USE OF PFM IN IMPLEMENTING ALTERNATIVE INSPECTION AND FLAW EVALUATION REQUIREMENTS FOR CASS PIPING COMPONENTS

NUCLEAR

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CASS-Specific Challenges and Approach

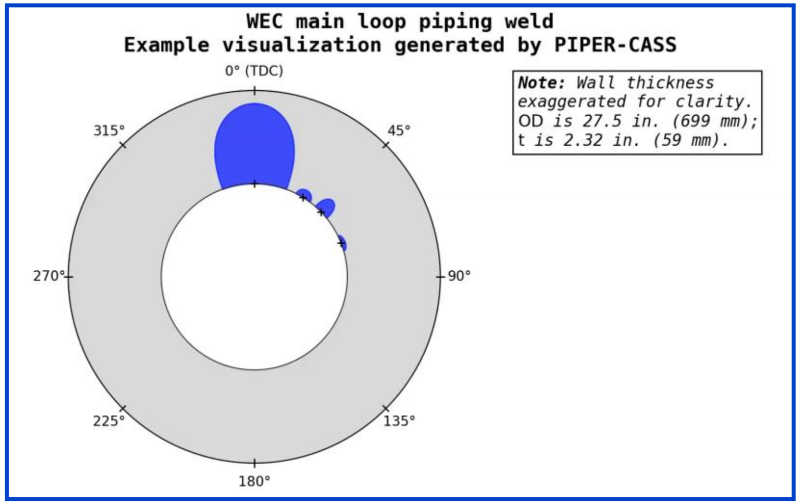
Background

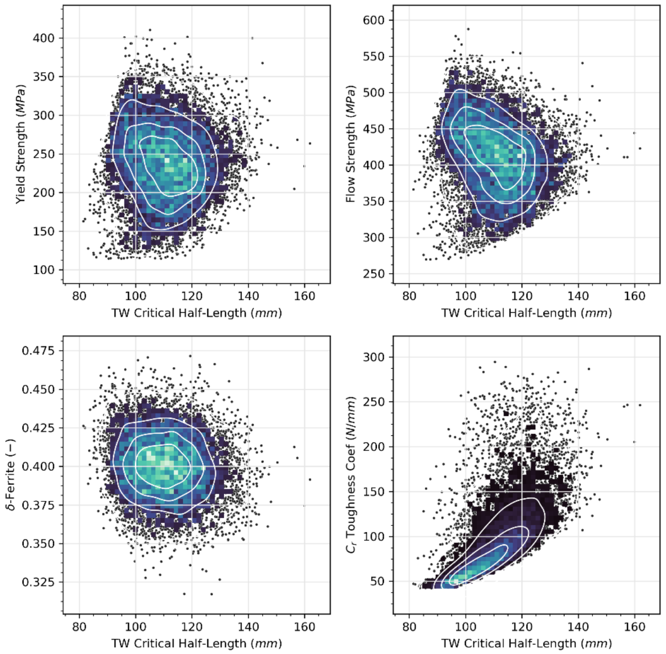
- Because of the heterogenous cast austenitic stainless steel (CASS) material microstructure, ultrasonic testing (UT) technology applied to CASS components is not capable of meeting the PDI qualification standards that have been developed for other piping materials, particularly with regards to:
  - Detection of axial flaws
  - Depth-sizing of circumferential flaws
- Different PFM approaches are applied to resolve each challenge
  - Results of the PFM analyses are documented in EPRI report 3002023893 (MRP-479)
  - MRP-479 provides the technical basis for the development of new ASME Code Cases (ASME Records 23-2033 and 24-1062)

PIPER-CASS

Piping Integrity Probabilistic Evaluation for Reactors – Cast Austenitic Stainless Steel

- Developed PFM code tailored for evaluation of CASS
  - Enhanced EPFM stability solver for degraded toughness materials like thermally aged CASS
  - Extension of EPFM stability checks to part-through-wall flaws
  - Greater flexibility when defining operating transients, with integrated thermal stress solver
  - Relationships included to reflect nature of variability in CASS material properties, including additional correlation parameters
- Reasonable runtimes for matrix of cases at 10^6 or 10^7 realizations achieved using multiprocessing and batch execution
- Automatic visualizations and plain-text diagnostic/error messages
- Unified, text-based code structure facilitates version control and static code reviews
- Successfully benchmarked versus xLPR





For details see 4th ISPMNA CD-03

Inspection without Crediting Axial Flaw Detection (ASME Record 23-2033)

