U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Mass and Activity of Key Radionuclides Potentially Released from the Saturated Zone Over Time

Presented to:

U.S. Nuclear Waste Technical Review Board

Presented by:

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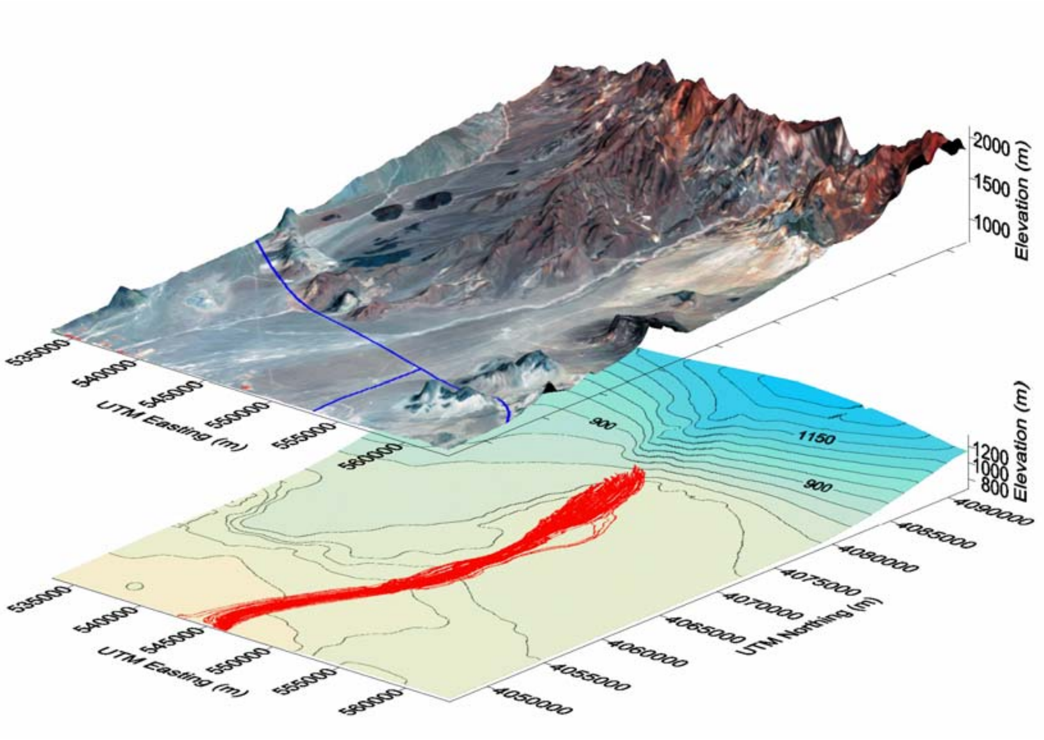
Outline

- Summary of Saturated Zone (SZ) Flow and Transport Modeling Approach and Abstraction
- Key Processes that Affect Releases
- Key Assumptions
- Key Uncertainties
- Affects of Spatial Distribution of Releases from the Unsaturated Zone (UZ)

General Approach to SZ Flow and Transport Abstraction in TSPA

- **3-D SZ site-scale flow and transport models used to simulate radionuclide mass transport to the accessible environment from a point mass source (4 source regions below the repository)**
- **Convolution integral method will be used to couple radionuclide source term from the UZ with the SZ transport in the TSPA calculations**
- **Radionuclide concentration in groundwater source to the biosphere calculated by dividing radionuclide mass crossing the boundary of the accessible environment by the representative groundwater volume of 3,000 acre-ft/year**
- **Climate change incorporated by scaling radionuclide mass breakthrough curves in proportion to SZ flux changes**
- **Abstracted 1-D transport model used for radioactive decay chains**

SZ Site-Scale Flow and Transport Model



- **Particle tracking method includes radionuclide transport processes of advection, dispersion, matrix diffusion in fractured volcanic units, and sorption**
- **Simulated flow paths from the repository occur in the upper few hundred meters of the SZ**
- **Simulated flow paths cross the boundary of the accessible environment approximately 5 km west-northwest of the highway intersection at Amargosa Valley**

Uncertainty Analysis

- Monte Carlo analysis is conducted by sampling uncertain parameters using the Latin Hypercube sampling method
- Multiple simulations (200 realizations) of radionuclide transport in the SZ are produced using these uncertain parameter vectors in the 3-D SZ Site-Scale Transport Model
- Radionuclide transport simulation results consist of radionuclide mass breakthrough curves
- The resulting “library” of breakthrough curves will be used in the TSPA model for probabilistic risk assessment analyses via the convolution integral method

Key Processes – Advection of Groundwater

- Advective flow of groundwater is conceptualized to occur through the relatively limited volume of fracture networks in the volcanic rocks of the SZ
- Groundwater flow is more uniformly distributed in the porous medium of the alluvium, with some channelization occurring in more permeable strata
- Simulated groundwater specific discharge generally increases along the flow path from beneath the repository to the boundary of the accessible environment due to convergent groundwater flow
- Specific discharge is a function of the local hydraulic gradient, permeability, anisotropy in permeability, and temperature

Key Processes – Advection of Groundwater (Continued)

