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Exploring the Need for Standard Approaches to Addressing Risk Associated with Multi-Module Operation in Plants using Small Modular Reactors

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Overview

- Background
- Multi-Unit and Multi-Module PRA Development
  - Current activities
  - Key technical issues
- Standards for Multi-Unit/Module PRA
- Conclusions

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Background

- A number of past studies of multi-unit risk exist, e.g.,
  - Seabrook
  - Browns Ferry
- Significant increase in interest in multi-unit PRA following accident at Fukushima
  - Simultaneous accidents in multiple units
  - Release of radioactivity from multiple sources
- Multi-module plant designs revealed during NRC pre-application engagement with small modular reactor vendors
  - Next Generation Nuclear Plant (multi-module HTGR)
  - NuScale (multi-module iPWR)
  - mPower (multi-module iPWR)

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Developments in Multi-unit/module PRA

- Multi-unit PRA development
  - PRA methods development with applications
    - multiple researchers in many countries
  - Integrated site level risk assessment
    - USNRC
- PRA development for Small Modular Reactor Designs
  - NuScale
  - Next Generation Nuclear Plant – INL
  - Licensing Modernization Project (DOE/Southern Co.)
  - Integrated simulation platform that combines PRA tools with multi-physics model-based simulation tools – multiple national Labs

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Some Key Technical Issues

- Identification, Classification and Modeling Unit-to-unit Dependencies
- Risk Metrics
- Dynamic Simulation Based PRA

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Unit-to-unit Dependencies

- Schroer and Modarres identified six main dependence classifications
- Le Duy developed a schema that includes two types of initiating events and three types of system dependencies
- NuScale:
  - considers six mechanisms that could couple an initiating event between multiple reactor-modules
  - thirteen potential coupling mechanisms between systems

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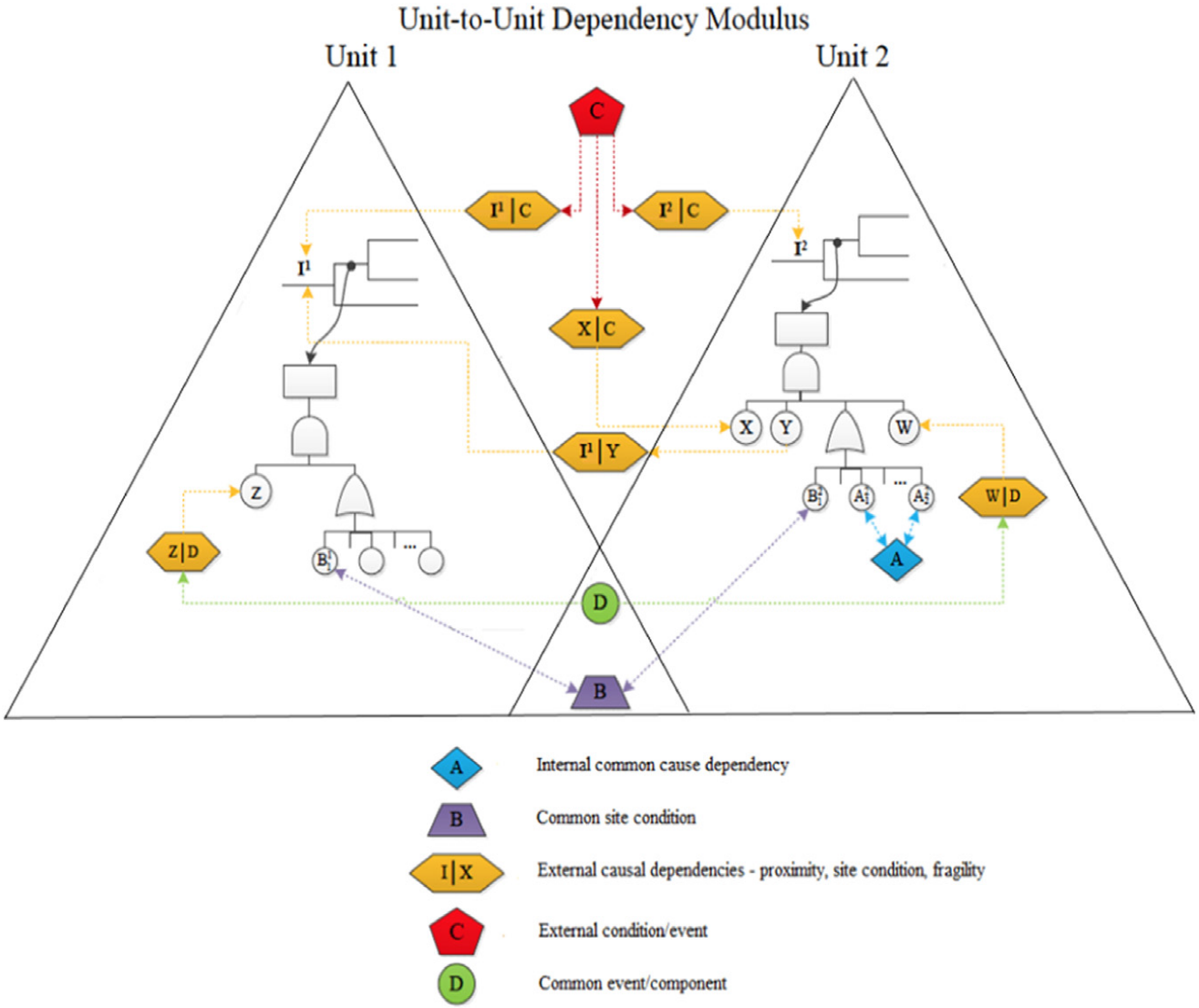
M. Modarres et al., Conceptual Example



