The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

H4.SMR/1645-34

"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

Seismic Hazard Representation

K. Campbell

EQECAT
USA

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

IAEA/ICTP Workshop on
Earthquake Engineering for Nuclear Facilities - Uncertainties in Seismic Hazard Assessment

"Seismic Hazard Representation"

Trieste, Italy, 14 – 25 February 2005

Unit 37 - K. Campbell, USA

Contents of the Presentation

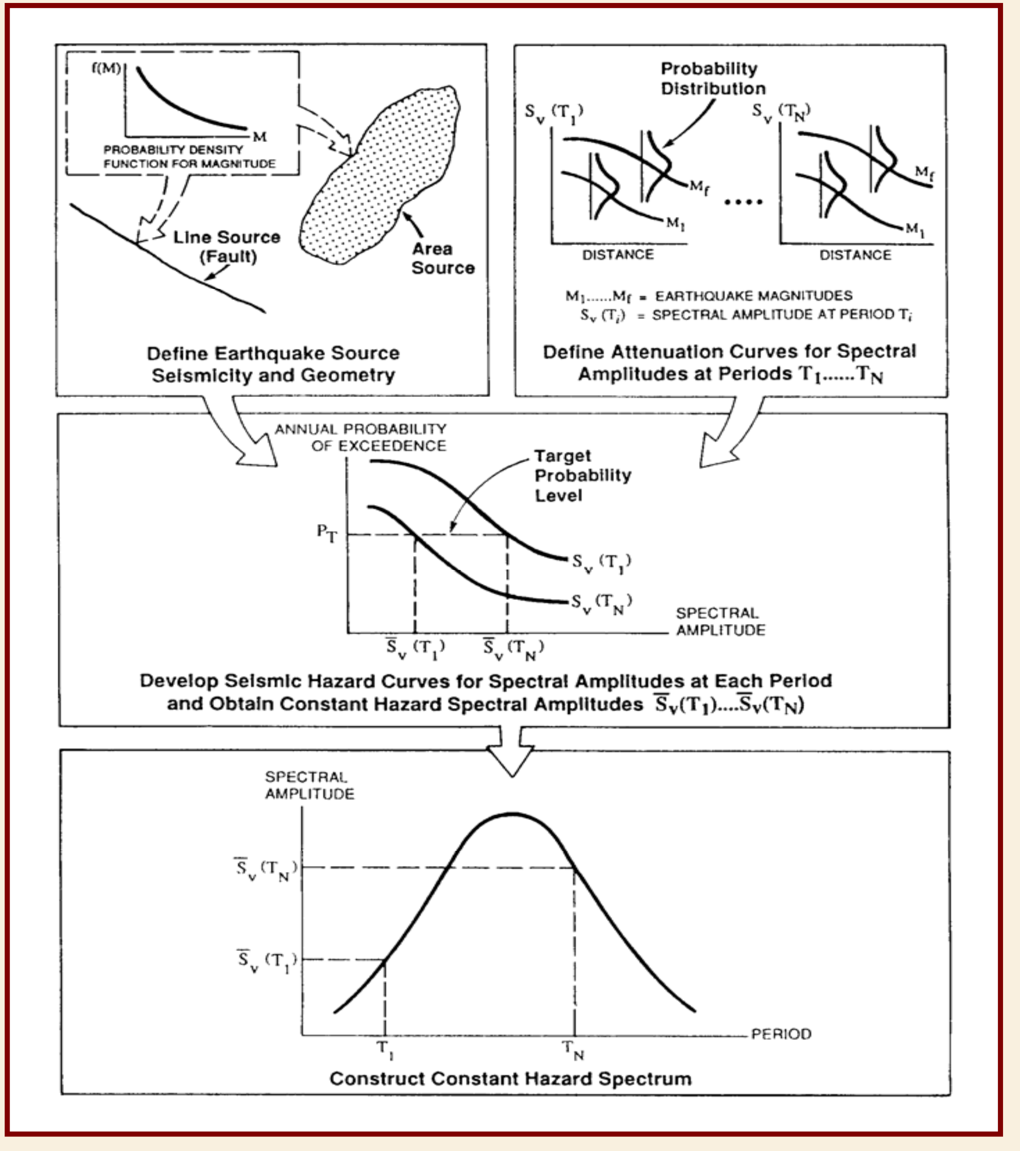
- Introduction
- Engineering representation of PSHA results
  - Deaggregation
  - Hazard-consistent earthquake scenarios
  - Time histories on reference site conditions
- Other engineering products
  - Site-response analysis
  - Site-specific time histories and response spectra
- Representation of epistemic uncertainties
- Summary of the presentation
- References and glossary

