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

Unsaturated Zone Flow and Transport

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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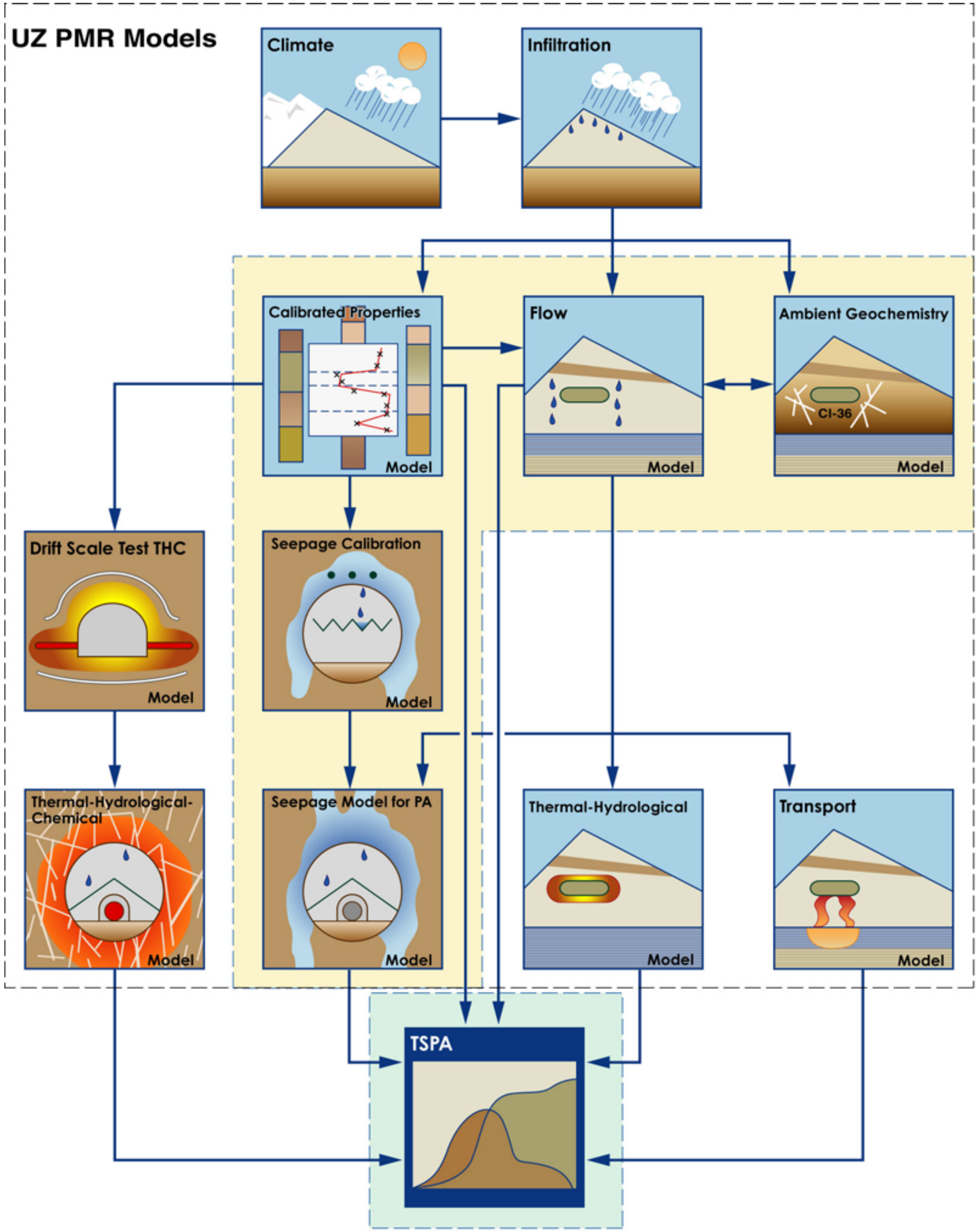
YUCCA MOUNTAIN PROJECT



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UZ Flow and Transport Process Model Factors

Key Attributes of Performance	Process Model Factor	TSPA-SR Input Parameters
Water Contacting Waste Package	Climate	• Climate states • Timing and sequence
	Net Infiltration	• Probabilities for different infiltration scenarios • Infiltration Rate
	Unsaturated Zone Flow	• Flow fields for different infiltration scenarios and climate states • Percolation flux at repository
	Coupled Effects on UZ Flow	• Percolation flux affected by TH
	Seepage into Emplacement Drifts	• Seepage flux and seepage fraction as a function of percolation flux • Percolation flux -- f (multiple locations, waste type, time, climate)
	Coupled Effects on Seepage	• Seepage flux and seepage fraction as a function of percolation flux • Seepage composition affected by THC

UZ Flow and Transport Process Model Factors

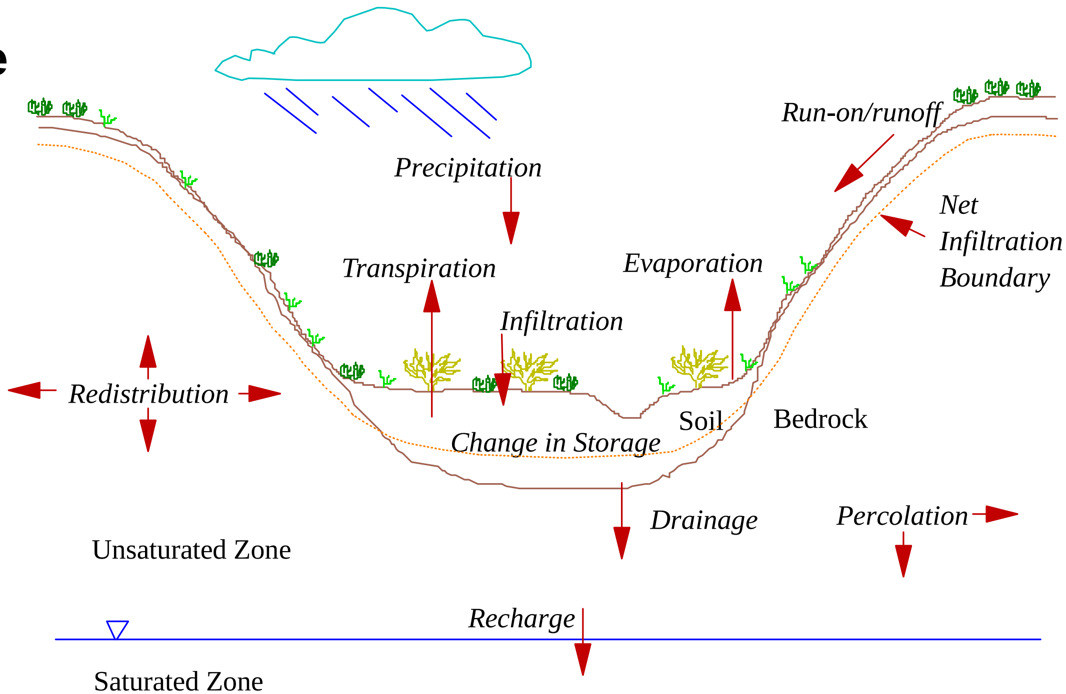
(Continued)

Key Attributes of Performance	Process Model Factor	TSPA-SR Input Parameters
Transport Away from the Engineered Barrier System	UZ Radionuclide Transport	• Fracture aperture and spacing in different units • Flow fields for different infiltration scenarios and climate states • K_d for all elements included in TSPA • Matrix diffusion coefficients – f (isotopes, units) • K_c and/or kinetic colloid parameters for Pu , Am, Th etc. • Colloid filtration factor
	SZ Radionuclide Transport	• Breakthrough curves – f (radionuclide, region) • Climate change flux multiplication factor • Capture zones and release locations within each zone. • Flow fields • Flowing interval spacing • Effective porosity for all units except the volcanic units • Dispersivity (longitudinal, horizontal transverse, vertical transverse) • Boundary definition of the alluvium • K_d for isotopes included in TSPA • Flowing interval porosity • Matrix porosity • Effective diffusion coefficient • K_c colloid parameters • Colloid filtration factor
	Wellhead dilution	• Annual groundwater usage
	Biosphere Dose Conversion Factor	• Biosphere dose conversion factor – f (radionuclide, irrigation time)

Climate and Infiltration Models

Objectives

- **Climate**
  - Analysis of potential future climate conditions-10,000 years
  - Estimate mean, upper and lower bounds for precipitation and air temperature
  - Provide input for Infiltration Model
- **Infiltration**
  - Provide spatially-distributed time-averaged estimates of net infiltration
  - Upper boundary of UZ Flow and Transport Model



Climate and Infiltration Models

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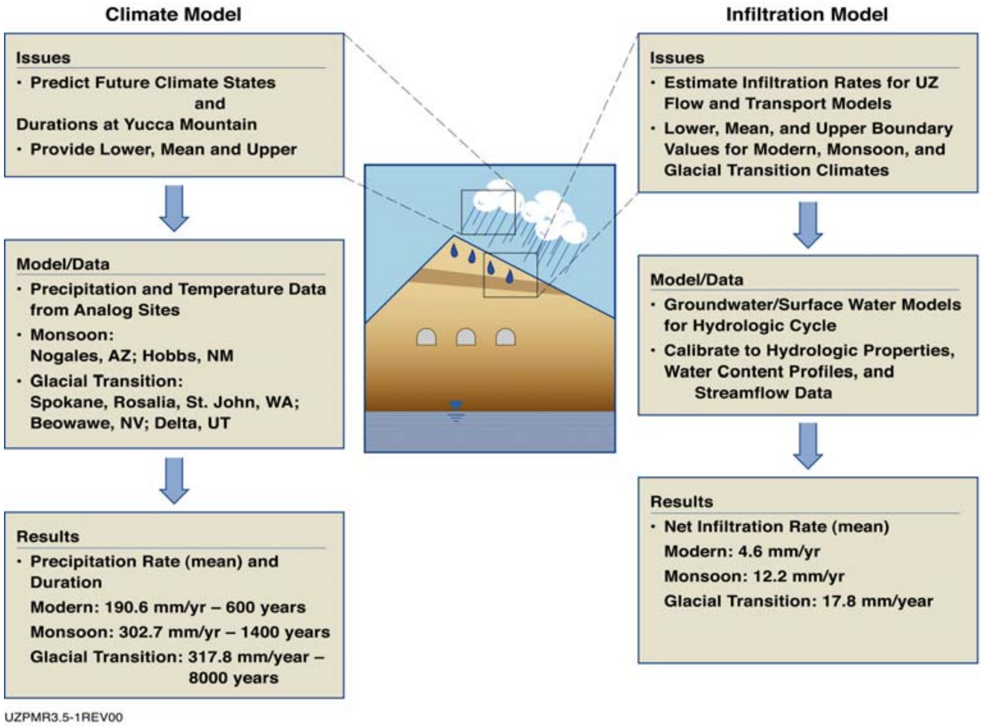
Assumptions

