# PSAR Seismic Analysis and Seismic SSC Classification Approach

a TerraPower & GE-Hitachi technology

NATD-LIC-PRSNT-0049

*SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054*

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# Natrium Reactor Overview

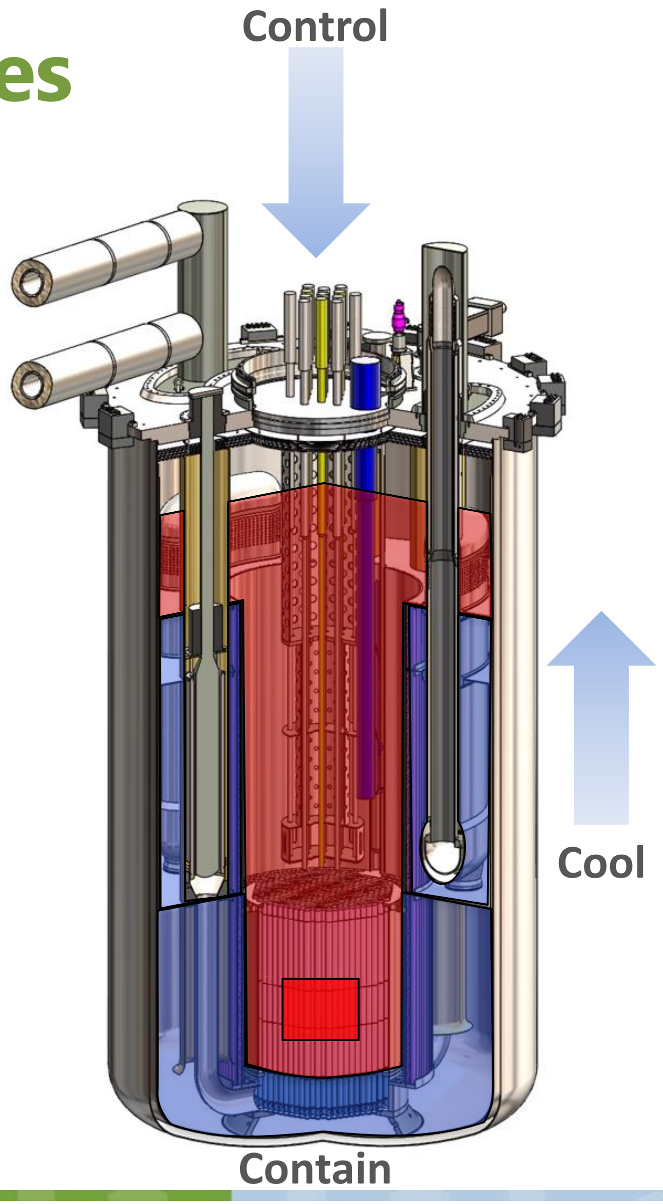
- The Natrium project is demonstrating the ability to design, license, construct, startup and operate a Natrium reactor.

- Pre-application interactions are intended to reduce regulatory uncertainty and facilitate the NRC's understanding of the Natrium design and its safety case.

- Future related meetings include:
  - Seismic isolation of Reactor Enclosure System
  - SSHAC Workshop 3

# Natrium Safety Features

- Pool-type Metal Fuel SFR with Molten Salt Energy Island
  - Metallic fuel and sodium have high compatibility
  - No sodium-water reaction in steam generator
  - Large thermal inertia enables simplified response to abnormal events
- Simplified Response to Abnormal Events
  - Reliable reactor shutdown
  - Transition to coolant natural circulation
  - Indefinite passive emergency decay heat removal
  - Low pressure functional containment
  - No reliance on Energy Island for safety functions
- No Safety-Related Operator Actions or AC power
- Technology Based on U.S. SFR Experience
  - EBR-I, EBR-II, FFTF, TREAT
  - SFR inherent safety characteristics demonstrated through testing in EBR-II and FFTF




## Control

- Motor-driven control rod runback and scram follow
- Gravity-driven control rod scram
- Inherently stable with increased power or temperature

## Cool

- In-vessel primary sodium heat transport (limited penetrations)
- Intermediate air cooling natural draft flow
- Reactor air cooling natural draft flow – always on

## Contain

- Low primary and secondary pressure
- Sodium affinity for radionuclides
- Multiple radionuclides retention boundaries

