U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Consideration of Uncertainties in Thermally-Driven Processes

Presented to:
Nuclear Waste Technical Review Board

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YUCCA MOUNTAIN PROJECT

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**

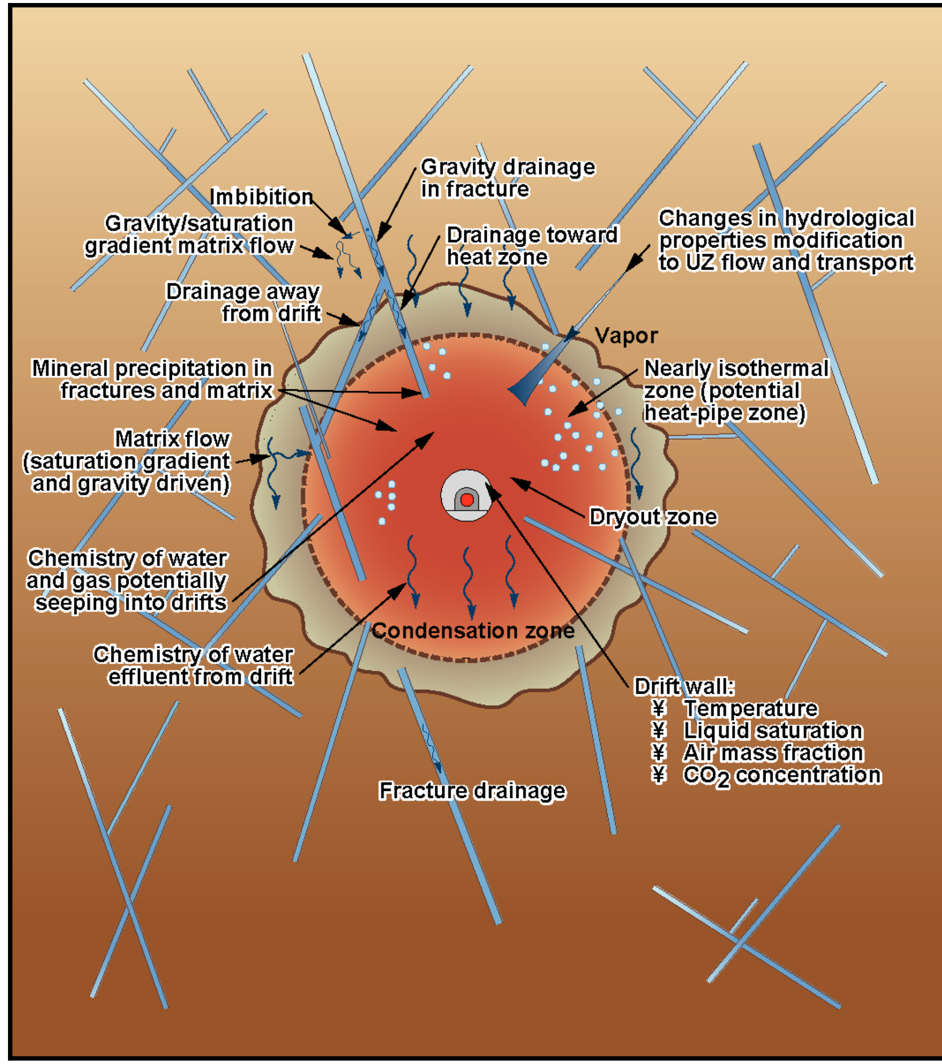
Near-Field Environment Processes

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

<u>Predictions</u>:
Maximum "boiling" extent occurs at approximately 200 - 500 years

