Geologic, Seismological and Geotechnical Engineering Review in Siting New US Nuclear Power Plants

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Regional Workshop on Seismic, Volcanic and Tsunami Hazard Assessment Related to Nuclear Power Plant Siting
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Outline

- What is the siting review purpose for a new NPP?
- What tools do we have in such a review?
- What we do in reviewing new applications?
- What have we learned from siting review process?
- Overview of Section 2.5 related contents, and highlights
- Summary

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New Reactor Siting Applications

*Review Suspended by Applicant

** COL Application Amended by Applicant to ESP on 03/25/2010

New Reactor Design Under Review

- ESBWR
- AP 1000
- APWR
- EPR
- Advanced Reactors, mPower and others (may arrive soon)

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Purpose of Siting Review

- Provide reasonable assurance that a site can safely host a future nuclear power plant or plants from the standpoint of:
  - Site safety
  - Environmental protection
  - Emergency planning
  - Safe and secure plant operation on the selected site

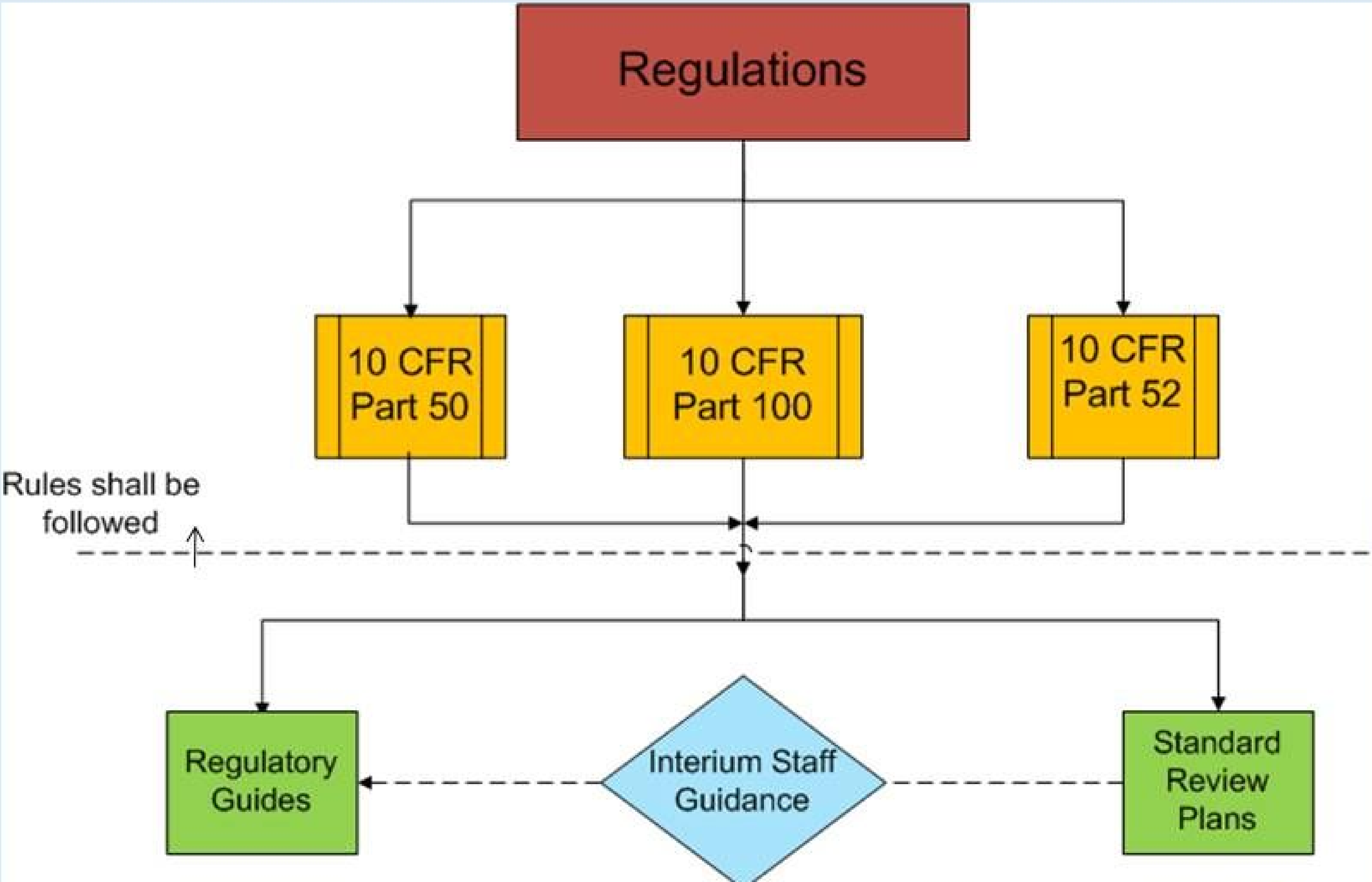
Concept of Design Basis

- Design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety (SSC).
- SSC must be designed to withstand effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunamis, and seichs as well as the effects of manmade hazards.
- These design basis for protection against all hazards are evaluated during the siting review.

Guidance Documents (Tools)

- Regulation (including DCD Tier 1 information after its approval)
- Regulation Guides
- Interim Staff Guidance
- Standard Review Plan

Hierarchy of Guidance



Related Siting Regulations

- **10 CFR Part 52** describes Licensing Processes
  - Design Certification
  - Early Site Permit
  - Combined License
- **10 CFR Part 50** describes traditional license processes
  - Construction Permit (CP)
  - Operating License (OL)
  - Limited Work Authorization (LWA)

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Related Siting Regulations

- **10 CFR 100** describes Reactor Siting Criteria
  - Physical Characteristics of the Site
    - Seismology
    - Geology
    - Geotechnical Engineering
    - Others

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Regulation Requirements on Siting

- **10 CFR Part 50 Appendix S** defines SSE as

  "Safe-shutdown earthquake ground motion is the vibratory ground motion for which certain structures, systems, and components must be designed to remain functional"
- **10 CFR Part 100.23** "Geologic and Seismic Siting Criteria" requires that the applicant determine the SSE and its uncertainty, the potential for surface tectonic and nontectonic deformations.
- **10 CFR Part 50 Appendix A** states "Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, …., without loss of capability to perform their safety functions".

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Related Regulatory Guides

- Contents of application (RG 1.206)
- Geology and Surface Faulting (RG 1.208)
  - Regional and Local Structures
  - Evidence of Past Earthquakes
- Seismology (RG 1.208)
  - Seismic Source Models
  - Ground Motion Prediction Equations
  - Safe Shutdown Earthquake – SSE (GMRS)
- Geotechnical Engineering (RG 1.132, 1.138, 1.198)
  - Site investigations
  - Laboratory testing methods
  - Liquefaction

Regulatory Guide Example

RG 1.208 provides general guidance on procedures acceptable to the NRC staff to satisfy the Geologic and Seismic Siting Criteria outlined in **10 CFR 100.23**. RG 1.208, published in March 2007, was developed as a replacement for RG 1.165, published in 1997.

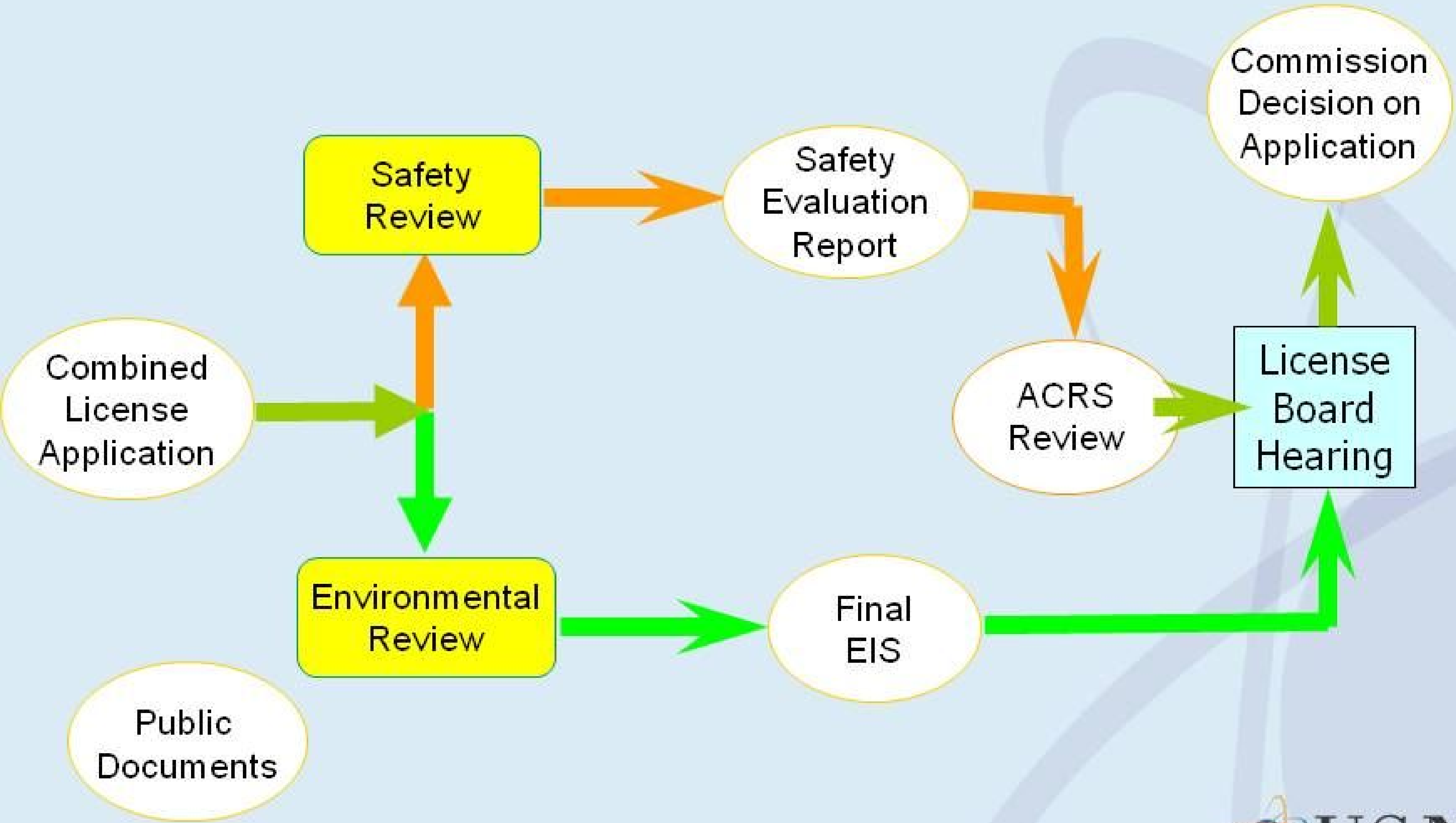
- Site and region specific geological, seismological, geophysical, and geotechnical investigations
- Perform a probabilistic seismic hazard analysis (PSHA)
- A site response analysis to incorporate the effects of local structure
- Determine site SSE using the performance-based approach

