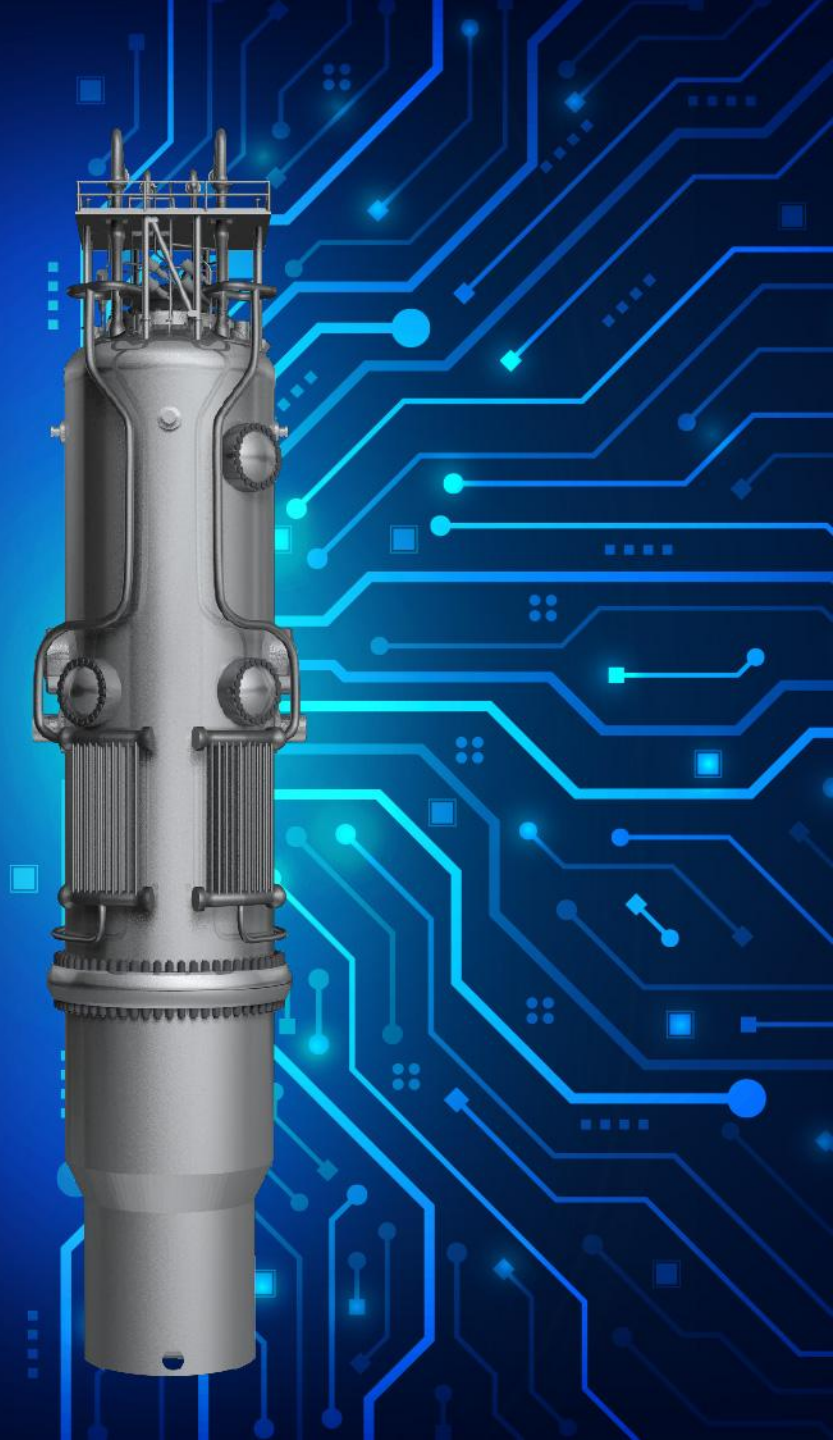




External Event Considerations in SMR Risk Assessment

2026 Biennial Workshop on Natural Phenomena Hazards (NPH)

Brandon Haley, Probabilistic Risk Assessment | NuScale Power
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About the Presenter



Brandon Haley

Probabilistic Risk Assessment Engineer

NuScale Power (2014 – Present): Probabilistic risk assessment engineer with expertise in system and component failure modeling and external hazard risk assessments.