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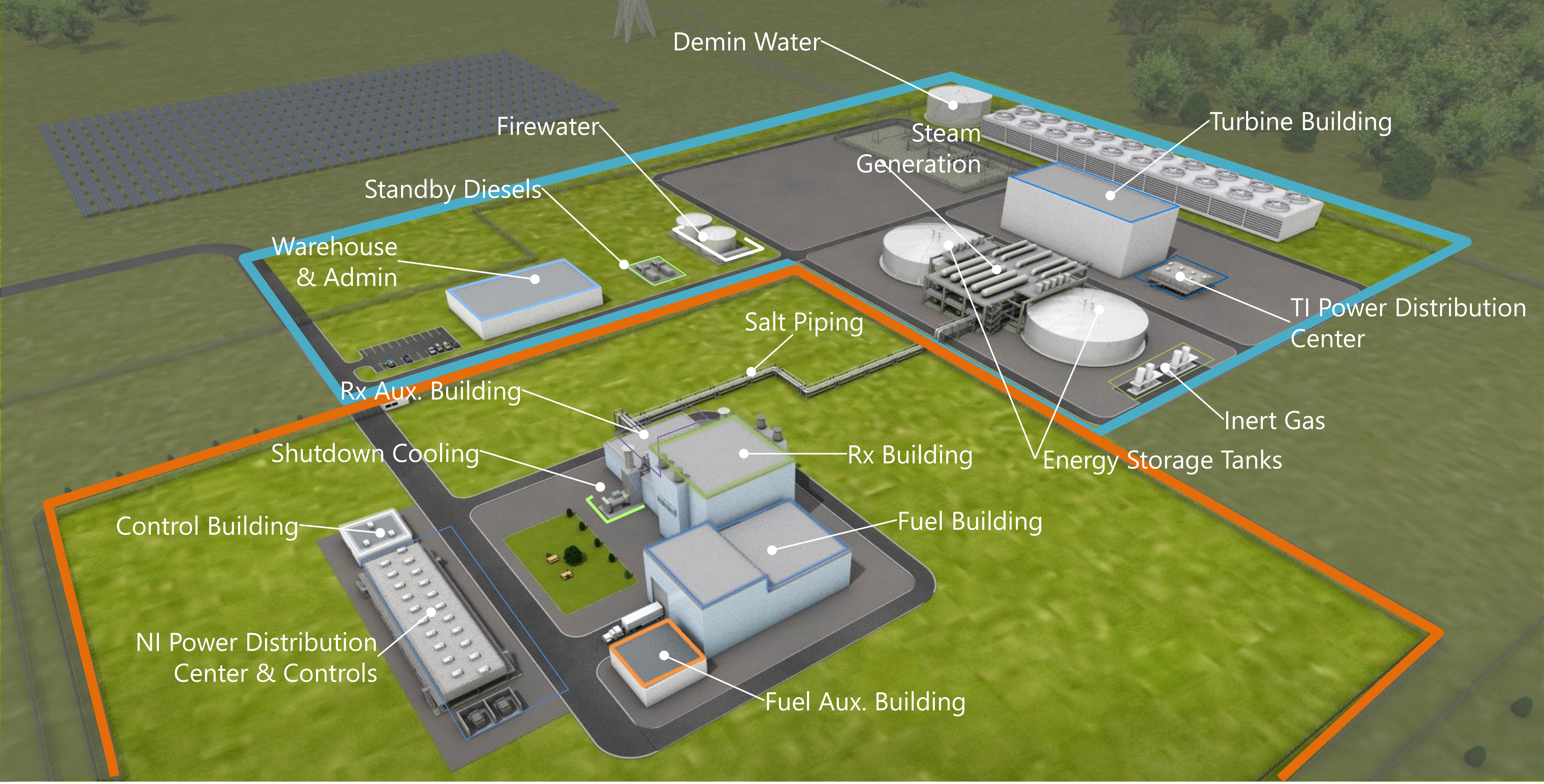
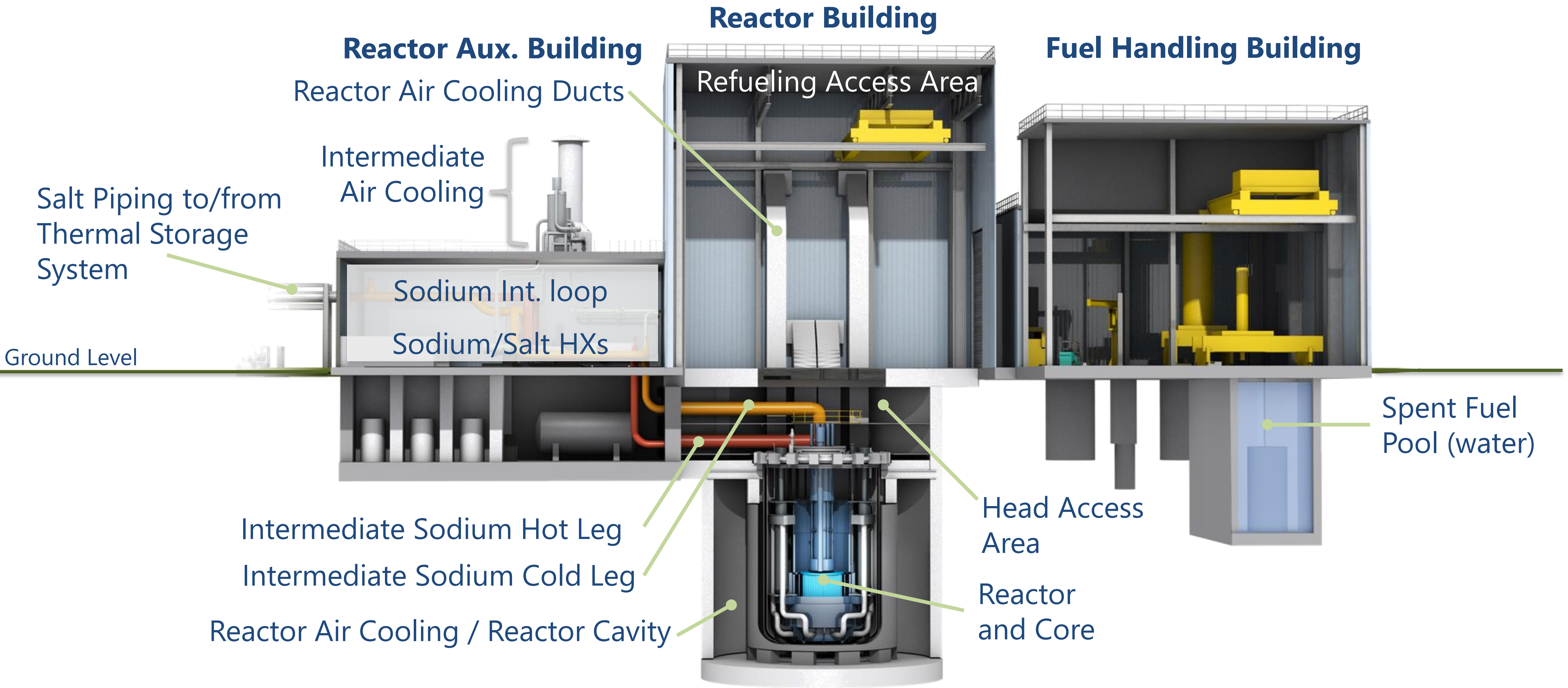

