A Proposed Alternative Risk-Informed and Performance-Based Regulatory Framework for Seismic Safety at NRC-Regulated Facilities

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Disclaimer

- This project was performed by Southwest Research Institute for the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC).
- Reported results are preliminary, and part of an ongoing research program.
- The expressed views do not necessarily reflect the views or regulatory position of the U.S. Nuclear Regulatory Commission.

Objectives of Project (Project Divided in Two Phases)

Phase 1 Objectives:

- Propose an LMP/ASCE* integration approach that:
  - Aligns with the LMP concepts with its emphasis on using event sequences and probabilistic risk assessment (PRA) to understand the safety importance of individual structures, systems, and components (SSCs)
  - Develops strategies linking ASCE 43 seismic performance goals to LMP risk-informed SSC categorization
  - Evaluates the adequacy of ASCE 43 criteria in meeting target performance goals

The Phase 1 draft report describes the proposed approach

*LMP: Licensing Modernization Project
ASCE: American Society of Civil Engineers

Brief Review of ASCE 43

- Seismic design criteria for structures, systems, and components in nuclear facilities

- The acceptable performance level (the target performance goal) for an individual SSC is achieved by selecting the return period of the DBE ground motion in terms of the Seismic Design Category (SDC)

- The Limit State (LS) defines the required performance in terms of the limiting acceptable design condition of the SSC and is adjusted based on the safety function and risk significance of the component

This approach allows the designer to control conservatisms and safety margins in accordance with the risk significance of SSCs, permitting more balanced design

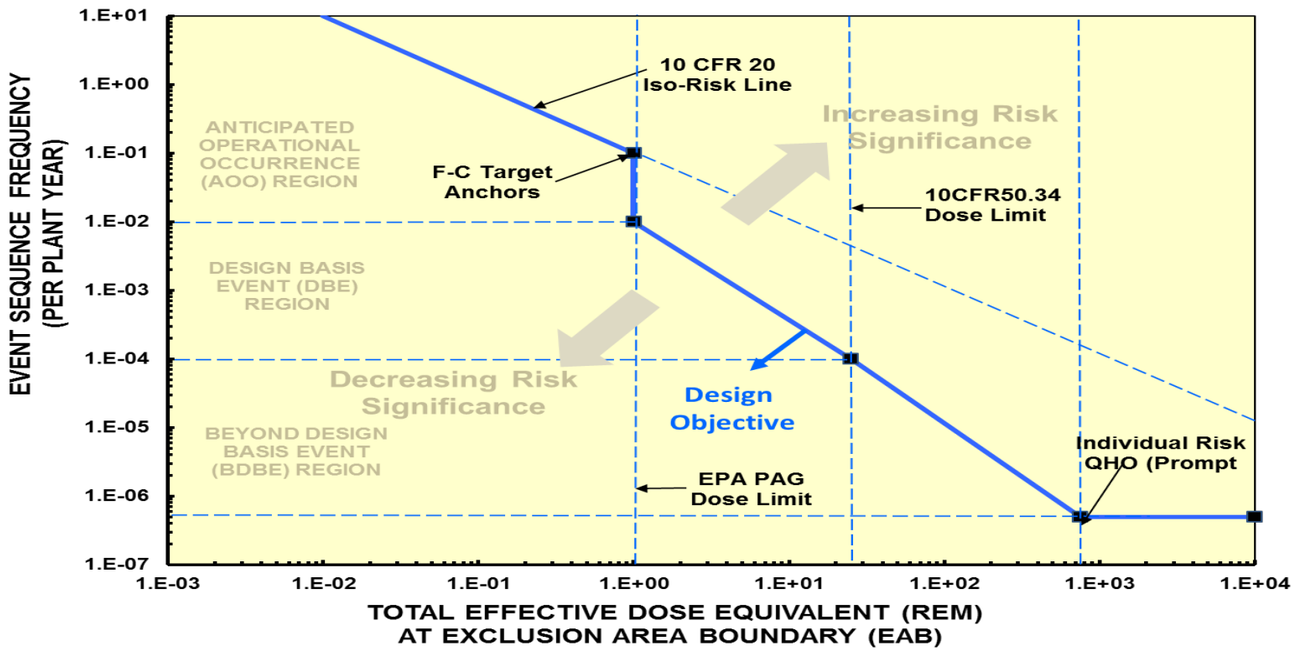
ASCE 43 –Seismic Design Categories (SDC) and Limit States (LS)