Education

B.S., Mechanical Engineering, Oregon State University, 2012

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Agenda

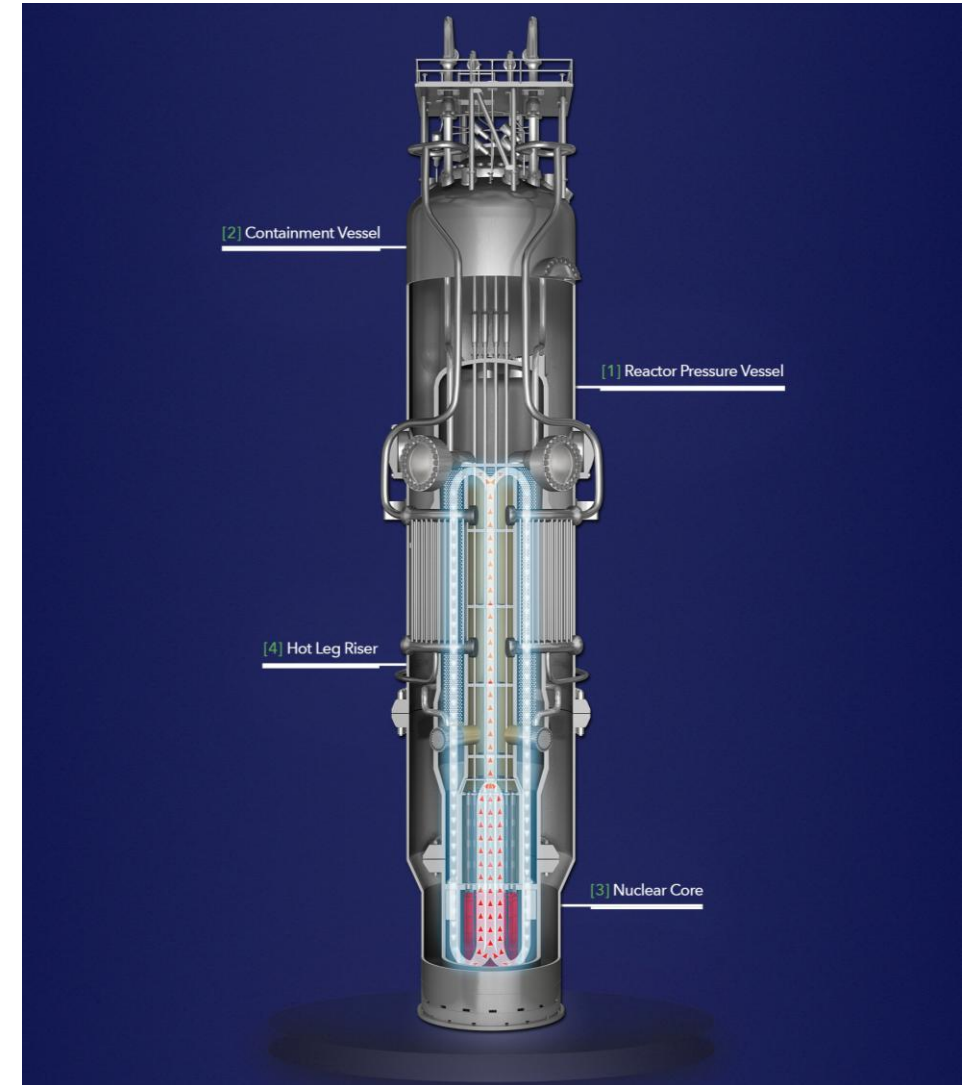
- NuScale Power Module (NPM) and Plant Design Overview
- Protections from Natural Phenomena Hazards (NPH)
- Risk Profile
 - Impact of Passive Safety Systems
 - Risk Comparison of Legacy and Advanced/Passive Designs
- External Hazards
 - Risk Contributions
 - Uncertainties
 - NuScale Seismic Margins Assessment (SMA) Example
- Risk Considerations and Summary

