U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Data Abstraction and Implementation of Postclosure Seismic Scenario in Total System Performance Assessment

Presented to:
Nuclear Waste Technical Review Board
Joint Meeting of the Natural System and Engineered System Panels

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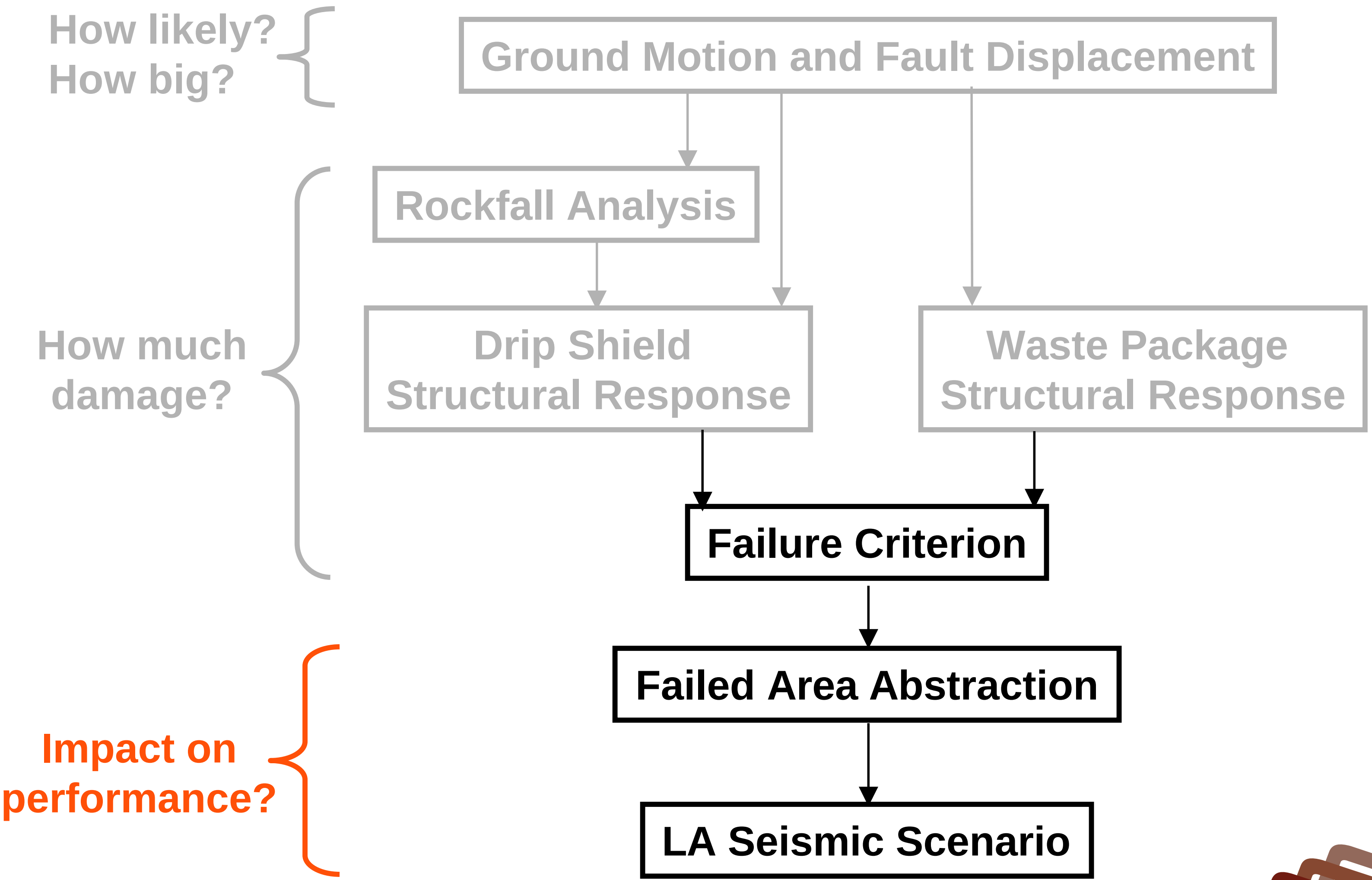
Objectives

- Describe the representation of barrier degradation
- Describe failure criterion
- Describe abstraction for failed area
- Describe computational approach for the seismic scenario

Components of the Postclosure Technical Approach



Structural Thicknesses

- **Structural response will be evaluated for an "almost intact" condition of the drip shield and waste package (WP)**
- **Almost intact condition conservatively accounts for corrosion over 10,000 years**
  - **WP outer shell has 18-mm of Alloy 22, 2-mm less than the design value of 20-mm**
    - **Corresponds to 88th percentile corrosion rate over 10,000 years**
  - **Drip Shield (DS) plates have 13-mm of Titanium Grade 7, 2-mm less than design value of 15-mm**
    - **Corresponds to 73rd percentile corrosion rate over 10,000 years**