Below "boiling" at drift wall at approximately 1200 - 2000 years

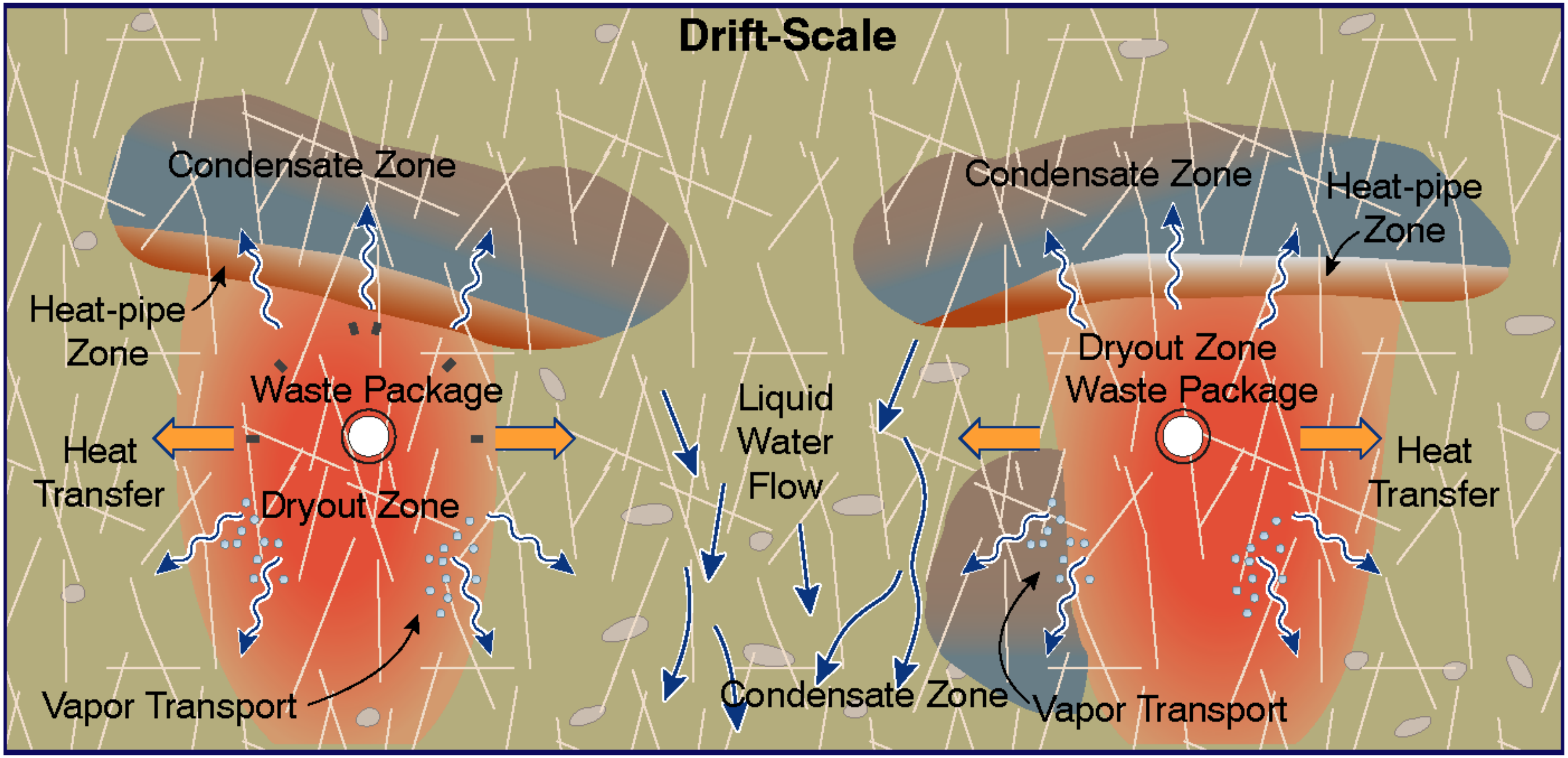
Drift wall approximately 50^{o}C at 10000 years



Uncertainties in Thermally-Driven Processes

Category	Description
Hydrologic	• Volume and fate of mobilized water
Mechanical	• Movement of rock above drift • Drift stability and rockfall
Chemical	• Mineral precipitation in fractures • Altered water chemistry (concentration, pH, Eh) • Mineral transformation
Corrosion	• Mechanism • Rate • Environment
Waste Form Degradation	• Degree of cladding degradation • Solubility • Rate

