

EPRI China Meeting

Plant Reliability & Resilience (PRR)
Long Term Operations (LTO) Research Topics



October 2025

EPRI Team



Mark Woodby

Director

Plant Performance



Michael Thow

Sr. Program Manager

Plant Reliability & Resilience



Kurt Crytzer

Sr. Principal Team Leader
Plant Reliability & Resilience
Thermal Performance, Hx



Andrew Mantey

Sr. Principal Team Leader
Plant Reliability & Resilience
Electrical Systems, Cables



Garry Young

Technical Executive
Operating Plant Initiatives
Long Term Operations



Cristina Quiros Corrales

Principal Technical Leader
Plant Reliability & Resilience
I&C, Human Factors, M&D



David Olack

Principal Technical Leader
Plant Reliability & Resilience
Cooling Water, EDG

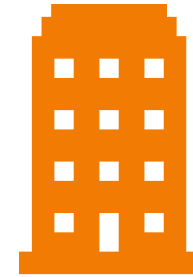
Introductions



Name



Title/Position



Company

Please introduce yourself

Day 1 Morning Agenda

Monday, October 20, 2025 – General Session		
Time	Topic	Lead
9:00 am	General Session Welcome and Opening Comments • Safety Message • Opening Comments • Introductions • Quick-Hit Research Highlights • How to Engage with EPRI	M. Thow, EPRI M. Woodby, EPRI
10:30 am	Break	
11:00 am	Member Presentation Topic1	Member TBD
11:30 am	Member Presentation Topic2	Member TBD
12:00 pm	LUNCH	

Day 1 Afternoon Agenda – Two Tracks

Monday, October 20, 2025 – Track 1 – LTO / Aging Management / LifeCycle Management

Time	Topic	Lead
1:00 pm	Technical Process for developing Aging Management Programs (AMPs) for Passive Components	G. Young, EPRI
2:30 pm	Break	
3:00 pm	AMP Implementation Example – AMP224 (Motors)	A. Mantey, EPRI
4:00 pm	LTO/EQ Open Discussion – Current Challenges in China	G. Young, EPRI A. Mantey, EPRI
5:00 pm	ADJOURN	

Monday, October 20, 2025 – Track 2 – Thermal Performance, Heat Exchanger and I&C Topics

Time	Topic	Lead
1:00 pm	Identifying Single Point Vulnerabilities in Digital I&C Systems - Adapting EPRI SPV Methodology for Modern Nuclear Control Systems	C. Corrales, EPRI
2:30 pm	Break	
3:00 pm	Thermal Performance ** - Establishing a Program - Cycle Isolation Monitoring Technology Overview - Data Validation & Reconciliation	K. Crytzer, EPRI
5:00 pm	ADJOURN	

Day 2 Morning Agenda

Tuesday, October 21, 2025 – General Session		
Time	Topic	Lead
9:00 am	Welcome / Day 1 Recap	M. Thow, EPRI M. Woodby, EPRI
9:15 am	LTO / NDE and Condition Monitoring Tools • Selective Leaching / NDE Methods Used • Electrical Insulation Testing	K. Crytzer, EPRI A. Mantey, EPRI
10:30 am	Break	
11:00 am	Member Presentation3	Member TBD
11:30 am	Member Presentation4	Member TBD
12:00 pm	LUNCH	

Day 2 Afternoon Agenda – Two Tracks

Tuesday, October 21, 2025 – Track 1 – LTO / Aging Management / LifeCycle Management		
Time	Topic	Lead
1:00 pm	Transformer Life Cycle Management Walkthrough Using the Long-term Asset Management Basis Design Application (LAMBDA)	A. Mantey, EPRI
2:30 pm	Break	
3:00 pm	Collecting Operating Experience and Best Practices for LTO	G. Young
4:00 pm	Treatment of Active Components in LTO and Aging Mgmt.	G. Young
5:00 pm	ADJOURN	

Tuesday, October 21, 2025 – Track 2 – Thermal Performance, Heat Exchanger and I&C Topics		
Time	Topic	Lead
1:00 pm	Intake and Cooling Water System Performance and Research	D. Olack, EPRI
2:30 pm	Break	
3:00 pm	Heat Exchanger Integrity and Operating Experience **	K. Crytzer, EPRI
5:00 pm	ADJOURN	

Day 3 Agenda

Wednesday, October 22, 2025 – General Session

Time	Topic	Lead
9:00 am	Equipment Reliability Roundtable Discussion China Utility members to share OE, challenges and Top 10 Plant Issues. EPRI SME's to help facilitate and provide insight.	Hao Yang, EPRI
10:30	Break	
11:00	Recap – Takeaways Action Items Topics for next Time	M. Thow, EPRI M. Woodby, EPRI
12:00 pm	ADJOURN	

Opening Comments



Please participate!



Engage EPRI and the PRR Team

Engage and provide meaningful dialog and opportunities to network and collaborate.



Share Impactful Research

Share information about the value of EPRI's research, recent success stories, and technology transfer opportunities.



Identify Member Opportunities

Work with members to identify opportunities or technical challenges facing the industry.

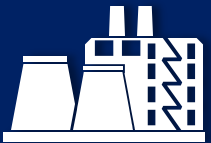


Strategic Focus Areas

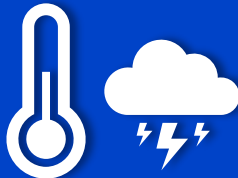
EPRI's Nuclear Research Focus



**MORE
MEGAWATTS**



**CLIMATE
RESILIENCE**



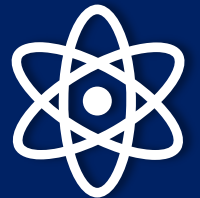
**WORKFORCE
DEVELOPMENT**



**ADVANCED
REACTORS**



FUSION



Fuels and Chemistry Strategic Priorities

- Evaluation of global critical mineral lists and control chemicals toxic to humans and biota may provide value
- Comprehensive evaluation of cost and benefits of closing the fuel cycle should be conducted
 - Technoeconomic analysis project good first step
- Revolutionary fuel concepts to enable such changes could be specified based on limitations of existing plants as boundary conditions
- Expanded use of decommissioning on the fly may provide value
- Work on advanced reactor conditions for waste and radiation protection is of value
- Optimized decommissioning to enable restart may be of interest

Materials Strategic Priorities

- Leveraging AI/ML for material Characterization
- Adaptive Feedback Welding leveraging AI
 - Canister Closure Welding at Hanford
- PM-HIP opportunities for larger scale components
- AI Technology for UT Inspections
 - Ringhals lead for qualification through the ENIQ framework
 - Used in June outage for RVUH Inspections with Level III UT technician reviewing flagged areas by AI vs reviewing all inspection Data
- Focused on new technology and how implementation will benefit the nuclear fleet long term
- How can we accelerate this work for the industry?
 - Leveraging our collaborative model

Plant Performance Strategic Priorities

- Integrating EPRI plant reliability tools into Daily Operations
 - Enabling easy access to EPRI datasets through API frameworks
 - Integrating AI and Machine Learning applications into PMBD
 - A system that transforms raw data into actionable insights for maintenance strategy optimization
- Leveraging Risk Insights and Condition Monitoring for Life Beyond 80
 - Using Risk Informed Aging Management to optimize inspection, repair and mitigation activities
 - Applying Continuous Online Monitoring technology to reduce or eliminate time-based preventive maintenance
- Reliability and Resilience in Extreme Environmental Conditions
 - Research and modeling for condition forecasting
 - Developing a graded approach to balance cost and risk to operations with a decision-making tool for implementation



Industry Issues Update

Industry Collaboration on Main Reactor Pump (MRP) Seal Reliability

INPO

- ❑ Industry trending and communicating insights from those reviews
- ❑ Addressing organizational and behavioral factors contributing to MRP Seal reliability

EPRI

- ❑ Focus on technical research to address industry gaps and needed solutions
- ❑ Direct EPRI SME member support
- ❑ Generic technical solutions, such as:
 - Main Reactor Pump Seal Best Practices, Revision
 - EPRI Newsletter: Seal Face Flatness
 - 2025 Planned Products
 - 3D Models
 - Failure Analysis MRP Symposium, 2025
 - Guide

OEMs

- ❑ Insights and implementation
- ❑ OEM's Reviewing and Revising Guidance

Owner Groups (BWROG/PWROG)

- ❑ NSSS-specific design and operation
- ❑ Insights and implementation

Industry Collaboration on Feedwater (FW) related scrams

INPO

- ❑ Industry trending and communicating insights from those reviews
- ❑ Note: EPRI does support these efforts with SMEs and technical insights
- ❑ Addressing organizational and behavioral factors contributing to FW reliability

EPRI

- ❑ Focus on technical research to address industry gaps and needed solutions
- ❑ Direct EPRI SME member support
- ❑ Generic technical solutions, such as:
 - Positioner Maintenance Guide
 - Feedwater Reg. Valve PMBD Template
 - Valve Online Monitoring
 - Feedwater Best Practices Guide (planned 2025 publication)
 - Many Feedwater Component/System Guidance Documents

Owner Groups (BWROG/PWROG)

- ❑ NSSS-specific design and operation
- ❑ Insights and implementation

Industry Collaboration on Transformer Reliability

TSUG

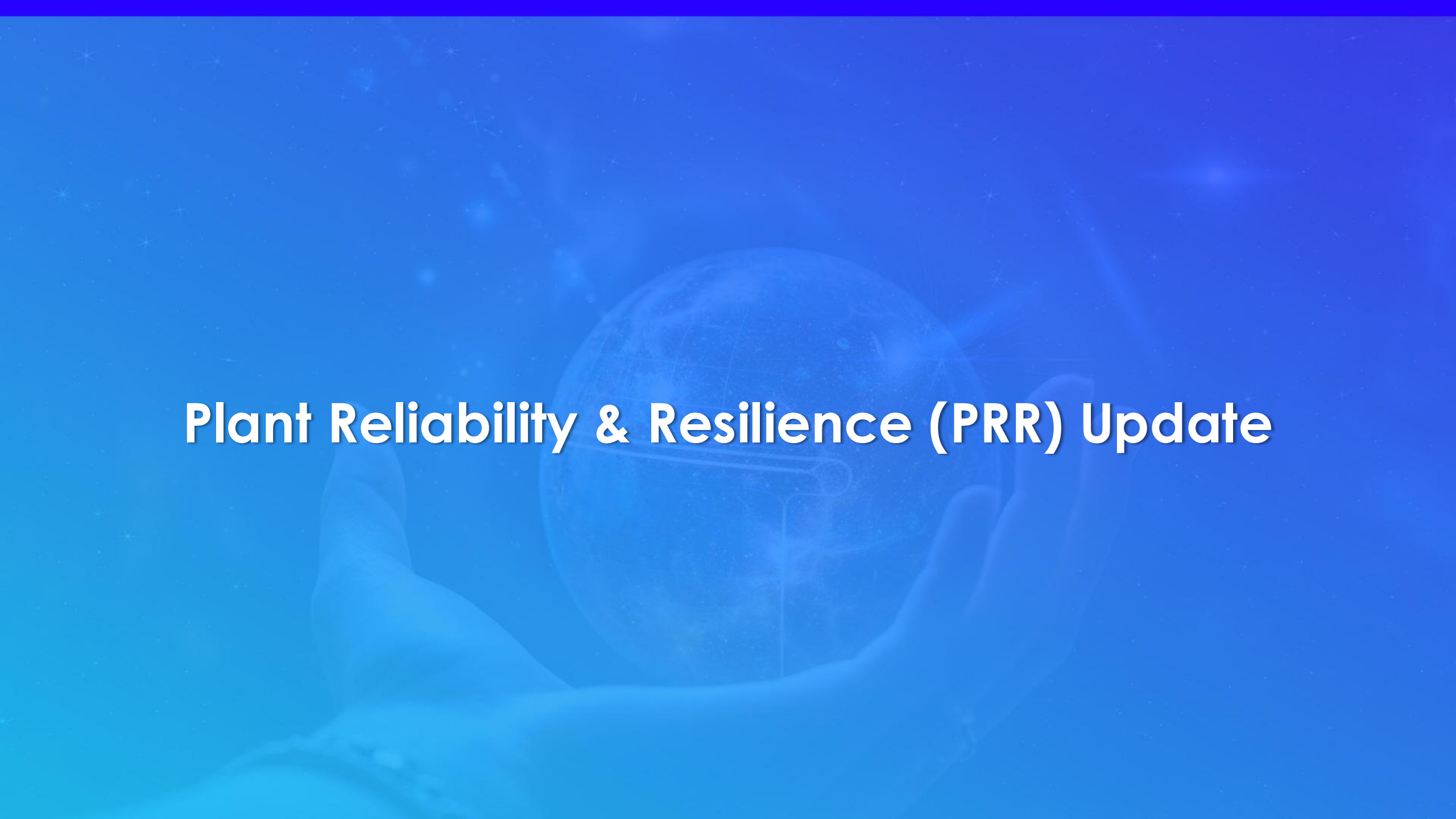
- ❑ Industry trending and communicating insights from those reviews
- ❑ revising the PMBD template to improve the maintenance and testing
- ❑ equipment monitoring devices/technology (bushing Monitoring and new techniques of oil analysis)
- ❑ electrical testing that would identify undesirable equipment conditions

EPRI

- ❑ Focus on technical research to address industry gaps and needed solutions
- ❑ Direct EPRI SME member support
- ❑ Generic technical solutions, such as:
 - revising the PMBD template to improve the maintenance and testing

Key Initial Actions

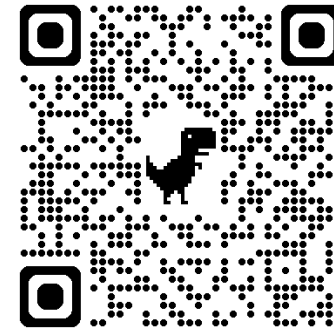
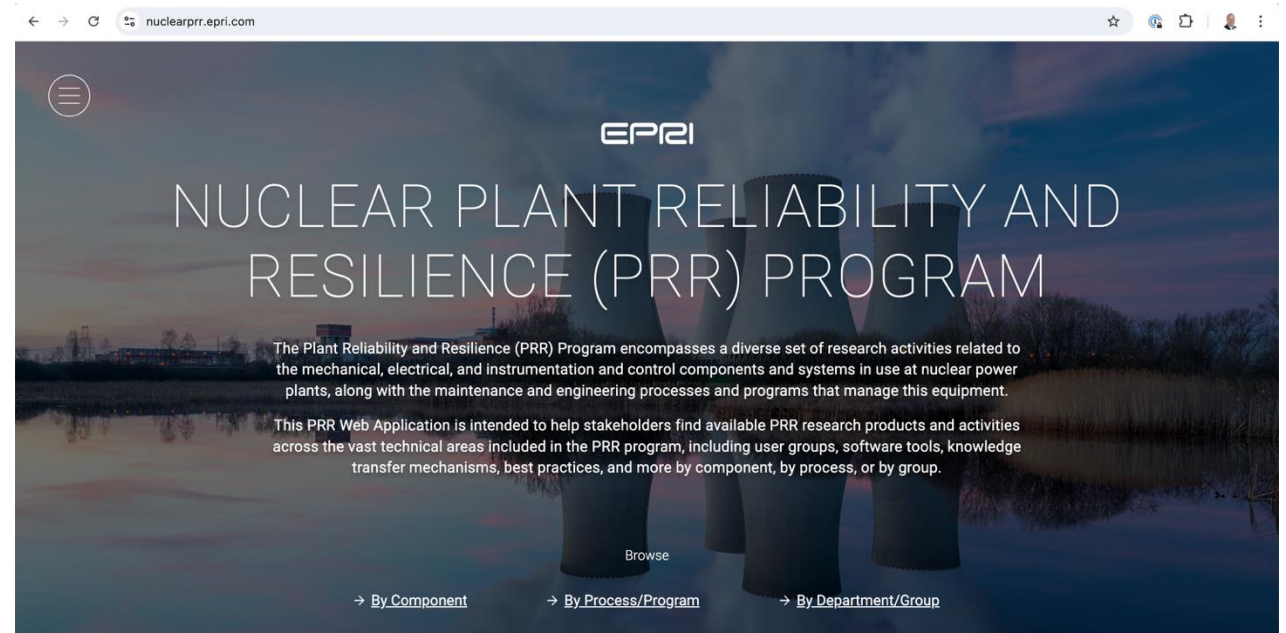
- ❑ Investigate stray gassing issues in new transformers - EPRI
- ❑ compile transformer and bushing testing data to identify best practices for sting protocols - EPRI
- ❑ Review all relevant transformer and bushing monitoring systems and present updates on remote monitoring improvements - EPRI



Plant Reliability & Resilience (PRR) Update

EPRI Nuclear PRR WebApp

- Please visit and bookmark this link
- PRR WebApp is gateway to an organized suite of EPRI PRR research products and resources
- It covers all the engineering and maintenance areas included in the PRR program.
- Designed to help you find what you need quickly
- Designed to be international friendly; for all EPRI PRR members



<https://NuclearPRR.epri.com>

Statistics and Notables for PRR in 2024 [2025]

- 👍 Over 61 User Group or Large Workshops in 2024 [62 in 2025]
- 👍 28 TTA Nominations Submitted - 2 wins [48/TBD]
- 👍 ~1000 Member Hot Line assists [>900 to date]
- 👍 4 CBT's developed [6 in 2025]
- 👍 More Wiki Content released (2024 and 2025 wiki releases)
- 👍 PRR Website AND User Forums released
- 👍 ~33 completed deliverables in 2024 [40+ in 2025]

Example 2025 PRR Focused Work

- Collaboration and Integration
 - PMBD 7.5 Beta
 - RCP Seal and Feedwater engagement across industry
 - Extreme Environmental Conditions
 - DSE Framework (Over 11 different guidelines being harmonized)
 - CHECWORKS 5.0
 - Thermal Performance Troubleshooting Webtool Beta
 - Global OE / Lessons Learned being collected. Get involved!
 - New Wiki's are being planned, Minor improvements to the PRR website



2025 PRR: Deliverables

Product ID	Title	Content Type	Planned Completion Date
3002031639	Transformer and Switchyard Walk-down Inspection Checklist v2.0	SOFTWARE	6/20/2025
3002032007	Maintenance Work Instruction Planning Guidance, Rev 3	TECHNICAL REPORT	7/31/2025
3002031963	Monitoring and Diagnostics Alert Management CBT	SOFTWARE	7/31/2025
3002033233	DG Tune - Emergency Diesel Generator (EDG) Governor Tuning Aid and Post-Maintenance Test (PMT) Tool for the Nuclear Industry	WHITE PAPER	7/31/2025
3002029529	Transformer and Switchyard Wiki	SOFTWARE	8/9/2025
3002033213	Digital Engineering Guide, Revision 1-Training for Practitioners	TRAINING	9/12/2025
3002032013	Common CBM Analysis Platform Demonstration	TECHNICAL BRIEF	10/3/2025
3002032005	Torsional Vibration Monitoring: A Health Monitoring Strategy for Wear in Deep Draft Vertical Pumps	TECHNICAL REPORT	10/17/2025
3002031996	Annual Instrumentation and Control (IC) Operational Data Review: 2024 Baseline Report	TECHNICAL REPORT	10/31/2025
3002032019	Service Water Piping Guideline, Revision 1	TECHNICAL REPORT	10/31/2025
3002032017	Evaluation of FAC Predictions using the Homogeneous and Drift Flux Models for Two Phase Flow; CHUG Position Paper 14, Revision 1	WHITE PAPER	10/31/2025
3002031207	Cyber Security Technical Assessment Methodology (TAM)- Risk Informed Exploit Sequence Identification and Mitigation: Revision 2	GUIDE	11/1/2025
3002031208	Network Design Guide (NDG)- Use Case Based Approach for Operational Technology (OT) Networks: Revision 1	GUIDE	11/1/2025
3002031209	Digital Maintenance and Management Guide (DMG): Revision 0	GUIDE	11/1/2025
3002031210	Digital Systems Configuration Management Guide (DCMG): Revision 1	GUIDE	11/1/2025
3002031211	Digital Systems Requirements Engineering Guide (DREG): Revision 1	GUIDE	11/1/2025
3002031212	Digital Systems Testing Strategies and Methods (DTS): Revision 1	GUIDE	11/1/2025
3002031213	Digital IC Lifecycle Strategy Guide (DLSG): Revision 2	GUIDE	11/1/2025
3002031215	Human Factors Analysis Methodology (HFAM) for Digital Systems- A Risk-Informed Approach to Human Factors Engineering: Revision 1	GUIDE	11/1/2025
3002031216	Digital Reliability Analysis Methodology (DRAM): Revision 1	GUIDE	11/1/2025
3002031217	Hazards and Consequence Analysis for Digital Systems (HAZCADS): Revision2	GUIDE	11/1/2025
3002031218	Digital Engineering Guide (DEG) - Decision Making Using Systems Engineering: Revision 1	GUIDE	11/1/2025
3002032246	Program on Technology Innovation: Data Visualization Tool for Cooling Water Intake Structure Event Forecasting - Phase 3	TECHNICAL UPDATE	11/1/2025
3002032010	Limitorque Valve Actuator Life Extension Part 2 - Qualification, Aging, and Mechanical Loading Evaluation	TECHNICAL REPORT	11/14/2025
3002031974	Circuit Board Battery Failures: Embedded Battery Application and Maintenance Evaluation for IC Circuit Cards	TECHNICAL REPORT	11/21/2025
3002031973	Commercial Grade Dedication Method 1, Special Tests and Inspection -On-demand training	SELF PACED TRAINING	11/21/2025

2026 PRR: Maintenance and Engineering Planned Deliverables

Deliverable Title	Type
CHECWORKS 5.0 - Beta Version	Web Application
Flow accelerated corrosion in BWR Bottom Head Drain Lines: 2026 Update	Technical Report
Feedwater Heater Integrity Assessment Guide	Technical Report
EPRI Feedwater Reliability Guide	Technical Report
Extreme Environmental Conditions: Digital Twin Evaluation	Technical Report
Methodologies and Processes to Optimize Environmental Qualification Replacement Intervals – Update to TR-104873	Technical Report
Beyond Tan Delta Research Update	Technical Update
Evaluation of Insulation and Conductor Degradation in Wetted Low Voltage Cables – Tech Update	Technical Update
TI Use of Graphene Coating for Anti- and De-Icing	Technical Brief
TI Debris Forecasting Project, Phase 4	Tech Update
Preparing station HVAC systems for climate change	Technical Report
Evaluation of Transformer Test Data using AI	Software
Operating Experience and Lessons Learned on Single Point Vulnerabilities, Mitigations and Eliminations strategies	Technical Report
Limitorque Life Extension: Phase 2 Update	Technical Report
CT Installation Testing Guide	Technical Report
Extreme Environmental Conditionals – Jellyfish Projection	Tech Update
Condenser Fix-a-Flat: Scale up and Environmental Testing	Tech Update
Recommended Practices for Evaluating and Installing Non-Structural SIPP Liners	Technical Report

2026 PRR: I&C Planned Deliverables

Deliverable Title	Type
Advanced Risk-Assurance Methods Report	Technical Report
Radiation Monitor Calibration and Source Utilization: Key Concepts and Definitions	Guide
Radiation Monitor Replacement Change Management	Guide
Radiological Monitoring Topics During Accident Conditions	Technical Report
Efficacy of Equipment Certification for EMC	Technical Report
Digital Twins for Nuclear Power Plant Applications	Technical Report
Cybersecurity Program Guide	Guide
Electromagnetic Compatibility Assessment Methodology (EMCAM): Revision 1	Guide
EPRI Training on EMC Fundamentals, TAM, HFAM	Training
DEG Implementation for Managers Training	Training
Annual Instrumentation and Control Operating Experience Review: 2025 Baseline Report	Technical Report

2026 EPRI PRR User Group Meetings - Planned

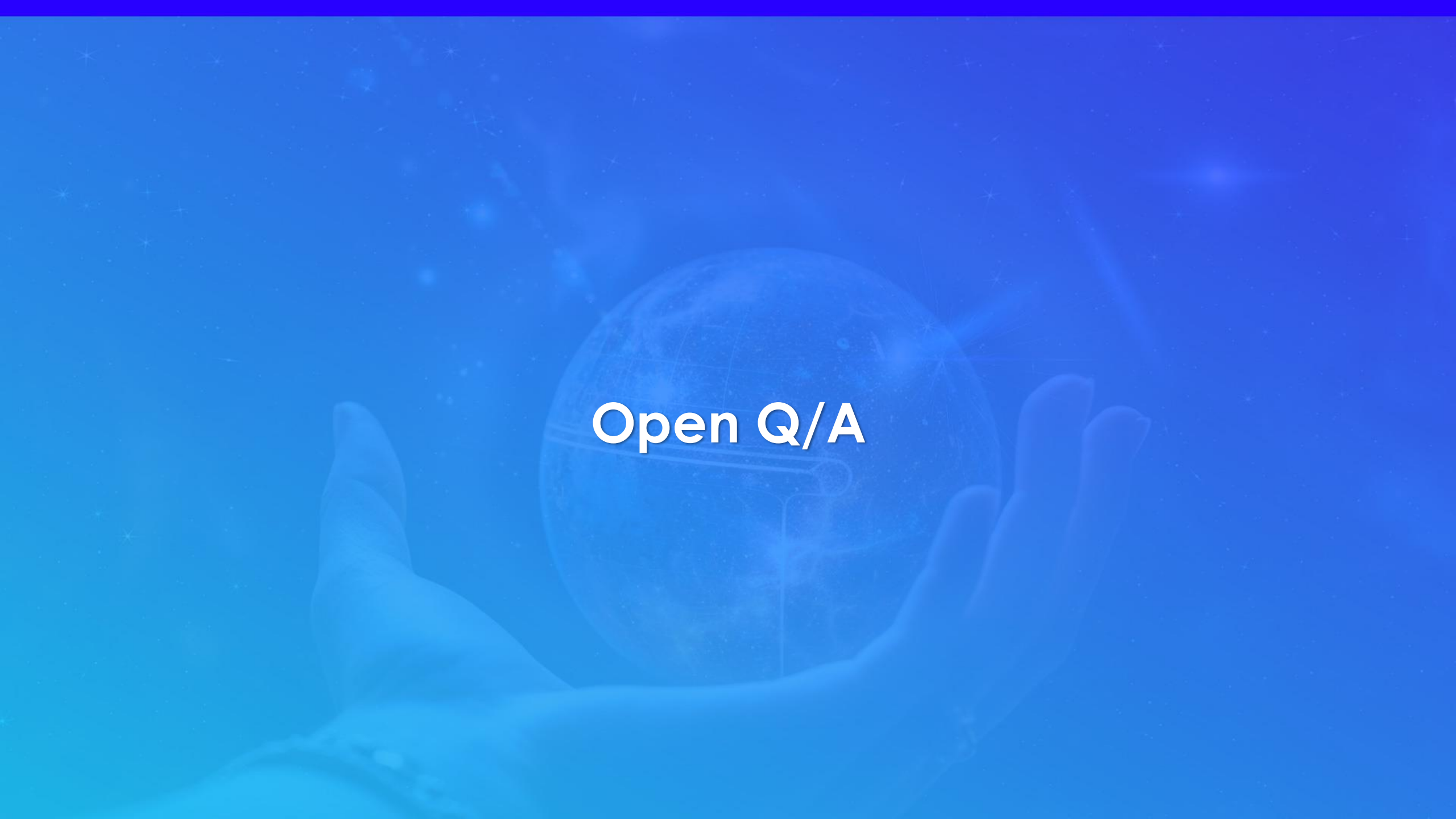
Meeting Name	Dates	Location
Maintenance Rule User Group (MRUG)	January 21-23, 2026	Charlotte, NC
Large Electric Motors User Group (LEMUG)	January 26-29, 2026	Austin, TX
Digital Systems Engineering User Group (DSEUG)	January 27-28, 2026	Charlotte, NC
CHECWORKS UG	January 27-29, 2026	Charlotte, NC
PRR RIC and NPC Advisory Meeting	February 9-12, 2026	Phoenix, AZ
Procurement Engineering and Related Topics Symposium (PeARTS)	February 16-20, 2026	Clearwater, FL
Equipment Reliability Working Group (ERWG)	March 2-6, 2026	Charlotte, NC
Cyber Security UG	March 16, 2026	TBD
European PRR Workshop	March 24-26, 2026	Manchester UK
Digital Operational Technology UG (DOTUG)	May 12-14, 2026	Charlotte, NC
Fleetwide M&D Workshop	May 19-21, 2026	Birmingham, AL
Balance-of-Plant Corrosion and Heat Transfer Conference	June 8-12, 2026	Westminster, CO
Seismic Qualification Reporting and Testing Standardization (SQRSTS)	June 9-11, 2026	Charlotte, NC
Hoisting, Rigging, Cranes User Group (HRCUG)	June 9-11, 2026	Phoenix, AZ
Cable Users Group	June 15-19, 2026	Washington, DC
Nuclear Utilities Coating Council (NUCC)	July 7-9, 2026	Charlotte, NC
Condition Based Maintenance (CBM) and Terry Turbine (TTUG)	July 20-24, 2026	Clearwater, FL
Transformer Switchyard User Group (TSUG)	July 20-25, 2026	Boston, MA
Maintenance Rule User Group (MRUG)	August 4-6, 2026	Charlotte, NC
Procurement Engineering and Related Topics Symposium (PeARTS)	August 11-13, 2026	Clearwater, FL
Digital Systems Engineering User Group (DSEUG)	August 18-19, 2026	Charlotte, NC
Electromagnetic Compatibility User Group (EMCUG)	August 20, 2026	Charlotte, NC
PRR RIC and NPC Advisory Meeting	August 31-September 3, 2026	San Diego, CA
Electrical and I&C Reliability User Group	September 8-10, 2026	Virtual (Webex)
Equipment Reliability Working Group (ERWG)	September 14-17, 2026	Charlotte, NC
Monitoring & Diagnostics UG	September 17, 2026	Virtual (Webex)
VVER Club	October 2026 (TBD)	Central Europe (TBD)
Digital Operational Technology UG	November 11, 2026	Virtual (Webex)
International PeARTS	TBD – 1 or 2 Week November	TBD - Europe
Maintenance Work Planning User Group (WPUG)	TBD	Charlotte, NC



TOGETHER...SHAPING THE FUTURE OF ENERGY®



Day 1 Wrap-up



Open Q/A



Group Photos

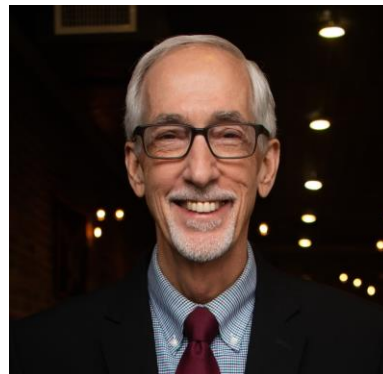
Developing Aging Management Programs (AMPs) for Passive Components

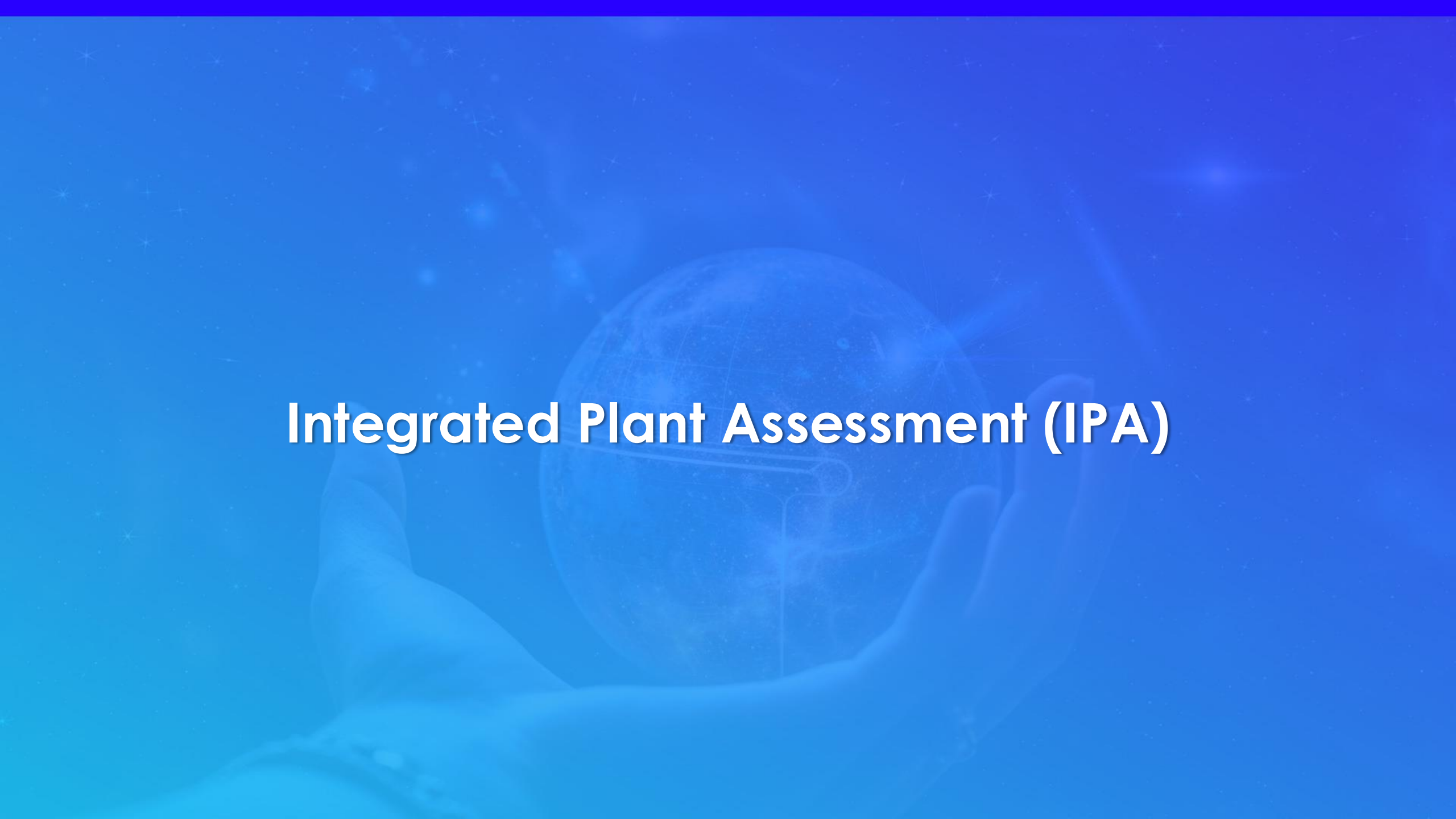
Safe, Successful, and Supported – Long-Term Operation



Garry G. Young
Technical Executive

EPRI Nuclear Plant Performance Workshop
Shanghai, China
October 20-22, 2025

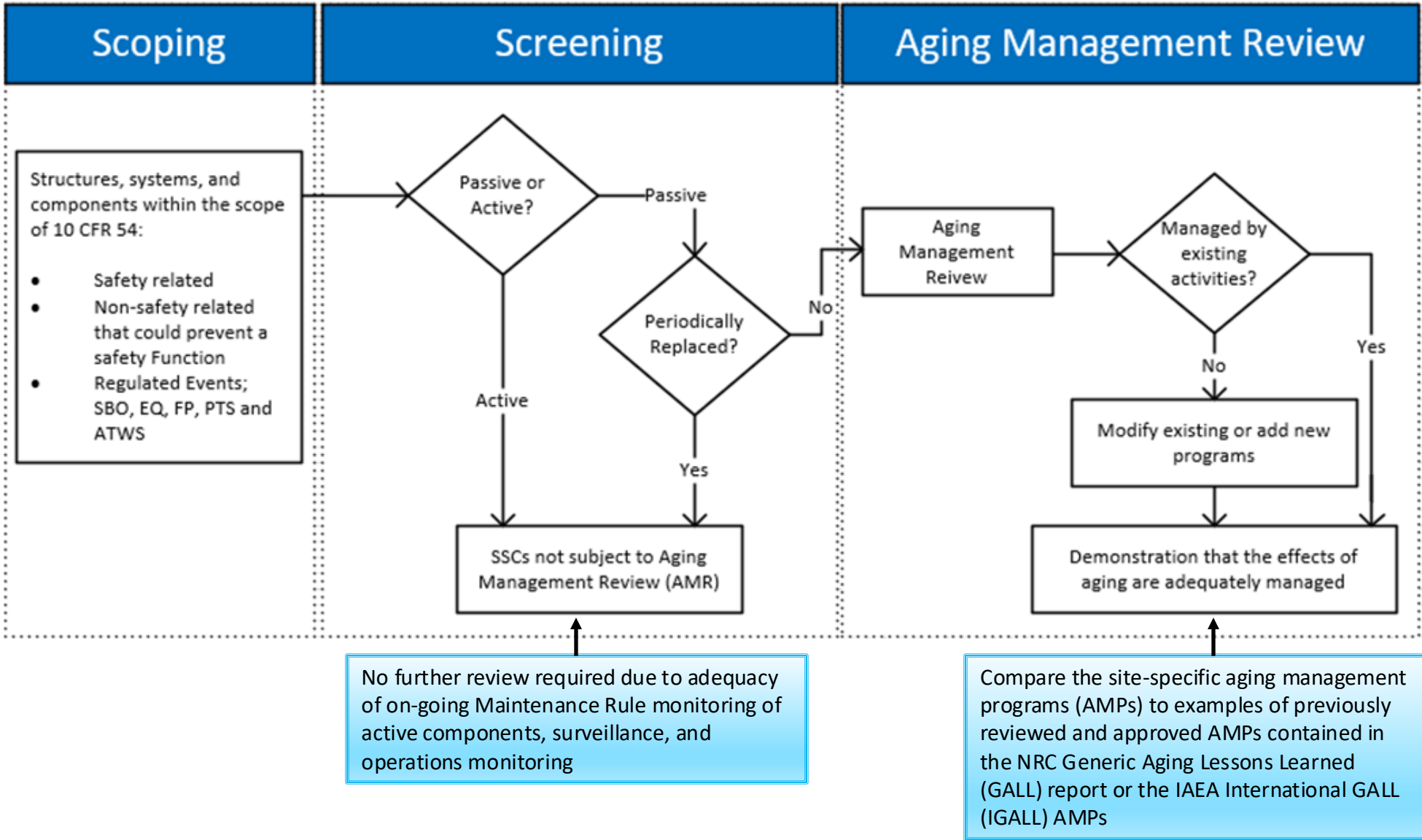




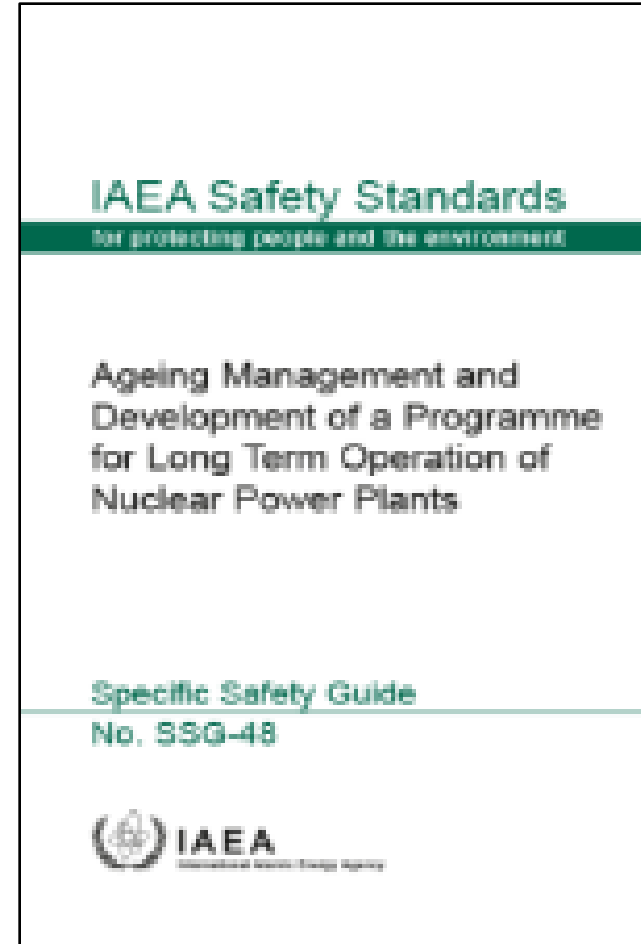
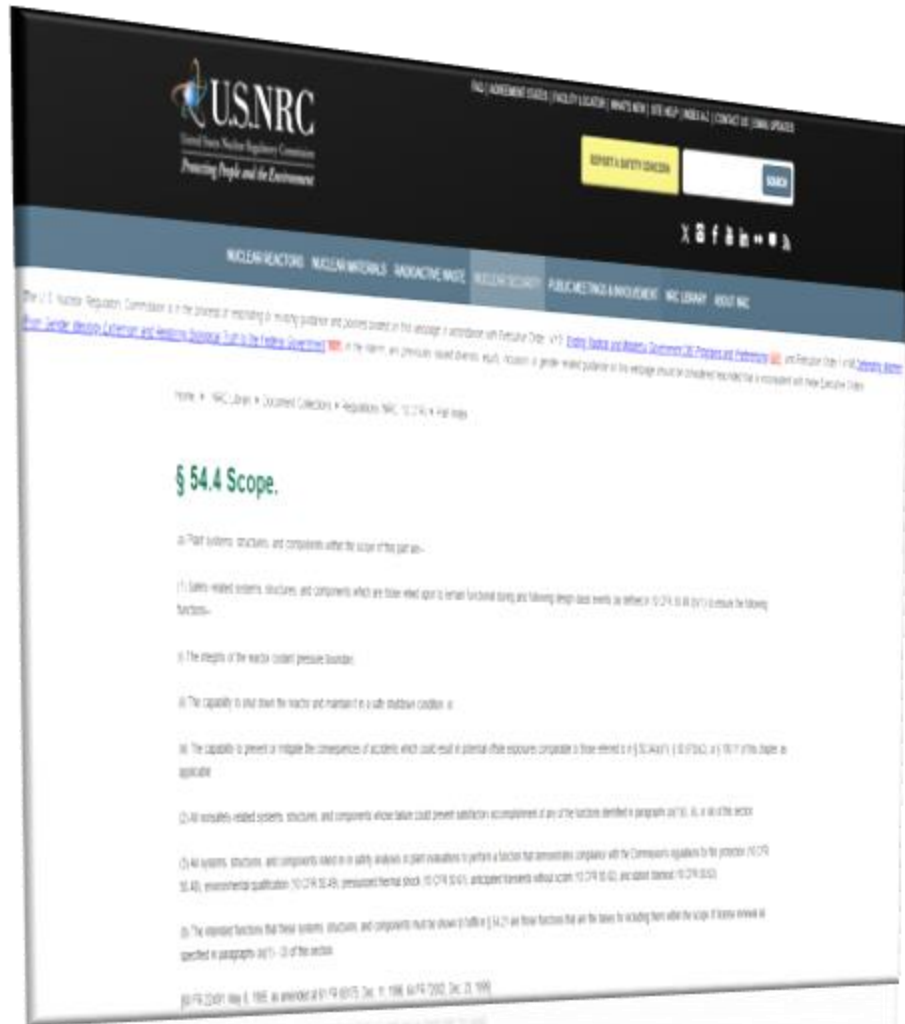
Integrated Plant Assessment (IPA)

Integrated Plant Assessment (IPA) Flowchart

A plant owner assessment that demonstrates that a nuclear power plant facility's structures and components subject to aging management review have been identified and that the effects of aging on the functionality of such structures and components will be managed to maintain continued operation such that there is an acceptable level of safety during the period of extended operation (PEO).



What Components are “in-scope”?



IPA Scoping – “Safety-Related” (SR)

- Safety-related systems, structures, and components (SSCs) which are relied upon to function during and following design-basis events to ensure the following functions:
 - Integrity of the reactor coolant pressure boundary
 - Capability to shut down the reactor and maintain it in a safe shutdown condition
 - Capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures

IPA Scoping – “Non-Safety Related” (NSR)

- All non-safety related SSC's whose failure could prevent satisfactory accomplishment of any function identified as SR; examples:
 - Nonsafety-Related SSCs that [functionally] support Safety-Related functions
 - Nonsafety-Related Systems, Structures, and Components directly connected [and provide structural support] to Safety-Related SSC's
 - Nonsafety-Related Systems, Structures, and Components with potential for spatial interaction with Safety-Related SSCs

IPA Scoping – “Non-Safety Related” (NSR) *Continued*

[functional] support of Nonsafety-Related SSCs for a safety-related function.

Examples:

- A nonsafety-related deep well system credited for supporting SR Service Water system as back-up source of make-up water
- A nonsafety-related instrument air system that is relied upon to operate main steam relief valves.
- Nonsafety-related service air components that maintains air pressure on fuel pool gate seals

IPA Scoping – “Non-Safety Related” (NSR) *Continued*

Nonsafety-Related SSCs directly connected [**and provide structural support**] to Safety-Related SSCs:

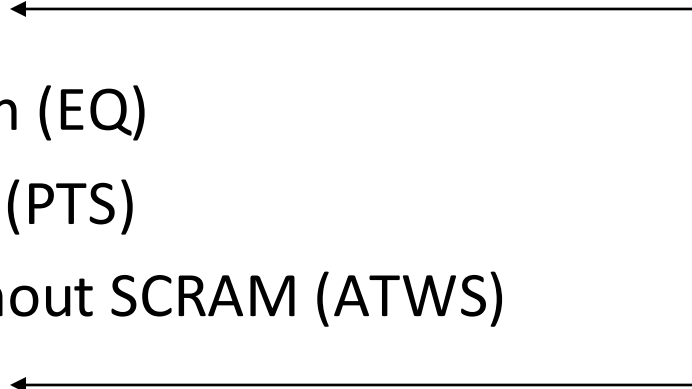
- Typically applies to Safety-Related / Nonsafety-Related interfaces
- For this condition, the Nonsafety-Related piping/components/supports up to and including the first seismic/equivalent anchor beyond the interface, would be in scope.

IPA Scoping – “Non-Safety Related” (NSR) *Continued*

Nonsafety-Related SSCs with potential for **spatial interaction** with Safety-Related SSCs:

- Where any Nonsafety-Related piping system (either not connected to Safety-Related piping, or beyond the equivalent anchor), could fail and affect a Safety-Related intended function.
- This is typically addressed on a ‘spaces’ approach.
 - Identify all the spaces that contain Safety-Related SSCs, and all the Nonsafety-Related SSCs in that same space would be in scope. Site-specific walkdowns are typically performed to confirm these conditions.
- Alternative: mitigative measures (pipe whip restraints, jet impingement shields, seismic supports, spray and drip shields, flood barriers) can be credited and managed for aging instead

IPA Scoping – Other Regulatory Requirements

- All SSCs relied upon in safety analyses or plant evaluations to perform a function that demonstrates compliance with regulations for:
 - Fire Protection (FP)
 - Environmental Qualification (EQ)
 - Pressurized Thermal Shock (PTS)
 - Anticipated Transients without SCRAM (ATWS)
 - Station Black Out (SBO)
- 
- Most likely to bring buried pipe components into scope for LR

IPA Scoping Process

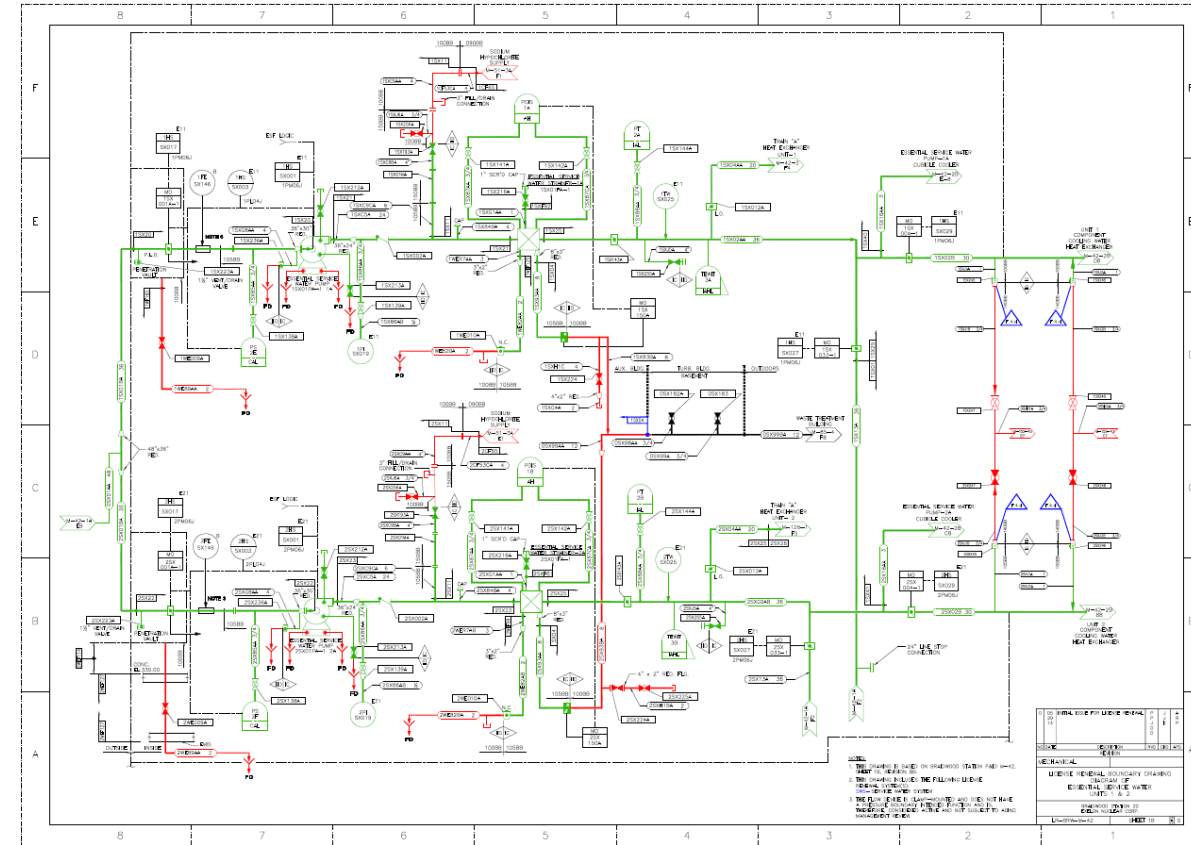
- Scoping is performed on a system and structure basis
- Every system and structure at the plant must be reviewed to determine if it is in scope of the IPA
- Only those systems and structures that are in scope will need to be described in project documents
 - A Scoping Basis Document is prepared to document the intended functions of the system/structure
- The reasons for a system or structure not being in scope must also be documented in project documents

Intended Functions

1. Provide primary containment boundary. The Compressed Air System includes piping that penetrates the containment and includes equipment used for testing the personnel air lock seals. The containment penetrations, including containment isolation valves, are relied upon to ensure containment integrity. 10 CFR 54.4(a)(1)
2. Resist nonsafety-related SSC failure that could prevent satisfactory accomplishment of a safety-related function. Nonsafety-related service air components are required to provide functional support to maintain air pressure on the fuel pool gates inflatable seals. The Compressed Air System includes nonsafety-related piping that is directly attached and provides structural support to safety-related piping. The Compressed Air System also includes nonsafety-related water filled drain piping that has the potential for spatial interaction with safety-related SSCs. 10 CFR 54.4(a)(2)
3. Relied upon in safety analyses or plant evaluations to perform a function that demonstrates compliance with the Commission's regulations for Environmental Qualification (10 CFR 50.49). Solenoid valves and position switches associated with Compressed Air System air-operated containment isolation valves are included in the scope of the Environmental Qualification Program. 10 CFR 54.4(a)(3)

IPA Scoping Process – Continued

- Boundary drawings are prepared for each mechanical system:
 - Drawings highlighted to show the system pictorially, typically using modified P&ID's
 - Boundary drawings show:
 - Systems that are within the scope of LR
 - Systems (& portions thereof) not within the scope of the IPA
 - Boundaries of system interfaces
 - Scoping function boundaries [SR vs NSR]



Green: SR function

Source: ML13154A218

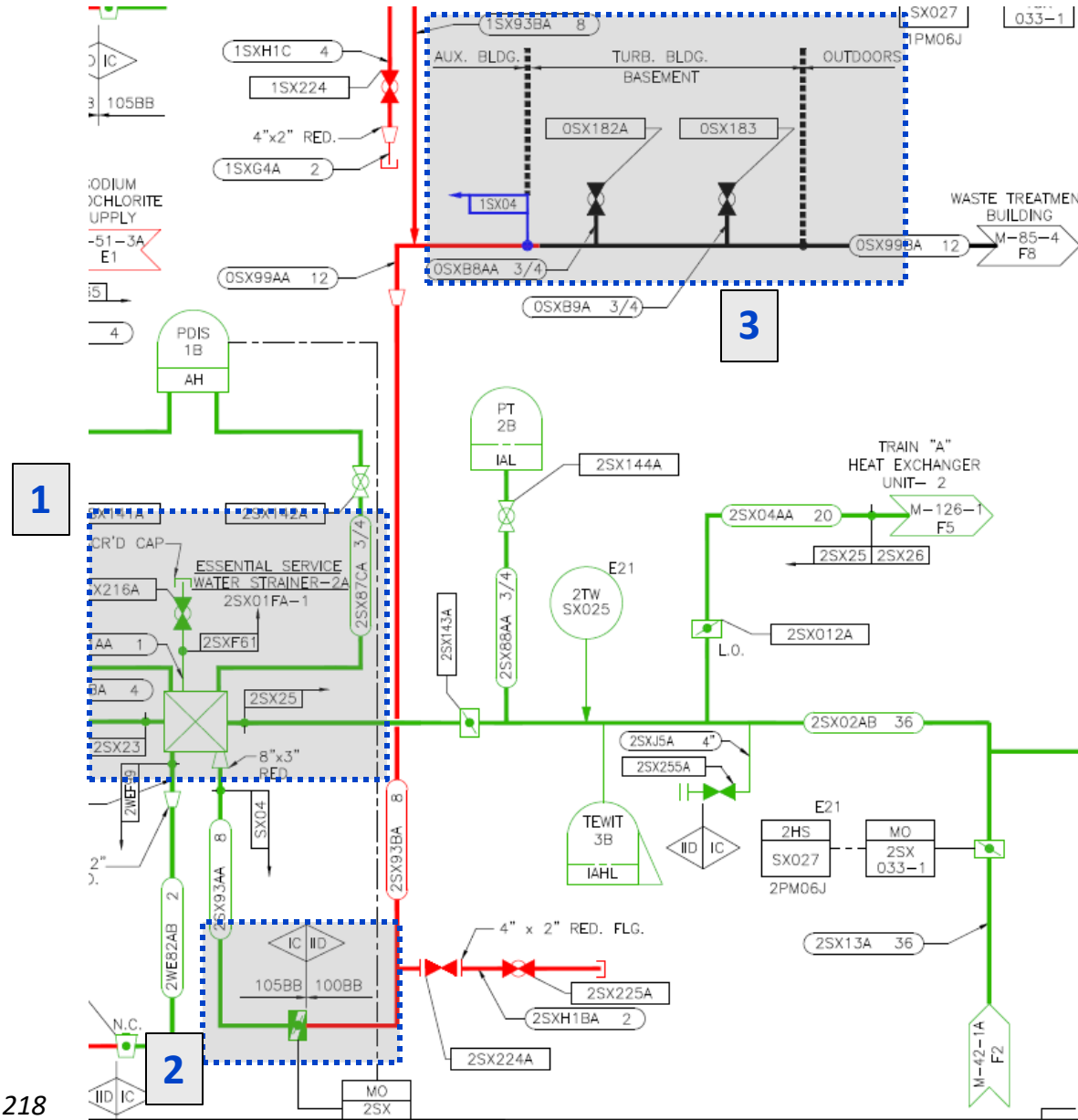
Red: NSR function

Black: not within scope

IPA Scoping Example

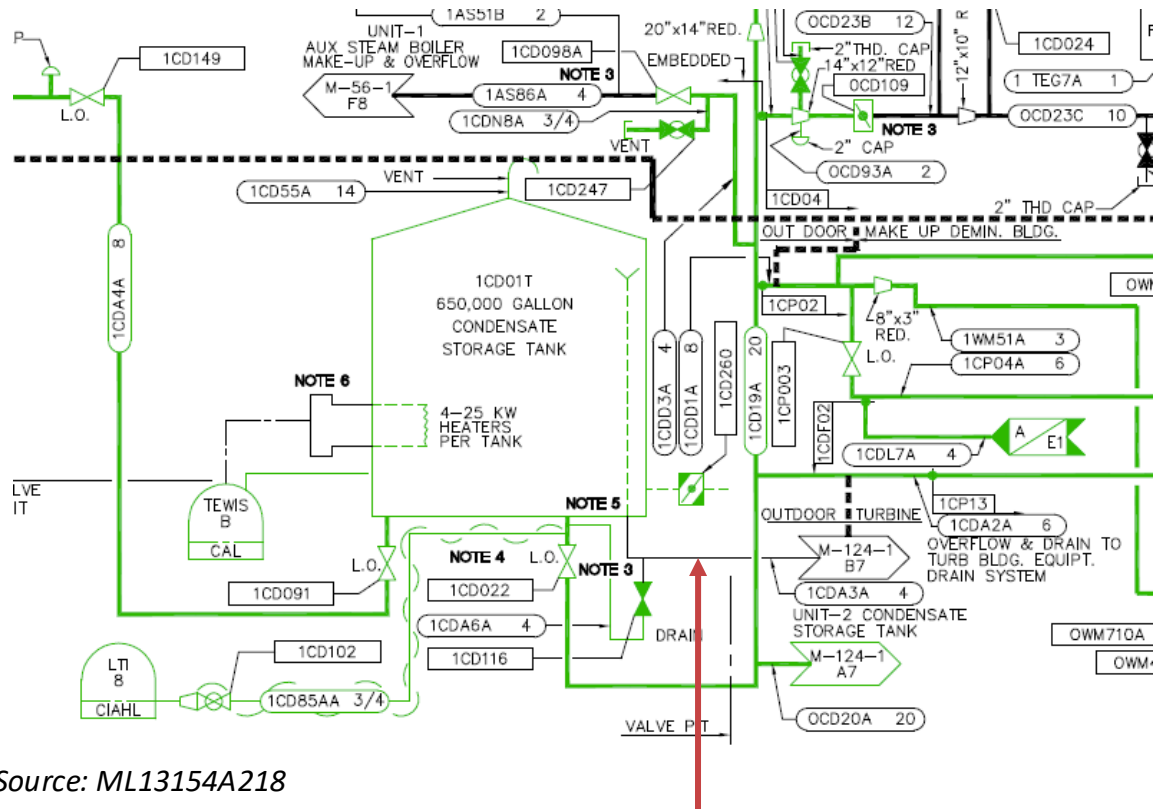
System:

- **Essential Service Water**
- 1) ESW Strainer (Aux Bldg)
 - 2) Class break (SR-NSR)
 - 3) Building transition
 - In-scope for structural support beyond wall
 - Past anchor in Turbine Building, no longer in scope for spatial or structural support



Source: ML13154A218

Using Boundary Drawings



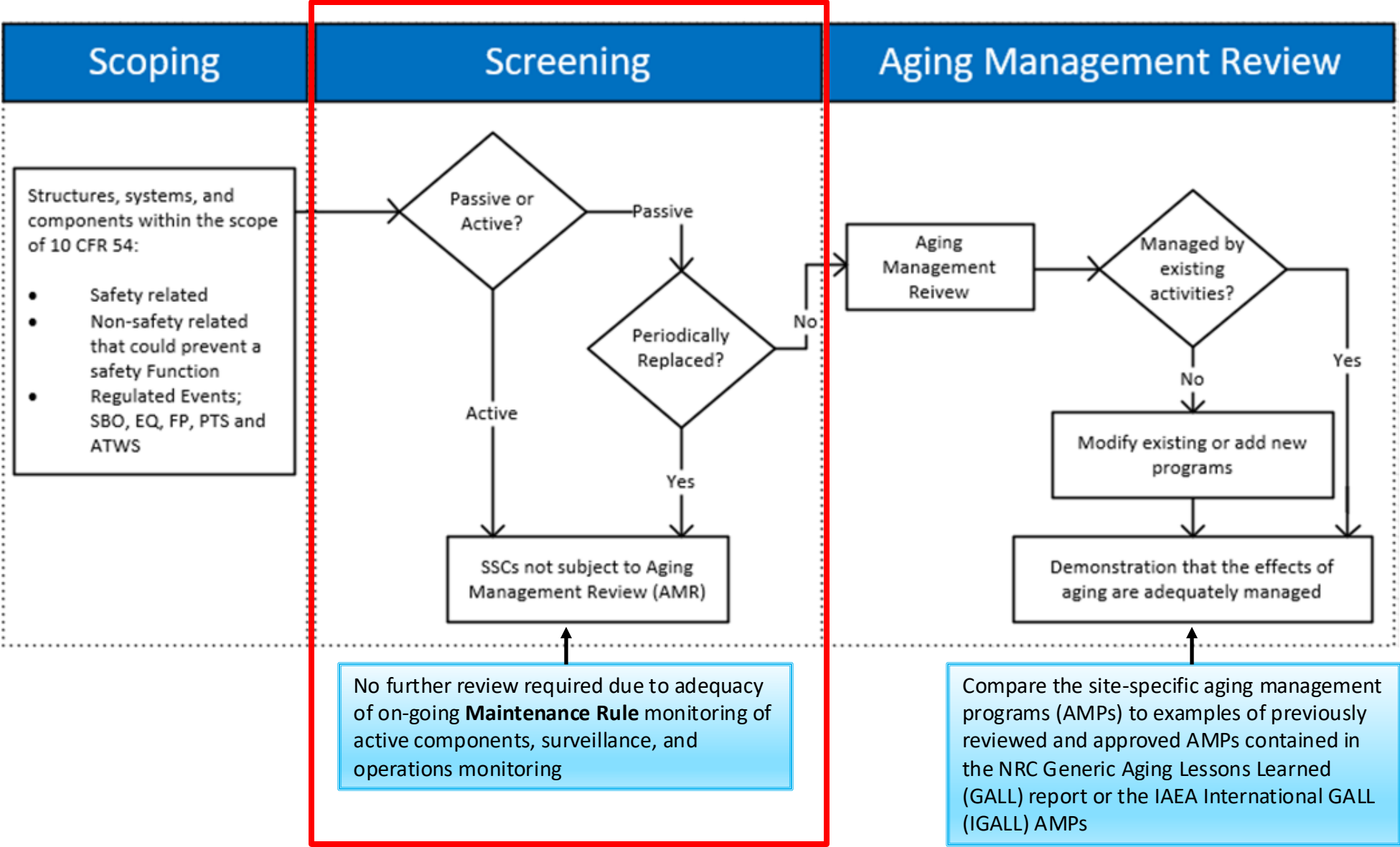
Source: ML13154A218

5. THE STANDPIPE SUPPORTS THE (A)(3) FUNCTION OF THE CONDENSATE STORAGE TANK BY MAINTAINING AN ADEQUATE WATER INVENTORY FOR THE AUXILIARY FEEDWATER SYSTEM. THE ATTACHED DRAIN PIPING IS NOT REQUIRED TO SUPPORT THIS FUNCTION. THE NONSAFETY-RELATED PIPING ATTACHED AT THIS BOUNDARY IS NOT REQUIRED FOR STRUCTURAL SUPPORT BECAUSE THE IN SCOPE PIPING IS NOT SAFETY-RELATED. THE PIPING BEYOND THIS BOUNDARY DOES NOT HAVE THE POTENTIAL FOR SPATIAL INTERACTION BECAUSE IT IS NOT LOCATED IN THE VICINITY OF SAFETY-RELATED COMPONENTS, AND IS, THEREFORE, NOT WITHIN THE SCOPE OF LICENSE RENEWAL.



