# Multi-Unit Risk Assessment

## EPRI's Perspective and Research Activities

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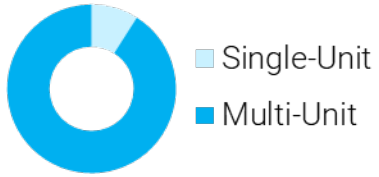
# Why Consider Multi-Unit Risk?

- Multi-unit sites are utilized by the nuclear industry (for good reasons).
- Multi-unit risk is an important consideration when developing risk insights.
- The assessment of multi-unit risk needs to be done “smartly.”

As of 2023, 91% of all operational reactors are located at multi-unit sites. As new projects take shape and new technologies emerge, the number and size of multi-unit sites are expected to grow.







Information based on the 2024 Edition of IAEA's *Nuclear Power Reactors in the World*.

# Potential for Unique Accident Sequences

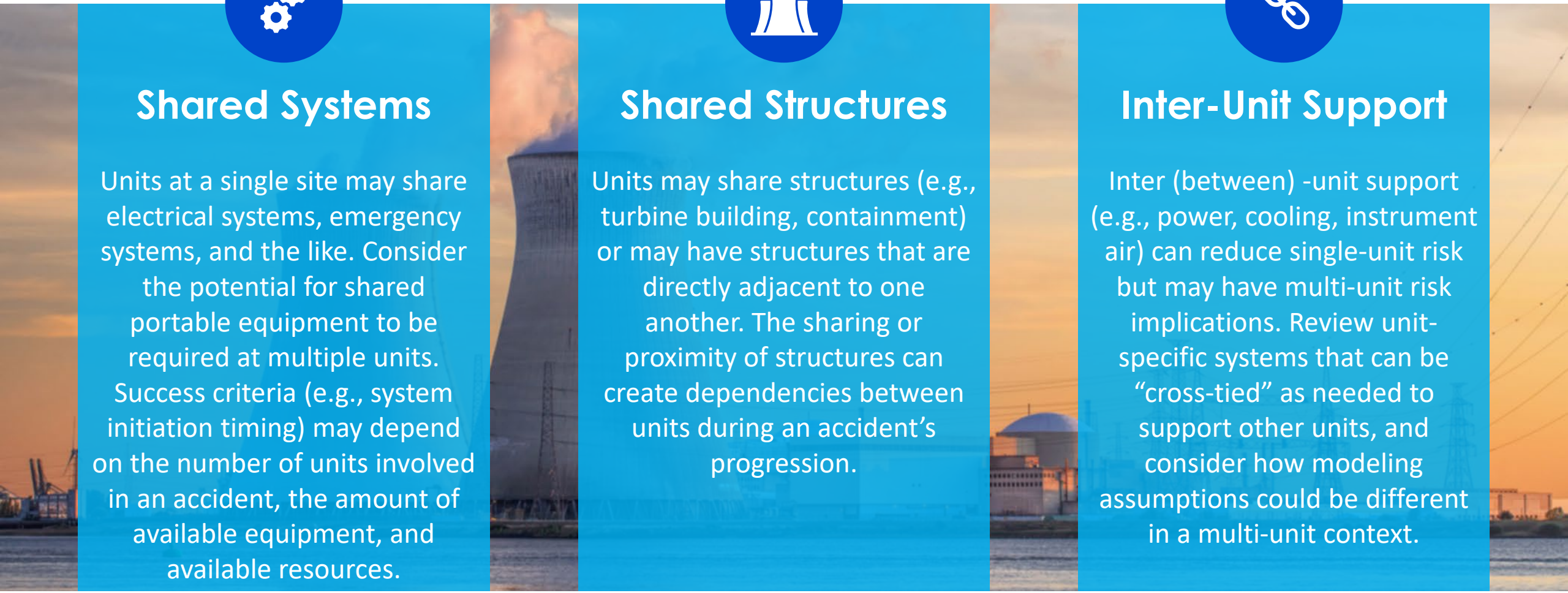
## Lessons Learned

The Fukushima accident generated renewed focus on accidents that can challenge multiple units at a single site. This event also highlighted the potential for a combination of external hazards to overcome a site's defense-in-depth methodology.

## Unique Considerations

Multi-unit accident sequences pose unique challenges that can be different from single-unit events and, therefore, require unique responses. The impact from a multi-unit event is not simply the sum of the single-unit impacts.

# Multi-Unit Sites Require Additional Considerations



## Shared Systems

Units at a single site may share electrical systems, emergency systems, and the like. Consider the potential for shared portable equipment to be required at multiple units. Success criteria (e.g., system initiation timing) may depend on the number of units involved in an accident, the amount of available equipment, and available resources.

## Shared Structures

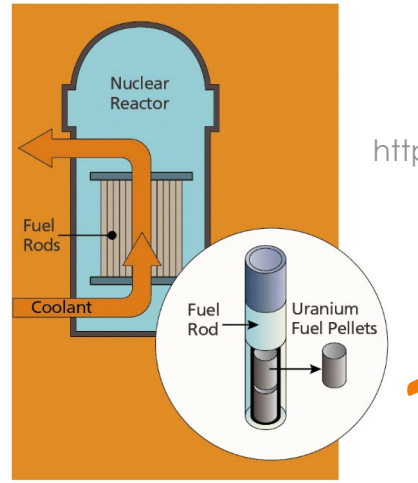
Units may share structures (e.g., turbine building, containment) or may have structures that are directly adjacent to one another. The sharing or proximity of structures can create dependencies between units during an accident's progression.

