Unsaturated Zone Flow and Transport

Presented to:
Nuclear Waste Technical Review Board

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Outline

- Objectives of Presentation – address NWTRB unsaturated zone questions
- UZ Model as a tool for estimating breakthrough times
- Major Parameters/Processes Affecting Breakthrough Times
- Current UZ Model Estimates of Conservative/Bounding breakthrough Times
- Geochemical Evidence of Breakthrough Times
- Refined Evaluations of Breakthrough Times
- Uncertainties in the Evaluation of Breakthrough Times
- Summary and Conclusions

Unsaturated Zone Questions

- What is the mean and variance of the travel time for a conservative species from the repository horizon to the water table?
- How did you arrive at this answer? (Include here a discussion of the significance of percolation flux.)
- What independent lines of evidence corroborate your estimates of unsaturated zone travel time ?
- What are the sources of uncertainty in these estimates? How much difference might the uncertainties make?

Unsaturated Zone Questions and Answers

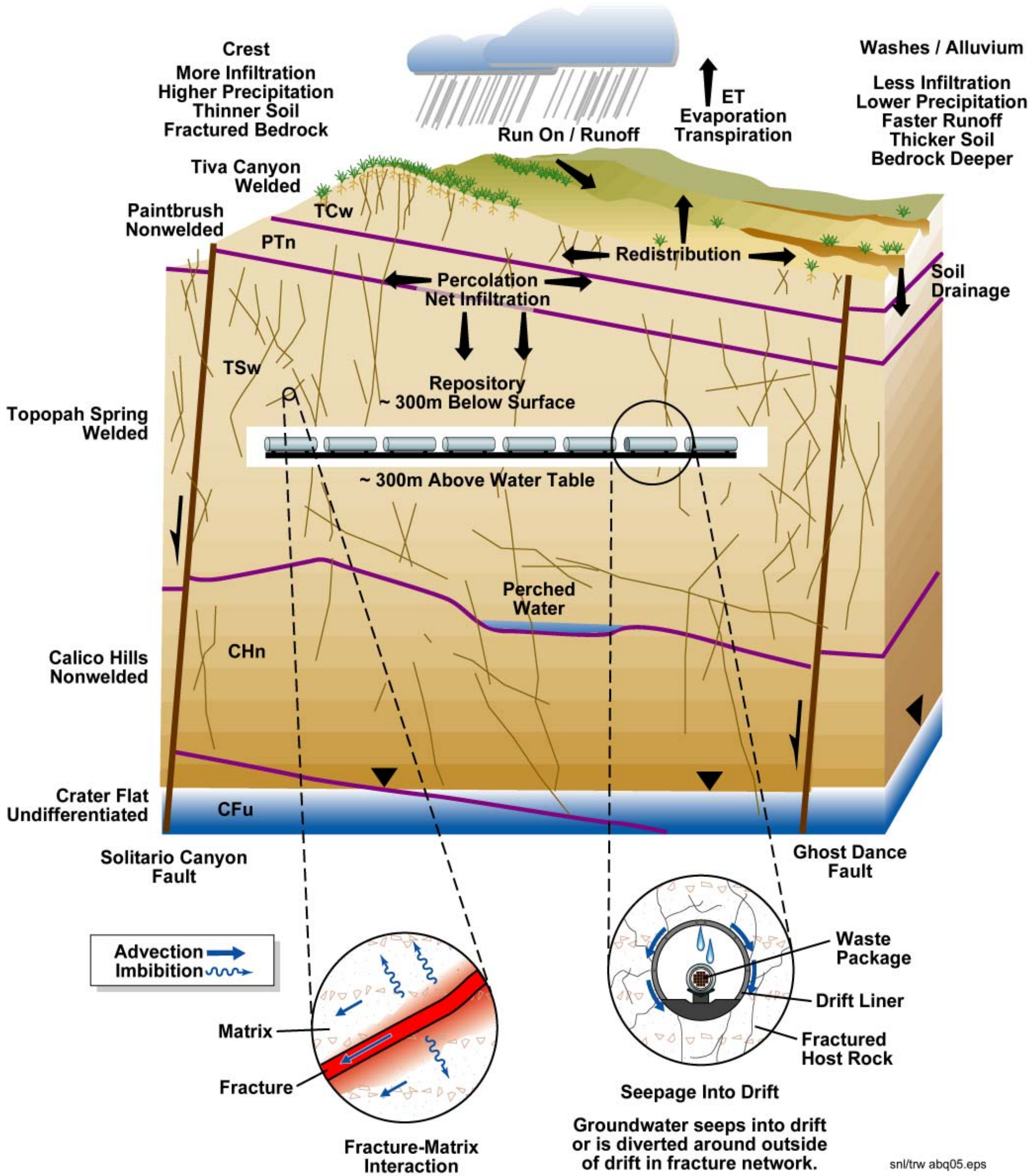
- What is the mean and variance of the travel time for a conservative species from the repository horizon to the water table? **With mean over 1000 years and variance ~ 1 order of magnitude (log scale), to be determined and verified with additional simulations.**
- How did you arrive at this answer? (Include here a discussion of the significance of percolation flux.) **With UZ model calibrated against all available data.**
- What independent lines of evidence corroborate your estimates of unsaturated zone travel time ? **Geochemical evidences in addition to hydrological data.**
- What are the sources of uncertainty in these estimates? How much difference might the uncertainties make? **Detailed and discrete features, processes, parameters to improve the quantification of travel time distributions (especially in long tails)**

Breakthrough Times Analysis for UZ

- **Current process models are primarily developed for TSPA and the evaluation of dose at the accessible environment**
- **In their current form, the UZ models include some conservative aspects (e.g., some fracture flow in vitric Calico Hills layers) that leads to conservative values of breakthrough times**
- **Rigorous analysis of breakthrough times in the UZ using systematic Monte Carlo simulations including uncertainty in all important parameters has not been performed**
- **Current UZ modeling only evaluates discrete cases in order to gain insights into parameters and processes, not to rigorously evaluate breakthrough times**

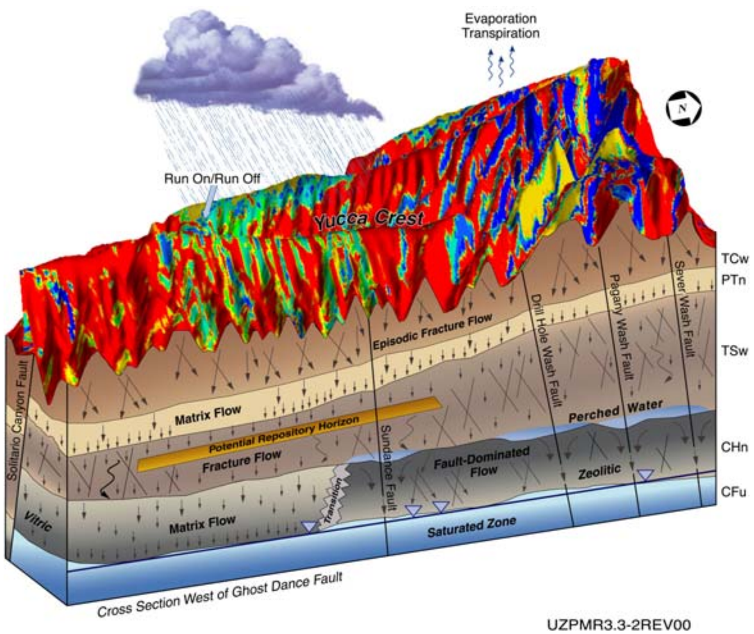
Major Issues Impacting UZ Flow and Transport

- **Ambient Percolation**
- **Matrix Diffusion**
- **Perched Water**
- **Fracture/Matrix Flow**
- **Faults as Potential Fast Flow Pathways**