Failure Criterion

Failure Criterion

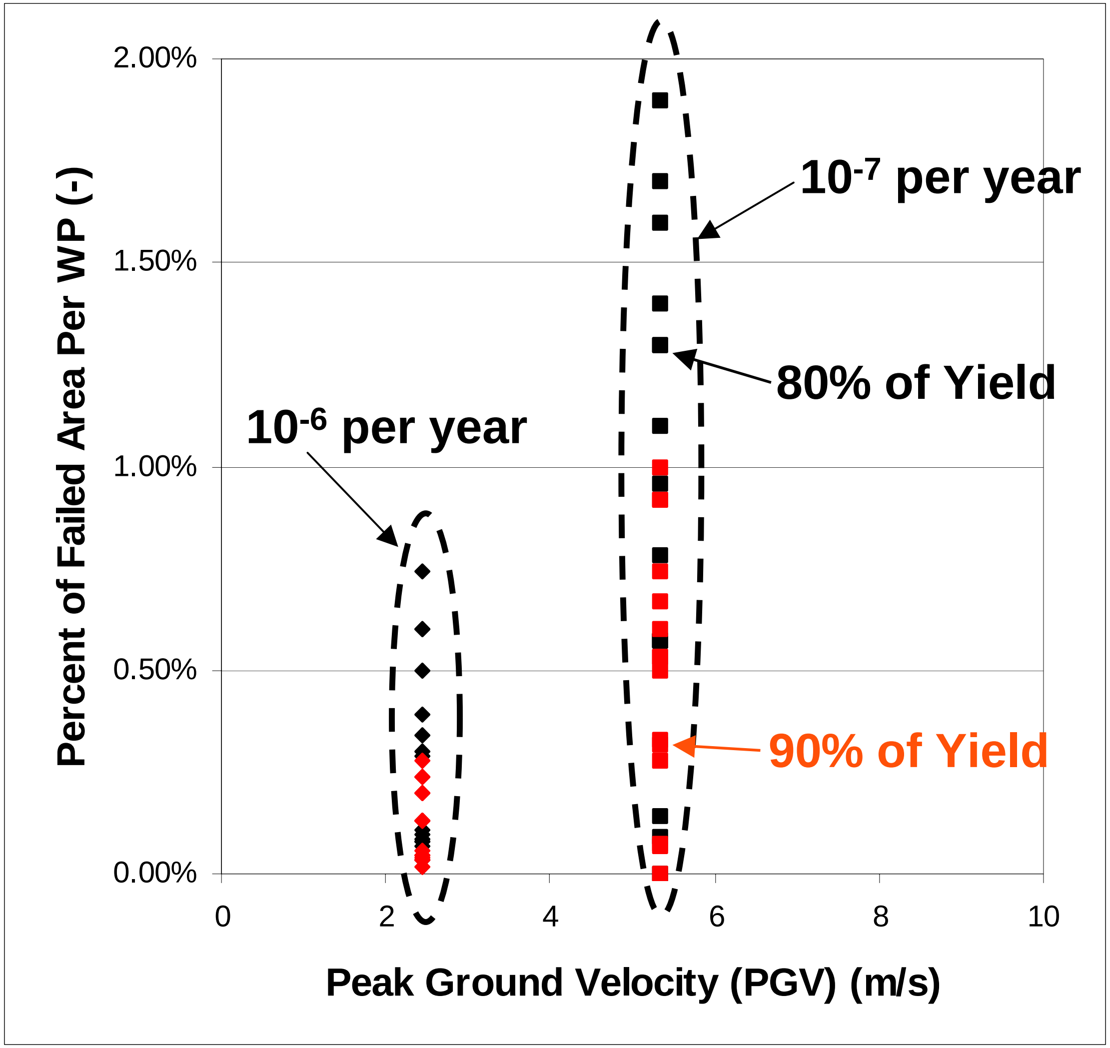
- **Regions whose residual stress exceeds a specified fraction of the yield strength will be considered to fail as a flow barrier**
  - **Alloy 22 may degrade rapidly when residual stress from structural deformation is greater than 80% - 90% of the yield stress**
  - **Titanium Grade 7 may degrade rapidly when residual stress from structural deformation is greater than 50% of the yield stress**

Failure Criterion
(Continued)

