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

Presented by:
Michael B. Gross
Bechtel SAIC Company, LLC / Beckman & Associates

February 24, 2003
Las Vegas, Nevada
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

How likely?
How big?

Ground Motion and Fault Displacement

Rockfall Analysis

Drip Shield Structural Response

Waste Package Structural Response

How much damage?

Impact on performance?

Failure Criterion

Failed Area Abstraction

LA Seismic Scenario
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

- 10^{-7} per year
- 80% of Yield
- 10^{-6} per year
- 90% of Yield

Percent of Failed Area Per WP (%) vs. Peak Ground Velocity (PGV) (m/s)
Abstraction with a Linear Fit to Mean and Standard Deviation

A graph is shown with the x-axis labeled "Peak Ground Velocity (PGV) (m/s)" and the y-axis labeled "Percent of Failed Area Per WP (\%)". The graph includes multiple lines and markers indicating mean and standard deviation at 80% and 90% confidence levels.
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 $5 \times 10^{-4}$ 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, $\lambda_i$:

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

with $\lambda_{\text{MIN}} < \lambda_i < \lambda_{\text{MAX}}$, $T = 10,000$ years, $\lambda_{\text{MIN}} = 10^{-08}$, and $\lambda_{\text{MAX}} = 10^{-05}$.
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

![Graph showing natural log of peak ground velocity (PGV) vs. natural log of % failed area per WP.](image)
Fragility Curves – Linear Fit

Horizontal Peak Ground Velocity, PGV (m/s)

Probability of Damage > X%
Fragility Curves – Power Law Fit

- 0.01% Damage at 80% of Yield
- 0.1% Damage at 80% of Yield
- 1% Damage at 80% of Yield
- 0.01% Damage at 90% of Yield
- 0.1% Damage at 90% of Yield
- 1% Damage at 90% of Yield

Natural Logarithm of Peak Ground Velocity (-)

Probability of Damage > Ln(0.01)
Procedure for Step 1

• Step 1a: How likely is the ground motion?
  - Sample for the annual exceedance frequency, $\lambda_i$, 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, $\lambda$
  - Hazard curve based on mean horizontal PGV
  - Determine the value $\text{PGV}_i$ corresponding to $\lambda_i$

![Graph showing annual frequency vs. peak ground velocity](image)
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 $\lambda_i$ 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