- **Climate**
  - Analysis based on examining paleoclimate records
  - Climate is cyclical with several alternating glacial and interglacial periods
- **Infiltration**
  - Model infiltration through root-zone only
  - Simplified "bucket-model" used to simulate infiltration process



Climate and Infiltration Models

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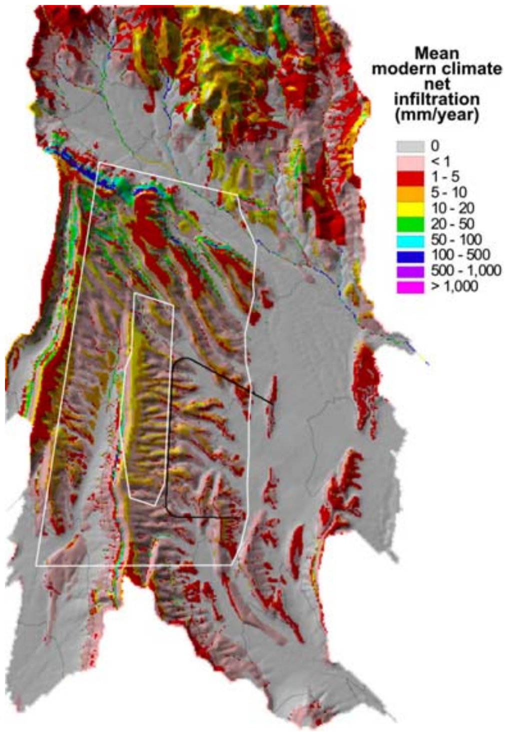
Results

- **Climate**

	Duration	Mean Precipitation Rate
– Modern:	400-600 years	190.6 mm/yr
– Monsoon:	900-1400 years	302.7 mm/yr
– Glacial Transition:	800-8700 years	317.8 mm/yr

- **Infiltration**

	Mean Infiltration Rate
– Modern:	4.6 mm/yr
– Monsoon:	12.2 mm/yr
– Glacial transition:	17.8 mm/yr



Climate and Infiltration Models

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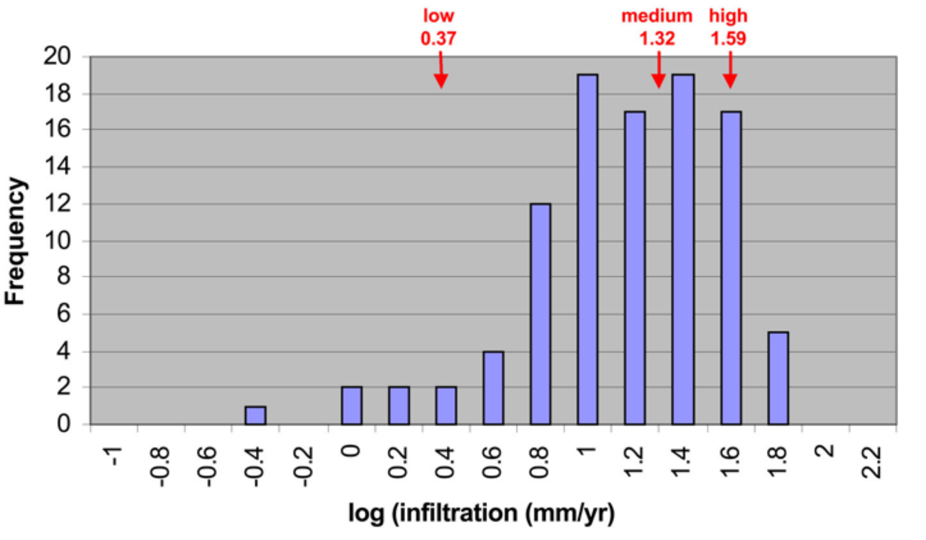
Uncertainty

- **Climate**
  - Not included in base TSPA simulations-indirectly through effects on UZ Flow Model
  - Future work: vary climate change times



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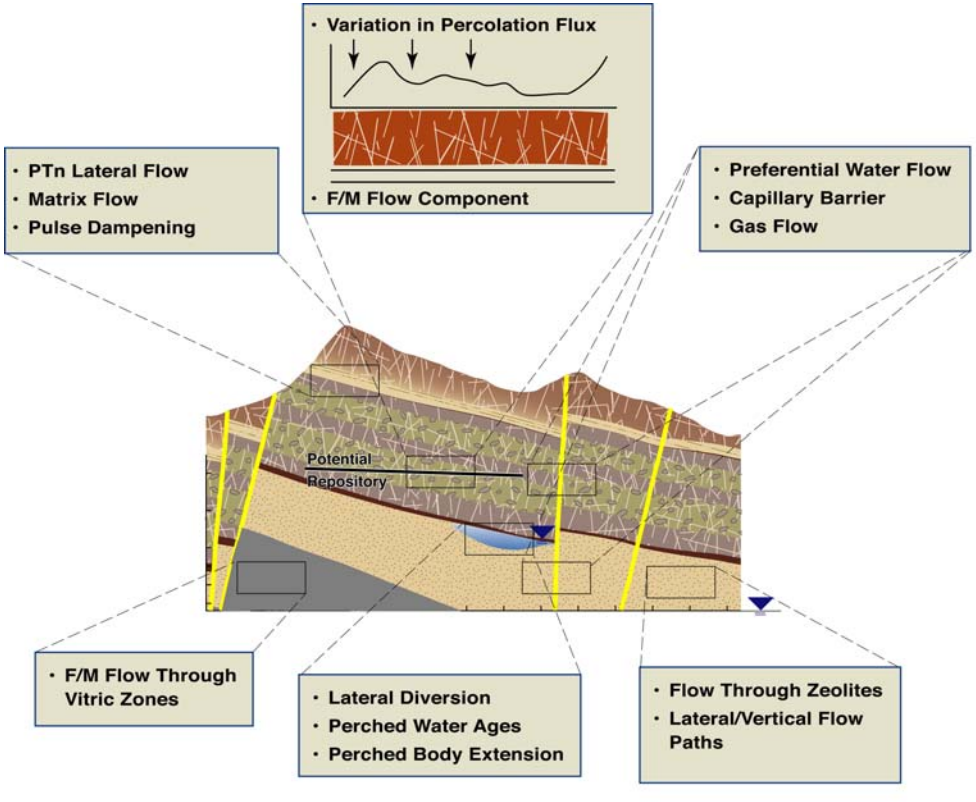
- **Infiltration**
  - Included indirectly in TSPA simulation as boundary condition on UZ Flow Model
  - Monte Carlo simulation varying parameters in Infiltration Model-generate infiltration histogram for each climate scenario
  - Weight climate scenario histograms for sampling in TSPA simulations

UZ Flow Model

Objectives

- To integrate the available data from the UZ system into a comprehensive 3-D model
- To develop several submodels for detailed studies of percolation and perched water through different units
- To quantify the flow of moisture, heat, and gas through the UZ, under present-day and estimated future climate scenarios
- To contribute model parameters and model input to other specific studies or models
- To provide TSPA with 3-D steady-state flow fields



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UZ Flow Model

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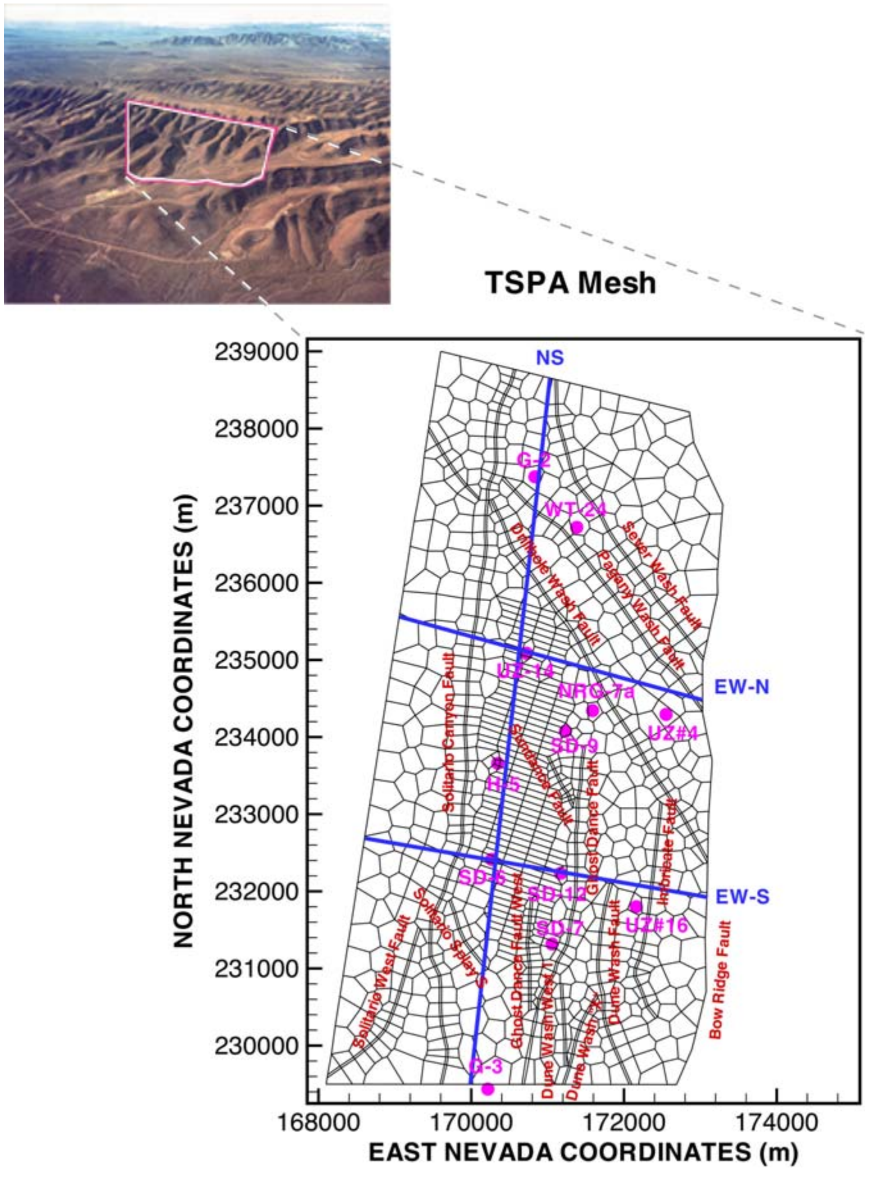
Assumptions

- Flow and transport processes can be described using a macroscopic continuum approach, using Darcy's law and Richards' equation for the two-phase flow
- Dual-permeability concept can be used to evaluate flow, transport and interactions in the fracture-matrix system.
- The UZ geology can be described using the GFM, approximated as a layered system with fluid and rock properties estimated from the Property Model
- The ambient unsaturated flow can be approximated by an isothermal, steady-state flow field, with surface infiltration described in the Infiltration Model
- Perched water occurrence is due to permeability barrier effects