NPH Analysis Issues

- Design improvement has removed, reduced, or mitigated many traditional contributors to risk
- Uncertainties drive remaining risk for both likelihood and consequence, particularly for low-frequency, high-intensity external hazards
 - Relevant risk insights are obscured by underlying uncertainties that are not traditionally impactful, as well as corresponding conservative modeling simplifications
 - Creates difficult conditions for identification of further design improvement, as well as justification of risk modeling and uncertainty management within risk-informed applications

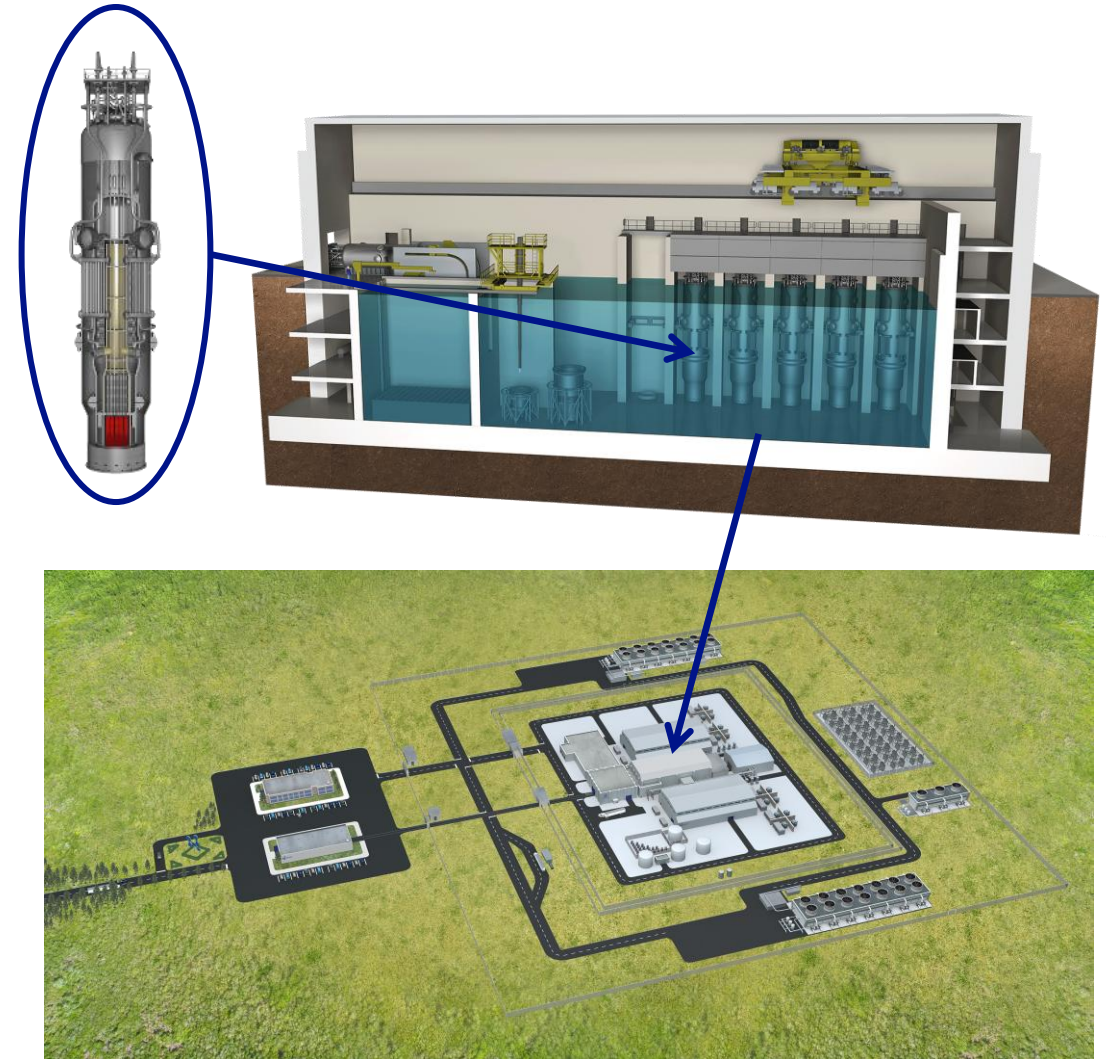
The NuScale Power Module™ (NPM)

