Uncertainties in Natural Hazard Assessments

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Common Challenges Among Natural Hazard Assessments

- Need for both best estimate and uncertainties
- Limited data and long return periods
  - 10^{-4} for seismic design & larger range for risk assessment
- Large uncertainty in rates of rare events
- Complex and sometimes contradictory data sets require the use of expert judgment
- Data permissive of alternate interpretations
- Needs to separate and address natural (aleatory) variability from epistemic (model) uncertainty

Use of Probabilistic Methods

- Use of probabilistic hazard and SPRA and seismic margin methods for IPEEE
- Development of SSHAC guideline for probabilistic hazard
- Development of design basis for new reactors using PSHA and performance-based criteria
- Performance of seismic margin/PRA for new reactors
- Fukushima recommendation implementations

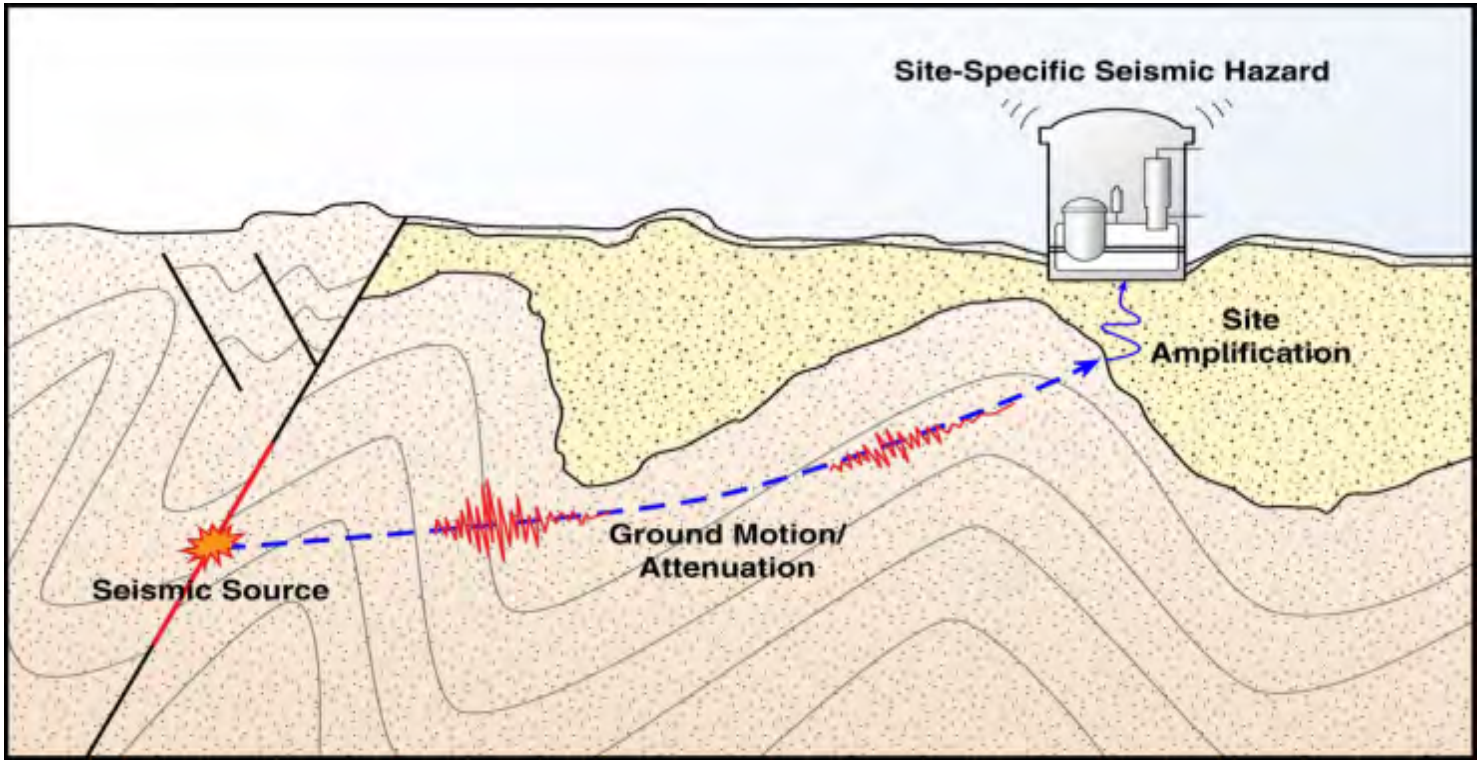
Senior Seismic Hazard Analysis Committee (SSHAC) Guidelines