Source: February BPIG 2018, Presentation C01

Integrated Plant Assessment (IPA) Flowchart



IPA Screening

- After Scoping is complete, next step in Integrated Plant Assessment (IPA) is Screening:
 - Determine which components are **ACTIVE vs PASSIVE and LONG-LIVED**
 - Passive: components that perform an intended function without moving parts or a change in configuration or properties
 - Long Lived: components that are not subject to replacement based on a qualified life or specified time period

IPA Screening

- Examples of Passive Intended Functions:

- Pressure boundaries
- Leakage boundaries
- Heat transfer

- Examples of Passive Components:

- Piping
- Heat exchangers
- Valves (valve body = passive, valve actuator = active)
- Pump casing
- Restricting orifice

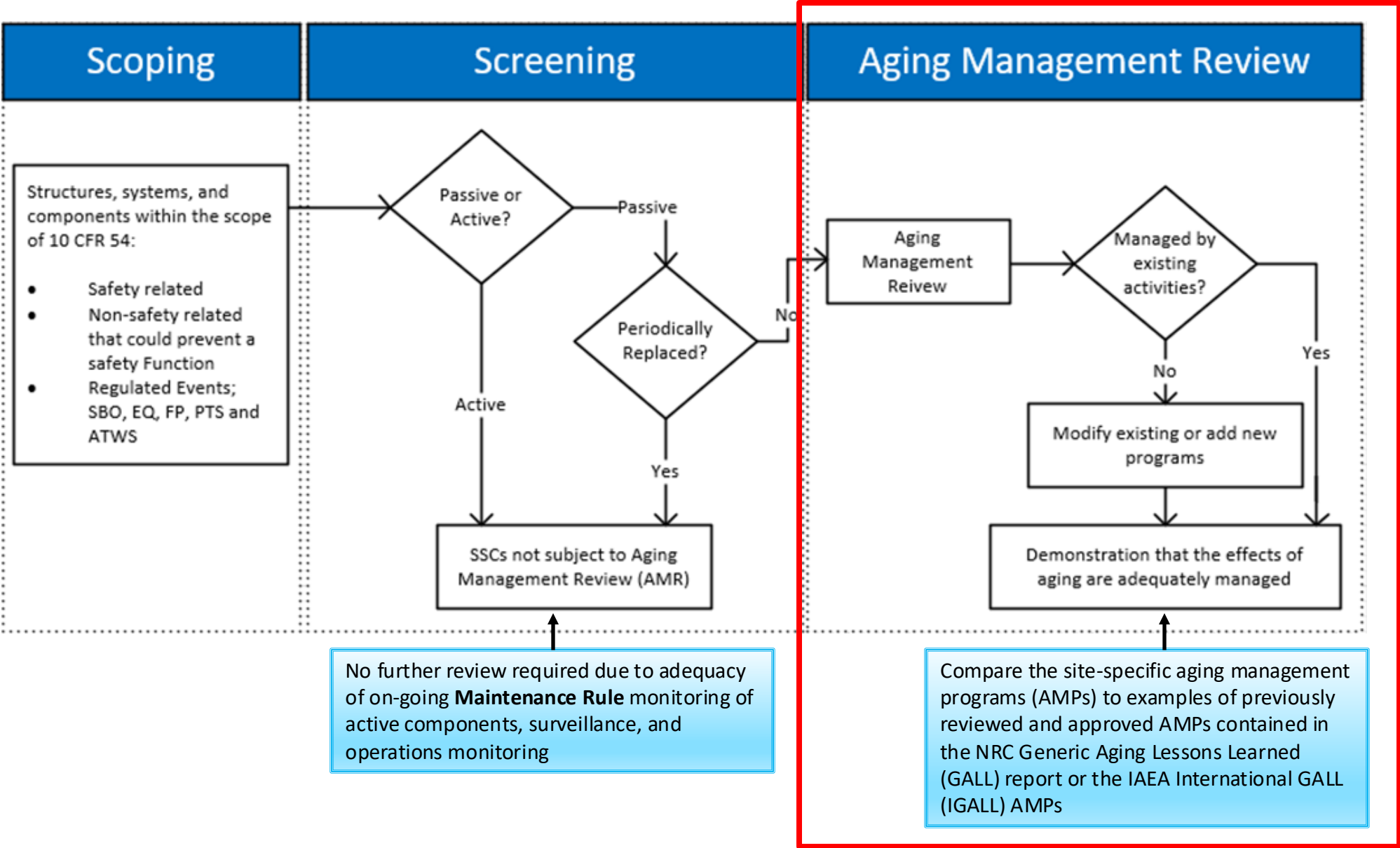
- Examples of Short-Lived Components:

- Oil, grease
- Fire extinguishers
- Any component planned and managed to be periodically replaced
- Fuel assemblies



Aging Management Review (AMR) Process

Integrated Plant Assessment (IPA) Flowchart



IPA Aging Management Review (AMR)

For each system:

- 1) Group components by generic component type
- 2) Use scoping results to identify component intended functions
 - Pressure boundary, leakage boundary, structural support, etc.
- 3) Determine materials of construction for each component type/function
 - Group materials by generic type, based on similarities in aging effect applicability
- 4) Determine different internal and external surface environments
- 5) Assess aging effects / mechanism
- 6) Determine which existing or new Aging Management Program currently or will manage the effects of aging

IPA Aging Management Review (AMR) – Outcome

- AMR documented 9-column tables for each system
- The AMR includes a comparison of the aging effect and the utility identified program to the same information in the GALL or IGALL Report

Table 3.4.2-3 Main Condensate and Feedwater System (Continued)						NUREG-1801 Item	Table 1 Item	Notes
Component Type	Intended Function	Material	Environment	Aging Effect Requiring Management	Aging Management Programs			
Piping, piping components, and piping elements	Leakage Boundary	Stainless Steel	Treated Water (Internal)	Loss of Material	Water Chemistry (B.2.1.2)	VIII.D1.SP-87	3.4.1-16	A
			Treated Water > 140 F (Internal)	Cracking	One-Time Inspection (B.2.1.20)	VIII.D1.SP-88	3.4.1-11	A
					Water Chemistry (B.2.1.2)	VIII.D1.SP-88	3.4.1-11	A
				Cumulative Fatigue Damage	TLAA	VII.E3.A-62	3.3.1-2	A, 4
				Loss of Material	One-Time Inspection (B.2.1.20)	VIII.D1.SP-87	3.4.1-16	A
					Water Chemistry (B.2.1.2)	VIII.D1.SP-87	3.4.1-16	A
	Pressure Boundary	Aluminum Alloy	Air - Outdoor (External)	Loss of Material	External Surfaces Monitoring of Mechanical Components (B.2.1.23)	VIII.H.SP-147	3.4.1-35	A
			Treated Water (External)	Loss of Material	One-Time Inspection (B.2.1.20)	VIII.D1.SP-90	3.4.1-16	A
					Water Chemistry (B.2.1.2)	VIII.D1.SP-90	3.4.1-16	A
			Treated Water (Internal)	Loss of Material	One-Time Inspection (B.2.1.20)	VIII.D1.SP-90	3.4.1-16	A
					Water Chemistry (B.2.1.2)	VIII.D1.SP-90	3.4.1-16	A
		Carbon Steel	Air - Indoor Uncontrolled (External)	Loss of Material	External Surfaces Monitoring of Mechanical Components (B.2.1.23)	VIII.H.S-29	3.4.1-34	A
			Air - Outdoor (External)	Loss of Material	External Surfaces Monitoring of Mechanical Components (B.2.1.23)	VIII.H.S-41	3.4.1-34	A
			Air with Borated Water Leakage (External)	Loss of Material	Boric Acid Corrosion (B.2.1.4)	VIII.H.S-30	3.4.1-4	A
					External Surfaces Monitoring of Mechanical Components (B.2.1.23)	VIII.H.S-29	3.4.1-34	A
			Soil (External)	Loss of Material	Buried and Underground Piping (B.2.1.28)	VIII.E.SP-145	3.4.1-47	B

Utility AMR

Comparison to
GALL / IGALL

IPA Aging Management Programs (AMR)

Credited AMPs include both New and Existing Programs

Existing Plant Programs

- ASME Section XI, Subsection IWB, IWC, IWD
- Flow-Accelerated Corrosion Program
- Buried Pipe Program
- Steam Generators
- Open-Cycle Cooling Water
- Water Chemistry
- Boric Acid Corrosion

New Programs

- Selective Leaching
- One-Time Inspection
- External Surfaces Monitoring of Mechanical Components



The GALL report – Aging Management Programs

Generic Aging Lessons Learned (GALL)

- **Purpose:**

- Provides the NRC's generic evaluation of aging management programs (AMPs) for license renewal.
- Streamline and standardize the NRC's review of LRA's

- **Use by Applicants:**

- Applicants may reference GALL to show their programs align with NRC-reviewed standards.
- Facilitates faster / streamlined review

- **Key Insights:**

- Many existing plant programs are adequate without modification.
- Some programs require **augmentation** for the period of extended operation.

- **Applicant Responsibility:**

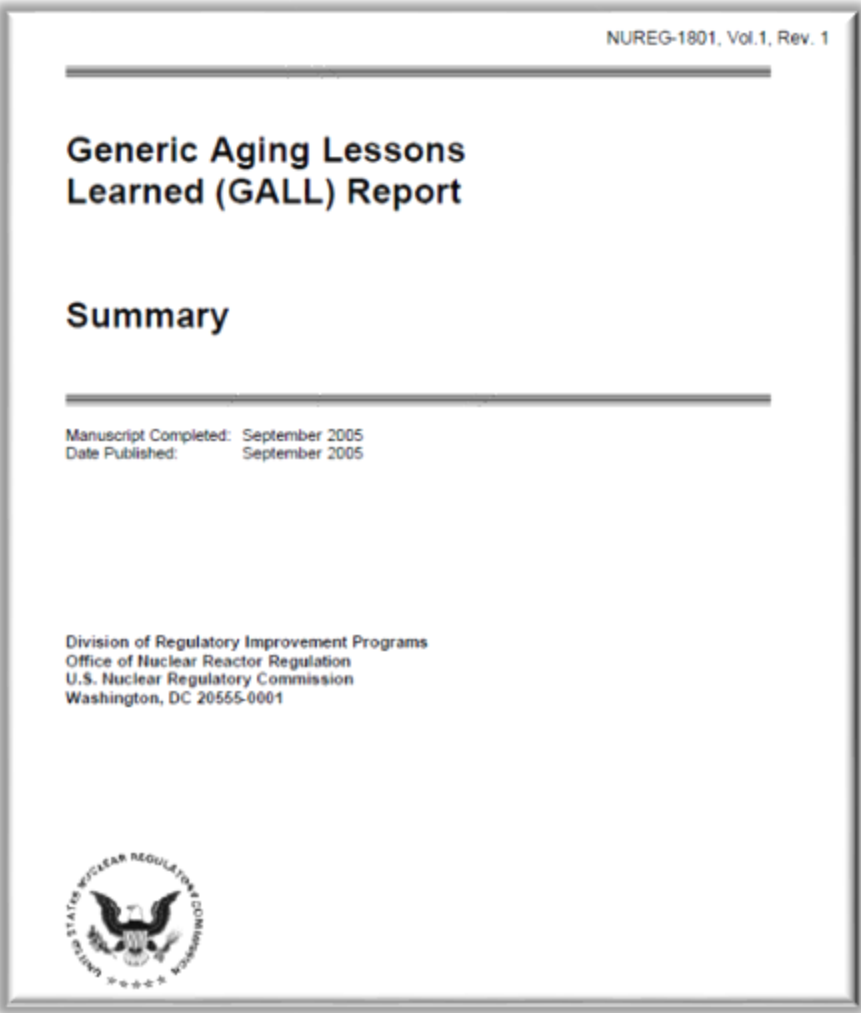
- Ensure plant conditions and operating experience are **bounded** by those in GALL.
- If not, applicants must **justify deviations** or **enhance programs** accordingly.

- **NRC Review Focus:**

- Enhanced programs
- Exceptions to GALL
- Plant-specific AMPs not covered in GALL



GALL / GALL-SLR: AMP Elements



- | | |
|--------------------------------------|----------------------------|
| 1. Program scope | 6. Acceptance criteria |
| 2. Preventive actions | 7. Corrective actions |
| 3. Parameters monitored or inspected | 8. Confirmation process |
| 4. Detection of aging effects | 9. Administrative controls |
| 5. Monitoring and trending | 10. Operating experience |

Comparison between Plant AMP & GALL AMP (typically) documented in a Program Basis Document

Enhancements / Exceptions to AMPs

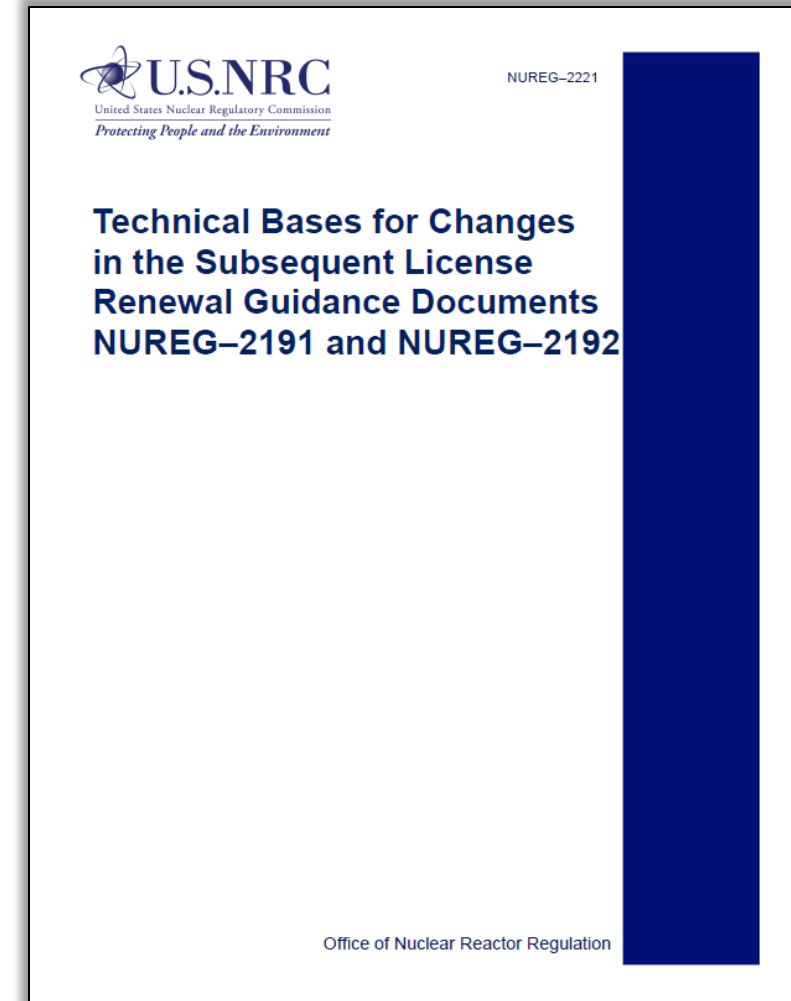
- **Enhancements** are changes made to an existing plant program to align with a GALL or IGALL program. Reasons:
 - Activities or recommendations in the GALL/IGALL program are not currently in place as part of the existing program.
 - To address unique site-specific operating experience for which the underlying assumptions of the generic GALL/IGALL program may not account for.
- **Exceptions** are intentional deviations from the GALL/IGALL AMP Recommendations.
 - May be due to the unique configuration or design of a plant (e.g. equipment functions, plant layout, materials, environments, etc.) or the result of site-specific OE.
 - The regulator will likely review these exceptions on a case-by-case basis, and dispositions of acceptance are generally documented.



Items of Interest & Awareness

GALL / GALL-SLR Revision

- GALL / GALL-SLR revisions undergo public comment periods
 - Anyone can submit comments for recommended changes to the programs
 - NRC disposition of comments are documented in NUREGs
 - NUREG-1832: Analysis of Public Comments on GALL R1
 - NUREG-1950: Disposition of Public Comments on GALL R2
 - NUREG-2222: Disposition of Public Comments on GALL-SLR
 - NUREG-2191, Appendix C: Disposition of Public Comments on Draft GALL-SLR R1
- Each GALL / GALL-SLR revision is accompanied by a Technical Basis for change NUREG
 - NUREG-1833: Technical Basis for Revision to GALL R1
 - NUREG-1950: Technical Basis for Changes to GALL R2
 - NUREG-2221: Technical Basis for GALL-SLR Changes
 - NUREG-2221, Supplement 1: Technical Basis for GALL-SLR R1 Changes



Example of GALL-SLR Changes

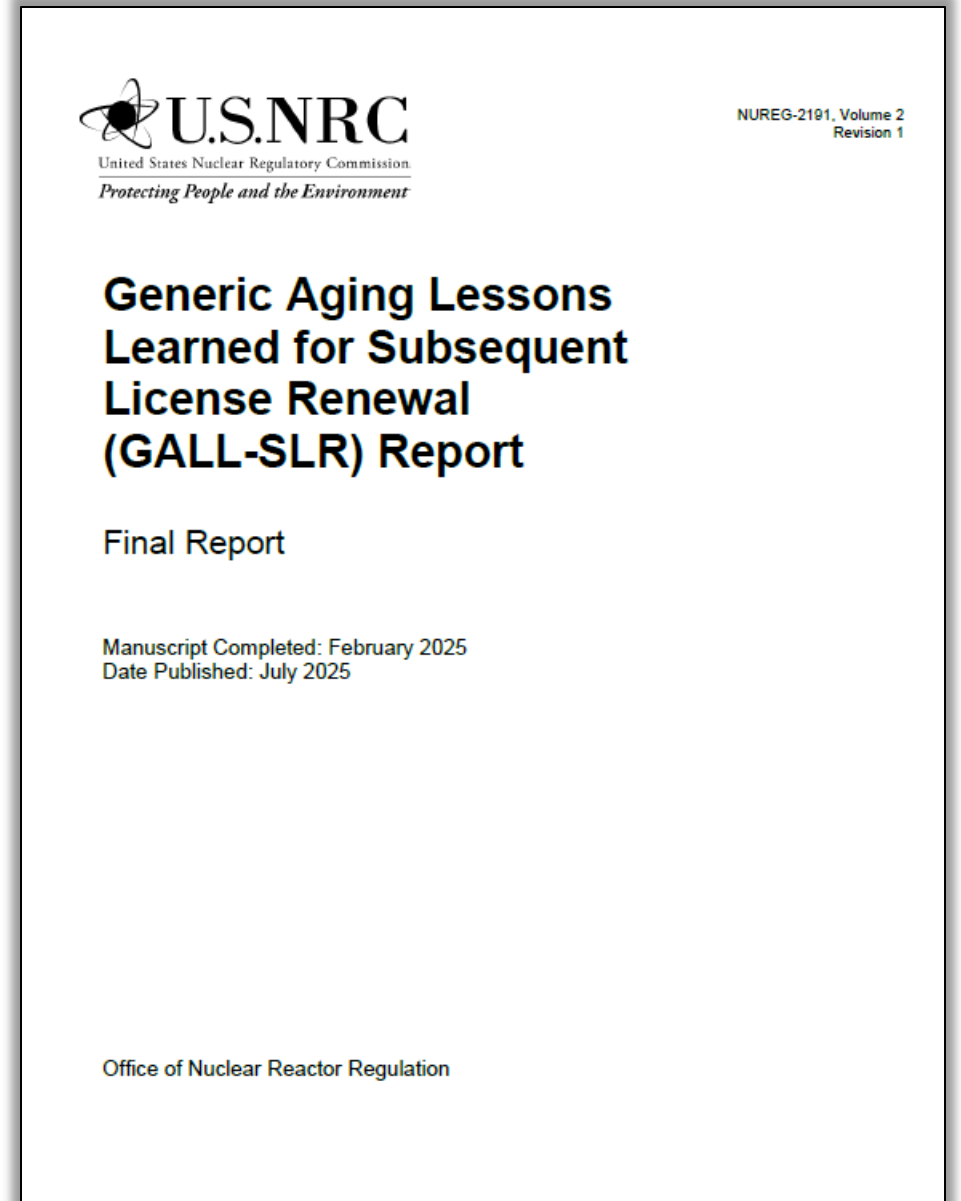
- XI.M33 Inspection Quantities reduced from GALL R2 -> GALL-SLR
- NUREG-2221 provides basis for this change
- Reason: partial reliance on inspection results pre- initial PEO + opportunistic inspections
 - Therefore, NOT a good basis to consider changing a utility SL AMP for initial LR

Table 2-29 GALL-SLR Differences from Chapter XI, Mechanical Aging Management Programs, GALL Report Revision 2 and Their Technical Bases		
Location of Change	Summary of Significant Changes	Technical Bases for Changes
Detection of Aging Effects		
Detection of Aging Effects	Revised to recommend specific inspection sizes and to include destructive examinations.	The size of the representative sample recommended in the previous version of AMP XI.M33 was 20% of the population with a maximum of 25 components. In the Commission's

Table 2-29 GALL-SLR Differences from Chapter XI, Mechanical Aging Management Programs, GALL Report Revision 2 and Their Technical Bases		
Location of Change	Summary of Significant Changes	Technical Bases for Changes
		version of AMP XI.M33 is documented in the response to industry comment No. 017-031.
		Based on the slow acting nature of the degradation mechanism and results of the licensee's one-time inspections conducted for the prior period of extended operation, the staff concluded that there is reasonable assurance that due to the size of the periodic samples (including both visual and destructive) starting 10 years prior to the period of extended operation and extending throughout the period of extended operation, loss of material due to selective leaching will be detected prior to a loss of intended function of in-scope components.
		In order to provide for a standardized inspection length when the component is a segment of piping, the AMP recommends that a 1-foot axial length section be examined. This is consistent with the sample length in other AMPs issued in LR-ISG-2012-02, "Aging Management of Internal Surfaces, Fire Water Systems, Atmospheric Storage Tanks, and Corrosion Under Insulation" (e.g., AMP XI.M36) and AMP XI.M42 issued with LR-ISG-2013-01, "Aging Management of Loss of Coating or Lining Integrity for Internal Coatings/Linings on In-Scope Piping, Piping Components, Heat Exchangers, and Tanks."
		The basis for reducing the number of destructive examinations for smaller populations is documented in the staff response to industry comment No. 017-031.

NUREG-2191 GALL-SLR Revision 1

- Officially Published July 15, 2025
- Notable changes for XI.M33 & XI.M41
 - ...see draft document, or 2024 US-NRC Update
- New AMP XI.M43 for HDPE/CFRP
- XI.M17 (FAC)
 - Included aspects of EPRI 3002005530 for erosion
 - Clarification on software QA activities



EPRI Long Term Operations Wiki Site

- Publicly available site
- Contains information on LTO, LR/periodic safety review processes for both US and Non-US plants.
 - Overview / links to regulatory documents
 - Overview of LR Application Process
 - Information on AMPs,
 - Including ISG's
 - NRC & Int'l review process of LRA
 - Pre- and Post-PEO Implementation
 - LR-based inspection processes (US & Int'l)

The screenshot displays the EPRI Long Term Operations Wiki Site. The left sidebar contains a navigation menu with links such as 'LTO Beta', 'LTO Home Page', 'LTO Acronyms and Descriptions', 'LTO Regulatory and Guidance Documents', 'LR Application Process', 'AMPs', 'TLAA', 'Implementation', 'Review of LRA (USNRC and International)', 'Pre-PEO', 'Post-PEO', 'Operation During the PEO', 'LR Inspections (USNRC and International)', 'Other International', 'US vs International LTO', 'PSR', 'Have Feedback? Need Help?', and 'Contact EPRI LTO'. The main content area is titled 'U.S. NRC License Renewal Inspections' and includes a 'Contents [hide]' section with a list of topics: 1 IP-71002 License Renewal Inspections, 2 US NRC IP-71003 Post-Approval Site Inspections for License Renewal, 3 Inspection for Initial and Subsequent License Renewal: Phase I, II, III, IV, V, and VI (with sub-sections 3.1 Initial License Renewal (40-60 Years) and 3.2 Subsequent License Renewal), 4 IP-71013 Site Inspection for Plants With a Timely Renewal Application, 5 Preparing for Post-Approval Site Inspections, 6 Related Non-License Renewal US NRC Inspections (with sub-section 6.1 IP-71111.21N.04 Age-Related Degradation), 7 International Approach (with sub-sections 7.1 Example of regulatory approach in Spain, 7.1.1 Inspections during the design life of NPP, 7.1.2 Inspections during the license renewal process, 7.1.3 Inspections during the Long-Term Operation of an NPP, and 7.1.4 Matrix of Inspections), and 8 Record of Revisions. Below the contents, there is a section for 'IP-71002 License Renewal Inspections' with a description of the site inspections and a table of related documents.

XI.M24, "Compressed Air Monitoring"	XI.M24, "Compressed Air Monitoring"
XI.M27, "Fire Water System"	XI.M27, "Fire Water System"

<https://lto.epri.com/LTO>



TOGETHER...SHAPING THE FUTURE OF ENERGY®

Aging Management Plan Implementation

Motor Aging Management



Andrew Mantey
Electrical Team Leader - PRR
Electric Power Research Institute

China Workshop
20-22 October 2025

AMP Scope Includes Systems, Structures, and Components (SSCs)



SSCs important to safety that are necessary to fulfil the fundamental safety functions.



Other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions.

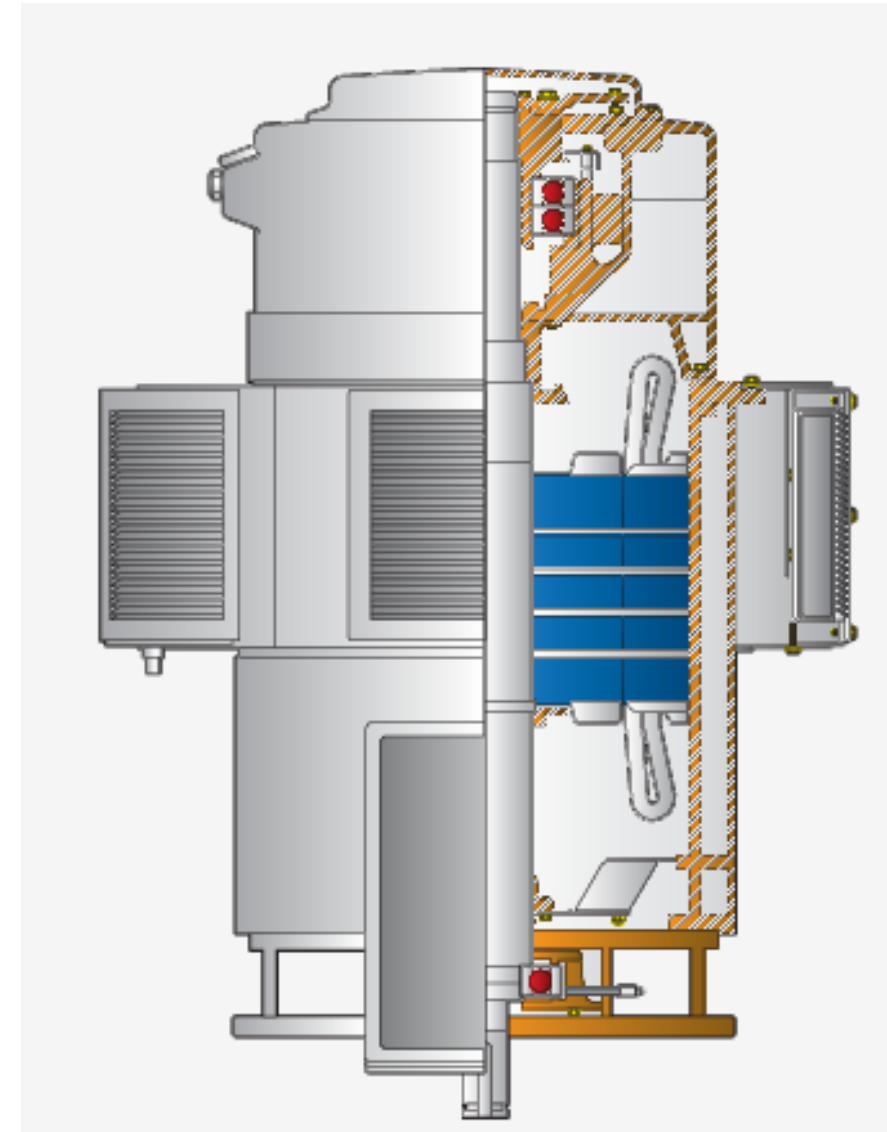


Other SSCs that are credited in the safety analyses (deterministic and probabilistic) as performing the function of coping with certain types of event, consistent with national regulatory requirements.

1. AMP Scope

- What's motor sub-components are managed?

Stator, rotor, frame, shaft, bearings, motor housing, motor mounting, cooling air fans and filters, lubricating oil system, bearing cooling, stator and rotor cooling, terminations, component cooling lines at the machine, heaters, and instrumentation sensors.



2. Identify Degradation Mechanisms and Stressors

Degradation Mechanism Examples

- Thermal degradation
- Partial discharge, corona, tracking
- Mechanical loading, vibration
- Radiolysis
- Surface (oil, boron) contamination
- Moisture intrusion

Stressor Examples

- Temperature (ambient, ohmic heating, etc.)
- Loss of dielectric strength
- Chemicals
- Steam
- Radiation
- Mechanical fatigue
- Humidity/water spray
- Vibration
- Foreign material intrusion

3. Actions to Minimize Aging Effects

- Control and monitor the environment (e.g., winding temperatures, thermography, Room cooling)
- Maintain winding insulation (e.g., visual inspections, condition-monitoring/electrical testing, periodic refurbishment, rewinds)
- Maintain bearings lubrication system (e.g., lube oil and particle wear analysis)
- Control mechanical wear (e.g., vibration monitoring, visual inspections)

Identifying How the SSC Degradation Can Be Managed

3. Detection of Aging Effects

- Parameters to monitor for ageing effects:
 - Electrical (power, voltage, current)
 - Insulation testing (winding),
 - Mechanical changes (power, speed and slip),
 - Temperature (thermocouples, winding resistance thermal detectors (RTDs))
 - Oil quality, particle counts

Identifying What to Monitor to Detect SSC Degradation

3. Detection of Aging Effects –Stator and Rotor

Stator:

- VLF tan delta/dielectric spectroscopy, partial discharge, polarization/depolarization tests (Pol/Depol), comparative surge test, insulation resistance /polarization index, current/power signature analysis, internal visual inspection, high potential test, insulation power factor test, infrared thermography and partial discharge test, space heater checks.

Rotor:

- Visual inspection (partial or full disassembly), borescope inspection, vibration monitoring, motor power or current signature analysis, static rotor test, infrared thermography, growler test, shaft alignment check

3. Detection of Aging Effects –Stator and Rotor

Bearings:

- Bearing temperature monitoring, vibration monitoring, bearing inspection, lube oil level, temperature, filtration monitoring, lube oil sampling and analysis, bearings and seals inspection, periodic check of lube oil system parameters (visual inspection, level, temperature, flow, periodic check of component cooling water(CCW) filter's delta pressure and supply to lube oil heat exchanger. In case of greases, vibration monitoring, lubrication quality testing, grease addition.

Motor frame, enclosure and mounting:

- Visual inspection, vibration monitoring

4. Monitoring And Trending of Ageing Effects

- EPRI motor/cable testing methodology is an option used for AMP in-scope motors. Data will be trended over time and against the EPRI criteria to evaluate aging.
- Another member recently used the EPRI method to determine a motor/cable test indicated a “wet” motor.
- Understanding what a test or trend can and cannot detect and for what degradation mechanism
- Time-based PMs will be required (e.g., inspections, partial disassembly) for those degradation mechanisms not detectable by trending or testing.

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	18.4 μArms	24.4 nF	1.2 GΩ	0.1 Hz	58.0	< 0.01
2	2.5 kVrms	37.0 μArms	23.5 nF	1.2 GΩ	0.1 Hz	58.8	< 0.01
3	3.7 kVrms	54.6 μArms	23.5 nF	1.1 GΩ	0.1 Hz	59.8	< 0.01

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	18.5 μArms	24.4 nF	1.1 GΩ	0.1 Hz	60.8	< 0.01
2	2.5 kVrms	37.3 μArms	23.7 nF	1.1 GΩ	0.1 Hz	61.9	< 0.01
3	3.7 kVrms	55.0 μArms	23.6 nF	1.1 GΩ	0.1 Hz	62.7	< 0.01

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	18.2 μArms	24.1 nF	1.2 GΩ	0.1 Hz	56.7	< 0.01
2	2.5 kVrms	36.8 μArms	23.4 nF	1.2 GΩ	0.1 Hz	57.5	< 0.01
3	3.7 kVrms	54.3 μArms	23.3 nF	1.2 GΩ	0.1 Hz	58.4	< 0.01

Capacitance [nF]	VLF Resistance [MΩ]	Frequency	TD [E-3]	Std. Dev. [%]
111	220	0.1 Hz	64.8	0.01
111	220	0.1 Hz	64.8	0.01
112	206	0.1 Hz	68.8	0.02

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	48.8 μArms	64.5 nF	317 MΩ	0.1 Hz	78.1	< 0.01
2	2.5 kVrms	101 μArms	64.3 nF	315 MΩ	0.1 Hz	78.6	< 0.01
3	3.7 kVrms	150 μArms	64.3 nF	312 MΩ	0.1 Hz	79.3	< 0.01

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	48.9 μArms	64.6 nF	314 MΩ	0.1 Hz	78.6	0.01
2	2.5 kVrms	102 μArms	64.5 nF	312 MΩ	0.1 Hz	79.2	< 0.01
3	3.7 kVrms	150 μArms	64.4 nF	310 MΩ	0.1 Hz	79.8	< 0.01

Step	Voltage	Current	Capacitance	Resistance	Frequency	TD [E-3]	Std. Dev. [%]
1	1.2 kVrms	47.0 μArms	62.2 nF	358 MΩ	0.1 Hz	71.8	< 0.01
2	2.5 kVrms	97.5 μArms	61.9 nF	354 MΩ	0.1 Hz	72.6	< 0.01
3	3.7 kVrms	144 μArms	61.9 nF	351 MΩ	0.1 Hz	73.4	< 0.01

Capacitance [nF]	VLF Resistance [MΩ]	Frequency	TD [E-3]	Std. Dev. [%]
279	49	0.1 Hz	117	< 0.01
279	49	0.1 Hz	116	0.01
280	48	0.1 Hz	119	0.01

Data Needs to Be Known to Track with Specific Aging Stressor

5. Mitigating Ageing Effects

Stator

- Motor cleaning based on winding temperature trends
- Rewinds (consider insulation system level upgrade)
- Air filter replacements (if applicable)
- Install surge capacitors Infrared thermography (motor core, air discharge temperatures, bearing temperatures)
- Periodic inspections/refurbishment

Rotor

- Periodic visual or borescope inspection
- Monitoring and trending vibration
- Monitoring and trending motor amperes, rpm, winding temperature
- Monitoring and trending bearing temperature
- Precision alignment and balancing.

6. Establish Acceptance Criteria

- Tests and trend data should be assigned limits for when action may be required.
- If absolute limits are not available, then levels such as good, further study, action required should be set.
 - **Good**: Next test on the established frequency
 - **Further study**: Increase test frequency (typically ½ of “Good” test frequency)
 - **Action Required**: Repair/replacement, or limited return to service (typically only if a Hi-pot test passes)
- Levels should be set to manage reliability at acceptable levels (e.g., avoid in-service failures)

Condition	VLF Insulation Resistance with Cable Guarded Out	Action
Good	>25 MΩ	None required
Further study required	20 MΩ ≤ VLF IR ≤ 25 MΩ	Perform a VLF withstand test. Decrease interval between tests. Boroscopic inspection.
Action required	≤20 MΩ	Separate motor from cable and retest. Inspect. Repair as needed.

Motor VLF Insulation Resistance Acceptance Levels

Condition	Percent Standard Deviation of Tan Delta Measurements at a Particular Test Voltage
Good	≤0.02
Further study required	0.02+ <percent standard deviation <0.04
Action required	>0.04

Motor % Standard Deviation Acceptance Levels

7. Corrective Actions

- Corrective actions may be taken to resolve the aging, degradation or failure if the detected parameters do not meet the acceptance criteria set by the plant for each individual motor.
 - Preventive/corrective maintenance;
 - Replacement or modifications as per plant procedures;
 - Performance analysis
 - Extent of condition

8. Operating Experience (OE)

- Gathering relevant internal and external OE is typically required to be used to improve aging management programs
- EPRI uses “user groups” for sharing of OE (in anonymous format) for members to review for applicability to their AMPs
 - LEMUG meets annually and summarizes OE made available to us and invites members to share case histories of relevance to the industry
- Members set up peer teams typically driven by one of their own subject matter experts or sometimes the corporate AMP owner (if one exist) to hold periodic webcast to share OE and case histories
- Another example would be to have a country-wide peer teams that share OE and case histories on a routine frequency (quarterly, semi or annually)



TOGETHER...SHAPING THE FUTURE OF ENERGY®

Identifying Single Point Vulnerabilities in Digital I&C Systems

Adapting EPRI SPV Methodology for Modern Nuclear Control Systems



Cristina Corrales, Principal Technical Leader

Plant Reliability and Resilience – China EPRI Members Workshop
October 20-22, 2025

Why are we talking about SPV for Digital I&C systems?

**N
E
E
D
S**

Identifying the strategies for adapting traditional I&C SPV analysis to digital I&C systems

Share experiences and lessons learned

Today's Discussion Objectives

- Context data and how big is the issue.
- Learn how to adapt SPV with data and EPRI's design and analysis methods/guides.
- Explore methods for SPV management in digital environments.
- Review real-world digital SPV events and mitigation strategies.





CAPTURING DIGITAL I&C TRENDS MOTIVATIONS AND CONTEXT

MOTIVATION - Why Operational Data Analysis?

ISSUE: Ineffective OpEx Reviews

- Not adequately scoped
- No effective process in place
- No incentive to improve process, or correct the scope



Feels like looking for a needle in the haystack

OBJECTIVE: build Operational Data Knowledge model to

Facilitate the extraction of validated insights that:

- Effectively inform I&C lifecycle activities
- Allow us to identify emergent issues
- Facilitate adoption of Risk-Informed, Performance-Based methods

How does this research can inform the EPRI SPV management process?

DI&C Operational Data Analysis Process and Results

Process carried by SMEs

SOURCES
INPO
WANO
NRC
MEMBERS



Report



10101010
10101010
10101010
10101010

Data Set

SPV definition

- A subset of critical components that include the components whose failure will directly result in a reactor scram or turbine trip that will result in a reactor scram.



Reference: EPRI 3002023784

DISCUSSION - What is the definition of SPV at your plants?

2025 update – Data cut off 2024-12-31



> 4,700 RECORDS



4 SOURCES



202 SITES



34 COUNTRIES



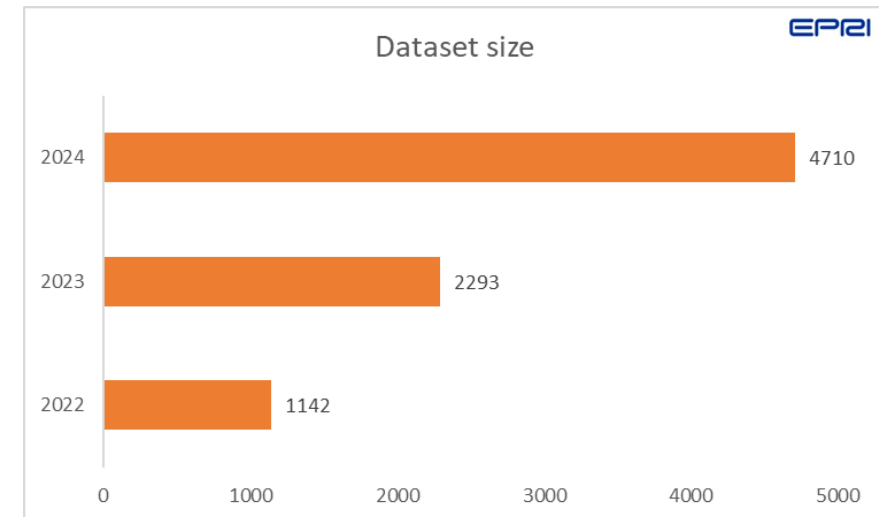
450 PLANT TRIPS



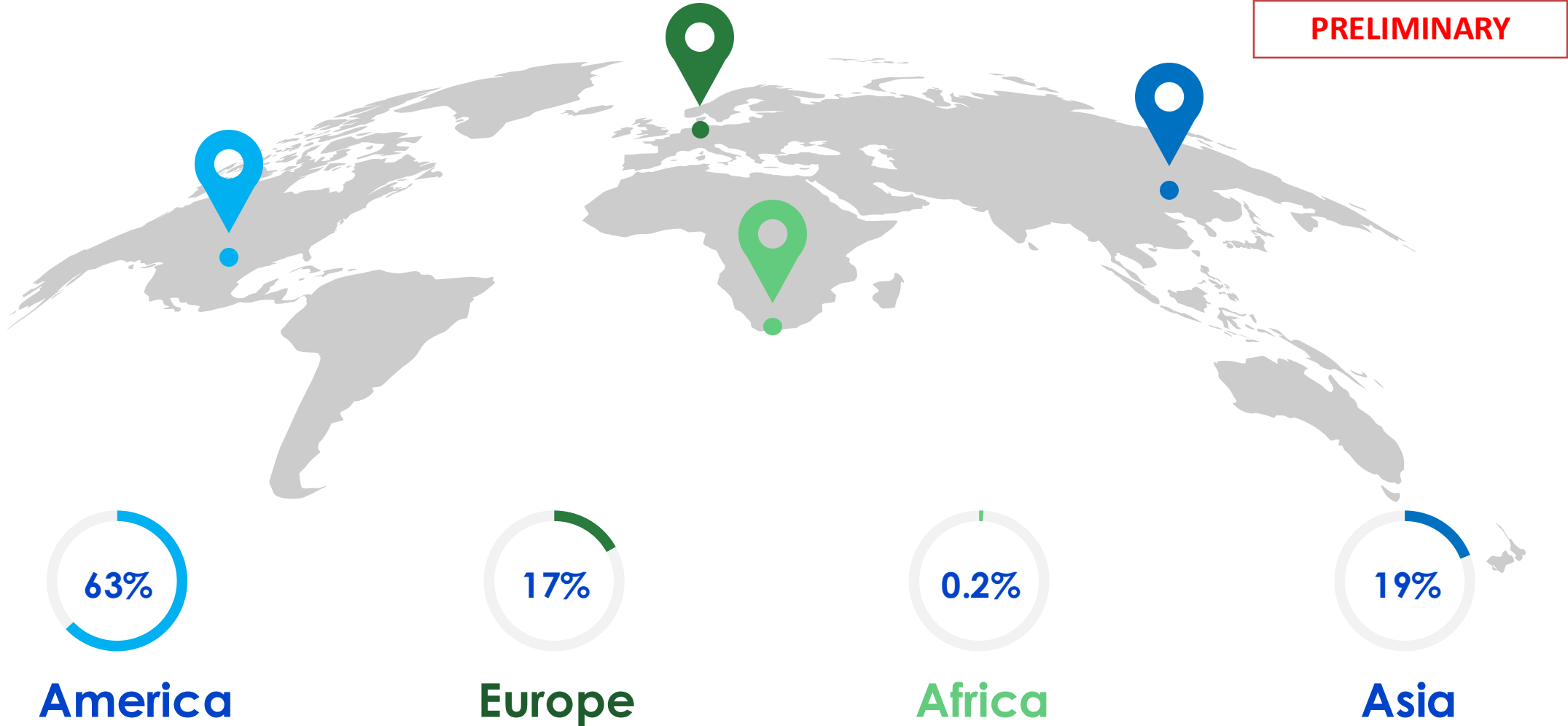
77.5 % NO IMPACT ON
PLANT AVAILABILITY

PRELIMINARY

- Data collection uses keywords and predefined filters (WANO and INPO).
- New search filters apply to 2010 – 2024.
- Filters increase efficacy of data collection. More records are applicable now than using keywords.

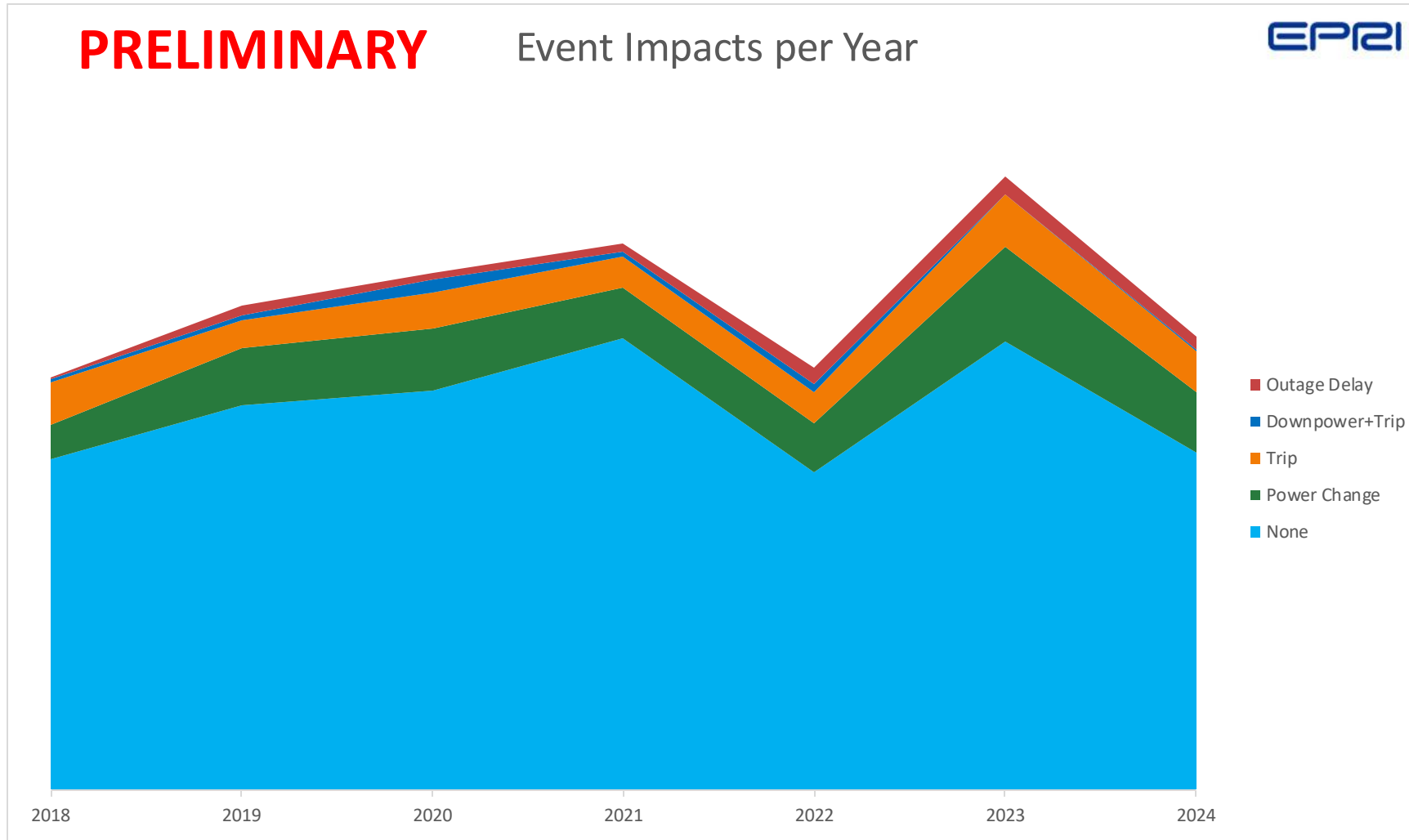


Geographical Data Representation



2025 data brings an increase on global experience

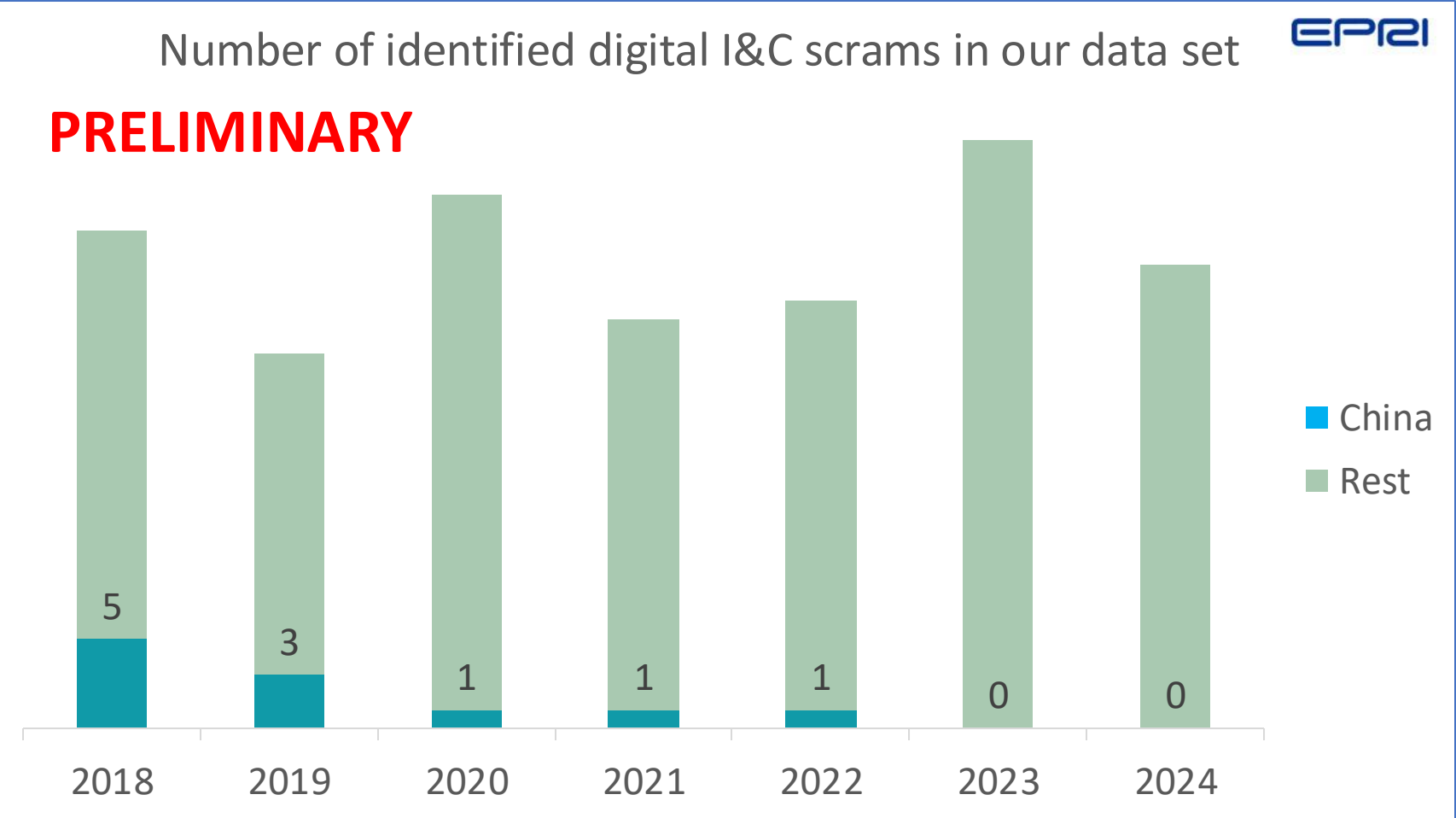
How are Digital I&C events impacting plant operations?



In the data analyzed since 2018 the events are distributed as follows:

- No operational impact: 73 to 83%
- Power change: 9 to 15%
- Trips: 6 to 10%
- Downpower+trip: < 3%
- Outage delays: 0.4 to 4%

Minimizing Scrams – Digital I&C Contribution – China



Note: the report does not include stats by country

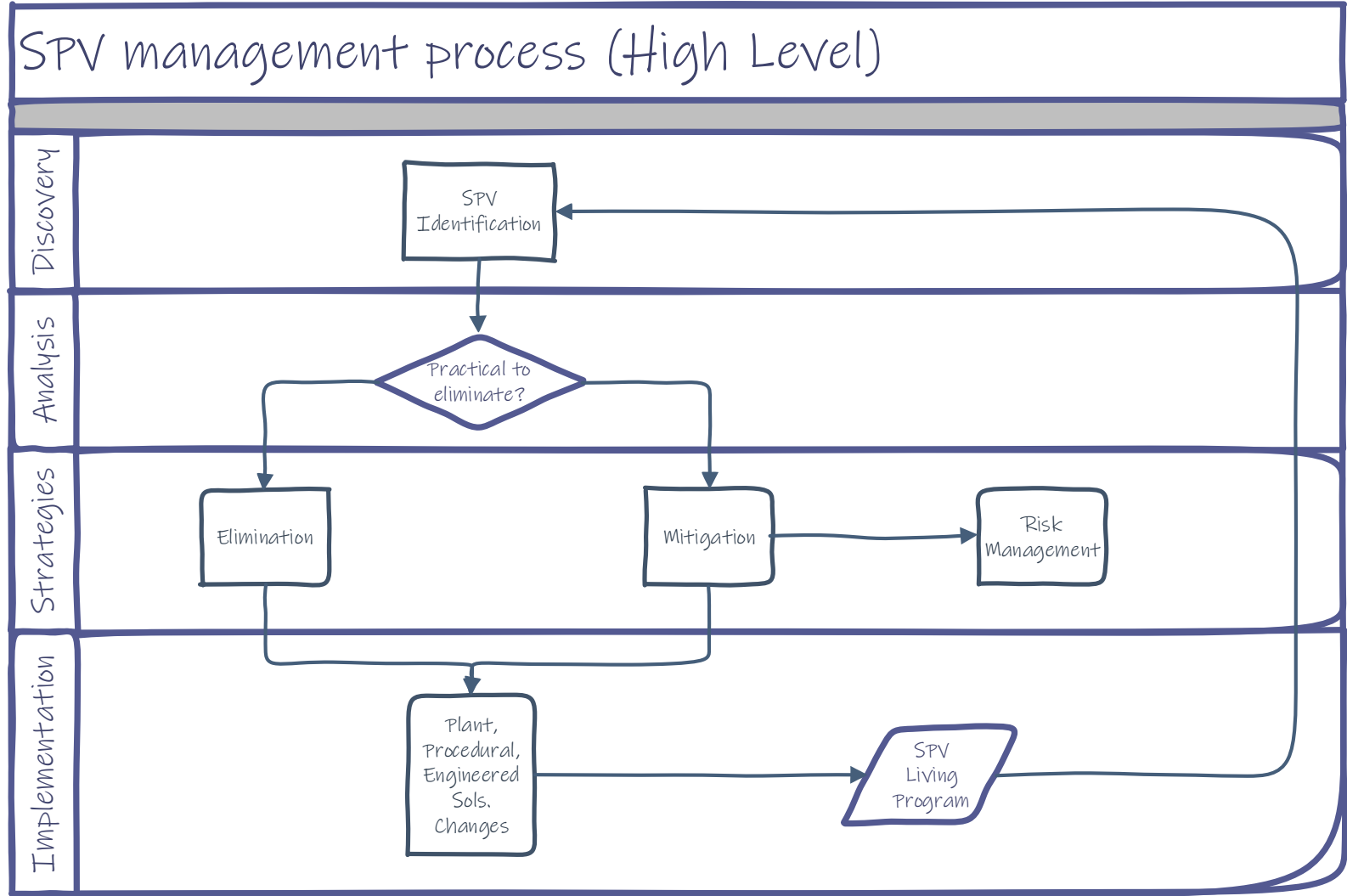
The term scram in this presentation refers to events leading to auto or manual plant trips.

