Industry/NRC Materials Technical Exchange Meeting

Materials Reliability Program Report

Pål Efsing
RIC Chairman (Ringhals AB, Vattenfall)

Bob McGill
EPRI-MRP Program Manager

June 17-18, 2025

Presentation Agenda

- EPRI-Materials Reliability Program Overview
- Overview of Major Projects and Industry Engagement
  - MRP projects of interest
  - Industry focus groups

MRP is not planning on submitting any reports for NRC review in 2025.

EPRI-MRP Overview

MRP Overview

- The EPRI Materials Reliability Program (MRP) was formed in the late 1990s in response to several PWR-specific materials issues
- MRP conducts research beneficial for all our members in managing materials degradation in PWR primary systems
- MRP research is guided by industry operating experience, technology advancements, and materials degradation state-of-knowledge gaps

MRP Member Utilities/OEMs for 2025

Europe

- Axpo (Switzerland)
- EDF Energy (UK)
- Foro-CEN (Spain)
- NEK (Slovenia)
- Rolls-Royce SMR (UK)
- Rolls-Royce Submarines (UK)
- Vattenfall (Sweden)

North America

- Ameren Services Company
- American Electric Power, Inc.
- Constellation Energy Corp.
- Dominion Energy, Inc.
- Duke Energy Corp.
- Entergy Services, LLC
- Evergy Services (Wolf Creek)
- NextEra Energy, Inc.
- Pacific Gas & Electric Co.
- Palisades Energy
- Pinnacle West Capital Corp.
- PSEG
- Southern Nuclear
- STP Nuclear Operating Co.
- Tennessee Valley Authority
- Vistra Energy Corp.
- Xcel Energy Services, Inc.

Asia

- CGN Power
- China National Nuclear Power
- Emirates Nuclear Energy Corp.
- Hokkaido Electric Power [NEW]
- Japan Atomic Power Company
- Kansai Electric Power Company
- Korea Hydro & Nuclear Power
- Kyushu Electric Power
- Shandong Nuclear Power Company
- Shikoku Electric Power Company

South America

- Eletronuclear S.A.

THE MRP TEAM for 2025

Bob McGill, Program Manager
(rmcgill@epri.com)

- Three former utility engineers
- Four former NSSS engineers
- Six active ASME Code members
  - Section III and Section XI
- Advanced engineering degrees
  - Four Masters of Science
  - Three Doctorates

Kyle Amberge, RPV Internals, OE
(kamberge@epri.com)

Tom Damiani, Fatigue Management
(tdamiani@epri.com)

Amy Freed, Project Management
(afreed@epri.com)

Nate Glunt, RCS Piping, xLPR
(nglunt@epri.com)

Elliot Long, RPV Integrity
(elong@epri.com)

Heather Malikowski, Nickel-based Alloys
(hmalikowski@epri.com)

Morgan Provance, Program Communications
(msaucier@epri.com)

DJ Shim, Fracture Mechanics
(dshim@epri.com)

Feng Yu, International Engagement – China
(fyu@epri.com)

MRP Organization and Advisory Structure

Research Integration Committee

Provides TAC oversight and makes project funding decisions

Chair - Pål Efsing, Vattenfall

MRP RIC PM - Bob McGill

Technical Advisory Committees

Internals & Integrity

Chair - Corey Thomas, Southern

Vice Chair - Josh Morton, Vistra

MRP TAC PM - Elliot Long

All technical issues related to reactor pressure vessel internals assessment, stainless steel alloys, and reactor pressure vessel integrity

Pressure Boundary

Chair - Lora Drenth, Constellation

MRP TAC PM - Heather Malikowski

All technical issues related to nickel-based alloys and thermal, vibration, and environmentally-assisted fatigue

Inspection

Chair - Dale Brown, Southern

Vice Chair - Todd Davis, Constellation

MRP TAC PM - Bob Grizzi

All technical issues related to inspection technique, available equipment, and reliability of results

