Risk Insights and Information to Support Aging Management

An Overview of EPRI's RIAM Framework

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IAEA Training Course on PLiM for LTO - Repair, Replacement for LTO
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Bio:

Mark Wishart is a senior technical leader in EPRI's nuclear power sector and is a member of EPRI's risk and safety management (RSM) team. Mark is responsible for research focusing on developing and communicating risk information and insights. Mark also supports the development and knowledge transfer of PRA methods, tools, and techniques.

Before joining EPRI in 2022, Mark was a manager with the risk-informed services team at Jensen Hughes and supported multiple aspects of clients' risk management programs. Mark has experience in PRA model development, model updates, and risk-informed applications across several hazard types. Before joining Jensen Hughes, Mark worked for the Consolidated Edison Company of New York, Inc.

Mark holds a Bachelor of Science degree in mechanical engineering (with a minor in physics) from Lafayette College and a Master of Science in mechanical engineering from The Ohio State University.

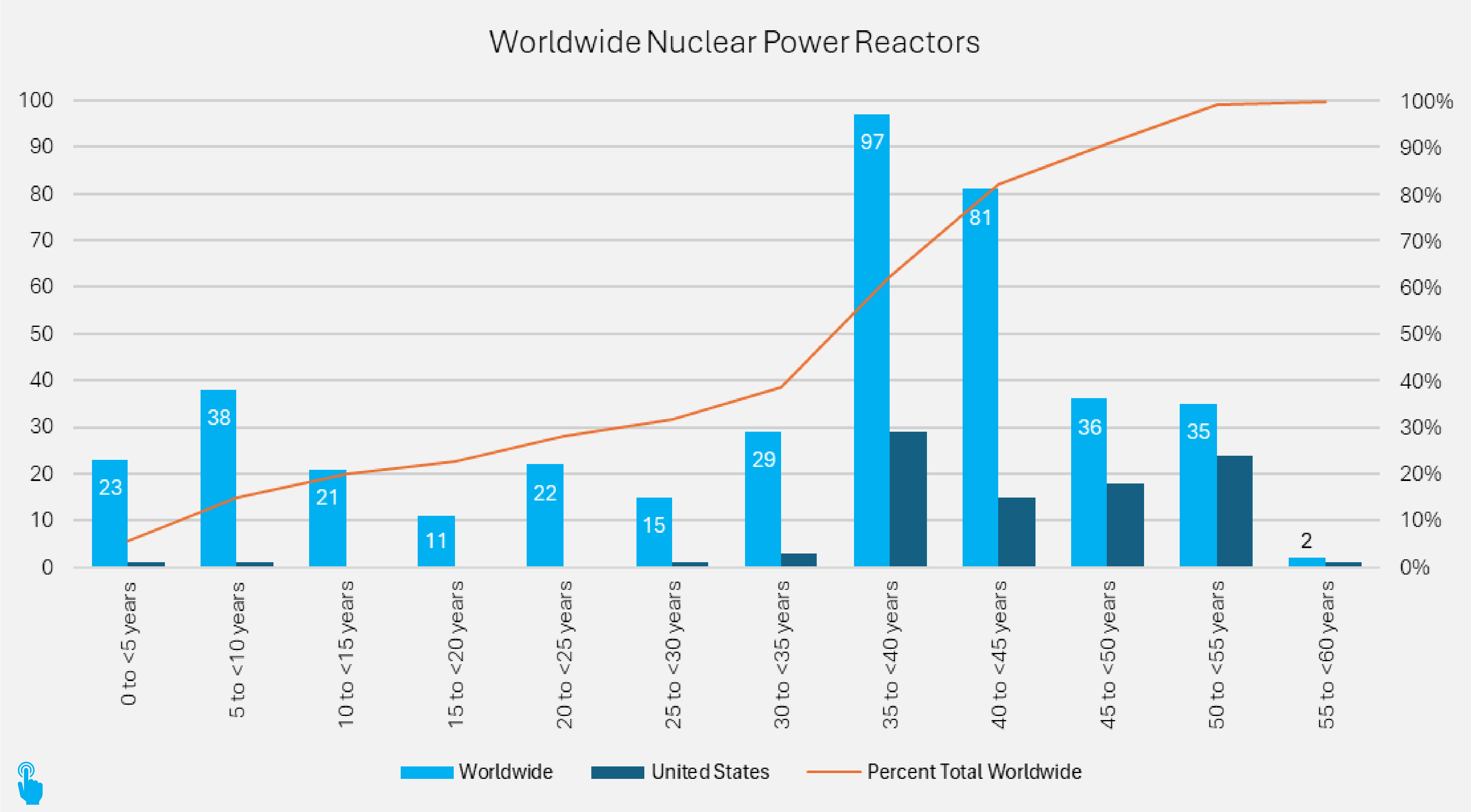
Areas of Expertise:

Risk-Informed Decision-Making (RIDM), Risk-Informed Applications, Probabilistic Risk Analysis (PRA) Modeling and Methods, and Risk Management.

