U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Saturated Zone Flow and Transport and Biosphere for TSPA-SR

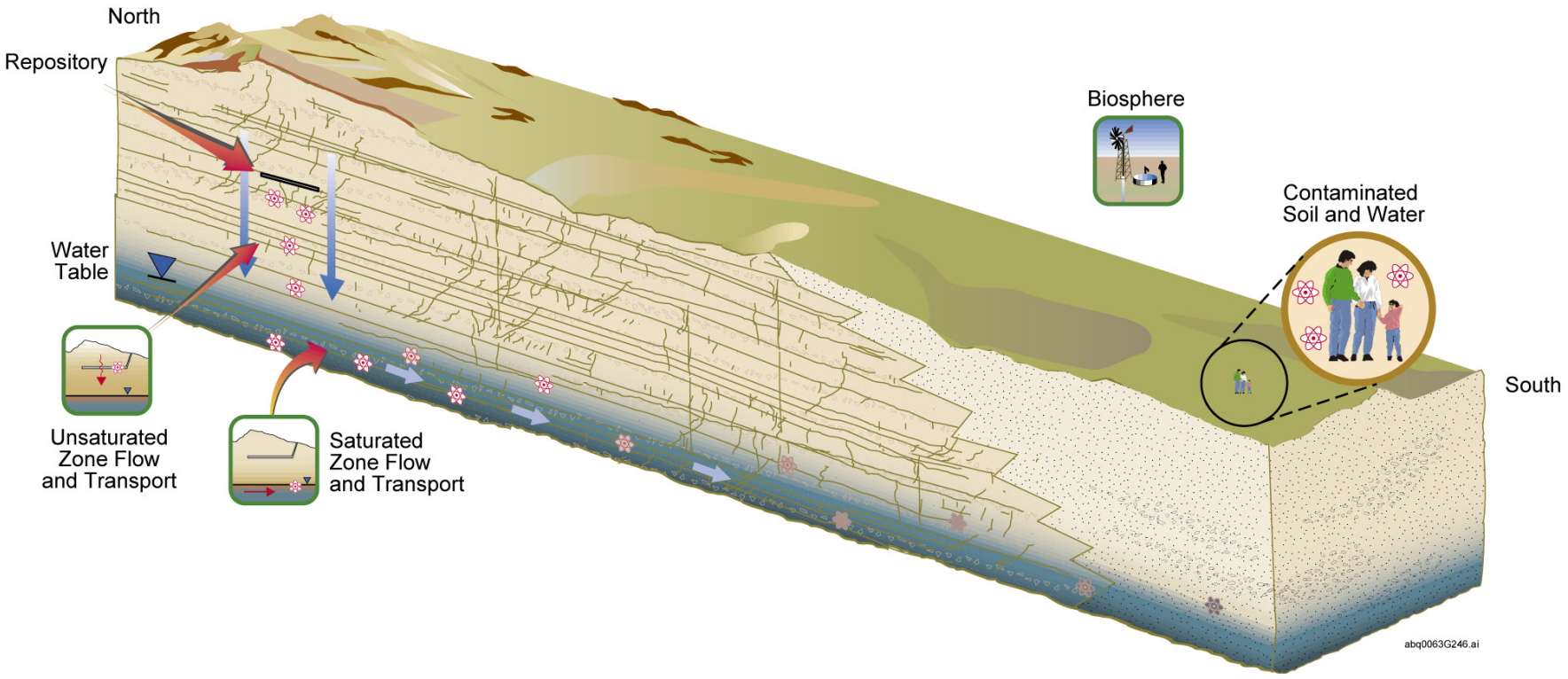
Presented to:
NRC/DOE Technical Exchange on Total System Performance Assessment (TSPA) for Yucca Mountain
San Antonio, Texas

Presented by:
Bill W. Arnold
Performance Assessment Department
CRWMS M&O/Sandia National Laboratory

