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

# Total System Performance Assessment for the Site Recommendation - Approach and Preliminary Results

Presented to:
**Nuclear Waste Technical Review Board**


Presented by:
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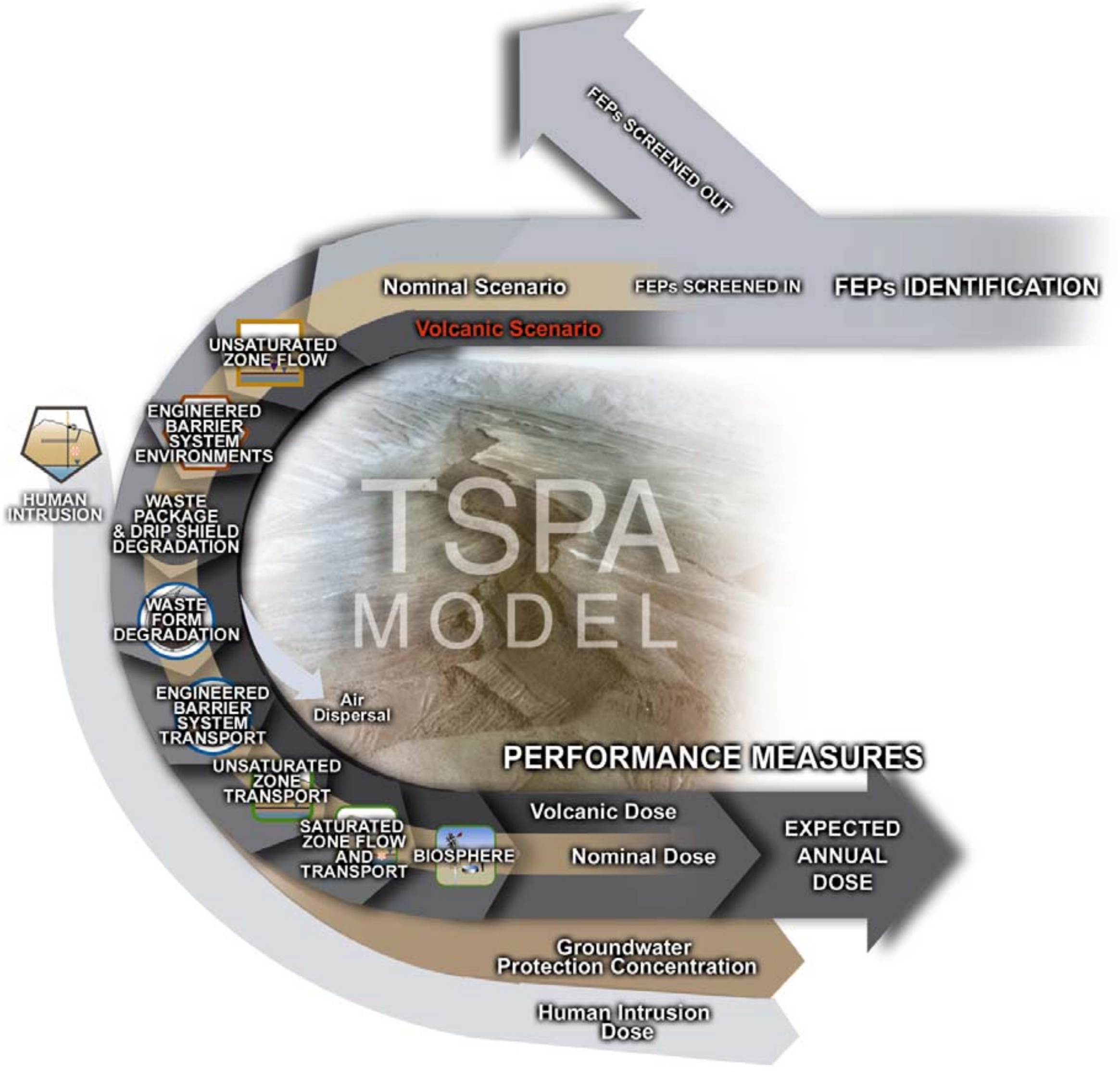
**August 1, 2000**