PFM Approach

- **Objective:** Investigate axial fatigue cracking assuming no benefit of periodic NDE nor online leak detection
  - Assess whether inspections to detect axial cracking are necessary to maintain structural and leak tight integrity
- Fatigue crack growth for 80 years is modeled using probabilistic fracture mechanics (PFM) to bound the concerns for both fatigue crack initiation and manufacturing flaws
  - Custom PFM code (PIPER-CASS) shares many of the same models as xLPR, but is tailored for evaluation of CASS (e.g., added part-depth flaw EPFM stability solvers)

MRP-479 Conclusions: Axial Cracking

- **PFM modeling results show that periodic examination to detect axially oriented flaws is unnecessary to ensure pipe structural and leak tight integrity for the following cases:**
  - WEC main loop piping in both base load PWRs and PWRs operating under flexible power operation (FPO)
  - CE surge lines in base load PWRs
- For WEC main loop piping:
  - The analyses show a benefit for significantly reduced fatigue crack growth when the power ramp rate is limited to less than 0.5% per minute for routine loading and unloading operation
- For CE surge lines:
  - The analyses show a benefit for significantly reduced fatigue crack growth when insurge and outsurge events are reduced in frequency
  - Under FPO, there is an increased concern for fatigue crack growth due to the potential for a large number of insurge/outsurge transients to be triggered by FPO power shifts

Periodic examination to detect axially oriented flaws is unnecessary

Overview of Record 23-2033

- Provides alternative inspection requirements that do not require examinations to detect axial cracking in CASS piping components at circumferential butt welds in the main loop and surge line
  - The Code Case applies to axial flaws in PWSCC-resistant weld material if the beam would need to pass through CASS to examine that volume
  - Examinations still required to be demonstrated to detect axial flaws in PWSCC-susceptible or ferritic material and to detect circumferential flaws
- Scope includes PWR piping and vessel nozzle butt welds with CASS base materials
  - Does not apply to AP-1000 SG to RCP nozzle-to-nozzle weld

Group	Presentation	Ballot Status
TG-I	May Code Week	Comments addressed
WG PQVE, WG ISC, WG PFE	August Code Week	Out for ballot in September
SG NDE, SG WCS	November Code Week	Prior to February
BPV XI	February Code Week	TBD

Evaluation of Circumferential Flaws without Crediting Depth Sizing (ASME Record 24-1062)

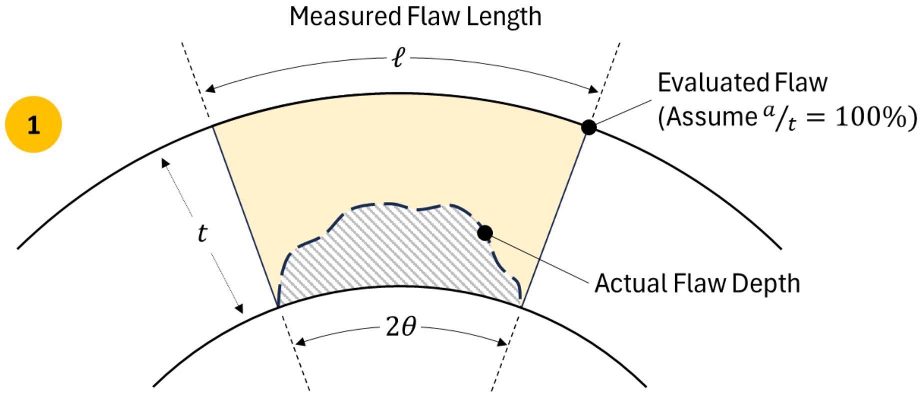
PFM Approach

- **Objective:** Investigate circumferential fatigue cracking assuming periodic NDE without a qualified flaw depth-sizing capability
  - Assess whether an alternative flaw evaluation methodology that assumes the detected flaw is an idealized through-wall flaw results in acceptably low rupture probabilities for lengths up to the limit of applicability
- Custom PIPER-CASS code models fatigue crack growth of a through-wall flaw in main loop piping at a plant under FPO for one fuel cycle (up to 2 years) to assess rupture probability of a flaw accepted for continued service using the proposed methodology

