SUBJECT: THERMO/HYDROLOGICAL EFFECTS

PRESENTER: DR. THOMAS A. BUSCHECK

PRESENTER'S TITLE: HYDROLOGIST
AND ORGANIZATION: LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA 94550

PRESENTER'S TELEPHONE NUMBER: (415) 423-9390

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Code Development and Verification
  - V-TOUGH
  - Stochastic Models
  - Dual Porosity Models

Nonisothermal Modeling Studies
  - Laboratory Scale Models
  - In Situ Field Scale Models
  - Mechanistic Models
  - Scaling Laws

Laboratory Experiments

Fracture-Matrix Interaction
  Numerical/Analytical Modeling Studies
  - Fracture-Dominated Flow
  - Transitional Fracture/Matrix Flow
  - Matrix-Dominated Flow
  - Flow Criteria

In Situ Field Tests

Integrated Parameter
  In Situ Field Scale Models

Case-Specific Scenario Evaluation

Performance Assessment Modules

Stochastic Fracture Network Models

Comprehensive Theory of Fracture-Matrix interaction
Fractures play a key role in drying and wetting behavior.
Waste package geometry and heating rate strongly affect near-field moisture movement and temperatures

- Drying rate is strongly dependent on heating rate, $Q_h$ for radial flow, drying rate $\approx Q_h^{5/2}$

- Tests conducted at accelerated $Q_h$ improperly scale vaporization relative to imbibition and conduction
  
  — Hydrothermal-geochemical coupling is distorted
  
  — Thermo-mechanical coupling is distorted

- Model validation will require that the perturbed zone extend over the scale of heterogeneities (e.g., fractures and matrix heterogeneity)
Fracture/matrix interaction

- What is the QUANTITY and CHEMISTRY of water contacting the waste packages?

- Where can it come from?
  - perched water
  - construction/drilling fluids
  - vapor condensation during heating
  - rainfall events
  - seismic pumping of the water table

- How is it getting there?
  - fracture-dominated flow
  - matrix-dominated flow
We have been addressing fracture/matrix interaction with a combination of numerical and analytical models.
Parallel Fracture System

2b

2a

$S_i^m < 1$

$S_i^f \approx 0$

$b = 50 \mu m$

$a = 0.25 m$
48 hour infiltration event with $P_0$ fixed

Fracture-dominated flow with maximal matrix interaction results in the liquid front moving with a $t^{1/2}$ dependence.
Saturation profiles following a 48 hour infiltration event

Matrix imbibition results in insignificant fracture flow subsequent to the removal of the infiltration source.
Fracture penetration is proportional to $b^3$.

A twofold increase in fracture aperture results in an eightfold increase in fracture penetration.

100 μm Fracture Aperture Case

50 μm Fracture Aperture Case
Parameter sensitivity study of fracture/matrix flow

Cases were considered using repository horizon data. For most cases the liquid front movement has a $t^{1/2}$ dependence.
Ten hour infiltration event with $P_0$ fixed.

Due to closely spaced fractures, the saturation fields interfere within three hours, resulting in the liquid front moving linearly with $t$. 
Fractures are not capillary barriers to matrix-dominated flow

\[ P_0 \]

\[ S_i^m < 1. \]

\[ S_i^f \approx 0. \]

\[ b \]

\[ \ell_a \]

\[ \ell_t \]
Matrix-dominated flow across a fracture

Even $\frac{I_a}{I_t} = 0.01$ has a modest effect on retarding flow across the fracture.
Code Development and Verification

- Developed and partially verified V-TOUGH code

Nonisothermal Modeling Studies
- Identified key mechanisms of heat and fluid flow around waste packages
- Partially validated a model using data from field testing in G-Tunnel

Fracture-Matrix Interaction
Numerical/Analytical Modeling Studies
- Analyzed interaction of fracture and matrix flow and identified major flow regimes
- Developed criteria to determine whether fracture- or matrix-dominated flow

Case-Specific Scenario Evaluation
- Numerical and analytical models can identify conditions for which liquid flow to the waste packages is possible