EPRI's Multi-Unit Framework and Multi-Module Plant Designs

Modeling Multi-Unit Risk

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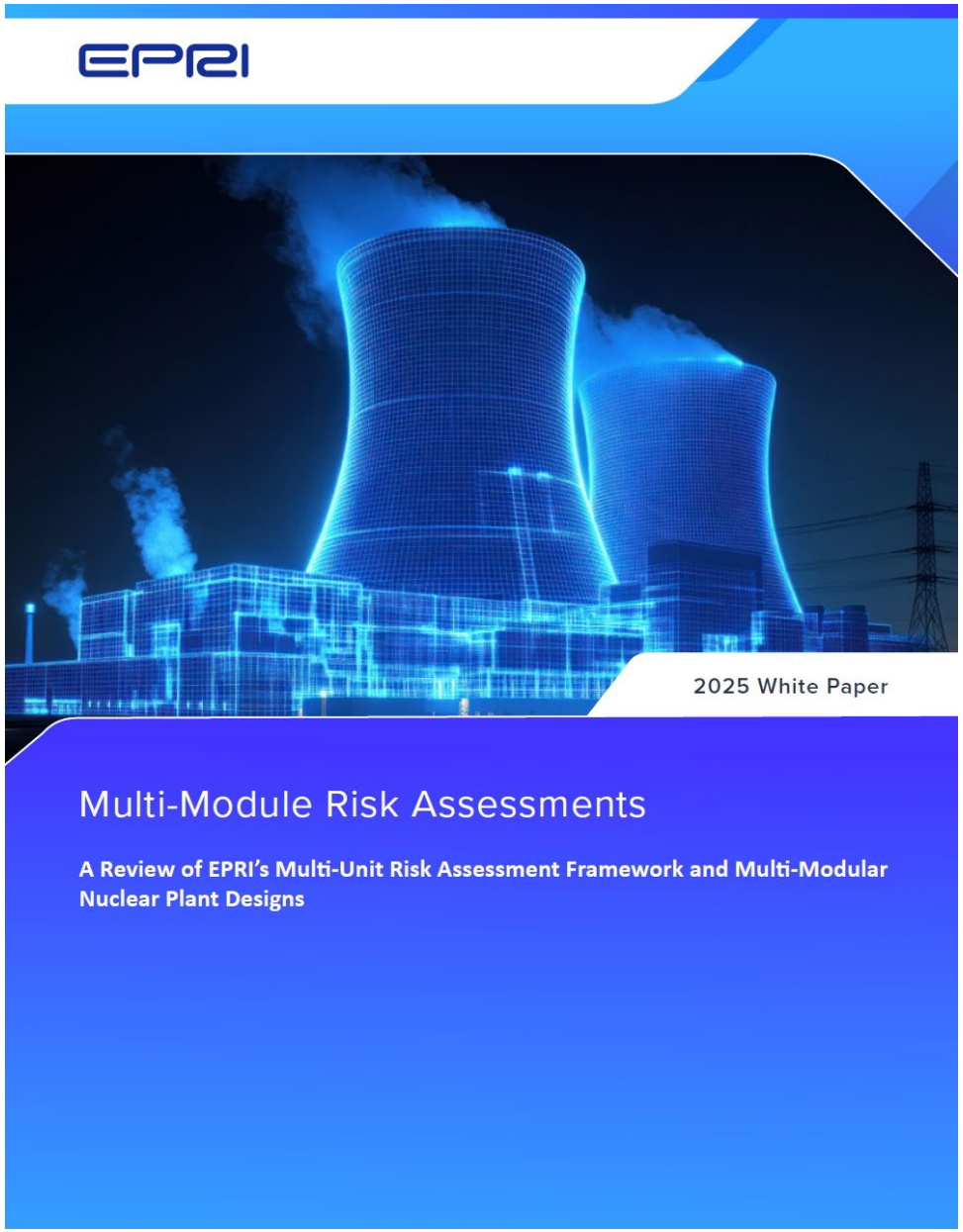
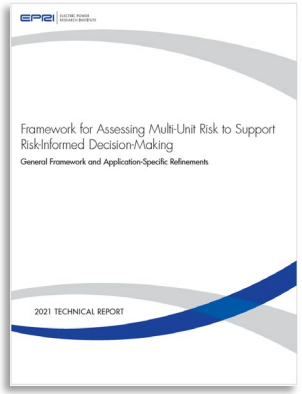
Introduction