Volcanic Units

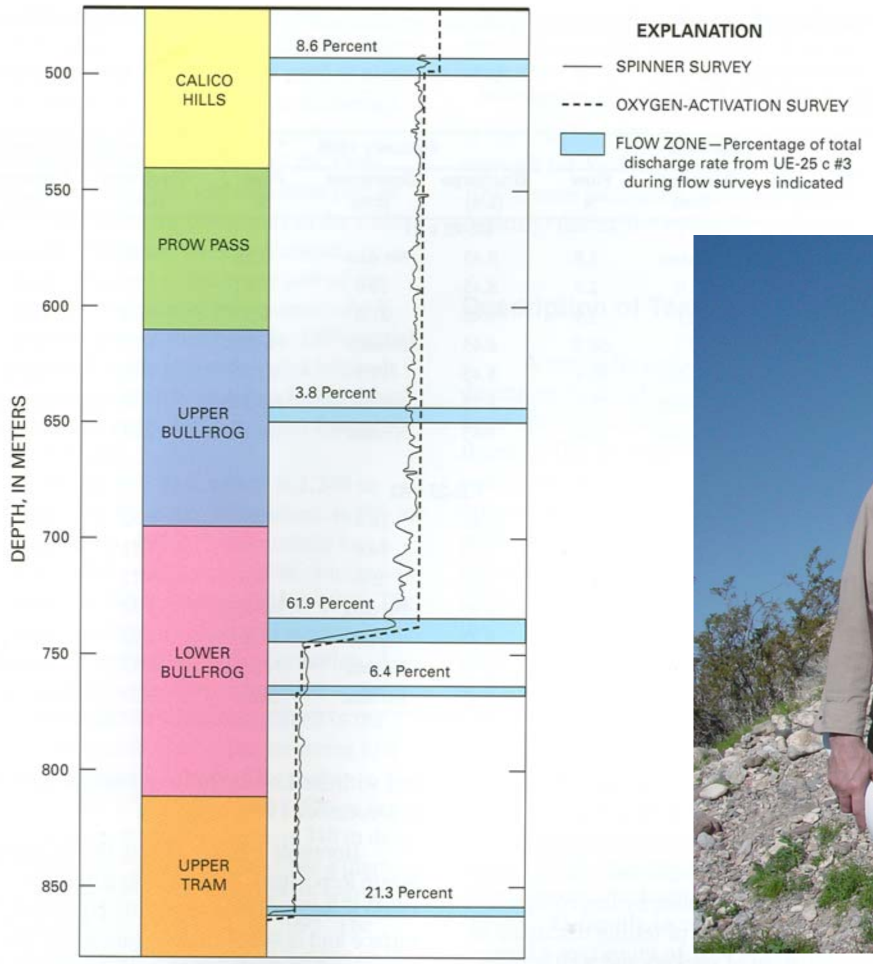
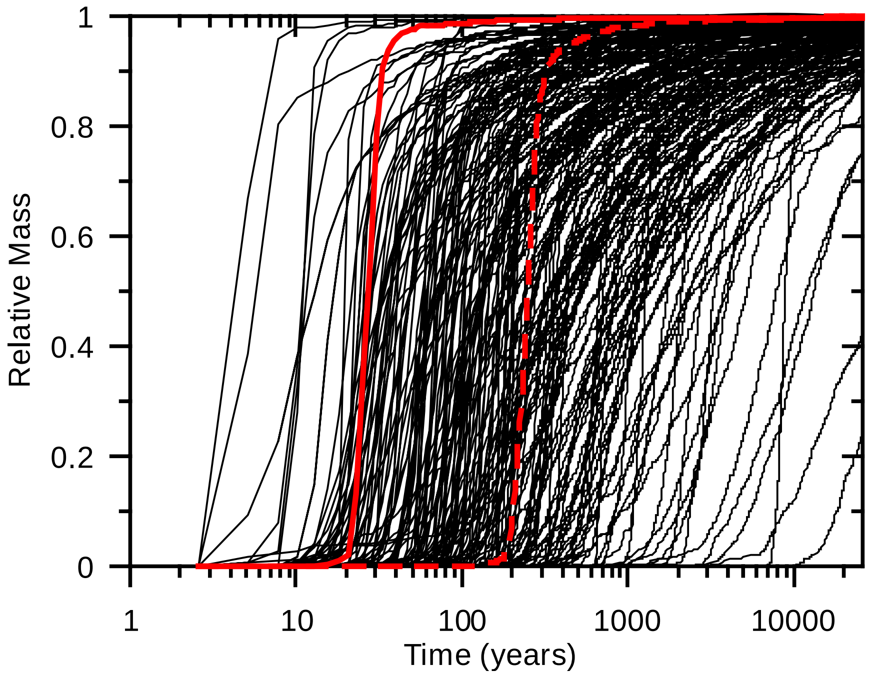


Figure 10. Flow surveys in UE-25 c #3 during the hydraulic test in June 1995.

from Geldon et al. (2002)

Alluvium

Key Processes – Advection of Groundwater (Continued)

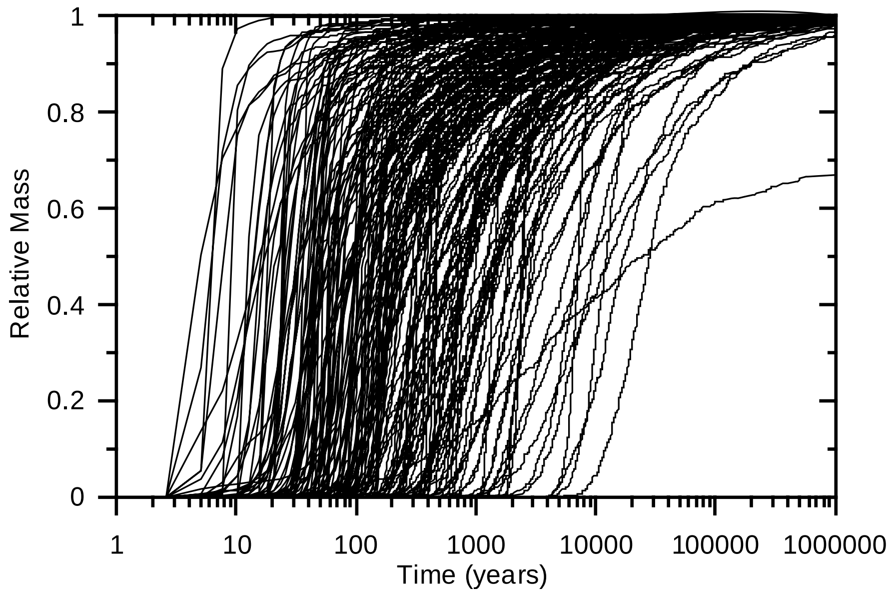


Note: Breakthrough curves are for a continuous source and do not include radioactive decay or sorption. Results are scaled for glacial-transition climatic conditions.