Why Aging Management Matters

410
operating reactors

33 years
average age

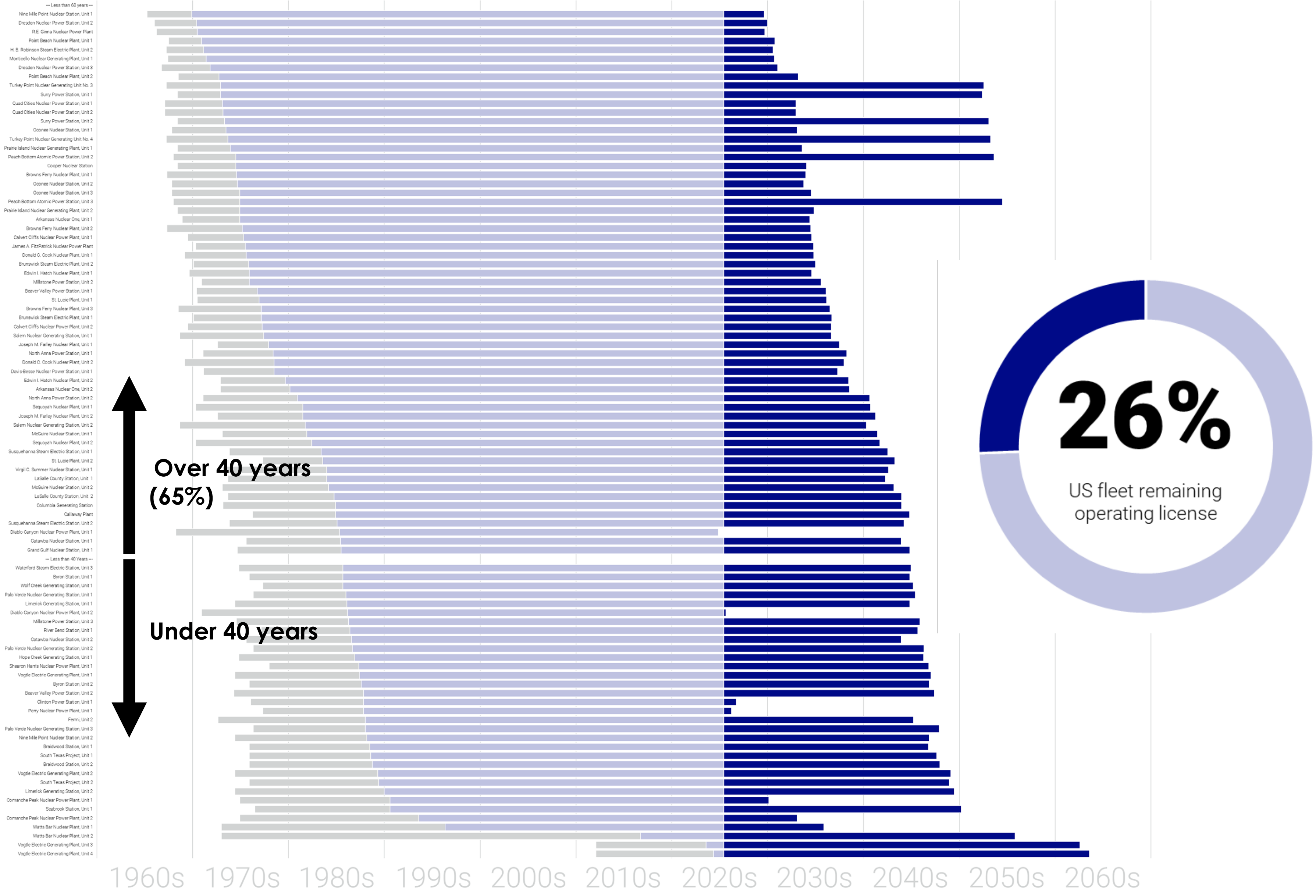


IAEA's "Nuclear Power Reactors in the World," 2024 Edition, Table 14 Data

Current Operating Fleet in the United States

43 years

average age



Construction

Operated

Remaining License

Current Approach to Aging Management in the United States

Long-Term Operations and Aging Management

- NUREG-1801, "The Generic Aging Lessons Learned (GALL) Report" contains generic evaluations of existing plant programs and documents:

Existing AMPs that are adequate without modification	Existing AMPs that should be augmented for long-term operation

- Many existing programs are adequate to manage the effects of aging for long-term operations.
- The GALL report recommends how existing programs should be augmented for long-term operations.
- Plants taking credit for programs in the GALL report must ensure that the conditions and operating experience in the GALL report bound their conditions and operating experience.
- If these bounding conditions are not met, the plant must address the additional effects of aging and appropriately augment the aging management programs.

Applies to nuclear power plants within the United States

Risk Information and License Renewal

- The U.S. has an approach that allows for risk-informed categorization and treatment of structures, systems, and components (known as "50.69").

- The NRC has recognized that the license renewal process could allow for the use of risk insights to evaluate the robustness of aging management programs.

> "…licensees can renew their licenses in accordance with Part 54 by demonstrating that the §50.69 treatment provides adequate aging management in accordance with §54.21."
>
> 10 CFR 50.69, Section II.4.10.8

Aging Management Programs and Risk Information

Some license renewal aging management programs use existing plant programs that **already use risk**. For example, Buried and Underground Piping and Tanks (XI.M41) and the use of Risk-Informed In-Service Inspection (RI-ISI).

Applicable References:

- NUREG-1801, Revision 2
- NUREG-2190 (for SLR)
- NEI 09-14 (underground piping and tanks)
- EPRI Technical Report 3002018352

Include guidance for the use of risk information

Risk Information and Making Decisions

What is nuclear "risk" and how does it apply?

In the nuclear industry, risk can be defined using the following three questions:

Risk

What can go wrong?	How likely is it to occur?	What are the consequences?