Digital I&C events causing scrams represent 7-9% of all Digital I&C events.

Graph includes all sources (CNNP CR, WANO, INPO, NRC) of Operational Data mined for the 2025 update

Does this represent accurately the situation?

Following a Structured Process to Address SPVs



Two active research areas can be leveraged to address SPVs on Digital I&C Systems:

1. The Digital Systems Engineering Framework
2. The Operational Data Analysis

For details [3002023784](#): Single Point Vulnerability Process Guide Revision

Additional guidance needed

- Specific direction is needed to identify the following commonly overlooked SPVs:
 - SPV components in equipment below the level of detail of the master equipment database,
 - Current- or signal-carrying devices (connections, breakers, switches, ...)
 - Digital equipment—software SPVs.

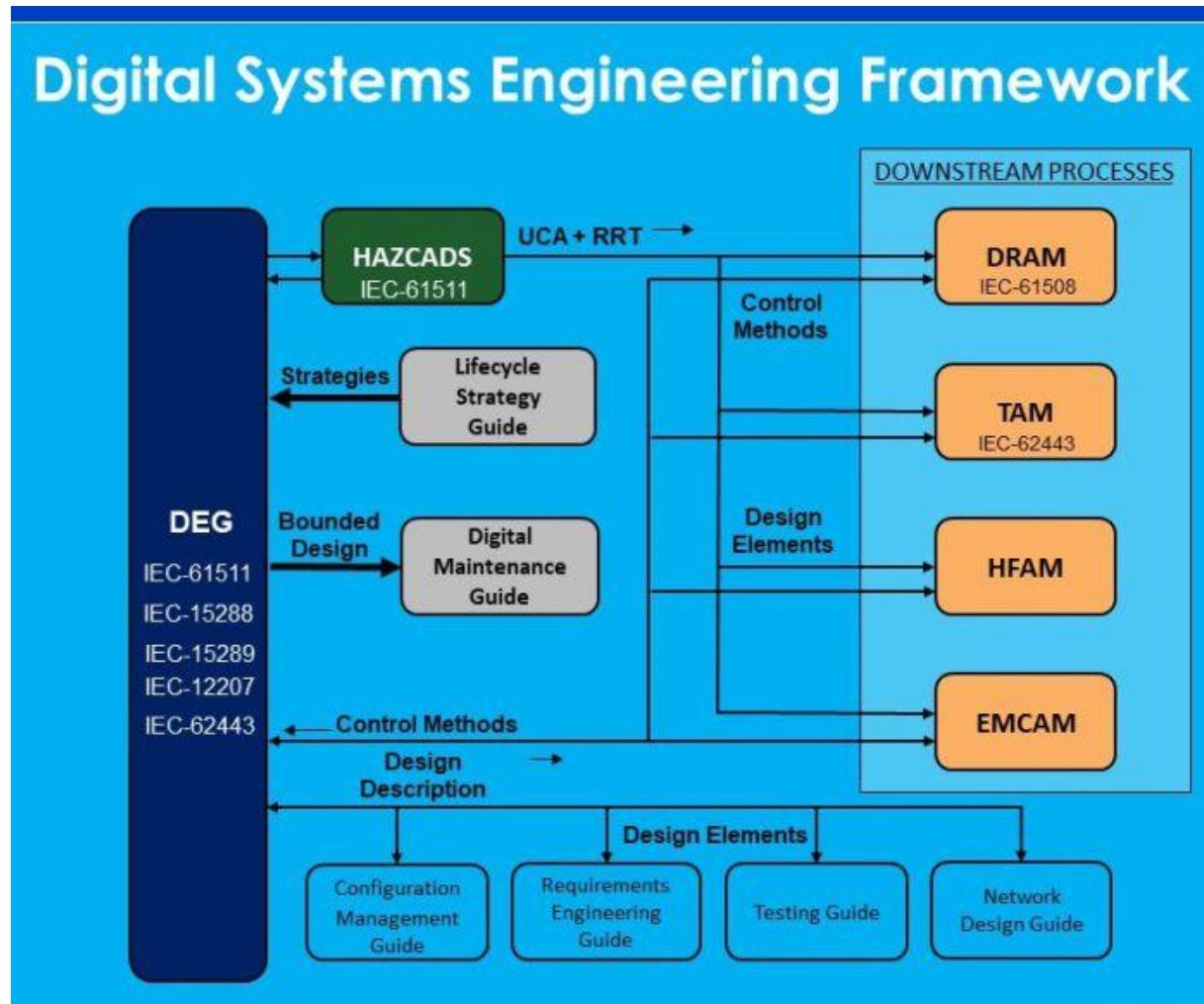


All of the identified gaps apply to Digital I&C systems

The background of the slide is a solid blue color. In the center, there is a faint, semi-transparent image of a pair of hands holding a globe. The globe shows some landmasses and is surrounded by a network of thin, glowing lines, suggesting a digital or global network. The background also features a subtle pattern of small, white, star-like specks, giving it a cosmic or high-tech feel.

SPV Process Leveraging Digital Systems Engineering Framework

DSE Framework: managing SPVs in design time



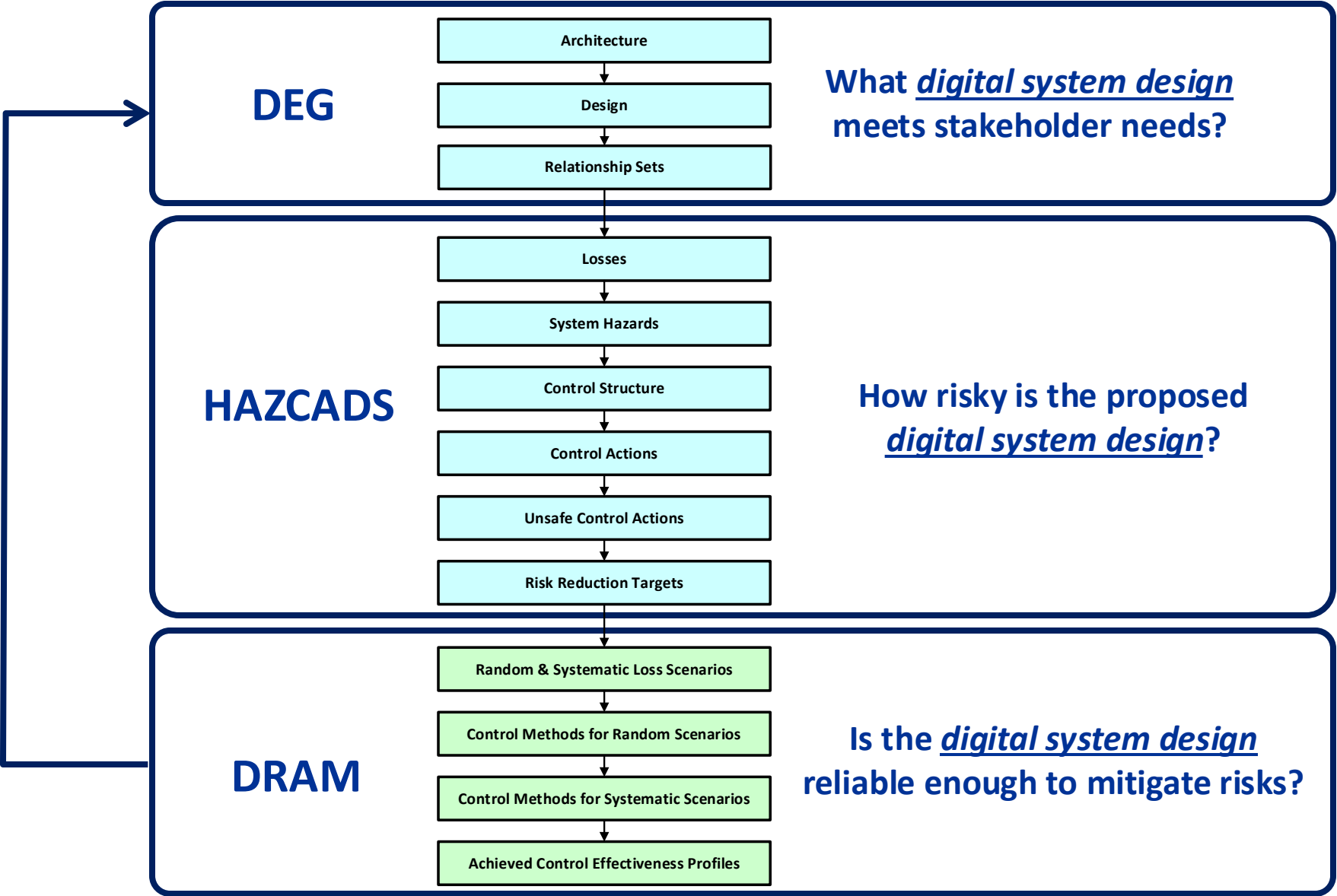
The EPRI DSE framework is conceived to address design process safely and efficiently, but the methods and guidance in it will help inform existing-design reviews to identify SPV.

ACRONYMS LIST

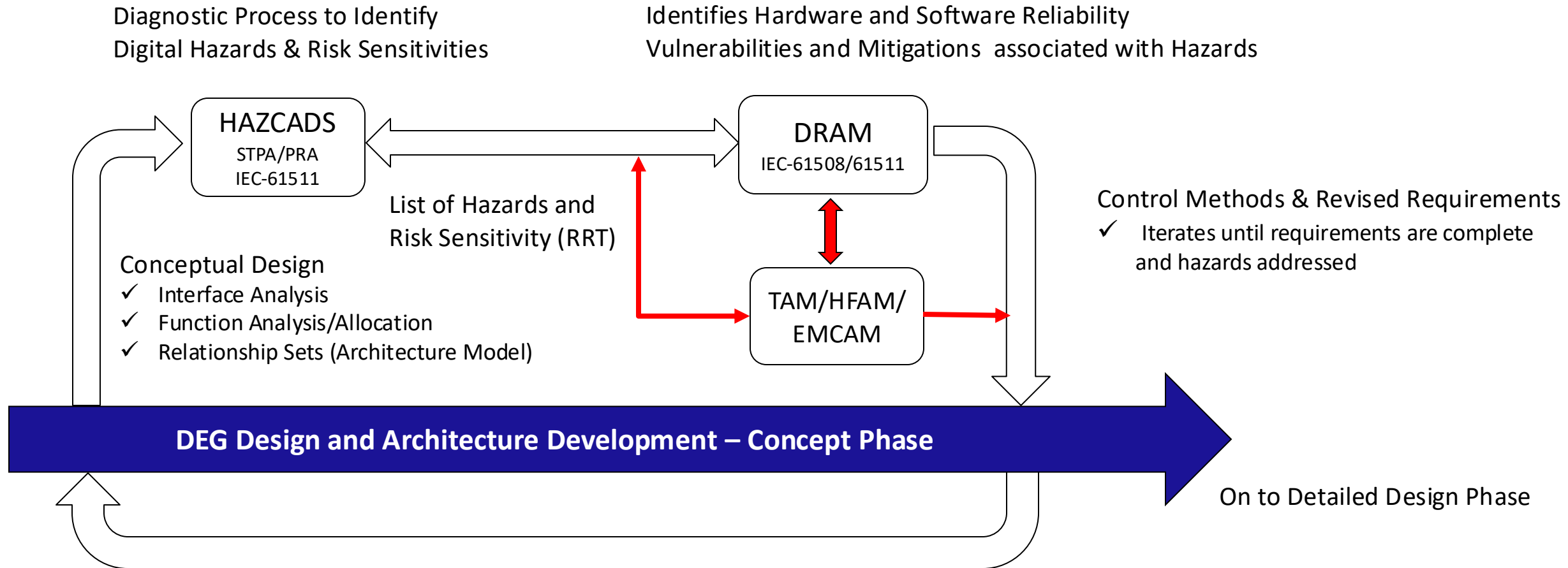
- DSE – Digital Systems Engineering Framework
- DEG – Digital Engineering Guide
- HAZCADS – Hazards and Consequences Analysis for Digital Systems
- DRAM – Digital Reliability Analysis Methodology
- TAM – Cyber Security Technical Assessment Methodology
- HFAM – Human Factors Analysis Methodology
- EMCAM – Electromagnetic Compatibility Assessment Methodology

I&C WIKI – [Link to DSE Framework](#)

Three Fundamental Questions



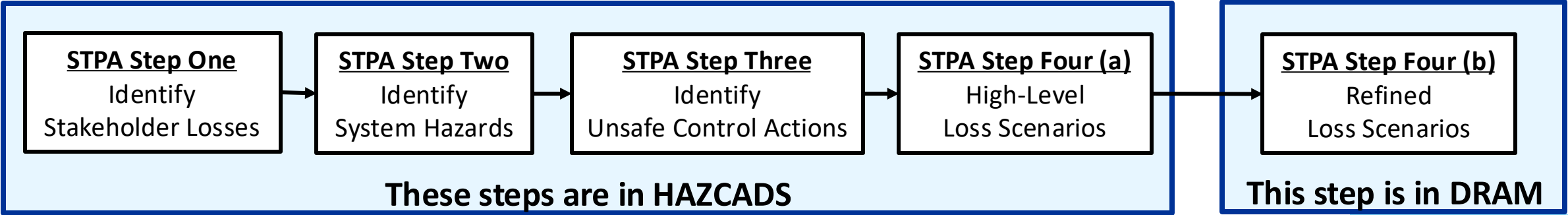
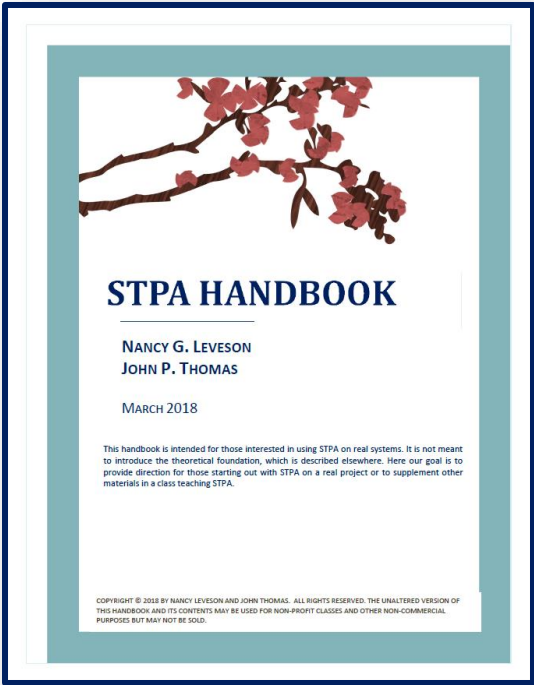
Diagnostic & Discovery Workflow – DSE Framework Route 1 (Conceptual Phase)



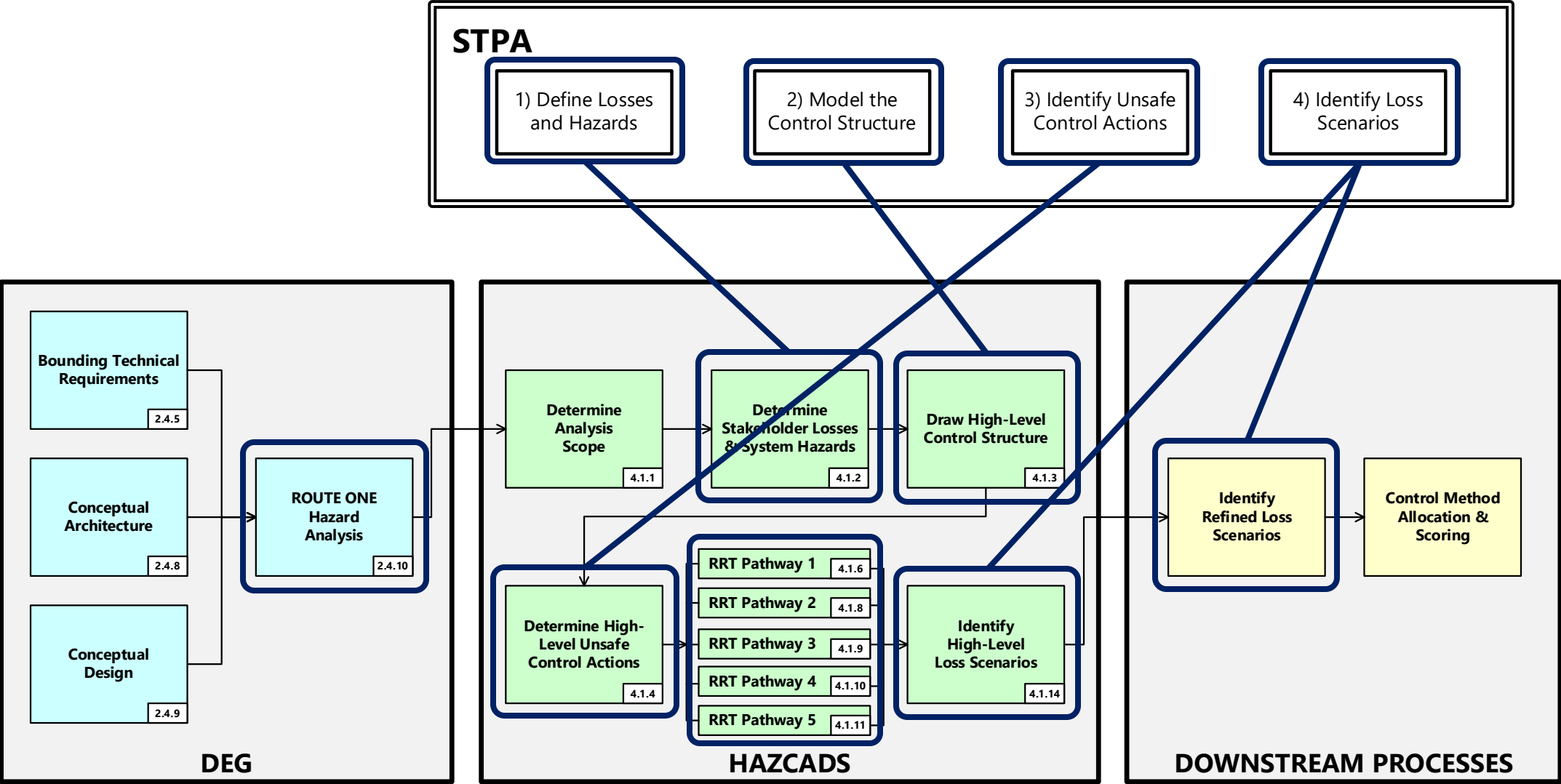
The high-performance discovery and diagnostic workflow for designing digital I&C systems, provides the tools to identify digital systems hazards (including SPVs) and evaluate elimination and mitigation strategies for them. It will propose control methods to address any hazards that are commensurate with the risk reduction targets.

HAZCADS & DRAM Basis: Hazard Analysis via STPA

- IEC Std. 61508-1 (2010) requires a determination of hazards of the Equipment Under Control (EUC) and the EUC control system, and “*consideration shall be given to the elimination or reduction of the hazards.*”
- For the determination of hazards and their causes, HAZCADS and DRAM/TAM/etc. apply the four-part Systems Theoretic Process Analysis (STPA) developed by MIT. STPA is an efficient and proven method, successfully applied in many safety-critical domains, and evaluated in multiple EPRI workshops.



STPA Implementation in the EPRI Framework

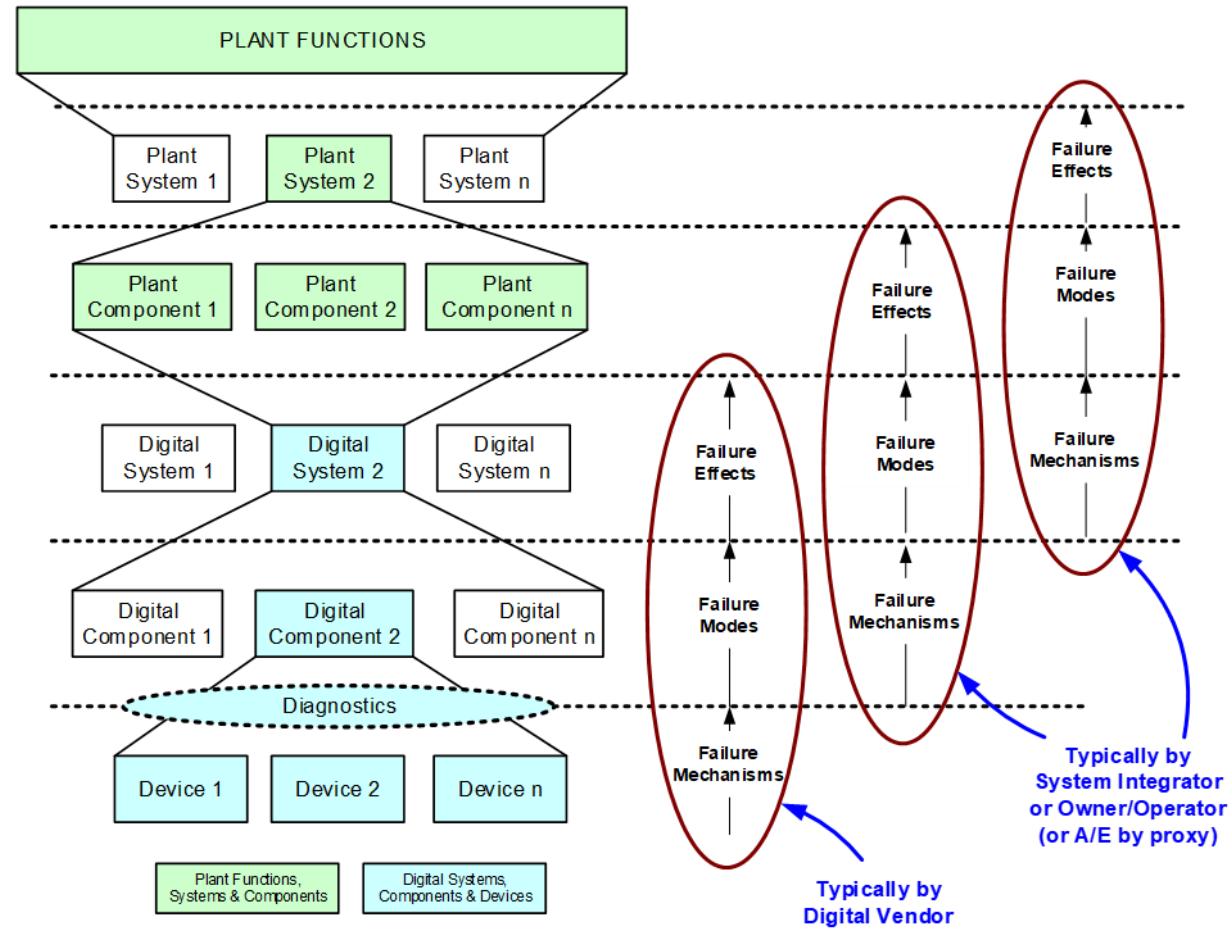


RRT –Risk Reduction Targets

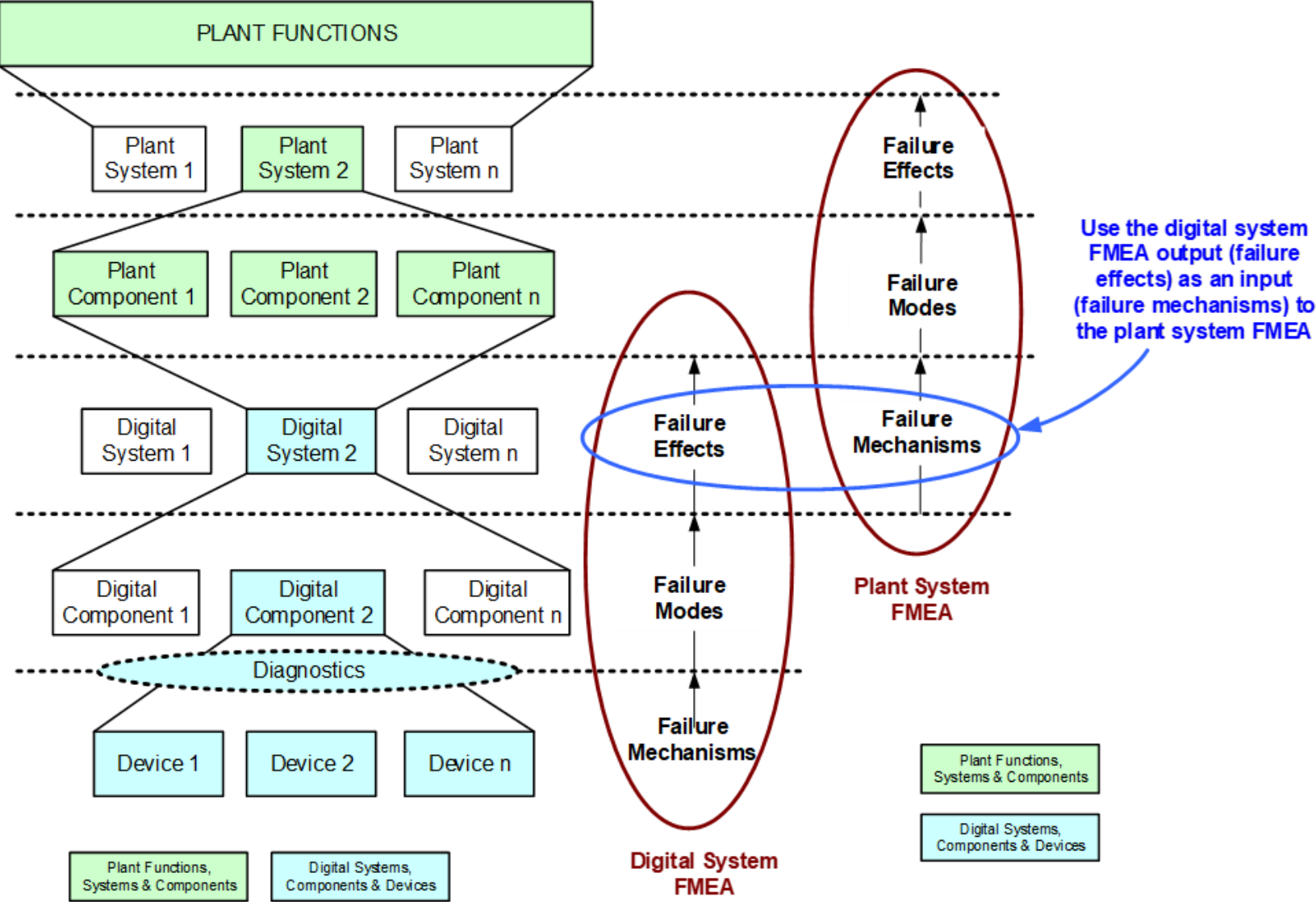
Acronyms List

FMEAs for digital systems - SPV Identification

- A design engineer can use a Failure Modes and Effects Analysis (FMEA) to evaluate the system design and assess it for single failure vulnerabilities.



FMEA Activities – 1. *Identify the Level(s) of Interest*



FMEA Activities – 2. *Block Diagram of the System of Interest*

- Integrated view of physical and functional representations of the system.
- Add supplemental information to a block diagram to fully describe the system physical and functional characteristics.
- Prepare more than one version of the block diagram to represent different system conditions that may arise in the operations and maintenance phase of its lifecycle.
- Each version of the block diagram would be analyzed using the remaining steps of the Failure Modes and Effects Analysis process.

FMEA Activities – 3. *Boundary around Components of Interest*

- Verify equipment interfaces described in technical information that is provided with the digital system or components of interest (e.g., a technical manual).
- Examine interfaces on the actual equipment if it is available, via walkdown or inspection (e.g., terminal blocks and data communication ports).

Performing this activity for each system condition (representing different Operations and Maintenance phases of its lifecycle) will ensure accounting is made for interfaces used on a temporary or intermittent basis.

FMEA Activities – 4. *Summary Description of the System of Interest*

- Helps the analyst determine the failure modes of each component.
- Helps anyone reading the FMEA results understand the basic functions of the system or components being analyzed.

It is helpful to include a table that lists each component or component type and its basic functions. If a systems engineering approach was followed for the design, the systems and components functions should be documented already.

FMEA Activities – 5. FMEA Data Sheet

Table E-1
FMEA data sheet

Functional Level

System: _____
Subsystem/Component: _____

Diagram

See Figure _____

Sheet: _____ of _____

Design Phase: _____

Rev: _____

Component Identification	Function(s)	Failure Modes	Failure Mechanisms	Effect on System	Method of Detection	Remarks

Prepare one for each component inside the boundary

FMEA Activities – 6. *Analyze Redundancies*

- FMEA method will focus on a detailed analysis of all functions and components, as developed by listing each component in a system and evaluating the impact of the component failure on the system for each failure mode.
- For systems exhibiting some degree of redundancy this approach is very detailed and contains redundant reviews.
- For redundant architectures, the scope of an FMEA can be reduced to a single redundancy in terms of the components and interfaces that are analyzed, if:
 - Clearly identify the extent to which divisions, channels, or other redundancies are fully redundant and independent.
 - The sharing of data, signals, or information is assessed to determine if any one redundancy is dependent on one or more of the other redundancies in order to satisfy functional or performance requirements, including behaviors that are required to respond to faults and failures in the other redundancies.

FMEA Activities – 7. *Apply the results*

- Apply the FMEA results by integrating the reliability control methods specified by each data sheet into the elimination and mitigation strategies.

Table E-1
FMEA data sheet

<u>Functional Level</u>		<u>Diagram</u>		Sheet: ____ of ____		
System: _____		See Figure ____		Design Phase: _____		
Subsystem/Component: _____				Rev: _____		
Component Identification	Function(s)	Failure Modes	Failure Mechanisms	Effect on System	Method of Detection	Remarks

SPV Identification – Other ideas

- Start with existing active SPV list, Blend Digital Platform FMEA with a Plant System FMEA.
- Leverage the Digital Systems Engineering elements to harden digital I&C mods and new designs against SPVs.
 - Become proficient with DEG's iterative process improves requirements identification and refinement. Use guidance for software fault analysis.
 - Review testing guidance that will assist on identifying missing SPVs.
 - For high-configurability, high-consequences projects, leverage HAZCADS as a highly effective method to identify Unsafe Control Actions.
- Consider a cross functional team with Digital I&C, operations, network design, cyber security and risk experts.



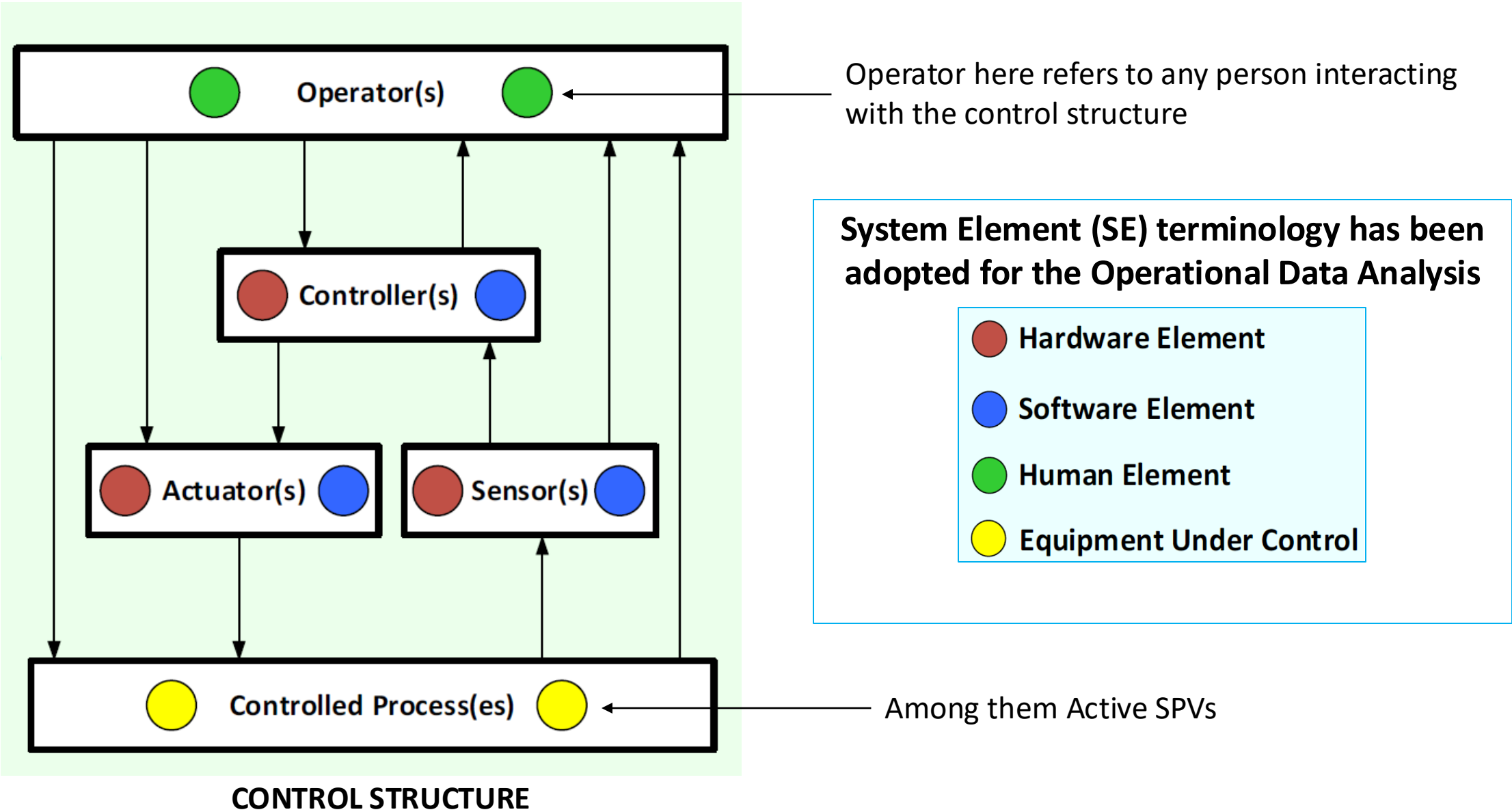
SPV Process Leveraging Operational Data Analysis

Operational Data Analysis can inform SPVs Process



- Providing pointers to focus the SPV identification (target systems, common causes, components)
- Assisting on identifying control methods to eliminate and mitigate SPVs.

Control Structures and System Elements



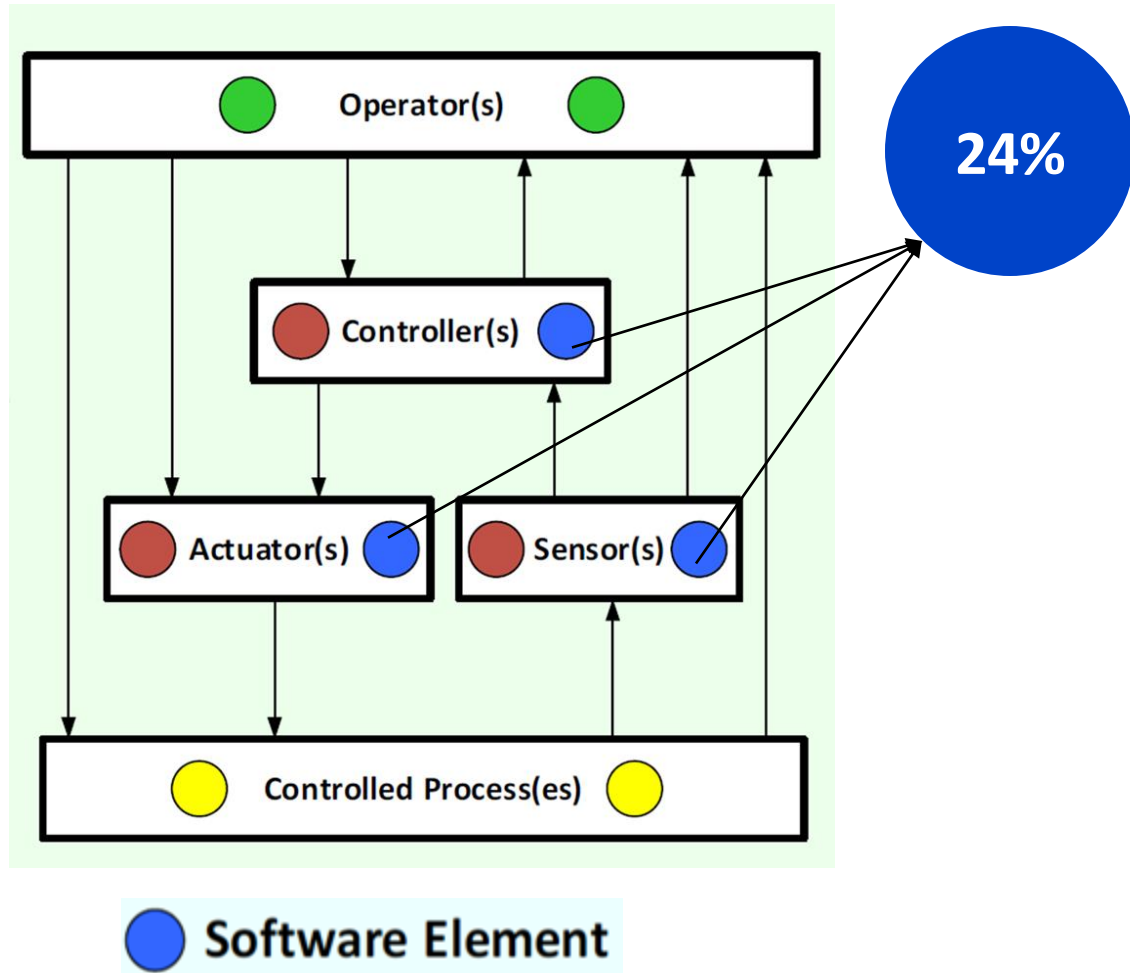
SPV Identification - Prioritized system-by-system (2018-2024)

System Categories	SPV %
Condensate/Feedwater	30.68%
Main Steam	19.89%
Power Systems	17.05%
Reactor Protection/ESFAS	10.23%
Reactivity Control	6.82%
Cooling Water	6.25%
Monitoring Systems	5.68%
Plant Process Control	2.27%
HVAC Systems	0.57%
Miscellaneous	0.57%
Grand Total	100.00%

- The review of **digital I&C systems** shows that feedwater and condensate, main turbine and generator and main transformers are leading systems to host DI&C SPVs.

PRELIMINARY

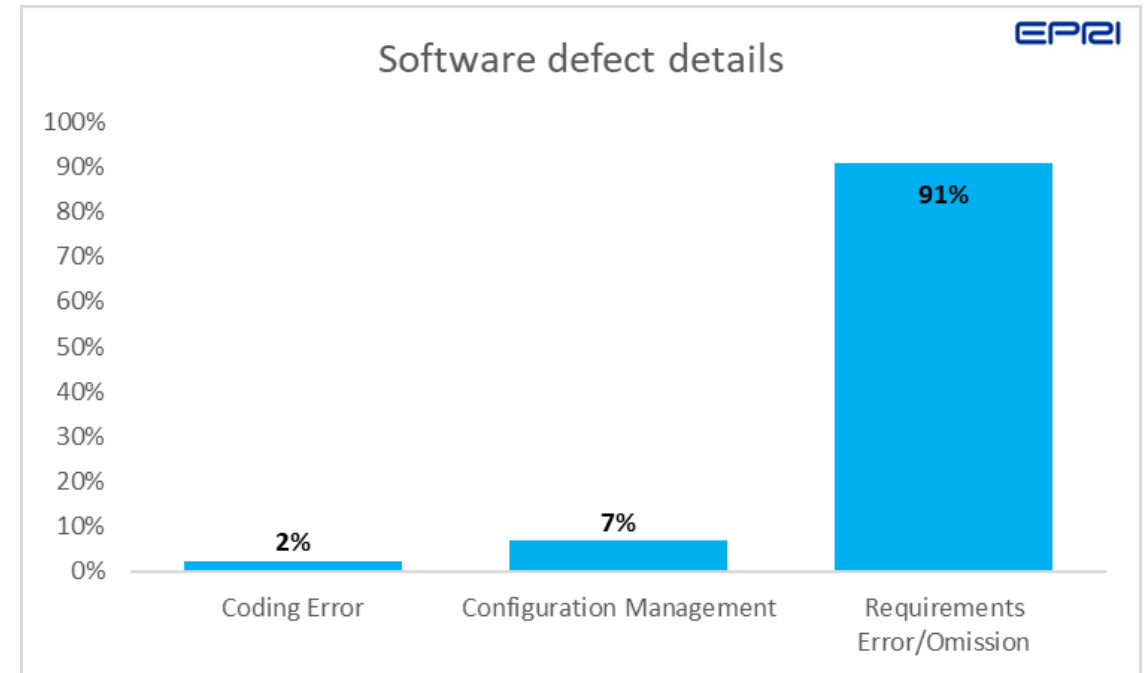
Digital I&C Single Point Vulnerabilities (2018-2024)



- About a quarter of the identified SPVs are initiated by software elements.
- They are all caused by defects (design or implementation of the software) in its majority introduced at the application level or in the configuration of parameters.
- Poorly defined or missing requirements are the underlying causal factors in most of the design defects.

Software SPVs Insights – Causes and Contributing Factors

- Software/Firmware Issues: Including latent faults, outdated versions, and misconfigured logic.
- Latent Faults: Setpoint errors, interlock failures, and lack of redundancy.
- Instrumentation Errors: Faulty sensors and signal mismatches.
- Organizational and Procedural Factors: Deficient oversight, poor communication, and inadequate testing.



Software SPVs Insights – Elimination and Mitigation Actions

- Software Updates: Firmware upgrades and application logic and parameters configuration corrections.
- Improved Configuration control of software items.
- Design Process Improvements: Better identification of requirements, design documentation and testing protocols. Refer to DSE Framework
- Vendor Engagement: Increased oversight, closer collaboration during design changes and support.

Prevention:

- Workforce development: development of training for digital I&C.

Case Study 1

Software Logic Error in Feedwater Control

- **Plant:** PWR
- **Event:** Incorrect logic in control algorithm led to unstable feedwater flow
- **SPV:** Single logic block controlling multiple valves
- **System Element Initiator:** Software at the application level
- **Cause:** Design defect - system and component level critical characteristics and parameters were embedded within the application software that were not identified, evaluated, and mitigated in the engineering change package
- **Mitigation:** Peer review of software logic and modular control design

Reference: ML14268A080

Case Studies

Case 2: Network storm causes instability in Feedwater Flow

- **Plant:** PWR
- **Event:** Network Fault of Distributed Control System Resulted in Shutdown of the Unit
- **SPV:** Single network switch fault caused a DCS network storm
- **System Element Initiator:** Hardware Network Switch impacting controllers that affected Feedwater Pump speed control.
- **Cause:** Age related degradation – no effective maintenance program in place to monitor or replace network switch condition.
- **Mitigation:** implement blocking mechanism to prevent network storms progression. Reexamine independence requirements for controllers providing main control functions. Revise maintenance program for network switch and possible implementation of network monitoring functions.

Other Lessons Learned

- The intent of redundant instrumentation is to eliminate a single point failure. If the design does not address the single point vulnerability of the cable or connection, then a single point of vulnerability still exists.
- Loss of single power sources could initiate a plant event, including reactor trips.
- Network Storms or even increased network traffic caused by failed network switches or a poorly hardened interface on data paths can have cascading effects leading to scrams and constituting SPVs.

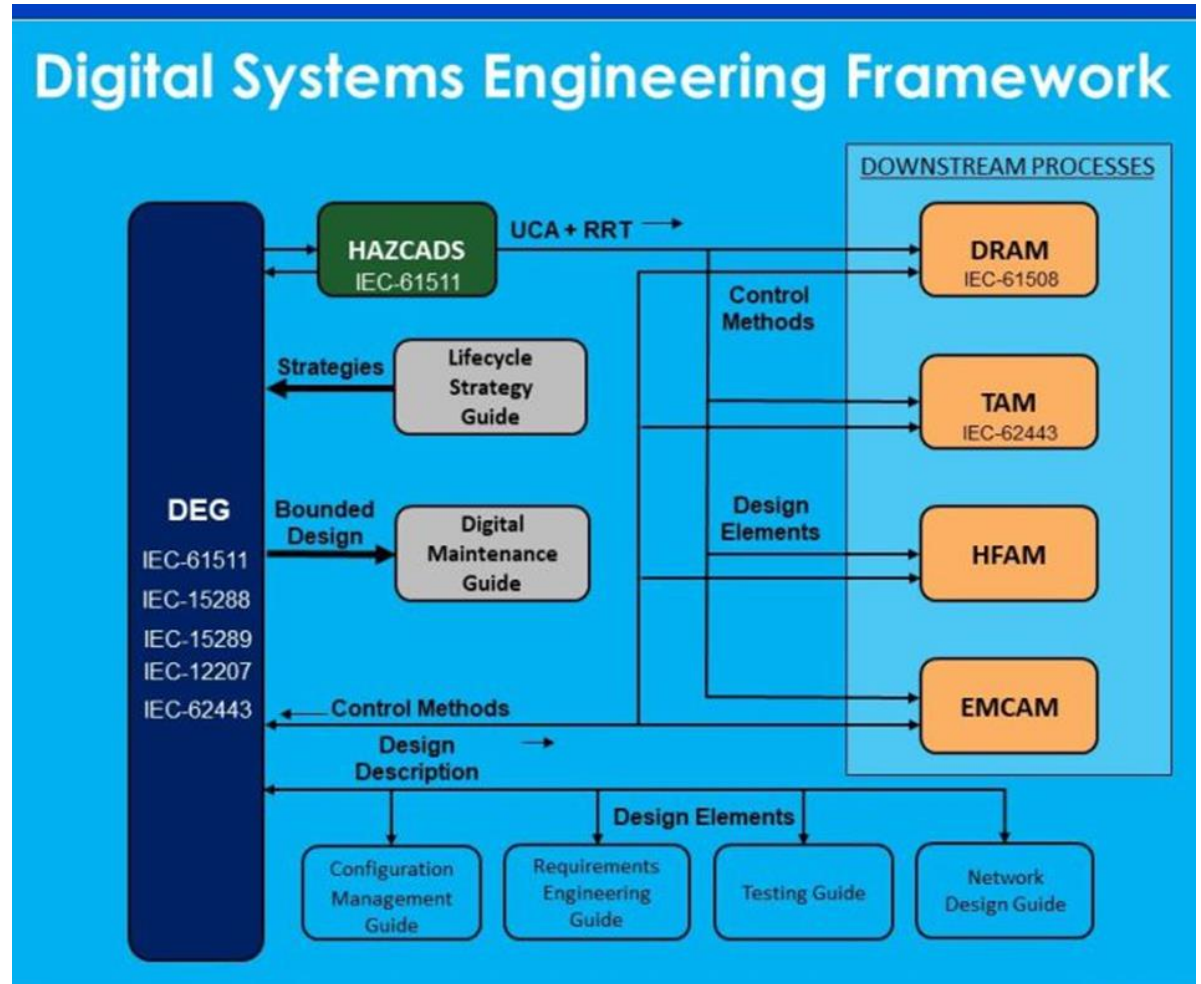
To summarize

- EPRI's Operational Data Analysis help provide insights into systems, components, causes and control methods. Making it an efficient use of experience for the Digital I&C SPV process.
- A more complete data set would improve guidance and overall value.
- Digital I&C systems present unique challenges that might require adaptation strategies to implement point vulnerability process.



To summarize

- For new designs or modifications, use of the EPRI DSE Framework elements provides high-performance methods to assist on designing out SPVs.
- Utilization of Failure Modes and Effects Analysis for digital I&C systems should consider interface analysis and software failure analysis for digital systems.
- Design reviews, testing and verification and validation activities assist when proficiently performed, in the identification of SPVs.





TOGETHER...SHAPING THE FUTURE OF ENERGY®

Condition Monitoring of Electrical Insulation



Andrew Mantey
Electrical Team Leader - PRR
Electric Power Research Institute

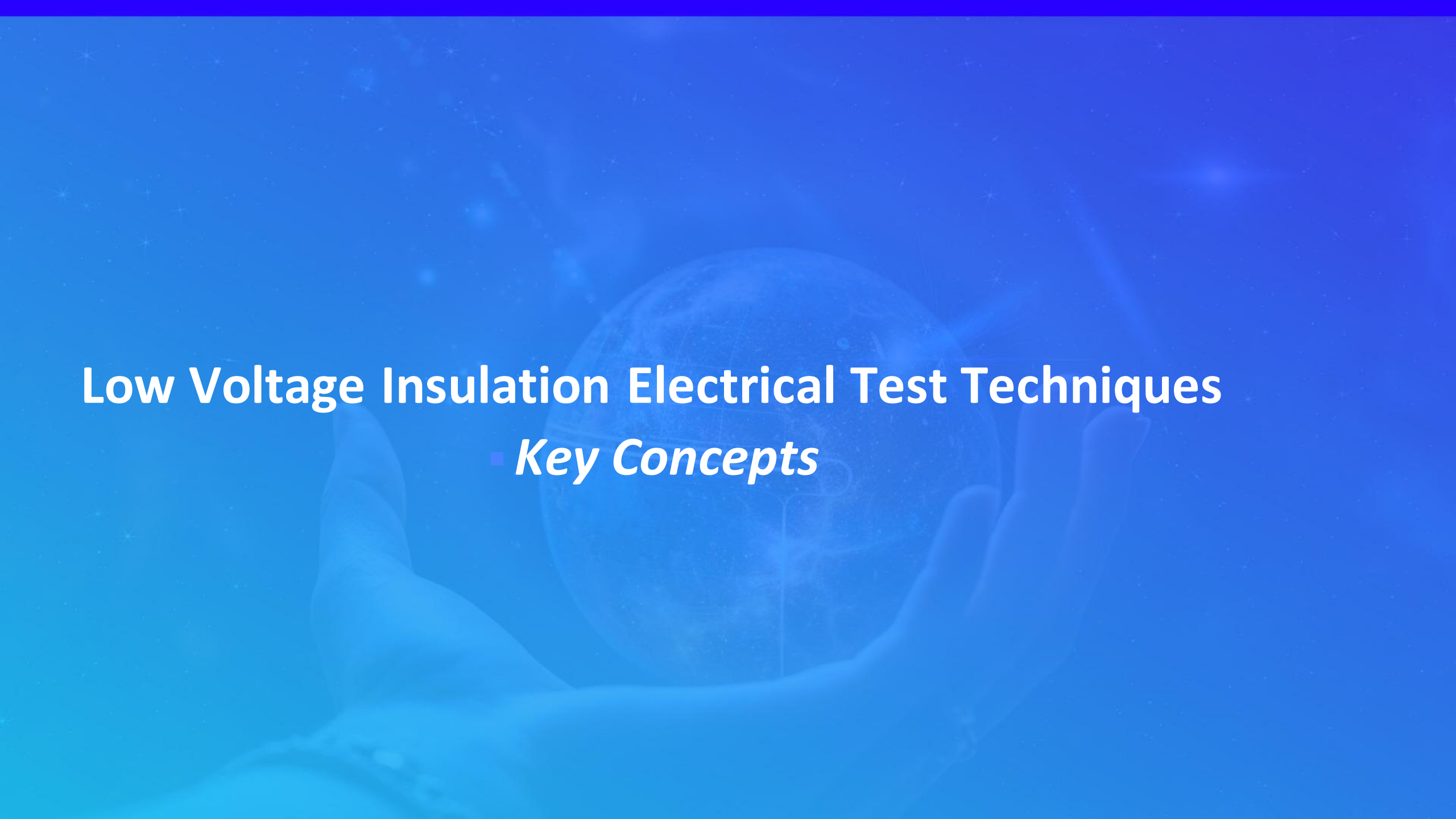
China Workshop
20-22 October 2025

Condition Monitoring Concepts

Degradation Mechanisms of Electrical Insulation

- Electrical insulation degradation mechanisms
 - Environmental stressors (heat, radiation, water/moisture intrusion, etc.)
 - Dielectric Stress (importance increases with applied voltage)
 - Ohmic heating
 - Contamination
- Primary concern is the insulation condition
 - Directly affects functionality of component
 - Identifying degradation provides opportunity to correct prior to failure





Low Voltage Insulation Electrical Test Techniques

- *Key Concepts*

Global vs. Local Electrical Sensitivity - Review

Global Sensitivity

- Test methods which provide results averaged over the whole length of the cable system (including any accessories) and lack '*spatial sensitivity*'. Examples:
 - Insulation Resistance (DC)
 - Dielectric Spectroscopy (AC)
 - Polarization Depolarization Current (DC)
- Some advanced diagnostic 'features' from specific globally sensitive techniques may help discriminate certain types of localized degradation from global degradation

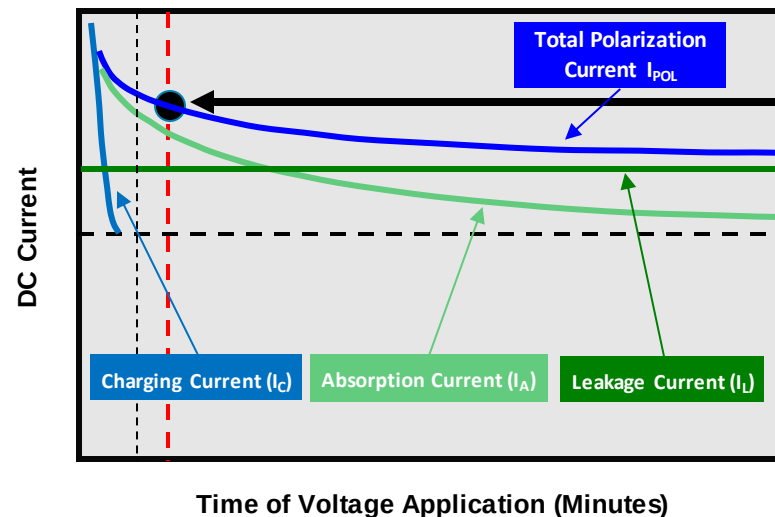
Local Sensitivity

- Test methods which are '*spatially sensitive*,' containing features which can identify and discriminate localized sources of degradation in cable system (mainly due to usage of high frequency methods based on transmission line theory). Examples:
 - Time Domain Reflectometry (RF)
 - Frequency Domain Reflectometry / LIRA™ (RF)
- Some diagnostic features may be possible to use for 'global assessment' with caution.

DC Insulation Resistance Testing

Global Test

- Application of a DC voltage across the cable insulation (250 or 500V_{dc} commonly used)
- Leakage current at a fixed time (typically 60 seconds) converted to a resistance based on applied voltage
- Results are dependent on length and temperature, rough correction factors for temperature are available in some industry guidance
- Test is difficult to trend



$$DCIR = \frac{V}{I_{POL}} @ 60 \text{ seconds}$$

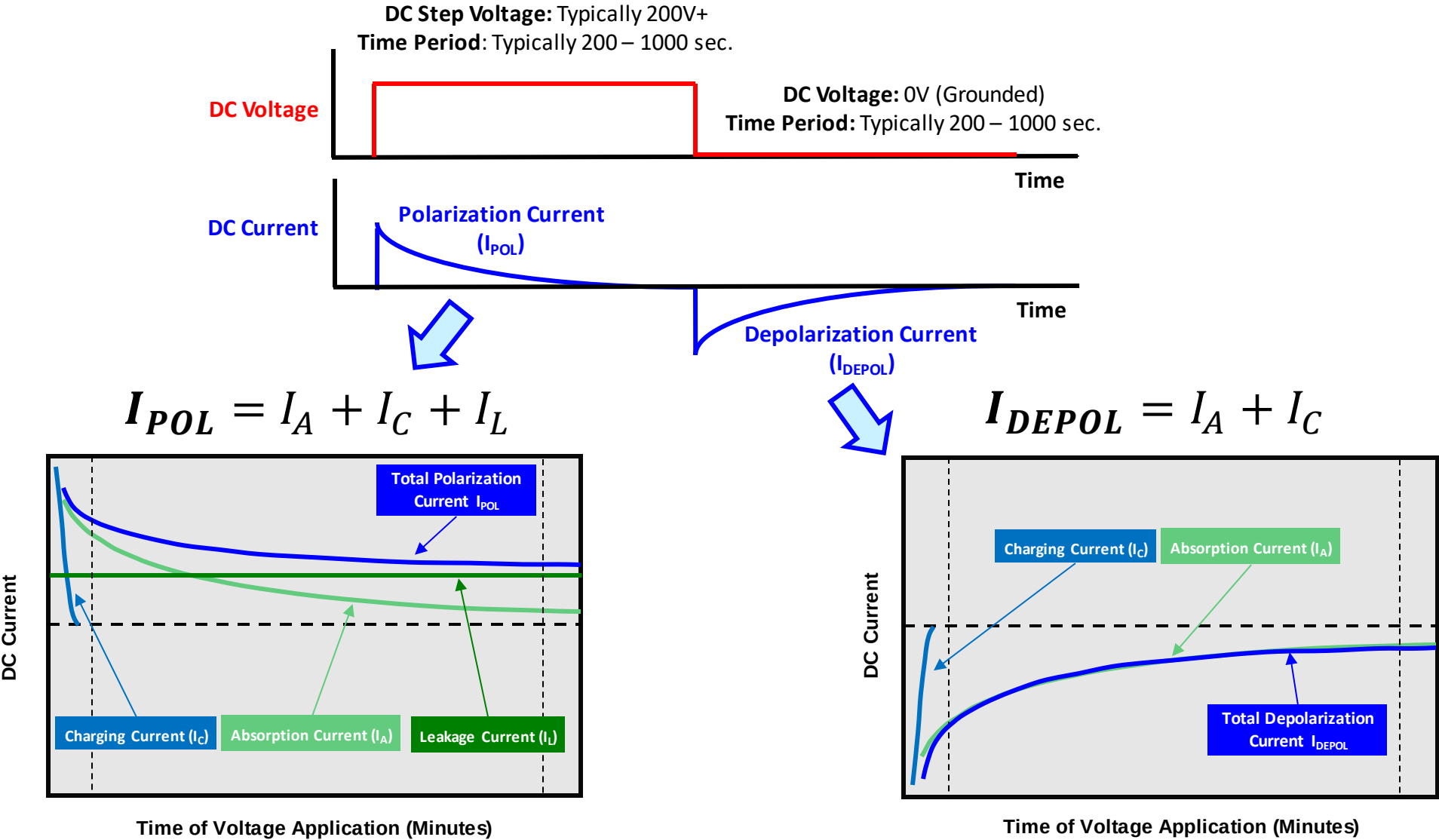
DC Insulation Resistance Testing

Global Test

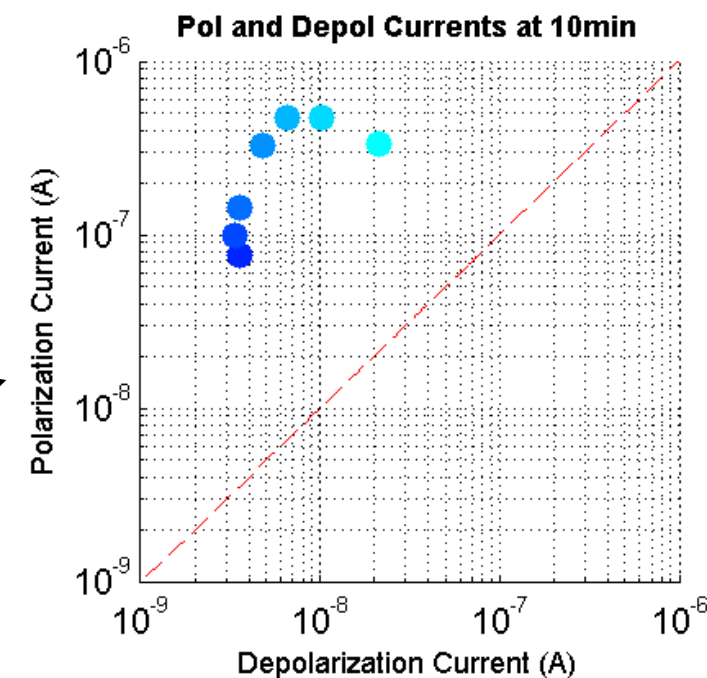
- Check for severe e.g., ‘gross’ defects = ‘Basic’ Approach
 - Insulation failure / short / ground
 - Severe moisture ingress
 - Should be used in conjunction with more sensitive diagnostic tests
- Other metrics
 - Polarization Index (10/1min. IR Ratio),
 - Dielectric Absorption Ratio (60/30sec. IR Ratio),
 - DCIR voltage dependence
- Acceptance Basis (EPRI 3002010641)
 - Significant degradation likely when $DCIR \leq \text{approximately } 30.4M\Omega \text{ (} 100M\Omega \text{)}$

- Measure charging (polarization) current during application of a DC voltage step
- Measure discharging (depolarization current) when DC supply is turned off and sample is grounded.
 - *Optionally* - convert current responses from time domain to frequency domain using approximations. Also referred to as Time Domain Dielectric Spectroscopy
- Insulations degradation can be due to increased conductivity (leakage current increases)
- This method can be applied to a wide variety of insulation systems (cables, generator/motor stator windings, transformer windings, solenoids, etc.)

