

# BWRVIP-100 Update

“Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds”

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INDUSTRY/NRC MATERIALS TECHNICAL EXCHANGE MEETING  
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# Background

- BWRVIP-100, Rev. 1-A (published in 2016) contains fracture toughness (FT) vs. fluence criteria for evaluation of flaws in irradiated stainless steel core shroud materials
- Several testing activities were carried out by the BWRVIP from 2016 to 2020 to obtain additional FT data of irradiated stainless steels
  - Core internals material removed from José Cabrera (a.k.a., Zorita)
  - Weld specimens from the core shroud of Barsebäck Unit 2
- The EPRI Materials Reliability Program (MRP) and Argonne National Labs also tested materials from Zorita
- EPRI reevaluated the BWRVIP-100 correlations based on available FT data since publication of BWRVIP-100, Rev. 1-A

# Reevaluation of Fracture Toughness Data

- 10 CFR Part 21 – Transfer of Information (TOI) issued on February 19, 2021
  - The re-evaluation of FT data indicates that the analysis procedures published in BWRVIP-100 are non-conservative in the fluence range from  $5E20$  n/cm<sup>2</sup> to  $3E21$  n/cm<sup>2</sup> when considering the newly acquired weld metal data
  - Specifically, the lower bound FT of 50 ksi-vin specified in BWRVIP-100 may be reached at a fluence of  $5E20$  n/cm<sup>2</sup> as opposed to the previously defined limit of  $3E21$  n/cm<sup>2</sup>

# Actions Taken by EPRI/BWRVIP to Address Part 21

- Evaluations, recommendations, and guidance provided to utilities to assess the impact of the Part 21 TOI
- 1. BWRVIP conducted a structural margins assessment of potentially impacted internals
  - Surveyed internals fluence distributions, inspection experience, and dimensions and loads for affected internals
    - Core shroud H3 (TG support ring), H4 (beltline) and H5 (CP support ring)
    - Jet pump riser weld RS-3 (inlet riser elbow), 8/9 (riser pipe to brace welds)
    - Top guide grid beams
    - Core plate assembly
    - Orificed fuel support casting
  - Focus on core shroud as limiting component
- 2. Acceptance and screening criteria in BWRVIP-76, Rev. 1-A revised for determining impact on inspection intervals for both horizontal and vertical core shroud welds (repaired and non-repaired shrouds)

Conclusion: There is a reasonable expectation that a structural margin to unstable crack extension of at least 1.0 exists for flaws in irradiated BWR internals components in the operating fleet

# NRC “Virtual” Meetings

- Meeting on May 27, 2021 to review the background and status on the Part 21 TOI
- July 23, 2021 to provide overview of the structural margins assessment (SMA)
- August 10, 2021, NRC Technical Exchange meeting to provide summary of SMA

# Additional Topics

- NRC LIC-504 Evaluation
- BWRVIP-100 Analytical Approaches and Further Investigations of Selected Weld Fracture Toughness Tests
- Part 21 Survey Results
- Ongoing work to close out Part 21

# NRC LIC-504 Evaluation of Non-Conservatism in BWRVIP-100, Rev. 1-A: Brief Summary

- NRC conducted an evaluation of the BWRVIP-100, Rev. 1-A Part 21 per LIC-504 – integrated risk-informed decision-making process for emergent issues
  - Documented in ADAMS ML21312A544 and ML21312A545
- Options considered by the NRC staff included the following;
  - Option 1: Issue Shut Down Orders,
  - Option 2: Leverage NRC Inspection Programs, and
  - Option 3: Take No Action
- The staff concluded the BWRVIP-100 non-conservatism is not an imminent safety concern and consequently, Option 2 was the appropriate action to take

