Implementation of Repository Safety Strategy in TSPA-SR

Presentation to:
Nuclear Waste Technical Review Board (NWTRB)

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Outline

• TSPA - an Element of the Repository Safety Strategy
• Objectives and Scope of TSPA-SR
• Changes from TSPA-VA to TSPA-SR to Address
  – regulatory requirements
  – comments received on TSPA-VA
    » traceability
    » transparency
  – enhanced analyses and models
• TSPA-SR Contents
Elements of DOE’s Repository Safety Strategy - Steps to Development of the Safety Case

- Total system performance assessment
  - repository system concept
  - performance assessment analyses
- Design margin and defense-in-depth
  - sensitivity and importance analyses
- Explicit assessment of disruptive processes and events
- Insights from natural analogs
- Performance confirmation plan
  - long-term testing to confirm models used in analyses

[Analysis of first 3 bullets documented in TSPA-SR]
Objectives of TSPA-SR

• Provide part of technical basis for DOE decisions regarding site recommendation
• Evaluate system compliance with applicable post-closure performance requirements
• Evaluate significance of various barriers and barrier components to system performance
Scope of TSPA-SR

• Develop and apply TSPA methodology consistent with regulatory requirements
• Use reasonably representative models based on defensible process-level models and abstractions
• Calculate expected dose to average member of critical group
• Evaluate sensitivity of system performance to uncertainties in process and abstraction models
• Document assessments in a manner suitable to assure transparency and traceability
Factors Driving Changes from TSPA-VA to TSPA-SR

• Repository Safety Strategy
• Regulatory requirements
  – Site specific criteria
  – IRSR acceptance criteria
• External and internal reviews of TSPA-VA
  – NRC; NWTRB; DOE; USGS; ACNW; Peer Review Panel
• New/revised site and design information
  – analyses; models; data
• Design changes
• Improved QA processes and procedures
(a) The geologic repository shall include multiple barriers, consisting of both natural barriers and an engineered barrier system.

(b) The engineered barrier system shall be designed so that, working in combination with the natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE at any time during the first 10,000 years after permanent closure . . .

(c) The ability of the geologic repository to limit radiological exposures to those specified in paragraph (b) of this section shall be demonstrated through a performance assessment that meets the requirements specified at Sec. 63.114, uses the reference biosphere and critical group specified at Sec. 63.115, and excludes the effects of human intrusion.
Performance assessment means a probabilistic analysis that:

(1) Identifies the features, events and processes that might affect the performance of the geologic repository; and

(2) Examines the effects of such features, events, and processes on the performance of the geologic repository; and

(3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the geologic repository.
## Comparison of VA and SR TSPA Requirements

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<td>Average member of critical group / Reasonably maximally exposed individual</td>
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<td>Location</td>
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<td>20 km (or 5, 18, or 30 km)</td>
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<td>Time</td>
<td>Peak dose to 1,000,000 years</td>
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Comparison of VA and SR TSPA Requirements

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Performance Assessment Method

1. Develop and Screen Scenarios From FEPs
   - Scenario 1: Select
   - Scenario 2: Select
   - Scenario 3: Reject

2. Develop Process and Abstraction Models and Alternatives
   - Integrated Site
   - UZ Flow and Transport
   - Near Field Environment
   - EBS Degradation and Transport
   - WP Degradation
   - WF Degradation
   - SZ Flow and Transport
   - Biosphere
   - Tectonics

3. Evaluate Parameter Ranges and Uncertainty
   - Climate Change
   - Rock Porosity
   - pH in Drift

4. Perform Calculations and Sensitivity/Uncertainty Analyses

5. Document Results
TSPA-SR Approach
Part 63.113(c)
Stylized Human Intrusion
Excluded

Regulatory Framework
• 10 CFR 63.114 and .115
• NRC IRSRs
• 10 CFR 960
• 40 CFR 197.20 and .21

Component Models and Model Abstractions

Changes in Regulatory Requirements - Development and Screening of Scenarios

• Identify and classify features, events and processes (FEPs) (10 CFR 63.2)

Screen FEPs
– probability criterion [10 CFR 63.114 (d) and 40 CFR 197.40]
– consequence criterion [10 CFR 63.114 (e) and (f)]

Construct scenarios from retained FEPs

Screen scenarios
– probability criterion
– consequence criterion

Implement retained scenarios in TSPA

Probabilistic Total System Model Runs
Results: multiple scenario-conditional 20-km dose histories

Deterministic Total System Model Runs
Results: single scenario-conditional 20-km dose histories

Probabilistic Sc consulting Analyses
Results: Significance of uncertain parameters and models