DC Polarization & Depolarization Current



- Used for LV cable insulation condition monitoring testing, anomaly investigation
 - Sensitive to thermal aging related degradation
- Application of a DC voltage in the range of 200V – 500V_{DC} typically between 1 or more cable conductors and adjacent conductors (or shield if available)
- Measured Metrics (Examples)
 - I_{POL} / I_{DEPOL} at Fixed Time (i.e. 60 sec.)
 - I_{POL} vs. I_{DEPOL}
 - $(I_{DEPOL} \times t)$ versus Time (Isothermal Relaxation Current)



- Thermal Aging Trends in I_{POL} vs. I_{DEPOL} 22/C BIW EPR/CSPE LV Cable

Test Results

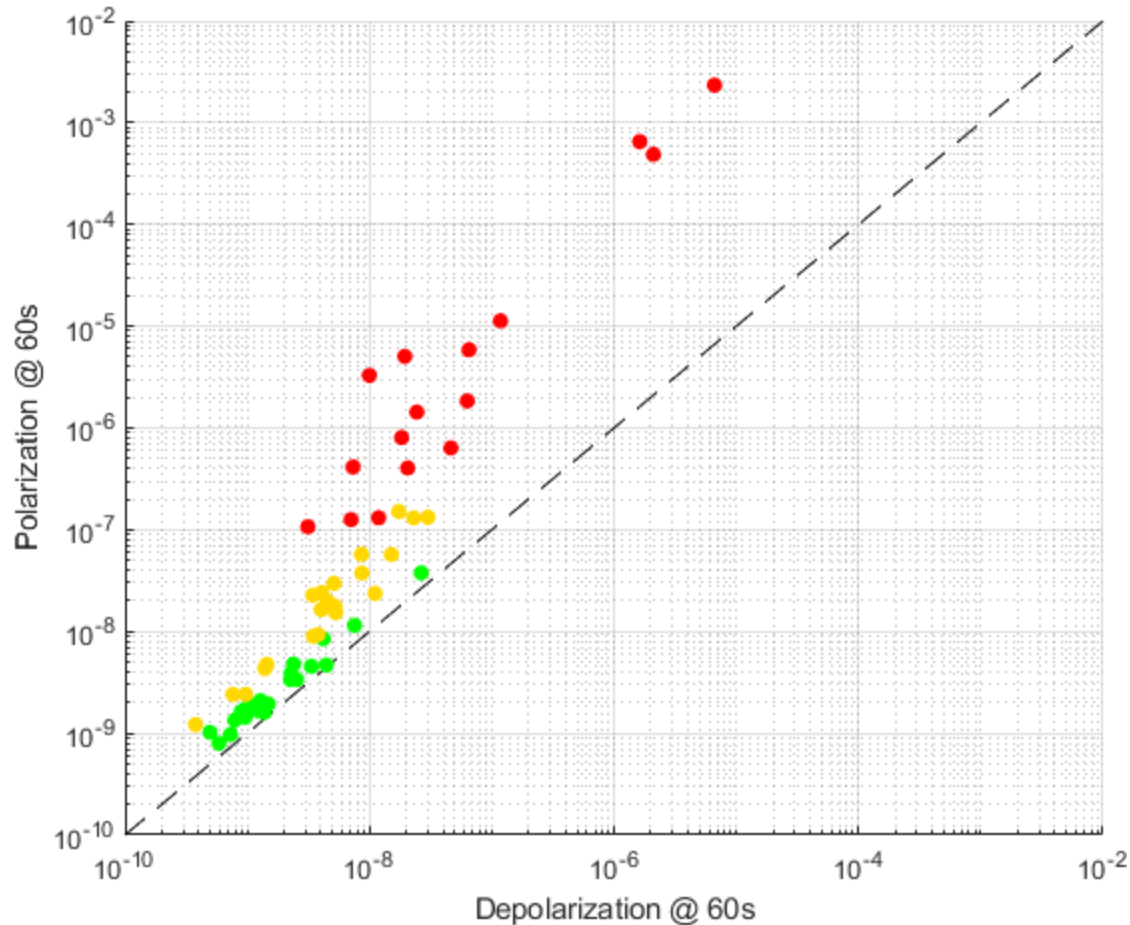
Provisional Assessment Basis (Based on EPRI 3002020818)

- Polarization Depolarization Current

DIAGNOSTIC ASSESSMENT METRIC		GOOD (Due to No Anomalies Observed)	FURTHER STUDY REQUIRED (Due to Anomalies of Moderate Concern)	ACTION REQUIRED (Due to Anomalies of High Concern)
Polarization / Depolarization Current (PDC)	DC Insulation Resistance (IR) (1 min.)	Measured Value > 100MΩ per 1000' length [6]	N/A	Measured Value $\leq$ 100MΩ per 1000' length [6]
	Pol. Current Slope ⁴ (Log-Log Scale)	Measured Value < 0	Measured Value $\approx$ 0	N/A
	IRC ($I_{DEPOL} \times \text{Time}$) (30s or 60s)	Measured Value $\approx$ Baseline ¹	Baseline ¹ $\approx$ M.V. < Maximum ²	M.V. $\geq$ Maximum ²
	Pol. / Depol. Current Ratio (I_{POL} / I_{DEPOL}) (30s or 60s)	Measured Value $\approx$ 1 OR (whichever is greater) Measured Value $\approx$ Baseline ¹	1 $\approx$ M.V. < Maximum ² OR (whichever is greater) Baseline ¹ $\approx$ M.V. < Maximum ²	M.V. $\geq$ Maximum ²

Example PDC Results

PDC – I_{POL} VS. I_{DEPOL}



**No Anomalies Observed
(i.e. 'No Action Needed')**

☐ $I_{pol} / I_{depol} \approx 1$

☐ 36% of Population

**Moderate Anomalies Observed
(i.e. 'Investigate/Trend')**

☐ $I_{pol} / I_{depol} > 1$

☐ 33% of Population

**High Anomalies Observed
(i.e. 'Action Recommended')**

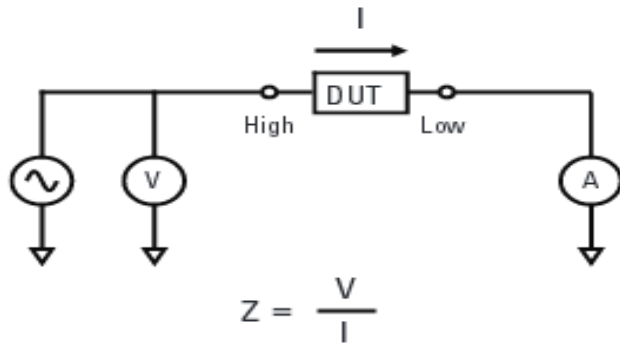
☐ $I_{pol} / I_{depol} \gg 1$

☐ 25% of Population

☐ 6% of population could not be calculated

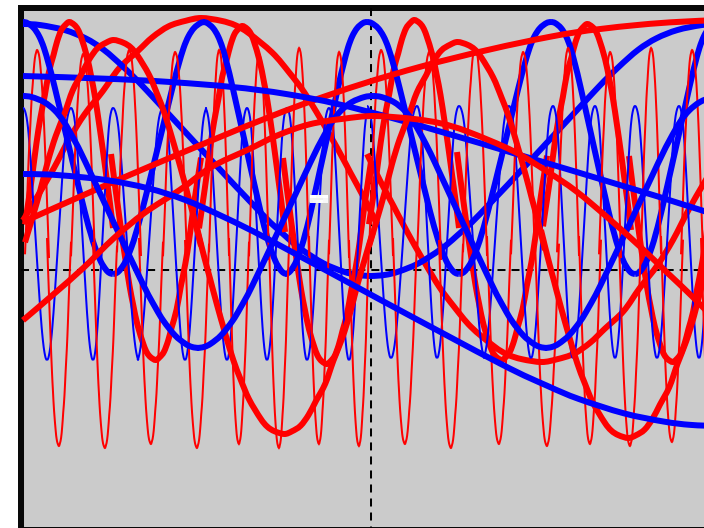
Dielectric Spectroscopy (DS)

- Measure frequency response of complex capacitance (C' and C'') and dielectric loss ($\tan \delta$) across a wide frequency range
- Degradation of electrical insulation resulting from permittivity changes of the dielectric can be measured by changes in their response as the test voltage frequency is applied
 - 0.001 Hz to 1kHz for example, cable dependent or at a single frequency (0.1 Hz Tan Delta)
- This method can be applied to cables, motor/generator windings, transformer windings to measure effects like moisture content (transformer/bushing insulations, water treeing of cable insulation, contamination and moisture in motor insulations) and thermal oxidative aging of the insulation



Basic DS Measurement Concept

— Voltage
— Current



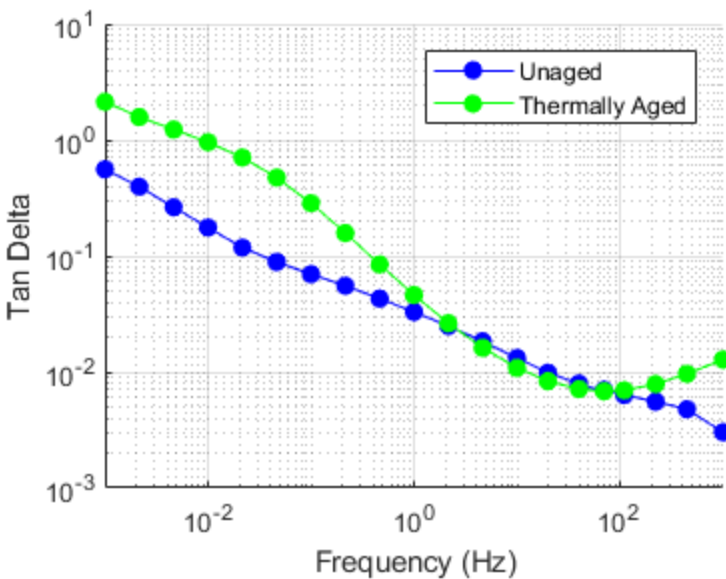
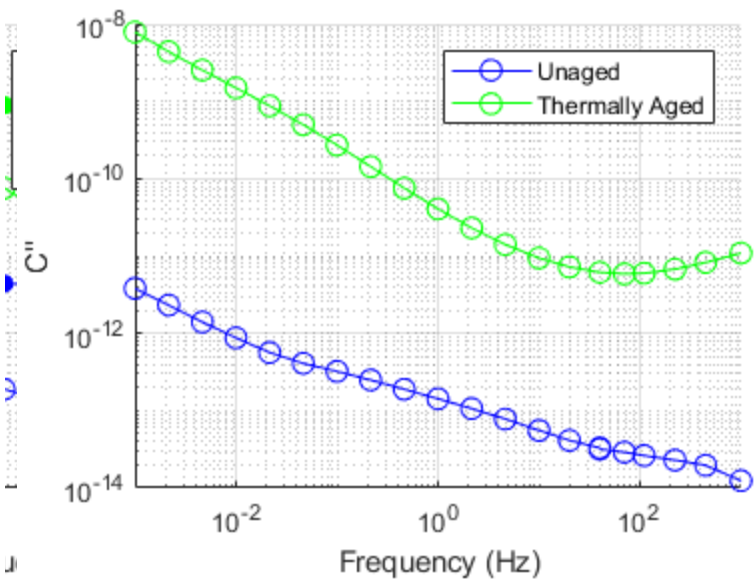
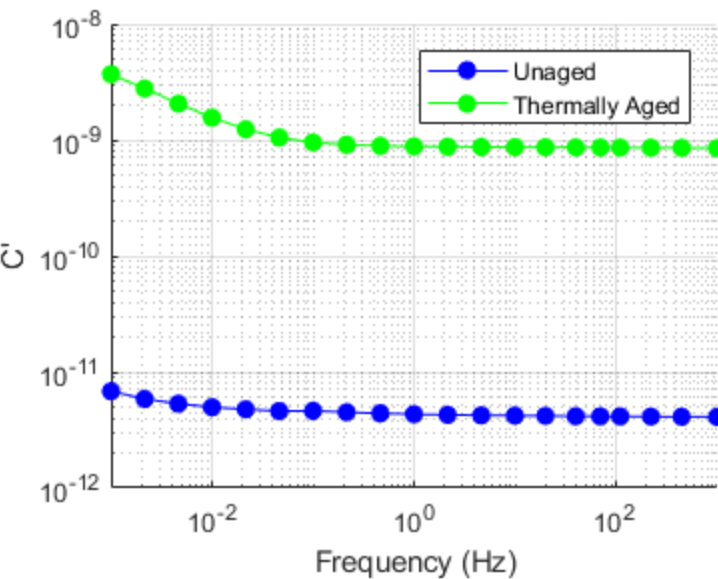
Phase

Basic DS Calculation Basis

$Z(\omega) = \text{Complex Impedance} = \frac{1}{j\omega C(\omega)}$ where

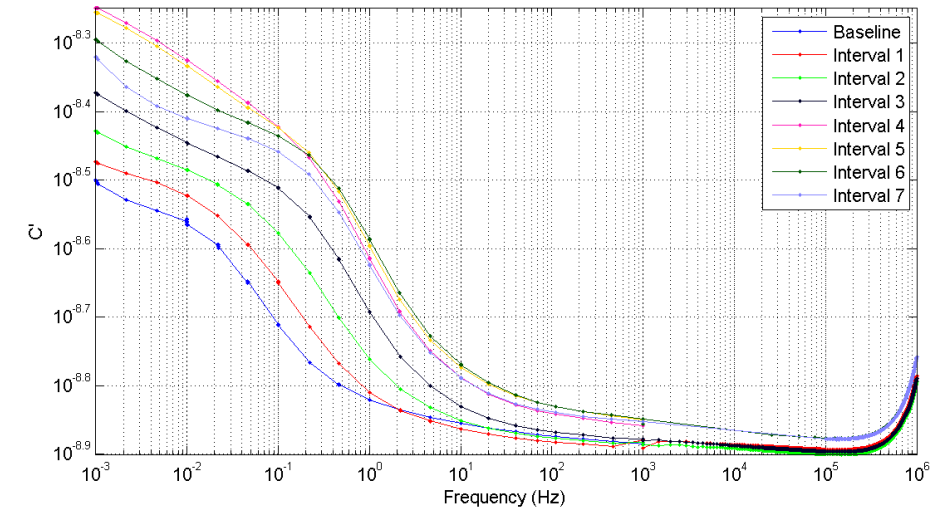
$C(\omega) = \text{Complex Capacitance} = C'(\omega) - jC''(\omega)$

$\tan \delta(\omega) = \text{Dielectric Loss} = \frac{C''(\omega)}{C'(\omega)} \left[\frac{\omega \epsilon'' + \sigma}{\omega \epsilon'} \right]$



Dielectric Spectroscopy

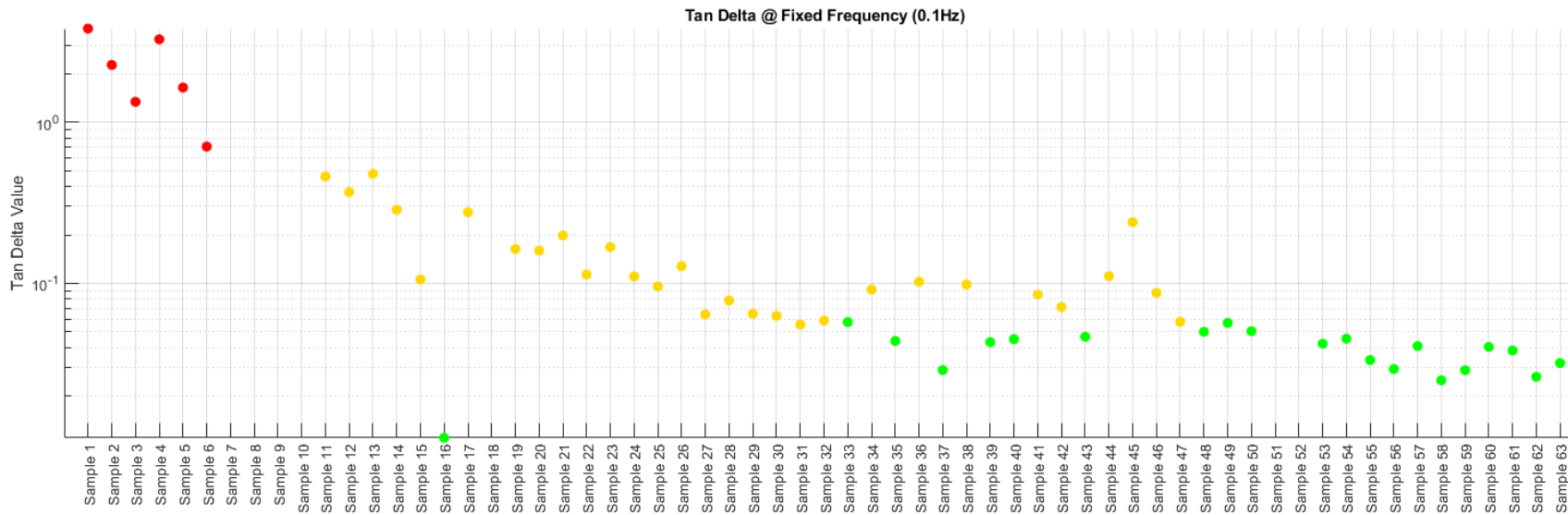
- Application of AC voltage of typically 200V (higher voltage possible) typically between 1 or more conductors and adjacent conductors (or shield if available)
- Measured Metrics (Examples)
 - Mean $\tan \delta$, C'' or C' Frequency Dependence
 - Mean $\tan \delta$ Fixed Frequency Values - at non-standard fixed frequencies (0.01, 0.1, 10Hz).



Thermal Aging Trends in Capacitance (C') in 22/C CSPE/EPR LV Cable

Example DS Results

Population - Tan δ vs. Frequency



No Anomalies Observed
(i.e. 'No Action Needed')

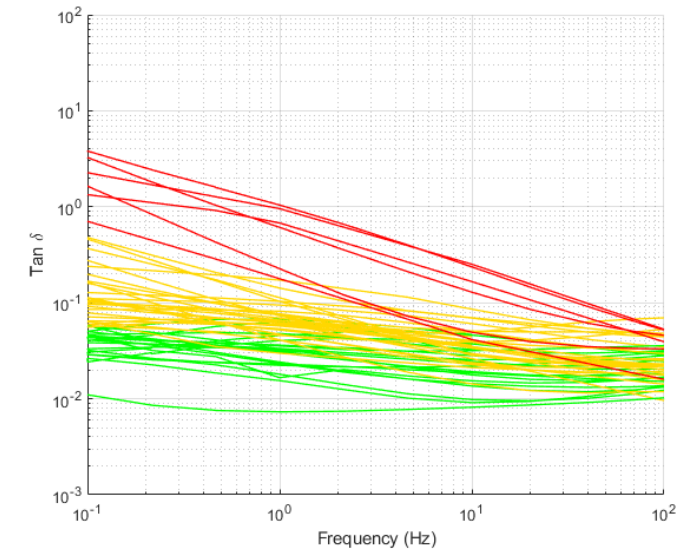
- ☐ Relatively low Tan δ Magnitude
- ☐ 33 % of Population
- ☐ 11% of population could not be calculated

Moderate Anomalies Observed
(i.e. 'Investigate/Trend')

- ☐ Moderate Tan δ Magnitude
- ☐ 46% of Population

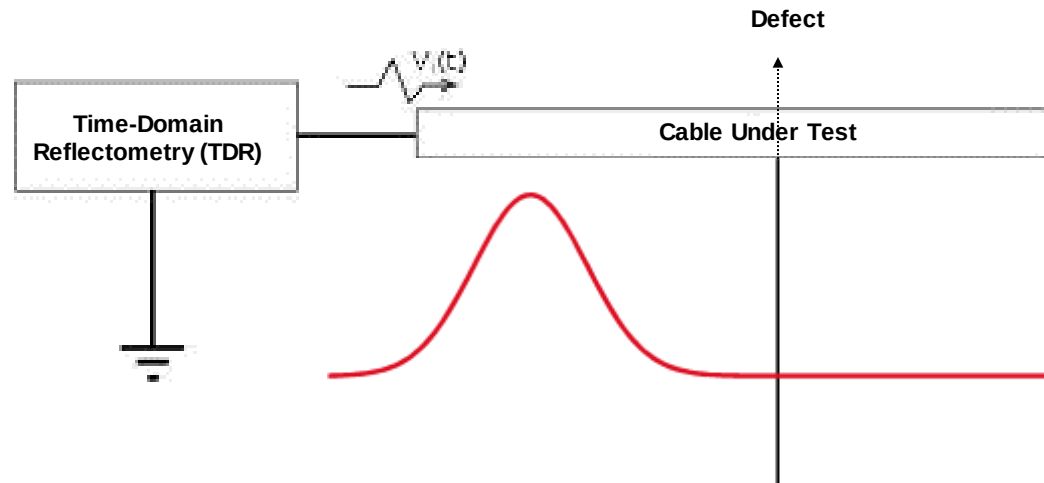
High Anomalies Observed
(i.e. 'Action Recommended')

- ☐ Relatively large Tan δ Magnitude
(compared to reference values)
- ☐ 10% of Population



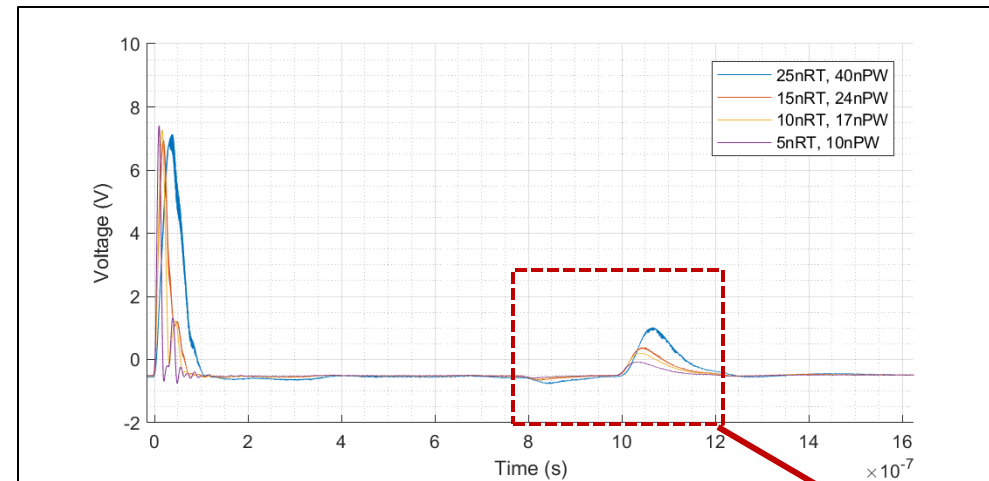
Time Domain Reflectometry (TDR)

- Diagnostic test which uses a fast pulse with steep front to detect any changes in the impedance within the insulation
- Impedance discontinuities will cause some of the injected pulse shape (incident signal) to be reflected back towards the source
- Used for maintenance testing, anomaly investigation, fault location, baselining

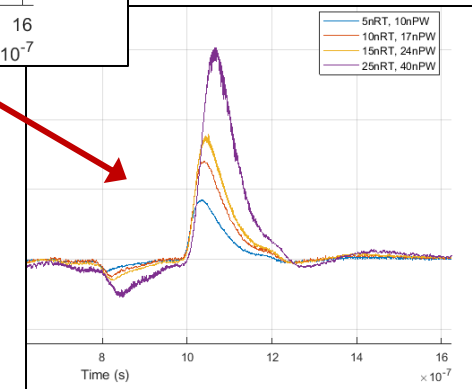


Time Domain Reflectometry (TDR)

- 'Basic' TDR instruments lack ability to change pulse characteristics
- Varying pulse parameters allows to overcome cable related limitations such as attenuation
 - $\sim < 20V_{PK}$ (Pulse) – can be higher
 - Rise-time between $\sim 5ns - 1\mu s$, width between $\sim 10ns - 10\mu s$
- Measured Metrics
 - Injected and reflected pulse voltage versus electrical length.
 - Cable propagation speed (m/ μs)
 - Signal energy loss
- No pass/fail guidelines
 - Troubleshooting and trending



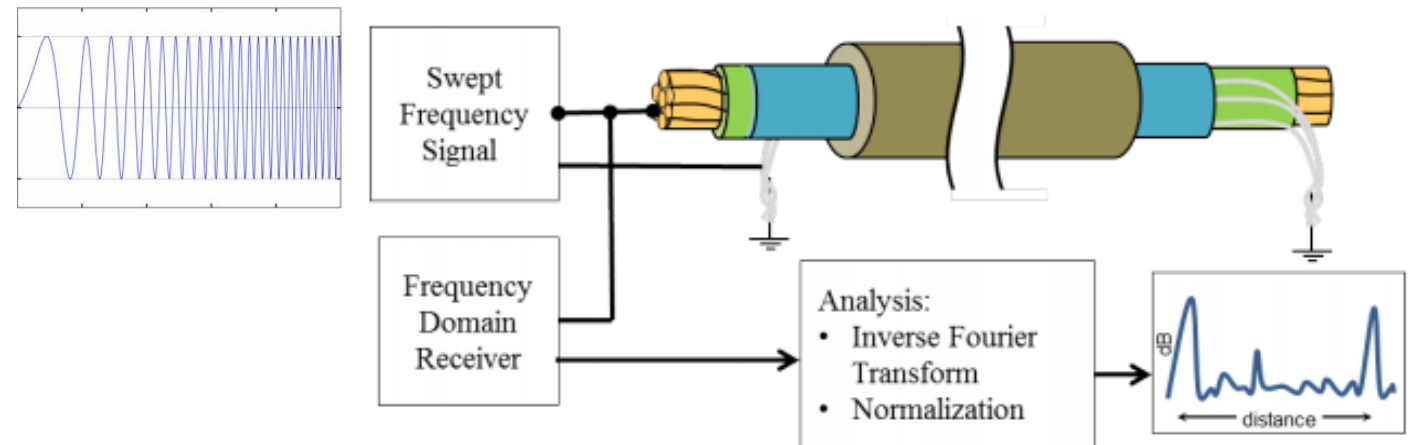
Advanced TDR Anomaly Example: Trace from ~ 440 ft., 600V 2/C 14 AWG Unshielded LV Cable, XLPE Insulation



Frequency Domain Reflectometry (FDR)

Localization Test

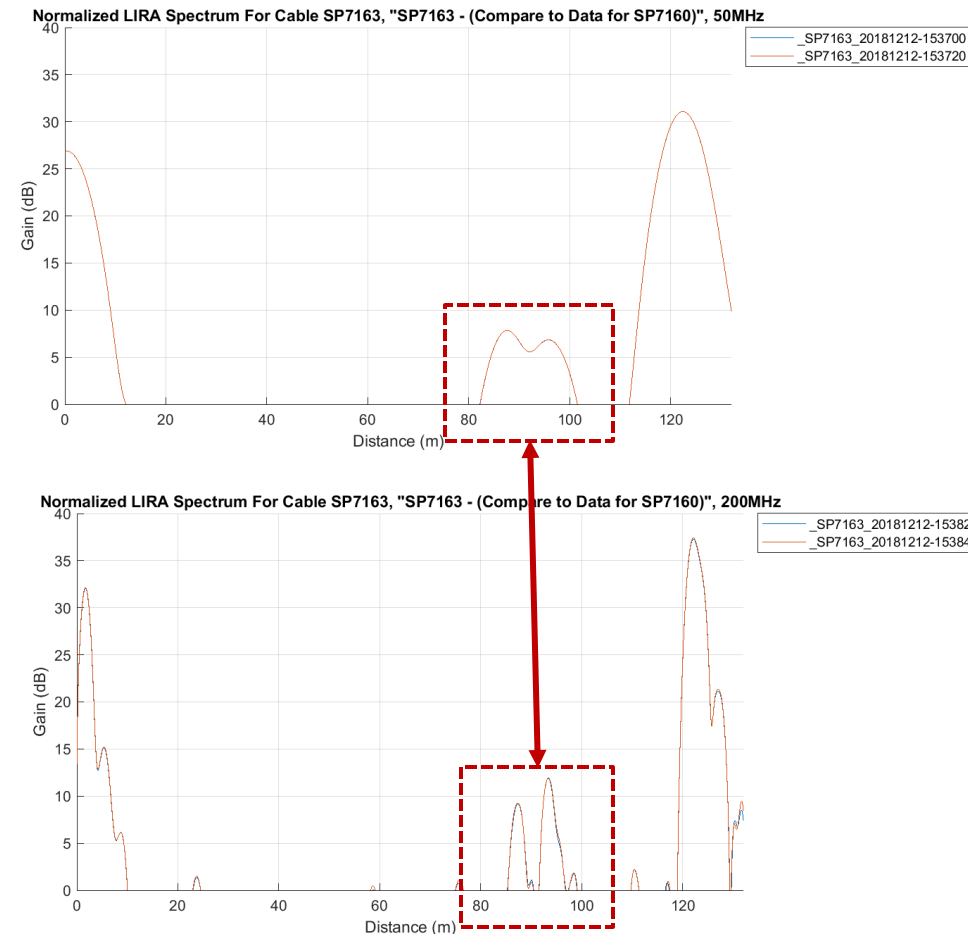
- Sweep is performed with stepped frequency sine waves, using a Vector Network Analyzer (VNA)
 - Signal reflected back in the frequency domain at impedance discontinuities
- LIRA™, CHAR™ are commercial variants of FDR



Physics-Based Modeling of Cable Insulation Conditions for Frequency Domain Reflectometry (FDR), S.W. Glass, A.M. Jones, L.S. Fifield, T.S. Hartman, N. Bowler, PNNL and ISW, US DOE, 2017.

FDR Analysis

- Test parameters
 - $\sim 3V_{\text{RMS}}$ (Swept Frequency Sinusoidal)
 - $\sim 10\text{MHz}$ to 1300MHz (depending on cable length)
- Measured Metrics
 - Impedance Gain (dB) and phase versus frequency (converted to electrical length via IFFT).
 - Cable propagation speed ($\text{m}/\mu\text{s}$)
 - Various other RF parameters

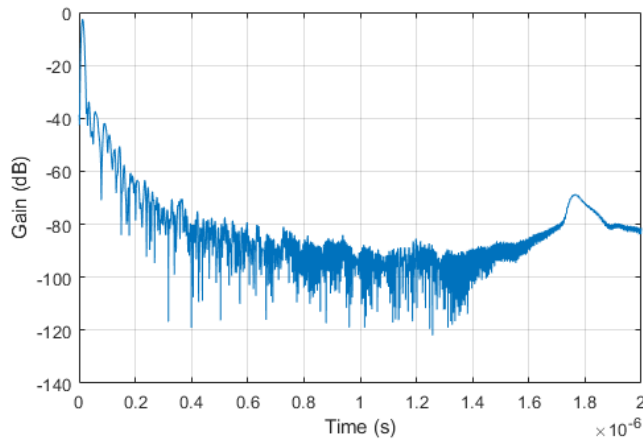
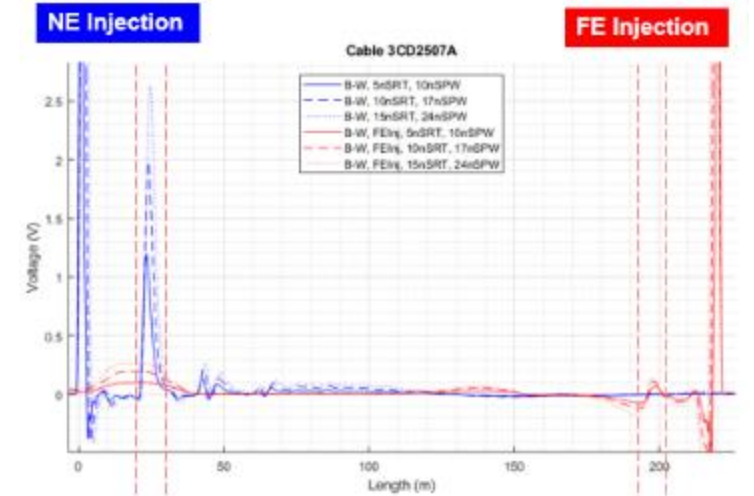
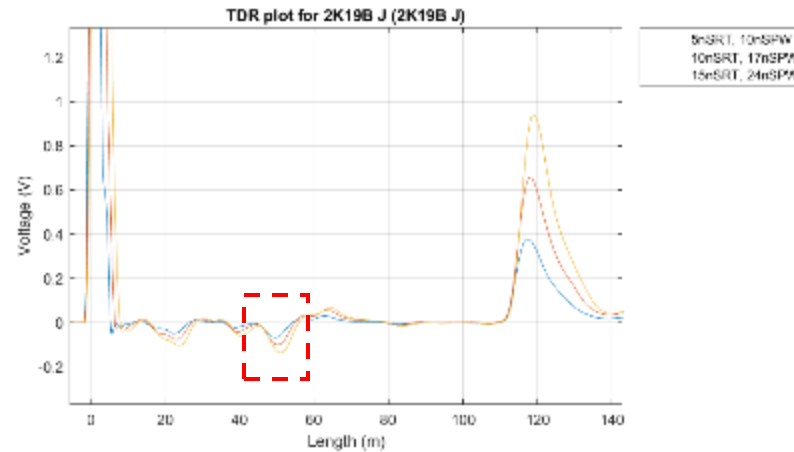
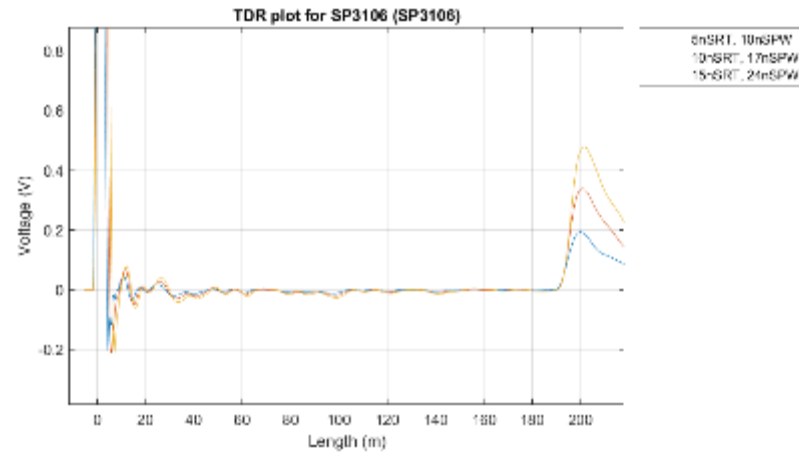


FDR / LIRA Anomaly Example: Trace from ~ 440 ft., 600V 2/C 14 AWG Unshielded LV Cable, XLPE Insulation

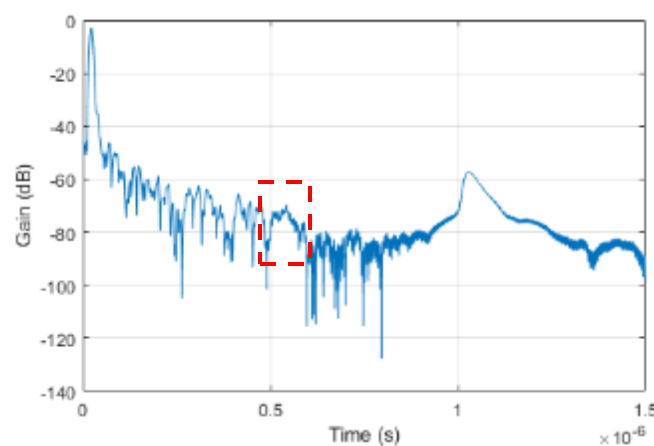
- Both sensitive to significant impedance changes along cable length
- FDR typically more sensitive to ‘soft’ defects such as insulation (non-electrical) aging including thermal, wet aging
 - Can also be more sensitive to geometric issues (i.e., bends, mechanical damage)
- Can be used to determine if thermal damage (or physical damage) has occurred to cables that are inaccessible (in conduits or at difficult to reach or access areas)

Example Test Results

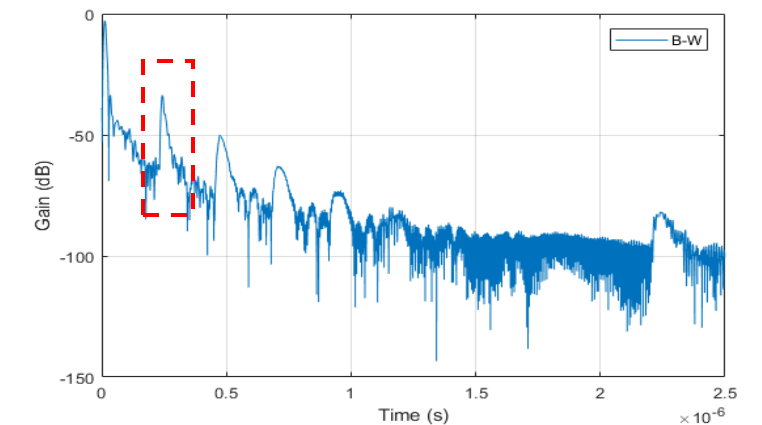
Advanced Time and Frequency Domain Reflectometry (TDR and FDR)



No Anomalies Observed
(i.e. 'No Action Needed')



Anomalies Observed
(i.e., Investigate / Trend)



Significant Anomalies Observed
(Indication of Fault) – i.e., Action
Recommended



High Voltage Insulation Electrical Test Techniques

- *Key Concepts*

Electrical Test Methods Important for Higher Voltage Insulations



Very Low Frequency Tan Delta Testing



Withstand (Pass/Fail) Testing

Simple Withstand (Insulation)
Monitored Withstand (Insulation)



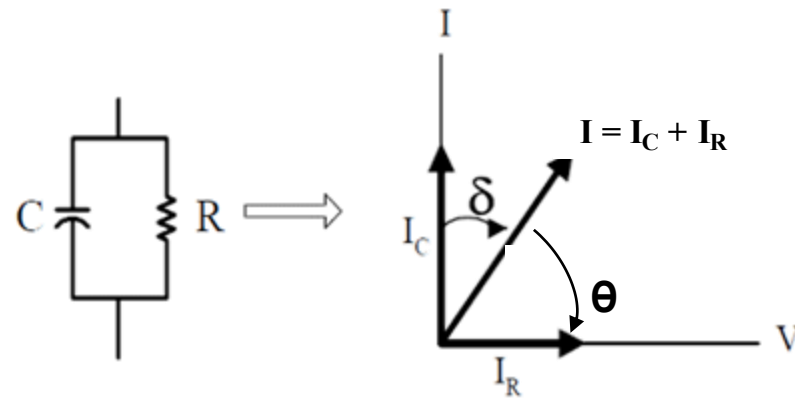
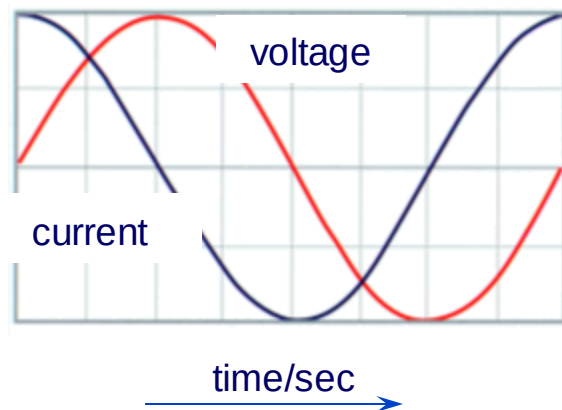
Locally Sensitive Diagnostic Testing

Partial Discharge (PD)
FDR and TDR

Very Low Frequency Tangent Delta (Tan δ) Testing – Background

■ What is it?

- Measure Dielectric Loss (Tan δ)
- Based on principle that insulation in its ‘pure’ state behaves as a perfect capacitor, with current I leading voltage by 90°
 - Bulk or severe local degradation in insulation (particularly from water-treeing) ‘throws off’ the perfect capacitor by introducing/enhancing resistive current (I_R).
- Difference in angle is δ , and tangent of angle $\tan \delta = I_R/I_C$
- Effects are more pronounced as frequency is lowered (i.e., $\tan \delta \propto 1/f$).
- 0.1Hz is most common fixed frequency but can also be done at variable frequencies (*dielectric spectroscopy*)



VLF Tan δ Testing – Application Basis

- **Why is it used?**
 - Sensitive to bulk or severe local moisture related degradation (i.e., water-treeing, wet joints).
 - Sensitivity is inversely related to applied frequency
 - Provides ‘global’ parameter for aging management or baselining.
 - Defect **identification** and **assessment**
- **Where to apply?**
 - MV cables, motors, generators
 - Mainly for maintenance / aging management type applications, baselining, or anomaly investigation.
 - Part of Basic or Advanced approaches

AC Dielectric Loss	
VLF (0.1Hz) Tan δ	
Target Deterioration	
Wet Aging	
‘Dry Electrical’	
Neutral Corrosion/Resistance	
Connector Corrosion/Resistance	
Thermal	
Chemical	
Contaminated Interfaces (Internal or External)	
Diagnostic Function (IDLA)	
Identification	Is there a problem?
Discrimination	Is it an internal and real problem? What is the nature of the problem?
Localization	Where is the problem?
Assessment	How bad is the problem?

- **What is it?**

- Apply voltage to an insulation system $>$ nominal voltage (U_o), for a prescribed duration, as per standards / guidelines

- **Why is it used?**

- Initiate failures due to gross point defects present in an insulation system during test, to reduce in-service failure risk
- Aid in defect **identification** and **assessment**
- Condition defects to consider time-dependent effects
- Allow option to abort test prior to in-test failure or shorten duration

- **Where is it used?**

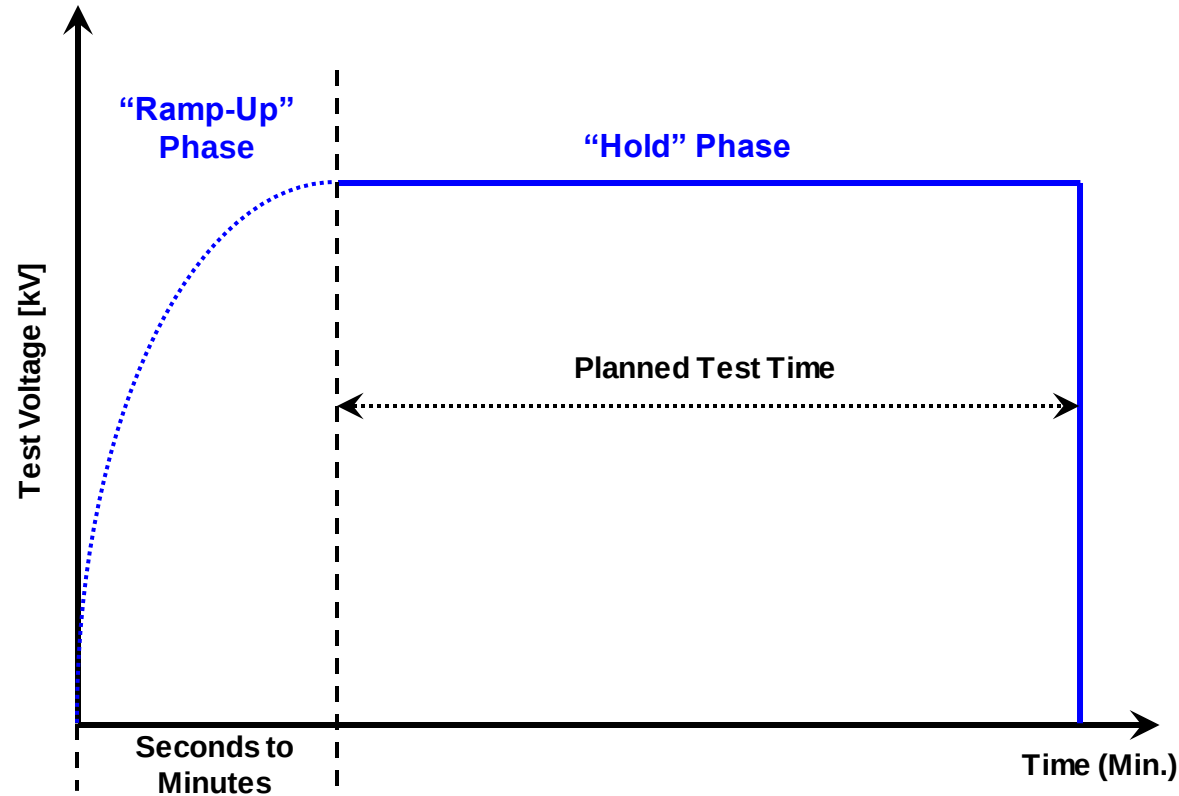
- Context dependent – primarily for standards-based commissioning applications, critical maintenance / aging management and post-repair applications

Non-Destructive for non-degraded insulations systems

Withstand Testing – Selection Considerations

Global Test

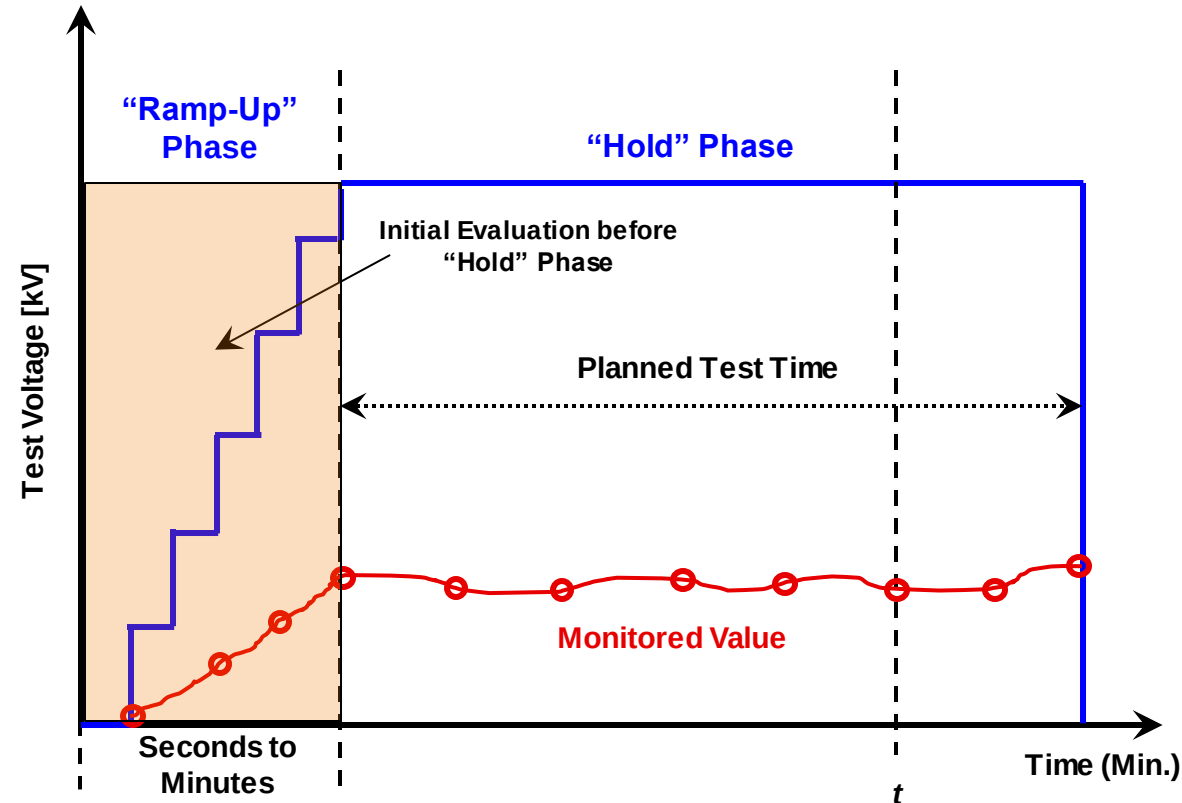
- **Simple** versus Monitored Withstand (MWS)



'Simple' schematic of a Simple Withstand Test

Withstand Testing – Selection Considerations

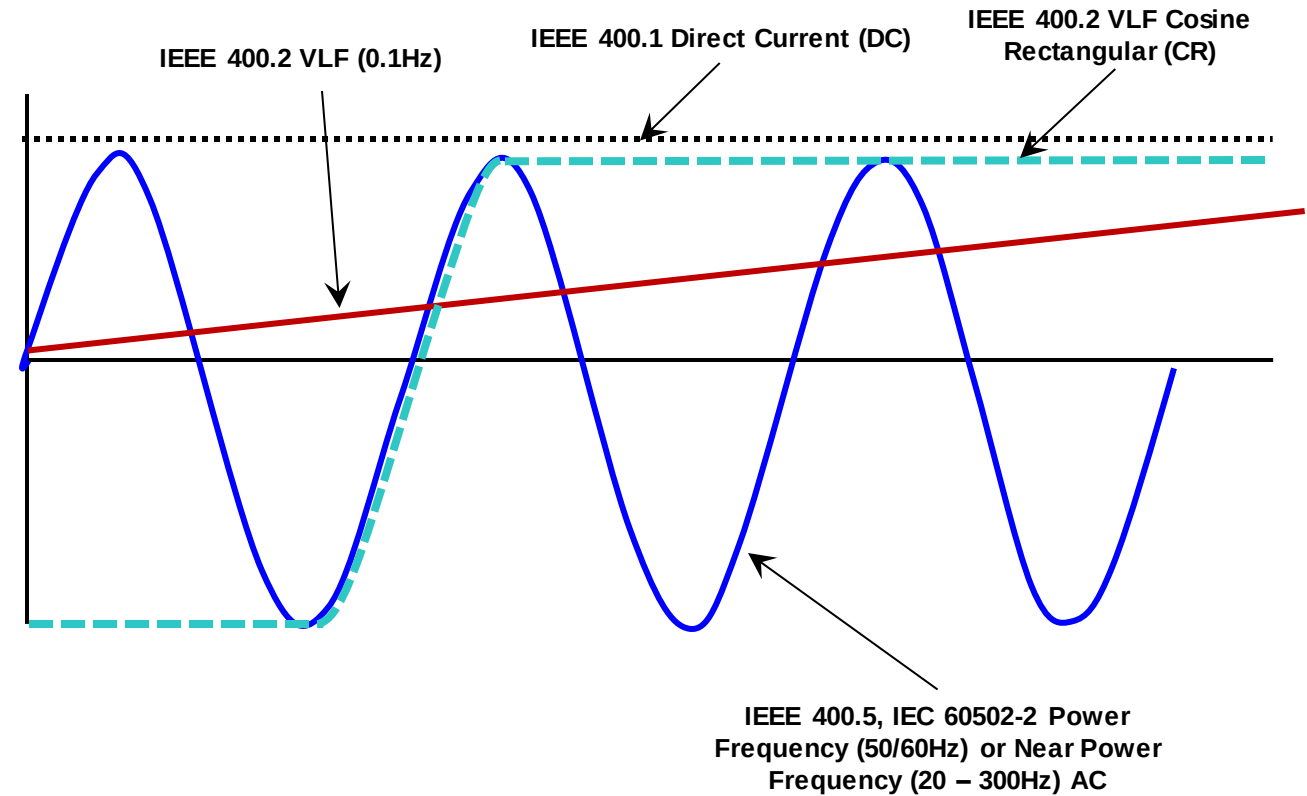
- Simple versus **Monitored Withstand (MWS)**



‘Simple’ schematic of a Monitored Withstand Test with a Diagnostic Monitored Value

■ Withstand Test Options

- DC (Direct Current)
- Power Frequency (50/60Hz)
- Near Power Frequency (20 – 300Hz)
- VLF 0.1Hz Sinusoidal
- VLF Cosine-Rectangular



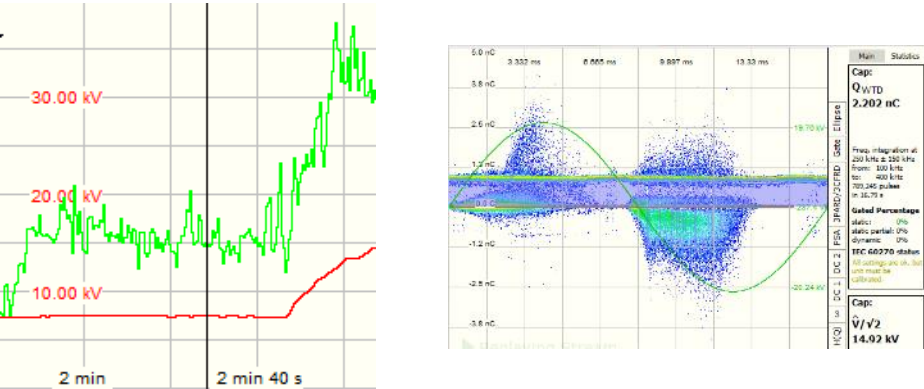
For NPP MV Cable Withstand Testing, VLF (0.1Hz) or Power Frequency (50/60Hz) are recommended options

- **Voltage & Duration:**
 - Test voltages must apply sufficient stress and duration to cause breakdown of gross defects during test. Otherwise – defect may partially progress to failure during test but fail in-service
 - Duration should account for conditioning effects
- **Typical Ranges:**
 - Voltage: Non-DC range from $\sim 1.5 U_o$ to $3U_o$, DC $> 3U_o$
 - Durations: Range from Minutes (Power Frequency) to up to an Hour (VLF 0.1Hz or VLF-CR)
- **Acceptance Basis**
 - Simple Withstand: Pass/Fail
 - Monitored Withstand: Pass/Fail + monitored diagnostic parameter may be used for assessment / decision-making purposes



Withstand Testing – Examples

- AC Partial Discharge (PD) Monitored Withstand
 - PD Monitored 60Hz Withstand (Commissioning) Testing per IEC 60502-2 of 25kV XLPE Cable Circuits. Test Aborted prior to failure of terminations, avoiding failure under test and allowing for on-site investigation / repair.



Phase B Time vs. PD / Voltage Profile (UNTIL ABORTED)

Ramp Up to 0.5U_o

RED: Voltage,

GREEN: PD, HVCC, f_c = 250kHz, Δf = 300kHz



Phase B Time vs. PD / Voltage Profile (FOLLOWING TERMINATION REPAIR)

Ramp Up to 1.7U_o (Withstand Voltage)

RED: Voltage,

GREEN: PD, HVCC, f_c = 250kHz, Δf = 300kHz

PD Effects on Polymer Insulation



Repetitive discharges lead degraded oxygen and nitrogen products



Electrons, ions and oxidation produced from the discharge are deposited at polymer surface.



Surface eroded

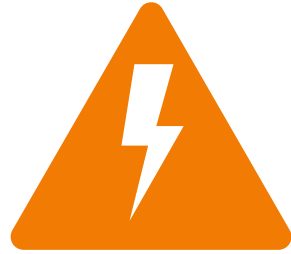


Charges move beyond surface into insulation



If not corrected, insulation will degrade and fail

Partial Discharge Inception Voltage



PDIV: voltage at which discharge starts

Hence there is a voltage below which discharges will not occur

- ---or at least cannot be measured



PDIV depends on

Gas nature in the void (generally air)

Void size and shape

Pressure

Temperature

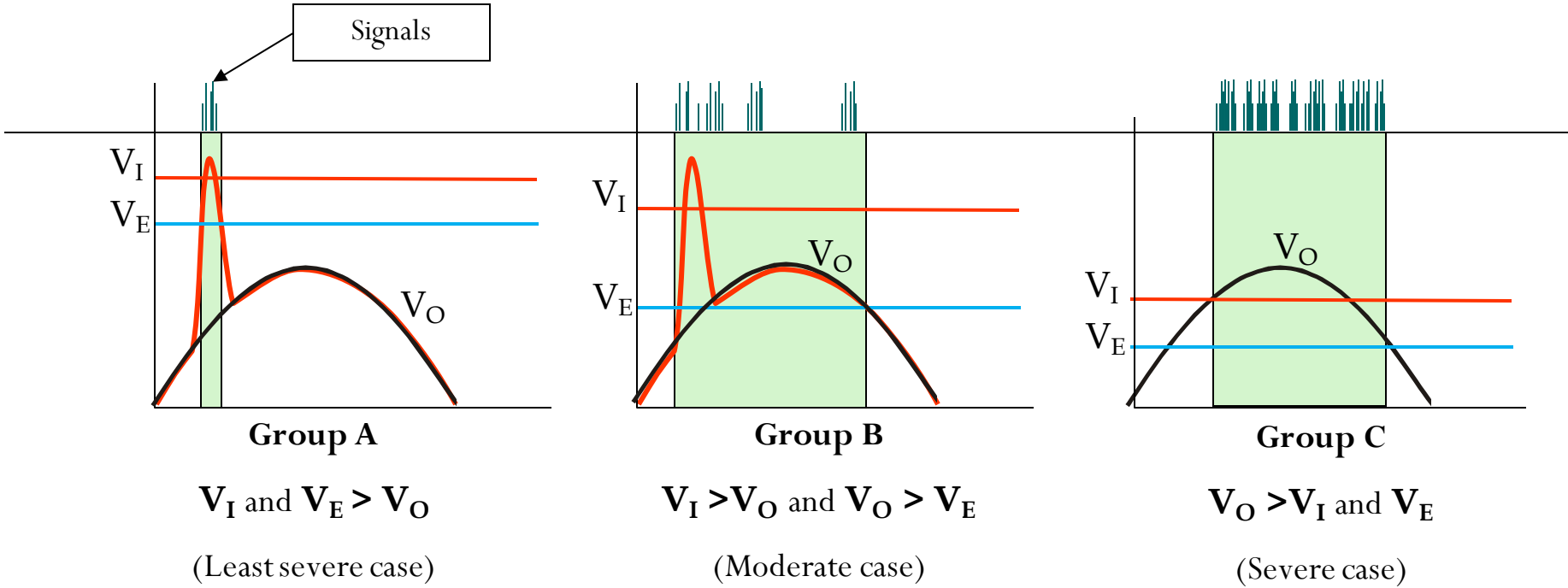
Shield/insulation interface

Insulation nature-affects subsequent events

Partial Discharge Extinction Voltage (PDEV)

- After PD occurs, when voltage then drops below PDEV, discharges 'disappear'
- PDEV
 - PDEV is always less than PDIV
- PDEV must be greater than operating voltage
 - If less, discharge never cease, and this will result in insulation degradation (electrical treeing)

Based on PDIV and PDEV phenomena, discharges can be classified in three groups:



PD can be initiated momentarily during voltage surge but not sustained.

No PD during normal operation.

PD can be initiated during voltage surge and can be sustained during normal operation.

No PD prior to surge

PD always occurs during normal operating conditions.