UZ Flow Model

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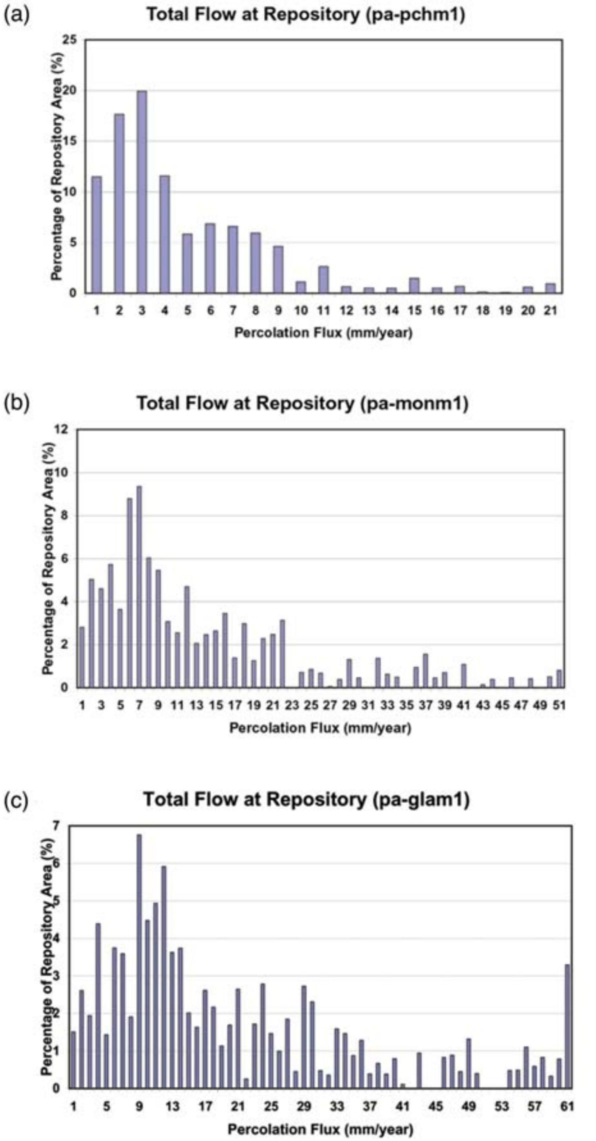
Results

- Model Calibration completed
- Several submodels developed for PTn, faults, and CHn/perched water
- Percolation fluxes, flow patterns and fracture-matrix flow components predicted using nine infiltration scenarios

Factors/Conservatisms/Optimisms

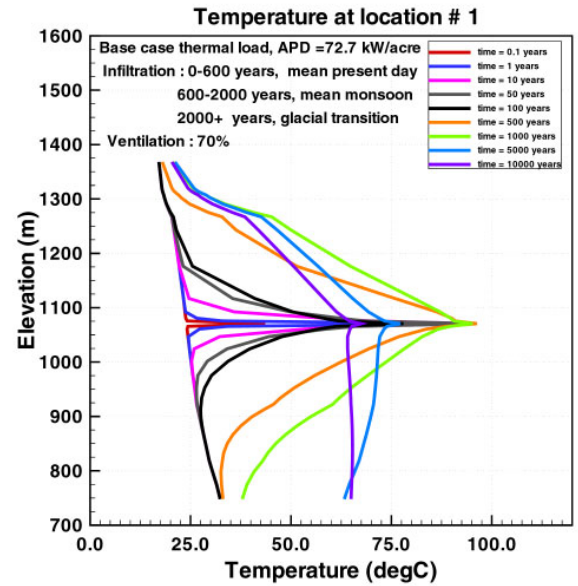
- Surface net infiltration rates
- Heterogeneity of the hydrogeological system
- Characterization of faults



Mountain Scale Coupled Processes: TH Mode

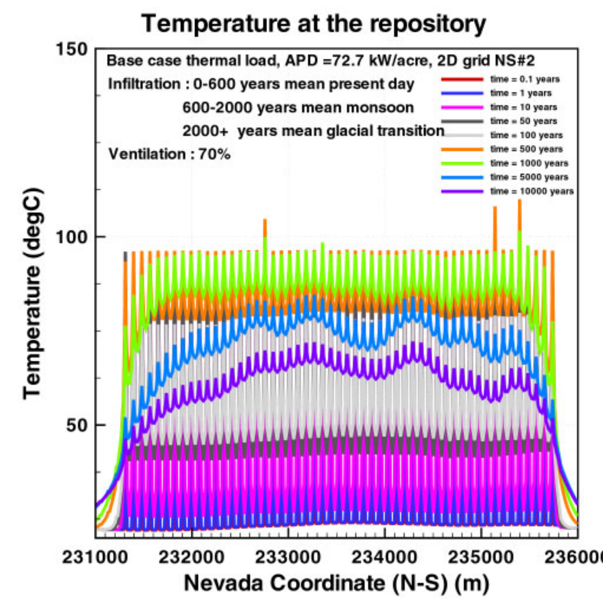
Objectives

- Evaluate temperature changes over the Mountain size of the 2-phase zone, temperature at Reposit PTn, CHn, and water table
- Evaluate the effects of heat on liquid and gas distribution.
- Evaluate the effects of heat on liquid and gas flov the far field; close to drifts; drainage in the pillars



Assumptions

- Uniform heat distribution at repository; ventilatio removes only heat
- Layer constant flow properties; not effected by thermal load; no hysteresis
- Fixed temperature top and bottom boundary conditions
- Modeling approach supported by:
  - Geothermal natural analog continuum mode
  - Drift Scale Heater Test



Mountain Scale Coupled Processes: TH Model

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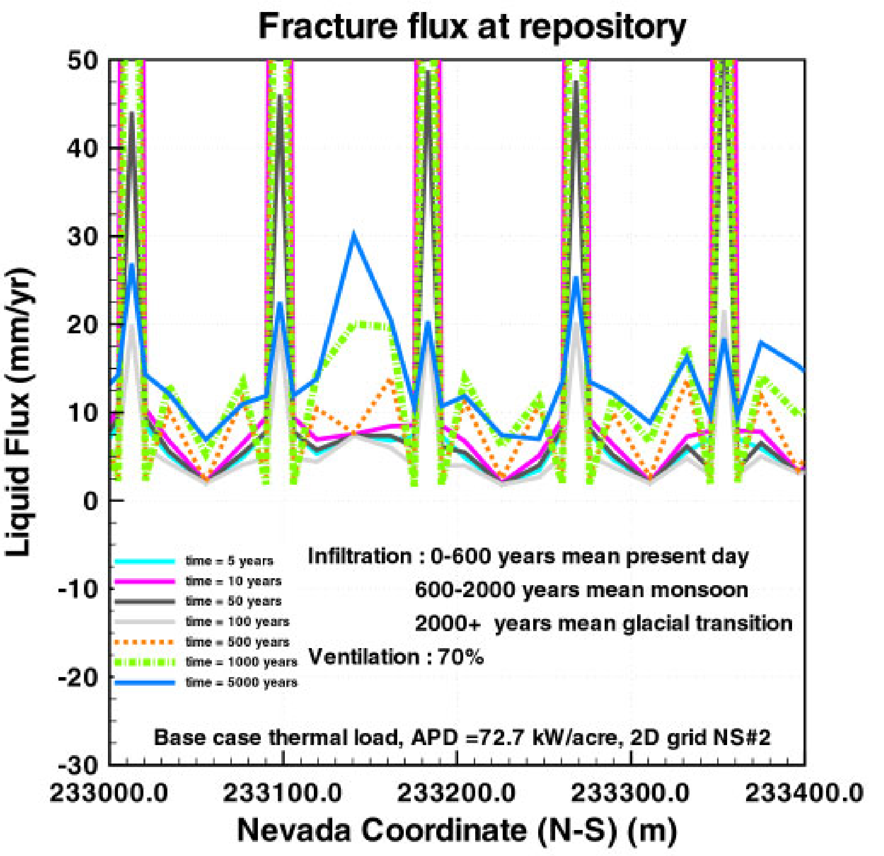
Results

- The two-phase zone is confined to less than 10-20 m from drifts
- Temperatures at the repository drifts rises to above boiling conditions (>97 °C) Temperatures of pillars is 80-85 °C, 70-75 °C CHn and 67-70 °C at water table
- High fracture permeabilities allow for easy and rapid drainage in pillars between drifts
- Liquid flux towards the drifts may exceed 400 mm/year, but is all vaporized by repository heat. Drainage between the drifts is enhanced by condensate water



Factors that may impact predictions

- Lateral variation properties across layers; focussed and channelized flow of condensate through fractures and heterogeneous features
- Changes in long term distribution of ambient surface infiltration and effects of climate

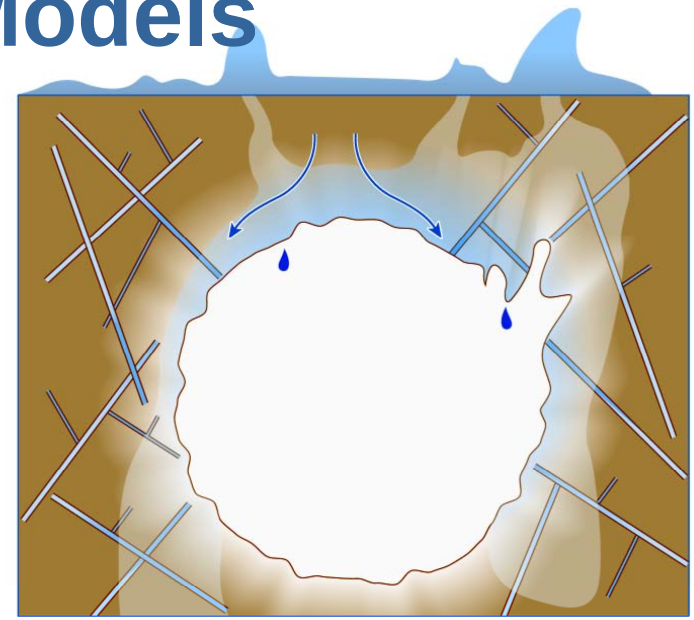
Drift Seepage Models

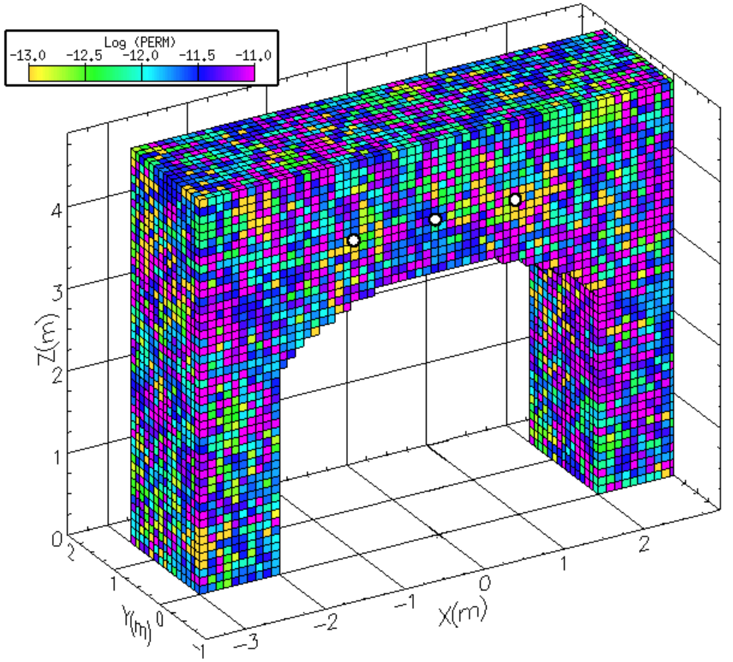
Objectives

- Determine fraction of waste packages affected by seepage
- Determine seepage flux

