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**U.S. Industry
Evaluation of Thermal
and Irradiation
Embrittlement of Cast
Austenitic Stainless
Steels for Light Water
Reactor Pressure
Vessel Internals**



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**U. S. Industry Evaluation of Thermal and Irradiation
Embrittlement of CASS Reactor Vessel Internals**

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 - GALL
 - MRP-227 Topical Report (TR) & NRC Safety Evaluation (SE)
 - NRC Guidance in "Grimes Letter"
- MRP-276: Thermal Aging & Neutron Embrittlement Assessment of CASS and Stainless Steel Welds in PWR Internals
- BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals
- BWRVIP/MRP CASS Focus Group
- Application to RV Internals
- Recent Industry and NRC Interactions
 - BWRVIP/MRP Initial joint screening recommendation
 - NRC Position on screening criteria
 - BWRVIP/MRP Revised joint screening recommendation
- Status and Future Actions

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**Background
GALL**

- Generic Aging Lessons Learned (GALL) Report (NUREG-1801, Rev. 2) provides aging management criteria to evaluate the thermal embrittlement (TE) and irradiation embrittlement (IE) susceptibility of cast austenitic stainless steels (CASS) components for reactor vessel (RV) internals
 - Chapter XI.M9 for BWR Internals
 - Chapter XI.M.16A for PWR Internals
- NRC screening criteria for TE and IE are contained in a May 19, 2000 letter from Christopher Grimes (NRC), to Douglas Walters (NEI), "License Renewal Issue No. 98-0030, Thermal Aging Embrittlement of Cast Stainless Steel Components" (ADAMS Accession No. ML003717179) herein referred to as *Grimes letter*

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Background
MRP-227-A, PWR Inspection and Evaluation Guidelines

- Chapter XI.M.16A in GALL refers to MRP-227
- The NRC Safety Evaluation (SE) of MRP-227 stated in Section 3.3.7:
 - “For CASS, if the application of applicable screening criteria for the component’s material demonstrates that the components are not susceptible to either thermal embrittlement or irradiation embrittlement, or the synergistic effects of thermal embrittlement (TE) and irradiation embrittlement (IE) combined, then no other evaluation would be necessary.”
 - “For assessment of CASS materials, the licensees or applicants for LR may apply the criteria in the Grimes letter as the basis for determining whether the CASS materials are susceptible to the thermal aging embrittlement mechanism.”
 - “...additional analyses should consider impacts of aging ... on the intended functions ... and the possible impact that a potential loss of fracture toughness may have ... as a result of both a thermal aging embrittlement mechanism and potentially a neutron irradiation embrittlement mechanism [referred to as Applicant/Licensee Action Item (A/LAI) 7]”

Background
NRC Guidance in Grimes letter

- TE screening based on casting method, molybdenum content, and percent ferrite
- IE screening based on a fluence value of 1×10^{17} n/cm² as a screening value for IE
 - Fluence value selected was associated with 10 CFR 50 Appendix H (for RPV low-alloy steel embrittlement)
 - Considered to be a potential threshold for IE and was often used as the basis for license renewal applications
- Subsequent studies (by industry and NRC) have shown the IE (fluence) criteria to be extremely conservative for CASS
- In 2013, the question of combined effects of TE and IE of CASS RV internals was raised in public meetings between industry and NRC

MRP-276: Thermal Aging & Neutron Embrittlement Assessment of CASS and Stainless Steel Welds in PWR Internals (ML102950165)

Report Summary Regarding CASS IE Screening Criteria:

- Fracture toughness decreases rapidly with increasing neutron dose for neutron exposures between 0 and 10 dpa
- Because the austenitic stainless steel weld metals and CASS show much greater variability in initial values, their screening neutron exposure was conservatively established to be somewhat lower at > 1 dpa or 6.7×10^{20} n/cm², $E > 1.0$ MeV
- This screening criterion was suggested for use in evaluation of the potential synergistic effect of dose on thermal aging embrittlement
- It is clear from the available data that the NRC-recommended fluence screening criterion for a synergistic effect (that is, 1×10^{17} n/cm², $E > 1.0$ MeV) is overly conservative
- The conclusions of this study support a recommendation to withdraw GALL AMP XL.M13 to allow the establishment of requirements for aging management of CASS PWR internals items based on MRP-227 in GALL AMP XI.M16
- Based on the findings of this study, it is evident that implementation of the MRP-227, Rev. 0 Guidelines provides appropriate aging management for irradiated CASS

BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals

- This report evaluated the potential synergistic effects of thermal aging and neutron embrittlement of BWR internal components fabricated of CASS to determine if augmented inspections are necessary to detect degradation
- Ten BWR internal components fabricated of CASS were evaluated
- Screening/evaluation criteria included
 - Material specification and ferrite content
 - Neutron fluence
 - Material toughness
 - Applied stress
 - Inspections conducted to date
- Conclusion was that no augmented inspections are necessary for BWR CASS through end of license renewal period

