

# Managing Aging and Degradation of PWR Reactor Internals in the USA



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# MRP Overview



The EPRI Materials Reliability Program (MRP) was formed in the late 1990s in response to several PWR-specific materials issues



MRP research provides members guidance to assess, manage, and mitigate materials degradation in PWR primary systems



MRP research is guided by industry operating experience, technology advancements, and materials state-of-knowledge gaps

# MRP Member Utilities/OEMs for 2025

## 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.

## Europe

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

## Asia

- CGN Power
- China National Nuclear Power
- Emirates Nuclear Energy Corp.
- Hokkaido Electric Power
- 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.



# MRP Strategic Objectives

## Increase member value

- Work toward closing IMT knowledge gaps
- Continued focus on supporting LTO of PWRs worldwide
- Expand knowledge transfer and retention products
- Identify and develop new technologies for member benefit

## Serve the industry

- Be active in the ASME Code
- Support regulatory engagement
- Collaborate with other industry organizations

## Increase membership



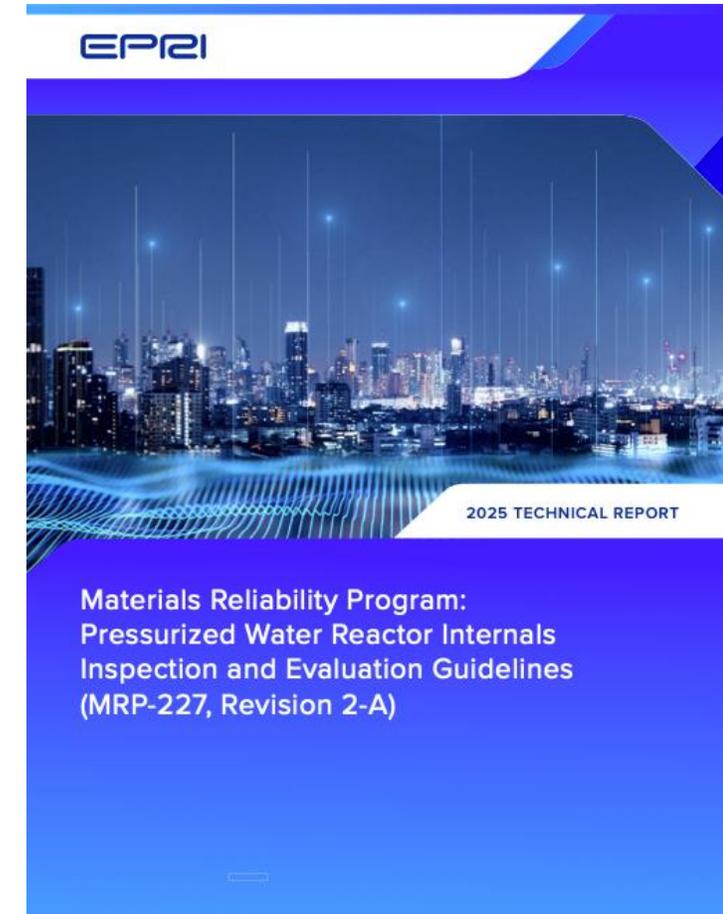
# EPRI's PWR Internals Aging Management Overview

# Background on EPRI's PWR Internals Aging Management

- Built upon successful model of GE-design Boiling Water Reactors
  - Aging management component inspections used since early 1990s
- Technical Basis Supporting PWR Internals Aging Management
  - MRP-134 – Framework and Strategies for Managing Materials Aging
  - MRP-175 – Materials Degradation Screening Parameters
  - MRP-191 – Screening and Ranking Process for PWR Internals
- PWR Reactor Internals Components Failure Rankings in USA
- Use of Aging Management Program (AMP) for PWR Internals
  - MRP-227 has been successfully implement by CNNP for Qinshan-I

