SUBJECT: HEAT-DRIVEN FLOW PROCESSES AT A POTENTIAL YUCCA MOUNTAIN REPOSITORY

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DENVER, COLORADO
JULY 13-14, 1993
U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

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Repository Behavior at Yucca Mountain

Complex Processes

- Heat transfer: conduction, convection, vaporization, and condensation
- Flow of liquid water and gas under gravity, capillary, and pressure forces
- Vapor-air diffusion with pore-level phase change effects
- Strong coupling between fluid flow and heat transfer
- Highly nonlinear relative permeability and capillary pressure behavior
- TOUGH/TOUGH2 codes: borrow from geothermal and petroleum reservoir simulation methodology
Repository Behavior at Yucca Mountain

(Continued)

Complex Hydrogeologic Setting

- Heterogeneity on many different scales: layering, tilting, faults, fractures
- Initial and boundary conditions: surface topography, atmospheric forcings
No fractures

With fractures

Effective continuum

No fractures

With fractures

Effective continuum

Immobile

Liquid in fractures

Mobile

Temperature (°C)

Time (year)
Schematic of Heat Transfer Regimes in Plane Perpendicular to the Axis of the Waste Packages

Similarity variable $r/\sqrt{t}$ (not to scale)
Comparison of TOUGH2 Results with Similarity Solution
## Characteristic Times for Multiphase Processes (*)

<table>
<thead>
<tr>
<th>Process</th>
<th>Hydrogeologic Unit</th>
<th>Hydrogeologic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topopah Spring</td>
<td>Calico Hills</td>
</tr>
<tr>
<td>Heat conduction</td>
<td>29,900 yrs</td>
<td>51,100 yrs</td>
</tr>
<tr>
<td>Liquid flow</td>
<td>234,700 yrs</td>
<td>176 yrs</td>
</tr>
<tr>
<td>Gas flow</td>
<td>207 days</td>
<td>127 yrs</td>
</tr>
<tr>
<td>Vapor diffusion</td>
<td>1,480 yrs</td>
<td>1,480 yrs</td>
</tr>
<tr>
<td>Air diffusion</td>
<td>84,600 yrs</td>
<td>26,900 yrs</td>
</tr>
</tbody>
</table>

* For a propagation distance of $x = 1000$ m, calculated from $t = \frac{x^2}{D}$, where $D$ is the appropriate diffusivity
Conceptual Model of Flow at Yucca Mountain

(from Klavetter and Peter, SAND85-0855, March 1986)

(BEST AVAILABLE COPY)
Land surface

Fractured

Porous

Fractured

Elevation

T = 12.85°C
P = 0.85 bar
S_f = 0

-100 m

Waste package

Repository

Radius R = 1500 m

-375 m

-475 m

Porous

Water table

T = 30.85°C
P = 0.9107 bar
S_f = 100%
Temperatures (°C) after 1000 years

Yucca Mountain Repository Model
Liquid saturations after 1000 years
Gas velocities after 1000 years

Yucca Mountain Repository Model

Depth (m)

Radial distance (m)

1 m/yr
Simulated Water Saturation Profiles

RZ Liquid Saturation Profiles (R=705.16 m)

XZ Liquid Saturation Profiles (X = 1100 m column)

Legend
- 0 year
- 100 year
- 1000 year
- 10000 year
Temperature History, Drying and Rewetting Times at Node AC 2, 3 cm from Waste-Package Surface

Years After Waste Emplacement

Temperature °C

Drying $S_l = 0$

Rewetting, $S_l > S_r$

Rewetting, $S_l > S_r$

114 KW - Mixed
114 KW - 10 yr
28.5 KW - 10 yr
57 KW - 10 yr
Dry Repository Operation?

You can

- Keep some of the waste packages dry all of the time
- Keep all of the waste packages dry some of the time

but you cannot

- Keep all of the waste packages dry all of the time
Obstacles Against Dry Repository Operation

- Thermodynamics: vapor pressure lowering, salinity
- Infiltration
- Heterogeneity: channelized water flow, release of ponded water
Temperature (°C) vs. $P_{suc}$ (Pa)