- Integral pressurized water reactor
 - Reactor core, steam generators, and pressurizer contained within the reactor pressure vessel (RPV)
- Natural circulation primary loop, eliminates:
 - Reactor coolant pumps
 - Large diameter piping
 - Emergency coolant injection systems
- RPV housed in small, high-pressure steel containment vessel (CNV), partially submerged in the Ultimate Heat Sink (UHS)
- Passive safety systems
 - Automatic shutdown, automatic actuation of safety systems, indefinite cooling
 - Significant UHS inventory – NPM air coolable after 30 days
 - Safe shutdown without AC/DC power, operator actions, or added water



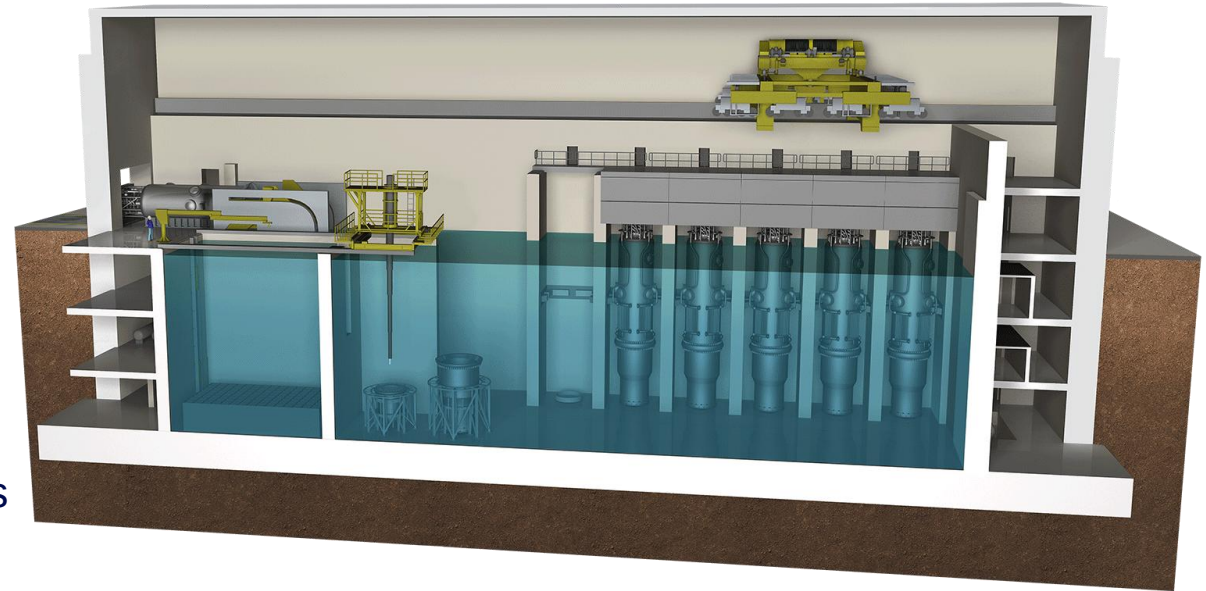
Plant Overview

- Multiple NPMs housed in the Reactor Building (RXB)
 - Each NPM produces up to 77 Mwe
 - Dedicated power conversion system for flexible, independent operation – limiting plant-wide trips
 - 100% turbine bypass capability
 - NPMs are incrementally added to match load growth
- Seismic Category (SC) I RXB
 - Partially below-grade
 - Physical protection of safety-related components from external hazards
 - UHS is completely contained within the RXB