Overview of Major Projects and Industry Engagement

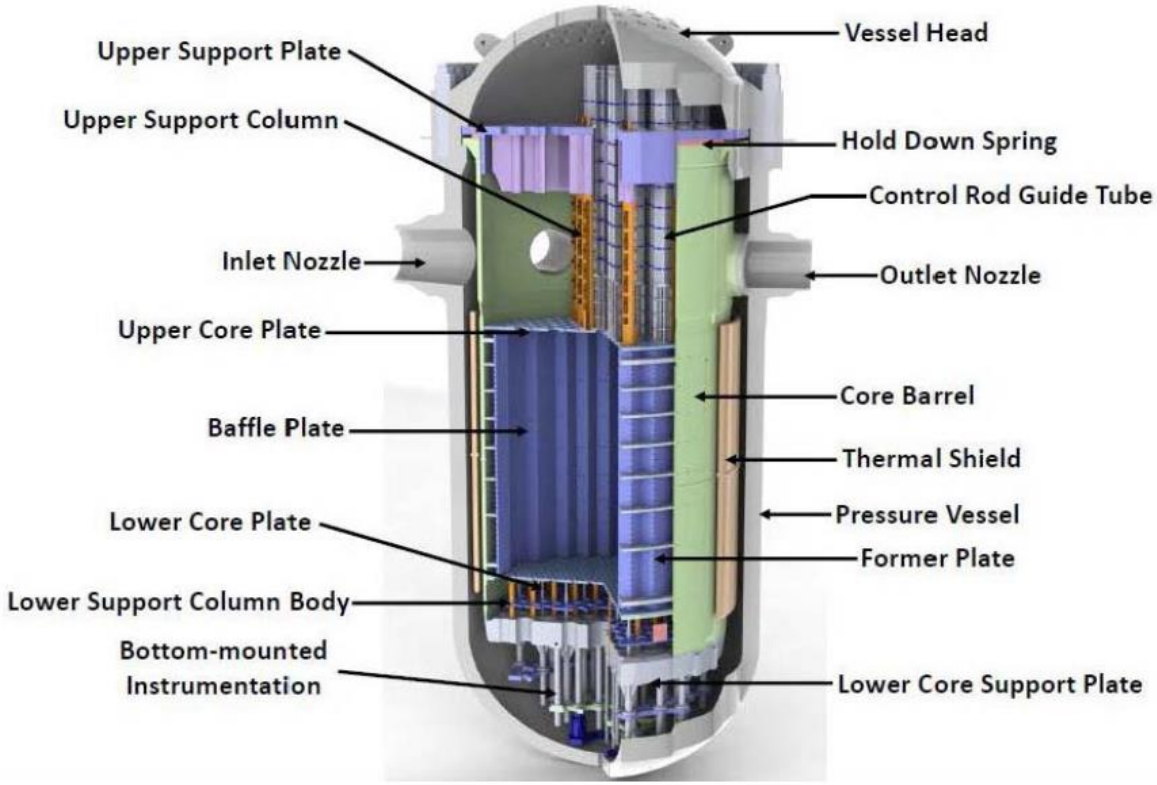
PWR Internals Inspection & Evaluation Guidelines MRP-227, Rev. 2-A

Kyle Amberge

EPRI Activities on PWR Internals Aging Management

PWR Internals Inspection & Evaluation Guide Rev. 0 issued in Dec. 2008

- NRC-approved version of PWR Internals Inspection and Evaluation (I&E) Guidelines, MRP-227-A (Product ID 1022863) was issued in Dec. 2011
  - Rigorous exams done in year-40, -50, -60 and year-70 ISI RFOs
- Updated guidelines:
  - MRP-227, Rev. 1 was issued in October 2015 (ML15358A046)
    - NRC Safety Evaluation completed May 2019 (ML19081A001)
  - NRC accepted MRP-227, Rev. 1-A in May 2020 (ML20141L315)
  - MRP-227, Rev. 2 was issued in May 2022 (ML22129A138) – covers all periods of L.R. (40-80)
    - NRC SE of Rev. 2 was completed Jan. 2025 (ML24305A007)
  - MRP-227, Rev. 2-A was issued in May 2025 (ML25142A175)
- PWR utility owners expect to implement by 2027



