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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: PACIFIC NORTHWEST LABORATORIES (PNL) MODEL: ASSUMPTIONS METHODOLOGY, DATA, AND RESULTS

PRESENTER: DR. PAUL W. ESLINGER

PRESENTER'S TITLE AND ORGANIZATION: PROGRAM MANAGER, PERFORMANCE ASSESSMENT SCIENTIFIC SUPPORT
PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

PRESENTER'S TELEPHONE NUMBER: (509) 376-2792

DALLAS, TX
APRIL 7-8, 1992

Scenarios Modeled

- **Undisturbed repository performance**
  - Gas-phase transport
  - Liquid-phase transport
- **Human intrusion from exploratory drilling**
- **Volcanic disruptions from basaltic dike intrusion**
- **Water table change from tectonic activity**

Source Term Model Assumptions

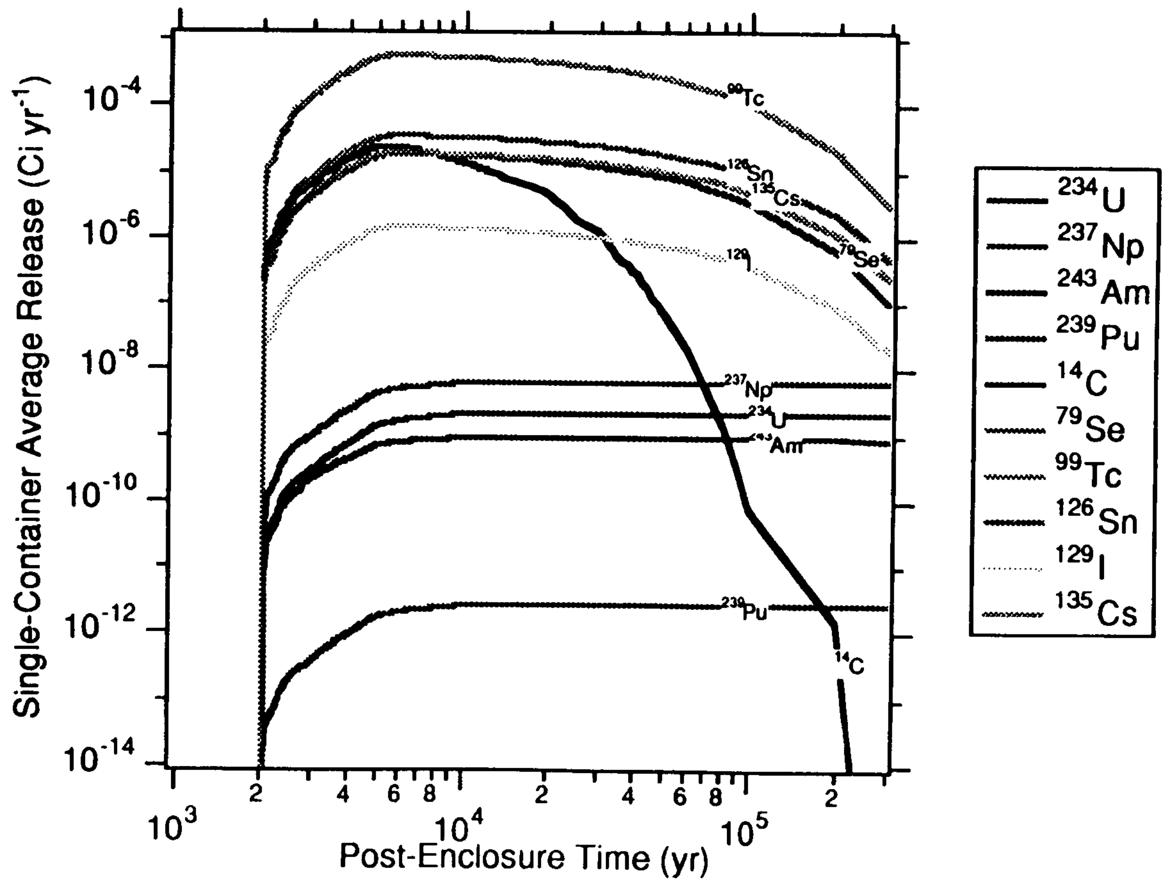
- Spent fuel model considered inventory of crud, gap, grain boundaries, and fuel matrix
- Glass dissolution model used SRL-202 glass
- Release rate limited by fuel and glass alteration rates and/or radionuclide solubilities
- 1-D advective-diffusive "flow-through" mass transport model from waste containers into the host rock
- Species solubilities controlled by water geochemistry
- Liquid-phase releases start after temperature drops below boiling
- Container failure times from assumed statistical distribution

Assumptions Governing Generation of the Source Term

- **Model Domains Analyzed**
  - Unsaturated Zone
  - Saturated Zone
- **Radionuclide inventories**
  - Spent fuel: ORIGEN runs for 40% BWR and 60% PWR fuel mix
  - Glass: Reference inventories for SRL-202 glass
- **Groundwater flow and saturations from hydrologic model**
  - Unsaturated zone: Infiltration rates ranged from 0.0 to 0.5 mm/yr
  - Saturated zone: Pore velocities from 0.001 to 70 m/yr
  - Water flow rate the only "random" variable
- **Analysis limited to 10 radionuclides**

Release from the Engineered Barrier System

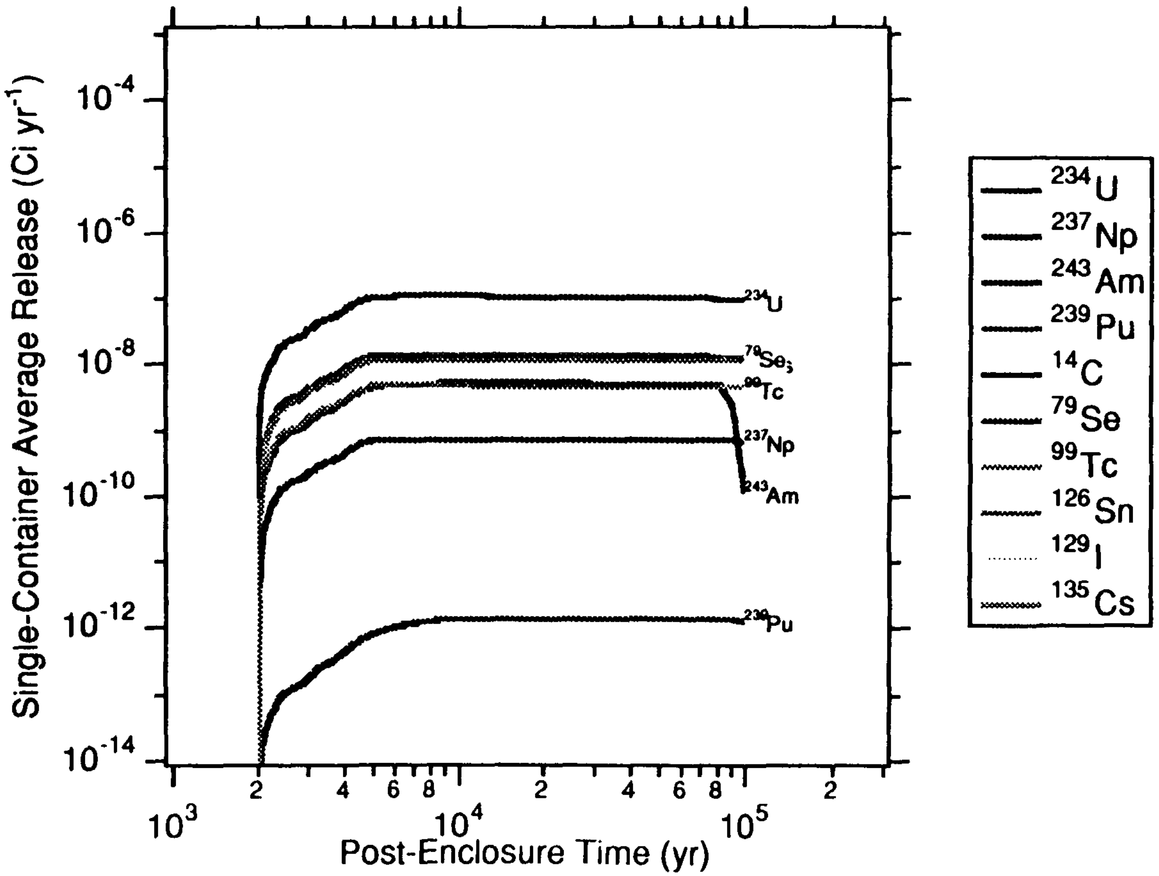
Base Case Analysis (Spent Fuel)



Infiltration = 0.01 mm/yr

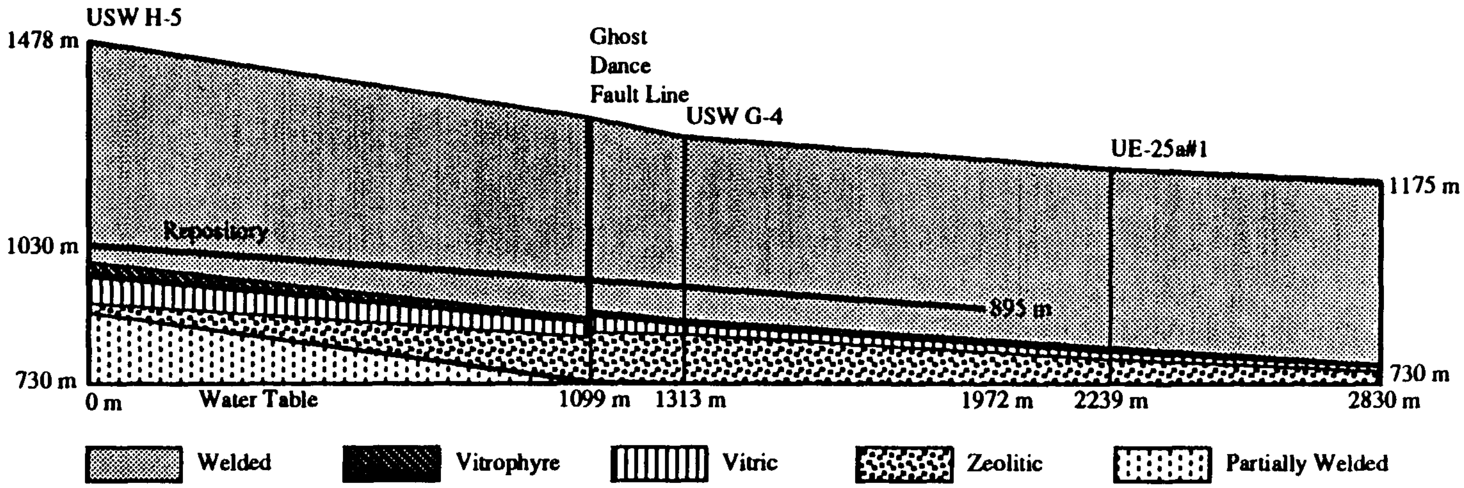
Release from the Engineered Barrier System

Base Case Analysis (SRL-202 Glass)