UZ Model – Key Components

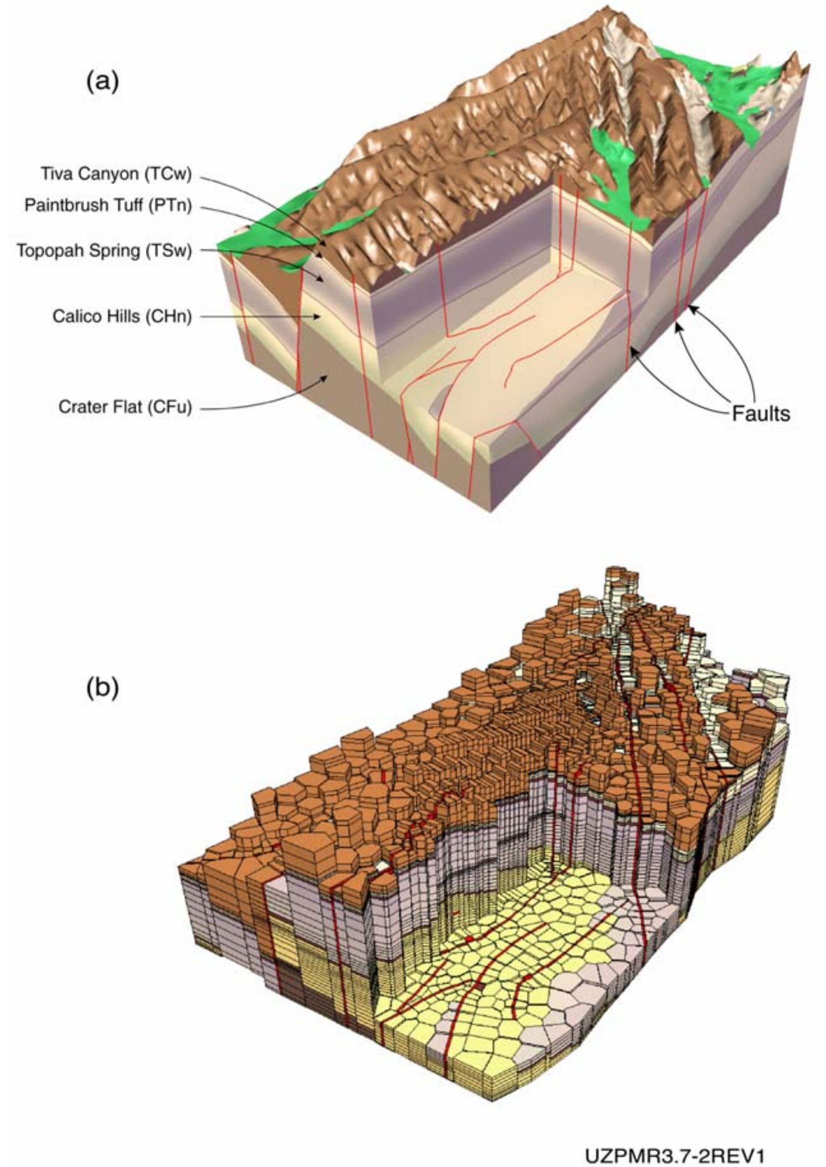
- Conceptual Model and Processes
- Modeling Approaches of Fractured and Layered Tuff Bounded by Faults
- Model Calibrations against Available Data
- Detailed Studies of Perched Water, PTn, CHn, TH, …
- Drift-Scale Studies of Seepage, THC, Ambient and Thermal Tests, Moisture Monitoring, …
- Predictions of Breakthrough Times, Radionuclide Migration, …
- Credible Model Inputs to TSPA, Repository Design, …



Conceptual Model for UZ Flow

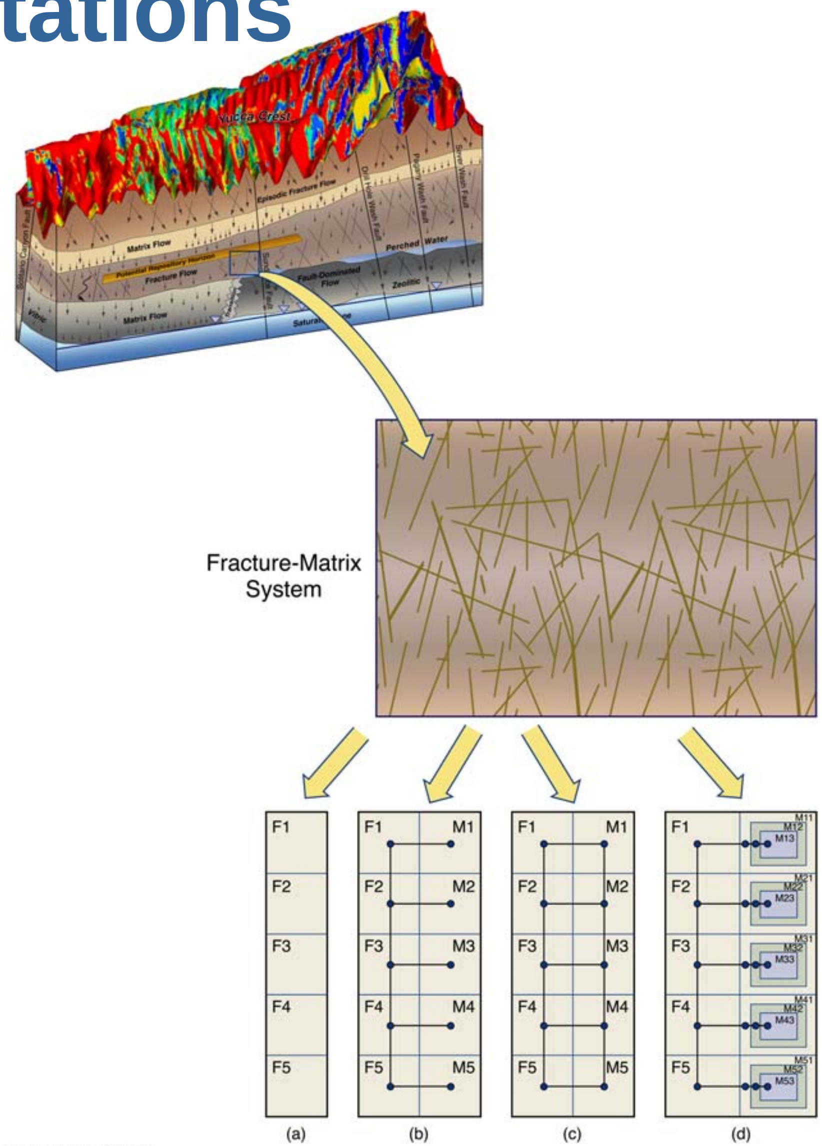
UZ Modeling Approach – Gridding

- **Geological Framework Model Inputs to Accurately Represent the Tuff Layers and Faults**
- **Discrete Grid Representations of the UZ System**
- **Nested Refinements for Specific Features (e.g., Drifts, Interfaces, … - graphically not shown)**



UZ Modeling Approach – Fracture/Matrix Representations

- **Dual Continuum Approach - to model flow and transport processes through fractures and through matrix**
- **Active Fracture Model – to represent fracture/matrix interaction and saturation-dependent interface area**
- **Continuum Model Parameters determined by Calibrations against data from boreholes, along drifts, and in ESF test beds**



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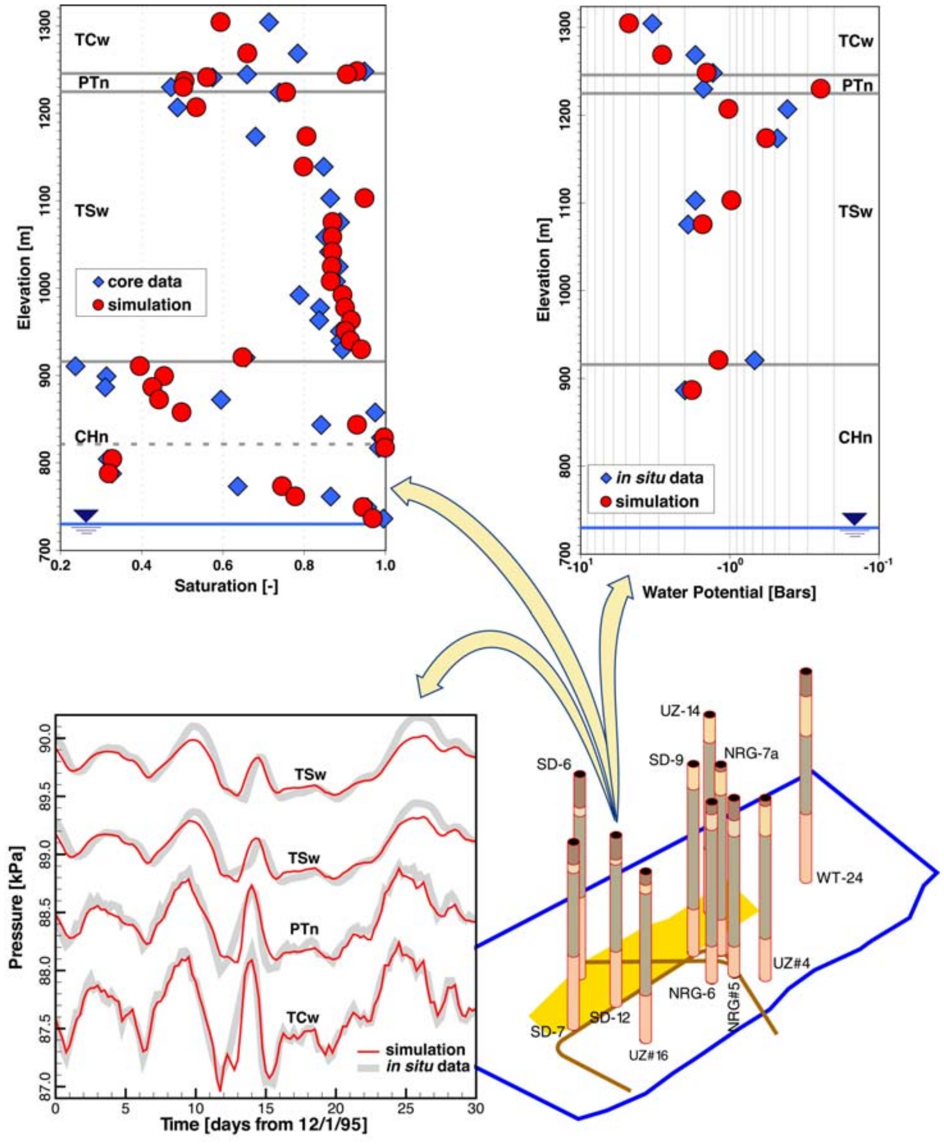
UZ Model – Calibration with Moisture and Pneumatic Data

