Overview of Component Integrity Research Activities

Industry/NRC Materials Programs Technical Information Exchange

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Component Integrity Branch
Division of Engineering
Office of Nuclear Regulatory Research

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Research Areas

- Points of Contact
  - Raj Iyengar, Branch Chief, Component Integrity Branch
  - Robert Tregoning, Senior Level Advisor

- Research Areas
  - Reactor Pressure Vessel Integrity – Mark Kirk
  - Piping Integrity - Patrick Raynaud/Sara Lyons
  - Probabilistic Fracture Mechanics – Patrick Raynaud/Matt Homiack
  - Nondestructive Examination – Carol Nove
  - Advanced Non-light Water Reactors (ANLWR) – Raj Iyengar/Matt Gordon/Sara Lyons
  - ASME Section XI Coordination & 50.55a Regulatory Guide Rulemaking – Michael Benson/Bruce Lin

RPV Integrity

- Overview
  - Objective:
    - Confirm the continued operating integrity of the RPV (including the SLR period)
    - Assess the accuracy of formulae that predict future embrittlement states for vessel materials
  - Driver: User need from NRR; Assistance request from NRO; RAR from NRR for training; Support of RGGIB in periodic RG reviews (e.g., RG 1.99)
  - Collaboration: JAEA, JNRA
- Ongoing activities
  - RPV Embrittlement
    - Assessment of shallow flaw effects on RPV integrity
    - Prediction of fluence beyond the belt-line
    - REAP maintenance and addition of new surveillance data
  - Codes & Standards: ASME Section XI; ASTM
  - Finalization of PTS regulatory guide (RG 1.230) and technical basis document (NUREG 2163)

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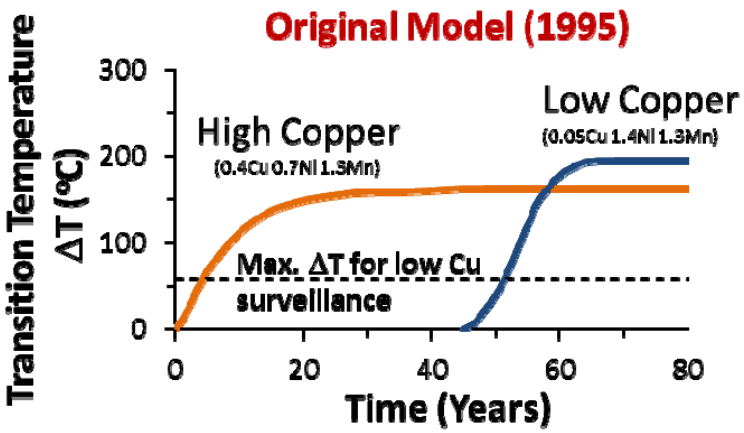
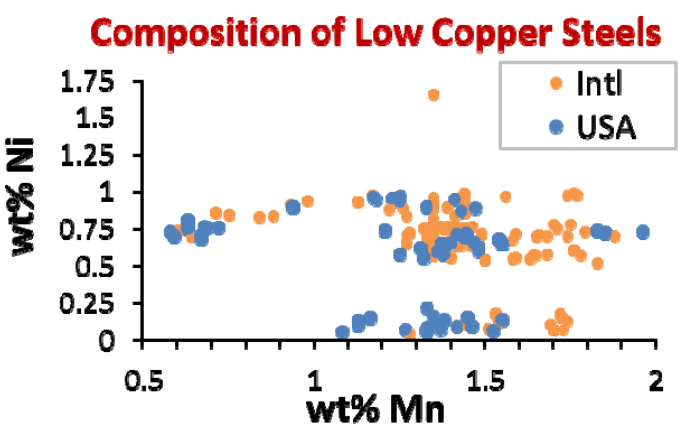
Accomplishment Highlight: Late Blooming Phases





- **<u>Possible Concern</u>**: Possible rapid embrittlement in low-copper steels with high nickel & manganese. Mechanism not accounted for by USNRC predictions.

- **<u>RES Review</u>**: Comprehensive literature review & surveillance data assessment demonstrate LBPs are *not* of concern for US RPVs.
  - Level of Ni > 1% postulated for LBP occurrence
  - Steel alloys / conditions of possible concern largely absent from USA fleet
  - Evidence of delayed accelerated embrittlement is lacking

- **<u>Current Status</u>**: Ongoing research (DOE, intl.) to better understand LBPs. New data suggests no "sudden" late embrittlement and much smaller ΔT values for USA steels.

RPV Integrity Accomplishments and Path Forward

- Accomplishments
  - TLR on RPV fluence evaluation methodology for beyond the active core region
  - Independent review of NuScale Power Pressure and Temperature Limits (PTL) Methodology report for NRO

- Path Forward
  - Support NRO for NuScale application review
  - Continue codes and standards support (ASTM E10; ASME CC N830 revision)

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Piping Integrity

- Overview
  - Objective: Develop/Enhance analytical methods and tools to assess structural integrity of reactor piping systems
  - Driver: NRR User Need Request
  - Collaboration: EPRI, NEA/CSNI

- Ongoing activities
  - Development of modeling guidelines for assessment of weld residual stress (WRS) effects in assessment of component integrity
  - Assessment of research and industry experience in peening of reactor components
  - Participation in ASME Boiler and Pressure Vessel Code, Section XI
  - Coordination of ASME BPV Code Case Regulatory Guides to incorporate by reference into 10 CFR 50.55a
  - Evaluation of Extended Finite Element Method (xFEM) for applicability in crack growth (PWSCC) analyses