Infiltration = 0.01 mm/yr

Yucca Mountain Unsaturated Zone Conceptual Model



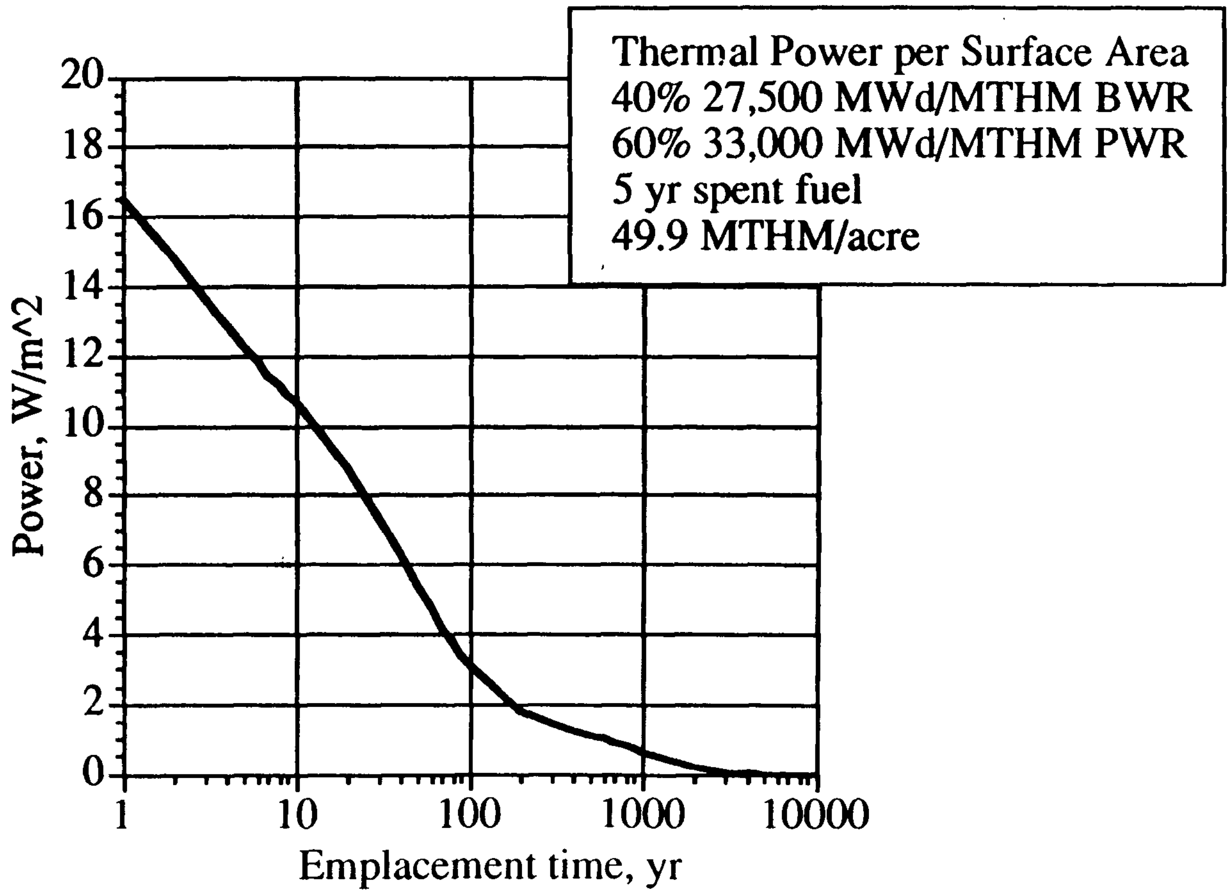
Mathematical Model Governing Gas-Phase Transport of ^{14}C

- Two-phase flow in porous and fractured media
- Two-phase heat transfer by convection and conduction
- Two-phase dilute species transport with radioactive decay
- Air-water binary diffusion
- Fracture models: discrete and dual porosity
- Multiple porosities: total, diffusive, effective

Primary Gas-Phase Model Assumptions

- No capillary hysteresis
- Thermal equilibrium between pore fluids and rock
- Equilibrium thermodynamics
- No conductive heat transfer through the gas-phase

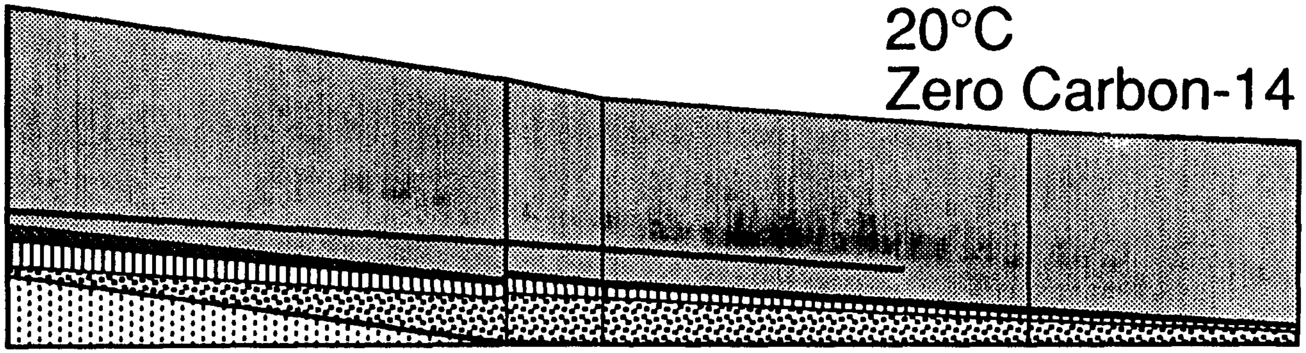
Decay Heat Source



Boundary Conditions

Surface Conditions
Applied infiltration
Standard atmosphere
10% Relative humidity
20°C
Zero Carbon-14 conc.

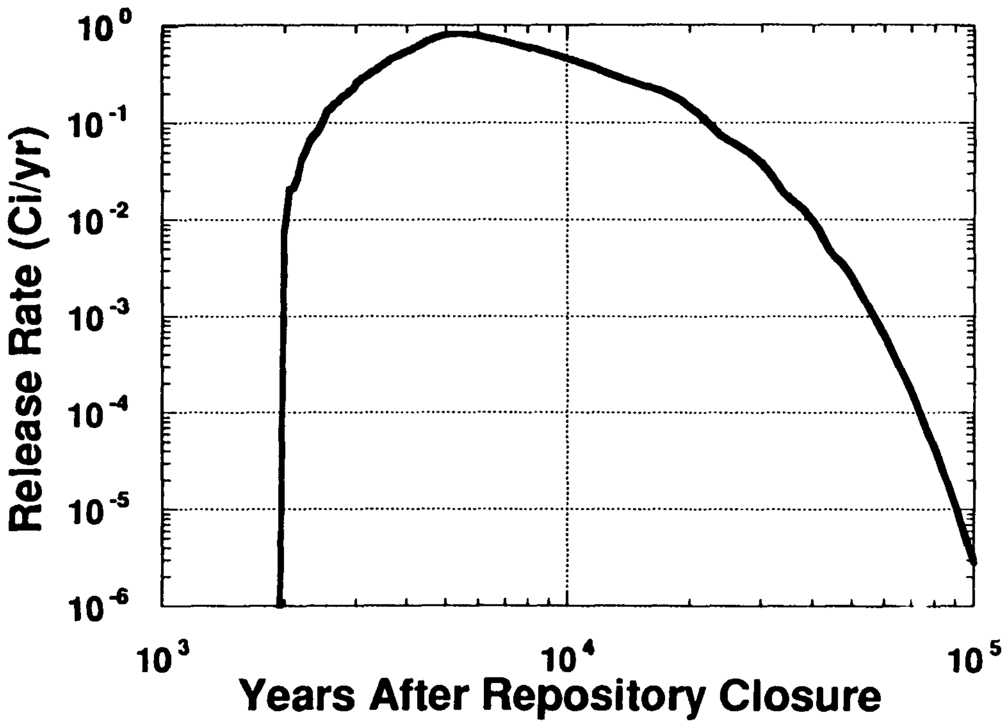
Zero Flux



Zero Flux

Water Table Conditions
Saturated
Zero gas flux
30°C
Zero Carbon-14 conc.

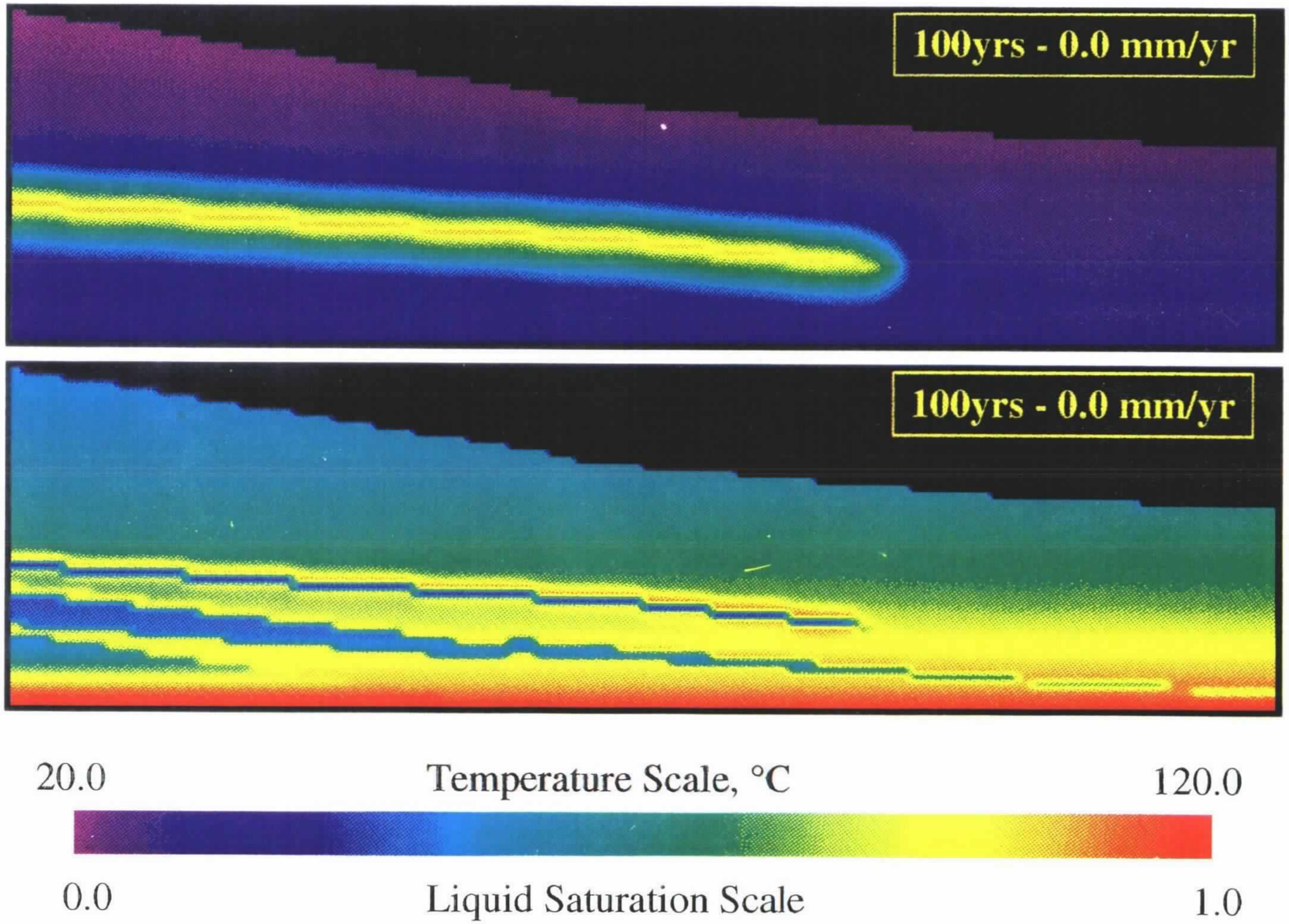
^{14}C Releases from the Engineered Barrier System