Condition Assessment through Combined Testing

Why is there no Silver Bullet?

	Withstand Testing** (Not a Diagnostic)	Partial Discharge	AC Dielectric Loss		DC Dielectric Response		Metallic Resistance	RF Reflectometry	
			VLF (0.1Hz) Tan δ	Dielectric Spectroscopy	DCIR	PDC	Shield / Conductor Resistance	TDR	FDR / LIRA
Target Deterioration									
Wet Aging	MED Influence	LOW Influence	HIGH Influence	HIGH Influence	MED Influence	HIGH Influence	LOW Influence	LOW Influence	MED Influence
'Dry Electrical'	MED Influence	HIGH Influence	LOW Influence	LOW Influence	LOW Influence	LOW Influence	LOW Influence	MED Influence	MED Influence
Neutral Corrosion/Resistance	MED Influence	MED Influence	LOW Influence	MED Influence	LOW Influence	LOW Influence	HIGH Influence	HIGH Influence	HIGH Influence
Connector Corrosion/Resistance	MED Influence	MED Influence	LOW Influence	LOW Influence	LOW Influence	LOW Influence	HIGH Influence	MED Influence	MED Influence
Thermal	MED Influence	MED Influence	MED Influence	HIGH Influence	MED Influence	HIGH Influence	MED Influence	LOW Influence	HIGH Influence
Chemical	MED Influence	MED Influence	MED Influence	MED Influence	MED Influence	MED Influence	LOW Influence	LOW Influence	MED Influence
Contaminated Interfaces (Internal or External)	MED Influence	MED Influence	HIGH Influence	HIGH Influence	MED Influence	MED Influence	LOW Influence	LOW Influence	MED Influence
Diagnostic Function (IDLA)									
Q: Is there a problem?	Identification	Identification	Identification	Identification	Identification	Identification	Identification	Identification	Identification
Q: Is it an internal and real problem? Q: What is the nature of the problem?	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination
Q: Where is the problem?	Localization	Localization	Localization	Localization	Localization	Localization	Localization	Localization	Localization
Q: How bad is the problem?	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment

- No single diagnostic parameter / test can cover all the deficiencies observed in aged MV insulation systems – a combination of diagnostics will be required in contexts where diagnostic accuracy is of concern.

	No / Minimal Influence across Majority of Scenarios
	Medium / Variable / Severity-Specific Influence across Scenarios
	High (Severity-Specific) Influence across Scenarios

Why is there no Silver Bullet?

	Withstand Testing** (Not a Diagnostic)	Partial Discharge	AC Dielectric Loss		DC Dielectric Response		Metallic Resistance	RF Reflectometry	
			VLF (0.1Hz) Tan δ	Dielectric Spectroscopy	DCIR	PDC	Shield / Conductor Resistance	TDR	FDR / LIRA
Target Deterioration									
Wet Aging									
'Dry Electrical'									
Neutral Corrosion/Resistance									
Connector Corrosion/Resistance									
Thermal									
Chemical									
Contaminated Interfaces (Internal or External)									
Diagnostic Function (IDLA)									
Q: Is there a problem?	Identification	Identification	Identification	Identification	Identification	Identification	Identification	Identification	Identification
Q: Is it an internal and real problem? Q: What is the nature of the problem?	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination	Discrimination
Q: Where is the problem?	Localization	Localization	Localization	Localization	Localization	Localization	Localization	Localization	Localization
Q: How bad is the problem?	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment

- No single diagnostic parameter / test can cover all the deficiencies observed in aged MV cable systems – a combination of diagnostics will be required in contexts where diagnostic accuracy is of concern.**

	No / Minimal Influence across Majority of Scenarios
	Medium / Variable / Severity-Specific Influence across Scenarios
	High (Severity-Specific) Influence across Scenarios

Combining Test Techniques

- Minimal industry guidance currently exists on:
 - Combining test techniques to achieve condition assessment goals (including EPRI, IAEA, NRC, IEC, IEEE etc.)
 - Tailoring such approaches to match different end-user needs in terms of diagnostic accuracy and application / context.
- ‘MV Cable Testing Strategy Matrix’ developed as part of international working group (CIGRE Technical Brochure 924) covering T&D and generation contexts (non-nuclear and nuclear)
- Provides recommendations for combined testing considering:
 - **‘Conventional’ Testing Contexts:** Commissioning (Acceptance), Post-Repair, Maintenance (Condition Assessment)
 - **‘Unconventional’ Testing Contexts:** Anomaly Investigation / Trouble-Shooting
- Considers ‘Levels’ of Strategies – i.e., **Basic, Moderate, Advanced** etc. – since there will be no ‘one size fits all’ approach



TOGETHER...SHAPING THE FUTURE OF ENERGY®

Selective Leaching



Kurt Crytzer
Senior Principal Team Leader

Plant Resiliency, Reliability and Modernization Technology Workshop
October 20-22, 2025

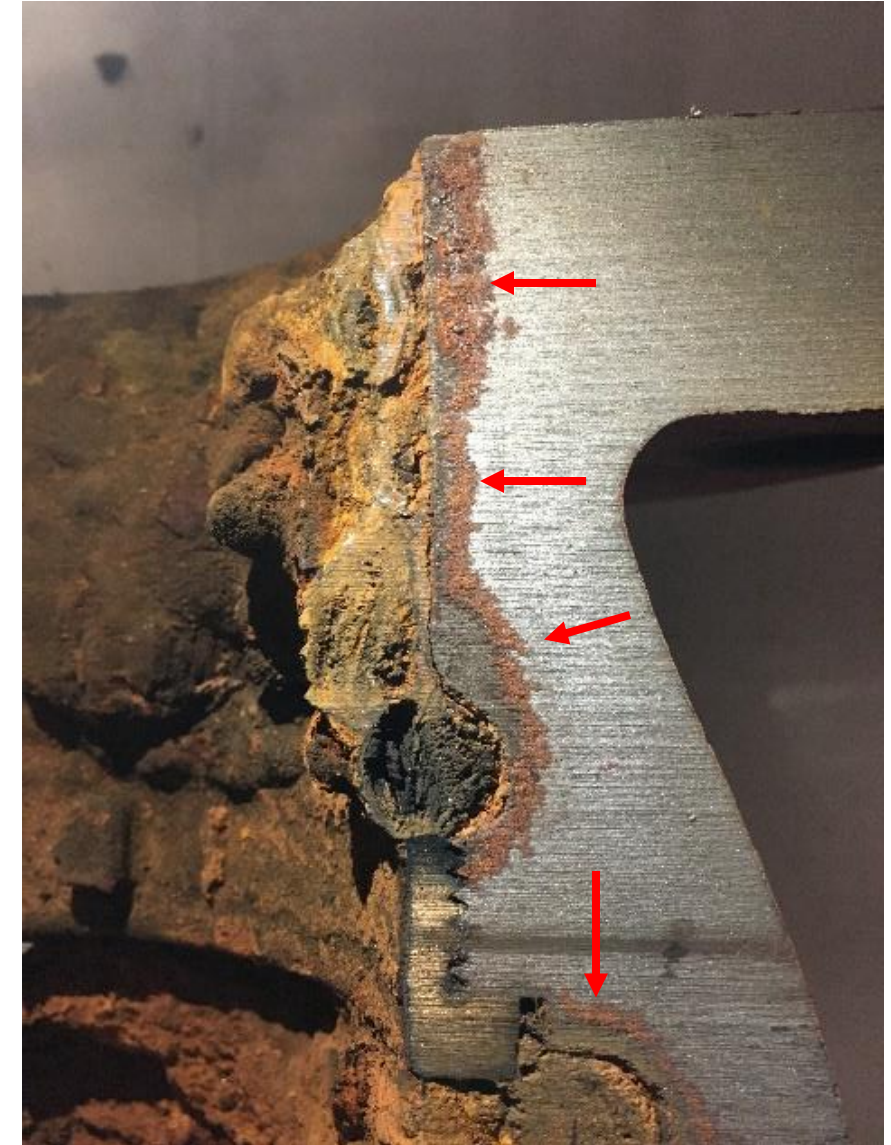
Selective Leaching Challenges

- Unique corrosion mechanism, where one element is preferentially removed from alloy, often without any change in dimension
- Relevant susceptible materials
 - Ductile iron & gray cast iron
 - Aluminum bronze with >8% aluminum
 - Copper alloys with > 15% zinc
- Examples of affected systems
 - Fire Protection
 - Condensate
 - Auxiliary Feedwater
 - Emergency Diesel Generator
 - Service Water



Why Selective Leaching Research is Important?

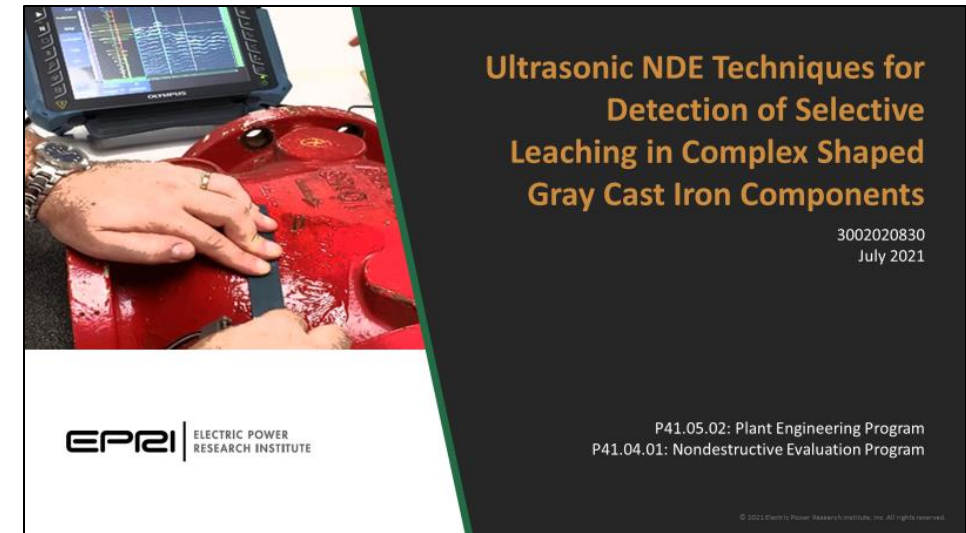
- Impact on power reactors licensed to operate beyond 40 years (and even more so for those licensed beyond 60 years)
- Industry incurs significant expenses to meet aging management commitments for long term operations
 - Large inspection population sample sizes
 - Development of periodic inspection programs
- Inspection Difficulties
 - Corrosion features are complex (local plug type and uniform)
 - Susceptible components are difficult to inspect (e.g., valve & pump casing)



Selective Leaching NDE Reports

"Inspection Techniques" Research

- [3002020830](#) – Ultrasonic Techniques for Selective Leaching in Gray Cast Iron Components
 - Scope: detection of internal selective leaching from outside surface examination (opposite surface)
 - 3 techniques successful demonstrated on field removed components for detection and characterization of opposite surface SL
- [3002020832](#) – Electromagnetic NDE Techniques for Gray Cast Iron Piping
 - Four (4) different techniques evaluated on field removed piping components
 - Includes both internal and external techniques
 - Two (2) more techniques were evaluated in 2022



Reports Provide Techniques and Quantitative Results of Demonstration

Examples of Electromagnetic NDE Techniques

Pulsed Eddy Current



Remote Field Testing
(internal)



Through-Transmission



LFET



MFL

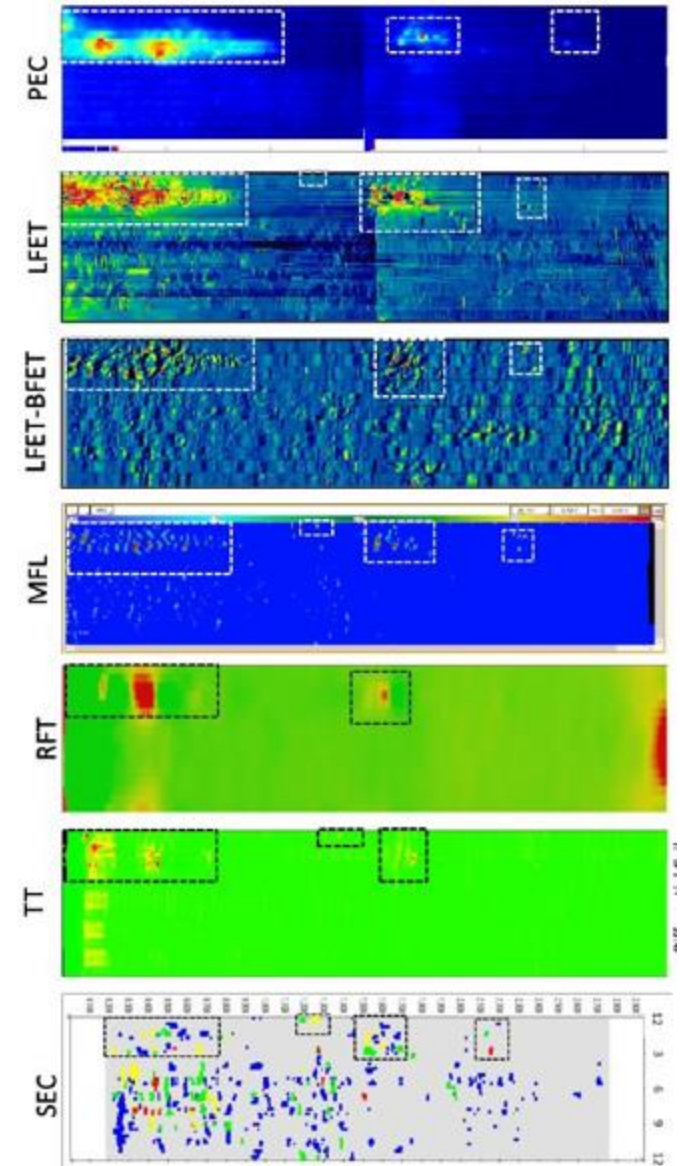


SLOFEC



Selective Leaching NDE Reports

- Technical Brief: 3002020830 “Ultrasonic Techniques for Selective Leaching in Gray Cast Iron Components”
 - Scope: detection of internal selective leaching from outside surface examination (opposite surface)
- Technical Brief: 3002020832 “Electromagnetic NDE Techniques for Gray Cast Iron Piping”
 - Four (4) different techniques evaluated on field removed piping components
 - Includes both internal and external techniques
- Technical Report: 3002023785 “Evaluation of Electromagnetic NDE Techniques for Detection of Wall Thinning Due to Selective Leaching Degradation in Gray Cast Iron Piping”
 - More details and analysis of results from EM techniques
 - Includes results for two (2) additional techniques evaluated



Reports Provide Techniques and Quantitative Results of Demonstration

Selective Leaching Program Implementation

- Visual:

- Beneficial to record conditions in the as-found condition, after surface preparation, and after examination (i.e., if mechanical examination is performed to remove material)

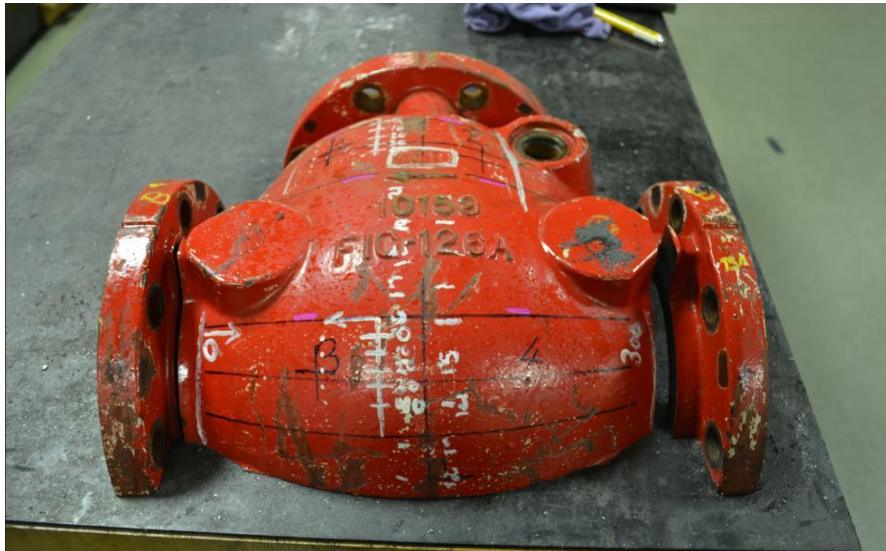
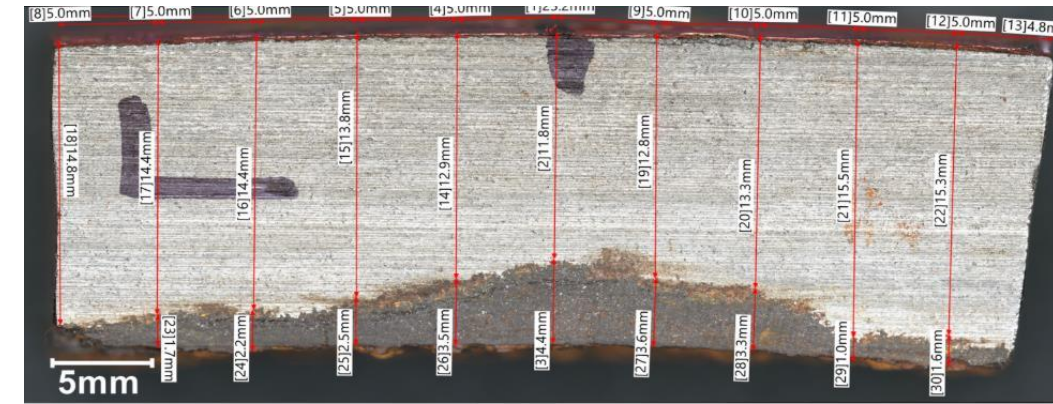
- Mechanical:

- Scratching / scraping surface to remove softer corrosion product
- Procedures should define permissible inspection instruments
- Beneficial to give inspectors samples of previously removed components to gain experience with performing mechanical exams
- Caution statements regarding work on pressurized equipment



Destructive Detection Methods

- Used to further investigate and assess areas of detected selective leaching
- Allows quantification of selective leaching damage (depth into the component wall)



Abrasive Cleaning Case Example



EPRI Gray Cast Iron Pipe Sample GCP-016 on-arrival
Diameter: 12-inch (30 cm)
Length: ~65-inch (1.7 m)



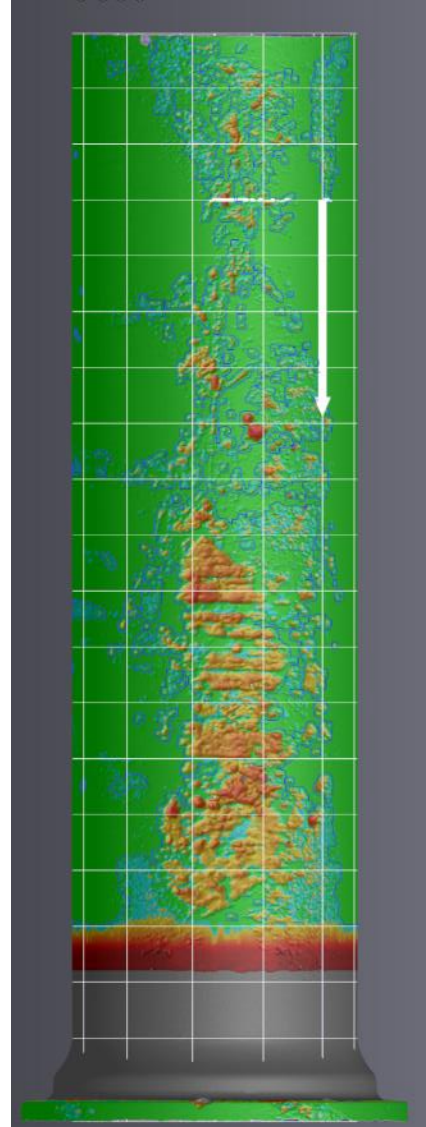
EPRI Samples GCP-016 & GCP-017 after wire-brush
cleaning (no visually detectable wall loss)

Abrasive Cleaning Case Example



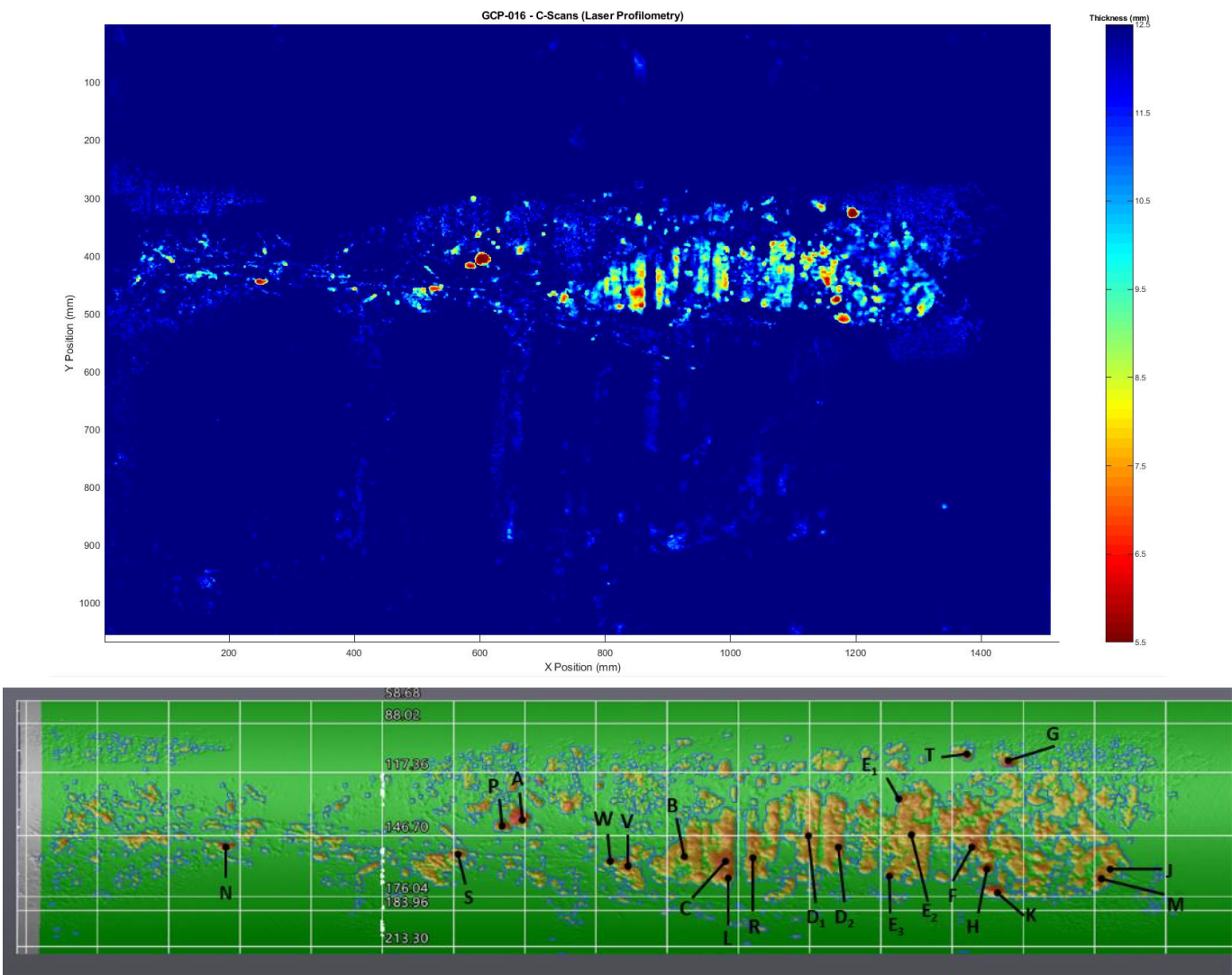
- Pipe after abrasive blasting to remove material affected by selective leaching.
- Extensive wall loss observable across outside surface, ranging from 20 – 70% through-wall.

Assessing Selective Leaching



- Surface Profilometry
 - NDE technique that can use laser or white light to measure changes in surface profile
 - Can be used to re-create 3D models of components, or measure corrosion
 - Can be used to measure depth of corrosion in high resolution
 - $< .0009\text{-in} / .025\text{ mm}$
 - Does not take into account any material loss on the opposite surface
 - Field deployable technique (not just laboratory)

Assessing Selective Leaching



Pit	Pit Gauge Depth (inch)	Pit Gauge RWT (inch)	Pit Gauge Depth (mm)	Pit Gauge RWT (mm)	Pit Gauge RWT (%)	LP Depth (mm)	LP RWT (mm)	LP Depth (inch)	LP RWT (inch)	LP RWT (%)
A	0.352	0.148	8.9	3.8	30%	8.8	3.9	0.348	0.152	30%
B						4.7	8.0	0.186	0.314	63%
C	0.2625	0.238	6.7	6.0	48%	6.5	6.2	0.254	0.246	49%
*D1						4.5	8.2	0.177	0.323	65%
*D2						5.7	7.0	0.226	0.274	55%
*E1						5.9	6.8	0.231	0.269	54%
*E2						5.2	7.5	0.204	0.296	59%
*E3						5.5	7.2	0.217	0.283	57%
*F						6.8	5.9	0.269	0.231	46%
G	0.335	0.165	8.5	4.2	33%	8.5	4.2	0.335	0.165	33%
*H						7.5	5.2	0.294	0.206	41%
J	0.16	0.340	4.1	8.6	68%	3.7	9.0	0.146	0.354	71%
K	0.3	0.200	7.6	5.1	40%	6.7	6.0	0.265	0.235	47%
L	0.32	0.180	8.1	4.6	36%	7.0	5.7	0.276	0.224	45%
M	0.234	0.266	5.9	6.8	53%	5.6	7.1	0.221	0.279	56%
N	0.29	0.210	7.4	5.3	42%	7.0	5.7	0.277	0.223	45%
P	0.282	0.218	7.2	5.5	44%	7.1	5.7	0.278	0.222	44%
Q	0.11	0.390	2.8	9.9	78%	2.5	10.2	0.098	0.402	80%
R	0.205	0.295	5.2	7.5	59%	5.5	7.2	0.217	0.283	57%
S	0.247	0.253	6.3	6.4	51%	6.2	6.5	0.245	0.255	51%
T	0.224	0.276	5.7	7.0	55%	5.6	7.1	0.222	0.278	56%
V	0.22	0.280	5.6	7.1	56%	6.3	6.5	0.246	0.254	51%
W	0.219	0.281	5.6	7.1	56%	5.4	7.3	0.213	0.287	57%

Destructive Examinations

- Can be most effective way to confirming selective leaching
- Not efficient
- Leverage components being removed from service for other reasons
- Cross-sectioning: allows confirmation of wall loss being due to selective leaching
 - Cut location may not occur at deepest / worst case locations
- Abrasive cleaning: provides additional information on areas away from cross-sectioned locations
 - removes the dealloyed region, so may not be able to confirm the wall loss was due other reasons
- Laboratory analysis using scanning electron microscopes (SEM) with energy dispersive spectroscopy (EDS) can help with identifying and confirming dealloying



Past EPRI Research on Selective Leaching

Report Number	Title	Year Published
3002026340	Recommendations for Implementing an Effective Program to Manage Selective Leaching Degradation	2023
3002023785	Evaluation of Electromagnetic NDE Techniques for Detection of Wall Thinning Due to Selective Leaching Degradation in Gray Cast Iron Piping	2023
3002020822	Accelerated Testing and Evaluation of Factors Affecting Selective Leaching Susceptibility	2021
3002020832	Electromagnetic NDE Techniques for Gray Cast Iron Piping	2021
3002020830	Ultrasonic Techniques for Selective Leaching in Gray Cast Iron Components	2021
3002016057	Selective Leaching: State-of-the-Art Technical Update	2019
3002013168	Nondestructive Evaluation: Guidance for Conducting Ultrasonic Examinations for the Detection of Selective Leaching	2018
3002008013	Assessment of Available Nondestructive Evaluation Techniques for Selective Leaching: Technology Review	2016
1025218	Nondestructive Evaluation: Correlation of Selectively Leached Thickness to Hardness for Gray Cast Iron and Brass	2012
1019111	Nondestructive Evaluation: Update to NDE for Selective leaching of Gray Cast Iron Components	2009
1018939	Nondestructive Evaluation: NDE for Selective leaching of Gray Cast Iron Components	2009



TOGETHER...SHAPING THE FUTURE OF ENERGY®



LAMBDA

Long-term Asset Management Basis Design Application Detailed Walkthrough



Andrew Mantey
Electrical Team Leader - PRR
Electric Power Research Institute

China Workshop
20-22 October 2025

Long-term Asset Management Basis Design Application

LAMBDA provides decision makers with a standard methodology that assists in the formation of an optimal long-term asset management strategy.

Create a New Model

Work With an Existing Model

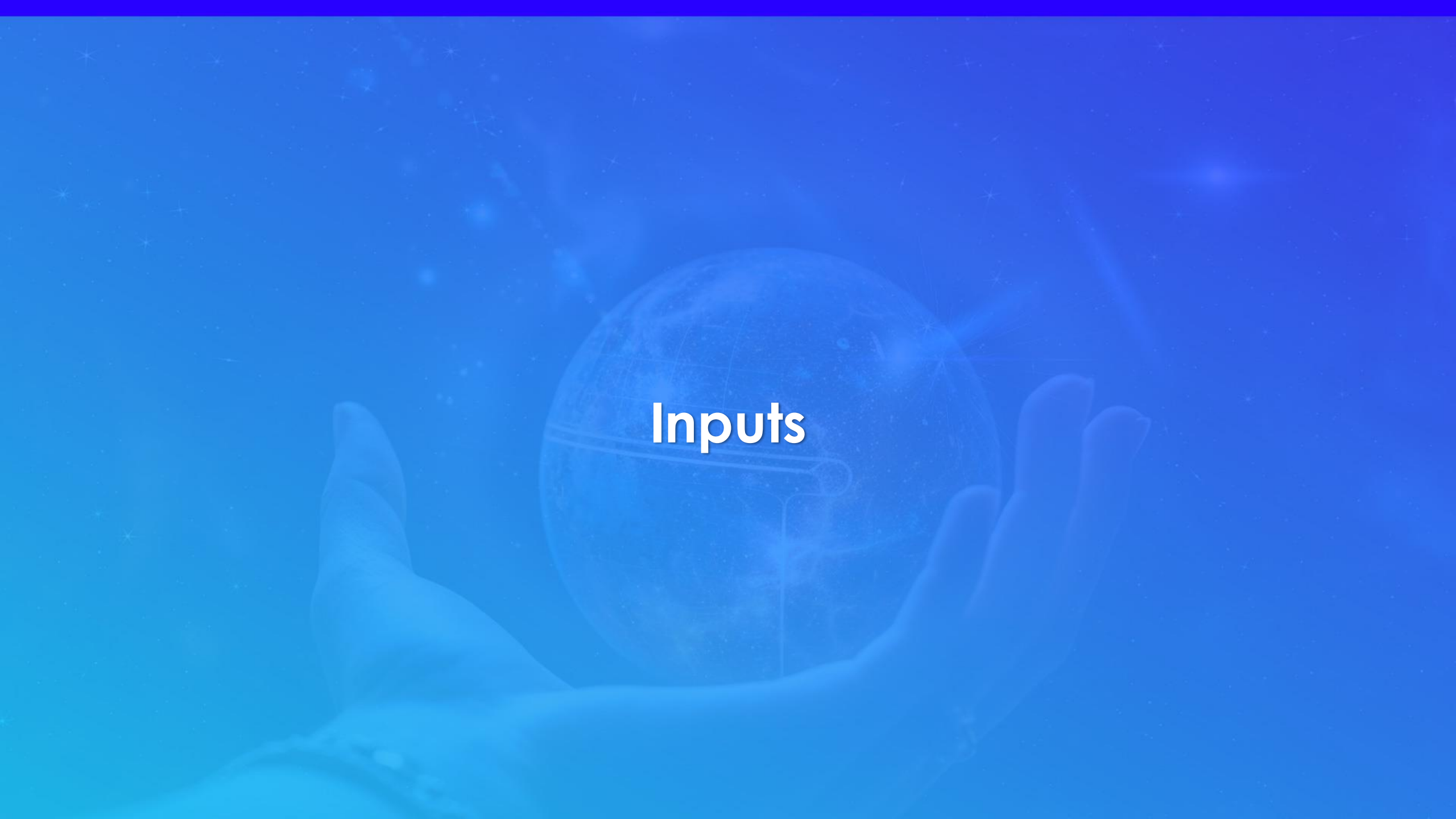
What Does LAMBDA Do for You?

Standard
Methodology
for Long-Term
Asset
Management

01 Assists in the formation of an optimal long-term asset management strategy.

02 Framework for prioritizing capital spending.

03 Insights into capital cost for long-term operations (LTO).

The image features a blue-tinted background with a subtle pattern of stars and light trails. In the center, a pair of hands is shown holding a globe. The globe has a grid of latitude and longitude lines. Overlaid on the globe is the word "Inputs" in a white, sans-serif font.

Inputs

What do you get from LAMBDA?

Component Parameters, Financial
Parameters, and Maintenance History



LIKELIHOOD OF FAILURE

Displays the probability that a component will fail.

CONSEQUENCE OF FAILURE

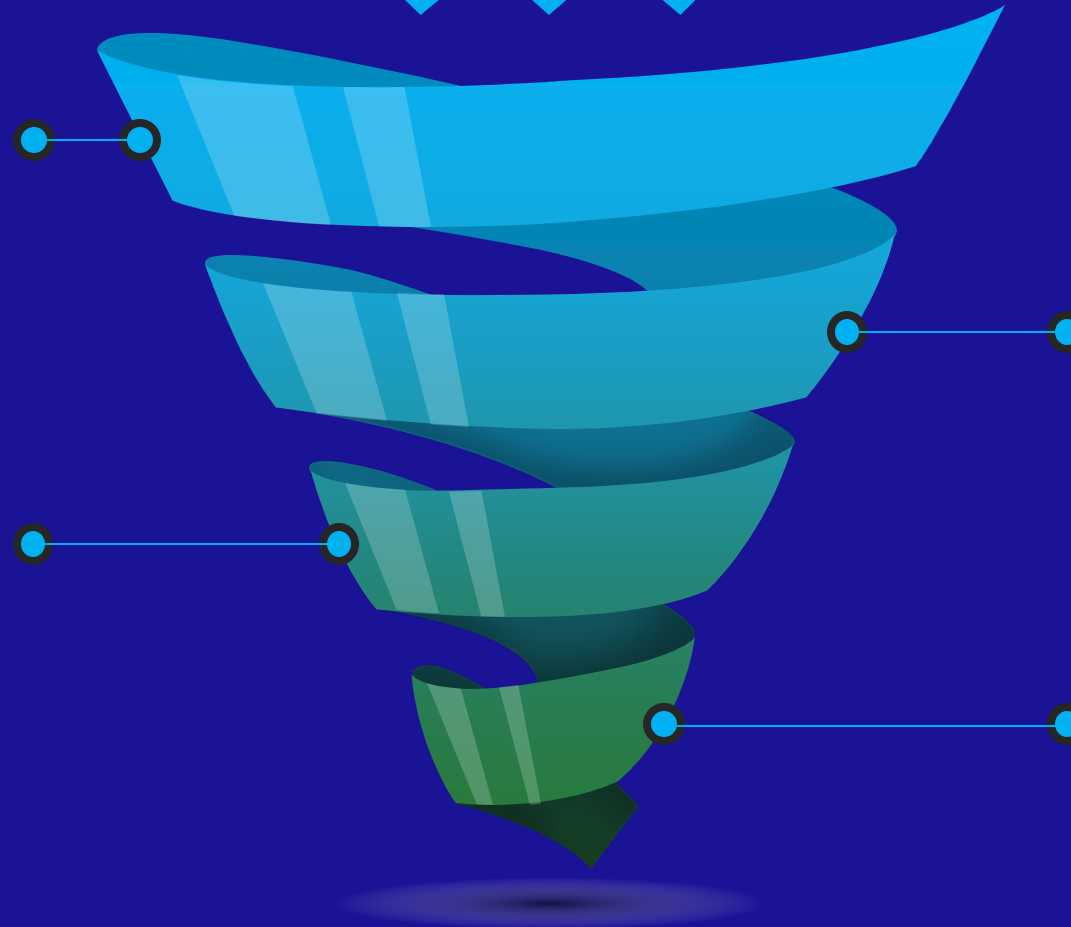
Displays the likelihood of failure compared with the financial consequences of failure.

NET PRESENT VALUE

Displays the results calculated for when to proactively replace a component.

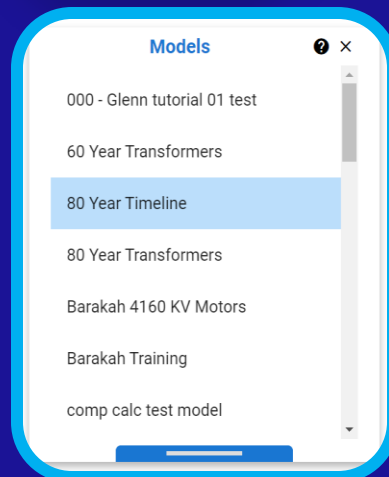
PORTFOLIO COMPARISON

Displays NPV, Investment Value, and Risk of each strategy.

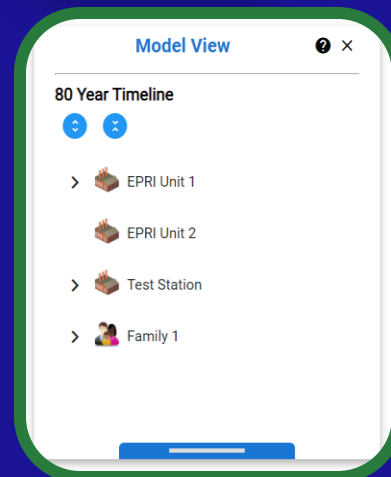


What is a Panel Layout?

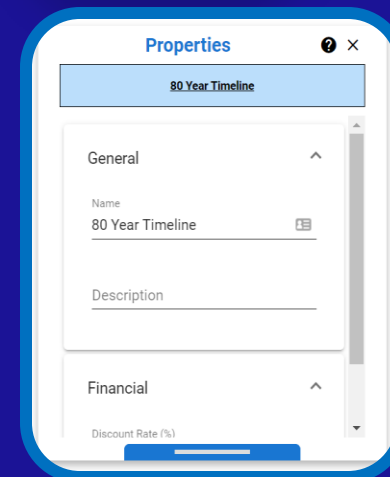
Models



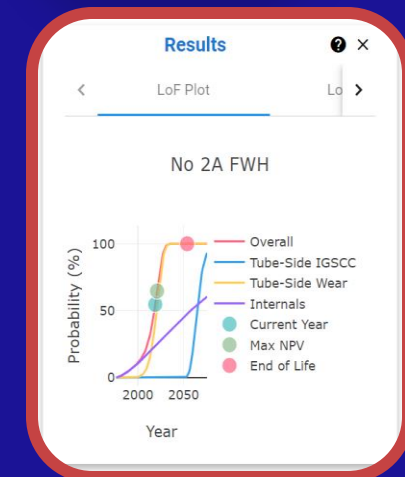
Model View



Properties



Results



4 Steps to Creating a Model



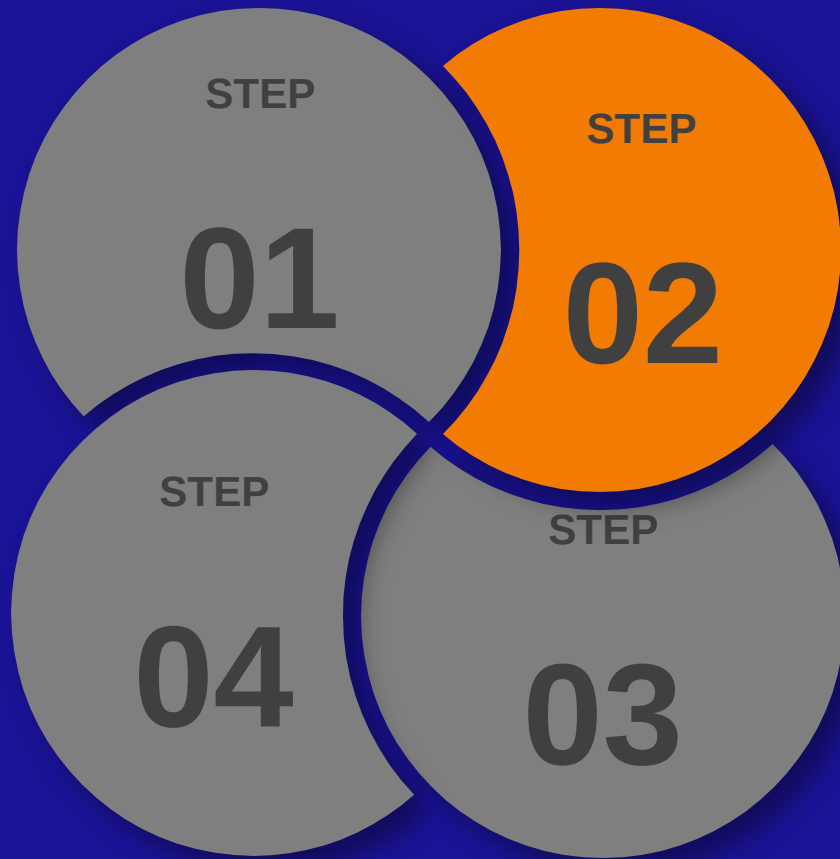
4 Steps to Creating a Model



Model Properties

General and financial properties are entered into the Model Properties section. This includes your company's Discount Rate.

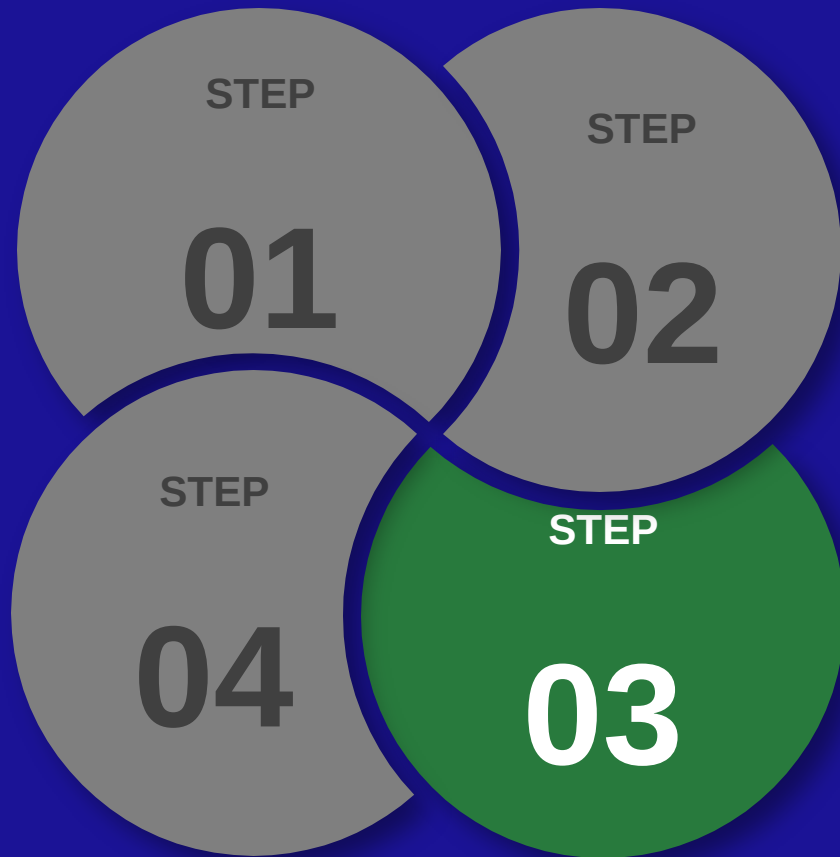
4 Steps to Creating a Model



Station Properties

The station name and description are entered. This stage in the hierarchy serves as a container for units and components.

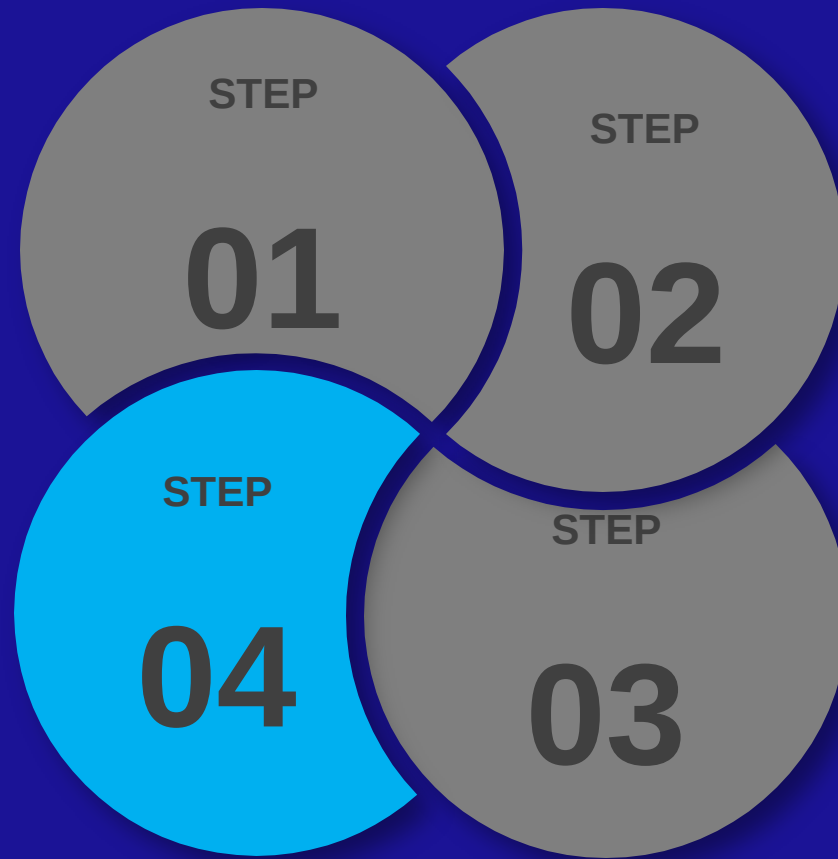
4 Steps to Creating a Model



Unit Properties

Unit properties are also General and Financial. It houses parameters such as the unit commission year, planned life, and outage and derate costs.

4 Steps to Creating a Model



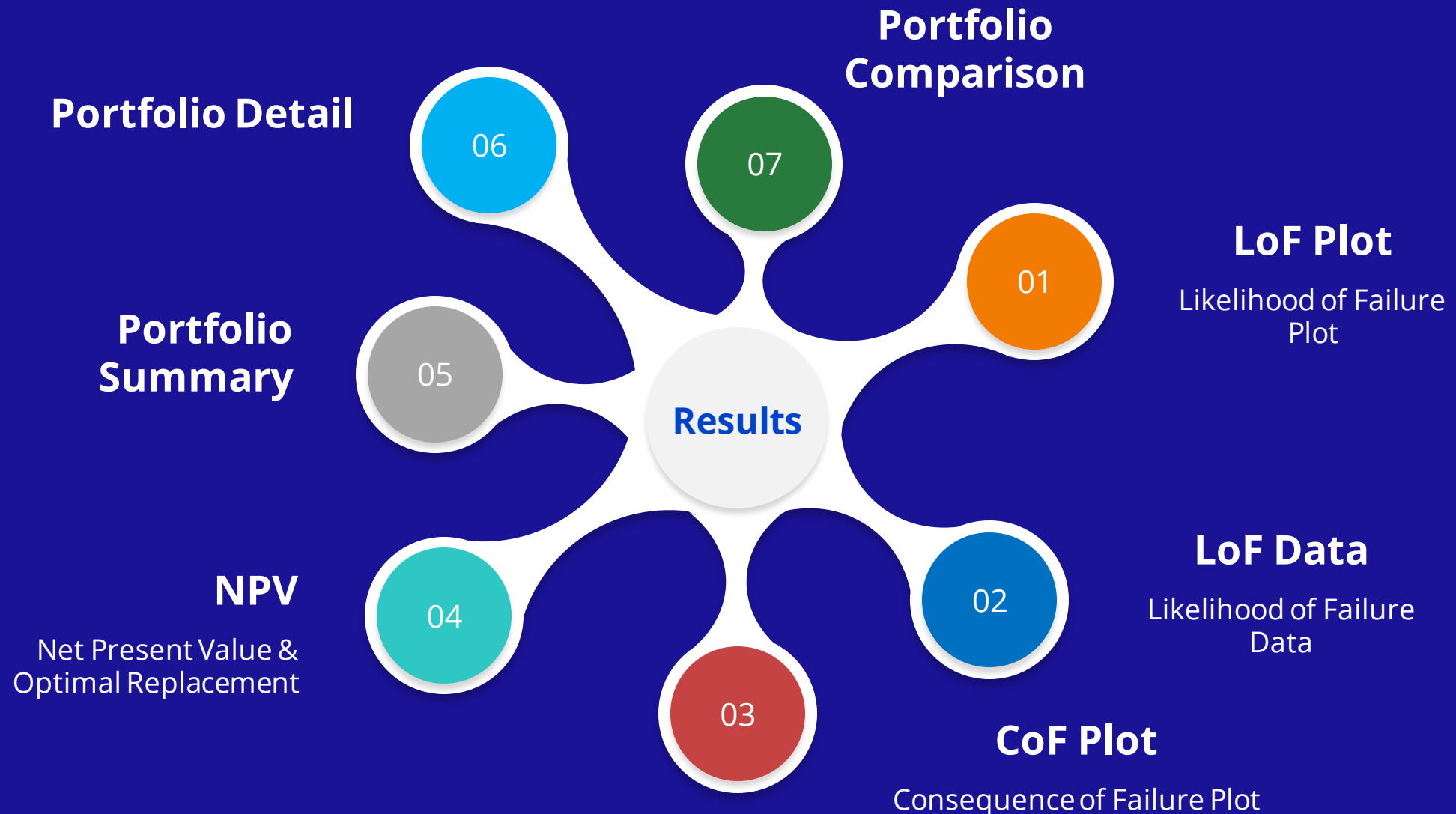
Component Properties

Component properties are utilized to determine the likelihood of failure (or replacement) and financial aspects of each component. Component properties include, general and specific details, such as component parameters, financial details, and maintenance history.

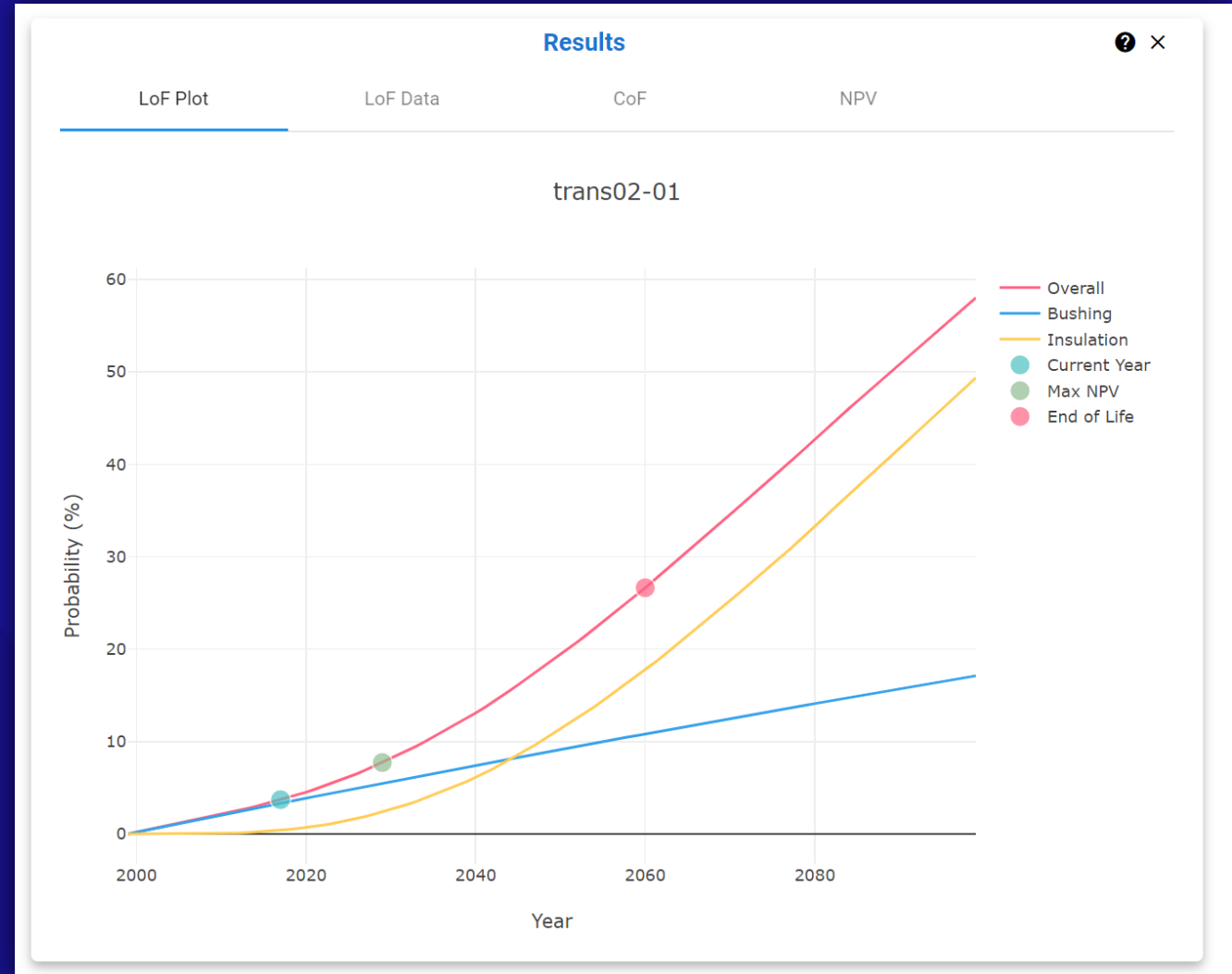
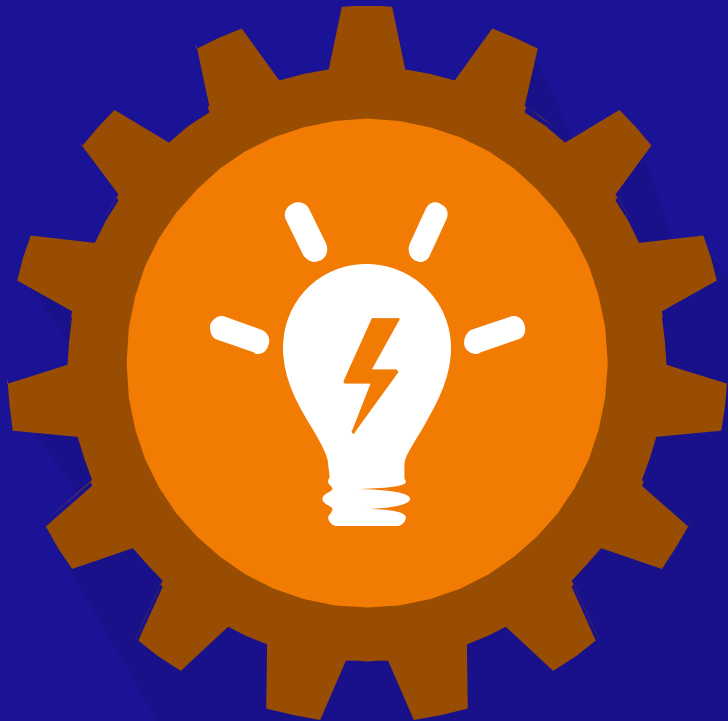


Outputs

Outputs



Likelihood of Replacement Plot

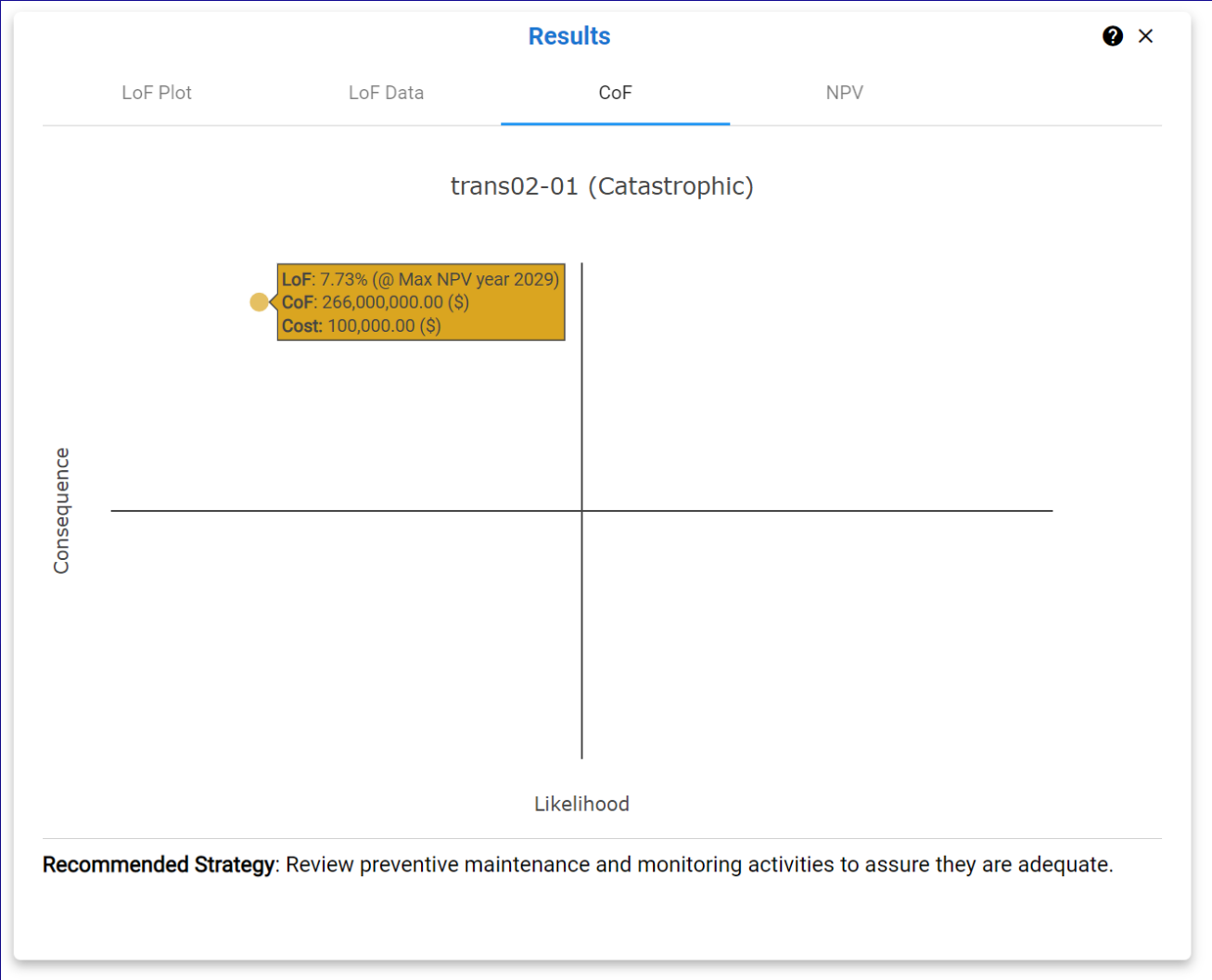


Likelihood of Replacement Data

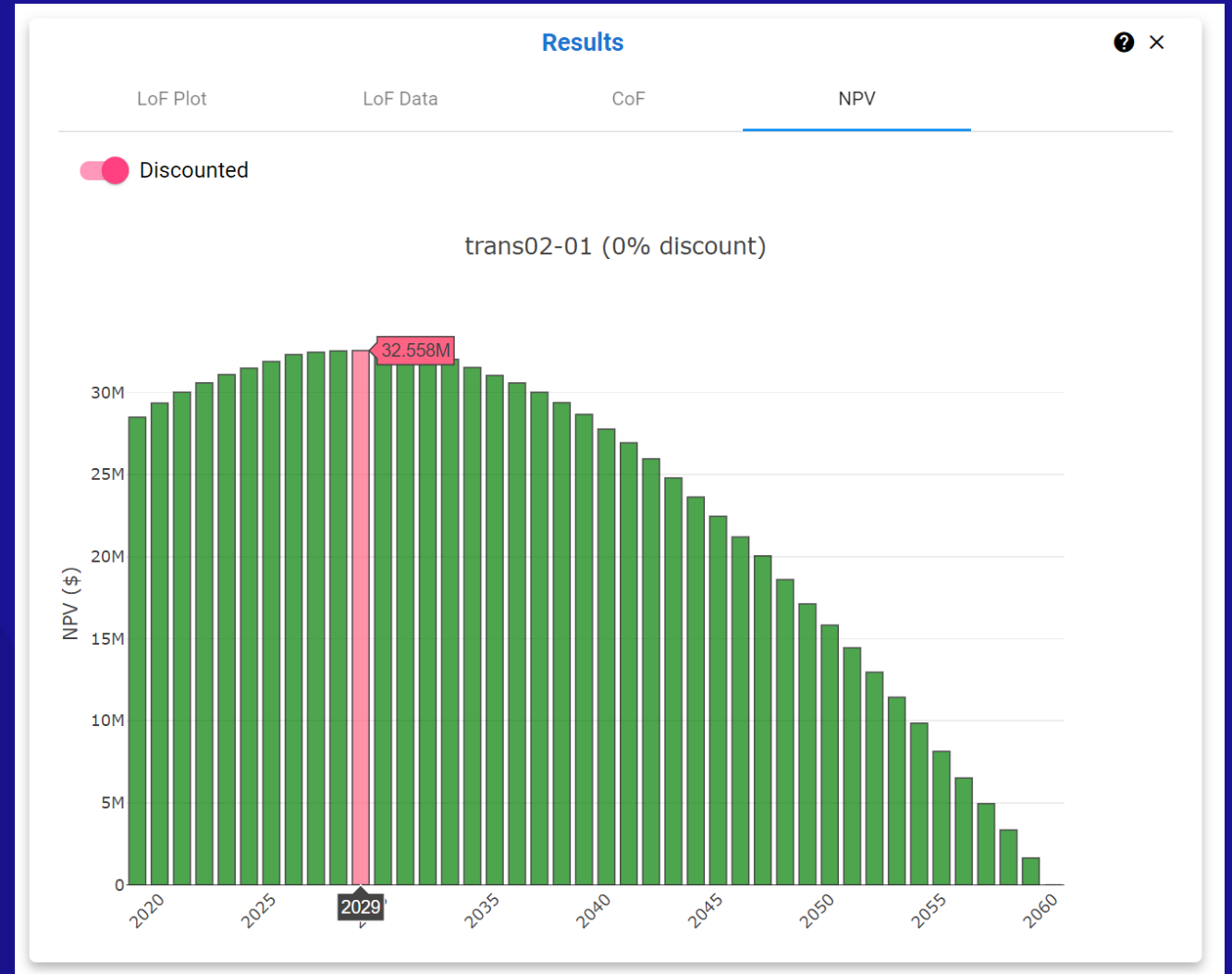


Results			
LoF Plot	LoF Data	CoF	NPV
Year	Overall (%)	Bushing (%)	Insulation (%)
1999	0	0	0
2000	0.19	0.19	0
2001	0.37	0.37	0
2002	0.56	0.56	0
2003	0.75	0.75	0
2004	0.94	0.93	0
2005	1.12	1.12	0
2006	1.31	1.31	0.01
2007	1.51	1.49	0.02
2008	1.7	1.68	0.02

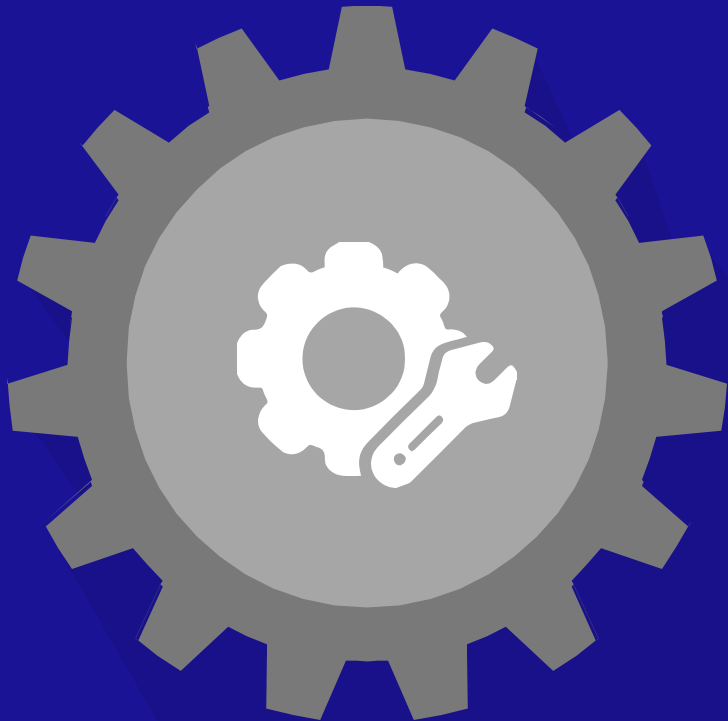
Consequence of Failure Plot



Net Present Value



Portfolio Summary



Results ? ×			
Portfolio Summary	Portfolio Detail	Portfolio Comparison	
Strategy	Investment (\$)	NPV (\$)	Risk (%)
Component	112,978.00	-209,235.00	77.79
Optimal	0.00	0.00	8.59
User Defined	140,286.00	-2,686,240.00	88.10

Portfolio Detail



Results

Portfolio Summary

Portfolio Detail

Portfolio Comparison

Asset	Cost (\$)	Component Year	Component NPV (\$)	Optimal Year	User Defined Year
station01 / Unit 1 / trans01-01	100,000.00	2054	0.00	2061	2031
station02 / Unit 1 / trans02-01	100,000.00	2021	9,781,073.89	2061	2032
Spare Part 1	50,000.00	N/A	N/A		2026

Items per page: 10

1 – 3 of 3

|<

<

>

>|

Portfolio Comparison





Application Detailed Walkthrough



TOGETHER...SHAPING THE FUTURE OF ENERGY®

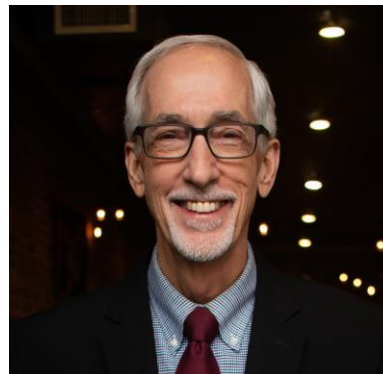
Collecting Operating Experience for LTO

Safe, Successful, and Supported – Long-Term Operation



Garry G. Young
Technical Executive

EPRI Nuclear Plant Performance Workshop
Shanghai, China
October 20-22, 2025



Implementation Challenges for Aging Mgmt. Programs

- GALL vs IGALL
- Use Cases of Challenges for Aging Management Programs
 - Using existing programs
 - Experiencing significant OE during IPA Review
 - Common issues across Industry



GALL vs IGALL

GALL vs IGALL

- Generic Aging Lessons Learned (GALL) and the International Generic Ageing Lessons Learned (IGALL) are used by Nuclear power plants to develop effective aging management programs for those utilities seeking to extend the operating period for its nuclear plants.
- GALL ([NUREG-1801](#), initial License Renewal (LR) and [NUREG-2191](#) Subsequent License Renewal (SLR)) was developed by the US Nuclear Regulatory Commission (NRC) based on previously approved AMPs and is a formal part of the licensing process for US Nuclear plants.
- IGALL ([SRS-82](#)) was developed by the International Atomic Energy Agency (IAEA) and is a compilation of best practice recommendations for aging management. Its use in regulatory context is determined by various national regulatory agencies.