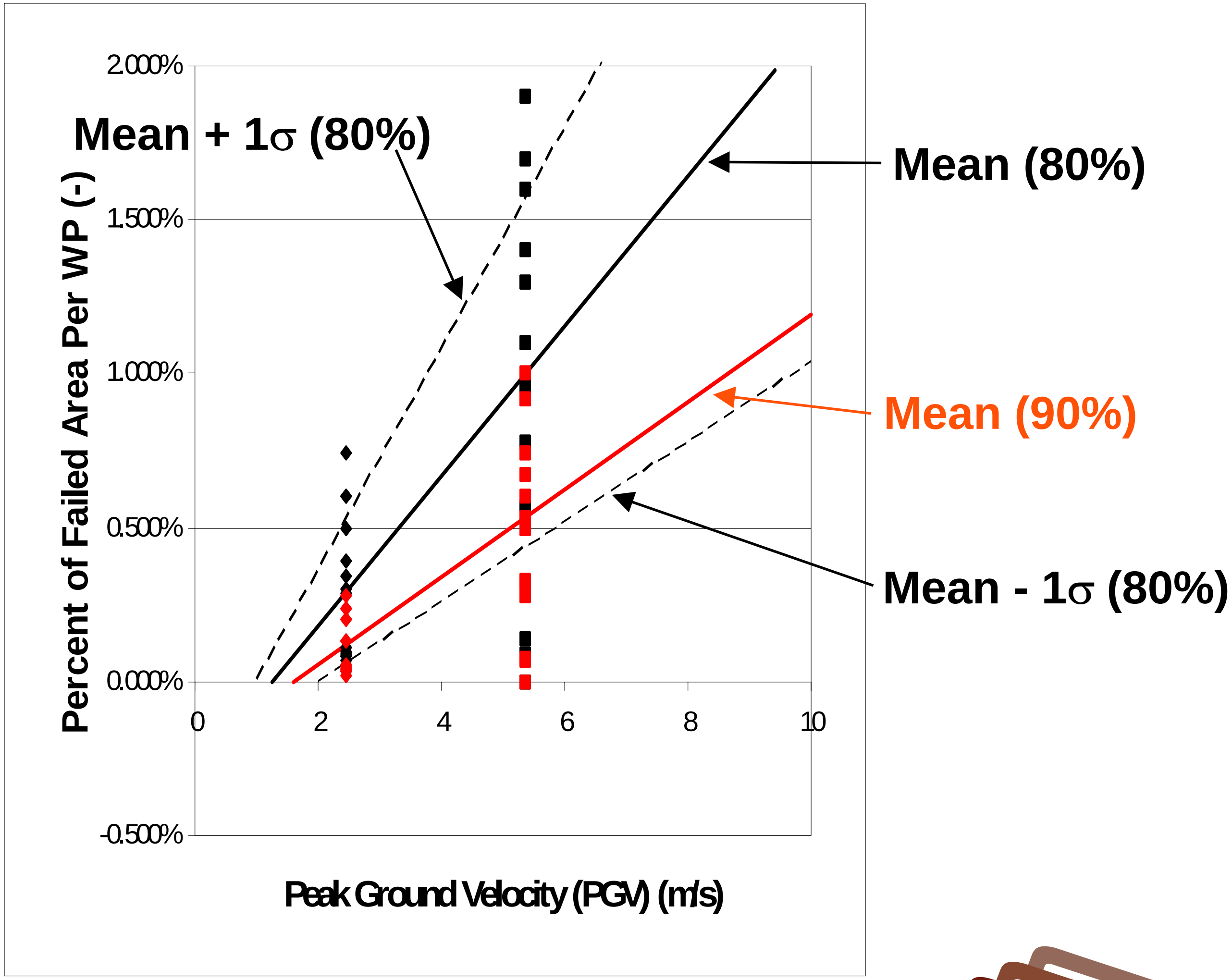
- Basis for Failure Criterion
  - Metal exceeding these limits is likely to be heavily cold-worked and subject to enhanced general and localized corrosion
  - 80% of yield strength for Alloy 22 is an initiation criterion for stress corrosion cracking elsewhere on the project
  - Accelerated corrosion will generate failed openings at lower stress levels than tensile (purely mechanical) failure
- Regions whose residual stress exceeds these criteria are conservatively assumed to fail as a barrier to flow and transport
  - Potential for network of stress corrosion cracks to block advective flow is ignored in the model

Failed Area Abstraction

Waste Package Damage Data



Abstraction with a Linear Fit to Mean and Standard Deviation



Abstraction of Failed Area

- **Total System Performance Assessment (TSPA) requires damage over a range of peak ground velocity (PGV) values, hence the need for the abstraction**
  - **10^{-5} per year ~ 1 m/s (at Point B)**
  - **10^{-8} per year ~ 10 m/s (at Point B)**
- **Damage at 10^{-5} per year is estimated to be zero, based on**
  - **Extrapolation of linear fits for 80% or 90% of yield stress**
  - **Calculation of WP response for the 5×10^{-4} per year level**
- **Damage at 10^{-8} per year is ~2.5%, based on 80% of yield stress**
  - **Note conservatisms in calculation of end-to-end impacts of waste packages**
    - **Synchronicity of ground motions may eliminate end-to-end impacts**
    - **Rigid barrier overestimates damage**
- **Linear, power law, and modified power law fits are being considered**

Summary of Abstraction Procedure

- **Determine failed areas, based on residual stress from structural response under vibratory ground motion and rockfall**
  - **Use ~15 ground motion accelerograms for two probability levels (i.e., 10^{-6} and 10^{-7} per year), sampling other uncertain input parameters appropriately**
  - **Determine rockfall in lithophysal and nonlithophysal zones**
  - **Determine response of drip shield under rockfall and ground motion**
  - **Determine response of waste package under ground motion**
  - **Determine failed area, based on residual stress**
  - **Abstract failed area (mean and standard deviation) as a function of the PGV**