Standard Review Plan

- **Purpose of the Standard Review Plan**
  - Provides guidance **to NRC staff** in performing safety reviews of applications under 10 CFR Part 52 (including requests for amendments).
  - Assures the quality and uniformity of staff safety reviews.
  - Makes information about regulatory matters widely available.
  - Describes methods or approaches that staff has found acceptable for meeting NRC requirements.

Combined License Review Process

(what we do)



Steps in Siting Safety Reviewing

- **Applicants submits** Safety Analysis Report for early site permit or combined license application
- **Acceptance Review**
  - Staff go over application files and identified missing data and important information and decide if the application is acceptable or not
- **Site Visit**
  - Staff and its contractor visit an application site to observe field investigation contents, including boring, mapping and sampling as well as others

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Steps in Siting Safety Reviewing

- **Request for additional Information (RAI)**
  - During review, the staff asks questions
  - The staff also implements its own confirmative analyses on, for example, site response and sensitivity of source hazard.
- **Audit**
  - The staff bring its questions to the site and hold a face to face discussion with the applicant (open to public)

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Steps in Siting Safety Reviewing

- **Safety Evaluation Report**
  - Staff summaries the application and concludes its own evaluation on RAIs and each
- **Briefing ACRS**
- **Mandatory Hearing**

Challenges Issues

- **Design (DCD) and Siting (COL) Reviews going on simultaneously**
  - Any design change would impact the siting review
- **Applications timing**
  - Resources limitations due to many applications rushed in at the same time
- **Interactions among different disciplines**
  - Multi-discipline issue needs to be tackled by integrated team

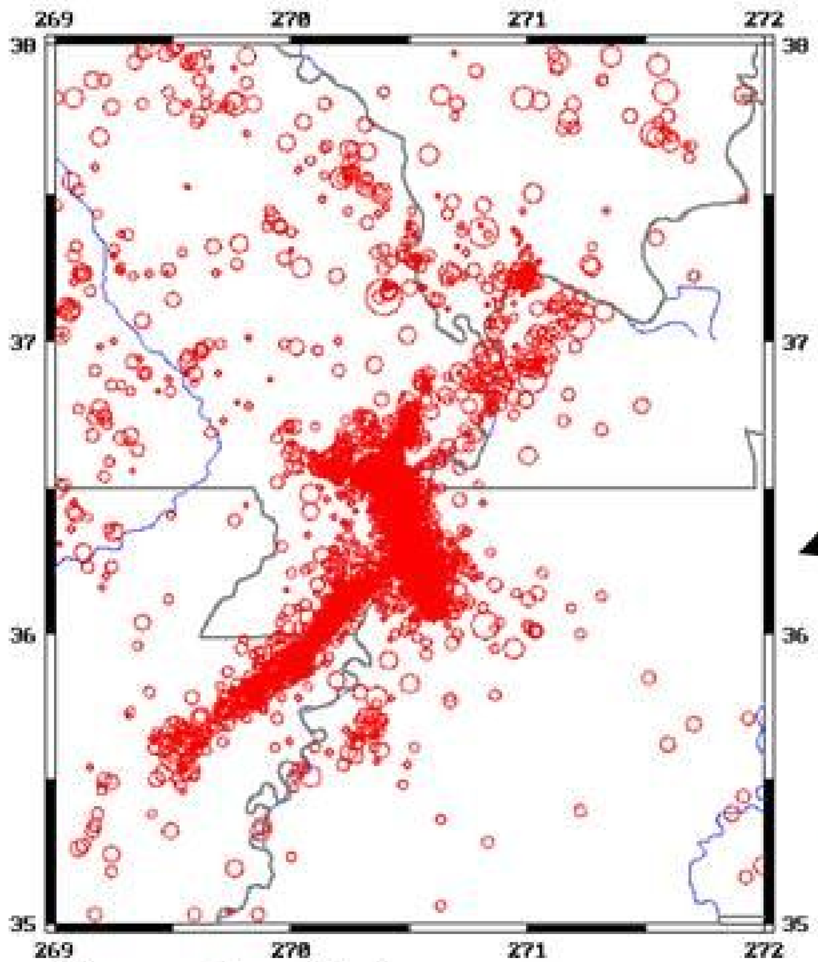
Overview of Section 2.5 Review

- Geology Review
  - Using paleoseismic studies to understand earthquake return periods and potentially the magnitude.
- Seismological Review
  - PSHA based seismic hazard characterization
  - Performance based approach to determine ground motion
- Geotechnical Engineering Review
  - Backfills
  - Two over One

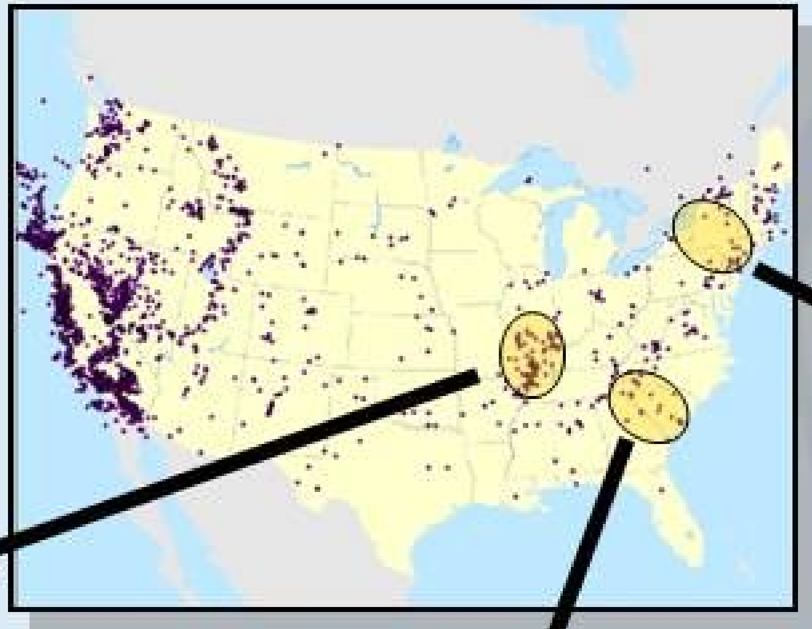
Geological Review

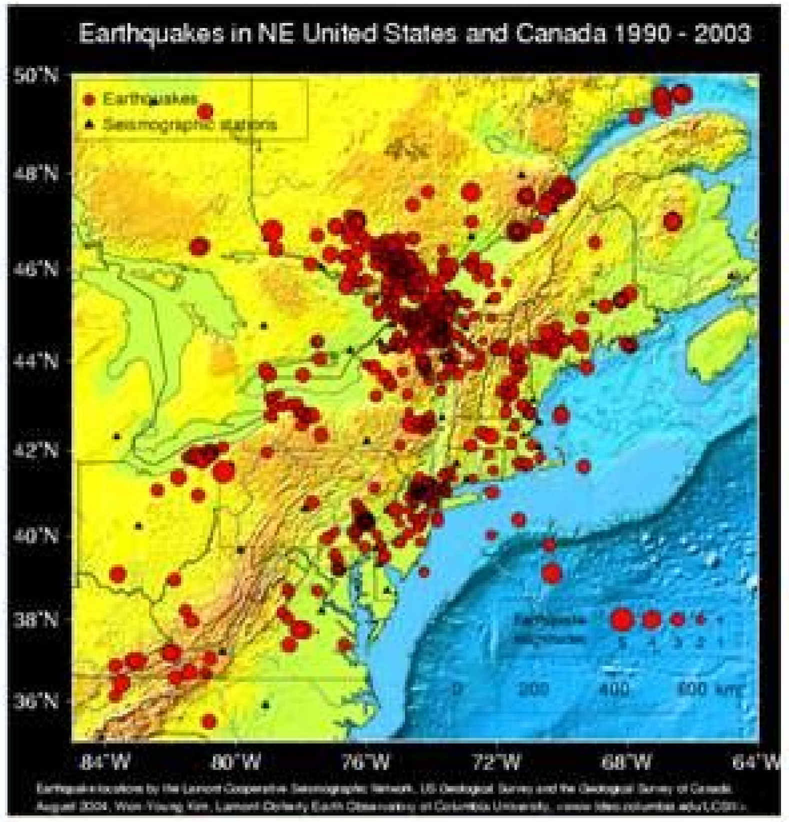
- Geology and Surface Faulting (RG 1.208)
  - Regional and Local Structures
  - Evidence of Past Earthquakes
  - Identify capable structures for earthquakes and for displacements