# BWRVIP-100 Analytical Approaches and Further Investigations of Selected Weld Fracture Toughness Tests



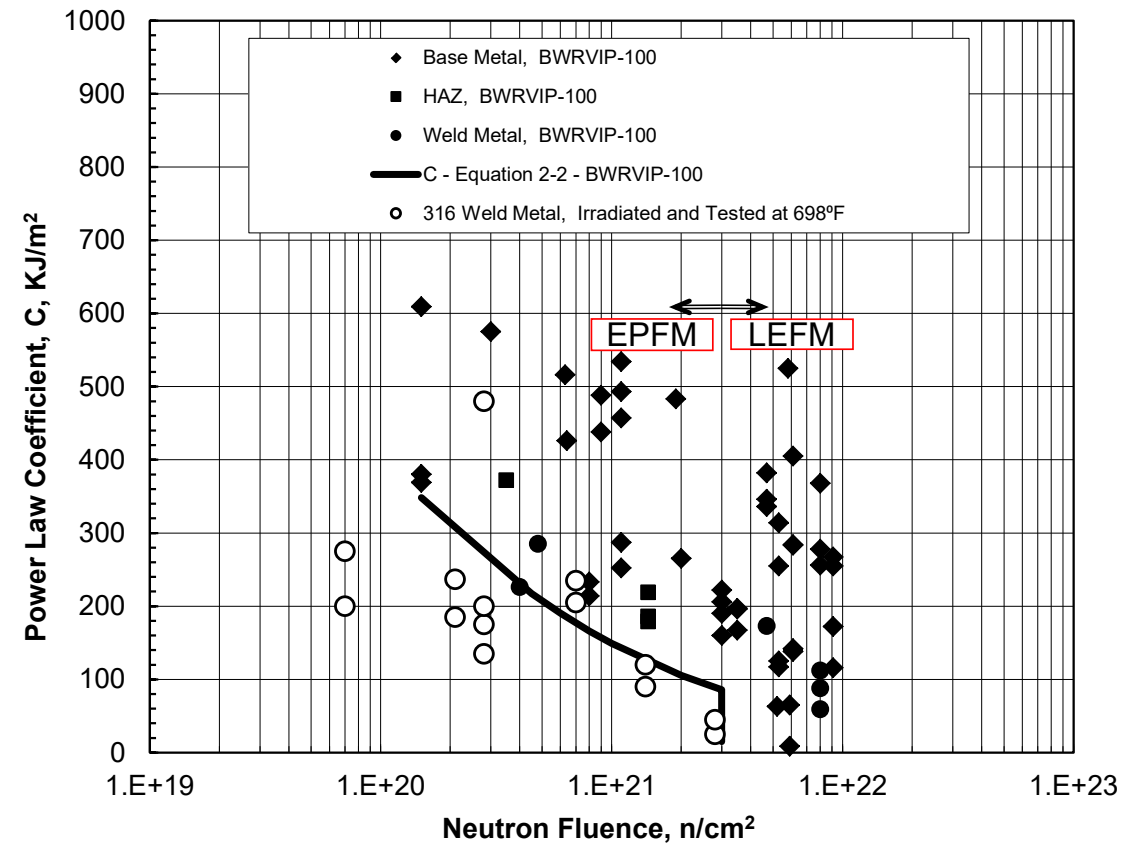


# Analytical Approaches used in BWRVIP-100, Rev. 1-A

- Limit Load (LL)
  - Net section collapse, i.e., extensive plastic deformation
- Linear-elastic fracture mechanics (LEFM)
  - Limited plastic deformation prior to failure
  - Conservative for ductile materials and rather simple in application
- Elastic-plastic fracture mechanics (EPFM)
  - Takes into account stable ductile crack extension of an existing flaw as a function of applied load
  - More complex analytical method but more accurate in terms of determining actual margin to failure
  - Used in BWRVIP-100 to assess applicability of LL and LEFM

# “C” Correlation - BWRVIP-100, Rev. 1-A

- Dating back to 2016, there was no clear distinction for the “C” coefficient between weld, base metal and HAZ materials (solid black symbols) from data corresponding to BWR operating conditions.
- Consequently, the same C correlation was used for weld, base metal and HAZ in BWRVIP-100.
- There were, however, weld data (open circles) that fell outside the “C” correlation. These data were irradiated and tested at a temperature of 698°F - well beyond the range of BWR operating conditions and were not considered applicable to BWRs.



