EPRI Perspectives on the Use of Probabilistic Fracture Mechanics

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Introduction

- Materials Reliability Program (MRP) and Boiling Water Reactor Vessel and Internals Project (BWRVIP) have managed numerous projects involving probabilistic fracture mechanics (PFM)
- Projects have included efforts to:
  - Support development of new PFM Codes
  - Address emergent issues by using PFM to assess safety significance of the issues
  - Reduce conservatisms for use in ASME Code and NRC regulations

FAVOR Code and the Alternate PTS Rule 10 CFR 50.61a

- Issue – Multiple PWR plants were projected to exceed the pressurized thermal shock (PTS) screening criteria before the end of the license renewal period
- Approach – NRC / Oak Ridge National Laboratory developed the FAVOR Code and performed a risk re-evaluation of PTS events
- EPRI Role – EPRI coordinated industry input to the NRC risk re-evaluation including input to pilot plant analyses, validation and verification (V&V) of uncertainty treatment, industry review of draft reports, etc.
- Results
  - Revised PTS screening criteria published in Alternate PTS Rule, 10 CFR 50.61a. Implemented by one plant to date with others expected in the license renewal and second license renewal (SLR) periods
  - FAVOR Code recognized as an independently vetted tool for reactor vessel (RV) PFM analysis

xLPR (Extremely Low Probability of Rupture)

- Issue – Some weld locations previously approved for Leak-Before-Break (LBB) were later determined to be susceptible to Primary Water Stress Corrosion Cracking (PWSCC)
- Approach – Develop a PFM tool capable of evaluating the PWSCC mechanism along with repair and mitigation activities to demonstrate an extremely low probability of rupture in accordance with General Design Criteria 4.
- EPRI Role – PFM tool is being developed under a joint NRC/EPRI program. EPRI's primary responsibility is in the development of models and inputs and overall coordination of industry input.
- Results – Tool is currently under development

BWR RV Circumferential Weld Inspection Relief

- Issue – Access and interference issues prevent completion of ASME required circumferential weld exams for BWR reactor vessels (RV)
- Approach – A PFM analysis was performed showing an acceptably small risk impact of eliminating inspections of BWR RV circumferential welds
- EPRI Role – BWRVIP funded and managed program
- Result
  - Basis for elimination of BWR RV circumferential weld examination published and approved by NRC (GL 95-05) in report BWRVIP-05
  - Implemented by majority of BWR fleet

Assessment of Postulated Hydrogen Flaking

- Issue – Hydrogen flaking detected in the beltline ring forgings of two international PWRs raised questions regarding the potential safety significance for RVs with beltline forgings in the US
- Approach – Perform a FAVOR PFM analysis postulating a distribution of hydrogen flakes in the most limiting US PWR with beltline ring forgings
- EPRI Role – MRP funded and managed program
- Result
  - Risk of RV failure, even with postulated hydrogen flaking, meets regulatory guidance for acceptable risk.
  - Results published in report MRP-367 and provided to NRC for information

Assessment of Uncertainty in Estimated Initial Fracture Toughness of RPV Steels

- Issue – Some NUREG-0800 BTP 5-3 methods used to estimate initial fracture toughness properties of RV steels for older plants recently identified as being potentially non-conservative
- Approach – Quantify the uncertainty in the estimation methods and use FAVOR PFM to evaluate the risk impact
- EPRI Role – Joint MRP/BWRVIP program
- Results
  - PFM results indicate that uncertainty in initial fracture toughness has a negligible impact on vessel failure risk; negligible safety benefit to updating plant operating limits to account for uncertainty in initial fracture toughness properties
  - Results published in report MRP-401/BWRVIP-287 and provided to NRC for information

Risk-Informed Appendix G

- Issue – Plant operating limits, as determined by ASME Appendix G, are overly restrictive for some plants and challenge other operational and personnel limits
- Approach – Use FAVOR PFM to develop a revised methodology for determining plant pressure-temperature (P-T) limit curves that still allow NRC risk guidelines to be met
- EPRI Role – Jointly funded by MRP and BWRVIP. Coordinated with appropriate ASME Code committees.
- Result
  - Risk-informed Appendix G alternative approved by ASME
  - NRC has not approved use of risk-informed alternative due to their position that a different set of flaw assumptions should be used in the analysis
    - NRC flaw assumptions provide more conservative results
    - Additional effort initiated by EPRI/industry to address NRC flaw assumptions

Observations

- Vetting of models, inputs, and assumptions is critical to obtaining confidence and acceptance of results
- Small “enhancements” or “fixes” to PFM Codes can have large impacts on results and conclusions and therefore V&V is essential
- Due to complicated model interactions, small changes to inputs can sometimes have larger than expected or counter-intuitive results
  - Sensitivity studies are important to fully ensure that results are being interpreted correctly
- Simplistic models allow increased confidence but also provide more conservative results

Conclusions

- PFM is a powerful tool for addressing:
  - Complex issues associated with multiple degradation mechanisms, failure modes, and mitigating factors related to the RPV and piping
  - Cases where analysis by conventional deterministic methods can result in overly conservative results
- PFM provides a framework for assessing the significance of emergent issues and communicating that significance to the NRC
- Application of PFM has allowed for appropriate allocation of industry resources to address safety significant and higher importance issues

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