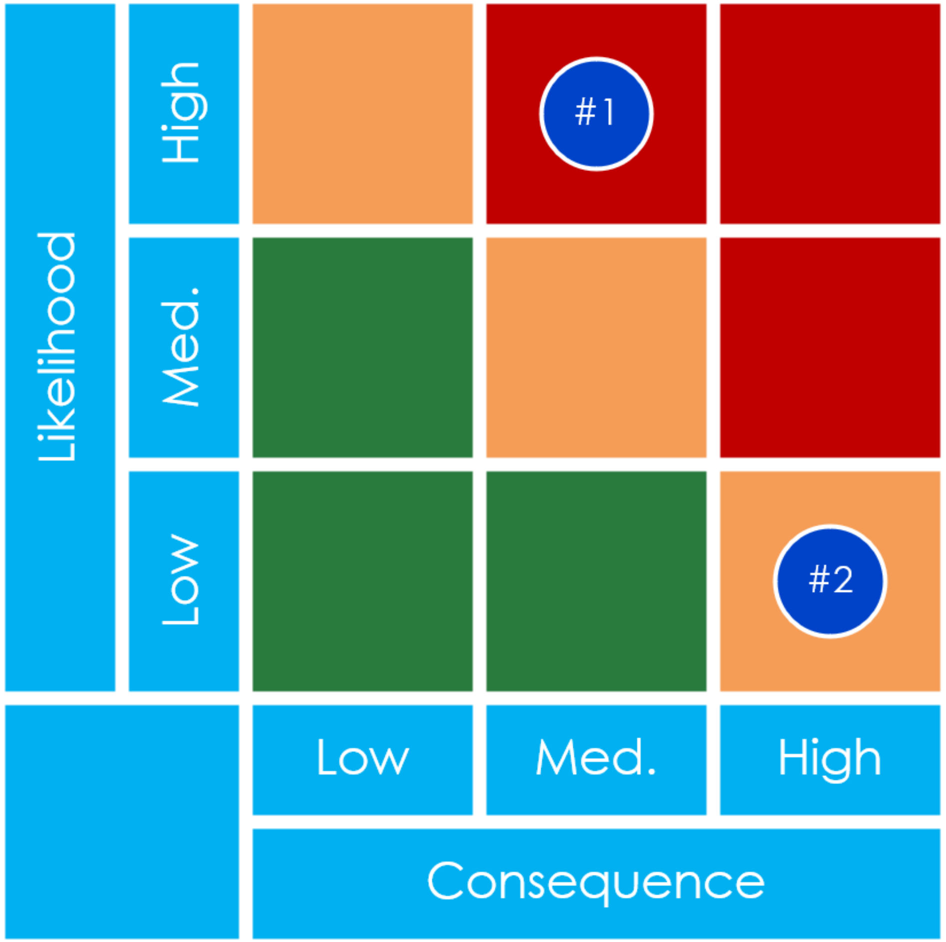
Likelihood and **Consequence**

Often referred to as the "risk triplet"

Risk Information and Making Decisions

- **Decision-Making:** Making a choice in the presence of possible alternatives (e.g., option #1 or #2).

- **Available Information:**
  - Cause(s) of a risk event (**likelihood**)
  - Impacts(s) of risk events (**consequence**)



Using risk information to help compare options

The Goal of using Risk Information

- Choose the option that minimizes the risk and maximizes the utility (benefit) – this is an "optimal decision."

- "Minimal" risk is a subjective term and depends on the decision-maker's risk appetite, among other factors.

In general, the goal is not to eliminate risk – this is typically not possible or would be prohibited by other decision-making parameters (cost, availability of physical resources, time). This is tied to the concept of **Risk Management**.

The Role of Risk Information

Risk-Based

Decision-making is solely based on the numerical results of a risk assessment.

The U.S. NRC does not endorse an approach that is “risk-based.”

Risk-Informed

Risk insights are considered with other factors to better focus attention on issues commensurate with their importance to public health and safety.

Such approaches lie between the “risk-based” and purely deterministic approaches.

Risk-Informed, Not Risk-Based

Performance-Based Regulations

A regulatory approach that <u>focuses on desired, measurable outcomes, rather than prescriptive processes, techniques, or procedures</u>. Performance-based regulation leads to defined results without specific direction regarding how those results are to be obtained. Performance-based regulatory actions focus on identifying performance measures that ensure an adequate safety margin.

Performance Based

The use of **measurable or calculable outcomes (results)** with flexibility as to the means of meeting those outcomes.

This approach to regulation is one that **establishes performance and results** as the primary basis for regulatory decision-making and incorporates measurable parameters, objective criteria to assess performance, flexibility to determine how to meet the criteria, and assurance that performance deficiencies will not result in an immediate safety concern (safety margin and defense in depth).

Focus on the desired outcome

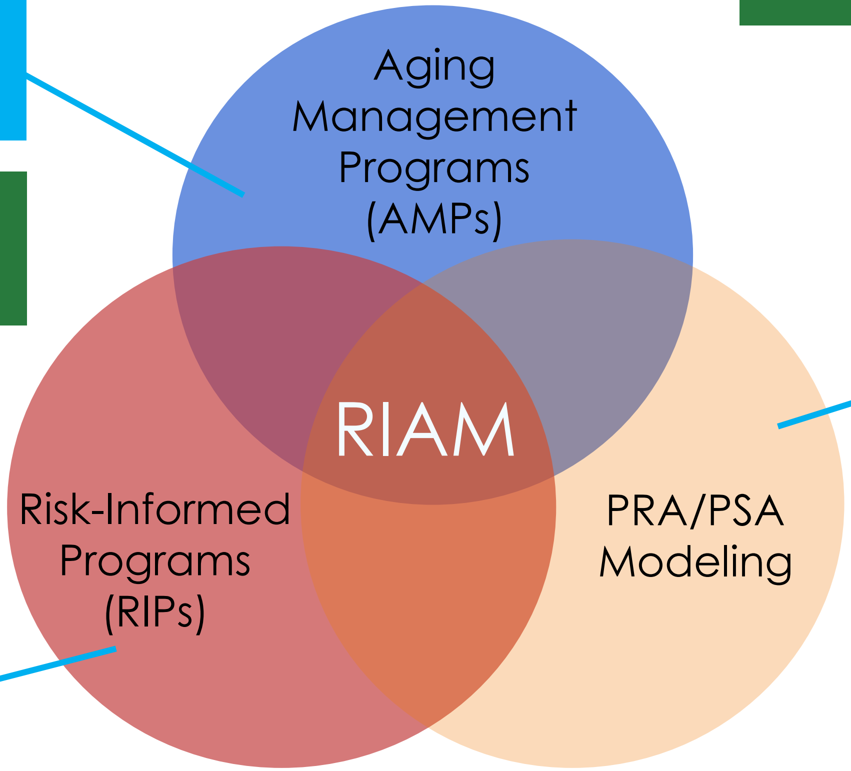
Developing Risk Insights to Support Aging Management

Overlap Between AMPs, RIPs, and PRA/PSA

Aging management programs provide information to address aging effects. See the NRC's Generic Aging Lessons Learned, and the IAEA International Generic Ageing Lessons Learned (IGALL) Reports.

Largely developed using deterministic methods.

Risk insights are developed using already established risk-informed applications, such as risk-informed in-service inspection, risk-informed in-service testing (RI-IST) and risk-informed repair and replace (RI-RRA).



Leveraging risk insights provides an additional approach to optimizing aging management resources and activities while allowing a reduction of lower-value activities.

For example, internal flooding PRA/PSA models consider flood sources with the potential to produce risk contributions to overall plant safety. This includes spray, floods, major floods, and high energy line breaks. Modeling also considers the capabilities for isolation and specific impacts to components (SSCs) within the flood's impact area.