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

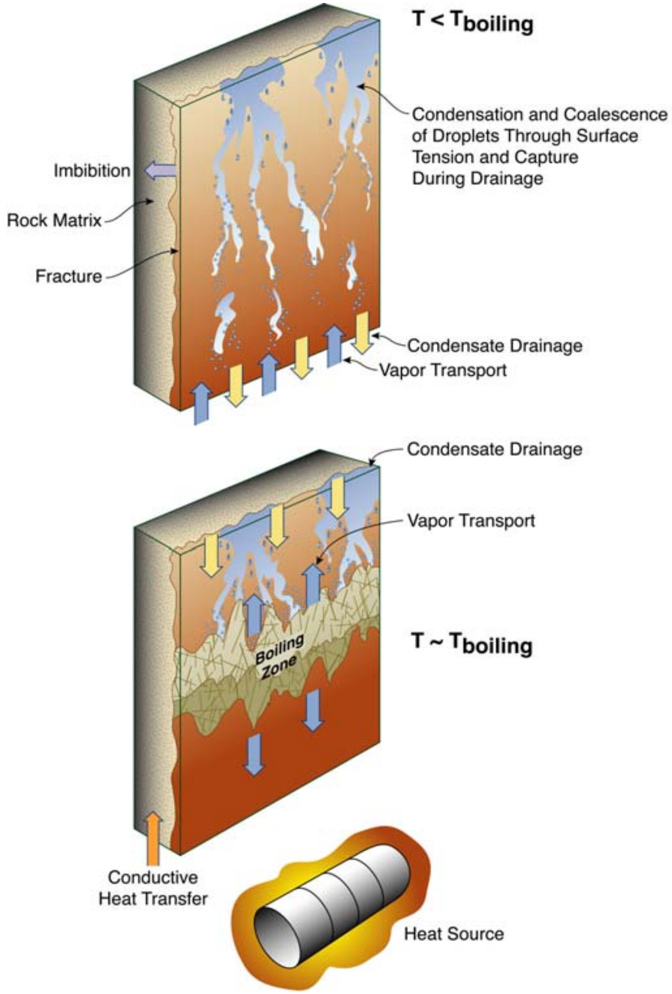


Diagram Showing TH Processes

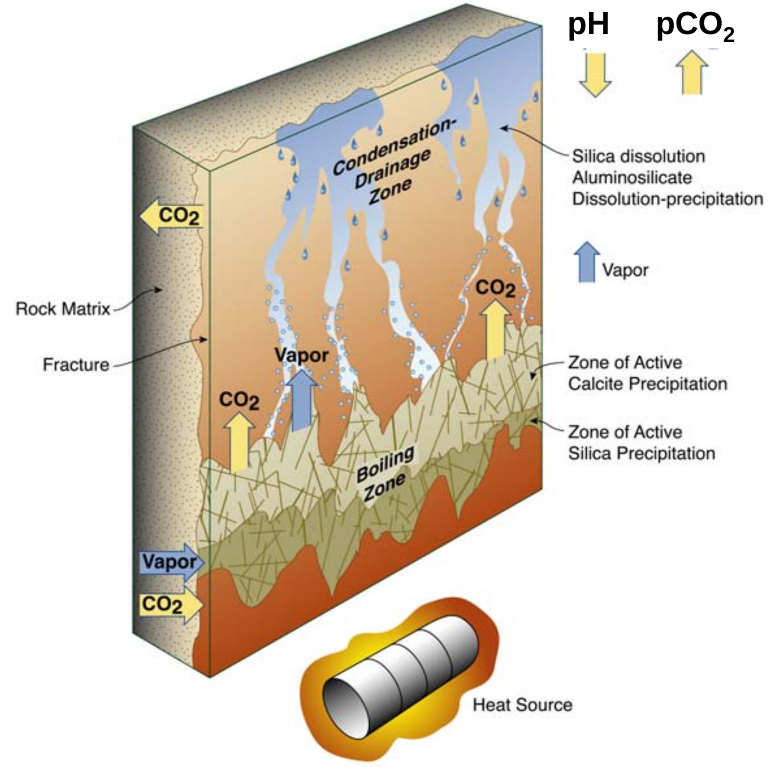
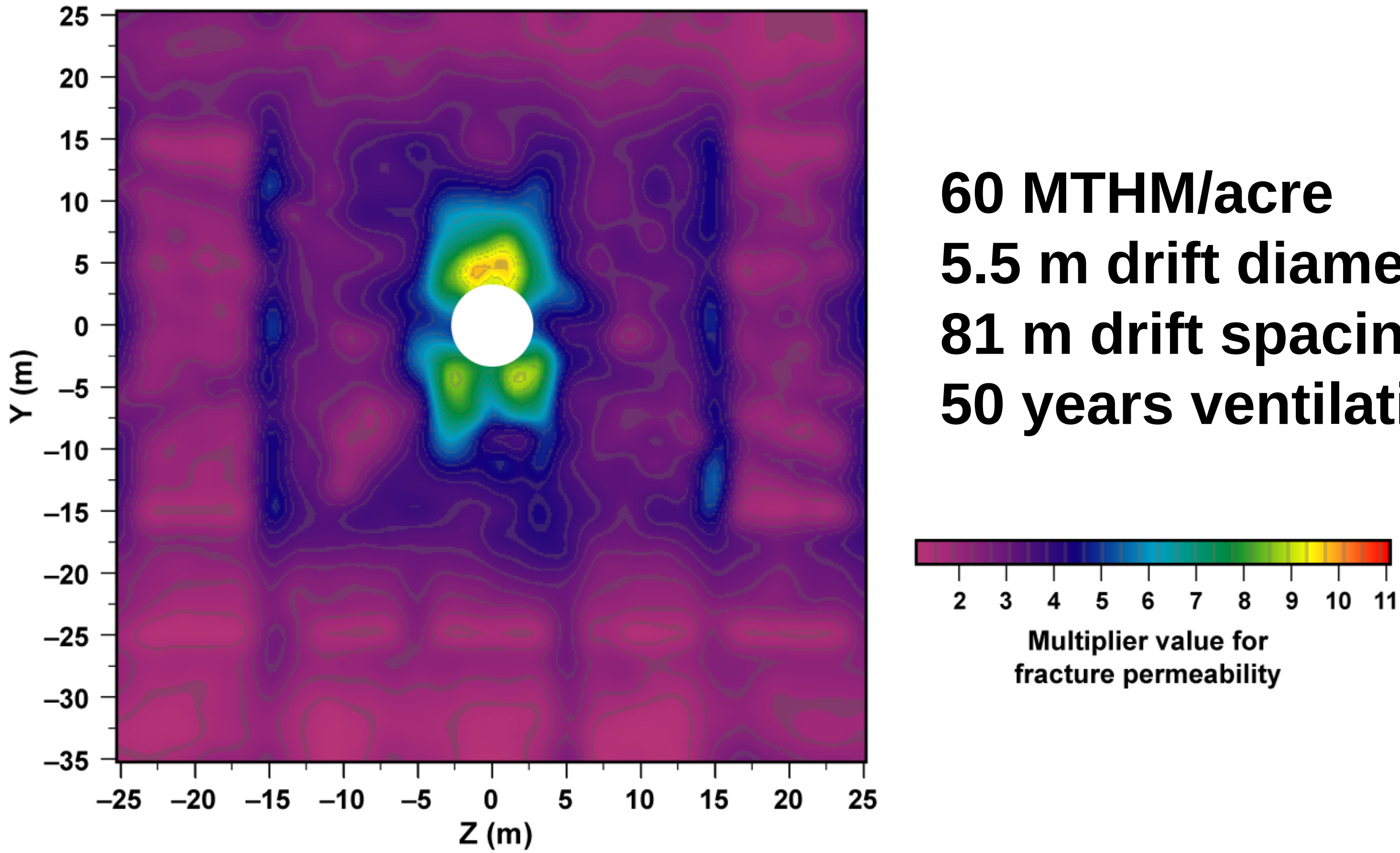


Diagram Showing THC Processes

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

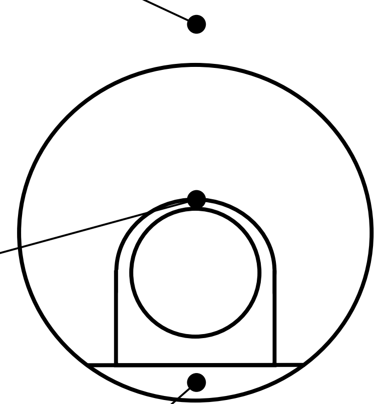
SR Design Conditions

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
  - UO_x dissolution rate varies by one order of magnitude between 25°C and 96°C

Testing and Analyses to Address Uncertainties

Category	Description	Testing and Analyses
Hydrologic	• Volume and fate of mobilized water	DST,SHT, LBT, *CDTT*, Geothermal Analogs, Krasnoyarsk Analog, DECOVALEX
Mechanical	• Fracturing of rock above drift • Drift stability and rockfall	DST, SHT, LBT, *CDTT*, DECOVALEX
Chemical	• Mineral precipitation in fractures • Altered water chemistry (concentration, pH, Eh) • Mineral transformation	DST, SHT, LBT, *CDTT*, Geothermal Analogs, Paiute Ridge Analog
Corrosion	• Mechanism • Rate	Laboratory Corrosion Testing, Iron Meteorite Analogs
Waste Form Degradation	• Degree of cladding degradation • Solubility • Rate	Laboratory Waste Form Testing, Laboratory Cladding Testing, Laboratory Solubility Testing, Pena Blanca Analog