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Le Duy Classification of Initiating Events

Event Class	Type I Events (single unit events)	Type II Events (multi-unit events)
Internal Events	only effects one unit	can affect multiple units due to common source or propagation
Internal Hazards	fires, floods etc. that cause an event in one unit only, or an internal hazard which does not cause an event in the home unit but propagates to another unit and causes an event in that unit	fires, floods, etc. that cause an event in the home unit and spread from one unit to other units and cause events in those units also
External Hazards	N/A	external hazards (e.g. seismic events, extreme winds, external flood, etc.) are those events which originate outside the plant and may potentially affect both units at the same time

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Le Duy Classification of Common Systems

Common System Type	Identical Systems in Both Units	Systems with Unit Crossties	Site Shared Systems
Key Characteristics	have no possible interconnections	one system supports both units or identical systems in both units which can support either unit	unique for the site; may support both units at one time if designed to do so or one unit at a time
Important Failure Considerations	subject to inter-unit and intra-unit common cause failure	subject to inter-unit common cause failure	system failure impacts both units concurrently

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Risk Metrics

- Light-water reactor work focused on defining multi-unit versions of traditional single unit metrics (CDF, LRF)
  - NuScale has used probability of CD or LR in multiple modules conditional on CD or LR in an initial single module.
- Schroer and Modarres introduced the notion of site core damage frequency (SCDF) and several other researches have adopted it.
- Moddares has investigated alternative ways for expressing SCDF and SLRF