Seismic Scenario for License Application

Total System Performance Assessment–License Application Seismic Scenario

- **Technical Approach**
  - Define separate scenario for postclosure response
  - Focus on estimating mean release for low probability ground motions
  - Consider ground motion levels that produce significant structural damage
  - Consider fault displacements that produce significant structural damage
  - Consider ground motion levels that produce significant damage to the cladding

Two Step Process

- **Step 1**
  - **Generate "R" realizations that have robust sampling of all levels of ground motion that may cause structural damage**
    - **Estimate that "R" is between 300 and 500 realizations**
    - **Each realization is for 10,000 years**
- **Step 2**
  - **Calculate mean or expected dose time history as a weighted sum of dose time histories from the "R" realizations created in Step 1**

Step 1

- Generate "R" realizations of future performance with the TSPA model
  - Each realization has a single seismic hazard occurring at a random time during the realization
    - Sample over the full range of seismic hazards with significant structural damage
  - The response of the drip shield, waste package and cladding are calculated from failed area response curves as a function of PGV
  - Dose to the affected population is determined by flow and transport through the failed areas in the EBS
    - Transport through Unsaturated Zone (UZ) and Saturated Zone (SZ) identical to the nominal scenario

Step 2

- **Each realization in Step 1 determines the dose from a single ground motion occurrence**
- **The mean dose, *D(t)*, is calculated as a weighted average of the individual dose, $D_i(t)$, from the i^{th} realization. Assuming uniform sampling for the time of occurrence, T_i, and log-uniform sampling for the annual exceedance probability, λ_i:**

$$D(t) = \frac{T}{R} \ln\left(\frac{\lambda_{MAX}}{\lambda_{MIN}}\right) \sum_{i=1}^{R} (\lambda_i) D_i(t \mid \lambda_i, T_i)$$

$$\text{with } \lambda_{MIN} < \lambda_i < \lambda_{MAX},$$

$$T = 10{,}000 \text{ years},$$

$$\lambda_{MIN} = 10^{-08}$$

$$\text{and } \lambda_{MAX} = 10^{-05}$$

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Summary

- Structural thickness is based on a conservative approach for the 10,000 year containment period
- Failed area is based on residual stress because this is the limiting process, rather than tensile failure
- TSPA will use Monte Carlo sampling of abstractions and of the ground motion hazard curve to define failed areas and conditions for each realization
- The mean or expected dose will be determined as a weighted average of the doses from individual realizations with a single seismic occurrence

Backup

Convolution Versus Direct Sampling

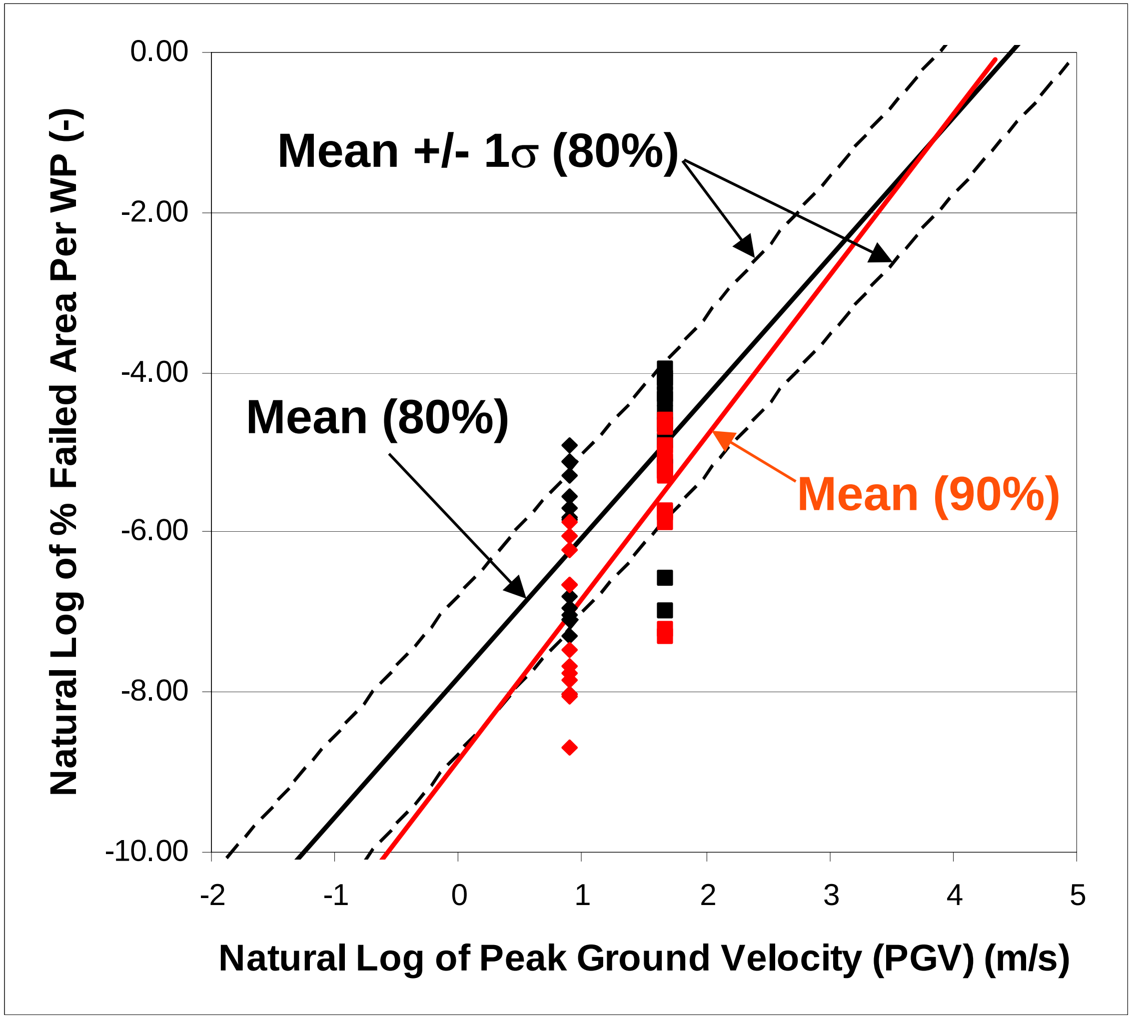
- Probabilistic risk assessments often convolve a fragility curve with the seismic hazard to generate the annual risk of failure for components and for the plant
  - Convolution necessary to represent complex reactor event sequences and the associated fail/no-fail states of components and of the plant in fault tree analyses
- TSPA uses a Monte Carlo approach that samples distributions to define future repository conditions
  - Event initiator for postclosure repository (i.e., a ground motion occurs) is similar to probabilistic risk assessment (PRA) for NPP and plant systems
  - The engineered barriers at Yucca Mountain Project do not have complex system states that require detailed fault tree event models
  - Further, component and system response for failed area are continuous functions

