PWSCC Stress Analyses Projects

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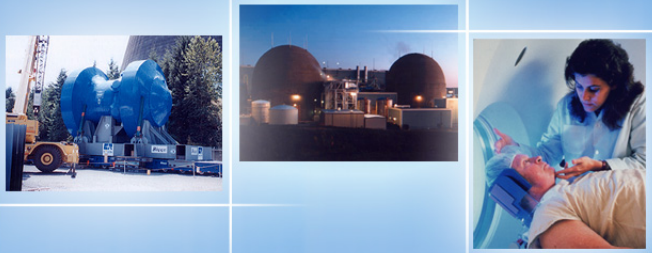
PWSCC Programs

- RES is conducting confirmatory research in response to two high priority user need requests from NRR focused on PWSCC.
- Research needs include developing the technical bases for the regulatory requirements addressing PWSCC in:
  - Leak-Before-Break (LBB) systems
  - Susceptible Ni-base primary pressure boundary components.
- In response, RES developed a research plan to address these needs through various programs at:
  - Pacific Northwest National Lab (PNNL)
  - Engineering Mechanics Corporation (EMC^2)
  - Battelle Memorial Institute (BMI).



PWSCC in LBB Systems

- Develop a strategy to manage PWSCC in LBB piping:
  - Quantify the impact of PWSCC on LBB systems by assessing the susceptibility of primary pressure boundary butt welds to degradation, leakage, and rupture due to PWSCC.
  - Quantify the changes in operational risk that PWSCC susceptibility creates for acceptability of the LBB criteria as found in Appendix A of General Design Criterion-4 (GDC-4).
  - Evaluate industry proposed PWSCC mitigation methods
  - Provide ISI recommendations for proposed mitigation methods
  - Develop criteria for NRR’s assessment of approved and future LBB applications.
- PRO-LOCA code development is key to this effort.



Task 1: Management by Inspection or Monitoring

- Determine if current inspections are adequate to ensure the probability of rupture is extremely low:
  - Describe the range of dissimilar metal butt weld configurations encompassed by NRR-approved LBB applications.
  - Describe specific weld aspects with limited inspectability.
  - Evaluate available information on NDE reliability to detect PWSCC flaws for the range of dissimilar metal butt welds configurations among NRR-approved LBB applications.
  - Assess inspection intervals and the need for mitigation to demonstrate that the probability of rupture is extremely low.
- Deliverable – 7 months after project initiation.



Task 2: Mitigation by Stress Improvement (SI)

- Evaluate residual stresses due to an SI process to assess the behavior of undetected flaws:
  - V&V of BMI and EMC^2's FEA models to benchmark their results to actually measured residual stress distributions.
  - Evaluate commercially available SI processes that could be used for primary coolant piping welds.
  - Provide a summary of issues that NRR should consider in connection with industry SI proposals.
  - Evaluate the likely residual stress and operating stress profiles remaining after SI, for typical dissimilar metal weld configurations approved for LBB applications.
  - Evaluate the behavior of flaws that may go unidentified by NDE with FEA results and proposed crack growth rates.

Task 2: Mitigation by Stress Improvement (SI)

- Evaluate residual stresses due to SI to assess the behavior of undetected flaws (continued):
  - Assess challenges for subsequent NDE on post-SI inspections
  - Assess post-SI short- and long-term inspection strategies to detect potential flaws not confined to post-SI compressive stress regimes
  - Assist NRR in reviewing and codifying industry-proposed welding and inspection criteria for SI processes.
- Deliverable – 12 months after project initiation.



Task 3: Mitigation by Environmental Modification

- Stay informed of industry studies related to mitigating PWSCC through modification of the chemical environment (water chemistry):
  - Summarize existing applicable studies.
  - Evaluate the effectiveness of the proposed environmental modification strategies.
  - Assist in the regulatory review of the industry’s environmental modification proposal.
- Deliverables – 3-12 months after project initiation.