# Aging Management Implementation by International PWRs

- Many international utility owners have successfully applied the generic aging management program guidance in MRP-227
  - Guidance useful for long-term operations beyond original licensing period
  - Many international utility owners receive license renewals in 10-year terms
- MRP-227 has been implemented for LTO/license renewal overseas in:
  - Sweden (Ringhals)
  - Spain (Almaraz/Asco)
  - Slovenia (Krško)
  - China (Qinshan-I)
  - Brazil (Angra)
  - Switzerland (Beznau)
- Swedish utility (Vattenfall), Chinese utility (CNNP), and Spanish utility (CNAT) received EPRI technology innovation awards in 2016 and in 2023 for implementation of MRP-227 guidance during LTO at PWR units





**Technical Basis Reports Supporting PWR Internals  
Materials Aging Management in the USA**

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- MRP-134 technical report provides materials screening criteria
- Proposes an overall framework and associated strategies for managing the effects of aging in PWR internals during the period of extended operations (PEO) beyond 60 years of life
- Overall technically sound strategy that incorporates existing and available knowledge of component design, materials, and degradation mechanisms from ongoing research programs
- Provides a recommended methodology and the related technical basis for utilities planning aging management programs for PWR internals

PUBLIC Ref. <https://www.nrc.gov/docs/ML1031/ML103160381.pdf>

PUBLIC Ref. [Report 1008203, "Materials Reliability Program: Framework and Strategies for Managing Aging Effects in PWR Internals \(MRP-134\)."](#)

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- MRP-175 technical report provides materials screening criteria
- Provides the screening and threshold parameters for eight (8) aging degradation mechanisms applicable to reactor vessel internals during the period of extended operations (PEO) beyond 60 years of life
  - Parameters such as operating stress, temperature, and fluence

PUBLIC Ref. [Report 1012091, "Materials Reliability Program: PWR Internals Material Aging Degradation Mechanism Screening and Threshold Values \(MRP-175\)."](#)

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- MRP-175 provides technically sound age-related degradation mechanism screening criteria for management of aging effects
  - Stress Corrosion Cracking
  - Wear
  - Fatigue
  - Thermal Aging Embrittlement
  - Irradiation-Assisted Stress Corrosion Cracking
  - Irradiation Embrittlement
  - Irradiation induced Void Swelling
  - Irradiation Stress Relaxation and Irradiation Creep
- Screening criteria for various material types include parameters such as stress, fluence, temperature, and ferrite content

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- EXAMPLE - Screening for stress corrosion cracking:

*Stress corrosion cracking screening criteria for PWR internals materials*

Material <sup>a</sup>	Parameter <sup>b,c</sup>	Value
Austenitic SS	Stress <u>and</u> Material	≥ 30 ksi (207 MPa) <u>and</u> Cold-work ≥ 20% <u>or</u> Welded Locations <sup>d</sup>
Austenitic SS Welds <sup>e</sup>	Stress <u>and</u> Material	≥ 30 ksi (207 MPa) <u>and</u> Ferrite < 5%
Martensitic SS <sup>f</sup>	Stress	≥ 88 ksi (607 MPa)
Martensitic PH SS <sup>f</sup>	Stress	≥ 88 ksi (607 MPa)
Austenitic PH SS	Stress <u>and</u> Material	≥ 70 ksi (483 MPa) <u>and</u> Surface cold-work or cold-drawn spring wire
	Hot-headed <u>or</u> shot-peened bolting that meet the stress criterion is to be evaluated for SCC.	
CASS <sup>e</sup>	Stress <u>and</u> Material <sup>g</sup>	≥ 35 ksi (241 MPa) <u>and</u> Ferrite <5%
Austenitic Ni-base Alloys <sup>h</sup>	Stress	≥ 30 ksi (207 MPa)
Austenitic Ni-base Welds <sup>h</sup>	Stress	≥ 35 ksi (241 MPa)
Austenitic PH Ni-base (Alloy X-750)	Stress <sup>i</sup>	≥ 100 ksi (689 MPa)
	AH and BH condition considered more susceptible than HTH condition.	
Austenitic PH Ni-base (Alloy 718)	Stress <sup>i</sup>	≥ 130 ksi (896 MPa)
Co-base Alloys	Alloys not susceptible in PWR internals locations.	