Other PRA/PSA modeled hazards may also provide valuable insights.

EPRI's RIAM Framework (2022)

Report 3002020713

Leveraging Risk Insights for Aging Management Program Implementation: 2022


Leveraging Risk Insights for Aging Management Program Implementation: 2022

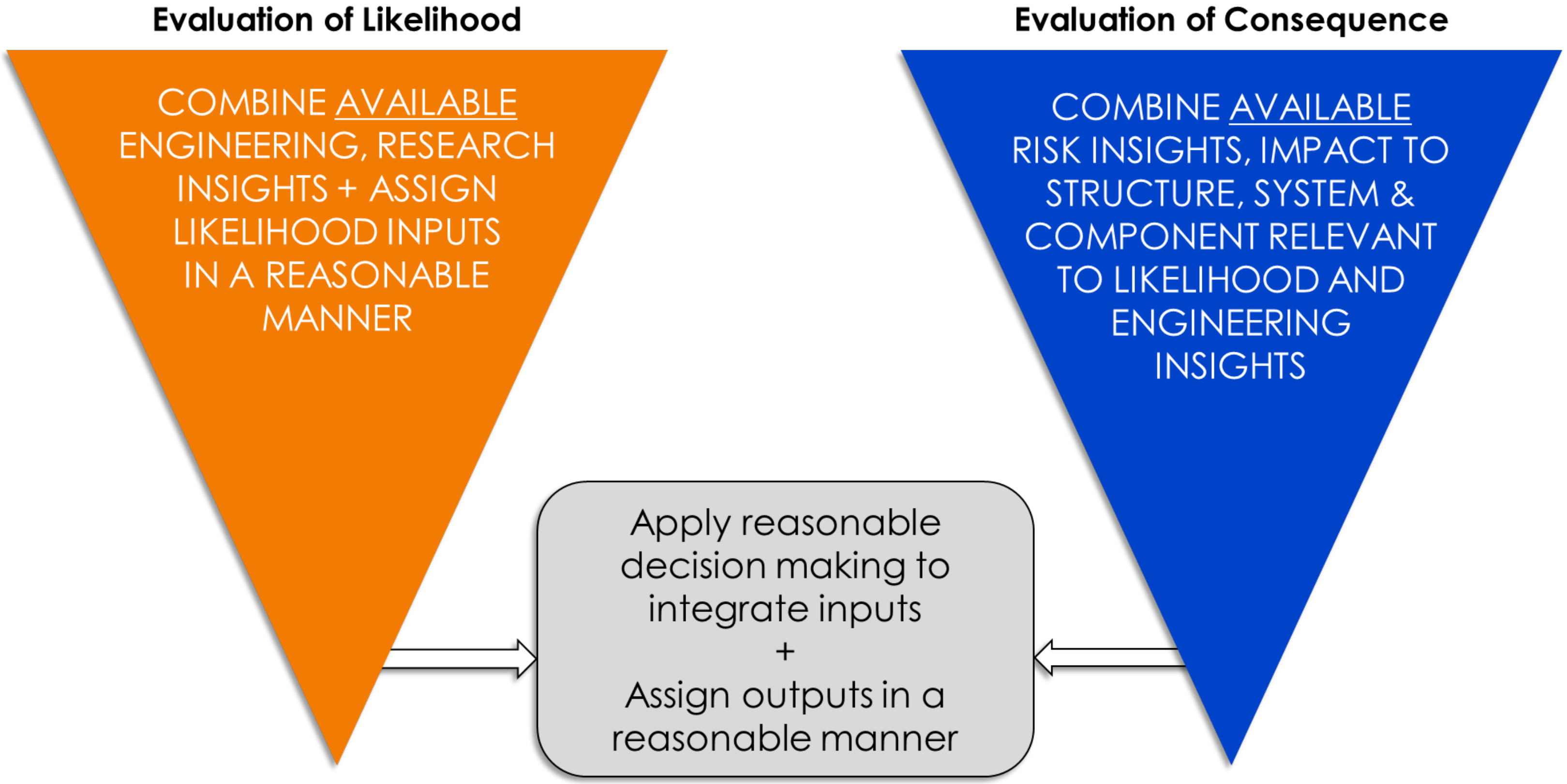
2022 TECHNICAL REPORT

This report presents the framework and pilot results of leveraging risk insights for AMP implementation. The pilot results showcase that current available information can support the robust use of risk insights in support of aging management programs.