	Seismic Design Category			
	2	**3**	**4**	**5**
Target performance goal, P_F , per year	4×10^{-4}	1×10^{-4}	4×10^{-5}	1×10^{-5}
DBE response spectrum (DRS) or acceleration time series	$DRS = SF \times UHRS_{Hp}$ $H_p = P_F$ UHRS = Uniform Hazard Response Spectra SF = Scale factor at each spectral frequency SF accounts for slope characteristics of a hazard curve			

Limit State	Structural Deformation Limits
A	Large permanent distortion, short of collapse
	Significant damage
B	Moderate permanent distortion
	Generally repairable damage
C	Limited permanent distortion
	Minimal damage
D	Essentially elastic behavior
	Negligible damage

Cornerstones of LMP Framework

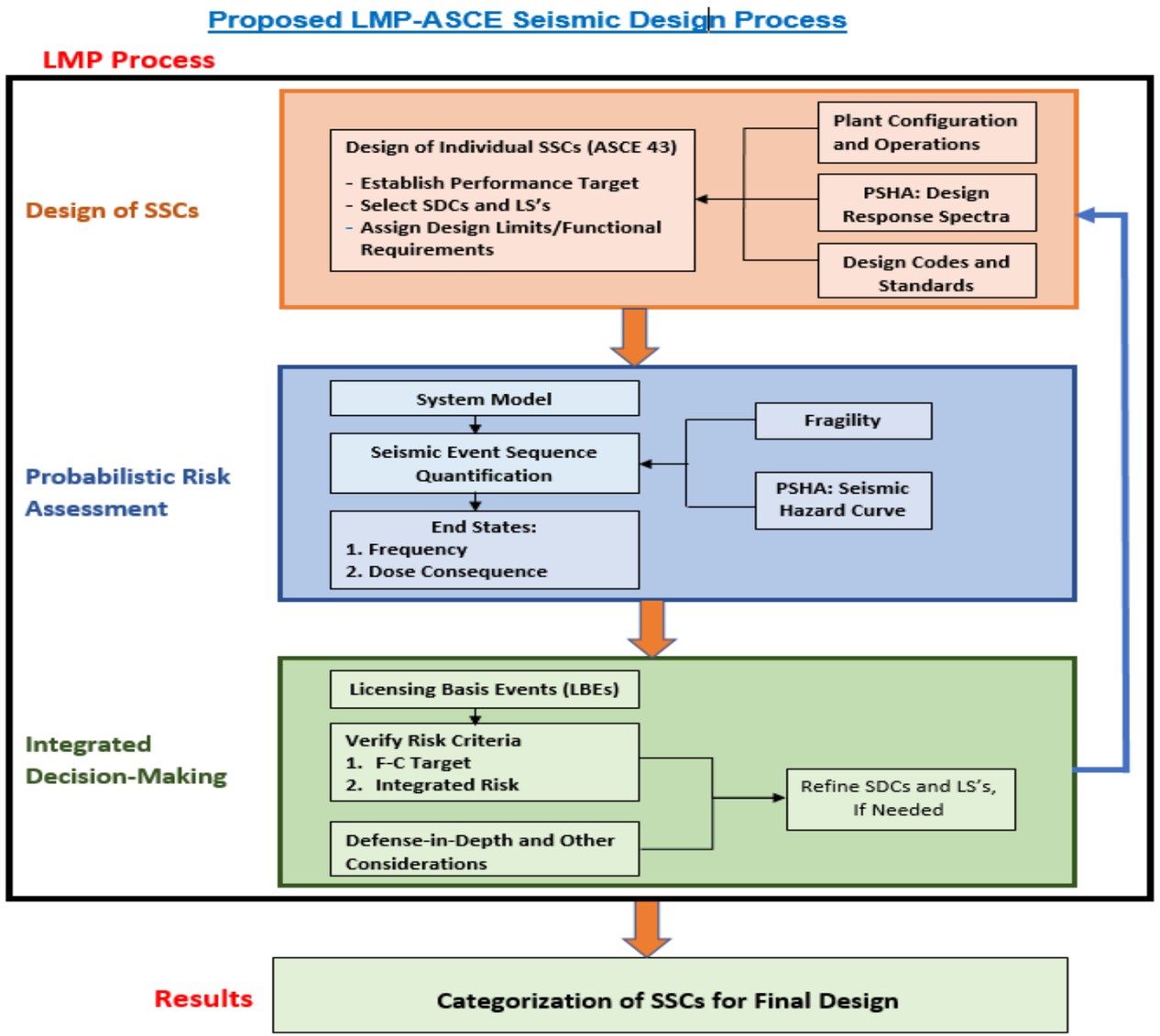
- Selection and evaluation of licensing basis events (LBEs)
- Frequency - Consequence (F-C) target and LBE risk-significance criteria
- SSC classification and performance requirements
- Defense in depth adequacy evaluations



A probabilistic risk analysis (PRA) for non-light water reactors (LWR) is an essential element of the proposed RIPB LMP framework.

