PWR Irradiated Stainless Steel Fracture Toughness Conservatism

(MRP Program Update)

Technical Background for PWRs

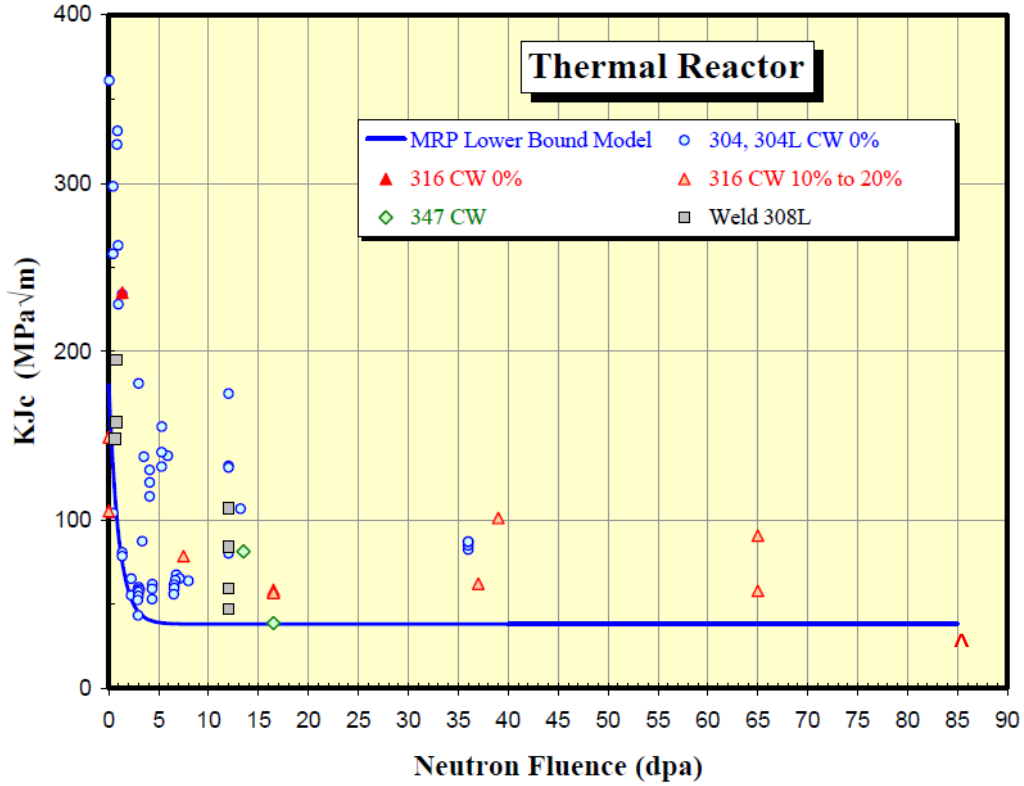
- Irradiated fracture toughness of stainless steels only has implications if a flaw (crack) is identified in a component
- MRP-210 and MRP-211 technical reports include datasets associated with fracture toughness information
- MRP-227 mandates use of NRC-approved methods for flaw evaluations when degraded components are identified
  - For PWRs, one example method is WCAP-17096-NP-A
- MRP-227-A originally was based on BWRVIP-100-A (NRC-approved) evaluations for fracture toughness versus fluence
- Based on Part 21, these may no longer be conservative

Fracture Toughness Data and Evaluations for PWRs

- MRP-210 discusses fracture toughness data and gives example
  - *Materials Reliability Program: Fracture Toughness Evaluation of Highly Irradiated PWR Stainless Steel Internal Components (MRP-210)*. EPRI, Palo Alto, CA: 2007. 1016106. (transmitted to NRC in ML092230734)
- Example flaw tolerance evaluations for five postulated flaw types
  - Flaw types represent the most highly irradiated PWR internal components such as the core support cylinder, the baffle plate, and the former plate
- Maximum expected neutron fluence of highly irradiated reactor vessel internal components during a 60-year PWR lifetime is estimated to be about 100 dpa; 80-years will likely be 130-140 dpa
- Lower bound fracture toughness value of 38 MPa√m (34.6 ksi√in) was established in MRP-210 and used for PWR-RVI flaw evaluations
  - This was incorporated by PWROG into WCAP-17096 guidance in 2008-2009
  - Discussed in detail in response to NRC RAIs in 2012, see ML12342A006

