

NRC's Aging and Materials Research Activities

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Nuclear Regulatory Commission

**NRC International Workshop on Age-Related Degradation of
Reactor Vessels and Internals**

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NRC Headquarters Rockville, MD

Materials and Aging Research

- Research Objectives
 - Improve timeliness of regulatory decision-making on the use of new materials, manufacturing technologies, and in-service inspection techniques through independent and confirmatory research
 - Address knowledge gaps related to materials degradation during long-term plant operation to 80 years
 - Inform and enhance the use of risk-information in regulatory decision-making
- Strategic Focus Areas
 - Support resolution of safety significant technical issues
 - **Maintain core capabilities to support emerging technical needs related to corrosion, metallurgy, component integrity assessment, and non-destructive examination**
 - Enhance modeling/analytical tools to support efficient regulatory decision-making
 - Foster collaborations with domestic and international counterparts to stimulate information sharing and cooperative research approaches
- High level summary of activities follows: More information contained in NUREG-1925 (<https://www.nrc.gov/docs/ML1807/ML18071A139.pdf>)

Materials and Aging Research

- Points of Contact
 - Raj Iyengar, Branch Chief, Component Integrity Branch
 - Istvan (Steve) Frankl, Branch Chief, Corrosion & Metallurgy Branch
 - Rob Tregoning, Senior Level Advisor

- Research Areas
 - Environmentally Assisted Degradation
 - Primary Water Stress Corrosion Cracking
 - Irradiated Assisted Stress Corrosion Cracking
 - Steam Generator Tube Integrity
 - Aging Management during Long Term Operation
 - Spent Fuel Dry Storage
 - Neutron Absorber Materials in Spent Fuel Pools
 - Advanced Manufacturing Technologies for Reactor Components
 - Reactor Pressure Vessel Integrity
 - Piping Integrity
 - Probabilistic Component Integrity
 - Nondestructive Examination
 - *Advanced Non-light Water Reactors (ANLWR) Materials*

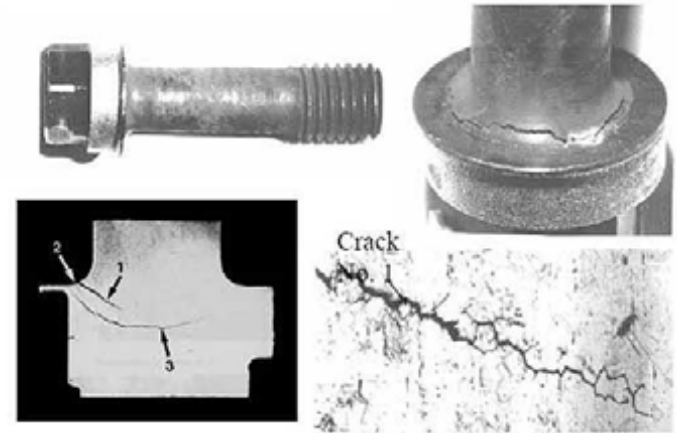
Primary Water Stress Corrosion Cracking (PWSCC)

- Overview
 - **Objective:** Evaluate PWSCC crack initiation and crack growth rate (CGR) susceptibility of nickel-based alloys
 - **Motivation:** Provide assurance of reactor coolant pressure boundary integrity
 - **Regulatory Application:** Support reviews of proposed changes to the inspection requirements in the ASME Code and associated rulemaking
 - **Collaboration:** EPRI
- Recent Accomplishments
 - “Experimental Plan for Primary Water Stress Corrosion Crack Initiation Testing” (ADAMS ML15272A300)
 - NUREG/CR-7226, “Primary Water Stress Corrosion Cracking of High-Chromium, Nickel-Base Welds Near Dissimilar Metal Weld Interfaces” (ML18018A562)
- Next Steps
 - Publish initial report on Alloy 600/182 PWSCC initiation testing (2019)
 - Complete CGR testing of Alloy 690/52/152 (2020)
 - Publish NUREG/CR reports on CGR testing (2020)
 - Complete crack initiation testing of Alloys 600/182 and 690/52/152 (2021 – 2022)