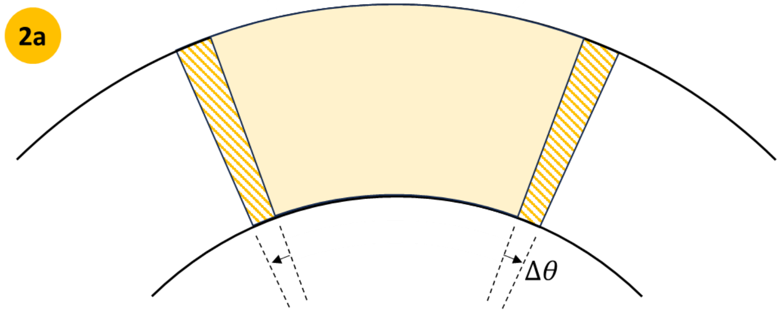
EPRI

Approach: Alternative Flaw Evaluation Methodology

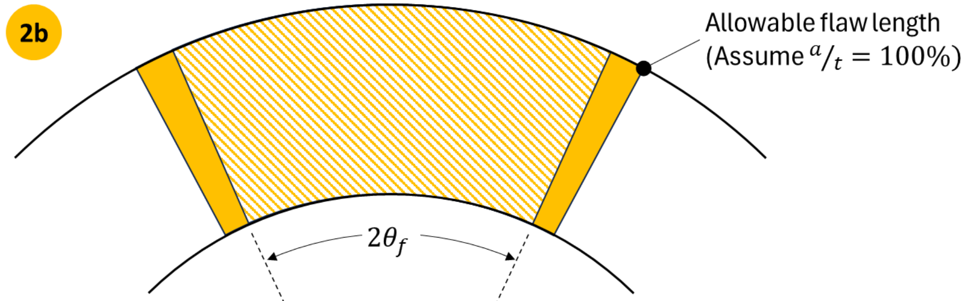
1. Determine length of detected flaw through qualified NDE
2. Perform a Nonmandatory Appendix C flaw evaluation, except modify the procedure to conservatively assume a through-wall flaw (a/t = 100%)
   a. Consider subcritical fatigue crack growth of detected flaw to predict the end-of-evaluation-period flaw length in accordance with IWB-3641(d), conservatively assuming a through-wall flaw
      – Methodology only applies if ending length is less than the limit of applicability, total length (2θ) ≤ 32°
   b. Perform flaw stability check for the assumed though-wall flaw having the end-of-evaluation-period length using the equations specified by C-6320, with:
      – the appropriate Z-factor for the cast alloy and ferrite content of the flawed component, and
      – a/t = 1.0 in C-5320 equations



Characterize the flaw as a circumferential planar through-wall flaw bounding the measured flaw length (per qualified procedure)



Obtain predicted end-of-evaluation-period flaw length ($\theta_f = \theta + \Delta\theta$), with growth per IWB-3641(d) no longer than until the next refueling outage



Calculate allowable flaw angle per C-6320 with appropriate Z-factors and assuming $a/t = 1.0$

Compare allowable flaw angle versus end-of-evaluation-period flaw length to determine acceptability of detected flaw; $2\theta_f$ must also be $\leq 32°$

MRP-479 Conclusions: Circumferential Cracking

- PFM modeling results show that the alternative flaw evaluation methodology that does not rely on depth sizing information ensures pipe structural integrity for one fuel cycle (up to 2 years) of continued operation when applied to circumferential cracking in WEC main loop CASS piping components
  - This methodology does not generically apply to flaws with a full-length (2θ) longer than 32° or to flaws in surge line locations, but a component- or plant-specific analysis may justify its use at these locations
- The assumption of an idealized through-wall crack for both the PFM and modified flaw evaluation methodology addresses the lack of a qualified depth sizing process

Alternative flaw evaluation methodology applies to flaws in main loop piping with total length ≤ 32°

Overview of Record 24-1062

- Proposed Code Case for alternative to IWB-3642 for flaw evaluation requirements for circumferentially oriented flaws in CASS piping components (to address flaw-depth sizing challenge for CASS)
  - Alternative flaw evaluation follows the Nonmandatory Appendix C process, except that a depth (a/t) of 1.0 is assumed
  - Alternative permits acceptance of flaws not demonstrated to have an a/t less than 0.75, but flaws that are visibly leaking remain unacceptable per IWB-3522
- Scope includes PWR main loop piping and vessel nozzle circumferential butt welds with CASS materials
  - Does not include surge line piping or AP-1000 SG to RCP nozzle-to-nozzle weld
- Code Case can be repeatedly applied to continue to defer repairs if the flaw remains acceptable by the alternative evaluation

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TG-I	May Code Week	Comments addressed
WG PQVE, WG PFE	August Code Week	Out for ballot in September
SG NDE, SG ES	November Code Week	Prior to February
BPV XI	February Code Week	TBD