June 6, 2000

YUCCA MOUNTAIN PROJECT

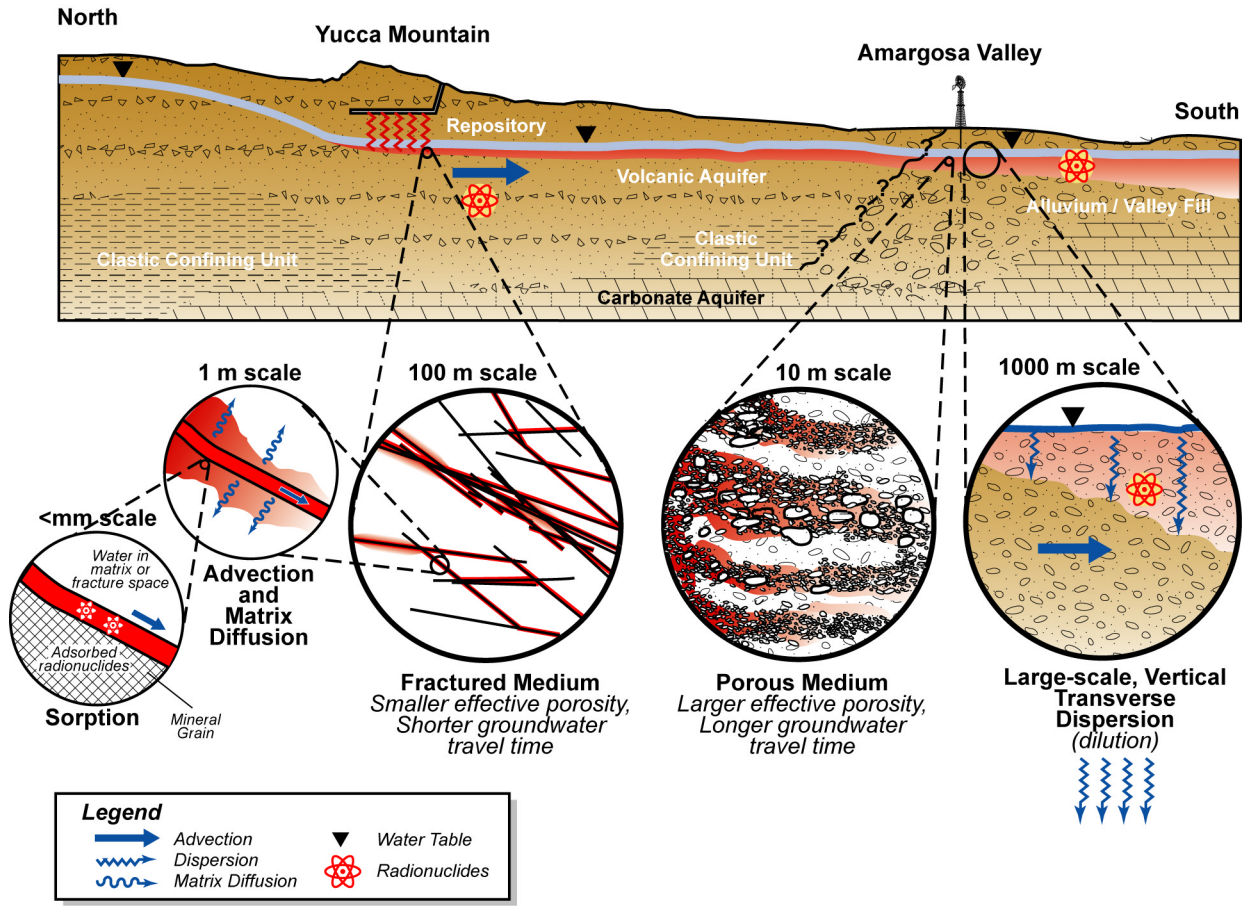
Radionuclide Migration in the Saturated Zone (SZ) and Biosphere



Key Technical Issues

- **Relevant Integrated Subissues from the Total System Performance Assessment and Integration Issue Resolution Status Report Rev. 2 include:**
  - **Flow Paths in the Saturated Zone**
  - **Radionuclide Transport in the Saturated Zone**
  - **Dilution of Radionuclides Due to Well Pumping**
- **Other relevant acceptance criteria may be found in the following Issue Resolution Status Reports:**
  - **Radionuclide Transport**
  - **Structural Deformation and Seismicity**
  - **Unsaturated and Saturated Flow Under Isothermal Conditions**
- **Acceptance criteria related to this topic will be discussed in greater detail at the Saturated Zone Flow and Transport Technical Exchange scheduled for July 27, 2000.**

Conceptual Model of Radionuclide Transport Processes in the SZ



General Approach to SZ Flow and Transport Abstraction in TSPA-SR

- **SZ site-scale flow and transport model used to simulate radionuclide mass transport to 20 km distance from a point mass source (4 source regions below the repository)**
- **Convolution integral method used to couple radionuclide source term from the Unsaturated Zone (UZ) with the SZ transport in the TSPA-SR calculations**
- **Radionuclide concentration in groundwater source to the biosphere calculated by dividing radionuclide mass crossing the 20 km "fence" by the average annual groundwater usage of the hypothetical farming community**
- **Climate change incorporated by scaling radionuclide mass breakthrough curves in proportion to SZ flux changes**
- **Abstracted 1-D transport model used for some radioactive decay chains**

