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Engineering of Structures
and Building Enclosures

Uncertainties in Seismic PRA

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NRC/EPRI PRA Model Uncertainty Workshop

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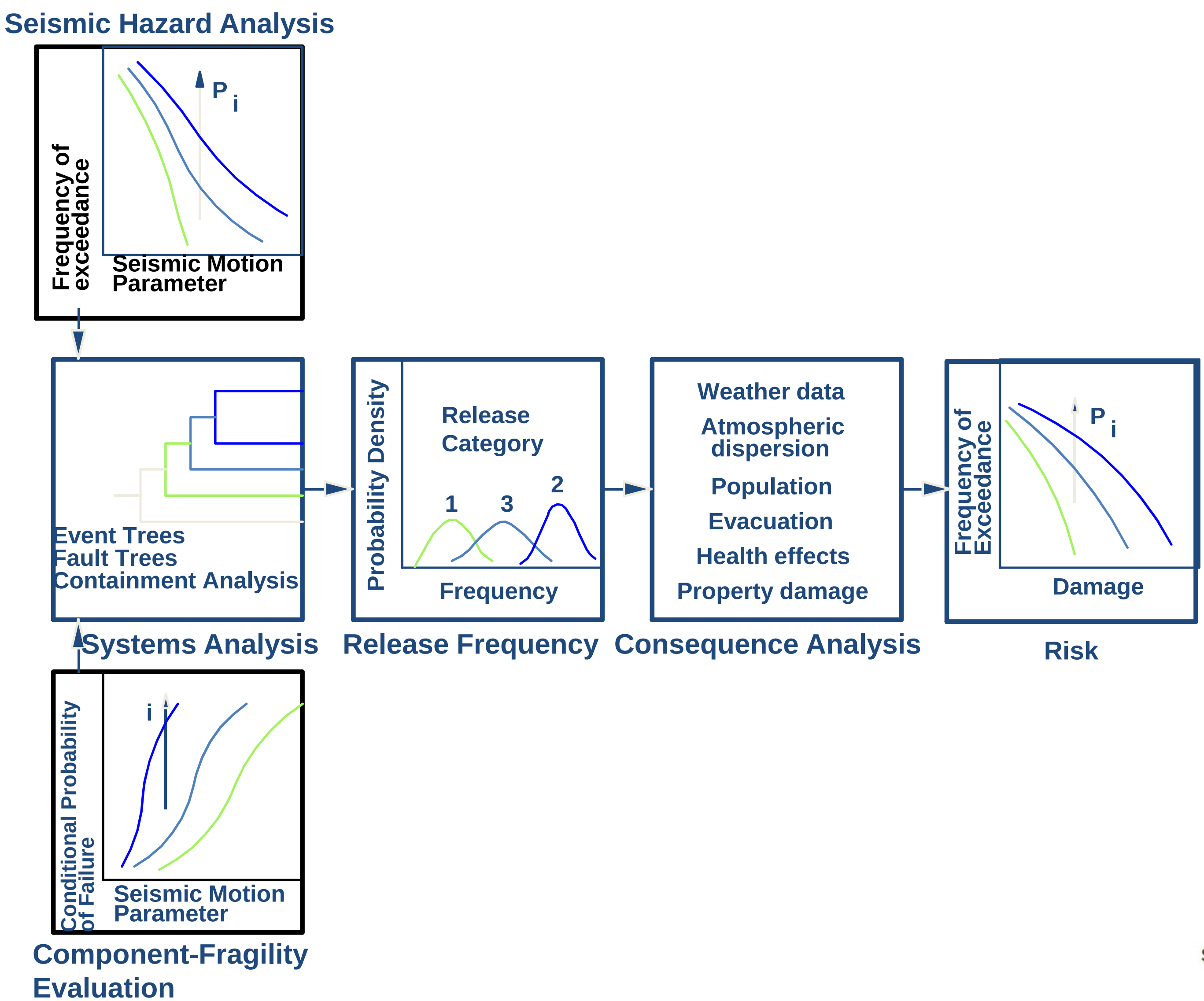
Seismic Probabilistic Risk Assessment



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Sources of Uncertainty in Seismic PRA

- Seismic Hazard
  - Seismic Source Characterization (Medium)
  - Ground Motion Prediction Equations (High)
  - Site Amplification (High for Soil Sites, Low for Rock)
- Seismic Fragilities
  - Seismic Capacity (Includes Governing Failure Mode Determination) (Medium)
  - Seismic Response (High)
- Systems Analysis and Quantification
  - Plant Logic Model (Medium-Low)
  - Risk Quantification (Low)
  - HEP (High-Medium)

