Treatment of Epistemic Uncertainty in PSHA Results

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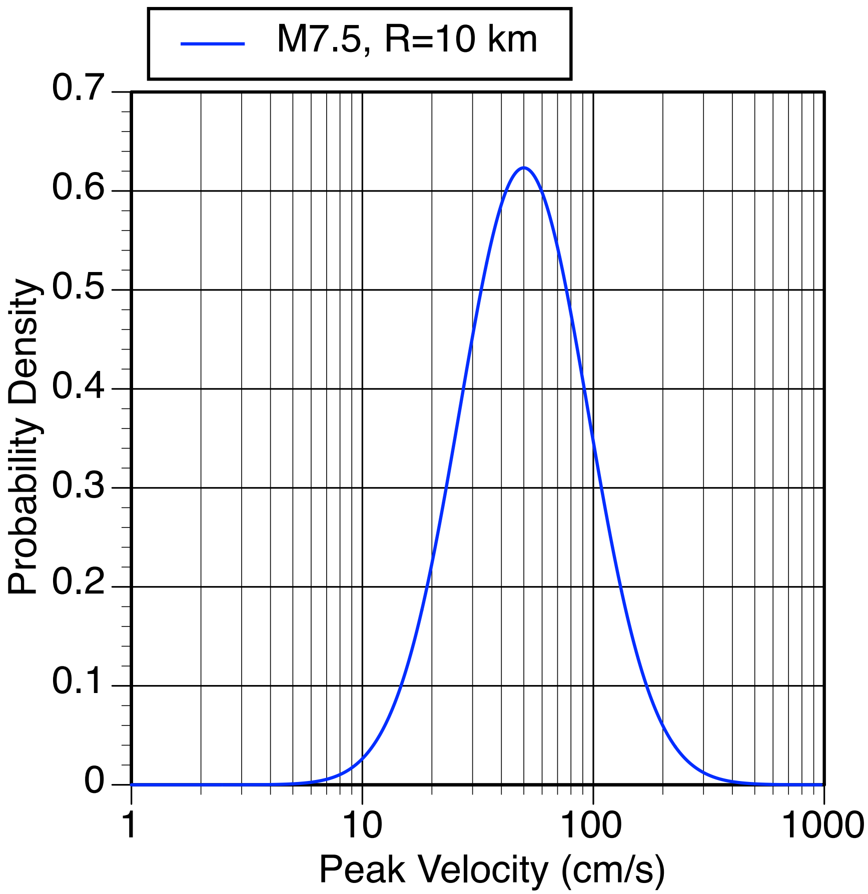
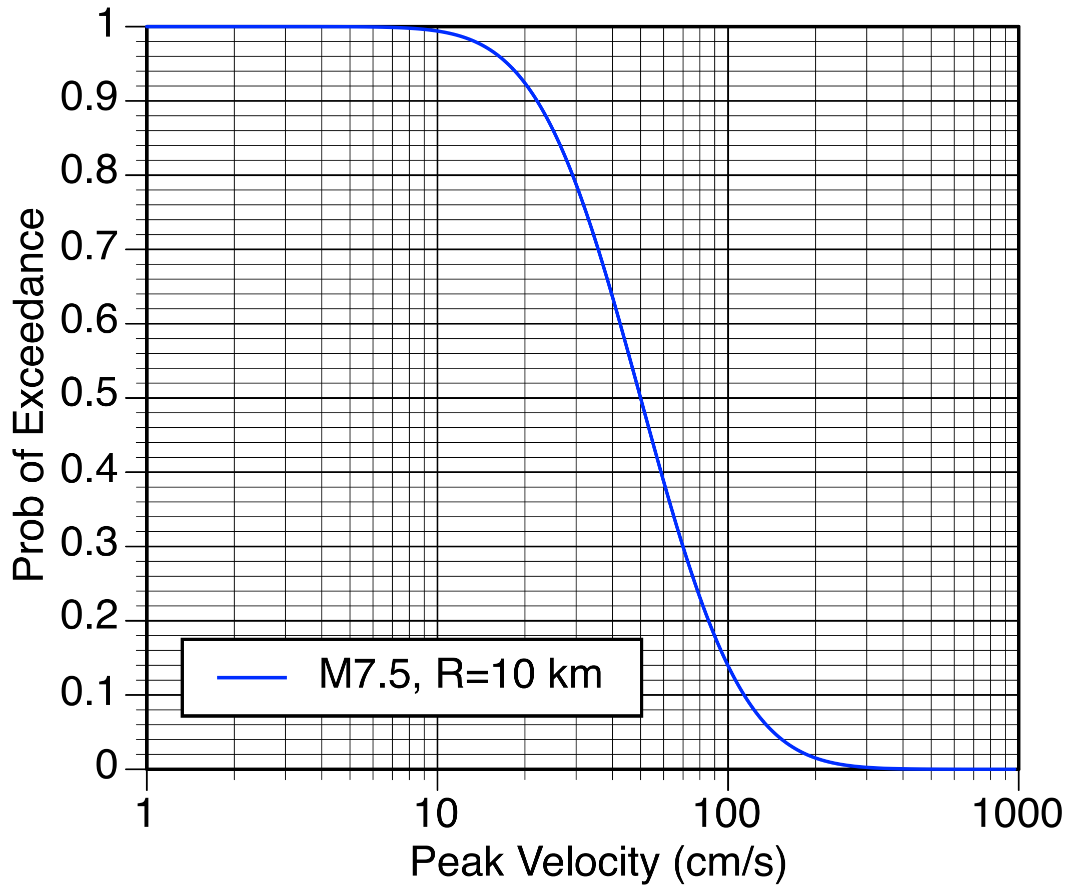
$$Haz(GM > z) = \sum_{i=1}^{Nscenarios} Rate(Scenario_i)P\left(GM > z \mid Scenario_i\right)$$

- Scenario
  - Magnitude
  - Mechanism
  - Rupture Dimension
  - Rupture Location

