EPRI’s Yucca Mountain TSPA, ‘Phase 5’

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Outline

- Purpose of EPRI TSPAs
- Scope of ‘Phase 5’ report [November 2000]
- Model Components and Assumptions
- Base Case Results
- Identification of ‘Barriers’
- DOE and EPRI conservatisms/optimisms
- Performance confirmation
Purpose of EPRI Yucca Mountain TSPAs

- Independent assessment of technical issues
  - Inform smart business decisions through third-party expert scientific insight
  - Provide input to utilities on regulatory and legislative issues
- Provide insight to outside review bodies such as TRB, ACNW
EPRI TSPA Scope - Scenarios Considered and not Considered

- Considered: “Normal release scenario”
  - Container degradation, waste dissolution, contaminant transport, biosphere

- Not considered:
  - Colloid-aided transport
  - Volcanism
  - Human intrusion
EPRI TSPA Model Components

- IMARC: Integrated Multiple Assumptions and Release Code
  - *Mostly* logic tree format (i.e., not Monte Carlo)
  - Container failure times are Monte Carlo simulations
    - 54 branches total
- IMARC ‘shell’
  - Time steps
  - Most ‘global’ inputs
  - Liberal use of lookup tables
- Submodel Links
  - Source term
  - UZ/SZ transport
Net Infiltration
[Stuart Childs, Kennedy/Jenks]

- Based on three climate states [Austin Long, U. AZ]
- Infiltration assumed uniform over the entire repository footprint
  - Infiltration rates [mm/yr]:

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse</td>
<td>1.9</td>
<td>11.3</td>
<td>19.2</td>
</tr>
<tr>
<td>Interglacial</td>
<td>1.11</td>
<td>7.2</td>
<td>9.6</td>
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<tr>
<td>Full glacial maximum</td>
<td>6.8</td>
<td>19.6</td>
<td>35.4</td>
</tr>
</tbody>
</table>
Focused Flow Factor
[Ben Ross, Disposal Safety]

• Based on March 2000 AMR: “Abstraction of Drift Seepage”

• Zero focusing: percolation rate = net infiltration rate repository-wide

• Focusing factor of 22: 4.5% of the repository gets 22 times the area-average infiltration rate
Drip Shield/Waste Package Combined Failure Distribution

[Dave Shoesmith (UWO), John Massari (CNS)]

- Drip Shield degradation
  - General corrosion, HIC
  - 14 failed at emplacement

- Container degradation
  - Aqueous corrosion at T<120C
  - Localized corrosion above 100C
  - SCC only on outer lid weld

IMARC Phase 5 review.9
Fuel Rod Cladding Failure Distribution
[Shoesmith and Massari]

- 2.44% initial cladding failures
- General corrosion (not specifically driven by F⁻)
- Localized corrosion considered unlikely

IMARC Phase 5 review.10
Source Term General Approach
[Wei Zhou; Mike Stenhouse, Monitor Scientific]

\[\text{Dripping Water} \quad \downarrow \quad \text{Waste} \quad \uparrow \quad \text{Corrosion Product} \quad \downarrow \quad \text{Canister} \]

(1) General (2) Localized

\[\text{Invert} \quad \downarrow \quad \text{Near-Field Rock Matrix} \quad \text{Near-Field Rock Fracture} \]

\[\uparrow : \text{diffusion} \]
\[\downarrow : \text{advection} \]

- Compartments are assumed well connected
- Advection directly into local flowing fracture
- 100% of waste form in failed cladding assumed exposed
UZ/SZ Flow and Transport Model

[Frank Schwartz, OSU; Ed Sudicky, U. Waterloo]

• UZ:
  – 1-D, dual K continuum
  – Simplified vertical columns

• SZ:
  – 3-D, dual porosity, dual permeability
  – SZ thickness: 200 meters
  – Vertical dispersion significant
Biosphere Dose Conversion Factors
Conceptual Model
[Smith et al., QuantiSci, Ltd.]