Assumptions

- Heterogeneous fracture continuum
- Flow focusing
- No evaporation/condensation
- Partial drift collapse
- Large variability and parameter uncertainty





Drift Seepage Models

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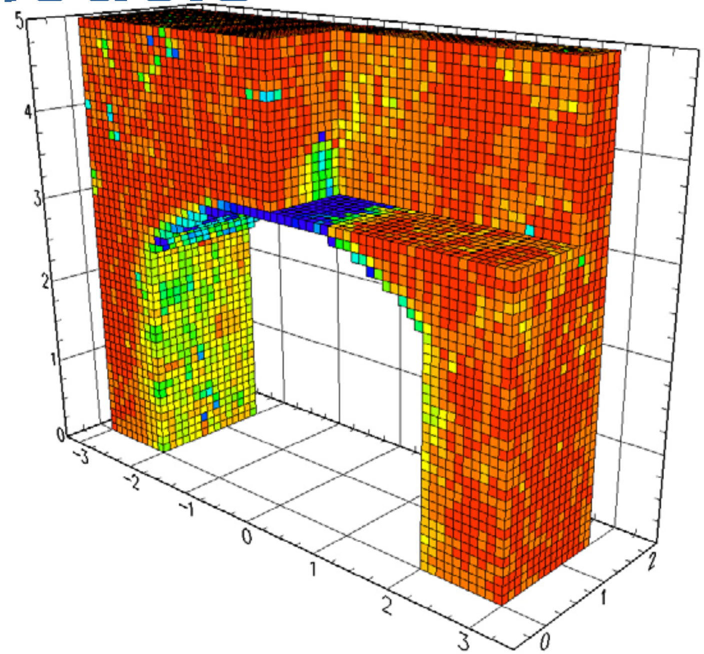


Results

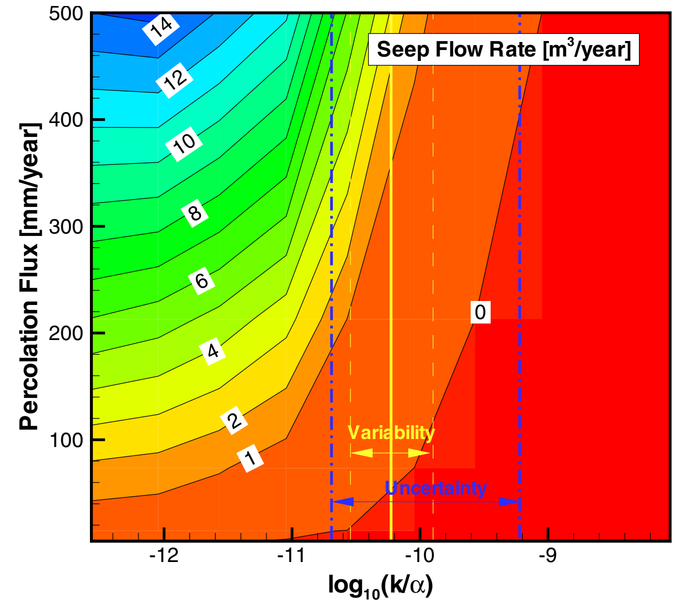
- Seepage-relevant parameters determined from seepage experiments
- Calculated seepage fraction and seepage flux for large range of parameters

Factors

- Percolation flux
- Channeling effect
- Effective capillary strength of fractures
- Fracture permeability

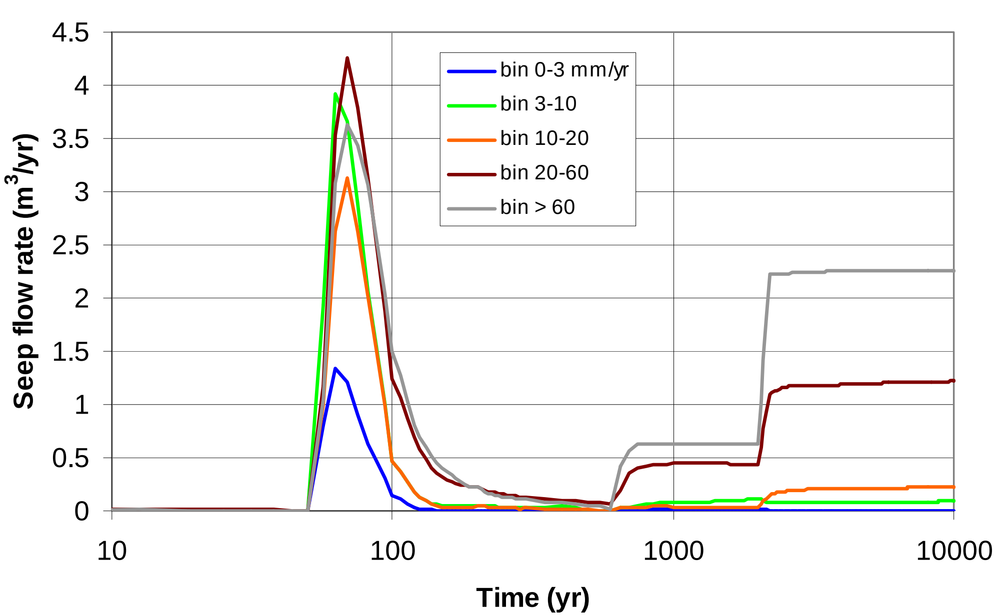
Conservatisms/Optimisms

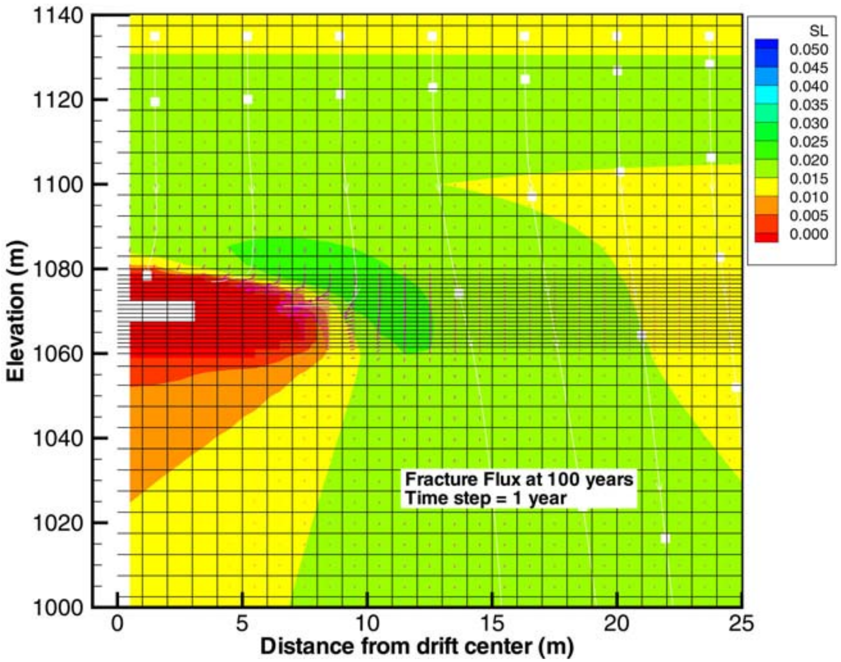
- Conservative parameter values
- Ignore ventilation/ evaporation
- Ignore in-drift condensation



Seepage During Thermal Period

- Percolation flux 5 m above the drift is used in seepage calculations
- Capillary driven flow towards drifts produces a pulse of seepage at around 100 years. This abstraction is conservative and has little effect on TSPA results
- Recent model simulations using heterogeneous fracture properties show no seepage and efficient drainage in pillars

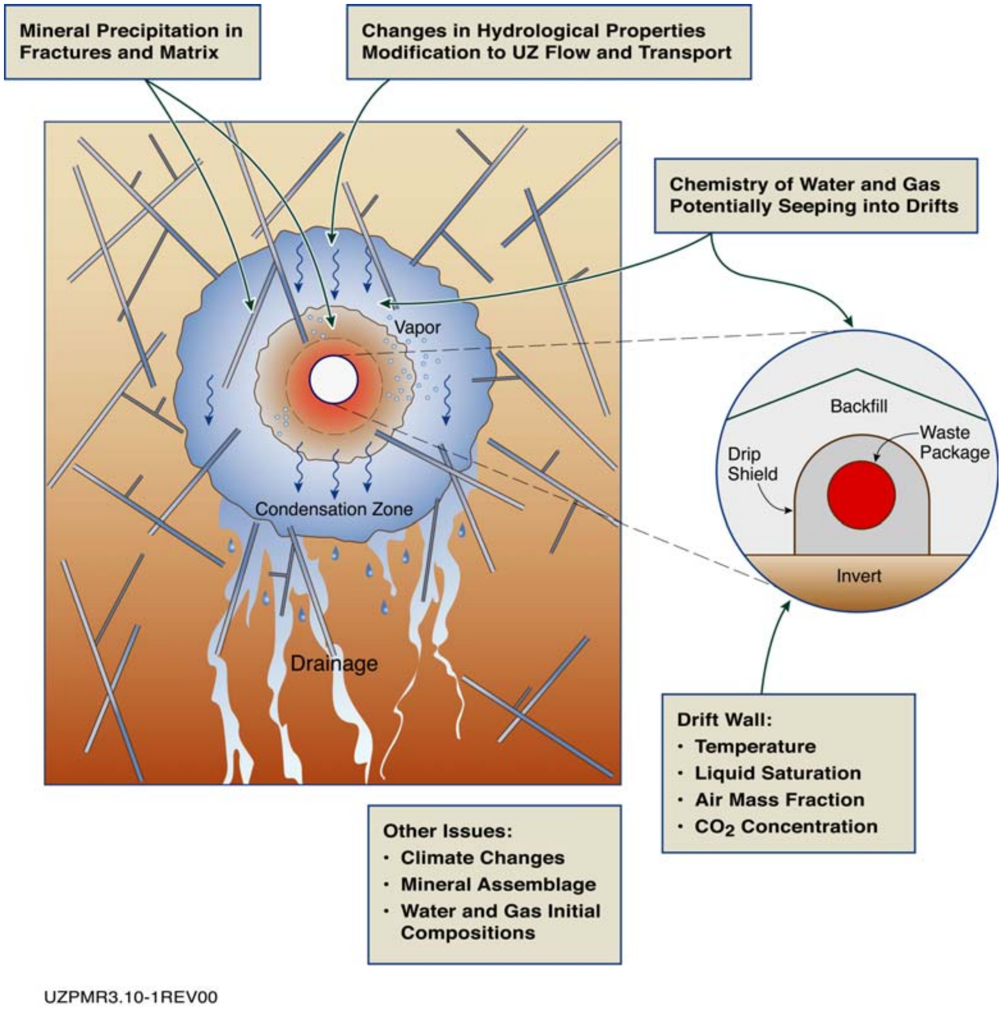




Drift Scale THC Models

Objectives

- Predict the chemistry of water and gas that will seep into drifts
- Evaluate changes in hydrological properties due to mineral precipitation/dissolution
- Calibrate/validate model using the chemical evolution of water, gas, and minerals in the Drift Scale Test