GALL vs IGALL (con't)

Aging Management Topic	GALL	IGALL
Aging Management Programs	One acceptable way to manage aging effects for license renewal. 10 elements for an effective program	Proven practices on managing the ageing of in-scope SSCs of nuclear power plants to support the application of the IAEA safety standards on design, on commissioning and operation, ageing management and LTO and periodic safety review. 9 attributes for an effective program
Guidance on Active Components	No (Use 10CFR50.65 Maintenance Rule)	Yes
Guidance on Passive Components	Yes	Yes
Differences in definitions of Structures and Components, Materials, Environments, Aging Effects, Aging Mechanisms, TLAAs and AMPs	See Section 2 in EPRI report 3002009324, Assessment of Differences Between the Technical Bases of the IGALL and GALL Report	



Use Cases of Challenges for Aging Management Programs

Crediting Existing Programs as AMPs

- A US site, in order to credit their existing RG 1.127 Program as their AMP for in-scope Water-Control Structures submitted an exception and two enhancements as part of their application.
- **Exception:** Proposed an inspection frequency of 10 years for submerged portions of the water control structures.
 - During AMP review the regulator flagged as inconsistent with the GALL AMP (XI.S7, RG 1.127 Inspection of Water-Control Structures Associated with Nuclear Power Plants) and requested the technical basis for the longer frequency (10 yrs vs 5 yrs).

Crediting Existing Programs as AMPs (con't)

- **RAI (Request for Additional Information) Response:**
 - Site indicated its RG 1.127 program did not include submerged structures and that the 10-year frequency was based on operating history.
 - Site intended to perform a baseline inspection of underwater structures and evaluate identified age-related degradation to establish if a more frequent inspection is required.
- The regulator disagreed that performance history was sufficient to justify longer frequency.

Crediting Existing Programs as AMPs (con't)

- End result:

- Site committed to perform a baseline inspection prior to PEO and thereafter gradually extend the frequency to 10 years in 2 year increments evaluating after every inspection if a more frequent inspection is required.

Crediting Existing Programs as AMPs (con't)

- **Enhancements:** The applicant also submitted two enhancements to their RG 1.127 program to maintain consistency with GALL AMP XI.S7.
 - 1. Expanded scope of RG 1.127 program to include submerged components and trash racks, the fire pond dam and submerged components in the fire pond dam.
 - 2. Expanded the parameters monitored in RG 1.127 program to include monitoring for changes in material properties of concrete due to leaching of calcium chloride and aggressive chemical attack, monitoring steel components for loss of material due to corrosion and pitting and monitoring wooden piles and sheeting for loss of material and change in material properties.
- **Justification:** Enhancements needed to ensure their RG 1.127 program scope adequately addressed the required license renewal scope.
- **End result:** Regulator found the enhancements acceptable and consistent with GALL AMP XI.S7 and will provide reasonable assurance that the effects of aging will be adequately managed. Additionally, the regulator added the material/environment aging effect and AMP combination for Group 6: Wooden Piles; sheeting to the AMR tables in Revision 2 of the GALL.

Experiencing Significant OE during LRA Review

- A US site submitted their application for Subsequent License Renewal (60-80 yrs) in October 2018. In July 2019, while this application was still under review by the regulator, the site experienced two ruptures of segments of buried gray cast iron fire protection piping. This also resulted in both fire pumps starting and the draining of ~424,000 L (112,000 gallons) from fire water tanks.



Source: February 2020 BPIG Presentation C06, "Selective Leaching Operating Experience Update"



Experiencing Significant OE during LRA Review (con't)

- In accordance with 10 CFR 54.21(b) in October 2019 the site submitted its *Annual Amendment and Supplement to Subsequent License Renewal Application Change Notice 4* which contained proposed changes to the site's SLRA as a result of the fire protection piping rupture experienced 3 months earlier.
 - 1. A description of this OE was added to the Fire Water System program
 - 2. The AMR table was updated to include the new material/environment combination due to the replaced piping and valve changing to ductile iron vice gray cast iron.
 - 3. The Selective Leaching program exclusion for buried components with external coatings was deleted for buried components that are susceptible to selective leaching.

Site's Letter - ML19294A044

Experiencing Significant OE during LRA Review (con't)

- Following the receipt of this annual report the regulator requested more information on the cause of the piping failure, the extent of condition, the corrosion mechanism and aging effect, and if it was selective leaching, what changes will the site make to their Selective Leaching program?
- The site responded that the cause of the ruptures were graphitic corrosion (selective leaching) due to the prolonged exposure to groundwater. The site also submitted additional revisions to the Selective Leaching program that included 25 exploratory holes for groundwater, corrective actions for presence of groundwater and sample expansion for the fire protection loop piping

Applicable Site Final Safety Evaluation Report related to this issue

Experiencing Significant OE during LRA Review (con't)

■ End Result:

- The regulator concluded that the identified changes to the Selective Leaching program were capable of detecting adverse conditions due to groundwater immersion that may lead to graphitic corrosion and identifying ongoing degradation of the buried gray cast iron fire protection loop piping.
- Additionally, there were two documented non-concurrences by NRC personnel to the final SER for the site questioning the adequacy of the site's augmented program to provide reasonable assurance that the effects of aging will be adequately managed given other information that was discovered during the casual investigation of this piping failure. However, despite these, it was determined that changes to the AMPs to address other possible issues, if necessary, will be identified as the site completed its development of corrective actions.
 - No changes as a result of the casual investigation showing inconsistent soil corrosivity parameters throughout the site.
 - No discussion of actions that will result if the exploratory holes detect system leakage vice groundwater

Selective Leaching Background

Selective leaching (SL) corrosion preferentially removes one alloying element from the parent matrix, enriching the remaining elements. Typically associated with exposure to untreated internal or external aqueous environments.



Affected material may stay in place with wall thickness remaining nominal

- Relevant susceptible materials (NUREG-1801 & -2191, IAEA I-GALL)
 - Ductile iron & gray cast iron
 - Aluminum bronze with >8% aluminum
 - Copper alloys with > 15% zinc
- Examples of affected systems
 - Fire Protection
 - Condensate
 - Auxiliary Feedwater
 - Emergency Diesel Generator
 - Service Water



Selective Leaching Challenges

- Impact on power reactors licensed to operate beyond 40 years (and even more so for those licensed beyond 60 years)
 - NRC Information Notice 2020-04, Operating Experience Related to Failure of Buried Fire Protection Main Yard Piping
- Inspection Challenges
 - Lack of previously demonstrated NDE techniques
 - Susceptible components can be difficult to inspect (e.g., valve & pump casing)
 - Many utilities have resorted to destructive evaluations
- Industry incurs significant expenses to meet aging management commitments for long term operations
 - Large inspection population sample sizes
 - Development of periodic inspection programs
 - Destructive examinations



Selective Leaching NDE Reports

“Inspection Techniques” Research

- Technical Brief: [3002020830](#) “Ultrasonic Techniques for Selective Leaching in Gray Cast Iron Components”
 - Scope: detection of internal selective leaching from outside surface examination (opposite surface)
 - 3 techniques successful demonstrated on field removed components for detection and characterization of opposite surface SL
- Technical Brief: [3002020832](#) “Electromagnetic NDE Techniques for Gray Cast Iron Piping”
 - Four (4) different techniques evaluated on field removed piping components
 - Includes both internal and external techniques
- Technical Report: [3002023785](#) “Evaluation of Electromagnetic NDE Techniques for Detection of Wall Thinning Due to Selective Leaching Degradation in Gray Cast Iron Piping”
 - More details and analysis of results from EM techniques
 - Includes results for two (2) additional techniques evaluated in 2022



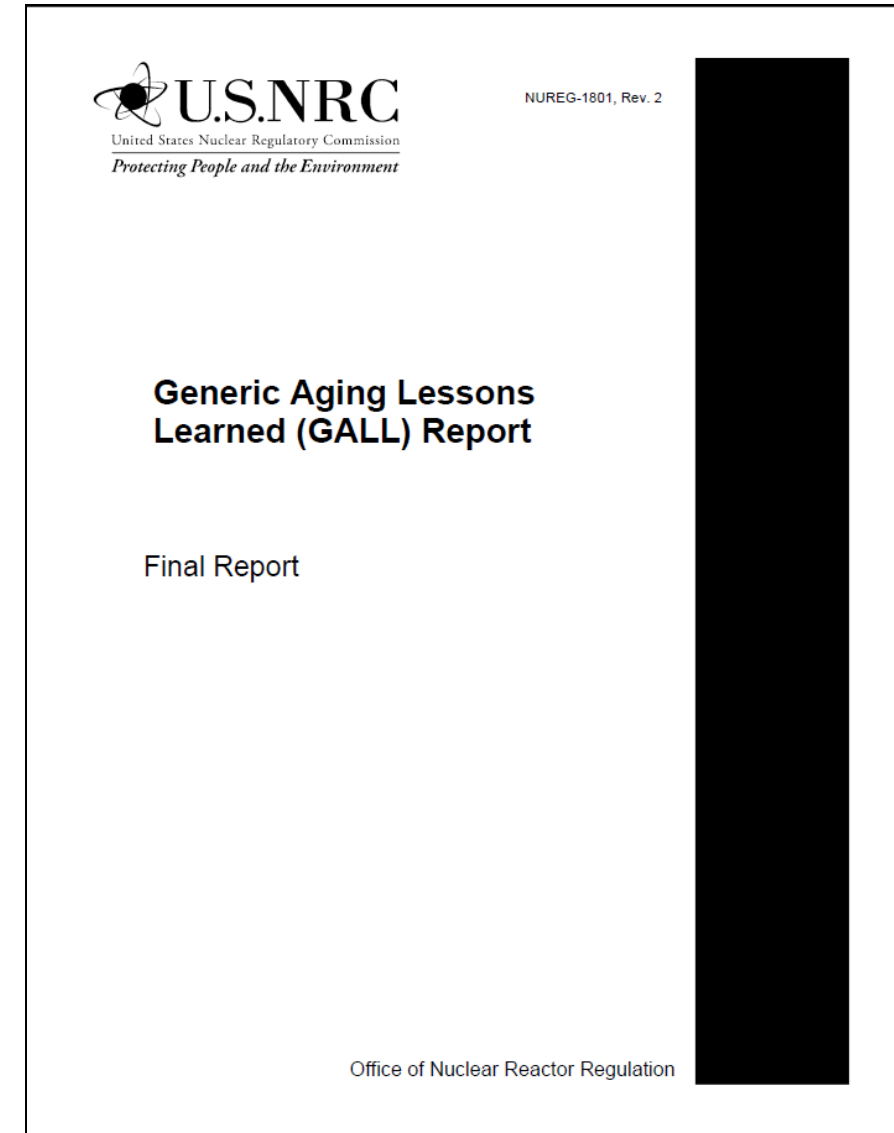
Reports Provide Techniques and Quantitative Results of Demonstration



General Issues Experienced by Multiple Plants

One-Time Inspection Program: Background

- Purpose
 - Used to verify effectiveness of chemistry programs
 - Verify absence or insignificance of an aging effect in a given environment
- Inspection Scope:
 - Safety-related and nonsafety-related components
 - 20% of population, maximum of 25 components, in each material-environment combination
 - GALL-SLR: Inspection quantities are per unit
- Inspection Techniques
 - Visual, surface, and/or volumetric (ultrasonic)
- Challenges
 - Large quantities of inspections (>100)
 - Logistical challenges of scheduling

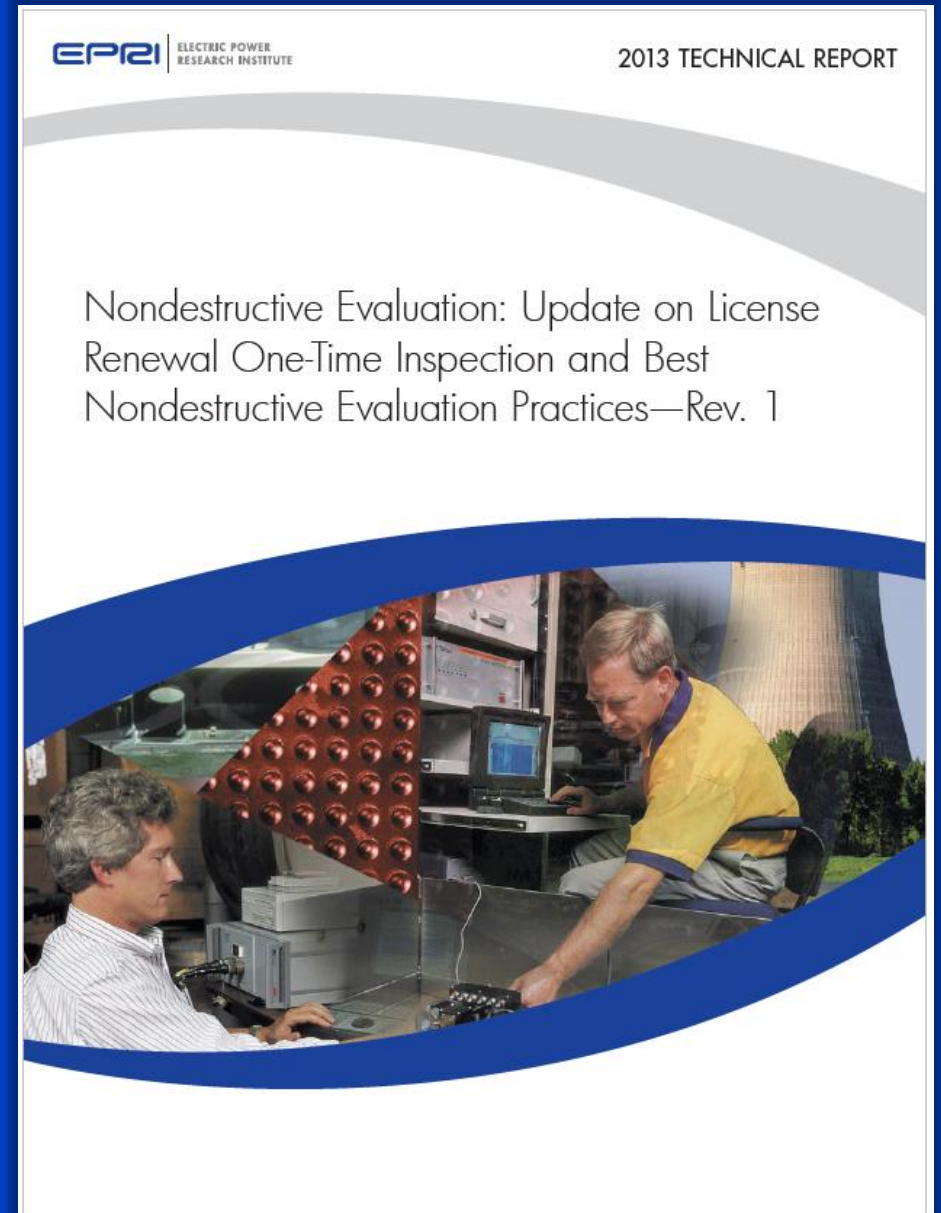


One Time Inspection Program

- Challenges
 - Creation of hundreds of new work orders
 - Scheduling
 - US utilities have frequently reported difficulties with successfully getting inspections scheduled in outages; many get deferred
 - Leads to large amounts at or near the last outage before the period of extended operation
 - Tracking completion of all inspections
 - Selection of samples
 - Program implemented on sampling basis
 - How to choose locations for inspections? (e.g., stagnant, low flow, opportunities)
 - Inspection difficulties
 - Component access
 - Techniques & components geometries (small diameter, complex shaped components)

EPRI Project: One-Time Inspection Program Results Review

- Report Objectives:
 - Develop common template for capturing industry-wide OTI results
 - Compile findings and assess prevalence of identified aging
 - Capture NDE best practices
- OTI results collected for nine (9) nuclear plants
- Over 1500 inspections performed; >1100 applicable to GALL Rev. 2
- Potentially unacceptable aging effects observed
 - Fuel Oil = 0/50 (0.0%)
 - Lube Oil = 1/100 (1.0%)
 - Treated Water = 20/982 (2.0%)
 - < 4% of all inspections performed identified potential aging
 - < 2% of all inspections performed identified aging assessed to be unacceptable
- NDE Best practices identified and shared



EPRI Project: One-Time Inspection Program Results Review

- Objective:
 - Update 2013 report ([3002000459](#))
 - Evaluate effectiveness of industry chemistry programs
 - Capture best practices, lessons learned, implementation strategies

- Status
 - April 2024: Project Initiated
 - May 2024: OTI Data Collection Template Developed
 - June 2024: Project placed on hold,
 - based on NRC communicated changes to XI.M32 OTI AMP
 - Removal of OTI's for water chemistry, fuel oil, and lube oil environments
 - February 2025: US industry representatives supportive of continuing project on pilot basis
 - Limited number of utilities will provide data to EPRI
 - Utilities: will assess time commitment to document and complete the inspection template
 - EPRI: will evaluate results on pilot plants and target informal results in August

2024-2025 Project

Inspection of Internal Surfaces in Miscellaneous Piping and Ducting Components

Challenges

- Program relies on opportunistic inspections
- How to ensure opportunistic inspections are performed?
- Tracking various material-environment populations and ensuring sufficient minimum quantities are inspected
- Questions on training requirements for personnel?

Implementation Approaches

- Revising work planner procedures to include directions to plan/include inspection tasks when components are opened
- Modifying work planning processes to automatically generate inspection tasks for corrective maintenance work orders involving in-scope components
- Training of maintenance personnel using EPRI Aging Training courses (or derivatives)

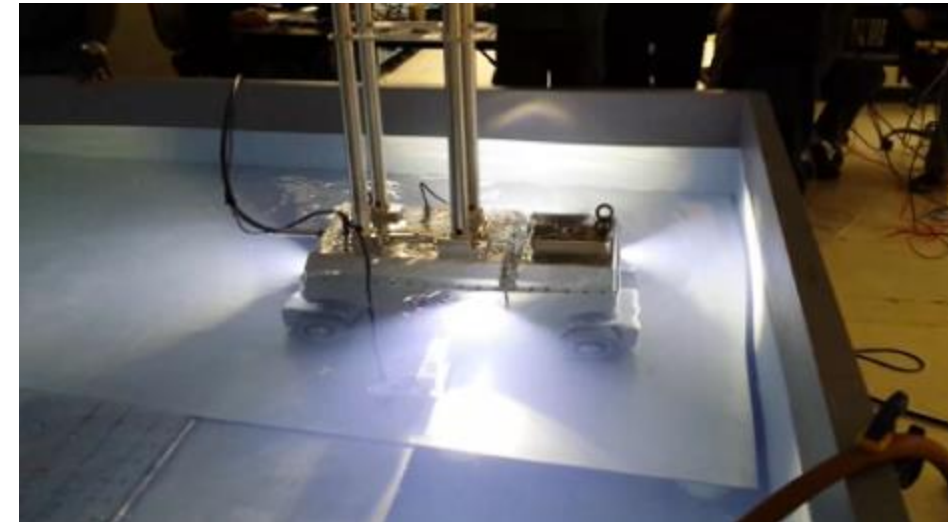
Aboveground Tanks Program

■ Challenges

- Removal of insulation to perform inspections of tank exterior surfaces, including sides and roof
- Draining of tanks to facilitate internal inspections

■ Implementation Approaches

- Removal of insulation
- Cutting 'windows' into insulating and jacketing to allow for periodic access to tank external surface to complete inspections
- Draining of tanks and internal volumetric inspections of tank floor
- Underwater tank inspections, avoiding having to drain tanks



3002013172 – NDE Assessments for Tanks and Containment Liners: Readily Available NDE Methods to Inspect Tanks and Containment Liners



TOGETHER...SHAPING THE FUTURE OF ENERGY®

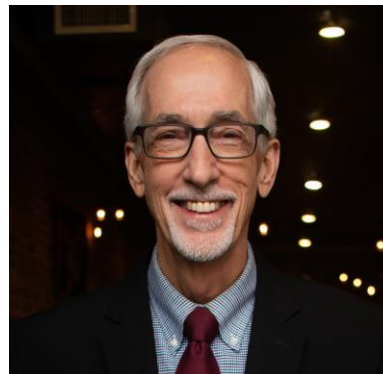
Developing Aging Management Programs (AMPs) for Active Components

Safe, Successful, and Supported – Long-Term Operation

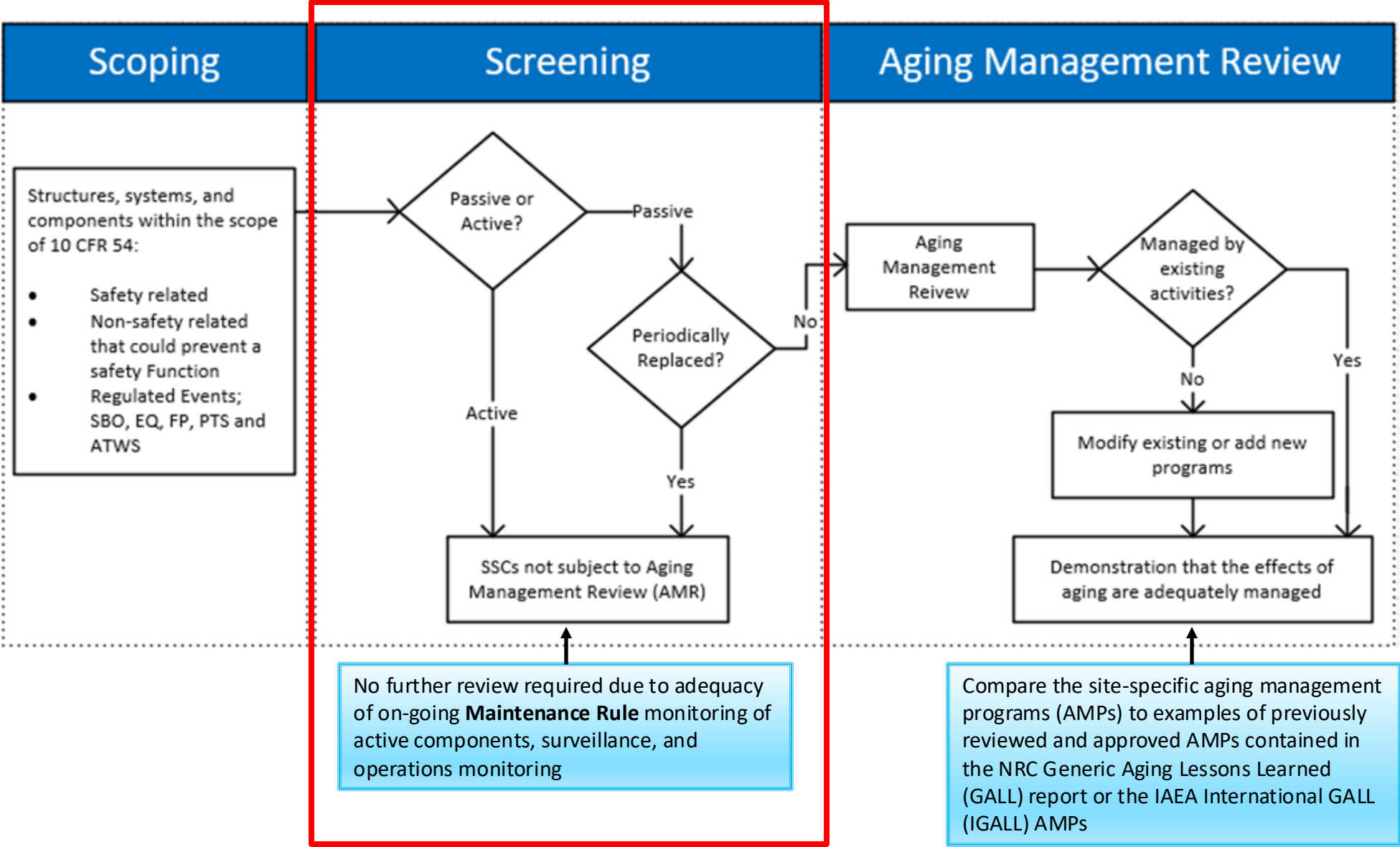


Garry G. Young
Technical Executive

EPRI Nuclear Plant Performance Workshop
Shanghai, China
October 20-22, 2025



Integrated Plant Assessment (IPA) Flowchart



What do we mean by “Active Components”

IAEA-TECDOC-626, “Safety Related Terms for Advanced Nuclear Plants,” September 1991

- Active systems or components
 - Those where “there exists any reliance on external mechanical and/or electrical power, signals or forces.”
 - These systems are susceptible to potential “causes of failure such as lack of human action or power failure.”
- Passive systems of components
 - These where “reliance is instead placed on natural laws, properties of materials and internally stored energy.”
 - “It is important to note that passive devices remain subject to other kinds of failure, such as those resulting from mechanical or structural failure or willful human interference. Therefore, passive safety is not synonymous with inherent safety or absolute reliability.”
- Systems can have active and passive characteristics at different times and in different conditions.
- Active components and systems often include equipment such as pumps, valves, motors, diesel generators, cooling fans, batteries, relays, and switches



Active Components in the IGALL

- “Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL),” Safety Series Report 82 (Rev 1), August 2020
 - “This publication addresses ageing management of passive and active structures and components for water moderated reactors that can have an effect, directly or indirectly, on the safe operation of the plant and that are susceptible to ageing degradation.”
 - “In some Member States, the focus of ageing management for LTO is on passive structures and components only, **since the reliability of active structures and components is addressed by current requirements in the maintenance regulation which provide a performance-based approach to ensure component reliability and include maintenance, testing, and surveillance**. In other Member States, ageing management deals with both active and passive structures and components.

USA
approach



What do we mean by “Risk-Informed”

- Definition of “risk” includes both the likelihood of failure and the impact of failure

<i>Risk</i>	=	<i>Frequency</i>	X	<i>Consequences</i>
Consequence Magnitude / unit of time		Events / unit of time		Magnitude/event

- What can go wrong?
- How likely is it to go wrong?
- What are the consequences (e.g., core damage/dose impact to public) if it does go wrong?
- “Risk-Informed” → means analyses (quantitative and/or qualitative) are used as **PART** of the process or decision-making

The background of the slide features a blue-toned image of two hands cupping a globe. A faint, glowing circuit or orbital line is visible on the surface of the globe. The overall aesthetic is technological and global.

Maintenance Rule US NRC

Background and Context

What was the driver for adding maintenance requirements to the regulation of NPPs in the US?

- State of Operational Practice in the 80's
 - Healthy industry concern for nuclear safety
 - Balance of Plant (BOP) and other non-safety related issues generally not a safety concern
 - SCRAMS were generally expected to happen – and indication/confidence that the safety system was working
 - If a non-safety related SSC caused a plant transient, the plant would correct the deficiency in the SSC, and then resume operation
 - Capability/capacity factors were routinely around 60%
 - A nominal design capability/capacity factor of 80% was assumed. (Note: This is the origin of “7000 hours critical” (79.9%) assumption)
- NRC concerns relative to maintenance practices
 - Data showing industry was experiencing a high number of equipment issues
 - Secondary plant impact on transient initiation 1985 – NRC estimated > 35% of “abnormal occurrences” reported to Congress in the previous 10 years were directly attributable to maintenance deficiencies
 - NRC concerned that ineffective maintenance (including BOP SSCs) could affect plant safety
 - Note: PRA/PSA analysis also supports the conclusions scrams and transients are initiating events which result in elevated risk, and non-safety related SSCs can have significant impact on plant risk.

“The Maintenance Rule (MR)”

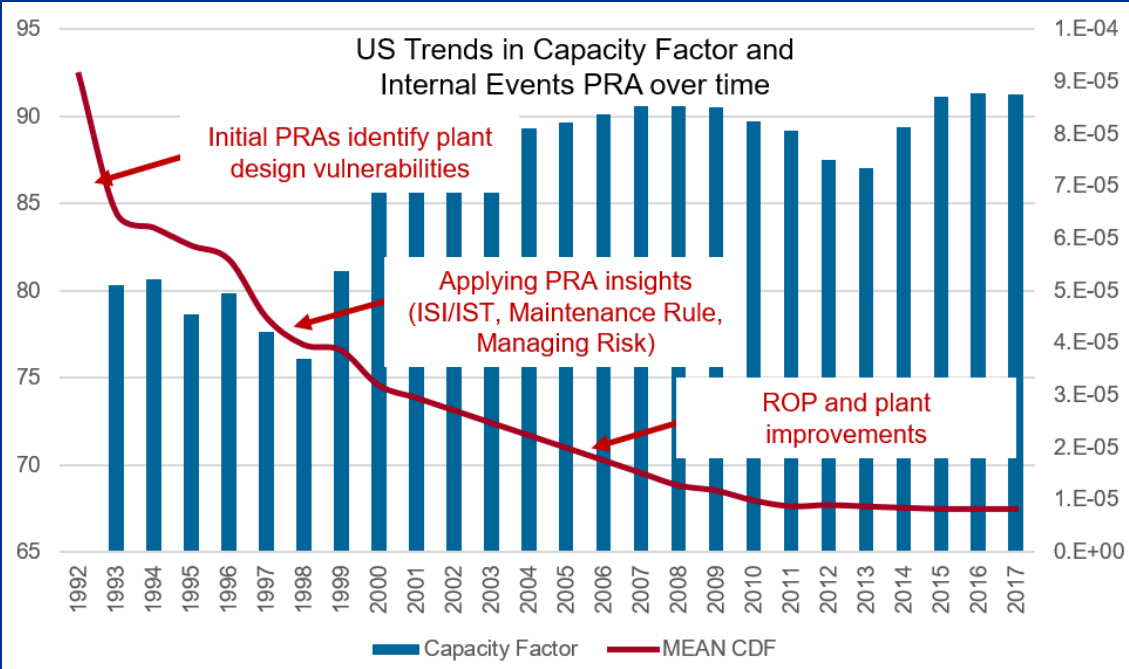
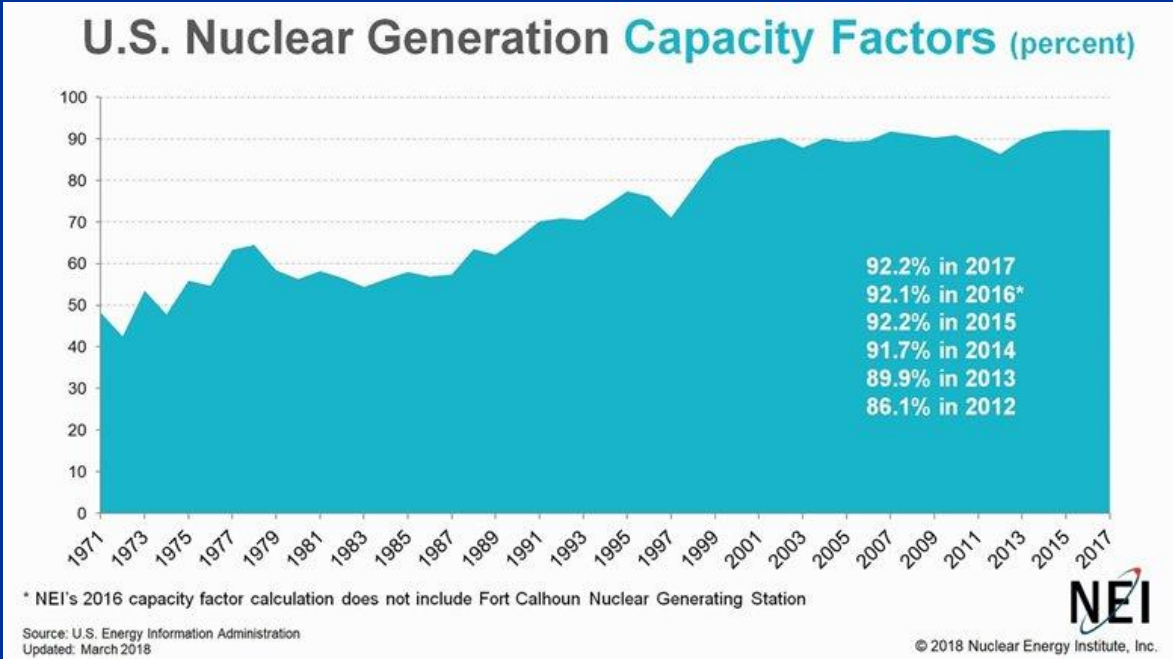
- US NRC Requirement for nuclear power plants
- Found in US law – [10CFR50.65](#), “Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants”
 - 1980’s – US NRC begins to consider the need to establish regulatory requirements for maintenance activities at NPPs
 - June 1988 – NRC Commission directs NRC staff to draft regulatory requirements for maintenance
 - Nov 1988 – US NRC initial proposal was a very detailed, process-oriented set of requirements for maintenance
 - 1989-1990 – Industry concern for overly-prescriptive and inflexible requirements
 - July 10, 1991 – 10CFR50.65, MR, was officially issued
 - 1992-1996 – US NRC reviews and accepts the industry-proposed NUMARC 93-01 as an acceptable method of implementing the MR
 - July 10, 1996 – 10CFR50.65, MR becomes effective at all NPPs
 - July 10, 1998 – NRC completed MR baseline inspections

What does the MR say?

- The Maintenance Rule (10CFR50.65):
 - (a)(1) – Some in-scope SSCs need to be monitored against goals
 - (a)(2) – Some in-scope SSCs do not have to be monitored against specified goals
 - (a)(3) – Program must be periodically evaluated and balanced
 - (a)(4) – Risk must be assessed and managed before performing maintenance activities
 - (b) – Some SSCs are in the program scope, and some are not
- MR was an historic regulation in the US
 - First risk-informed regulation (considers metrics and insights from probabilistic risk analysis)
 - First performance-based regulation (defines and evaluates based on outcomes/results, not detailed requirements)
 - Considered a compromise
 - NRC achieved regulatory oversight of maintenance
 - Licensees retained control over how maintenance is implemented, but are evaluated based on outcomes
 - In hindsight (30 years after implementation), MR is seen to have been a highly effective regulation

MR was the first risk-informed, performance-based regulatory requirement in the US

Impact of MR



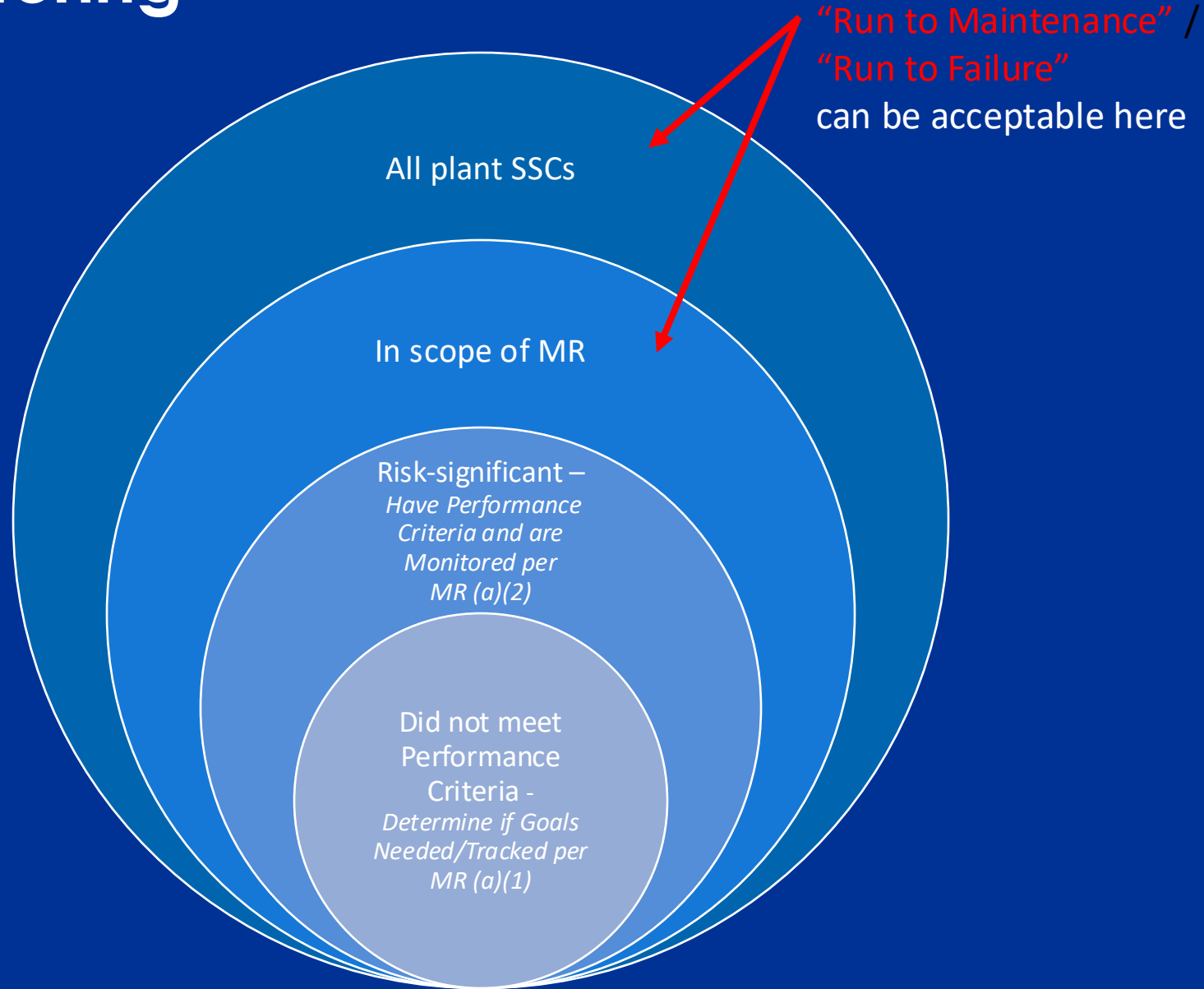
[EPRI 3002002325](#), “Maintenance Rule, 10CFR 50.65 Implementation History and Lessons Learned”

MR – Classification of Components

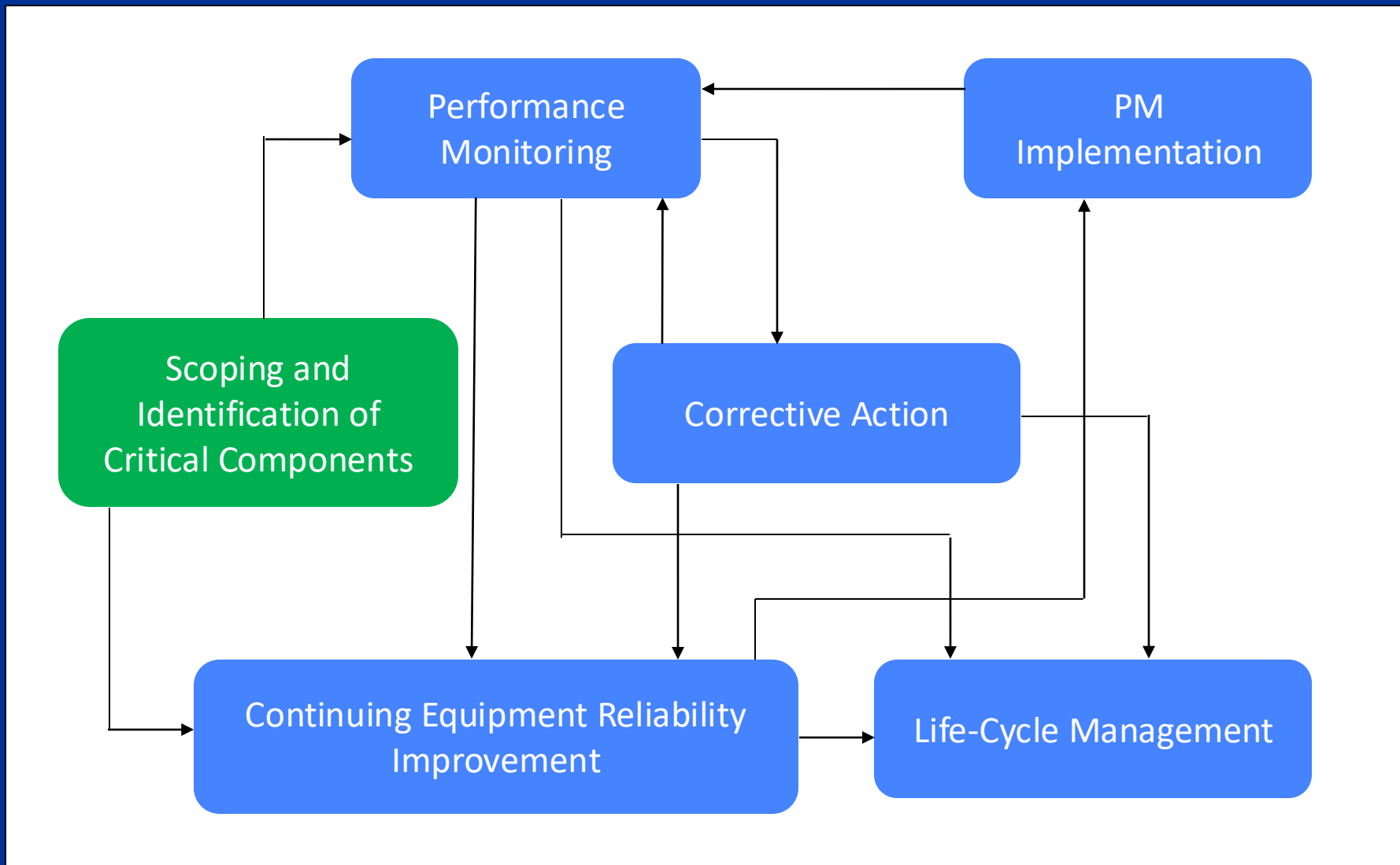
- 10CFR50.65 - “What” is required
- NUMARC 93-01 - Implementation document that tells “how” to do it
 - Classification must be based on the function of the system/structure
 - Not all failures impact the function
 - Not all functions are functions that contribute to safety
 - “In scope of MR”
 - Safety-related SSCs relied on to remain functional during and following design-basis accidents to
 - Ensure the integrity of the reactor coolant boundary,
 - The capability to achieve and maintain safe shutdown of the reactor
 - The capability to prevent or mitigate the consequences of an accident
 - Non-safety related SSCs:
 - That are relied on to mitigate accidents or transients, or are used in plant emergency operating procedures (EOPs)
 - Whose failure could prevent safety-related SSCs from fulfilling their safety-related function
 - Whose failure could cause a scram or actuation of a safety-related system
 - “Outside the scope of MR”
 - SSCs that do not meet the above criteria are outside the scope of the Maintenance Rule.
 - These SSCs will continue to have appropriate maintenance activities performed on them.
 - For these SSCs, the degree of maintenance attention will be dependent upon factors such as the consequence of SSC failure on power production and economic importance

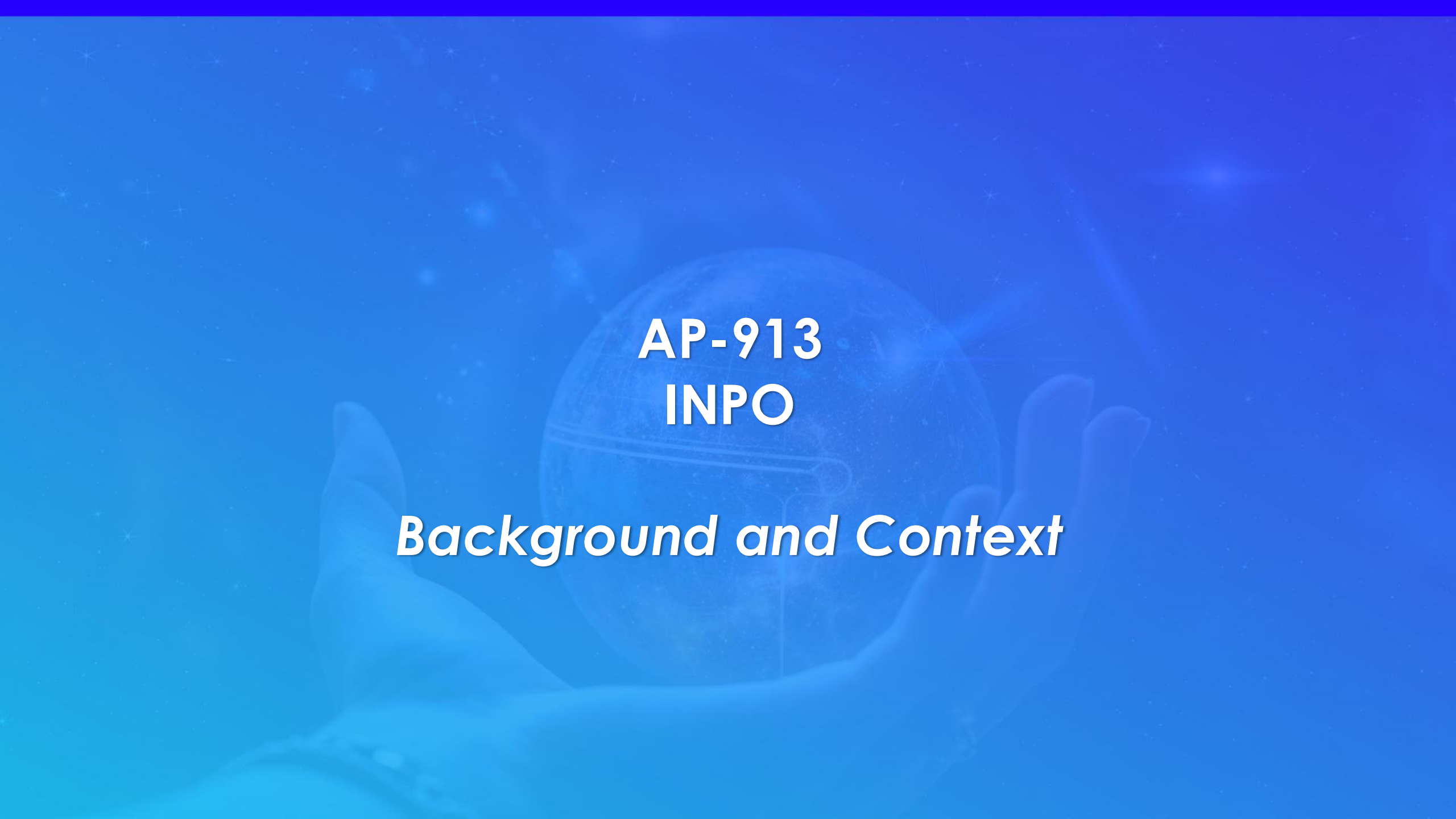
MR – Performance Monitoring

- “All SSCs within the scope of MR are subject to effective PM program”
 - Include in the formal PM program for the plant
 - Justify that the component is “inherently reliable”
 - Can “be allowed to run to failure (provide little or no contribution to system safety function).”
- For MR (a)(2) –
 - Risk-significant SSCs
 - Generally, comes from quantifiable PRA-based metrics (e.g., Fussell-Veseley, Birnbaum, Risk Reduction Worth, Contribution to Core Damage Frequency, Risk Achievement Worth)
 - SSC can be risk-significant for one failure mode, and non-risk significant for another failure mode
 - Final selection of SSCs that are risk-significant and within the scope of (a)(1) based on Expert Panel
 - Non-risk SSCs that are in standby (not normally operating, but required to function on a demand)
 - These SSCs have Performance Criteria
 - Criteria are determined by the licensee
 - Should be SSC availability, reliability, or condition
 - For non-risk significant SSCs in standby, performance is observed based on testing



Equipment Reliability Process





AP-913
INPO

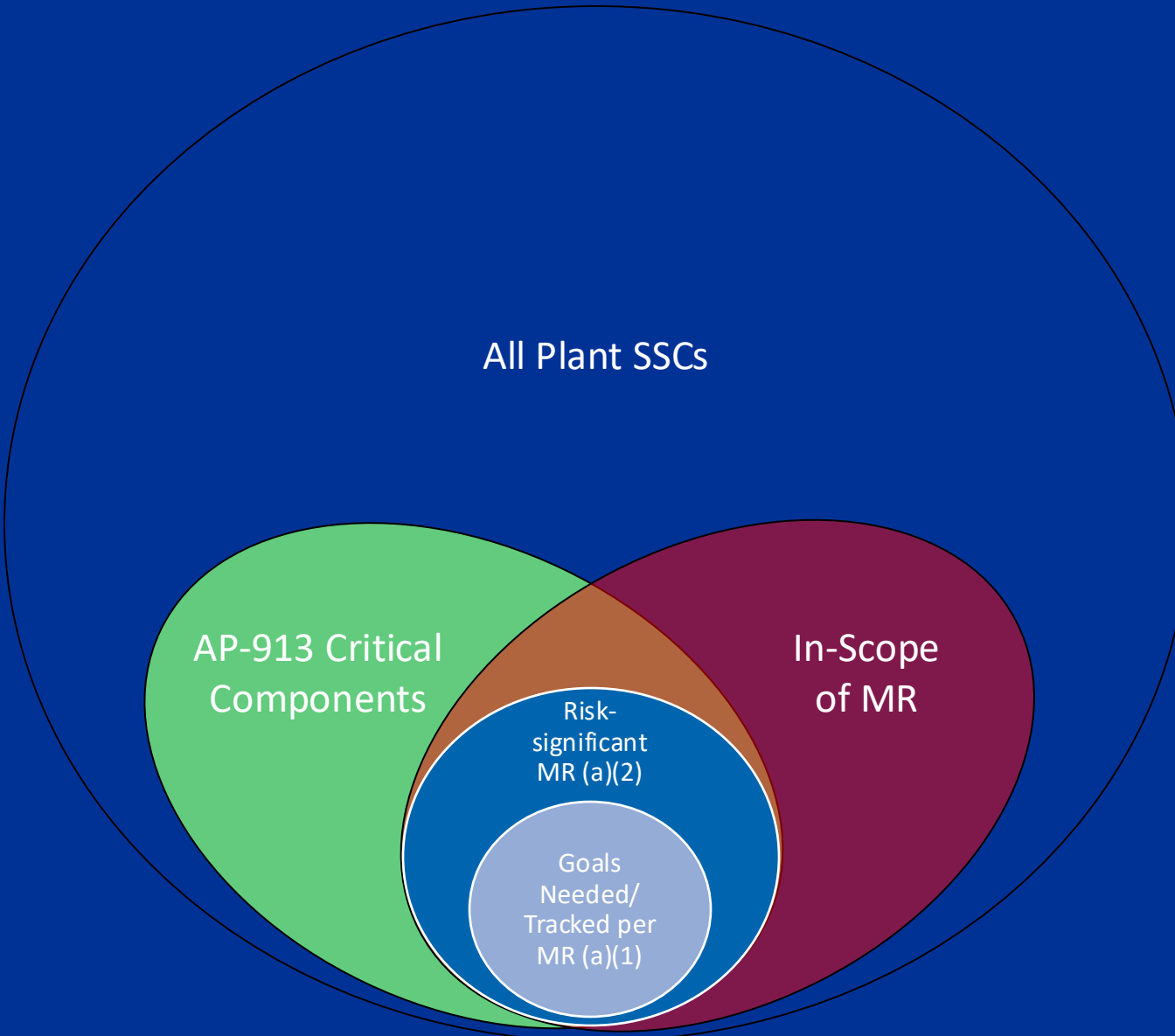
Background and Context

Comparing and Contrasting

- Maintenance Rule
 - REGULATION specifying the requirements for effective maintenance
 - MR is focused on nuclear risk and safety and is both risk-informed and performance-based
 - MR is not about “optimizing” maintenance or about plant performance
- AP-913, “Equipment Reliability Process Description”
- WANO GL 2018-02 “Equipment Reliability”
 - Describes a process that CAN be implemented by licensees
 - Focused on high levels of safety and plant reliability
 - Developed by INPO based on collaboration with the Equipment Reliability Working Group (ERWG)
 - Includes graded approach based on significance and the concept of maintenance task optimization