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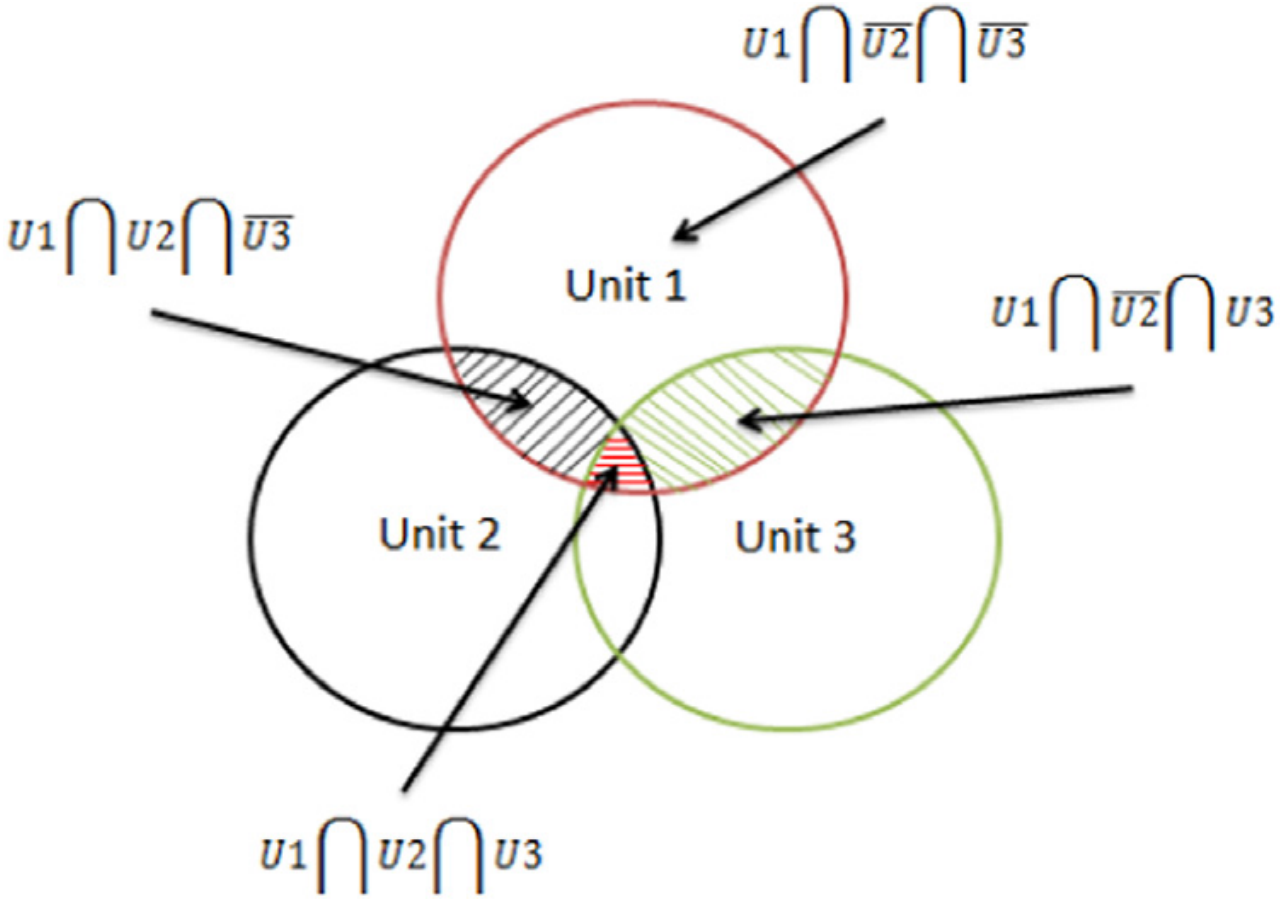
Modarres Depiction of Multi-unit CD as single event



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Risk Metrics

- CDF and LRF not best metrics for some non-LWR designs
  - HTGR
  - Molten salt
- Some metrics proposed for HTGR:
  - dose at the exclusion area boundary as a function of accident frequency
  - cumulative frequency of all BDBE sequences with dose to individual > 50 millisieverts should be less than 1E-6/reactor-year

