Treatment of Uncertainties in Seismic PRA

Presented by

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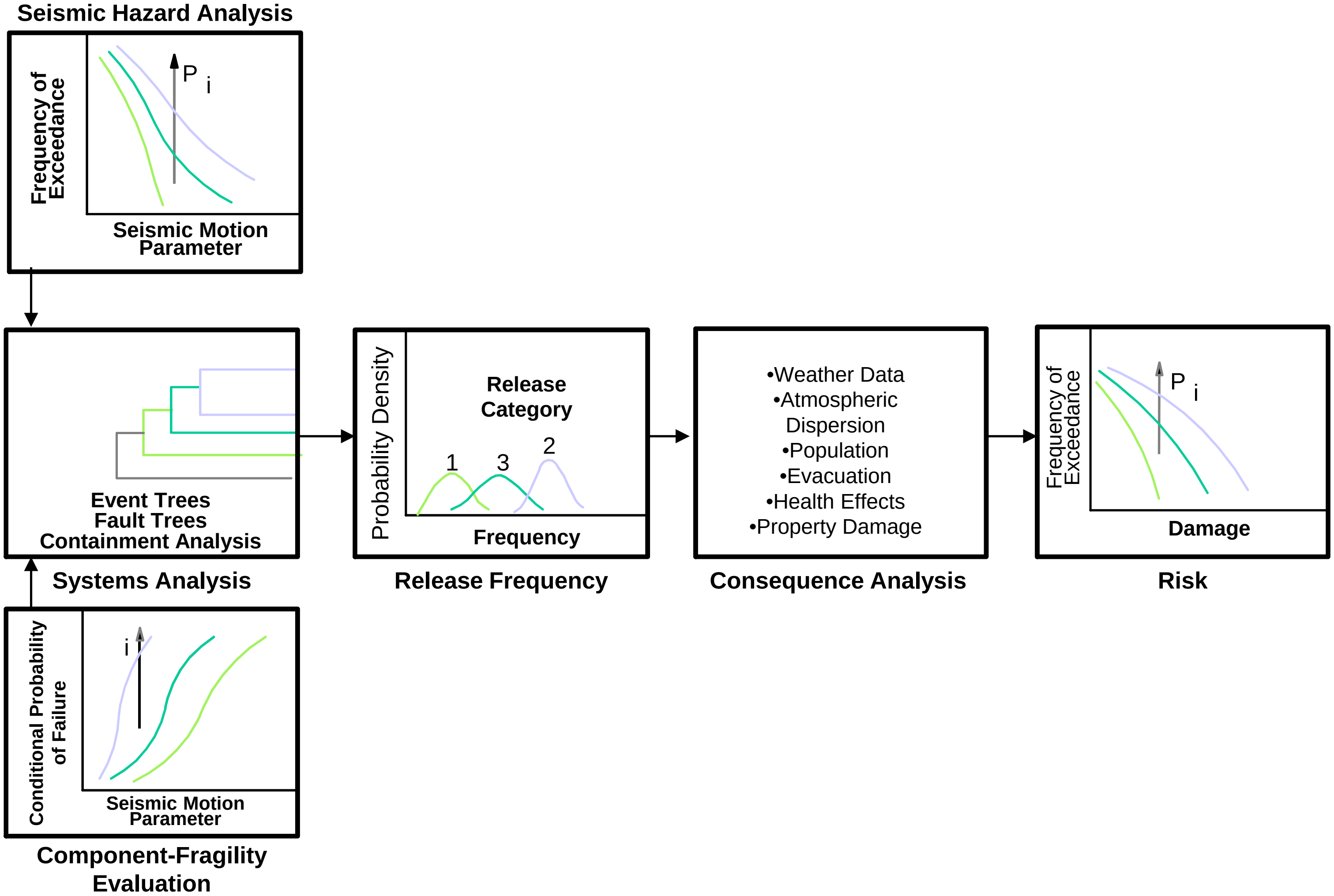
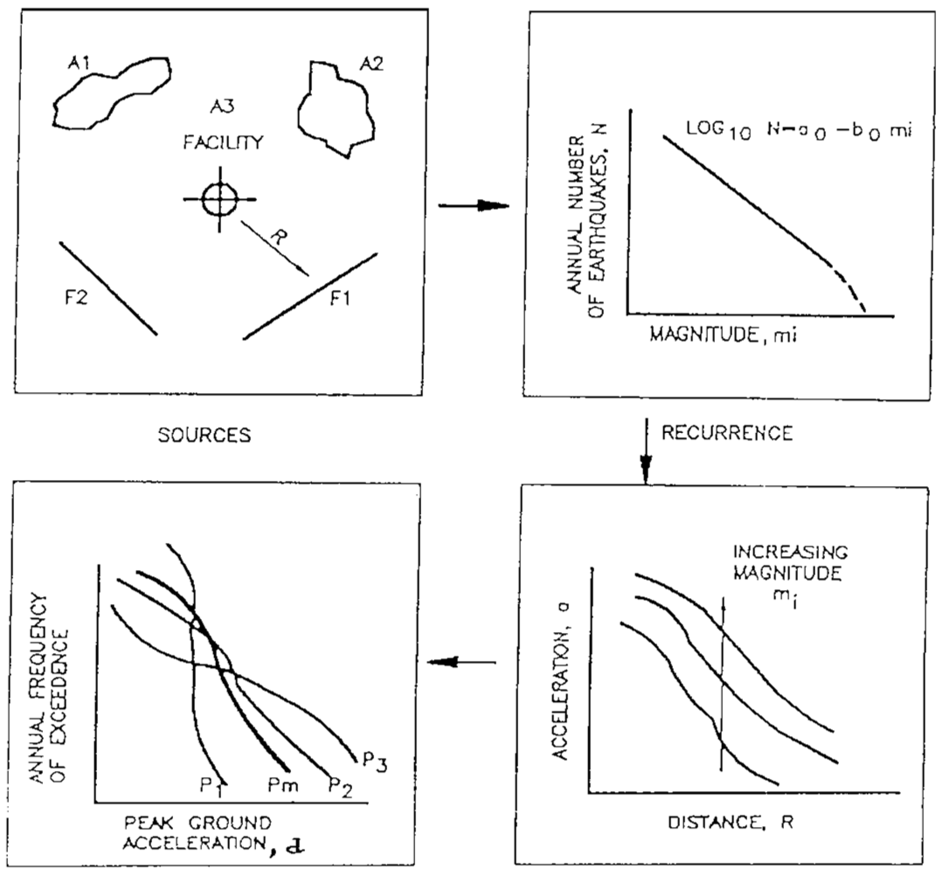
Seismic Probabilistic Risk Assessment