## Inter-Unit Support

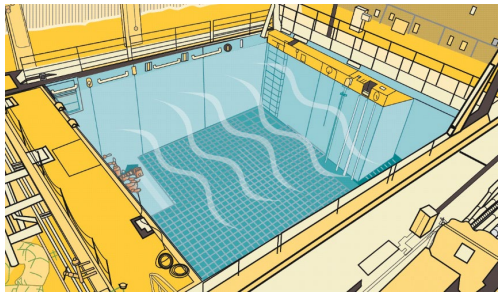
Inter (between) -unit support (e.g., power, cooling, instrument air) can reduce single-unit risk but may have multi-unit risk implications. Review unit-specific systems that can be "cross-tied" as needed to support other units, and consider how modeling assumptions could be different in a multi-unit context.

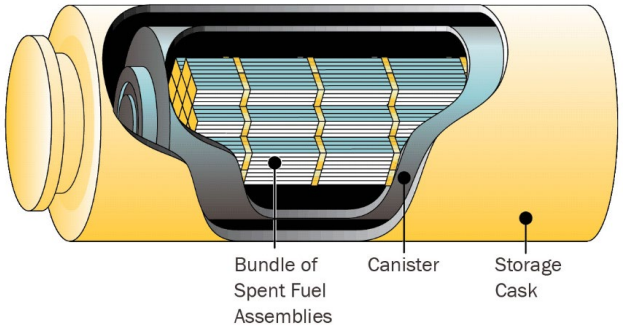
# Considering Multiple Sources

- Multi-unit risk provides a means to assess the risk of multiple units and various radiological sources (e.g., reactor core, spent fuel pool, dry cask storage).
- Multiple sources could include sites that have implemented multiple reactor technologies, including advanced reactor designs.
- The selection of appropriate risk metrics is critical when considering different technologies and the aggregation of risks from multiple radiological sources.




https://www.nrc.gov/images/waste/spent-fuel-storage/generation-storage.gif





# Sites Implementing New Technologies

- In the United States, although a multi-unit PRA model is not required, a PRA model should explicitly account for any identified impact of shared SSCs, human actions, and initiators. Also, accident sequences should be reviewed to identify those that can impact multiple units. **(ML23249A003)**

- Current single-unit surrogate risk metrics (core damage and large early release) may not be appropriate for the next generation of nuclear power plants. **(ML14150A330)**

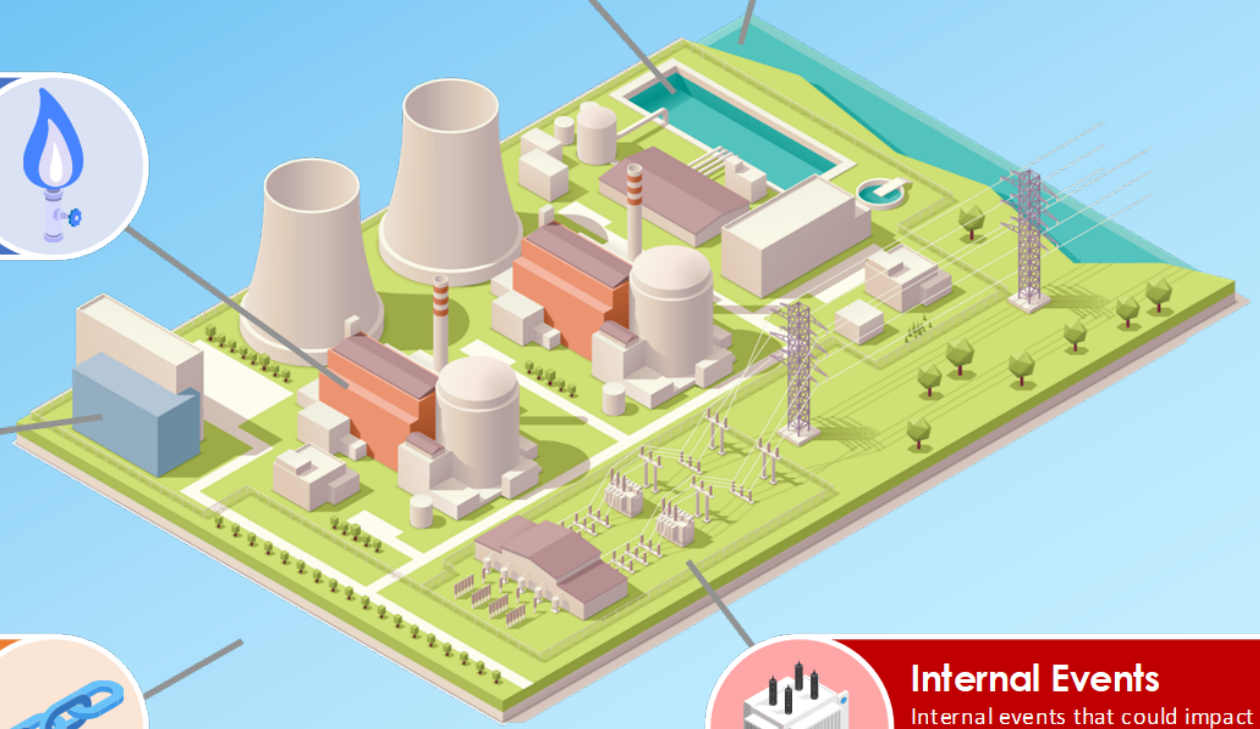
# Regulatory Considerations

- Some regulatory agencies consider the aggregation of risk (whole-site risk) for comparison against safety goals.

- In the United States, risk-informed performance-based regulations focus on per-reactor safety goals; single-unit core damage and single-unit large early release. **(ML13255A370)**

- The United States Nuclear Regulatory Commission (NRC) is conducting a full-scope site Level 3 PRA. One objective is to address considerations not previously considered; multi-unit risk. **(SECY-11-0089)**

# The Scope of a Multi-Unit Risk Assessment



## External Hazards
Seismic events, external flooding, high winds, and other hazards that could impact multiple units across a site.

## Shared Structures, Systems, and Components
Modeling of common or shared SSCs and physical resources in various combined operating states.