Assumptions

- Dual-permeability model
- Initial water chemistry in fractures and matrix pore water is the same
- Geochemical systems considered adequately capture the ambient system

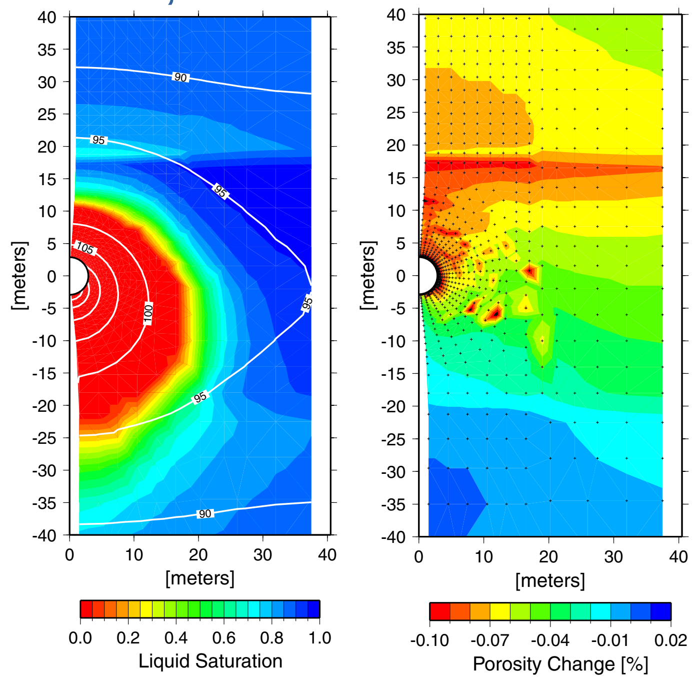
Drift-Scale THC Models

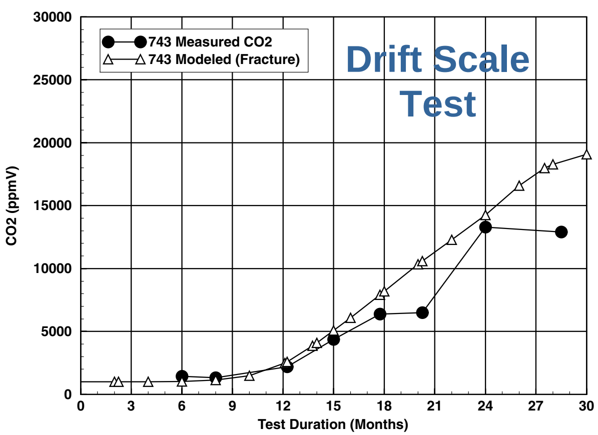
(Continued)

Results and Validation

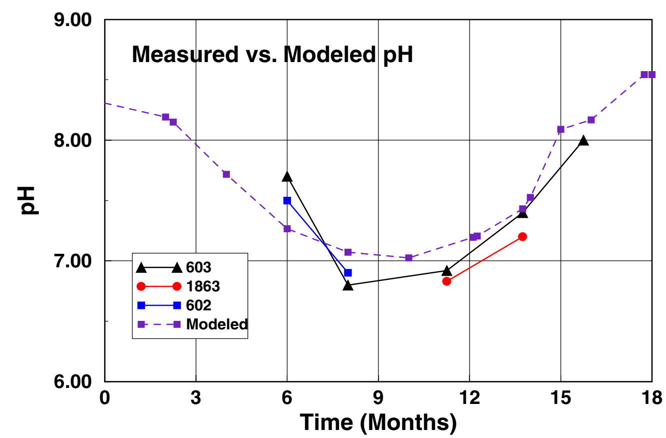
- A large zone of increased gaseous CO_2 concentrations was predicted in the DST and has been confirmed by analyses
- Modeled fracture water chemistry in the DST shows a similar trend in pH over time to waters collected from boreholes
- The pH of water flowing in fractures to the drift wall during the rewetting period is near neutral to slightly alkaline (~ 7.5 to 9) and is not strongly concentrated in salts
- Porosity and permeability changes over the first 10,000 years are small and effects on flow fields minimal

10,000 Year Predictions





Drift Scale Test



Drift-Scale THC Models

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Conservatisms/Optimisms

- **Initial water chemistry is more concentrated in many components than the average UZ pore water, and thus would give a conservative estimate on salt concentrations and mineral precipitation from boiling alone**
- **Changes in permeability that are based on porosity changes are likely to be underestimated (optimistic), because mineral precipitation/dissolution may be localized**

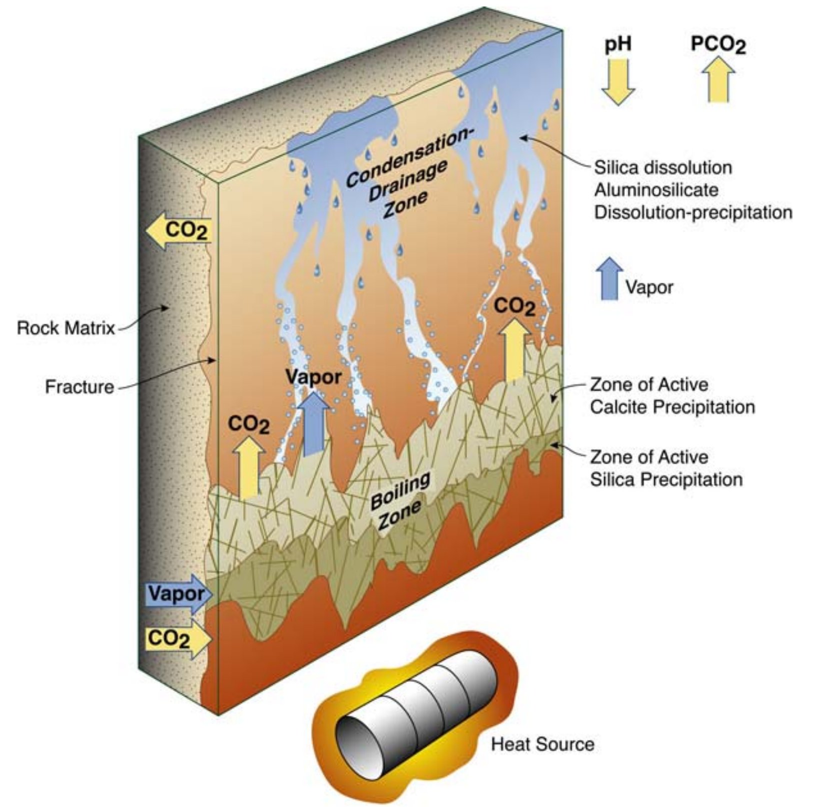


Diagram Showing THC Processes

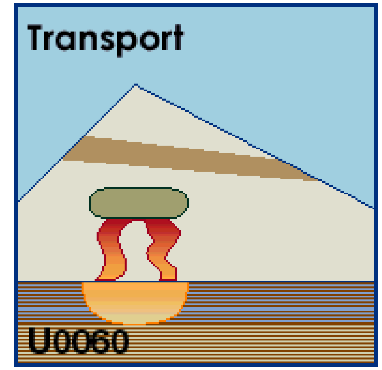
UZ Transport Model

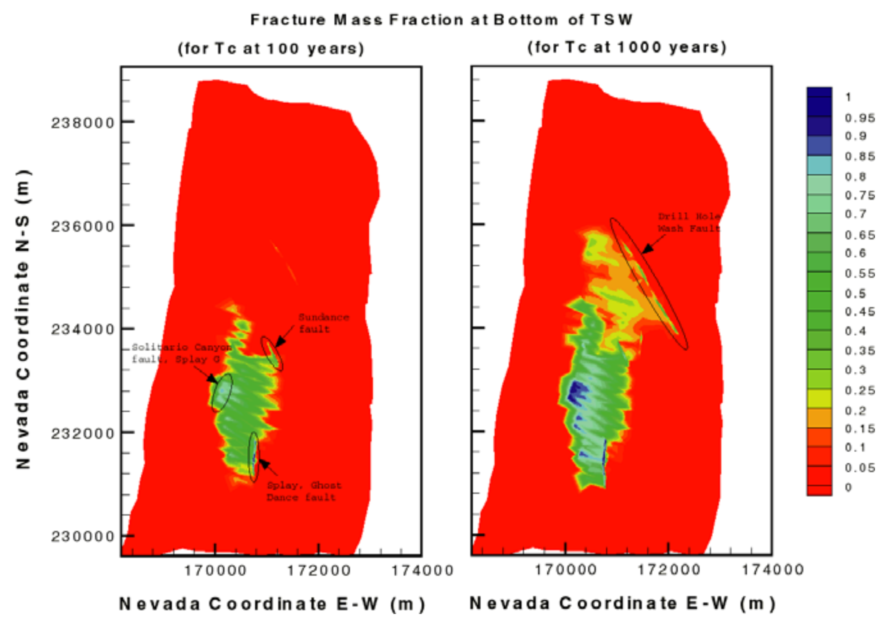
Objectives

- Develop a model for investigating radionuclide solute and colloid transport in UZ to support PA abstraction for TSPA

Assumptions

- Flow component the same as for the UZ Flow Model
- Governing transport processes (advection, dispersion, diffusion, sorption, radioactive decay, colloid filtration, and colloid-assisted transport)