- *Colors indicate Degree of Uncertainty Contribution to SPRA (Note: these can be very site specific)*

Fragility Derivation

- F_S = Strength Factor
- F_μ = Ductility Factor
- F_{SS} = Spectral Shape Factor
- F_δ = Damping Factor
- F_{SSI} = Soil-Structure Interaction Factor
- F_M = Modeling Factor
- F_{MC} = Mode Combination Factor
- F_{GMI} = Ground Motion Incoherence Factor
- F_{QM} = Qualification Method Factor
- F_{ECC} = Earthquake Component Combination Factor
- B's are lognormal standard deviations of the variables

Classification of Uncertainties

- Inherent randomness (aleatory)
  - Uncertainty explicitly recognized by a stochastic model
  - Irreducible
- Knowledge-based (epistemic)
  - Uncertainty in the model itself and in its descriptive parameters
  - Reducible

- *Comment: The distinction is somewhat arbitrary/judgemental. Prime importance is that all sources of uncertainty are properly accounted for in the analysis.*

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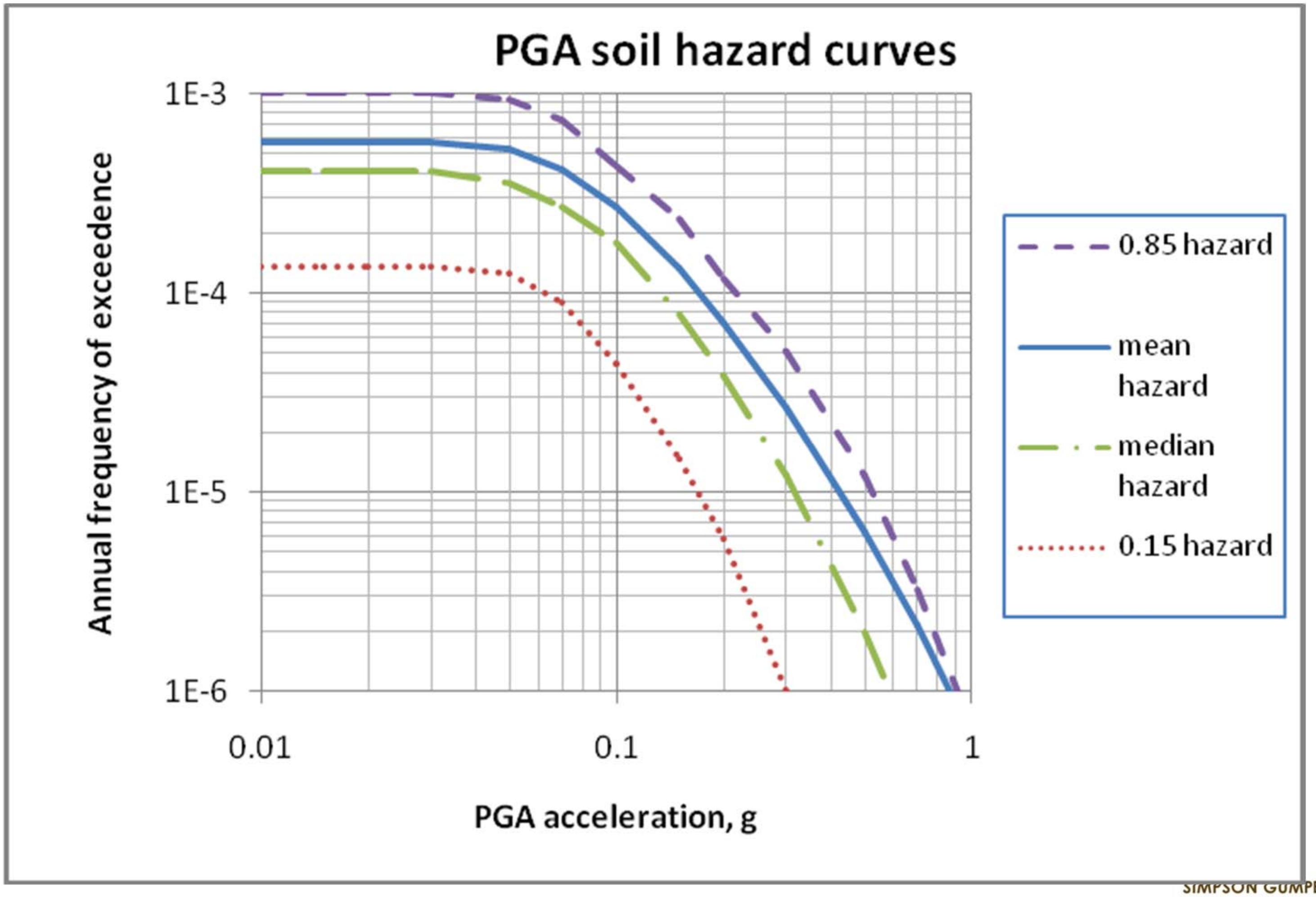
Uncertainty Analysis for Two Recent SPRAs