- NUREG/CR-6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts”
- Developed in the 1980s as a result of differing NRC and EPRI Seismic Hazard Assessment Studies - the *method* used to engage experts differed more than the *technical input*
- SSHAC provides a framework for incorporating experts into scientific assessments through structured processes and interactions

Objective of a SSHAC Study

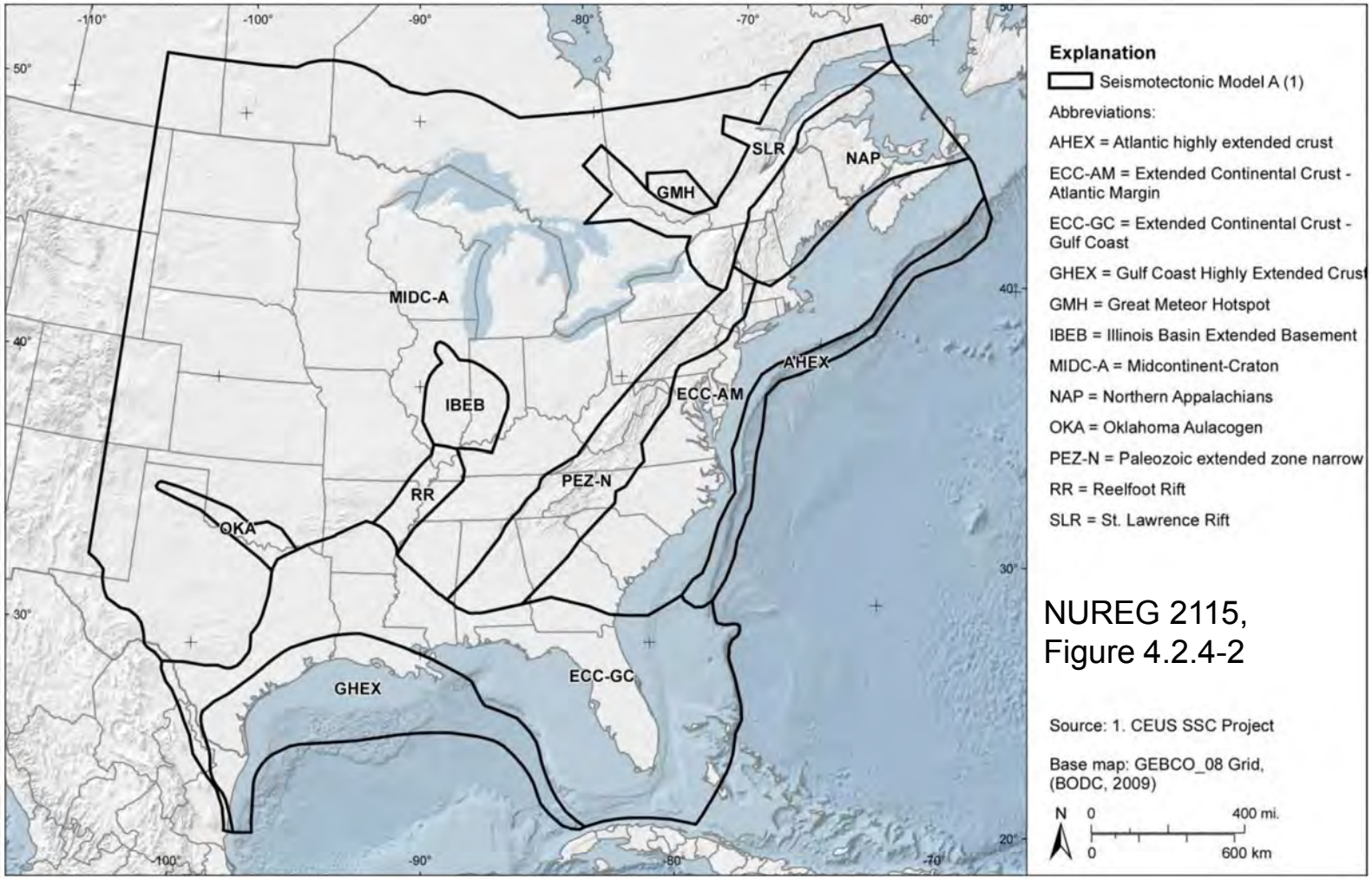
- Develop a model that represents the center, body and range of technically defensible interpretations of available data
  - Center-best estimate
  - Body-shape of the distribution
  - Range-extreme values of the distribution
- Achieved through a process with well defined evaluation and integration phases

Evaluation Methods: Hazard



- Hazard reevaluation should be, in general, consistent with regulatory guidance and methods used for ESP and COL reviews
- Determine Ground Motion Response Spectra (GMRS) for site using probabilistic seismic hazard analysis (PSHA)