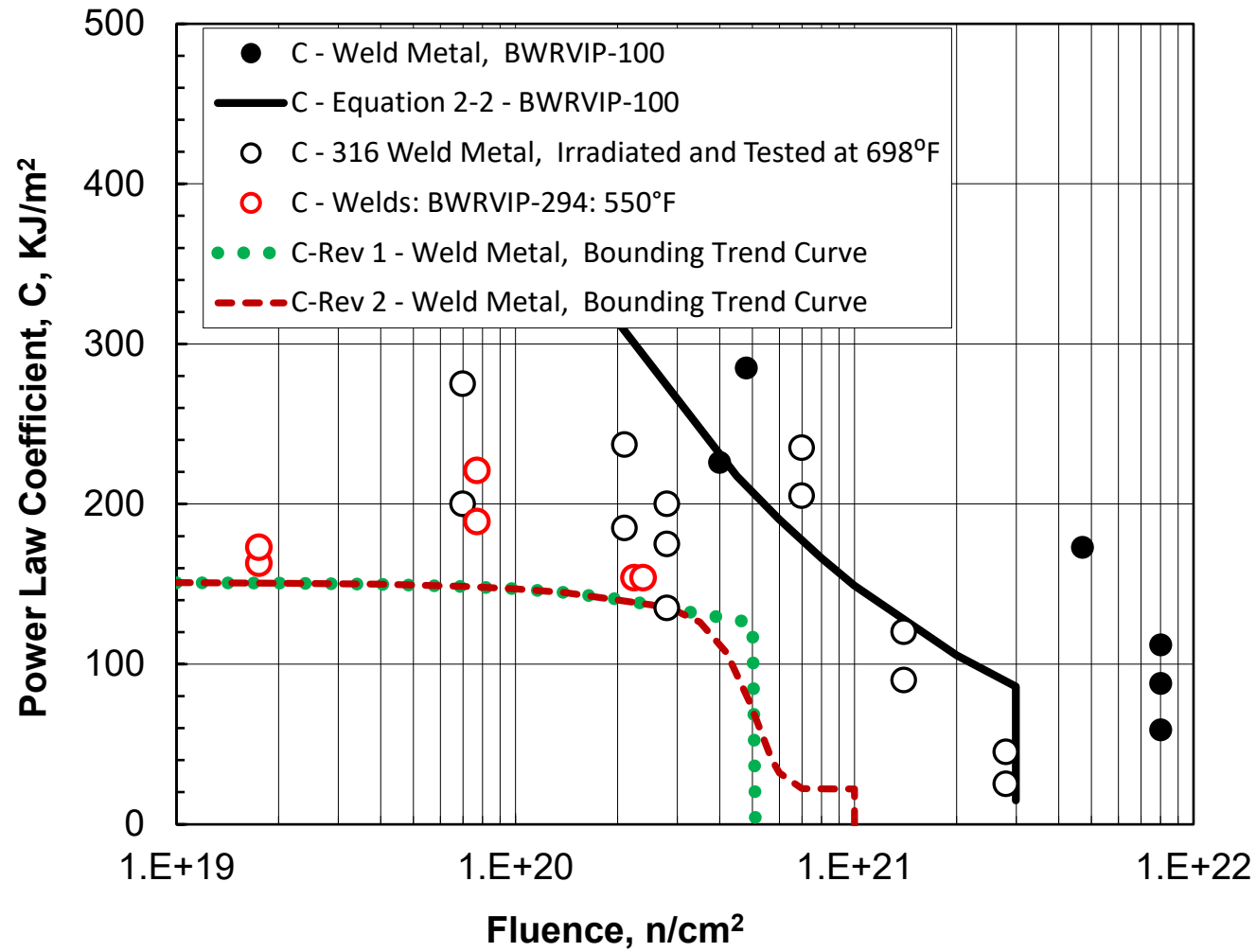
## Further Investigations Regarding Low Toughness Weld Results from Zorita Testing (1 of 2)

- A total of 21 experiments were conducted to develop JR curves for weld metal specimens irradiated in the fluence range from  $1.7E19$  to  $1.1E21$  n/cm<sup>2</sup>. The results from these tests are reported in BWRVIP-294, Rev. 2 and MRP-451.
- Of the 21 specimens, JR curves were developed initially for 6 specimens whose test results were in compliance with ASTM Specification E1820. These specimens were in the fluence range from  $1.7E19$  to  $2.3E19$  n/cm<sup>2</sup>.