Overview of Typical Westinghouse Internals

EPRI MRP Thermal Ageing Testing Program Summary

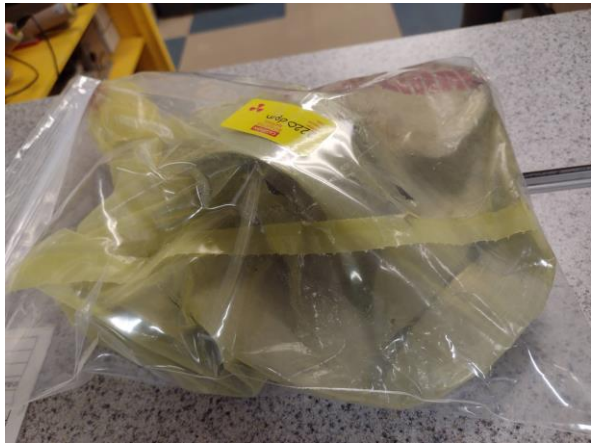
Elliot Long

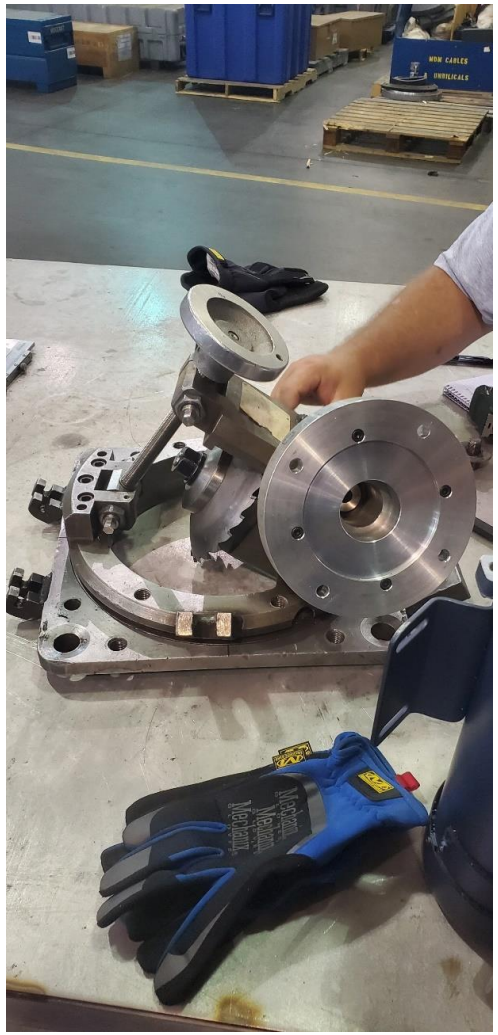
Evaluation of Thermal Embrittlement of Low Alloy Steel Exposed to Pressurizer Temperatures (MRFA 4.1.6)

- Materials Issue Being Addressed:
  - Low alloy steel (LAS) is susceptible to thermal ageing
  - Thermal ageing is caused by slow diffusion and segregation of impurity elements (e.g., primarily phosphorus, P) into grain boundaries at operating temperature
    - Results in an increase in the ductile-brittle transition temperature (DBTT)
    - Degree of embrittlement is a function of P, temperature, and time
- Objectives of the Thermal Ageing Project
  - Analytical
    - assess the potential impact of PZR thermal ageing embrittlement based on a comparison of PZR and RPV Pressure-Temperature (P-T) limit curves
      - MRP-463, 2021 for WEC/CE NSSS Plants
      - MRP-474, 2022 for Framatome NSSS Plants
  - Testing
    - to identify high ductile-brittle transition temperature (DBTT) by testing and to identify the potential causes of thermal aging.
      - MRP-491 documenting the results of testing completed on the harvested IPP2 PZR specimens completed in 2024 [*summarized herein*]