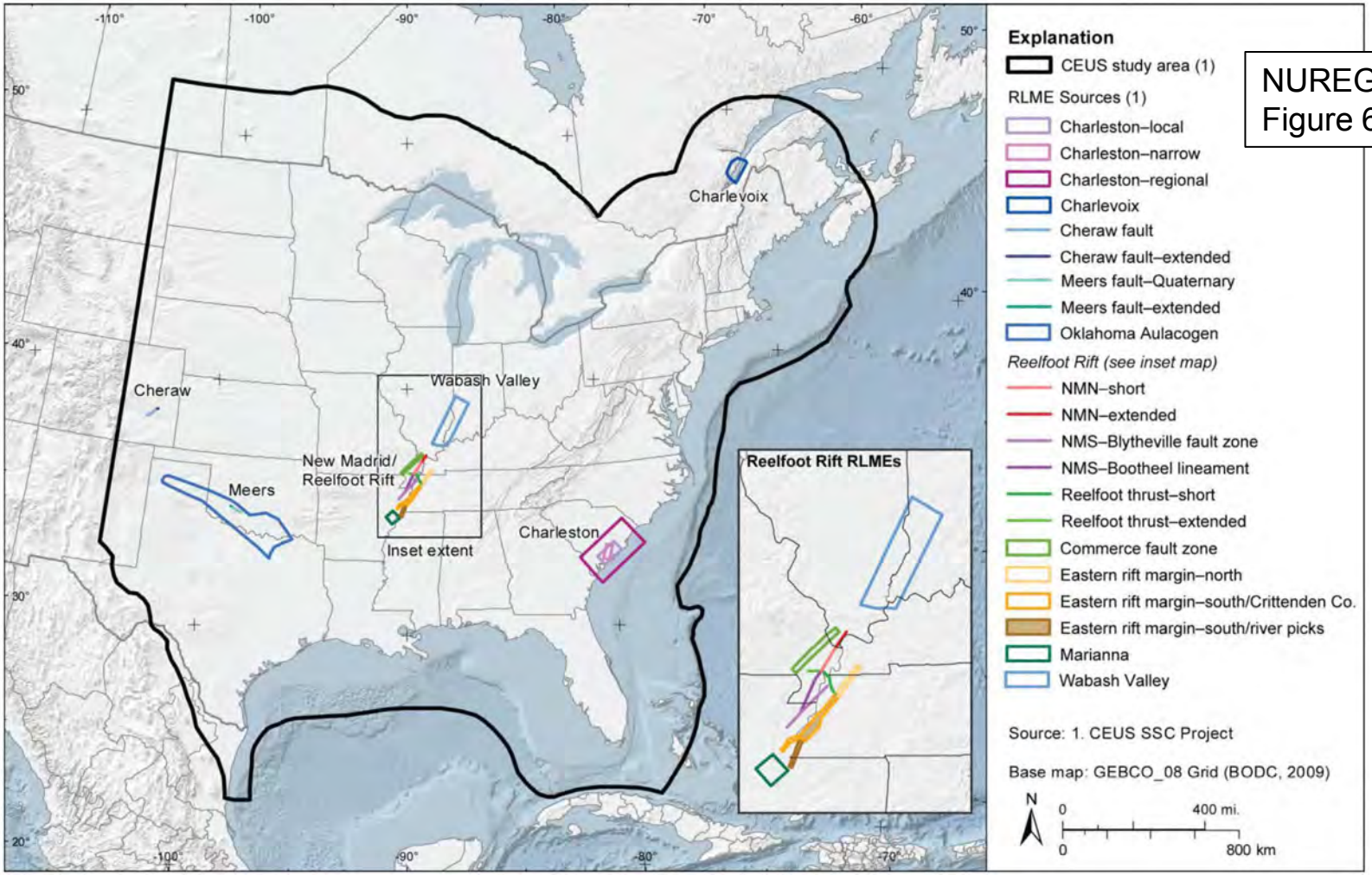
Background Seismic Source Zones



NUREG 2115, Figure 4.2.4-2

- Magnitude-frequency relationships for each zone
- Alternative zones considered in PSHA

Recurring Large-Magnitude Earthquake Zones



NUREG 2115
Figure 6.1-1

- Magnitude-frequency relationships for each RLME zone
- Alternative zones also considered in PSHA (shown)