- **Development of hydrological parameter sets using field data and inverse modeling approach**

- **3-D model calibration using saturation, water potential, pneumatic data, perched water, temperature, and geochemical isotopes**



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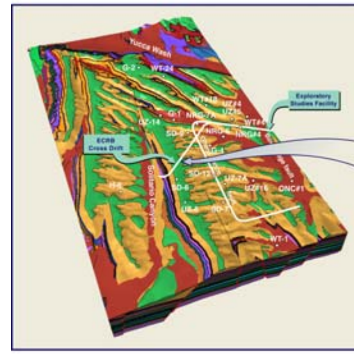
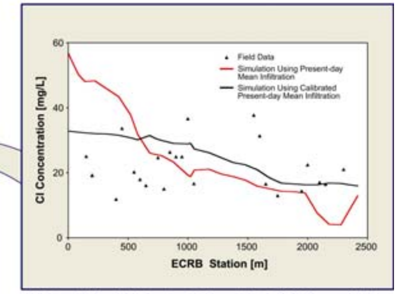
UZ Model – Calibration with Geochemical Data

- Chloride distribution along drifts to quantify percolation distribution
- Calcite profiles along borehole to check the magnitude of percolation flux
- Strontium depletions to elucidate the zeolite’s exchange capacity
- Cl-36 for fast flow

Geochemical Measurements on Borehole and ESF Samples



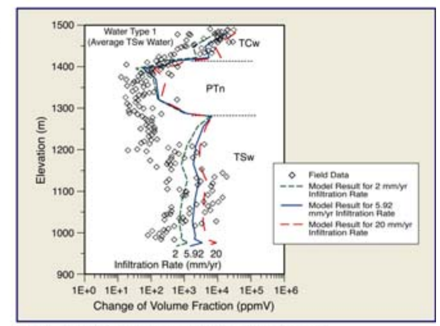


(a) Total Chloride Contents Along the ECRB Cross Drift

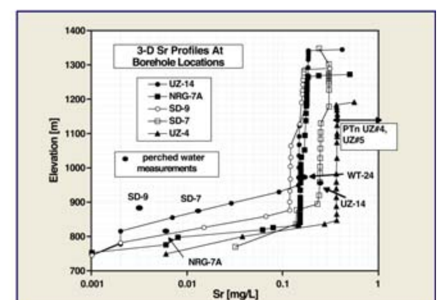
Objectives:
- Provide data to define geochemical evolution of water in the UZ.
- Provide data to estimate percolation flux at depth.

Approaches:
- Collect gas and perched water samples by pumping.
- Extract pore water by compression, ultracentrifuge, or vacuum distillation.
- Determine major ion concentrations by chemical analyses.

Results:
- Total dissolved solid and chloride are used to estimate infiltration rates and percolation fluxes.
- Pore waters are related to soil-zone processes: evapotranspiration, dissolution and precipation of pedogenic calcite and amorphous silica.
- Deep pore waters are used to evaluate restricted water-rock interactions and significant lateral movement within Calico Hills unit.



(b) Calcite Distributions Used for Infiltration and Percolation Evaluations



(c) Strontium Profiles Used for Zeolite Quantification

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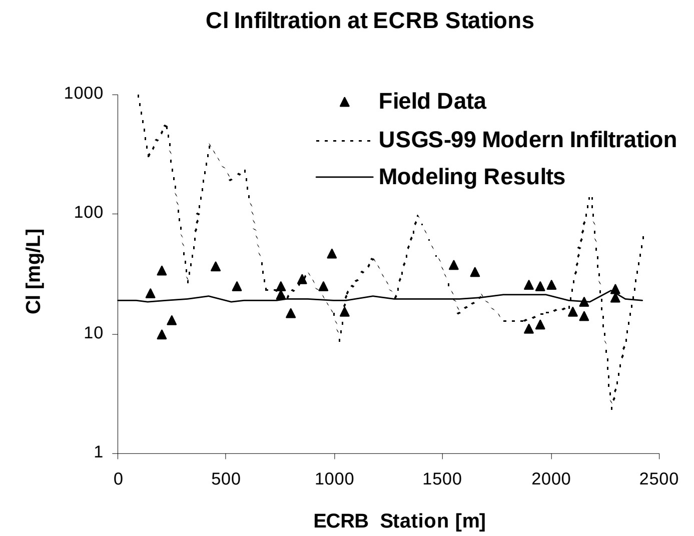
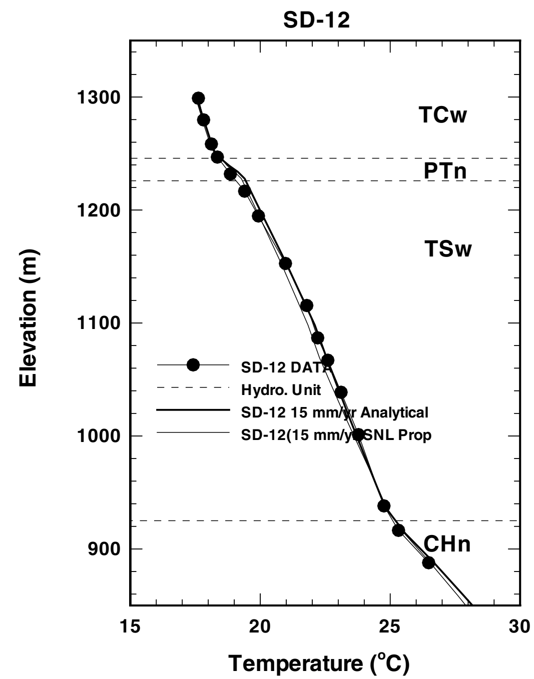
UZ Model – Calibrated with Chloride and Temperature Data

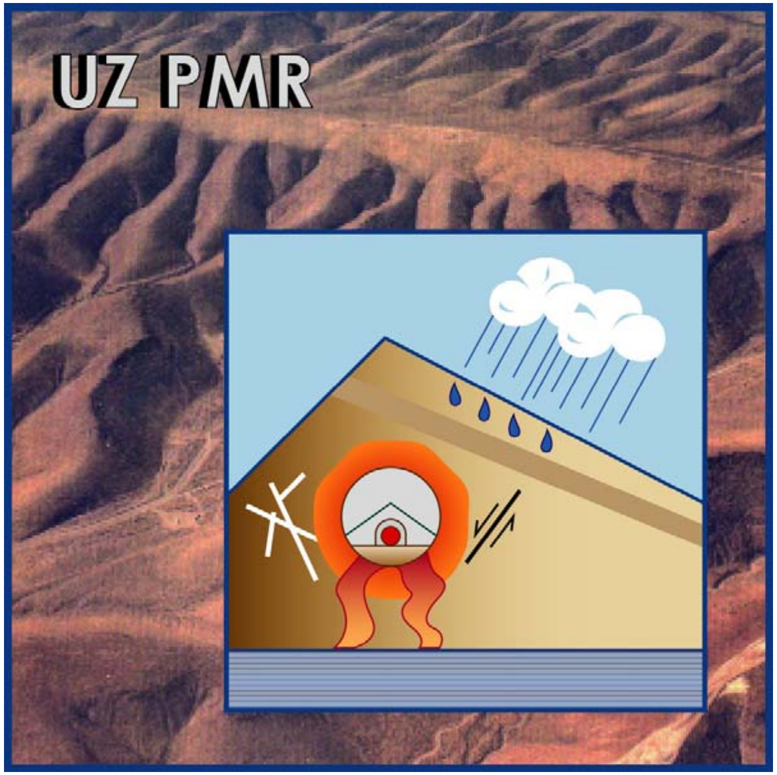
- **Total chloride and temperature data are available for many boreholes, and along both drifts (ESF and the ECRB)**
- **Calibration with all chloride data results in a modified infiltration map, which is lower and more uniform than the infiltration maps based on surface based studies**
- **Temperature data provide convincing constraints on percolation flux - Convective contribution to heat transfer**