Eastern US Seismic Zones

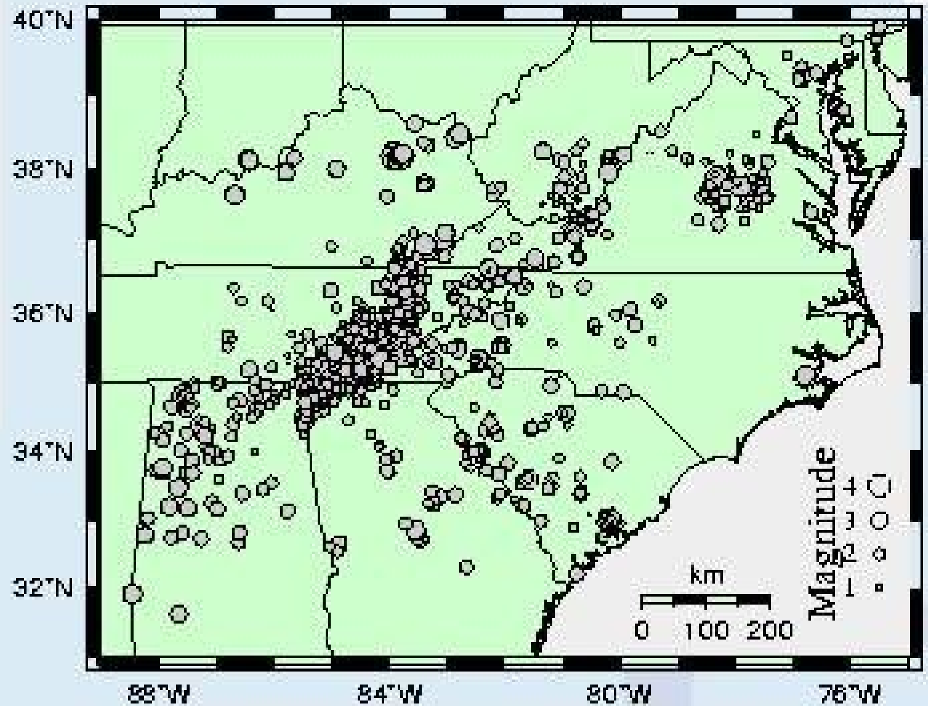


New Madrid



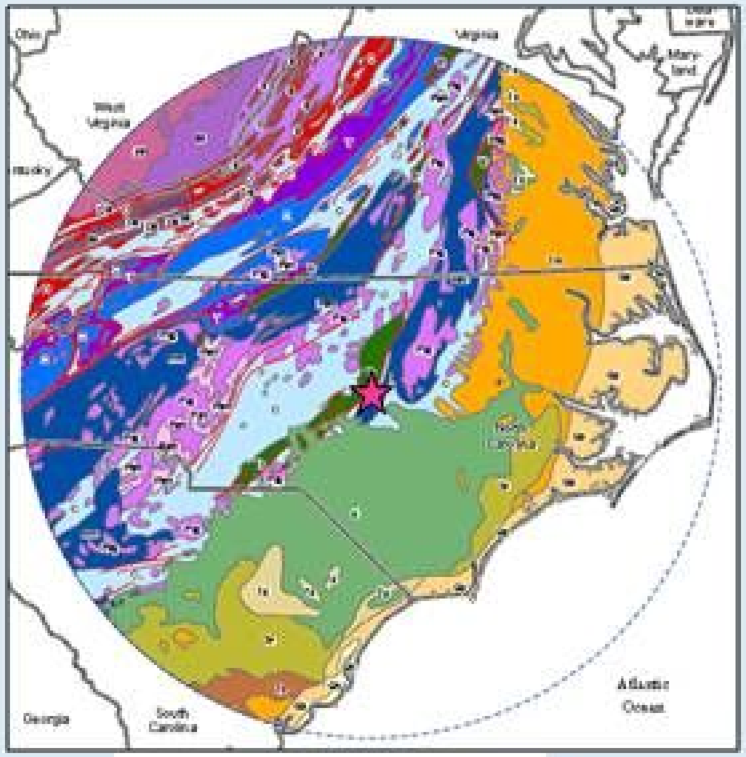


North Eastern US



Central VA/
Eastern Tennessee/
S. Carolina

Regional to Local Geologic Mapping



320 km radius

40 km radius

1 km radius

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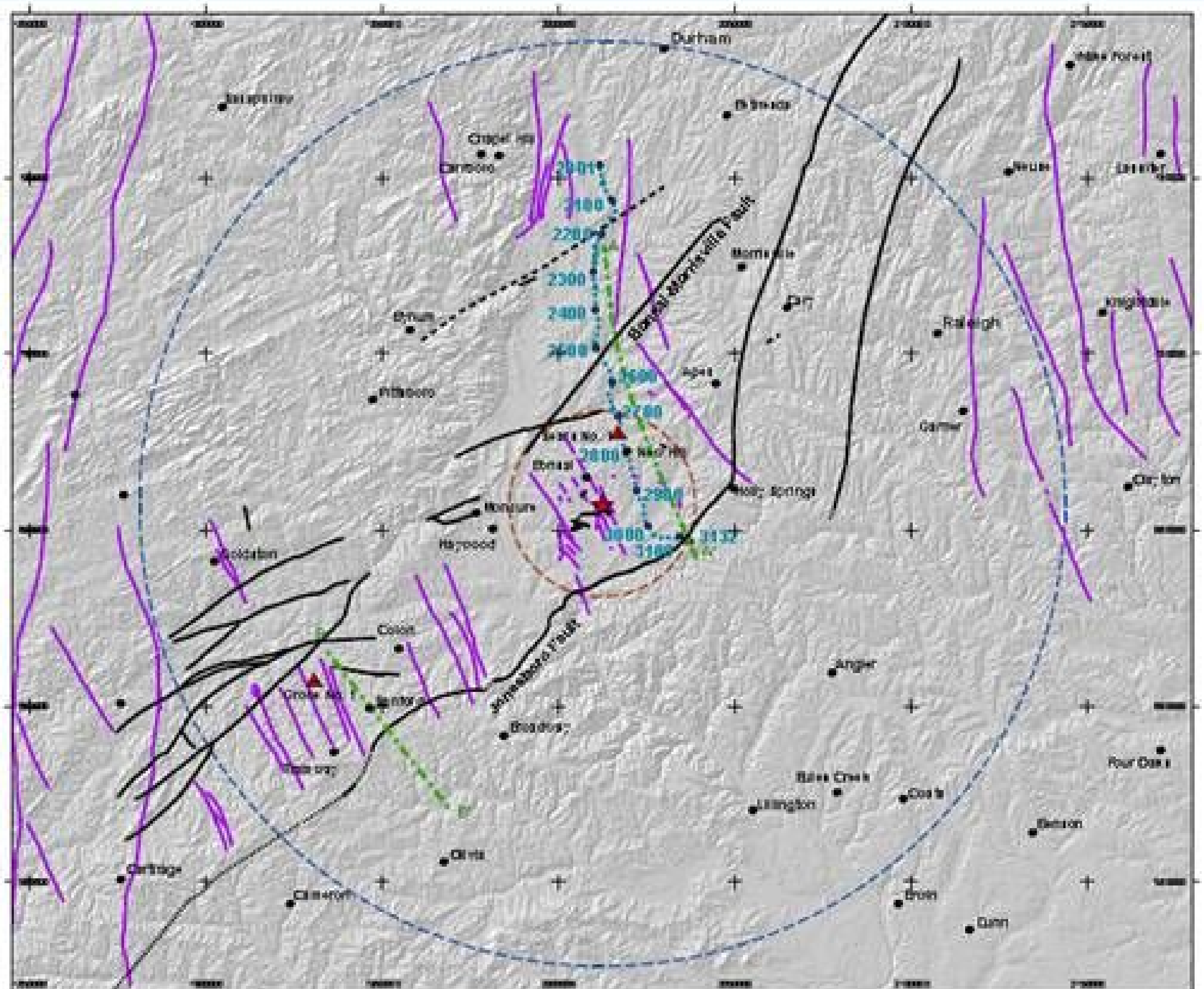
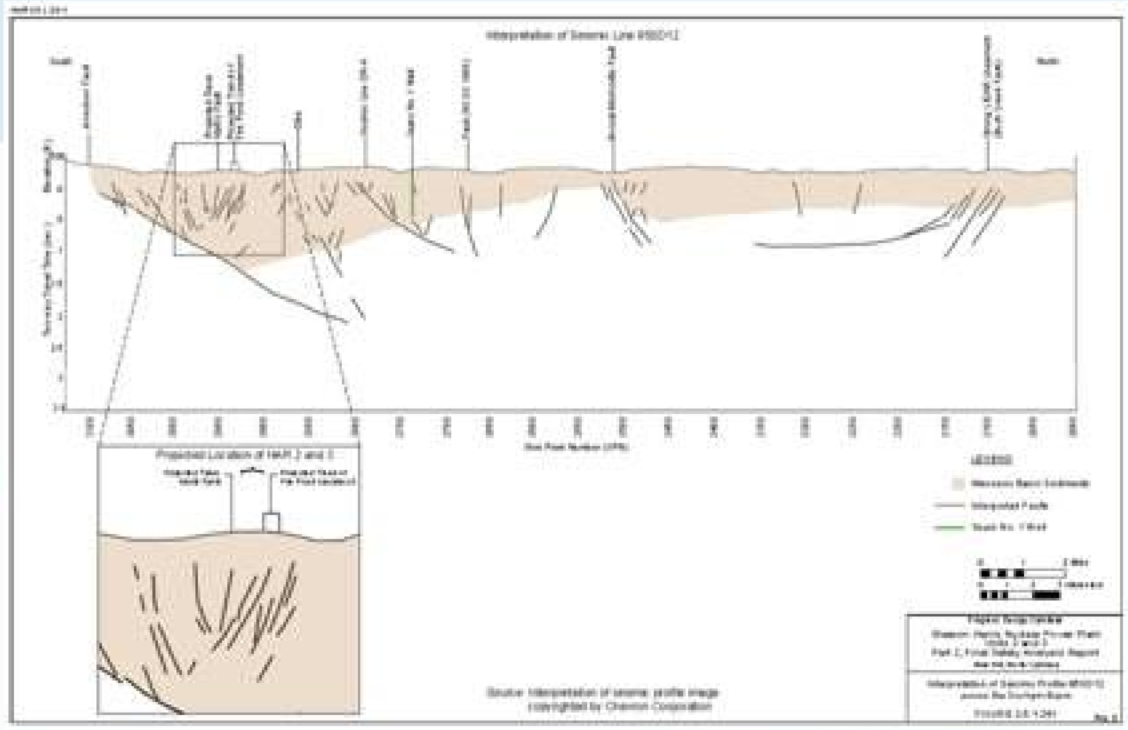
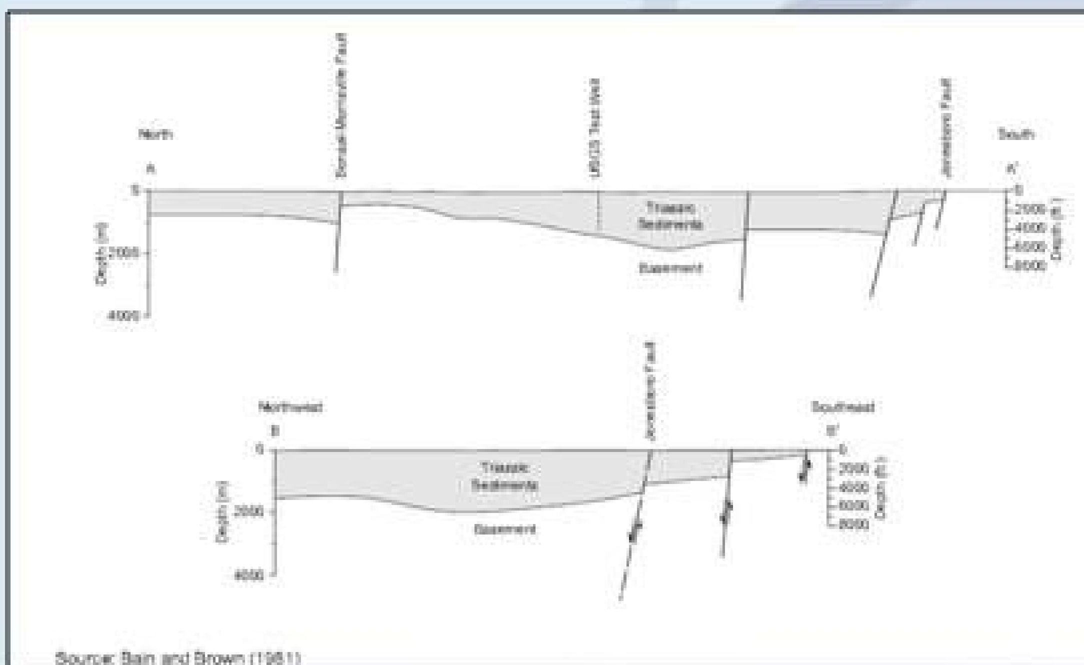
Subsurface Investigations