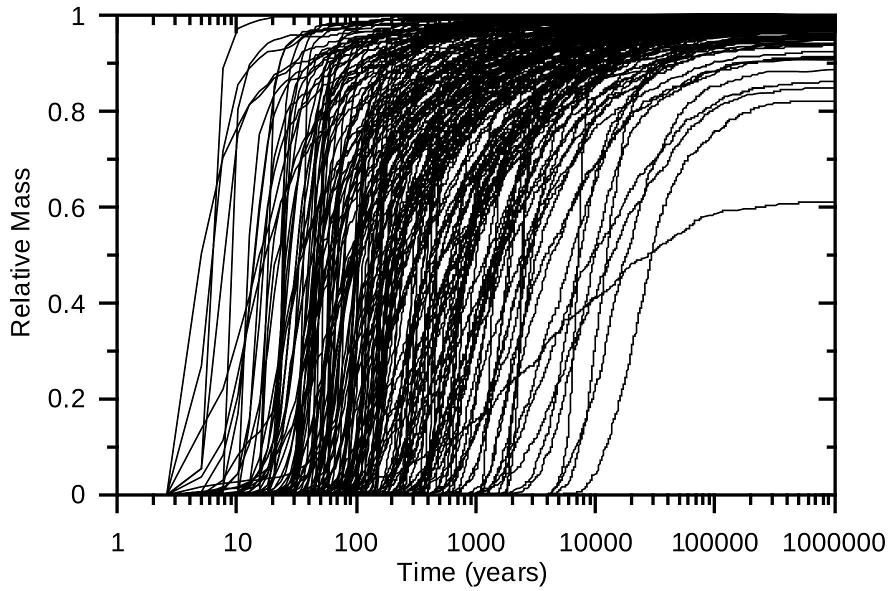
- **Breakthrough curves from Monte Carlo SZ transport simulations and sampling all uncertain parameters shown with black lines**
- **Transport simulation using the 90th percentile of groundwater flow rate (and median values for other uncertain parameters) shown with solid red line**
- **Transport simulation using the 10th percentile of groundwater flow rate shown with dashed red line**
- **Uncertainty in advection encompasses a significant portion of overall uncertainty in radionuclide transport rates**

Key Processes – Radioactive Decay

No Decay



With Decay – ^{99}Tc (Half Life = 213000 years)

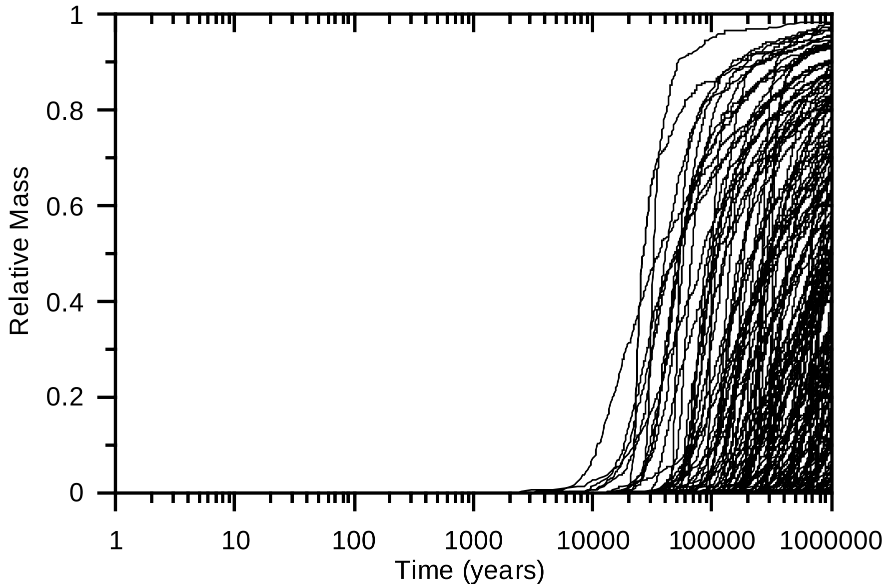


Note: Breakthrough curves are for a continuous source. Results are scaled for glacial-transition climatic conditions.

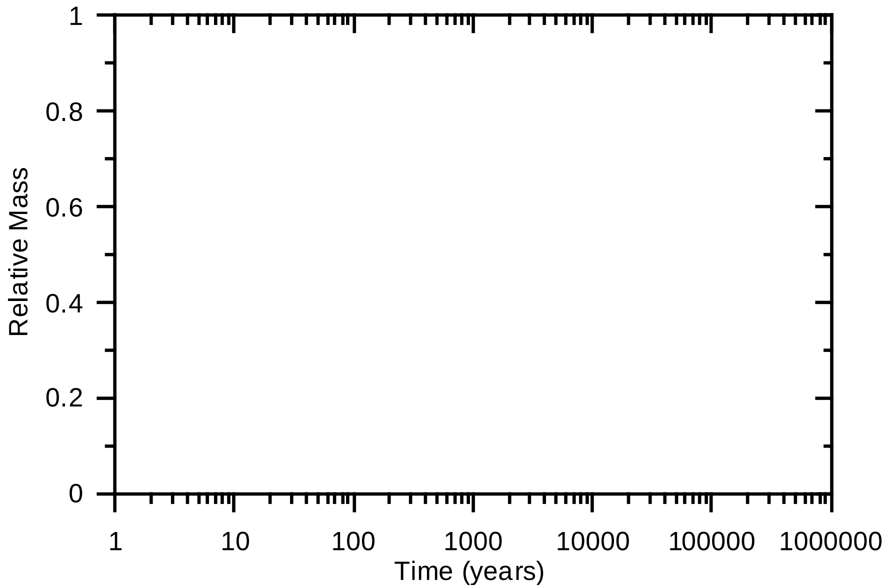
Key Processes – Radioactive Decay

(Continued)

No Decay



With Decay – ^{137}Cs (Half Life = 30.1 years)



Note: Breakthrough curves are for a continuous source. Results are scaled for glacial-transition climatic conditions.