Introduction

Basic PSHA Results

- Mean and fractile seismic hazard curves for reference site conditions
- Mean and fractile uniform hazard response spectra (UHRS) for reference site conditions

Derivation SH Curves and UHRS



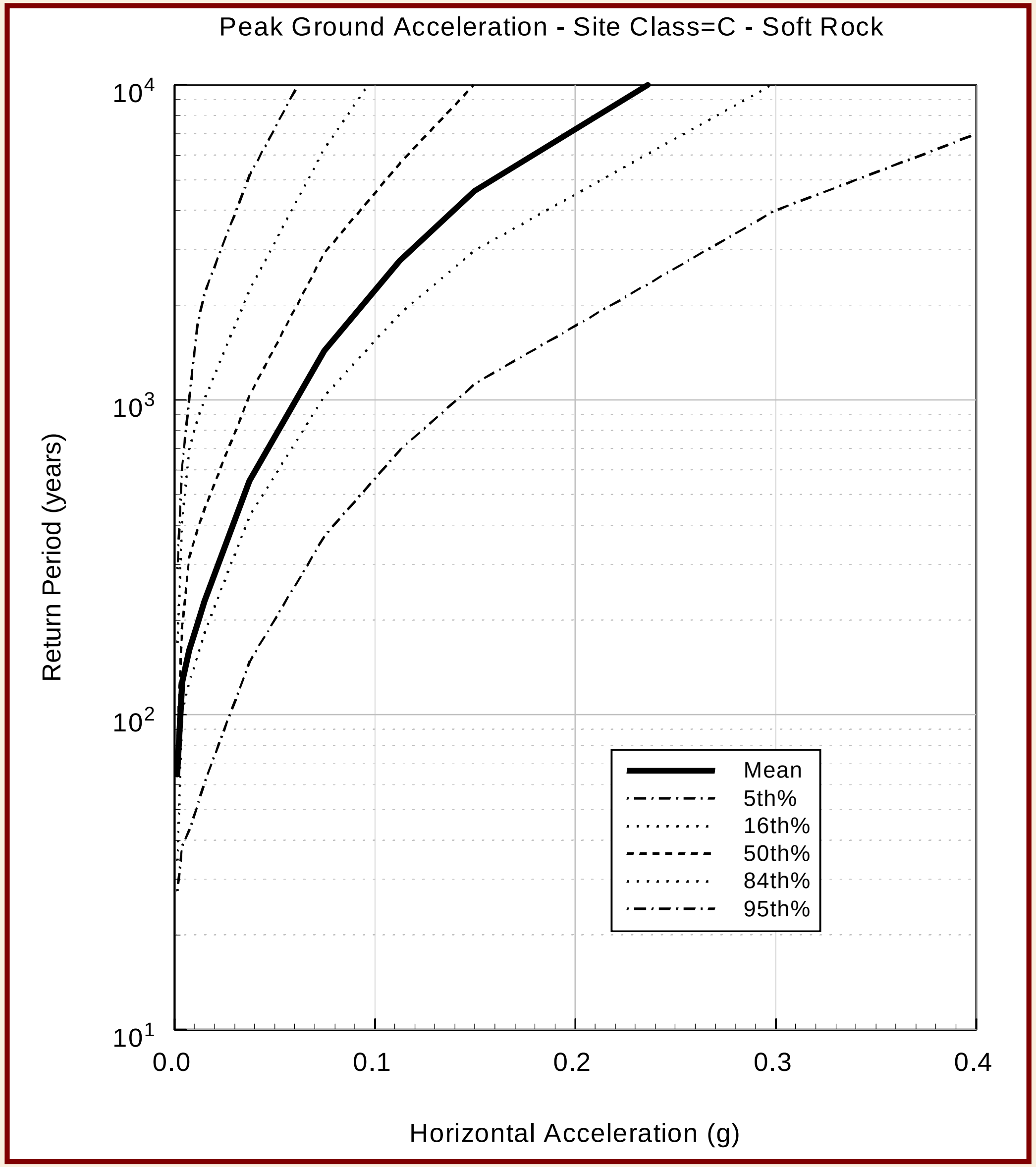
Seismic Hazard Equation

$$\nu(Y>y) = \Sigma_{src} \int_M \int_R \nu \times P[Y>y|m,r]\ f_R(r|m)\ f_M(m)\ dr\ dm$$