## Further Investigations Regarding Low Toughness Weld Results from Zorita Testing (2 of 2)

- The results for the remaining 15 specimens did not meet all the requirements in E1820 because there were too few data points or there were unstable ductile crack extensions during the tests
- A reevaluation of the results for these 15 specimens was performed by Studsvik and Westinghouse in an effort to develop JR curves
- The reevaluation indicated that “reasonable” JR curves could be obtained for 10 or 11 specimens. However, the results from the remaining specimens, which were irradiated at about  $1E21$  n/cm<sup>2</sup>, indicate that JR curves could not be defined at this fluence level, and that LEFM is a conservative approach for determining the load carrying capacity for flaws in welds at fluence  $\geq 1E21$  n/cm<sup>2</sup>.

# Current Assessment of “C” Correlation



# BWRVIP Survey – Utility Actions Regarding Part 21

- BWRVIP issued letter 2021-073, “Request for Responses to 10 CFR Part 21 Survey Regarding BWRVIP-100, Rev. 1-A,” 9/20/2021
  - Objectives were:
    - To understand what specific actions utilities have taken, or are in the process of taking, to address the 10 CFR Part 21 TOI associated with the evaluation of flaws in their BWR core shrouds and other components
    - To gain an understanding of whether additional BWR internals are impacted by the Part 21 TOI
    - To provide direction to BWRVIP tasks that are being undertaken to address the potential non-conservatisms of BWRVIP-100 that resulted in the issuance of the 10 CFR Part 21 TOI

# Summary of Responses

- 31 U.S plants and 1 international plant responded to the survey
- U.S. plants have incorporated the Part 21 into their CAPs
- Issues / actions taken to address the Part 21 can be described as follows:
  - Only one utility reported that their inspection frequency was reduced to 4 years from 10 years
    - EPRI provided technical assistance in developing flaw solutions to help this plant retain a 10-year interval
  - Additional fluence calculations and flaw evaluations are in process to evaluate existing inspection frequencies and/or maintain a 10-year inspection interval – to be completed in early to mid 2022
  - Additional finite element analysis performed by a vendor, the re-inspection interval of 10 years was re-established
  - Conservative estimates of fluence were used to establish existing inspection frequencies, thus no changes required at this time
  - The NRC placed a condition on one utility that the core shroud reinspection interval must be shortened. The utility plans to inspect one outage earlier than initially planned (2-year shortened interval)

# Conclusions

- BWRVIP-100, Rev. 1-A specified the application of LEFM using FT of 50 ksi-Vin for fluence  $\geq 3E21$  n/cm<sup>2</sup>
- Initial evaluation of FT data (post BWRVIP-100, Rev. 1-A) concluded that the FT of 50 ksi-Vin is reached at a fluence of  $5E20$  n/cm<sup>2</sup> as opposed to the previously defined limit of  $3E21$  n/cm<sup>2</sup>, resulting in a Part 21 TOI
- In response to the Part 21, EPRI/BWRVIP issued guidance to utilities for updating flaw evaluations and associated inspection intervals where necessary
  - The SMA demonstrated that the structural margin to unstable crack extension of at least 1.0 exists for flaws in irradiated BWR internals components in the operating fleet
- Preliminary evaluation (considering the revised test results from Studsvik and Westinghouse) indicate that the fluence limit can be increased to  $1E21$  n/cm<sup>2</sup> while continuing to maintain a FT of 50 ksi-Vin
- Various plant-specific flaw evaluations have been performed to confirm structural margins and/or revise inspection frequencies accordingly
- Update of BWRVIP-100 expected by end of 2022



A blue-tinted photograph of four people, two men and two women, standing together. They are wearing white lab coats or work shirts, some with the EPRI logo. The man on the far right is wearing a hard hat. They appear to be in a professional or industrial setting.

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