U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

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

PRESENTER: DR. KARSTEN PRUESS

PRESENTER'S TITLE AND ORGANIZATION: SENIOR SCIENTIST, EARTH SCIENCES DIVISION
LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 486-6732

DENVER, COLORADO
JULY 13-14, 1993

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Repository Behavior at Yucca Mountain

Complex Processes

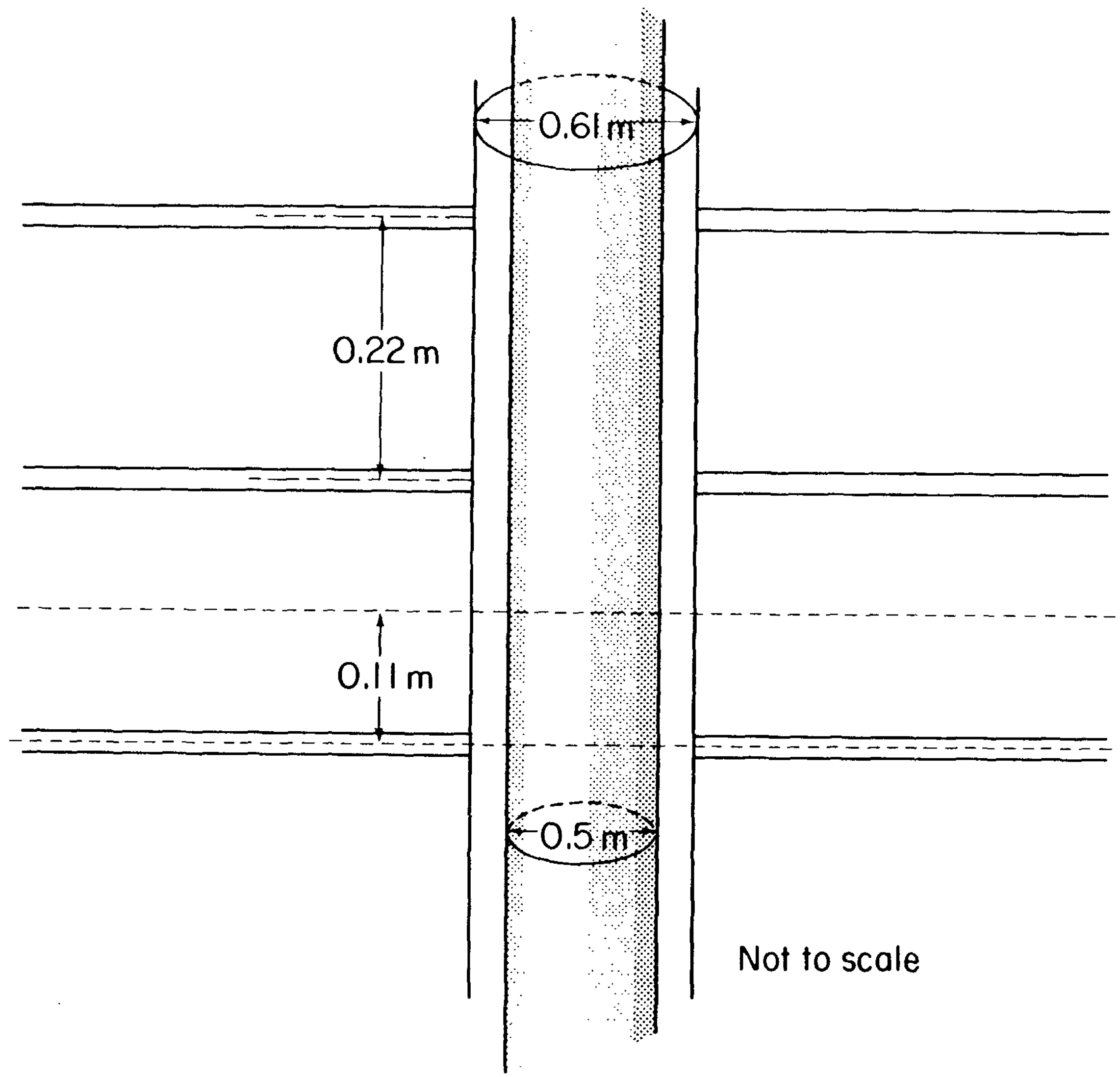
- Heat transfer: conduction, convection, vaporization, and condensation
- Flow of liquid water and gas under gravity, capillary, and pressure forces
- Vapor-air diffusion with pore-level phase change effects
- Strong coupling between fluid flow and heat transfer
- Highly nonlinear relative permeability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

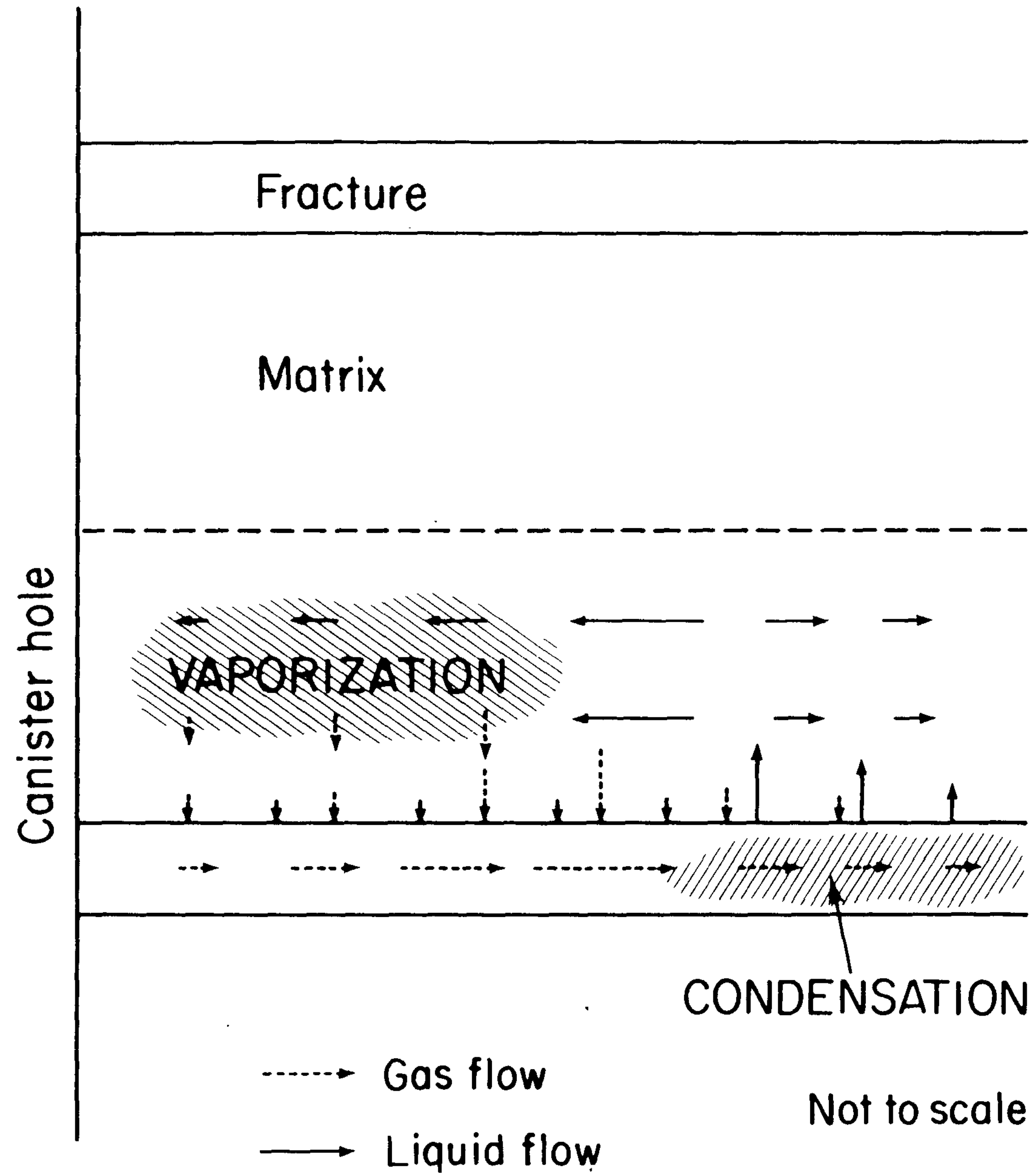
Repository Behavior at Yucca Mountain

(Continued)

Complex Hydrogeologic Setting

- Heterogeneity on many different scales: layering, tilting, faults, fractures
- Initial and boundary conditions: surface topography, atmospheric forcings