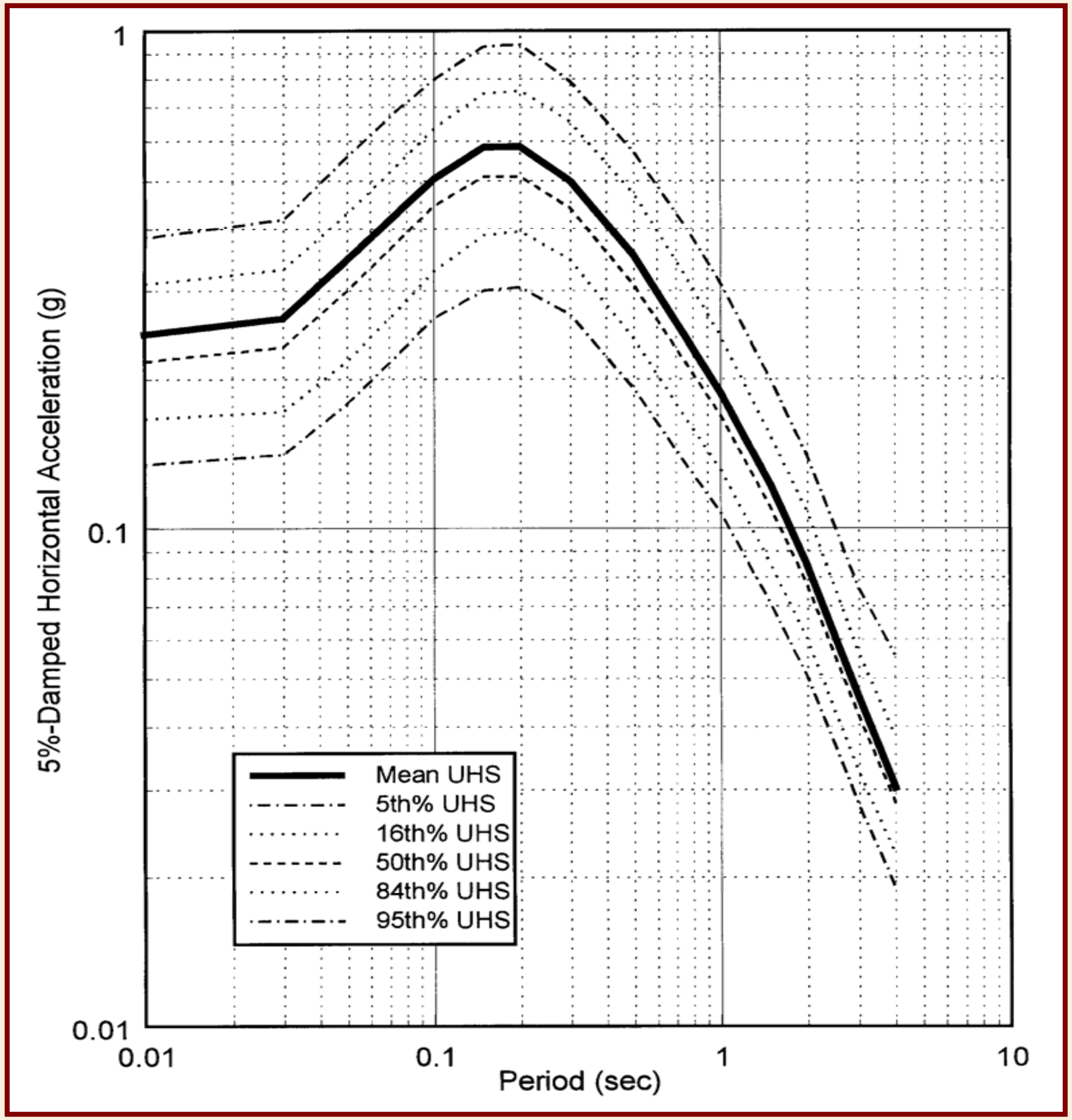
where,

- $\nu(Y>y)$ = annual exceedance frequency
- $\nu = \nu|m,r$ = recurrence frequency of m, r
- M,m = earthquake magnitude
- R,r = source-to-site distance
- $f_M(m)$ = probability that $M = m$
- $f_R(r|m)$ = probability that $R = r$ given m
- $P[Y>y|m,r]$ = probability of $Y>y$ given m,r