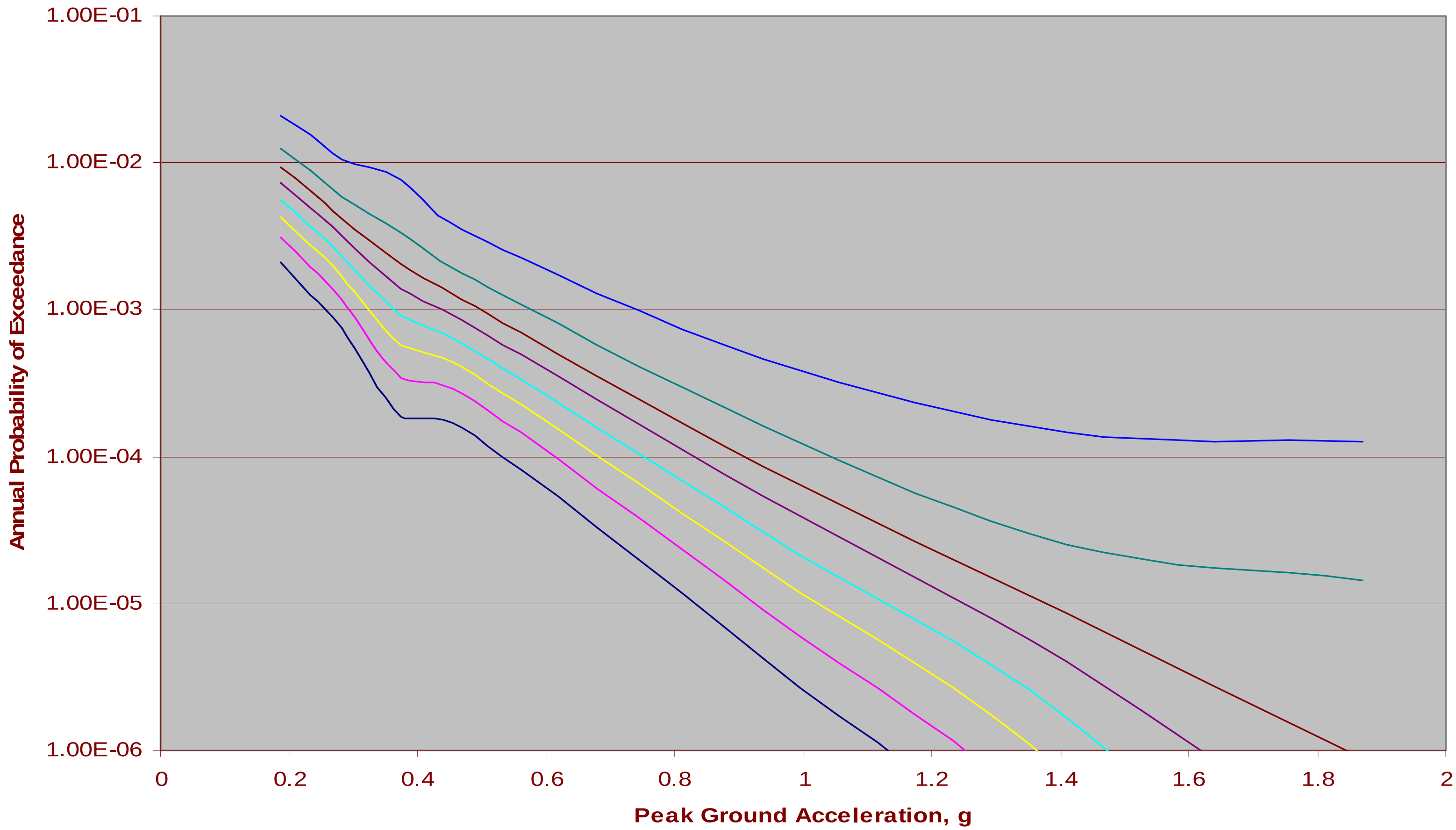
Dictionary on Uncertainty in SPRA

- Seismic Hazard
  - Aleatory uncertainty
  - Epistemic uncertainty
  - “Informed” community distribution
  - SSHAC Process
  - Hazard curves with subjective probability weights
- Fragility
  - Randomness in Capacity (aleatory uncertainty)
  - Uncertainty in Median Capacity (Modeling uncertainty) (Epistemic uncertainty)
  - Fragility curves at different confidence levels
- Risk Metrics: CDF and LERF
  - Probability Distribution on CDF and LERF