0.01 mm/yr infiltration

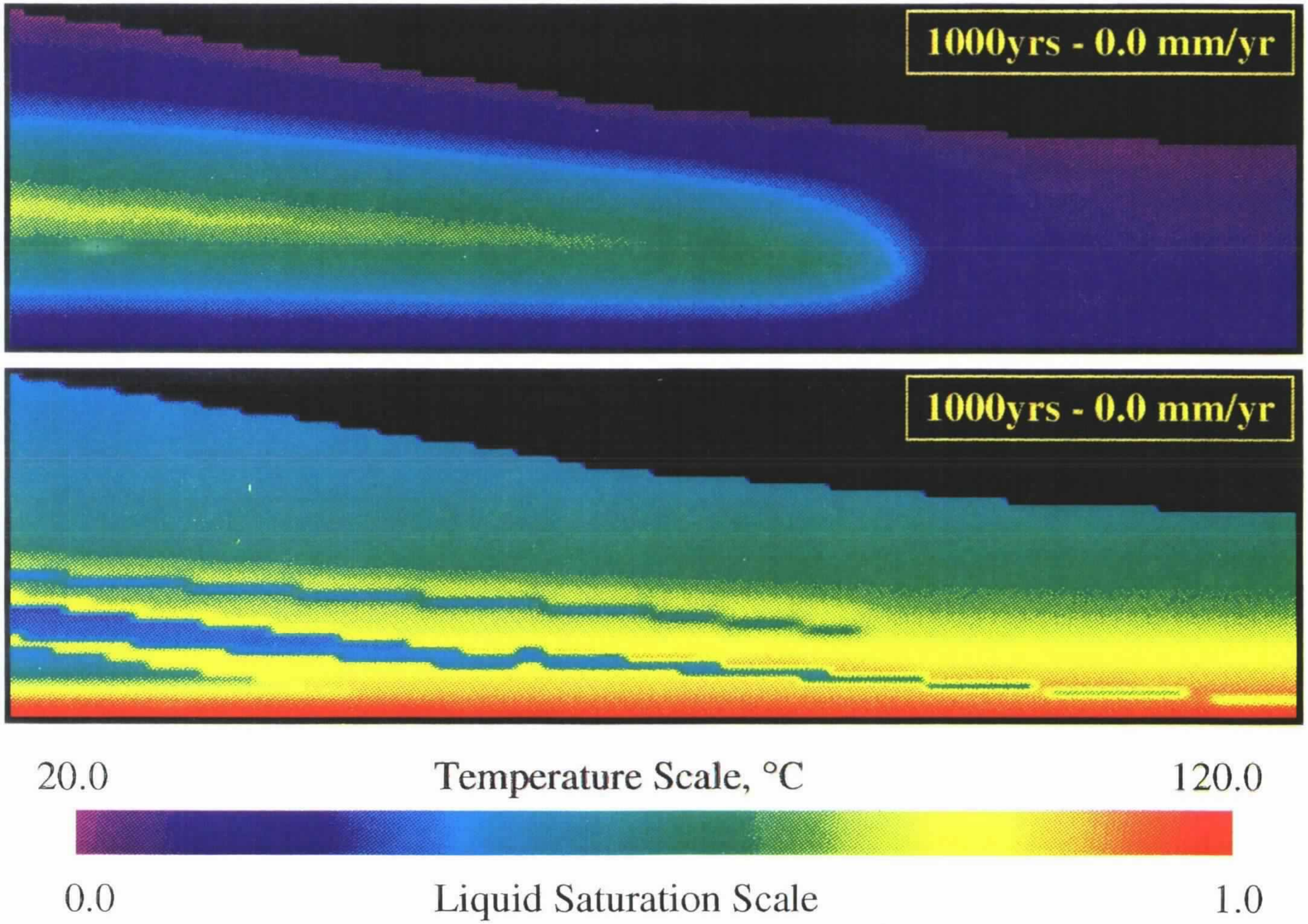
Temperature and Liquid Saturation at 100 yr

Pacific Northwest Laboratory



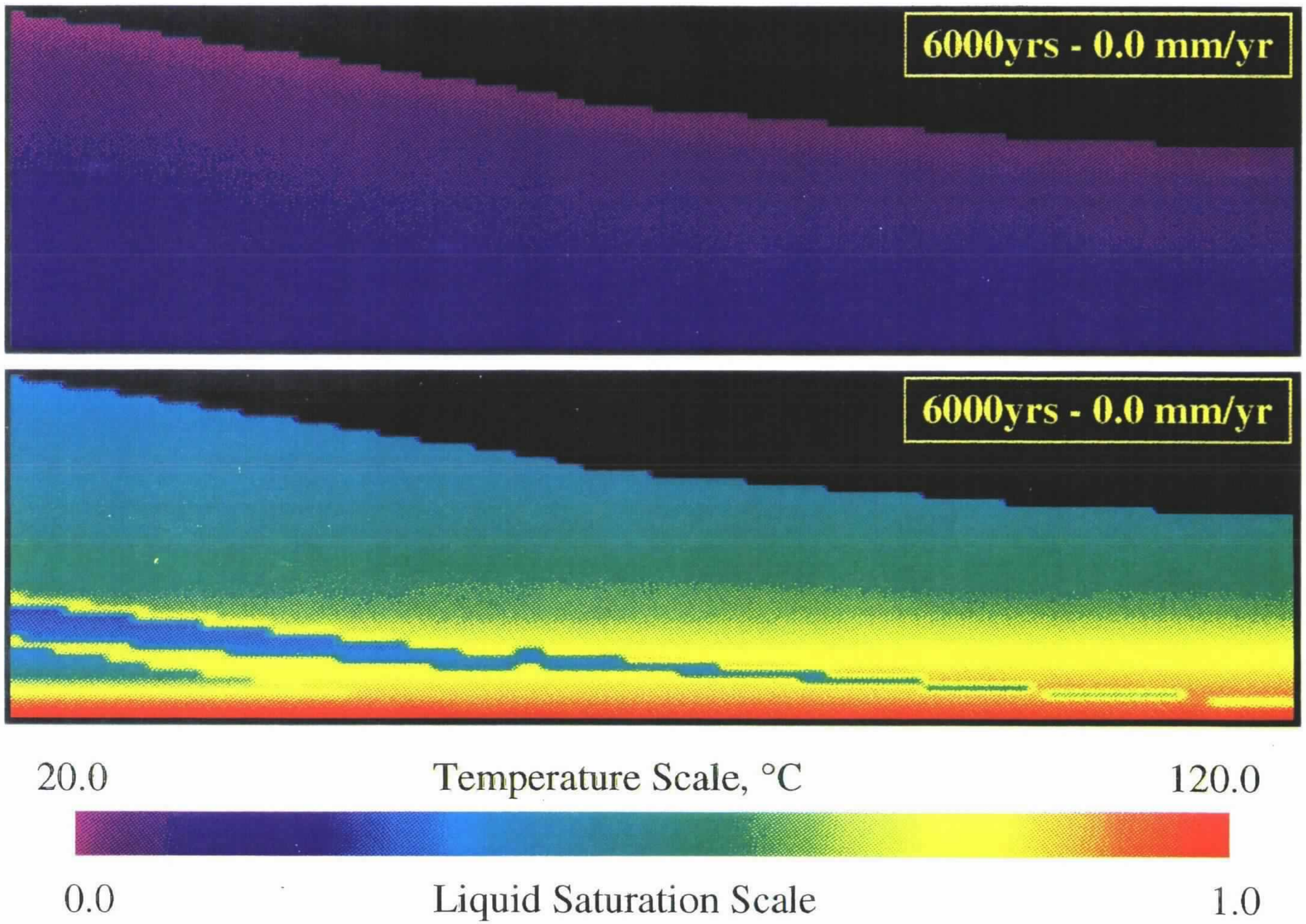
Temperature and Liquid Saturation at 1000 yr

Pacific Northwest Laboratory



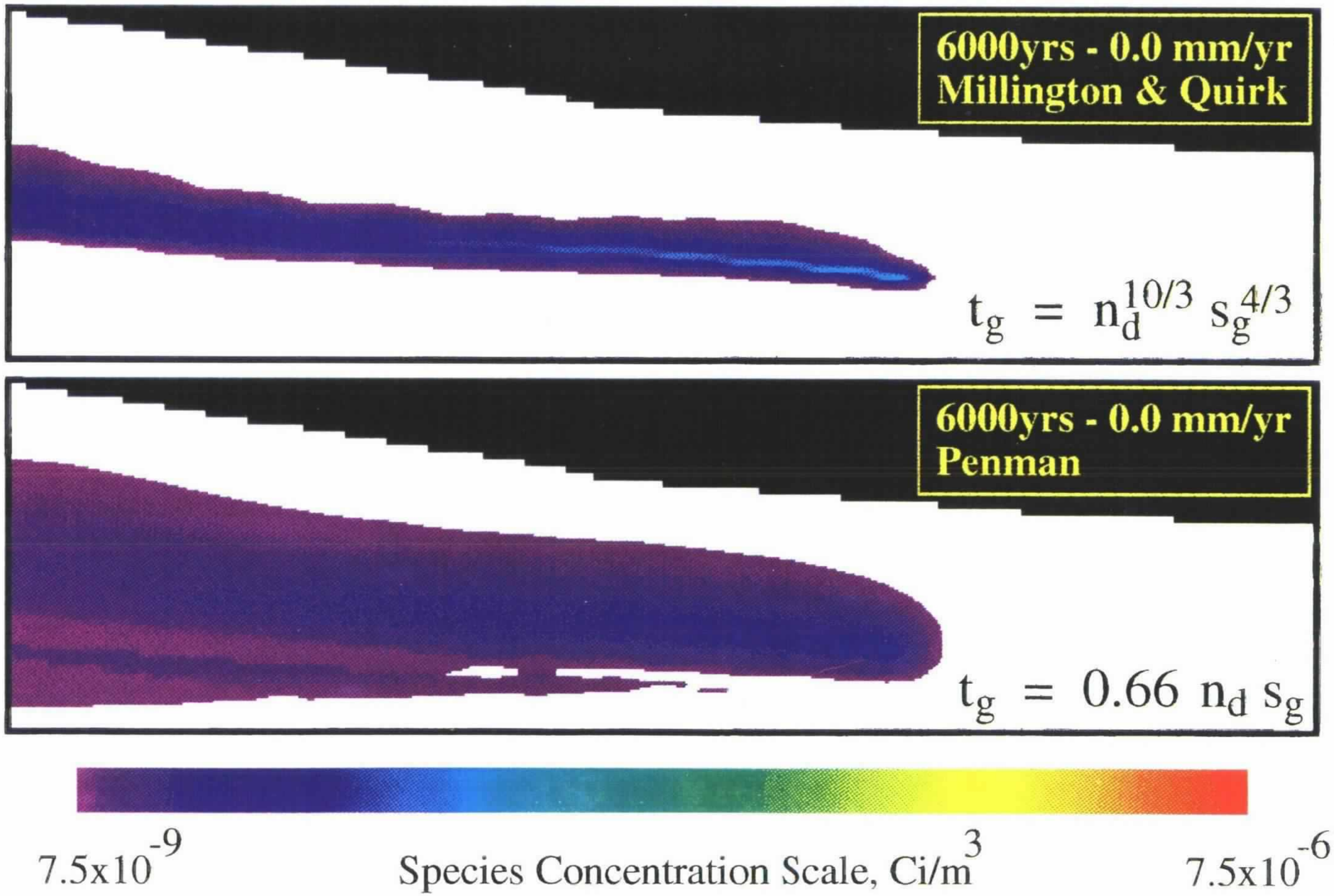
Temperature and Liquid Saturation at 6000 yr