Combined Scenario
Results: 20 km expected dose history

Probabilistic Sensitivity Analysis
Results: Significance of uncertain parameters and models

Dose History Screening
Results: Significance of uncertain parameters and models

M&O Graphics Presentations/NWTRB/YMAndrews-091499.ppt
TSPA-SR Approach
10 CFR Part 63.113(d)
Stylized Human Intrusion

Regulatory Framework
- 10 CFR 63.114 and .115
- NRC IRSRs
- 40 CFR 197.25 and .26

Nominal Scenario

Stylized Human Intrusion Activity Scenario

Component Models and Model Abstractions

10,000-Year Total System Model Simulations

Probabilistic Total System Model Runs
Results: single scenario-conditioned 20-km dose histories

Sensitivity Analyses
Results: Important Parameters

- Evaluation of Human Intrusion Effects

Legend
- Model
- Analyses
TSPA-FEIS Approach
40 CFR Part 197.30

Regulatory Framework
- 40 CFR 197.30

FEPs Screening

Nominal Scenario

Igneous Activity Scenario

Other Scenarios

Component Models and Model Abstractions

1,000,000-Year Total System Model Simulations

Deterministic Total System Model Runs
Results: single scenario-conditional dose histories
- different distances
- different inventories

Probabilistic Total System Model Runs
Results: expected peak dose to reasonably maximally exposed individual

Combined Scenarios
Results: \(E[y]\) dose history

- Comparison with DEIS simulations

Legend
- Model
- Analyses
Synopsis of Issues and Concerns from Reviews of TSPA-VA

- Traceability of model results to underlying models and data
- Transparency of model results
- Treatment of alternative models
- Definition of major assumptions and their effects on results and conclusions
- Validity/confidence in process and abstraction models
Traceability of Process/Abstraction Models

**Regulatory Objectives**
- NRC-10 CFR Part 63
- EPA-40 CFR Part 197
- DOE-10 CFR Part 960

**Technical Objectives/Criteria**
- NRC IRSN Acceptance Criteria; Observations on TSPA-VA
- NWTRB Comments on VA
- DOE Repository Safety Strategy
- DOE and USGS Reviews of TSPA-VA
- TSPA-VA Peer Review Suggestions
- State of Nevada: Affected Units of Local Government
- Public

**Prior TSPAs**
- DOE TSPA-91, 93, 95, TSPA-VA, TSPA-DEIS
- NRC IPA-1, -2, -3.1, -3.2
- EPRI TSPA Phases 1, 2, and 3

**Process Model Reports**
- Integrated Site Model
- Unsatuated Zone Flow and Transport Model
- Near-Field Environment Model
- Engineered Barrier System Degradation Model
- Waste Package Degradation Model
- Waste Form Degradation Model
- Saturated Zone Flow and Transport Model
- Biosphere Model
- Tectonics Model

**Site and Design Information**
- Site Description Document
- Repository Design
- Waste Package Design
- Laboratory Data
- In situ Data
- Analog Data
Information Flow in TSPA-SR

TOTAL SYSTEM PERFORMANCE ASSESSMENT (TSPA) MODEL

Waste Form Dissolution Abstractions (F0055, F0060, F0065)

UZ Colloid Transport Model (S0055)

Climate Model (U0005) & Infiltration Uncertainty Model (U0095)

Transport Model (S0055)

SZ Flow & Transport Properties (S0050)

Climate Model (U0005) & Infiltration Uncertainty Model (U0095)

Biosphere RIP

SZ Flow & Transport Properties (S0050)

Waste Package Degradation Model WAPDEG.DLL & RIP

Waste Forms

Nuclear Activities

SZ Info

UZ Info

Climate Info

TSPA Model

External DLL's & RIP

External Inputs

WAPDEG.DLL & RIP

BDCF

Radionuclide Tracking & Removal

EBS Water

Wellhead Dilution

Wellhead Dilution Abstractions (E0005)

Wellhead Dilution (E0005)

BDCF Abstractions (E0075, E0055, E0005)

Faecal Activity (T0015, T0070)

Well Head Dilution

Near Field

Thermodynamic Environment Abstractions (E0130)

UZ Flow Fields Abstractions (U0050, U0115)

Climate Model (U0005) & Infiltration Uncertainty Model (U0095)

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SZ Transport

UZ Colloid Transport Model (S0055)
Basis for Changes in Models from TSPA-VA to TSPA-SR

• Revised design
  – near field and EBS environments
  – drip shield
  – waste package