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Importance of Paleoseismic Studies in Geologic Siting of NPPs

Special circumstance in CEUS

- Not many active fault exposure,

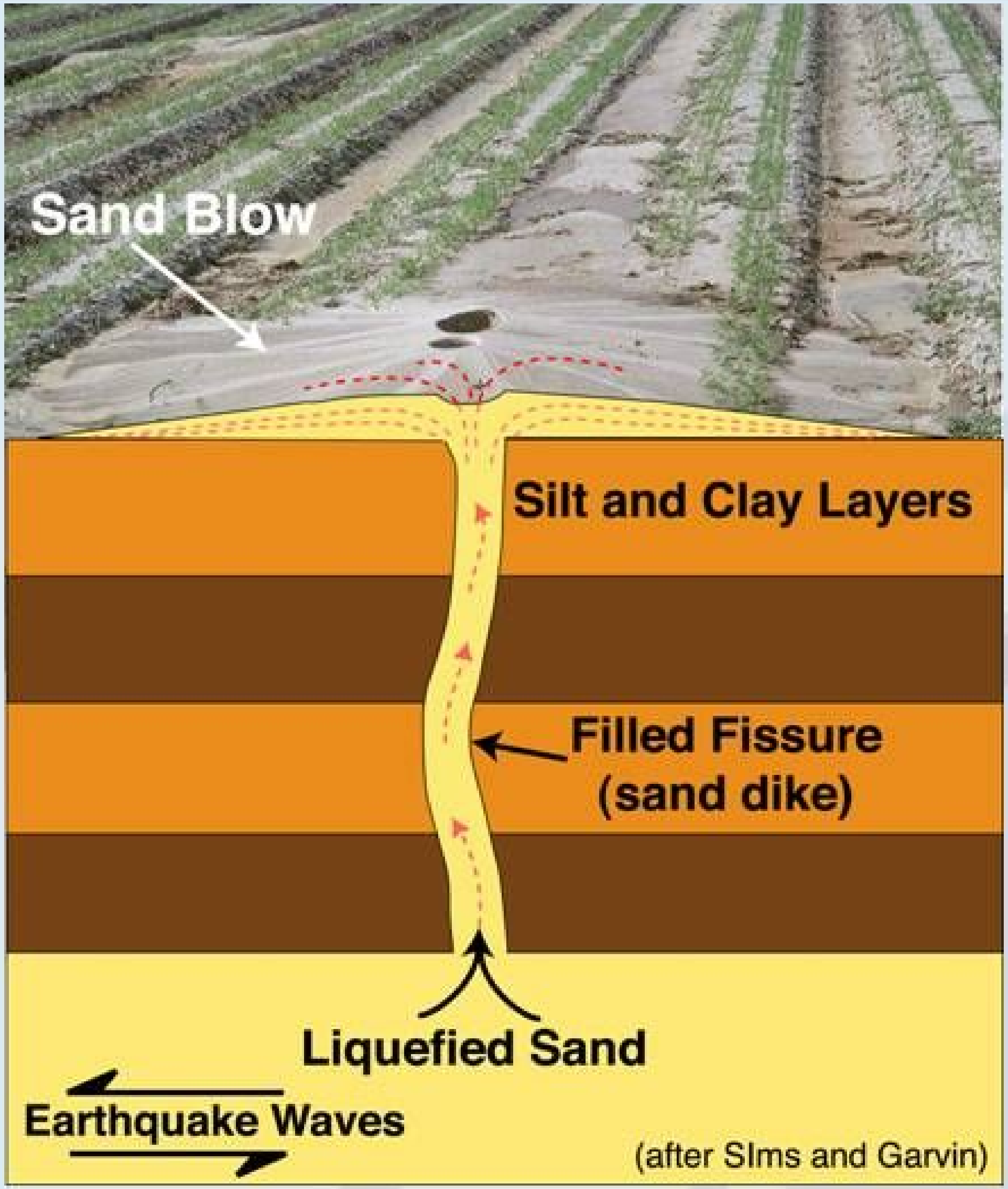
  No frequent large earthquakes

Paleoseismic study has been proved to be a powerful method to provide information on the recurrence of large earthquakes with a possibility to estimate their magnitudes for

- New Madrid Seismic zone
- Charleston seismic zone
- Eastern Tennessee seismic zone (ongoing)

Paleoliquefacion Phenomena

Liquefaction phenomena associated with an earthquake (commonly seeing in major seismic zones in CEUS)



