RISK-INFORMED PERFORMANCE-BASED (RIPB) DESIGN METHODS FOR EXTERNAL HAZARDS

Application of the Licensing Modernization Project (LMP) Criteria

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Risk-informed, Performance-based Principles and Policy Committee (RP3C) Community of Practice (COP)

4 April 2025

Research Overview

Objectives

- Evaluate ongoing industry activities on risk-informed performance-based (RIPB) design **for external hazards** following the Nuclear Energy Institute (NEI) 18-04 framework
- Identify challenges, gaps, and best practices for effective implementation for advanced reactors (ARs)

Approach

- Literature review
- Stakeholder input through surveys, workshops, etc.
- **Develop and execute demonstration design example (seismic)**
- **Summarize gaps, challenges, and best practices**
- Publish insights in EPRI 3002029295 (September 2024)

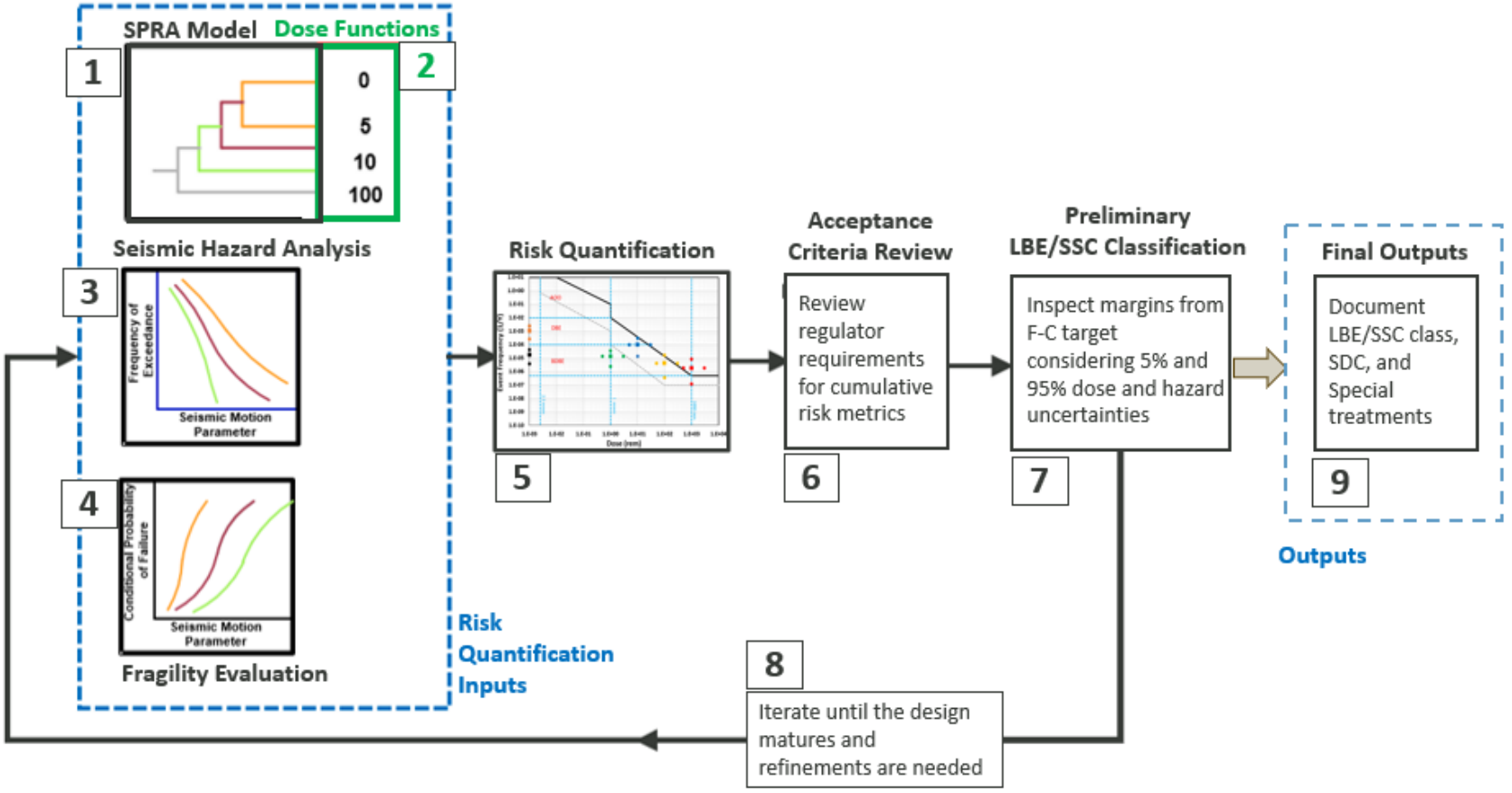
Demonstration Example

Framework Overview

Purpose: Demonstrate key parts of the process; identify challenges & needs.