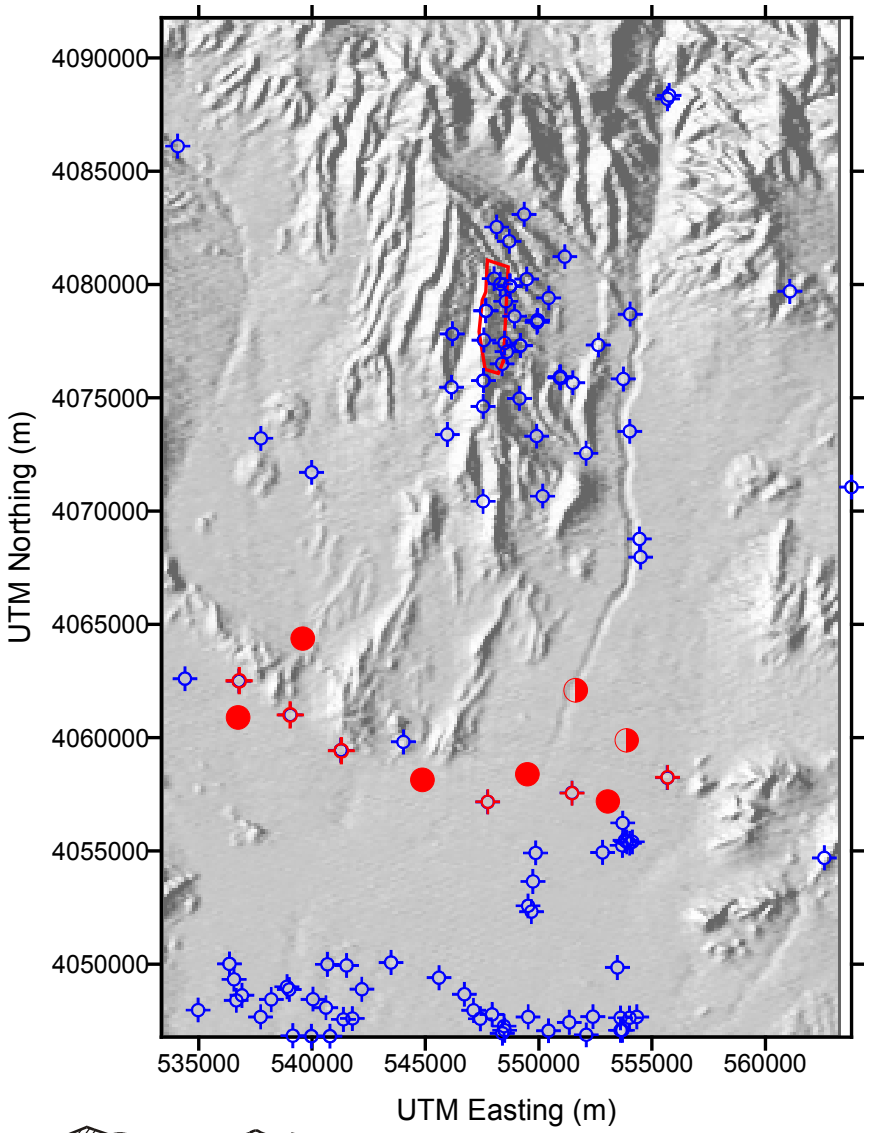
Changes in Approach from TSPA-VA

- **The 3-D SZ site-scale flow and transport model is used to simulate radionuclide transport in TSPA-SR (vs. the streamtube approach in TSPA-VA)**
- **Radionuclide concentrations are calculated in the water supply of the hypothetical farming community in TSPA-SR (vs. concentration in the SZ, as in TSPA-VA)**
- **Matrix diffusion is explicitly simulated in the SZ site-scale model for TSPA-SR (vs. use of the effective porosity approach for transport in fractured media used in TSPA-VA)**
- **Particle tracking method used for radionuclide transport in the SZ site-scale model for TSPA-SR (vs. finite element transport method used in streamtubes for TSPA-VA)**
- **Minor sorption of Tc and I in alluvium for TSPA-SR (vs. no sorption in TSPA-VA)**

SZ Site-Scale Flow and Transport Model

- 3-D model implemented with FEHM software code has domain 30 km x 45 km x 2750 m below water table
- Hydrogeologic framework model contains 19 units
- Orthogonal grid with 500 m horizontal spacing and variable resolution in the vertical direction
- Flow model calibration used automated inversion
- Model calibration and validation uses data including:
  - Water level measurements in wells
  - Simulated groundwater fluxes at lateral boundaries
  - Inferred flow paths from hydrochemical data
  - Upward hydraulic gradient from carbonate aquifer
  - Ranges of measured permeability
  - Average specific discharge in volcanic aquifer

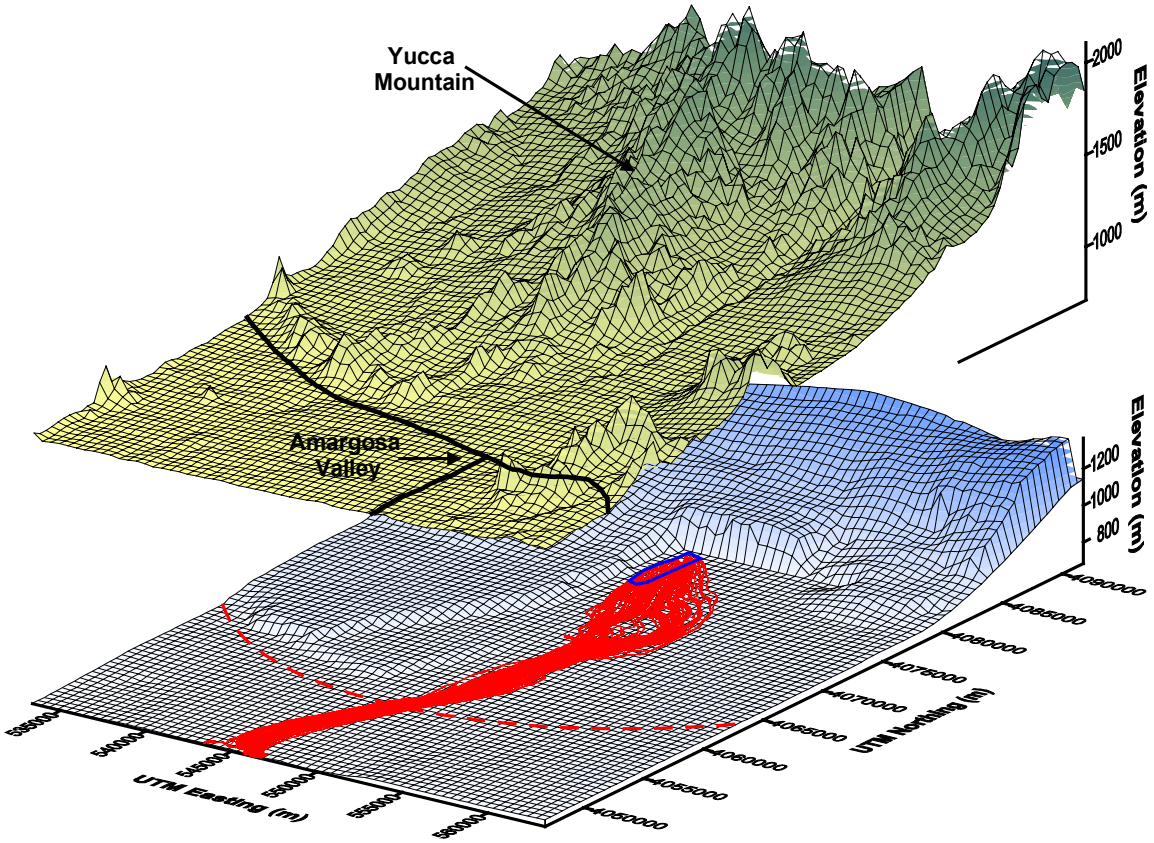
SZ Well Data Used in the SZ Site-Scale Flow and Transport Model



- 115 water-level measurements used in calibration of the SZ site-scale model for TSPA-SR
- Water-level measurements at 6 locations from the Nye County drilling program were used
- Batch sorption tests of alluvium samples from 3 Nye County wells were performed for sorption of Np, Tc, and I
- Ongoing work of the Nye County drilling program includes wells at 7 locations for FY00, including alluvial tracer complex.