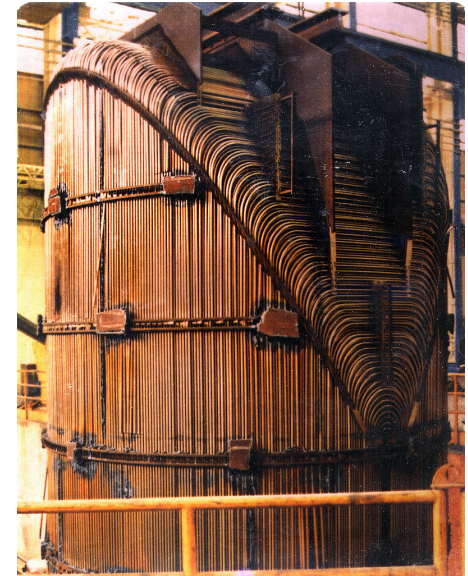
Irradiation-Assisted Stress Corrosion Cracking (IASCC)

- Overview
 - **Objective:** Evaluate IASCC degradation mechanisms during long-term operations (LTO)
 - **Motivation:** Confirm adequacy of reactor internal aging management programs
 - **Regulatory Application:** Support reviews of internals inspection/evaluation guidance, ASME Code changes and associated rulemaking
 - **Collaboration:** EPRI, Halden Reactor Project, International Regulators
- Recent Accomplishments
 - NUREG/CR-6909 Rev. 1, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials” (ML16319A004)
 - NUREG/CR-7185, “Effect of Thermal Aging and Neutron Irradiation on Crack Growth Rate and Fracture Toughness of Cast Stainless Steels and Austenitic Stainless Steel Welds” (ML15202A007)
- Next Steps
 - Complete cooperative research on Zorita reactor internal materials (2019-2020)
 - Complete initial testing of Zorita materials at ANL (2019 – 2020)
 - Identify opportunities for further irradiation or harvesting of reactor internals (2020)



Steam Generator Tube Integrity Program (SG-TIP)

- Overview
 - **Objective:** Assess NDE reliability and associated tube integrity for emerging inspection procedures and plans
 - **Motivation:** Confirm adequacy of industry practices used for in-service inspection
 - **Regulatory Application:** Review acceptability of advanced techniques or implementation plans proposed by industry
 - **Collaboration:** EPRI, CNSC, KINS, KAERI, and IRSN
- Recent Accomplishments
 - NUREG/CR-7217, “Application of Automated Analysis Software to Eddy Current Inspection Data from Steam Generator Tube Bundle Mock-up” (ML16271A090)
 - NUREG/CR-7225, “Stability of Circumferential Flaws in Once-Through Steam Generator Tubes Under Thermal Loading During LOCA, MSLB and FWLB” (ML17324B296)
- Next Steps
 - Complete report summarizing eddy current inspections and pressure testing of U-bend tubes with PWSCC flaws (2019)
 - Complete report on detection of cracking near volumetric indications (2019)
 - Evaluate issues related to eddy current detection and auto-analysis techniques



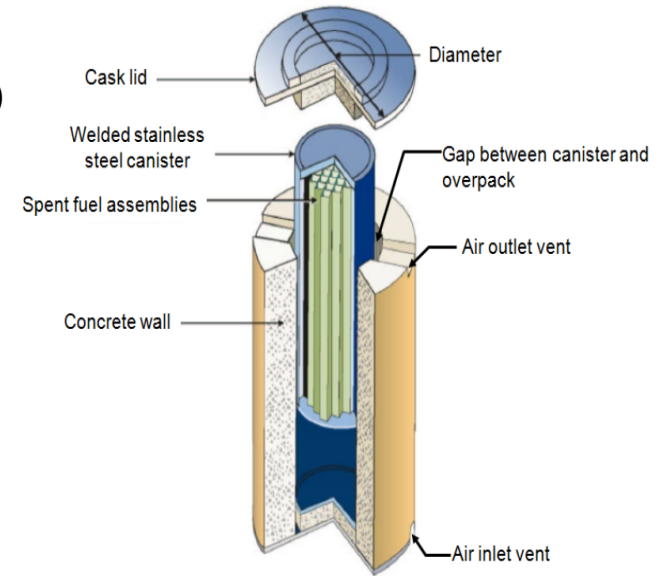
Long-Term Operation (LTO) & Aging Management