Vapor pressure = 2 bars
1.5 bars
1 bar

$1E+6$  $1E+7$  $1E+8$  $1E+9$
Waste Heat ↔ Infiltration

Heat rate per waste package, \( G \) (W)
Area per waste package, \( A \) (m\(^2\))
Net infiltration, \( q \) (mm/yr)
Net infiltration per waste package, \( Q \) (kg/s)
\[
Q = A q p^w
\]
Heat requirement for vaporization
\[
Q (h_v - h_l) \leq G
\]
Heat Output and Vaporization
(Single Waste Package)
Water Flow in Unsaturated Fractured Media

- **Heterogeneity**
  - Layering
  - Fracture networks
  - Individual fractures

- **Preferential Paths**

- **Stripa Experiment**
  - Validation drift: 50 m long, 3 m diameter
  - 57% of inflow occurred over 0.2% of drift area

- **Water at Yucca Mountain**
  - Channelized flow, ponding vs.
  - Thermal effects, imbibition
Vertical Water Channel: Temperature and Liquid Saturation at Repository Horizon

Temperature

Liquid Saturation

Channel walls
-impermeable
-permeable

Time (years)

Temperature (°C)

Liquid Saturation

0 100 200 300 400 500

0 0.3 0.4 0.5 0.6 0.7 0.8

DCTRBKC24.12S.NWTRB/7-13/14 93
Inundation of Waste Packages by Ponded Water?

<table>
<thead>
<tr>
<th>Waste Form</th>
<th>Total Heat Capacity (MJ/°C)</th>
<th>Vaporization Capability (kg)</th>
<th>(m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>15.85</td>
<td>1754.5</td>
<td>1.83</td>
</tr>
<tr>
<td>(2)</td>
<td>5.85</td>
<td>646.9</td>
<td>0.68</td>
</tr>
<tr>
<td>(3)</td>
<td>3.27</td>
<td>362.2</td>
<td>0.38</td>
</tr>
</tbody>
</table>

(1) Package for drift emplacement, with 21 PWR spent fuel assemblies

(2) Package for vertical emplacement, with consolidated fuel from 3 PWR or 4 BWR assemblies

(3) Package for vertical emplacement, with unconsolidated fuel (intact assemblies)

* Data from Gary Johnson, LLNL, private communication
## Generation of Heat and Condensate from 10-Year-Old Waste Packages

<table>
<thead>
<tr>
<th>Time After Emplacement (years)</th>
<th>Cumulative Heat Generation ((10^{12} \text{ Joules}))</th>
<th>Maximum Cumulative Condensate Generation(^\dagger) ((10^6 \text{ kg}))</th>
<th>Maximum Cumulative Condensate Generation(^\dagger) ((10^3 \text{ m}^3))(^\ddagger)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>.8658</td>
<td>.3303</td>
<td>.3447</td>
</tr>
<tr>
<td>(10^2)</td>
<td>4.488</td>
<td>1.712</td>
<td>1.786</td>
</tr>
<tr>
<td>(10^3)</td>
<td>12.39</td>
<td>4.726</td>
<td>4.932</td>
</tr>
<tr>
<td>(10^4)</td>
<td>27.59</td>
<td>10.52</td>
<td>10.98</td>
</tr>
<tr>
<td>(10^5)</td>
<td>51.05</td>
<td>19.47</td>
<td>20.32</td>
</tr>
</tbody>
</table>

\(^\dagger\) Based on converting water at 13 °C to 100 °C vapor; \(h_{vl} = 2621.5 \text{ kJ/kg}\)

\(^\ddagger\) Based on water density of 958.3 kg/m\(^3\) at 100 °C
Heat-Driven Flow Processes at a Potential Yucca Mountain Repository: Current Status of Modeling Activities

- Coupled multiphase fluid and heat flows
- Complex heterogeneous hydrogeological setting
- Large range of space and time scales
- Modeling capabilities adequate for the highly non-linear flow processes
- Obtained basic understanding of fluid and heat flow mechanisms
- Present models are schematic and approximate, can only provide a rough outlook on repository behavior
- Lack of quantitative information, especially on multiphase behavior of fractures
- Need more realistic representation of heterogeneity on a multitude of scales
- Interpret model predictions with caution!