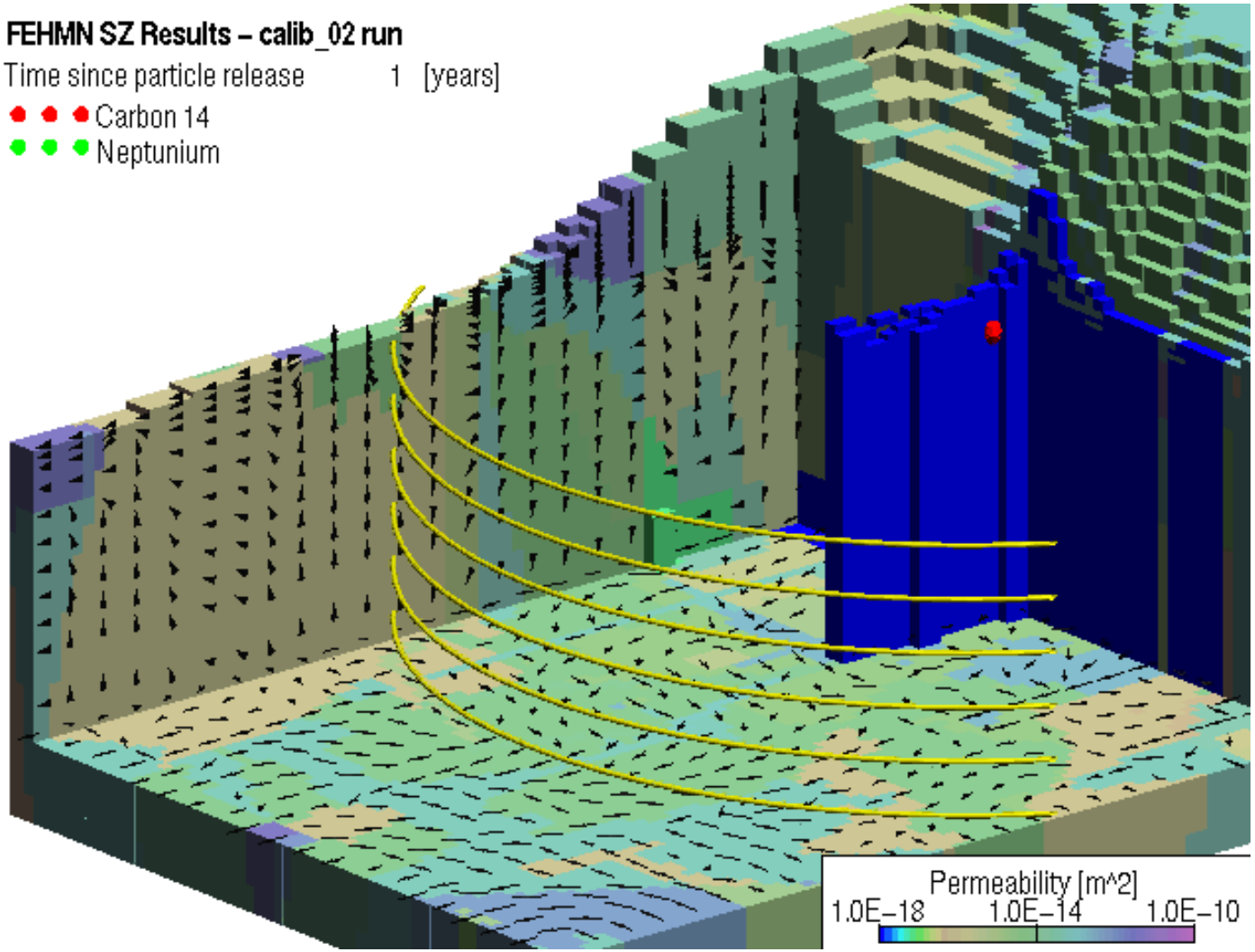
SZ Site-Scale Flow and Transport Model

Radionuclide Pathways in the Site-Scale Saturated Zone Flow and Transport Model Area