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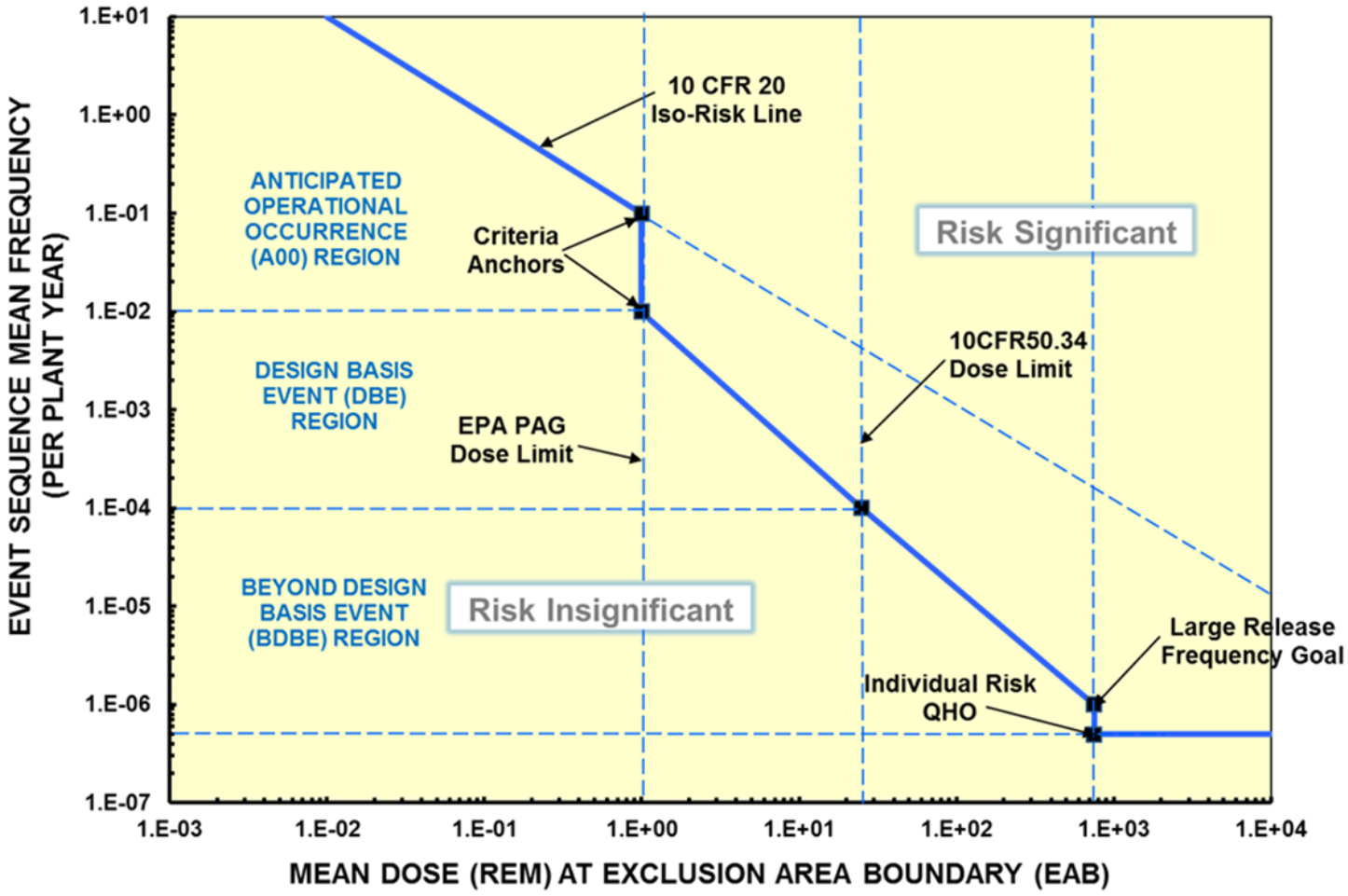
Frequency-Consequence Evaluation Criteria
Licensing Modernization Project



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Dynamic Simulation Based PRA

- PRA model is integrated with models that simulate physics of accident progression
- Method accounts for timing of events in the risk assessment
- Codes have been developed and refinement is an active area of research
  - University of Maryland is expanding the capabilities of the ADS-IDAC computer code to analyze multiple reactors in a dynamic PRA framework
- NRC and DOE are supporting this work

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Standards for Multi-unit/Multi-Module PRA

- Current PRA Standard endorsed by NRC is for analysis of a single unit or module
- Any dependency of unit under analysis on a sister unit(s) must be accounted for in the analysis, e.g.,
  - Shared systems
  - Cross-ties
  - Propagation of initiating event
- Consensus Standards for modeling simultaneous accident progression in multiple units or modules do not exist
- Some requirements for an integrated multi-unit Level 3 PRA included in draft Standard for non-light water reactors
  - Being informed by integrated multi-unit PRA development projects

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Conclusions

- Multi-unit and multi-module PRA methods develop is ongoing world wide
- Development of standards for multi-unit and multi-module PRA has begun and will be informed by development and application of multi-unit and multi-module PRAs
- Standards are needed to assure that true risks of multi-unit operation and multi-module designs are understood