<table>
<thead>
<tr>
<th>SOURCE ZONE</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
<th>1.9</th>
<th>2.0</th>
<th>2.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Compartment model (AMBER)
  - Thin arrows: nuclide migration processes
  - Thick arrows: exposure pathways

IMARC Phase 5 review.13
ANNUAL DOSE VS. TIME
Dose from Highest Concentration at AE

Base Case: All Exposure Pathways

Full 54 Branch Case
3 Infiltrations
3 Retardations
2 Focused Flow Factors
3 Solubility / Alt. Rates
Conservative Individual
All Exposure Pathways

Dose Rate (mrem/yr)

Time (years)
ANNUAL DOSE VS. TIME
Dose from Highest Concentration at AE

- Total
- $^{79}\text{Se}$
- $^{99}\text{Tc}$
- $^{129}\text{I}$
- $^{237}\text{Np}$
- $^{233}\text{U}$
- $^{229}\text{Th}$
- $^{231}\text{Pa} (+^{227}\text{Ac})$

Base Case: Drinking Water Pathway Only

Full 54 Branch Case
3 Infiltrations
3 Retardations
2 Focused Flow Factors
3 Solubility / Alt. Rates
Conservative Individual
Water Only
Barrier Importance Analyses

• Purpose
  – Assign “value” to various components of Yucca Mountain System
    • Are all eggs in one (or two) basket(s)?
  – Provide insight on important Features, Events, and Processes (FEPs)
  – EPRI uses a “Hazard Index” approach
    • Variant of ‘full neutralization’
“Hazard Index” Approach to Identifying Potential Barriers

- Begin by eliminating ALL barriers
- Add potential barriers one-by-one
- Amount ‘Hazard Index’ (dose rate) is reduced indicates potential barrier importance
Starting Point - Highest "Imaginable" Dose

- All 70,000 MTU of spent fuel dissolved in 0.6 m³ water
- One individual drinks it in one year
- Starting total Hazard Index, $H_{\text{tot}} \approx 10^{17}$ [mrem/yr]
- Why start so unrealistically?
  - *All* FEPs can be evaluated quantitatively
    - Basic engineering decisions (e.g. repository layout)
13 FEPs Added One-by-One

- 4% of Repository Wet
- 3,000 year Alteration Time
- Moderate Solubility
- Cladding Fails Over Time
- Containers Fail Over Time
- Drip Shield Fails Over Time
- Dilution in the UZ
- EBS Sorption
- Accessible Environment (AE) at 5 km
- UZ/SZ Moderate Retardation
- AE in Front of Alluvium
- AE at 20 km
- Dose from All Pathways
TOTAL HAZARD REDUCTION

Annual Dose from Water Only

Hazard index curve for all radionuclides

- Hazard Index
- 4% of Repository Wet
- 3,000 yr Alteration Time
- Moderate Solubility
- Cladding Fails over Time
- Containers Fail over Time
- Drip Shields Fail over Time
- Dilution in the UZ
- EBS Sorption
- AE at 5 km
- UZ/SZ Moderate Retardation
- AE in front of Alluvium
- AE at 20 km
- Dose from All Pathways

Dose Rate (mrem/yr)

Time (years)
# Hazard Reduction Factors

<table>
<thead>
<tr>
<th>Hazard Reduction</th>
<th>Time of</th>
<th>Barrier</th>
<th>&quot;Engineered&quot; or &quot;Natural&quot;?</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-1}$</td>
<td>2000</td>
<td>4% of repository wet</td>
<td>both</td>
</tr>
<tr>
<td>$10^3$</td>
<td>3000</td>
<td>3,000 year alteration time</td>
<td>both</td>
</tr>
<tr>
<td>$10^2$</td>
<td>200,000</td>
<td>Moderate solubility</td>
<td>natural</td>
</tr>
<tr>
<td>$10^{0.1}$</td>
<td>200,000</td>
<td>Cladding fails over time</td>
<td>engineered</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>600,000</td>
<td>Containers fail over time</td>
<td>engineered</td>
</tr>
<tr>
<td>$10^{-0}$</td>
<td>700,000</td>
<td>Drip shields fail over time</td>
<td>engineered</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>700,000</td>
<td>Dilution in the UZ</td>
<td>both</td>
</tr>
<tr>
<td>$10^3$</td>
<td>700,000</td>
<td>EBS sorption</td>
<td>mostly engineered</td>
</tr>
<tr>
<td>$10^2$</td>
<td>500,000</td>
<td>AE at 5 km</td>
<td>natural</td>
</tr>
<tr>
<td>$10^{0.5}$</td>
<td>600,000</td>
<td>UZ/SZ moderate retardation</td>
<td>natural</td>
</tr>
<tr>
<td>$10^{-0.5}$</td>
<td>600,000</td>
<td>AE in front of alluvium</td>
<td>natural</td>
</tr>
<tr>
<td>$10^{-0}$</td>
<td>600,000</td>
<td>AE at 20 km</td>
<td>natural</td>
</tr>
<tr>
<td>$10^{-18}$</td>
<td></td>
<td>Total Hazard Reduction</td>
<td></td>
</tr>
<tr>
<td>$10^{5.14}$</td>
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<td>Hazard reduction due to “engineered” features</td>
<td></td>
</tr>
<tr>
<td>$10^{5.14}$</td>
<td></td>
<td>Hazard reduction due to “natural” features</td>
<td></td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td></td>
<td>Hazard “reduction” (i.e., increase) due to all pathways</td>
<td></td>
</tr>
</tbody>
</table>