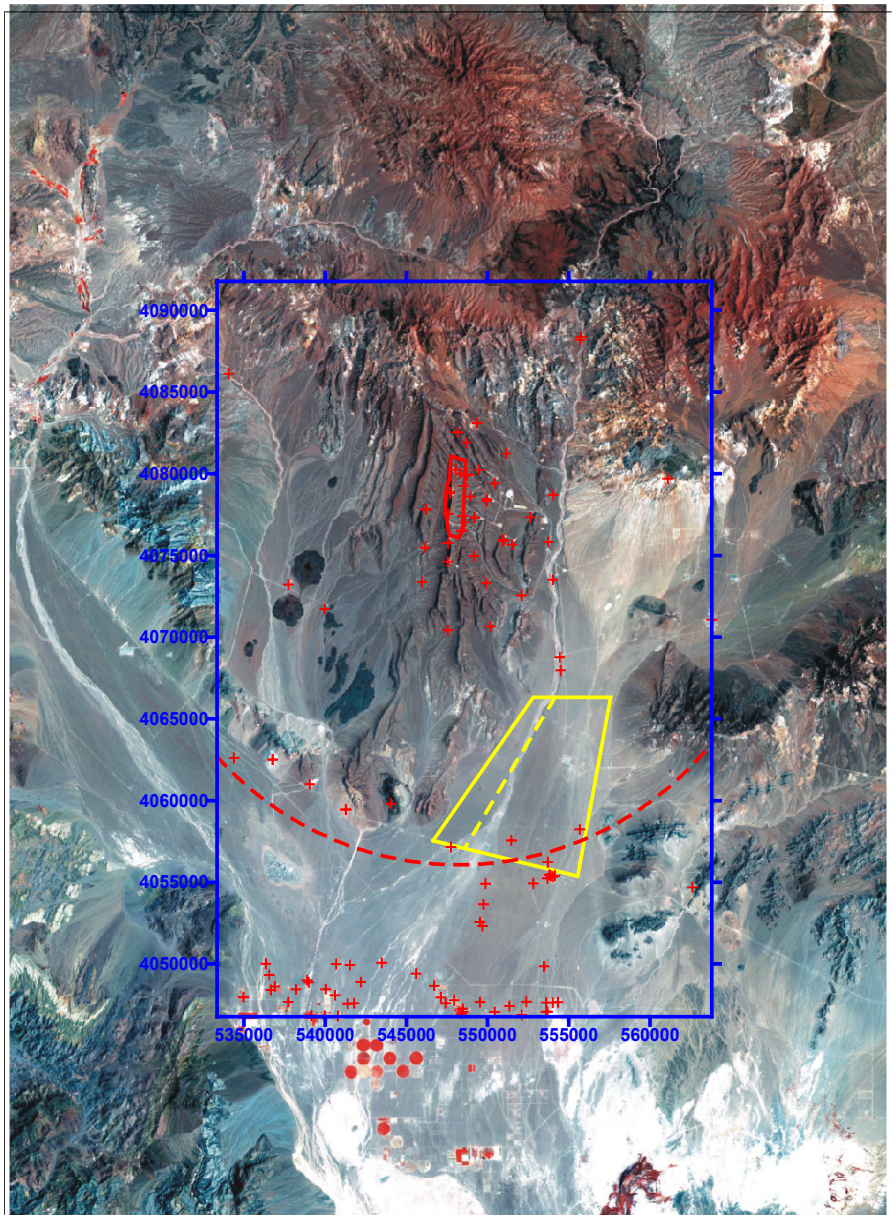
- Particle tracking method includes radionuclide transport processes of advection, dispersion, matrix diffusion in fractured volcanic units, and sorption
- Simulated flow paths from the repository occur in the upper few hundred meters of the SZ
- Simulated flow paths cross the 20 km "fence" approximately 5 km west of the town of Amargosa Valley

SZ Site-Scale Flow and Transport Model



Uncertainty in SZ Flow and Transport

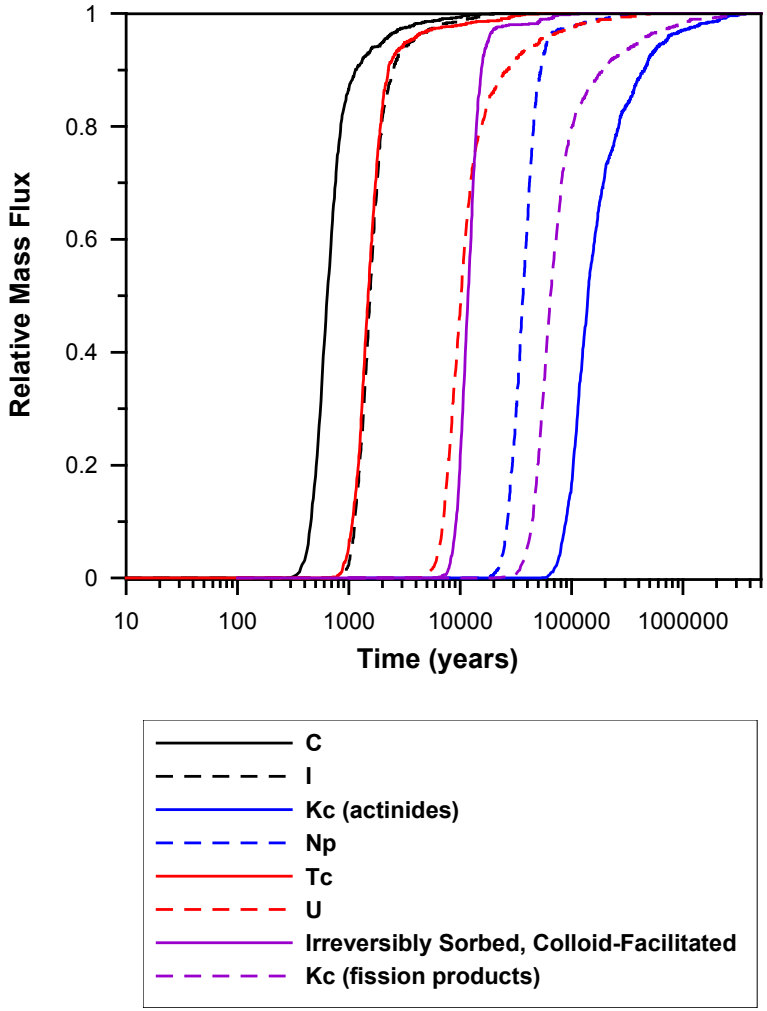
- Three discrete cases (low, medium, and high) of SZ groundwater flux are used. Probabilities for each case are based on uncertainty in permeability and gradient, and on expert elicitation results
- Two discrete cases (isotropic and 5:1 anisotropic) of horizontal anisotropy in permeability of volcanic units are used
- Alluvial uncertainty zone defined to account for uncertainty in the location of the tuff/alluvium contact along the flow path
- Stochastic parameters relevant to matrix diffusion used in TSPA are flowing interval spacing, effective diffusion coefficient, and flowing interval porosity (for fractured volcanic units)
- Other stochastic parameters are effective porosity in alluvium, dispersivity, K_ds, colloid retardation factor, source location, and K_c
- Colloid-facilitated radionuclide transport occurs by two modes: 1) irreversible attachment to colloids and 2) reversible, equilibrium attachment to colloids (K_c model)