- Thank you to Eric Thornsbury (EPRI), and Andrea Maioli (WEC) for supporting this research.
- Based on the insights presented in the 2025 EPRI whitepaper 3002032033.
- The whitepaper explores regulatory definitions, design characteristics, and operational considerations influencing tightly coupled reactor modules.



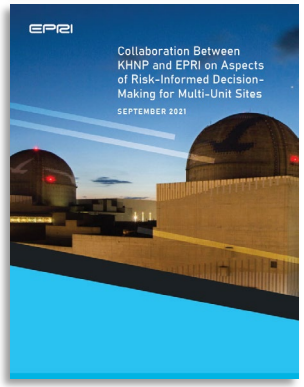
EPRI's Multi-Unit Framework and Research



3002020765 (2021)

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

Free to the public



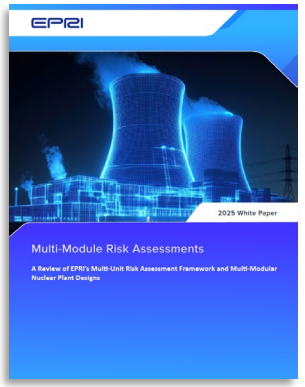
3002020756 (2021)

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

3002029304 (2024)

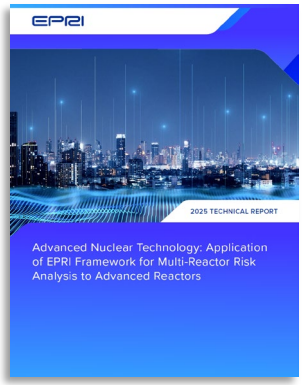
Application of Multi-Unit Probabilistic Safety Assessment Strategies in Canada – Multi-Unit Risk for CANDU Nuclear Generating Stations Operating in Canada

Considerations for Next Generation Sites



3002032033 (2025)

Multi-Module Risk Assessments: A Review of EPRI's Multi-Unit Risk Assessment Framework and Multi-Modular Nuclear Plant Designs



3002032224 (2025)

Advanced Nuclear Technology: Application of EPRI Framework for Multi-Reactor Risk Analysis to Advanced Reactors

EPRI's framework supports a graded approach, building from single-unit assessments and considering the degree of coupling between units. This framework is broadly applicable to different degrees of coupling and is generally suitable for future technologies and site configurations.

Multi-Unit Considerations

Shared Systems

Units at the same 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 may depend on the number of units involved in an accident, the amount of available equipment, and available resources.