Key Processes – Climate Change

- The scaling factors of groundwater specific discharge in the SZ for monsoonal and glacial-transition climate states are 2.7 and 3.9, respectively
- These scaling factors are based on the ratios of average infiltration in the UZ site-scale flow model for these climate states
- The scaling factor for the glacial-transition climate is corroborated by steady-state flow simulations using the Death Valley regional groundwater flow model

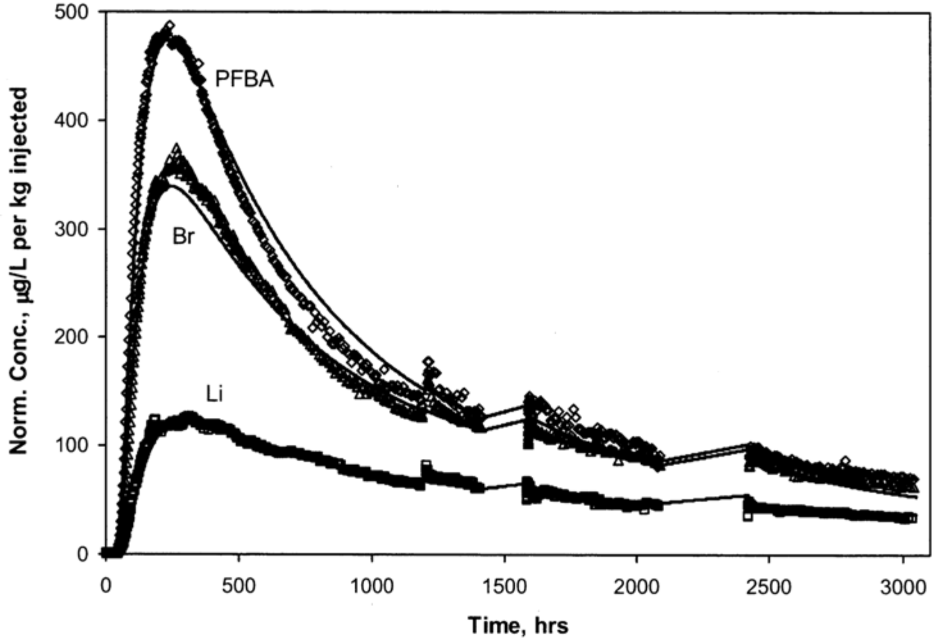
Key Processes – Matrix Diffusion

- **What is known about matrix diffusion**
  - Extensive database of laboratory-scale studies and measurements of effective diffusion coefficient in volcanic rock matrix
  - Field-scale demonstration of the matrix diffusion process in cross-hole tracer tests at the C-wells
- **Uncertainties in the matrix diffusion process**
  - Uncertainty in channelization of groundwater flow (effective fracture spacing) in fractured volcanic units
  - Uncertainty in flow porosity in fractured volcanic rocks
  - Uncertainty in effective diffusion coefficient

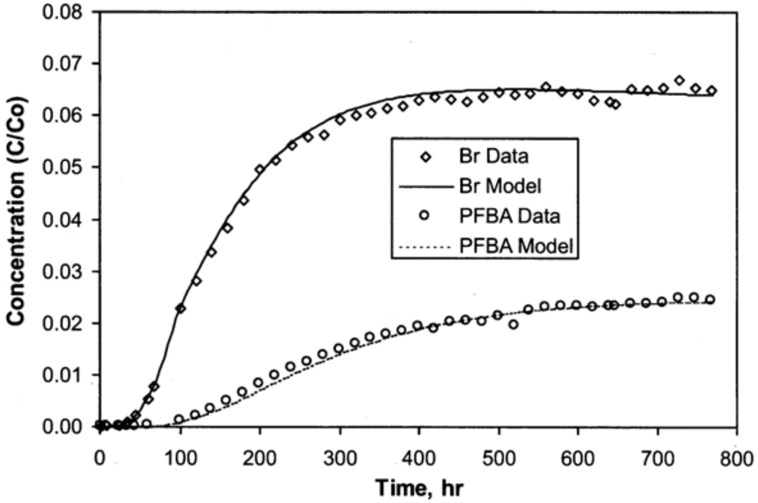
Key Processes – Matrix Diffusion

(Continued)