Nine basic steps:

1. Plant Response Model
2. Dose Functions
3. Seismic Hazard Characterization
4. Seismic Fragility Evaluation
5. Risk Quantification
6. Acceptance Criteria Review
7. LBE and SSC Classification and Risk-Significance Review
8. Design Revisions / Trade-offs
9. RIPB Design Decisions



LBE: Licensing Basis Event

SSC: Structure, system, or component

Important Processes

Important processes exercised in the demonstration example:

- Defining LBEs (per NEI 18-04)
- Classifying LBEs and SSCs (per NEI 18-04)
- Iterating between design and probabilistic risk assessment (PRA) development / quantification
- Defining performance-based seismic design criteria and special treatments for SSCs
  - Includes code &standard (C&S) provision selection
- Estimating initial fragilities based on SSC's seismic design criteria
- Checking regulatory acceptance criteria following NEI 18-04 approach for external hazards
- Investigating options for design revisions and design decision-making

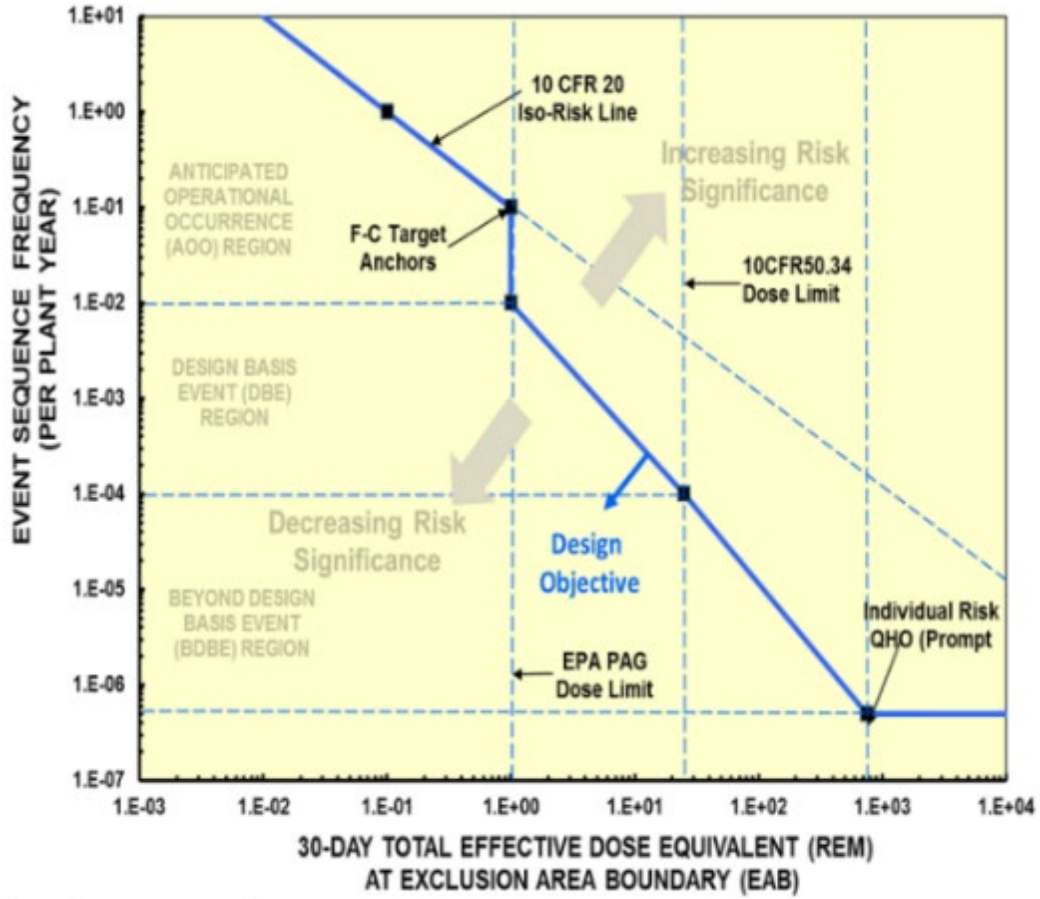


Figure 3-1. Frequency-Consequence Target

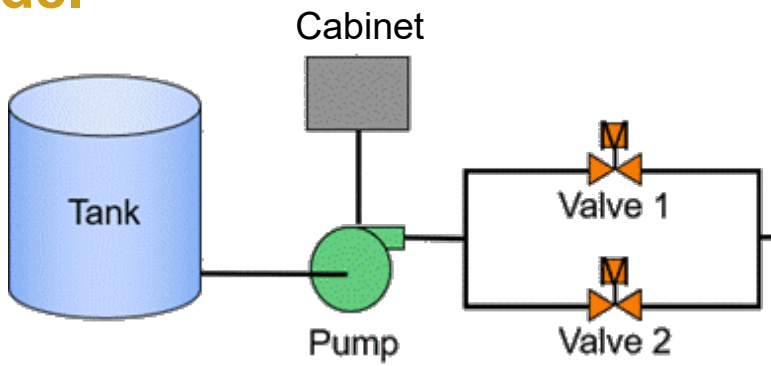
NEI 18-04: Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development.