## Internal Hazards
Fires, floods, and other hazards that could impact multiple units across a site.

## Human Performance
Shared human resources such as operators, and considerations for similar or common operating procedures, command and control, and the like.

## Common Cause
Consideration of cross-unit common-cause failure event grouping and parameter estimation.

## Internal Events
Internal events that could impact multiple units, such as loss of offsite power.

# Multi-Unit Risk and Informed Decision-Making

- Apply additional detail and complexity where it yields new risk insights and information.

- Consider how current single-unit PRAs/PSAs can be utilized, leveraged, and modified (as needed) to gain these additional insights.


Utilizing the existing single-unit PRA/PSA can provide a great advantage when developing the multi-unit risk assessment.

# 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.

# Applied Effort Commensurate with the Gained Insights

- Balance the required resources with risk significance and insights.

- Consider how different levels of detail can support the assessment of multi-unit risk:

**Quantitative Approaches**
Probabilistic risk/safety assessments

**Qualitative Approaches**
Screening analysis

"Be implementable with state of practice resources and not be overly burdensome when compared with SUPSA modelling."

IAEA Safety Report No. 110

# Screening vs. Full Scope Risk Analysis

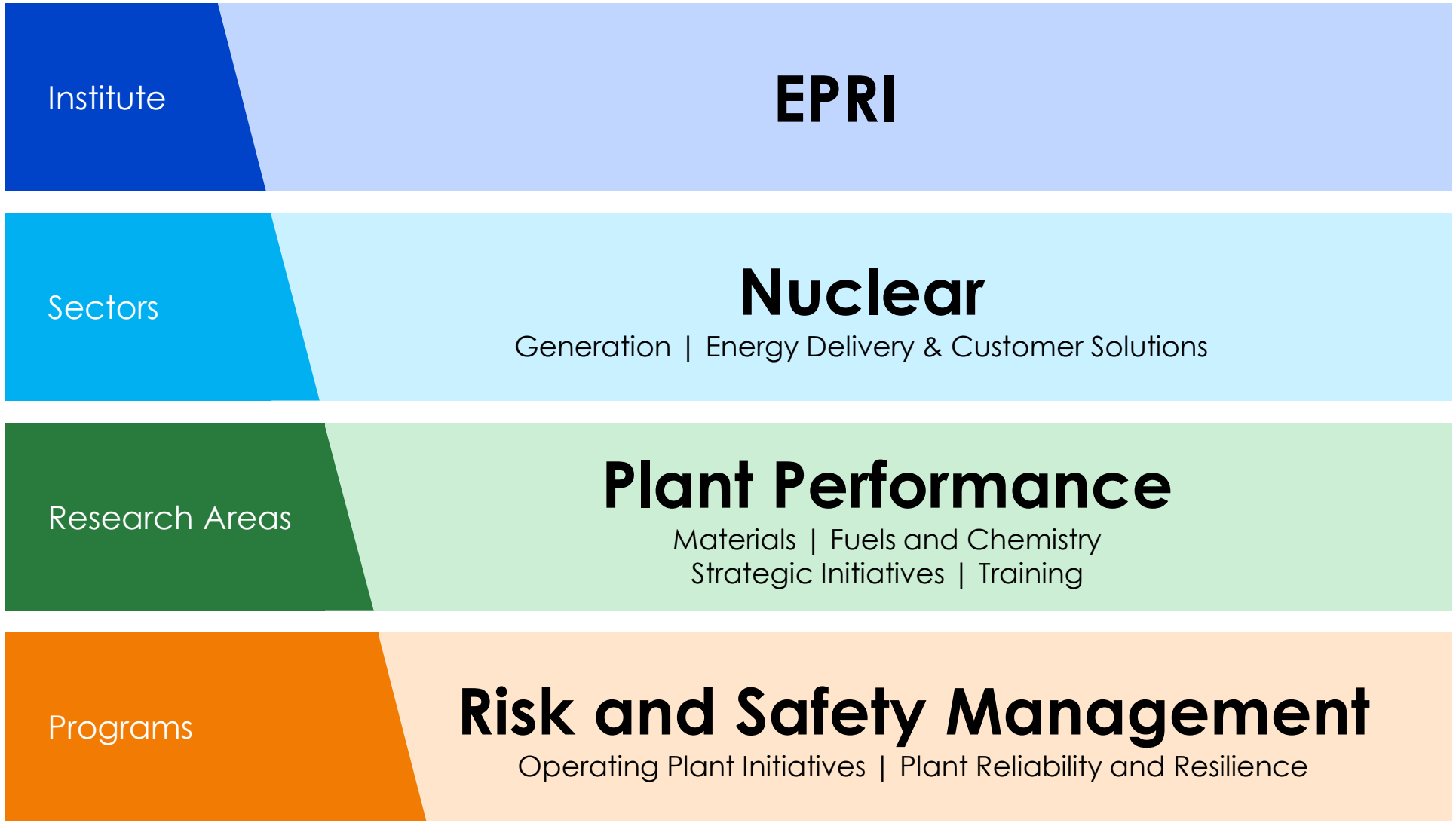
Increasing level of detail

| | Screening | Bounding | Full Scope |
|---|---|---|---|
| Cost to perform: | Low | Medium | High |
| Timeframe to perform: | Short | Medium | Long |
| Internal Events: | Yes | Yes | Yes |
| Internal & External Hazards: | Select Hazards | Select Hazards | All Hazards |
| Level of Analysis: | 1 | 1, 2 | 1, 2, 3* |
| Evaluation Methods: | Deterministic | Qualitative + Quantitative | Quantitative |
| Risk Results: | Screen In or Out | Bounding Cutsets | Detailed Cutsets |
| Uncertainty in Results: | Not Quantified | Risk is Overestimated | More Realistic |