Pathway to Performance-Based GMRS

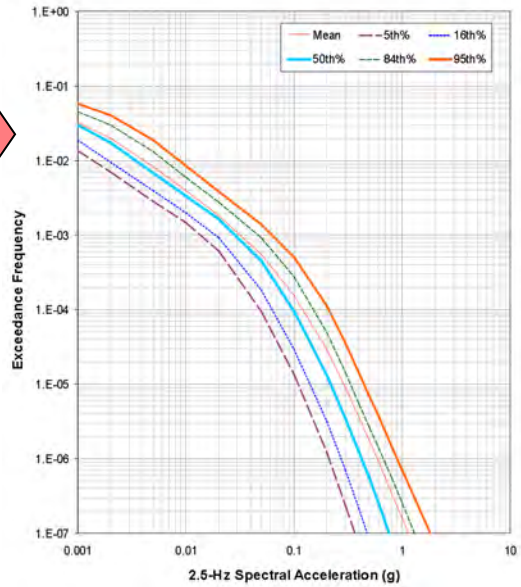
Seismic Source Models
Based on geologic investigations

Ground Motion Prediction Equations

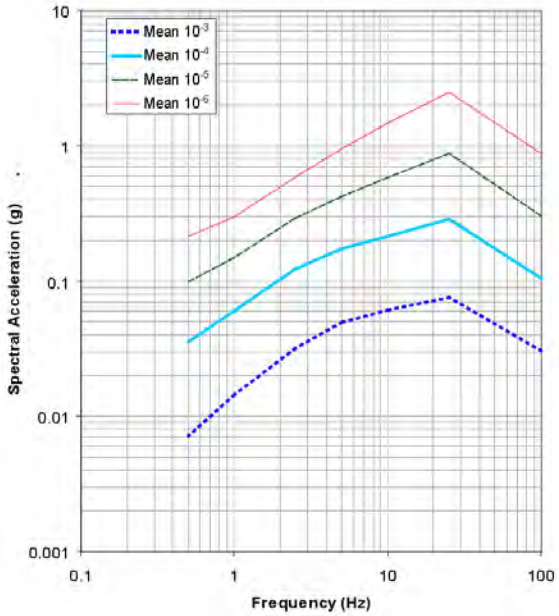
Earthquake Catalog

PSHA

Seismic Hazard Curves

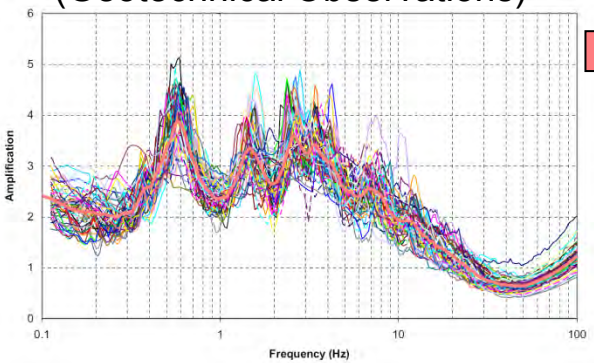


Generic Rock, Uniform Hazard

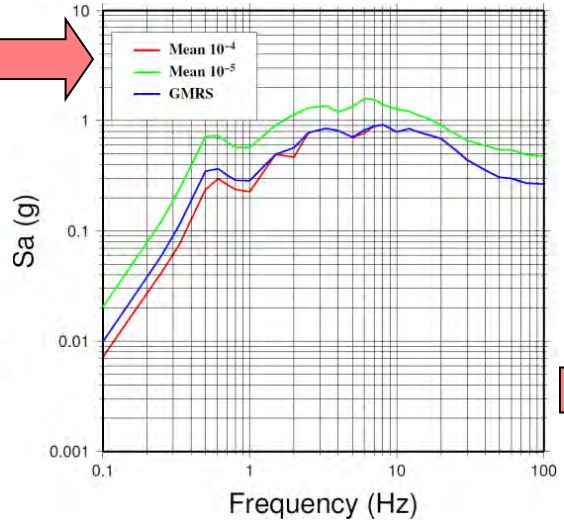


Site-specific Corrections

(Geotechnical Observations)