Example System Model

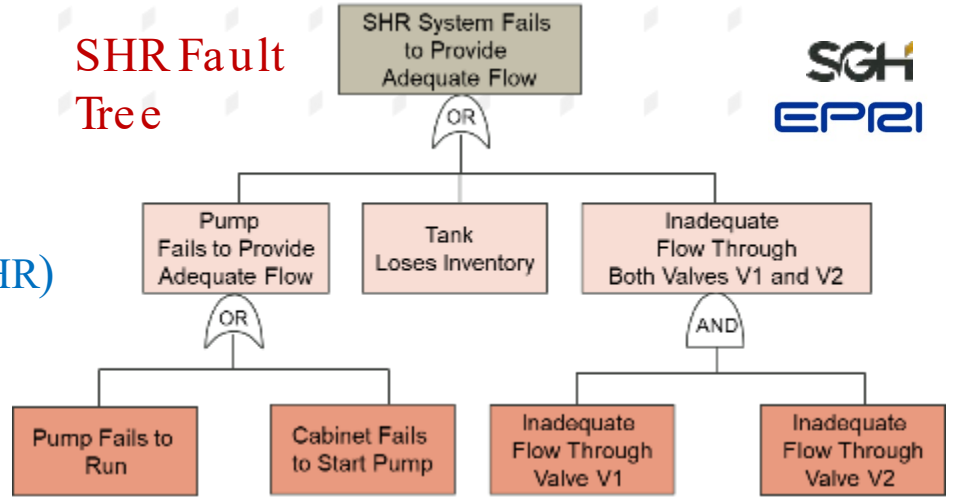
General, AR-relevant model

- For each item in the model, establish initial assumptions:
  - Safety-Related
    - Safety-Related design standards, factors of safety, performance requirements, etc.
  - Non-Safety-Related with Special Treatment
    - Commercial standards with special treatment necessary to achieve the performance target
  - Non-Safety-Related
    - Commercial standards, factors of safety, performance requirements, QA, etc.
- Each of these choices establishes the seismic fragility and resulting performance

System for Heat Removal (SHR)



SHR Fault Tree



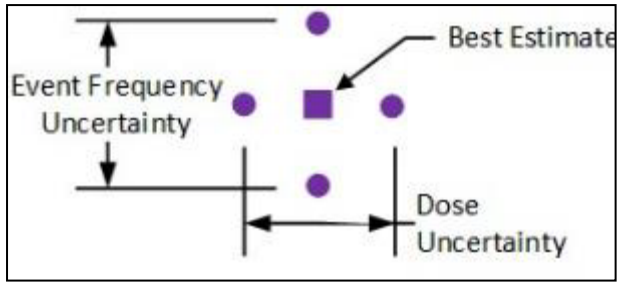
Event Tree

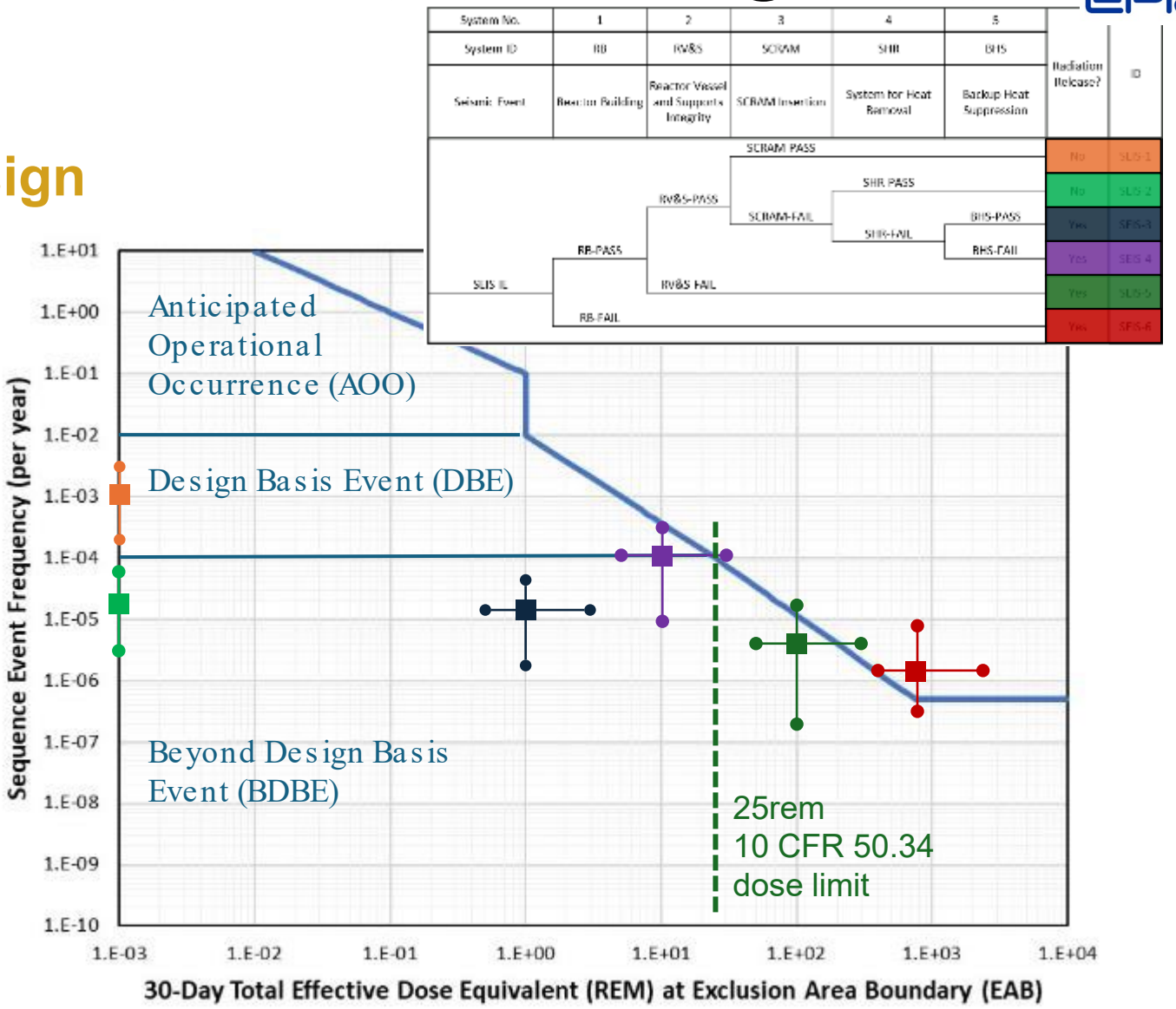
System No.	1	2	3	4	5	Radiation Release?	ID
System ID	RB	RV&S	SCRAM	SHR	BHS		
Seismic Event	Reactor Building	Reactor Vessel and Supports Integrity	SCRAM Insertion	System for Heat Removal	Backup Heat Suppression		
SEIS-IE	RB-PASS	RV&S-PASS	SCRAM-PASS	SHR-PASS	BHS-PASS	No	SEIS-1
					BHS-FAIL	No	SEIS-2
				SHR-FAIL		Yes	SEIS-3
			SCRAM-FAIL			Yes	SEIS-4
		RV&S-FAIL				Yes	SEIS-5
	RB-FAIL					Yes	SEIS-6