- Overview
 - **Objective:** Support guidance development, coordinate related research activities, develop a systematic approach for harvesting materials and components from reactors
 - **Motivation:** Provide assurance that aging effects will be adequately managed during LTO
 - **Regulatory Application:** Refine, as appropriate, existing aging management plans and guidance
 - **Collaboration:** DOE and EPRI
- Recent Accomplishments
 - NUREG-2221, “Technical Bases for Changes in the Subsequent License Renewal Guidance Documents NUREG–2191 and NUREG–2192” (ML17362A126)
 - PNNL-27120 Rev. 1, “Criteria and Planning Guidance for Ex-Plant Harvesting to Support Subsequent License Renewal” (ML19081A006)
- Next Steps
 - Drafting joint roadmap for metals research (RPV, internals, piping) (2019)
 - Considering international workshop to coordinate harvesting activities (2019)
 - Planning international workshops on cables and concrete (2020 – 2021)



Spent Fuel Dry Storage

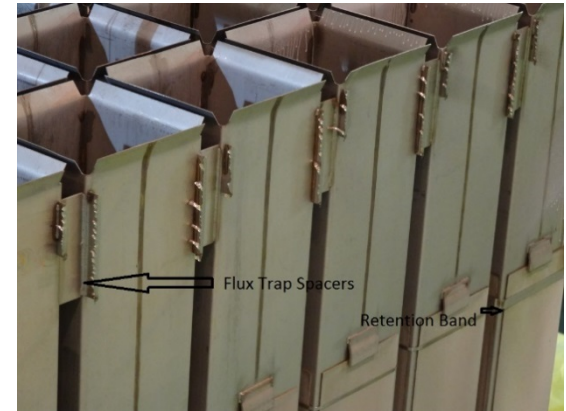
- Overview
 - **Objective:** Assess chloride-induced SCC (CISCC) and adequacy of associated NDE techniques
 - **Motivation:** Provide assurance of dry cask storage systems (DCSSs) integrity during extended storage
 - **Regulatory Application:** Support development of regulatory guidance for aging management of spent fuel DCSSs
 - **Collaboration:** DOE and EPRI
- Recent Accomplishments
 - NUREG/CR-7170, “Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts” (ML14051A417)
 - PNNL-24412 Rev. 1, “Nondestructive Examination Guidance for Dry Storage Casks” (ML16270A535)
- Next Steps
 - Finalize crack growth test plan for CISCC CGR testing planned in cooperation with DOE (2019)
 - Evaluate detection and sizing capability of in-situ NDE methods
 - Support evaluation of implementation of ISI requirements within ASME Code



Neutron Absorber Materials (NAM)

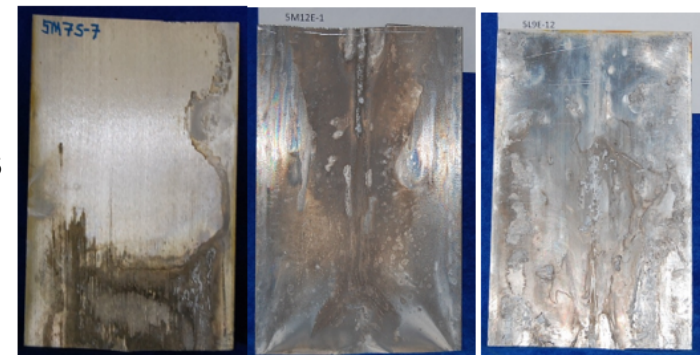
- Overview

- **Objective:** Assess degradation mechanisms and surveillance methods for NAMs utilized for maintaining sub-criticality margins in spent fuel pools
- **Motivation:** Support technical bases for regulatory decisions related to subsequent license renewal (SLR)
- **Regulatory Application:** Support review of criticality safety analyses for SLR applications
- **Collaboration:** EPRI



- Recent Accomplishments

- Completed the evaluation of Boral® NAM panels obtained from the decommissioned Zion SFP.
- SRNL-TR-2018-00244, “Characterization and Analysis of Boral® from the Zion Nuclear Power Plant Spent Fuel Pool” (ML19140A365 – available in July 2019)



- Next Steps

- Release SRNL report on the evaluation of the Zion NAM panels (2019)
- Publish report on the estimated total measurement uncertainty of ^{10}B areal density measurements using the BADGER system (2019)

Advanced Manufacturing Technologies (AMT)