0.61 m
0.22 m
0.11 m
0.5 m
Not to scale



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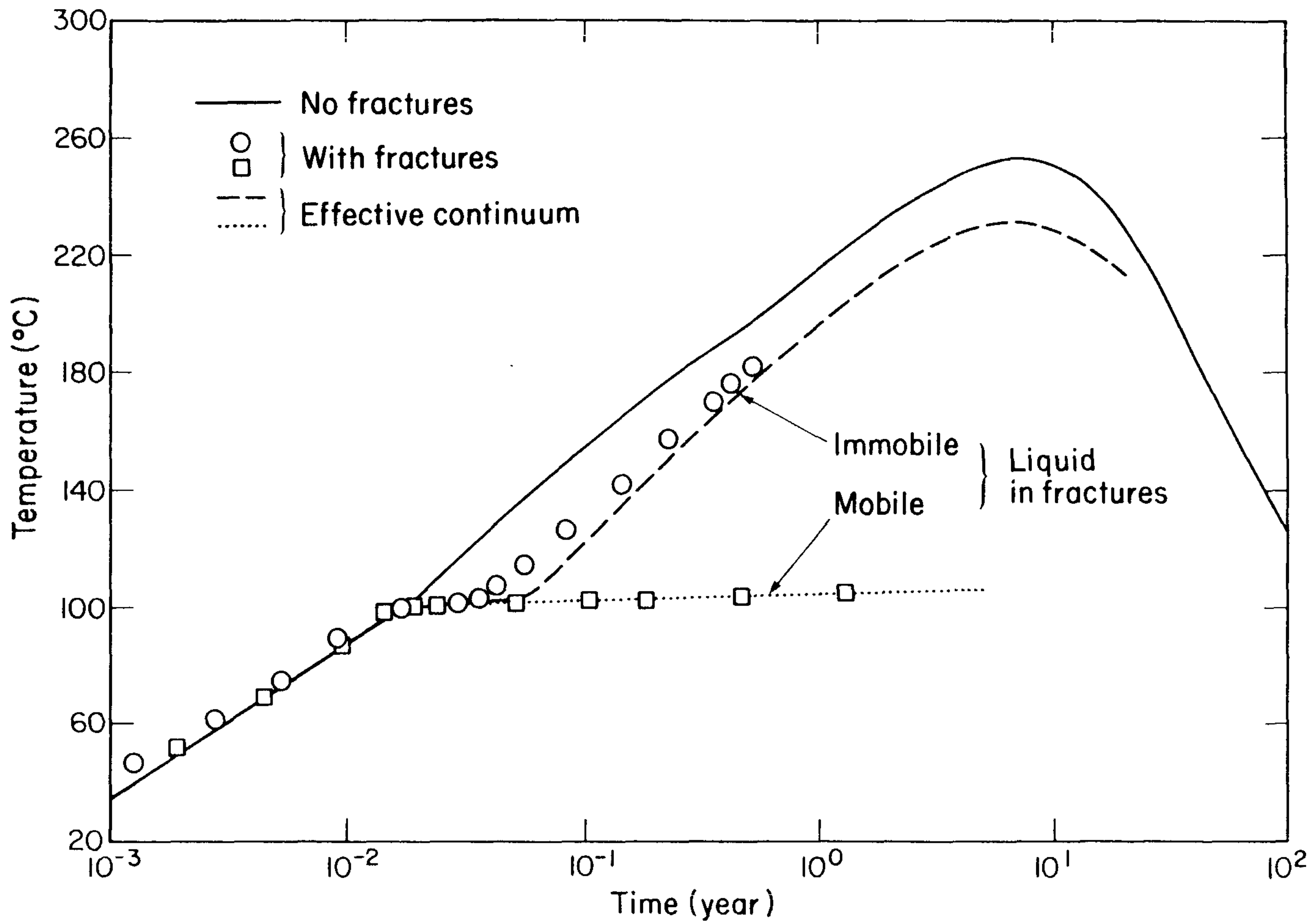
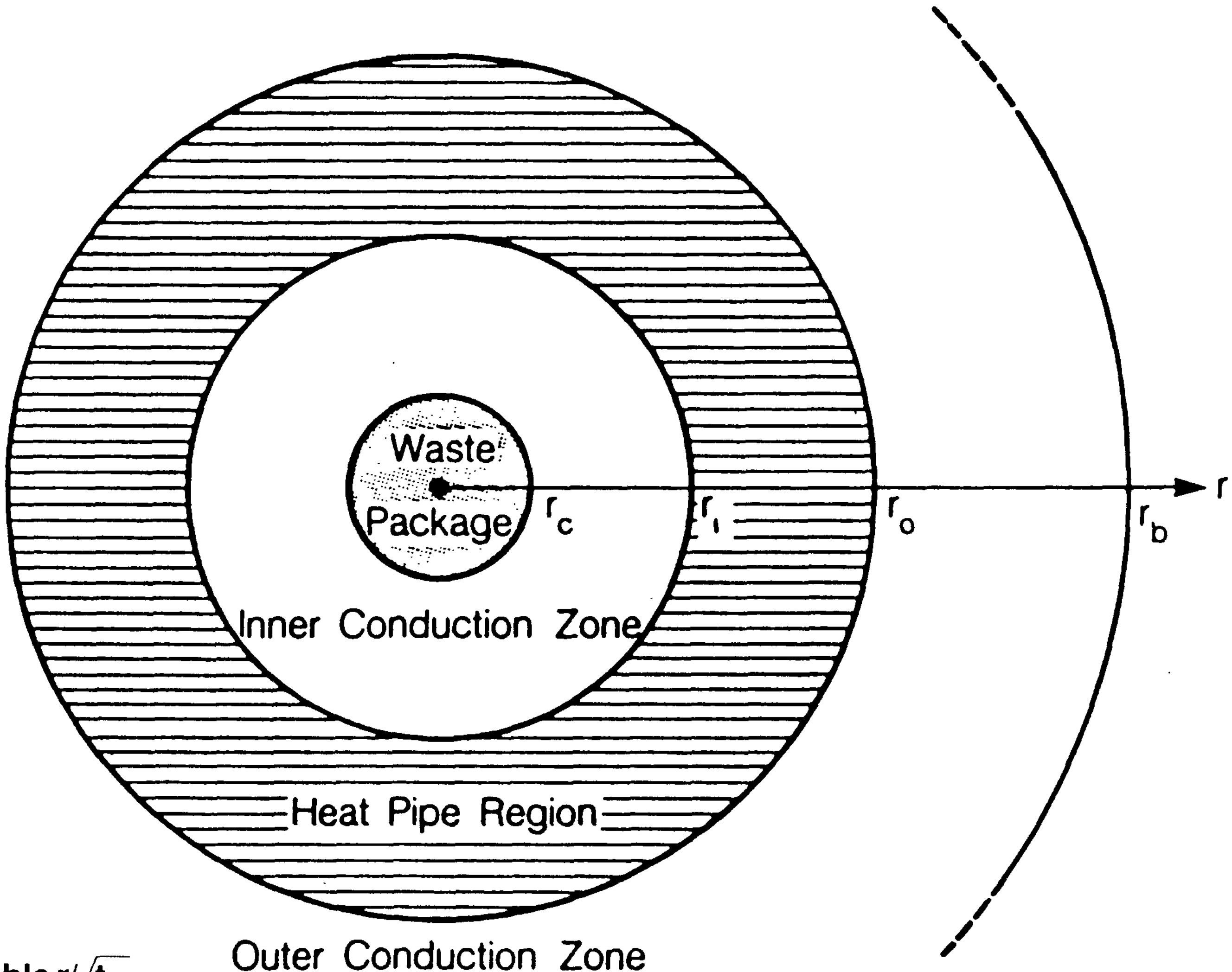