Pacific Northwest Laboratory

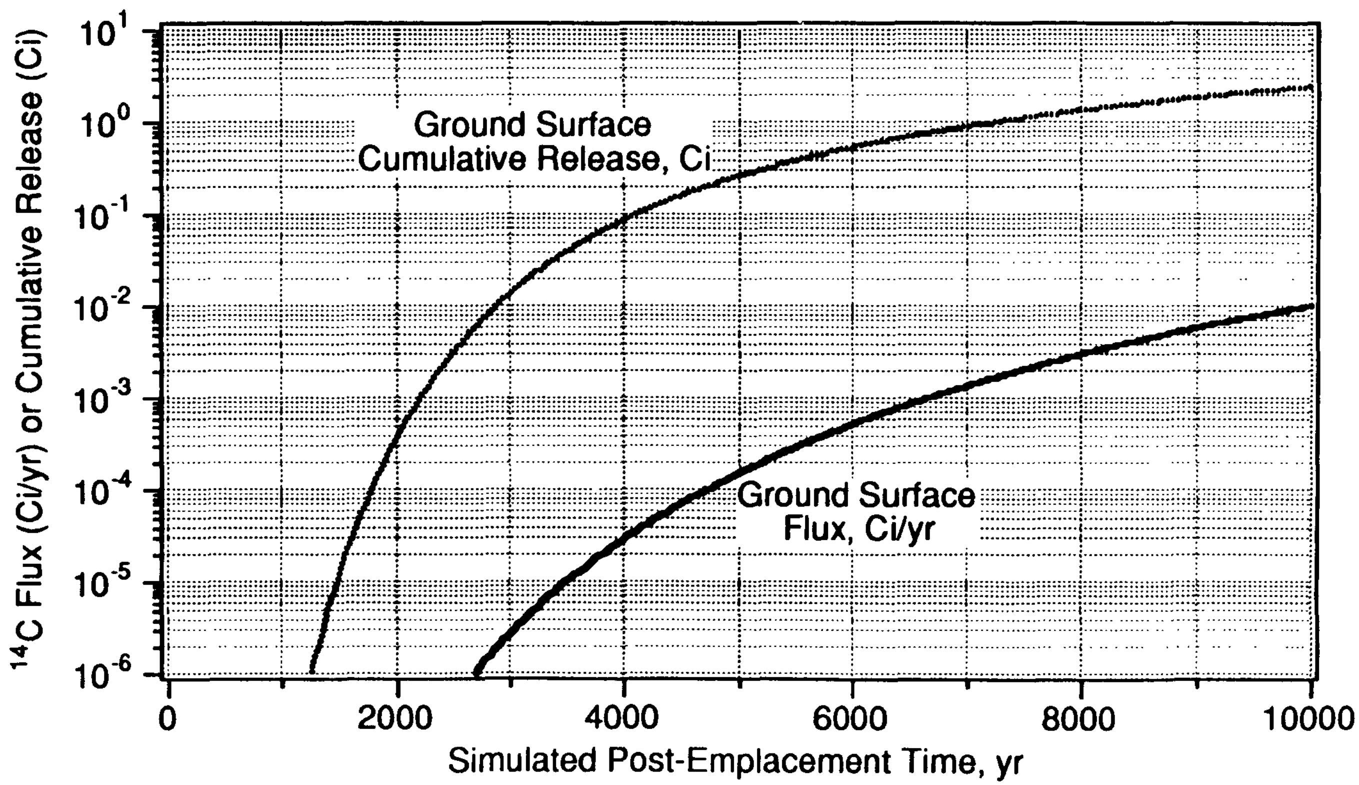


Species Transport at 6000 yr

Pacific Northwest Laboratory



Cumulative Release of ^{14}C to the Ground Surface in 10,000 yr



Effects of Increased Infiltration Rates on Gas-Phase Transport

- There is a strong coupling between gas tortuosity and saturation

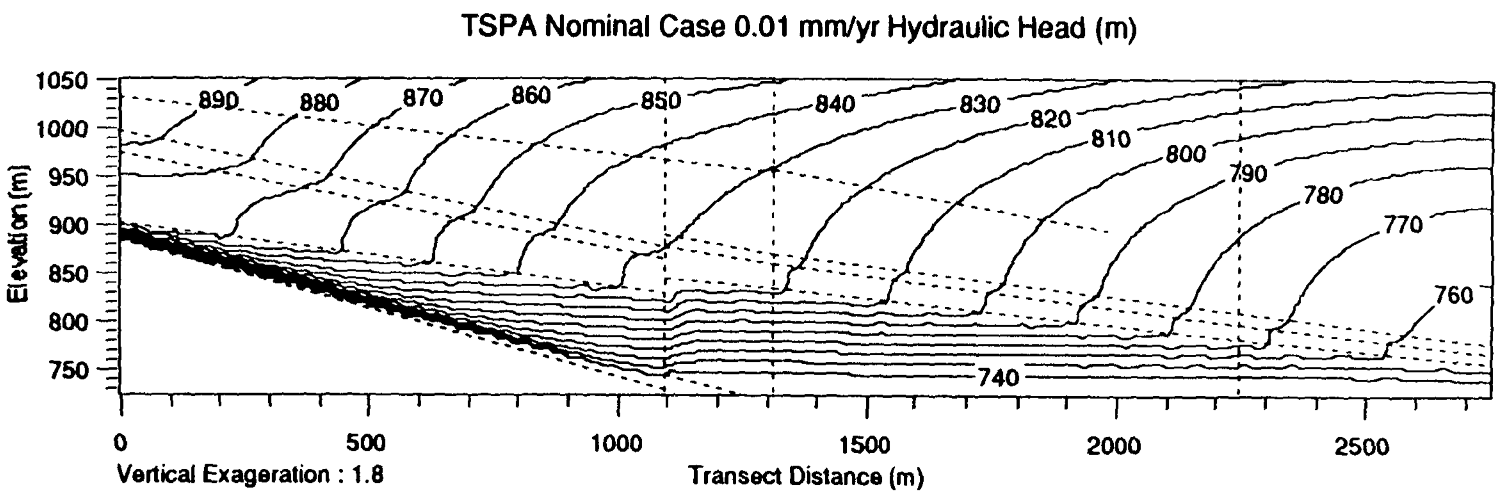
- Higher infiltration rates increase the groundwater saturation, thereby decreasing gas-phase diffusion

- At 0.01 mm/yr infiltration, there were no gas-phase releases to the surface

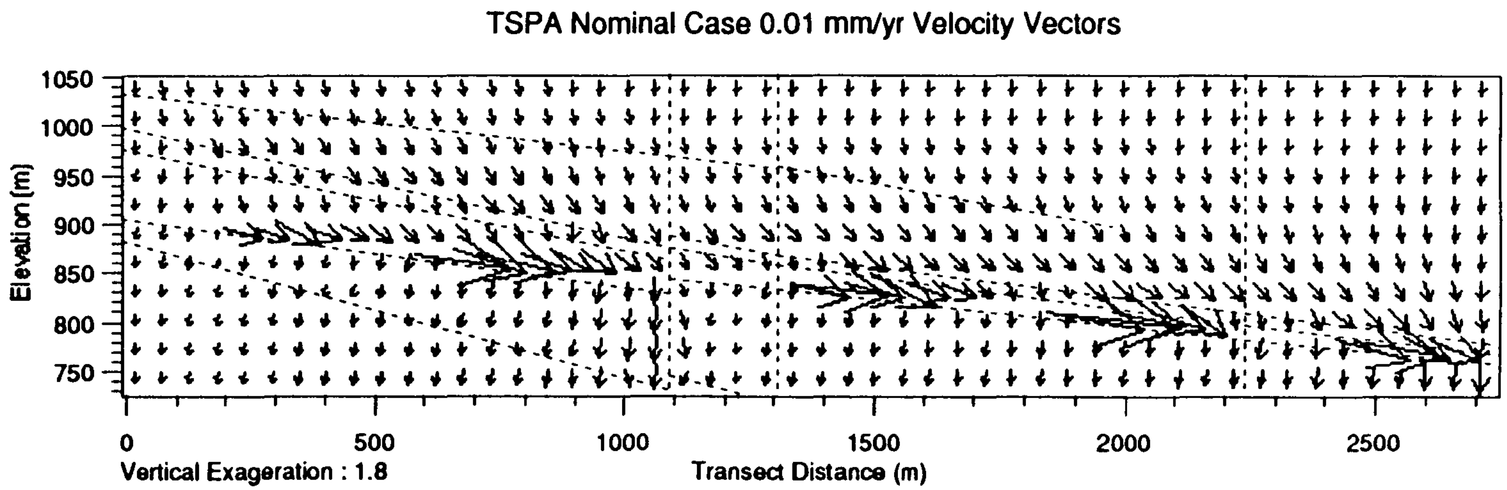
Mathematical Model
Liquid-Phase Transport in Unsaturated Zone

- Isothermal
- Single-phase flow
- Steady-state hydrology solution (Richards equation)
- Constant infiltration rate
- Composite fracture-matrix hydraulic conductivity approach
- Radioactive chain decay
- 2-dimensional model domain