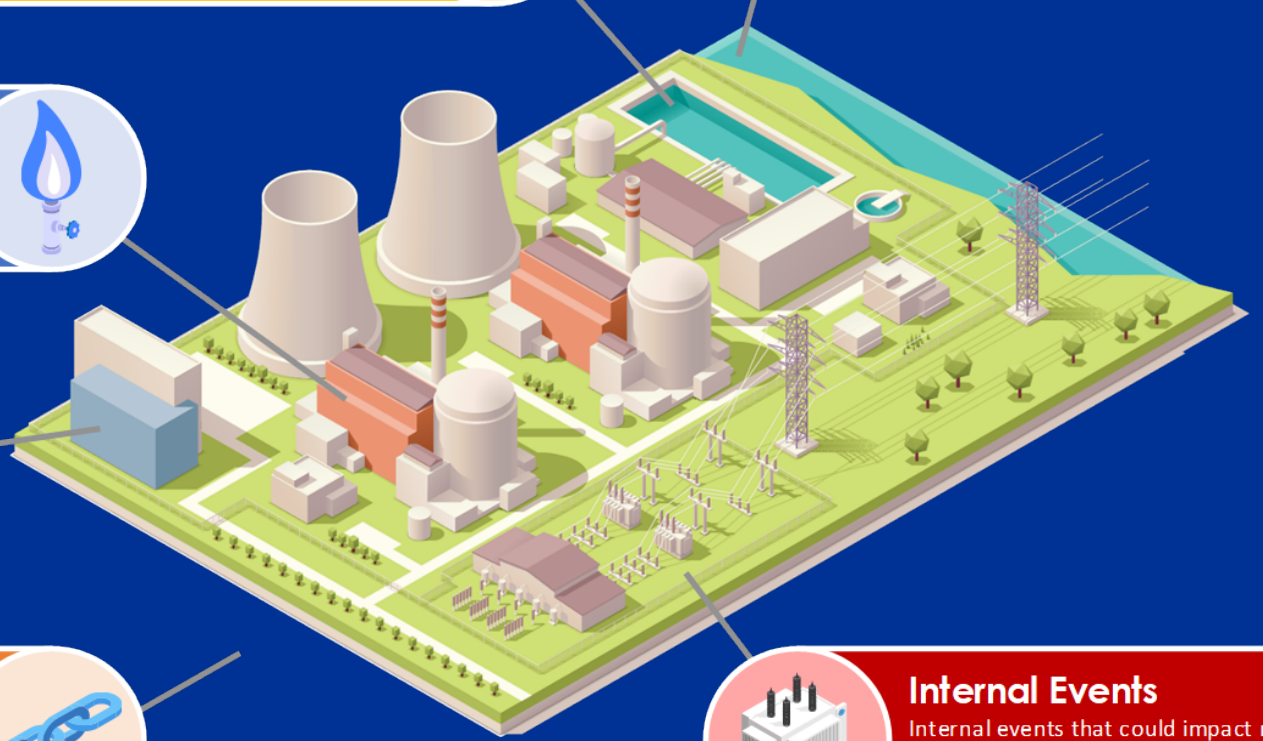
Shared Structures

Units may share structures (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 as an accident progresses.

Inter-Unit Support

Inter (between) -unit support (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.

The Potential 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.

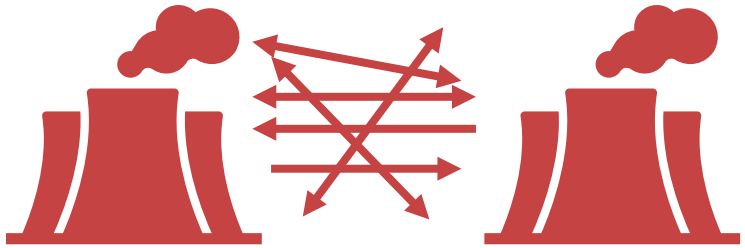
Common Cause
Consideration of cross-unit common-cause failure event grouping and parameter estimation.

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

Degree of “Coupling” Between Units

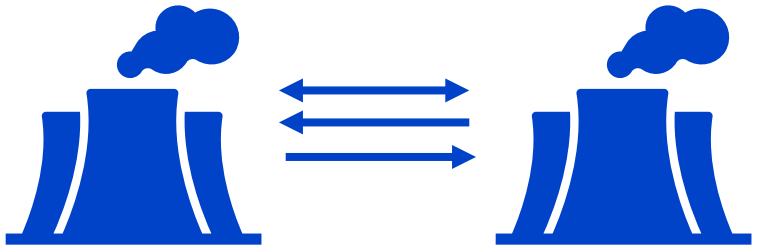
For practical purposes, ranges exist

Tightly-Coupled



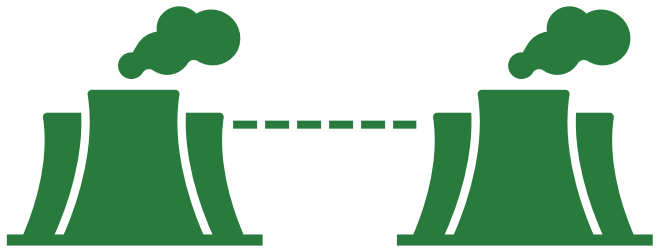
Tightly-coupled sites/units have complex dependencies between the units. Some qualitative screening may be possible. These complex interactions may require complicated risk modeling but may also provide benefit when considering mitigation pathways.