Demin Water
Firewater
Steam Generation
Turbine Building
Standby Diesels
Warehouse & Admin
TI Power Distribution Center
Salt Piping
Rx Aux. Building
Inert Gas
Shutdown Cooling
Rx Building
Energy Storage Tanks
Control Building
Fuel Building
NI Power Distribution Center & Controls
Fuel Aux. Building

# Plant Overview

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TerraPower NATRIUM

# PSAR SEISMIC ANALYSIS APPROACH

# Phased Design Development Approach

- Simplified design stages
  - Conceptual Design
    - Establish plant-level requirements, architecture and technology selection, and planning and maturing key component design
    - Emphasize long-lead times and safety-significant nuclear island systems
  - Preliminary Design – submit PSAR during this stage
    - Complete system designs for major mechanical systems and architecture-level design for electrical systems
    - Complete preliminary physical and structural design for safety-significant SSCs
  - Final Design – submit FSAR during this stage
    - Complete plant specifications, drawings, calculations

# Phased Design Development Approach

- Design stages with increasing level of maturity and concurrent development of SSC design, risk, and safety analysis
- Major decisions and design efforts during Conceptual and Preliminary Design phase impacting seismic approach:
    - Building and system layout and general arrangement
    - Site investigation – determine excavation and construction strategy
    - Hazard characterization – SSHAC process
    - Requirements development, trade studies, preliminary risk insights, and preliminary analysis