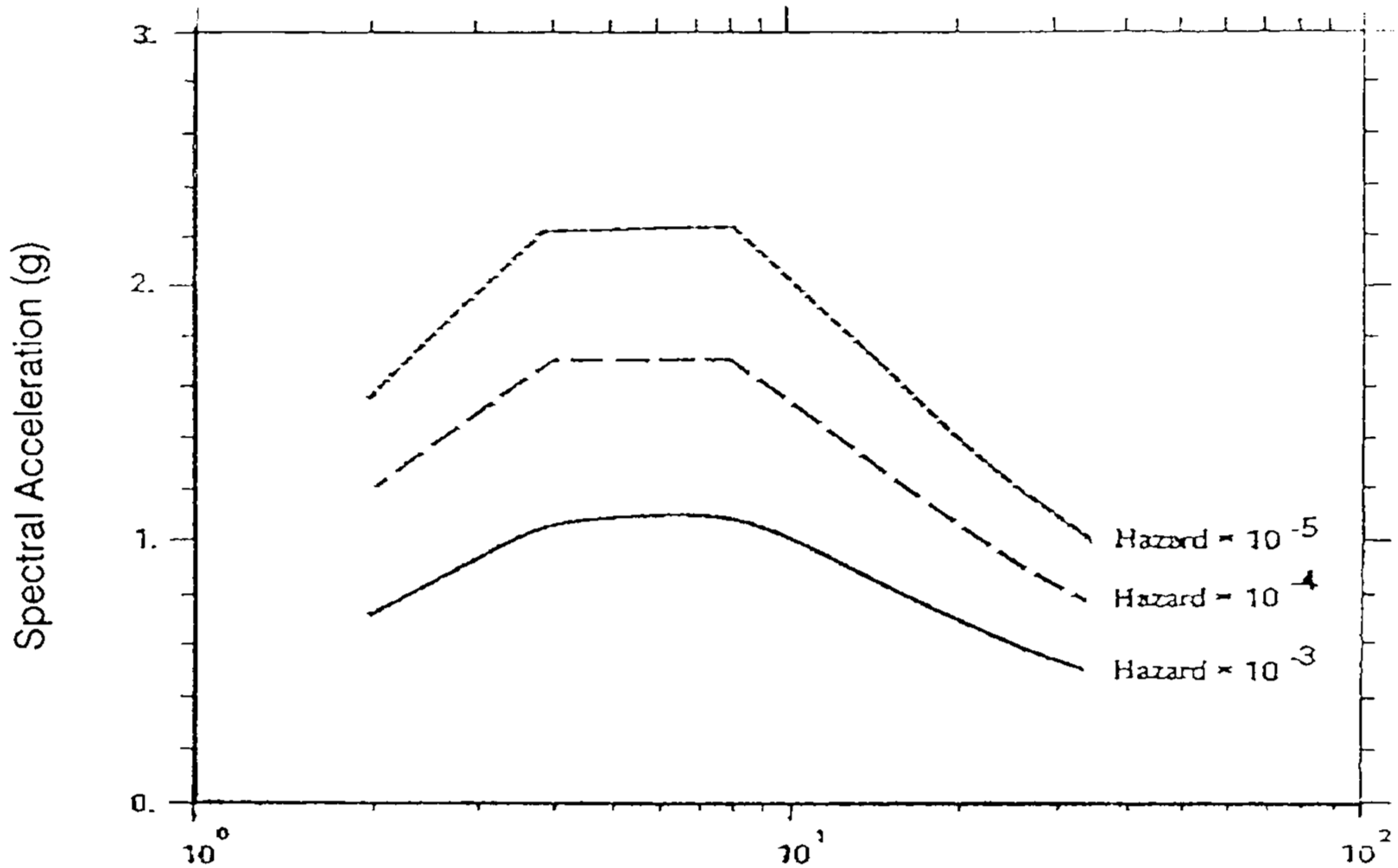
Estimation of Hazard Frequencies

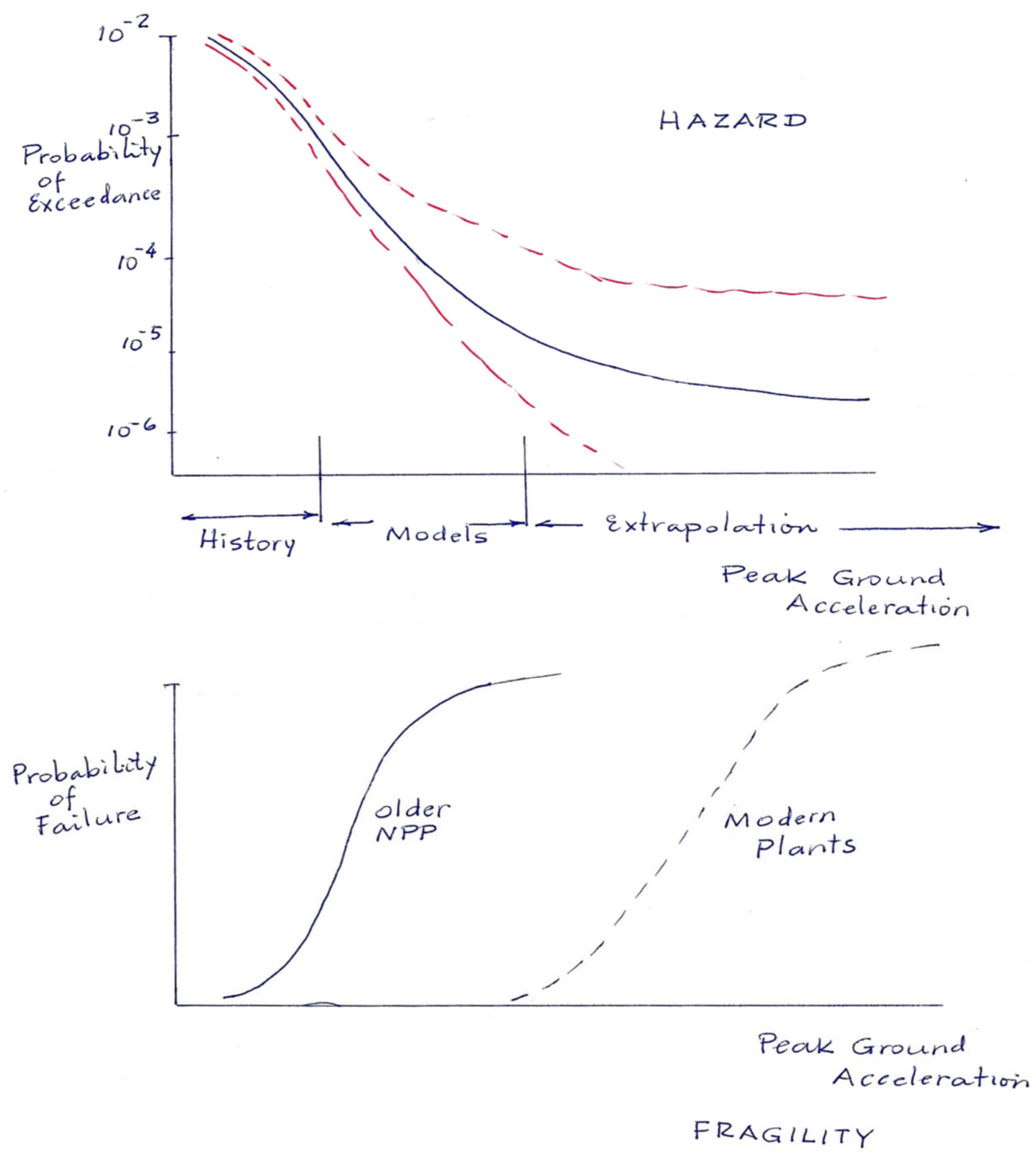


Seismic Hazard Curves



Uniform Hazard Spectra



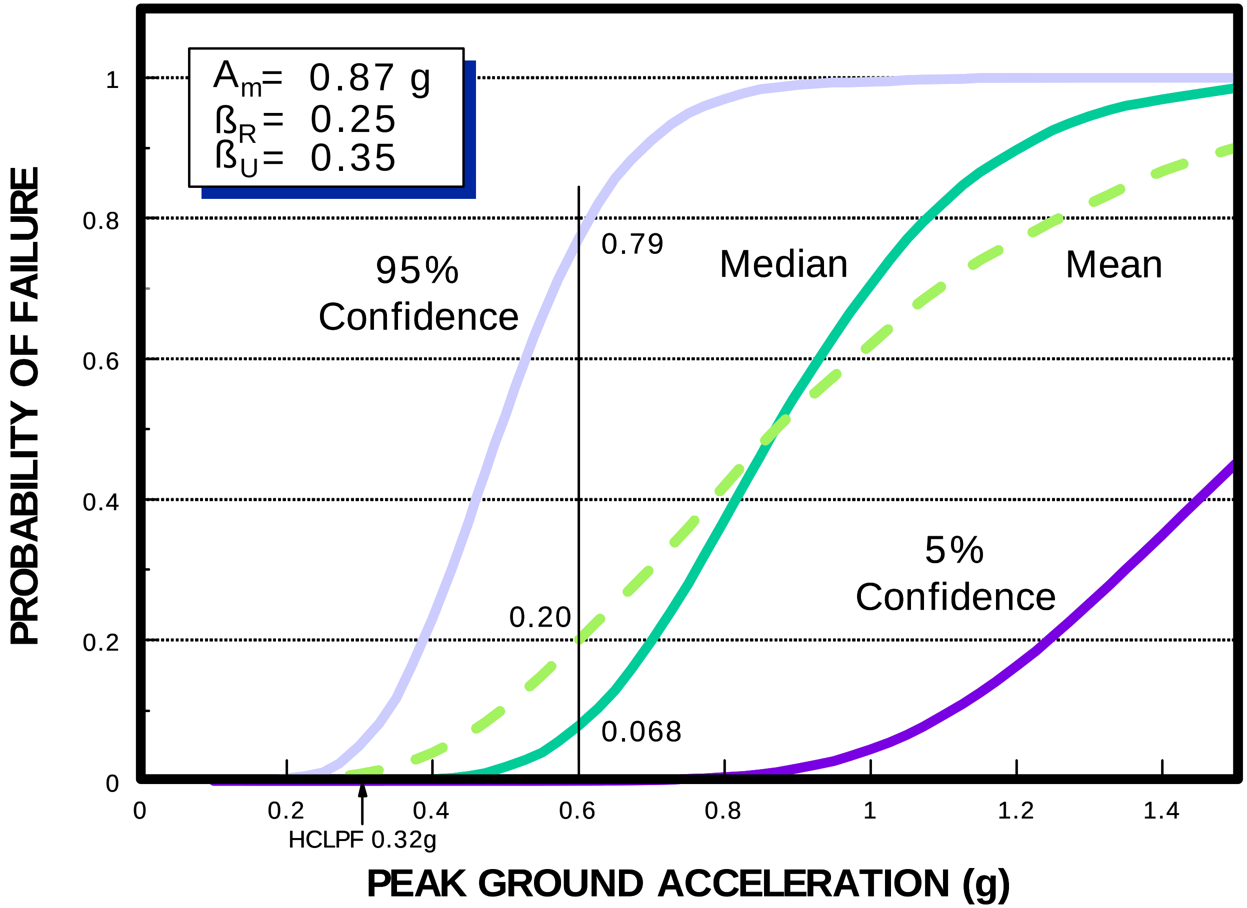


10^{-2}
10^{-3}
Probability of Exceedance
10^{-4}
10^{-5}
10^{-6}
HAZARD
History
Models
Extrapolation
Peak Ground Acceleration
Probability of Failure
older NPP
Modern Plants
Peak Ground Acceleration
FRAGILITY

Develop Seismic Sytem Models (Event Trees and Fault Trees)

- Utilize/modify existing event trees and fault trees from internal events PRA.
- Little or no event tree modification is expected; fault trees will require several modifications.
- Seismically-induced initiating events to consider are:
  - Loss of offsite power (no recovery).
  - Loss of offsite power and small LOCA.
  - Either of the above combined with other support or frontline system failures important to plant risk (seismically-induced or random failures).
- Must account for both seismic and non-seismic (random) impact on important safety equipment.
- Output: Seismic Equipment List

Seismic Fragility Curves



Seismic Fragility vs Random Unavailability

- Rate of failure to start or run as random events can be obtained by routine periodic testing during the life of the plant.
- Starting point is industry wide generic data; it is used as “prior” and subjected to Baysian updating using plant specific test data.
