low 0.5% max (CF-3 and CF-8)	static	TE + IE	> 15%
		No	≤ 15%
	centrifugal	No	All

Table C Screening for Components with > 1.5 dpa neutron exposure

Molybdenum (wt. %)	Casting Method	Susceptibility	Delta ferrite %
High 2.0-3.0% (CF-8M)	static	TE + IE	> 10%
		IE	≤ 10%
	centrifugal	TE + IE	> 15%
		IE	≤ 15%
Low 0.5% max (CF-3 and CF-8)	static	TE + IE	> 15%
		IE	≤ 15%
	centrifugal	IE	All