- Overview

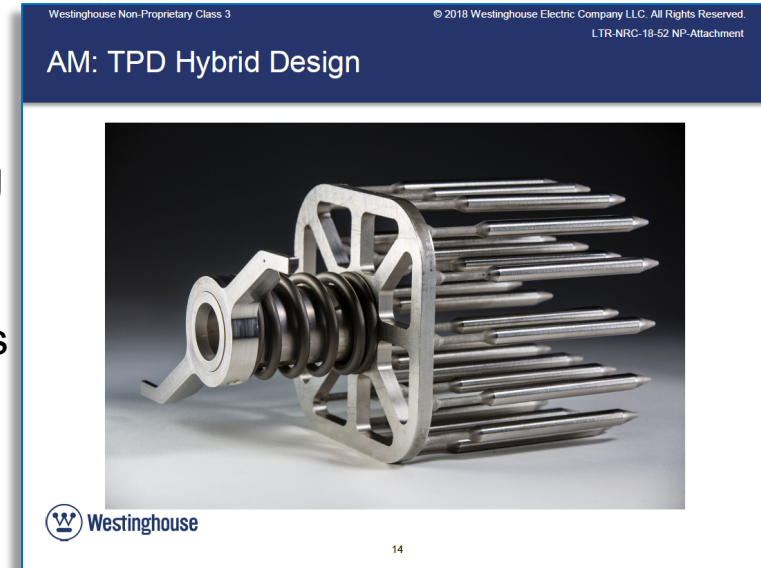
- **Objective:** Develop sufficient expertise and guidance for efficient review of advanced manufacturing technologies for use in existing and future nuclear reactors
- **Motivation:** Prepare NRC for expected submittals to use AMTs in nuclear applications
- **Regulatory Application:** Support review of AMT submittals and development of associated guidance
- **Collaboration:** DOE, EPRI, and NIST

- Recent Accomplishments

- NUREG/CP-0310, “Proceedings of the Public Workshop On Additive Manufacturing For Reactor Materials And Components” (ML18221A109)
- Published initial AMT Agency Action Plan (ML19029B355)

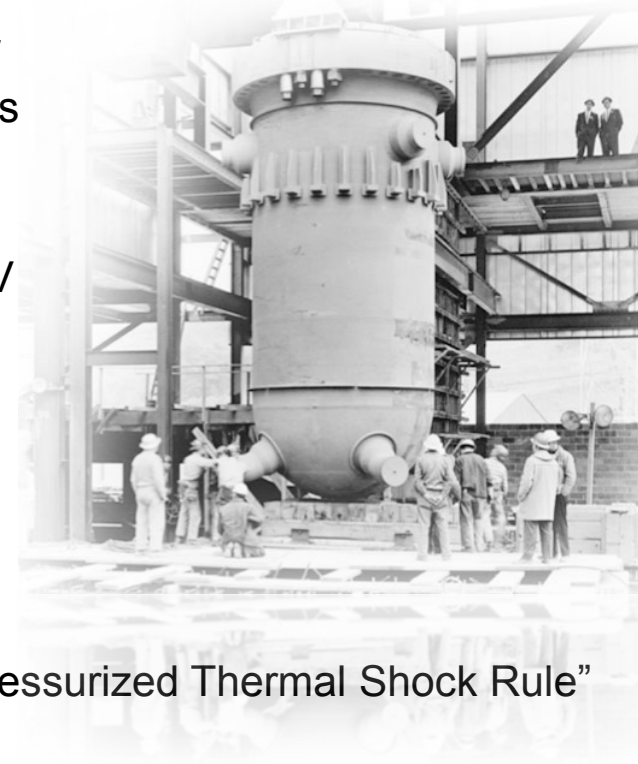
- Next Steps

- Complete technical and regulatory documents for licensing candidate AMT (2019)
- Develop knowledge management plan (2019)
- Develop generic technical information needed in AMT submittals (2019)



Reactor Pressure Vessel (RPV) Integrity

- Overview
 - **Objective:** Continue development and verification of FAVOR and assess embrittlement prediction formulas
 - **Motivation:** Confirm continued integrity of RPV during LTO
 - **Regulatory Application:** Enhance guidance for RPV structural integrity and fluence calculations
 - **Collaboration:** JAEA, JNRA, and CSNI
- Recent Accomplishments
 - NUREG-2163, “Technical Basis for Regulatory Guidance on the Alternate Pressurized Thermal Shock Rule, Final Report” (ML15058A677)
 - RG-1.230, “Regulatory Guidance on the Alternate Pressurized Thermal Shock Rule” (ML15344A402)
- Next Steps
 - Evaluate continued efficacy of Regulating Guide - 1.99, Revision 2 (2019)
 - Document fluence calculation methodology study for extended beltline and reactor internals (2019)
 - Complete FAVOR verification and validation and software quality assurance (2020)
 - Complete shallow flaw structural integrity investigation (2020 - 2021)