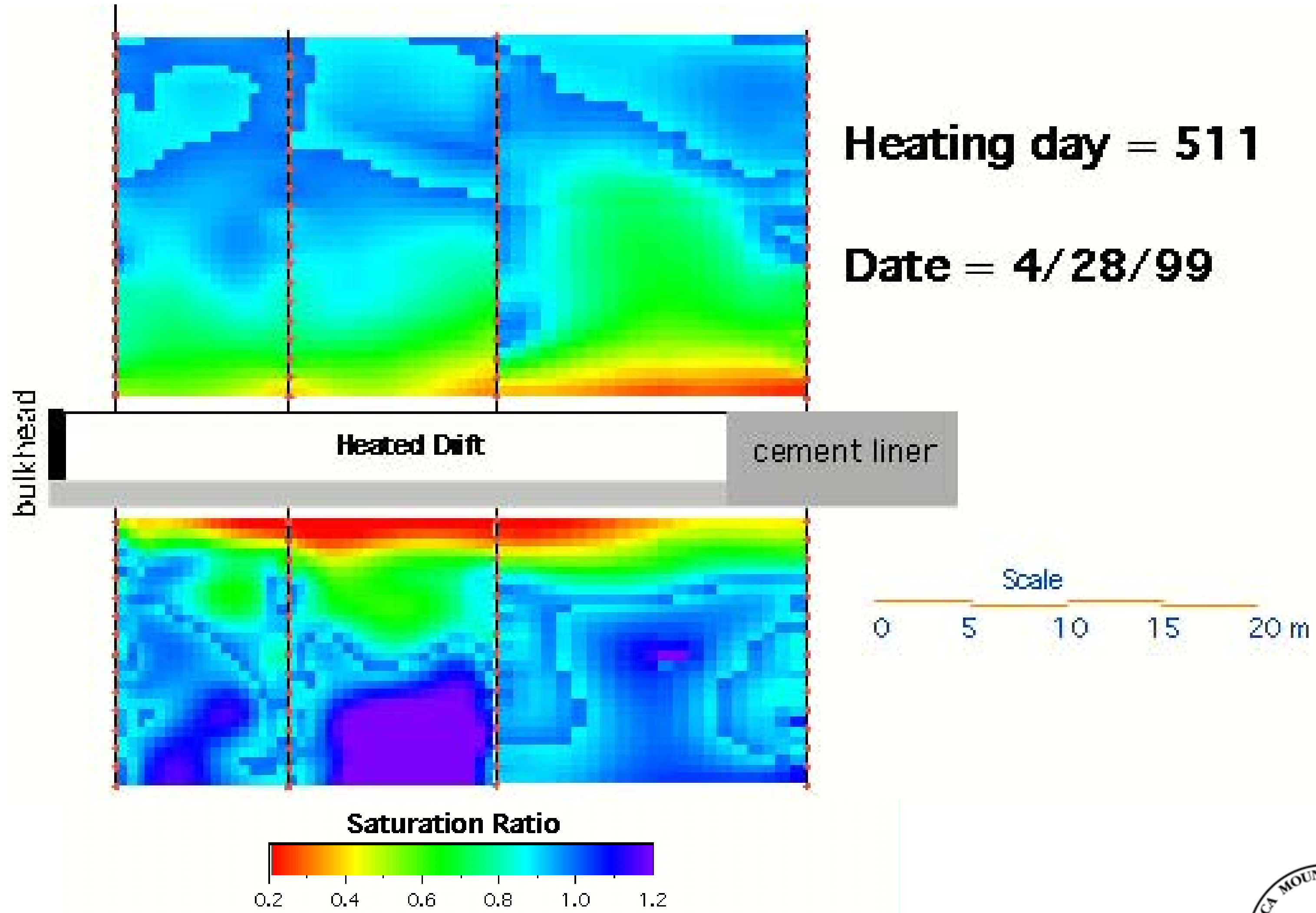
Complete or Ongoing Except *Planned (italics)*
Drift Scale Test (DST)
Single Heater Test (SHT)
Large Block Test (LBT)
Cross Drift Thermal Test (CDTT)

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



Uncertainties Included in TSPA-SR

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

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