Alluvial Uncertainty Zone

- Northern boundary of the alluvium varies across the entire uncertainty zone
- Western boundary of the alluvium varies approximately from the Fortymile Wash channel to the tuff outcrops to the west
- Flow path length in the alluvium varies from about 1 up to 9 km

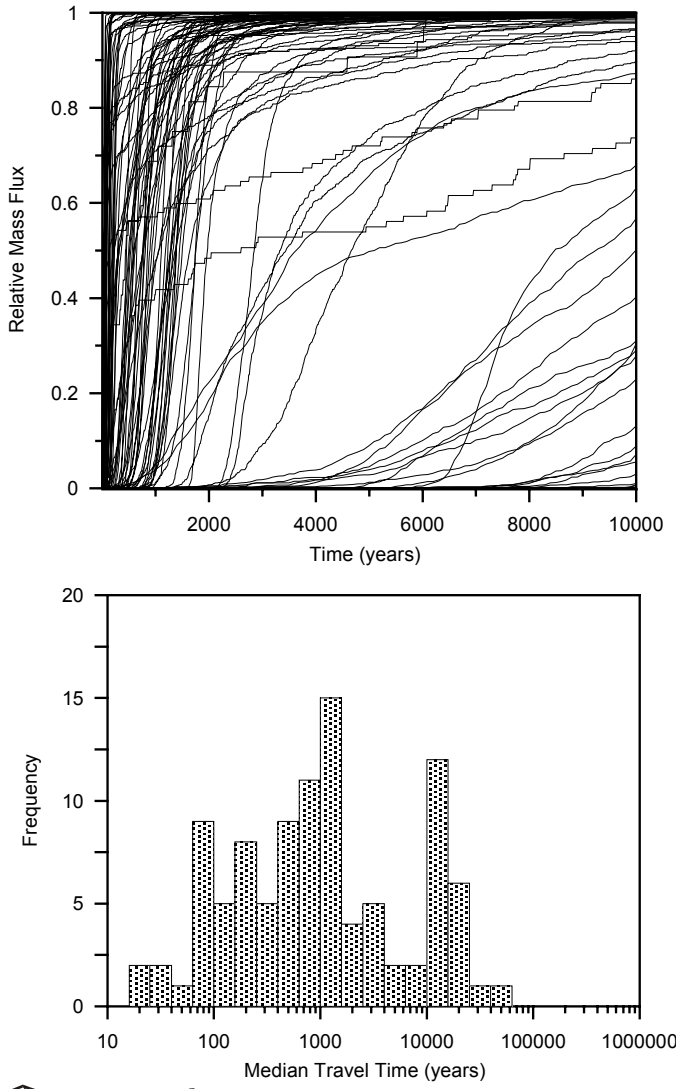
SZ Site-Scale Transport Results (Median-Value Case, Present Climate)



- **Using expected values for stochastic parameters, travel times for non-sorbing species are generally less than 1000 years**
- **Travel times for slightly sorbing ^{99}TC and ^{129}I are mostly 1000 to 2000 years**
- **Travel times for U and colloids are in the range of several thousand years to greater than 10,000 years**
- **Travel times for ^{237}Np and colloid-facilitated radionuclides are greater than 10,000 years**

SZ Site-Scale Transport Results

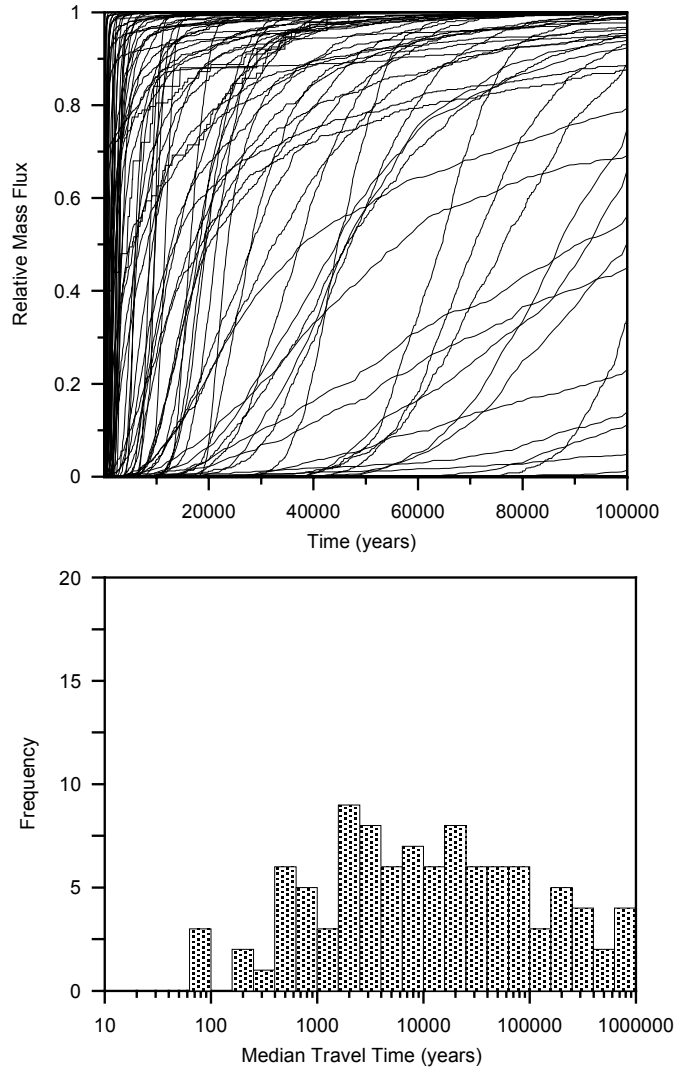
Simulated Unit Breakthrough Curves and Histogram of Median Travel Times of Mass Flux for Technetium, Present Climate