YUCCA MOUNTAIN PROJECT

# Outline

- TSPA-SR Process
- Attributes of Repository Performance
- TSPA-SR Nominal Scenario – Process Model Factors
- Overview of Uncertainty/Variability/Conservatism in TSPA-SR
- TSPA Results
  - TSPA-VA
  - TSPA-SR Nominal Scenario Results (preliminary)
  - TSPA-SR Volcanic Scenario Results (preliminary)
  - TSPA-SR Nominal Scenario Example Sensitivity and Barrier Importance Analysis (preliminary)
- Summary

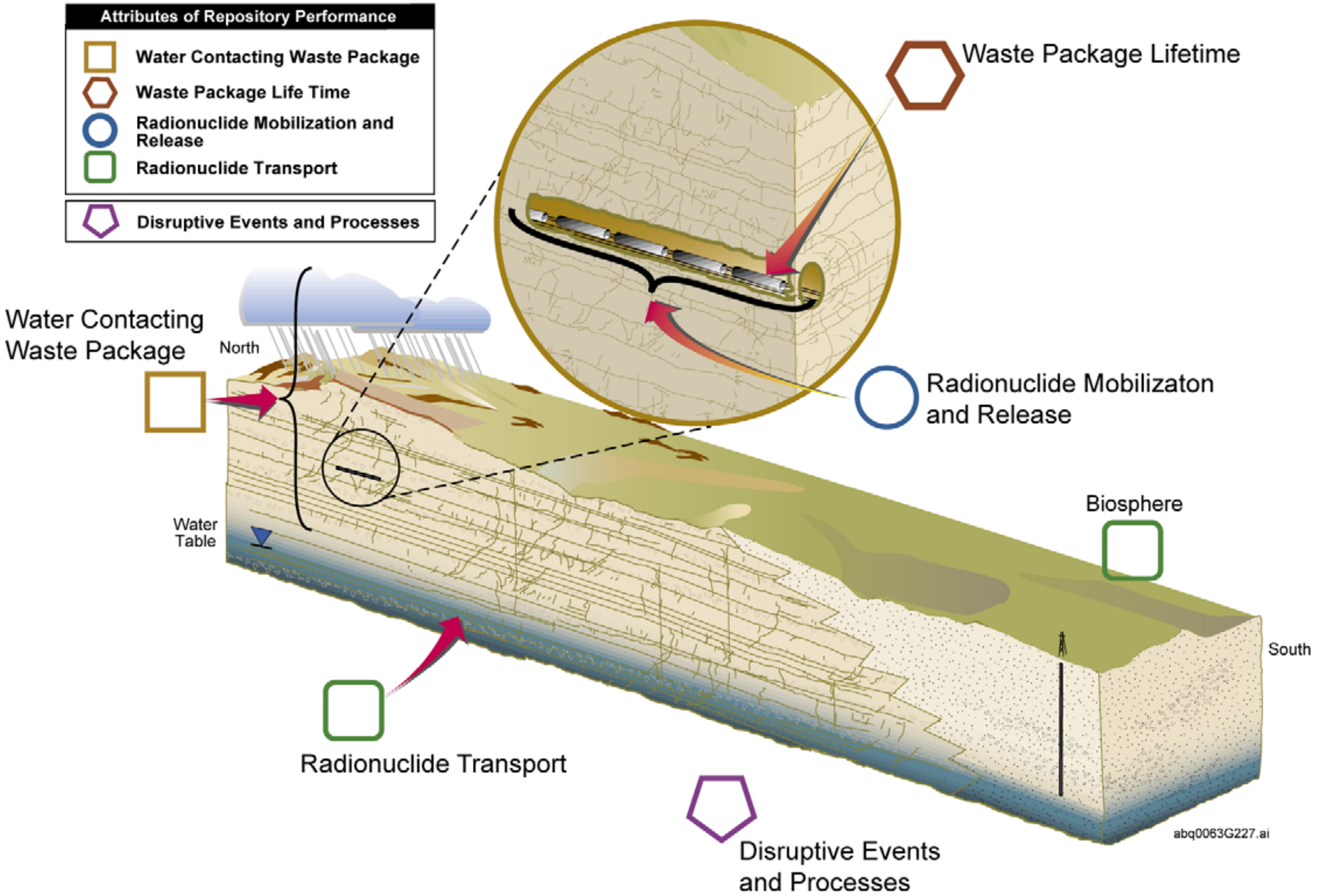
# TSPA-SR Process



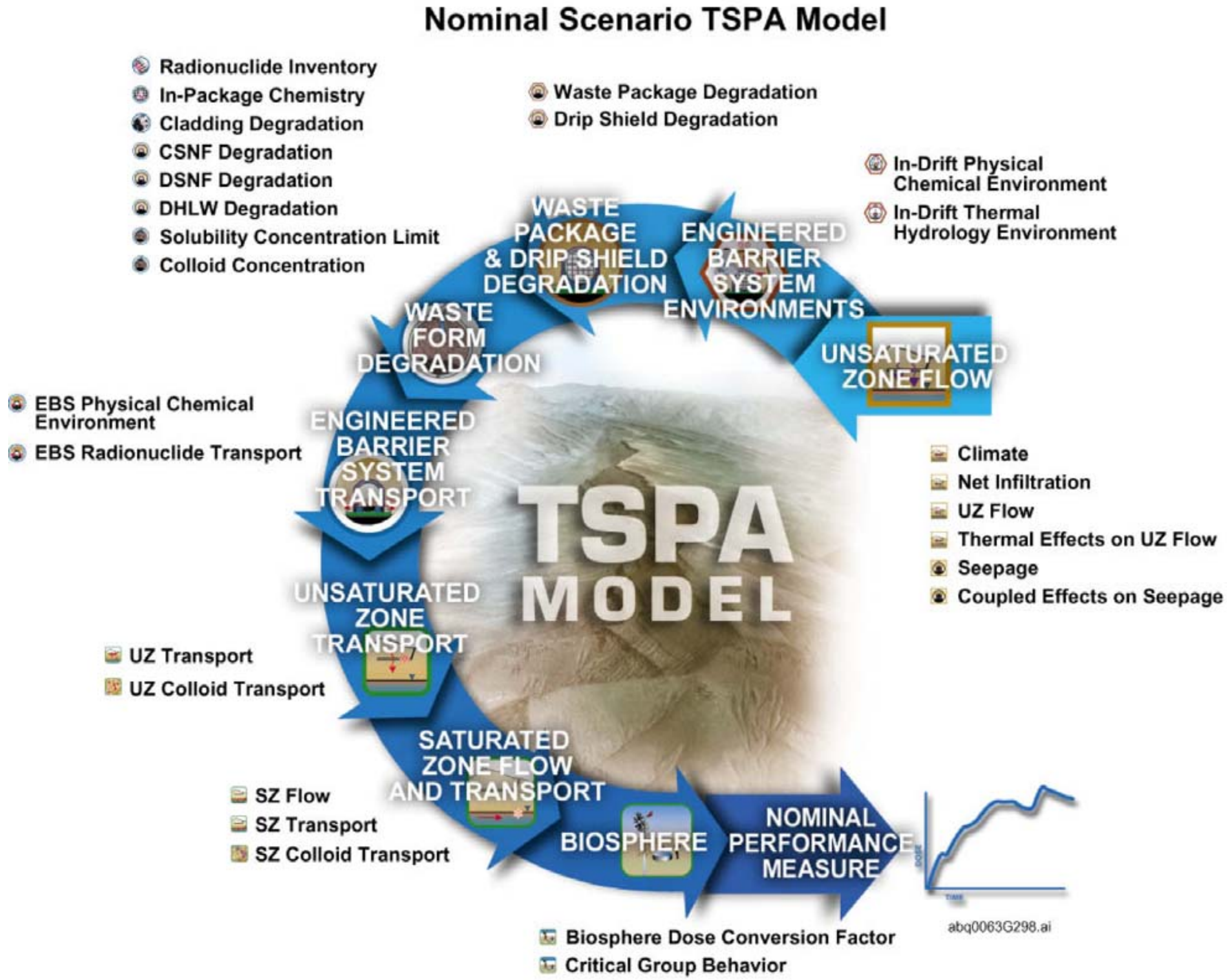
# TSPA-SR Process

1. **Screen features, events and processes to determine those that must be retained in performance assessment**
2. **Develop models, along with their scientific basis,  for each process included in TSPA**
3. **Identify uncertainty in models and parameters**
4. **Construct integrated TSPA model using all retained processes**
   - **"Nominal" performance model contains all features, events and processes likely to occur**
   - **"Disruptive event" performance model contains low probability events (e.g., volcanism)**
5. **Evaluate total-system performance (individual dose and groundwater protection) and significance of quantified uncertainty**