Hydraulic Head Distribution

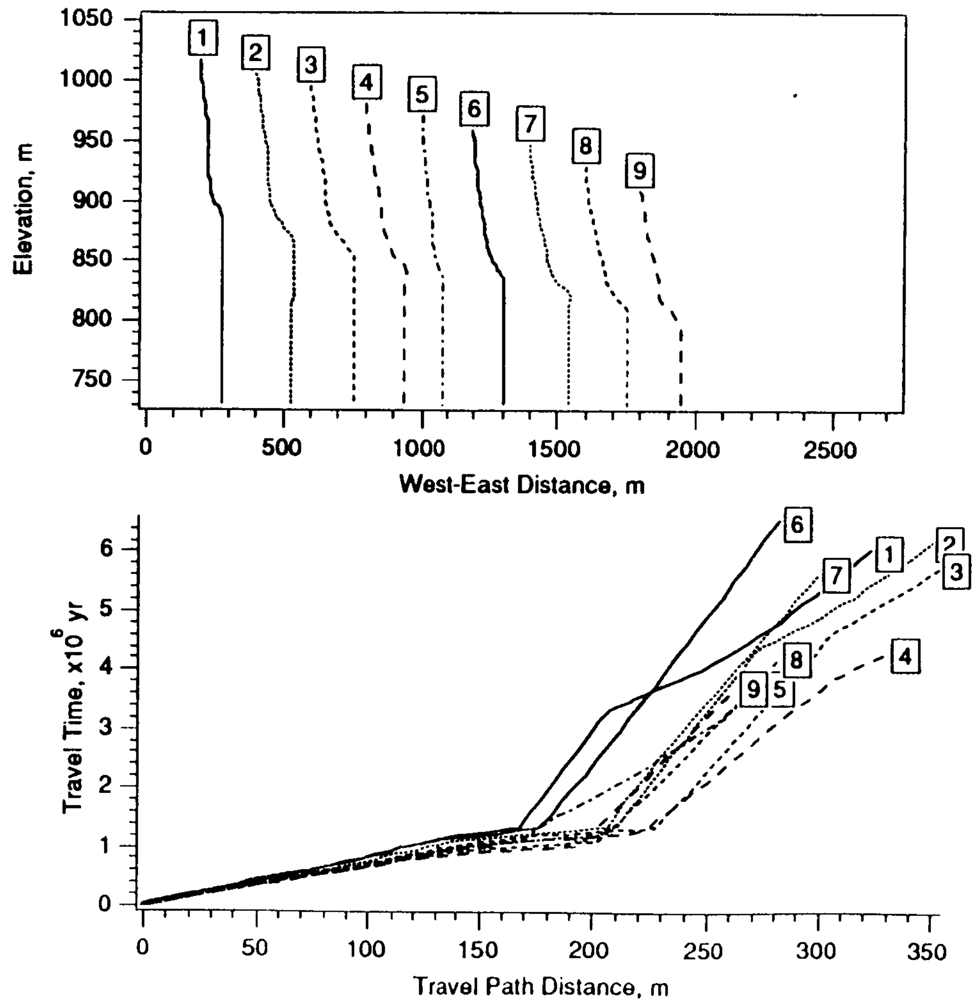


Darcy Velocity Vectors



Unsaturated Zone Ground-Water Travel Times

Recharge Rate
0.01 mm/yr



Cumulative Release to Water Table

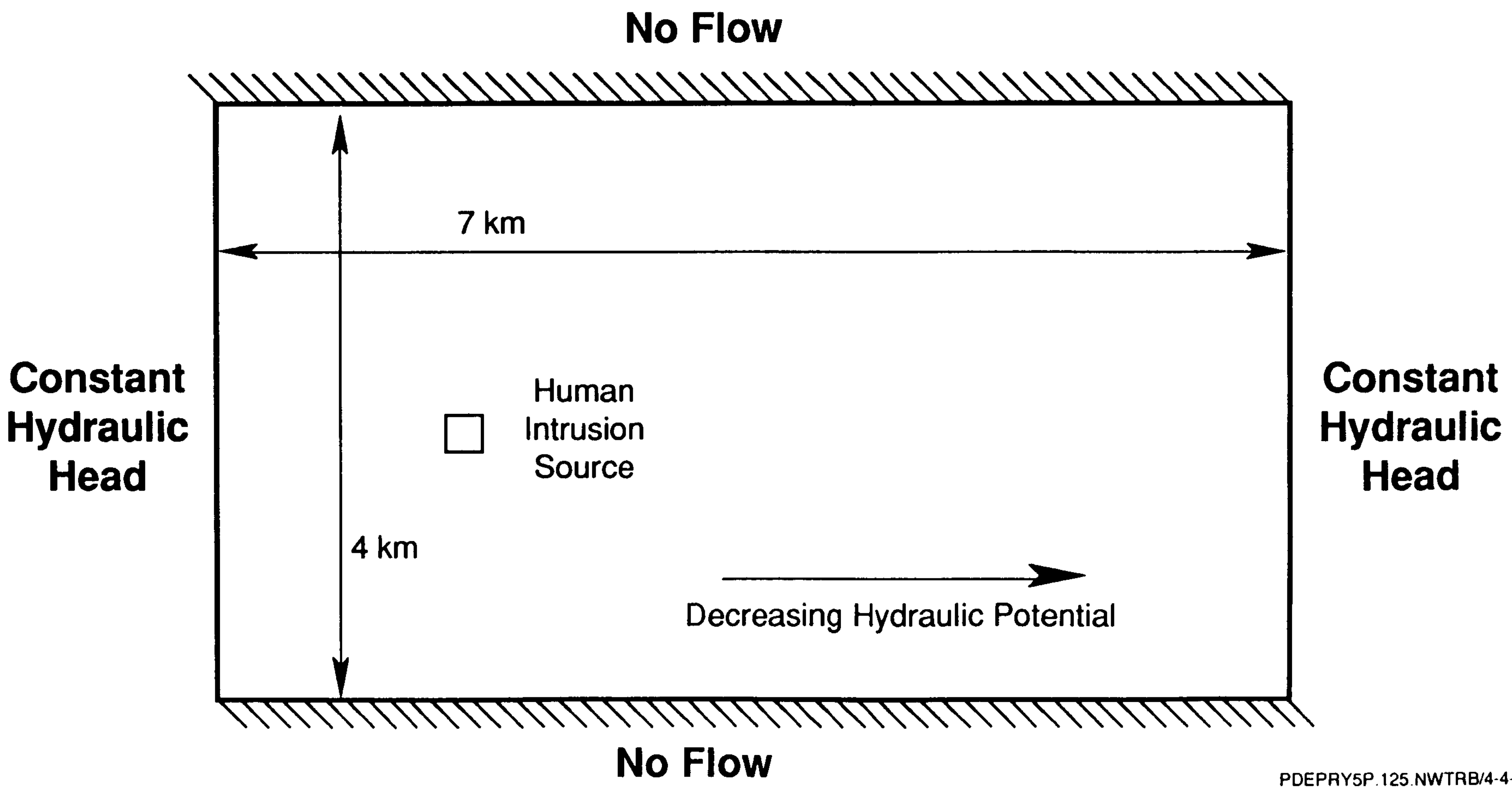
- **None**
- **Assumed modeling conditions**
  - 10,000 yr transport
  - Infiltration rates up to 0.5 mm/yr
  - No significant water flow through fractures

Model Assumptions for Saturated Zone Flow and Transport

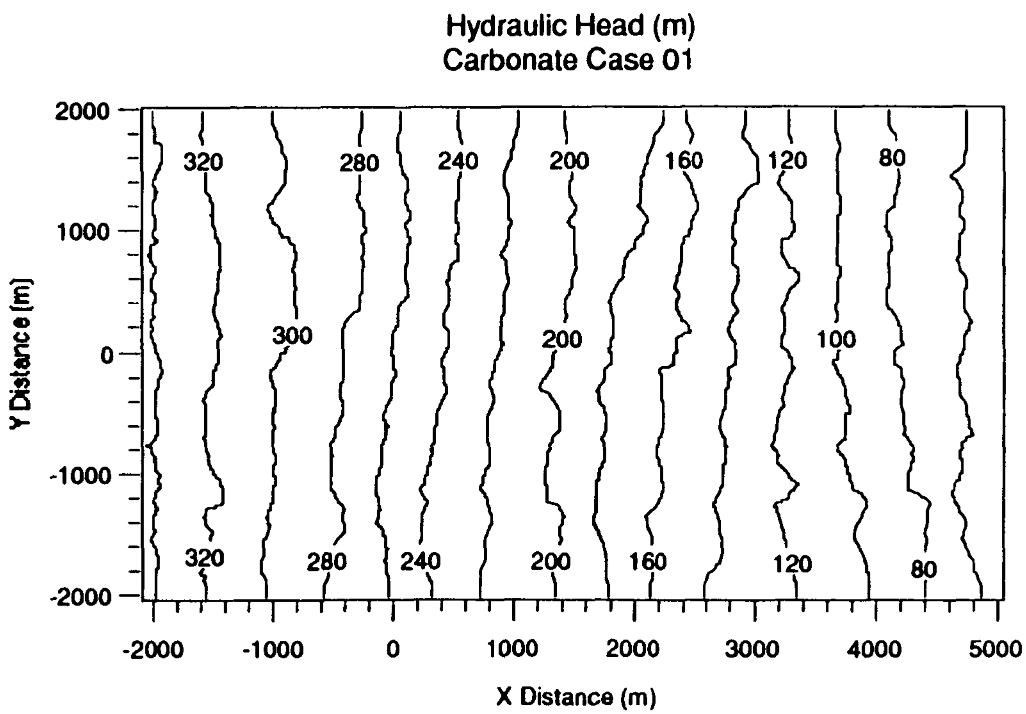
- Homogeneous, isotropic, porous media
- Isothermal, single-phase flow
- 2-D conceptual model domain
- Parameters with statistical distributions
  - Hydraulic gradient
  - Spatially correlated hydraulic conductivities
  - Radionuclide sorption values
  - Time of drilling events (for human intrusion analysis)

Conceptual Model
Liquid-Phase Transport in Saturated Zone

2-D Horizontal Slice in the Deep Carbonate Aquifer



Hydraulic Head Distribution for a Stochastic Hydraulic Conductivity Field



Summary for Saturated Zone Hydrology

- Hydraulic conductivity field generates pressure head fields that are essentially one-dimensional

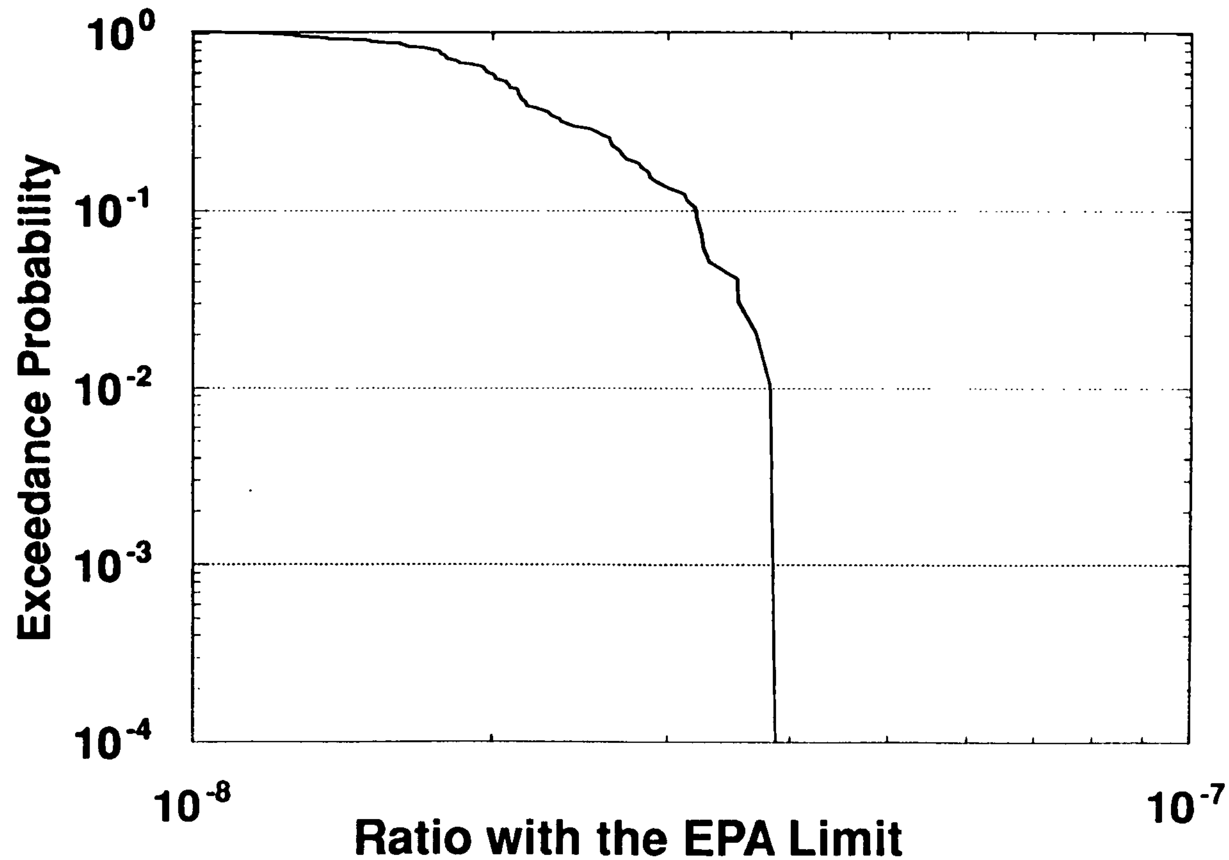
- Particle travel times are strongly dependent upon the hydraulic gradient