Protection from Natural Phenomena

- Many external hazards expected to result in a loss-of-offsite power; successful plant response is
 - Actuation of passive safety systems
 - Core heat removal to the UHS
 - Operator actions, active nonsafety systems, and makeup not required
- Protection afforded to NPMs by RXB, and independent passive safety systems
 - Reduces vulnerability to external hazard sequences
 - Hazard uncertainties are managed through robust design and reliable response of passive safety systems
- Low absolute risk – high-intensity external hazards dominate relative risk
 - Managed by understanding margins, interactions, and uncertainties



Risk Profile of the NPM

- Risk is very low
 - Independent passive systems (e.g., ECCS, DHRS, CNTS)
 - Active support systems available for beyond design basis events
 - No single event or hazard dominates risk
- External Events
 - External hazard insights come from understanding where structural margins tighten under extreme loading (e.g., SMA – proximity interactions)

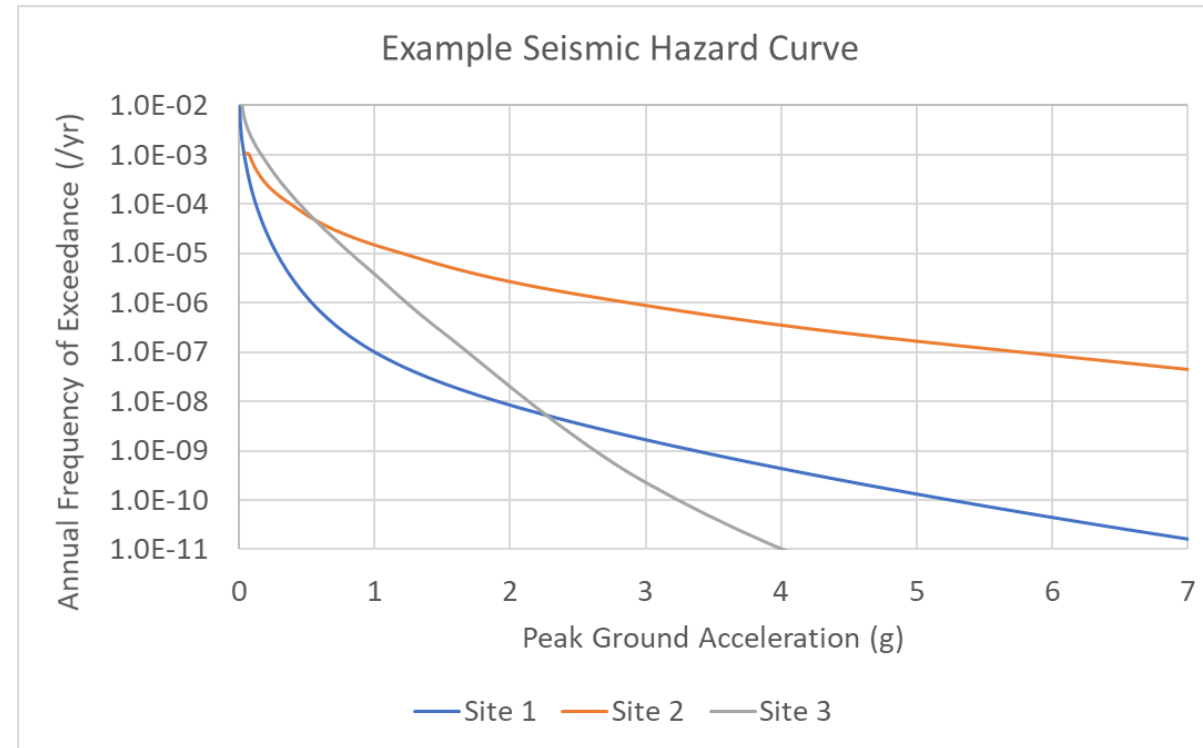
Table 19.1-60: Revision 2 of Chapter 19 of the NuScale US460
Standard Design Approval Application