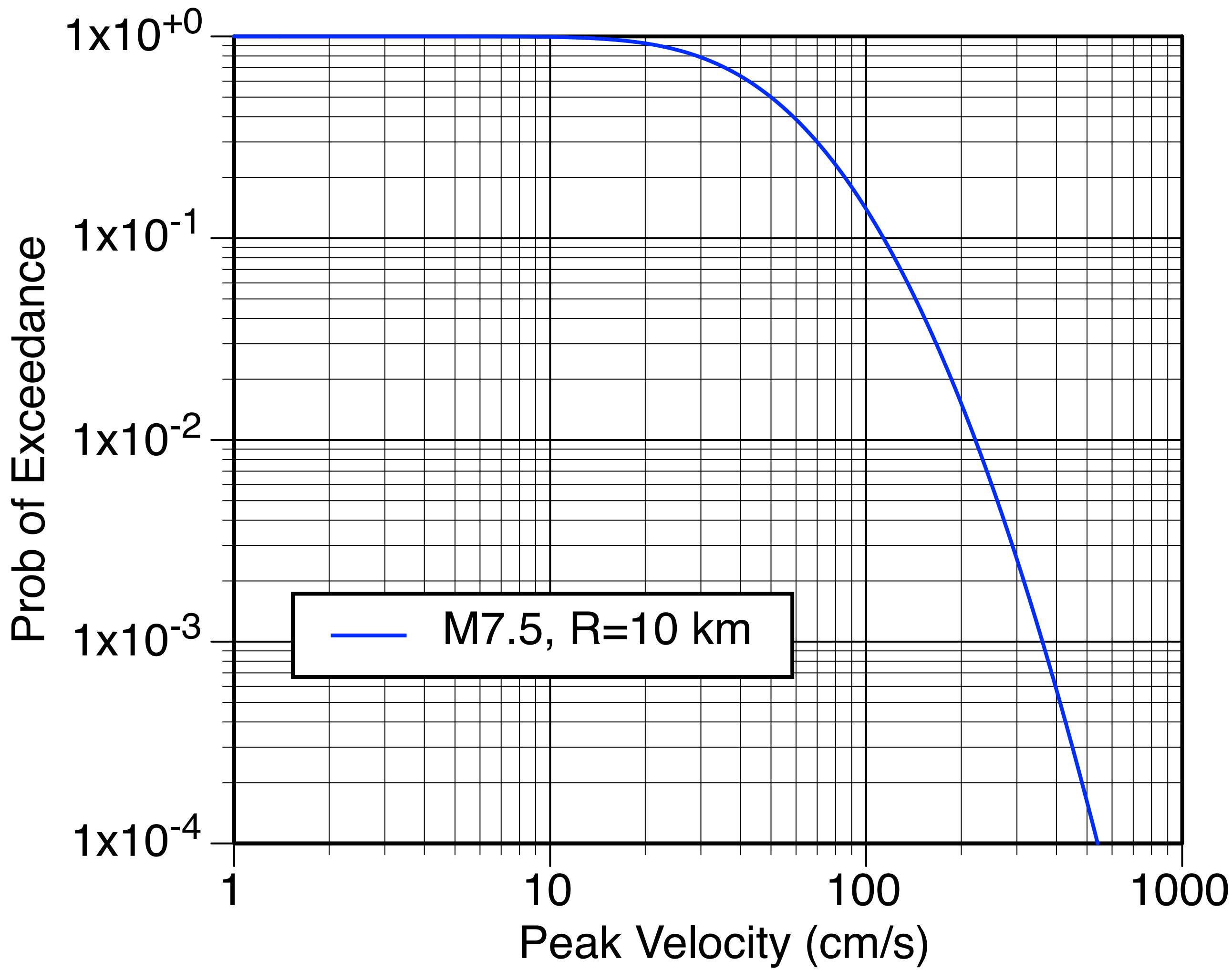
PGV Distribution



$$P\left(GM > z \mid Scenario_i\right)$$



Select Appropriate Ground-Motion Probability Level



Select Appropriate GM Probability Level (for a single scenario)

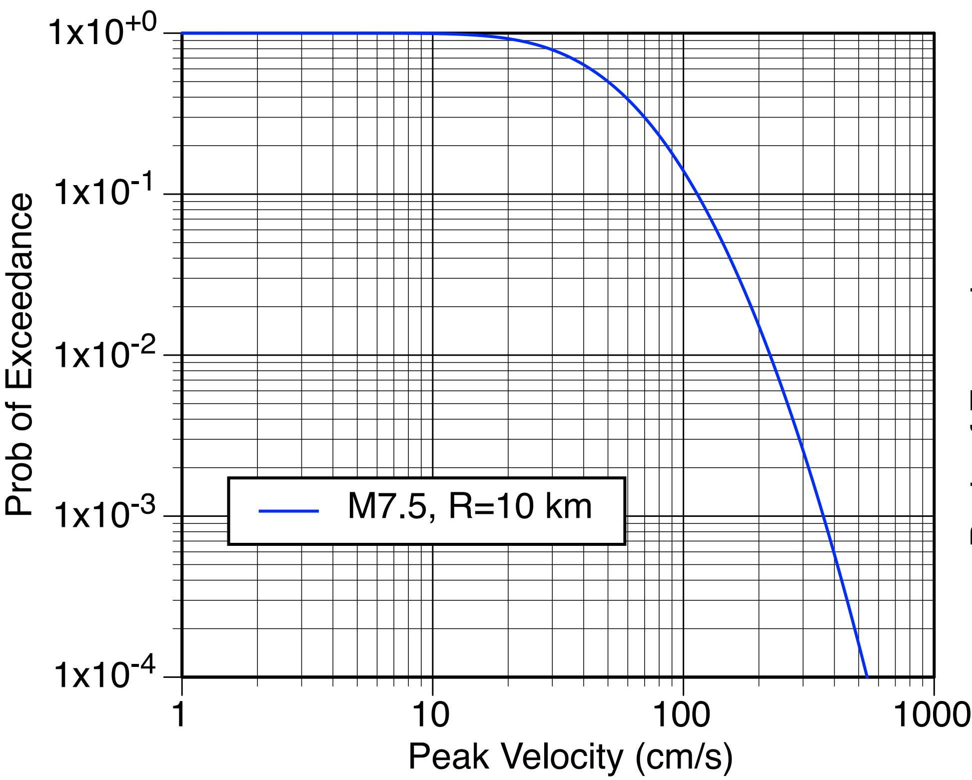
- Deterministic Seismic Hazard
  - Choose a probability level for the number of standard deviations (epsilon) of the ground motion:

$$P(PGV>z|M,R)$$

- Probabilistic Seismic Hazard
  - Choose a probability level for the combined chance of the earthquake occurring and the number of standard deviations of the ground motion:

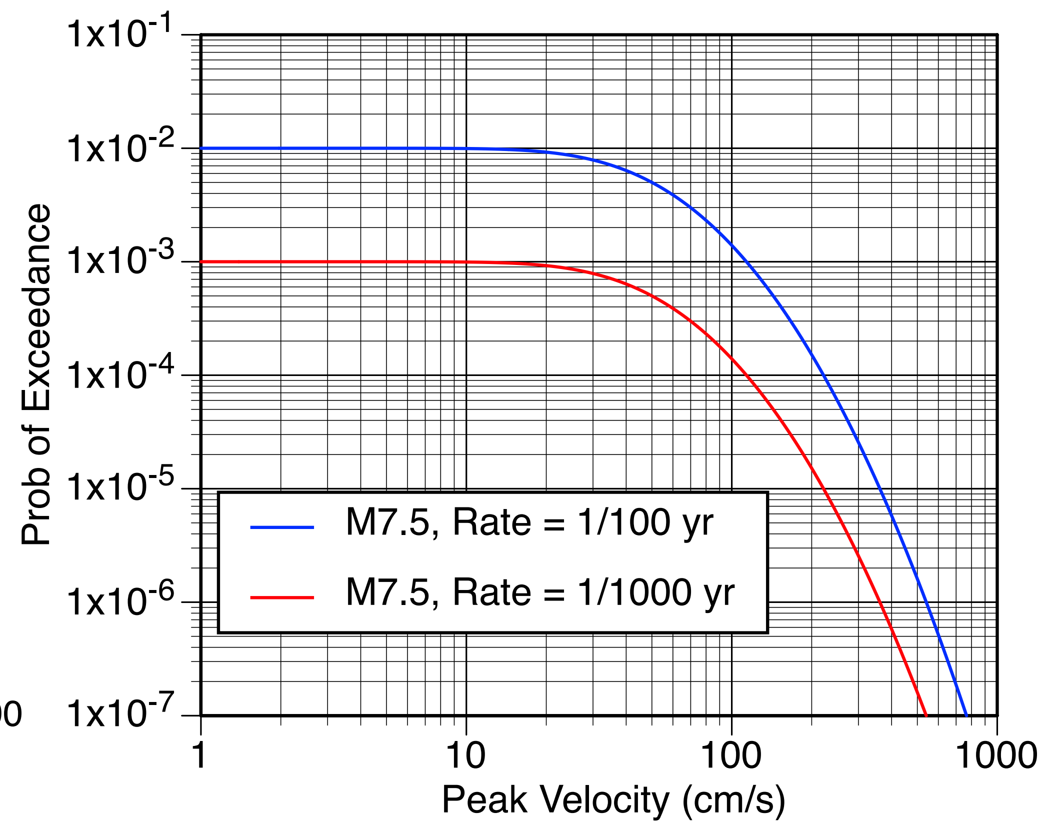
$$Rate(eqk) * P(PGV>z|M,R)$$

Deterministic

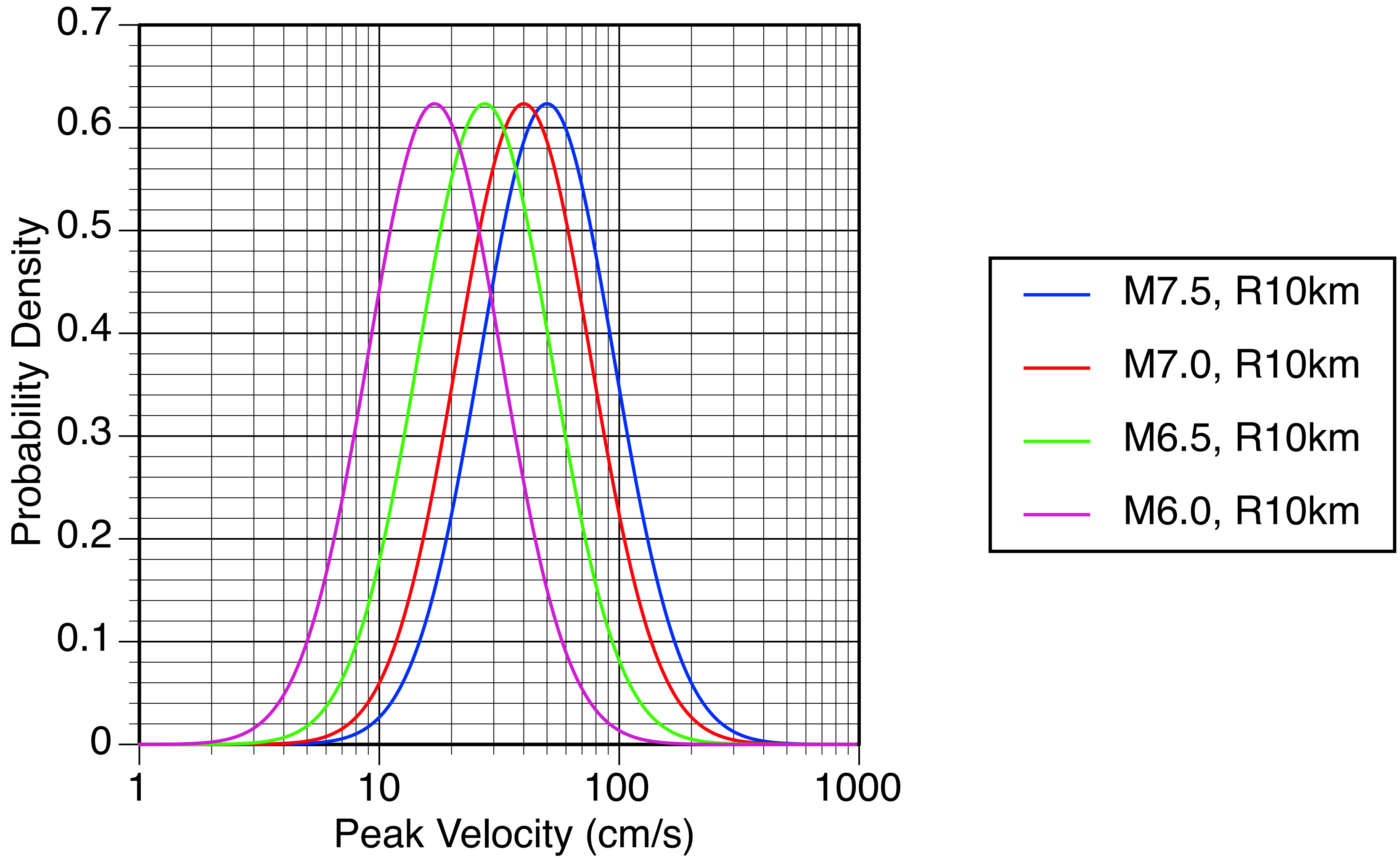


Probabilistic

Haz(z) = Rate(eqk) * P(PGV>z|M,R)