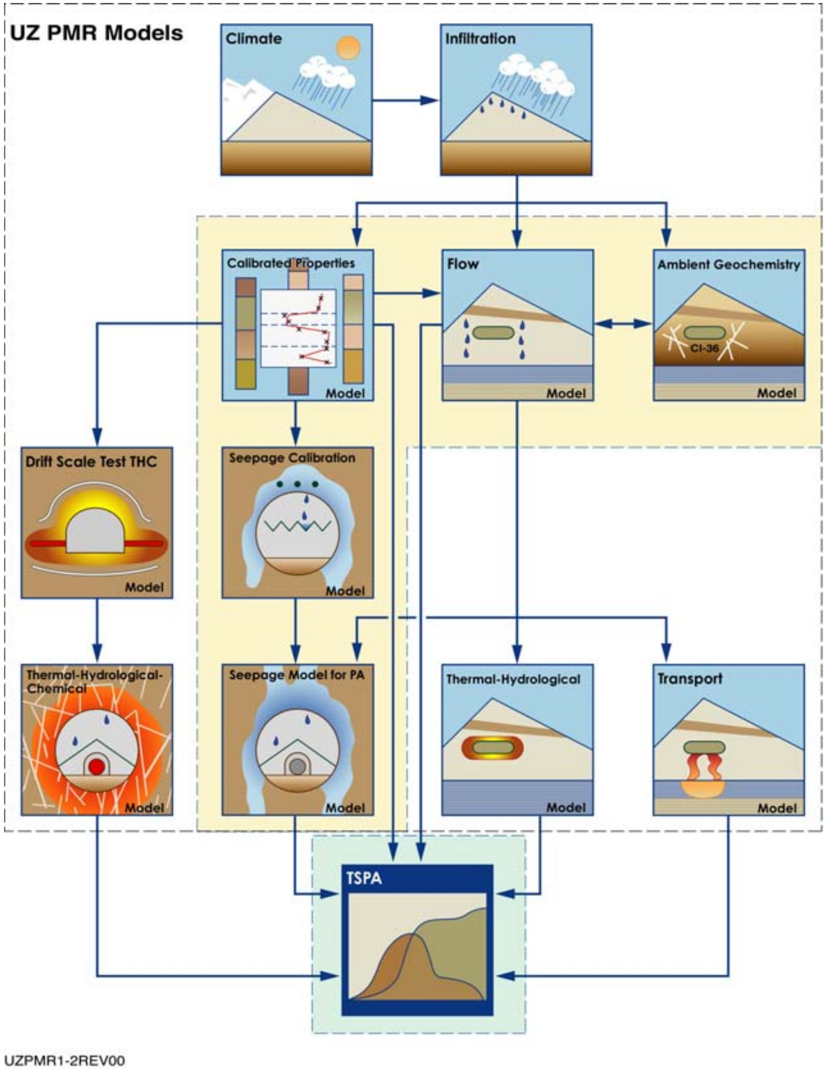
UZ Flow and Transport Model Process Model Report

- **UZ Model is presented in the UZ Flow and Transport PMR**
- **Rev 01 will summarize 27 contributing AMRs which develop the UZ models and submodels**



UZ Model – Main Models Included in UZ PMR

- Current and Future Climate/Infiltration
- Calibrated Properties, Flow, Ambient Geochemistry
- Seepage Calibration against Niche Tests, Drift-Scale THC Tests
- Seepage Model for PA, THC, TH Mountain Scale, Transport to Water Table
- Abstractions for TSPA



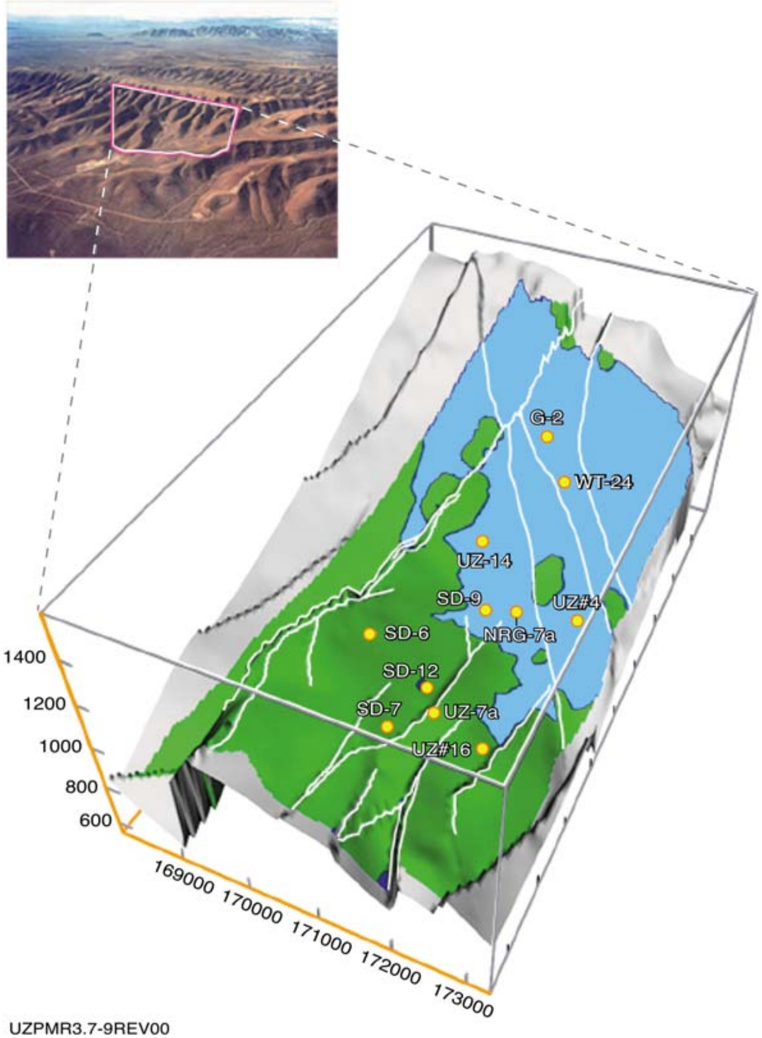
Breakthrough Times in UZ Flow and Transport AMRs

- *Radionuclide Transport Models Under Ambient Conditions*. MDL-NBS-HS-000008 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0529.