This report is publicly available

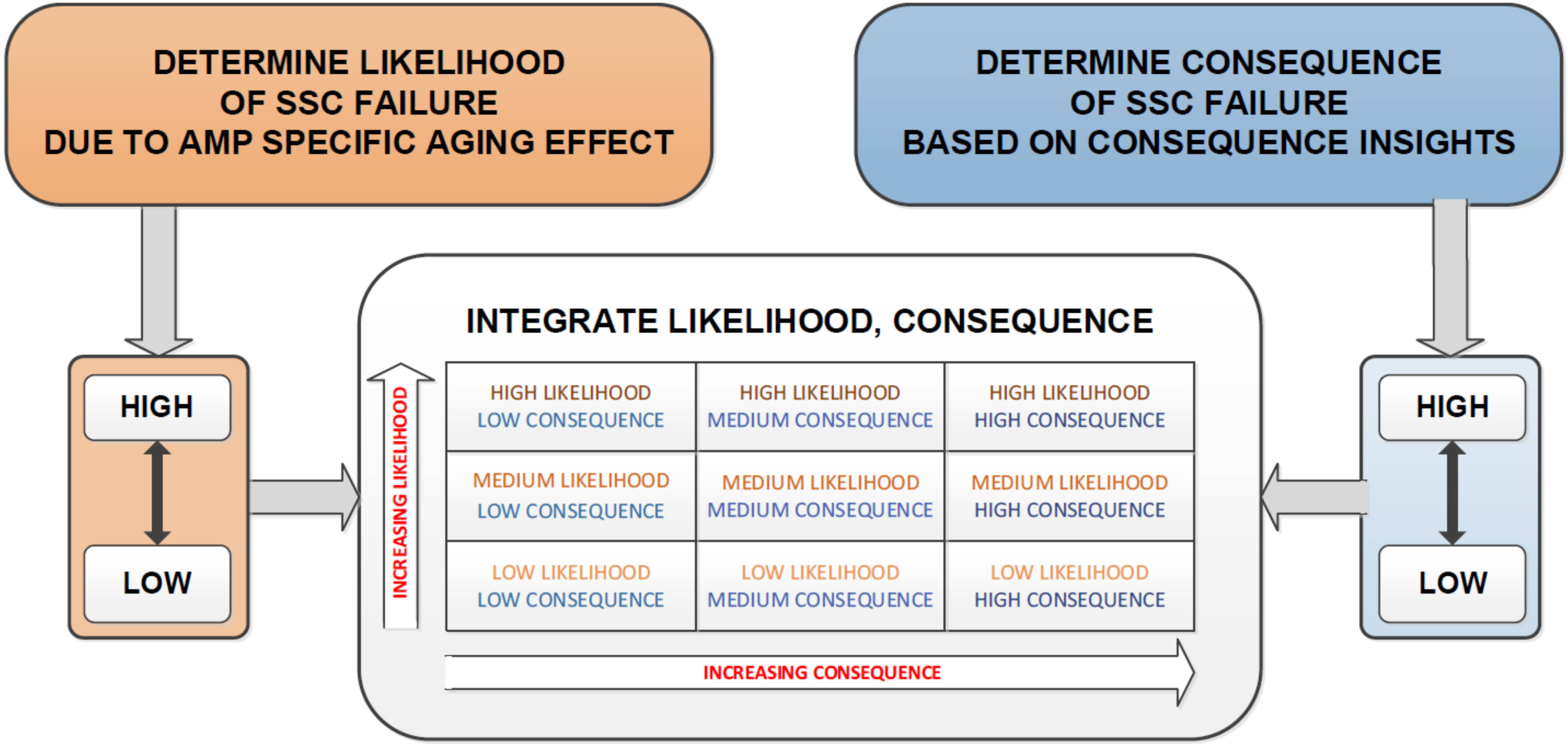
Using Risk to Inform Aging Management

Using risk insights to support aging management programs requires evaluating and categorizing an SSC's likelihood and consequence of failure.



Consider both Likelihood and Consequence

A risk matrix can be used to illustrate the relative importance of SSCs.



Overview of RIAM Steps in the EPRI Pilots

- Select AMP for RIAM development
- Develop the core team and identify stakeholders
- Collect the necessary information
- Identify and group SSCs
- Consider the necessary **likelihood** Inputs and perform analysis
- Consider the necessary **consequence** inputs and perform analysis
- Develop the risk matrix
- Revise aging management strategies

EPRI Pilot Studies

Selective Leaching

- A slow aging mechanism affecting specific materials (cast iron and copper alloys)
- Nondestructive evaluation methods are not yet conventionally recognized (i.e., must perform destructive evaluations).
- Regulatory requirements/scrutiny are increasing for such aging mechanisms, and this must be addressed for renewing operating licenses beyond 40 years.

Power Cables

- Failures of medium voltage cables subjected to wet environments were increasing until AMP implementation – now decreasing.
- In 2009, EPRI research recommended a conservative 6-year inspection cycle using very low-frequency diagnostic testing.
- License renewal includes testing and inspection requirements for “inaccessible” cables (wet or potentially wet)

Categorizing Passive Components

Risk-Informed Categorization

- Risk-informed categorization of SSCs helps focus attention on SSCs important to plant safety and allows for greater operational flexibility.

- NEI 00-04 provides the guidelines for SSC categorization in support of 10 CFR 50.69, *Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors.*

? Can information gained from the risk-informed categorization of SSCs be used to support decision-making related to aging management programs?

Passive and Active Components & Functions

Active Components & Functions

Passive Components & Functions

Passive and Active Components & Functions

Active Components & Functions

The guidance presented in NEI 00-04 provides a method for classifying active components. However, the classification of passive components or the passive function of active components should use other guidance, such as ASME Code Case N-660 and EPRI's Risk-Informed Repair and Replacement methodology.

Passive Components & Functions

Aging management programs focus on passive components (sometimes referred to as pressure boundary components) or the passive function of active components.

Leveraging risk insights for aging management programs requires an evaluation of passive components and functions.

How to Categorize Passive Components?

- The U.S. nuclear industry started with ASME Code Case N-660, *Risk-Informed Safety Classification for Use in Risk-Informed Repair/Replacement Activities.*

- Experience with this Code Case found that the methodology was impractical, and a better solution was needed.

- ANO Unit 2 was the industry pilot for an updated method to categorize passive components.

How to Categorize Passive Components?

- Piping segments are categorized based on the conditional consequence of failure utilizing the risk-informed safety classification (RISC) process.

- Each selected system is divided into piping segments that are determined to have similar consequences of failure.

- After they are categorized, the **safety significance** of each piping segment is identified.

Risk-Informed Safety Significance

High Safety-Significant (HSS)

These components continue to meet ASME Section XI rules for repair/replacement activities.

Low Safety-Significant (LSS)

These components are exempt from ASME Section XI requirements and can be repaired and/or replaced according to normal commercial and industrial practices.

Quantitative Indices for Consequence Categorization

Table 3-1
Correspondence of Consequence Categories to Numerical Estimates of Conditional Core Damage Probability (CCDP) and Conditional Large Early Release Probability (CLERP)

Consequence Category	Corresponding CCDP Range	Corresponding CLERP Range
HIGH	CCDP > 1E-4	CLERP > 1E-5
MEDIUM	1E-6 < CCDP ≤ 1E-4	1E-7 < CLERP ≤ 1E-5
LOW	CCDP ≤ 1E-6	CLERP ≤ 1E-7

EPRI TR-112657REVB-A
Revised Risk-Informed In-Service Inspection Evaluation Procedure

Table 2-5
Quantitative Indices for Consequence Categories

Conditional Core Damage Probability (no units)	Conditional Large Early Release Probability (no units)	Consequence Category
$>10^{-4}$	$>10^{-5}$	High
$10^{-6} <$ value $\leq 10^{-4}$	$10^{-7} <$ value $\leq 10^{-5}$	Medium
$\leq 10^{-6}$	$\leq 10^{-7}$	Low
No change to base case	No change to base case	None

EPRI 1022945
Risk-Informed Repair/Replacement Methodology

Consequence Inputs and Analysis

- Based on available risk information, such as risk-informed applications and PRA/PSA outputs, determine the severity of the consequence for each SSC within the scope of the AMP.
- Assign consequence of failure rankings (e.g., high/medium/low) based on the consequence/severity assessment.