- Testing for random unavailability is relatively cheap and data will be accumulated over the life of the plant
- Failure rate is generally not affected by external stresses
- Seismic fragility has to be calculated using a combination of analysis, qualification test data and earthquake experience data.

Seismic Fragility vs Random Unavailability (contd)

- Seismic fragility (and hazard) varies with the input earthquake motion
- Screening of components is done using plant walkdown which is an expensive task.
- Fragility tests are not routinely done to obtain failure statistics; instead, qualification test data results are extrapolated.
- Seismic PRA is not regularly updated whereas internal event PRAs are conducted often (e.g., risk monitors).

Component Fragility

- Fragility parameters A_m, $ß_R$ and $ß_U$
- With perfect knowledge, conditional probability of failure f_o, for a given peak ground acceleration level a is:

$$f_o = \phi\left[\frac{\ln(a/A_m)}{\beta_R}\right]$$

- Fragility

$$F = \phi\left[\frac{\ln(a/A_m) + \beta_U \phi^{-1}(Q)}{\beta_R}\right]$$

Fragility Model

$A = A_m \varepsilon_R \varepsilon_U$

ε_R and ε_U are lognormal variables

Parameters: A_m, β_R, β_U

HCLPF capacity = $A_m \exp[-1.65(\beta_R + \beta_U)]$
$= A_m \exp[-2.33\beta_C]$

$\beta_C = \sqrt{\beta_R^2 + \beta_U^2}$

Fragility Model (Cont.)