# Phased Design Development Approach

- CPA submittal during Preliminary Design stage:
  - Maturing the major Conceptual Design decisions into building general arrangement and system size envelopes and requirements
  - Incorporate evolving design information with increasing maturity for concurrent design efforts
  - Preliminary seismic design and analysis consistent with the nature of the design stage

The focus of the first portion of this meeting

# Phased Design Development Approach

Phased seismic analysis (preliminary and final) corresponds to design phases with appropriate level of maturity

- Preliminary seismic SSI analysis for PSAR:
  - Provides confidence in meeting required performance criteria
    - Develops dynamic response models and representative SSI models to support rapid iteration
      - Comprehensive SSI analysis is not conducive to iterative design. Iteration during the preliminary design stage is an intrinsic part of an RIPB approach
    - Considers iterative dynamic response evaluation, dynamic coupling, and design iterations between building, reactor, and other key systems
- Final seismic SSI analysis for FSAR:
  - Perform comprehensive SSI analysis to develop seismic demands for final SSC design and qualification in FSAR

# Preliminary Seismic SSI Analysis and Design

Seismic SSI analysis will support CPA submittal:

- Account for SSI effects in representative manner
- Utilize simplified SSI models consistent with SSC design maturity:
  - Coarse finite element mesh
  - Lower passing frequency
  - Conservative and soil and seismic hazard inputs
- Develop seismic response inputs to support SSC design and confirm adequacy for margin of safety

# Seismic SSI Analysis and Design PSAR Content

- Seismic SSI analysis reflects preliminary seismic analysis and design, consistent with applicable regulations to support PSAR:
  - 10 CFR 50.34, Contents of applications; technical information

    A preliminary analysis and evaluation of the design and performance of structures, systems, and components of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents…
  - 10 CFR 50 Appendix S, Earthquake Engineering Criteria

    The evaluation must take into account soil-structure interaction effects and the expected duration of vibratory motion…
- Seismic analysis and structural model uncertainty is accounted for in the risk-informed safety evaluation during phased design per PRA standard (ASME/ANS RA-S-1.4-2021)
- The SSC design, analysis methods, criteria, and safety functions are not expected to change significantly between PSAR and FSAR

# Seismic SSI Analysis and Design PSAR Content

- Chapter 2: Methodologies and Analyses
  - Seismic analysis methodology and applicable standards
- Chapter 6: Safety-Significant SSC Criteria and Capabilities
  - Seismic performance requirements and design criteria
- Chapter 7: Descriptions of Safety-Significant SSCs
  - Seismic design and analysis summary
    - Description of how structures will meet seismic requirements
    - Description of how components and systems will meet seismic requirements

PSAR content backed by calculations and references reflecting preliminary design phase

- Seismic analysis results
- Response analysis to demonstrate seismic adequacy of structures
- Section cut building forces
- In-structure demands that inform SSC seismic design

# SEISMIC SSC CLASSIFICATION APPROACH

# Existing and Draft Seismic Classification Guidance

Existing regulatory guidance

- RG 1.29 R6, Seismic Design Classification for Nuclear Power Plants (conformance under evaluation)
  - Position C.1 lists SSCs that should be designated Seismic Category I for existing LWR technology
  - Positions C.2 through C.4 are being evaluated with Natrium seismic strategy development

Draft regulatory guidance

- October 2022 draft RG, TI RIPB Methodology for Seismic Design of Commercial Nuclear Plants (not selected)
  - Intended for 10 CFR Part 53 applications
  - Uses ASCE 43-19 (not yet endorsed)
    - Design and analysis complexity to accommodate multiple SSE hazard levels with existing SSI methods
    - Special treatment applied through ASCE 43-19 references NQA codes and standards for low seismic significant SSCs





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# Natrium Seismic Classification Motivation