C-Wells Multiple-Tracer Test in Prow Pass Tuff

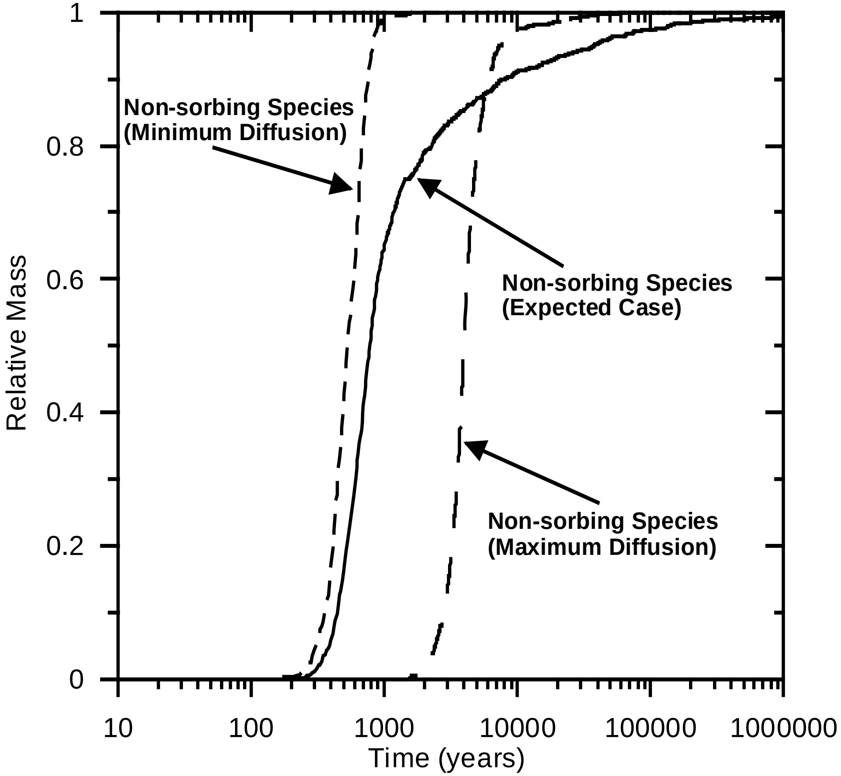


Laboratory Diffusion Cell Test – Prow Pass Tuff



PFBA – pentafluorobenzoic acid

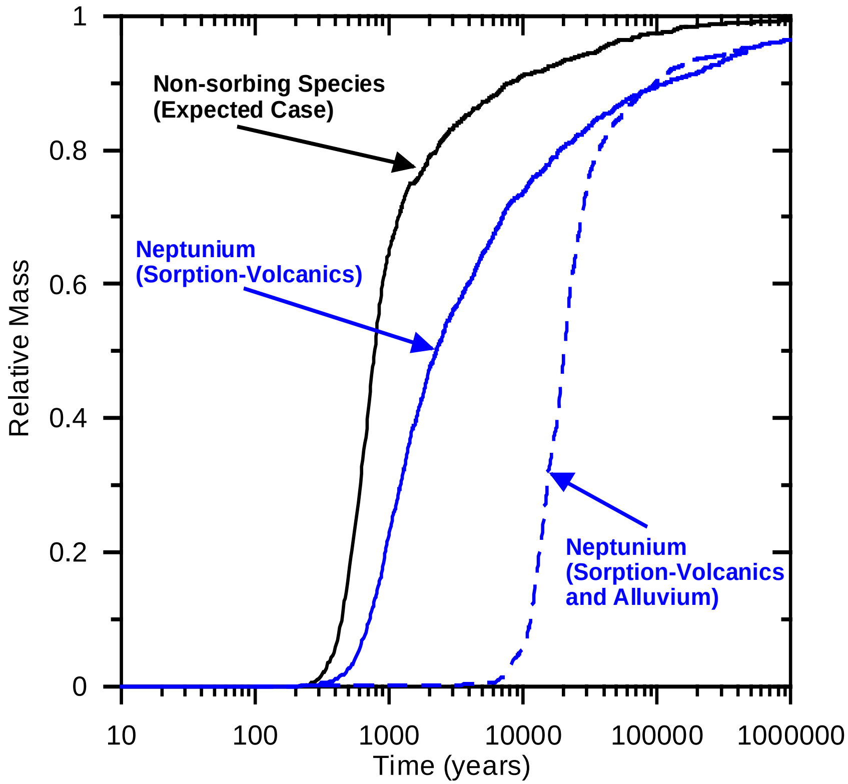
Sensitivity to Matrix Diffusion



Note: Breakthrough curves are for a continuous source and do not include radioactive decay.

- **Transport simulations using expected (median) values for uncertain parameters, isotropic horizontal permeability, and present-day climatic conditions**
- **Radionuclide mass breakthrough curves at the boundary of the accessible environment**
- **Expected-value case includes significant matrix diffusion, but a majority of mass arrives at times closer to the minimum diffusion case**

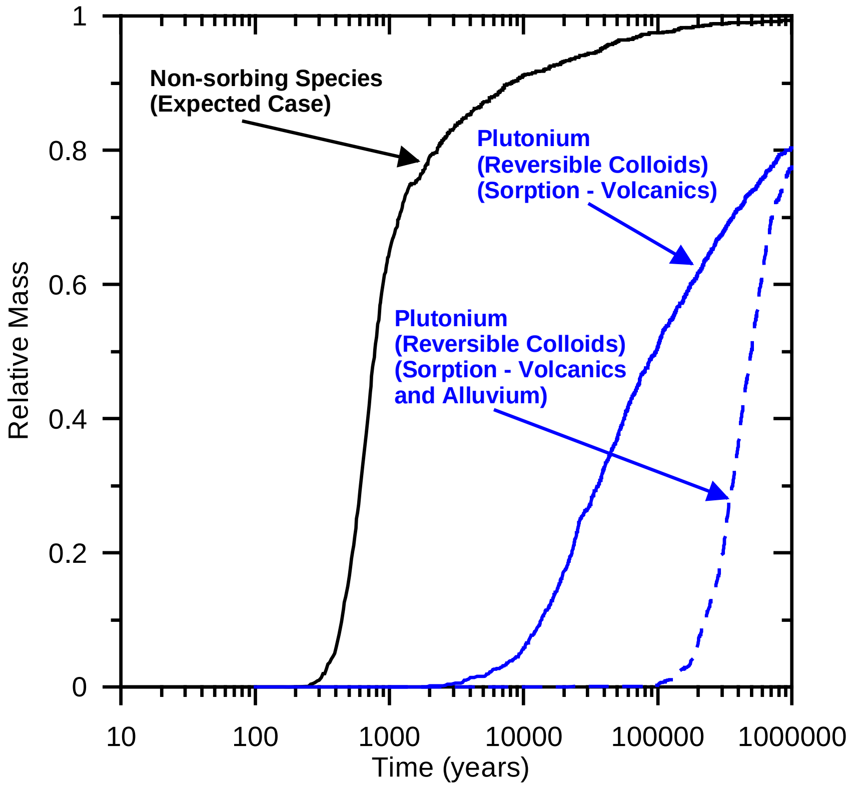
Sensitivity to Matrix Diffusion and Sorption



Note: Breakthrough curves are for a continuous source and do not include radioactive decay.

- **Transport simulations for moderately sorbing neptunium show additional retardation due to the sorptive capacity of the rock matrix**
- **Sorption in the volcanic rock matrix amplifies the retardation effects of matrix diffusion**
- **For expected parameter values, sorption in the alluvium provides the majority of the retardation of neptunium**

Sensitivity to Matrix Diffusion and Sorption (Continued)



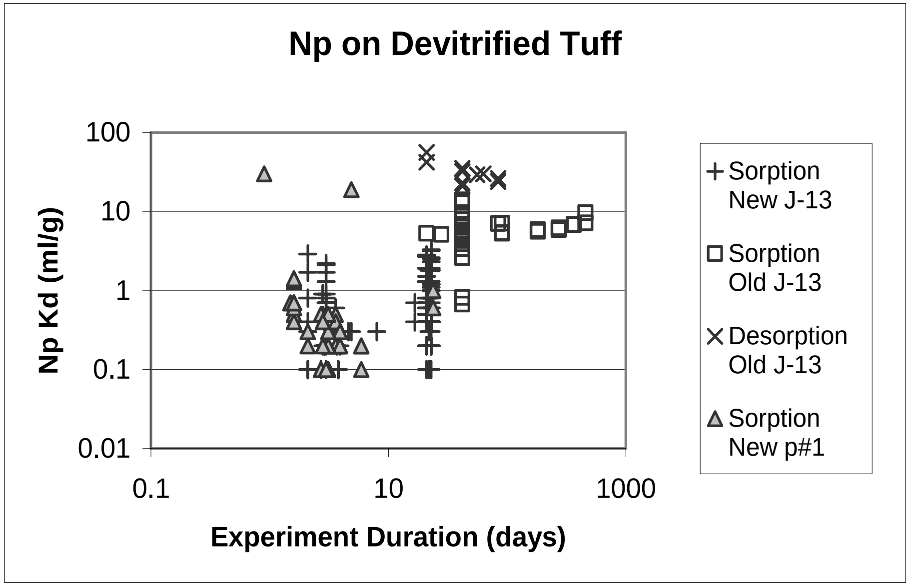
Note: Breakthrough curves are for a continuous source and do not include radioactive decay.