Convolution Versus Direct Sampling

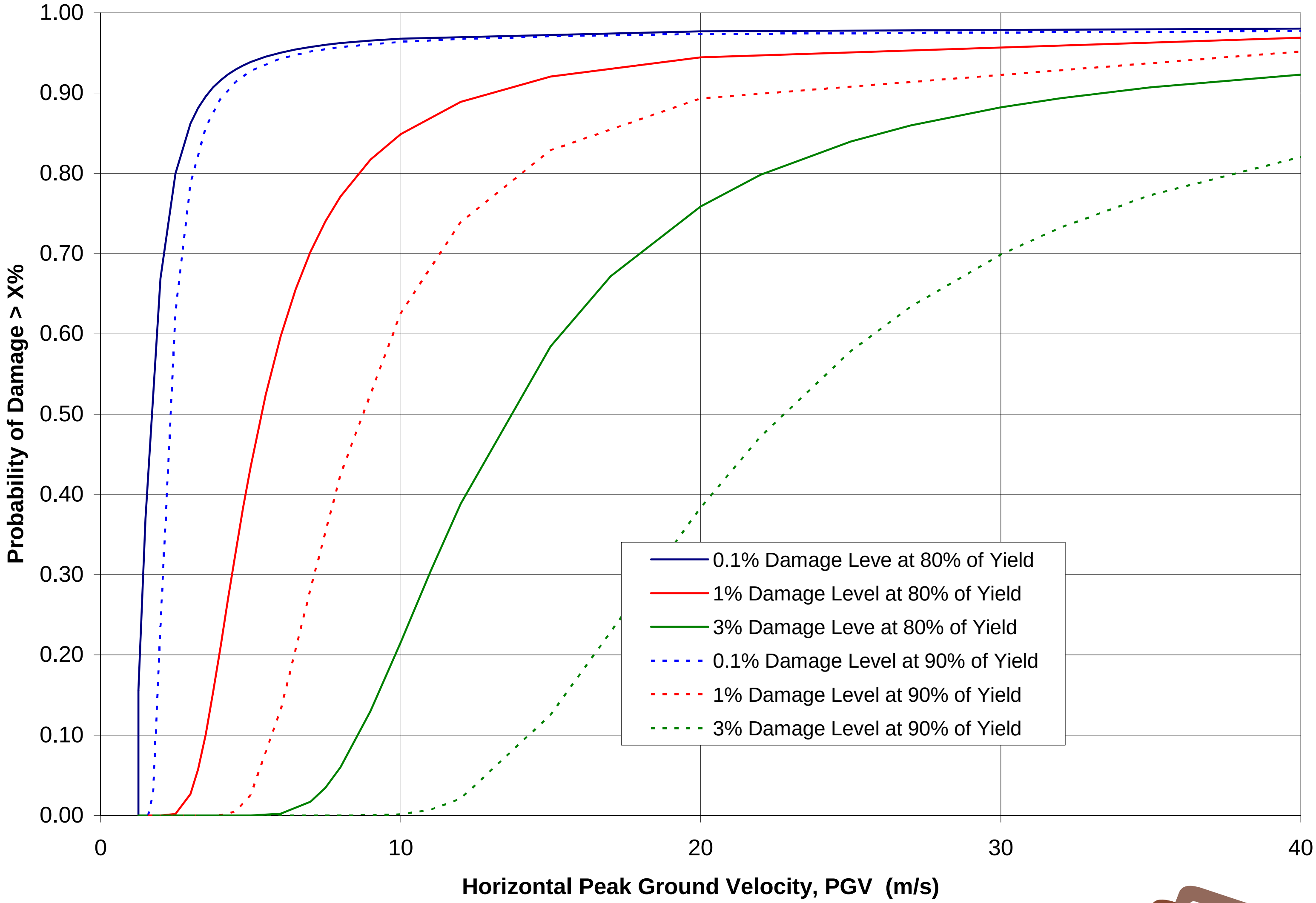
(Continued)