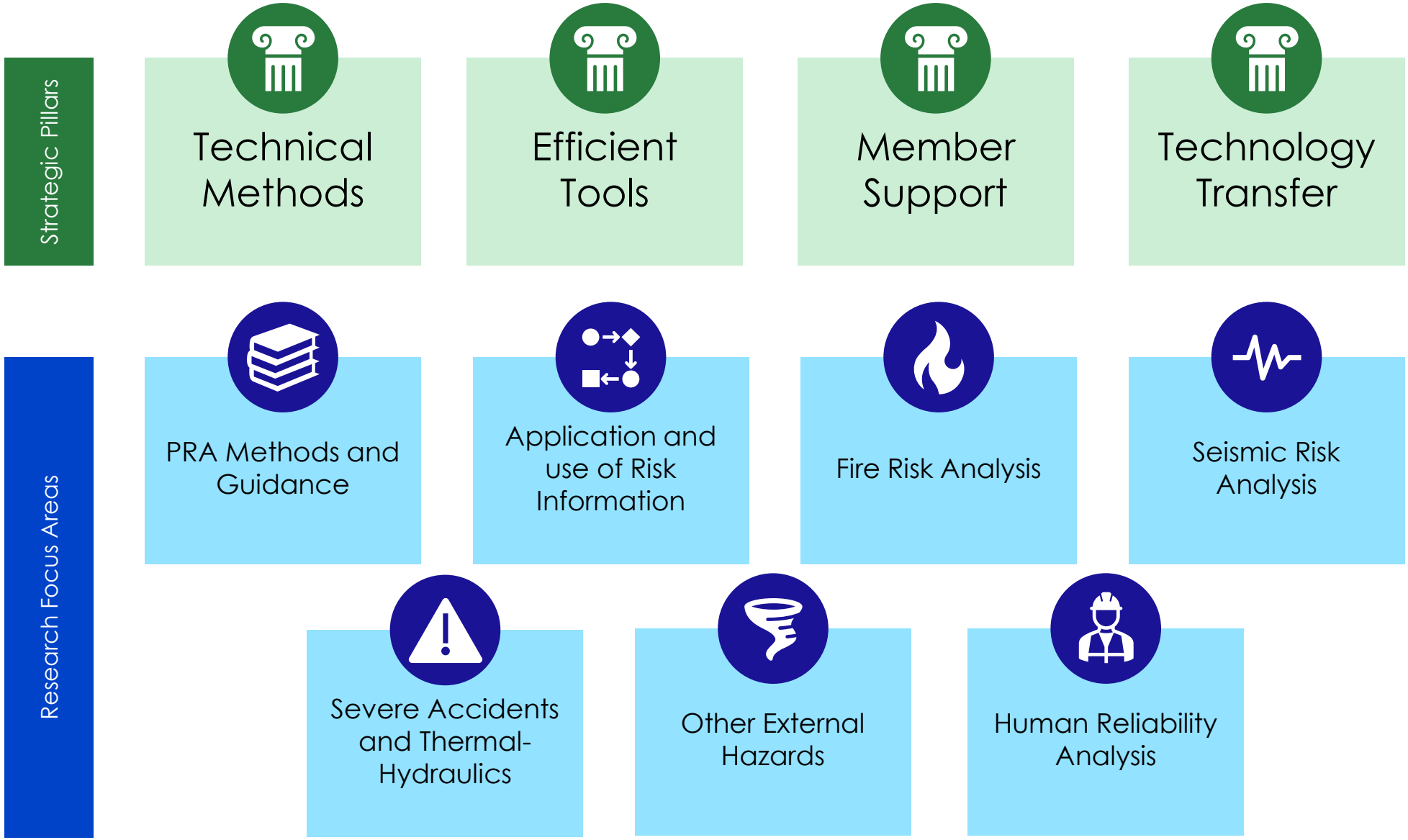
*Typically, a Level 3 consequence analysis is not performed when conducting a full scope single-unit PRA. Such an analysis may or may not be appropriate when evaluating multi-unit risk.