- Particle travel time rages
  - Carbonate:
    14 to 9790 yr
  - Partially welded tuff:
    5.20E+3 to 2.86E+6 yr
  - Zeolitized tuff:
    1.40E+7 to 1.40E+10yr

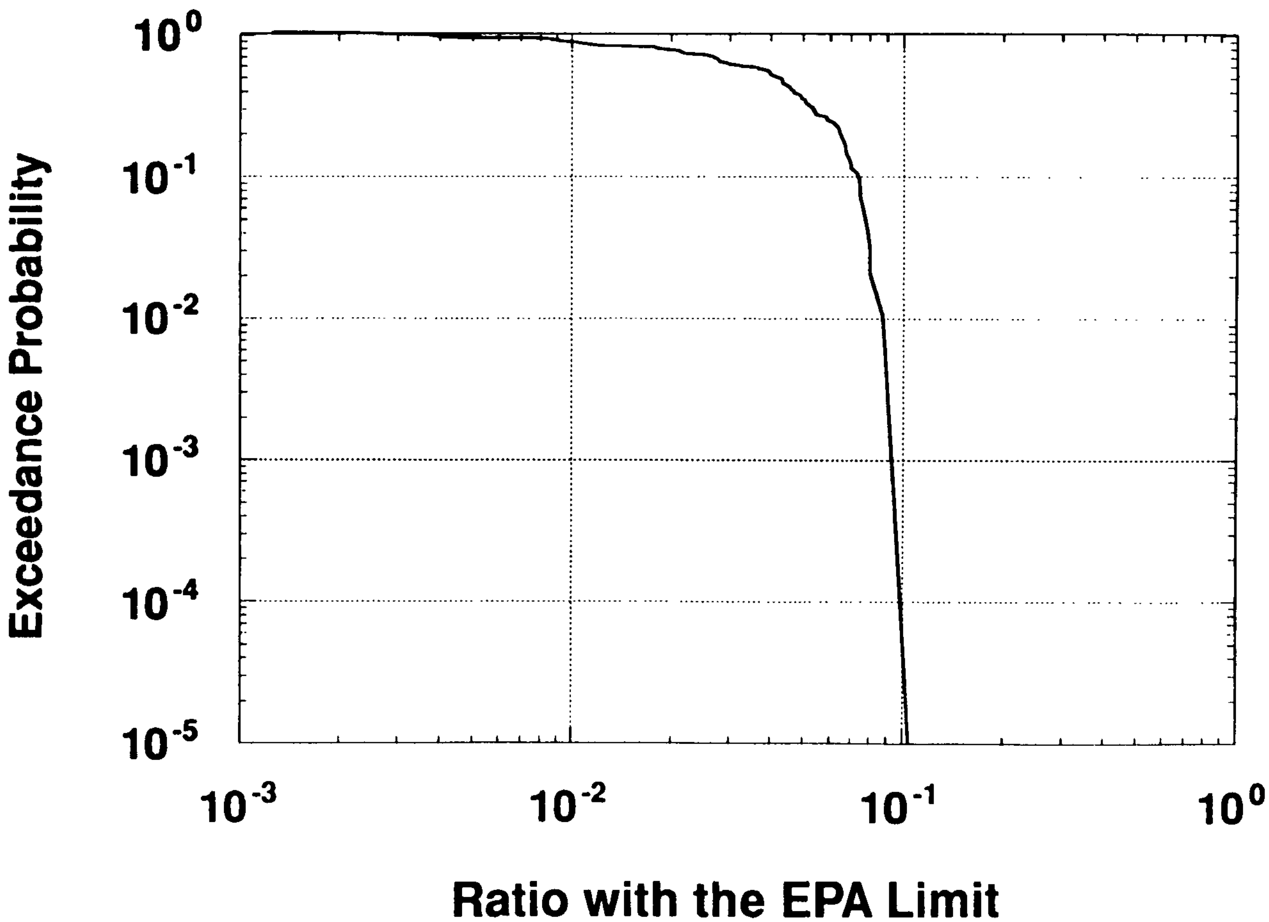
Discussion of Human Intrusion Models

- **Analysis limited to exploratory drilling for water or minerals**
- **Drilling rates taken from 40 CFR 191**
  3 holes / km^2 / 10,000 yr
- **Holes have 30 cm diameter**
- **Drilling Scenarios**
  - Exhumed waste container
  - Exhumed contaminated soil column
  - Injection of single waste container into the Tuff aquifer
  - Injection of single waste container into the Carbonate aquifer

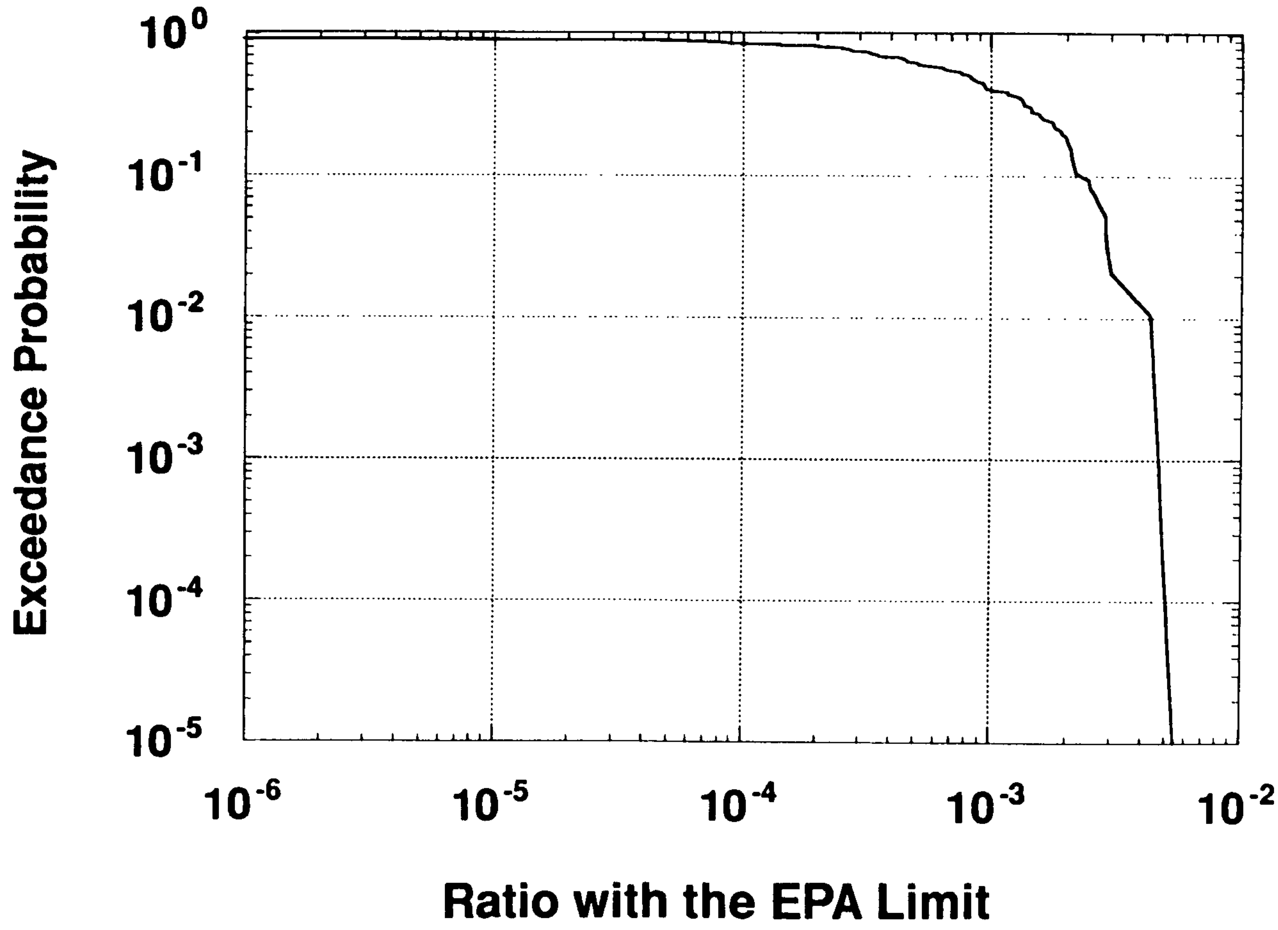
Conditional CCDF for Surface Releases Where Driller Misses All Waste Packages



Conditional CCDF for Surface Releases from Drilling into a Single Waste Package



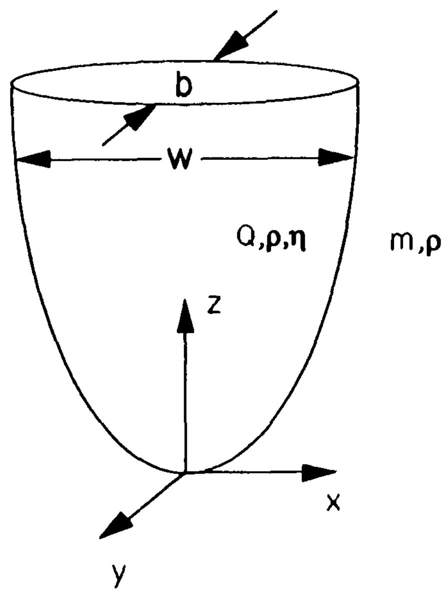
Conditional CCDF for Releases into the Carbonate Aquifer Based on Human Intrusion



Basaltic Intrusion Model Assumptions

- Isothermal, low Reynolds number, undersaturated conditions
- Linear partition function for magma/repository system interactions
- Contaminants instantaneously homogenized in magma
- Basaltic dike intrudes from depth to the land surface