Full Power (per mcyr)				
Hazard	CDF (mean values)	95th percentile	LRF (mean values)	95th percentile
Internal Events	6.0E-09	2.1E-08	6.6E-13	1.5E-12
Internal Fires	4.6E-09	1.6E-08	1.3E-11	3.0E-11
Internal Floods	1.6E-10	5.5E-10	3.4E-14	2.8E-14
External Floods	9.5E-09	3.5E-08	1.4E-13	4.3E-12
High Winds (Tornado)	2.6E-09	9.5E-09	1.6E-13	4.9E-13
High Winds (Hurricane)	1.9E-08	7.0E-08	1.3E-12	4.3E-12
Seismic (SMA) ¹	0.92g			
Notes:				
1. A seismic margins assessment is performed; results are presented in terms of the HCLPF (i.e., peak ground acceleration at which there is 95% confidence that the conditional failure probability is less than 5%).				

*Results based on generic bounding site characteristics suitable for design; not site-specific hazards

Risk Profile – SMR Considerations

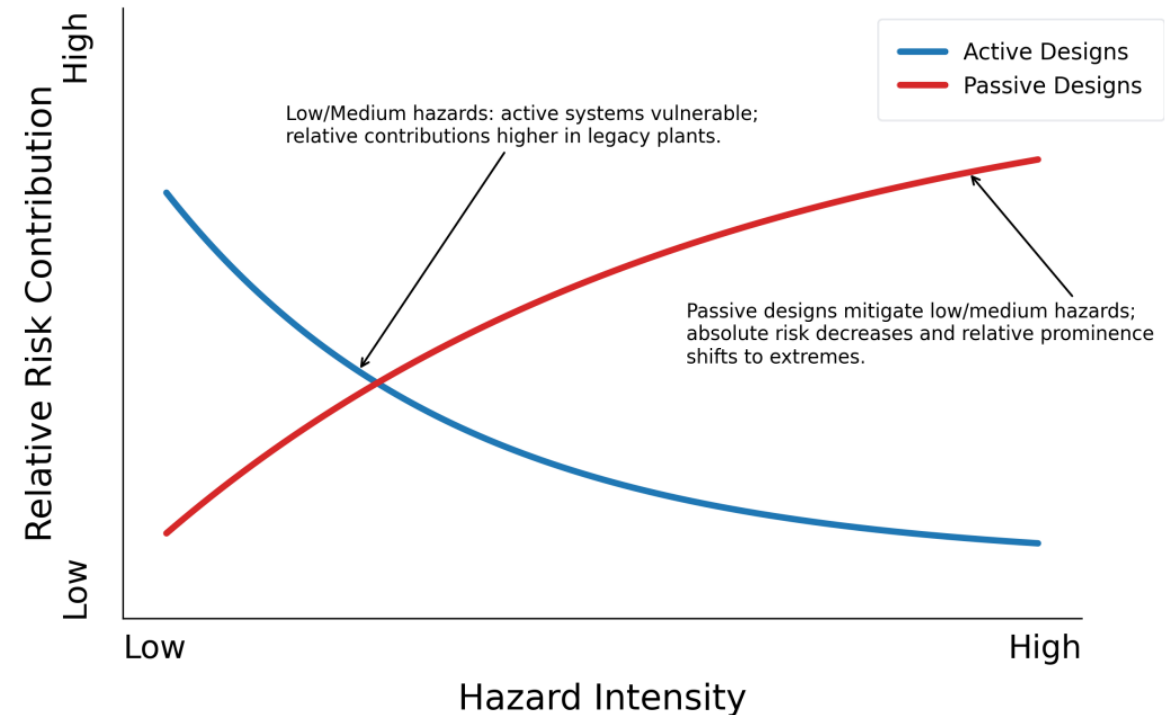
- Reduction of absolute risk contributors
- Passive safety systems remove contributions from low- and medium-intensity events
- High-intensity events impose large loads on plant infrastructure (e.g., reactor building, heavy equipment, proximal members)
- Bounding simplifications are applied for high-consequence, high-uncertainty scenarios
- High uncertainties impose a “floor” (i.e., hazard curve flattening) on hazard frequency
 - Increases in aleatory and epistemic uncertainties
 - Age of earth $\sim 2\text{E-}10$