# EPRI and Multi-Unit Risk?

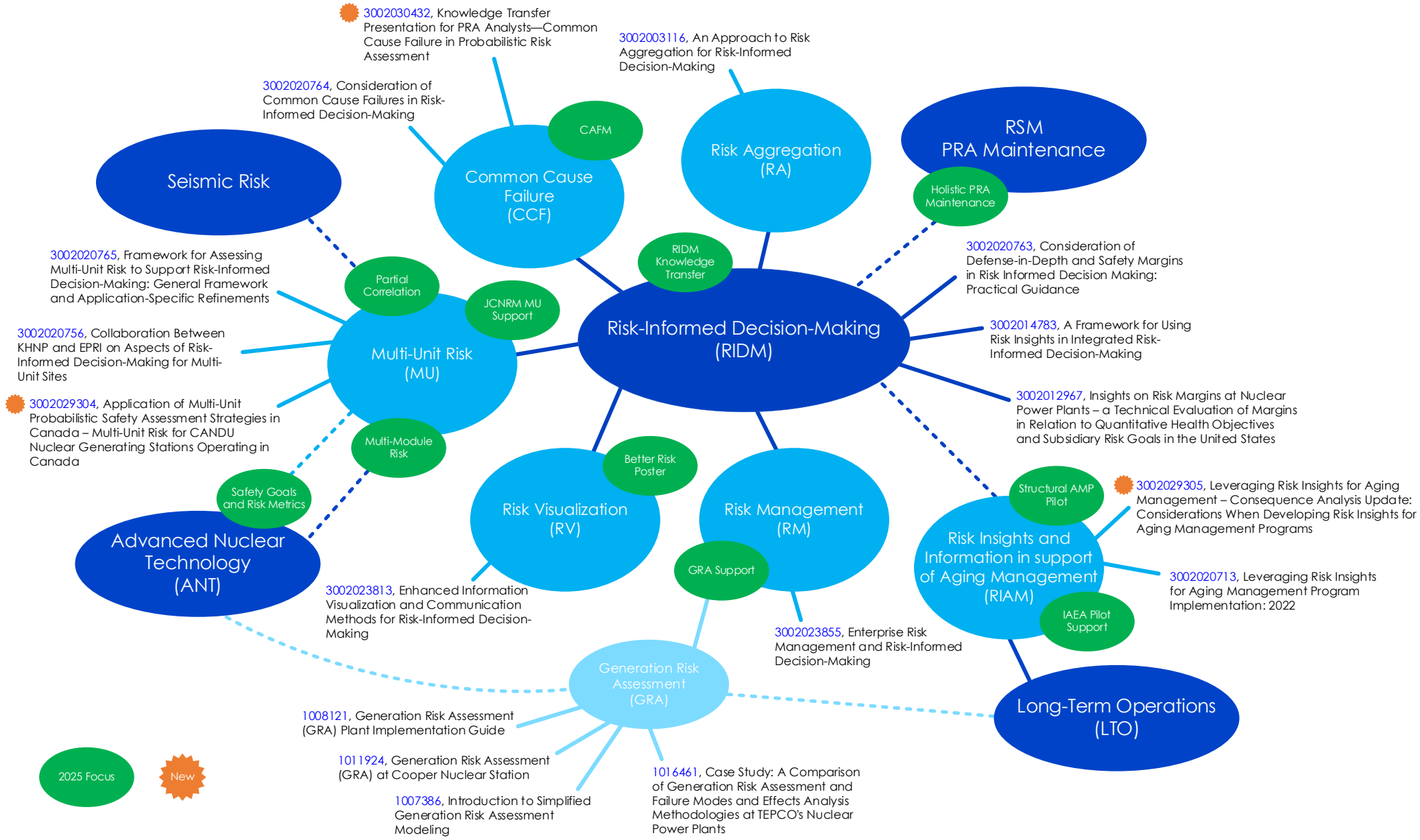
# Overview of EPRI and our Research



# Risk and Safety Management (RSM)



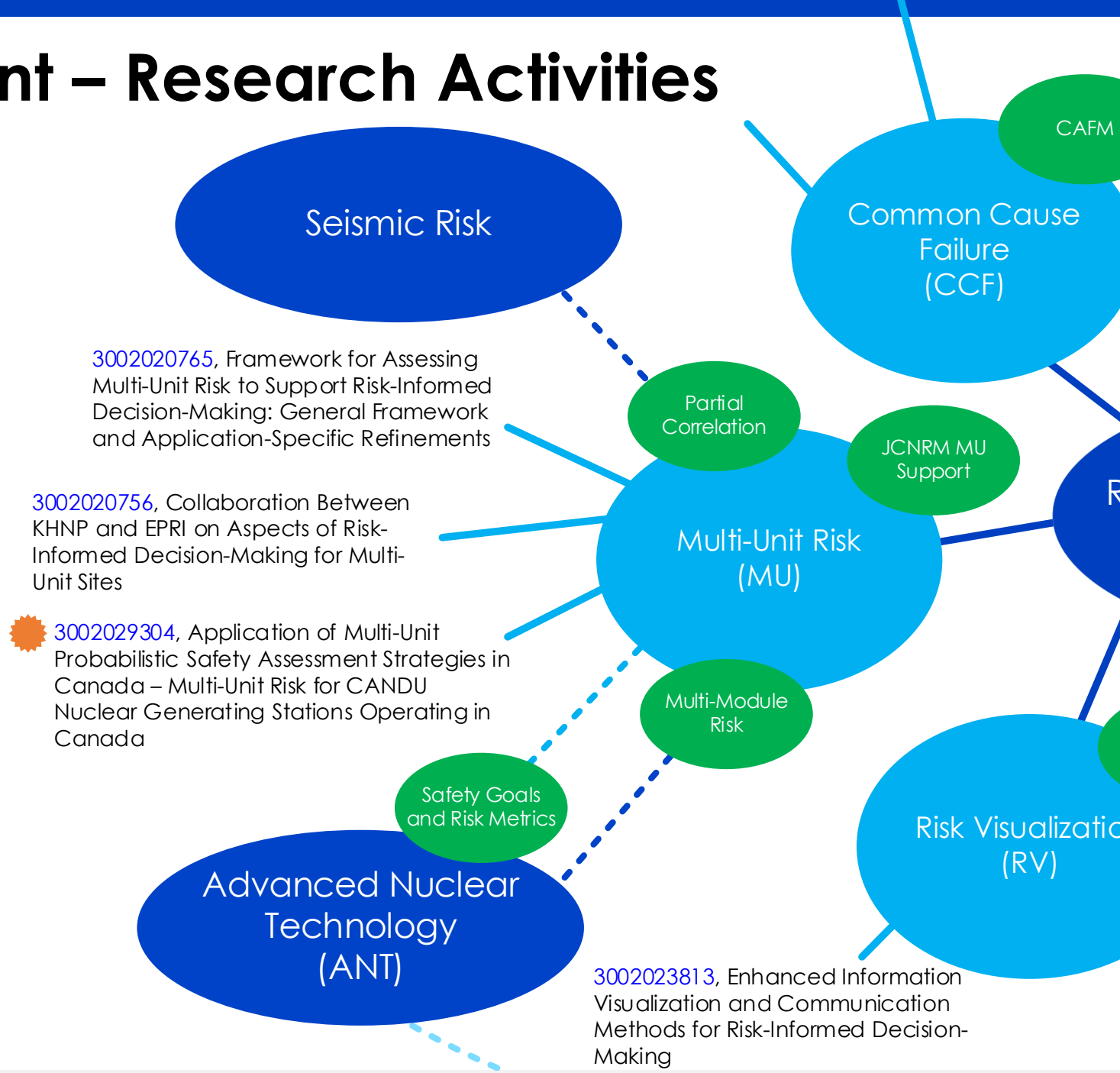
# Risk-Informed Decision-Making (RIDM)