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BWRVIP/MRP CASS Focus Group

- During 2013, NRC issued Requests for Additional Information (RAIs) on MRP-227-A (PWR Internals I&E Guidelines) plant program submittals to several PWR utilities regarding evaluation of CASS components
- In May 2013, NRC issued a 2nd set of RAIs on BWRVIP-234
- The industry determined that some RAIs regarding CASS were common to BWRs and PWRs
- An Industry/NRC meeting was held on May 21, 2013 to review issues related to the evaluation of CASS
 - NRC requested a common BWRVIP/MRP screening approach for thermal embrittlement (TE) and irradiation embrittlement (IE)
- A BWR/PWR Industry Focus Group was formed in June 2013 to address CASS issues
 - Significant technical work was conducted to address TE and IE issues
 - Follow-up meetings and conference calls were held with NRC in August 2013, November 2013, and December 2013
- The BWR/PWR CASS FG proposed common replacement TE and IE screening criteria was discussed on a February 3, 2014 NRC call with generally favorable remarks and an agreed timeline to formally submit along with the BWRVIP-234 RAI responses

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BWRVIP/MRP CASS Focus Group

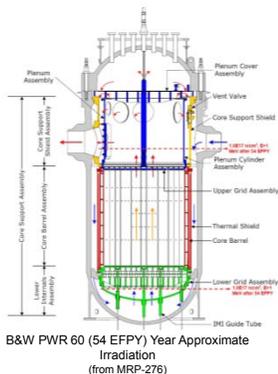
- Response to RAIs on BWRVIP-234, dated May 23, 2014 provided supplemental technical information with a proposed common BWR and PWR approach to screen CASS RV internal components for both TE and IE
- Two phase screening approach:
 1. TE screening same as contained in *Grimes letter*
 2. If not susceptible to TE, then screen for IE by CASS material type and fluence
- No compelling data to suggest there is a synergistic effect of TE and IE

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PWR Application

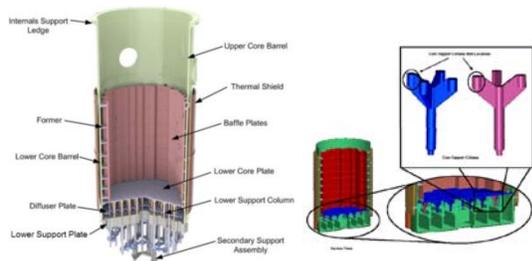


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PWR Application



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BWR Application

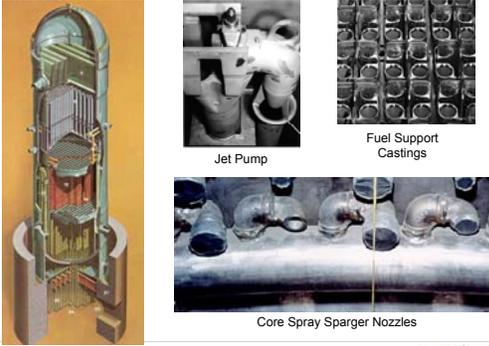
- If industry proposed screening is approved numerous revisions to the BWRVIP-234 will be required; however, the conclusions currently stated in BWRVIP-234 will remain unchanged
- Most, if not all, BWR Internals components fabricated of CASS will not require augmented inspection through 60 years of operation under the industry proposed screening criteria

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Sample of BWR Applications



Jet Pump

Fuel Support Castings

Core Spray Sparger Nozzles

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Recent Industry and NRC Interactions on CASS TE an IE

- BWRVIP/MRP Industry Position
 - Issued via BWRVIP Letter 2014-087 dated May 23, 2014 (ML14216A612)
- NRC Position
 - Issued on June 25, 2014 (ML14174A719)
- Follow-up meeting
 - July 15, 2014 public meeting at NRC Headquarters
 - Additional technical bases to support industry position (based on July 15, 2014 meeting) informally submitted to NRC on Oct 7, 2014
- Conference call held with NRC on November 20, 2014 to discuss additional industry technical bases
- NRC feedback indicated that the industry revised position may not be acceptable in that the staff remains favoring their June 25, 2014 position

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Previous BWRVIP/MRP Industry Proposed Screening

Min. (Wt%)	Casting Method	Ductile Ferrite %	Primary Screening Thermal Embrittlement Susceptibility	Secondary Screening Irradiation Embrittlement Susceptibility
High 2.6 to 3.6	Inert	>14%	Potentially unacceptable in TE. Conduct inspection or component specific evaluation.	No need for SE screening Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Potentially unacceptable in SE - Conduct inspection or component specific evaluation.
		≤14%	Not Inspectable in TE	Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Not potentially inspectable in SE - Screen per additional monitoring.
	Cast/Forge	>10%	Potentially unacceptable in TE. Conduct inspection or component specific evaluation.	No need for SE screening Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Potentially unacceptable in SE - Conduct inspection or component specific evaluation.
		≤10%	Not Inspectable in TE	Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Not potentially inspectable in SE - Screen per additional monitoring.
Low 0.9 Min	Inert	>10%	Potentially unacceptable in TE. Conduct inspection or component specific evaluation.	No need for SE screening Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Potentially unacceptable in SE - Conduct inspection or component specific evaluation.
		≤10%	Not Inspectable in TE	Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Not potentially inspectable in SE - Screen per additional monitoring.
	Cast/Forge	>10%	Potentially unacceptable in TE. Conduct inspection or component specific evaluation.	No need for SE screening Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Potentially unacceptable in SE - Conduct inspection or component specific evaluation.
		All	Not Inspectable in TE	Fluxes - 8.7 x 10 ¹⁸ n/cm ² (10yrs) Not potentially inspectable in SE - Screen per additional monitoring.

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