- **Travel times for stochastic realizations vary over several orders of magnitude**
- **Small amount of retardation for ^{99}Tc in alluvium results in somewhat longer travel times than conservative species**
- **Many realizations exhibit median travel times of less than 1000 years**

SZ Site-Scale Transport Results

Simulated Unit Breakthrough Curves and Histogram of Median Travel Times of Mass Flux for Neptunium, Present Climate



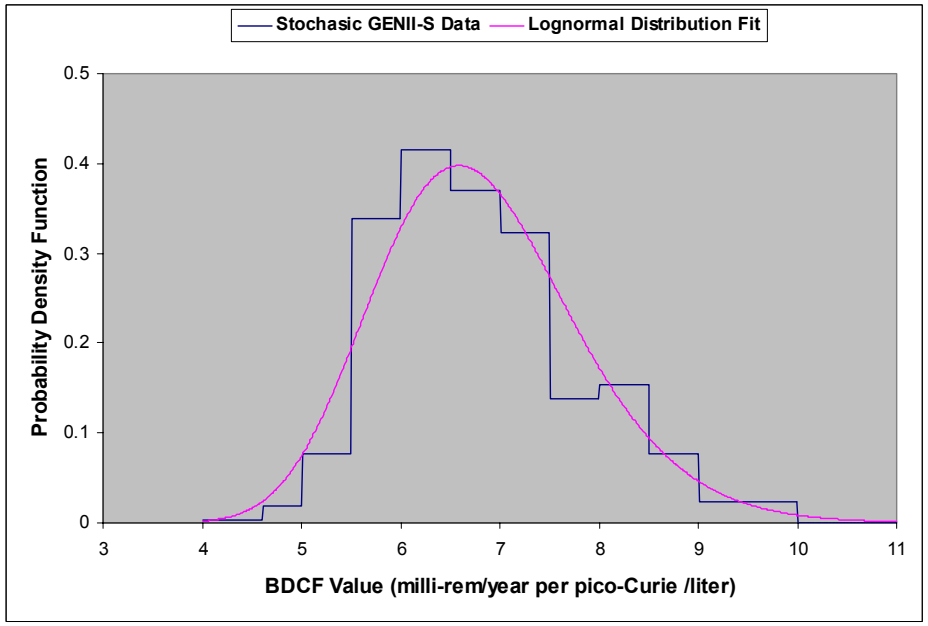
- **Variability in travel times among realizations for transport of ^{237}Np extends from less than 1000 years to 1,000,000 years**
- **Sorption and retardation for ^{237}Np is generally moderate in alluvium and minor in the matrix of fractured volcanic units**
- **Approximately half of the realizations exhibit median travel times of greater than 10,000 years in the SZ**

Biosphere Modeling for TSPA-SR

- General approach for simulating the uncertainty in biosphere dose conversion factors (BDCF) with GENII-S software code in TSPA-SR was the same as TSPA-VA. Effort focused on quality assurance of data used in BDCF modeling for TSPA-SR
- Receptors based on definitions in draft regulations by both NRC and EPA
- Analysis of uncertainty in annual groundwater usage by the hypothetical farming community performed as proposed by NRC
- Analysis of radionuclide build-up in soils from long-term irrigation with contaminated groundwater performed for TSPA-SR

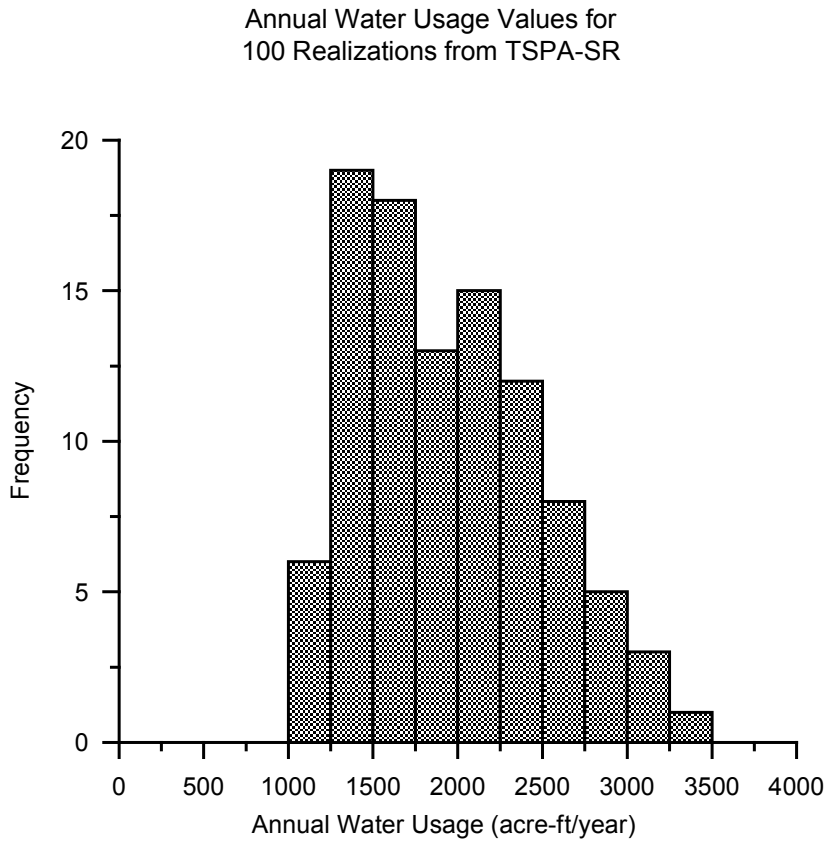
Biosphere Dose Conversion Factor for Average Member of the Critical Group

The probability distribution for the ^{237}Np BDCFs for the nominal case as generated by the GENII-S code and the optimally fitted lognormal distribution.