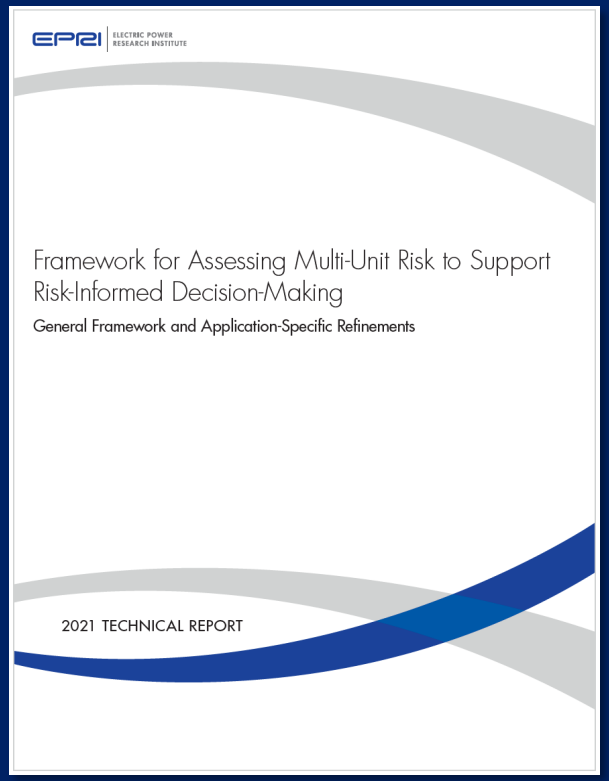
# Multi-Unit Risk Assessment – Research Activities

- The evaluation of multi-unit risk supports **risk-informed decision-making**.

- EPRI's multi-unit research and framework uses a graded approach, building from already available single-unit PRAs/PSAs.

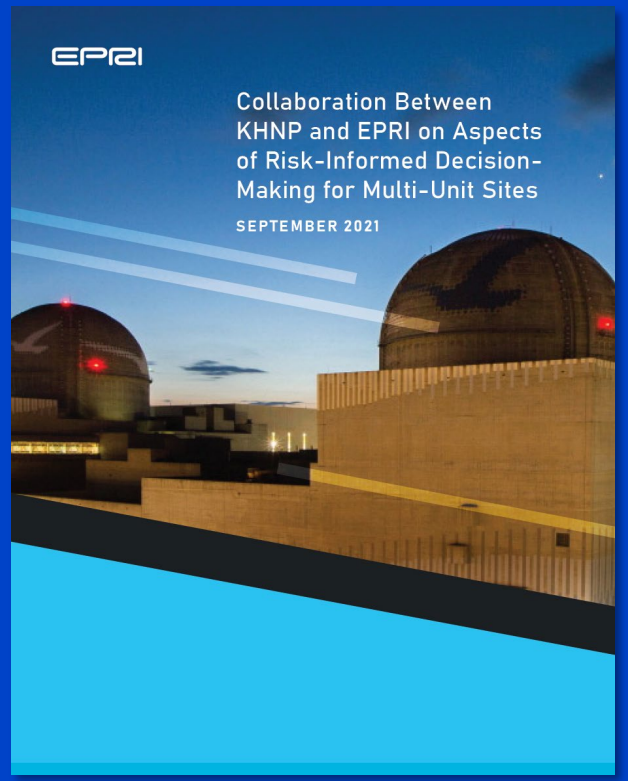


# EPRI's Multi-Unit Research and Framework




**3002020765**

Framework for Assessing Multi-Unit Risk to Support Risk-Informed Decision-Making: General Framework and Application-Specific Refinements




**3002020756**

Collaboration Between KHNP and EPRI on Aspects of Risk-Informed Decision-Making for Multi-Unit Sites