Seismic PRA technology is mature and well-practiced

Basic Concept of LMP/ASCE Integration Approach

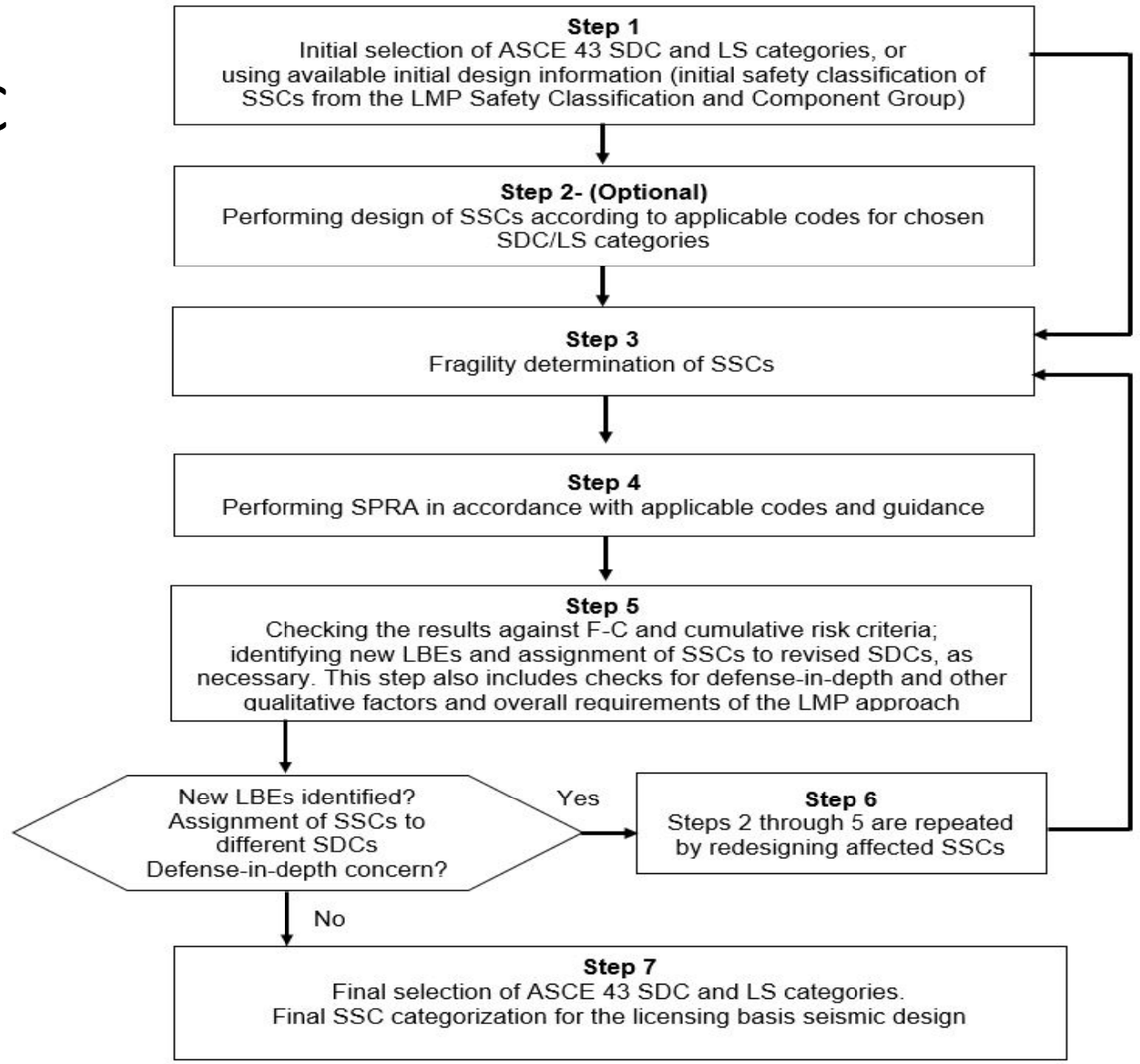


Seven Step Process

Step 1 -Initial Selection of the ASCE 43 SDC and LS categories based on an internal event PRA

Step 2 – Seismic Design (Optional)
Step not intended as a rigorous re-design, but as a design assessment, if necessary.