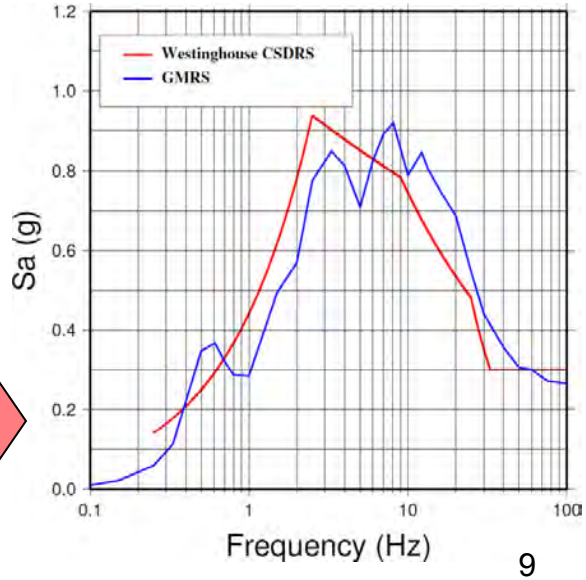


Surface UHRS at site



GMRS

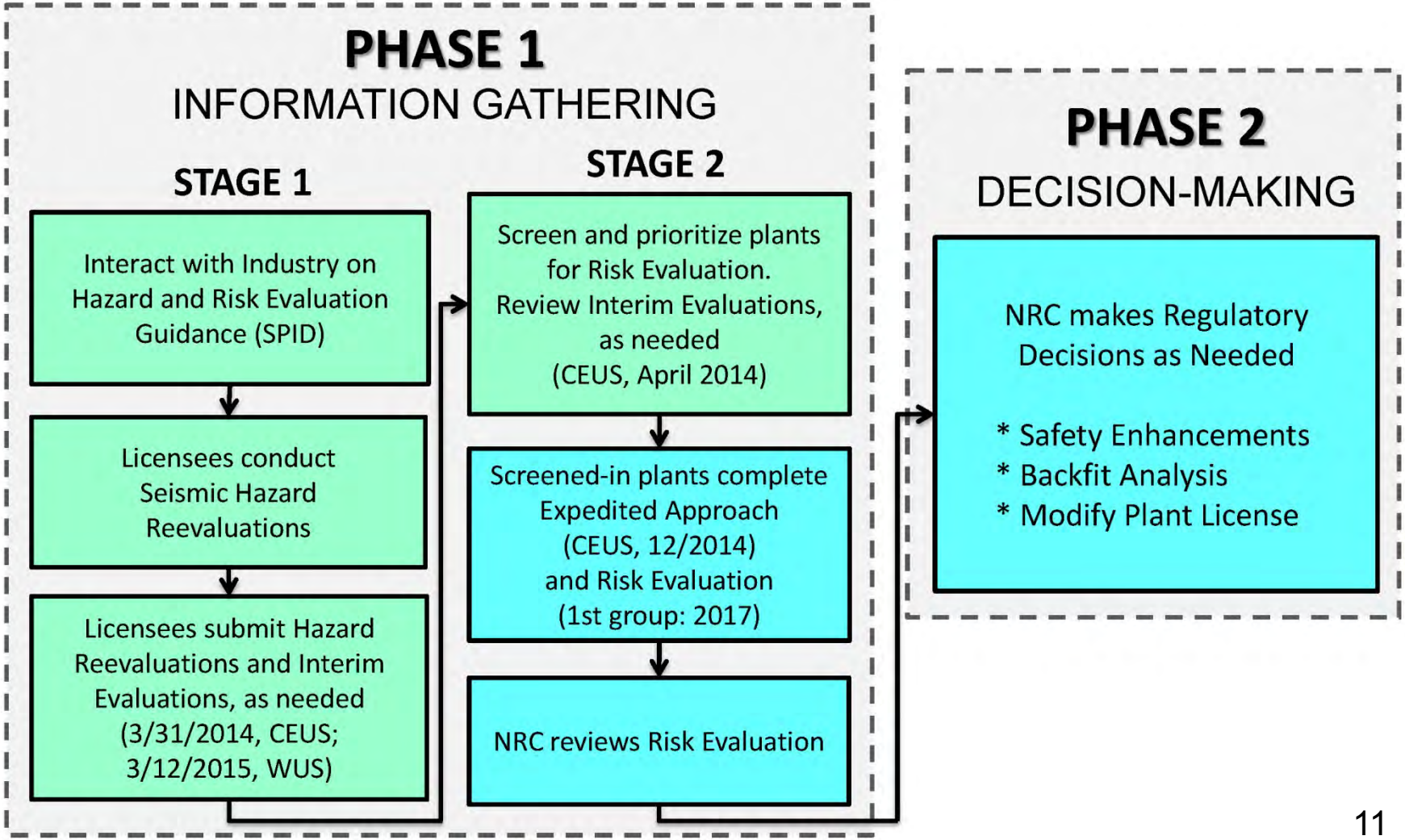
Comparison with Design



Use of Probabilistic Methods

- Implementing Fukushima recommendation 2.1 for seismic hazard reevaluations
- Probabilistic hazard analysis to estimate new potential design basis hazard
  - Use seismic sources developed jointly by EPRI, USGS, and NRC using SSHAC Level 3 for CEUS
  - Use ground motion models updated with SSHAC Level 2 for CEUS
  - Site-specific SSHAC Level 3 for WUS