Summary of Classification in AP-913



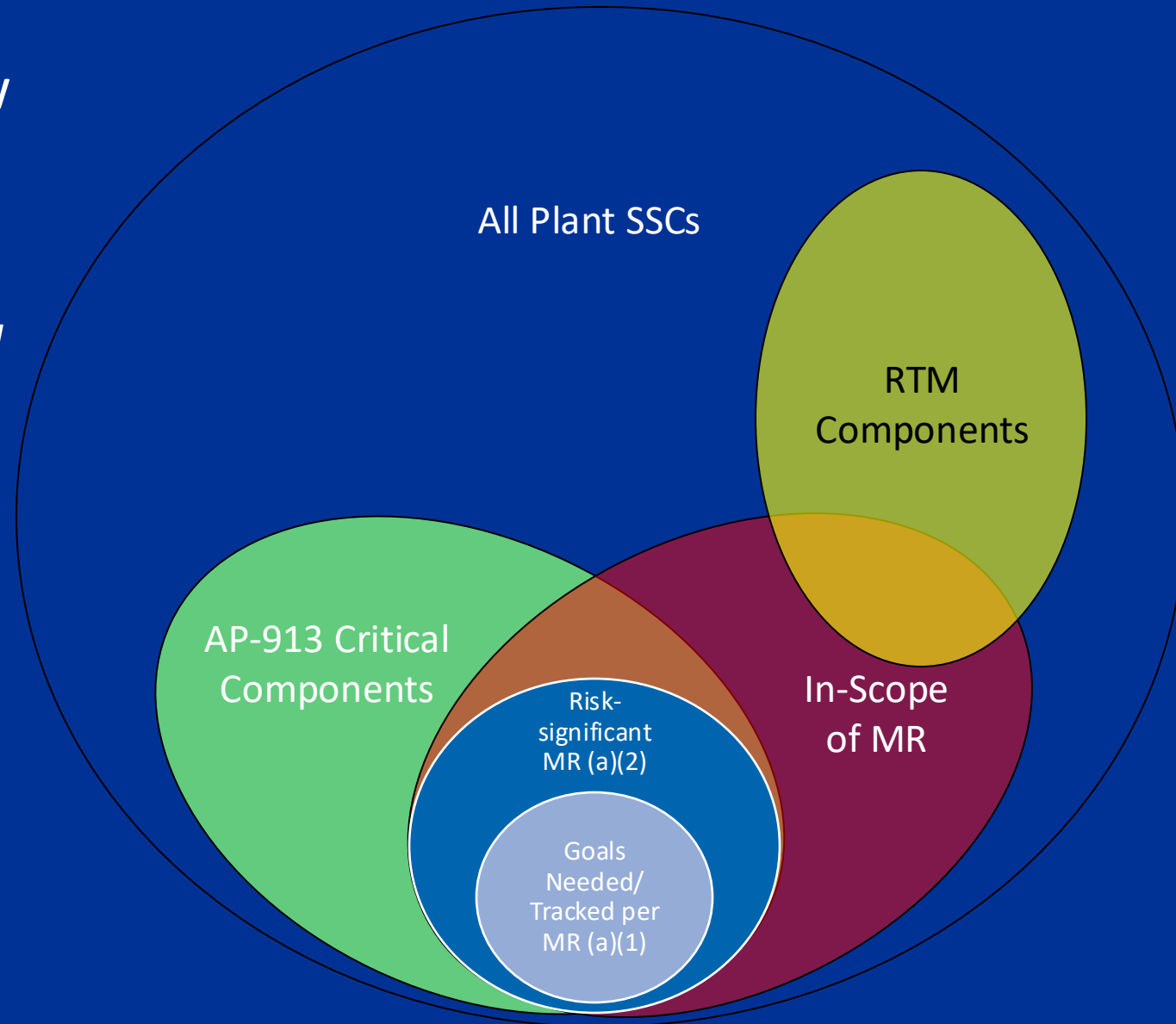
- Critical Components – those SSCs whose failure is unacceptable and would result in
 - Plant trips (i.e., Reactor scrams and turbine trips that lead to reactor scrams)
 - Large sustained MW losses (e.g., more than minimal production losses)
 - Loss of a critical safety function (e.g., heat removal, reactivity control, containment isolation, etc.)
 - Failure of a Mitigating Systems Performance Index (MSPI) component
 - Failure that results in loss of MR risk-significant function

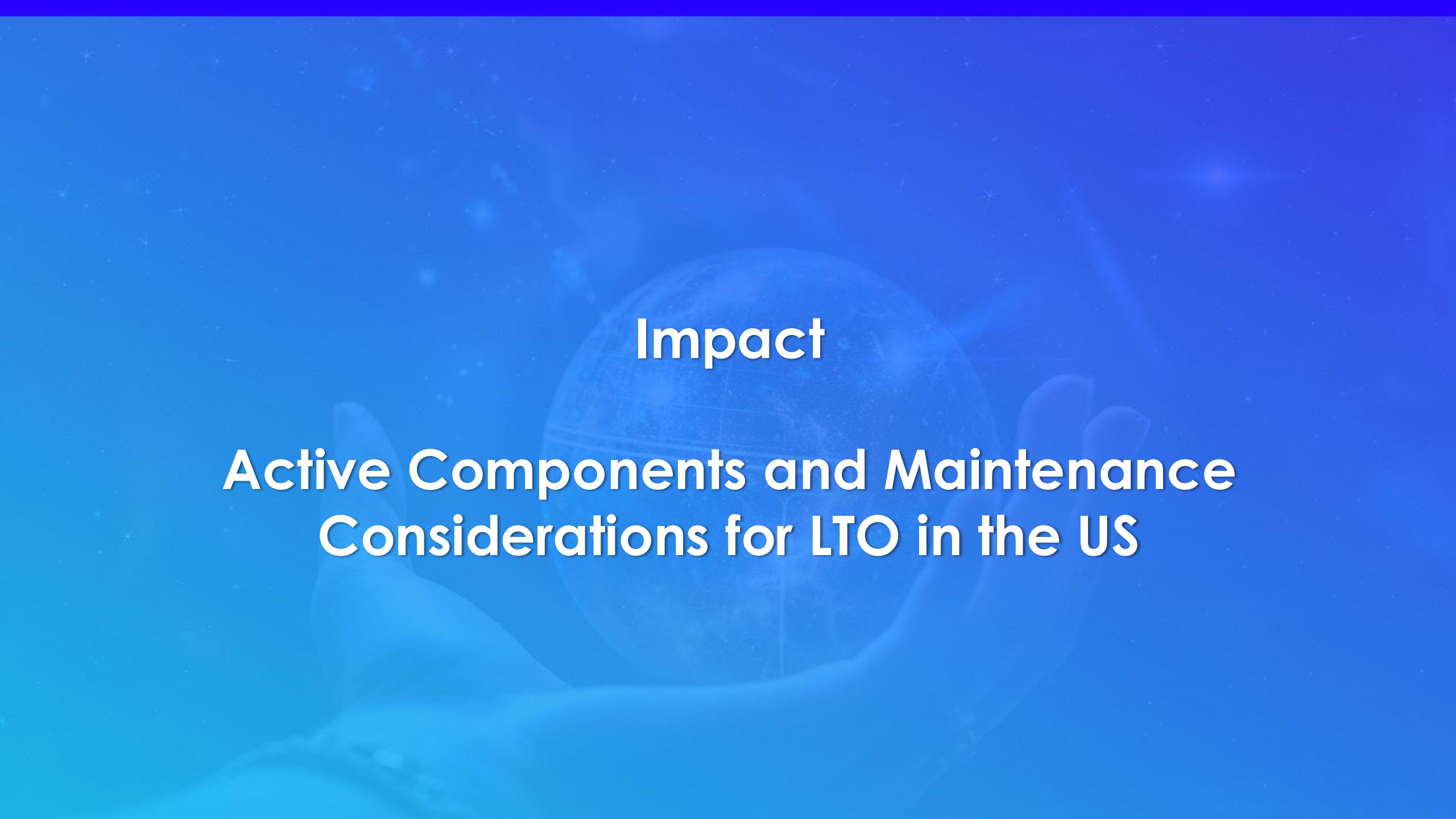
Non-critical Components

- Non-critical components – Those SSCs that are not Critical
 - Maintenance strategies (including reliability/performance considerations and life-cycle management) are developed to ensure necessary targets for performance are met
 - Performance targets may come from
 - Regulatory/code requirements (e.g., Tech Specs, In-Service Testing, MR, etc.)
 - Business needs (e.g., generation goals, insurance metrics, costs, etc.)
 - May or may not Run to Maintenance (RTM) components

Run to Maintenance (RTM)

- “Run to Maintenance (RTM)” is now the preferred term, but basically means the same as “Run to Failure (RTF).
(The word “failure” as applied to anything nuclear may have a negative public connotation.)
- RTM
 - Applies to SSCs where the risk and consequences of a failure are acceptable
 - Considers
 - Cost of preventive versus corrective maintenance
 - Can be excluded from formal PM program





Impact

**Active Components and Maintenance
Considerations for LTO in the US**

Relevant to LTO and LR/SLR Processes in the US

- “SCs that are not subject to aging management review (AMR) are those that are active, such that their failure will be identified during surveillance and testing in accordance with the Maintenance Rule (MR) of 10 CFR 50.65, or replaced on a fixed schedule.”
 - “The NRC on-going regulatory process activities described above represent the NRC [i.e., regulatory oversight of plants in the US] activities that NRC contends are sufficient to meet the objectives of [a] Periodic Safety Review (PSR).”
 - “NRC credits the MR processes in excluding active components from the scope of LR as described in Paragraph 5.17 of IAEA, SSG-48 – “Ageing Management and Development of a Programme for LTO of NPPs”
 - Structures and components that satisfy both of the following conditions can be excluded from the scope of ageing management:
 - (a) Structures and components subject to periodic replacement or to a scheduled refurbishment plan on the basis of predefined rules (based on a manufacturer’s recommendation or other basis and not on an assessment of the condition of the structure or component, which would comprise implementation of ageing management for the structure or component); and
 - (b) Structures and components that are not required by national regulatory requirements to be included in the scope.

Active Components are outside the Scope of LR/SLR in the US

Conclusions

- Maintenance of active components in the US is addressed by
 - Maintenance Rule (MR) - Regulatory requirement
 - AP-913 – Process for optimizing performance and reliability
- In both AP-913 and MR
 - Classification of components considers “risk”
 - RTM strategies are allowed for low risk-significant components
- When classified correctly, RTM components cannot be
 - AP-913 Critical Components
 - Components within the scope of MR (a)(2) or (a)(1)

Maintenance of active components is a risk-informed process and does allow for RTM components



TOGETHER...SHAPING THE FUTURE OF ENERGY®

Intake Challenges

A graphic on the right side of the slide featuring a blue rounded rectangle with the word "Nuclear" in white. This rectangle is set against a background of a nuclear reactor with steam rising from it, all enclosed within a dark blue border.

Nuclear

David Olack
Principle Technical Leader

Plant Resiliency, Reliability and Modernization Technology Workshop
October 20-22, 2025

Importance of Reliable Sourcing of Cooling Water

- Reliable sources of cooling water are crucial for thermal power generation including nuclear, coal, natural gas combined cycle, solar-thermal, geothermal, and biomass power plants
- About 90% of the total water requirements of these plants are for cooling purposes
- The importance of the ultimate heat sink and a reliable cooling water intake system is vital to the efficient operation of the turbine plant condenser and the auxiliary cooling systems

Intake Reliability Research at EPRI



Long-term ecological change is affecting intake reliability and power production



The industry needs research to inform, advise, and provide evidence-based solutions and continue to support research to automate and improve intake performance



The **Nuclear & Generation** staff collaboratively supporting the **Service Water Assistance Program (SWAP)** and **Intake Reliability Interest Group (IRIG)** are uniquely positioned to address these concerns through collaborative research projects

Anticipating Future Challenges – a Today Task!

The nature of intake cooling water issues are changing, and the frequency of new challenges and events are increasing, therefore plant operators need to:

- Start thinking and planning for the long-term
- Start communicating amongst the industry
 - observed & expected changes
 - review intake operational capacity and performance
- Be proactive not reactive
 - Review preventative maintenance program
 - Revisit design basis
 - ✓ water quality in relation to material selection
 - ✓ equipment and operational settings (and past assumptions) in relation to evolving debris types

EPRI provides a framework and the expertise to launch new research in support of adaptation to gradual changing environmental conditions

Background

- Long-term ecological change affects power plant reliability
- Environmental conditions are causing more frequent derating and forced outages
- Environmental changes include:
 - Increased storm-related debris events
 - Increased nuisance species (e.g., jellyfish, hydrozoa)
 - Water conditions (increased temperature, chemistry changes, extreme levels) affecting equipment integrity
- EPRI's Intake Reliability Interest Group (IRIG) provides a framework and expertise to launch new research





Intake and Reliability Interest Group (IRIG)

Intake Reliability Interest Group (IRIG)

VALUE

- Minimize or prevent unscheduled outages or reduced operating efficiencies
- Guidance on state-of-technology on intake screen design, operation and optimization
- On-call assistance for emergency intake management issues
- Contribute to and benefit from a network of informed industry peers and subject matter experts

OBJECTIVES & SCOPE

- Provide a forum to discuss intake blockages, operational impacts, O&M and screen optimization
- Develop BMPs to address emerging debris and traveling screen issues
- Support nuclear reporting requirements
- Host webcasts, workshops, newsletters and technical briefs to disseminate information



Minimize Outages through Improved Operation and Maintenance Practices of Water Intake Structures

Newsletters

- Announcement for upcoming events – webcasts and workshops
- Technical library (Collaboration site)
- Debris and biofouling events in the news
- Optimization issue developments
- New peer-reviewed literature
- Schedule & Content of New Tech Briefs
- Contact information for members
- Links to EPRI resources

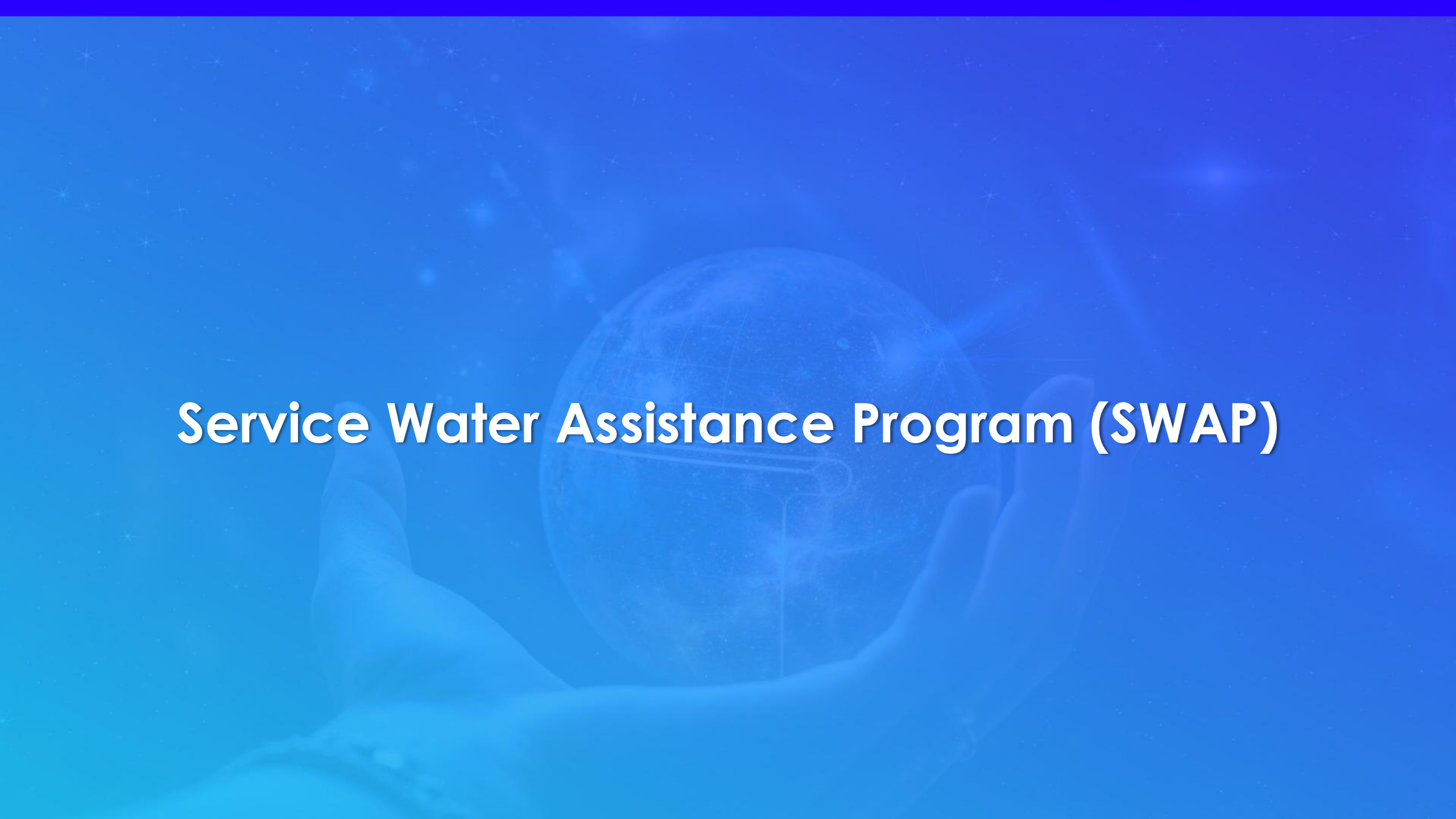


Technical Briefs

- Hydrilla ([3002002526](#))
- Bryozoans and Hydroids ([3002003052](#))
- Jellyfish ([3002014362](#))
- Fish Kills ([3002004640](#))
- Event Forecasting ([3002005150](#))
- Cooling Water Intake Debris Management: Coatings for Biofouling Control ([3002007621](#))
- O&M Issues as a Result of Continuous Screen Operation and other Fish Protection Features ([3002011144](#))
- Marine Debris: Issue, Modeling, & Detection ([3002016687](#))
- Harmful Algal Blooms ([3002018397](#))
- Cooling Water Intake Operation, Maintenance and Optimization Interest Group: Presentations 2009-2020 ([3002022100](#))
- Remote Sensing ([3002023101](#))
- Results of zebra and quagga mussel member survey ([3002025119](#))
- Sedimentation ([3002026056](#))
- Corbicula ([3002027540](#))
- Underwater Ice Caused By Supercooling Events ([3002030476](#))

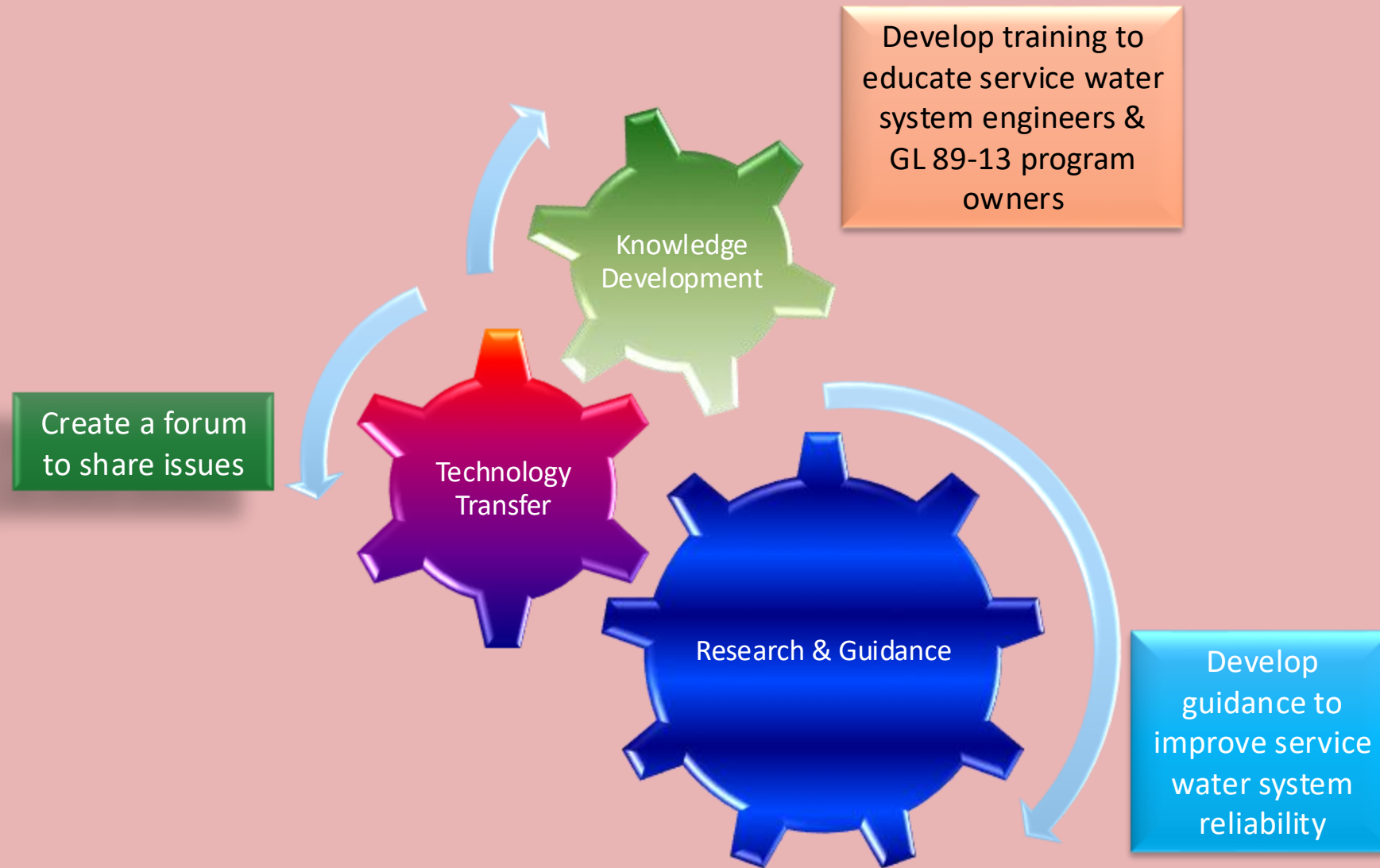
A diversity of topics





Service Water Assistance Program (SWAP)

The SWAP Mission



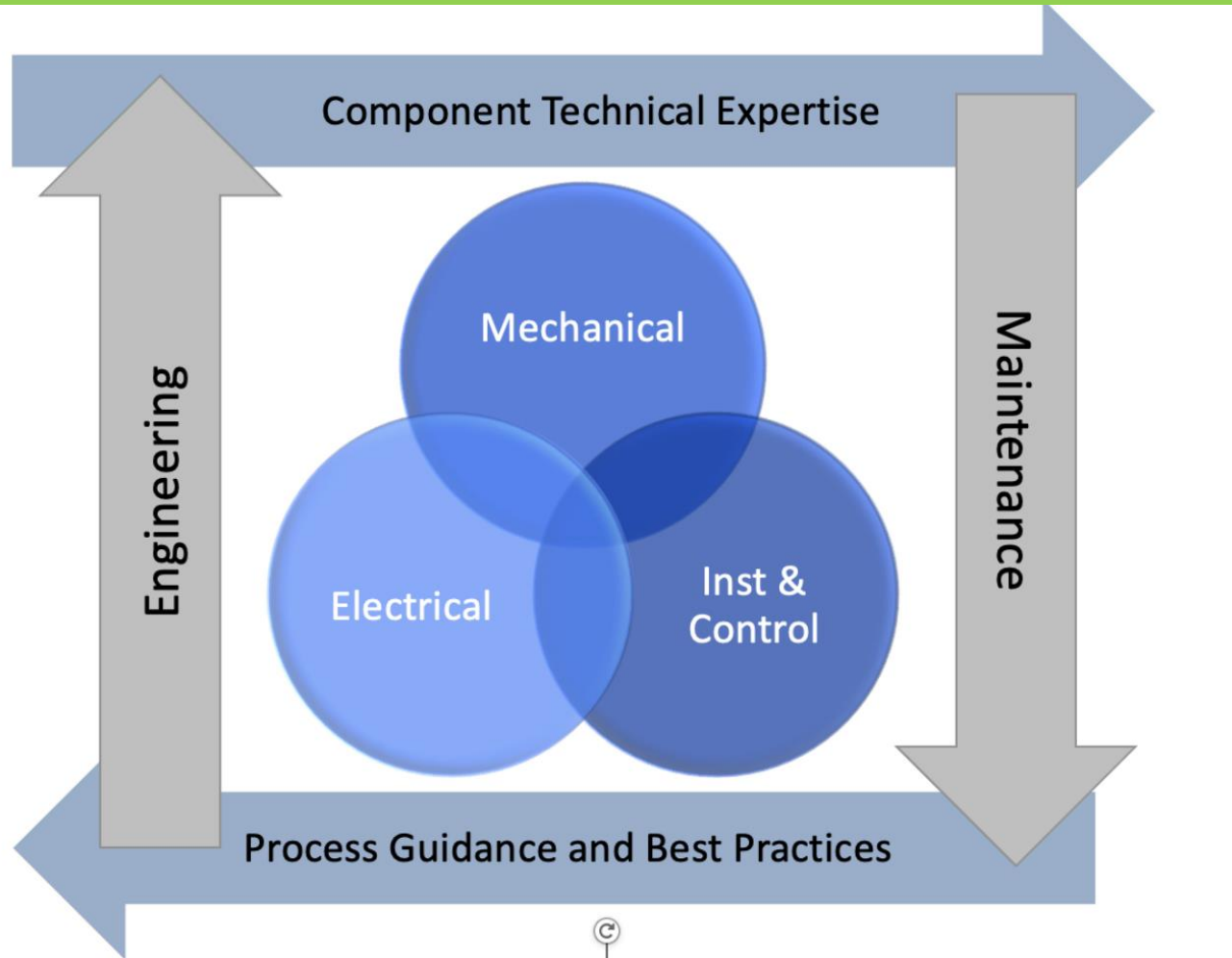
What is SWAP?

- SWAP is the oldest of all Plant Engineering user groups and was established in 1988 to address GL89-13. With the always changing climate and environmental conditions or aging of plant systems, those long periods of normal operations can suddenly be upset with an unexpected challenge.
 - When you are challenged with system issues, the goal is for SWAP to be there to provide the resources to support you as you investigate, troubleshoot or otherwise address them.
- ✓ Interactions during annual meetings
 - ✓ SWAP Surveys
 - ✓ EPRI Technical Reports
 - ✓ Plant System Equipment Database (PSENV)
 - ✓ Periodic Webcasts
 - ✓ Peer visits and support
 - ✓ Other EPRI SME support



Service Water Assistance Program
(SWAP) | EPRI Micro Site

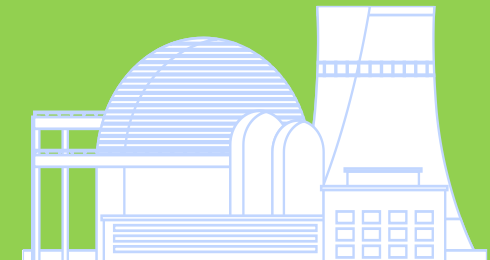
Plant Reliability and Resilience (PRR) Research



One program includes

- » Maintenance/Active Mechanical
- » **BOP/Passive Mechanical**
- » Electrical
- » Instrumentation & Control (I&C)
- » Engineering & Maintenance Processes (e.g., ER, SPV, Procurement, etc.)

Includes research scope of former EPRI programs: NMAC, PE, and I&C



The background of the slide features a blue gradient with a faint, glowing network of lines and nodes. In the center, a pair of hands is shown holding a transparent globe. The globe has a grid of latitude and longitude lines and is overlaid with the same network pattern seen in the background. The hands are positioned as if they are carefully supporting the globe from below.

PRR Forums

Plant Reliability and Resilience

<https://nuclearprforum.epri.com/index.php>

PRR Forums

EPRI

ForumsSearchSearch FilesCalendarAbout

Welcome back, David_Olack

User SettingsModeratorView New PostsView Today's Posts

Plant Reliability and Resilience

Active Mechanical Users Groups

Forum	Threads	Posts	Last Post
 Terry Turbine Users Group For nuclear industry owners of Terry Turbine Systems for AFW/RCIC/HPCI current information on industry Terry Turbine operating experience and any recent design/maintenance issues within the operating fleet	17	55	HPCI EG-R Clearance Accep... 01-22-2025, 02:27 PM, Daniel_Barb
 Hoisting, Rigging, and Cranes Users Group	50	79	Site Crane Maintenance 02-12-2025, 09:59 AM, Jacob_Brooks
 Condition Based Maintenance (CBM) Users Group	2	5	NFPA 70B 2023 Discussion 01-23-2025, 05:43 AM, Sam_Gill
 Work Planning Users Group	19	91	Operational Release 11 hours ago, Matthew_Hinman

BOP/Passive Mechanical Users Groups

Forum	Threads	Posts	Last Post
 Buried Pipe Integrity Group (BPIG) Sub Forums: ● Cathodic Protection	5	16	Treatment of Vendor Repor... 01-31-2025, 09:25 PM, Alvin_Addisho
 Checworks™ (FAC) Users Group	1	1	Welcome 11-14-2024, 11:48 AM, Ryan_Wolfe
 Heat Exchanger Perf Users Group	10	25	Individual Tube Pressure ... 02-12-2025, 09:58 AM, Kyle_Patterson

PRR Forums/Passive Mechanical

Plant Reliability and Resilience > BOP/Passive Mechanical Users Groups

Forums in 'BOP/Passive Mechanical Users Groups'

Forum	Threads	Posts	Last Post
Buried Pipe Integrity Group (BPIG) Sub Forums: Cathodic Protection	5	16	Treatment of Vendor Repor... 01-31-2025, 09:25 PM, Alvin_Addisho
Checworks™ (FAC) Users Group	1	1	Welcome 11-14-2024, 11:48 AM, Ryan_Wolfe
Heat Exchanger Perf Users Group	10	25	Individual Tube Pressure ... 02-12-2025, 09:58 AM, Kyle_Patterson
Plant Perf Enhancement Prog (Thermal Perf)	8	38	Detection of condenser tu... 02-18-2025, 12:08 PM, Amanda_Mast
Nuclear Utility Coatings Council (NUCC)	4	4	BWR Torus Downcomer Coati... 02-10-2025, 03:45 PM, David_Olack
Service Water Assistance Program (SWAP)	9	16	Silt Trending and Removal 02-20-2025, 05:53 PM, Dustin_Platt

Users browsing this forum: David_Olack

PRR Forums/SWAP

Plant Reliability and Resilience > BOP/Passive Mechanical Users Groups > Service Water Assistance Program (SWAP)

Post Thread

Service Water Assistance Program (SWAP)

Mark this forum read / Unsubscribe from this forum

Thread / Author	Replies	Views	Last Post [asc]	☐
★ Localized Corrosion/Pitting on Piping - Causal Investigation Kelsi_Eiane	1	7	05-08-2025, 04:23 PM Last Post: Travis_Garrett	☐
★ Benchmarking Request for Service Water Piping Material OE Travis_Garrett	5	46	04-18-2025, 02:51 PM Last Post: Kelsi_Eiane	☐
★ ECCS Room Cooler Leak Trend Tim_Tchou	3	18	04-15-2025, 03:56 PM Last Post: Lorrie_Bell	☐
★ ESW Carbon Steel Pipe Leak Carissa_Richardson	1	15	03-27-2025, 03:40 PM Last Post: Kelly_Ehrhart	☐
★ Silt Trending and Removal Kelly_Ehrhart	2	13	03-25-2025, 09:37 AM Last Post: Marko_Turalija	☐
★ Developing Corrosion Management Performance Indicators David_Olack	0	8	02-18-2025, 11:45 AM Last Post: David_Olack	☐
★ EPRI BOP/NDE Symposium – July 2025 David_Olack	0	4	01-31-2025, 09:53 AM Last Post: David_Olack	☐
★ Service Water Strainers AL6XN Materials Jim_Melchionna1	 1	17	01-23-2025, 04:18 PM Last Post: Travis_Garrett	☐
★ INPO SOER 07-2 Benchmarking David_Olack	1	17	01-23-2025, 10:17 AM Last Post: Dustin_Platt	☐
★ 2024 LTEC Workshop and OMOIG Annual Meeting David_Olack	 0	9	10-21-2024, 02:59 PM Last Post: David_Olack	☐
★ SWAP Survey 2024-04 David_Olack	0	18	10-16-2024, 08:39 PM Last Post: David_Olack	☐
★ Welcome! David_Olack	1	17	09-10-2024, 11:34 AM Last Post: Eric_Sorg	☐



Intake Systems Products

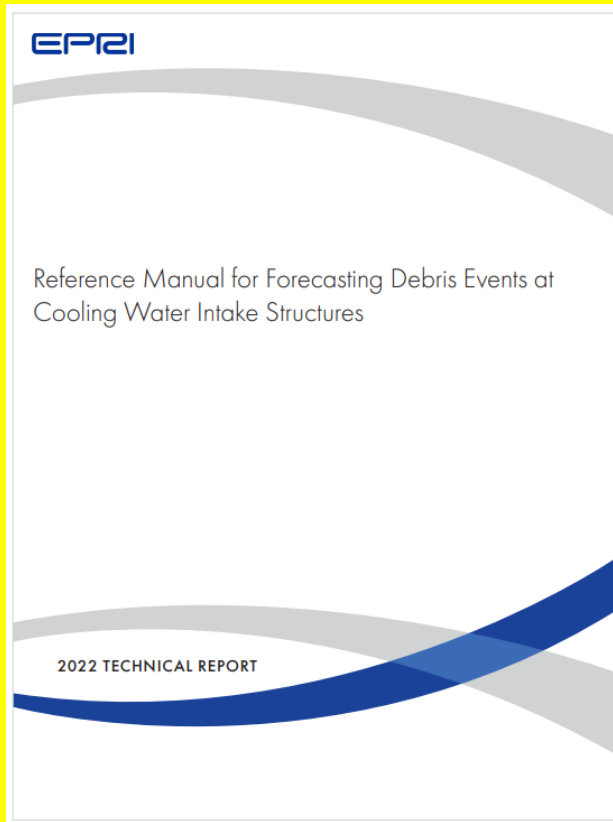
BMP Project

3002019660

Best Management Practices (BMP) for Preventing Cooling Water Intake Blockages

- Guidance published in June 2021
- International participation was limited; current guidance includes international events
- New screen types and designs
- With international input, we increase knowledge
 - Both successful and unsuccessful mitigation/forecasting efforts
 - Application of specific (novel?) intake system types
 - Add to the body of OE related to debris management at intakes



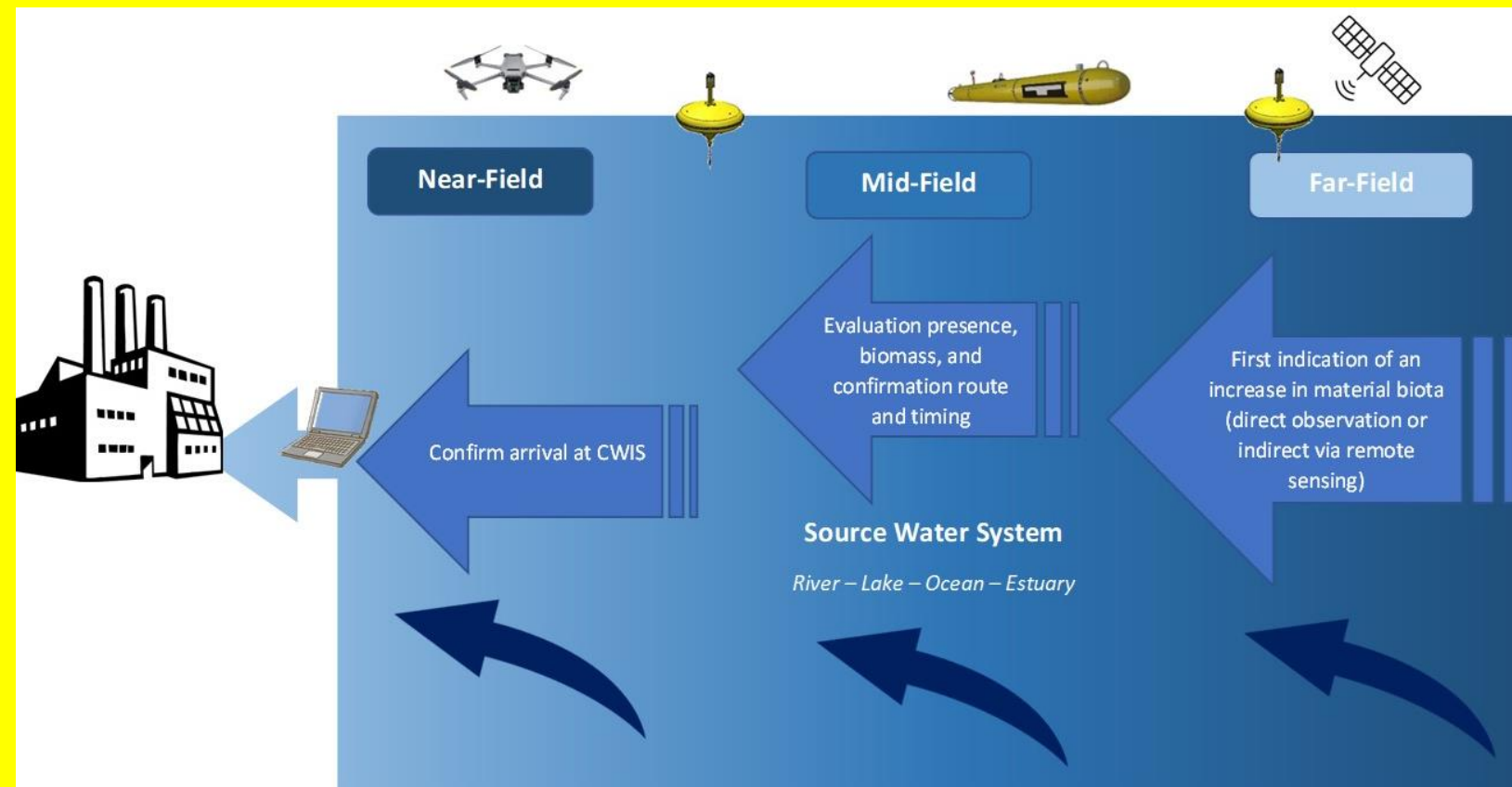


Reference Manual for Forecasting

3002024512

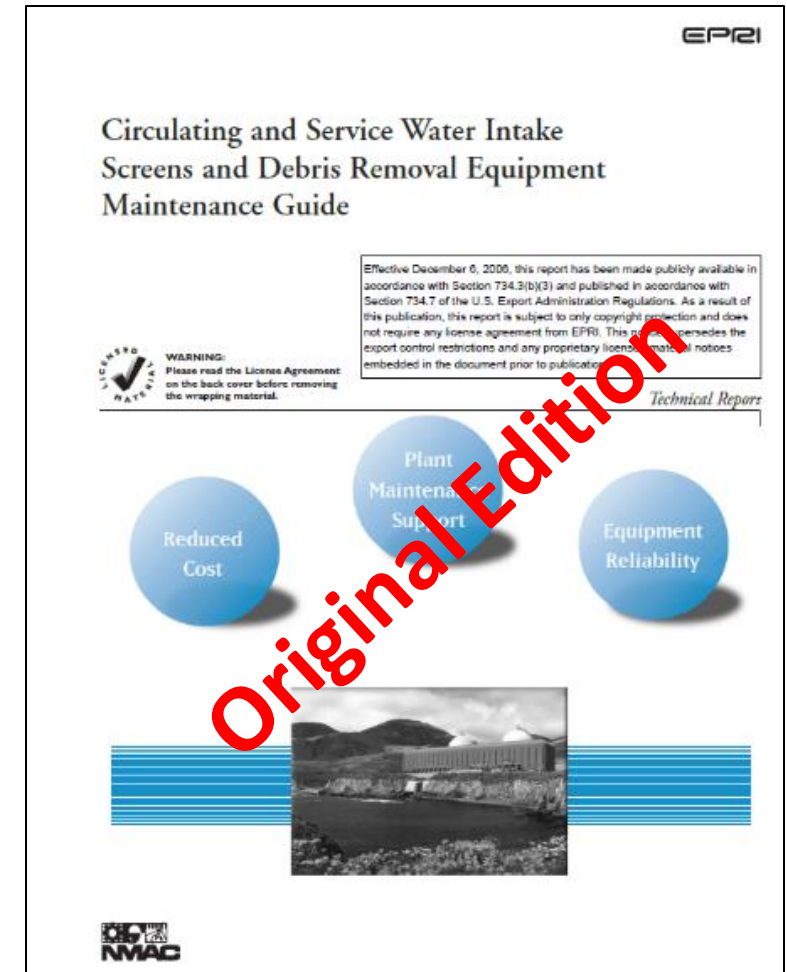
- Describes major components necessary to develop a debris forecasting system

- Provides a step-by-step guide illustrating integration of key components
- Hypothetical case study for illustration



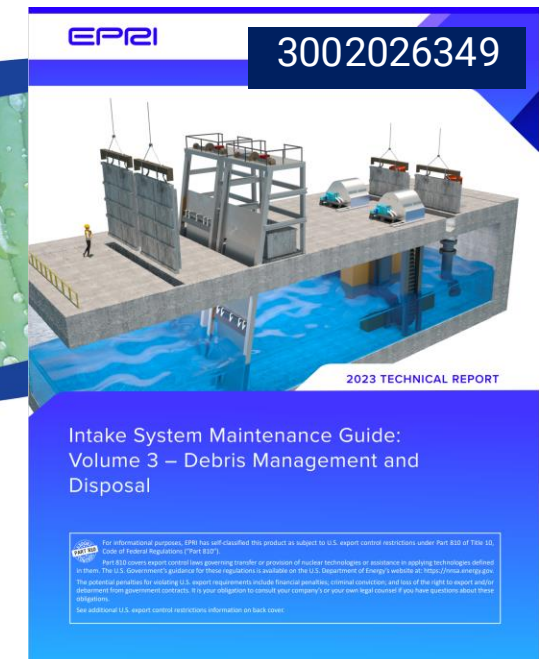
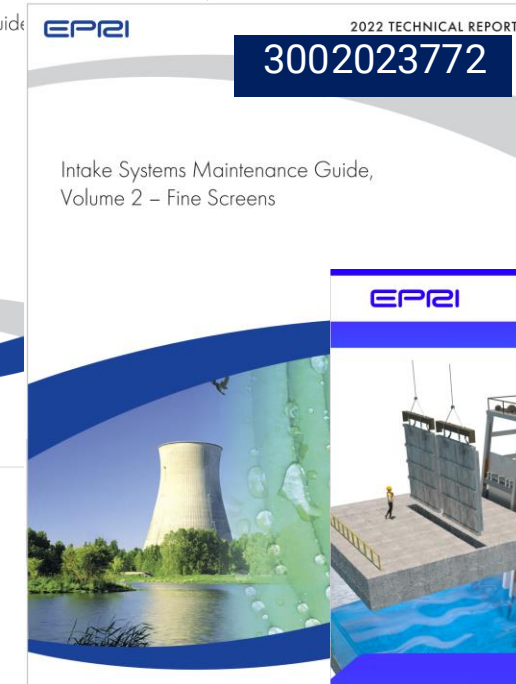
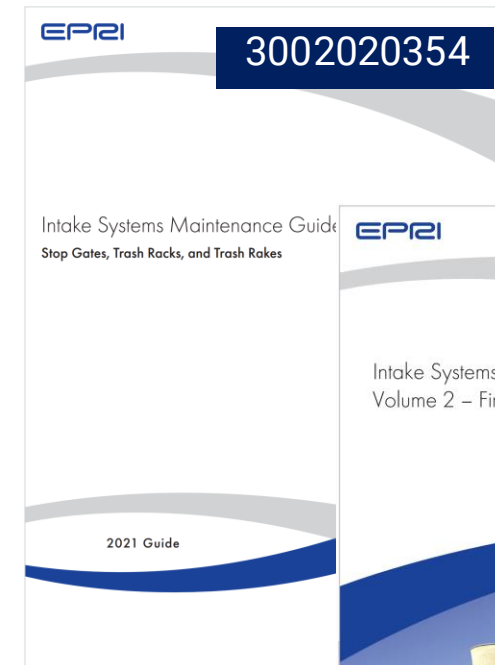
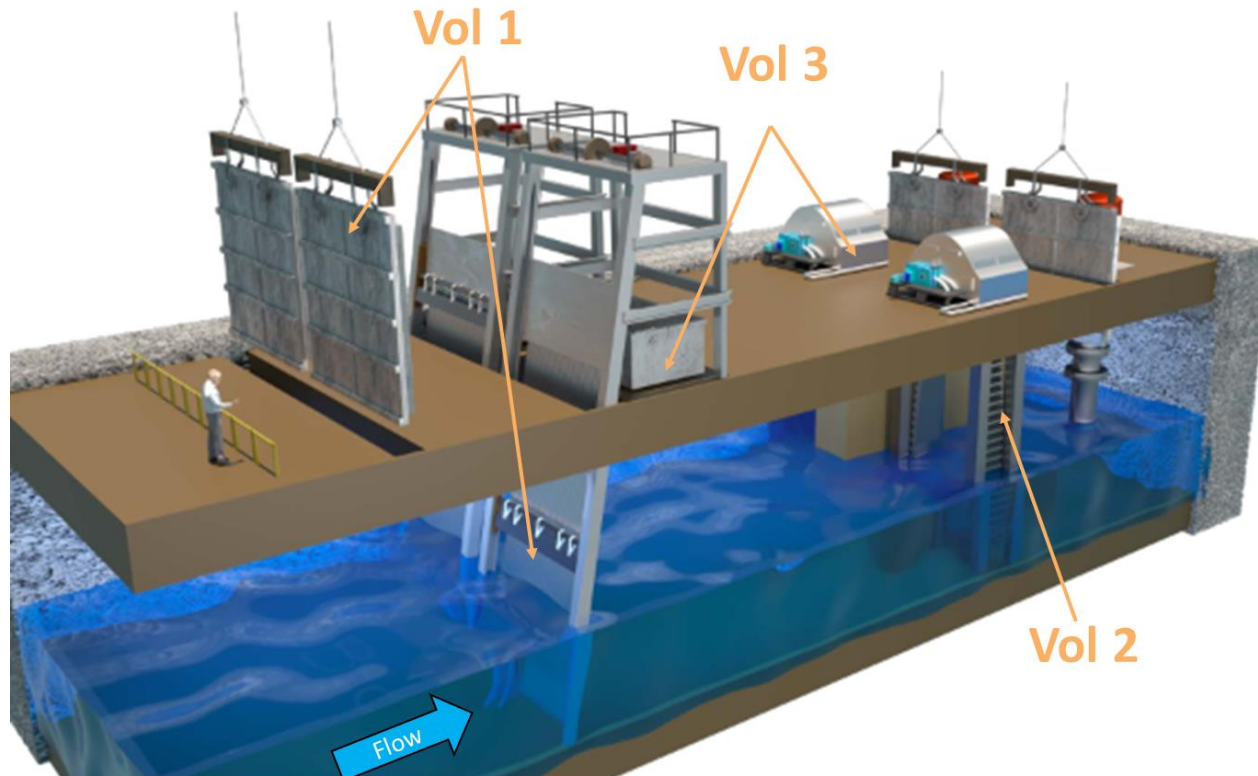
Intake Systems Maintenance Guide

- Original guide was published in 2004
- New guide was published as three new volumes
- Revised content includes input from Generation, Nuclear, Environmental and EPRI's Industry User Groups
- New PMBD Templates have been added, and existing templates revised



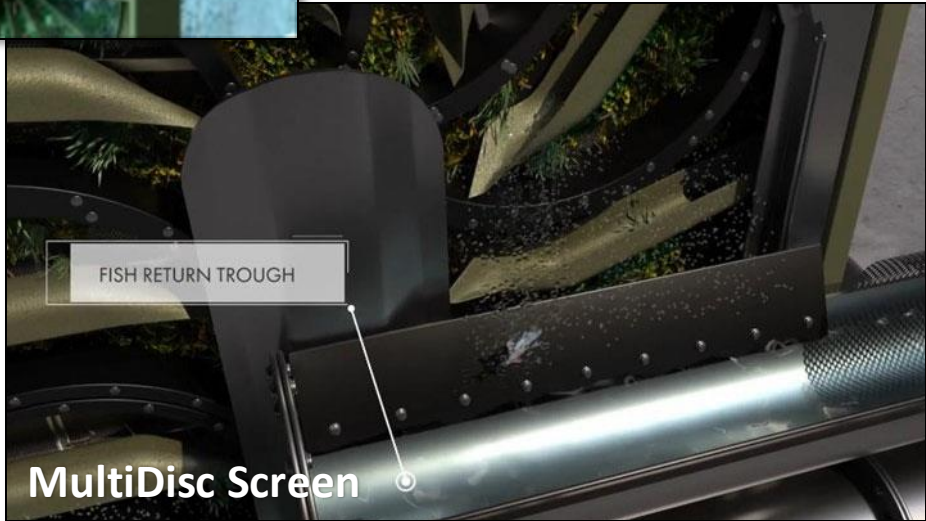
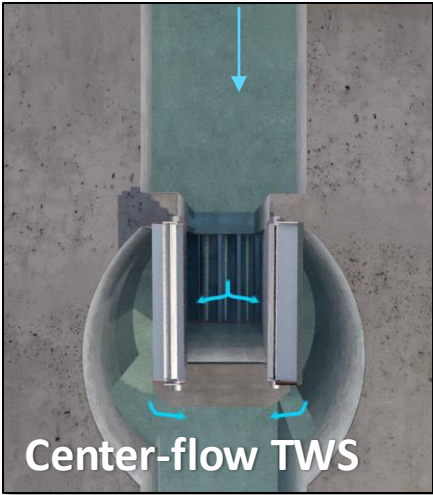
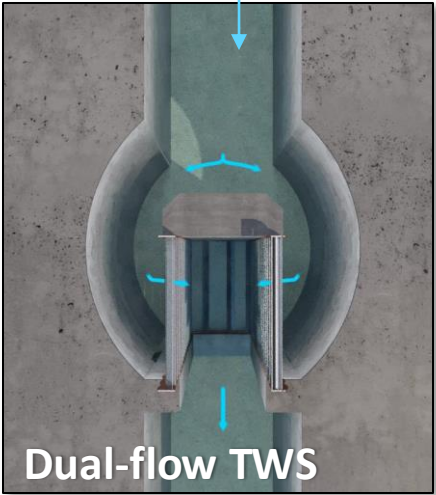
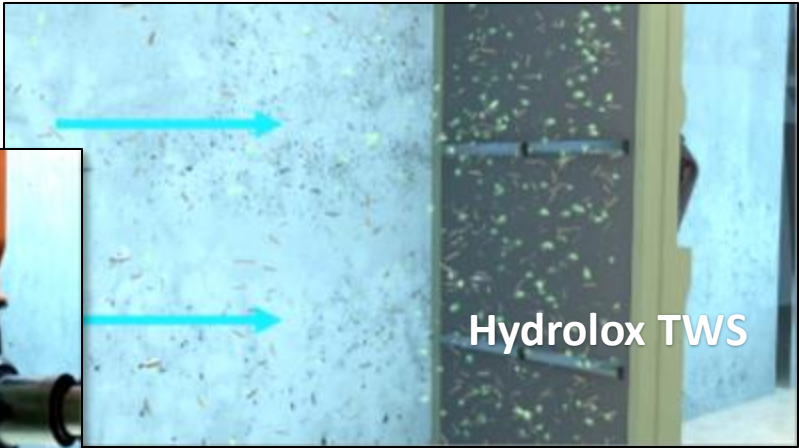
Intake Systems Maintenance Guide

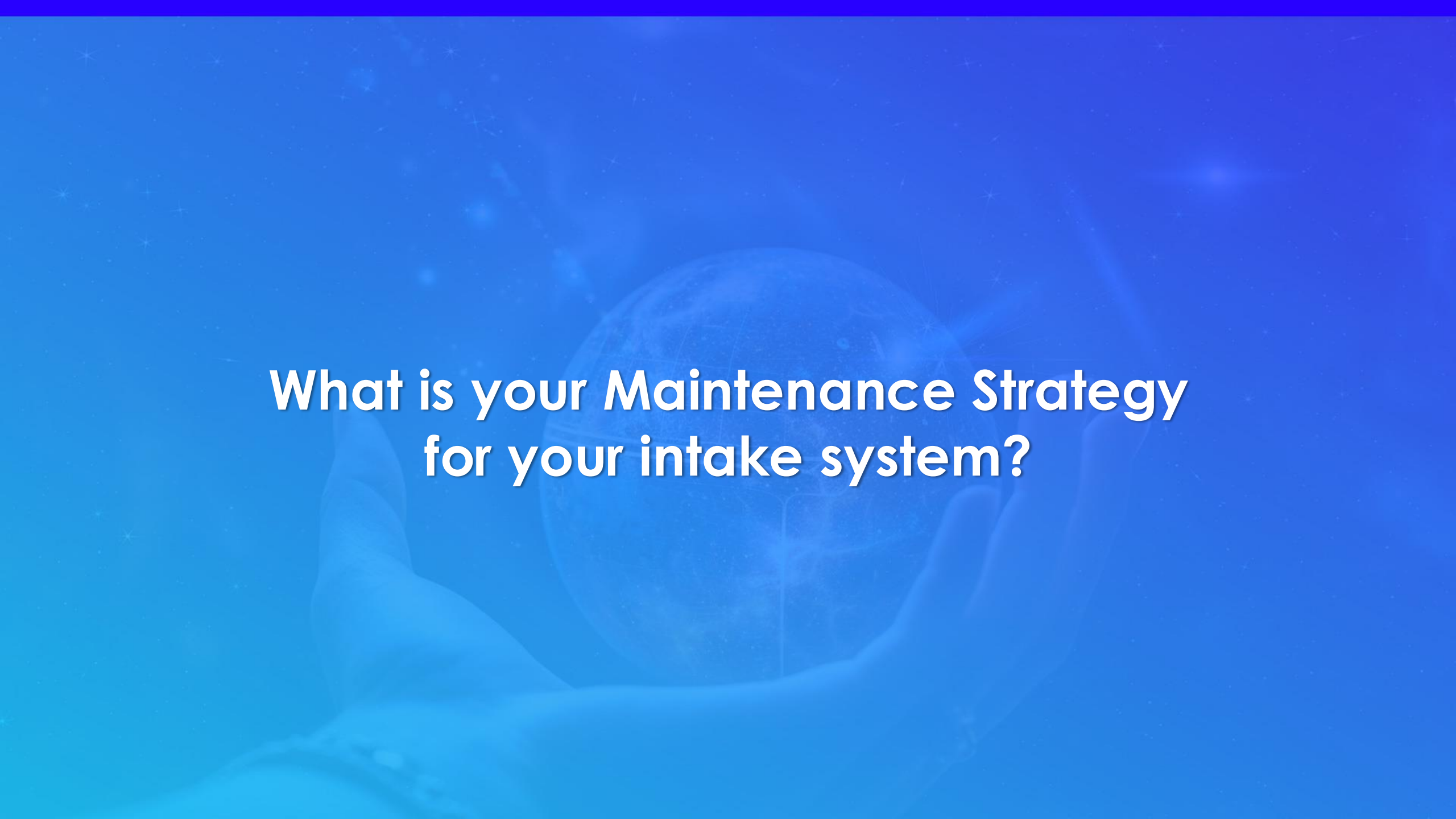
- Updated TWS Technologies
- Updated graphics and animations
- Global application
- EPRI's Preventive Maintenance Basis Database (PMBD) <https://pmbd.epri.com>



Intake Systems Maintenance Guide Series

Updated TWS Technologies





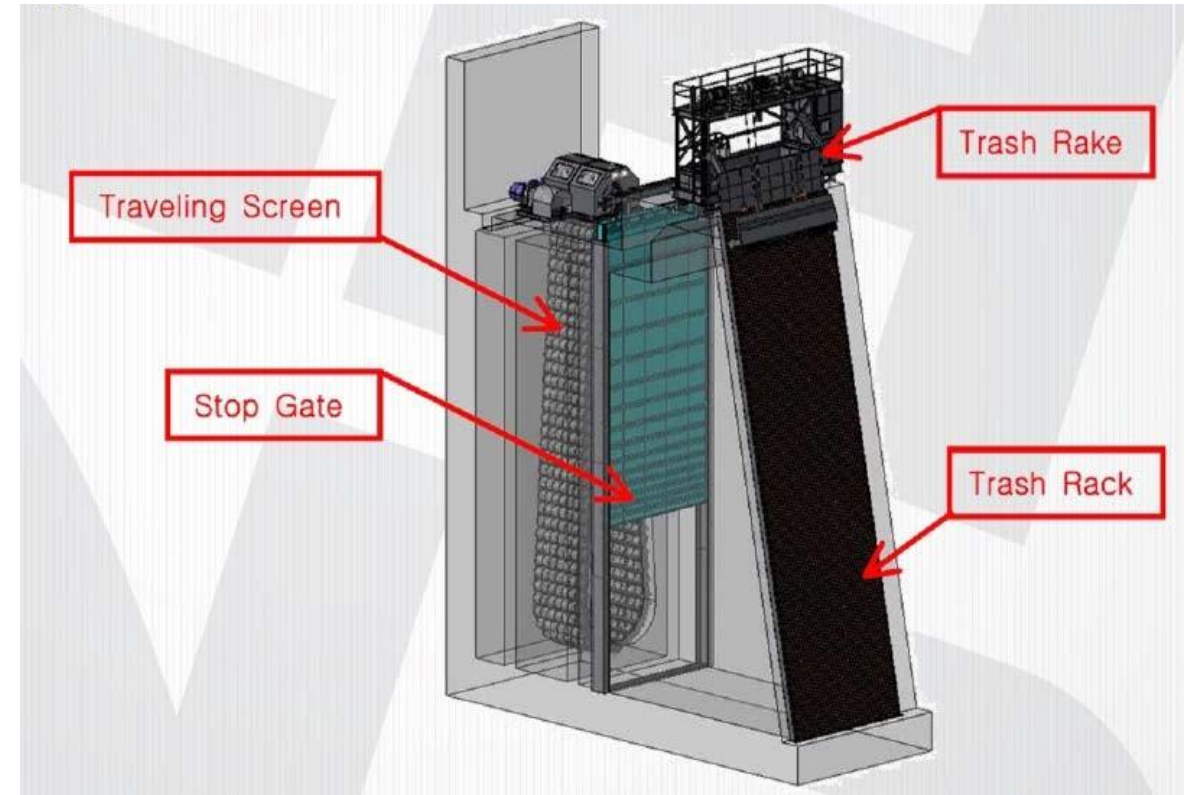
**What is your Maintenance Strategy
for your intake system?**



Preventative Maintenance Basis Database

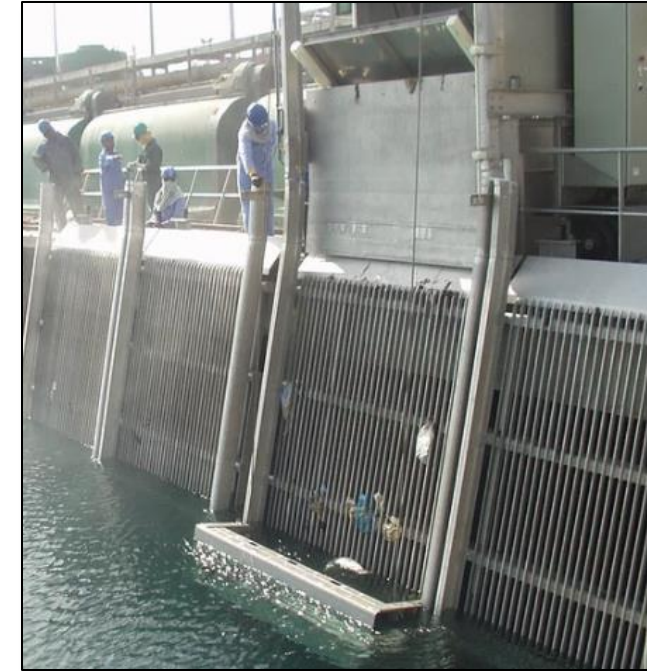
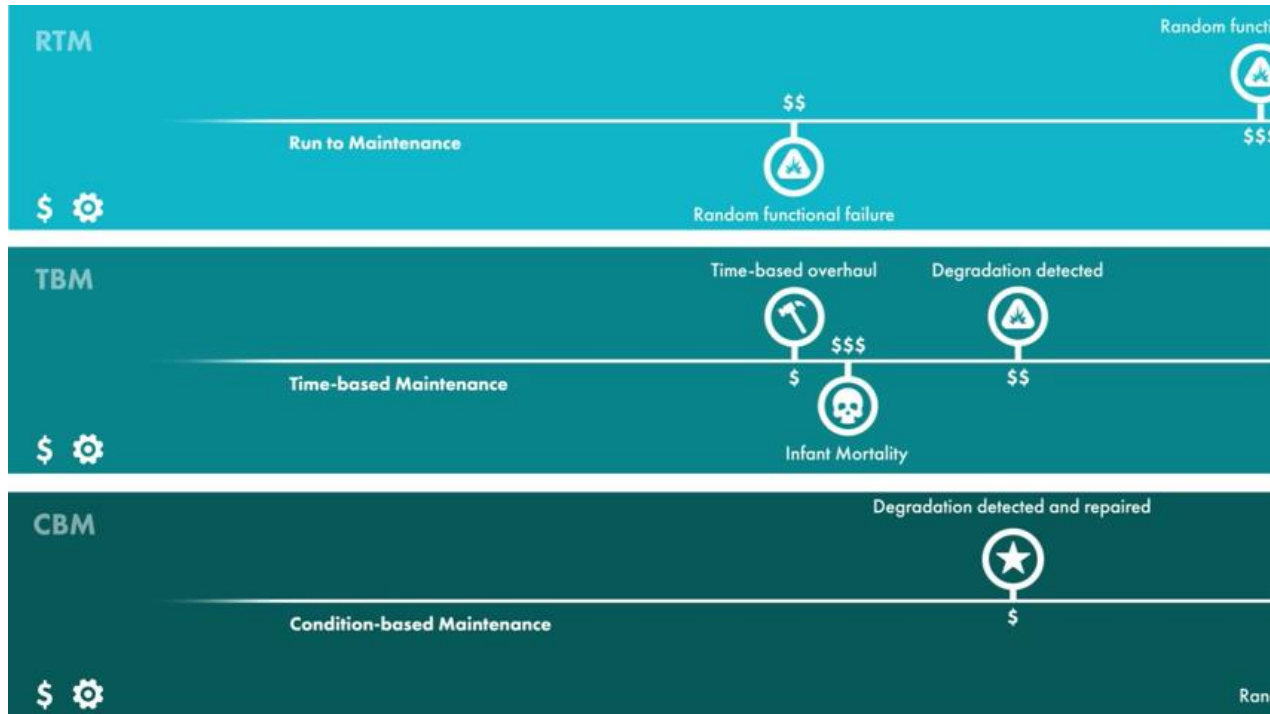
What Is A Maintenance Strategy?