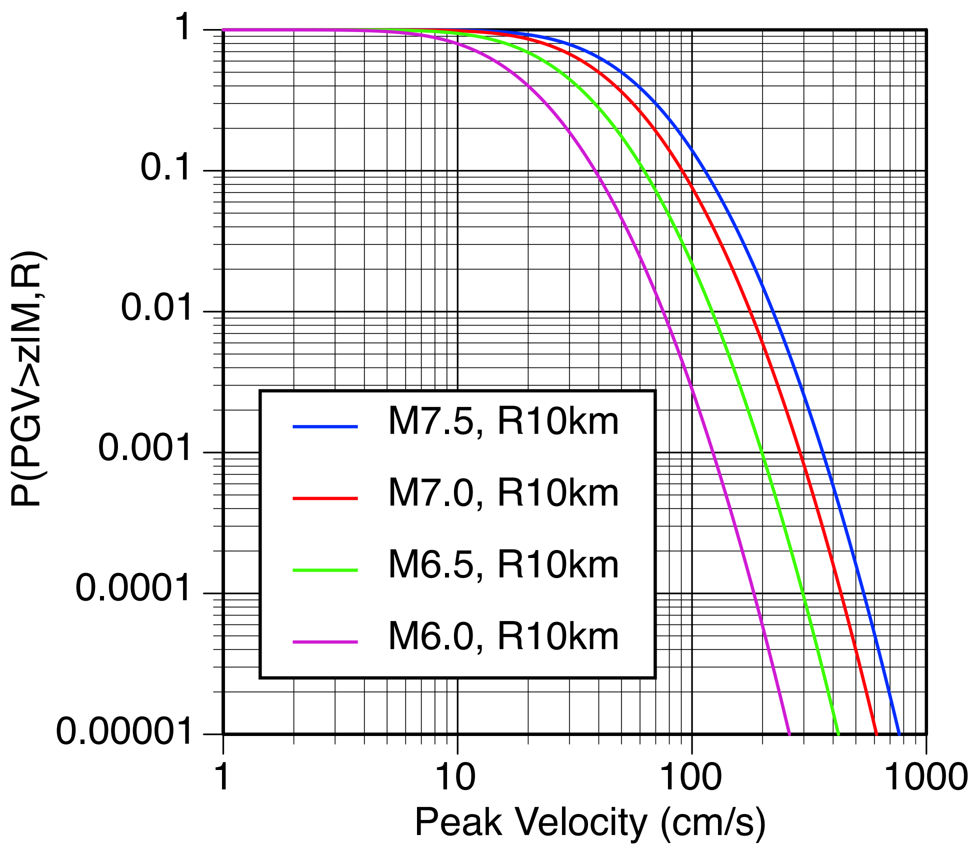


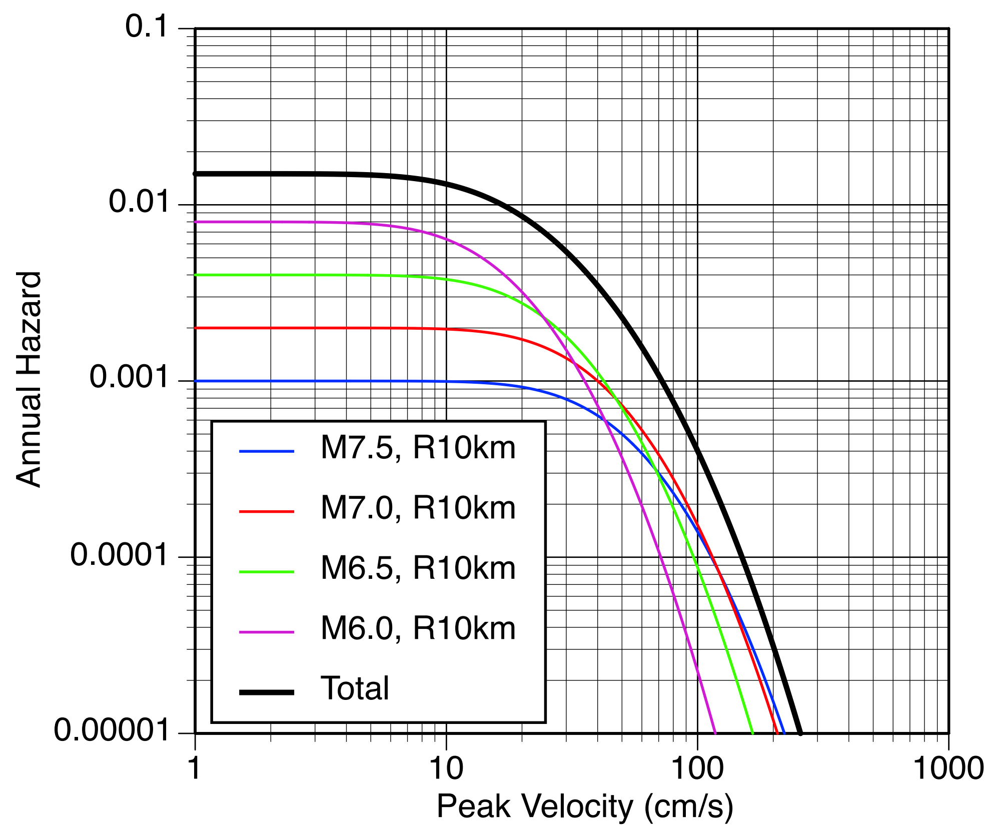
Large Variability Leads to Overlaps of Ground Motion Distributions



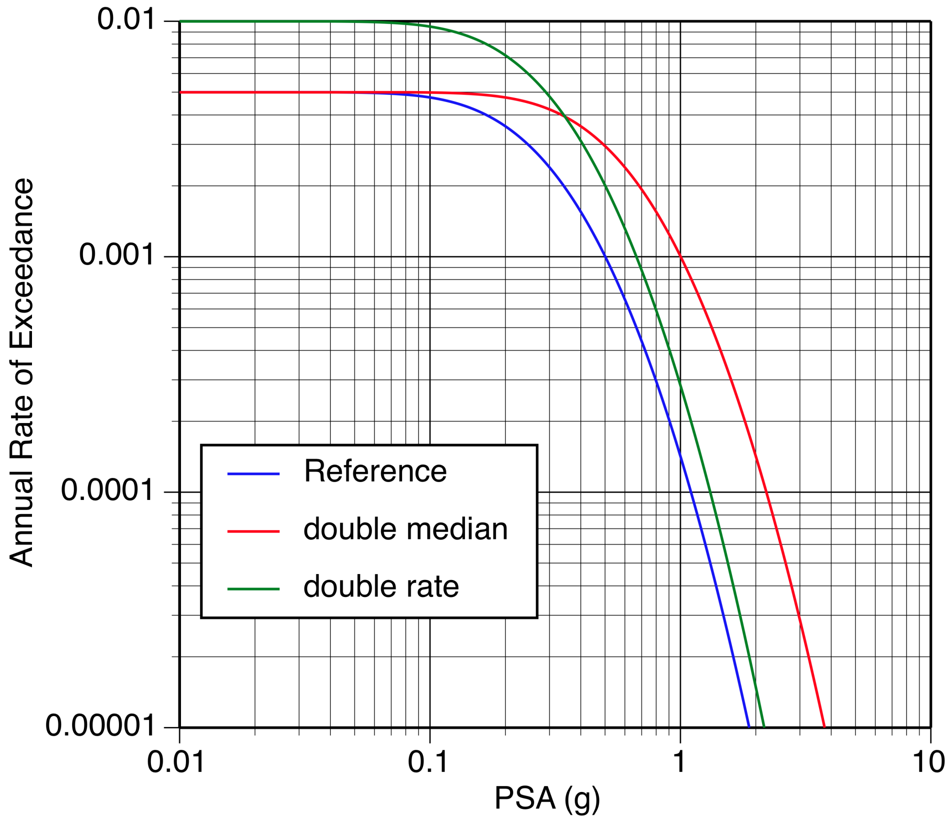
Multiple scenarios

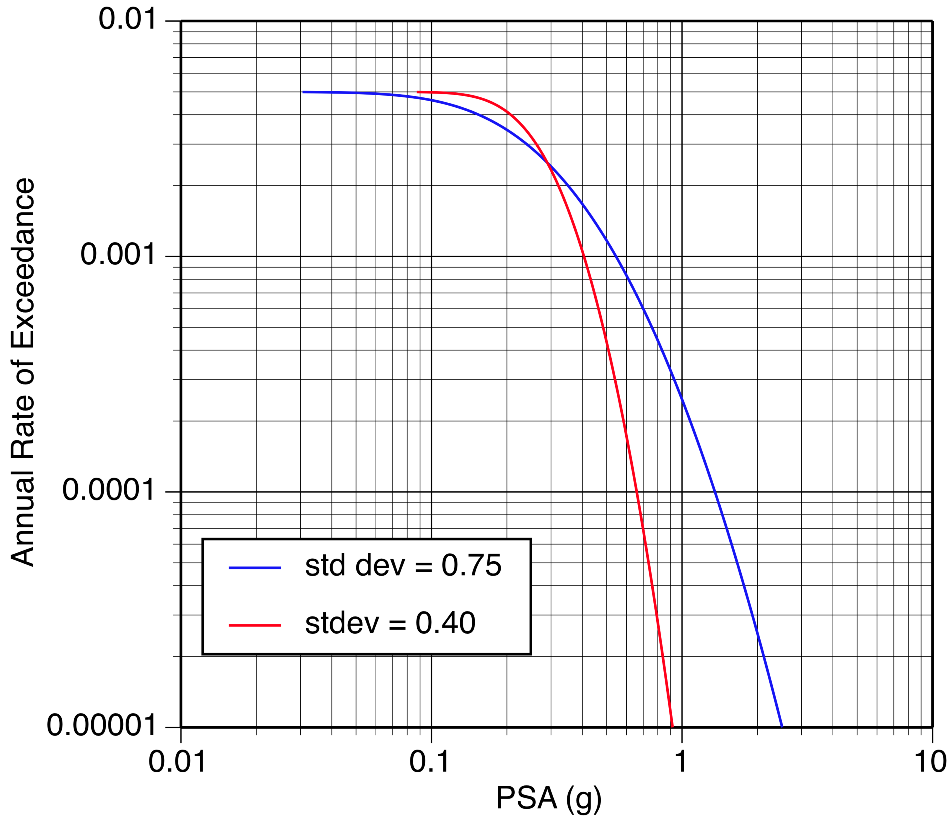
$$Haz(PGV > z) = \sum_{i=1}^{NScenario} Rate_i\, P(PGV > z \mid M_i, R_i)$$