Frequency-Consequence – Initial Design

Key Results from Risk Quantification Using Initial Design Assumptions

- Several LBEs exceed F-C Target (unfavorable)
- One Design Basis Accident (DBA) based on the DBEs does not meet the 25rem regulatory dose limit in 10 CFR 50.34
  ➔Design revision is necessary

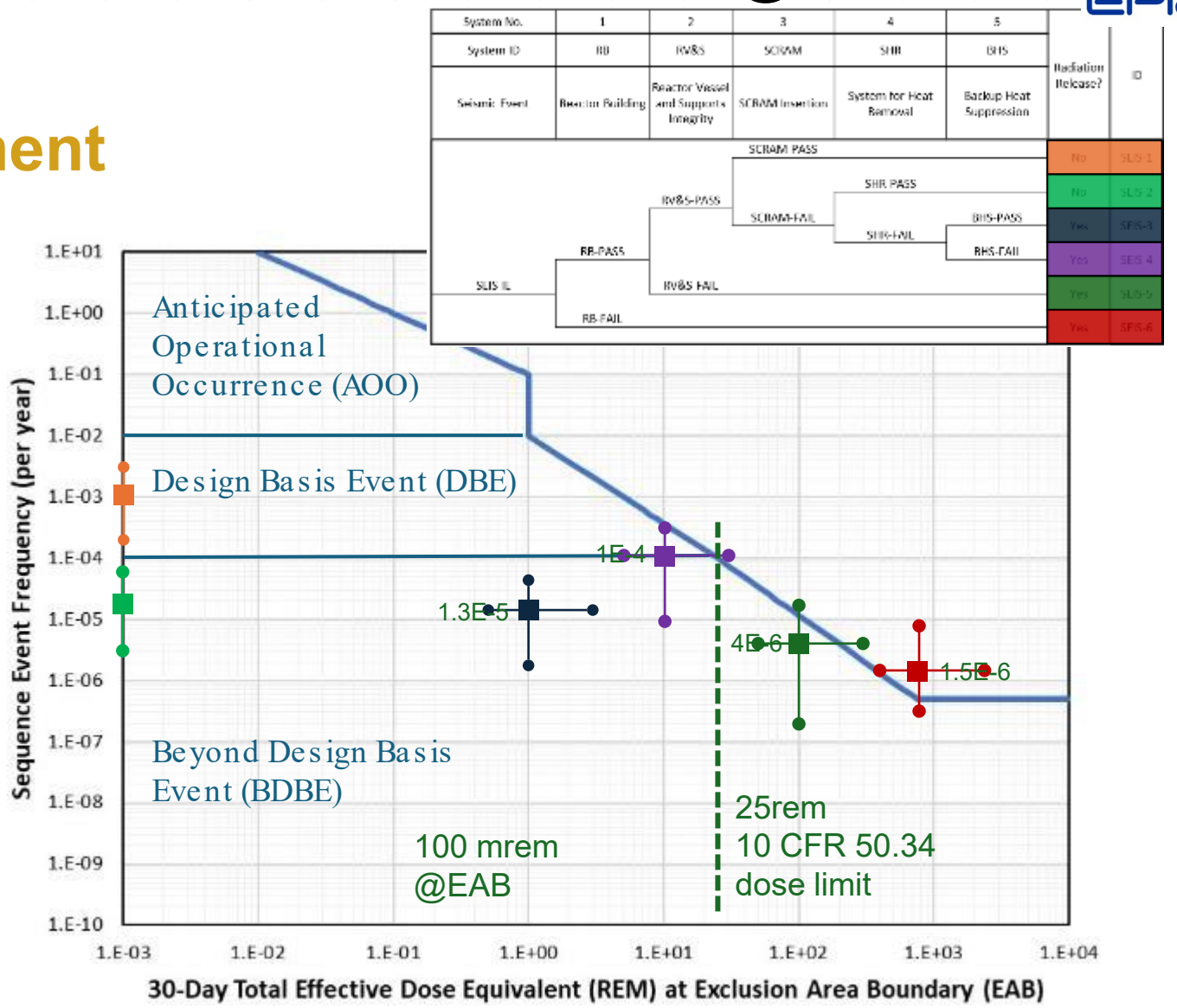




Frequency-Consequence – Initial Design

Cumulative Risk Requirement

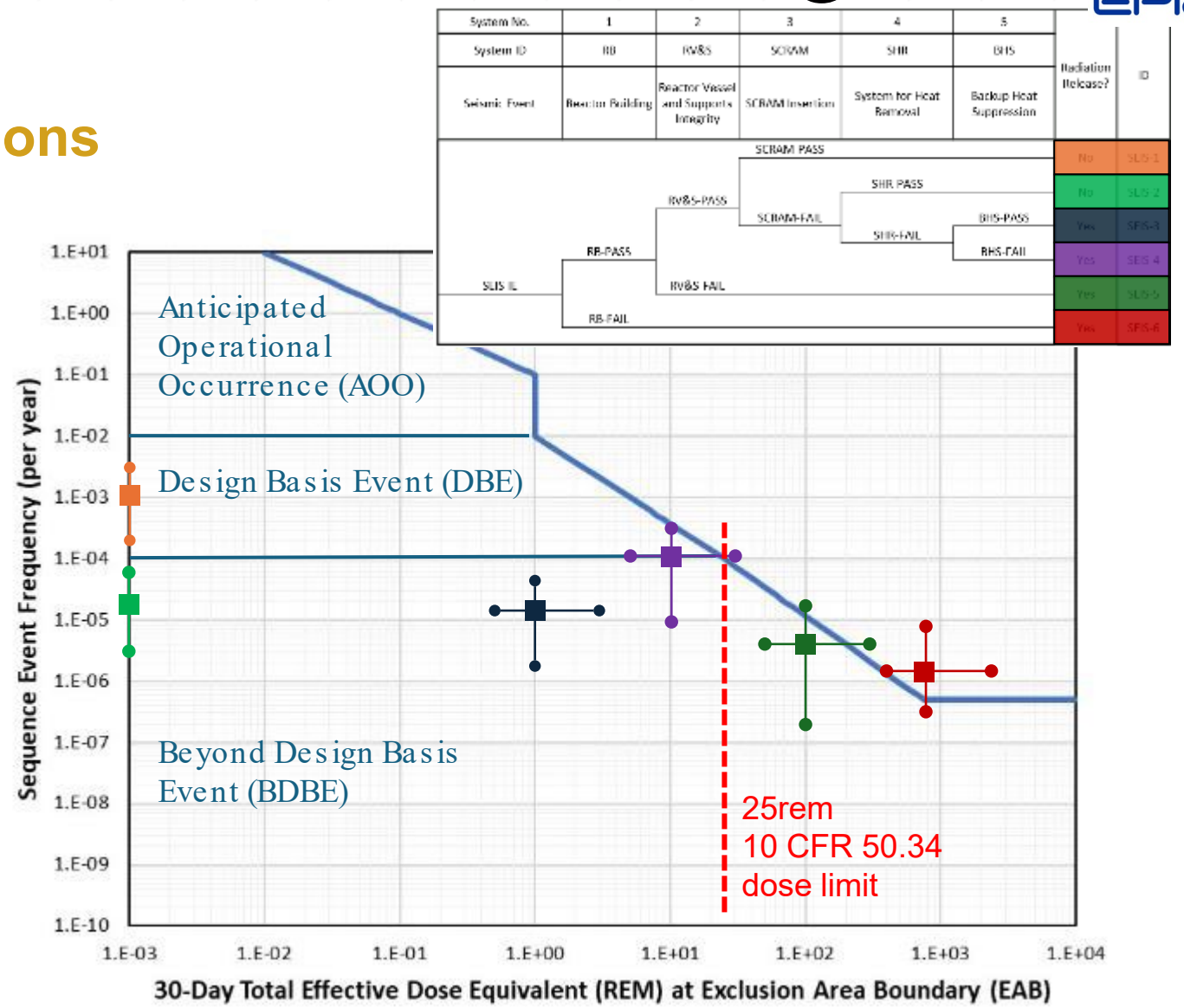
- Cumulative mean frequency of LBEs exceeding 100 mrem at the Exclusion Area Boundary (EAB)
- Meets regulatory requirement
  - Σ = 1.2E-4/yr << 1/yr (~0.01%)
  - Seismic only
- Quantitative health objective (QHO) req'ts not evaluated for simplicity
  - Requires dispersion analyses



Frequency-Consequence – Revise Design

Potential Design Revision Options

- Reconsider seismic design criteria selected for SSCs
- Impose special treatments on SSC designs
- Reclassify SSCs
- Limit dose consequences by introducing barriers
- Refine performance targets
  - Capability / limit state
- A combination of the above