Thermal Ageing – PZR Project: Testing Program

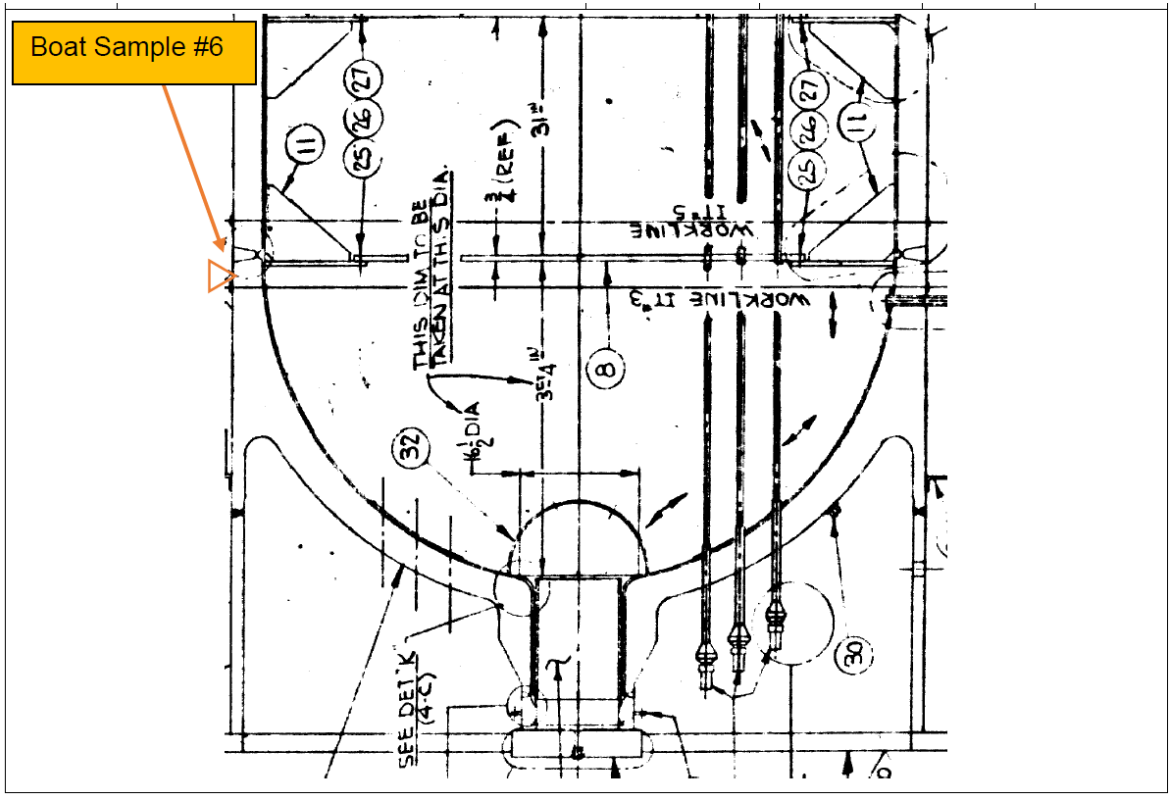
- Indian Point Unit 2 (35 EFPY) was the best domestic candidate for the PZR material samples
  - Ability with this decommissioning unit to obtain 10 boat samples, not just EDM scrapings, from the plate, casting, HAZ and weld
    - Samples removed via mechanical process; minimizing heat input
  - Field Services work at Indian Point Unit 2 was completed in Fall of 2022
  - Samples arrived at the Churchill Labs shortly thereafter with testing commencing in 2023