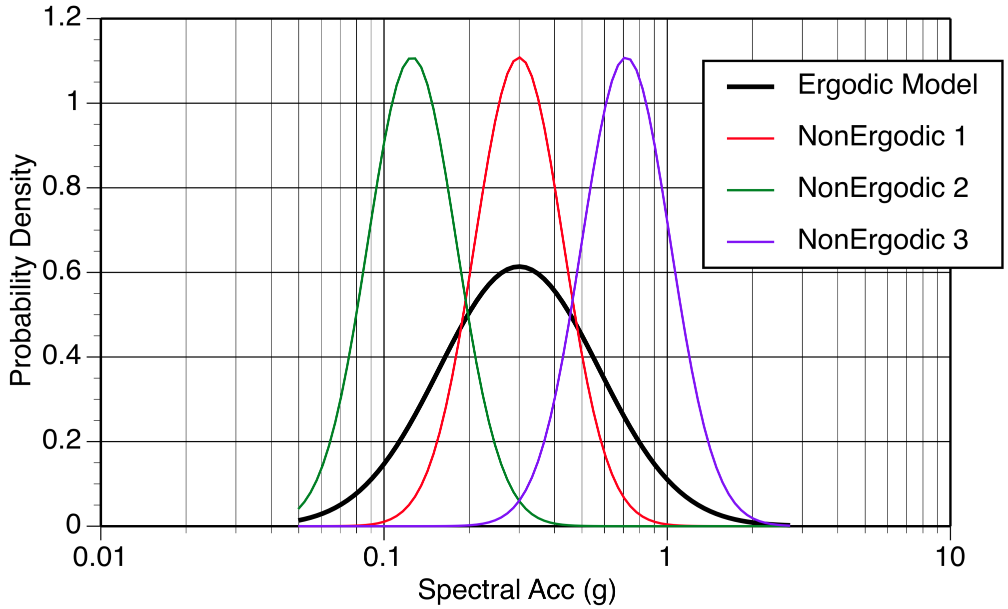


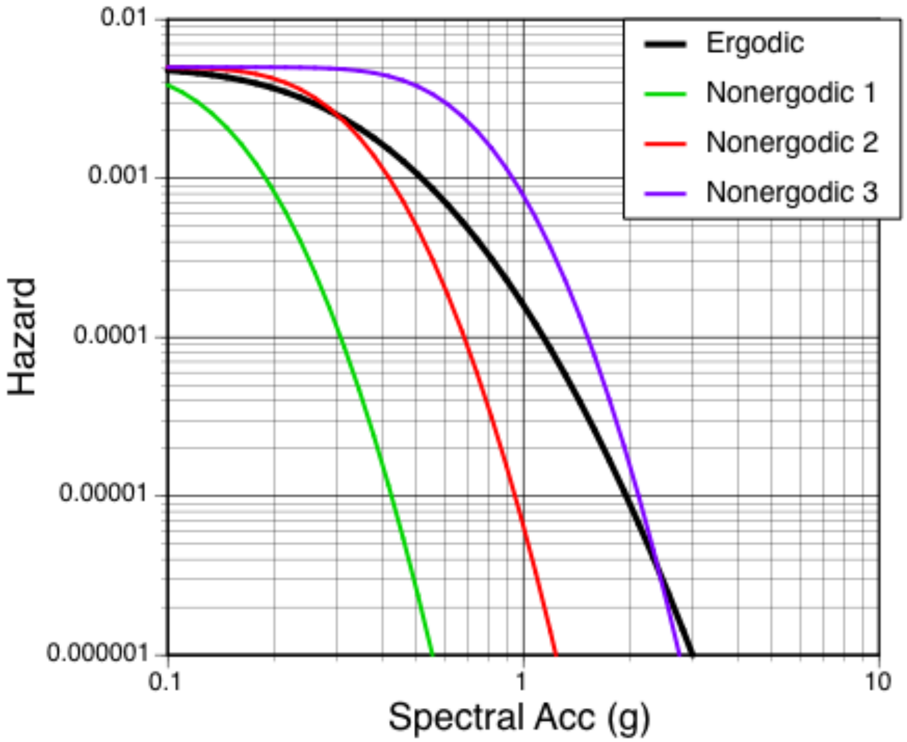
Hazard Sensitivity



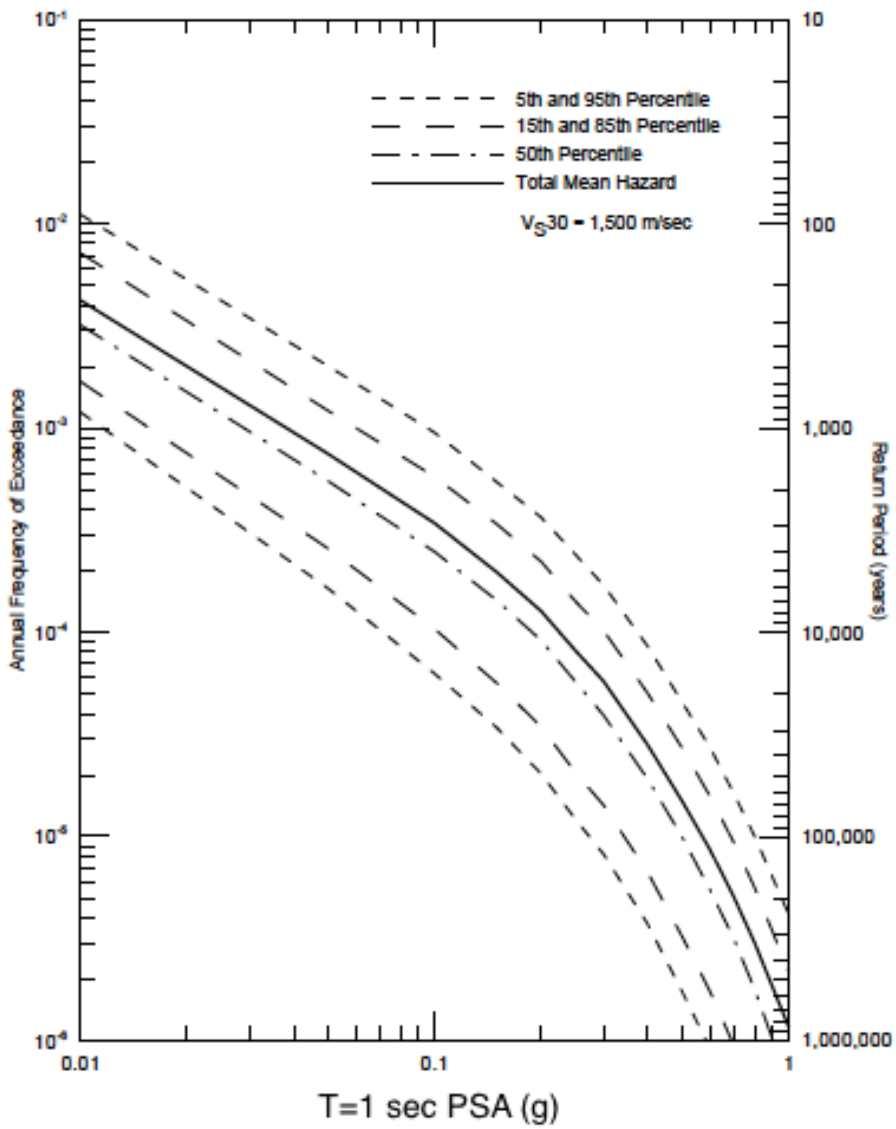


Epistemic Uncertainty for Nonergodic GM Models





Example Uncertainty in Hazard

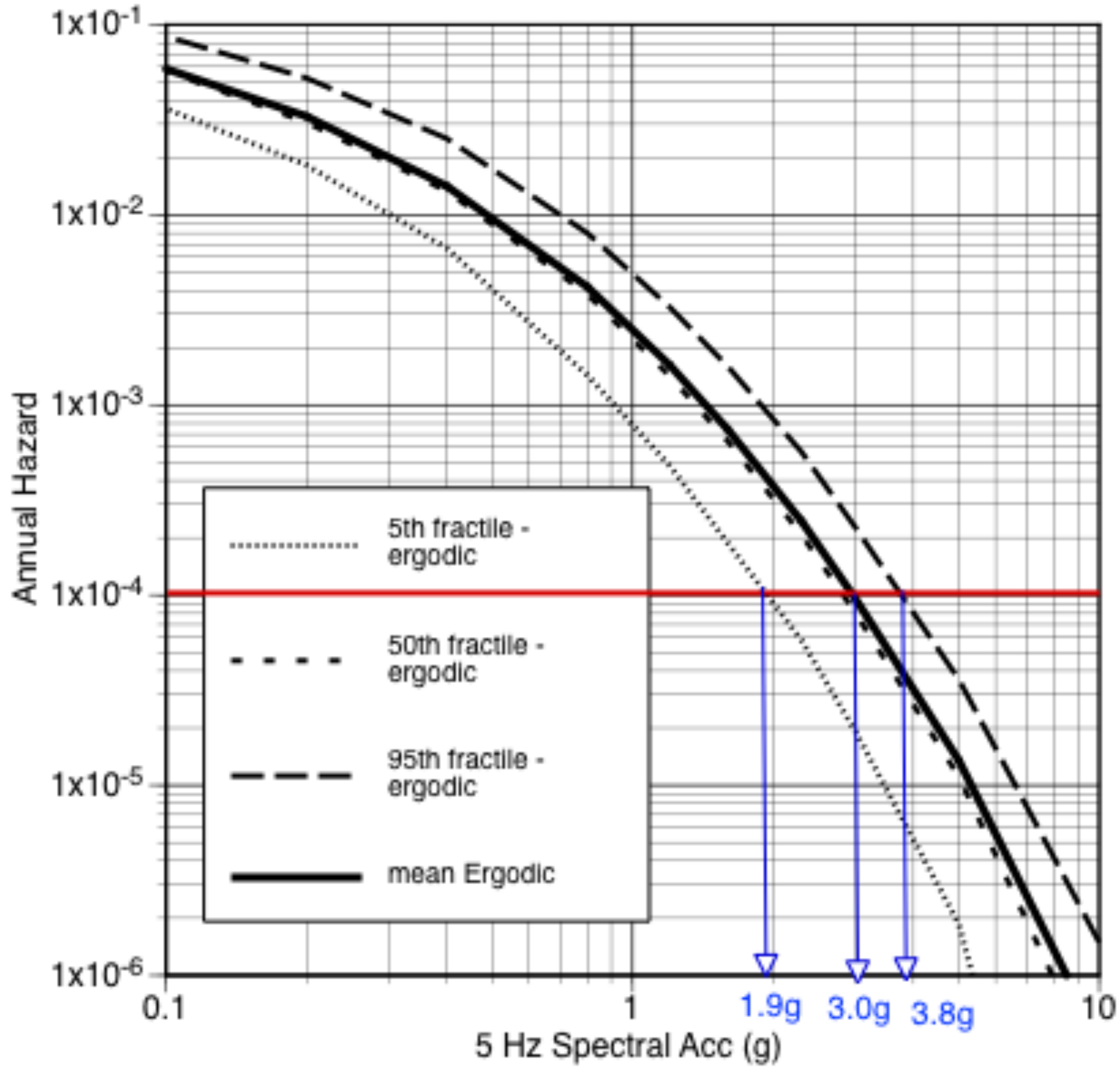


- Full range of hazard curves is the result