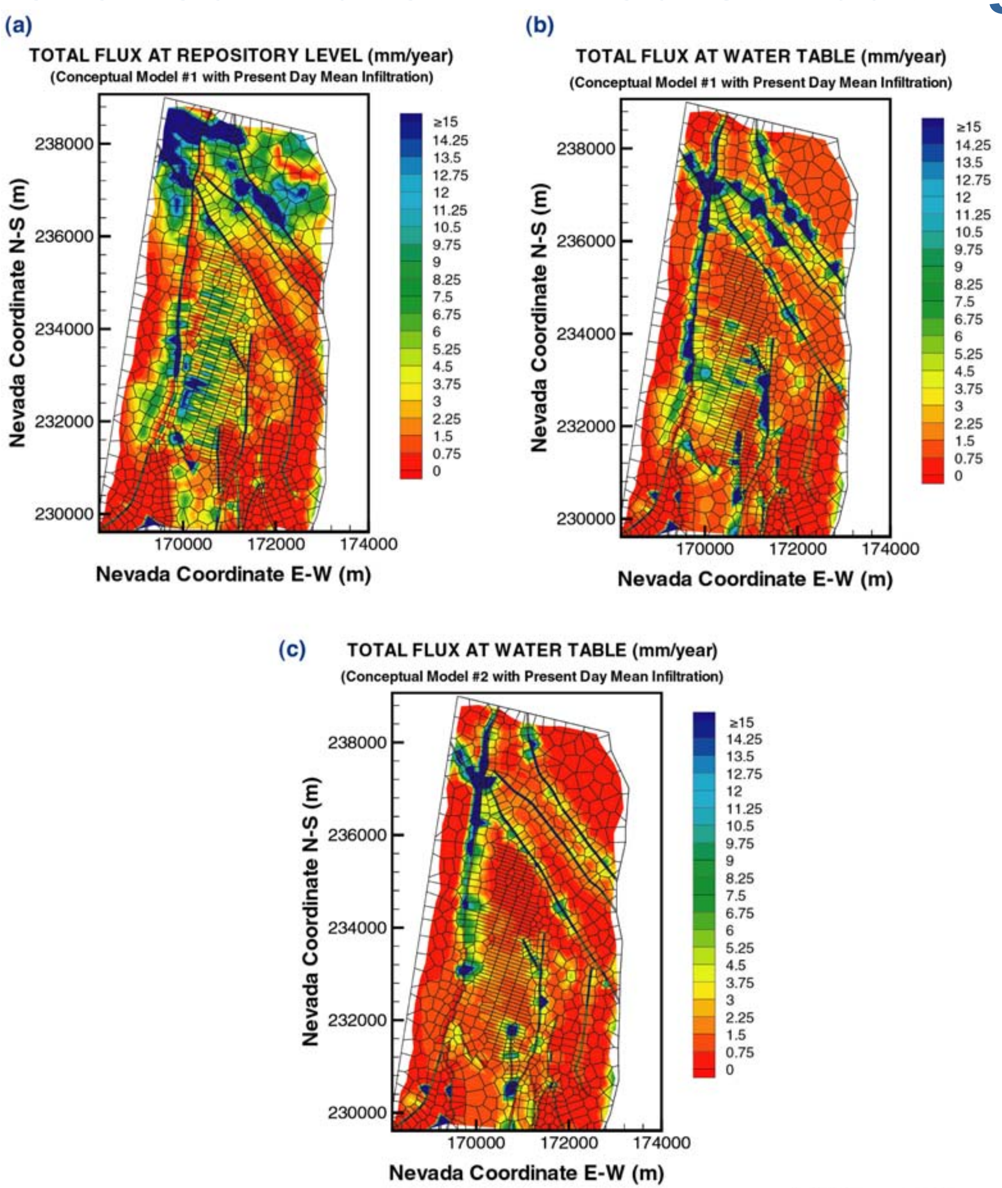
- *UZ Flow Models and Submodels*. MDL-NBS-HS-000006 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0527.

Important Parameters for Breakthrough Time Estimation

- **Percolation Flux**
- **Fracture-Matrix Flow Components**
- **Flow through Faults**
- **Perched Water Zones**
- **Radionuclide Transport**



Effects of Perched Water in Redistributing Percolation



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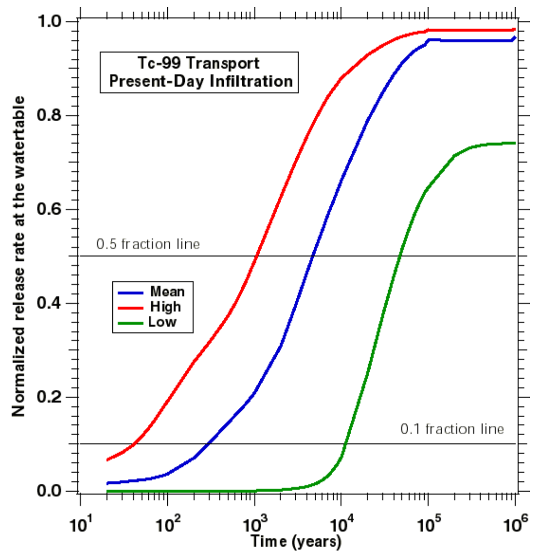
UZ Transport Model Prediction

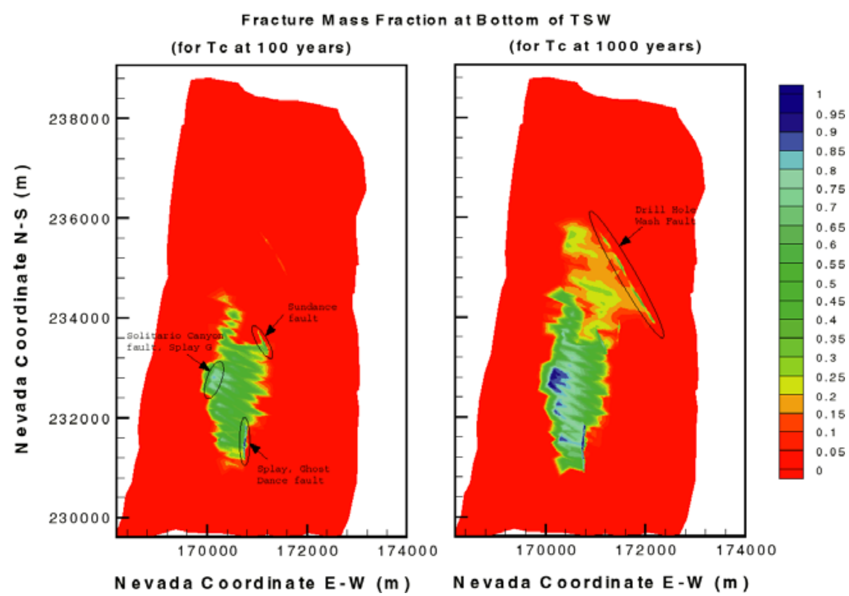
Results

- Faults dominate and control the transport
- Fractures are the main pathway
- Matrix diffusion and sorption are main retardation mechanisms
- ^{239}Pu decay chain products are important
- Colloidal transport could be important

Important Factors

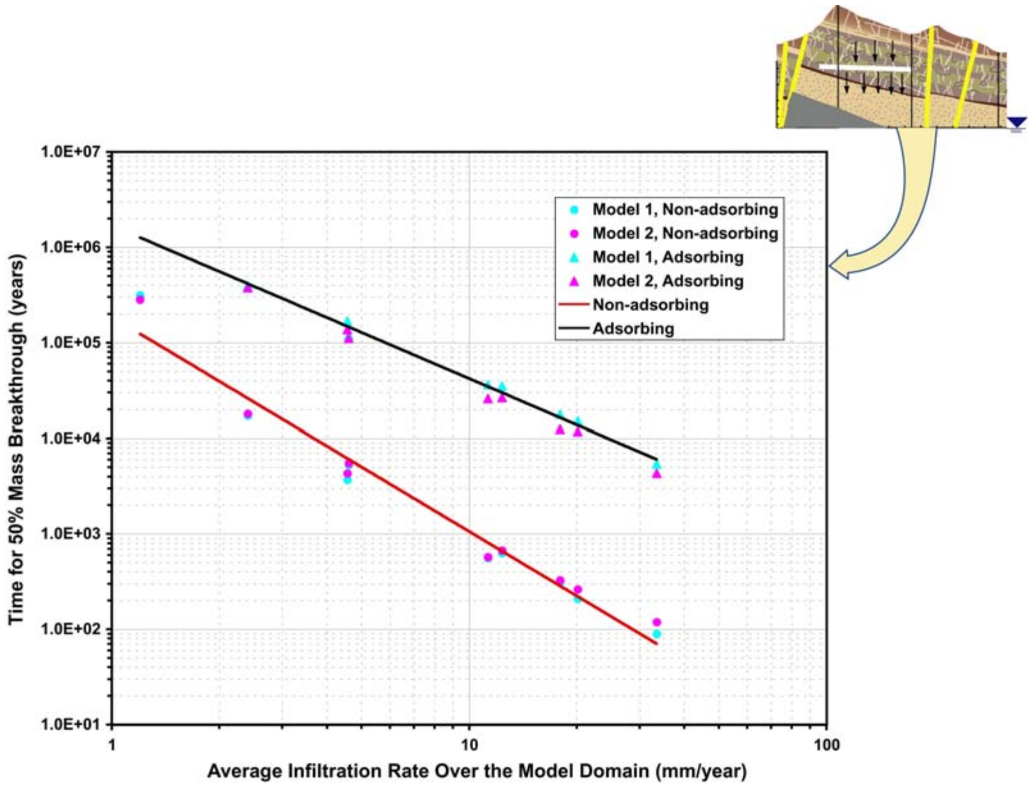
- Faults and fractures
- Matrix diffusion and sorption
- Colloidal filtration parameters