Dike Emplacement Model
(Lister 1990, Lister & Kerr 1991)



$$w = \left[\frac{1.808\,(Q\eta)^3}{zm(g\Delta\rho)^2} \right]^{\frac{1}{10}}$$

$$b = \frac{3.75\,Q\eta}{g\Delta\rho\, w^3}$$

Parameters and Variables

Variables

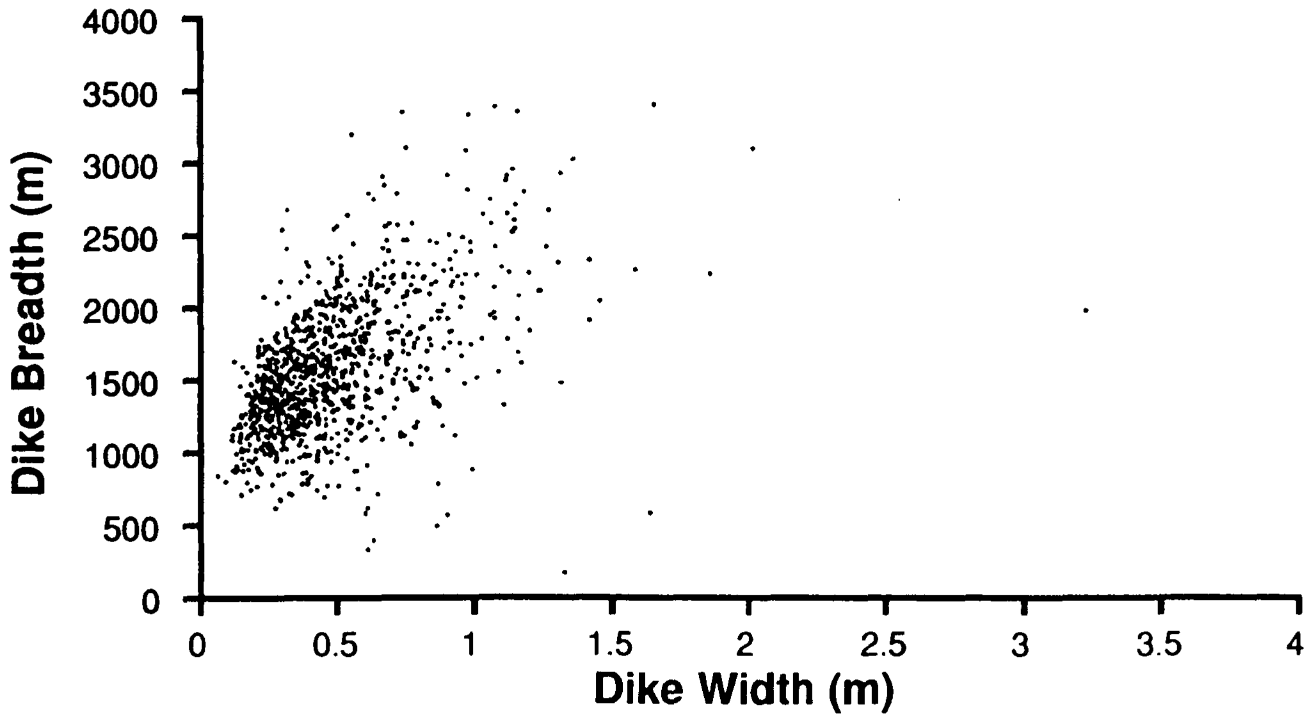
w, dike width, m

b, dike breadth, m

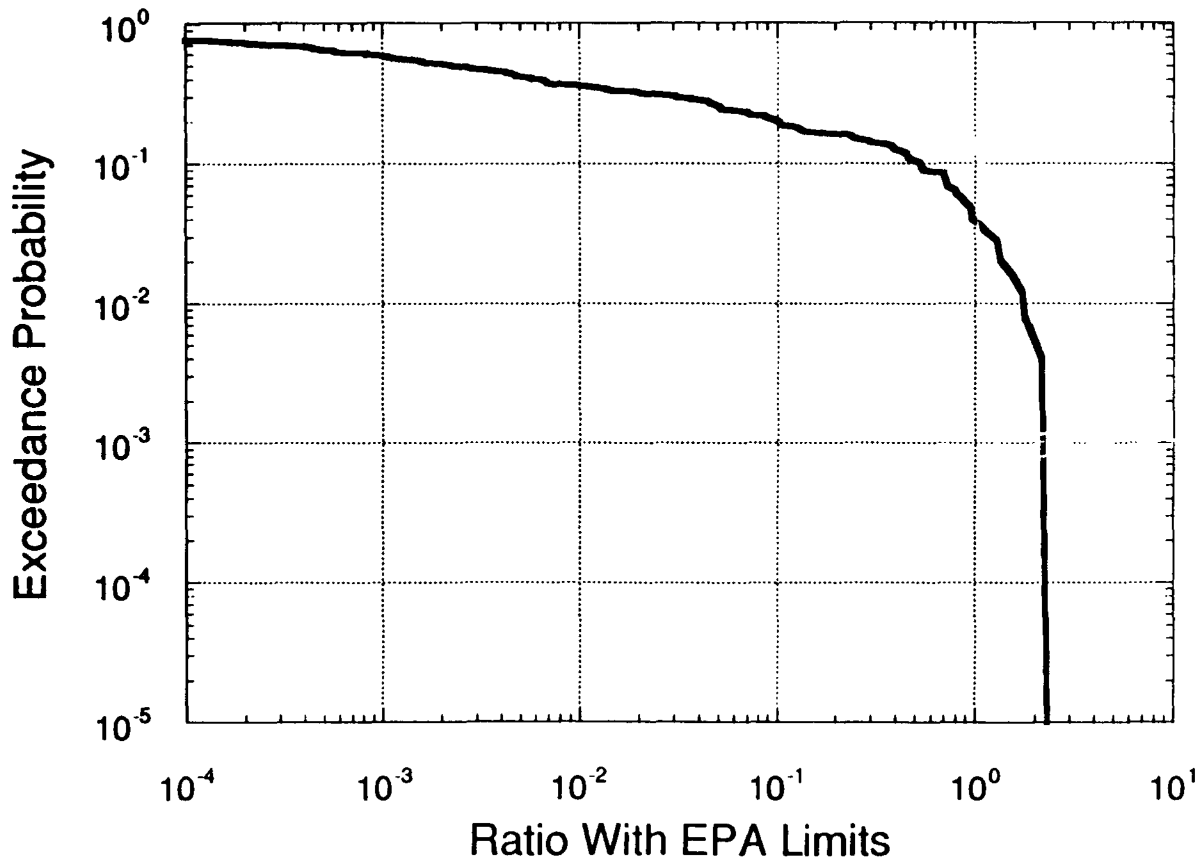
Parameters

Q, discharge	100 m^3/s	$10 <> 10^5$
η, viscosity	100 Pa * s	10<>1000
m, elastic factor	$2x10^{10}$ Pa	$10^9 <> 5x10^{10}$
ρ, density	300 kg/m3	100<>1000
z, source depth	10,000 m	fixed

Volcanic Dike Dimensions



Conditional CCDF for Basaltic Dike Intrusion



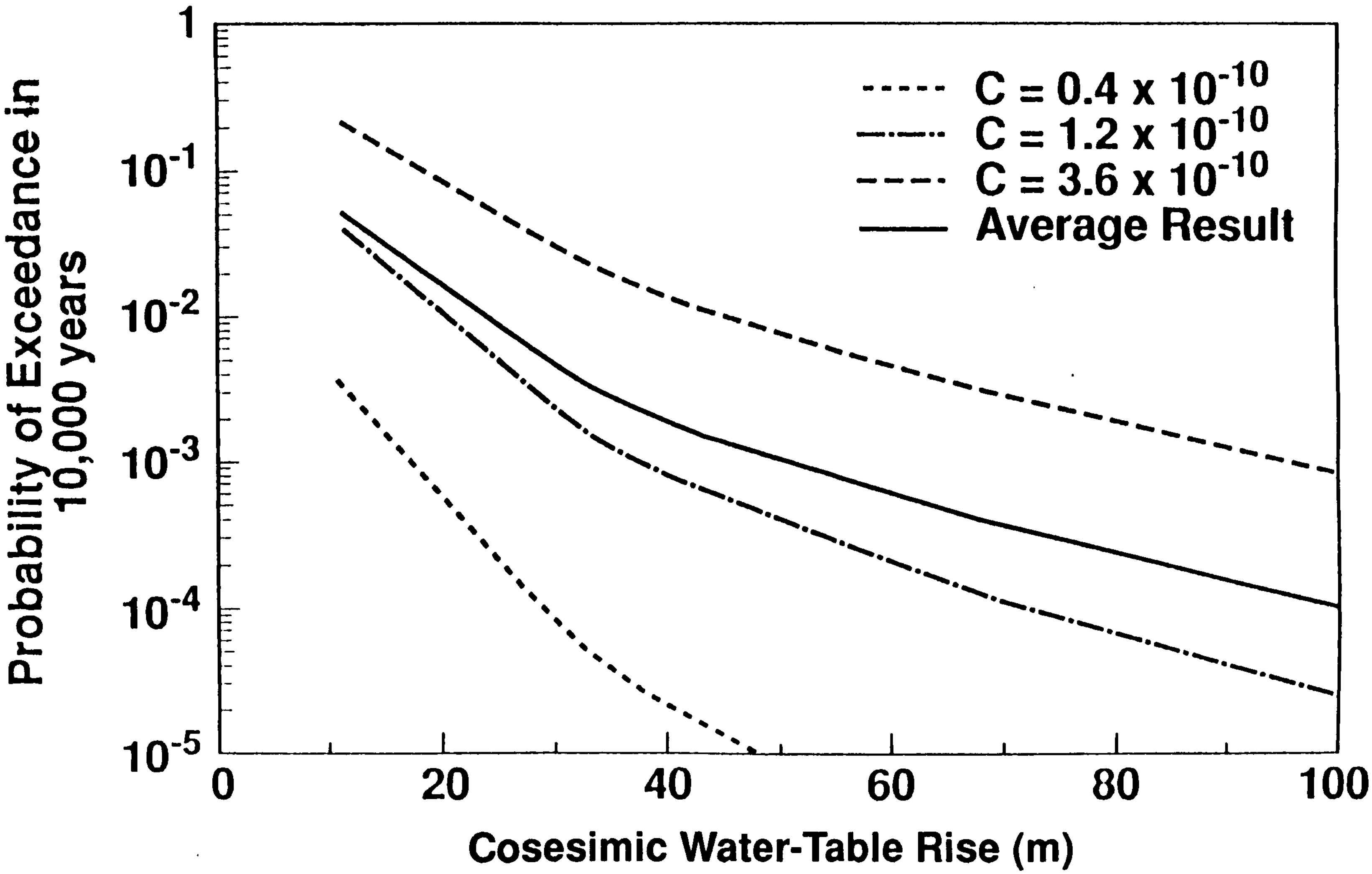
Tectonic Processes of Potential Impact

- Early failure of containers due to faulting
- Changes in rock permeability due to faulting
- Rise in the water table due to earthquake stresses

Discussion of Water-Table Rise from a Seismic Event

- **Normal faulting earthquake relieves tensional stress, leading to compression of rock pore space**
- **Parameters needed**
  - Magnitude of compressive stress increase
  - Area affected by stress increase (earthquake location)
  - Bulk compressibility of rock mass
  - Porosity of rock layers above the water table
- **Model by EPRI (1991) adopted for this analysis**