- **Alternative to convolution is direct sampling of PGV hazard curve and failed area abstraction**
  - Direct sampling more transparent with Monte Carlo process
    - Separately answers the questions: “What level?”, “How big?”, and “What is the damage?”
    - Easier to explain and document
  - Direct sampling maintains capability to evaluate sensitivity of dose to individual parameters
    - Integration process for convolution masks impact of individual parameters on dose to affected population
    - Direct sampling maintains functional relationships
- **Procedure for TSPA will be based on direct sampling**

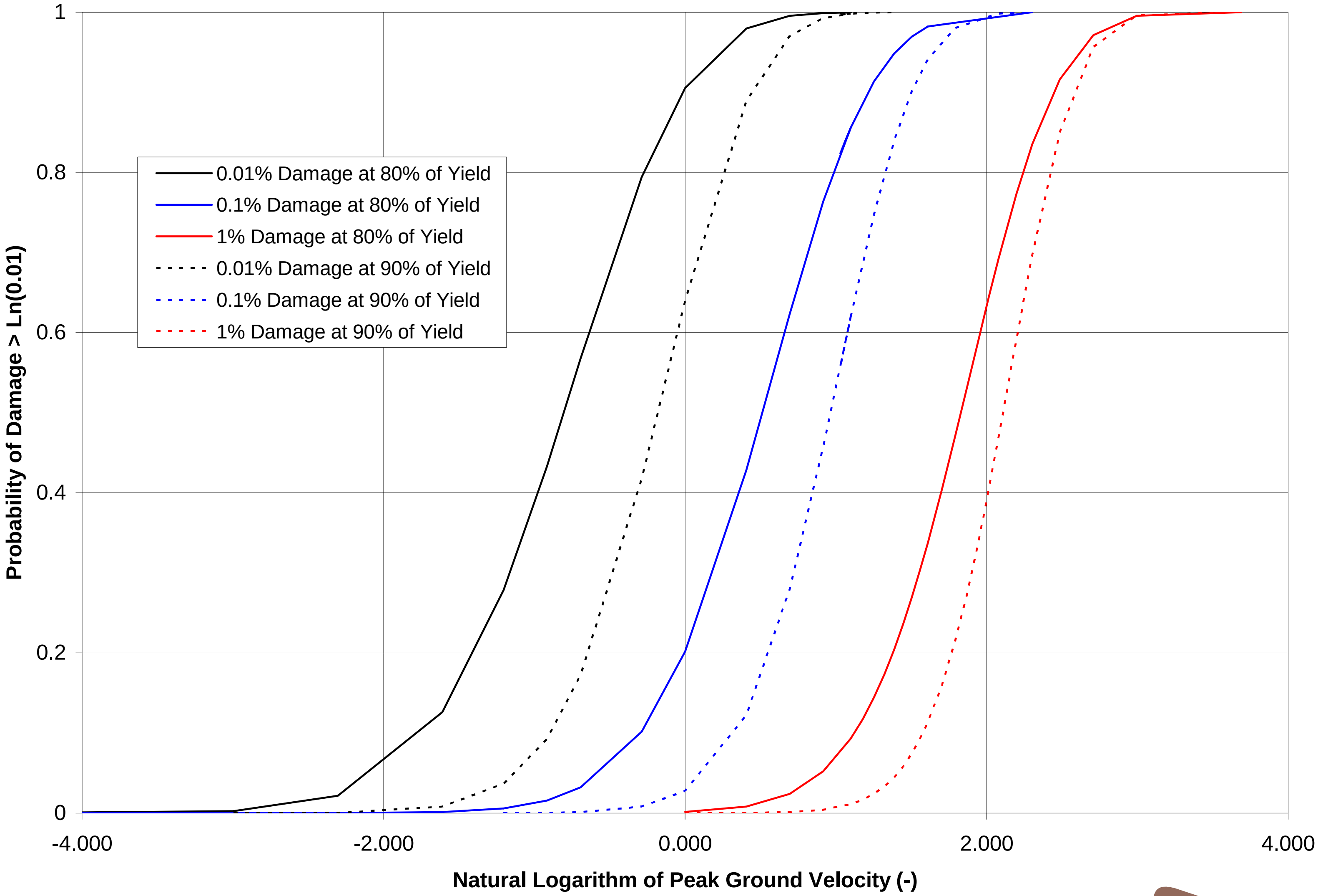
Abstraction With A Power Law Fit to Mean And Standard Deviation