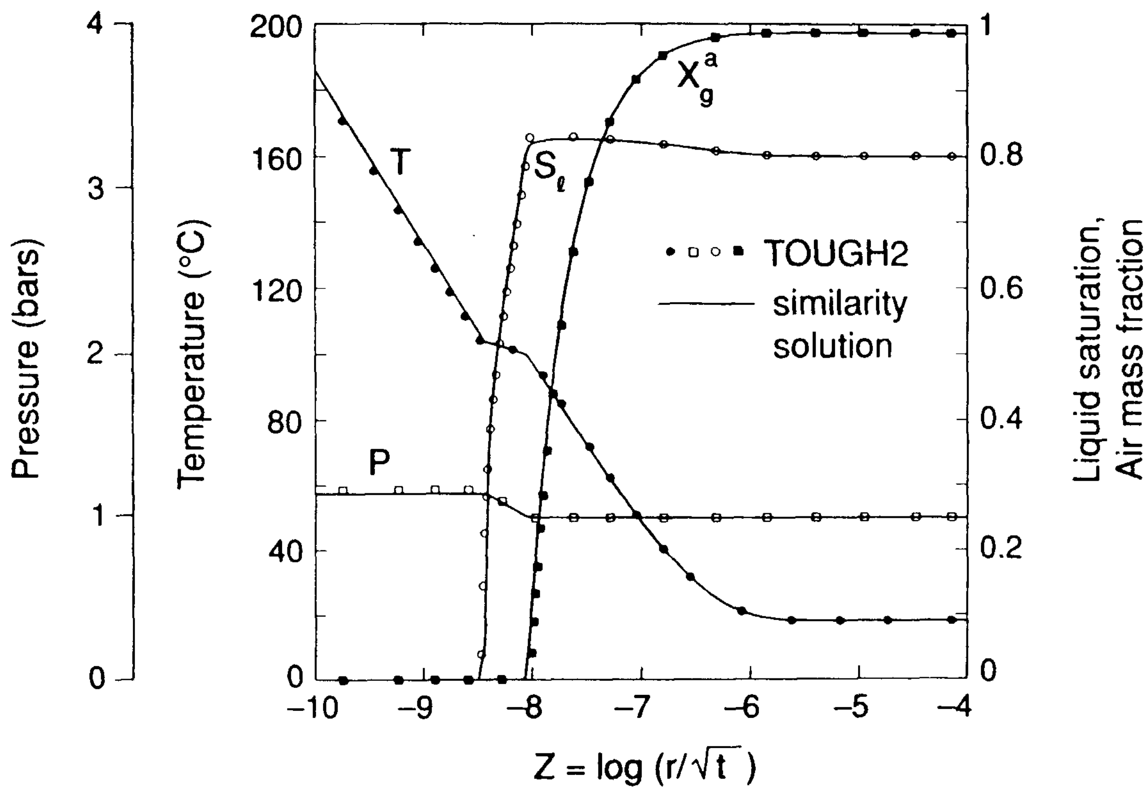
No fractures
With fractures
Effective continuum
Immobile
Mobile
Liquid in fractures
Temperature (°C)
Time (year)
300
260
220
180
140
100
60
20
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

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



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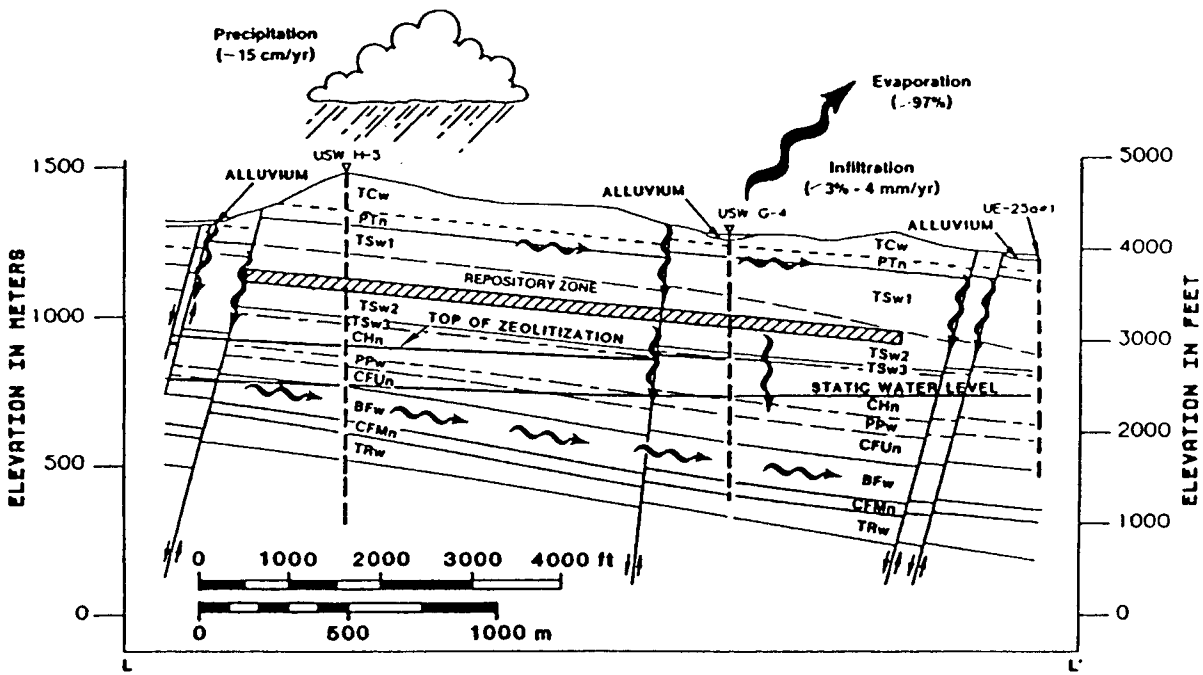
Characteristic Times for Multiphase Processes (*)

Process	Hydrogeologic Unit	
	Topopah Spring	Calico Hills
Heat conduction	29,900 yrs	51,100 yrs
Liquid flow	234,700 yrs	176 yrs
Gas flow	207 days	127 yrs
Vapor diffusion	1,480 yrs	1,480 yrs
Air diffusion	84,600 yrs	26,900 yrs

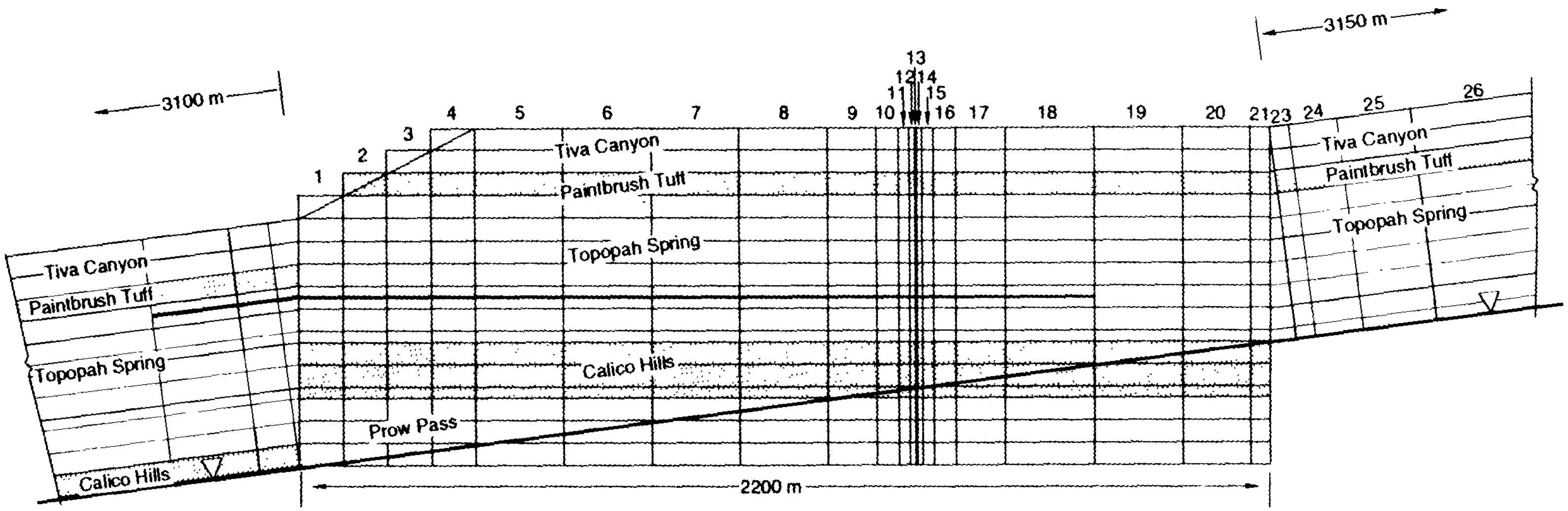
* For a propagation distance of $x = 1000$ m, calculated from $t = x^2/D$, where D is the appropriate diffusivity

Conceptual Model of Flow at Yucca Mountain



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

(BEST AVAILABLE COPY)