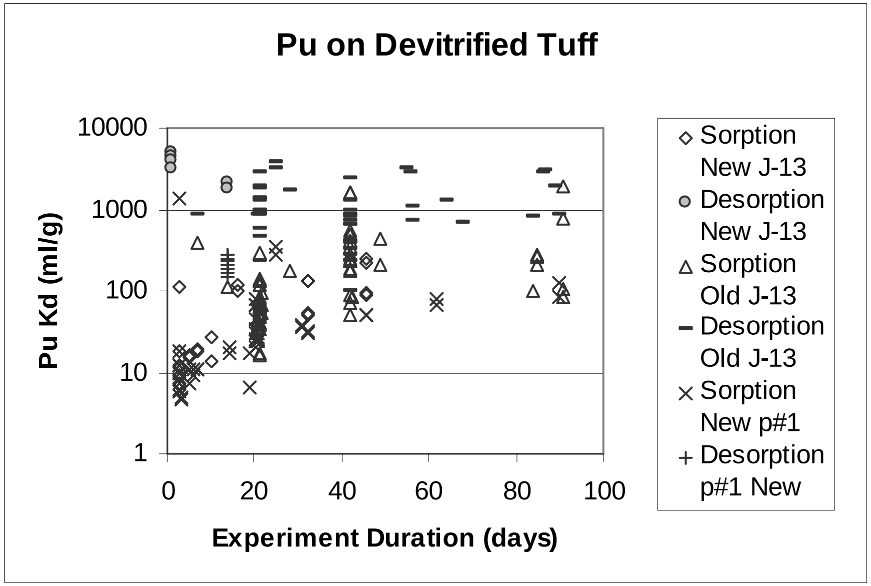
- **Transport simulations for highly sorbing plutonium show significantly greater retardation than for neptunium due to the sorptive capacity of the rock matrix**
- **For expected parameter values, sorption in the alluvium provides additional retardation of plutonium, particularly for mass that arrives before 50% of the breakthrough**

Key Processes – Sorption Conceptual Model

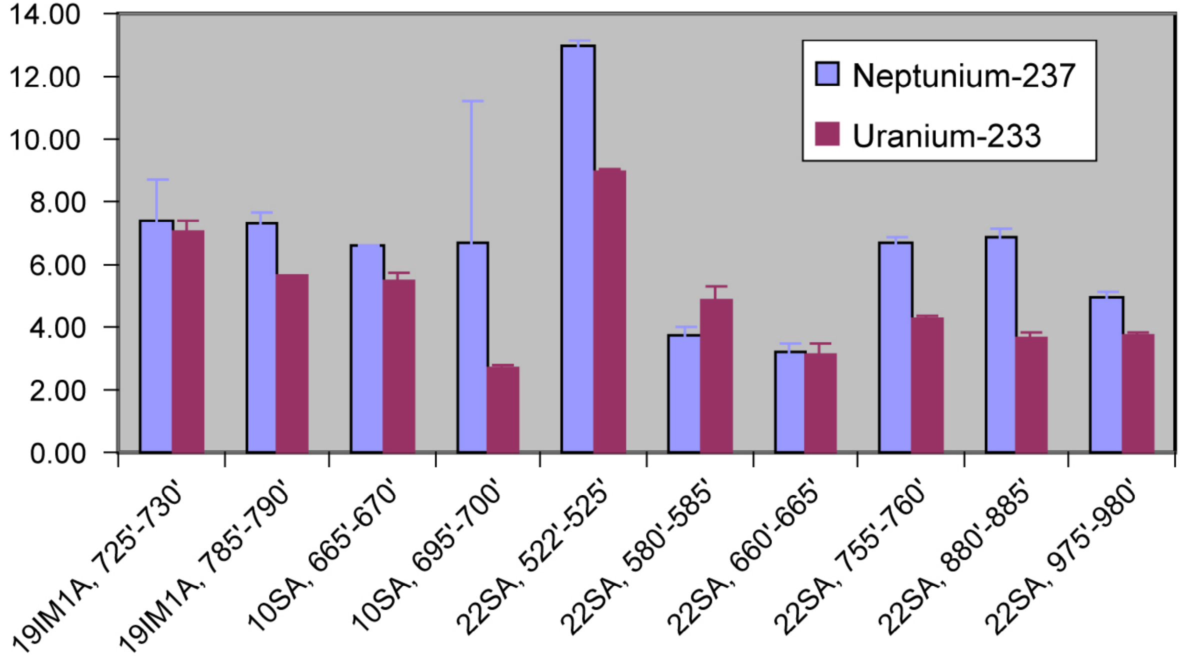
- Local equilibrium between radionuclides in the aqueous phase and sorption onto aquifer material (sorption reactions are rapid and reversible)
- Linear relationship between radionuclide mass sorbed on the solid phase and mass in the aqueous phase (Kd approach)
- Sorption reactions are influenced by local chemical conditions
  - Water chemistry (pH, Eh, Conc. CO_3^{2-}, etc.)
  - Rock types (Devitrified and zeolitic tuffs, alluvium)
  - Radionuclide concentrations
- Scaling and uncertainties considered with regard to these factors
- Oxidizing conditions are assumed in the SZ

Key Processes – Sorption





Key Processes – Sorption
(Continued)



NOTE: Experiments terminated after two weeks. Liquid to solid ratio (L/S) of the experiments is 20 ml/g. NC-EWDP-19D Zone 1 water was used for the experiments with alluvium from NC-EWDP-19IM1A and NC-EWDP-22SA, and NC-EWDP-10S water was used for the experiments with alluvium from NC-EWDP-10SA.