Ongoing Activity:
Applying xFEM Techniques to PWSCC Growth

- Application of Extended Finite Element Method (xFEM) to predict PWSCC crack growth in 3D component geometries.
- Conventional FEM:
  - Uses idealized crack shape and growth model (semi-elliptical)
  - Assumes planar (2D) crack growth
  - Uses 2D WRS profile for crack growth which is path dependent and user defined
- xFEM:
  - Mesh-independent analysis of flaws
  - SIF calculation of multiple cracks shapes without major changes to model
  - 3D crack growth without re-meshing
- Participation in international effort on benchmarking of xFEM capabilities. (OECD-CSNI)

Piping Integrity Accomplishments and Path Forward

- Accomplishments
  - Draft NUREG on WRS validation
  - Section XI Standards Committee and Executive Committee participation
  - Issued draft Regulatory Guides for ASME Code Cases, 2009-2013 and 2015 editions to incorporate by reference into 10 CFR 50.55a
- Path Forward
  - Issue final reports on WRS validation
  - Develop and implement research plan for validation xFEM-A analysis for PWSCC predictions
  - Continue ASME Section XI engagement
  - Prepare draft Regulatory Guides for ASME Code Cases for 2017 Edition of the Boiler and Pressure Vessel Code

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Probabilistic Component Integrity

- Overview
  - Objective: Develop probabilistic methods to ensure structural integrity of piping systems
  - Driver: NRR User Need Request
  - Collaboration: EPRI, JNRA, JAEA, SSM, CNSC

- Ongoing activities
  - Support NRR in the acceptance and application of xLPR v2
  - Development of Probabilistic Fracture Mechanics Regulatory Guide
  - Continue effort on V&V of FAVOR code, maintenance, applications, development, and modernization

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Probabilistic Component Integrity Accomplishments and Path Forward

- Accomplishments
  - xLPR verification and validation testing
  - xLPR code theory and hands-on training provided to NRC staff
  - xLPR PWSCC initiation model parameter development, confirmatory analyses, and validation
  - Completed draft report on "Increasing Confidence in PFM Analyses"
  - Initiated work on FAVOR V&V, maintenance, and applications
- Path Forward
  - Support NRR regulatory acceptability review for xLPR
  - Complete efforts to ensure public release of xLPR
  - Initiate studies on leak-before-break applications with xLPR
  - Develop PFM Draft Regulatory Guide, with NUREG technical basis document and PFM pilot studies to test guidance
  - Bring FAVOR up to modern standards, adapt FAVOR to solve evolving reactor pressure vessel issues

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Non-Destructive Examination

- Overview
  - Objective: Evaluate effectiveness and reliability of NDE techniques
  - Driver: NRR User Need Request
  - Collaboration: EPRI, DOE, International

- Ongoing activities
  - Completion of comprehensive summary of NDE research on CASS and assessment of state-of-the-art in inspecting welds in CASS materials
  - Assessment of industry's CASS round robin (rigorous, statistically-based)
  - Provide technical basis for conducting, interpreting, and applying the results of ultrasonic testing (UT) Modeling
  - Assess the effects of incomplete examination coverage
  - Assessment of human factors issues in NDE
  - Support codes & standards activities (ASME – Section XI)
  - Assessment of inspection systems for storage casks

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ANLWR Materials and Component Integrity

- Overview
  - Objective: Assess the performance needs and issues for structural materials to be used in advanced non-LWRs (ANLWRs); Support the development of a regulatory framework for materials-related issues for ANLWRs
  - Driver: NRC Vision and Strategy on ANLWRs
    - Strategy 2: Acquire/develop sufficient computer codes and tools to perform non-LWR regulatory reviews
    - Strategy 4: Facilitate industry codes and standards needed to support the non-LWR life cycle
- Ongoing activities
  - Identification of regulatory gaps for sodium fast reactors and molten salt reactors, building on the past efforts for high-temperature gas reactors
  - Assessment of materials/component integrity issues for molten salt reactors (MSR)
  - Operational experience compendia for materials/component integrity issues for sodium fast reactors (SFR) and high-temperature gas reactors (HTGR)
  - Participation in ASME Codes and Standards Sections III and XI activities

ANLWR Materials Accomplishments

- **Technical gap assessment for materials/component integrity for molten salt reactors - ORNL**
  - Draft report summary:
    - Limited high-temperature creep data at the highest possible core outlet temperatures
    - Limited data on salt purity effects on coolant compatibility and performance
    - Limited data and mechanistic understanding on irradiation degradation effects
- **Operational experience compendia for sodium fast reactors (SFRs) and high-temperature gas reactors (HTGR) - EWC-Commercial**
  - Over 100 OpE sources have been identified and reviewed for SFRs [Phenix, SuperPhenix, FFTF, EBR-II] and HTGRs [Fort St Vrain, Peach Bottom, AVR and THTR-300]
    - Weld design and quality are critical for SFRs
    - Thermal fatigue is much more significant in SFRs than LWRs
    - Design flaws seem to dominate HTGRs, resulting in unexpectedly high temperatures, moisture and oxygen ingress, and "trapped" pebbles
  - Separate bilateral engagements with Office of Nuclear Regulation, UK; IRSN- France; and JAEA and JNRZ – Japan

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ANLWR Materials Accomplishments and Path Forward

- Support knowledge and data enhancement of environmental effects on reactor components (internals, piping, welds, coatings) at high temperatures. (corrosion, radiation effects)
- Develop/Enhance computational codes for component integrity applicable to ANLWRs
- Explore opportunities to obtain information, data, and assessment tools through domestic and international collaboration
- Conduct research activities to develop technical bases to resolve major materials related issues

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