Piping Integrity

- Overview

- **Objective:** Develop and enhance analytical methods and tools to assess structural integrity of reactor piping systems
- **Motivation:** Confirm continued integrity of safety-critical piping systems during LTO
- **Regulatory Application:** Enhance guidance for performing piping structural integrity calculations
- **Collaboration:** EPRI and CSNI



- Recent Accomplishments

- PVP2017-66104, “Finite Element Analysis of the Effect of Mechanical Stress Improvement Process on Weld Residual Stress and Flaw Growth in a Thick-Walled Pressurizer Safety Nozzle”
- PVP2018-84931, “Exploring Finite Element Validation for Weld Residual Stress Prediction”

- Next Steps

- Publish report on modeling guidance for weld residual stress modeling (2019)
- Participate in CSNI benchmark projects on LBB, xFEM, and leak rate (2019 - 2020)
- Implement research plan for validating xFEM-A for PWSCC predictions (2020)
- Complete testing/evaluation of carbon fiber reinforced polymer repair methods (2020)

Probabilistic Structural Integrity (PSI)

- Overview

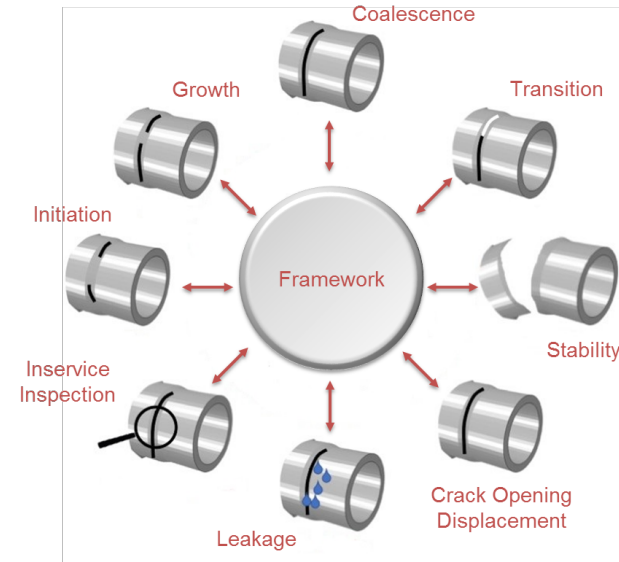
- **Objective:** Develop probabilistic methods to assess structural integrity of primary coolant pressure boundary (PCPB) components
- **Motivation:** Confirm continued integrity of safety-critical piping systems during LTO
- **Regulatory Application:** Develop guidance for performing probabilistic structural integrity analyses
- **Collaboration:** EPRI, JNRA, JAEA, SSM, CNSC

- Recent Accomplishments

- Technical Letter Report, “Important Aspects of Probabilistic Fracture Mechanics Analyses” (ML18178A431)
- “Acceptance Criteria for Use with xLPR Version 2 Code” (ML16271A436)
- “xLPR External Review Board Summary Documents & Close-out Letter” (ML17276A650)

- Next Steps

- Complete efforts to publicly release xLPR (piping code) (2019)
- Support regulatory acceptance review for xLPR (2019 – 2020)
- Complete draft PSI regulatory guide with supporting technical basis report (2020)
- Complete studies on leak-before-break applications with xLPR (2020 – 2021)



Non-Destructive Evaluation (NDE)

- Overview

- **Objective:** Evaluate effectiveness and reliability of NDE techniques
- **Motivation:** Confirm adequacy of industry procedures and practices
- **Regulatory Application:** Support reviews of ASME Code modifications and proposed revisions of current requirements
- **Collaboration:** EPRI, IRSN, and PIONIC



- Recent Accomplishments

- PNNL-27441, “Human Factors in Nondestructive Examination: Manual Ultrasonic Testing Task Analysis and Field Research” (ML18176A055)
- PNNL-27712, “Interim Analysis of the EPRI CASS Round Robin Study” (ML18219B319)
- PNNL-28362, “Ultrasound Modeling and Simulation Status Update” (ML19010A072)
- NUREG/CR-7235, “Results of Blind Testing for the Program to Assess the Reliability of Emerging Nondestructive Techniques” (ML17159A466)

- Next Steps

- Complete state-of-the art report on inspecting CASS and welds in CASS (2019)
- Conduct PIONIC – international follow-on to PARENT program (2019 – 2021)
- Develop technical basis to support guidance for UT Modeling & Simulation (2022)