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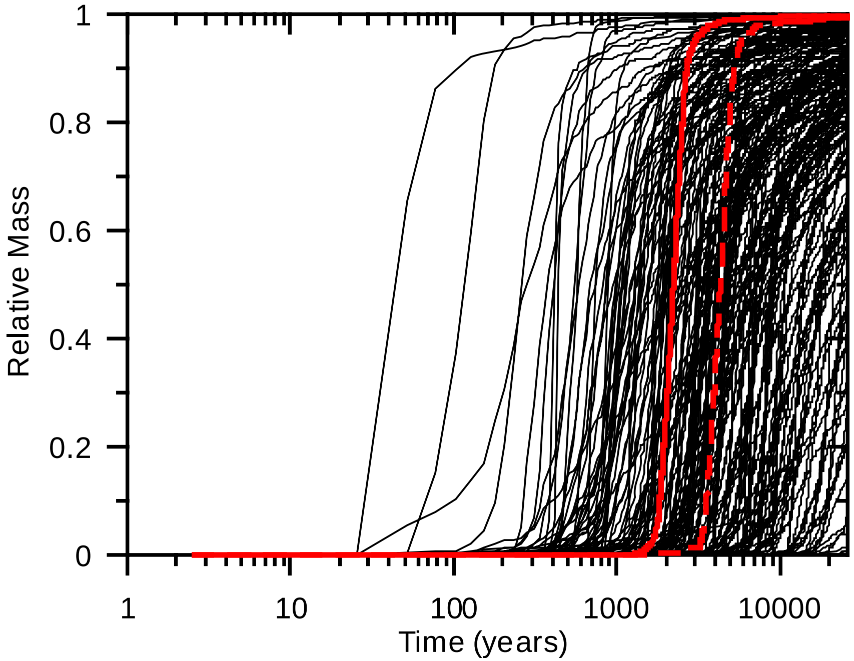
Key Processes – Sorption

(Continued)



Note: Breakthrough curves are for a continuous source and do not include radioactive decay . Results are scaled for glacial-transition climatic conditions.

- Breakthrough curves from Monte Carlo simulations of neptunium transport and sampling all uncertain parameters shown with black lines
- Transport simulation using the 10th percentile of Np sorption coefficient (and median values for other uncertain parameters) shown with solid red line
- Transport simulation using the 90th percentile of Np sorption coefficient shown with dashed red line
- Uncertainty in Np sorption encompasses a moderate portion of overall uncertainty in radionuclide transport rates

Key Assumptions

Current information forms the basis for the following assumptions:

- Steady-state groundwater flow simulated in the SZ
- Instantaneous change in SZ groundwater flux with climate change; no change in flow paths
- Matrix diffusion from uniformly spaced, parallel fractures in the fractured volcanic units, as implemented in the Sudicky and Frind (1982) analytical solution
- Equilibrium, linear sorption occurs in tuff matrix and alluvium
- No sorption of solutes on fracture surfaces/coatings
- Radionuclide mass from fracture and matrix flow in UZ is input to SZ in fractures

Key Assumptions

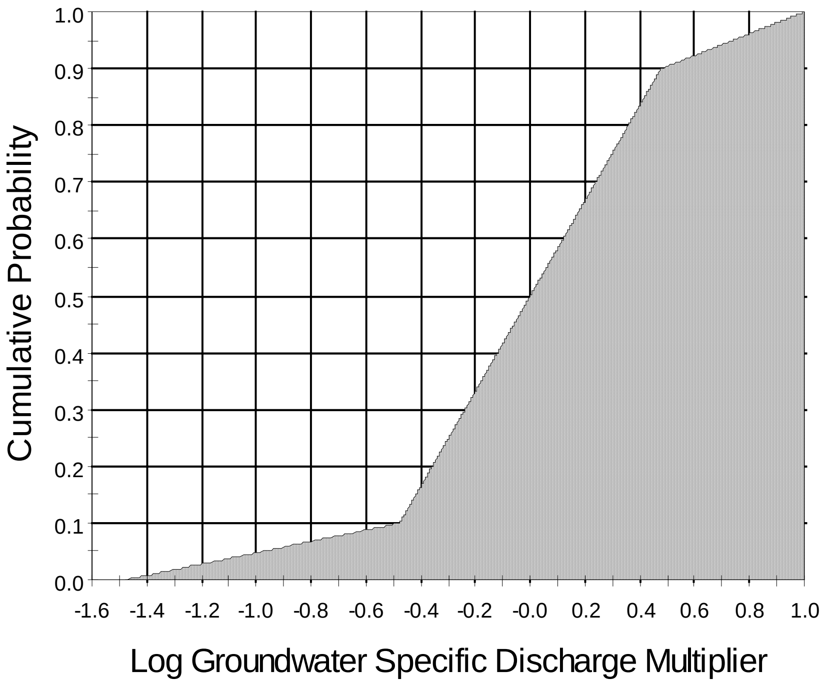
(Continued)

- Oxidizing conditions are assumed in the SZ with regard to sorption coefficients and solubility limits of redox-sensitive radionuclides (e.g., ^{99}Tc and ^{237}Np)
- For transport of radionuclides reversibly attached to colloids, local equilibrium is assumed among the colloids, the aqueous phase, and the aquifer material
- For radionuclides irreversibly attached to colloids, it is assumed there will be no desorption of radionuclides from the colloids
- Colloids are subject to attachment and detachment from the mineral grains, but no permanent filtration of colloids occurs