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

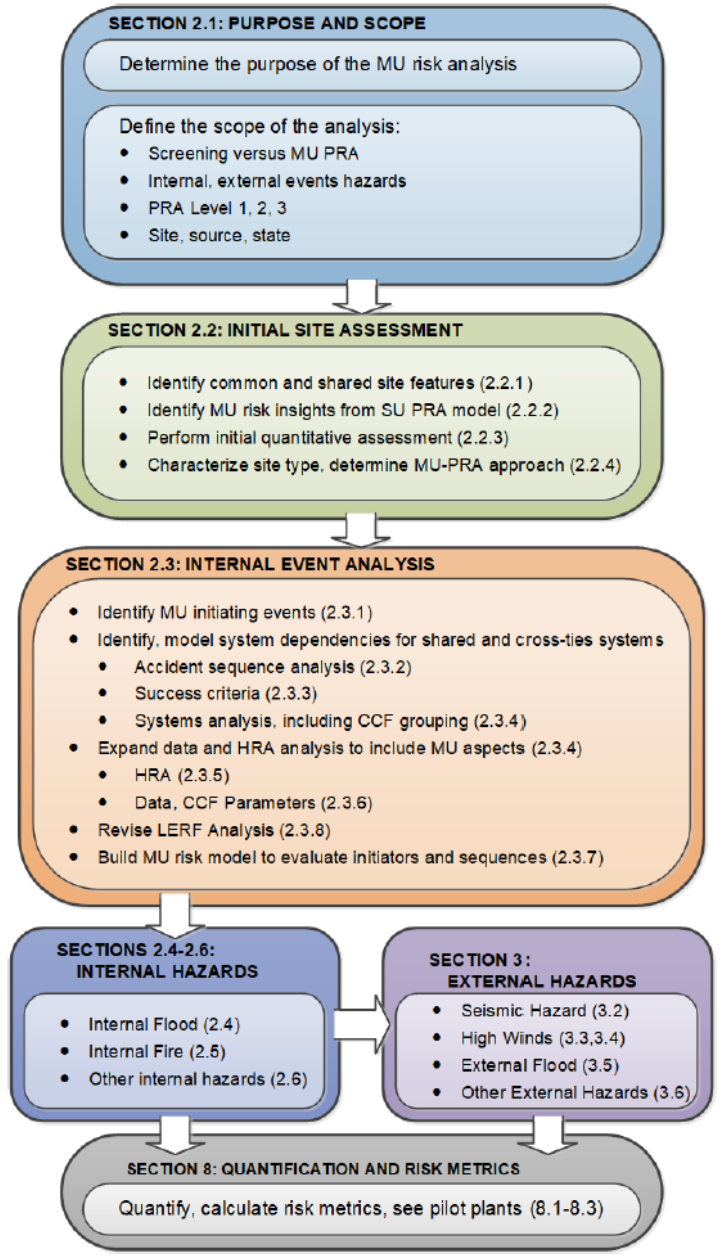


Uncoupled sites/units present an opportunity to screen out specific multi-unit aspects. There may be some coupling due to physical proximity, such that external hazards may dominate the multi-unit risk assessment.

Multi-Unit Risk Assessment Framework

The multi-module research finds that while unique configurations and designs may need tailored risk assessment approaches, in general, **current multi-unit framework's remains broadly applicable**.