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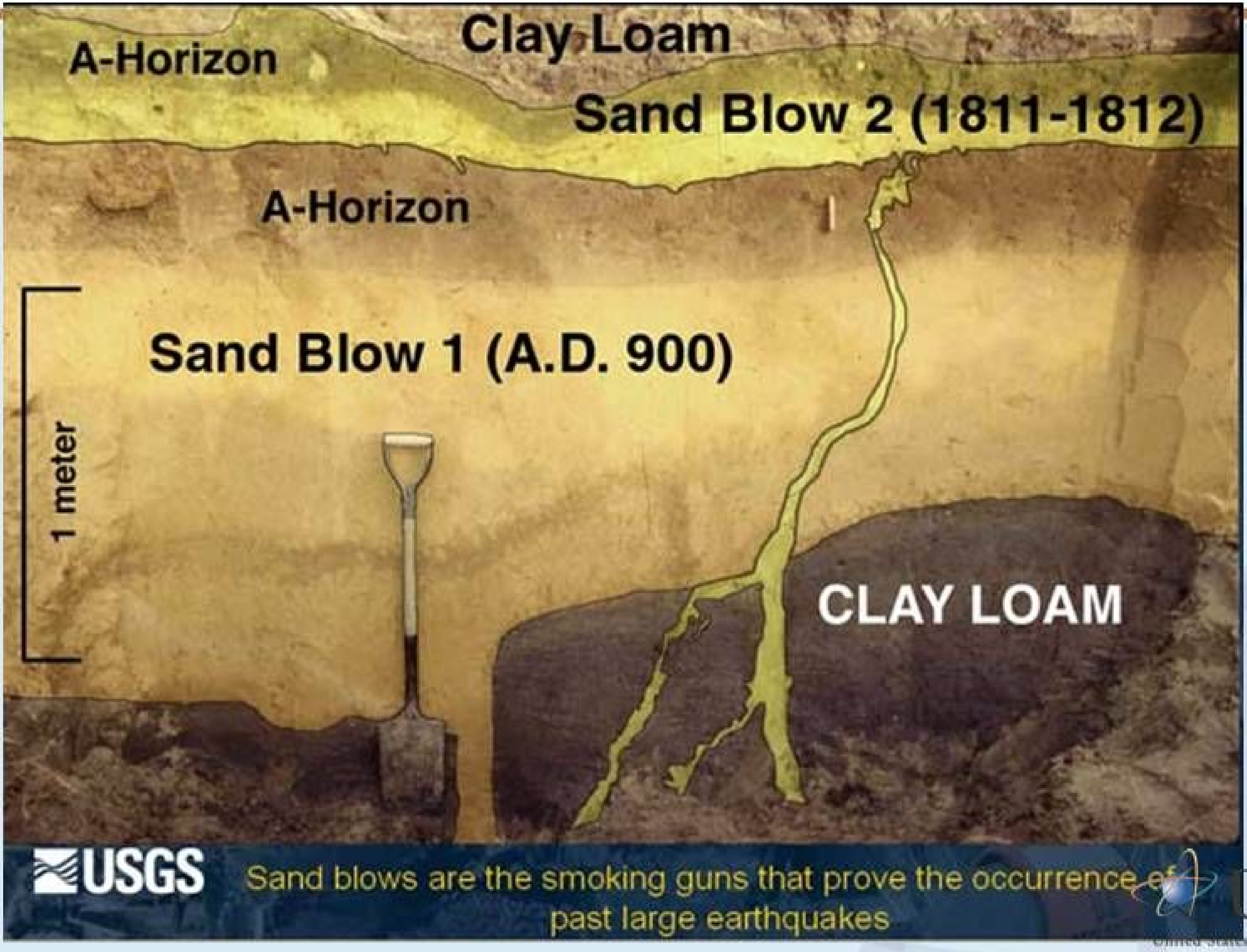
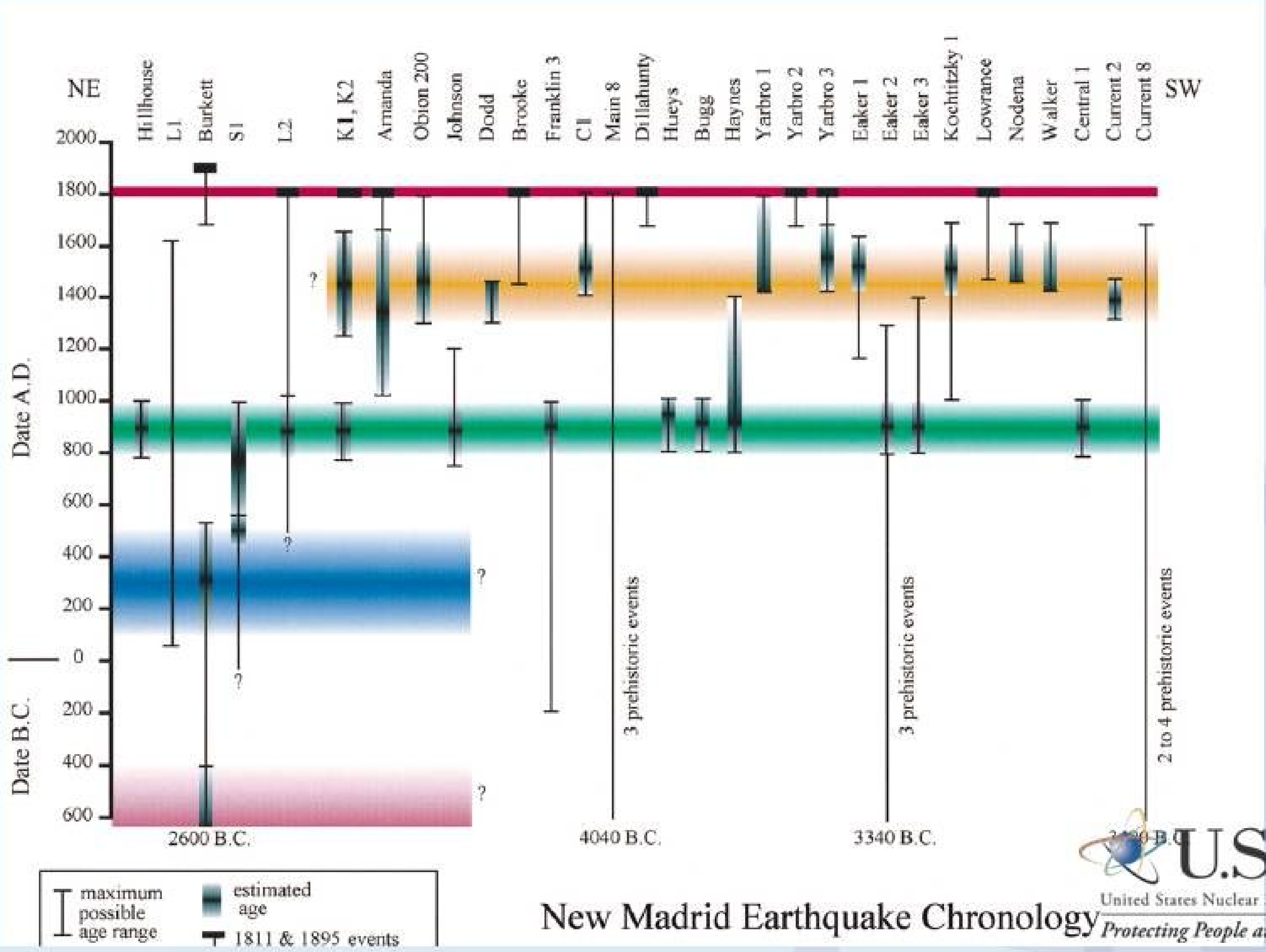
Paleoseismology in NMSZ



Paleoseismology in NMSZ



New Madrid Earthquake Chronology

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Seismological Investigations

- Seismology
  - Characterizing seismic sources
  - Ground Motion Prediction Equations
  - Site responses
  - Performance based Safe Shutdown Earthquake – SSE (GMRS)

Features of PSHA

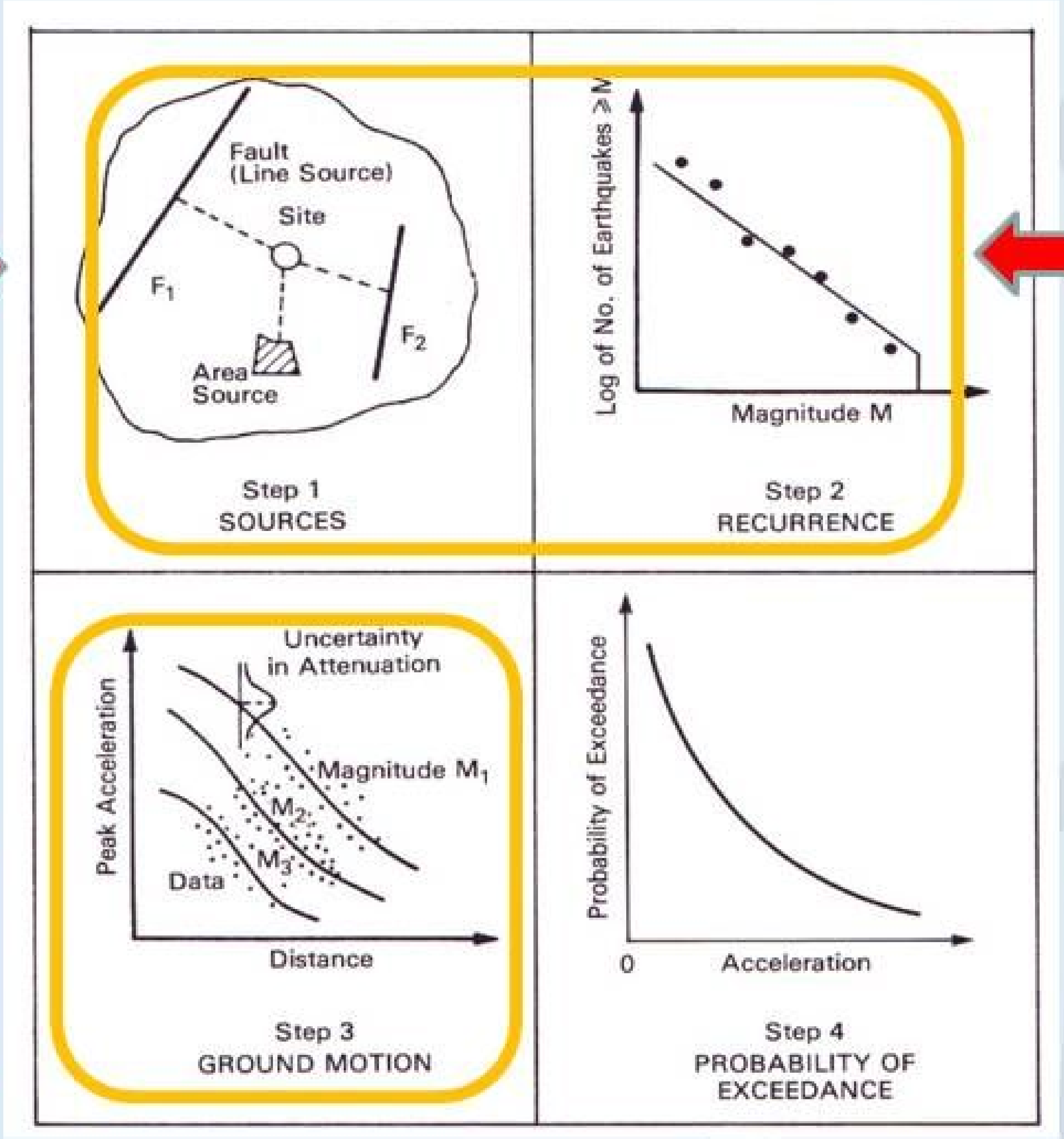
- PSHA includes seismic source characterization (source locations, magnitude distribution and rate of occurrence), ground motion characterization and probability analysis
- PSHA facilitates incorporation of new information on earthquake occurrence and source parameters
- PSHA allows uncertainties (both aleatory and epistemic) in the size, location, rate of occurrence, propagation of seismic waves and others to be explicitly considered in the seismic hazard evaluation
- PSHA applications can be used to make informed decisions on hazard estimate in the presence of uncertainty