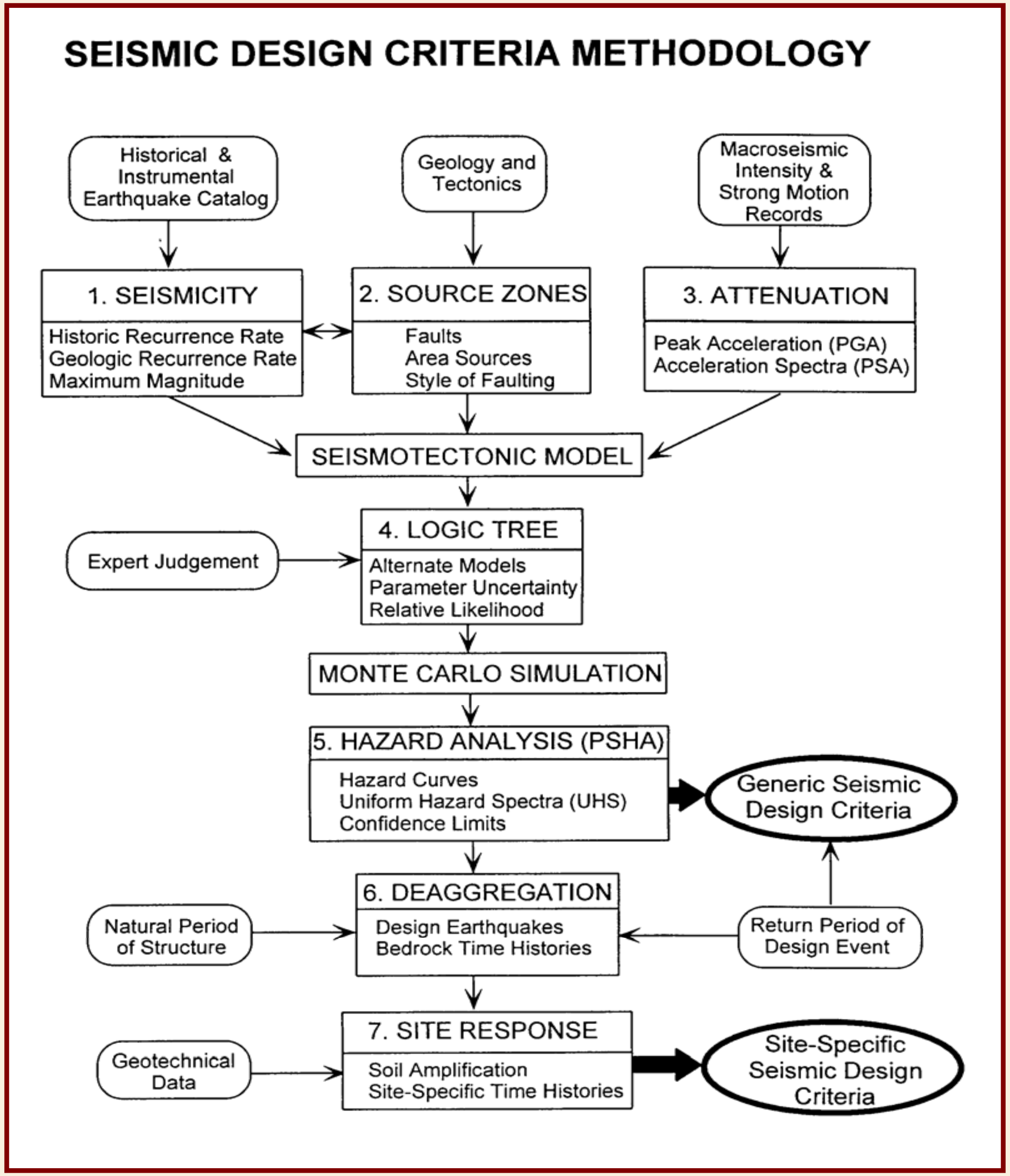
Example PGA Seismic Hazard Curve



Example 5%-Damped UHRS



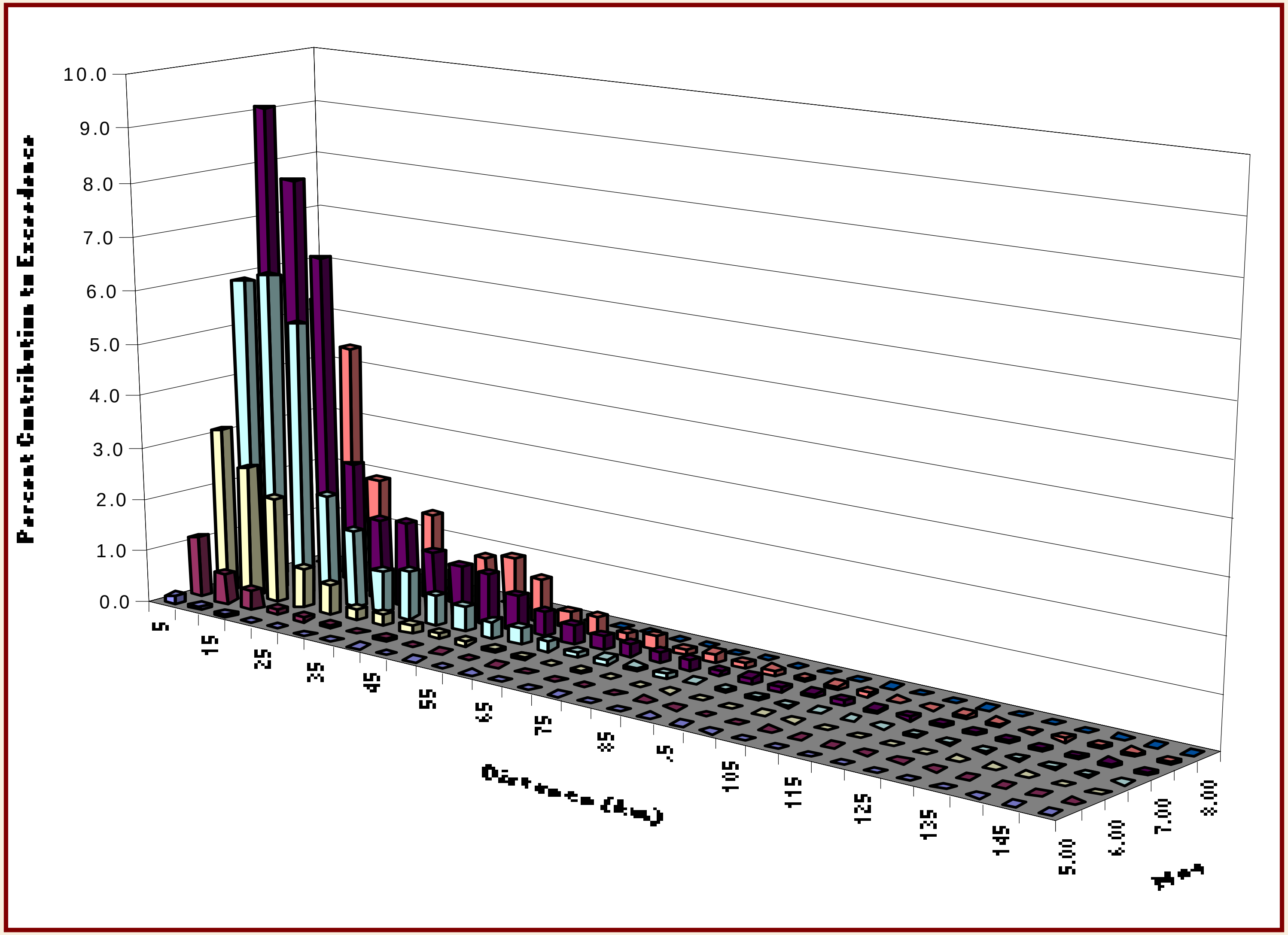
Engineering Representation of PSHA Results


SEISMIC DESIGN CRITERIA METHODOLOGY
Historical & Instrumental Earthquake Catalog
Geology and Tectonics
Macroseismic Intensity & Strong Motion Records
1. SEISMICITY
Historic Recurrence Rate
Geologic Recurrence Rate
Maximum Magnitude
2. SOURCE ZONES
Faults
Area Sources
Style of Faulting
3. ATTENUATION
Peak Acceleration (PGA)
Acceleration Spectra (PSA)
SEISMOTECTONIC MODEL
Expert Judgement
4. LOGIC TREE
Alternate Models
Parameter Uncertainty
Relative Likelihood
MONTE CARLO SIMULATION
5. HAZARD ANALYSIS (PSHA)
Hazard Curves
Uniform Hazard Spectra (UHS)
Confidence Limits
Generic Seismic Design Criteria
Natural Period of Structure
6. DEAGGREGATION
Design Earthquakes
Bedrock Time Histories
Return Period of Design Event
Geotechnical Data
7. SITE RESPONSE
Soil Amplification
Site-Specific Time Histories
Site-Specific Seismic Design Criteria