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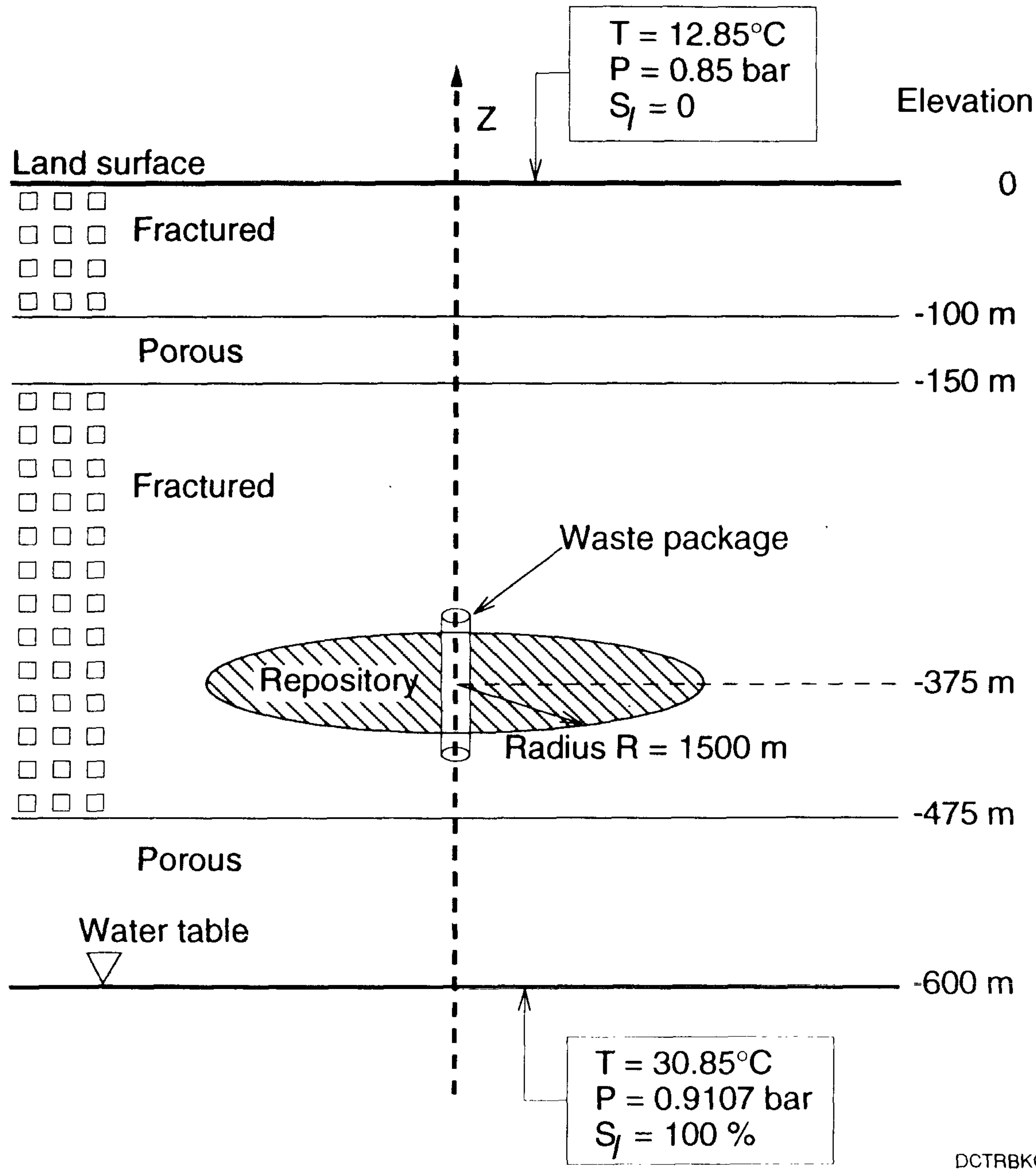

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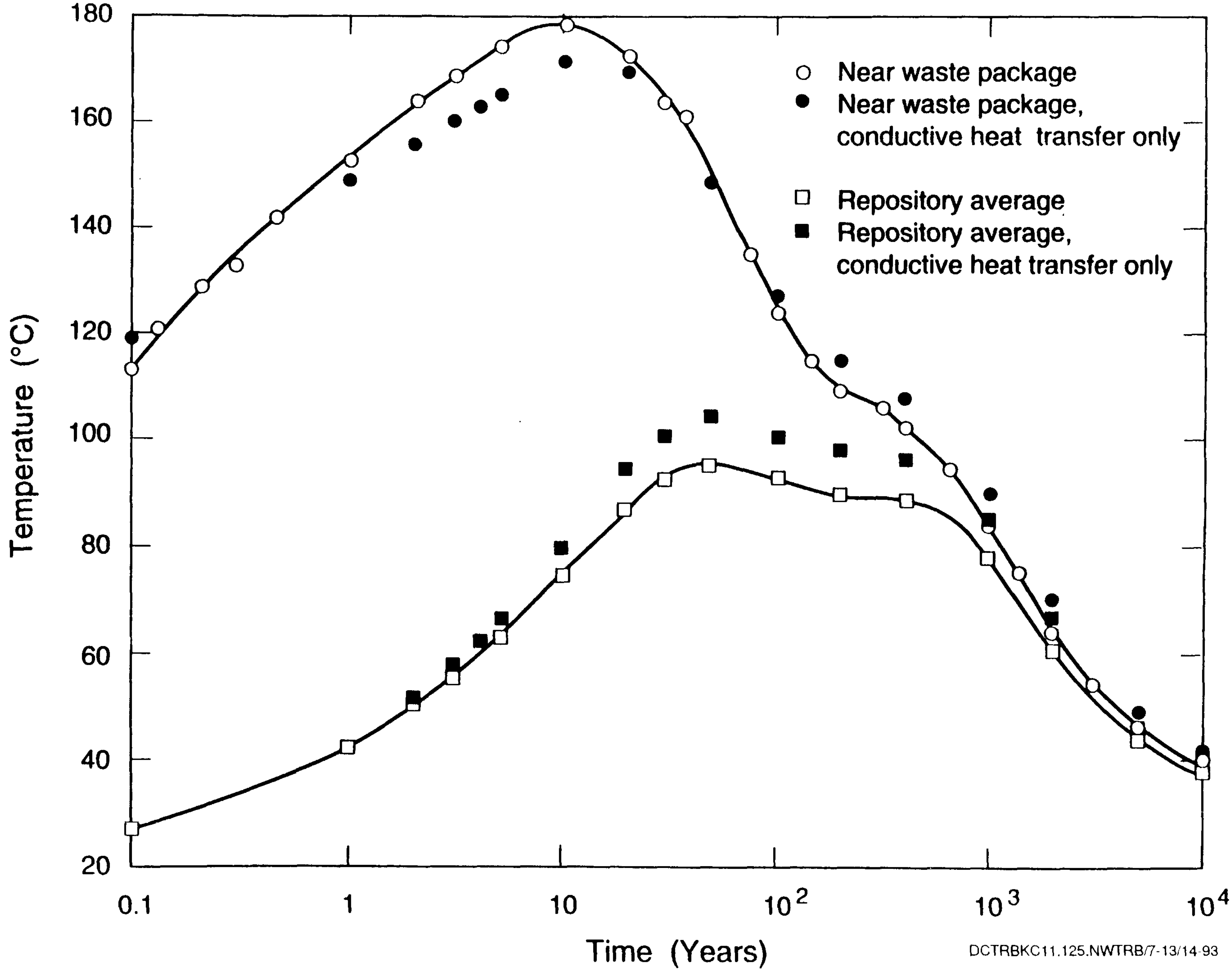

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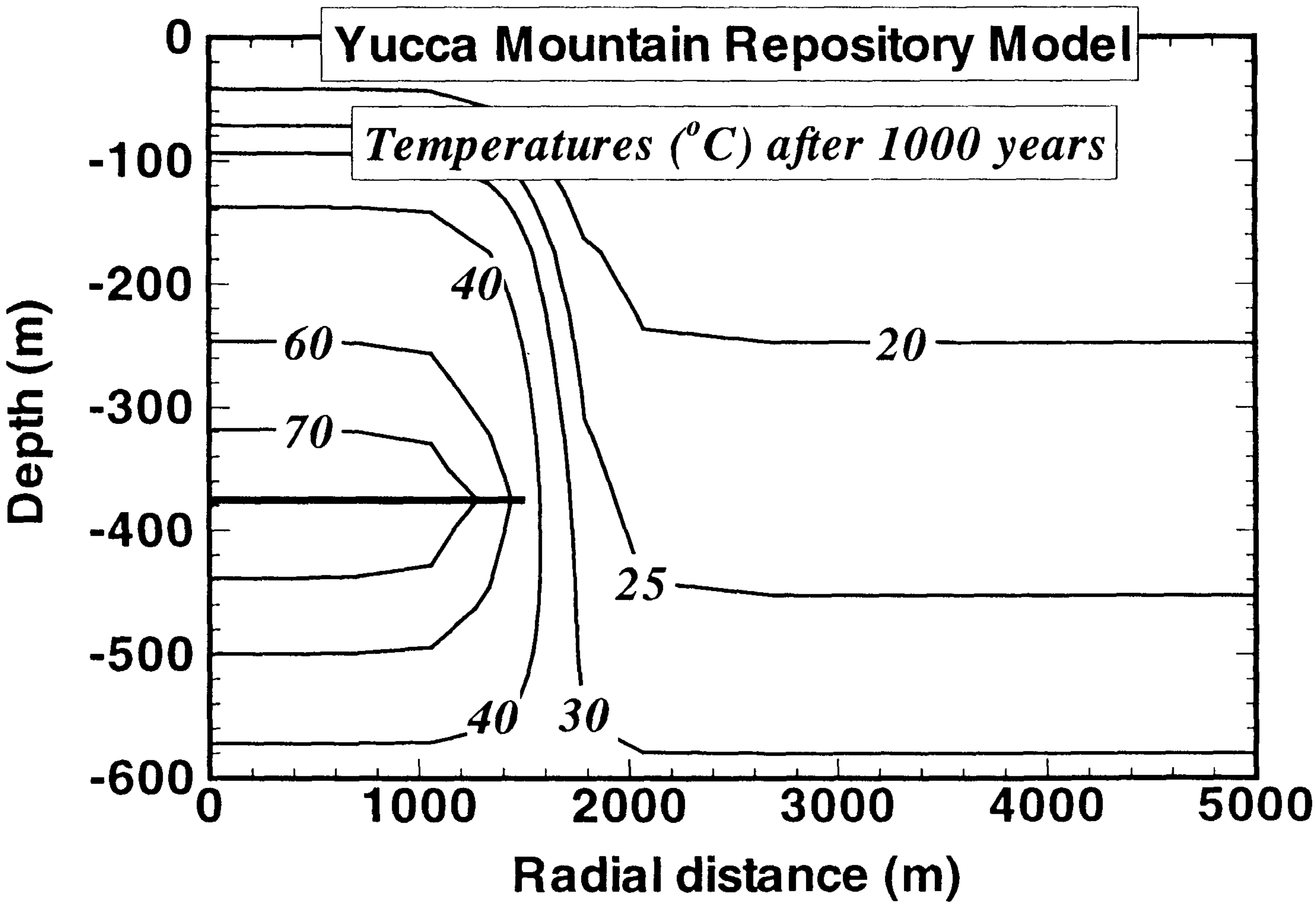