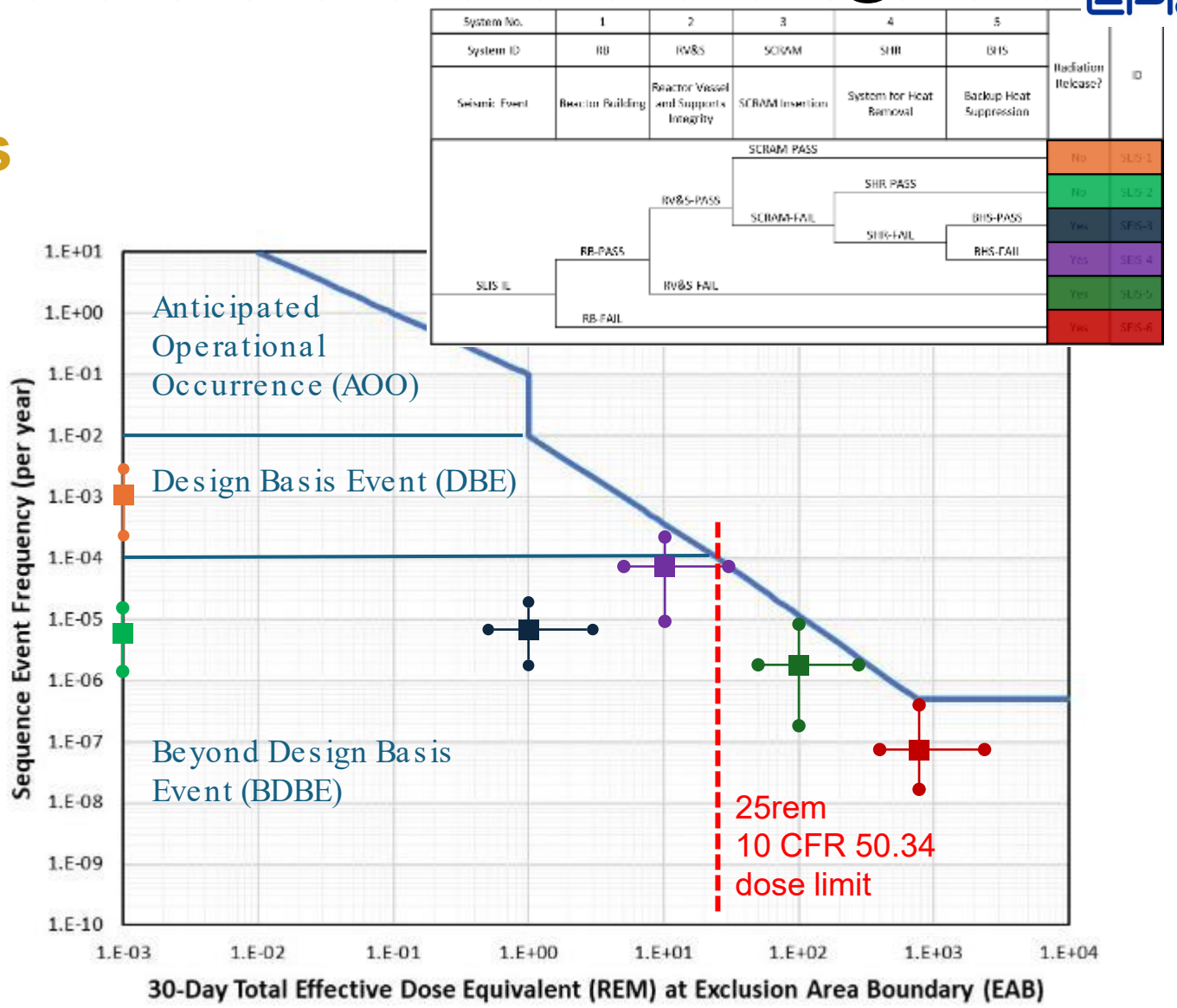
Frequency-Consequence – Revised Design

Selected Design Revisions

- Special treatment:
  - Limit the demand-to-capacity ratio for RB, RV&S, and SCRAM
- Best cost-benefit of several options considered

Key Takeaway

- LMP allows optimizing design for cost-benefit purposes as it progresses



Insights

LMP and RIPB Design for External Hazards – Insights

Challenges

- An initial PRA is needed at early RIPB design stages, which can be challenging since there is limited site-specific data and the early PRA insights may have high uncertainty
- Implementing RIPB/LMP framework requires close collaboration between multiple technical disciplines in design and PRA teams

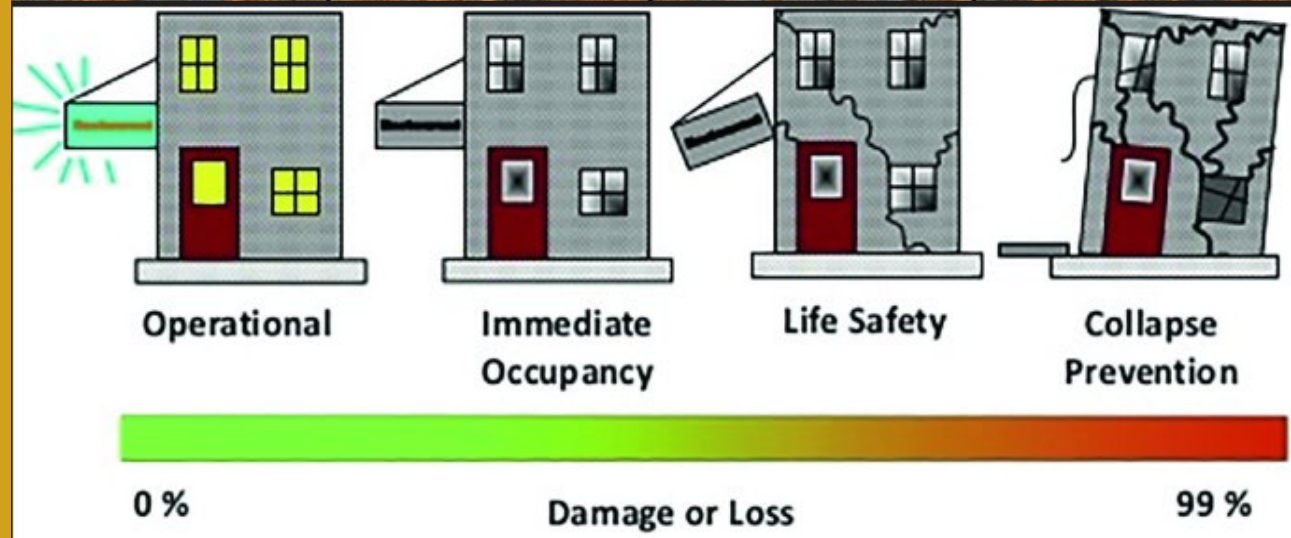
Benefits

- RIPB external hazards design can be used to risk-inform design requirements and holds potential to make plant designs more cost-effective, while maintaining high levels of safety
- RIPB design considerations can inform C&S selection