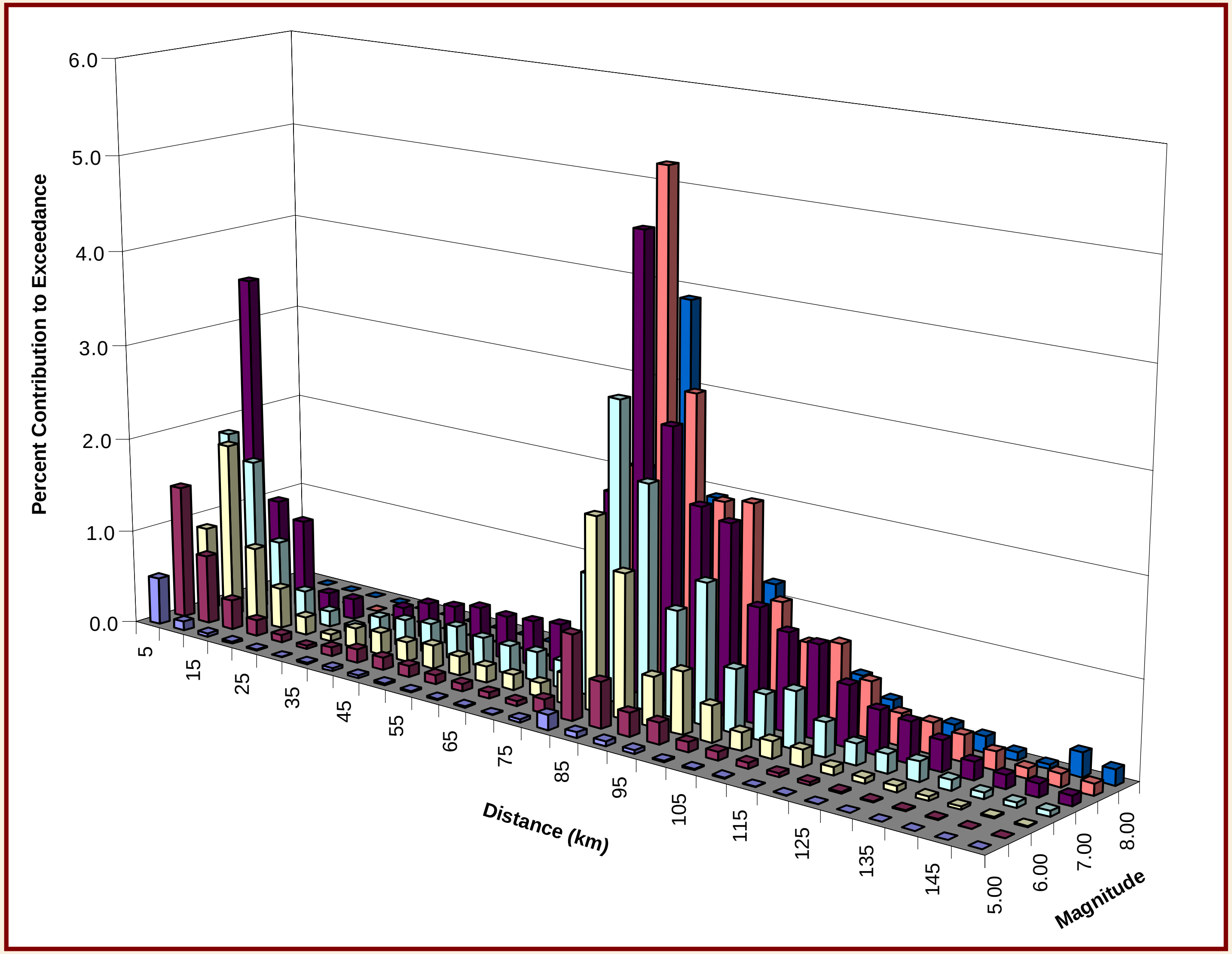
Deaggregation

- Select a reference value of mean exceedance frequency (e.g., 10^{-4}) or, equivalently, mean return period (e.g., 10,000 years) based on regulatory or other criteria
- Using this reference hazard, scale the reference value of the selected ground-motion parameter (e.g., PGA or S_a at 10 Hz) from the appropriate seismic hazard curve
- For the reference ground-motion value, compute the relative contribution to the reference hazard of selected ranges of *M* and *R* by repeating the PSHA for each range
- Derive hazard-consistent earthquake scenarios
  - Mean *M* and mean *R* (U.S. NRC)
  - One or more modal scenarios (Cornell)