Parameter Uncertainties

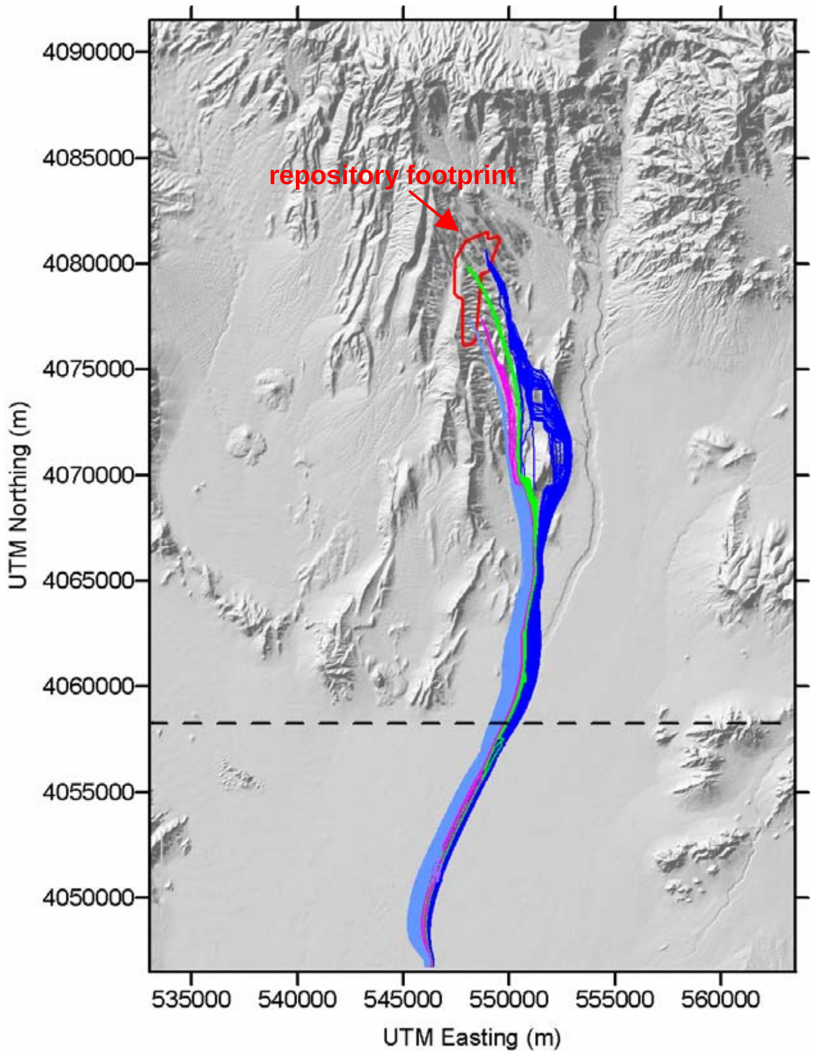
- **Groundwater flow and geological uncertainty:**
  - Groundwater specific discharge
  - Horizontal anisotropy in permeability (fractured tuff)
  - Alluvium – tuff contact in the subsurface
- **Radionuclide transport uncertainty:**
  - Matrix diffusion in fractured tuff
    - Flowing interval spacing
    - Effective diffusion coefficient in tuff matrix
    - Flow porosity in tuff
  - Sorption coefficients (tuff matrix and alluvium)
  - Dispersivity (longitudinal, transverse horizontal and vertical)
  - Effective porosity of alluvium
  - Source location
  - Colloid retardation factor (tuff and alluvium)
  - Sorption coefficients onto colloids
  - Groundwater colloid concentration

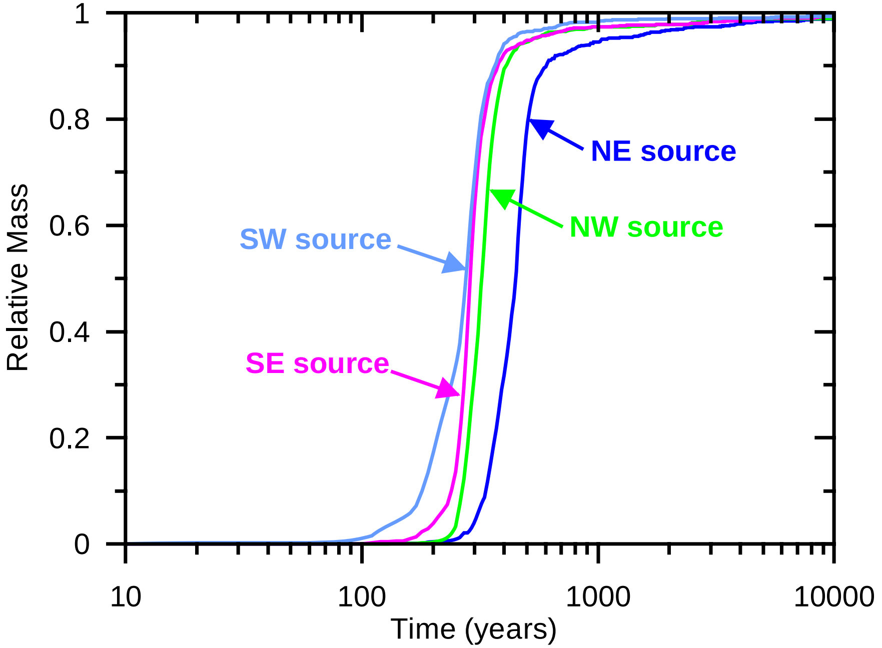
Uncertainty in Specific Discharge



- **Uncertainty in specific discharge is based on results of the SZ expert elicitation and more recent well testing at the alluvial tracer complex**
- **The discrete cumulative distribution function used for uncertainty has 80% of probability between 1/3 and 3 times the best estimate of specific discharge**
- **The tails of the distribution are taken from the SZ expert elicitation**

Spatial Distribution of Releases





Note: Breakthrough curves are for a continuous source and do not include radioactive decay or sorption. Transport simulations use median parameter values and are for present-day climatic conditions. Colors of breakthrough curves correspond to the colors of particle paths shown from four source locations shown on map.

Conclusions

- The calibrated 3-D SZ site-scale flow and transport models form the basis for abstracted radionuclide transport simulations in the TSPA
- Several key processes and their impacts on releases of radionuclide mass from the SZ are discussed:
  - Advection of groundwater
  - Radioactive decay
  - Climate change
  - Matrix diffusion
  - Sorption
- Spatial variations of releases to the SZ do not have large impacts on simulated releases from the SZ, relative to other uncertainties