Probability of Coseismic Water-Table Change



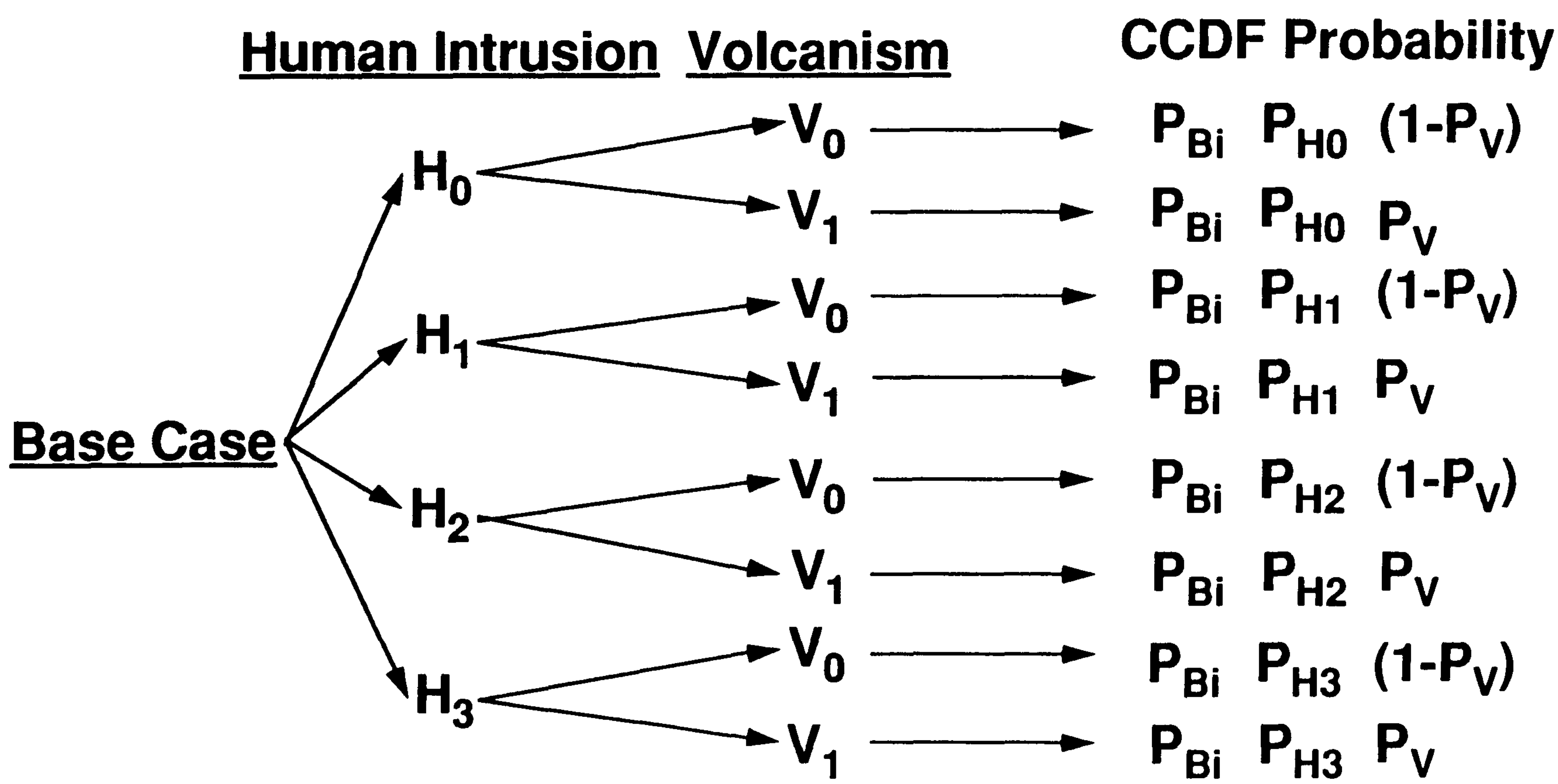
Change in Performance from a Permanent Water-Table Rise

No releases to the water table

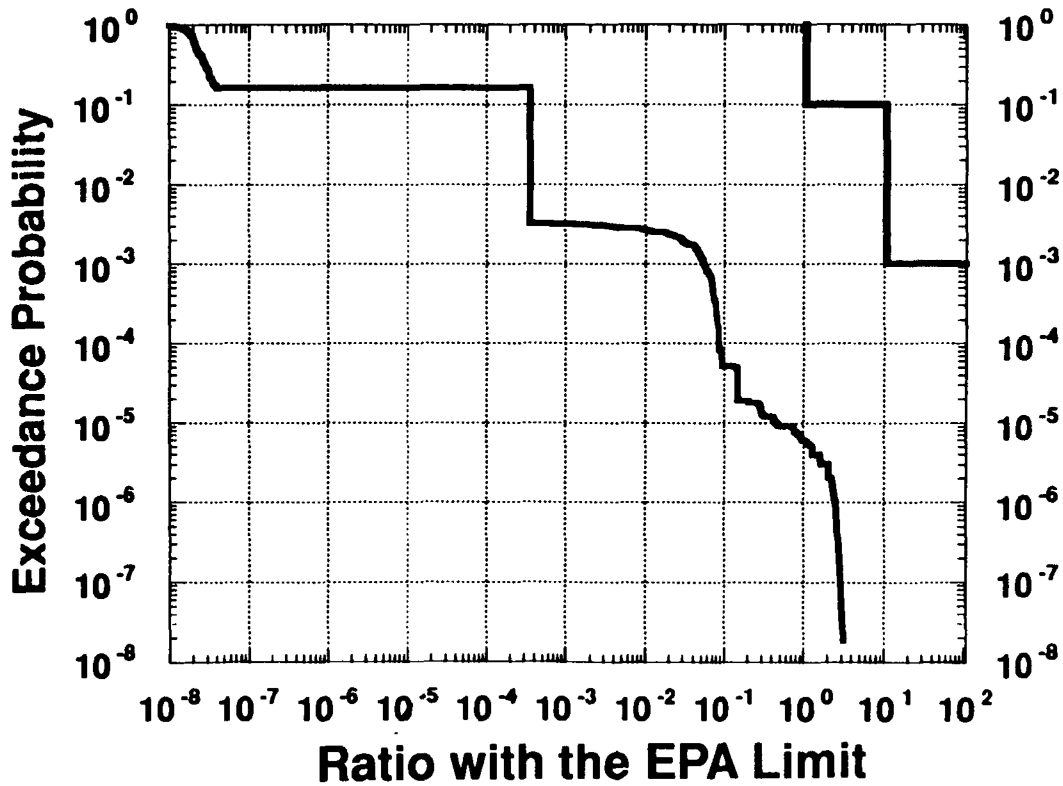
Change in Performance from a Permanent Water-Table Rise

No releases to the water-table

Combination of Conditional CCDFs



CCDF for Total System Performance



Summary

- Methods have been found to incorporate the effects of some scenarios into a total systems model
- A total systems analysis has been demonstrated for a few scenarios using preliminary models and data
- The modeling results show no reason not to continue with site characterization

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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: PRELIMINARY DOSE ESTIMATES FOR THE POTENTIAL REPOSITORY AT YUCCA MOUNTAIN, NEVADA

PRESENTER: DR. PAUL W. ESLINGER

PRESENTER'S TITLE AND ORGANIZATION: PROGRAM MANAGER, PERFORMANCE ASSESSMENT
SCIENTIFIC SUPPORT
PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

PRESENTER'S TELEPHONE NUMBER: (509) 376-2792

DALLAS, TX
APRIL 7-8, 1992

Overview of Regulations

- 40 CFR 191 (1985) Version)
  - Individual protection for 1000 yr for ground-water pathway
  - Computed only for significant source of ground water
- 40 CFR 191 (Working Draft 4, Feb. 3, 1992)
  - Individual protection for 10,000 yr for the ground-water pathway assuming undisturbed repository performance
  - Population protection for all scenarios--no individual protection limit for disturbed performance

Exposure Pathways Considered

- **Undisturbed repository performance**
  - Gas-phase transport of ^{14}C to the ground surface
  - Liquid-phase transport of radionuclides to a well 5 km from the repository
- **Human intrusion from exploratory drilling**
  - Driller exposure
  - Post-drilling dweller exposure

Dose Model

- **ICRP 26 cumulative dose equivalent model (as modified in ICRP 30 and 40)**
  - Dose equivalent is a linear combination of organ doses
  - Exposure time for dose
    - Driller: 40-hour exposure, 50-year commitment
    - All others: 70-year exposure, 70-year committtment
- **Individual doses reported (not necessarily a maximally exposed individual)**

Farm Scenario Assumptions

- 20,000-m^2 farm
- Irrigate 6 months at 150 L/m^2/mo (1.8E+7 L/yr)
- Farm supports all edible plant, beef, eggs, poultry, and milk intake
- Spend 4380 hr outdoors each year
- Exposure pathways include ingestion, external exposure, and inhalation of resuspended dust

Garden Scenario Assumptions

- 2500-m^2 garden
- Irrigate 6 months at 150 L/m^2/mo (2.25E+6 L/yr)
- Garden produces 25% of fruits and vegetables
- Spend 2920 hr outdoors each year
- Exposure pathways include ingestion, external exposure, and inhalation of resuspended dust

Food Consumption Rates

	Rate	Units
Leafy vegetables	15	kg/yr
Other vegetables	276	kg/yr
Eggs	20	kg/yr
Meat	80	kg/yr
Milk	230	L/yr
Poultry	8.5	kg/yr
Water	730	L/yr

Source: Hanford Defense Waste Environmental Impact Statement (1987)

Radionuclide Releases

- Radionuclide source terms for the dose estimates were based on transport models and scenarios developed to estimate cumulative releases
- Release models were run by both PNL and SNL

Doses from Gas-Phase Release of ^{14}C

	Time (yr)	Source (Ci/yr)	Dose (mrem/yr)	Max. Organ	Max. Pathway
PNL	10000	1.00E-2	8.5E-3	Red Marrow	Ingestion
SNL (Component)	3550	1.42E+0	1.2E-1	Red Marrow	Ingestion
SNL (Weeps)	3550	5.59E-4	5.0E-5	Red Marrow	Ingestion

Air concentration usd 10-m mixing depth, 3.3-m/s average wind speed, and width of the repository

Garden scenario produces 25% of the individual's fruit and vegetables

External and inhalation doses are less than 10% of ingestion doses

Doses from a Direct Drilling Hit on One Spent-Fuel Waste Container

Drill Time (yr)	Driller Dose (mrem)	Post-drilling Garden Dose (mrem/yr)	Post-drilling External Dose (mrem/yr)
2400	1.4E+4	2.7E+5	3.3E+4
5839	3.7E+3	8.3E+4	9.1E+3
3963	1.2E+4	2.6E+5	3.0E+4
9396	3.7E+3	9.7E+4	8.8E+3

^{243}Am maximum nuclide for driller dose

^{237}Np maximum nuclide for post-drilling dweller dose

Variable fraction of container inventory is exhumed

40-hour driller exposure, ingested dirt dominates dose

Individual protection limits do not apply

Doses from SNL Modeling Runs

Run ID	Time of Maximum Dose (yr)	Max. Dose (mrem/yr)	Exposure Scenario	Dominant Nuclides
TOS (Base)	53410	4.3E-4 to 4.3E-1	DW Only	Tc-99, I-129
WEE (Base)	4200	4.9E-7 to 4.9E-4	DW Only	Tc-99, I-129
TUF (Drill)	24360	8.0E-6 to 8.0E-3	DW Only	Np-237
CAR (Drill)	700	2.1E-3 to 2.1E+0	Farm	Np-237

Aquifer dilution values highly uncertain

Aquifer assumed 500 m thick and 10 km wide

Drilling injects one waste container into the aquifer

Doses from Injecting One Container into the Carbonate Aquifer (PNL)

Run ID	Drill Time (yr)	Time Maximum Dose Received (yr)	Maximum Dose (mrem/yr)
1	2466	2940	1.1E-4 to 1.1E-1
2	147	4900	3.7E-3 to 3.7E+0
3	589	7140	1.1E-2 to 1.1E+1
5	1191	9940	1.1E-5 to 1.1E-2
6	8336	9870	3.2E-5 to 3.2E-2

Aquifer dilution values highly uncertain

^{237}Np dominates the dose

Random sorption values

Summary

- Regulatory requirements for dose estimates are uncertain
- Doses have been computed for a few scenarios using preliminary transport models and data
- Individual dose limits from ground-water exposure are strongly dependent on aquifer dilution properties
- Modeling results indicate that DOE should continue with site characterization