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



See EPRI report 3002020765

Industry use of the Terminology

- The term **modular** has been used in the description and characterization of small modular reactors (SMRs) to:
  - describe the scalable nature of a specific design
  - describe the ability of a design to support different purposes
  - describe a design's construction methodology

- A **module** is comprised of a reactor and its associated safety and control features. This may include independent or integrated end use. Each reactor module is independent, and additional modules can be added over time. this definition is not fundamentally different from the current definition of a reactor unit.

- A **multi-module configuration** is comprised of multiple identical, independent, co-located reactor modules, potentially within a common structure, such that the same hazard can impact multiple modules, and/or be affected by events occurring at another module due to proximity and lack of physical separation.

Overview of Questions Asked and Insights Gained

What does "multi-module" really mean?	Seems to be a general "industry term" without a specific difference.
Is multi-module risk analysis fundamentally different from multi-unit risk analysis?	Based on a review of research, frameworks, and vendor feedback, no.
What are the key elements that differentiate multi-module risk from multi-unit risk?	There does not seem to be a specific difference between the two concepts.
How does EPRI's current multi-unit framework, support multi-module risk analysis?	In general, it applies, with some design specific considerations.

What are the key research questions that need to be answered?

Unit Coupling

It's difficult to model the different degrees of coupling and dependencies between units – for example, inter-unit common cause failure, human dependencies. Also, there are limited data sets to support detailed evaluations.

Risk Aggregation

It's challenging to appropriately aggregate the results of risk models that use different levels of detail (screening vs. full scope) and that carry varying degrees of uncertainty in their risk evaluations.

Model Complexity

Large/detailed multi-unit risk assessments are pushing current software tools and computational resources to (or beyond) their limits, resulting in longer quantification times.

The Human Element

When the same room or workstation is used to control multiple units, additional methodologies for assessing performance-shaping factors, such as stress and clarity of indications, may be needed. This includes communication and interfaces between operators across multiple units, as well as command-and-control associated with a multi-unit accident sequence.

Operating States

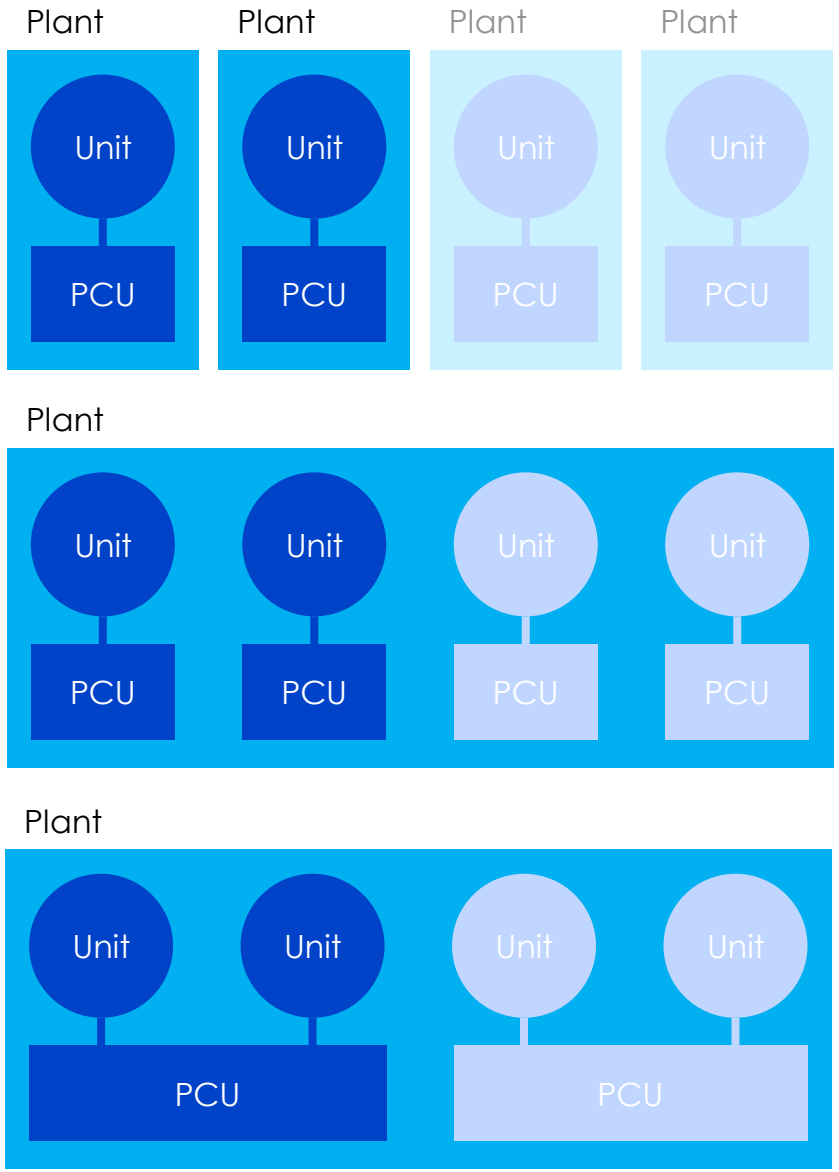
It can be difficult to account for the various combinations of plant operating states (at power or refueling), especially at sites with multiple units in different states.