Steps in Probabilistic Seismic Hazard Analysis (PSHA)

Seismic Source Characterization: SSC Model

Source Geometry

Earthquake Recurrence



Ground Motion Characterization: GMC Model

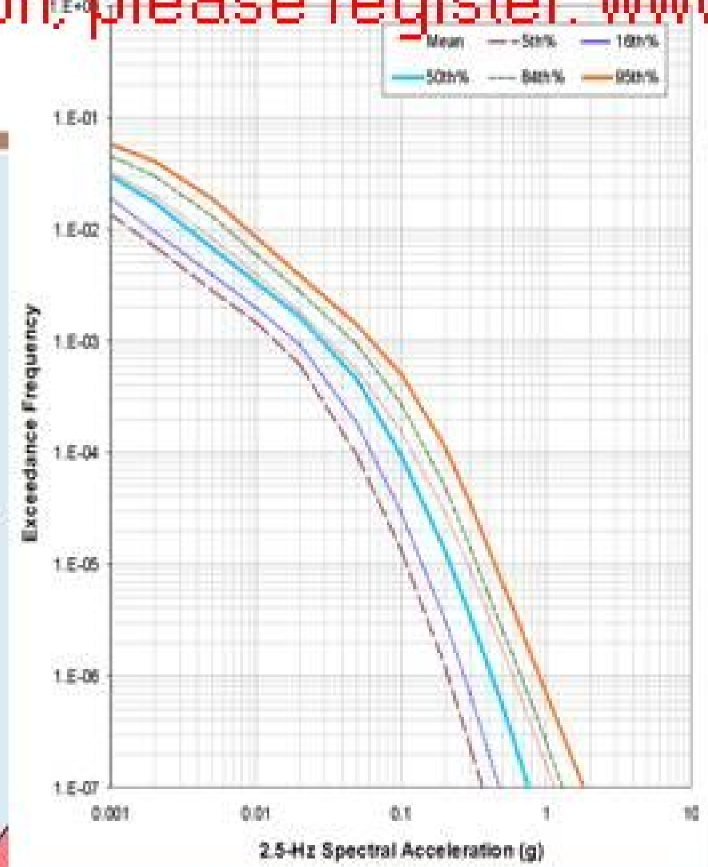
Reiter (1990)

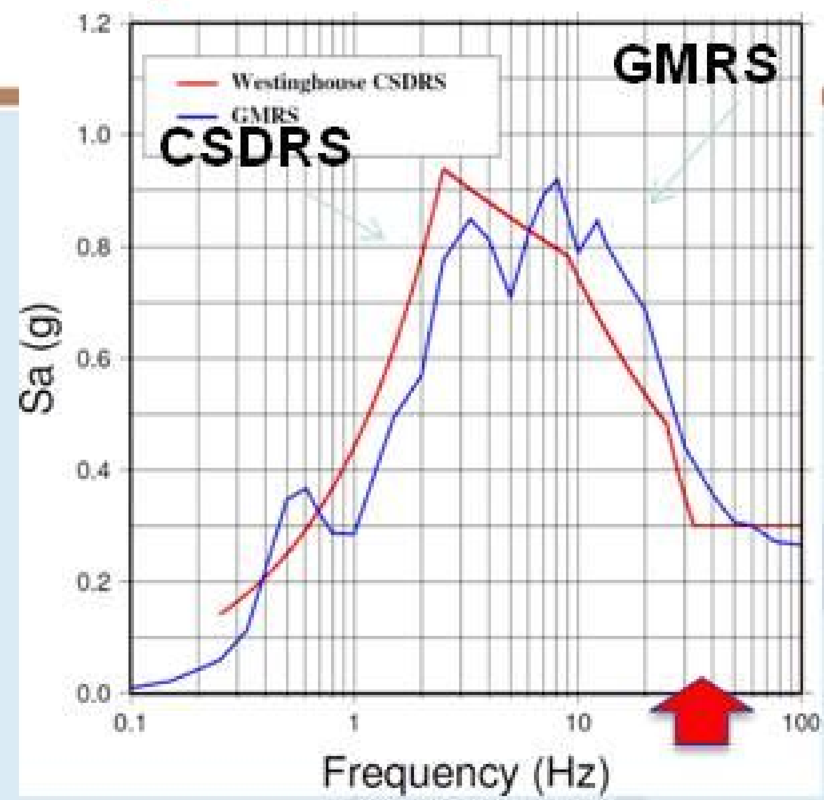
Pathway to Performance-Based GMRS

SSHAC

- Earthquake Catalog
- Source Models
- Ground Motion Models

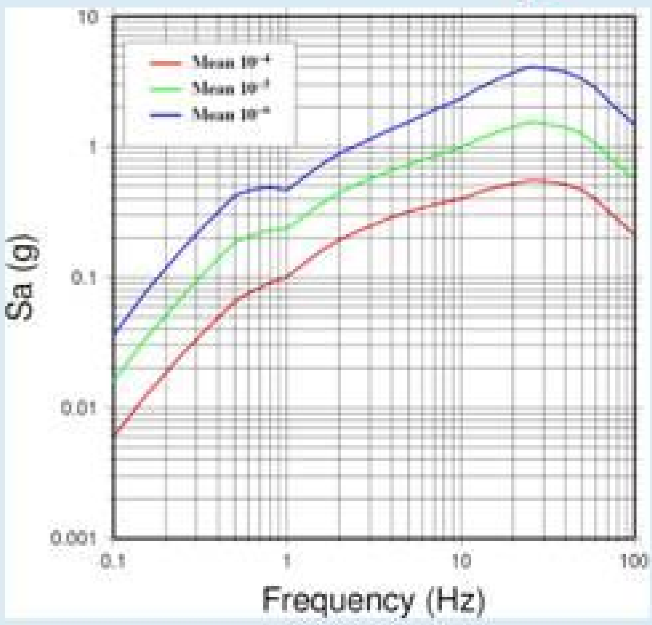
PSHA



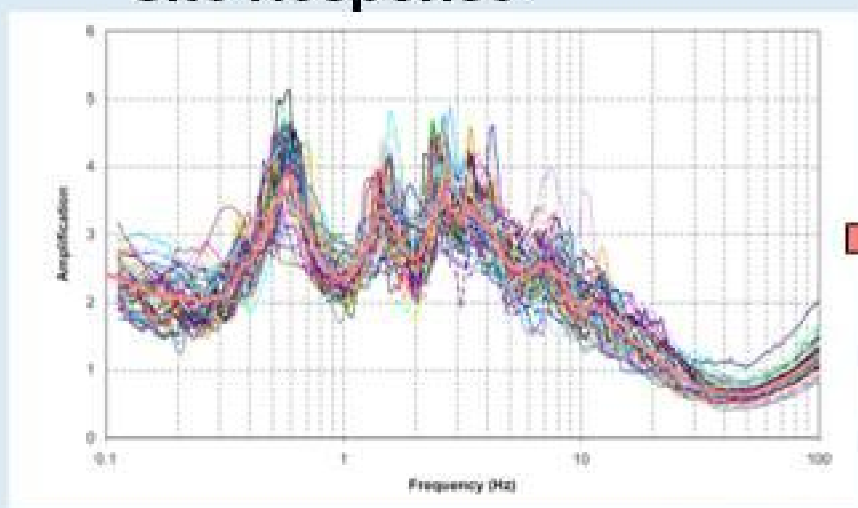


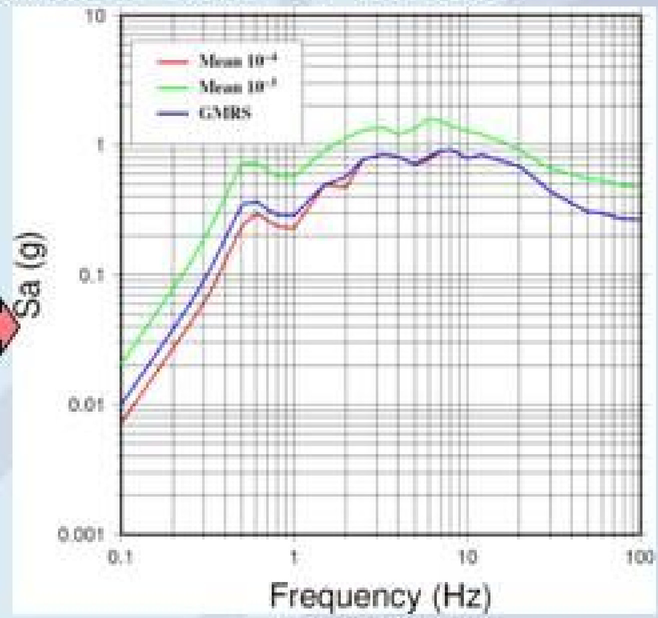
Surface UHS & GMRS

Base Rock UHS



Site Response





Local Structure

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Performance-Based Approach

- Develops a risk-consistent SSE
- Achieves both high and consistent level of seismic safety in the design of future NPPs