Risk Profile – SMR Considerations

- Risk reductions near analytical screening thresholds or numerical truncation levels
 - High-reliability passive systems
 - Reduced dependencies on support systems
 - Rigorous structure design criteria
- Increases relative risk contributions attributable to low-frequency, high-intensity external events
 - Only extremely severe events that challenge passive and active strategies drive residual risk
 - Increases relative risk contributions from extreme loading (e.g., seismic) on major structures

How Passive Designs Reshape Relative Risk Contributions



Risk Profile Comparison

NuScale SMR Design

- High-frequency, low-intensity events contribute minimally to risk because of passive safety system responses
- External hazards pose negligible risk
 - Lack of reliance on affected site equipment
 - Some extreme hazards are screened-out on low frequency against more likely scenarios
 - Passive designs with hardened site infrastructure intentionally minimize hazard impacts, reducing associated risk contributions

Conventional Design

- Higher combined absolute risk, though lower relative risk attributable to high-intensity external hazards
- Severe external hazards often contribute minimally to overall risk; higher likelihood but less extreme events still require:
 - Active mitigation dependent on availability of electrical power
 - Operator actions and personnel access

Example: NuScale External Hazard Analysis

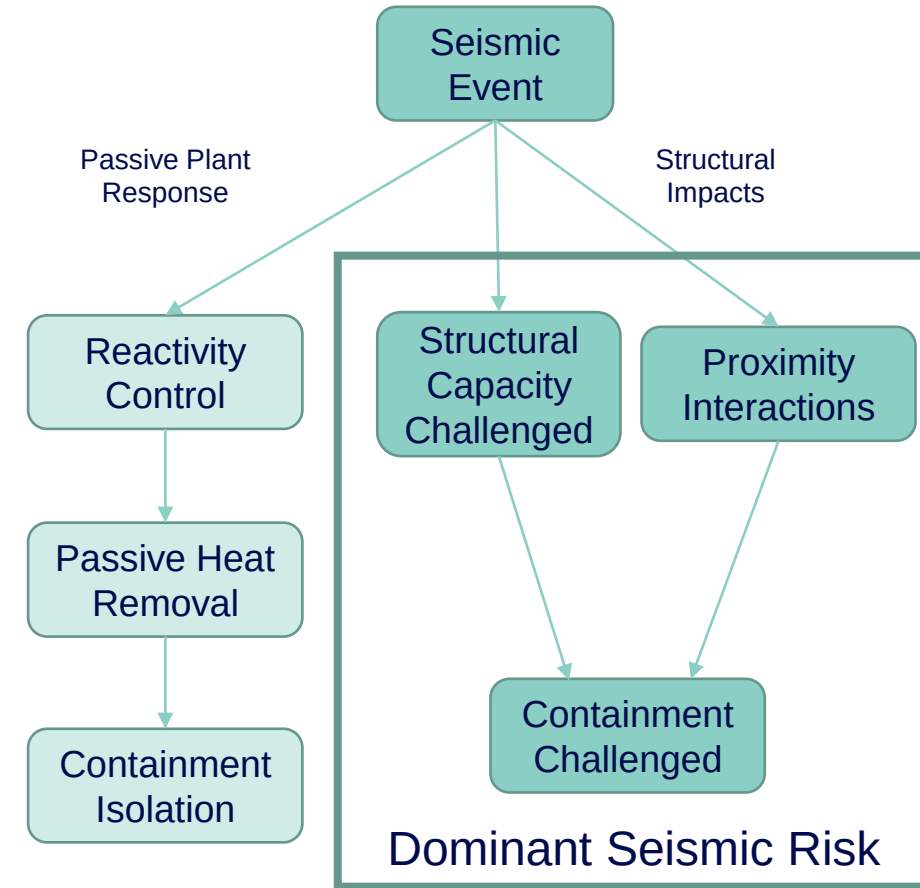
- Passive system response
 - External hazards assumed to result in a site-wide initiating event
 - No consideration of active support system availability for beyond design basis events
 - Response by safety-related, independent, passive systems housed in robust seismically-qualified RXB
 - Protected UHS
- Physical impact to plant structures; potential examples depending on site characteristics:
 - Direct seismic accelerations on plant structures and equipment
 - Volcanic impacts from lava flows, tephra