UZ Transport Model

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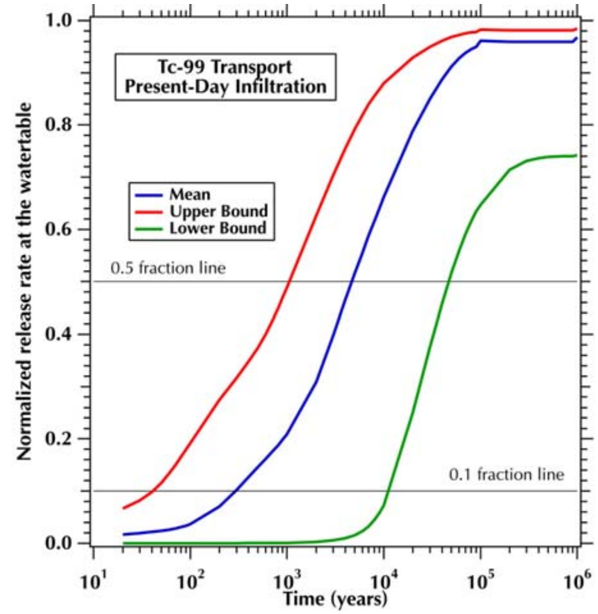
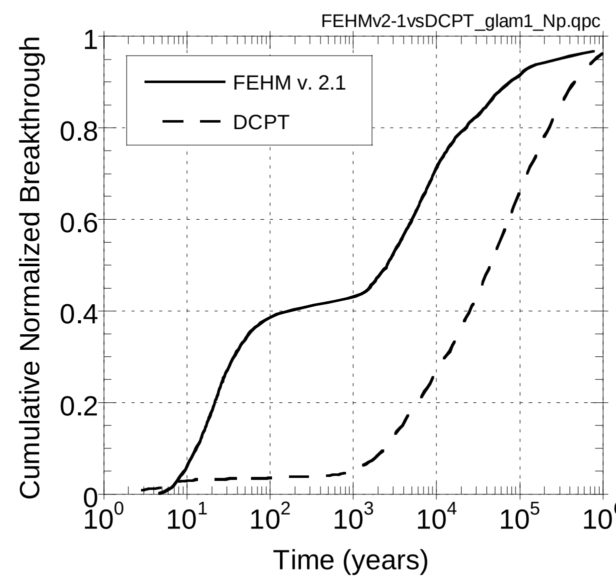


Mean, Glacial-Transition, Np



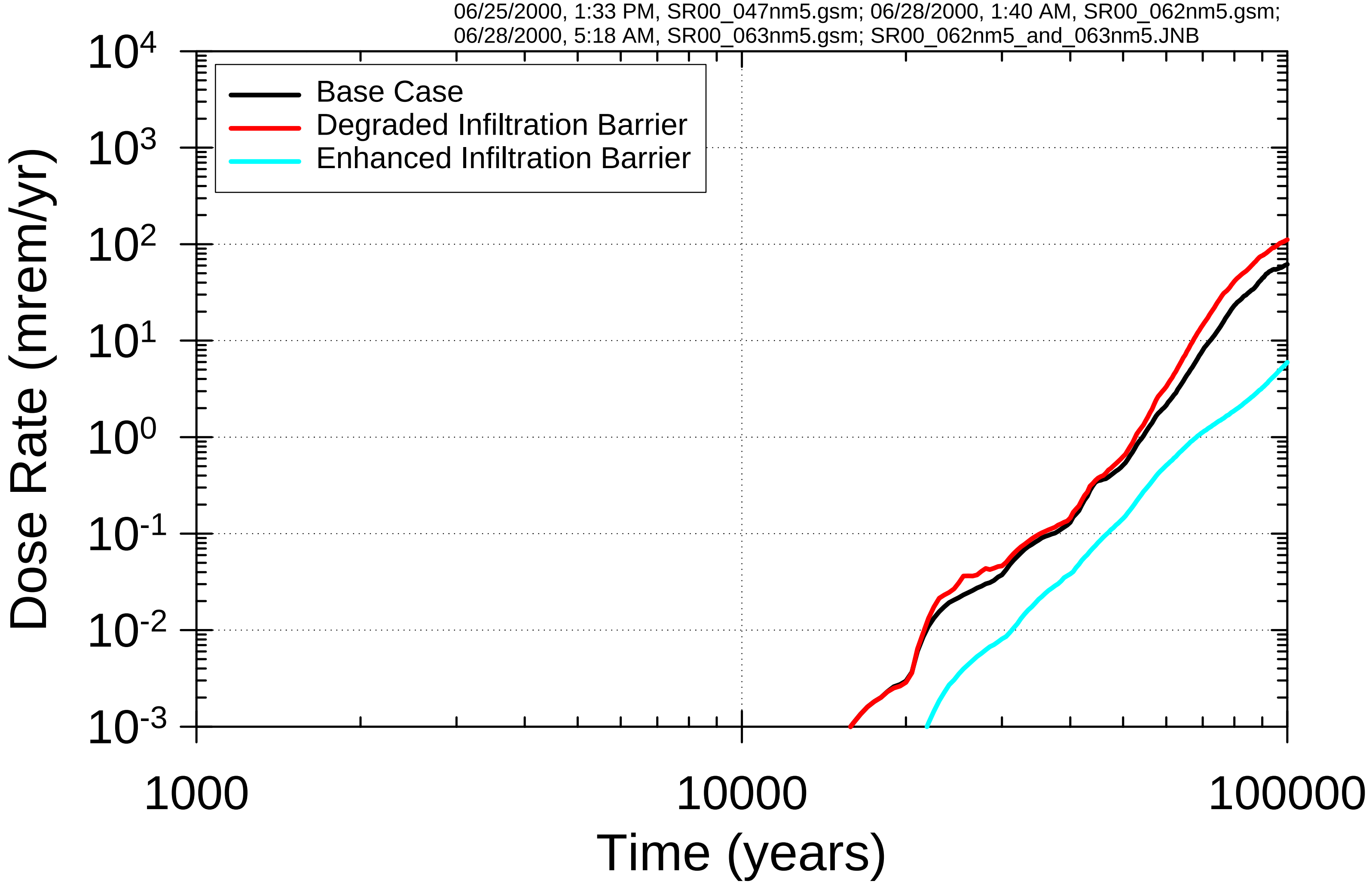
Results/Important Factors

- Faults dominate and control transport
- Matrix diffusion and sorption are main retardation mechanisms
- ^{239}Pu decay chain products are important
- Colloidal transport could be important
- Current PA transport model may be very conservative

Infiltration Barrier Sensitivity

- **Degraded Barrier**
  - **High infiltration case throughout the model**
- **Enhanced Barrier**
  - **Low infiltration case throughout the model**

Preliminary
Infiltration Barrier Sensitivity



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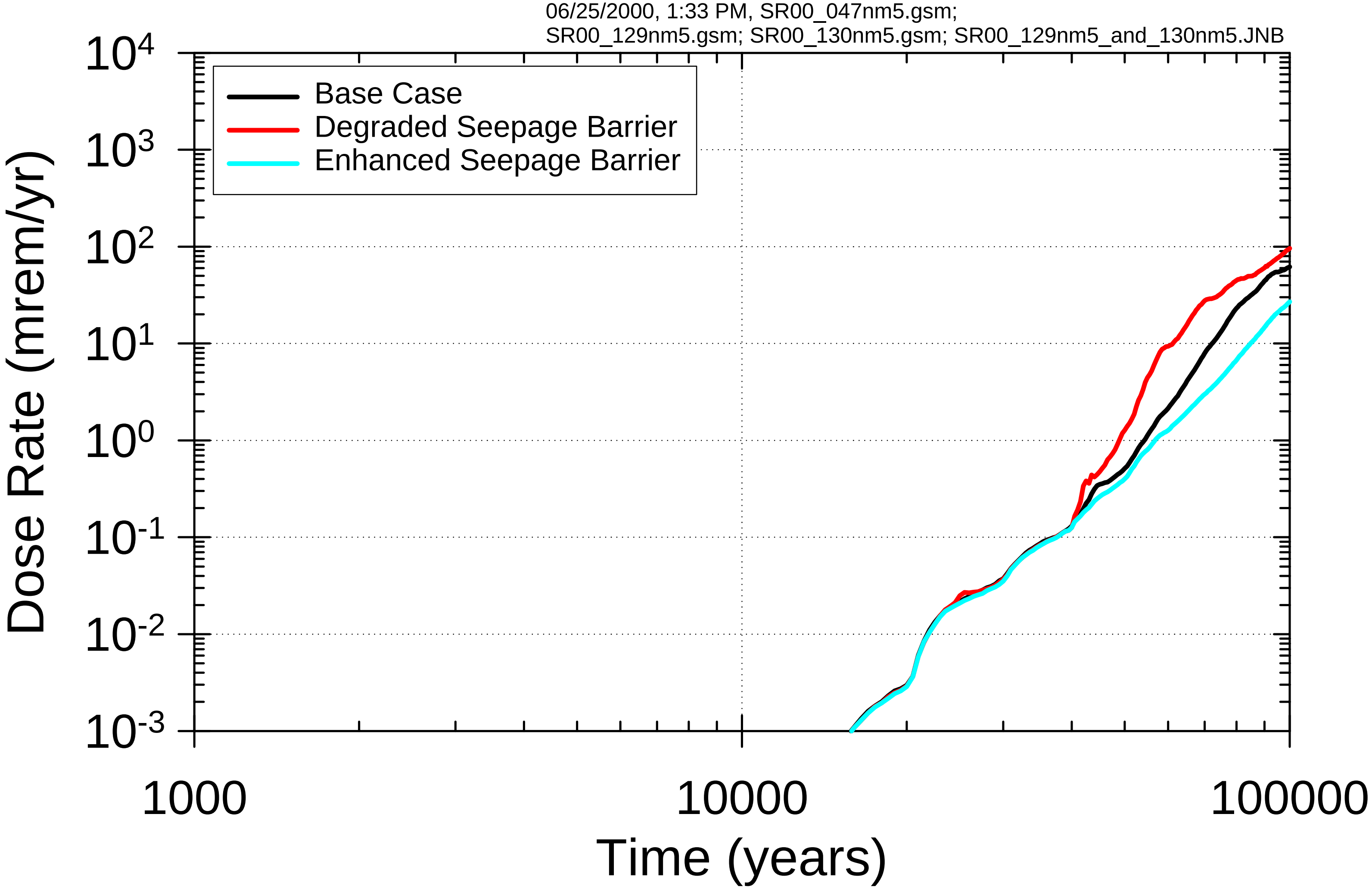
Seepage Barrier Sensitivity

- **Degraded Barrier**
  - 95th %tile flow focus factor
  - 95th %tile seepage uncertainty index (implies 95th %tile seepage fraction, 95th %tile mean seepage flux, & 95th %tile seepage flux standard deviation)
- **Enhanced Barrier**
  - 5th %tile flow focus factor
  - 5th %tile seepage uncertainty index (implies 5th %tile seepage fraction, 5th %tile mean seepage flux, & 5th %tile seepage flux standard deviation)