R2.1 Seismic - Overall Implementation Approach



R2.1 Interim Evaluations

- Provides confidence plants can cope with re-evaluated hazard while detailed risk assessments are ongoing.
- Supplements 2013 seismic walkdowns.
- **Interim Evaluations & Actions: (**March 2014) simplified deterministic evaluations that showed likelihood of core-damage did not increase significantly at new hazard levels.
- **Expedited Approach:** (December, 2014) evaluates seismic margin of installed plant equipment needed for FLEX (Phase1) necessary to respond to a loss of AC power/UHS.
  - Will typically include tanks and mechanical and electrical equipment
  - Structures and other SSCs (e.g., piping, cable trays, NSSS) would be addressed in the SPRAs or enhanced SMAs

R2.1 Seismic Risk Evaluation Methods

- Risk evaluations are conducted only if the new hazard exceeds the design/licensing basis
- Depending on Screening Criteria, perform
  - Seismic Margin Analysis (SMA)
  - Probabilistic Seismic Risk Analysis (SPRA)
- Most screened-in plants are conducting SPRAs

R2.1 Seismic Risk Evaluation Methods

- SMA or SPRA for small (e.g.,<1.3x) exceedance of SSE
- SPRA for larger exceedance of SSE
- SMA method is full-scope NRC SMA with enhancements (NRC ISG-2012-04)
- SPRA approach is Level 1 with estimate of Large Early Release Frequency (ASME/ANS Standard SA-2009, RG 1.200)
- Exceedances in the high frequency range (>10 Hz) to be addressed through component testing program
- Includes spent fuel pool integrity evaluations

Summary

- Use of probabilistic methods needs to consider alternate interpretations and uncertainties.
- Probabilistic risk assessment methods evaluate an integrated response of a plant to a natural hazard considering design and as-built and as-operated conditions.
- PRAs, along with other insights, provide a robust basis for risk-informed regulatory decisions.

Resolving Uncertainties in Seismic Hazards Assessments at Diablo Canyon NPP, U.S.A.

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Diablo Canyon NPP, U.S.A.

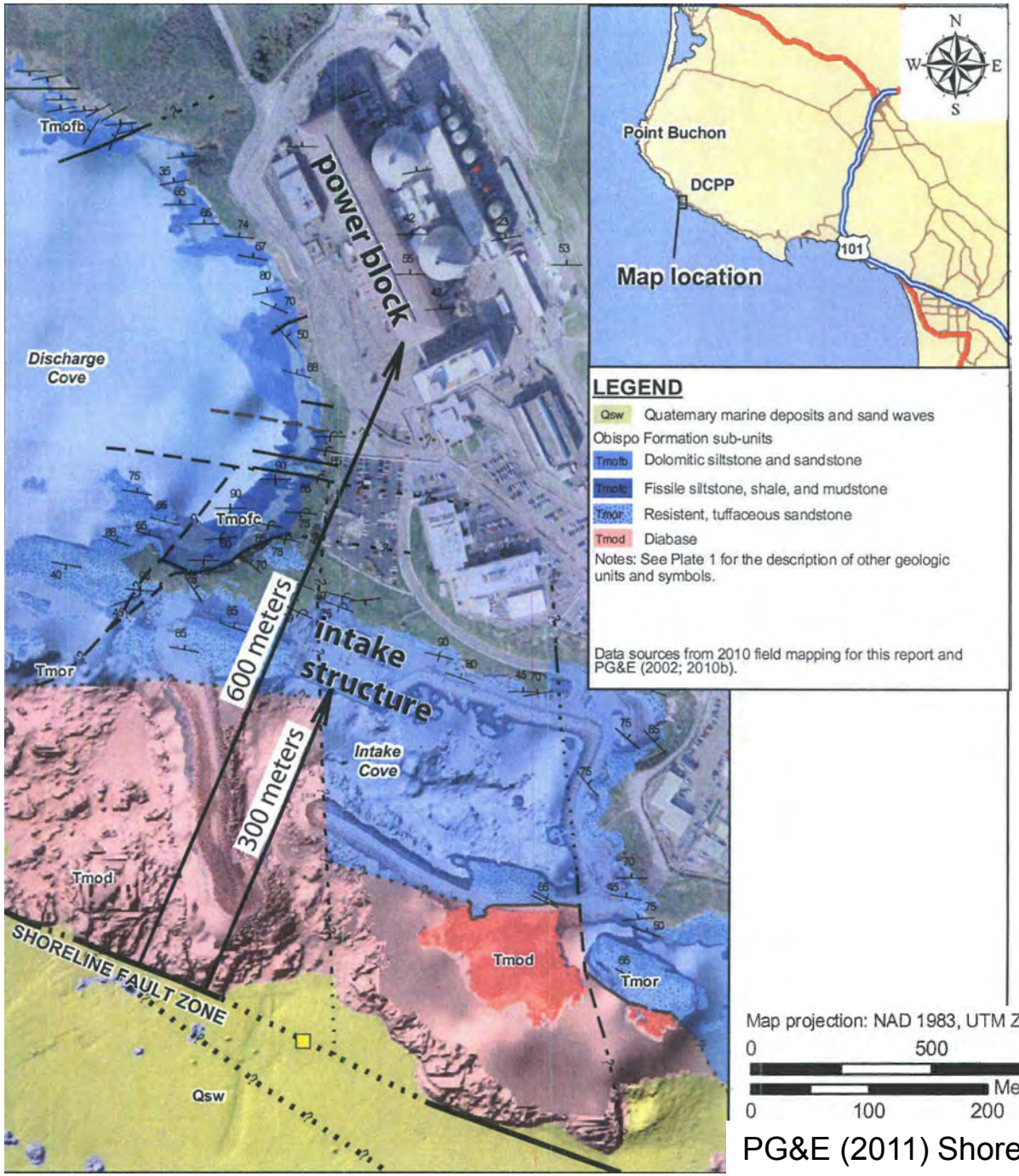
Diablo Canyon Long Term Seismic Program (LTSP) - Background