Risk-informed approaches should consider both qualitative and quantitative risk information. Both qualitative and quantitative results can yield meaningful insights.

Consequence Analysis Considerations (2024)

Whitepaper 3002029305

Leveraging Risk Insights for Aging Management – Consequence Analysis Update

This whitepaper focuses on important considerations when developing risk insights for aging management programs and reviews how to apply EPRI's risk-informed repair and replacement methodology (RI-RRA) when performing consequence evaluations.

This whitepaper is available to EPRI members

The Selective Leaching Pilot

Selective Leaching Pilot

The XI.M33 AMP requires expanding the scope of inspections and possibly creating an ongoing program during the extended period of operation.

GOAL: Use risk insights to guide the selection of SSCs for the extent of condition inspections and the scope of any ongoing AMP requirements.

The pilot site had performed the 50.69 categorization

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Collect Site Specific Information

- Selective Leaching Inspection Sample Basis Document
- SSC Aging Management Review Reports
- SSC Scoping Reports
- 10 CFR 54.4(a)(2) Scoping and Screening Basis Document
- Selective Leaching Inspection and Destructive Examination Analysis Reports
- Station 10 CFR 50.69 System Categorization Reports
- Station Risk-Informed ISI Procedures
- Corporate and Plant Nuclear and Enterprise Risk Management Procedures
- EPRI's Selective Leaching: State-of-the-Art Technical Update (3002016057)
- System Engineer input on normal system operating parameters
- Station Cathodic Protection Survey Report
- Station PRA results and products

Identification of SSCs

- The pilot plant had two material types located in buried or various water environments susceptible to selective leaching:
  - gray cast iron
  - copper alloy >15% zinc

- The scope of the pilot sites selective leaching AMP included approximately 300 components, 20 different component types, across 11 systems.

- None of the systems were high energy – pipe whip, jet impingement, and other high energy effects were not considered.

300
components

20
component types

11
systems

Likelihood Inputs

- Operational Experience
- Environment
- Condensation or Water Internal Environment-Specific Factors
  - Temperature
  - Flow Rate
- Soil External Environment-Specific Factors
  - Soil Corrosivity
  - Cathodic Protection
  - Coatings

For each SSC, these factors were evaluated and scored

Selective Leaching Likelihood Screening Table

Operational Experience		
Previous Selective Leaching Inspection Results Based on M/E	**Weighted Score**	**Result**
Loss of intended function has occurred due to Selective Leaching	5	
Advanced degradation has occurred due to Selective Leaching	3	
No available OE	2	
Little or no presence of Selective Leaching observed	1	
Environment		
Environment	**Weighted Score**	**Result**
Buried/Soil	4	
Raw Water	4	
Waste Water	3	
Condensation	3	
Treated Water	2	
Closed Cooling Water	1	
Condensation/Water [Internal]-Specific Factors		
Temperature	**Weighted Score**	**Result**
≥110ºF	5	
90-109°F	4	
70-89ºF	3	
50-69ºF	2	
<50ºF	1	

Operational Experience		
Flow Rate	**Weighted Score**	**Result**
Intermittent flow rate during normal operation	4	
Consistent flow rate during normal operation	3	
Stagnant during normal operation	1	
Buried/Soil [External]-Specific Factors		
Soil Corrosivity	**Weighted Score**	**Result**
High	3	
Medium	2	
Low	1	
Cathodic Protection	**Weighted Score**	**Result**
Not installed or not operating	3	
Operating but not monitored or maintained	2	
Periodically monitored and maintained	1	
Coatings	**Weighted Score**	**Result**
No coating present	3	
Coating present but not monitored or maintained	2	
Coating periodically monitored and maintained	1	
	Weighted Total	

Ranking is biased towards site-specific experience

Likelihood Results

High Likelihood (147)	Medium Likelihood (115)	Low Likelihood (0)
• Copper Alloy/Raw Water (48) • Gray Cast Iron/Closed Cooling Water (40) • Gray Cast Iron/Raw Water (35) • Copper Alloy/Closed Cooling Water (External) (16) • Gray Cast Iron/Treated Water (4) • Copper Alloy/Treated Water (4)	• Gray Cast Iron/Raw Water (39) • Gray Cast Iron/Closed Cooling Water (50) • Copper Alloy/Air and Gas Wetted (16) • Gray Cast Iron/Air and Gas Wetted (4) • Copper Alloy/Closed Cooling Water (Internal) (4) • Gray Cast Iron/Treated Water (2)	None

(number of identified SSCs)

