Consideration of Uncertainties in Thermally-Driven Processes

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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Management and Operating Contractor

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Purpose

- Summarize categories of uncertainties in thermally-driven processes
- Highlight testing, analysis, and modeling efforts to address uncertainties
- Obtain NWTRB feedback to ensure uncertainties are being considered appropriately
- Propose potential path forward for future interactions
Thermal Uncertainty Issues

- Thermally-driven processes increase the uncertainty in repository performance
  - Physical-chemical changes are a function of time and temperature
  - The magnitude, volume, and duration of coupled thermal-hydrologic-mechanical-chemical (THMC) effects increase with increasing temperatures
  - Repository time frame is much longer than testing period
  - Thermal disturbance is over a larger distance than probed by tests

- Performance predictions for Site Recommendation/License Application must include uncertainties in representations for thermally-sensitive processes
Near-Field Environment Processes

SR Design Features:
Preclosure period: 50 years
Thermal Loading: 60MTHM/acre
Waste package spacing: 0.1 m
Drift spacing: 81 m

Predictions:
Maximum “boiling” extent occurs at approximately 200 - 500 years

Below “boiling” at drift wall at approximately 1200 - 2000 years

Drift wall approximately 50°C at 10000 years
# Uncertainties in Thermally-Driven Processes

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
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<tbody>
<tr>
<td>Hydrologic</td>
<td>• Volume and fate of mobilized water</td>
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<tr>
<td>Mechanical</td>
<td>• Movement of rock above drift</td>
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<td>• Drift stability and rockfall</td>
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<td>• Mineral precipitation in fractures</td>
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<td></td>
<td>• Rate</td>
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<td>• Environment</td>
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<tr>
<td>Waste Form</td>
<td>• Degree of cladding degradation</td>
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<tr>
<td>Degradation</td>
<td>• Solubility</td>
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<td>• Rate</td>
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Thermal Hydrologic Processes

Approximately to scale: 5.5-m diameter waste package, 81-m drift spacing

AVERAGE extent of dryout zone shown in red
Hydrologic and Chemical Processes

Diagram Showing TH Processes

Diagram Showing THC Processes

Condensation and Coalescence of Droplets Through Surface Tension and Capture During Drainage

Condensate Drainage

Vapor Transport

T < T_{boiling}

Imbibition

Rock Matrix

Fracture

Condensate Drainage

Vapor Transport

T \approx T_{boiling}

Conductive Heat Transfer

Heat Source

pH

pCO_2

Silica dissolution
Alumino-silicate Dissolution-precipitation

Zone of Active Calcite Precipitation

Zone of Active Silica Precipitation

Vapor

Boiling Zone

Condensation-Drainage Zone

CO_2

Vapor

CO_2
Thermal Mechanical Impacts

Calculated Enhancement in Fracture Permeability Due to Thermally-Induced Shear

60 MTHM/acre
5.5 m drift diameter
81 m drift spacing
50 years ventilation
Corrosion
SR Design Conditions

Predictions Required:

**Near-Field Host Rock**
- Max. T > 96°C
- Min. RH << 0.5
- *Ppts/Salts* Accumulation which can subsequently interact with water flow and chemistry

**Drip Shield/Waste Package Surfaces**
- Max. T > 96°C
- Min. RH << 0.5
- *Ppts/Salts* Which can result in concentrated solutions (>10 molal) at the surfaces

**Invert**
- Maximum T > 96°C
- *Ppts/Salts* Accumulation in fractures (plugging) which can result in localized pooling of water

**CRM Corrosion**
- General and Localized Corrosion:
  - Low dependence on temperature for aqueous conditions
  - Pitting and Crevice Corrosion not strongly driven at expected aqueous conditions:
    - Continue to test
- Stress Corrosion Cracking:
  - Temperature Dependent Near 100°C, but less otherwise
  - Testing Chemistry Dependence
- Phase Segregation:
  - Low for temperatures below 260°C
  - Behavior obtained from testing
Waste Form Degradation

- **Degree of cladding degradation**
  - rate of cladding degradation increases rapidly above 350°C
- **Solubility**
  - mildly temperature dependent
- **Degradation Rates**
  - $\text{UO}_x$ dissolution rate varies by one order of magnitude between 25°C and 96°C
# Testing and Analyses to Address Uncertainties

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<td>Hydrologic</td>
<td>• Volume and fate of mobilized water</td>
<td>DST,SHT, LBT, <em>CDTT</em>, Geothermal Analogs, Krasnoyarsk Analog, DECOVALEX</td>
</tr>
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<td>Mechanical</td>
<td>• Fracturing of rock above drift&lt;br&gt;• Drift stability and rockfall</td>
<td>DST, SHT, LBT, <em>CDTT</em>, DECOVALEX</td>
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<tr>
<td>Corrosion</td>
<td>• Mechanism&lt;br&gt;• Rate</td>
<td>Laboratory Corrosion Testing, Iron Meteorite Analogs</td>
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<td>Waste Form Degradation</td>
<td>• Degree of cladding degradation&lt;br&gt;• Solubility&lt;br&gt;• Rate</td>
<td>Laboratory Waste Form Testing, Laboratory Cladding Testing, Laboratory Solubility Testing, Pena Blanca Analog</td>
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Complete or Ongoing Except *Planned (italics)*

- Drift Scale Test (DST)
- Single Heater Test (SHT)
- Large Block Test (LBT)
- *Cross Drift Thermal Test (CDTT)*
Illustration of Reduction of Uncertainties: Volume and Fate of Mobilized Water

- Drift Scale Test (DST) observations address uncertainties
- Prior to start of test, some model predictions indicated that water would pond above the drift due to the thermal response
- To date, observations indicate that water does not pond above the heated drift, but appears to move to the sides and below the drift
Drift Scale Test

ERT Saturation Ratio

Heating day = 511
Date = 4/28/99
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<th>Category</th>
<th>Uncertainty Parameter</th>
<th>Primary Effects on Performance</th>
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<tr>
<td>Hydrologic</td>
<td>• Flow Focussing factor</td>
<td>• Seepage fraction and amount</td>
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<tr>
<td></td>
<td>• Condensation</td>
<td>• Water flux on waste package</td>
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<tr>
<td>Mechanical</td>
<td>• Fracture flow characteristics</td>
<td>• Seepage fraction and amount</td>
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<tr>
<td></td>
<td>• Rockfall size and frequency</td>
<td>• Dripshield stresses and stress induced cracks</td>
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<td>• Near field geochemistry</td>
<td>• In-drift geochemistry</td>
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<tr>
<td></td>
<td>• Fracture and matrix transport characteristics</td>
<td>• Advective travel time in UZ</td>
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<tr>
<td>Corrosion</td>
<td>• In-drift geochemistry</td>
<td>• General corrosion, crevice corrosion and stress corrosion cracking initiation and rate</td>
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<tr>
<td></td>
<td>• Waste package temperature</td>
<td>• Rate of general corrosion</td>
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<tr>
<td>Waste Form</td>
<td>• Cladding temperature and chemistry</td>
<td>• Clad unzipping rate and fraction of fuel exposed</td>
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<tr>
<td>Degradation</td>
<td>• Radionuclide solubility</td>
<td>• Dissolved radionuclide concentrations and colloid stability</td>
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<td>• Waste form alteration</td>
<td>• Stability of secondary phase</td>
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Path Forward

- Categories of uncertainties will be investigated
  - Testing continues
  - Operational flexibility established
- Propose detailed NWTRB interactions covering
  - Current understanding of uncertainties
  - Testing and analysis to address uncertainties
  - Treatment of uncertainties in TSPA for Site Recommendation/License Application