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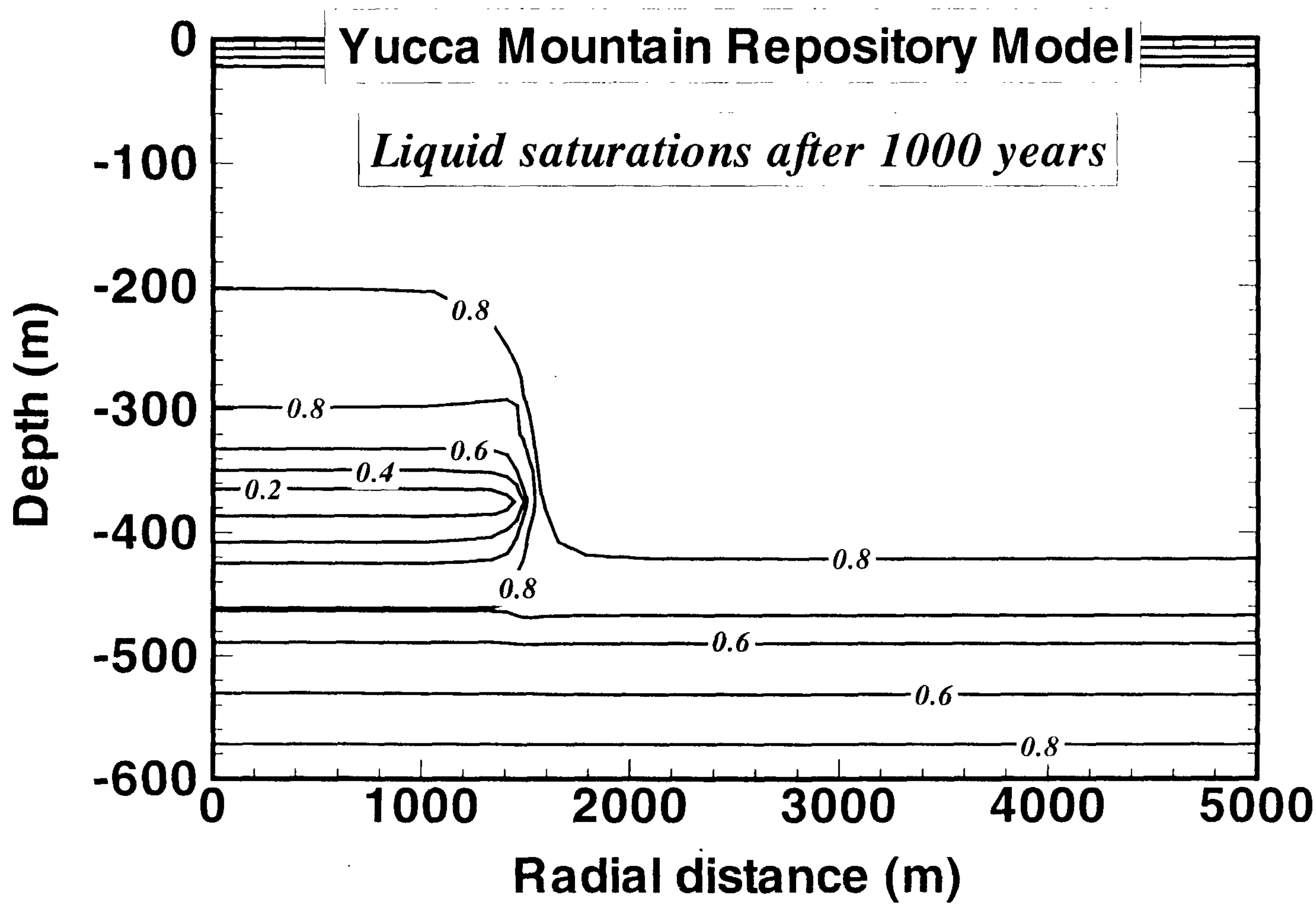