• Critiques of VA assumptions/models

• Improved process models and their abstraction

• Selective use of reasonably conservative/bounded analyses/models

• Hierarchy of controlled software, analyses and models
  – Implementation of improved QA processes and procedures
Approach to Defining Model Representations in TSPA-SR¹

- Use reasonable representations of process models where they are of sufficient defensibility
- For models of significant complexity or uncertainty, use reasonably bounded representations (using the Safety Case for guidance)
- Include uncertainty in models and parameters, as appropriate
- Incorporate alternative models considering their likelihood

¹See back-up slides for some examples
## Development of Traceable Inputs to TSPA-SR and Possible Subsystem Performance Measures for Transparency

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Scope and Content of TSPA-SR Rev. 00

- Develop and screen FEPs using regulatory criteria and consequence modeling results
- Implement controlled models, analyses, software, and data
- Evaluate the reasonable representation of expected total-system performance incorporating uncertainty within a probabilistic framework, including the effects of disruptive events
- Conduct human intrusion scenario analysis
- Conduct sufficient subsystem and system sensitivity and uncertainty analysis to evaluate significance of uncertainty
Scope and Content of TSPA-SR Rev. 01

- Revise analyses and documentation in response to comments on Rev. 00 to the extent practicable
- Revise Rev. 00 analyses based on significant changes in models or data
- Conduct impact analyses evaluating the effect of increased data and software qualification
Summary

- Comprehensive TSPA-SR, suitable for DOE decision making, is being prepared consistent with applicable (yet evolving) regulations
- Revised and improved TSPA component models are being developed and synthesized
- Technical defensibility of component models will be presented in Analysis/Model Reports (AMRs) and Process Model Reports (PMRs)
- Conformance to QA requirements will help ensure transparency and traceability
Back-Up Slides

• Regulatory Requirements for TSPA
• Process for Calculating Expected Annual Dose
• Probable Model Changes from TSPA-VA to TSPA-SR
Requirement to Conduct A Performance Assessment (10 CFR 63.113)

(a) The geologic repository shall include multiple barriers, consisting of both natural barriers and an engineered barrier system.

(b) The engineered barrier system shall be designed so that, working in combination with the natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE at any time during the first 10,000 years after permanent closure . . .

(c) The ability of the geologic repository to limit radiological exposures to those specified in paragraph (b) of this section shall be demonstrated through a performance assessment that meets the requirements specified at Sec. 63.114, uses the reference biosphere and critical group specified at Sec. 63.115, and excludes the effects of human intrusion.
Definition of Performance Assessment
(10 CFR 63.2)

Performance assessment means a probabilistic analysis that:

(1) Identifies the features, events and processes that might affect the performance of the geologic repository; and

(2) Examines the effects of such features, events, and processes on the performance of the geologic repository; and

(3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the geologic repository.
Requirement to Conduct A Performance Assessment (40 CFR 197.20)

- The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual receives no more than an annual committed effective dose equivalent of 150 microSiervert (15 mrem) from releases from the undisturbed Yucca Mountain disposal system . . .
Definition of Performance Assessment
(40 CFR 197.12)

Performance assessment means an analysis that:

(1) Identifies the processes, events, and sequences of processes and events (except human intrusion), and their probabilities of occurring over 10,000 years after disposal, that might affect the Yucca Mountain disposal system;

(2) Examines the effects of those processes, events, and sequences of processes and events upon the performance of the disposal system; and

(3) Estimates the annual committed effective dose equivalent received by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant processes, events, and sequences of processes and events
Implementation of Performance Assessment Concepts 10 CFR 63.102 (j)

- Demonstrating compliance with the postclosure performance objective specified at Sec. 63.113(b) requires a performance assessment to quantitatively estimate the expected annual dose, over the compliance period, to the average member of the critical group.

- The performance assessment is a systematic analysis that identifies the features, events, and processes that might affect performance of the geologic repository; examines their effects on performance; and estimates the expected annual dose.

- The features, events, and processes considered in the performance assessment should represent a wide range of both beneficial and potentially adverse effects on performance.
Implementation of Performance Assessment Concepts 10 CFR 63.102 (j)

- Those features, events, and processes expected to materially affect compliance with Sec. 63.113(b) or be potentially adverse to performance are included, while events of very low probability of occurrence (less that one chance in 10,000 over 10,000 years) can be excluded from the analyses.

- The expected annual dose to the average member of the critical group is estimated using the selected features, events, and processes, and incorporating the probability that the estimated dose will occur.
Requirements for Performance Assessment
10 CFR 63.114

Any performance assessment used to demonstrate compliance with Sec. 63.113(b) shall:

(a) Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system, used to define parameters and conceptual models used in the assessment

(b) Account for uncertainties and variabilities in parameter values and provide the technical basis . . .