- Need to choose a design ground motion from this range of curves
  - How safe do you want to be?
  - How confident do you want to be in the level of safety?
  - Mean hazard is selected for engineering application
  - Mean hazard it is not a forward prediction of rate of ground motions

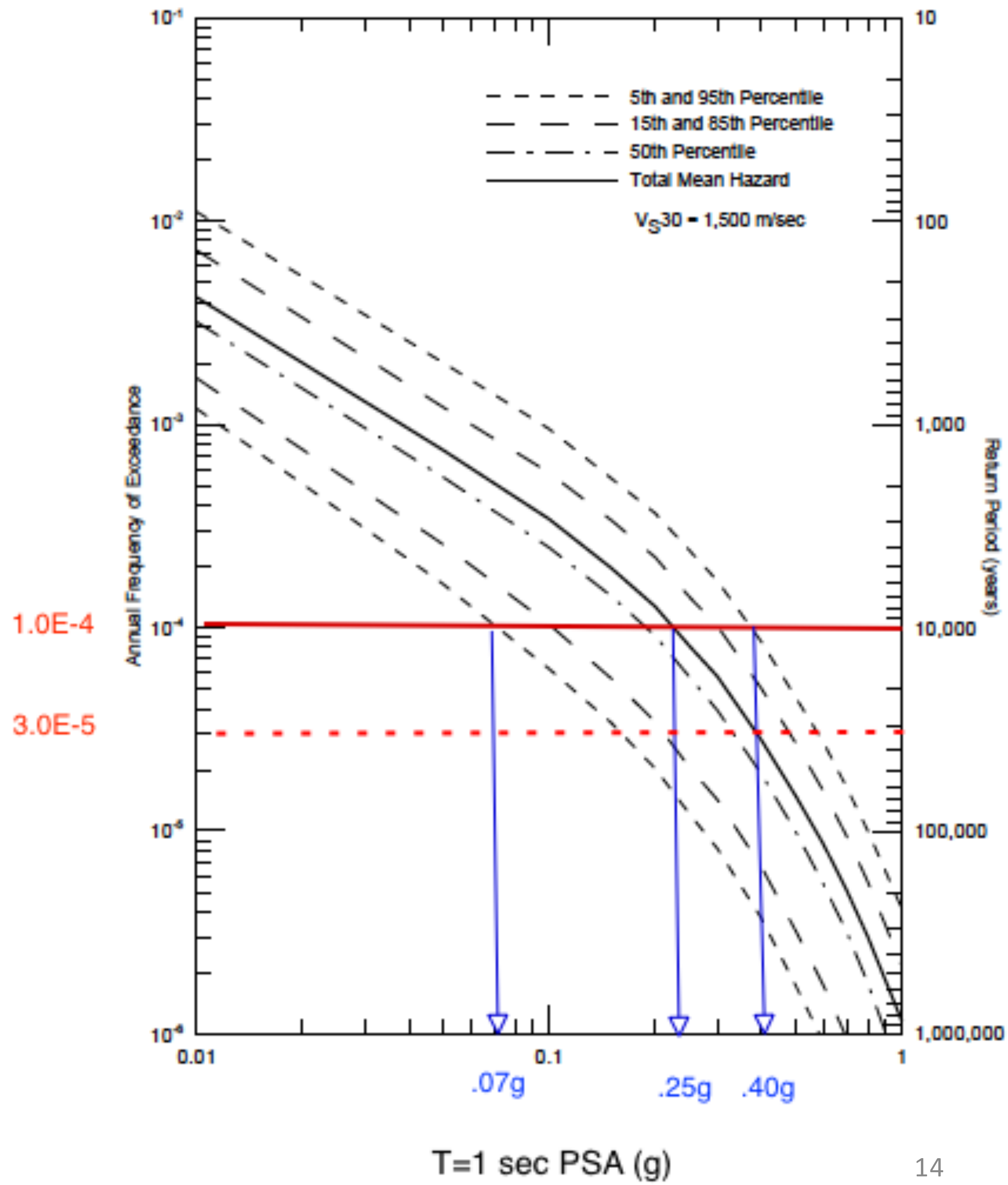
Why use Mean Hazard?