Unimodal Deaggregation Results



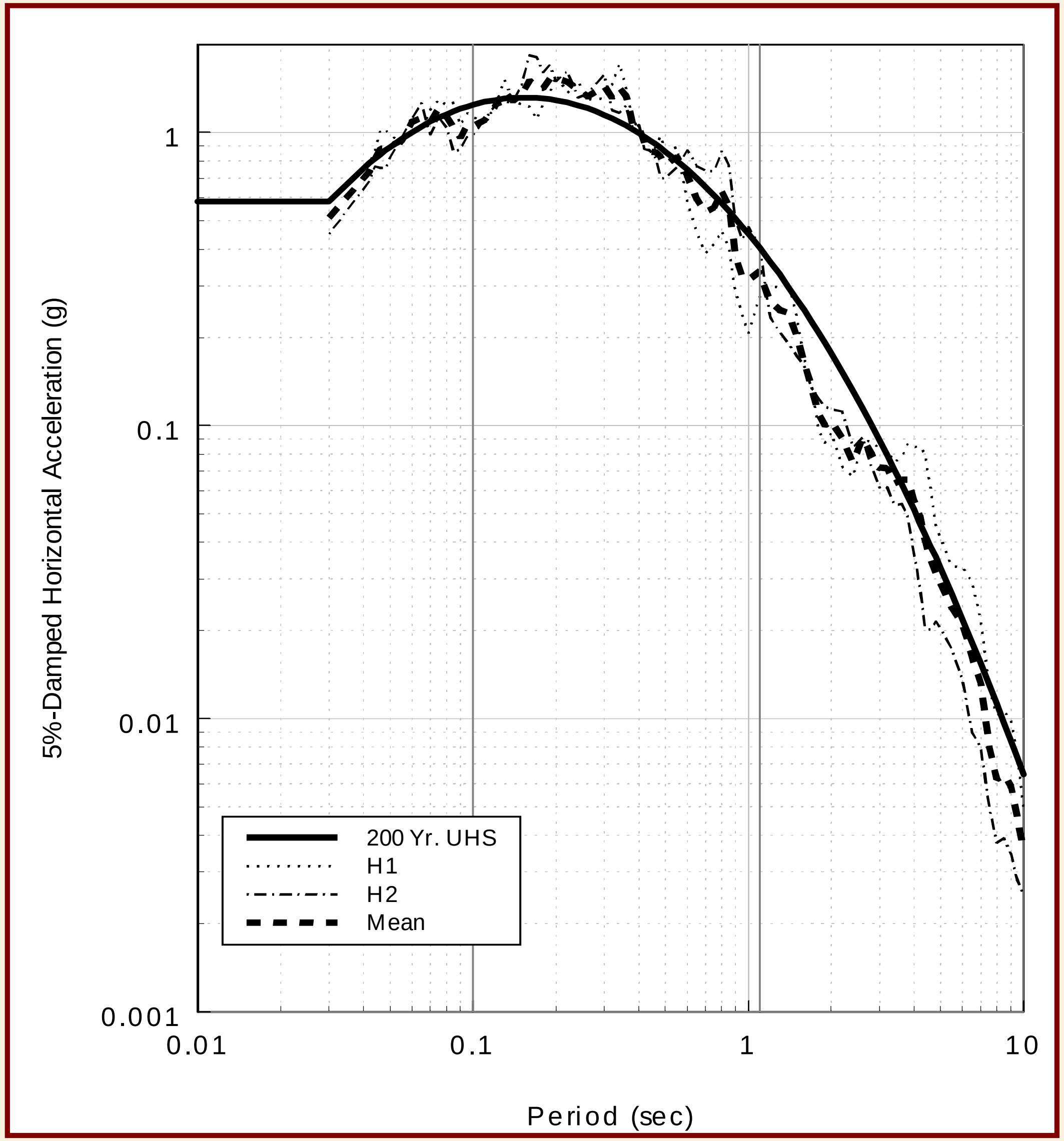
Bimodal Deaggregation Results



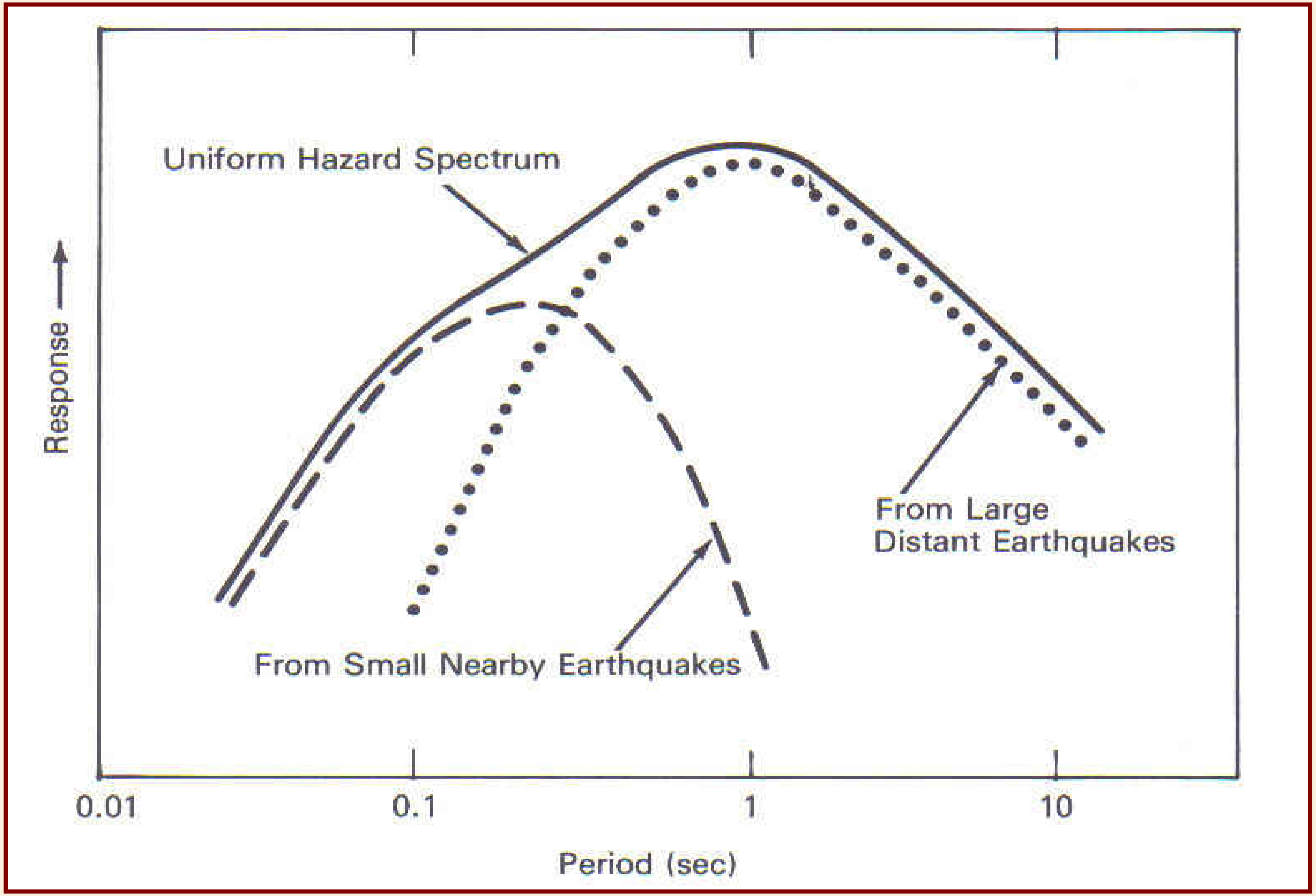
Development of Time Histories

- For the reference site conditions, develop time histories for the selected hazard-consistent scenarios (*M*,*R*)
  - Synthetic or artificial time histories
  - Recorded time histories
- Scale the time histories to the reference ground-motion value
  - Scale to PGA or PGV (not recommended)
  - Scale to limited range of spectral periods (U.S. NRC)
  - Scale to entire range of spectral periods using spectral matching techniques

Scaling Results for Unimodal Scenario



Scaling Results for Bimodal Scenario



Other Engineering Products

Other Engineering Products

- Site-response analysis
  - Develop a geotechnical profile
  - Perform 1D site-response analysis using time histories for reference site conditions
    - Equivalent-linear analysis (e.g., SHAKE)
    - Nonlinear analysis (e.g., DESRA)
- Time histories for actual site conditions
  - Output of site-response analyses
  - Calculate response spectra

Representation of Epistemic Uncertainties

Epistemic Uncertainties

- Multiple time histories for reference site conditions
- Alternative geotechnical profiles from parameter variabilities
- Multiple time histories for actual site conditions
- Multiple response spectra for actual site conditions

Summary of the Presentation

- Calculate seismic hazard curves and UHRS for reference site conditions using PSHA
- Deaggregate PSHA results for reference hazard to derive the following engineering products:
  - Hazard-consistent earthquake scenarios (*M*,*R*)
  - Time histories for reference site conditions
  - Site-response analysis
  - Site-specific time histories for actual site conditions
  - Site-specific response spectra for actual site conditions
- Represent epistemic uncertainties by deriving multiple time histories and geotechnical profiles

References and Glossary

McGuire, R.K. (2004). *Seismic hazard and risk analysis*, Engineering Monographs on Miscellaneous Earthquake Engineering Topics, MNO-10, Earthquake Engineering Research Institute, Oakland, California, 221 p.

Kramer, S.L. (1996). Seismic hazard analysis, In *Geotechnical Earthquake Engineering*, Chap. 4, Prentice-Hall, Inc., Upper Saddle River, New Jersey, p. 106–142.

Reiter, L. (1990). *Earthquake hazard analysis: Issues and insights*. Columbia University Press, New York, 254 p.

Somerville, P. and Moriwaki, Y. (2003). Seismic risk and risk assessment in engineering practice. In *International Handbook of Earthquake and Engineering Seismology*, Part B, Chap. 65, Ed. W.H.K. Lee, H. Kanamori, P.C. Jennings and K. Kisslinger, Academic Press, San Diego, p. 1065–1080.

References and Glossary

Senior Seismic Hazard Analysis Committee (SSHAC) (1997). Recommendations for probabilistic seismic hazard analysis: Guidance on uncertainty and use of experts. Prepared by Lawrence Livermore National Laboratory, NUREG/CR-6372, U.S. Nuclear Regulatory Commission, Washington, D.C.

Thenhaus, P.C. and Campbell, K.W. (2003). Seismic hazard analysis. In *Earthquake Engineering Handbook*, Chap. 8, Ed. W.F. Chen and C. Scawthorn, CRC Press, Boca Raton, Florida, 50 p.