EPRI SPRA Pilot Seismic PRA for Surry

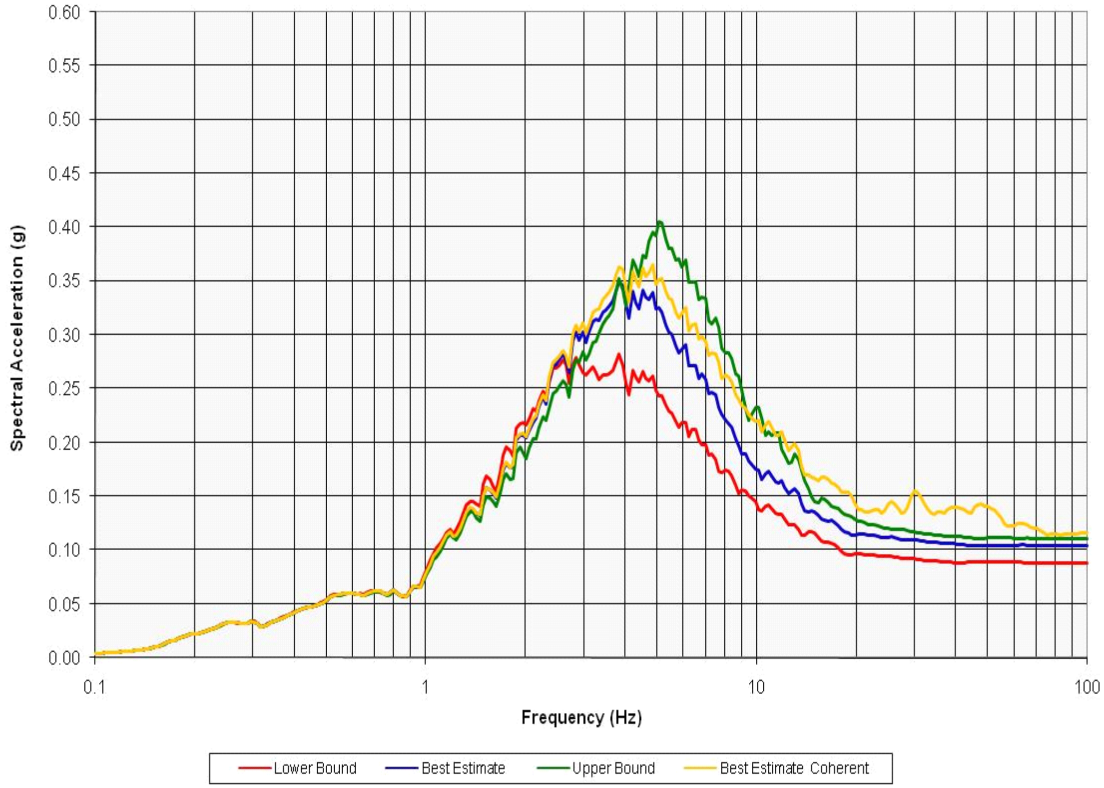
Background

- First Pilot for testing Std. ASME/ANS RA-Sa-2008/09
- Surry Selected as Pilot Tasks Shared by EPRI and Dominion
- Pilot Project to be Vehicle to Review the Standard and also Vehicle for Updating Surry IPEEE SPRA
- Pilot Project Started in Fall 2007
- Project Completed in June 2012
  - EPRI Product ID #1020756 “Surry SPRA Pilot Plant Review”

Mean and Fractile PGA Soil Hazard Curves (with CAV)



Surry Aux Building Foundation ISRS
Current & Past Evaluations
10,000 Year Earthquake, East-West Response



10^{-4} Best Estimate or Median	2007 Risk Engineering Input	1989 EPRI Input
PGA	0.10	0.08
Peak Spectra	0.34	0.21

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Background: SSEL and Fragility Analyses

- Over 600 items of SSCs are in the Surry Unit 1 SSEL.
- Most were Screened Out from a Detailed Evaluation via Walkdown and/or System Considerations.
- About 60 Fragilty Calculations Were Done that Considered Various Failure Modes. Scaling of Previous IPEEE Calculations was Done Where Possible. Fragilities for Six Relay Models Developed using Test Data. In Some Cases, Calculations are Preliminary / Generic Data Used
- About 55 SSCs were Determined to have HCLPF Capacity Below the Screening Criterion of 0.7g and they were Modeled in the PRA Event/Fault Trees.