**EPRI MRP-191 Technical Report Provides  
PWR Internals Component Screening/Ranking**

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- MRP-191 technical report provides component screening/ranking
- Describes the process and results of categorizing Westinghouse and Combustion Engineering (CE) designed pressurized water reactor (PWR) internals components according to age-related degradation and significance
- Key element in an overall strategy that uses knowledge of internals design, materials, and material properties and applies screening methodologies for known age-related degradation mechanisms to manage the effects of aging
- Used to establish rigorous basis for developing technically sound inspection and evaluation guidelines for aging management of PWR internals

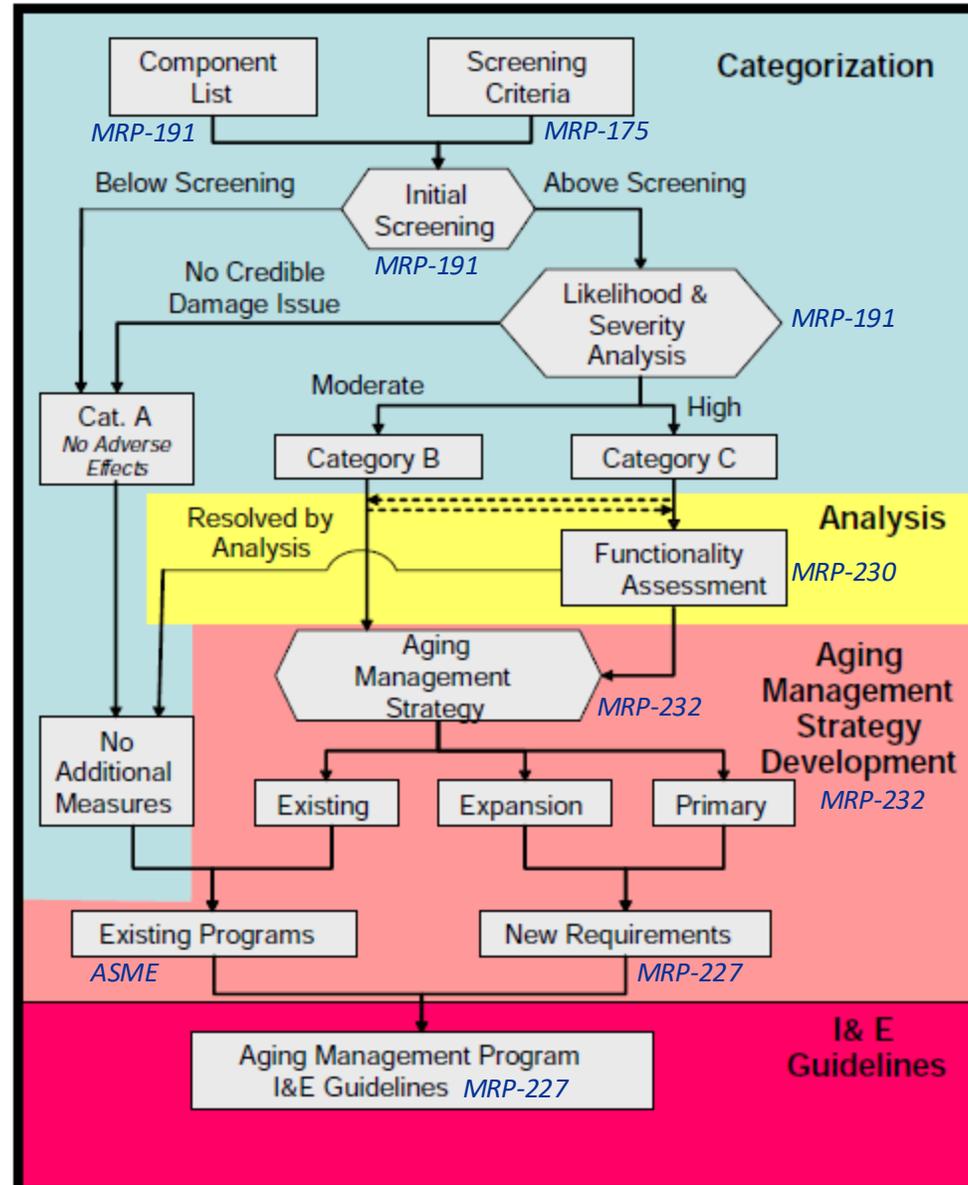
PUBLIC Ref. <https://www.nrc.gov/docs/ML0919/ML091910130.pdf>