$$A_m = F_m A_{SSE}$$

$$F_m = F_C F_{RS} F_{RE}$$

$$F_C = F_S F_\mu$$

$$F_{RS} = F_{SA} F_\delta F_M F_{MC}$$

$$F_{RE} = F_{SA} F_\delta F_M F_{MC}$$

$$\beta_F = (\beta_S^2 + \beta_\mu^2 + \beta_{SA}^2 + \ldots)^{1/2}$$

Fragility Analysis

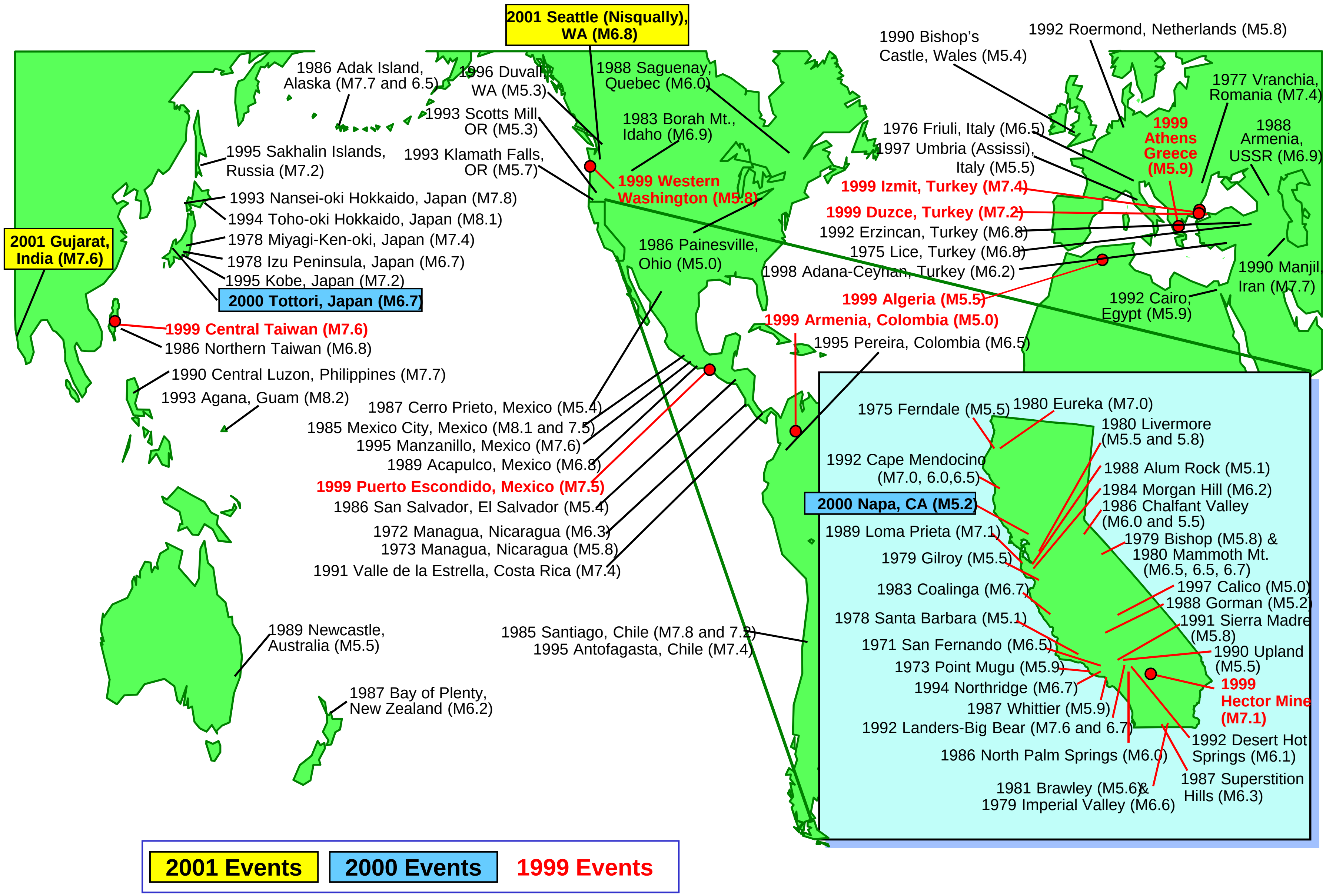
Variables considered:

- Strength
- Inelastic energy absorption
- Spectral shape
- Damping
- Soil-structure interaction
- Modeling
- Method of analysis/testing
- Combination of modes
- Combination of earthquake components

Seismic Walkdown and Screening

- Screening of high capacity components from SEL
- Identify potential failure modes
- Record any obvious seismic deficiencies (e.g., missing anchor bolts, loose mounting relays and excessive cracking of concrete)
- Identify spatial system interaction concerns that are judged to be potentially serious problems
- Evaluate the fire protection systems in the plant for seismic induced fire and inadvertent actuation of fire protection system issues and sources of seismic induced flooding

Over 100 Earthquakes Investigated



Seismic Fragility

"FAILURE" IS DEFINED AS THE EVENT WHEN AN ELEMENT REACHES A LIMIT STATE

<u>Element</u>	<u>Limit States</u>
Structures	➢ Inelastic Deformations Exceeding Operability Limits for Equipment
Piping	➢ Fracture or Collapse of Pressure Boundary ➢ Failure of Supports ➢ Attachment Failure
Equipment	➢ Structural - Bending, Buckling of Supports Anchor Bolt Pull-Out, Nozzles, etc. ➢ Functional - Binding of Valve, Excessive Deflection, Relay Chatter