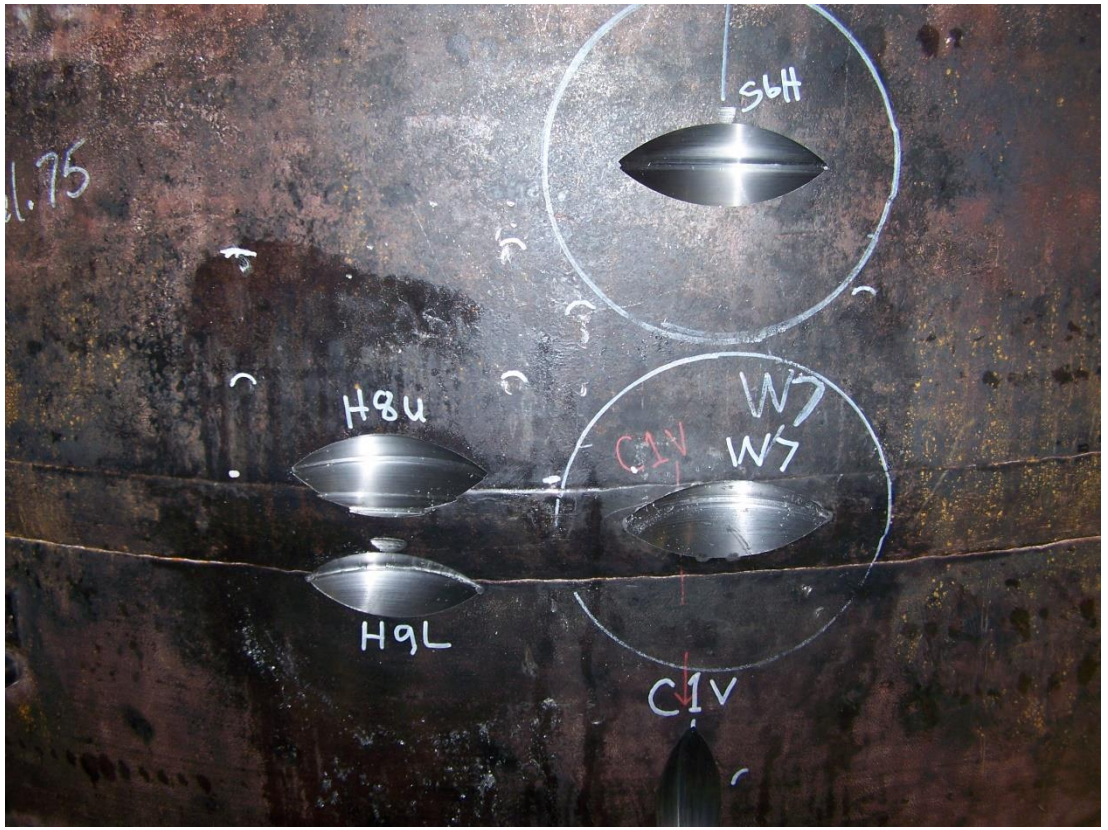




Thermal Ageing – PZR Project: Testing Program

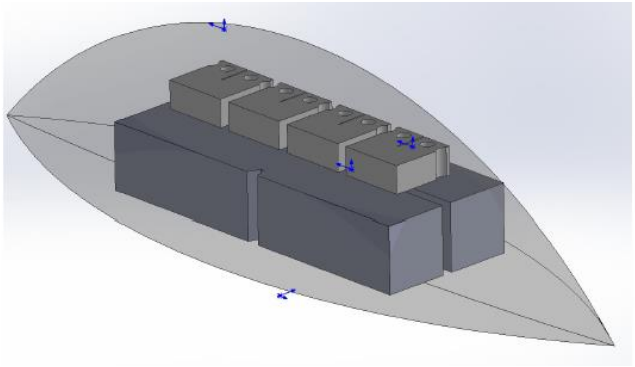
- Mechanical and Chemical Testing Included:
  - Charpy, Mini-CT, and Mini-Tensile Specimens
  - Bulk Chemistry, Grain Boundary Phosphorus Diffusion, Hi-Magnification Transmission Electron Microscope (TEM) Inspection, Fracture Surface Metallography