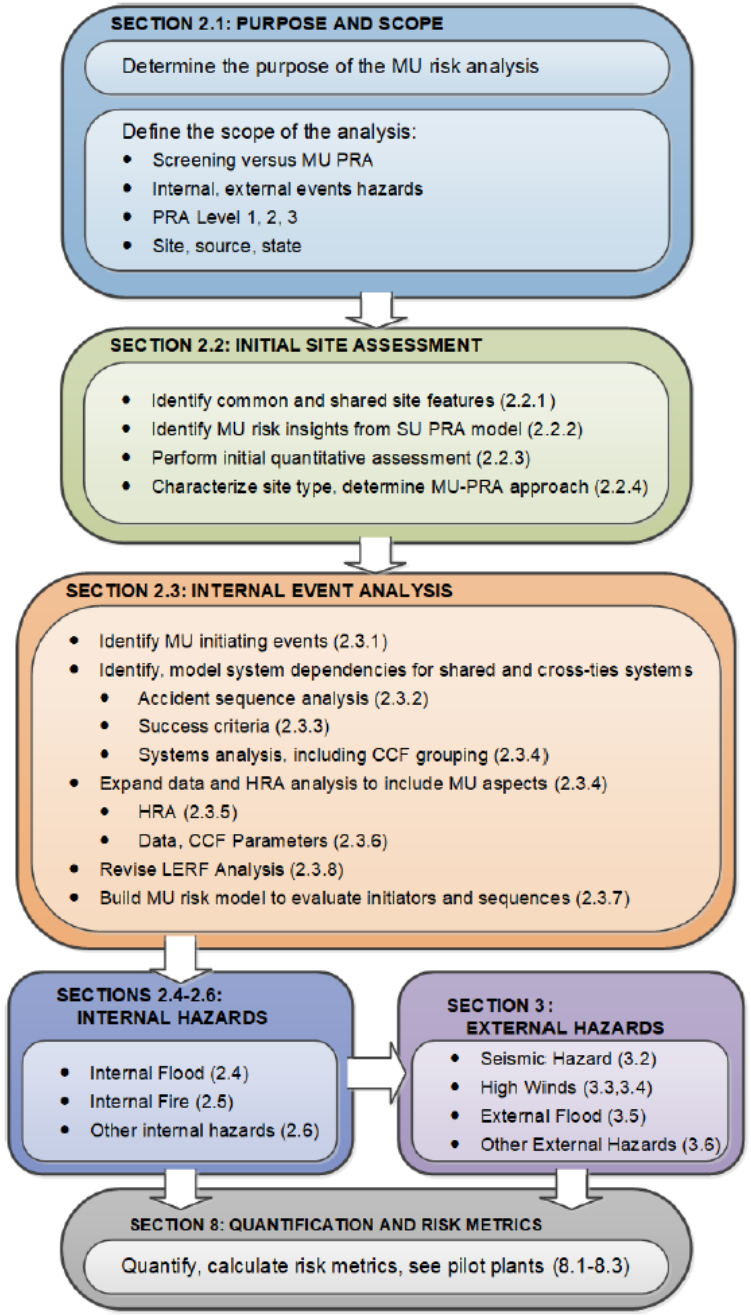

**3002029304**

Application of Multi-Unit Probabilistic Safety Assessment Strategies in Canada: Multi-Unit Risk for CANDU Nuclear Generating Stations Operating in Canada

# The Need for a Framework

The scope of a multi-unit risk assessment can be significant. EPRI's framework provides insights into the various factors that can influence a site's multi-unit risk profile, for example:

- Site Configuration and Physical Location
- Common and/or Shared Structures
- Common and/or Shared Systems
- Common and/or Shared Components and Identical Component Types
- Shared Physical and Human Resources and Common Procedures
- Common Emergency Response + Command and Control Considerations



# Multi-Unit Risk Initiators and Consequences

## Site-level Initiators

Multi-unit accident sequences due to site-wide initiating events that impact multiple units concurrently (e.g., LOOP and external hazards).

## Cascading Initiators

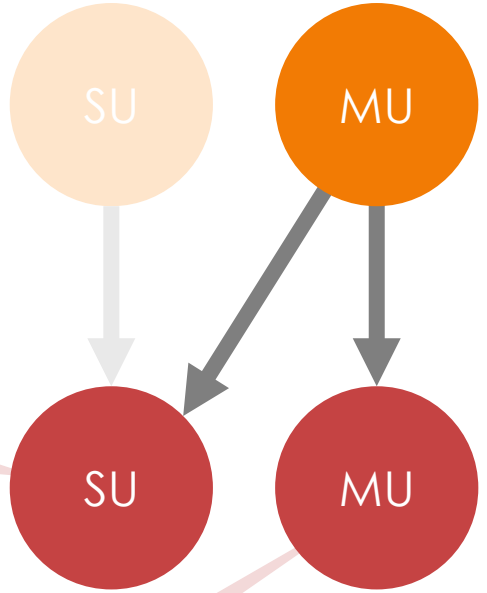
Events at one unit that impact the other unit(s) at the same site (e.g., internal events and internal hazards).

## Single-Unit Core Damage

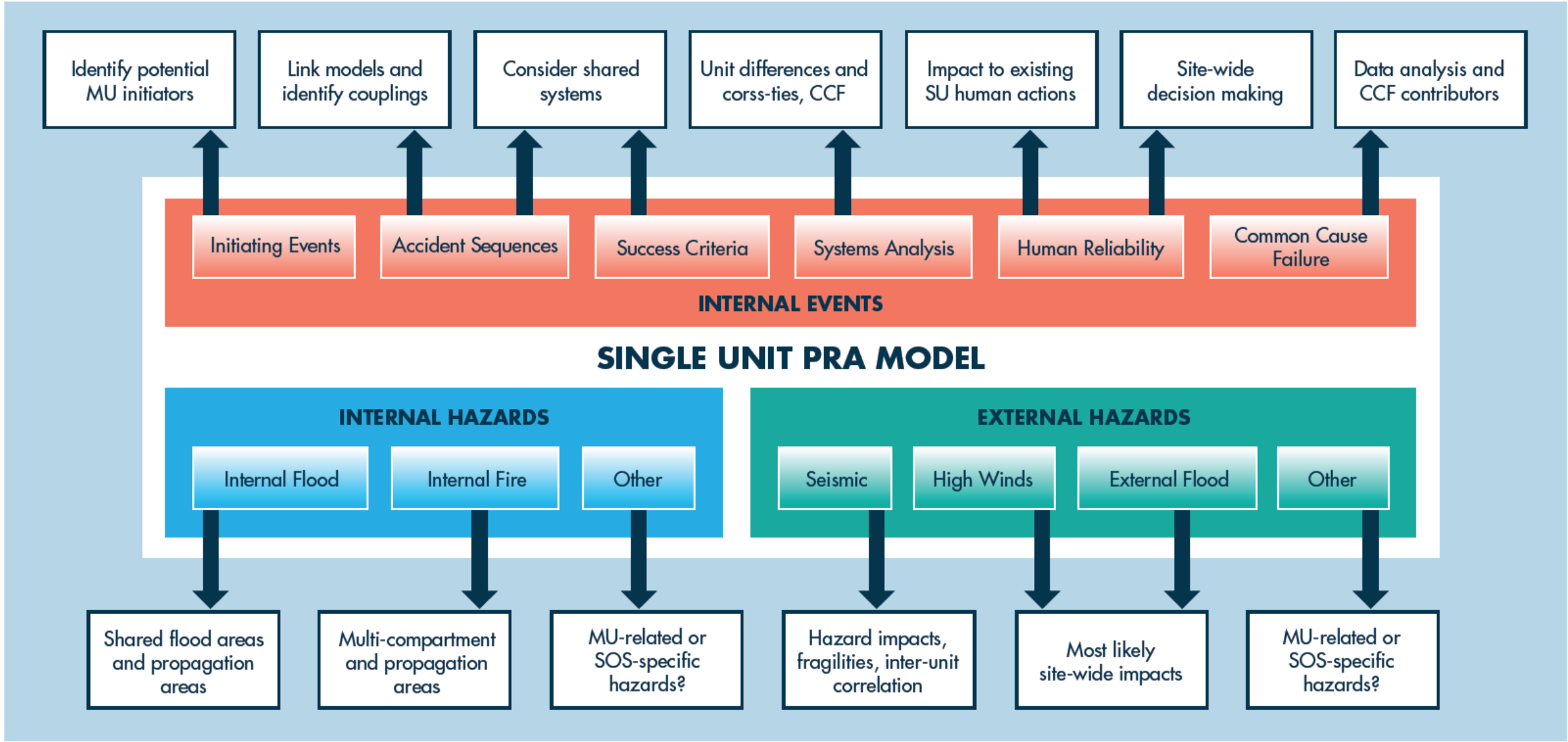
Only one unit is damaged, despite a multi-unit initiator. For this end state, dependencies between units need to be considered. Therefore, this end state may not be fully captured by single-unit PRAs/PSAs.