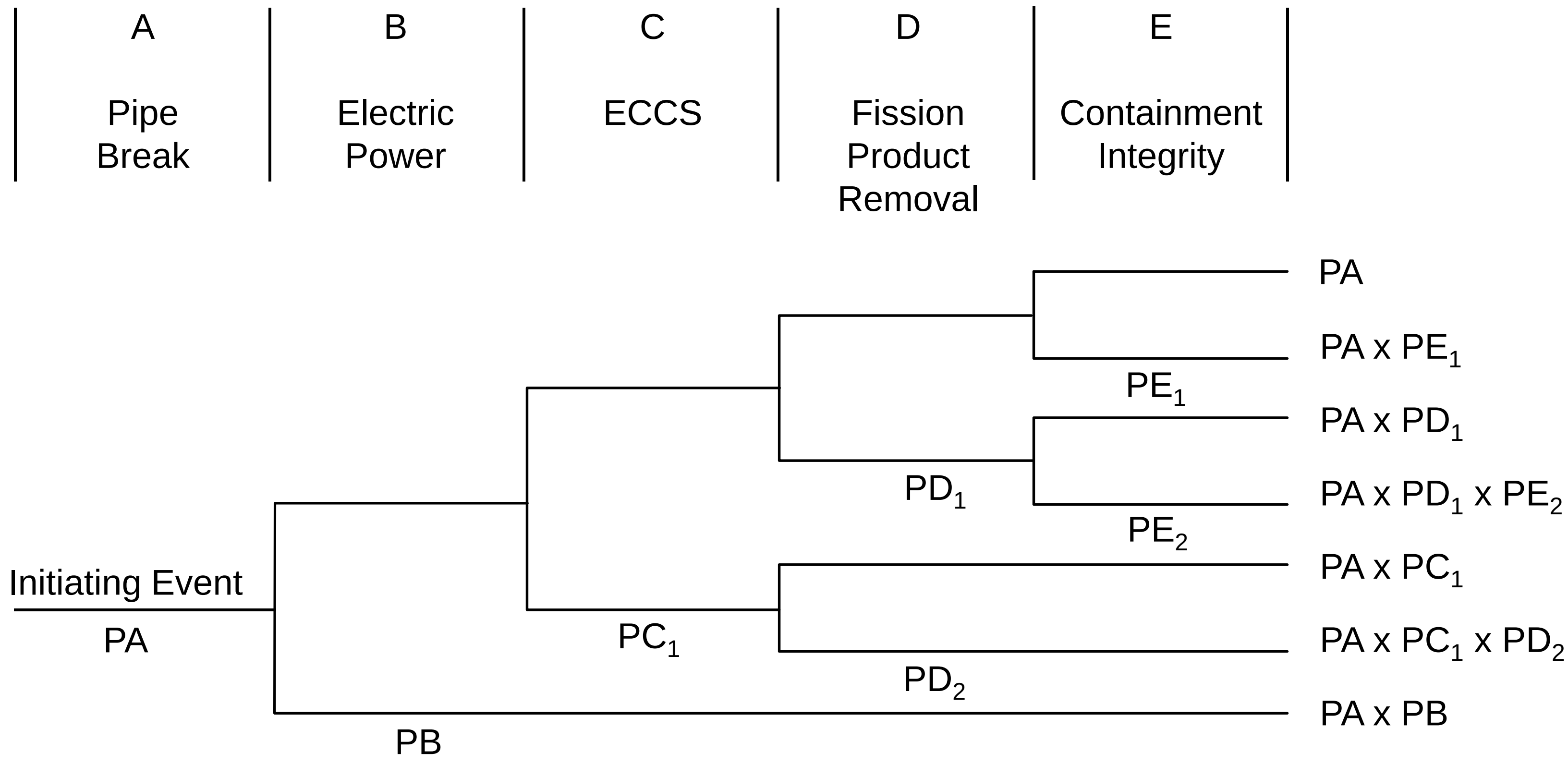
Data Sources

- Plant specific
  - Design analysis documents
  - Qualification tests
- Generic
  - Shock test data
  - Past performance
  - Fragility tests

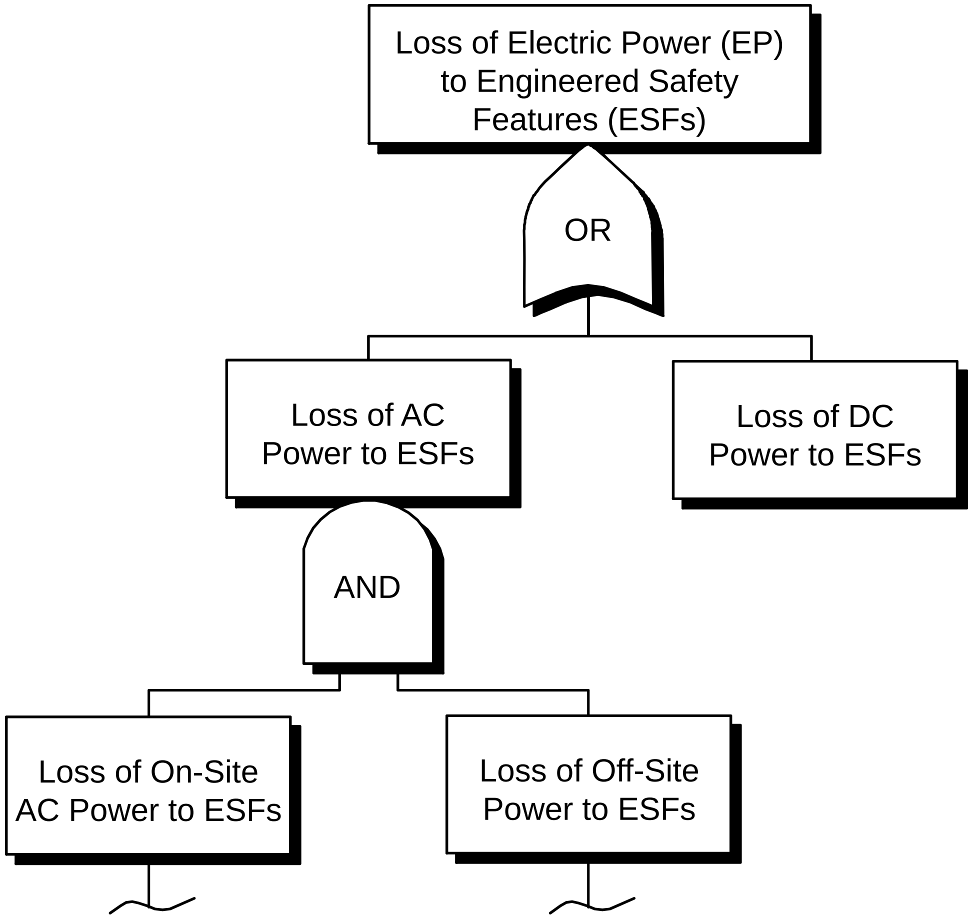
Systems Modeling

- Initiating events
  - Loss of offsite power
  - Small break LOCA
  - etc.
- Safety functions and associated front line and support equipment
- Event trees
- Fault trees
- Detailed equipment list
- Booleans for accident sequences
- Plant level fragility

Simplified Event Tree For A Large LOCA



Example Fault Tree



Example Boolean

- CD = 4 + 8 + 10 + 14 + 17 + 21 + (12 + 22 + 26) * 9

  + = OR

  * = AND

  4 Service water pumps
  8 Auxiliary building -- failure of concrete shear wall
  9 Refueling water storage tank
  10 Interconnecting piping/soil failure beneath reactor building
  12 Condensate storage tank
  14 Crib house collapse of pump enclosure roof
  17 125 VDC batteries and racks
  21 Service water system buried pipe 1020 mm diameter
  22 CST piping 500 mm diameter
  26 Collapse of pressurizer enclosure roof

Propagation of Uncertainty

- Uncertainties in seismic hazard, fragilities, random failure rates, and operator errors
- Develop point estimates for different accident sequences using mean hazard curve, mean fragilities and failure rates
- For significant accident sequences, conduct uncertainty analysis
- Important to consider success terms
- Softwares available based on DPD and Monte Carlo simulation

DPD Method for Sequence Fragility

- Each component is modeled by "n" fragility curves.
- We perform the required operation (union or intersection) on two components at a time for each of the "n" fragility curves.
- If the median uncertainties are independent, we obtain "n^2" fragility curves which is condensed back to "n" curves (if the median uncertainties are dependent, we obtain "n" curves).
- The "n" fragility curves of the combined event are then combined with the "n" curves of another component.
- This process is continued until all the component fragilities have been combined as given in the Boolean equation, finally resulting in "n" sequence fragility curves.