UZ Results – Conservative/Bounding

- **Based on the current UZ Flow and Transport model, with incorporation of nine future climate scenarios**
- **Infiltration rate has direct impact on transport times**
- **Adsorbing tracer has much longer transport time**



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Geochemical Evidence Related to Breakthrough Times

Isotopic studies, fracture coating studies, and hydrologic and geochemical data provide evidence of low infiltration, long residence times, low flux in the UZ, and a hydrologically stable environment at the potential repository horizon

- **Total chloride values, increased $^{87}Sr/^{86}Sr$ ratios within the PTn, ^{36}Cl levels at or below background levels in the ESF indicate that surface infiltration is small and that the matrix properties of the PTn slow and redistribute percolating water. This results in slow transport within and through the PTn and only minor release of flux (<5mm/yr) to the potential repository horizon**
- **U-Pb, U disequilibrium, and radiocarbon dating of opal and calcite fracture coatings from the ESF indicate slow, steady growth with over the past 8 million years**
- **Stable isotopes (^{2}H, ^{18}O) from pore waters and gas phase ^{14}C show ages increasing with depth in the TSw**
- **^{14}C, $^{36}Cl/Cl$, and stable isotopes from perched water bodies at the base of the TSw and in the CHn indicates ages from 2,000 to 12,000 years**

UZ Model Refinement

- **A best estimate case conceptual approach has been developed to provide more accurate predictions of ground water flow and transport in the UZ at Yucca Mountain**
- **The best estimate case approach refines key concepts which supply direct input to the UZ Model**

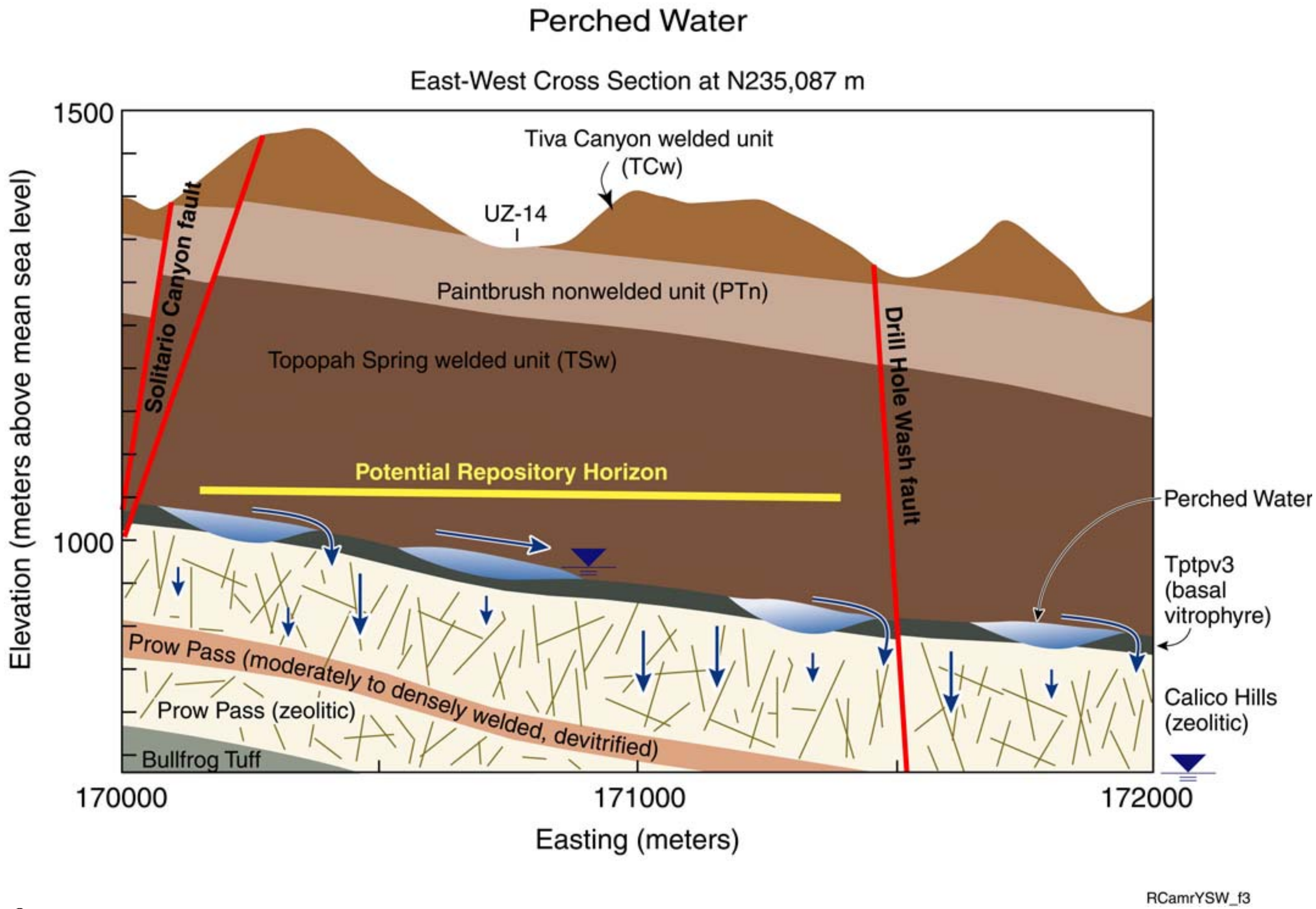
Major Model Refinements for UZ

- The effects of fractures in the vitric unit of the Calico Hills Formation are minimized based on Busted Butte data. Results show no significant difference in breakthrough times.
- Model studies to examine the effects of faults through sensitivity studies on fault properties. Results show no significant difference in breakthrough times.
- Various model studies (in progress) to examine seepage parameters/processes

Major Model Refinements for UZ

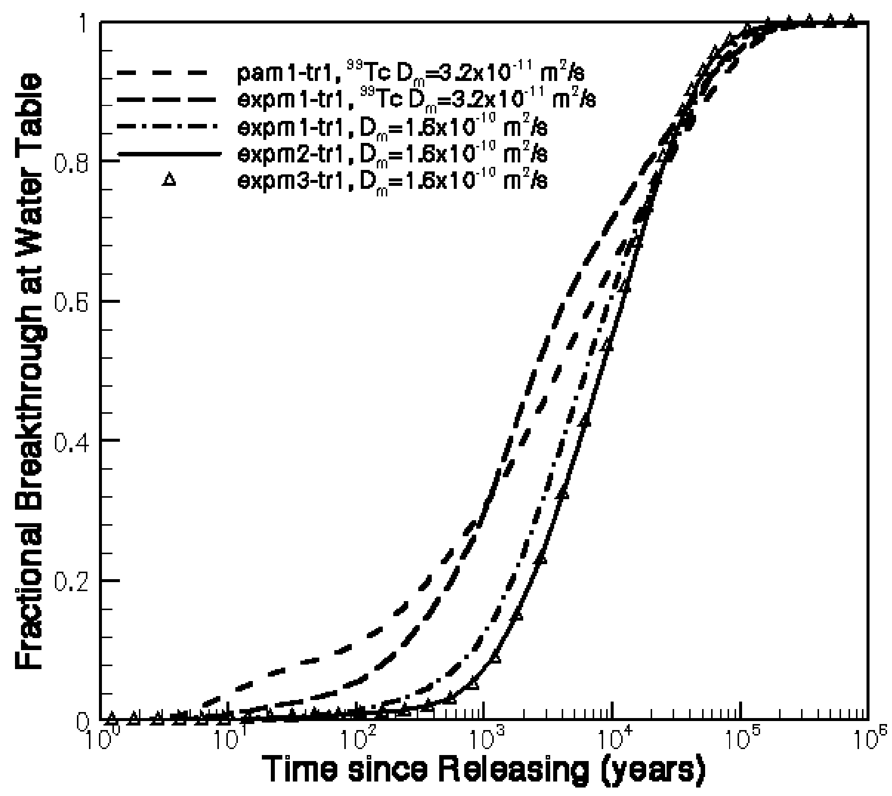
(Continued)

- A perched water conceptual model that assumes less extensive perched water bodies is utilized to more closely reflect observed data obtained from boreholes



Recent Results of UZ Refinement Studies

- **Best Estimate Case shows longer transport times**
- **20 % breakthrough >3,000 years vs. 300 years**
- **50% breakthrough ~7,000 years vs. 3,700 years**