- Examined range of likely critical groups and their general characteristics
- Defined critical group characteristics
  - Eat local food
  - Drink local milk
  - Drink local groundwater
- Include uncertainty in soil-plant uptake factors
- BDCF's also evaluated for the EPA RMEI
- BDCF's developed both for volcanic-eruption and nominal-case scenarios

Groundwater Usage by the Proposed Farming Community



- **Critical-group water usage is defined in a manner consistent with NRC guidance (small farming community of about 100 people)**
- **Uncertainty in the groundwater usage by the hypothetical farming community is based on water usage and demographic data from Amargosa Valley**
- **Number of farms varies stochastically from 15 to 25**
- **Average annual water usage per farm varies from 59.2 to 134.7 acre-ft/year**

Soil Build-Up Analyses

- Radionuclide build-up in soils assessed by calculating BDCFs with GENII-S software code as a function of years of prior irrigation with contaminated groundwater
- Net annual build-up = Inputs (irrigation) - Removal (erosion, leaching, decay, and crop removal)
- Estimates of annual surface soil removal based on USDA Soil Loss Tolerance Indices (T-values)
- Annual soil loss has a characteristic time constant of 250 years and affects build-up when other losses have a similar or longer time constant
- Soil build-up was included in the analysis, but for most radionuclides was found to have an insignificant effect on the BDCFs. Build-up has less than 10% effect on BDCFs for C, I, Np, Ac, Tc, U, and Pu

Summary

- 3-D SZ site-scale flow and transport model is used for radionuclide mass transport simulations in TSPA-SR
- Matrix diffusion is explicitly simulated by the particle tracking method in the SZ site-scale model
- Radionuclide concentration is calculated using radionuclide mass at 20 km and the average annual groundwater usage of the proposed hypothetical farming community
- 1-D radionuclide transport model is used to simulate SZ transport for decay chains
- Biosphere abstraction approach similar to TSPA-VA is used, with consideration of specified receptor groups (AMCG and RMEI) and radionuclide build-up in soils

BACKUP

Supporting Documentation (SZ)

- ***Saturated Zone Flow and Transport Process Model Report***. TDR-NBS-HS-000001
- *Hydrogeologic Framework Model for the Saturated Zone Site-Scale Flow and Transport Model*. ANL-NBS-MD-000033
- *Water Level Data Analysis for the Saturated Zone Site Scale Flow and Transport Model*. ANL-NBS-HS-000034
- *Modeling Sub Gridblock Scale Dispersion in 3-Dimensional Heterogeneous Fractured Media*. ANL-NBS-HS-000022
- *SZ Transport Methodology and Transport Component Integration*. ANL-NBS-HS-000036
- *Probability Distribution for Flowing Interval Spacing*. ANL-NBS-MD-000003
- *Abstraction of Colloid-Facilitated Pu Transport Modeling for TSPA*. ANL-NBS-HS-000031
- *Geochemical and Isotopic Constraints on Ground-Water Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain*. ANL-NBS-HS-000021
- *Calibration of the Site-Scale Saturated Zone Flow Model*. MDL-NBS-HS-000011
- *Uncertainty Distributions for Stochastic Parameters*. ANL-NBS-MD-000011
- *Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA*. ANL-NBS-HS-000030
- *Features, Events, and Processes in SZ Flow and Transport*. ANL-NBS-MD-000002

Supporting Documentation (Biosphere)

- ***Biosphere Process Model Report***. TDR-MGR-MD-000002
- *Input Parameter Values for External and Inhalation Radiation Exposure Analysis*. ANL-MGR-MD-000001
- *Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods.* ANL-MGR-MD-000002
- *Disruptive Event Biosphere Dose Conversion Factor Analysis.* ANL-MGR-MD-000003
- *Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis.* ANL-MGR-MD-000004
- *Identification of the Critical Group (Consumption of Locally Produced Food/Tap Water).* ANL-MGR-MD-000005
- *The Critical Group's Ingestion Exposure Pathway Parameters*. ANL-MGR-MD-000006
- *Groundwater Usage by the Proposed Farming Community*. ANL-NBS-MD-000006
- *Environmental Transfer Parameters Analysis*. ANL-MGR-MD-000007
- *Abstraction of BDCF Distribution with Soil Build-up*. ANL-NBS-MD-000007
- *Transfer Coefficients Analysis*. ANL-MGR-MD-000008
- *Abstraction of BDCF Distribution*. ANL-NBS-MD-000008
- *Non-Disruptive Event Biosphere Dose Conversion Factor Analysis*. ANL-MGR-MD-000009
- *Evaluate Soil/Radionuclide Removal by Erosion and Leaching*. ANL-NBS-MD-000009
- *Non-Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis.* ANL-MGR-MD-000010
- *Evaluation of the Applicability of Biosphere-related Features, Events and Processes*. ANL-MGR-MD-000011