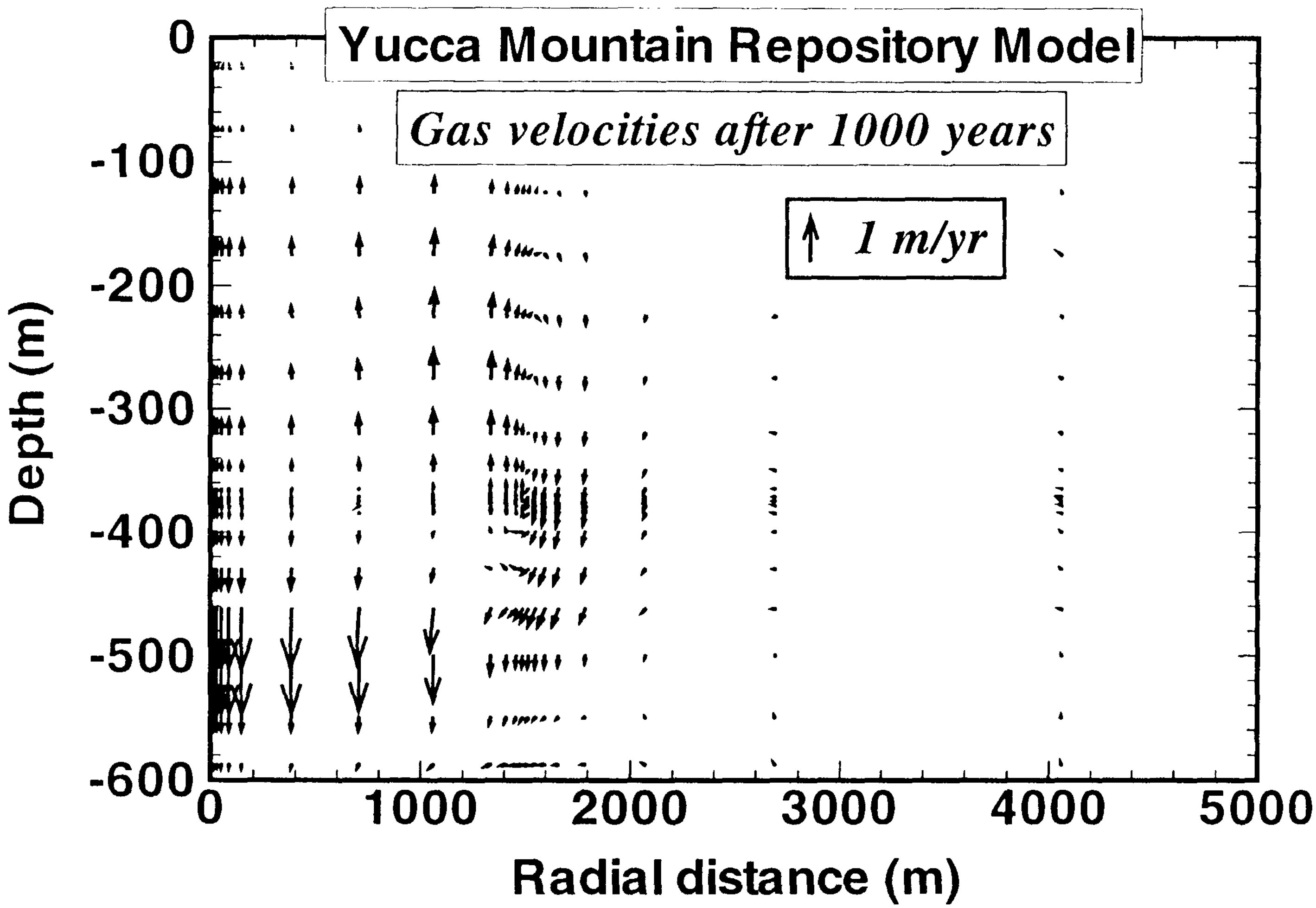
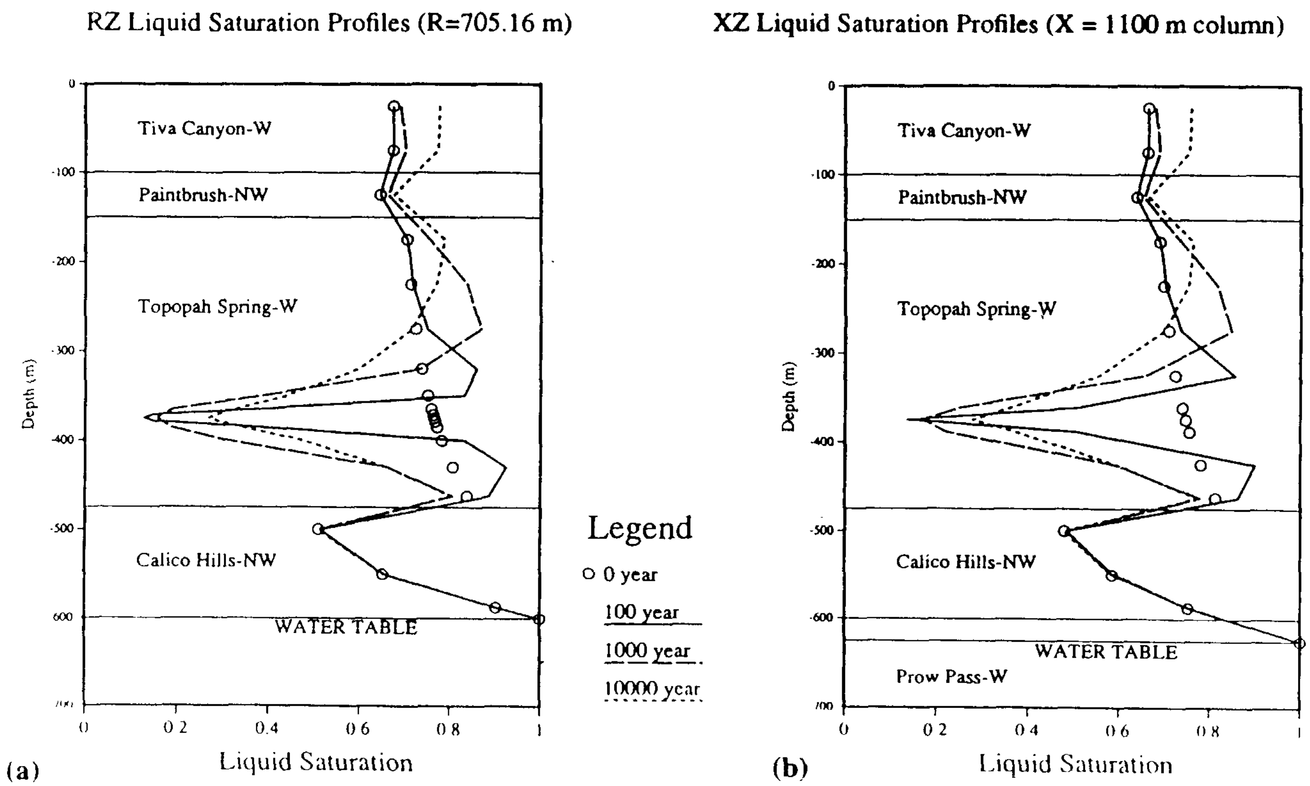
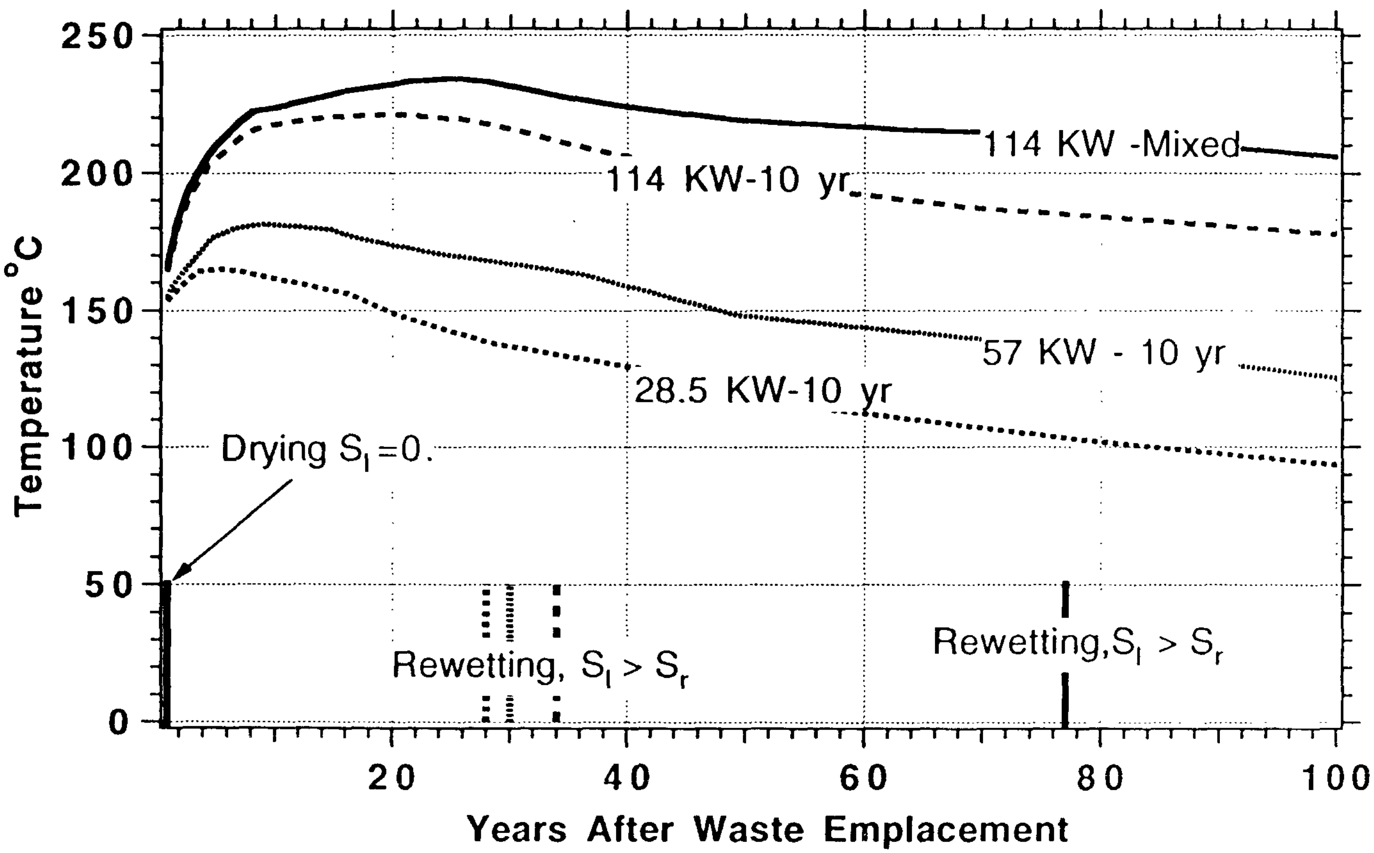