- New fault (Hosgri) >4.5 km offshore discovered after CP issued in 1969; appeared capable of large earthquakes.
- PG&E updated licensing basis, modified plant design.
  - No new potential for surface deformation at site.
- Condition for Operating license (1984): Develop and implement a long-term program to reevaluate the plant's seismic design bases
  - Identify and evaluate new geologic and seismic information
  - Use the new information to reevaluate site ground-motions
  - Use the new ground motions in PRA and deterministic studies to assure adequacy of seismic margins for the plant.
- PG&E submitted Final LTSP report on July 31, 1988.

Diablo Canyon LTSP – NRC Review and Findings

- Interactive review involving staff and external experts from academia, USGS, National Labs, and other stake holders.
- NRC Findings presented in SSER 34 (1991)
- Staff conclusion – "…..that the plant seismic margins are adequate to accommodate the spectral exceedances....the staff finds that License Condition 2.C.(7) of DPR-80 has been met."
- LTSP continues as a permanent program to assure adequate seismic margins

Diablo Canyon – Continuing LTSP



2008: Offshore fault (Shoreline Fault) discovered from seismicity patterns

>600 m [>1969 ft] to plant

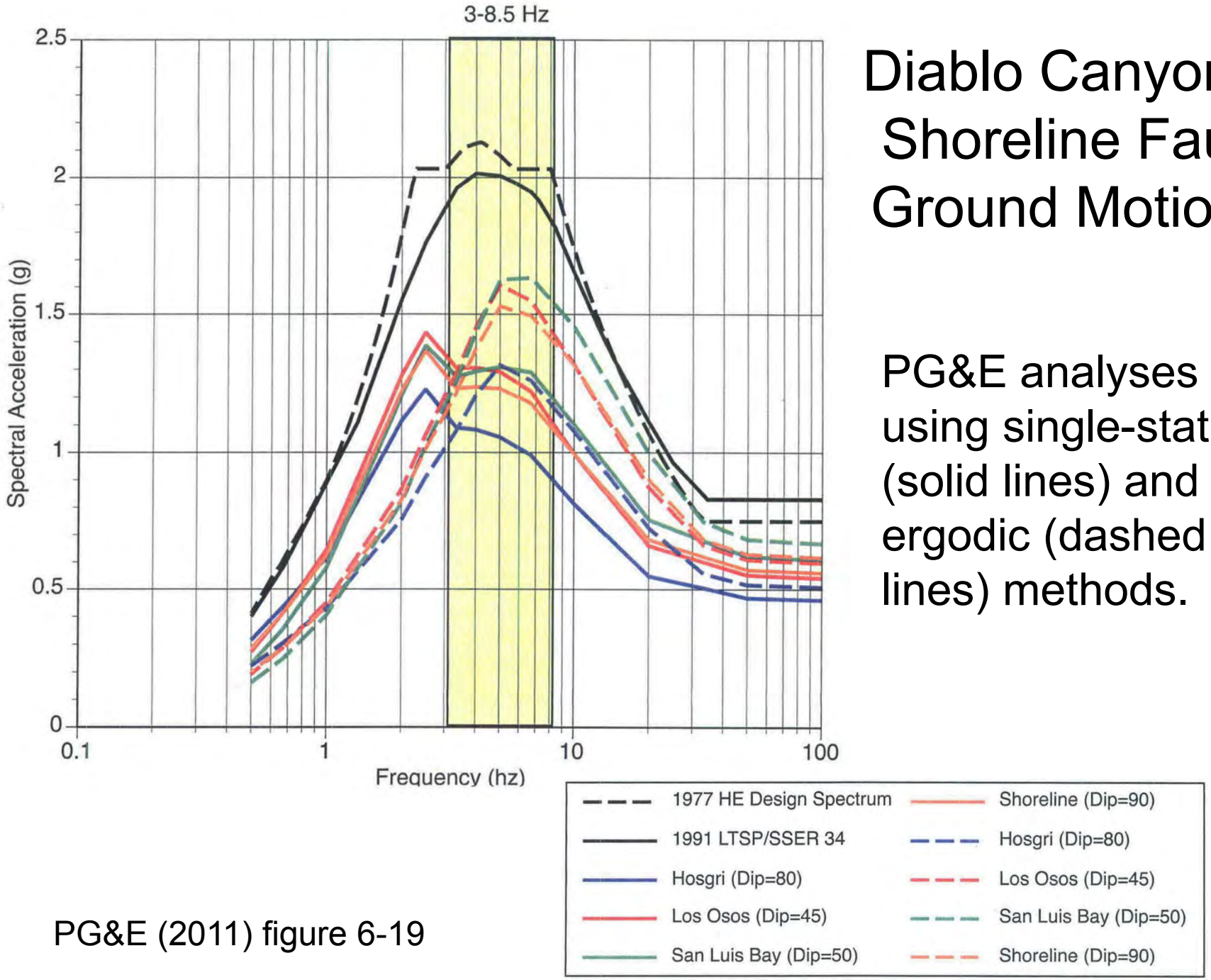
>300 m [>984 ft] to intakes

PG&E (2011) Shoreline Report

Diablo Canyon – Continuing LTSP

- PG&E and NRC evaluated significance of new Shoreline fault for seismic and deformation hazards (2008-2012).
- New seismic hazards bound by ground motions considered in LTSP and licensing.
- No significant potential for new, secondary fault deformation at Diablo Canyon plant.
- Continue PSHA for post-Fukushima 50.54(f) response.

Diablo Canyon – Shoreline Fault Ground Motions



PG&E analyses using single-station (solid lines) and ergodic (dashed lines) methods.

PG&E (2011) figure 6-19

Diablo Canyon – Shoreline Fault Secondary Ground Deformation

- Empirical method of Petersen et al. (2004, 2011) for secondary deformation near strike-slip faults.
- P_E = (Probability of M_w magnitude earthquake) *X* (Probability of surface rupture on main fault) *X* (Probability of rupture *L* distance from fault for given amount of displacement)
- $P_E = 2x10^{-7}$/yr for M_w=6.7 and 1 cm [0.4 in] displacement 300 m [984 ft] distance from fault.
- $P_E < 2x10^{-7}$/yr for Mw<6.7, >1 cm [0.4 in] displacements, or distances >300 m [>984 ft].

US NRC Regulations for Potential Surface Deformation Hazards