Fragility Curves – Linear Fit

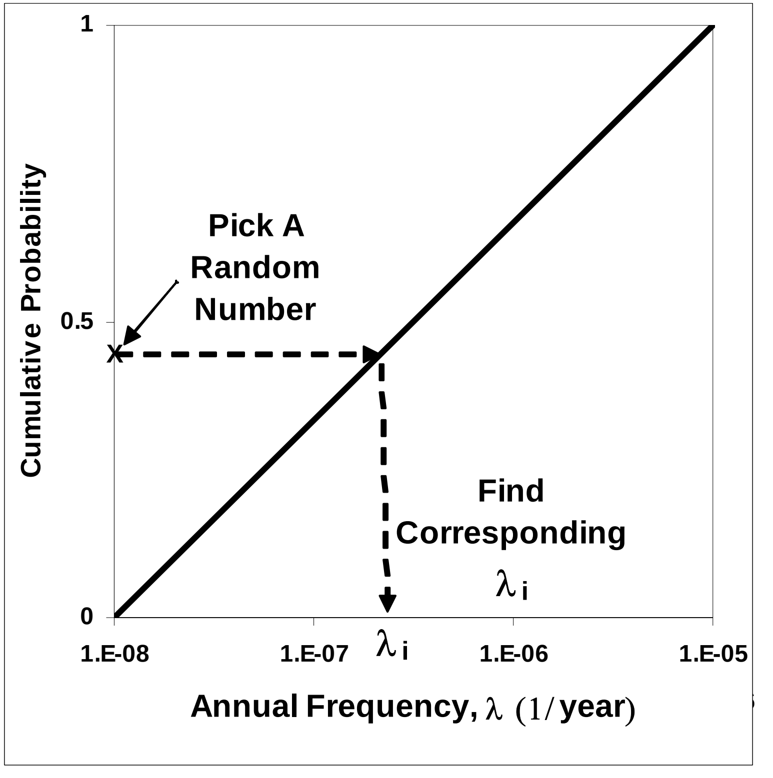


Fragility Curves – Power Law Fit



Procedure for Step 1

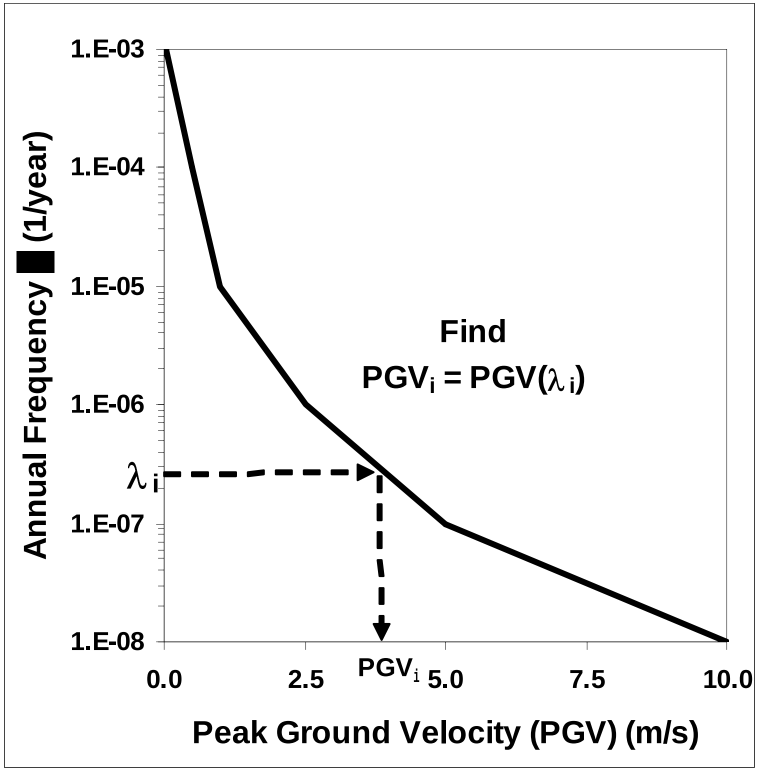
- **Step 1a: How likely is the ground motion?**
  - **Sample for the annual exceedance frequency, λ_i, over a range with structural damage**



Procedure for Step 1

(Continued)