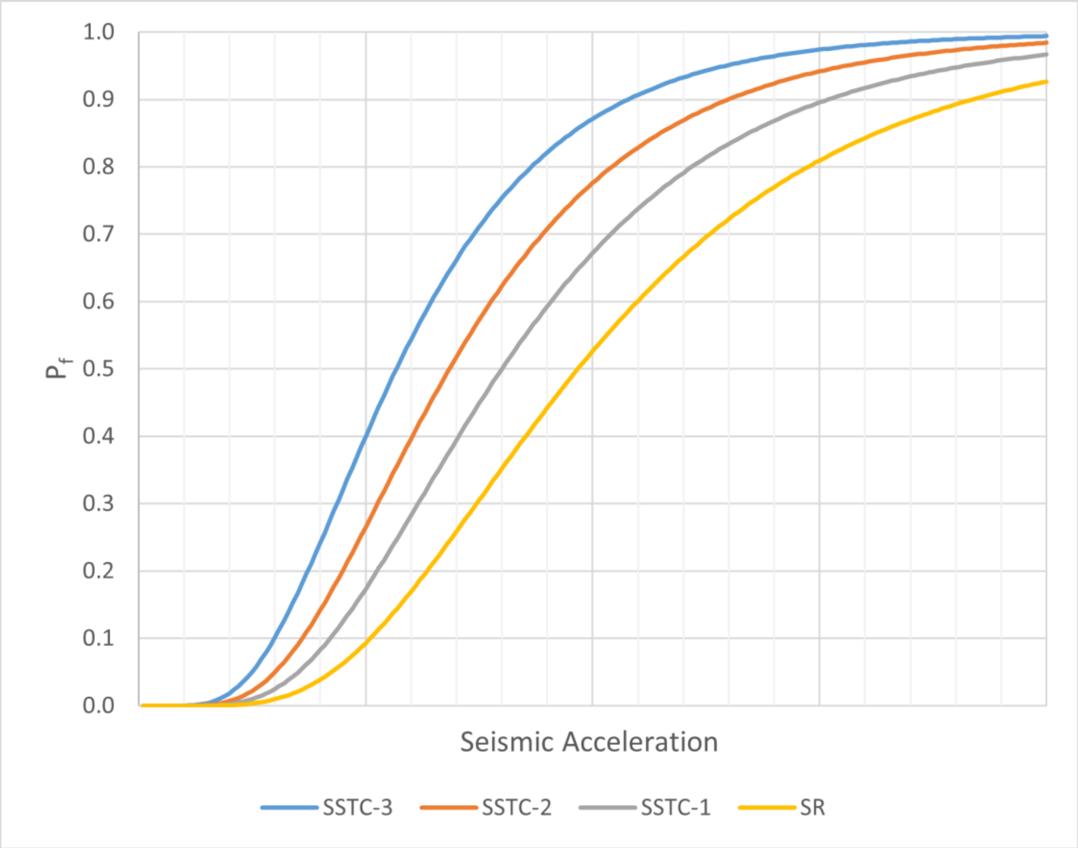
- Uses LMP and SPRA risk insights to develop seismic classifications, seismic performance criteria, and seismic design requirements
  - Right-sizing requirements by assigning special treatments based on SSC seismic risk significance
- Implements seismic special treatments and design requirements via graded application of codes and standards
  - Uses feedback between SSC design and LMP process to verify SSC seismic risk significance and assigned design criteria
  - Provides consistency with special treatment definitions determined through LMP
  - Graded special treatment and quality requirements for engineering, procurement, and construction for large number of NSRST SSCs
- Balancing deterministic design practices with risk-informed classification that integrates with the SPRA
- Defines the SSE consistent with regulatory guidance

# Risk-Informed Seismic Classification Process

1. Initial safety classifications assigned to SSCs through LMP process: SR, NSRST, NST
    a. Initial seismic criteria assigned to SSCs based on the SPRA model and required special treatment
    b. SSCs with common seismic criteria are grouped into seismic special treatment categories
2. Preliminary seismic design for SSCs performed based on assigned seismic criteria
3. Update SPRA using conservative SSC fragilities developed from assigned seismic criteria
4. Feedback from SPRA results used to evaluate SSC seismic risk significance and update SSC fragilities to meet LMP risk targets
5. Update SSC seismic design and fragilities, and iterate based on SPRA feedback as needed

# Risk-Informed Seismic Classification Process

- Use fragilities to adjust SSC seismic performance to meet risk targets during early design phases:
  - Representative fragilities are developed for each seismic special treatment category
    - Informed by seismic criteria and design parameters assigned to each special treatment category, (i.e., ASCE 7-16, SSE hazard level with range of risk categories and importance factors)
  - Assigning SSCs to different seismic special treatment categories will adjust SSC fragility for use in SPRA
- For risk-significant SSCs, calculate SSC-specific fragility to reflect seismic design margin
- Apply SSC-specific augmented seismic design requirements based on performance criteria identified through LMP