Preliminary
Seepage Barrier Sensitivity



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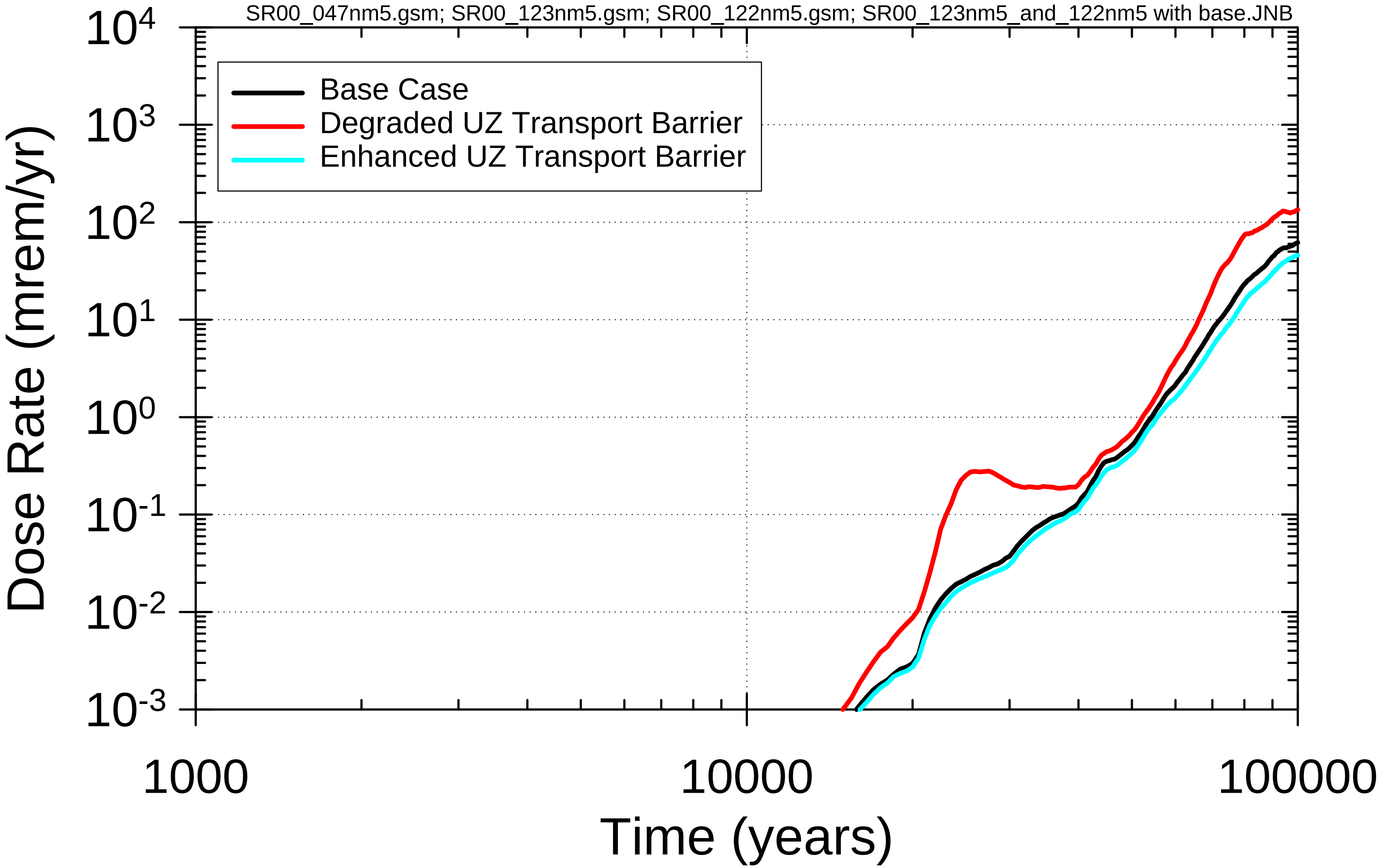
UZ Transport Barrier Sensitivity

- **Degraded Barrier**
  - 5th %tile matrix Kds for all radionuclides
  - 95th %tile Kc for reversible colloids
  - 5th %tile anion/cation matrix diffusion coefficients
  - 95th %tile fracture apertures for all units
- **Enhanced Barrier**
  - 95th %tile matrix Kds for all nuclides
  - 5th %tile Kc for reversible colloids
  - 95th %tile anion/cation matrix diffusion coefficients
  - 5th %tile fracture apertures for all units

Preliminary
UZ Transport Barrier Sensitivity



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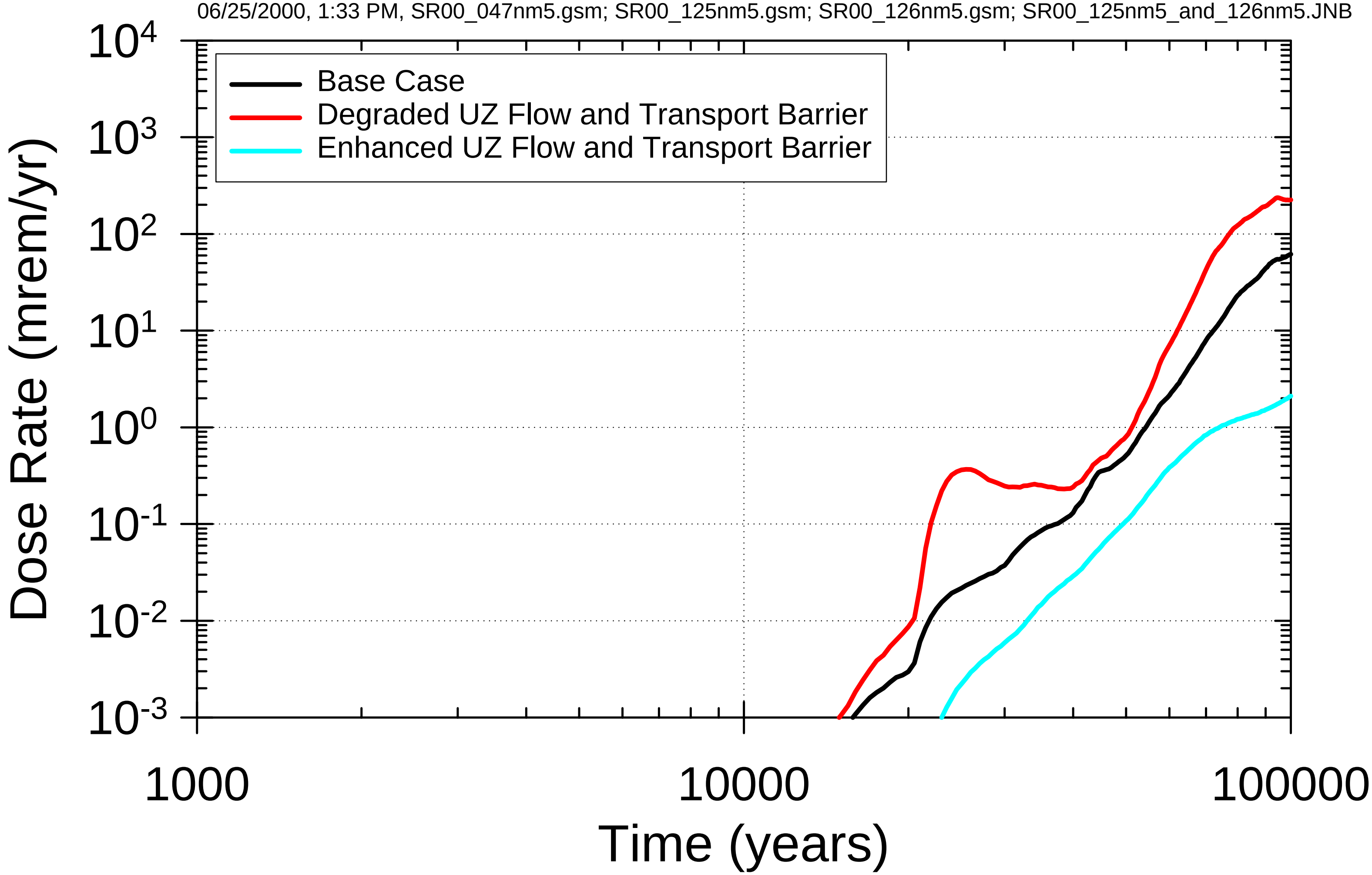
UZ Flow and Transport Barrier Sensitivity

- **Degraded Barrier**
  - **Degraded UZ transport barrier**
  - **Degraded Infiltration barrier**
- **Enhanced Barrier**
  - **Enhanced UZ transport barrier**
  - **Enhanced Infiltration barrier**

Preliminary
UZ Flow and Transport Barrier Sensitivity



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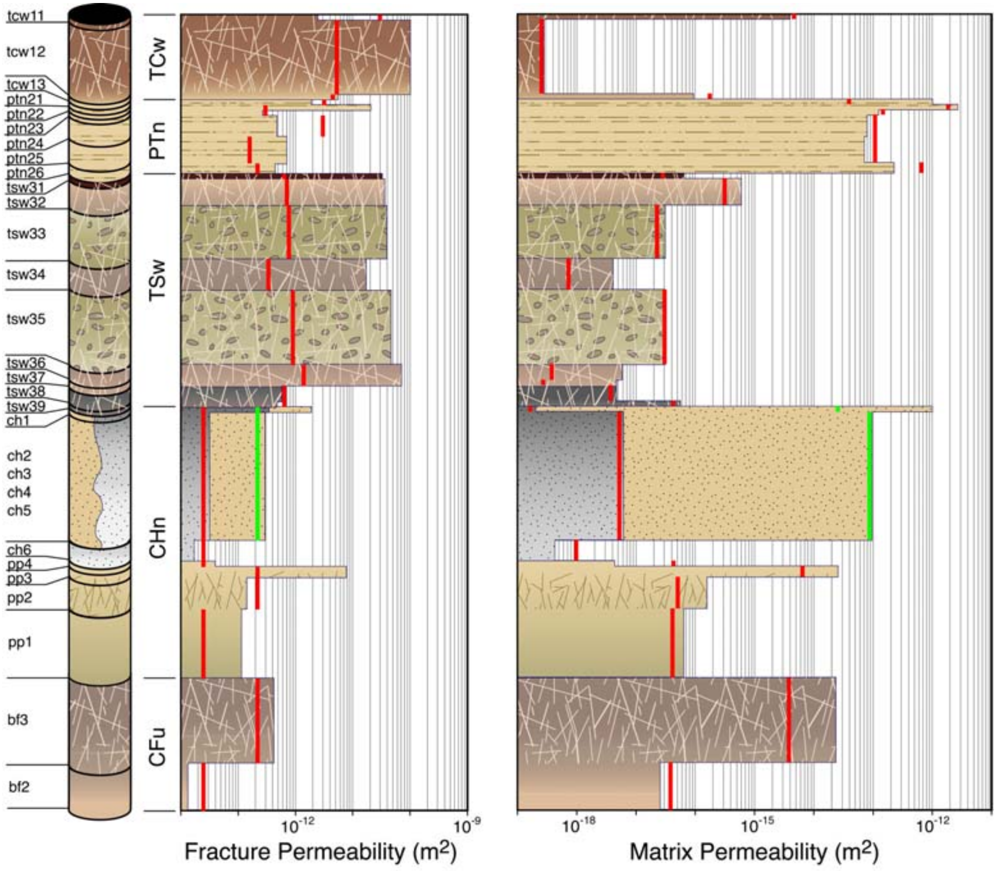
Backup

Calibrated Properties Model

Objectives

- Mountain-scale, calibrated parameters for entire UZ F&T Model
- Drift-scale, calibrated parameters for repository horizon and adjacent layers
- Fault, calibrated parameters for entire UZ F&T Model
- Thermal parameters (uncalibrated) for entire UZ F&T Model
- Estimate uncertainties for the parameters