Follow-up research

- Criteria for risk-informed codes &standards for structural design
- Treatment of very rare seismic events in RIPB design

Code & Standard Provisions for RIPB Structural Design



C&S for RIPB Structural Design

Overall approach for follow-up EPRI research

- LMP enables performance-based design of structures
- Structural performance defined by reliability and capability targets
- Commercial C&Ss can be (are regularly) used for performance-based design of structures
- Demonstrate by simple example use of commercial C&Ss to achieve target performance
- Address additional considerations, anticipate & address objections
- Outline ideas for further development, provided NRC agrees with concept

Background & Motivation

- SR building structures are major cost contributors
  - RIPB structural design: an opportunity to optimize costs while maintaining robust plant safety
- NRC staff acknowledged that some endorsed nuclear C&S may not provide safety benefits commensurate with the additional costs (see 2024 Action Plan)
- Limited time to develop design guidance and regulatory certainty
  - Incorporating the RIPB approach into revisions of consensus codes and standards (C&Ss) and getting the NRC endorsement will take time
  - A parallel path to address nearer-term needs:

→ Use provisions from currently available commercial C&Ss to design structures

Key Elements

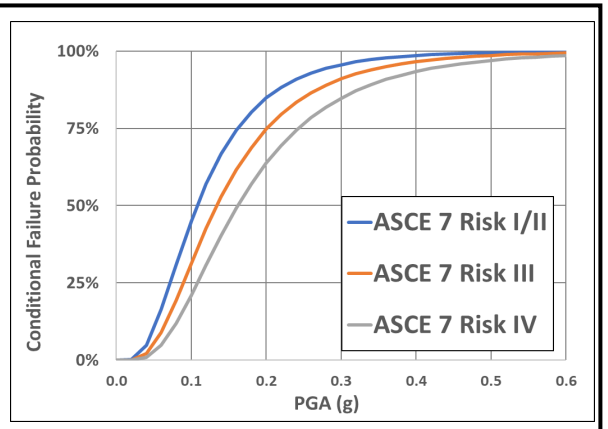
- **Capability targets** for structures are represented by limit states, beyond which they lose their ability to prevent/mitigate event sequences and the associated consequences.
- **Reliability targets** are the maximum allowable occurrence probabilities for those limit states, (expressed in terms of unconditional annual exceedance probabilities).

- A high-level implementation example will be used to demonstrate:
  - Specified reliability and capability targets can be achieved by commercial C&S provisions
  - Performance-based design using commercial C&S provisions can be implemented by performance targets that are informed by risk analysis

Example - reliability & Capability Target

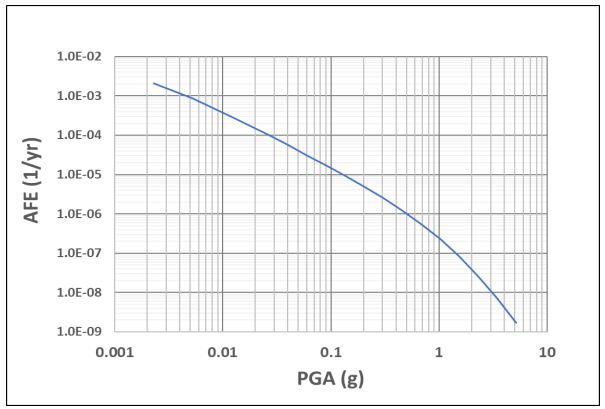
ASCE 43 vs ASCE 7

PRA Model



Structural Collapse Fragility

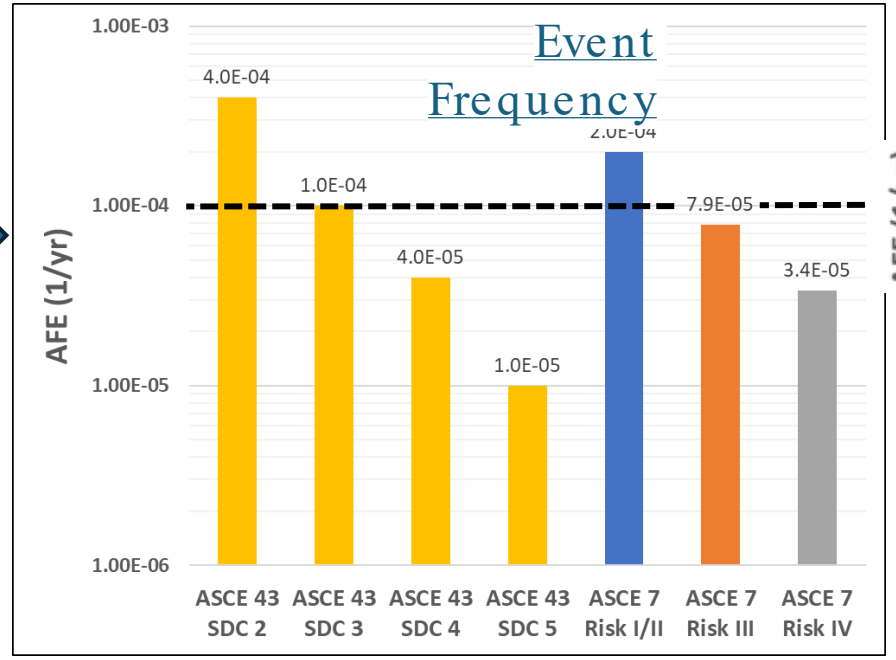
x



Structural collapse probability (as singleton)