System Analysis, Quantification and Sensitivity Analyses

- CAFTA Code Used for Quantification -Eight Acceleration Intervals Used, "UNCERT" Used for Uncertainty Analysis
- Seismic CDF and LERF Determined by Convolving PGA Hazard Curve with Fragilities
  - Turbine Building Failure Major Contributor, Followed by Loss of Offsite Power and ECST
- Sensitivity Analyses were done for several scenarios:
  - Turbine Building Improved Capacity
  - ACC Diesel Improvement
  - MCC Improvements
- **Uncertainties addressed via (1) statistical uncertainty analyses and (2) sensitivity studies**

Surry

- Uncertainty analysis used UNCERT (EPRI), and included fragility and random/human error uncertainties (1000 Monte Carlo samples)
- Seismic Hazard not included in this statistical uncertainty study

	CDF	LERF
mean	2.3E-05	1.5E-07
upper 95%	5.6E-05	3.8E-07
median	1.9E-05	1.2E-07
lower 5%	6.3E-06	4.2E-08
upper "EF"	2.9	3.2
lower "EF"	3.0	2.9

- EF = Error Factor (Upper Bound/ Median)

Surry

- Uncertainty for seismic hazard used sensitivity studies, and demonstrated that there is limited “upward” uncertainty, but significant “downward” uncertainty

	Baseline	15% Hazard Curve	Factor Decrease	85% Hazard Curve	Factor Increase
CDF	2.37E-05	9.46E-07	25	3.62E-05	1.5
LERF	1.68E-07	3.15E-09	53	2.42E-07	1.4

- Factor decrease is calculated by dividing the baseline by the 15% result. Similarly, the factor increase is calculated by dividing the 85% result by the baseline.
- A lower LERF truncation would have captured more cut sets for the LERF, and decreased the “Factor Decrease.”

Surry

- Sensitivity studies used to evaluate other uncertainties
  - Human error probabilities: 20 to 30 HEPs in SPRA. Increasing each of the HEPs to “1” (failed) did not significantly impact CDF for most operator actions, but 4 actions had CDF increases of about 50%
  - Turbine building failure let to impact on cables to isolation valves: If more detailed/realistic evaluation used, CDF could decrease by about 50%
    - More detailed non-linear structure modeling
    - Cable by cable review
  - Other modeling assumptions on MCCs and alternate AC did not demonstrate significant impact (10-15%)
- Correlation used standard assumptions. About 36% of CDF was due to correlated failures

PWR in Europe – Results from SPRA

- Various uncertainty analyses performed
- Fragility uncertainty higher than hazard uncertainty for this plant

		SEISMIC CDF/YR.				
	UNCERTAINTY CASE	MEAN	MEDIAN	5%	95%	EF
1	Only fragility uncertainty	2.47E-05	1.54E-05	4.74E-06	4.24E-05	2.8
2	All uncertainties	3.07E-05	1.81E-05	3.18E-06	9.98E-05	5.5
3	No hazard uncertainty (mean hazard curve)	2.98E-05	1.69E-05	4.64E-06	5.56E-05	3.3
4	No random uncertainty (EF's=1)	2.54E-05	1.62E-05	3.13E-06	7.43E-05	4.6
5	No fragility uncertainty (β's=0.001)	2.15E-05	1.72E-05	4.50E-06	5.44E-05	3.2
6	Only hazard uncertainty	1.58E-05	1.40E-05	5.83E-06	2.87E-05	2.1
7	Only random uncertainty	2.08E-05	1.59E-05	4.93E-06	3.53E-05	2.2

- *Random refers to random equipment failures and operator actions*

Comments

- The traditional uncertainty analysis (using techniques such as Monte Carlo or DPD) provides insight into the uncertainties of the hazard, fragilities, and random/human errors
- Sensitivity studies can provide insight into modeling uncertainties and assumptions
- Limited studies in this area (summarizing results from many SPRAs) have been conducted to date
- Current/Proposed Research Projects Attempting to Address SPRA Uncertainties; e.g.
  - Scenario Earthquake Approach
  - High frequency effects on fragility
  - NGA East seismic hazard
  - Structure modeling – Stick vs FEM