IMARC Phase 5 review.21
EPRI Analysis of Conservativisms and Optimisms in the DOE Models

- Conservativisms
  - Source term diffusion model
  - Volcanism consequences
  - Unsaturated Zone transport (FEHM particle tracker needs correcting)
  - Saturated Zone transport
- Optimisms
  - 70% heat removal by ventilation (?)
  - Choice between temperature and RH conservatism/optimism
- EPRI satisfied overall DOE assessment is conservative
Concept of a SZ "Flowing Interval"

- "Flowing Interval" spacing: ~20m
- Typical fracture spacing within the flowing interval: <1m
Sensitivity of Np-237 Drinking Water Dose Rate to SZ Sorption

Matrix Retardation Sensitivity
- Low
- Moderate
- High
- Integrated

Full 54 Branch Case
- 3 Infiltrations
- 3 Retardations
- 2 Focused Flow Factors
- 3 Solubility / Alt. Rates
- Conservative Individual
- Water Only

IMARC Phase 5 review.24
Impact of Eliminating Alluvium

- Best Estimate
- Alluvium Replaced

Dose Rate (mrem/yr)

Time (years)

IMARC Phase 5 review.25
Is it Necessary to Assess all Uncertainties?

• No
  – Many parameters we treat as fixed are truly unimportant to performance
    • Therefore, not worth the effort
  – Other, more important, fixed parameters could, during SR analyses, be investigated using expert judgment (non-Q OK)
    • ‘Conservative’ versus ‘best estimate’ to provide some insight on potential degree of conservatism

• EPRI encourages current M&O effort led by Coppersmith
Is TSPA an Appropriate Decision-Making Tool?

• Yes
  – Comprehensive and quantitative measure of the degree of public health protection
  – TSPA now based on many years of experience
  – Multiple practitioners arrive at consistent results
  – Most TSPA submodels are based on solid data
    • Years of R&D data incorporated directly or indirectly
  – Multiple lines of evidence built-in to TSPA
    • Many submodels already employ natural analog information
  – Performance confirmation will further bolster TSPA
Role of Performance Confirmation (and other Long-Term R&D) Activities

- Performance confirmation (and other long-term R&D) activity definition important for SR- not just for licensing
  - Helps provide clarity when managing many important uncertainties
  - Performance confirmation is an opportunity to improve understanding and bolster the safety case
  - SR decision makers can use long-term R&D plans, along with current knowledge
EPRI Two-Year Program to Clarify the Role of Performance Confirmation in SR/LA

- November 2000: 'Interim report' issued
  - Review of performance confirmation issues
    - What constitutes an appropriate performance confirmation activity
      - Has to be able to truly 'confirm' long-term performance
      - Has to have clearly defined goals and stopping criteria
    - Review of current DOE performance confirmation plan (May 2000)
      - Generally sound, but needs improvement
      - Other long-term R&D can provide bases for model improvements
  - Relaxing conservatisms could lead to a more efficient repository design
EPRI Performance Confirmation Plans for 2001

- External review of and recommendations for appropriate performance confirmation and other important long-term R&D activities (to help establish consensus).
- 'Bottom out' details of one or two performance confirmation activities
  - More detailed test plan
  - Supporting models to show how ~50-year data can be extrapolated to 10,000+ years
  - Definition of 'error bar(s)'
  - Will choose container degradation
  - May also investigate larger-scale thermal testing
- Planned completion is mid 2001
Conclusions

• DOE’s TSPA is conservative
• Repository performance is bolstered by a diverse range of multiple barriers
• Efforts to quantify uncertainties should be risk-informed
• TSPA is an appropriate tool for repository decision-making
• Performance confirmation should play an important role in repository decision-making