Example of Fragility Curves for Different Seismic Special Treatment Categories

# Risk-Informed Seismic Classification Process

- SR, Seismic Risk Significant SSCs:
  - Treated like Seismic Category I SSCs consistent with RG 1.29
    - Designed to withstand the effects of the SSE and remain functional
    - NQA codes and standards
- SR, Non-Seismic Risk Significant SSCs:
  - SR safety classification unaffected
  - Evaluated for potential graded seismic requirements consistent with seismic risk significance (e.g., alternate seismic qualification requirements)

# Risk-Informed Seismic Classification Process

- NSRST, SSCs with Graded Seismic Risk Significance:
  - SSCs are assigned to seismic special treatment categories based on SSC seismic risk significance ranging from seismic risk significant to non-seismic risk significant, commensurate with seismic risk contribution as informed by SPRA
    - Seismic performance associated with seismic special treatment categories (fragilities) are informed by ASCE 7-16 and SSE hazard level
  - Design criteria for seismic special treatment categories are graded through application of design parameters consistent with seismic risk significance
  - Special treatment is an enhancement to NST design criteria
- NST, Non-Seismic Risk Significant SSCs:
  - SSCs in this category require no seismic special treatment and are designed, constructed, and maintained to commercial codes and standards

# Risk-Informed Seismic Classification Summary

- Seismic classifications based on safety classification and seismic risk significance:
  - SR, Seismic Risk Significant
  - SR, Non-Seismic Risk Significant
  - NSRST, Graded Seismic Risk Significance
  - NST, Non-Seismic Risk Significance
- Use fragilities to adjust SSC seismic performance to meet risk targets during early design phases
  - Use ASCE 7 to develop representative fragilities for non-safety SSCs based on SSE hazard level
- Graded application of seismic special treatment based on SSC seismic risk significance
- NSRST and NST SSCs are evaluated and designed not to interfere with the performance of SR SSC required safety functions following an SSE
  - Design and evaluation requirements to mitigate seismic interaction developed on a case-by-case basis

# Seismic Classification Strategy Basis

- Safety demonstrated through LMP by meeting cumulative risk targets
  - Seismic special treatments defined for each SSC based on required seismic performance
- SR, Seismic Risk Significant SSCs are treated like Seismic Category I SSCs consistent with RG 1.29 R6
  - Designed to withstand the effects of the SSE and remain functional consistent with Position C.4
- Graded NSRST seismic requirements is consistent with NEI 18-04 R1 Table 4-1
  - User provided QA Program for non-safety SSCs
- Classification process utilizes SPRA that follows PRA standard (ASME/ANS RA-S-1.4-2021)
- Proposed framework is similar to 10 CFR 50.69 framework for risk-informed treatment of SR and nonsafety-related SSCs
- Seismic interaction between non-safety-related SSCs and SR SSCs is treated consistent with RG 1.29 R6 Position C.2 and NEI 18-04 R1
- Additional non-risk based seismic requirements will be applied for SSCs as needed for compliance with requirements outside the LMP scope

# Questions?

# Acronym List

ANS – American Nuclear Society
ASCE – American Society of Civil Engineers
ASME – American Society of Mechanical Engineers
CFR – Code of Federal Regulations
CPA – Construction Permit Application
EBR – Experimental Breeder Reactor
FFTF – Fast Flux Test Facility
FSAR – Final Safety Analysis Report
LMP – Licensing Modernization Project
LWR – light water reactor
NEI – Nuclear Energy Institute
NQA – Nuclear Quality Assurance
NSRST – Non-safety related with special treatment
NST – No Special Treatment
$P_f$ – probability of failure
PRA – probabilistic risk assessment
PSAR – Preliminary Safety Analysis Report
QA – Quality Assurance
R – revision
RG – Regulatory Guide
RIPB – Risk-Informed, Performance-Based
SFR – Sodium Fast Reactor
SPRA – seismic probabilistic risk assessment
SR – Safety-related
SSC – Structures, systems, and components
SSE – Safe Shutdown Earthquake
SSHAC – Senior Seismic Hazard Analysis Committee
SSI – Soil-structure interaction
SSTC – Seismic Special Treatment Category
TI – Technology Inclusive
TREAT – Transient Reactor Test