Conclusions

Conclusions

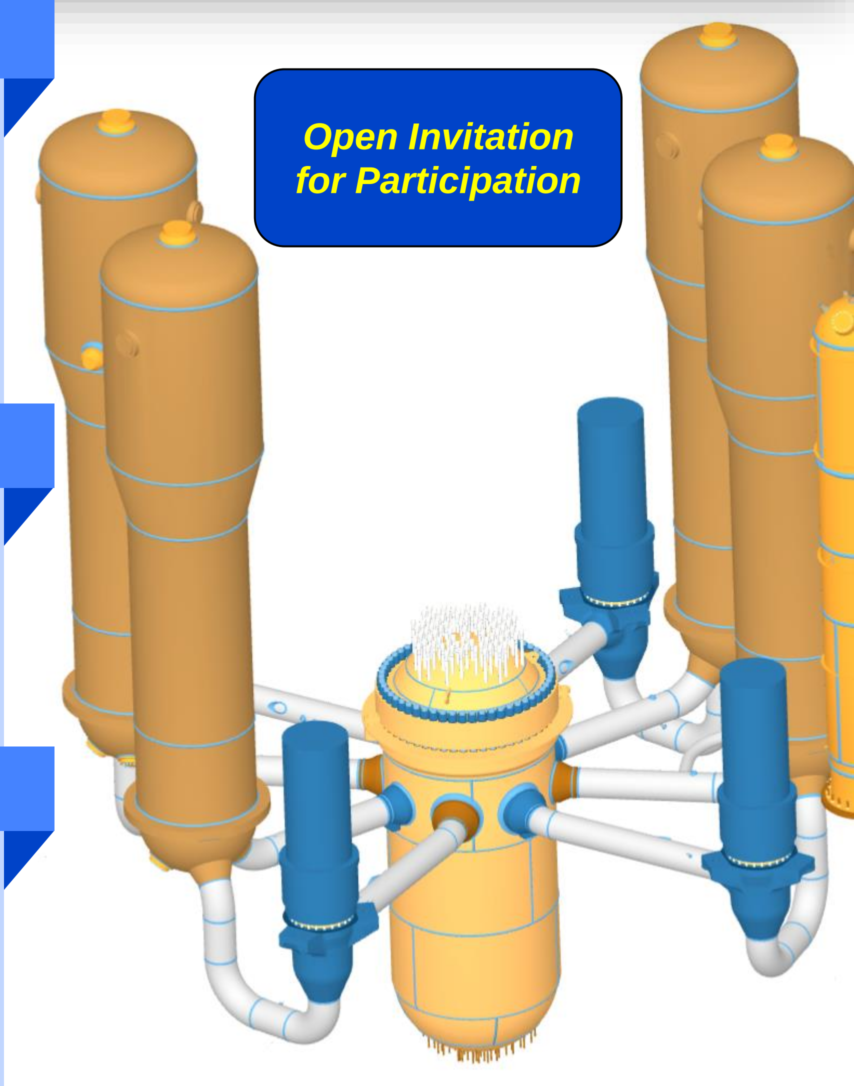
- EPRI is developing new ASME Code Cases to provide alternate requirements for CASS piping
  - ASME Record 23-2033 proposes a Code Case to exclude applicable CASS locations from requirement to detect axially oriented flaws during volumetric examinations
  - ASME Record 24-1062 proposes a Code Case implementing an alternative to IWB-3642 for flaw evaluation of circumferentially oriented flaws without crediting depth sizing capability
  - EPRI report 3002023893 (MRP-479) provides technical basis for both ASME Records 23-2033 and 24-1062
    - Freely downloadable at: https://www.epri.com/research/products/000000003002023893
- The following records are now out for ballot:
  - ASME Record 23-2033 balloted with WG PQVE, WG ISC, and WG PFE
  - ASME Record 24-1062 balloted with WG PQVE and WG PFE

EPRI Benchmark on Cast Austenitic Stainless Steel (CASS) Probabilistic Fracture Mechanics (PFM) Modeling

Objectives

This benchmark study is intended to address the following:

- Understand the effects of modeling differences among CASS PFM codes under a set of controlled problems
- Understand the differences in CASS PFM software design
- Understand the differences in underlying deterministic models used in CASS PFM codes
- Evaluate the importance of key input parameters for CASS PFM codes



Project Overview

Task 1: Survey Response

Task 2: Deterministic Benchmark

Task 3: Probabilistic Benchmark*

Codes without probabilistic capabilities are welcome to participate in Tasks 1 and 2

Contacts

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Questions?

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