Task 4: Mitigation by Material Replacement

- Develop criteria for evaluating the effectiveness of PWSCC-resistant weld overlays and inspectability of these modified configurations by evaluating:
  – Effects of weld overlays on through-wall stresses.
  – Weldability issues for overlays (including 52M and 52MS)
  – Future inspectability, including changes in access, surface condition, proposed changes in inspection volume, penetration through multiple layers (weld and base metal), and the effects of these considerations on NDE reliability
  – Flaw behavior (including depths and sizes) that are likely to remain undetected after NDE (derived from stress analysis results and best guidance on crack growth rates).
- Deliverables – 10-16 months after project initiation.



Task 5: Long-Term Strategy to Manage PWSCC

- Develop a long-term strategy to manage PWSCC and develop a position regarding appropriate approaches to ensure that GDC-4 will be met:
  - Identify methodologies involving inspection and mitigation that will be needed to ensure that the probability of fluid system piping rupture is extremely low.
  - Summary of the technical bases for the NRC position.
- Deliverable –16 months after project initiation.



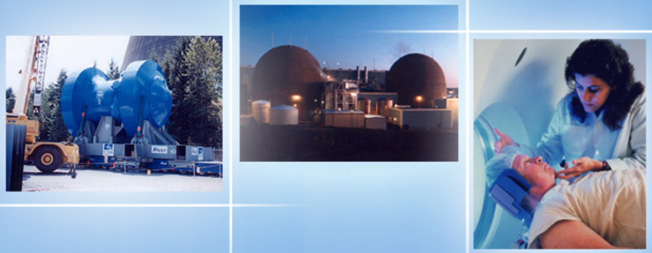
MERIT Project: PRO-LOCA Development

- MERIT: International Cooperative Program to Maximize Enhancements in Risk Informed Technology
- Purpose:
  - To enhance risk informed tools used by the NRC to support regulatory decision making by developing a probabilistic loss of coolant accident code (PRO-LOCA) for predicting the leakage and fracture probabilities in thin-walled components that may contain potential crack-like defects.
  - To fulfill the RES commitment to the Commission to revisit the LOCA redefinition on a 10-year basis; through the development and validation of tools, which were not available for the recent expert elicitation.



MERIT Project: PRO-LOCA Development

- PRO-LOCA Background:
  - Modular PFM code with a GUI interface
  - Initially proposed to risk inform the design-basis break size and ECCS requirements in 10 CFR 50.46
  - Currently augmented to address the effects of degradation mechanisms like PWSCC in thin-walled components
  - Potential future uses for PRO-LOCA are to:
    - facilitate reviews of LBB applications, i.e. ensure proposed mitigation methods keep the probability of rupture extremely low
    - to risk inform proposed ISI intervals
  - MERIT TAG prioritized consensus PRO-LOCA developments.
  - PWSCC projects fund NRC-specific PRO-LOCA developments.



MERIT Project: PRO-LOCA Development

- PRO-LOCA current and future improvements:
  - Added library of weld residual stress solutions for small, medium, and large diameter stainless and dissimilar metal welds, i.e. hot leg, surge nozzle, and spray nozzle
  - Incorporate PWSCC initiation statistics and growth model
  - Address discrepancy in crack growth (length vs. depth)
  - Stress distribution model to account for stress variations around circumference
  - New flaw distributions (pre-existing flaws)
  - DMW residual stress distributions
  - Adjust IGSCC model to account for HWC
  - Retain capability to adjust PWSCC model to account for potential PWR water chemistry modifications.