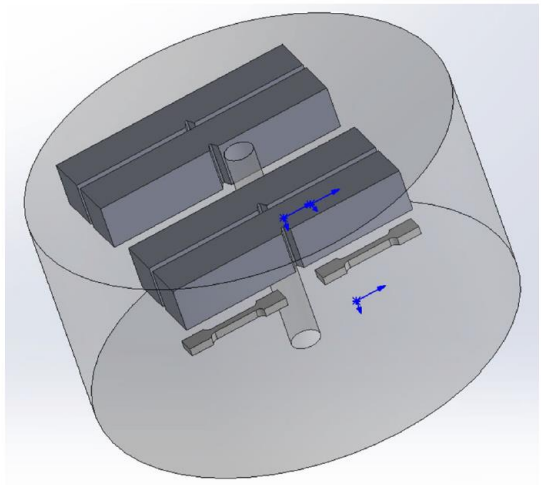


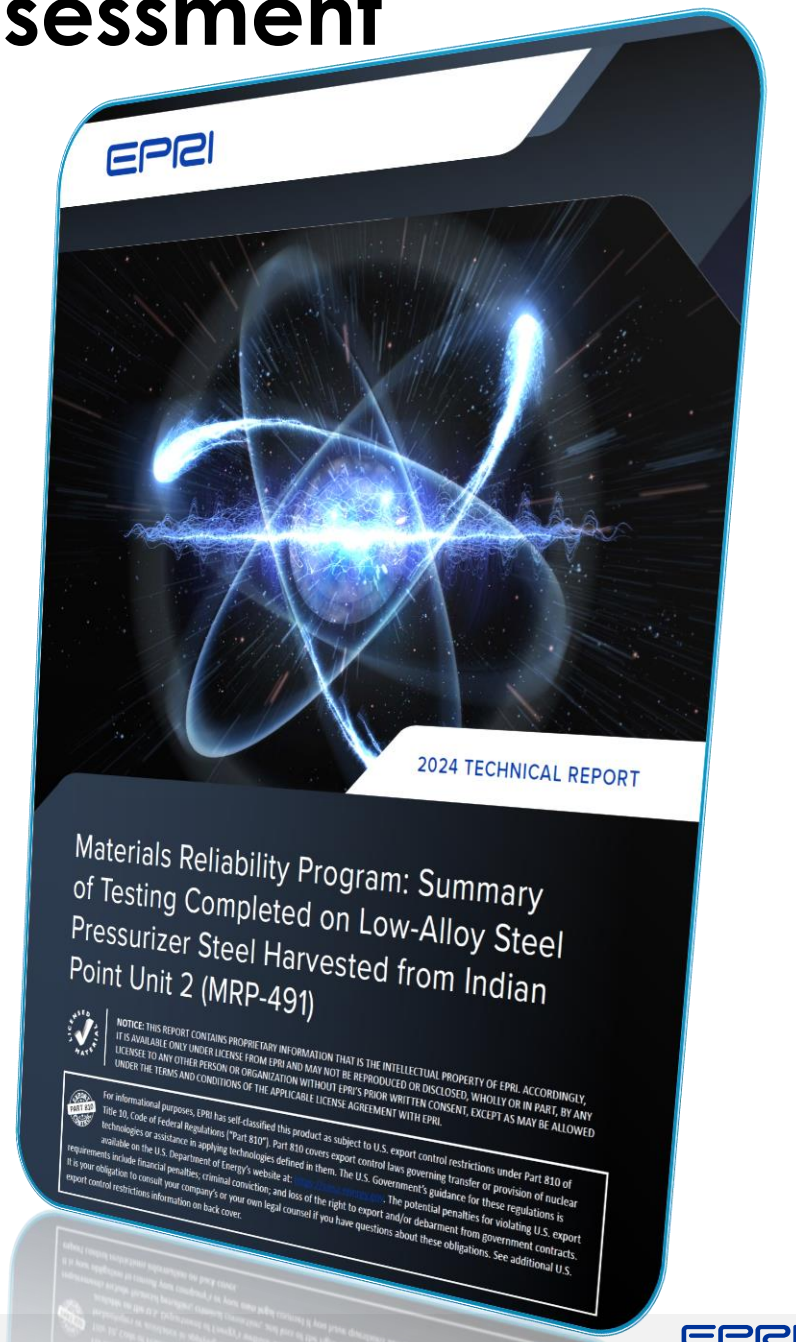


Thermal Ageing – PZR Project: Testing Assessment

- The project was completed in 2024
  - *Materials Reliability Program: Summary of Testing Completed on Low-Alloy Steel Pressurizer Steel Harvested from Indian Point Unit 2 (MRP-491)*
- Vendor: Westinghouse
  - Principal investigators:
    - Brian Hall and Catou Cmar
- EPRI Project Manager: Elliot J. Long
- Key Conclusions on next slide
- Plans for 2025 and Beyond
  - Assess need and ability to procure additional base metal from an international utility







MRP-491 – Testing of Low-Alloy Thermally Aged PZR Steel

- Key Conclusions: MRP-491
  - The mechanical property tests (Charpy V-Notch impact, tensile, fracture toughness, microhardness) showed *no indications* of ageing relative to the original certified material test report.
  - The mechanical property tests of the lower head casting relative to the tests on the lower operating temperature support skirt showed *no indications* of ageing.
  - The chemical composition measurements and transmission electron microscopy showed *no significant* P segregation to the grain boundaries.
  - All the aged material ductile-to-brittle fracture toughness transition temperature (RT_{T0}) values *are below* the initial RT_{NDT} (60°F) used for developing the assumed aged pressurizer cool down curves demonstrating that the assumed RT_{NDT} values in MRP-463 and MRP-474 *are conservative* for at least this PZR.
- Future utilization of results
  - Assess the need for future research or regulatory oversight
  - Potential for follow-on work on additional base metal from an international utility

Full MRP Project Portfolio

- Thermal Ageing of Low Alloy Steels
  - Focused multifaceted solution path
    - Literature Review → MRP-438 (2019)
    - PZR Analytical Assessment: P-T Limit Curves
      - MRP-463 → Assessment for WEC and CE plants (2021)
      - MRP-474 → Assessment for B&W Plants (2022)
    - PZR Material Harvesting and Testing Programs (2024, 2025-2026)
      - Indian Point Unit 2 (2024)
      - International utility (2025 – 2026)
  - Assess and compare results from Analytical and Testing Paths
    - 2025+ <As Needed>