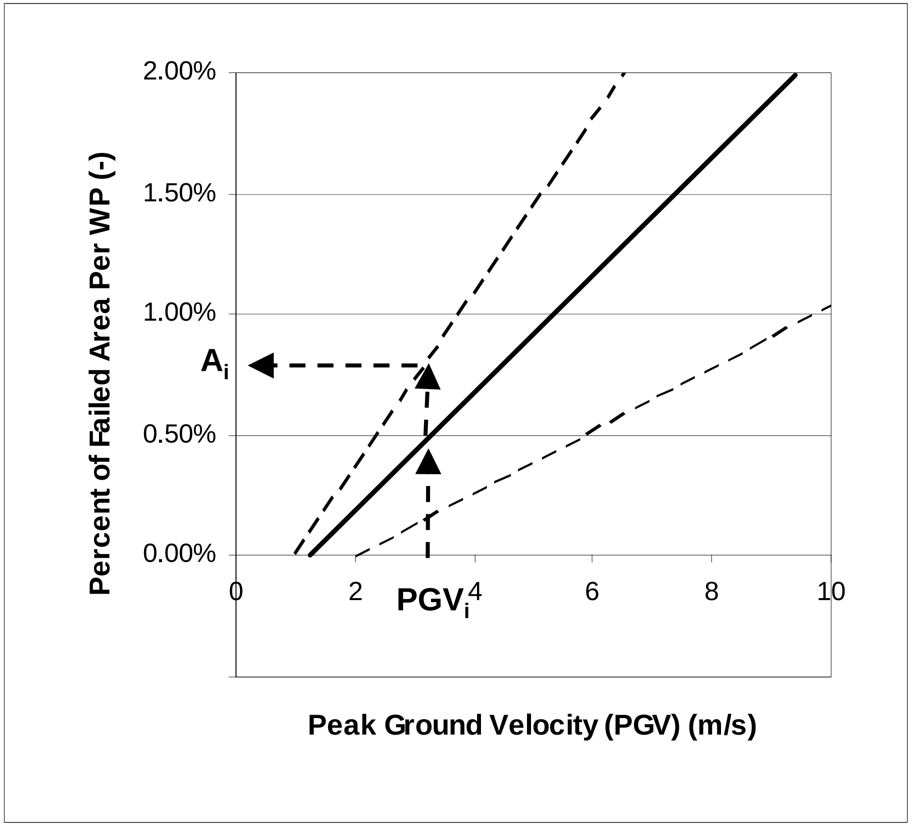
- **Step 1b: How "big" is the ground motion?**
  - Ground motion hazard curve defines the value of PGV as a function of the annual exceedance frequency, λ
  - Hazard curve based on mean horizontal PGV
  - Determine the value PGV_i corresponding to λ_i



Procedure for Step 1

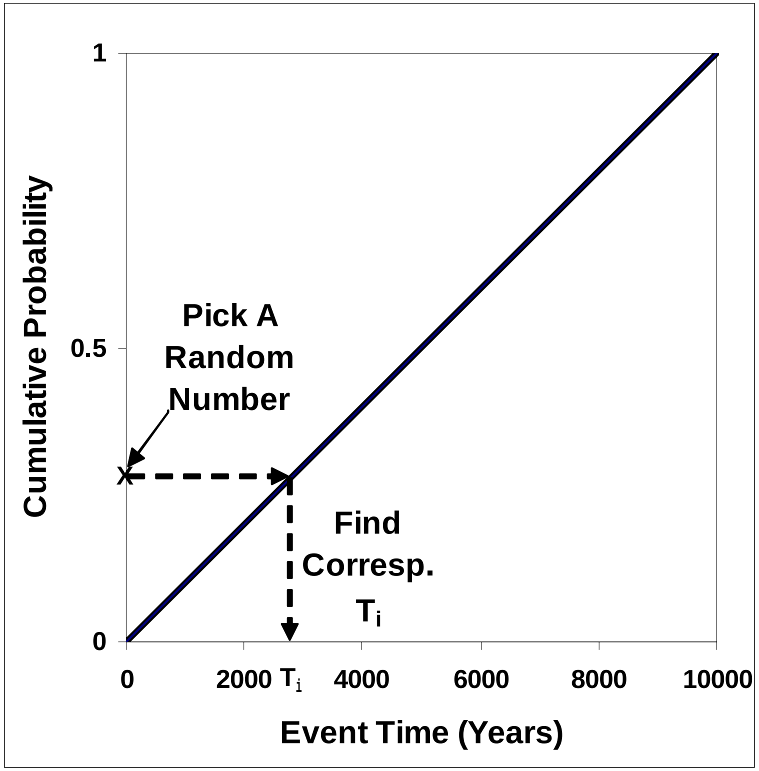
(Continued)

- **Step 1c: How much damage does this ground motion cause to the drip shield and waste package?**
  - Determine the failed area, A_i, corresponding to PGV_i
  - First calculate the mean value of failed area at PGV_i
  - Then modify the mean value based on a random sampling of the variance at PGV_i to determine the final value of the % damaged area.



Procedure for Step 1
(Continued)

- **Step 1d: When does the ground motion occur in this realization?**
  - **Sample a uniform distribution between 0 years and T years, where T is the duration of the calculation.**



Procedure for Step 1

(Continued)

- **Step 1e: Determine the dose time history, $D_i(t/\lambda_i, T_i)$, for the i[th] realization**
  - **Perform a TSPA analysis for 10,000 years, with a ground motion hazard of exceedance frequency λ_i occurring at time T_i**
  - **Response of the drip shield and waste package to this ground motion level is determined as illustrated in Steps 1b and 1c**
  - **The dose time history is determined by a full TSPA calculation for release from the EBS and transport through the unsaturated and saturated zones**