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US NRC Regulatory Approach for Surface Deformation

- Much of the U.S.A. has shown negligible potential for surface deformation in last ≈ 2.6 Myr.
- Before 1997, evaluated deformation from “capable faults” and nontectonic sources.
- After 1997, evaluate potential for surface deformation from all sources.
- Changed primarily because deterministic criteria for “capable faults” were not needed to support PSHA methods.

Capable Faults – USNRC Licensing Before 1997

- A *capable fault* has exhibited one or more of the following characteristics (10 CFR Part 100, Appendix A):
  - Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
  - Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
  - A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.

Potential for Surface Deformation – USNRC Licensing After 1997

- 10 CFR 100.23 siting criteria:
  - "The geologic and seismic siting factors considered for design must include …. the potential for surface tectonic and nontectonic deformations."
  - "Sufficient geological, seismological, and geophysical data must be provided to clearly establish whether there is a potential for surface deformation."
- 10 CFR 100.50 Appendix S engineering criteria:
  - "The potential for surface deformation must be taken into account in the design of the nuclear power plant by providing reasonable assurance that in the event of deformation, certain structures, systems, and components will remain functional."

Regulatory Guidance – RG 1.208

- “Sites that have a potential for fault rupture at or near the ground surface and associated deformation should be avoided.”
- “The presence or absence of Quaternary faulting at the site needs to be evaluated to determine whether there is a potential hazard that is caused by surface faulting.”
- “Where it is determined that surface deformation need not be taken into account, sufficient data or detailed studies to reasonably support the determination should be presented.”

NRC Review Guidance on Consideration of Surface Deformation in NPP Licensing

- A detailed geologic analysis covering the Quaternary period (≈2.6 Myr) should be conducted to determine the potential for surface faulting and seismic hazard at a nuclear power plant site.
- An absence of deformation in last ≈ 2.6 Myr generally indicates a negligible potential for future deformation.
- No operating commercial nuclear power plant in the U.S.A. includes surface deformation as a design basis (excluding minor foundation settlement).