- Used for Mean Risk
  - The mean hazard curve combined with the mean fragility curves leads to mean risk
- Mean Penalizes large uncertainty
  - Distribution of fractiles is skewed to high end (close to log normal)
  - For larger uncertainty, mean will be at a higher fractile
- Disadvantage
  - It leads to changing fractile levels depending on the amount of uncertainty and the selected return period
  - If only the mean is shown, then don't know the fractile level

Example PSHA for San Jose (high activity)



Example PSHA for Colorado (low seismicity)



Communicating Epistemic Uncertainties

- For critical facilities, epistemic uncertainties are shown in plots in the report, but summary tables of results often only show the mean hazard
- For better communication
  - The uncertainties should be included in all tables of results and in the executive summary

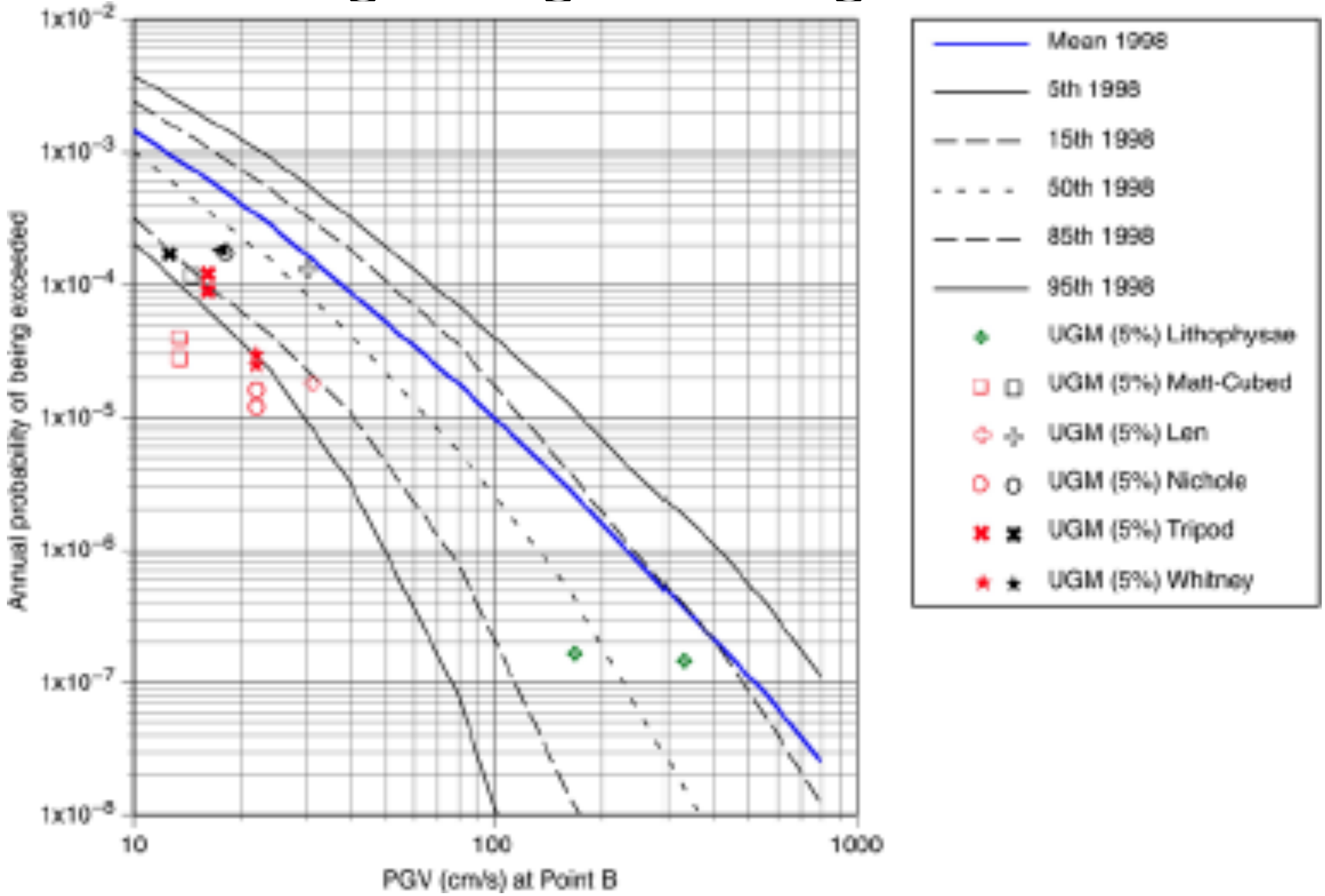
Uses of Epistemic Uncertainty

- Show the limitations of the current earthquake science to constrain the seismic hazard
  - Consider the uncertainty of the design ground motion when making engineering judgments
  - This can change engineering judgments
- Use a hazard fractile for the design ground motion rather than the mean hazard
  - e.g. select the 85^{th} fractile
  - Unlikely to be adopted
- Use the ground motion from a higher fractile (90^{th}) to check the design
  - Don’t apply design criteria limits, but avoid catastrophic failure

Uses of Epistemic Uncertainty - Retrofits

- Once the decision is made to retrofit, then a goal is not to have to retrofit again in short time (10 years).
- Consider designing the retrofit for a higher fractile instead of the mean
  - Use 90^{th} fractile to have confidence that the retrofit will not be found inadequate when the hazard is updated.

Example:
Use of precarious rock information at Yucca Mtn to change weights on logic tree branches



Underestimation of Epistemic Uncertainty

- Epistemic uncertainty is due to lack of data
  - Less data implies larger uncertainty
- In practice, not always the case

  Typically estimated using alternative <u>available</u> models/data
  - Few available studies lead to small uncertainty (few alternatives available)
  - Many available studies lead to larger uncertainty (more alternatives available)
- Often, our estimate of the epistemic uncertainty increases the more studies we do, indicating that the epistemic uncertainty tends to be underestimated when we have little information

Additional Epistemic Uncertainty (missing from current PSHA studies)

- Nonergodic GMPEs
  - New data sets with large number of earthquakes and recordings shows the size of the systematic source, path, and site effects
  - Most of the standard deviation in traditional GMPEs is from systematic effects, not random
    - Ergodic standard deviation is about 0.65 LN units
    - Removing systematic site, path, and source: 0.4 LN units

