Summary of the Total System Performance Assessment for Yucca Mountain License Application

Presentation to PSAM 2010

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Proposed Repository at YM
Yucca Mountain License Application

DOE/RW-0573 Rev 0 June 2008

- General Information (GI)
  - General Description
  - Proposed Schedules for Construction, Receipt and Emplacement of Waste
  - Physical Protection Plan
  - Material Control and Accounting Program
  - Site Characterization

- Safety Analysis Report (SAR)
  - Repository Safety Before Permanent Closure
  - Repository Safety After Permanent Closure
  - Research and Development Program to Resolve Safety Questions
  - Performance Confirmation Program
  - Management Systems

- Available from the NRC (http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html#appdocuments)
TSPA-LA Documentation

SNL 2008, Total System Performance Assessment Model/Analysis for the License Application, MDL-WIS-PA-000005 REV 00 AD 01

Four volumes
4272 pages

11,843 pages of supporting technical documents that provide direct input

<table>
<thead>
<tr>
<th></th>
<th>Total Pages</th>
<th>Number of Tables</th>
<th>Number of Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume I</td>
<td>1111</td>
<td>183</td>
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<td>Volume II</td>
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<td>41</td>
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<td>Addendum</td>
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<td>TOTALS</td>
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Core Regulatory Requirements for YM Repository

- Maximum value of mean dose to the reasonably maximally exposed individual (RMEI) over time interval \([0, 10^4 \text{ yr}]\) less than 15 mrem/yr
- Maximum value of mean dose to the RMEI over time interval \([10^4, 10^6 \text{ yr}]\) less than 100 mrem/yr
- Take uncertainties and gaps in knowledge into account
- Requirements lead to Performance Assessment that
  - Computes measures of performance (e.g. mean dose)
  - Accounts for and quantifies uncertainty in measures of performance
Four Questions Underlying TSPA

1. What events and processes can take place at the facility?

2. How likely are these events or processes?

3. What are the consequences of these events or processes?
   • Kaplan and Garrick (1979) “risk triplet”

4. How certain are the answers to the first 3 questions?
Nominal Scenario Class
- Nominal Modeling Case
  (included with Seismic Ground Motion for 1,000,000-yr analyses)

Early Failure Scenario Class
- Waste Package Modeling Case
- Drip Shield Modeling Case

Igneous Scenario Class
- Intrusion Modeling Case
- Eruption Modeling Case

Seismic Scenario Class
- Ground Motion Modeling Case
- Fault Displacement Modeling Case
### Mathematical Entities Underlying the YM TSPA

<table>
<thead>
<tr>
<th>EN1: Probability space characterizing what can happen in the future</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Answers “What can happen” and “How likely”</td>
</tr>
<tr>
<td>- Provides formal characterization of aleatory uncertainty</td>
</tr>
<tr>
<td><em>E.G. Assumption that igneous event occurrence is a Poisson process</em></td>
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</table>

<table>
<thead>
<tr>
<th>EN2: Mathematical models for predicting consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Answers “What are the consequences”</td>
</tr>
<tr>
<td><em>E.G. Flow and Transport Models</em></td>
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</table>

<table>
<thead>
<tr>
<th>EN3: Probability space characterizing uncertainty in TSPA inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Basis for answering “How certain are the answers to the other three questions”</td>
</tr>
<tr>
<td>- Provides formal characterization of epistemic uncertainty</td>
</tr>
<tr>
<td><em>E.G. Distribution assigned to rate for a Poisson process</em></td>
</tr>
</tbody>
</table>
Conceptual Calculation

• Regulation requests “mean” values of dose to a reasonably maximally exposed individual
• Uncertainty in future events $a$ and in model inputs $e$
• Calculation proceeds in three stages:

\[
\overline{D}(\tau) = E_E \left[ E_A \left( D(\tau \mid a, e) \right) \right] \\
= \int_E \int_A D(\tau \mid a, e) d_A(a \mid e) dA \left[ d_E(e) dE \right] \\
\sum_{MC} \left[ \int_A D_{MC}(\tau \mid a, e) d_A(a \mid e) dA \right] d_E(e) dE \\
= \int_E \sum_{MC} \int_A D_{MC}(\tau \mid a, e) d_A(a \mid e) dA \left[ d_E(e) dE \right]
\]
Example: Calculation of Expected Dose for Seismic Ground Motion Modeling Case

start

Sample Epistemic Uncertainty, \( e \), \( N_{LHS} = 300 \)
\( e = e \text{(parameter uncertainties)} \)

Select Aleatory Uncertainty, \( a \)
\( a = a \text{(event times, damage areas)} \)