These results are plant specific

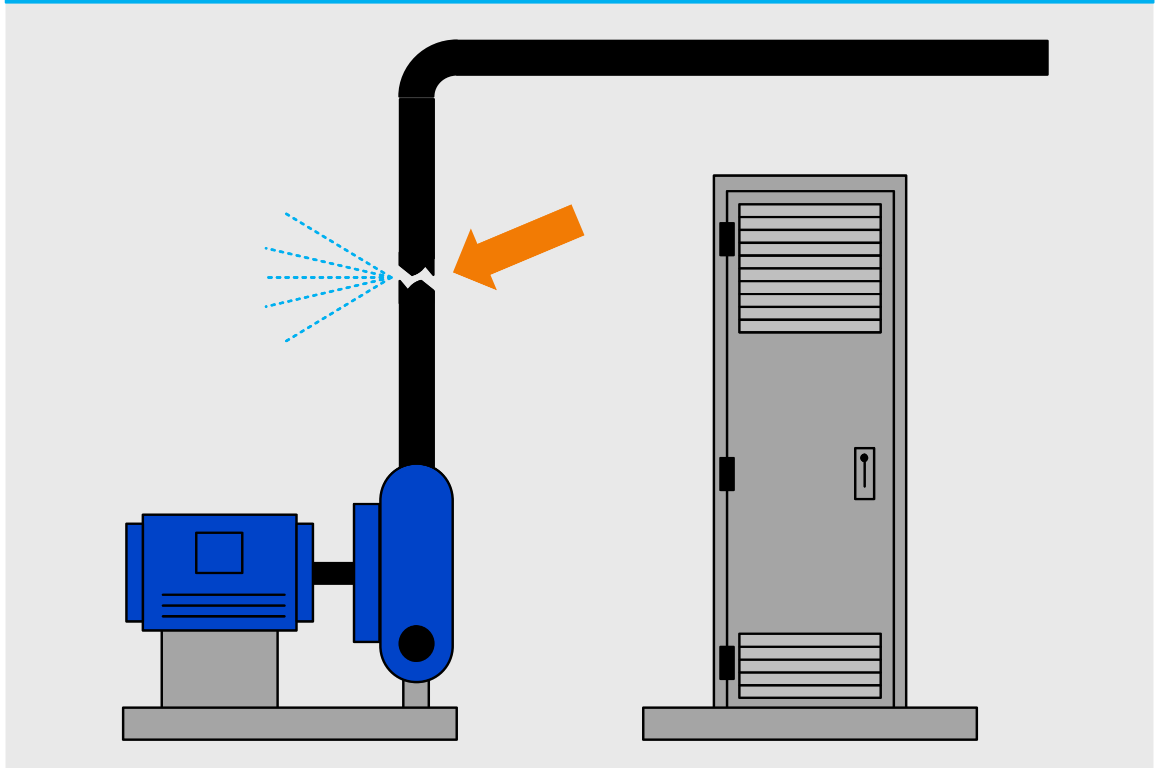
Consequence Inputs

- "Consequence" means the resulting effect from the **loss of the intended function** with respect to the overall plant risk for each SSC within the scope of this pilot.

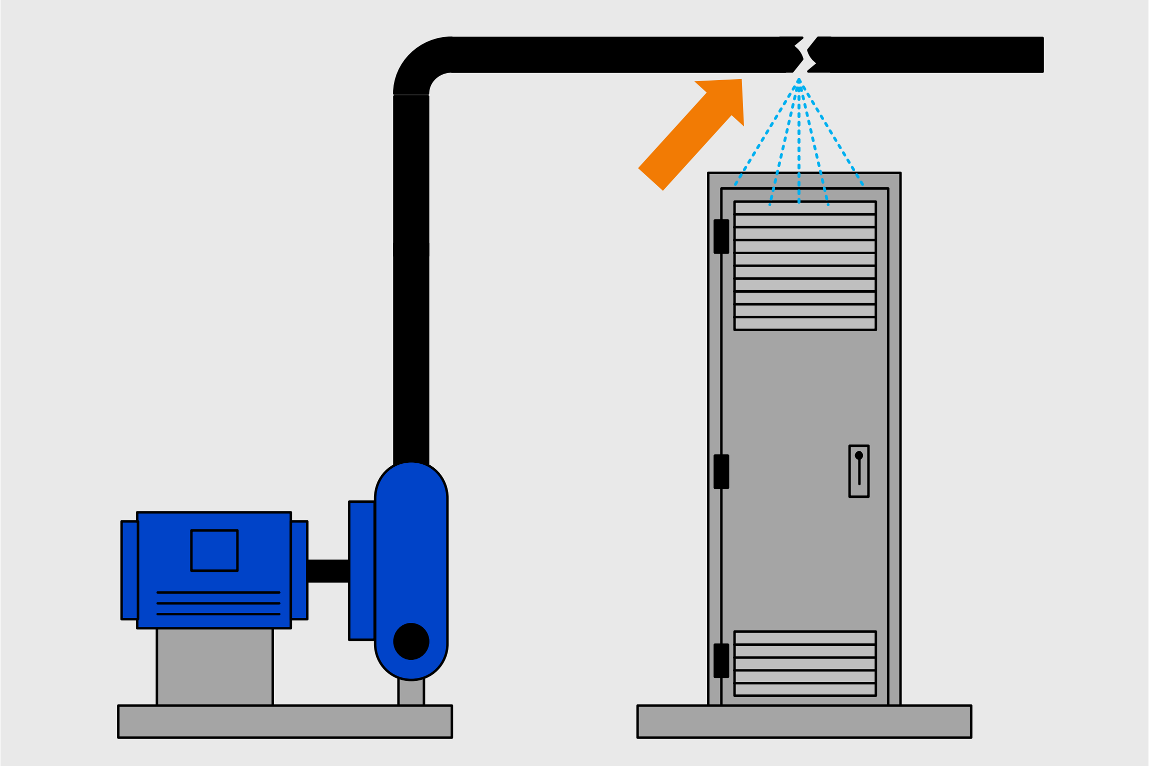
- Consequence information was developed using the following references:
  - The 50.69 categorizations for the system of interest
  - Risk-Informed Inservice Inspection (RI-ISI) results
  - PRA Basic Event data
  - Internal Events PRA data
  - Internal Fire PRA data
  - Internal Flooding PRA data

Direct and Indirect Impacts

Direct – Loss of a single SSC



Indirect – Loss of Multiple SSCs



Indirect impacts are particularly important when considering passive components

Consequence Ranking and Categorization

High Consequence (30)

Pressure boundary failures resulting in events that are important contributors to plant risk and/or pressure boundary failures which significantly degrade the plant's mitigative ability.

Medium Consequence (176)

This category is included to accommodate pressure boundary failures which fall between the high and low rank.

Low Consequence (56)

Pressure boundary failures resulting in anticipated operational events and/or pressure boundary failures that do not significantly impact the plant's mitigative ability.