Yucca Mountain Repository Model
Liquid saturations after 1000 years
0
-100
-200
-300
-400
-500
-600
Depth (m)
0.8
0.8
0.6
0.4
0.2
0.8
0.8
0.6
0.6
0.8
0
1000
2000
3000
4000
5000
Radial distance (m)


Yucca Mountain Repository Model
Gas velocities after 1000 years
1 m/yr
Depth (m)
0
-100
-200
-300
-400
-500
-600
0
1000
2000
3000
4000
5000
Radial distance (m)

Simulated Water Saturation Profiles



Temperature History, Drying and Rewetting Times at Node AC 2, 3 cm from Waste-Package Surface



Dry Repository Operation?

You can

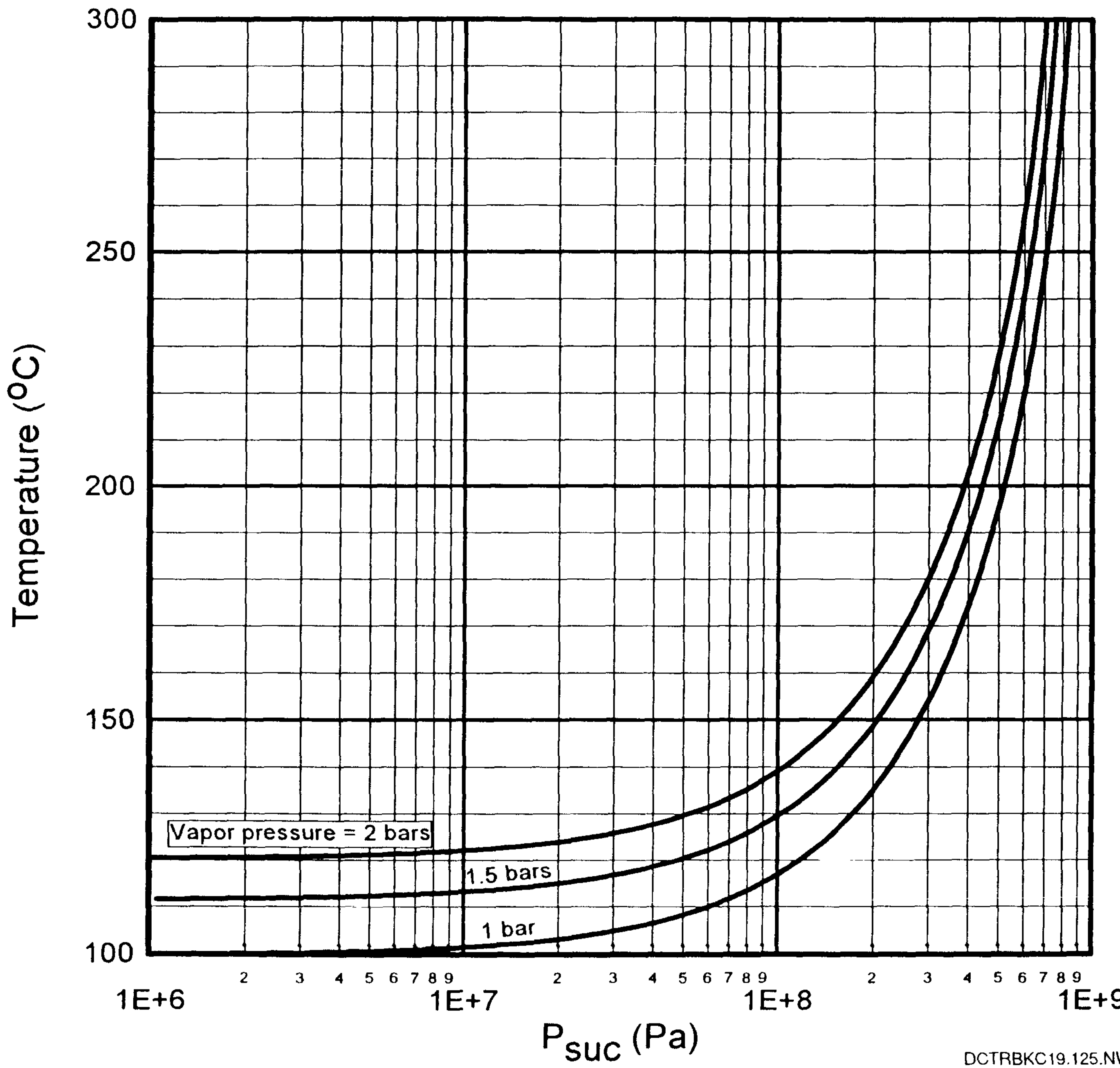
- Keep some of the waste packages dry all of the time
- Keep all of the waste packages dry some of the time

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



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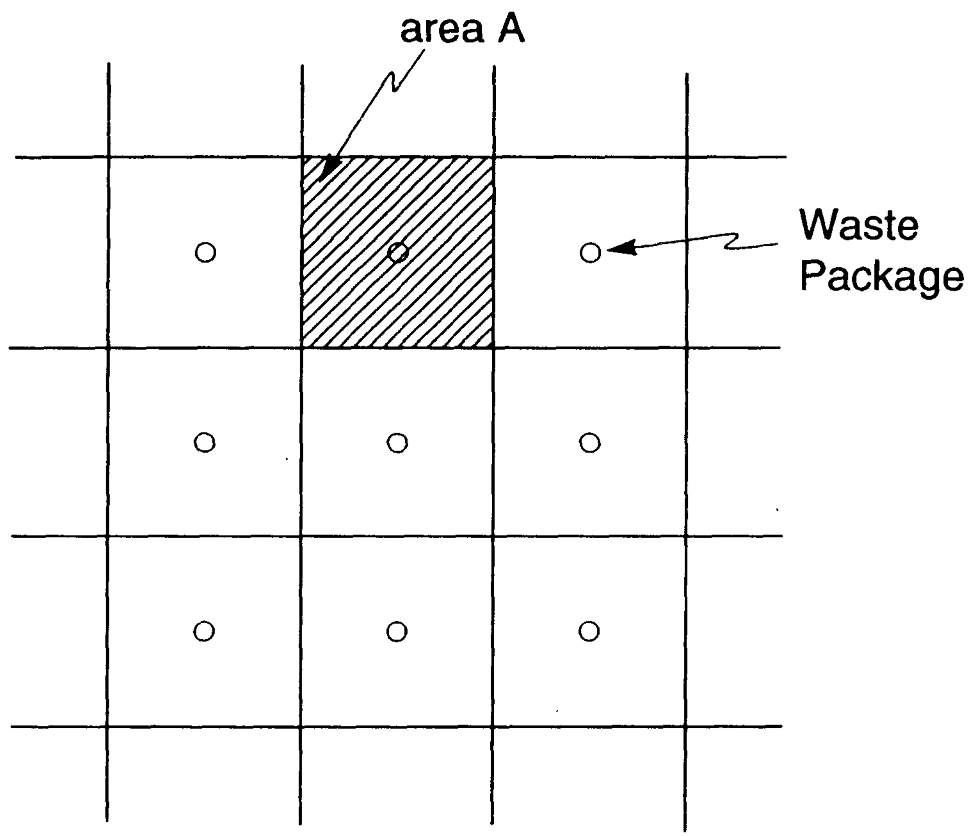
Waste Heat ⇔ Infiltration



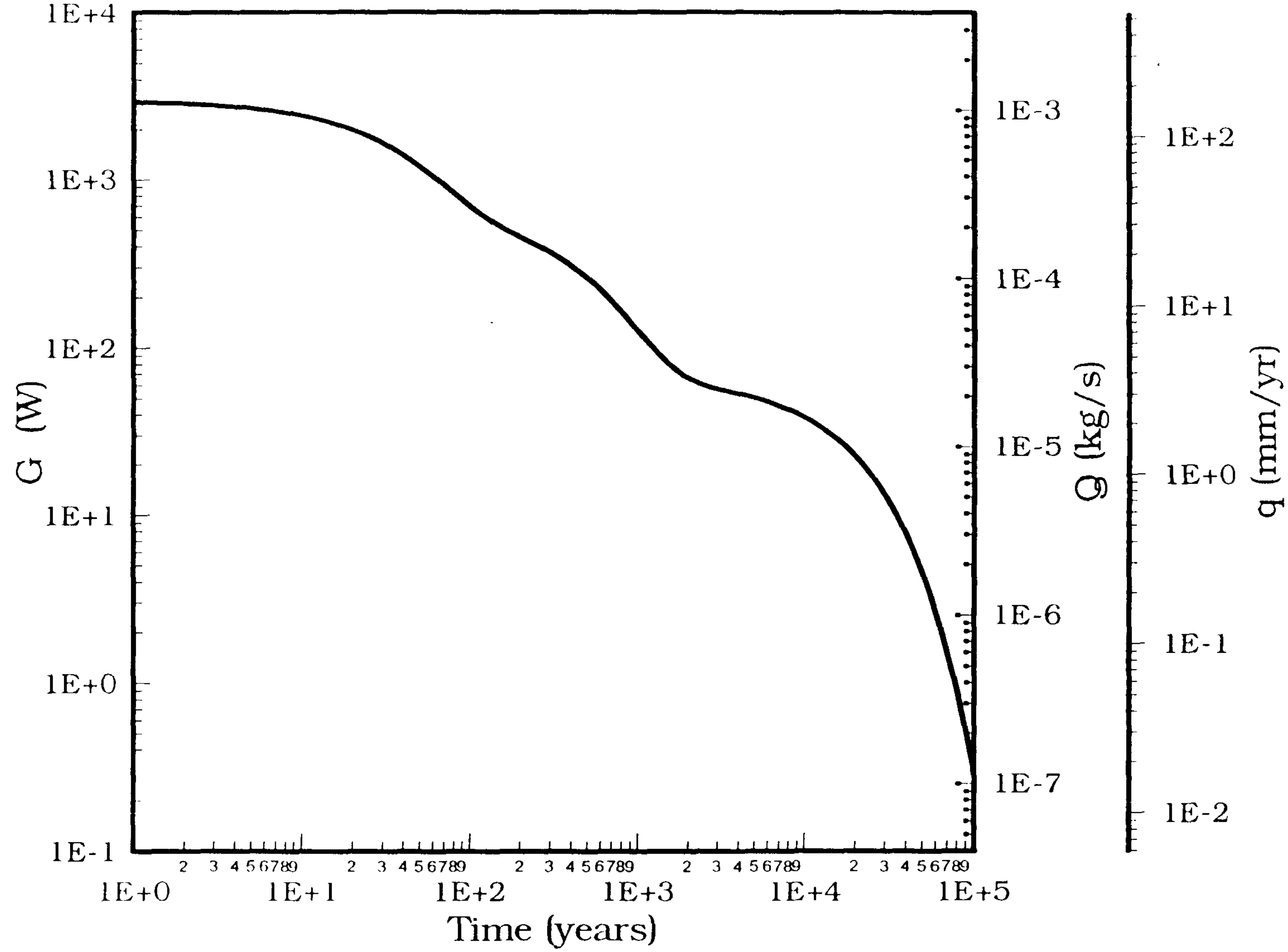
Heat rate per waste package, G (W)
Area per waste package, A (m^2)
Net infiltration, q (mm/yr)
Net infiltration per waste package, Q (kg/s)

$$Q = Aq\rho^w$$

Heat requirement for vaporization

$$Q\,(hv - hl) \leq G$$

Heat Output and Vaporization (Single Waste Package)