EAF Component Test Update

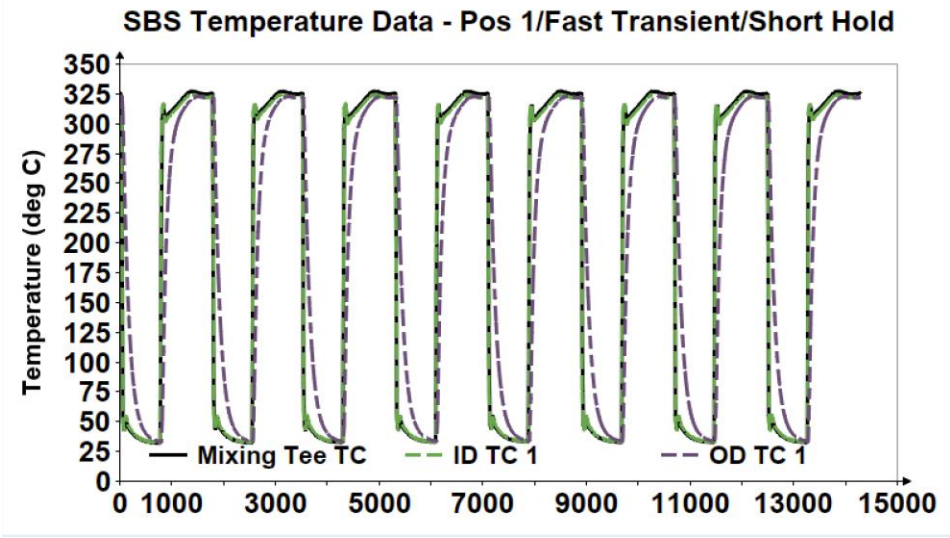
Tom Damiani

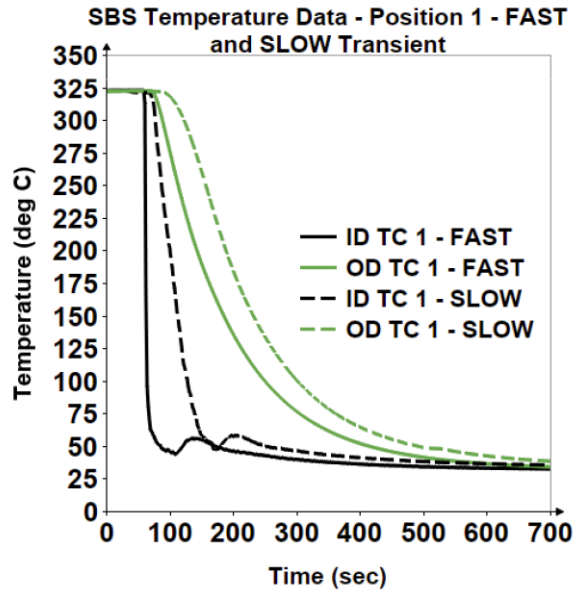
EAF Component Test Status – 2024

Test Loop Commissioning

- ✓ Loop Shakedown and Repeatability
- ✓ Strain and Thermal Benchmark Testing and Data Collection
- 

PWR Representative Water Chemistry





NDE Qualification Test

- 4 specimens installed
- FAST transient with short hold applied
- 500 cycles targeted for initiation
- Eddy Current (EC) inspections to detect initiation
- Phased Array UT (PAUT) to characterize crack growth from EC

	Assumed Cycles to Initiation		**500**							
Prescribed Loop Cycles for Initiation			**Cycles**	**Duration (Days)**		**Cycle**	**Duration (days)**			
Transient Type/Hold	FAST/900s	**Block A**	200	4.17						
Cycle Time (hr)	0.5	**Block B**	150	3.13	**Block SCG**	500	10.42	Max cycles to grow from 0.2 mm to 3 mm		
		Block C	100	2.08	**Block LEFM**	600	12.50	Min cycles to grow from 3 mm to 80% TW		
		Block D	50	1.04						
		Block E	50	1.04						

EAF Component Test – 2025 Schedule

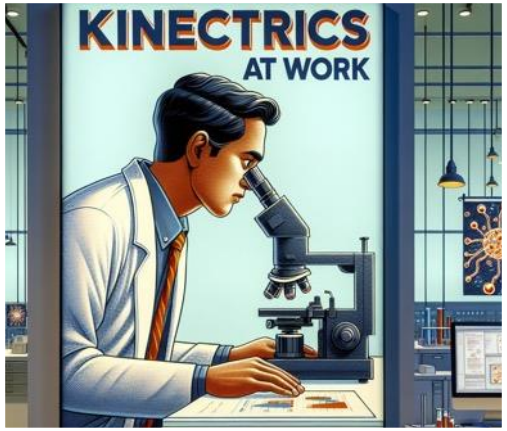
June-July 2025

Chemistry Commissioning/NDE Qualification Testing

- Meet PWR chemistry spec
- SIA revised analysis to predict initiation
- Stern testing with Nucleom inspections

August – October 2025

Post-Commissioning Work



- Benchmark Analysis Report
- Metallography of NDE Qualification Specimens
- Sizing of NDE methods
- Prototype Specimen Machining

November 2025 – January 2026

Prototype Testing

- Fast Transient Testing (900s hold)
- Medium Transient Testing (900-1100 s hold)
- Potential 3rd Test of TrueFlaw Specimens (already cracked)