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

- MRP-191 results showed that the majority of Westinghouse-designed PWR internals components fall into categories of little and moderate failure likelihood/damage consequence to the aging degradation mechanisms (Categories A and B)
- For the Westinghouse designs, 13 PWR internals components are of high damage likelihood/consequence (Category C)

# Technical Basis Reports Supporting RVI Aging Mgt. in USA

**MRP-134  
Strategy**





**MRP-191 Reactor Internals  
Component Failure Rankings**

# MRP-191 Reactor Internals Components Failure Rankings

- MRP-191 Failure Modes Effects and Criticality Analysis (FMECA)
  - Objectives are to ensure that all conceivable failure modes and their effects on the operational success of the system have been considered
- MRP-191 documents results of expert panel review of the potential failures and evaluate the magnitude of the effects
- Basic questions that are typically addressed:
  1. How can a part conceivably fail?
  2. What mechanisms might produce these modes of failure?
  3. What could the effects be if the failures occur?
  4. Is the failure in the safe or unsafe direction (relative to safe shut-down)?
  5. How might the failure be detected?
  6. What inherent provisions are provided in the design to compensate for the failure?

# MRP-191 Defines Reactor Internals Components Failure

*MRP-191 defines core damage and damage likelihood as:*

- Core Damage: Physical damage to one or more fuel assemblies or other internals components either through direct impact with the fuel, flow-jetting, loss of core support/fuel spring hold down force, loose parts, blockage/diversion of coolant flow, or loss of insertion ability for more than one control rod that would impair the ability to safely shut down the reactor
- Damage Likelihood: The conditional likelihood that component failure(s) results in core damage given that the failure occurs irrespective of the actual failure likelihood

# MRP-191 Defines Reactor Internals Components Failure

- MRP-191 defines four categories of conditional damage likelihood

Conditional Damage Likelihood

Category	Description
None	The component has no screened-in degradation mechanism. No need to assess damage probability; no financial impact.
Low	Expert panel believes there is no credible means for component failure(s) to cause damage but with potential financial impact.
Medium	Expert panel believes the potential exists for damage as a result of component (or multiple) failure(s) but that the ability to shut down the reactor in a controlled manner remains; financial impact.
High	Expert panel believes that some damage could possibly result from failure of the component(s); financial impact.

- MRP-191 Revision 2 incorporated ROM<sup>^</sup> cost estimates of impact

Category	Description (Rough order-of-magnitude cost levels)
None	No or trivial cost
Low	Cost that can be generally handled within existing plant outage budget/resources (<\$5M)
Medium	Cost that exceeds the normal plant outage budget and resources (>\$5M)
High	Cost that could potentially affect a utility's overall enterprise/financial health (>\$20M)

*Financial impact has been something that has impacted US utility business objectives for LTO* PUBLIC Ref. <https://www.nrc.gov/docs/ML1031/ML103160381.pdf>