- A structured approach of activities designed to manage the predominate Failure Modes of an asset to maintain long-term reliability, efficiency, and cost effectiveness over the lifecycle.
- A well-designed maintenance strategy will have optimized the total cost of ownership of the asset to achieve the best balance between reliability and cost efficiency.



Two Primary Types of Activities

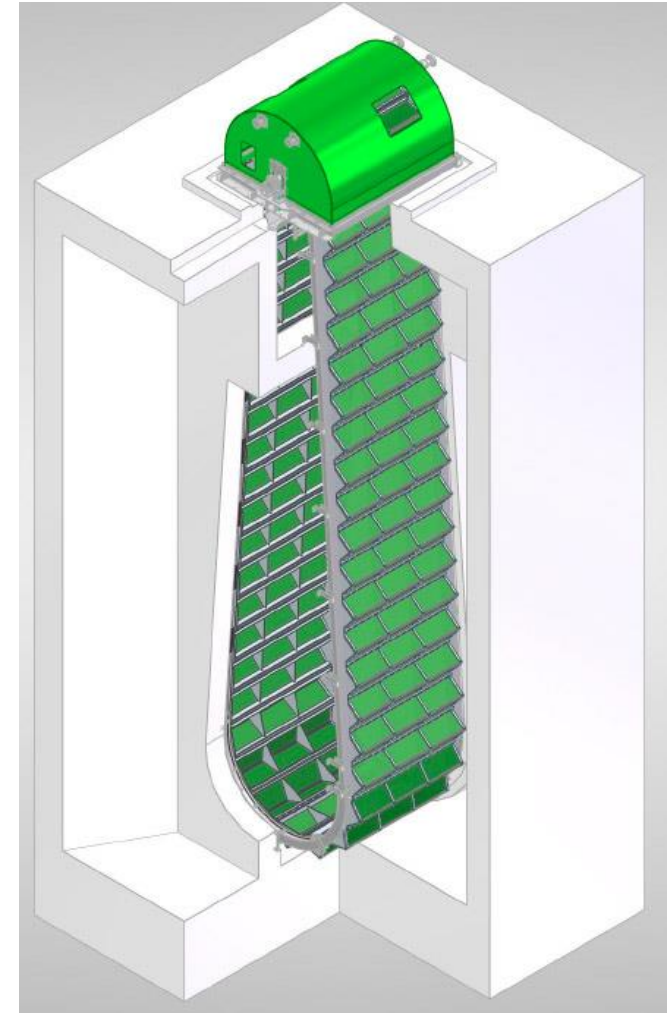
- Intrusive Maintenance
- Condition Monitoring



That is all!

Only Two Reasons To Perform Intrusive Maintenance:

- Renew or Replace a Part to Manage a Failure Mode
- Monitor a Specific Hidden Failure Mode



That is all!

Condition Monitoring:

- Vibration
 - Lubrication
 - Infrared
 - Other Technologies
-
- Operator Rounds
 - Process Parameter Trending
 - Performance Monitoring
 - Intrusive Maintenance Inspection Results



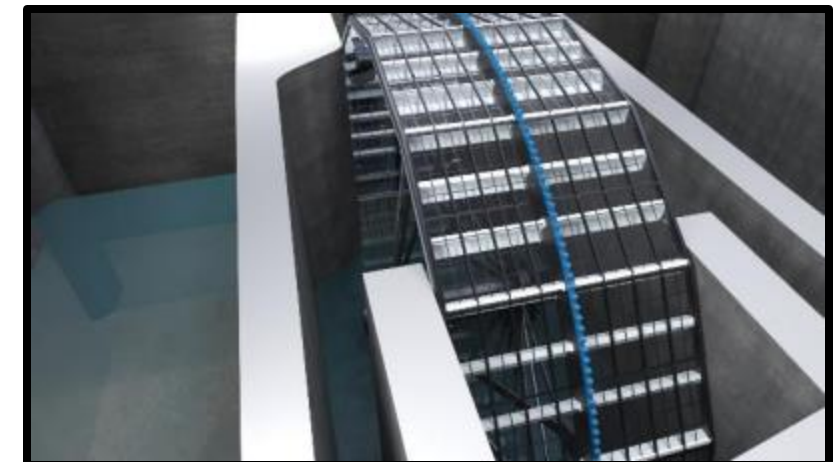
Template Updates – Intake System Components

Component Group	Template Name	Status
Intake System	Stop Gate / Logs - (Driver Gates)	Complete
	Trash Rack	Complete
	Trash Rake – Cable Operated	In-progress
	Trash Rake – Chain Operated	In-progress
	Drum Screen	In-progress
	Traveling Screens (Through Flow - Cross Flow)	Complete

[3002020354](#) - Intake Systems Maintenance Guide, Volume 1: Stop Gates, Trash Racks, and Trash Rakes

[3002023772](#) - Intake Systems Maintenance Guide Volume 2: Fine Screens

[3002026349](#) - Intake System Maintenance Guide: Volume 3 - Debris Management and Disposal



PMBD (cont.)

ELECTRIC POWER
RESEARCH INSTITUTE

[Home](#)

[Component Templates](#)

[Selected Template](#)

[Saved Analyses](#)

[Industry Documents](#)

[Troubleshooting](#)

[PRR Web App](#)

[Help](#)

[About](#)

EPRI 3420 Hillview Avenue, Palo Alto, California 94304
© Electric Power Research Institute, Inc. 2001-2025
All Rights Reserved

Preventive Maintenance Basis Database (PMBD) 7.5

≡

🔍

📞

?

David Olack

Component Templates

Using the 5 main categories below, view groupings of templates and select a template of interest to view more information.

General

Sensors

Industry

FLEX

Research

Group by Type

View as List

Reports

Component Template Report

Revision Notes Report

Revision Notes Report (Last 4 Years)

Revision Notes (Export to Excel)

Intake System3

Iso Phase2

Load Tap Changer6

Main Feedwater Turbine2

Main Generator9

Export to Excel

Component Template	Attributes	Revision	Last Reviewed
Stop Gate / Logs - (Driver Gates)		0	02/28/2023
Trash Rack		0	02/28/2023
Traveling Water Screen (Through Flow and Cross Flow)		2	08/15/2024

31

© 2025 Electric Power Research Institute, Inc. All rights reserved.



PMBD (cont.)

Preventive Maintenance Basis Database (PMBD) 7.5

David Olack

Component Template Name

Component Type

Attributes

Revision

Trash Rack

Intake System

0

EPRI Research References

Export to Excel

EPRI ID	Title	Link	Access	Pub ...	Type	Abstract
3002010651	Service Water Mentoring Web Resource	View	Member/Funder	2017-07-20	Software - eMedia	
3002005150	Service Water Intake Blockages: Event Forecasting for Minimizing Impacts	View	Public	2015-04-30	Technical Report	
1009672	NMAC Circulating and Service Water Intake Screens and Debris Removal Equipment Maintenance Guide	View	Public	2004-12-15	Technical Report	
NP-7088-R2	Underwater Maintenance Guide: Revision 2: A Guide to Diving and Remotely-Operated Vehicle Operations for Nuclear Maintenance Personnel	View	Public	1994-05-02	Technical Report	

1

20

records per page

1 - 10 of 10 items

PMBD (cont.)

A1

✕ ✓ *fx*

EPRI ID

	A	B
1	EPRI ID	Title
2	3002029364	Program on Technology Innovation: Data Visualization Tool for Cooling Water Intake Structure Event Forecasting - Phase 2
3	3002026349	Intake System Maintenance Guide: Volume 3 - Debris Management and Disposal
4	3002023772	Intake Systems Maintenance Guide Volume 2: Fine Screens
5	3002020354	Intake Systems Maintenance Guide, Volume 1: Stop Gates, Trash Racks, and Trash Rakes
6	3002019856	Remotely Operated Vehicle Use for Submerged Maintenance: A Technology Review with Assessment of Applicability for In
7	3002019660	Best Management Practices Manual for Preventing Cooling Water Intake Blockages
8	3002010651	Service Water Mentoring Web Resource
9	3002005150	Service Water Intake Blockages: Event Forecasting for Minimizing Impacts
10	1009672	NMAC Circulating and Service Water Intake Screens and Debris Removal Equipment Maintenance Guide
11	NP-7088-R2	Underwater Maintenance Guide: Revision 2: A Guide to Diving and Remotely-Operated Vehicle Operations for Nuclear Ma
12		
13		

PMBD (cont.)

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Home

Component Templates

Selected Template

Saved Analyses

Industry Documents

Troubleshooting

PRR Web App

Help

About

EPRI 3420 Hillview Avenue, Palo Alto, California 94304
© Electric Power Research Institute, Inc. 2001-2025
All Rights Reserved

Preventive Maintenance Basis Database (PMBD) 7.5

David Olack

Component Templates

Using the 5 main categories below, view groupings of templates and select a template of interest to view more information.

General

Sensors

Industry

FLEX

Research

Group by Type

View as List

Reports

Component Template Report

Revision Notes Report

Revision Notes Report (Last 4 Years)

Revision Notes (Export to Excel)

Intake System3

Iso Phase2

Load Tap Changer6

Main Feedwater Turbine2

Main Generator9

Export to Excel

Component Template	Attributes	Revision	Last Reviewed
Stop Gate / Logs - (Driver Gates)		0	02/28/2023
Trash Rack		0	02/28/2023
Traveling Water Screen (Through Flow and Cross Flow)		2	08/15/2024

34

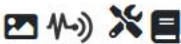
© 2025 Electric Power Research Institute, Inc. All rights reserved.

EPRI

PMBD (cont.)

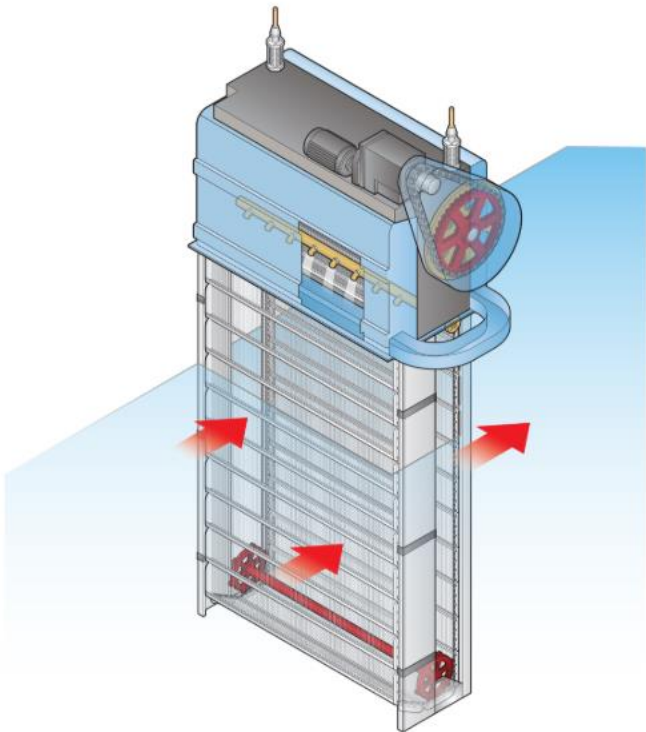
Component Template Name
Traveling Water Screen (Through Flow and Cross Flow)

Component Type
Intake System

Attributes


Revision
2 

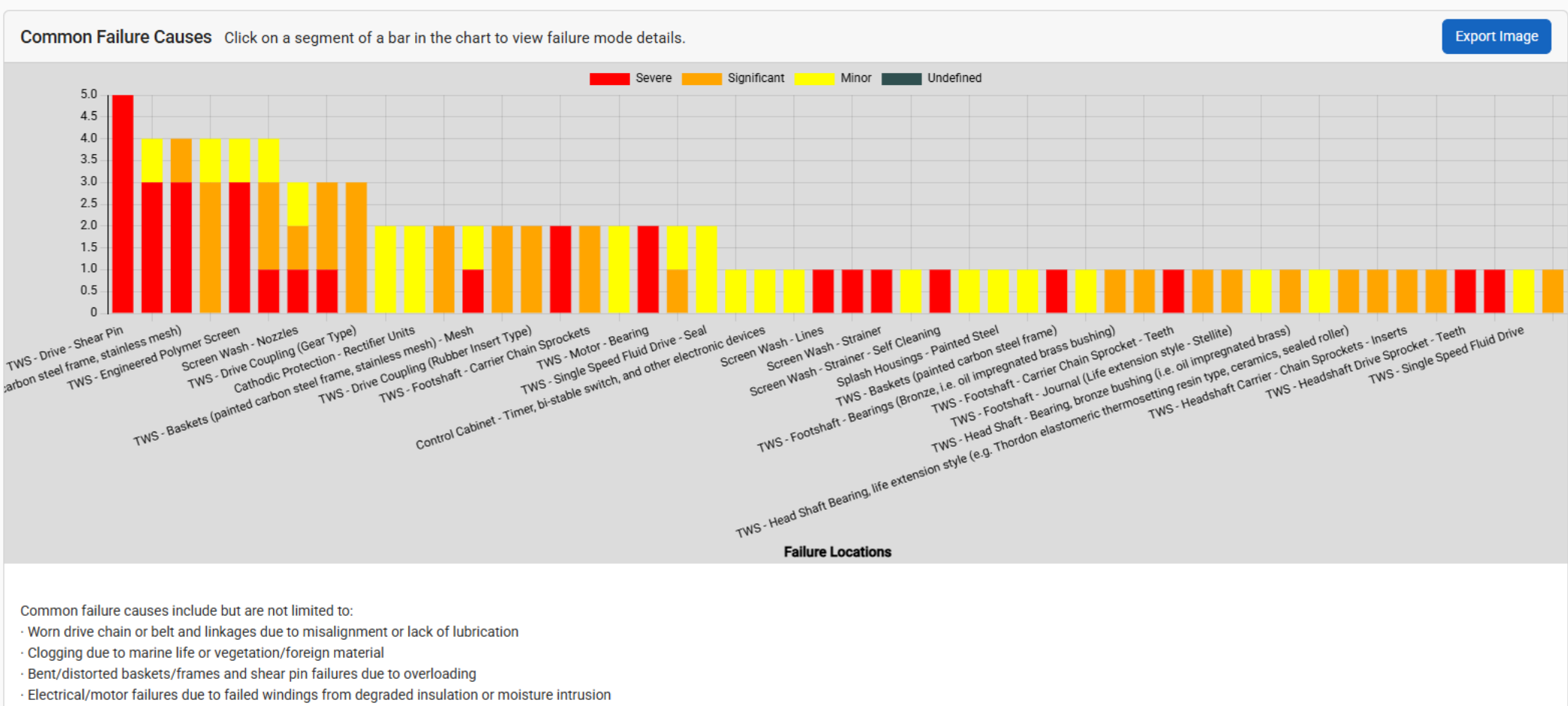
Information



Component Boundary

- Cathodic Protection - Cables/Wiring
- Cathodic Protection - Rectifier Units
- Cathodic Protection - Sacrificial Metal/Anode
- Control Cabinet - Timer, bi-stable switch, and other electronic devices
- Differential Pressure Switch
- Screen Wash - Lines
- Screen Wash - Nozzles
- Screen Wash - Sensing Lines
- Screen Wash - Strainer
- Screen Wash - Strainer - Housing
- Screen Wash - Strainer - Self Cleaning
- Splash Housings - Fiberglass
- Splash Housings - Painted Steel
- Splash Housings - Stainless Steel
- Trash Rack

PMBD (cont.)





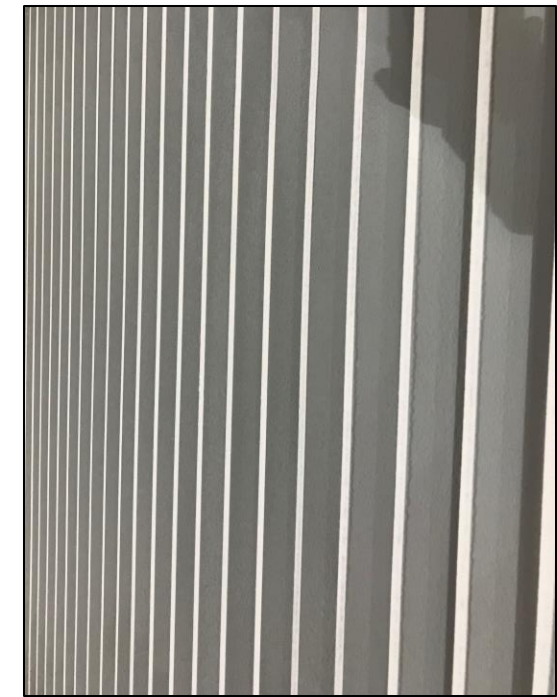
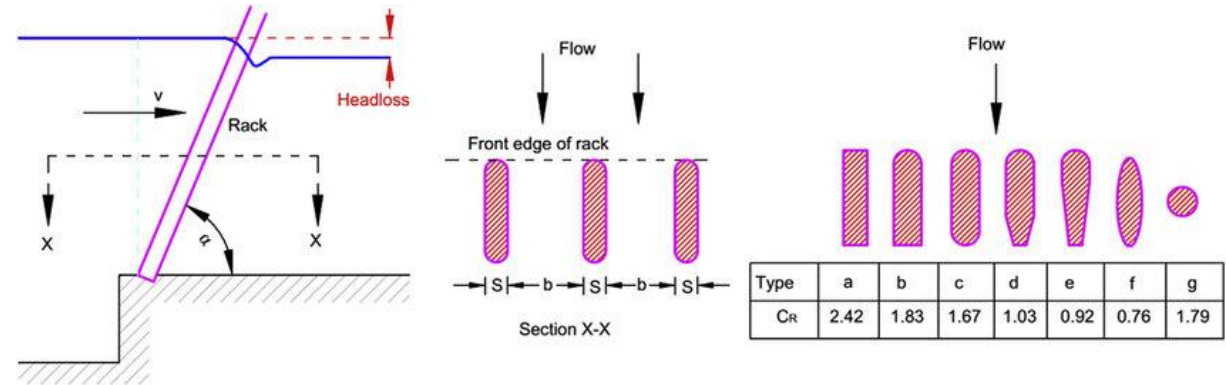
Intake Design Improvements

Basics

- Preconditions
 - Multiple unit forced outages are unacceptable
 - Traveling Water Screens must be capable of continuous operation during high debris (e.g. jellyfish sea salp, etc.) events to maintain design intake flow from the ultimate heat sink
- Potential Improvements
 - What pre-screening technologies could be deployed in reaction to inbound debris?
 - Can the current trash rack raking system be upgraded?
 - Can the debris disposal capacity accommodate a massive debris event?
- Practical Improvements
 - Automatic or rapid deployment screens
 - Reduce rack spacing
 - Upgraded trash rack material
 - Individual trash rakes for each trash rack section

1. Trash Rack Recommendations

- Material –new stainless steel racks
 - No need to coat
 - Check chlorination compatibility
 - Rack rotation less important
- Spacing – reduce spacing
 - To 20 – 50 mm
 - Vendors state 20-30 is typical
- Assess – head loss (shape bar members)
- Cleaning – mechanical and/or chemical

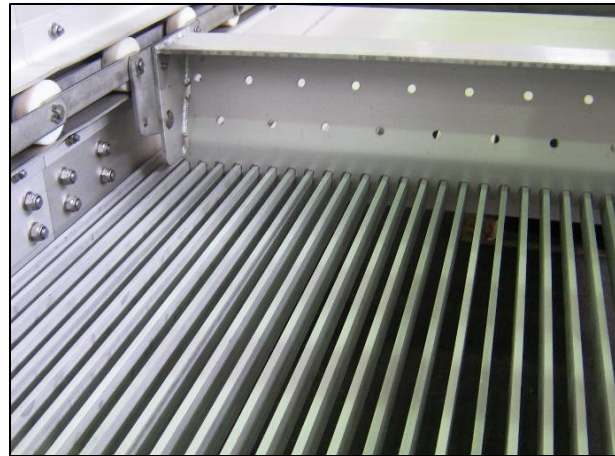


2. Raking System Recommendations

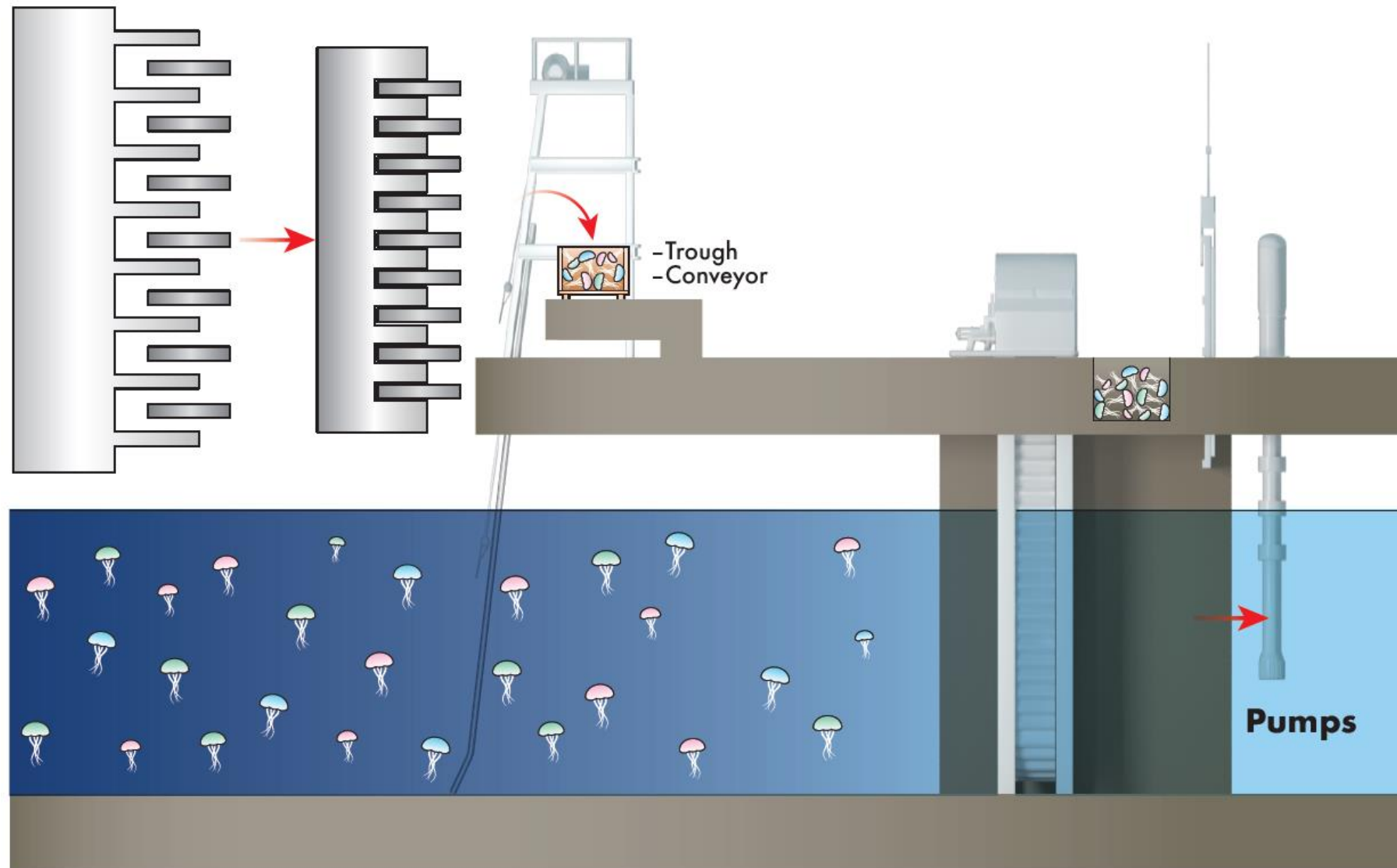
- Number – one rake per rack
 - Continuous revolving
 - Cable-hauled (with guidance)
- Rake/Beam Design
 - Optimize for jellies
 - Tight fit between teeth and rack members for bryozoans



A Bosker rake is not adequate for jellyfish removal

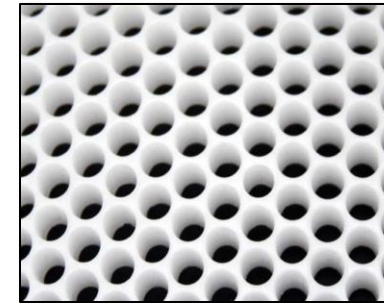
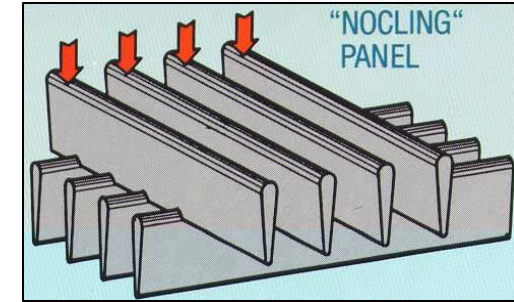


2. Raking System Recommendations



3. Traveling Water Screen Recommendations

- Capacity
 - should not collect 100% of jellies
- Assess
 - Mesh material (smooth, non-stick)
 - Spray-wash adequacy
 - Transfer efficiency to sluiceway
- Sluice to pit
 - Ensure sufficient water flow
 - Eliminate flow path imperfections
 - Apply friction reducing coatings



ProPaPanel®



Drilled polymer



4. Debris Disposal Recommendations

- Transport
 - Conveyors
 - Troughs
- Storage
 - Intake channel barge
 - Intake constructed lagoon
 - Land-based pond (based on transfer logistics)



Solution Sets – Rack and Rakes

Operational and structural aspects	Trash rack	Raking system only*		Rack + Raking System	
		Bosker (grab-style)	Fixed head cable-hauled	Fixed head cable-hauled	Continuous rake
Rake tooth	NA	Tooth need sufficient spacing for existing wavy bars	Tooth need sufficient spacing for existing wavy bars, Need for guidance over long height	Tooth can have high tolerance when replaced in tandem with new rack. Need for guidance over long height	Tooth can have high tolerance. Already guided
Holding capacity	NA	Low, not efficient for jellyfish	Good, but only per individual haul	Can lift larger loads, but at a lower rate	Continuous removal balances volume over multiple rake beams
Debris disposal	NA	Into one fixed dedicated debris pit/container at end of line	Into trough or conveyor directly	Into trough or conveyor directly	Into trough or conveyor directly
Material	Stainless steel with spares	Appropriate for conditions as per vendor recommendation	Appropriate for conditions as per vendor recommendation	Appropriate for conditions as per vendor recommendation	Appropriate for conditions as per vendor recommendation
Number	12/CW, 2/ESW, 24 SWB	One for all 12 racks (CW), one per two racks (ESW), one/ two for 24 racks (SWB)	One per individual rack 12 for CW, two for ESW, 24 for SWB	Per individual rack 12 for CW, two for ESW, 24 for SWB	Per individual rack 12 for CW, two for ESW, 24 for SWB
Cleaning speed	NA	Slow	Moderate	Quick option, but travel speed may be limited by maximum speed where jellyfish are not lost	Fastest option due to multiple consecutive rakes
Maintenance	Spare racks for intermittent replacement	One machine to maintain	Moderate	Minimal required (e.g., guides, rollers)	Substantial required (most maintenance on chain, similar to TWS)
Bryozoan removal	NA – Coating not required on stainless steel	Not efficient	Moderate	Efficient	Efficient
Space considerations	Space for spare racks on deck	Space required for dumping material, likely not available	Need for disposal trough or conveyor, but limited space for both machine and trough/conveyor	Need for disposal trough or conveyor, upper deck level will require offset between systems for drive mechanism (motor)	Need for disposal trough or conveyor, upper deck level will require offset between systems for drive mechanism (motor)
Debris removal effectiveness,	N.A.	Low	Moderate	Good	Good
Equipment reliability,		Low	Moderate due to bad rack integrity	Good	Good
Training needs,		Yes	Yes	Moderate	Moderate
Auto/manual operation, and.		No recommended	Both are option	Both are option	Both are option
Service life,	Low	Low	Good	Long	Long
Extent of structural modification required	Vendor recommendation	Low	Vendor recommendation Guidance required	Vendor recommendation Guidance required	Vendor recommendation Guidance required
Coatings	NA	Rake will damage coating and thereby increase risk of corrosion	Rake will damage coating and thereby increase risk of corrosion	No coating required	No coating required

Solution Set – Debris Disposal

	Basic principle		Disposal location		
Debris disposal technology	Pro	Con	Land-based pond	Floating barge	Jellyfish 'lagoon'
Conveyor	Direct transport, Dewatering, No head required	Long, multiple systems needed takes space, Many mechanical parts: high O&M, also when not operated, Limited load capacity with distance and weight, affects speed	Need several steps to get jellyfish on higher level (again)	Need for additional piping at end of conveyor	Need for additional piping at end of conveyor
Trough	Use of water flow and gravity (passive), No moving parts, Space-efficient if elevation is available	Needs slope/head/elevation, Needs pumps for flushing flow and potentially for jellyfish transfer	Need several steps to get jellyfish on higher level (again) + dewater	Lowest point possible, direct transport, System dewater itself	Lowest point possible, direct transport, System dewater itself
Floating pipe	No deck space required, No slope required, Needs in-water destination	Potential risk for rack/rake, supports/attachment required, Needs pump for flushing flow	Not an option for floating pipe	No need to bring jellyfish to higher level	No need to bring jellyfish to higher level
Other Aspects					
Safety	NA	NA	Manual labor may be required	No manual intervention Supports/attachment required	No manual intervention
Odor	NA	NA	Will be smelly	No smell	No smell

Solution Set – Debris Disposal Comparison

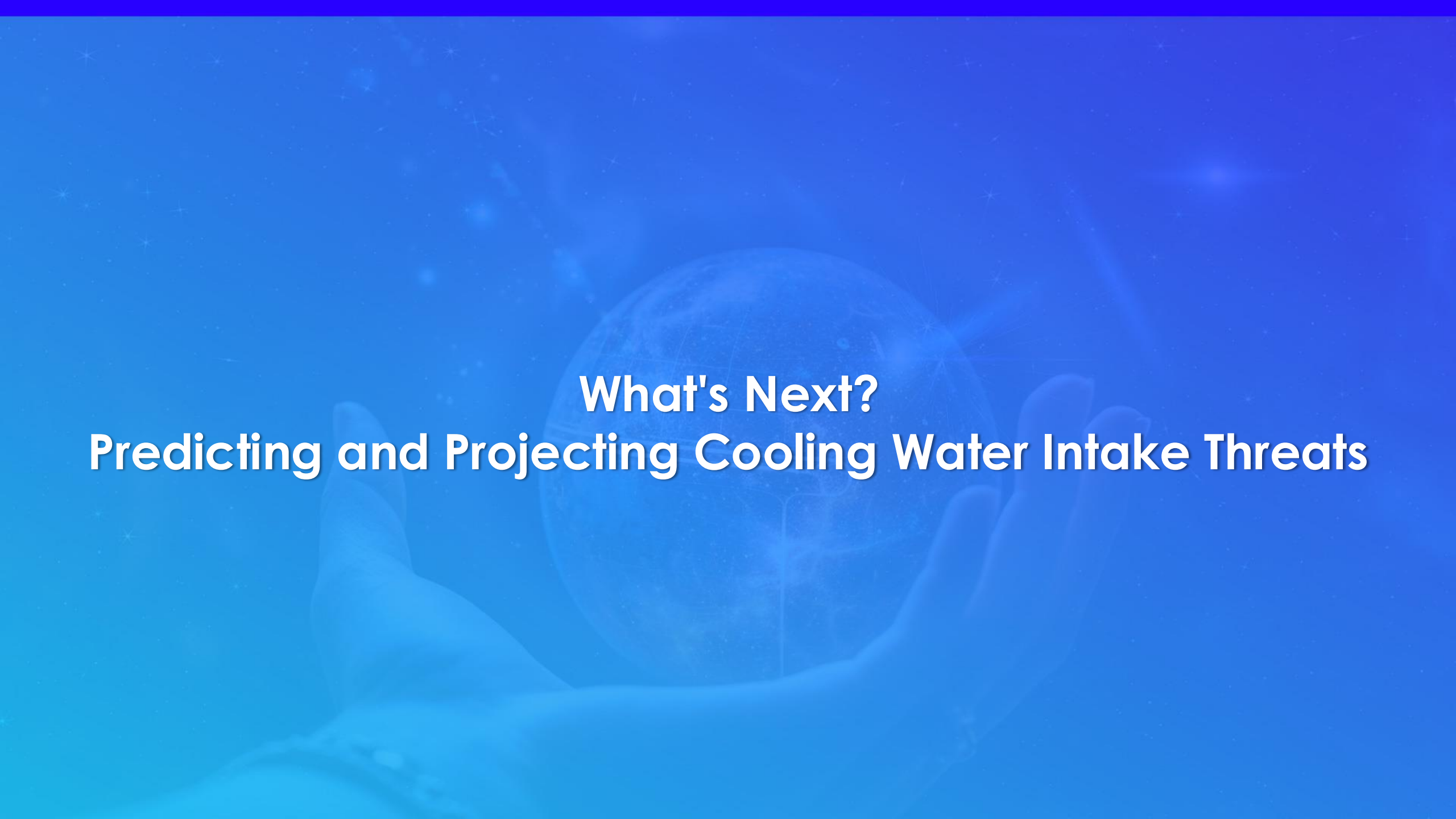
	Conveyor		Sluiceway/pipe	
	Barge	Land based pond	Barge	Land based pond
Debris removal effectiveness	Conveyor 1 long section, slow	Conveyor multiple long sections, slow	Short distance, moving water, efficient, aid of gravity	Less short distance, moving water, pump may be required close to pond
Equipment reliability	Moderate, high O&M	Moderate, high O&M	Minor	Moderate, pump O&M
System capacity	Capped at?	Capped at?	No limit	Good
Training needs	Yes	Yes	Minor	Yes
Ease of operation	Moderate	Moderate	Minor	Moderate
Auto/manual operation	Both	Both	Automatic	Both
Availability/deployment time	None, it is already there	None, it is already there	None, it is already there	None, it is already there
Service life	Moderate	Moderate	Long	Long (except for pump)
Sea snakes	Poses risk on conveyor	Poses risk on conveyor	No issue	Moderate, when in land based pond
Extent of structural modification required	Large because long piece of equipment, if space on deck allows a conveyor	Large because long piece of equipment, if space on deck allows a conveyor	Moderate, all parts are available	Moderate
Other factors that could influence the feasibility of proposed changes	Spacing on deck between rake machine and rail gantry crane	Spacing on deck between rake machine and rail gantry crane	Placement of barge in intake area	Routing over gantry crane rail

Current Intake Challenges

1. What have been the most challenging issues with the cooling water intake system?
 - Emergency screening material?
 - Trash racks
 - Trash rakes
 - Fine screens
 - Debris disposal
2. What actions have been taken/considered in response to WANO 24-003?



Other Intake Related Research



What's Next?

Predicting and Projecting Cooling Water Intake Threats

Current Technology Innovation (TI) Project Scope

The approach is to design and develop a Tool and the supporting field sensors to identify specific debris types, provide a warning signal and a forecast for the impending arrival at the site cooling water intake system.

The project aligns with the INPO recommendations that plant operators should be aware of and be prepared to respond to environmental and security threats.



Background

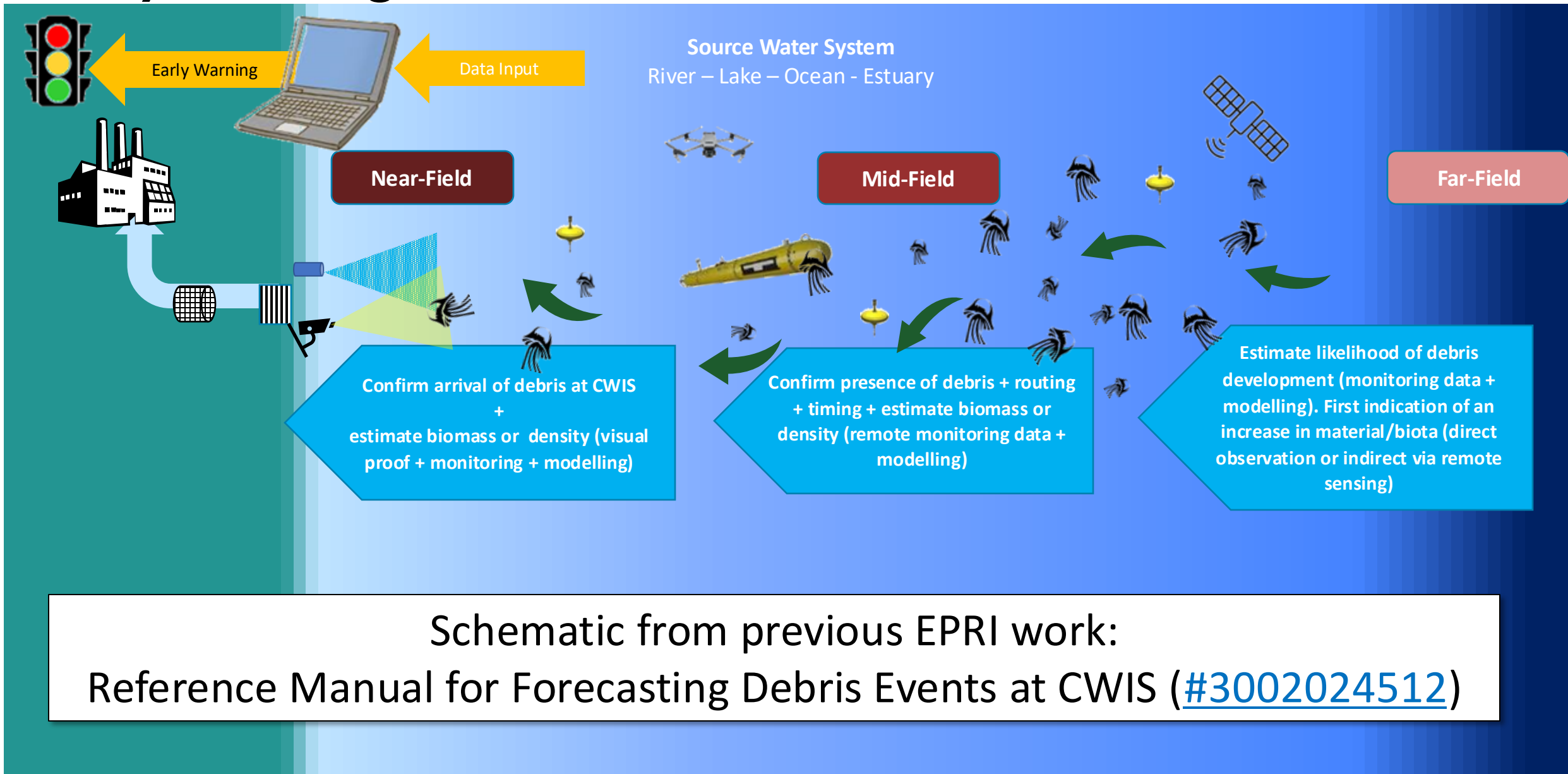
Cooling water debris events can adversely affect intake operation and power plant availability so avoiding both unplanned down-powers and shutdowns are paramount for power plant operators. Long-term environmental change may exacerbate the frequency and severity of debris events, and forecasting of debris events can help operators to prevent/minimize impacts. Technologies to empirically detect and verify debris events and forecast the arrival at the cooling water intake structure (CWIS) can help reduce false reports.



Aquatic vegetation at Civaux NPP
(Photos courtesy EDF)

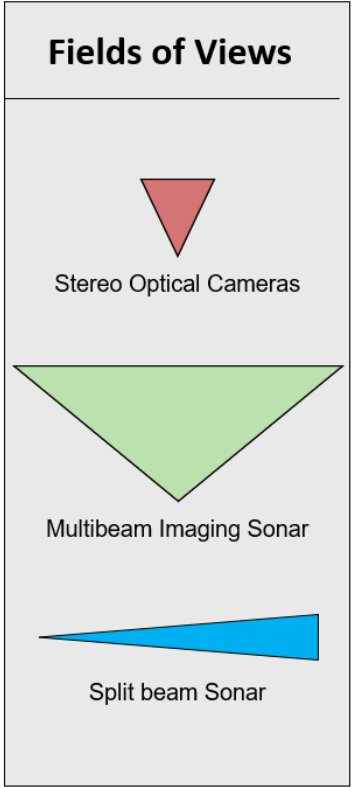
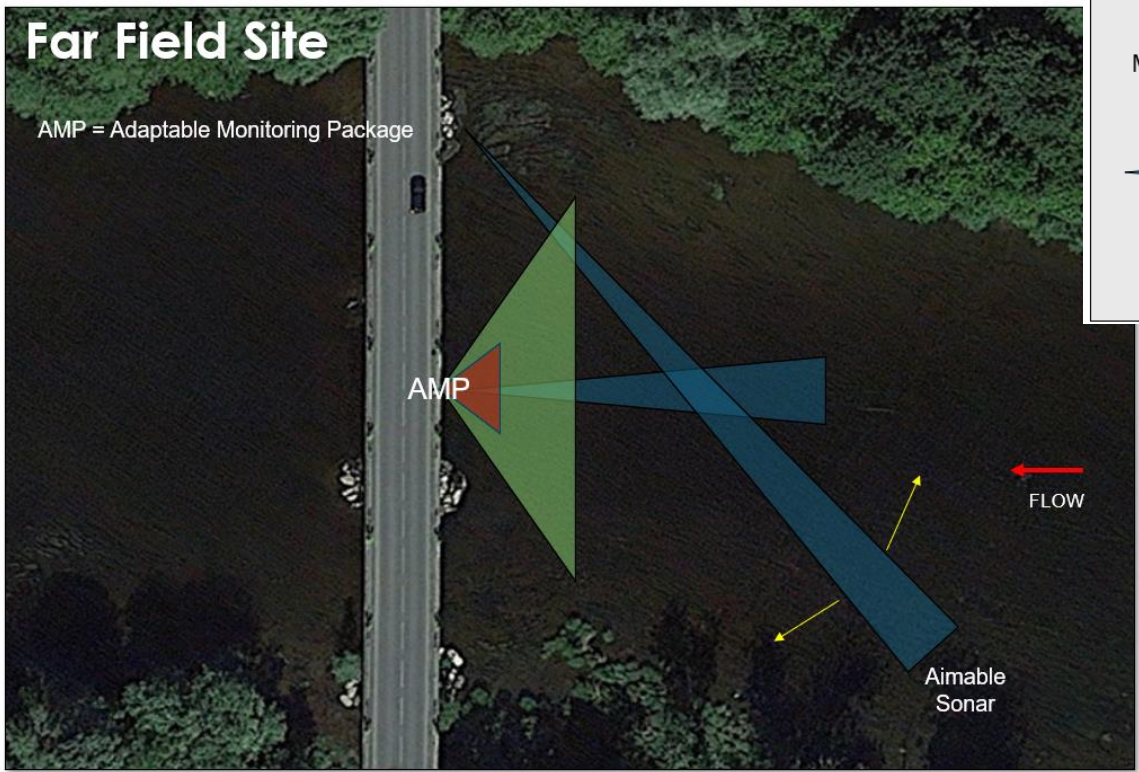
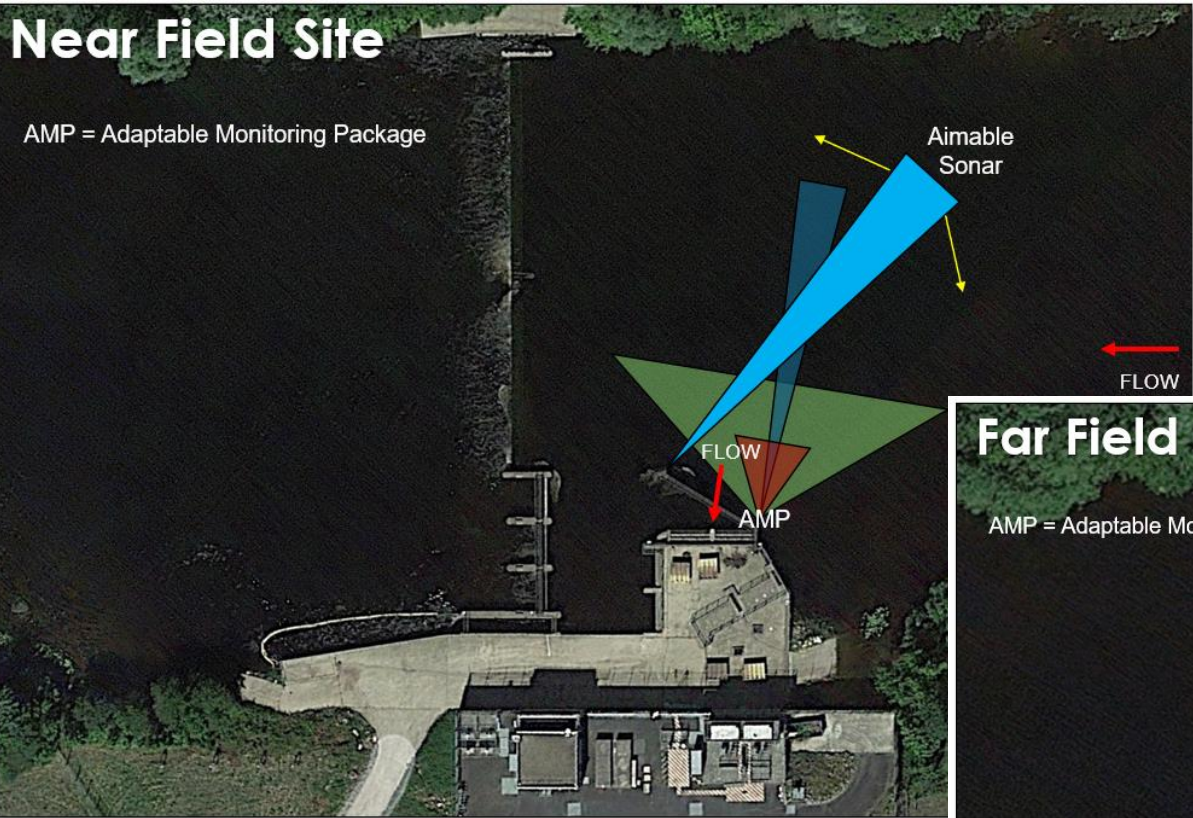
Development of a Tool that automatically enables, by applying artificial intelligence (AI) and machine learning (ML), real-time evaluation of key actionable information in advance of and/or during a debris event can assist plant operators in efficient response management and mitigation decision making.

Early Warning and Real-time Visualization



Schematic from previous EPRI work:
Reference Manual for Forecasting Debris Events at CWIS ([#3002024512](#))

Project Technologies – River Location



Project Technologies – Seawater Location

Two Sensor Node Locations

Integrated Target Detection, 3D tracking,
Classification & Total Biomass Assessment
Sensor System



Far Field Sonar

Aimable/ Scanning Split Beam/Cross Channel
Coverage Sonar - Range to 200 m

24/7 Target Detection / Biomass Quantification



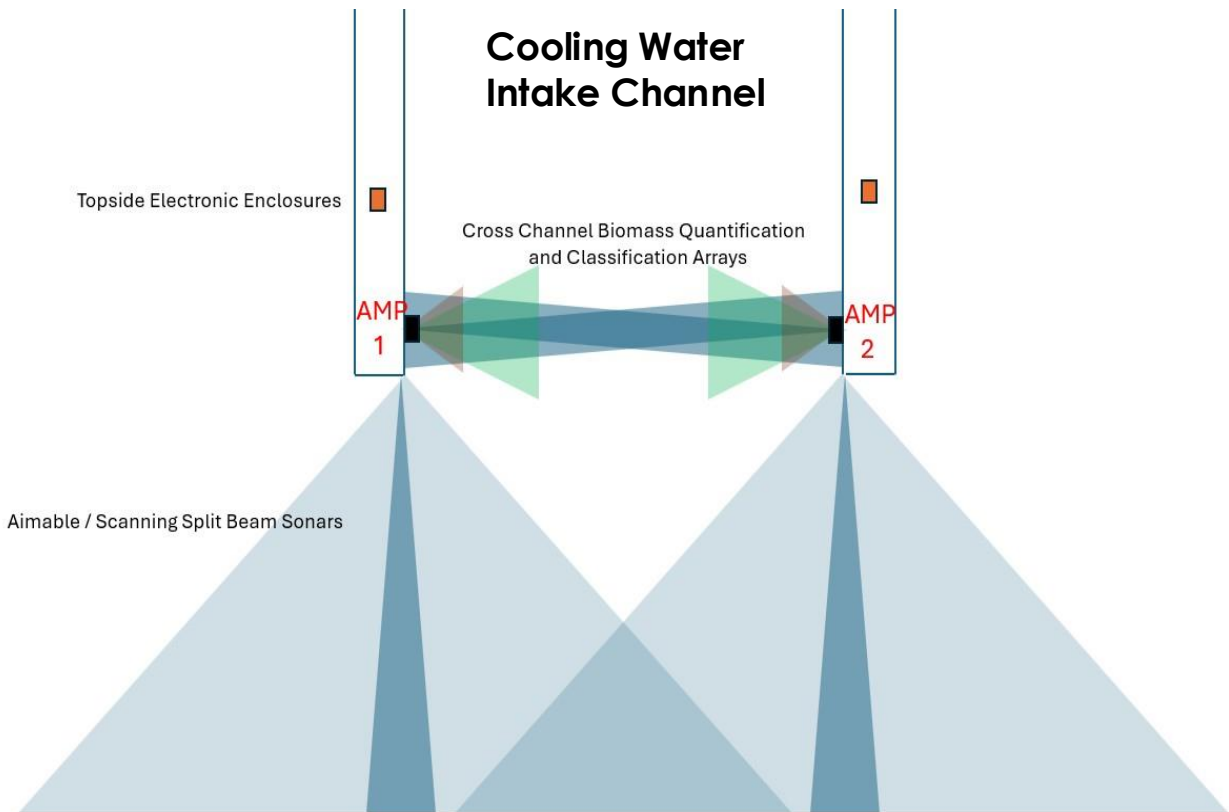
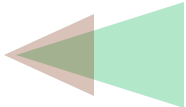
Near Field Camera & Imaging

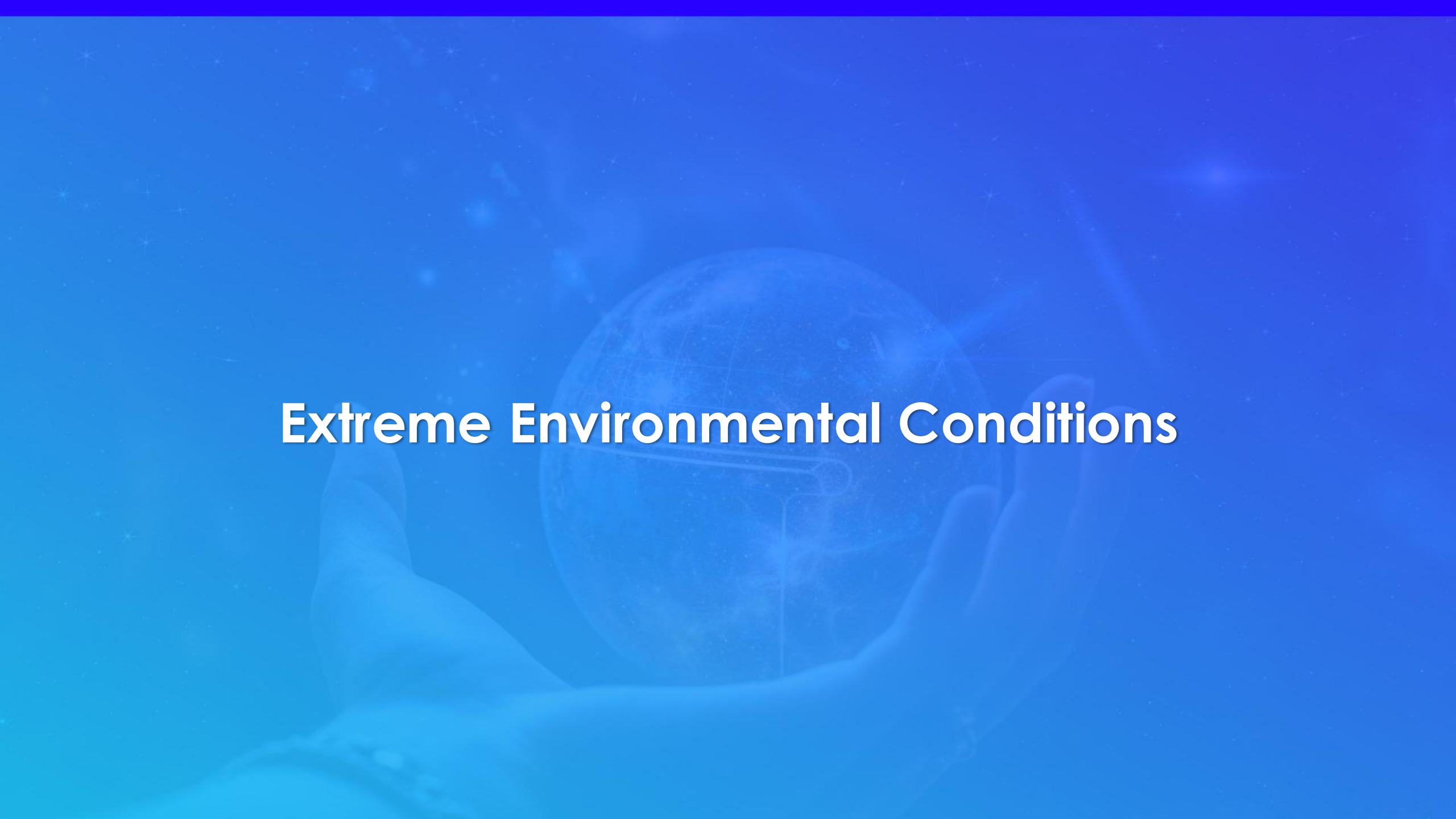
Optical Target Classification – Range to ~10 m

Imaging Sonar Target Classification – Range to ~40 m

Biomass Quantification Verification

Water velocity profile and water chemistry measurement





Extreme Environmental Conditions

Extreme Environmental Conditions Impact (GAP Project)

- Critical to identify areas where climate conditions may compromise equipment, systems, performance, and safety
- Material Degradation
 - Metals (Corrosion/Erosion)
 - Polymers
 - Concrete
- Heat Transfer
 - Increased heat duty
 - *Heat sink challenges*

Climate Vulnerability assessments identified key issues requiring mitigation plans to ensure resilience

Intake Resilience through Informed Decisions

- A related EPRI study evaluates the impacts of extreme condition on the heat duty and performance of equipment
- Coincident with performance is the flow of cooling water into the system heat sinks
- Recent increases in bio-diversity and propagation have challenged intake structures
- Jellyfish are notoriously difficult to identify in advance of reaching an intake structure
- A technology for identifying jellyfish movement patterns and propagation conditions would be beneficial for other bio-monitoring applications



Technology for monitoring and forecasting could be applied to other flora and fauna

Jellyfish Bloom Detection and Forecasting at Intakes

- Once-through cooling systems are increasingly vulnerable to disruptions caused by jellyfish blooms
 - Clogged intake structures
 - Damaged intake screening equipment
 - Forced derates or shutdowns
- Warm and nutrient/salinity water profile shifts create conditions conducive to more frequent and larger bloom patterns
- Detecting jellyfish in the water column is challenging
 - Gelatinous, translucent bodies blend into the surrounding water
 - Distribution is often patchy and unpredictable
 - A successful forecasting system must integrate advanced sensor technologies capable of detecting jellyfish or identifying the environmental precursors indicating the probability of a bloom



The ability to anticipate these events could greatly improve operational resilience

Jellyfish Study Objectives

- Develop an understanding of the biological and environmental drivers of jellyfish blooms
 - This includes identifying the species most associated with power plant disruptions
 - Environmental conditions that promote their propagation
 - These drivers will help identify the parameters to monitor for anticipating bloom formation.
- Identify available sensor technologies that could detect jellyfish or environmental indicators preceding blooms
 - Assess technical capabilities and operational feasibility
 - Review technologies may be deployed in the water or from above with UAVs or satellites
- Engage with the industry to gather operational insights and historical data on jellyfish events.
 - Can be used to hindcast events
 - Aid in identifying trends and inform the design of a practical and effective forecasting system
- The potential use of artificial intelligence to analyze large environmental datasets will also be explored to identify predictive patterns
- A successful outcome could be applicable to monitoring and projection other bio-blockage events

Multiphase Evaluation for Projection of Impending Events



TOGETHER...SHAPING THE FUTURE OF ENERGY®