Calculate Expectation over Aleatory Uncertainty

- Annual Dose Integrated over Damage Area, (6 event times)
- Interpolated Seismic Futures, (multiple event times)

- Annual Dose for Possible Seismic Futures, (6 event times, 5 damage areas)
- Expected annual dose curve, given \( e \)

300 Expected Annual Dose Curves

Summary metrics of uncertainty in expected annual dose curves

SAR Figure 2.4-8
Three questions:

1. What determines the shape of these curves?

2. What determines the magnitude of total mean dose?

3. What determines the uncertainty in total expected dose?
Modeling Cases Contributing to Total Mean Annual Dose

In order of importance:

Igneous Intrusion and Seismic Ground Motion
(includes effects of nominal processes)

Seismic Fault Displacement

Early Failure, Volcanic Eruption
Uncertainty in Total Expected Dose

**SCCTHRP** – Stress threshold for SCC initiation

**IGRATE** – Frequency of igneous events

**WDGCA22** – Temperature dependence in A22 corrosion rate
Features and Processes Contributing to Repository Performance

- Precipitation $\rightarrow$ infiltration $\rightarrow$ seepage into repository drifts

<table>
<thead>
<tr>
<th>Climate</th>
<th>Precipitation (mm/yr)</th>
<th>Infiltration (mm/yr)</th>
<th>Seepage (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present-day¹</td>
<td>150</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>Post-10k yr²</td>
<td>-</td>
<td>22</td>
<td>8.6</td>
</tr>
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</table>

¹ Nominal scenario, 10th percentile infiltration scenario, spatial averages, seepage converted from m³/WP/yr
² Seismic + nominal, 10th percentile infiltration scenario, spatial averages, seepage converted from m³/WP/yr

- Low likelihood of advection through WP outer barrier
  - WP outer barrier failure generally consists of stress corrosion cracking
  - Low likelihood of igneous events, rupture, general corrosion failures
  - Limited water available interior to WPs
- Iron oxyhydroxides from degraded WP materials sorb actinides, buffer water chemistry away from acidic conditions
- Travel times preclude transport of relatively short-lived radionuclides (e.g. $^{240}$Pu), reduce concentrations of long-lived radionuclides
Conclusions

• The TSPA-LA supports the DOE’s License Application to the NRC for authorization to construct a repository at Yucca Mountain.

• The TSPA provides probabilistic estimates of long-term performance, consistent with supporting technical information and taking into account uncertainties in the future occurrence of disruptive events and in knowledge of the repository system.

• All performance measures are well below regulatory limits.
TSPA Model Architecture

External Process Models

Run with GoldSim

Final Performance Measure

Output Parameters

Legend

MDL-WIS-PA-000005 REV 00 AD 01, Figure 3-2[a]
Radionuclides Important to Mean Dose

E indicates “early” and refers to the time period before ~ 200,000 yr. L indicates “late” and refers to the time period after ~ 200,000 yr.
Radionuclide Inventory

Early (in order of total activity):

$^{241}\text{Am}$, $^{239}\text{Pu}$, $^{240}\text{Pu}$

Late (in order of total activity):

$^{99}\text{Tc}$, $^{237}\text{Np}$

Note that activity in inventory does not necessarily correlate with importance to mean dose.
At 1M yr, total mean activity released from SZ is about 5% of total inventory.

Short-lived species (e.g., Sr-90, Cs-137) are fully contained.

Maximum releases of intermediate-lived species (e.g., Pu-239) are a small fraction of the total activity and occur before 1,000,000 yr.

Mean Activity Released from the Saturated Zone
Seismic Ground Motion Modeling Case
Representative Subset of all Radionuclides
MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.3-26[a,a]
Construction of Total Expected Dose

\[ \text{Volcanic Eruption} + \text{Igneous Intrusion} + \text{Seismic GM (+ Nominal)} \equiv \text{Total} \]
Composition of Seismic Ground Motion Dose

Stylized decomposition

- From seismic damage to CDSP WP (diffusion)
- From SCC failure of CSNF WP (diffusion)
- From general corrosion failure of both WPs (advection)

Expected Dose from Nominal processes

Expected Dose from Seismic and Nominal processes

Included
Computation of Expected Dose

Eruptive dose: 40 realizations of aleatory uncertainty conditional on a single eruption of 1 WP at time zero

Expected eruptive dose; 300 realizations, each showing expected dose from a single sampling of epistemic uncertainty with events at all times

Eruptive dose averaged over aleatory uncertainty associated with a single eruption of 1 WP, eruptions at multiple times

Summary curves showing overall mean dose from eruption