Major Uncertainties In UZ Breakthrough Times

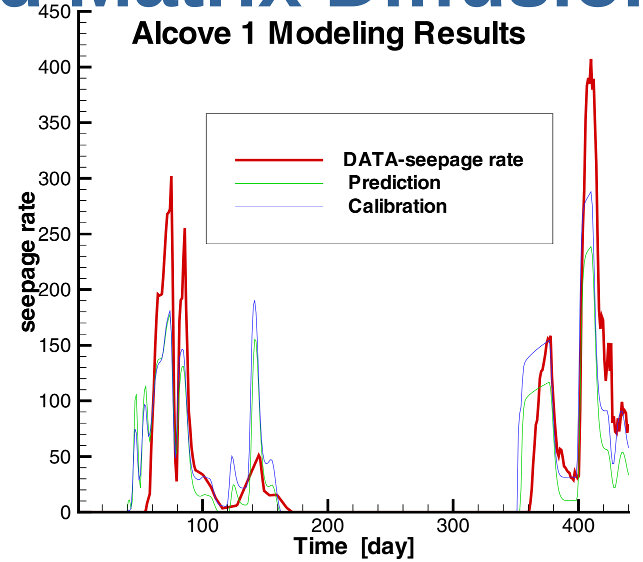
- Net Infiltration predictions for future climates
- Detailed spatial distribution of fracture, matrix, and fault properties (especially in the Calico Hills formation)
- Radionuclide transport properties in Tuff
  - Molecular diffusion coefficient
  - K_d of radionuclides
- Uncertainties with the geologic model
  - Fault distribution (potential fast flow pathways)
  - Mineral distribution (vitric vs. zeolitic)

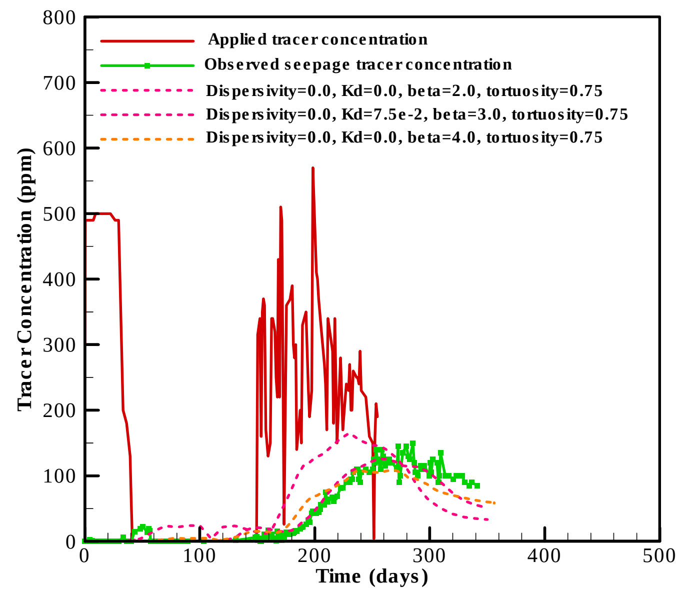
Strategies to Address Uncertainties in UZ Model

- **Field Testing and Associated Modeling to Determine Effective Parameters (Matrix Diffusion, Fault and Fracture Properties, Active Fracture Parameters, …) (see presentation by Peters)**
- **Additional incorporation of isotope data (especially for vitric and zeolitic units below potential repository to estimate transport times and pathways**
- **Systematic evaluation of uncertainties of processes and models (see presentation by Boyle)**
- **Sensitivity analyses of alternative models**

UZ Predictive Studies
Alcove 1 Test: Seepage and Matrix Diffusion

- The Alcove 1 flow and transport test consisted of infiltration above Alcove 1 and measurements of seepage and tracer concentration in the Alcove
- The seepage data allow for calibration with the seepage model. Calibration of phase 1 allowed for predictions for phase II
- The tracer test data allowed for predictions of fracture/matrix interaction and matrix diffusion
- The model results indicate that 50% of the fractures flowed and that matrix diffusion was very effective in retarding the tracer

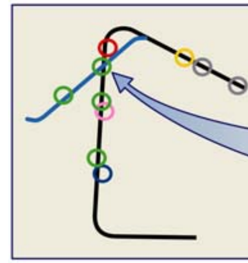


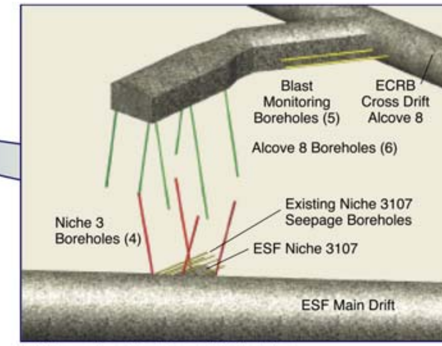


Alcove 8 – Niche 3 Cross-Over Tests at Potential Repository Horizon

- **Unique location near the cross-over point between ECRB Cross Drift and ESF Main Drift, ~20 m apart**
- **Controlled liquid releases of tracers from Alcove 8**
- **Seepage collection and wetting front detection at Niche 3**
- **Geophysical imaging and cross-hole air injection to map the liquid plumes**
- **Initially focus on a fault mapped during Alcove 8 excavation**

Alcove 8-Niche 3107 Cross-Drift Test





(a) Schematic of the Cross Drift Test Bed

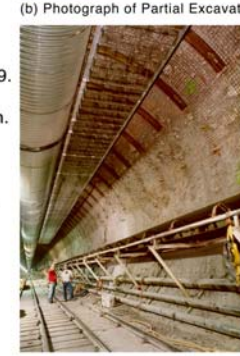
Objectives:
- Quantify large-scale infiltration and seepage processes in the potential repository horizon.
- Evaluate matrix diffusion mechanism in long-term flow and transport tests across an lithophysal-nonlithophysal interface.

Approaches:
- Water releases are in Alcove 8 and seepage collections are in Niche 3107.
- Niche 3107 is instrumented with seepage collectors and wetting front sensors.
- Geophysical tomographs are conducted in vertically slanted boreholes.

(b) Photograph of Partial Excavated Alcove 8 in ECRB Cross Drift

Status:
- Drill-and-blast phase of Alcove 8 excavation was completed in 1999.
- Tests are prepared to be conducted after alcove excavation.

Supporting Results:
- Seepage tests at Niche 3107 behind bulkhead demonstrate the existence of seepage threshold under high humidity conditions.
- During ECRB Cross Drift construction, no water was observed to seep into the ESF Main Drift 20 m below.