# Example of MRP-191 RVI Components Rank Categories

Categorization of Westinghouse Reactor Internals Components

Assembly	Subassembly	Component	Material	FMECA Group	Category
Upper Internals Assembly	Upper Support Plate Assembly	Flange	304 SS	0	A
		Inverted top hat (ITH) flange	304 SS	1	A
		Inverted top hat (ITH) upper support plate	304 SS	1	A
		Lock keys	316 SS	0	A
		Ribs	304 SS	0	A
		Upper support plate	304 SS	0	A
		Upper support ring or skirt	304 SS	2	B
Lower Internals Assembly	Baffle and Former Assembly	Baffle bolting lock bars	304 SS	1	A
		Baffle-edge bolts	316 SS 347 SS	3	C
		Baffle plates	304 SS	1	B
		Baffle-former bolts	316 SS 347 SS	2	C
		Barrel-former bolts	316 SS 347 SS	2	C
		Former plates	304 SS	1	B
	Bottom-Mounted Instrumentation (BMI) Column Assemblies	BMI column bodies	304 SS	1	B
		BMI column bolts	316 SS	1	A



**EPRI Review/Assignment of  
PWR Internals Inspection Strategy**

# EPRI-MRP Review/Assignment of Inspection Strategy

*MRP-230 and MRP-232 reports establish “Primary” and “Expansion” component list for inspections during life extension (beyond 40-years of life):*

- Primary: (P) those PWR internals that are highly susceptible to the effects of at least one of the eight aging mechanisms were placed in the Primary group
- Expansion: (E) those PWR internals that are highly or moderately susceptible to the effects of at least one of the eight aging mechanisms, but for which functionality assessment has shown a degree of tolerance to those effects
- Existing Programs: (X) those PWR internals that are susceptible to the effects of at least one of the eight aging mechanisms and for which generic and plant-specific existing AMP elements are capable of managing those effects
- No Additional Measures: (N) those PWR internals for which the effects of all eight aging mechanisms are below the screening criteria

# EPRI-MRP Review/Assignment of Inspection Strategy

- MRP-232 categorization and analysis processes do not supersede any of the ASME B&PV Code Section XI requirements
  - Any components that are classified as core support structures as defined in ASME B&PV Code Section XI IWB 2500 IWA 9000, and listed in Table IWB 2500-1 Category B-N-3 have requirements that remain in effect and may only be altered as allowed by 10CFR 50.55a
  - Utility owners must still comply with ASME B&PV Code Section XI requirements
- Of the total ~200 components identified for Westinghouse-designed PWR internals in the USA:
  - 9 are considered Primary components, must be inspected first during LTO
  - 9 are Expansion components, would be inspected upon finding degradation
  - 8 are Existing Programs components, routinely inspected during I.S.I. outages

PUBLIC Ref. <https://www.nrc.gov/docs/ML1031/ML103160381.pdf>

**MRP-227 is a SAMPLING inspection program, just like ASME Section XI**



# How does a Utility in the USA implement MRP-227?

*Case study example: Farley AMP*

# Example-RV Internals Materials Aging Plan for US Utilities

- Farley's Vessels Internals Inspection Plan identifies the reactor vessel internals components to be included for aging management review Identifies the augmented inspection plan for the PWR reactor vessel internals
- Program plan implements the Electric Power Research Institute's (EPRI) Materials Reliability Program (MRP) technical report
  - Pressurized Water Reactor Internals Inspection and Evaluation Guidelines (MRP-227-A) as endorsed by the US NRC
- This inspection program was developed so that the aging effects of the reactor vessel internals components are adequately managed
- Inspections provide reasonable assurance that the internals components continue to perform their intended function throughout the period of extended operation

Enclosure 1 to NL-15-1507  
FNP-1 RVI Aging Management Program

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Westinghouse Non-Proprietary Class 3

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WCAP-18011-NP  
Revision 0

**PWR Vessel Internals Program Plan for Aging Management  
of Reactor Internals at J.M. Farley Nuclear Plant Unit 1**

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\*Electronically approved records are authenticated in the electronic document management system.

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