Sequence Failure Frequency

- Each of the n sequence level fragility curves are convolved with each of the m seismic hazard curves for the site
- The convolution is expressed by the following

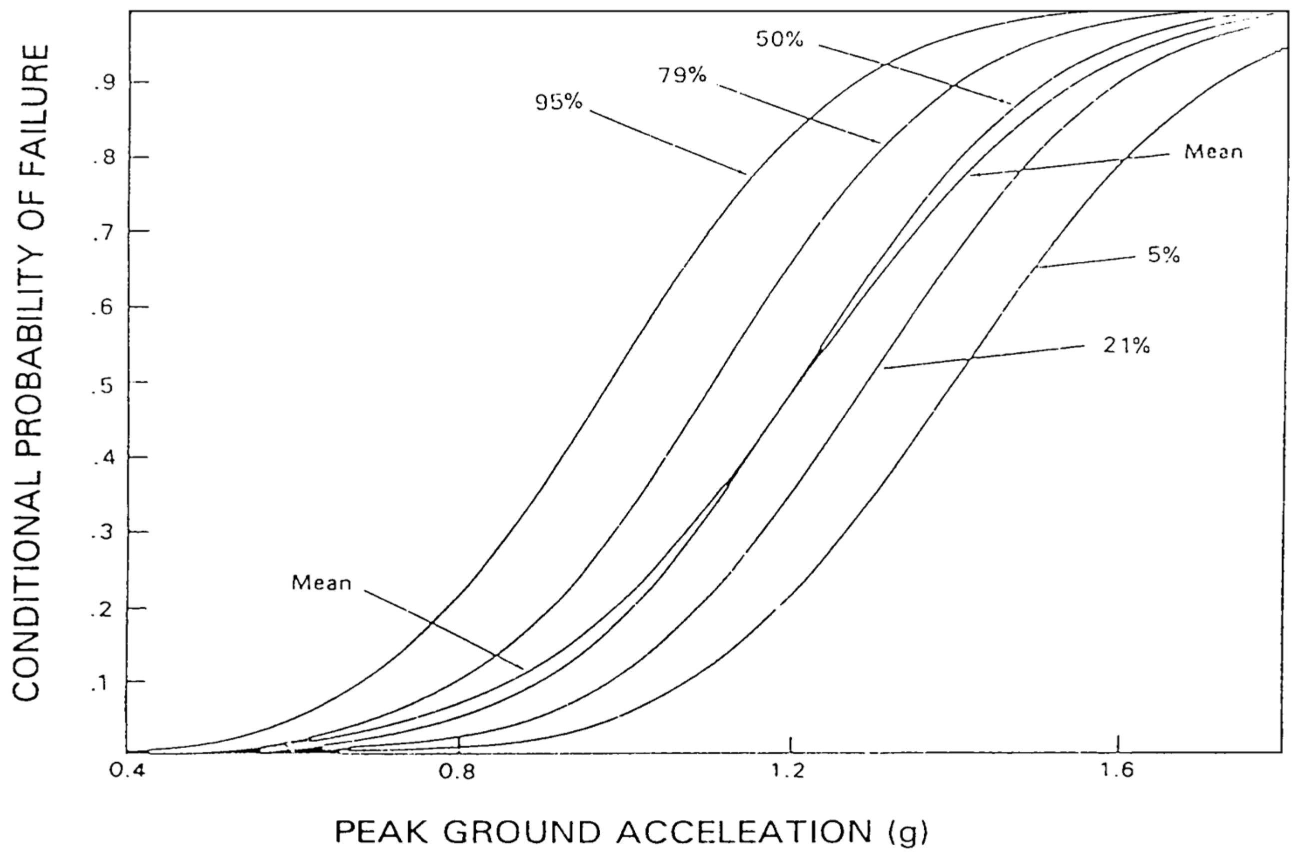
$$\int_{o}^{\infty} \frac{-dH(a)}{da} S(a)\, da$$

where $-\frac{dH}{da} =$ the frequency with which earthquakes occur in the size range da about a

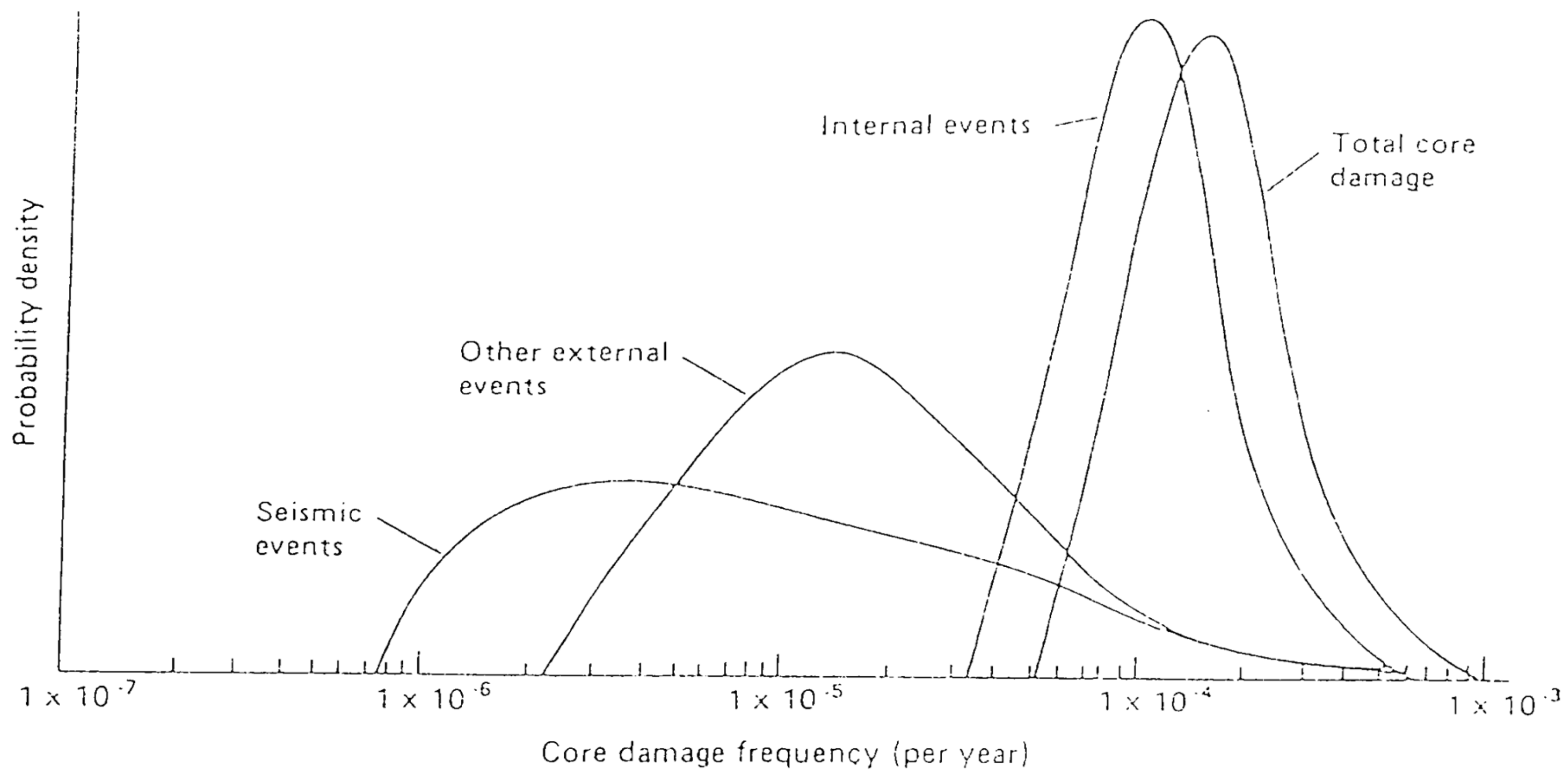
S(a) = conditional probability of accident sequence