(c) Photograph of Water Collection Trays on the Ceiling of the ESF Main Drift

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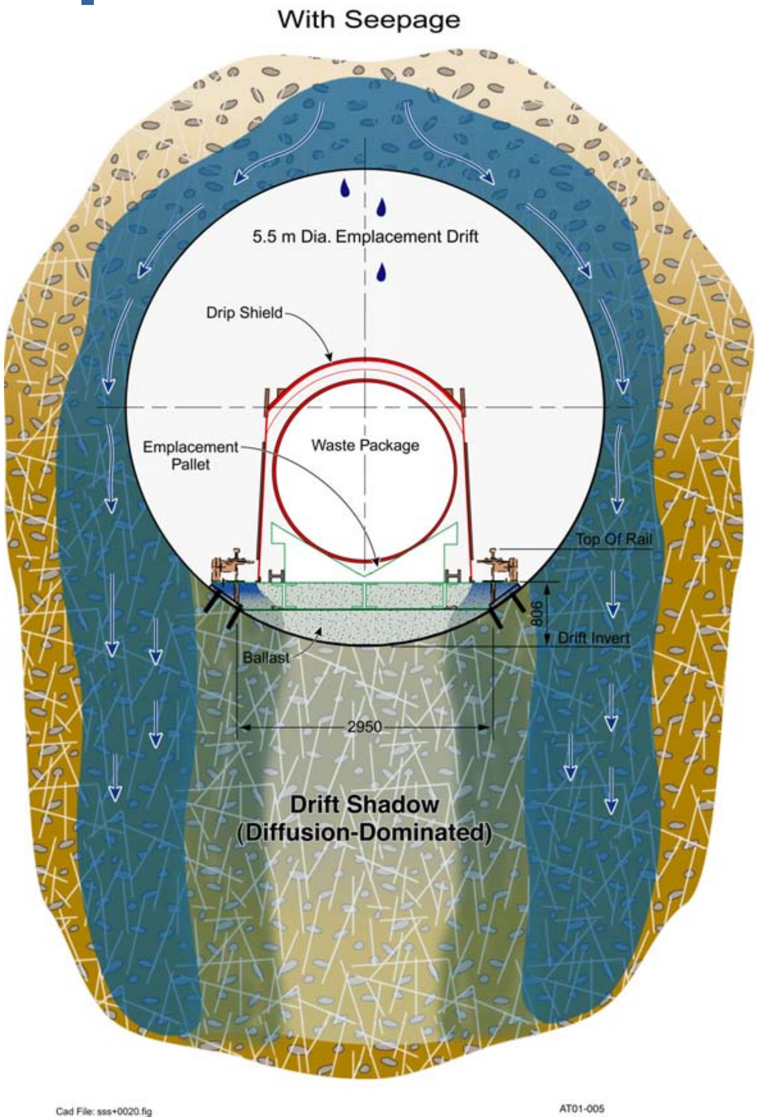
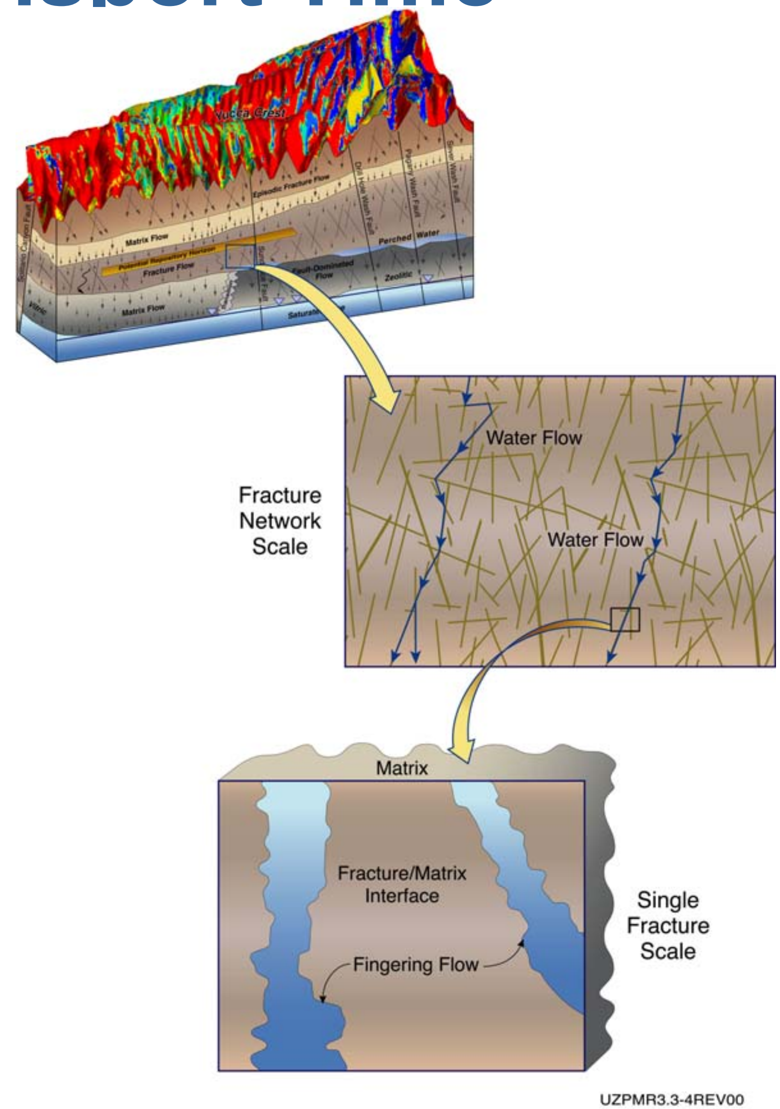
Drift Shadow as an Additional Factor Affecting UZ Transport Time

- Shadow Zone – Reduces the availability of radionuclides for transport
- The fractured tuff in the shadow zone below the drift could be potential diffusion barriers if liquid saturation is low and liquid films on tuff surfaces are discontinuous
- Integrated modeling analyses to consider seepage, diversion, diffusion, and drainage
- Evaluation of shadow zone has started through evaluation of uncertainties (see presentation by Boyle)

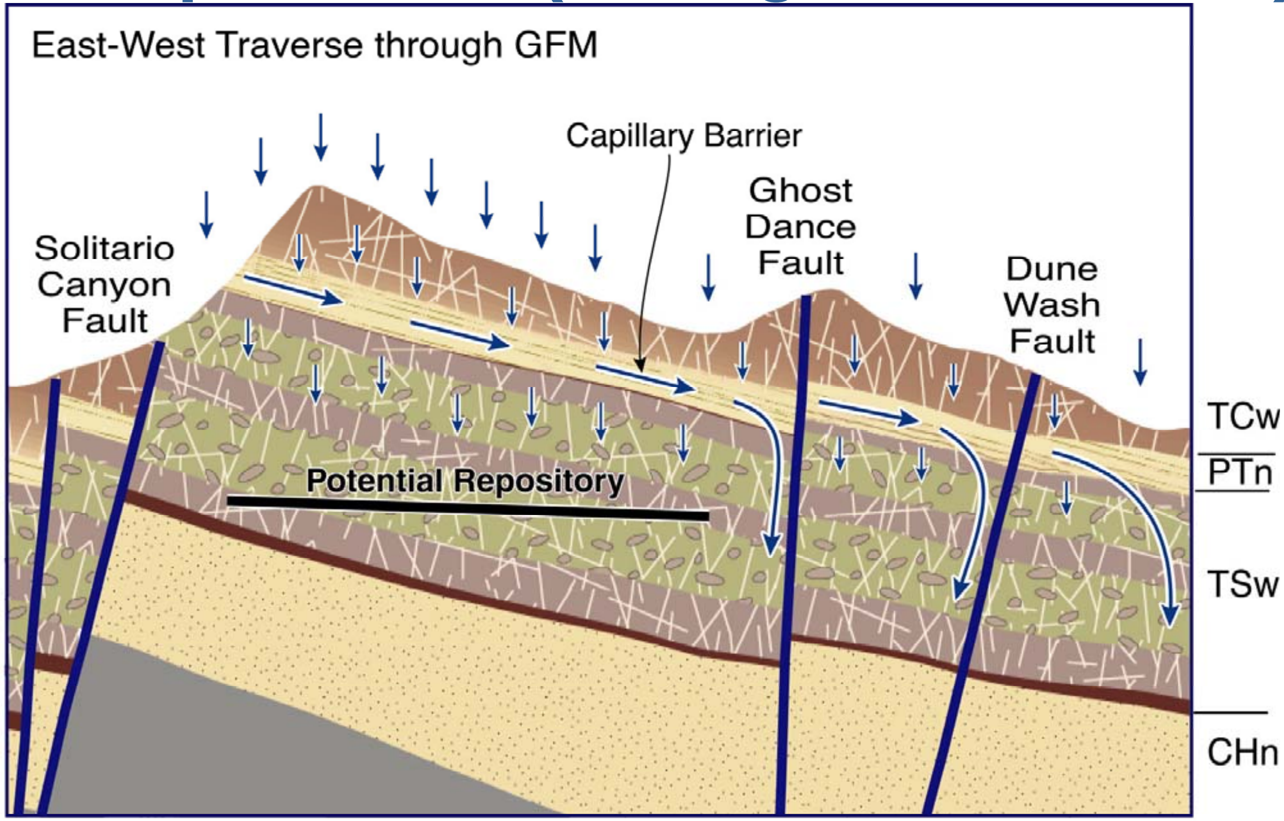


Discrete Features as an Additional Factor Affecting UZ Transport Time

- **Discrete Features – Flow through the UZ might be controlled by discrete features, such as fractures. Alternative modeling approaches will incorporate discrete features, rather than use the current continuum approach.**
- **Active fracture model parameters to be confirmed with detailed studies and comparisons with field testing results**



PTn Lateral Flow as an Additional Factor Affecting UZ Transport Time (through Percolation)



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- **Lateral flow in the PTn**
- **Infiltration pulse damping effect of the PTn**
- **Repository percolation flux may be reduced by over 50%**

Summary of UZ Modeling of Breakthrough Times

- **Breakthrough times and analysis in UZ PMR REV00 are are conservative and bounding**
- **Refinement of UZ models are underway resulting in breakthrough times of thousands of years for the UZ**
- **Current and planned field testing will verify UZ model results of breakthrough times**