Thoughts on Unit Coupling

- **Loose:** Designs that utilize a modular approach similar to current single-unit plants.

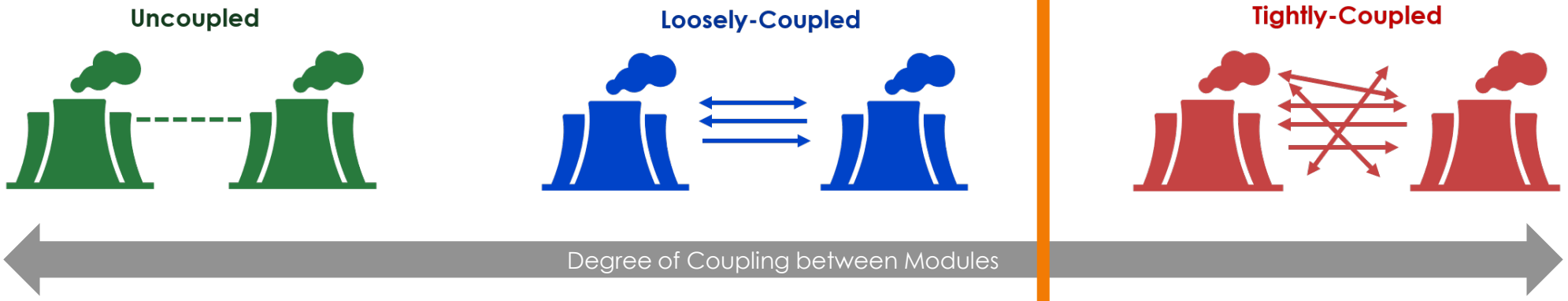
- **Tight:** Designs that locate multiple modules in a common structure or building.

- Independent vs. shared:
  - Containment structure
  - Power conversion units (PCUs)
  - Engineered safety systems
  - Control room



Thoughts on Unit Coupling

Consider the CANDU experience



	Site-Level	+ Cascading
Initiators	Accident sequences due to site-wide initiating events that impact multiple modules concurrently due to their physical proximity and/or shared resources (e.g., LOOP and external hazards).	Events in one module that impact the others (e.g., internal events and internal hazards).
Response	**Less Dependent**	**More Dependent**
	Considerations for CCF across modules, site or plant level responses to external hazards, sitewide command-and-control and the availability of various resources when responding to the accident sequences.	Considerations for shared/common control rooms, dependent human actions, dependent failures, and considerations for different operating states across multiple modules

Balance the Effort with the Potential for New Insights

- If following a phased approach to model development (single, then multi), consider how a **single-module risk assessment can be utilized, leveraged, and modified** to gain new multi-module insights.
- Apply additional detail and complexity where it could **identify new insights** beyond the single-module analysis.
- Consider how **different levels of detail** can support the development of both qualitative and quantitative insights.

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

IAEA Safety Report No. 110

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