## Multi-Unit Core Damage

An end state that considers multiple units (reactors) being damaged. This end state is not typically addressed by single-unit PRAs/PSAs.



# Using the Existing Single-Unit Models



# Building from the Internal Events Analysis

As with single-unit risk assessments, a multi-unit risk assessment is based on the internal events risk model.

**Identify potential multi-unit initiators:** This is intended to be a systematic, comprehensive search where potential initiators are identified for further analysis. This search should start with the existing single-unit initiators.

**Group and subsume:** This organizes the multi-unit initiators that do not screen out into a manageable set of initiators to be included in the multi-unit PRA/PSA, and quantified.

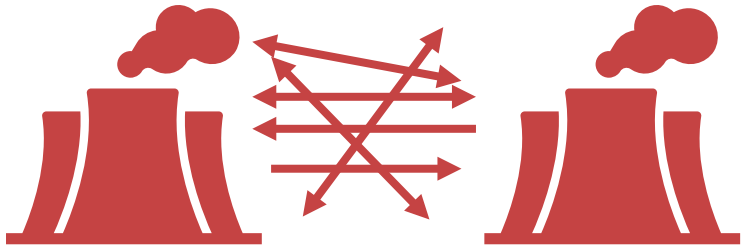
**Screen out potential multi-unit initiators:** This screening helps focus the multi-unit risk assessment on those initiators with some potential to contribute significantly to multi-unit risk. The initiators screened out need to have a clear, defined basis for the screening.

**Quantify the initiating event frequencies:** The frequencies of multi-unit initiators are based on generic and plant-specific data and system models – for example, when considering support system initiating events.

# Degree of “Coupling” Between Units

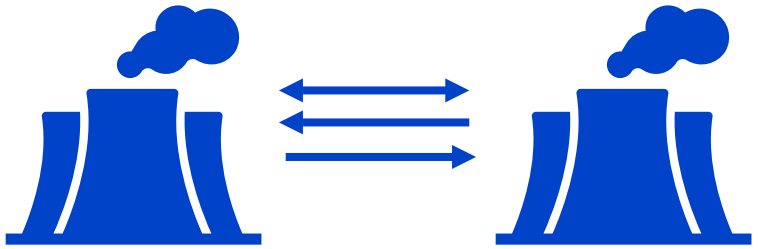
For practical purposes, ranges exist

Tightly-Coupled



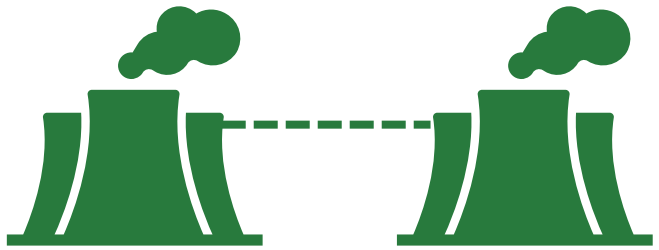
Tightly-coupled sites/units have complex dependencies between the units. Some qualitative screening may be possible. These complex interactions may require complicated risk modeling but may also provide benefit when considering mitigation pathways.

Loosely-Coupled



For loosely-coupled sites/units, some dependencies are expected for offsite power (grid and switchyard dependency), common component types (inter-unit common cause failure), common physical location, common cooling sources/intake, common emergency response organizations, and accident mitigation.

Uncoupled



Uncoupled sites/units present an opportunity to screen out specific multi-unit aspects. There may be some coupling due to physical proximity, such that external hazards may dominate the multi-unit risk assessment.

# Challenges when Modeling Multi-Unit Risk

- It can be difficult to assess and model the likelihood and consequence of hazards that result in multi-unit accidents.
- It can be difficult to model different degrees of coupling and dependency between units.
- Multi-unit risk assessments may push current software tools and computational resources to their limits.
- Regulatory interest continues to develop and evolve. As a result, requirements change and differ between countries.
- It can be difficult to appropriately aggregate the results of risk models that use various degrees of detail (screening vs. full scope).
- It can be difficult to consider the various combinations of plant operating states (e.g., at power, refueling), especially for sites with many units.

**This is not a complete list – EPRI and the Industry are working together to close the gaps**

# Conclusion

New insights and information gained from a multi-unit risk assessment support risk-informed decision-making.

Review EPRI's research on multi-unit risk assessments for additional information and detail.

Utilizing EPRI's multi-unit research and experience from multiple pilots can help sites as they develop multi-unit risk assessments.

EPRI's framework leverages single-unit PRAs/PSAs and utilizes graded approaches – adding detail as needed and where it adds value.

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