(c) Consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding, and evaluate the effects that alternative conceptual models have on the performance of the geologic repository.
(d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.

(e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in performance assessment . . .

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers . . .

(g) Provide the technical basis for models used in the performance assessment . . .
(h) Identify those design features of the engineered barrier system, and natural features of the geologic setting, that are considered barriers important to waste isolation.

(i) Describe the capability of barriers, identified as important to waste isolation, to isolate waste, taking into account uncertainties in characterizing and modeling the barriers.

(j) Provide the technical basis for the description of the capability of barriers, identified as important to waste isolation, to isolate waste.
Calculating the Mean Annual Dose for a Single Scenario

The mean of the $n$ realizations (or vectors) displayed here is conditional on the occurrence of the scenario.
Weighting the Conditional Mean by the Scenario Probability

\[ \text{Weighted Mean} = \text{Conditional Mean} \times \text{Scenario Probability} \]
NRC’s “Expected” Annual Dose

Weighted Mean Annual Dose Histories for Each Scenario are Summed to Generate the Expected Annual Dose Required by 10 CFR 63.113(b)
TSPA-SR Model Components

- Major model components are related to the attributes of the repository safety strategy
- Natural and engineered barriers comprise the total system
- Each major component requires an explicit model to represent the relevant processes
Probable Changes from TSPA-VA to TSPA-SR

• Improved Climate Model
  – present day, warmer/wetter than present, cooler/wetter glacial transition

• Improved Infiltration Model
  – surface water run off- run on
  – temperature and vegetation dependence
  – uncertainty explicitly quantified

• Improved UZ Flow Model
  – active fracture model for fracture-matrix interactions
  – alternative model for transport through perched water

• Improved Drift-Scale Seepage Model
  – new data from seepage tests in ESF
  – include effects of coupled processes
  – time varying with thermal-hydrologic effects
Probable Changes from TSPA-VA to TSPA-SR
(continued)

- **New THC Drift-Scale Model**
  - reasonably bound incoming water compositions
- **Revised TH Model**
  - incorporates SR design
  - new information from Drift Scale Test
- **New THM Drift-Scale Analyses**
  - conservative parameters to bound seepage
- **Improved In-Drift Geochemical Model**
  - coupled chemical process effects
  - assume T-H-C process can be decoupled, calculated separately, then linked
  - include uncertainty in drift boundary conditions
  - reasonably bound salt build-up effects on chemistry
Probable Changes from TSPA-VA to TSPA-SR
(continued)

- **New Drip-Shield Degradation Model**
  - mechanistic analysis of manufacturing defects
  - include HIC
  - include rock fall and seismic loading effects

- **Improved Waste Package Degradation Model**
  - mechanistic analysis of manufacturing defects
  - additional corrosion mechanisms (SCC, long-term phase stability and thermal aging)
  - integrated with total system model
  - representative lab data used, not expert elicitation
Probable Changes from TSPA-VA to TSPA-SR
(continued)

• Revised Waste Form Categories
  – combine stainless clad CSNF with DSNF inventory
  – revised list of key radionuclides with updated inventories
• Revised Cladding Degradation Model
  – direct evaluation of clad unzipping
  – conservatively bound initial defect conditions
• Revised Waste Form Degradation Model
  – similar to VA, incorporating new data
• Revised Solubility Limits
  – based on analysis of data not elicitation results
• Improved Colloid Formation Model
  – new data on sorption/desorption
  – add Americium colloids
Probable Changes from TSPA-VA to TSPA-SR  
(continued)

• Improved EBS Transport Model
  – in drift water distribution and removal
  – in package evaporation
• Improved UZ Transport Model
  – revised matrix diffusion model
  – revised colloid transport model
  – smaller release areas from EBS to UZ
• Improved SZ Flow and Transport Model
  – calibrated 3-D site scale flow model
  – smaller release areas from UZ to SZ
• Revised Biosphere Transport Model
  – updated water usage for critical group
  – dose conversion factors similar to VA
  – radionuclide buildup and removal in soils
Probable Changes from TSPA-VA to TSPA-SR (continued)

• Revised Analysis of Volcanic Disruptive Events
  – incorporate risk into expected dose using probability-weighted disruptive event scenario
  – revised entrainment parameters

• Revised Analysis of Seismic Disruptive Events
  – incorporate risk into expected dose in nominal scenario or using probability-weighted disruptive event scenario
  – incorporate seismic effects in drift collapse analysis