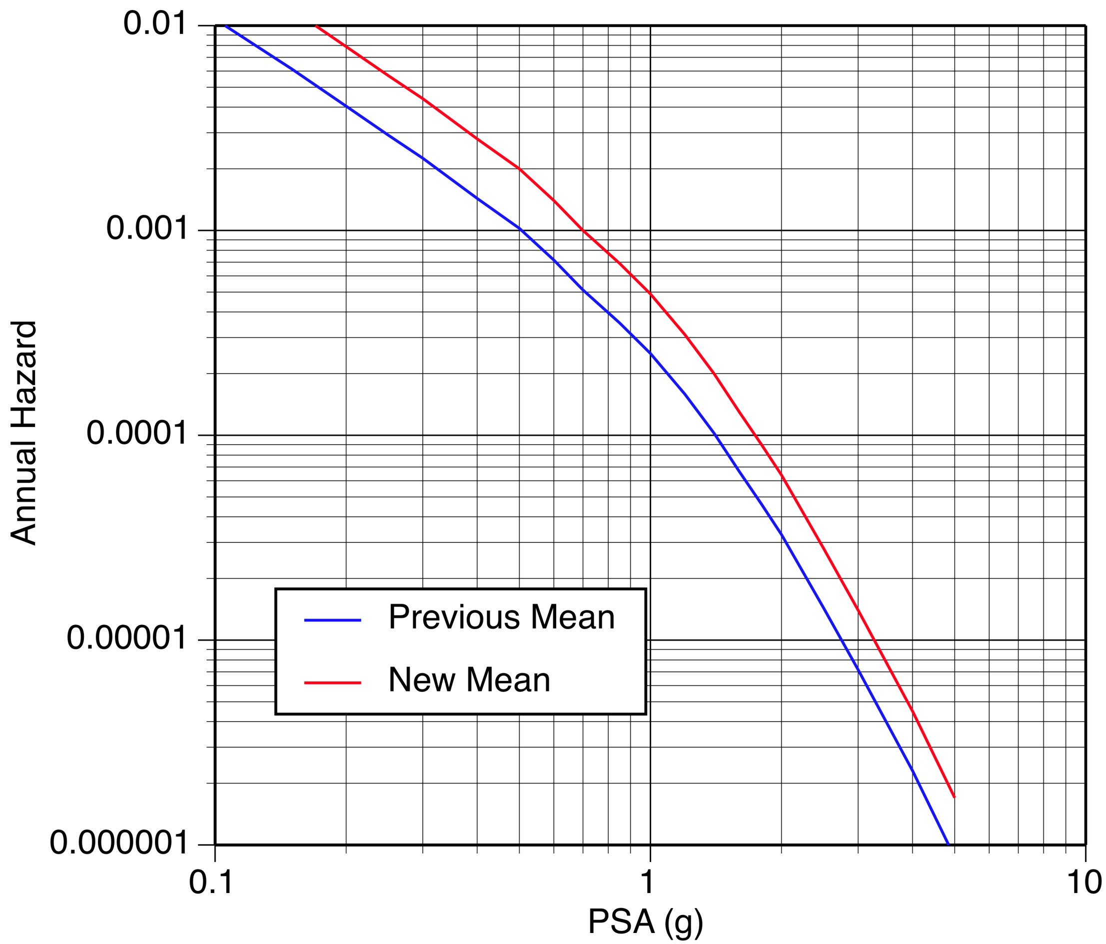
Additional Epistemic Uncertainty (continued)

- Nonergodic GMPEs
  - We now know how far off our global models can be for a site-specific application
  - In most cases, the systematic path and source effects are currently not well constrained
    - In the short term, expect to see a significant increase in epistemic uncertainty
  - Highlights the need to collect additional ground motion data and to develop of 3-D crustal models for use in numerical simulations of path effects
  - Business case for seismic instrumentation

Hazard Uncertainty and Stability of Results for Building Codes

- Need for stability of the design ground-motion maps for building codes
- Expect significant changes in the hazard results
  - Large epistemic uncertainties
  - Significant changes can be expected as new data are collected and new methods and models are developed
- What is an insignificant change?

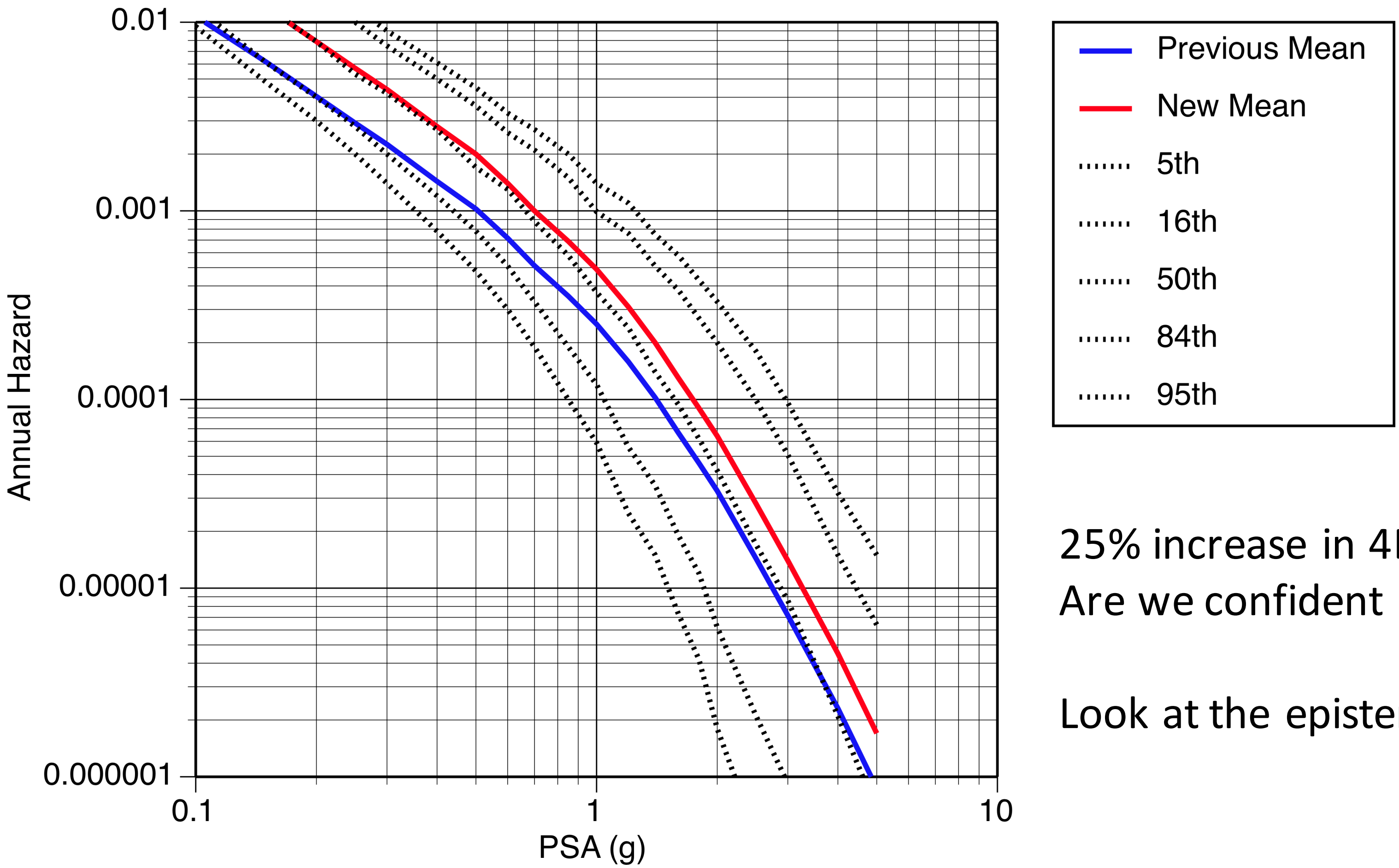
Example of Change in Mean Hazard



20% increase in 1E-4 UHS
Are we confident in the change?

Should the building code values be revised?

Change in Mean Hazard Considering Epistemic Uncertainty



25% increase in 4E-4 UHS
Are we confident in the change?

Look at the epistemic uncertainty range

Stability and Consideration of New Data &Models

- Need to decide when an update of the hazard is justified
- Is the change robust given the uncertainty in the earthquake science?

$$Is \ \ln\left(\frac{UHS\_new(T)}{UHS\_old(T)}\right) > 0.5\sigma_{\ln UHS}(T) \ ?$$

$$Is \ UHS\_old(T) \text{ outside of the updated 25th-75th fractiles } ?$$

Conclusions

- Large epistemic uncertainties in seismic hazard
  - This is the main limitation of PHSA, but it also is a key limitation of Deterministic approaches
- The epistemic uncertainty should be communicated to the engineers using the results
  - Consider GM epistemic uncertainty along with other uncertainties when making engineering judgments
  - Demonstrates the need for long-term research to reduce the uncertainty in the inputs to PSHA models
- The prediction from PHSA is the range of the uncertainty fractiles
  - Testing of PHSA results should consider the fractiles, not just the mean hazard