Step 3 – Fragility Determination
Choosing fragilities for alternate SDCs and LSs.



Seven Step Process (Cont.)

- Step 4 – Perform Seismic PRA

  Perform a SPRA using the fragilities developed in Step 3

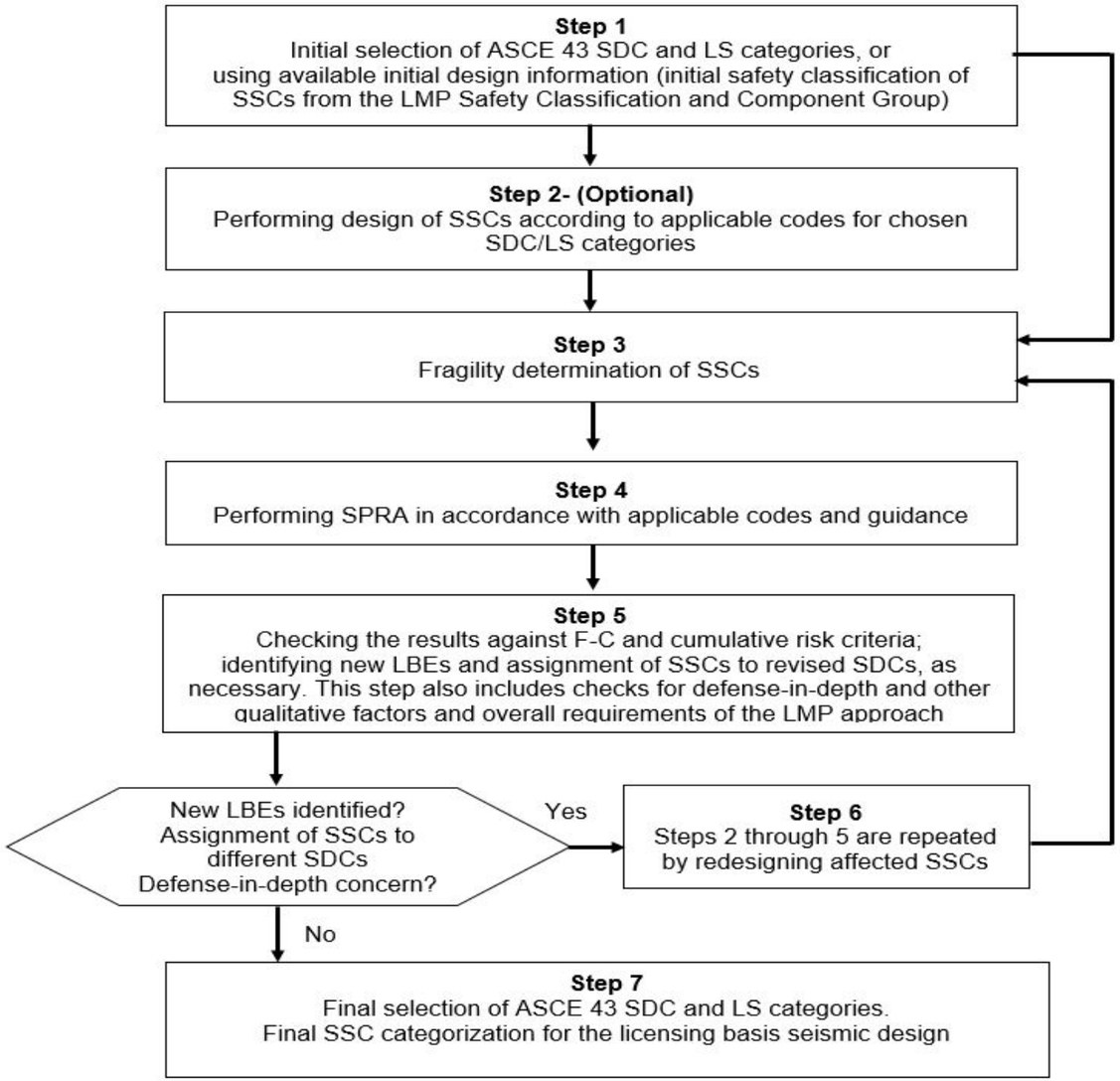
- Step 5 – Integrated Decision-Making

  Check the proposed classification against the risk criteria

- Step 6 – Iteration

  Based on the Step 5 results, this step determines whether additional iterations are needed