Example: NuScale SMA

- Risk contributions from SMA
 - Failure of structures and proximity interactions with heavy equipment and substructure members drive risk
 - Negligible impacts from loss of electrical power
 - At high ground motions, post-initiator operator actions may be impractical (e.g., access obstructions) – compromising control/availability of nonsafety active mitigating systems and success of operator actions
 - Minimal risk from low ground motions where power is available – robust passive systems
 - Minimal opportunities for support from mitigating systems at higher ground motions associated with dominant risk contributors (e.g., proximity impacts, no electrical power available)
 - Risk is predominantly driven by performance of structures in response to high-intensity events
- Physical demands on plant structures drive risk
 - Structure integrity and physical interactions

Example: NuScale SMA

- Important seismic accident sequences are those that compromise containment integrity directly
- Safety systems (e.g., ECCS, DHRS, CNTS) are fail-safe on loss of power or control
 - “Rigid” valve components have very high seismic capacities (i.e., random failures more probable)
 - High plant peak ground acceleration capacity driven by performance of structures, not plant response
- At low ground motions, all non-structural sequences are negligible contributors to seismic risk
- Structural failures are the dominant contributors to seismic risk (i.e., high ground motions drive seismic risk)
 - Risk contributions are driven by material performance (e.g., concrete, steel)



Example: NuScale SMA

- Risk metrics dominated by large, catastrophic events – absolute risk remains very low
 - Direct impacts to site facilities and infrastructure
 - Availability of societal services
- Frequency-related risk metrics (e.g., SPRA) are aligned with the shape and tail of hazard curves, which are often driven by large uncertainties
- Results in acknowledging large gross structure failures as significant risk contributors
 - Absolute risk remains very low – relative risk contributions increase
 - Limited practical opportunities for mitigation – highlights where potential enhancements (anchorage improvements, materials) may provide value commensurate with safety and risk
- Recognizing uncertainty in use of modeling conservatisms, including assignment of indeterminate sequence consequences

External Hazard Risk Considerations

- Risk significance (RS) determination
 - Contributions from very low frequency external hazards appear prominent, but only because of the low impact of high-frequency, less-severe hazards
 - SSC RS driven by conservative simplifications/assumptions; little connection to a credited function
- Emergency planning zone size determination
 - High reliability of passive safety systems shifts focus of sizing-basis to large seismic events with catastrophic consequences and significant uncertainty
- Frequency-weighted cost-benefit analyses
 - Focus on implementing practical safety improvements/risk reductions (e.g., structure capacity, robustness, and physical characteristics of construction materials)
 - Efforts balanced by the potential cost-benefit and risk improvement of implementing changes
 - For advanced reactor designs, likely limited benefit to increasing structure robustness above design-basis requirements (i.e., service level D limits) or beyond-design-basis margin metrics (i.e., plant-level HCLPF)

Summary

- Low baseline risk results in more focus on contributions from severe external hazards
- Passive system responses eliminate contributions from most high-frequency external hazards
- Risk contributions driven by external hazards with indeterminate or extreme consequences
- Changes paradigm of how external hazard risks are considered
 - Traditional risk contributions designed out; the relative share of extreme external hazards rise – even as absolute risk stays low
 - The breadth of uncertainties become more impactful on risk-informed applications
 - Continue to support adoption of practical and risk-informed frameworks; prioritize optimization of structural design and site-specific design, along with disciplined uncertainty management and accompanying risk interpretations
 - Emphasizes need for enhanced consideration of external hazards, including evolving hazard conditions (e.g., changes in hydrology, temperature, biofouling trends) as part of periodic reviews and screening confirmations



Thank You!

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