February – December 2026

Post-Test Work and Reporting

- Metallography of Test Specimens
- Calibrate Models to Test Results
- Potential Revision to F_{en} Based on Test Results
- Final Report

Industry Focus Groups

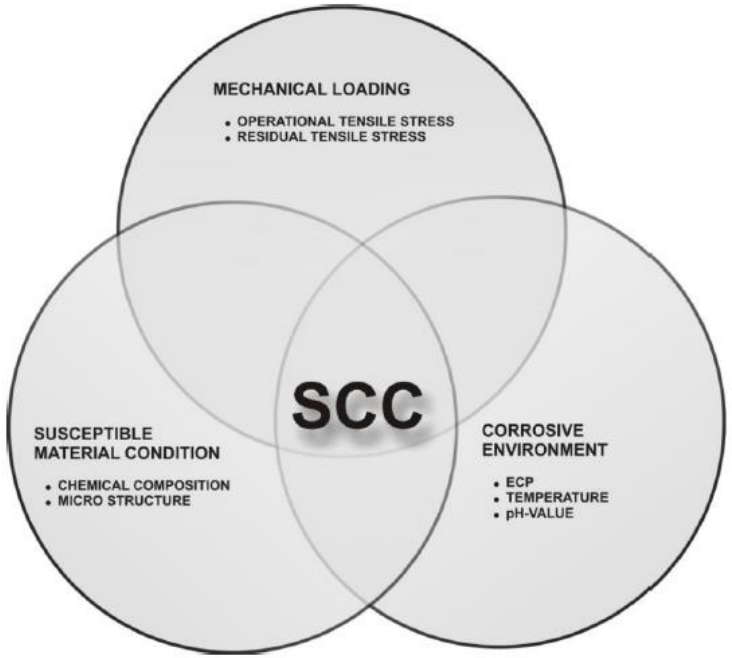
MRP/PWROG Core Barrel Focus Group

- MRP continues to support the Core Barrel Focus Group
- Testing of core barrel samples nearing completion – final report pending

Detailed update provided in a subsequent presentation

MRP/PWROG Auxiliary Piping SCC Focus Group

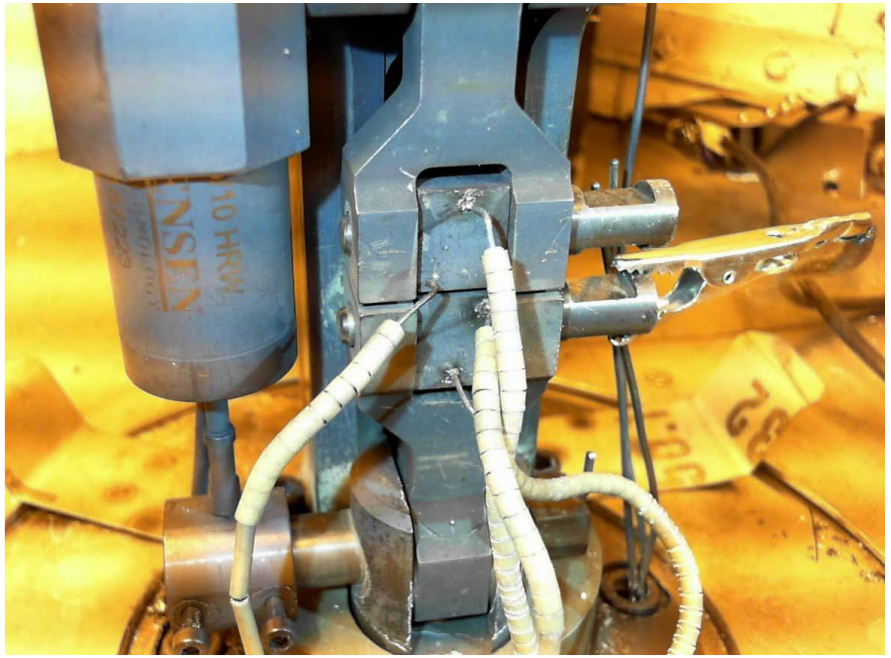
- MRP continues to support the Auxiliary Piping SCC Focus Group with the PWROG in response to the EDF stainless steel SCC OE
- PWROG applicability assessment to be published soon
- Draft of MRP-236, Rev. 2 to be ready for member review later this year



Detailed update provided in a subsequent presentation

Irradiated SS Fracture Toughness Focus Group

- Focus Group developed a list of 16 research ideas, which were prioritized by task duration and impactfulness
- Research recommendations under consideration by EPRI Issue Programs and the PWROG



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