- Step 7 – Final SSC Classification



Seismic Design of SSCs (What Follows After the Seven Step Process)

- The SDC/LS category for each SSC requiring a seismic design is determined based on the outcome of the LMP/ASCE 43 Integration approach
- The design response spectra for each SDC are derived from probabilistic seismic hazard analysis (PSHA) results using ASCE 43
- Seismic response analysis is performed using ASCE-4 methods – similar to current requirements
- Design of SSCs follows engineering approaches in appropriate codes and standards such as ACI-349 and 359, AISC N690, ASME, and IEEE.
- Design alternatives and sophistication can be pursued as appropriate
- Final SPRAs are performed at the end of design and various other stages
- In summary, there are no changes to current design practice except there may be more SDC/LS categories

Reductions in Ground Motion Levels for Various SDC Categories and Reduction in Seismic Demand for Alternate LSs

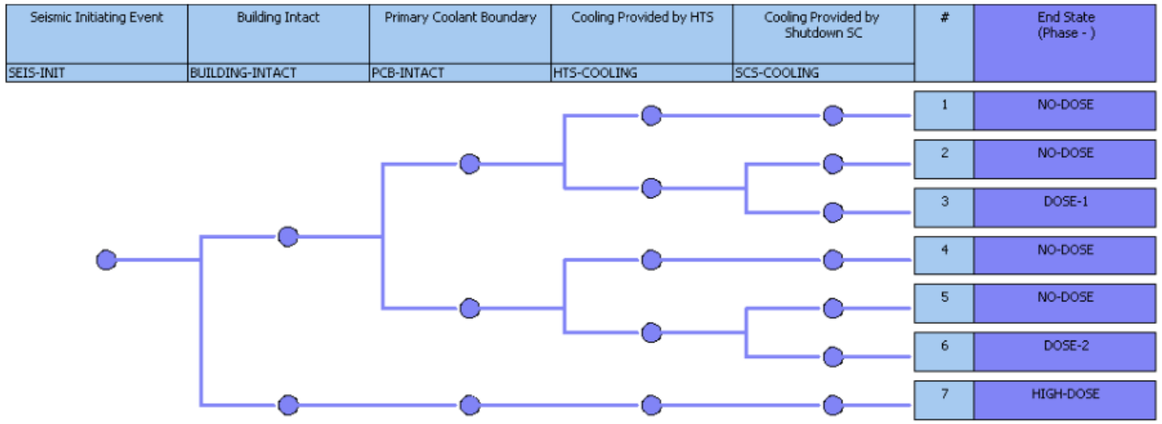
Site	Ratio of PGA Values		Ratio of Spectral Accelerations at 5 Hz.	
	SSDRS4 /SSDRS5	SSDRS3 /SSDRS5	SSDRS4 /SSDRS5	SSDRS3 /SSDRS5
A	0.49	0.29	0.50	0.30
B	0.48	0.30	0.50	0.30
C	0.67	0.49	0.65	0.46
D	0.56	0.37	0.57	0.37
E	0.57	0.39	0.60	0.42
F	0.50	0.30	0.45	0.26
G	0.52	0.32	0.51	0.31
H	0.55	0.38	0.58	0.40
I	0.58	0.40	0.60	0.42

Reinforced concrete shear walls, in-plane	Ratio of reduction of forces for different limit states compared to LSD		
Shear controlled walls Aspect Ratio: height/length < 2.0	LSA/LSD	LSB/LSD	LSC/LSD
	0.50	0.57	0.67