MERIT Project: PRO-LOCA Development

- PRO-LOCA current and future improvements:
  - I/O improvements: GUI interface
  - Improve modularity
  - Debugging, testing, and benchmarking
    - Sensitivity studies to investigate different variables
    - Validate PRO-LOCA with service experiences
    - Benchmark PRO-LOCA against other PFM codes
    - Round robin analyses
      - Weld residual stress analyses
      - PFM analyses

Review of PFM Models

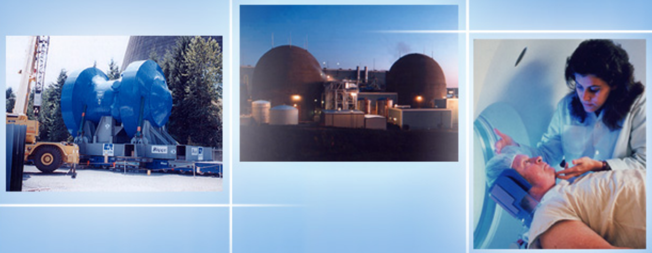
Code	Developer	Mechanisms	Failure probabilities	Notes
PROST	GRS	F	L, R	Preexisting defects
PRODIGAL	Rolls Royce	F	L, R	Preexisting defects
PROSACC	DNV	F, I	L,R	In plates
STRUREL	Germany	F, I	R	No predefined initiation growth or failure criteria
SRRA	Westinghouse	F, I	L,R	Known limitations, MRP116 (WCAP-14572 Rev 1 Sup 1) suggests Praise for better analyses per (2004)
NURBIT	DNV	I	L,R	2000
PRAISE	Engineering Mechanics Technology	F, I	L, R	1980s – updated continuously
PRO-LOCA	Battelle/Emc^2	F, I, P	L, R	2004-5 (Beta only)

F = fatigue, I = IGSCC, P = PWSCC, L = leak, R = Rupture



Review of PFM Models

Item	NURBIT	PRAISE	PRO-LOCA
Years in development	5	25	1-2
PWSCC	No	No*	Yes
SCC Crack initiation	No	Yes (questionable)	Yes – Statistical based – very conservative
Multiple crack initiation	No	later slide	Yes
Crack initiation biasing	No	No	Yes
Surface crack K	Unique K solutions	Elliptical – RMS - Harris	Elliptical - Anderson
Surface crack growth	Driven by unique K	Length and depth by K_{RMS}	Length and depth by K
Crack interaction	No	ASME	ASME



Review of PFM Models

Item	NURBIT	PRAISE	PRO-LOCA
Variable SCC crack growth?	No	Yes	Yes
SC stability	R6	Limit load/T_{mat}	SC.TNP/DPZP
TWC stability	R6	Limit load/T_{mat}	LBB.ENG2/DPZP
Leak rate/CMOD	SQUIRT (old Version)	Simple model	SQUIRT
Bimetal WRS?	No	No	Yes
Probabilistic method	FORM/SORM	MC	MC
Importance sampling	N/A	Yes	Planned
Material Library?	No	No	Yes
Modular code?	No	No	Yes
Analyze past and future behavior?	No	No	Yes

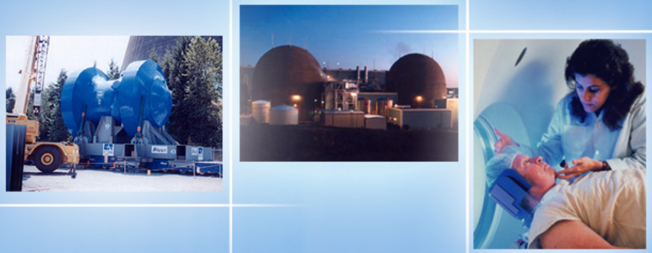
MERIT Project: PRO-LOCA Development

- Current Status:
  - Established priorities at the 02/06 TAG kick-off meeting
  - Battelle/EMC^2 addressing technical priorities
  - Current membership
    - U.S. NRC
    - SKI in Sweden
    - Rolls Royce in UK
    - Consortium of interests from South Korea
    - Consortium of interest from Canada
  - Each member yields over $1.5M of research value from a $300K investment.



PWSCC in LBB Systems Project Schedule

- PWSCC evaluations for LBB piping systems have varying deliverable dates ranging from 3 to 16 months from project initiation, e.g. < March 2008.
- EPRI’s PWR water chemistry guidelines ~2008.
- Current LBB guidelines require two mitigation strategies, e.g. water chemistry, SI, and/or material replacement (weld overlay).
- MERIT has a projected end date of August 2009.
- PRO-LOCA will be continuously updated.