Performance-Based Approach

- Step 1: Define Target Seismic Risk Goal (P_{FT}) to be achieved by Seismic Design Criteria
- Step 2: Establish the Required Degree of Conservatism for Seismic Acceptance Criteria
- Step 3: Establish Seismic Hazard Exceedance Frequency or "starting point" at which UHRS is defined
- Step 4: Define PB GMRS (e.g., Site SSE)

Step 1- Performance Target

- Performance Target (P_{FT}) is $1x10^{-5}$ per year
  - IPEEE Seismic PRAs conducted for 25 NPPs during mid/late 1990s determined annual seismic Core Damage Frequency values
  - Median SCDF is $1.2x10^{-5}$/yr
- Performance is measured in terms of Frequency of Onset of Significant Inelastic Deformation (FOSID), essentially elastic behavior

Step 2 – Required Degree of Conservatism

- Less than about a 1% probability of unacceptable performance for the design basis ground motion (GMRS)

- Less than about a 10% probability of unacceptable performance for ground motion equal to 150% of the design basis ground motion

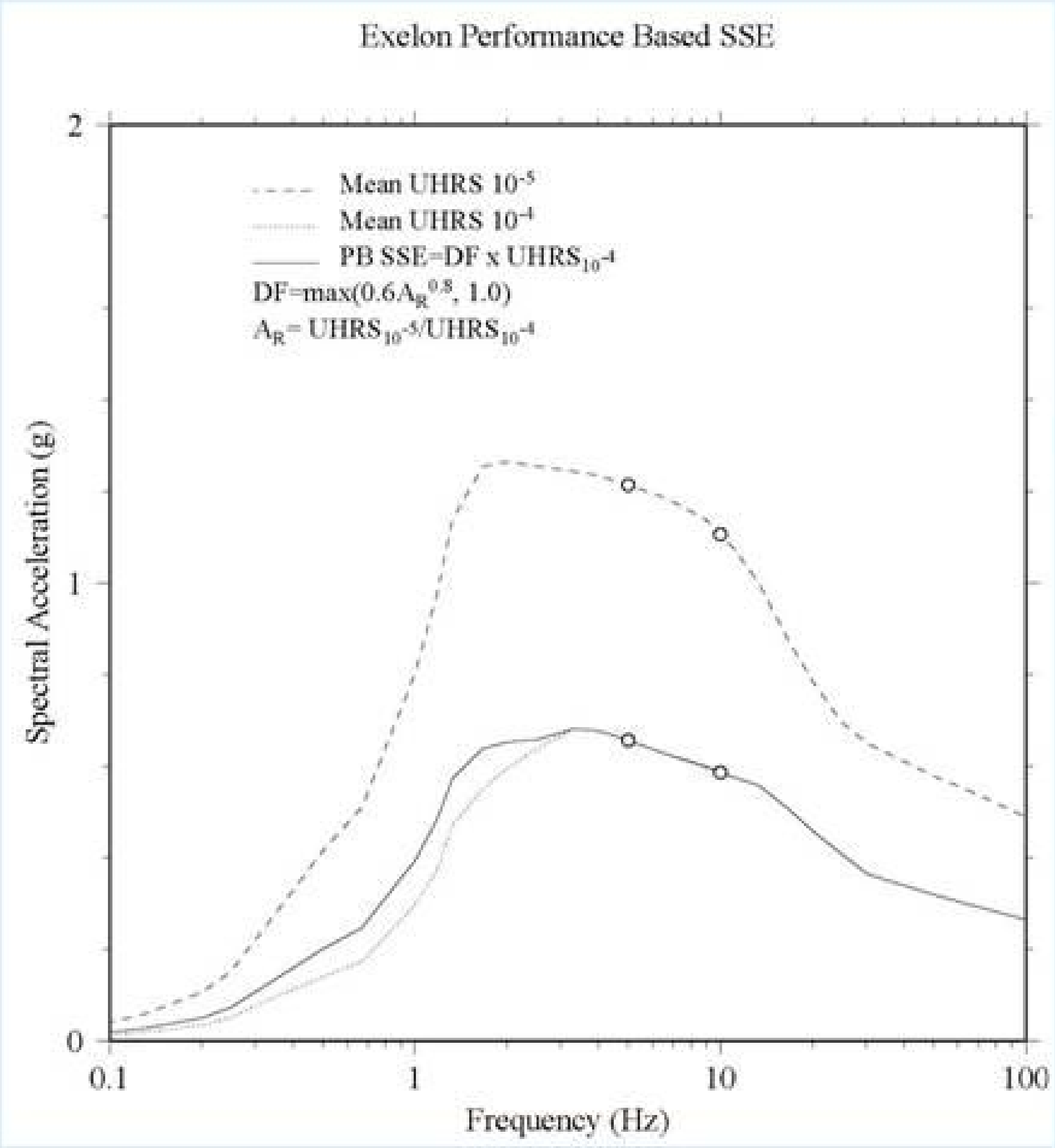
Steps 3 and 4

- Hazard Exceedance Frequency: 10^{-4}
- Define PB GMRS: $GMRS = DF \times UHRS_{10^{-4}}$
  - where

$$DF = \text{Max}(0.6 {A_R}^{0.8}, 1.0)$$

$$A_R = \frac{UHRS_{10^{-5}}}{UHRS_{10^{-4}}}$$

Performance-Based Approach Example



Spectral Frequency (Hz)	10-4 Mean UHRS (g)	10-5 Mean UHRS (g)	AR	DF	Horiz. SSE (g)
1	0.297	0.802	2.700	1.328	0.395
2.5	0.638	1.256	1.968	1.031	0.658
5	0.657	1.215	1.849	1.000	0.657
10	0.586	1.107	1.887	1.000	0.586

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Performance-Based Approach Assumptions