Consequence Category	Corresponding CCDP Range	Corresponding CLERP Range
HIGH	CCDP > 1E-4	CLERP > 1E-5
MEDIUM	1E-6 < CCDP ≤ 1E-4	1E-7 < CLERP ≤ 1E-5
LOW	CCDP ≤ 1E-6	CLERP ≤ 1E-7

Conditional Core Damage Probability (CCDP) and Conditional Large Early Release Probability (CLERP)

Based on EPRI TR-112657 Rev. B-A

Final Risk Matrix

	LOW CONSEQUENCE CCDP $\leq 10^{-6}$ or CLERP $\leq 10^{-7}$	MEDIUM CONSEQUENCE $10^{-6} <$ CCDP $\leq 10^{-4}$ or $10^{-7} <$ CLERP $\leq 10^{-5}$	HIGH CONSEQUENCE CCDP $> 10^{-4}$ or CLERP $> 10^{-5}$
HIGH LIKELIHOOD 15 ≤ BURIED/SOIL 12 ≤ COND/WATER	NSR GCI/RW x4	SR GCI/CCW x24 NSR GCI/CCW x16 NSR GCI/RW x25 NSR GCI/TW x4 NSR Brass/CCW x18 NSR Brass/RW x48 SR Brass/TW x4	NSR GCI/RW x6 SR GCI/WW x1 SR Brass/CCW x2 NSR GCI/WW x1 NSR GCI/Soil x1 NSR Brass/CCW x4 NSR Brass/RW x1
MEDIUM LIKELIHOOD BURIED/SOIL 11 ≤ 14 COND/WATER 7 ≤ 11	NSR GCI/CCW x44 NSR GCI/RW x6 NSR GCI/TW x2	NSR GCI/Air-Gas Wetted x4 NSR GCI/CCW x6 NSR GCI/RW x23 NSR GCI/Soil x3 NSR Brass/CCW x2 NSR Brass/Air-Gas Wetted x16	NSR GCI/RW x27 SR GCI/Soil x1 NSR GCI/Soil x1 NSR Brass/TW x2 NSR Brass/RW x1
LOW LIKELIHOOD BURIED/SOIL ≤ 10 COND/WATER ≤ 6			

Additional Considerations

Using Information from other Risk-Informed Applications

For this pilot, significant effort was undertaken to match the 50.69 SSCs with the selective leaching AMP SSCs. This was done to ensure the AMP’s intended function was addressed by the 50.69 categorization. A significant number of the AMP SSCs were matched to 50.69 categorizations, with a few outliers.

Active vs. Passive Categorization

SSCs may be identified as having high safety significance due to their active function, but their passive function could be low safety significance. Given that the focus of the AMPs is the passive function(s), it is important to carefully consider how the output of a risk-informed application is used to support the consequence evaluation.

Benefits of Risk Information and Insights

General Insights from this Research

Insights and Benefits

The EPRI pilots have demonstrated that risk insights can benefit aging management programs and extended plant operations.

The EPRI pilots have identified safety-significant inspection locations and improved inspection efficiency.

AMP Optimization

Considering risk information supports optimizing how plant resources (labor, funds, etc.) are allocated to support aging management activities.

Focus on the activities that add the most value via increased focus on plant safety!

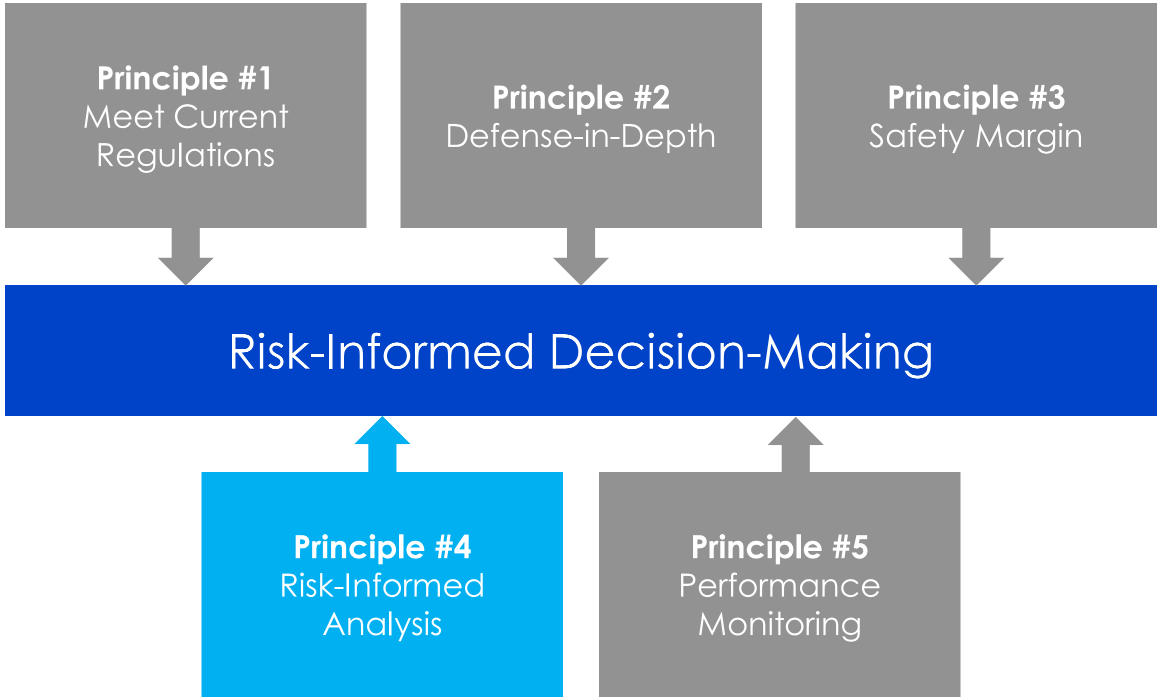
Future Research

Application of the EPRI framework to AMPs at non-U.S. plants.

The impact of non-safety risk factors (e.g., enterprise, financial, operational, and regulatory risk).

The Application of Risk in a Larger Context

Risk-Informed Decision-Making (RIDM) is an approach to regulatory decision-making in which insights from probabilistic risk assessments are considered with other engineering insights.



Based on the NRC's principles of Integrated Risk-Informed Decision-Making

An Approach for using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis (RG 1.174)

Risk Insights and Information Support Decision-Making

Quantitative Results…

A lot of focus is placed on CDF, LERF, and other quantified risk metrics…

Risk Insights…

…but most of the benefits are found in the cutsets, relative ranking, important components and operator actions, model completeness, key assumptions and sensitivities, uncertainty, and other elements.

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