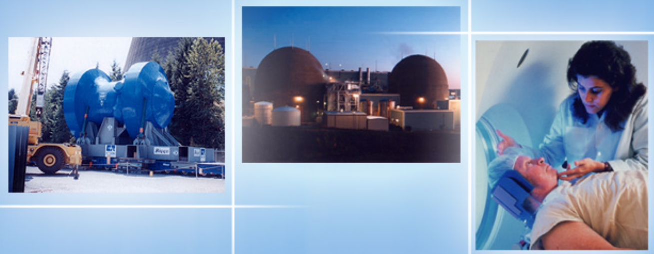
Integrity of Reactor Systems and Components

- Purpose:
  - Assess cracking in CRDM nozzles that were not predicted to experience cracking for at least 15 more years by evaluating crack-driving forces (weld residual stresses) and crack growth rates which are not given in the new ASME Code cases.
- Background:
  - Phase I – CRDM Cracking – This project was developed to take an initial look at the drivers for PWSCC in CRDM nozzles and develop an initial probabilistic code for determining the probability of ejection for CRDM tubes.
  - Phase II - Alloy 600 Cracking project was developed to continue the determination of the welding residual stress (WRS) and stress intensity solutions for cracking in CRDM nozzles and to support a NRR User Need Request (UNR) in identifying the regulatory requirements to address PWSCC of susceptible nickel-base alloy primary pressure-boundary components.



Integrity of Reactor Systems and Components: Task 1

- UNR: Review work on stress analysis for RPVH penetration nozzles for various nozzle angles and determine at what distance above the root of the J-groove weld and what distance below the toe of the J-groove weld that hoop stresses drop to 20ksi.
- Ensure appropriate stress analyses are being used to determine current inspection requirements and modify inspection requirements as appropriate.



Integrity of Reactor Systems and Components: Task 2

- Complete research work on effects of flaws in weld materials for Alloy 182/82 and continue work on the material property effects of flaws in Alloy 152/52/52M. Use current field data of similar numbers of construction related indications found in new RPVH partial penetration welds. Include an ASME Code Section III stress limit analysis to determine acceptable levels of construction related indications in new RPVH partial penetration welds for 60-year new RPVH lifetimes.
- Validate structural integrity of current and replacement RPVHs which have identified significant numbers of indications in partial penetration welds.



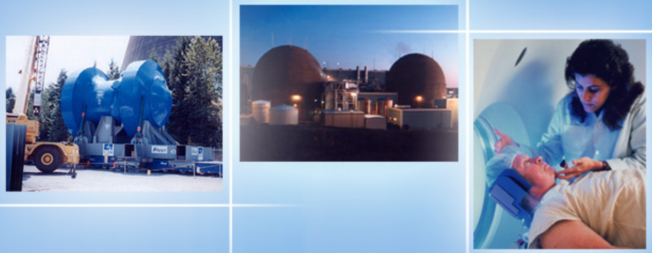
Integrity of Reactor Systems and Components: Task 3

- Continue ongoing analysis of the “complex model” of circumferential crack growth. Include in the analysis an application of conditions and stresses outlined by MRP-95 Rev. 1 for circumferential crack growth. Due to the possible controversy of these results, continue to compare and contrast analysis results to MRP work in this area, including base assumptions, computer codes used, and operational experience supporting results.
- Determine adequacy of current circumferential crack growth models, safety significance of complex circumferential crack growth, and adequacy of licensee flaw evaluations.



Integrity of Reactor Systems and Components: Task 4

- Simulate the effects of a 3-layer weld overlay on the OD of the improved stress analysis for RPVH Penetration Nozzles. Determine the effective change on stresses on the inside diameter of the penetration nozzle and on the OD above the weld.
- Ensure weld overlay repair process does not increase RPVH penetration nozzle susceptibility to PWSCC over the lifetime of the repair.