Fracture Toughness Data and Evaluations for PWRs

- MRP-210 show that reduction in fracture toughness occurs primarily between 1 and 10 dpa
- Results show that the fracture toughness reaches a minimum level^ after approximately 10 dpa
- One lower bound curve covers both base metal and weld
- For the Part 21 report, the region of interest is <5 dpa



^*Lower bound fracture toughness value of 38 MPa√m (34.6 ksi√in) was established in MRP-210 and used for flaw evaluations*

Potential Revised BWRVIP-100-A Fracture Toughness

- BWRVIP considering a revised fracture toughness/fluence relationship based on the new test data, for weld metal only
- Base metal fracture toughness relationship not likely to change
- Preliminary evaluation of irradiated stainless steel weld data acquired since publication of BWRVIP-100, R1-A indicate that the FT of 50 ksi-√in is reached at a fluence of 1E21 n/cm^2 as opposed to the previously defined threshold of 3E21 n/cm^2

If PWR incorporates the same change in WCAP-17096-NP

*For PWRs, **possible effect** on the fracture toughness assumption for welds only is shown below:*

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
$> 3\times10^{20}$ - ~~3×10^{21}~~ 1	> 0.5 - ~~5~~ 1.5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$>$ ~~3×10^{21}~~ 1 - 1×10^{22}	$>$ ~~5~~ 1.5 – 15	LEFM 50 ksi√in	LEFM using 50 ksi√in for fracture toughness	LEFM 50 ksi√in
$>1\times10^{22}$	> 15	LEFM 34.6 ksi√in	LEFM using 34.6 ksi√in for fracture toughness	LEFM 34.6 ksi√in ^

^Lower bound fracture toughness value of 38 MPa√m (34.6 ksi√in) was established in MRP-210 and used for flaw evaluations

Next Steps to Address this Potential Non-Conservatism

- Only currently affected PWR station is Saint Lucie unit 1
  - Off-axis (circumferential) cracking in base metal found in spring 2018
  - Re-inspection in fall 2019 identified no crack growth during operation
- EPRI-MRP working with BWRVIP and Westinghouse (WEC)
- WEC reevaluated the raw test data from recent tests documented in MRP-440 and MRP-451
  - Identify which specimen test results are suspect and why
  - Westinghouse reevaluation included both of the following:
    - Standard ASTM E1820 unloading compliance method
    - Normalization method according to Annex A15 of ASTM E1820
- EPRI letter report MRP 2022-009 was published on 3/31/2022
- PWR Owners Group to address further actions on WCAP-17906-A

PWROG

PWR Owners Group

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May 2022 NRC/Industry Materials Technical Exchange Meeting

Actions to Resolve the Impact of the BWRVIP-100, Rev. 1-A Fracture Toughness Issue on WCAP-17096-NP-A, Rev. 2 and WCAP-17096, Rev. 3

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Background

- Since the May 26, 2021 meeting with the Staff regarding the BWRVIP-100, Rev. 1-A fracture toughness issue, Westinghouse has been working with EPRI to:
  - Re-evaluate the fracture toughness data
  - Determine if there is an impact on the flaw tolerance methodologies and/or fracture toughness values in WCAP-17096-NP-A, Rev. 2 and WCAP-17096-NP, Rev. 3

Discussion

- EPRI funded Westinghouse to perform a 3rd party review and evaluation of the recently acquired fracture toughness data
- Additional work was proposed by Westinghouse to EPRI to:
  - A) Establish the technical basis for fracture toughness (FT) limits to be used for LEFM and EPFM analysis of PWR internals
  - B) Perform a fracture mechanics study to compare the margins that results from limit load, LEFM, and EPFM based on the fracture toughness values in Task A
- The objective of the additional EPRI work is to address concerns about the applicability of the BWRVIP-100, Rev. 1-A methodology in WCAP-17096-NP-A, Rev. 2 and WCAP-17096-NP, Rev. 3

Next Steps

- Complete additional EPRI work and publish results in an EPRI report
- Update WCAP-17096-NP to Rev. 4 consistent with findings in EPRI report and submit to staff for approval