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Calibrated Properties Model

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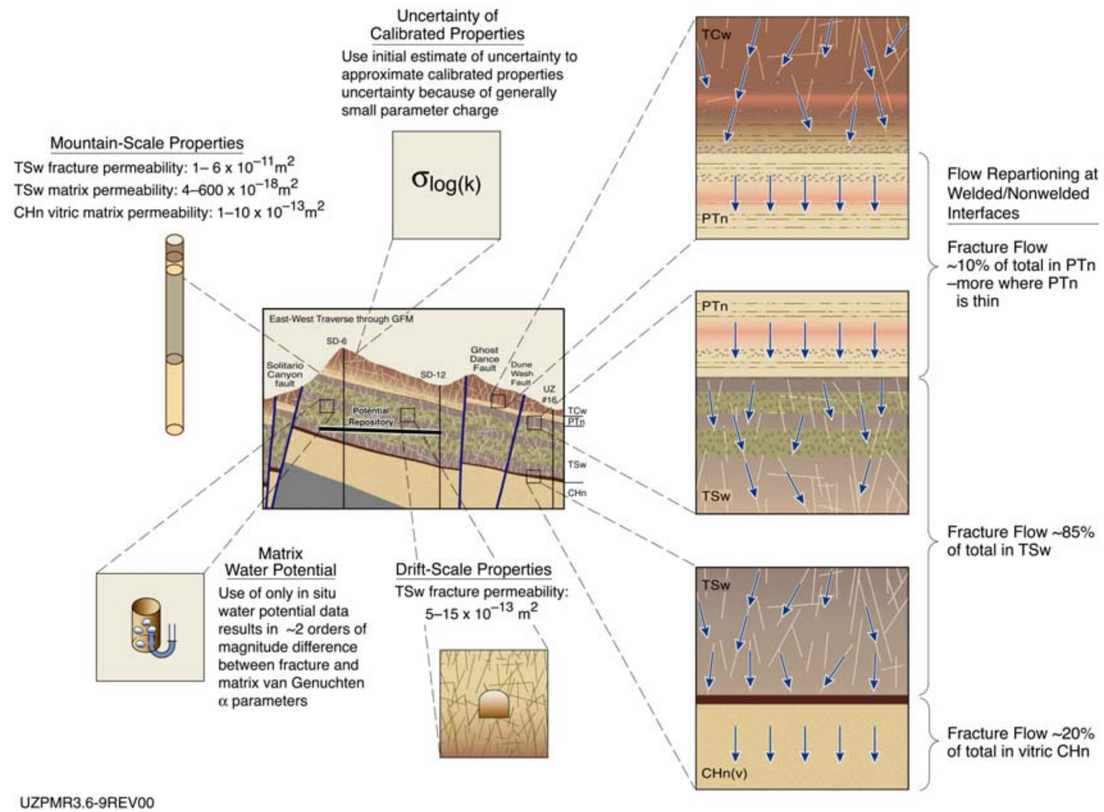
Assumptions

- Heterogeneity is controlled by hydrogeologic layering (i.e. properties are homogeneous within a layer)
- Liquid flow under ambient conditions is steady-state
- Flow is simulated using a dual-permeability model
- van Genuchten model is used for liquid relative permeability and water potential
- Brooks-Corey model is used for gas relative permeability
- An active fracture model is used to represent the effect of non-flowing fractures



Calibrated Properties Model

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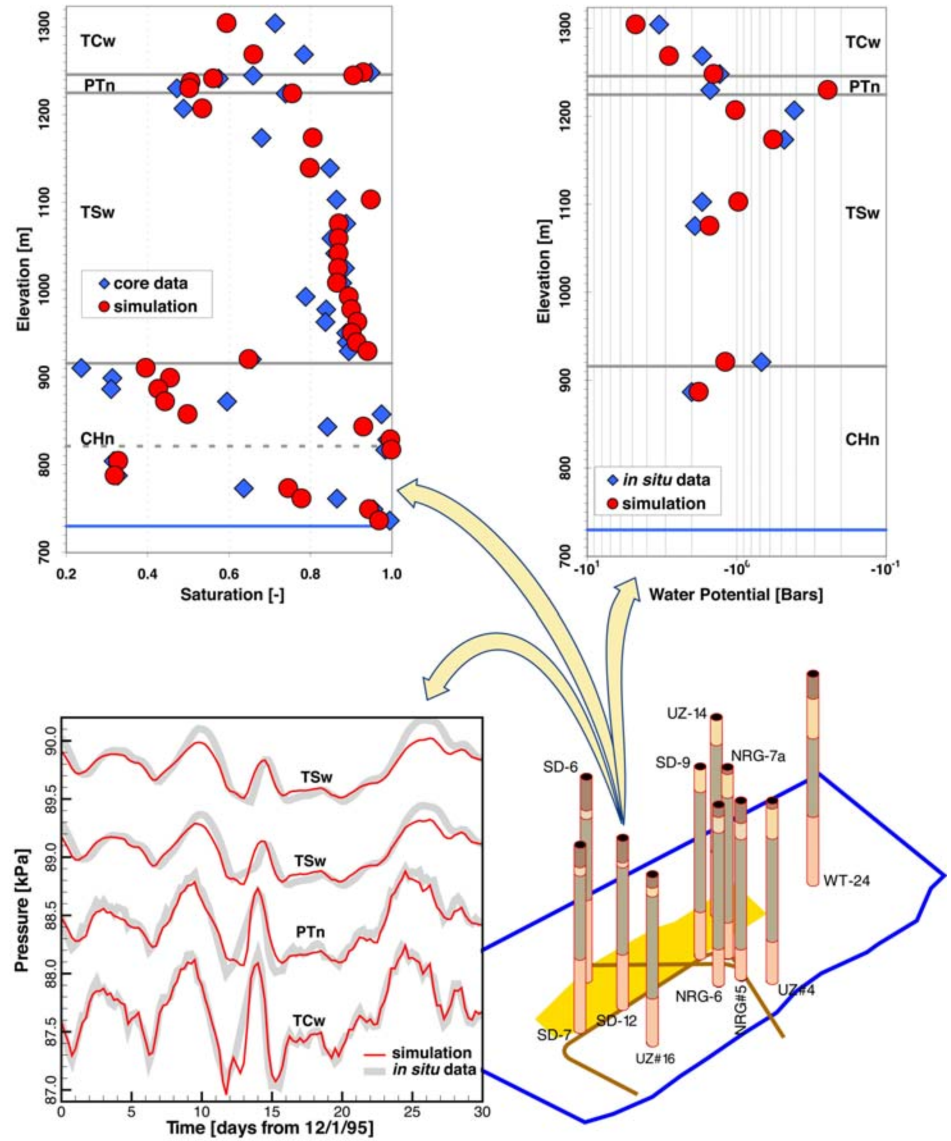
Results

- Simulated and measured saturation, water potential, and pneumatic pressure match well
- Calibrated hydrologic parameters and uncalibrated thermal parameters are validated against data not used for estimation and calibration
- iTOUGH2 code rigorously treats parameter sensitivities and uncertainties



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Calibrated Properties Model
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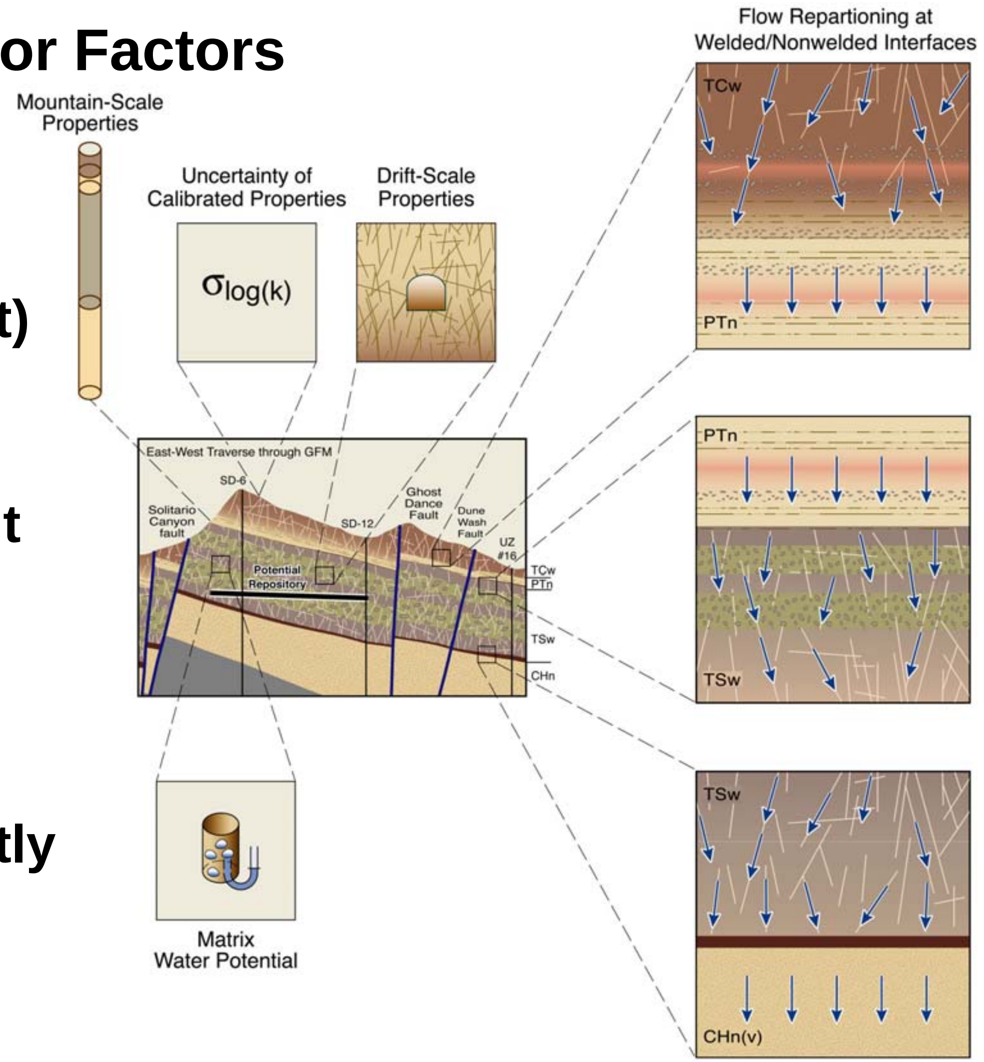
Conservatism/Optimism and Major Factors

- Continuous fracture pathways are assumed to exist from the mountain surface to the water table (conservative for transport)
- Calibrated parameters are controlled by limited dates especially in the Calico Hills unit
- At major hydrogeologic unit interfaces (e.g. TCw to PTn), calibrated parameters are controlled by the assumption of flow transition from dominantly fracture to dominantly matrix (or vice-versa)



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