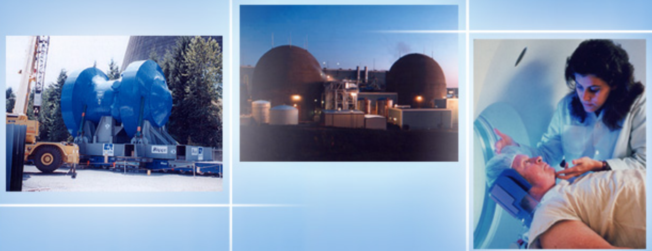


Integrity of Reactor Systems and Components: Task 5

- Continue probabilistic analysis work to assess the risk of failure and leakage caused by PWSCC of nickel-base alloys in reactor pressure boundary components.
- Compare and contrast the work with the information provided in MRP-105 and MRP-116. As with Task 3e, due to the possible controversy of these results, continue to compare and contrast analysis to MRP work in these areas, including base assumptions, computer codes used, and operational experience.

Integrity of Reactor Systems and Components

- Task 1: Determination of the distance from the CRDM J-groove weld where hoop stresses is below 20 ksi.
  - Inspect all Emc^2 CRDM analyses to develop area <20ksi
  - Compare to Industry and ASME Code Case inspection criteria
- Task 4: Determine effects of 3-layer weld overlay on CRDM J-weld
  - WRS analyses with A182/82 and A152/52 weld overlay
    - Using existing geometry and WRS analyses for J-weld
    - Including J-weld fillet geometry
  - Determine changes in residual stress with inclusion of overlay
  - Does this process change the 20 ksi area?
- Task 5: Continued development of probabilistic code for tube ejection
  - Include most recent K solutions
  - Compare results to MRP



Integrity of Reactor Systems and Components

- Task 2: Continue to develop effects of weld flaws in A182/82 and also A152/52
  - Conduct literature search and compare results for A152/52 and A182/82 data:
    - NRC In182/82 weld data developed from full solution-annealed weld, and at numerous temperatures at a strain rate simulating rates during weld solidification process ($\sim 10^{-3}$).
    - Fully annealed weld metal stress-strain curves at various temperatures are needed for WRS. Cold-work in weld determined by modeling each weld pass in the sequence the weld is made.
  - Conduct material property tests in A152/52 if needed
    - Tensile tests as a function of temperature on fully-annealed A152/52
  - Conduct WRS analyses and determine stress intensity solutions using these proper material properties



Integrity of Reactor Systems and Components

- Task 3: Develop model for complex circumferential crack growth – CRDM and pipe bimetallic butt welds
  - Mesh generator
  - Conduct analyses for complex crack growth in CRDM tubes/butt welds
    - Faster crack growth in length direction could be from small initiation sites close to end of initial surface crack linking with main crack, i.e., using laboratory crack growth rates would underestimate growth in length.
  - Compare and contrast results from MRP



Areas for Collaboration

- Need MRP reports to evaluate proposed industry PWSCC mitigation methods, guidelines
  - MRP-111
  - MRP-114
  - MRP-121
  - MRP-126
  - MRP-140
  - MRP-105
  - MRP-113
  - MRP-116
  - MRP-122
  - MRP-139
  - MRP-169
- Review EPRI’s V&V and benchmarking reports for various FEA models used to evaluate conventional and DMW residual stress distributions.



Areas for Collaboration

- Identify and propose representative DMW and weld overlay geometries.
- Participate at EPRI's PWSCC expert panel in April.
- Participate in an expert panel to develop a consensus best approach to handle PWSCC crack initiation/growth in PRO-LOCA (MERIT task):
  - How to address multiple crack initiation sites?
  - How to address the perceived discrepancy in crack growth in the length versus depth direction?
- Review/compare with service experience.



Areas for Collaboration

- PRO-LOCA V&V.
- Review/compare PRO-LOCA results to operating plant service experiences.
- PRO-LOCA benchmarking to other PFM codes.
- PRO-LOCA sensitivity analyses.