- The result is a probability distribution on the frequency of accident sequence

Plant Fragility Curve, Including Random and Nonseismic Failures



Results of a Probabilistic Risk Assessment



Sources of Uncertainty: Hazard

- Hazard modeling
  - Earthquake Sources
  - Ground motion
  - Local site response
  - Other hazards (liquefaction, landslide etc)
- Aleatory and Epistemic uncertainties
- Methodology
  - Earthquake history
  - Theoretical and empirical models
  - Expert elicitation SSHAC Process
- Development of family of seismic hazard curves

Sources of Uncertainty: Fragility

- Seismic capacity modeled as a product of multiple variables
- Limited empirical data to describe these variables
- Analyst is asked to estimate the aleatory and epistemic uncertainties for each variable
- Functional failure modes are not clearly tied to the structural deformations.
- Fragility is described in terms of a family of fragility curves.
- Limited test data for electrical components (one qualification test and no fragility tests)
- Loss of offsite power fragility
- Generic conversion of HCLPF to fragility

Sources of Uncertainty: Plant Response and Quantification

- Propagation of uncertainty
  -software
- Large uncertainty mainly from hazard uncertainty
- Simplifications
  - system model: initiating events and SSCs
  - correlation
  - human errors under seismic conditions
  - screening of components
- Comparison and integration with other events

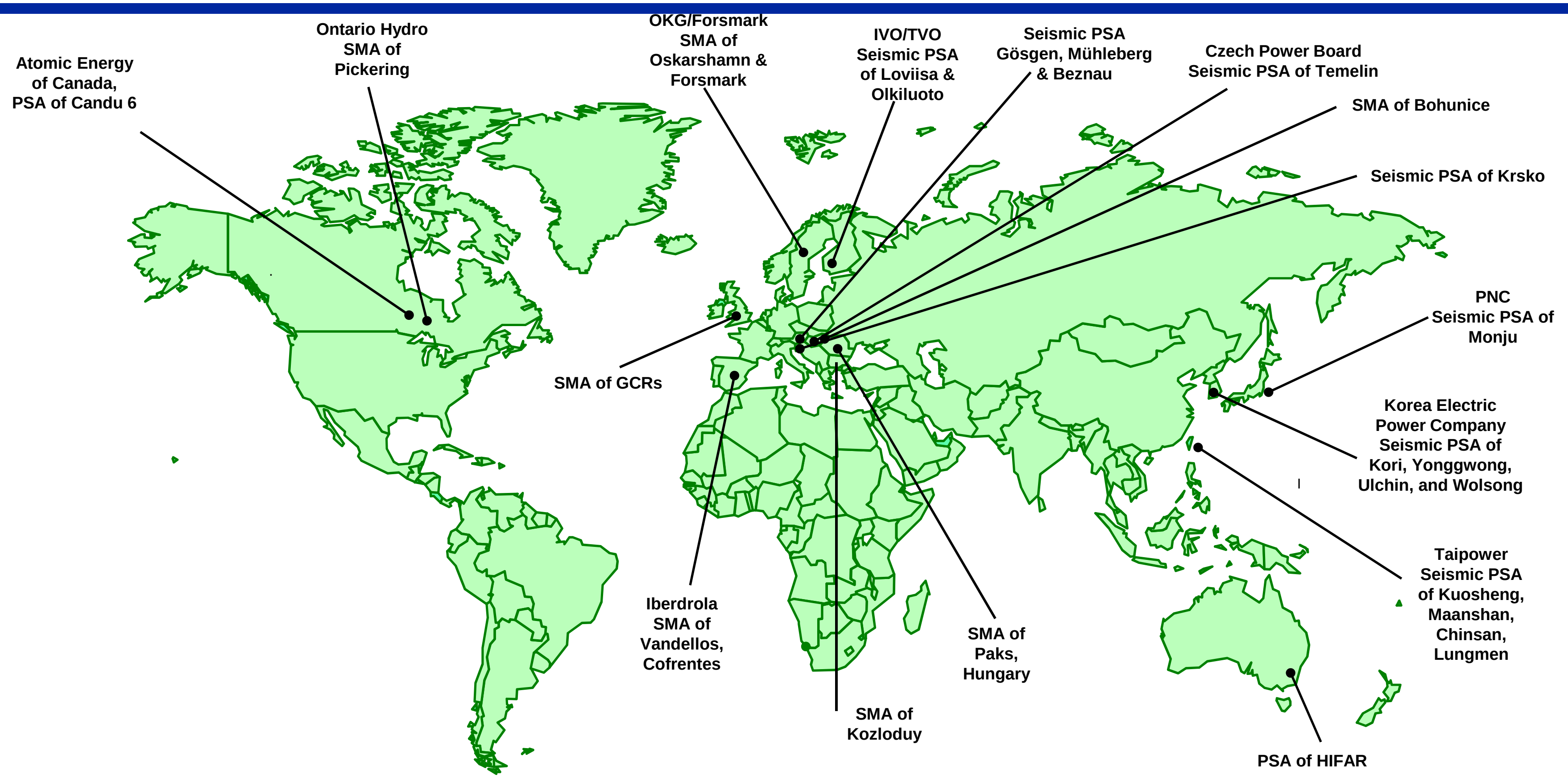
Model Uncertainty Significance

- Seismic Hazard HIGH
  - Process stabilizing
- Seismic Fragility MEDIUM
  - Process stable
  - Lack of test data
  - Limited resources
- Plant Response and Quantification LOW to MED
  - Process stabilizing
  - Software availability

Concluding…

- Seismic PRAs have been conducted for over 50 plants in the US and worldwide; useful insights have been obtained in spite of large uncertainties for plant safety upgrades and regulatory decisions
- Seismic PRA methodology allows and requires full treatment and propagation of uncertainty
- Seismic hazard uncertainty dominates the uncertainty in risk metrics CDF and LERF

Seismic PRA and SMA Projects for Existing Plants Around the World



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