- **Ratios of PGA and 5 Hz SA for Various SDC Categories**

SSDRS = Site-Specific Design Response Spectra

Application of the Seven Step Process

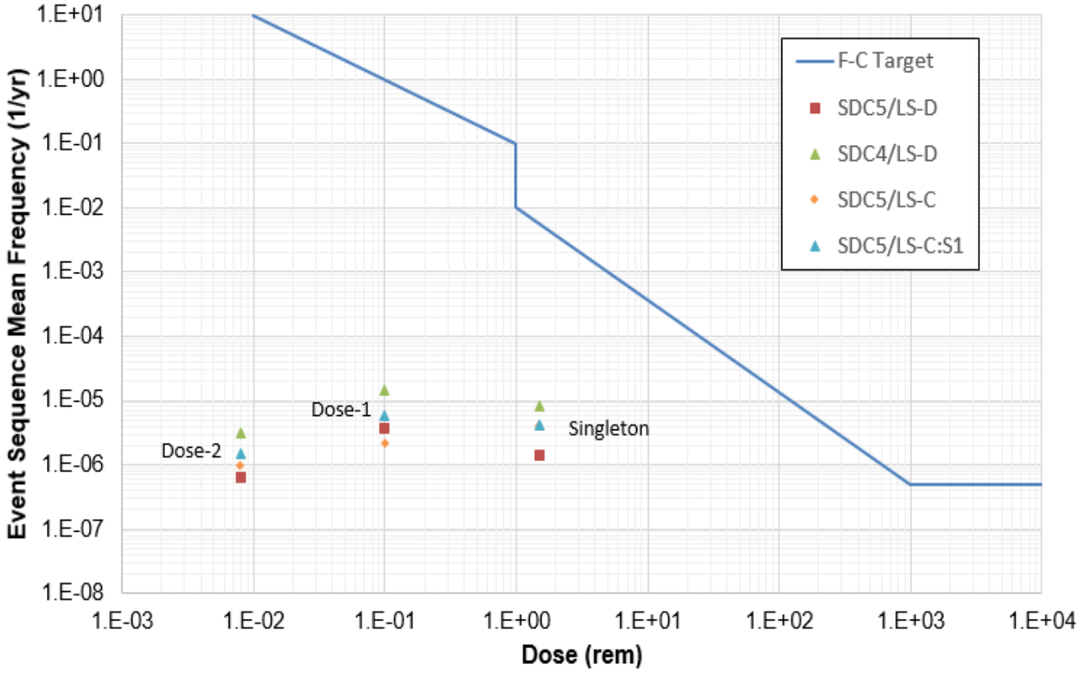


Simplified event tree for the modular high temperature gas-cooled reactor (MHTGR)

Results for a high hazard CEUS site

Site A Hazard Data; Three Design Options

	LMP Design 1 SDC5/LS-D		LMP Design 2 SDC4/LS-D		LMP Design 3 SDC5/LS-C		LMP Design 3 SDC5/LS-C Sensitivity S1	
	A_m	β_C	A_m	β_C	A_m	β_C	A_m	β_C
Shear Wall	2.9	0.43	1.45	0.46	1.93	0.43	1.93	0.43
Primary Boundary	2.9	0.43	1.45	0.46	1.93	0.43	1.93	0.43
HTS Cooling	1.24	0.40	0.62	0.4	1.24	0.4	0.93	0.4
SCS Cooling	1.24	0.40	0.62	0.4	1.24	0.4	0.93	0.4



Phase 2 Objectives and Example of Activities Under Consideration

- **Objectives**
  - Illustrate strengths and identify potential enhancements for the LMP/ASCE 43 Integration approach for seismic safety
  - Expand Phase 1 case studies to take full advantage of flexibility afforded by ASCE 43
  - Disseminate results and gather feedback
  - Refine the LMP/ASCE 43 Integration approach as needed from the insights gained
  - Provide a basis for development of guidance
- **Example of Activities**
  - Evaluate the seismic design of a small stylized structural system and selected equipment to more fully understand how to implement the guidance in standards such as ASCE 43, 4, and 1 within the proposed new LMP/ASCE 43 Integration process. Explore the impact on responses and fragilities from the use of alternate SDC and LS categories.
  - Use detailed SPRAs of a light water reactor and an advanced reactor design to better assess feasibility and advantages and limitations of the LMP/ASCE 43 Integration approach to seismic safety.

Collaborative and Parallel Efforts

- Activities related to detailed execution of SPRAs can be efficiently performed by owners and custodians of those SPRAs, providing opportunities for collaborative efforts.

- Industry and/or others (e.g., DOE) could undertake activities in parallel to further explore issues related to the use of ASCE 43 options.
  - For example, designing a complex structural system (e.g., non-symmetrical shear wall) to assess complexities, efforts, and benefits of LS-C design.

Summary

- Results from Phase 1 efforts presented at a public workshop in September 2020.
- No inherent technical impediments to the proposed LMP/ASCE-43 Integration approach. Conceptual feasibility demonstrated through some examples.
- Biggest benefit is the “flexibility” in design (not available in the current process)
- Process can be used for both Part 52 and Part 50 applications (any future licensing processes should also be accommodated)
- Process is technology inclusive, can accommodate different risk criteria, and preserves design stability and predictability
- Insights from Phase 1 activities support further exploration through Phase 2 activities
- The Phase 1 and Phase 2 efforts will provide a technical basis to develop a regulatory guide to establish acceptable conditions for implementing the process