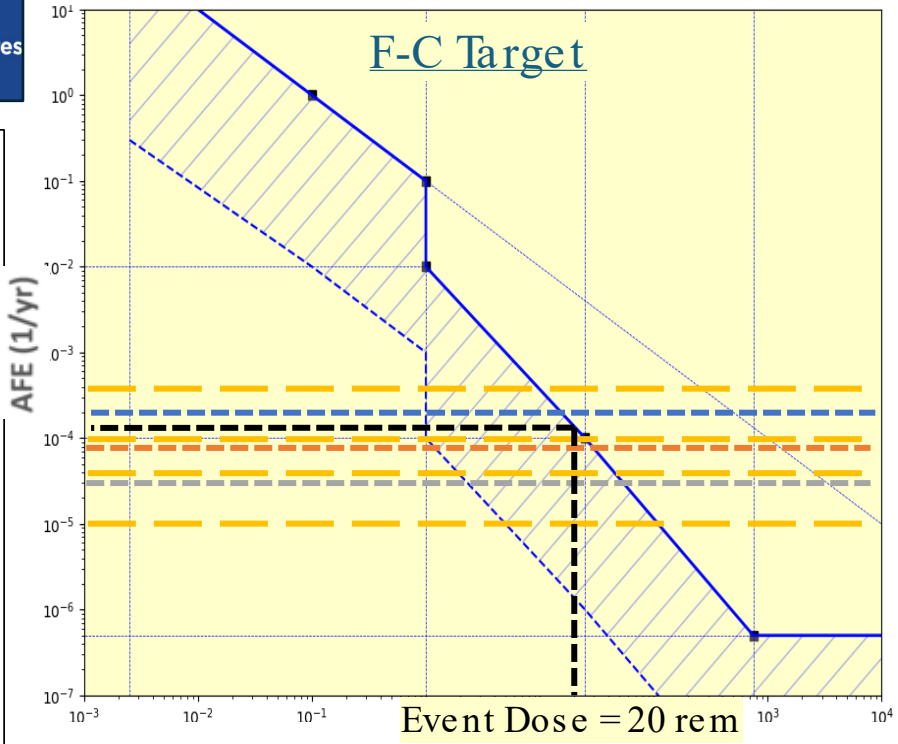
ASCE STANDARD ASCE/SEI 43-19 — Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

ASCE STANDARD ASCE/SEI 7-16 — Minimum Design Loads and Associated Criteria for Buildings and Other Structures



Resulting reliabilities

Disclaimer: Figures are to illustrate a concept only. Numerical values are works in progress and depend on various factors including site-specific information.



Target reliability - Max AFE (20 rem) ≈ 1E-4

Further Considerations & Anticipated Objections

Seems too easy. What else? The devil is in the details…

- C&S provisions not directly linked to reliability or capability
  - QA requirements (inspections, paperwork, etc.)
  - Materials requirements, e.g., higher strength, testing, prevention of aging mechanisms
- Gaps between nuclear and commercial C&S
  - Load combinations
  - Analysis procedures, e.g.:
    - Development of ISRS when designing for inelastic limit states
    - SSI analysis
- Guidance needed to drive consistency in implementation
  - Interpretation of margin levels available in various commercial C&Ss
  - Similar to the situation in the early days of seismic fragility analysis / SPRA

NRC Considering Endorsing Commercial C&S

Recommend focusing them in the right places…

Safety Class	Commercial C&Ss	
Safety Related (SR)	• Would be great to endorse commercial C&Ss for SR structures. • May require exceptions, clarifications, guidance, etc.	
Non-Safety Related Special Treatment (NSRST)	NSR… • Endorsement should not be needed: non-Safety-Related • Already endorsed in RG 1.233?	…ST • Likely very application-specific • Consider develop a more general method / guidance
Non-Safety-Related with No Special Treatment (NST)	• Endorsement neither needed nor desired. • Plenty of precedent designing non-SR structures using commercial C&S for LWRs.	

Some Closing Thoughts

Hot topic. Much research, guidance, and regulatory alignment needed.

- EPRI 3002029295 (Sept. 2024) demonstrated RIPB design for external hazards
- Ongoing follow-up research on C&S selection, treatment of very rare seismic events
- Attention from NRC (X-energy readiness review; Natrium PSAR draft Safety Eval.)
- Guidance needed:
  - Implementation w/ limited info at Construction Permit stage w/o excessive conservatism
  - "Mapping" commercial C&S provisions to LMP-type performance targets
  - …
- NSRST safety classification offers cost-benefit if "commercial+" C&S can be used
  - Industry & regulator still developing alignment on RIPB philosophy?
  - Would regulator be ok with a relatively "low" seismic fragility for NSRST SSC if risk insights indicate it has adequate performance?
  - Draft Part 53 suggested NSRST requirements very similar to SR

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Questions?