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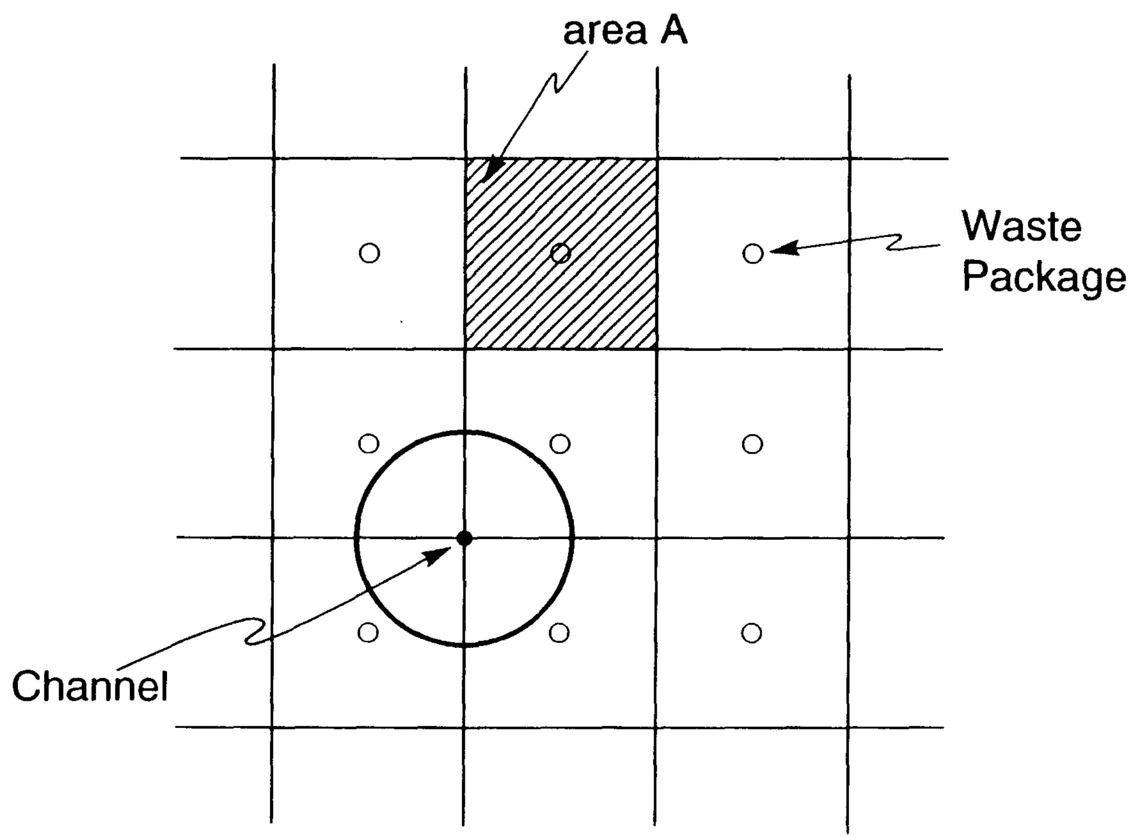
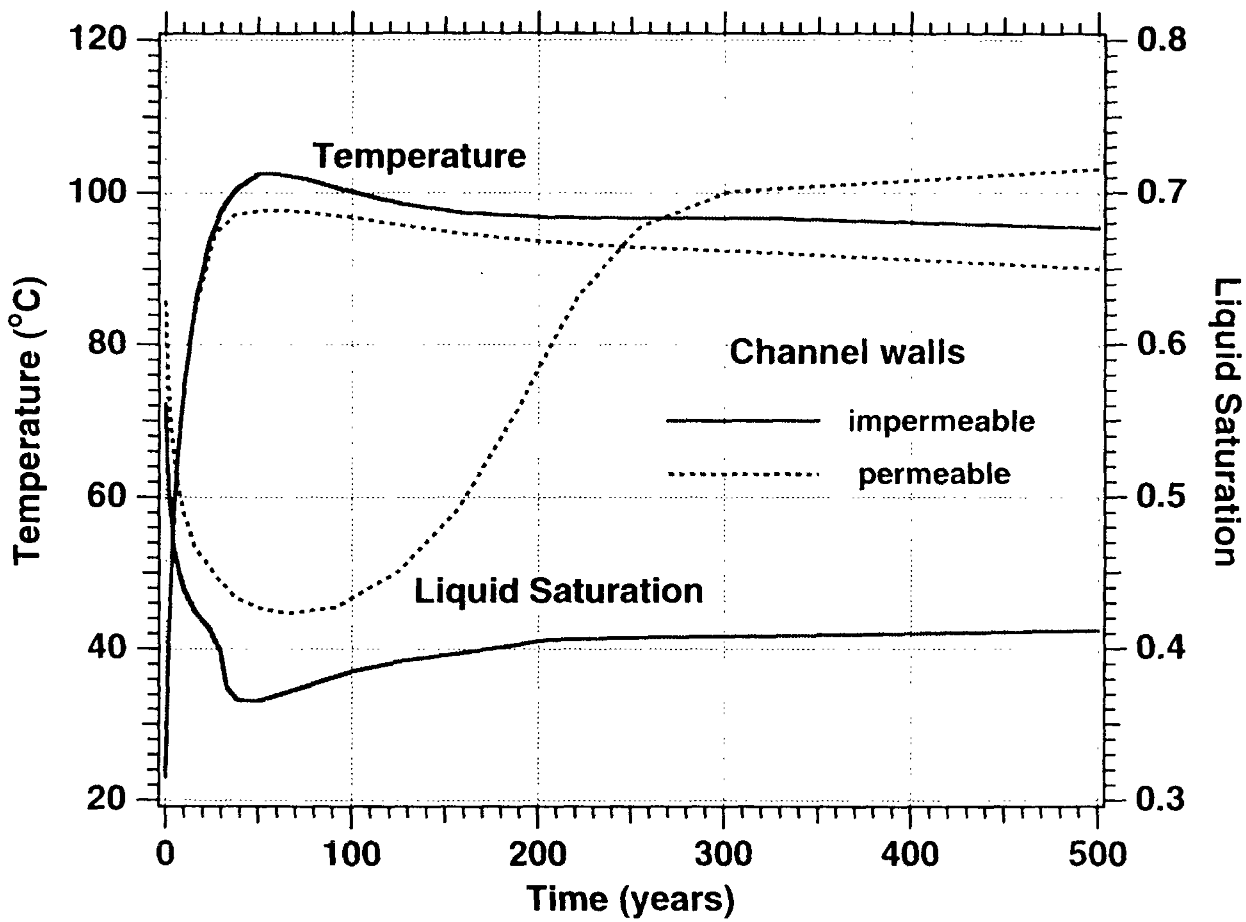
Water Flow in Unsaturated Fractured Media

- 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


area A
Waste
Package
Channel

Vertical Water Channel: Temperature and Liquid Saturation at Repository Horizon



Inundation of Waste Packages by Ponded Water?

Waste Form	Total Heat Capacity (MJ/°C)*	Vaporization Capability (kg)	Vaporization Capability (m^3)
(1)	15.85	1754.5	1.83
(2)	5.85	646.9	0.68
(3)	3.27	362.2	0.38

(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

Time After Emplacement (years)	Cumulative Heat Generation (10^{12} Joules)	Maximum Cumulative Condensate Generation† (10^6 kg)	(10^3 m^3)‡
10	.8658	.3303	.3447
10^2	4.488	1.712	1.786
10^3	12.39	4.726	4.932
10^4	27.59	10.52	10.98
10^5	51.05	19.47	20.32

† Based on converting water at 13 °C to 100 °C vapor; h_{vl} = 2621.5 kJ/kg

‡ 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!