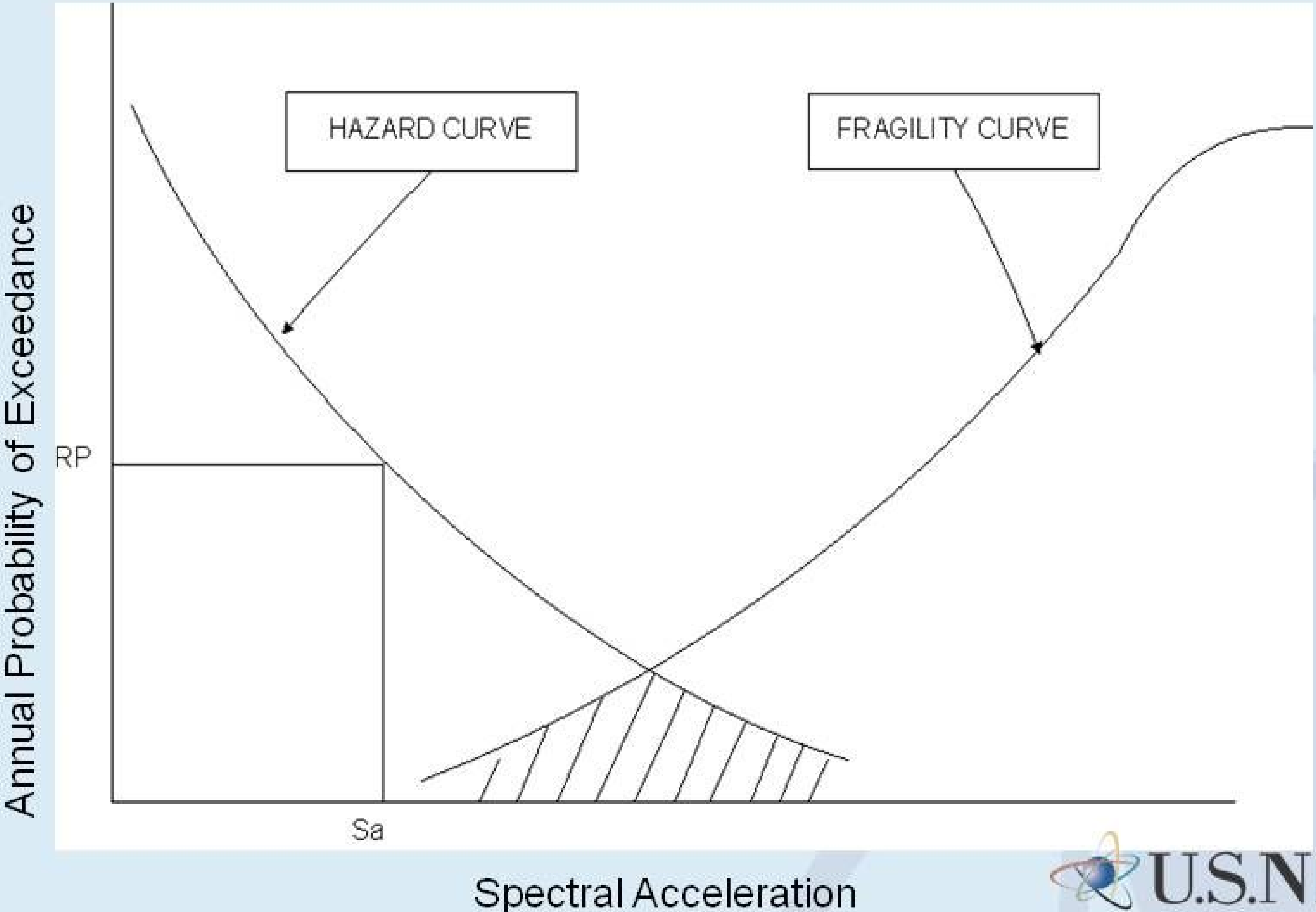
$$P_{FT} = \int H(a) f_c(a) da$$

P_{fT} = Target Performance Frequency

$H(a)$ = Seismic Hazard Curve

$f_c(a)$ = Probability Density Function for Plant - Level Seismic Fragility

Performance-Based Approach Assumptions



Derivation of Design Factor

- Hazard curve is approximated as linear in logarithmic space

$$H(a) = ka^{-1/\log Ar}$$

- Based on closed form solution of risk equation and substituted with all the parameters, exact DF can be derived

$$DF = \frac{1}{Ms}\left[\frac{k \cdot UHRS_{pref}^{-1/\log Ar}}{P_f}\right] \cdot \left[\exp(-2.32\beta / \log Ar + \frac{1}{2}(\frac{\beta}{\log Ar})^2\right]$$

Derivation of Design Factor

- Seismic Risk Equation

$$P_f = \int_0^{\infty} H(a) \frac{\mathrm{d}P_f(a)}{\mathrm{d}a} \mathrm{d}a$$

Annual probability of failure (P_f) is equal to the product of the annual probability that ground motion amplitude (seismic demand), exceeds *a* (H(a)) and the probability that the seismic capacity equals *a* ($dP_f(a)$), summed over all possible values of *a*

Derivation of Design Factor

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Direct Integration

SSE can be back-calculated using direct integration by assuming:

- Target $P_{FT} = 1x10^{-5}$/yr
- $\beta = 0.4$
- Seismic Margin = 1

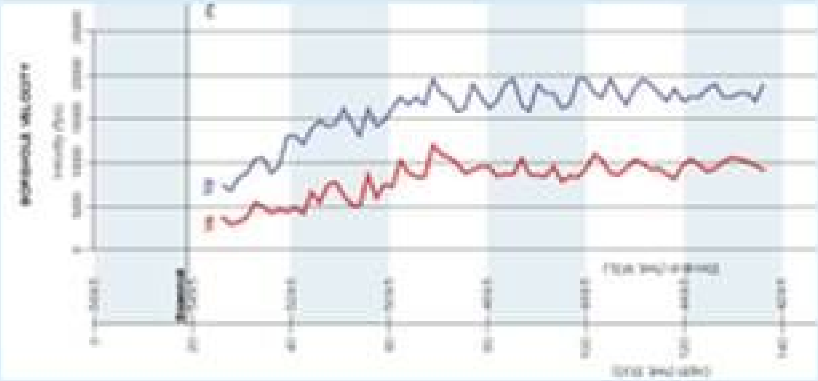
	SSE	
Frequency (Hz)	Risk Integral (g)	Design Factor (g)
1	0.337	0.395
2.5	0.574	0.658
5	0.604	0.657
10	0.559	0.586

Geotechnical Engineering Investigations

- Geotechnical Engineering (RG 1.132, 1.138, 1.198)
- Investigate subsurface material properties
  - Backfill issues
  - Two over one issue

Geotechnical Soil and Rock Properties

- **Field Observations**
  - Borings
    - Sampling (Disturbed/undisturbed)
    - Rock Coring
    - In-Situ testing for stress-strain-strength
  - Geophysical Measurements
    - Crosshole
    - Downhole
    - Suspension Logging
    - Spectral Analyses of Surface Waves (SASW)



- **Laboratory Tests**
  - Classification
  - Engineering properties
    - Total mass density
    - Moisture Content
    - Poisson's ratio
    - Shear and compressional wave velocities
    - Dynamic shear modulus and damping ratios

Regional Difference and Its Implication on Methodology

- Charactering seismic sources return periods
  - Western US relies more on fault exposures and corresponding slip rates
  - CEUS relies on paleo-liquefaction and paleo landslides and others
- Predicting ground motions
  - Ground motion prediction equations are different: Western US, seismic wave attenuates faster but CEUS seismic waves attenuates slower
  - Can not use same kind of reference rock (2.8 km/s)
  - Relatively, western rocks are softer, and CEUS rock are harder (higher shear wave velocity)

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Knowledge Gained From Siting Review

- Extensive usage of paleoseismic studies
- PSHA studies—Comprehensive studies in characterizing seismic sources to avoid surprises later
- SSHAC methodology– to get consensus form scientific community on modeling hazard and capture uncertainties
- Performance based approach to determine GMRS- risk informed approach
- Understand backfill material sources and properties in advance
- Pay attention at interactions between different category structures, category 1 and category 2

Summary

- Regulating new nuclear power plant is a comprehensive process and nuclear safety is number one goal
  - Need well established regulation tools
  - Need establish sufficient safety margin
  - Need multi level of cross check
  - Need public involvement (transparency and informed)

Tsunami Hazard Review

Back up slides

US Historical Tsunami Records (1837-2006 ?)

- Tsunamis were induced by
  - Earthquake (**71%**)
  - Landslides triggered by earthquakes (**13%**)
  - Landslides (**10%**)
  - Volcano (**2%**)

Earthquake Triggered Tsunami

- Local and remote seismic sources
  - Maximum Magnitudes, focal depth, fault dimension, orientation, displacement and the potential sea floor relocating volume
- Tectonic settings
  - Subduction zones (inter-plate thrust)
  - Out-rise normal faults, back-arc thrusts, deep intra-slab events
  - Strike-slip faults

Earthquake Triggered Tsunami

- Return period of the earthquakes associated with a specific tectonic setting
  - Historical data
  - Paleotsunami studies
- Tsunami earthquakes
  - Latest Japan studies indicate tsunami earthquake concept

Landslide Triggered Tsunami

- Submarine Landslides
  - Active and Passive margins
  - Submarine topography
  - Identify existing or potential landslides
    - Geologic composition, slope steepness, triggering mechanism, and pore pressure
- Subaerial Landslides
  - Geographically limited

Volcano Activity Triggered Tsunami

- Submarine Volcano Eruptions
  - Pyroclastic flows
  - Caldera collapse
  - Explosive eruption
  - Debris avalanche and flank failures

Interacting With Other Sections

- Tsunami source review is coordinated with Geology and Seismology Sections.

Regulatory Basis & Guidance

- 10 CFR Part 50, Appendix A - General Design Criterion 2
- 10 CFR Part 100 (Sections 20, 21, & 23)
- 10 CFR Part 52 (Sections 17 & 79)
- Regulatory Guide 1.102, “Flood Protection for Nuclear Power Plants,” Rev. 1 1976
- RG 1.206 , “Combined License Applications for Nuclear Power Plants,” 2007Section 2.4.6
- Regulatory Guide 1.59, “Design Basis for Nuclear Power Plants,” Rev. 2. 1977
- US NRC, Standard Review Plan, “Probable Maximum Tsunami Flooding,” Section 2.4.6

Applicants to consider the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

The most severe seismically induced floods reasonably possible should be considered for each site.

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Regulatory Basis & Guidance

Currently the US NRC has a tsunami research program that is focused on developing modern hazard assessment techniques and additional guidance through cooperation with the National Oceanic and Atmospheric Administration and the United States Geological Survey.

This has already led to several technical reports and an update to NUREG 0-800. The NOAA and USGS contractors are also assisting with NRO reviews of tsunami hazard. A new regulatory guide on tsunami hazard assessment is currently planned in the office of research, although it is not expected to be available in draft form until 2012.

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58

NRC Standard Review Plan – NUREG-00800

Section 2.4.6 Tsunami Hazards

1. Historical Tsunami Data

2. Probable Maximum Tsunami (PMT) - The staff also reviews source mechanisms, source parameters, propagation models, and near-shore inundation models.

3. Tsunami Propagation Models
4. Wave Runup, Inundation, and Drawdown

5. Hydrostatic and Hydrodynamic Forces

6. Debris and Water-Borne Projectiles

7. Effects of Sediment Erosion and Deposition

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Summary

- NRC updated tsunami related guidance documents after Indian Ocean Tsunami
  - Requires the applicant consider not only consider earthquake induced tsunami but submarine landslide induced tsunami too
  - Requires more detailed information on site inundation model, including understanding submarine topography
  - Requires not only consider local sources but remote source for tsunami too.