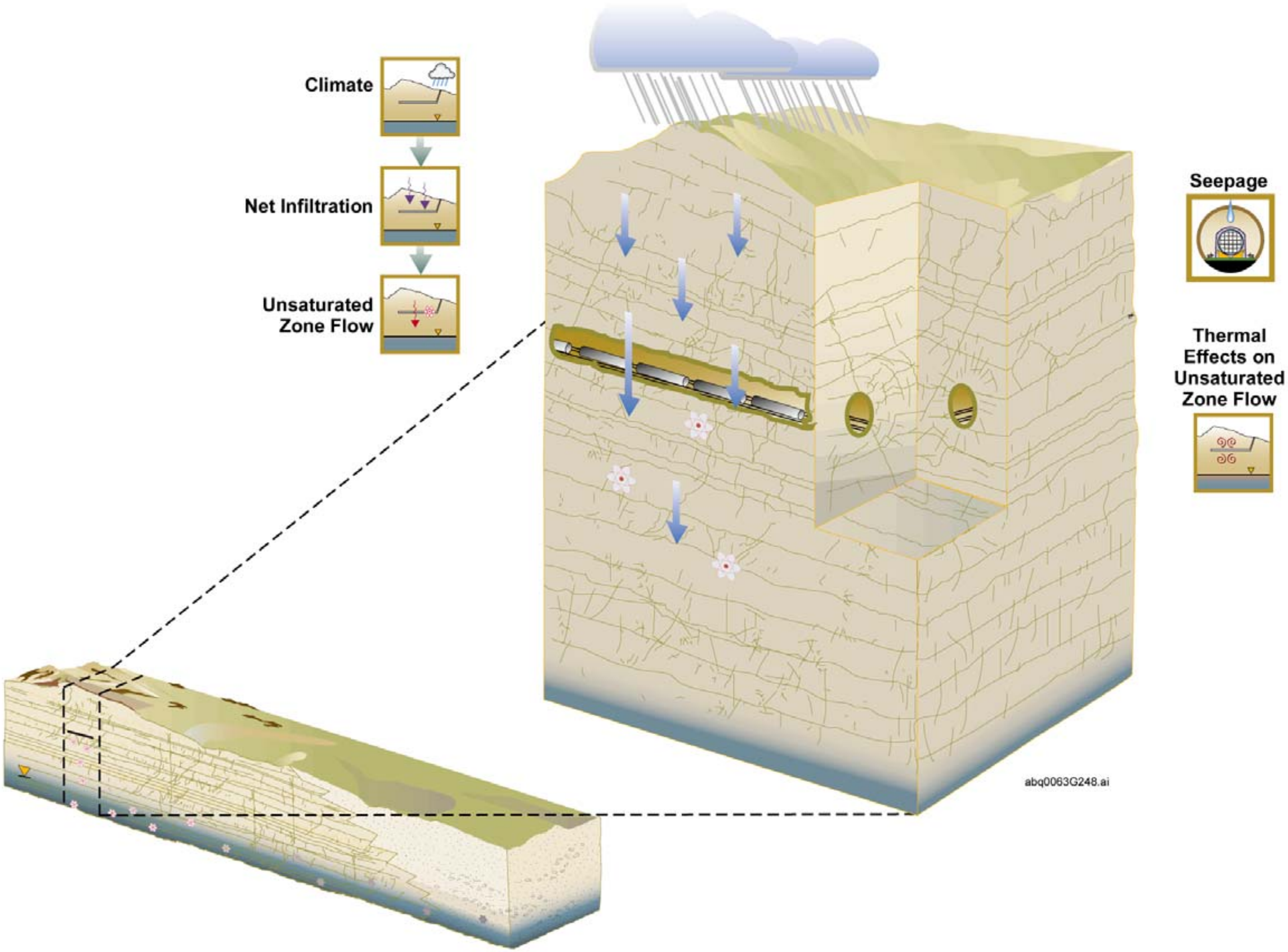
# Attributes of Repository System Performance



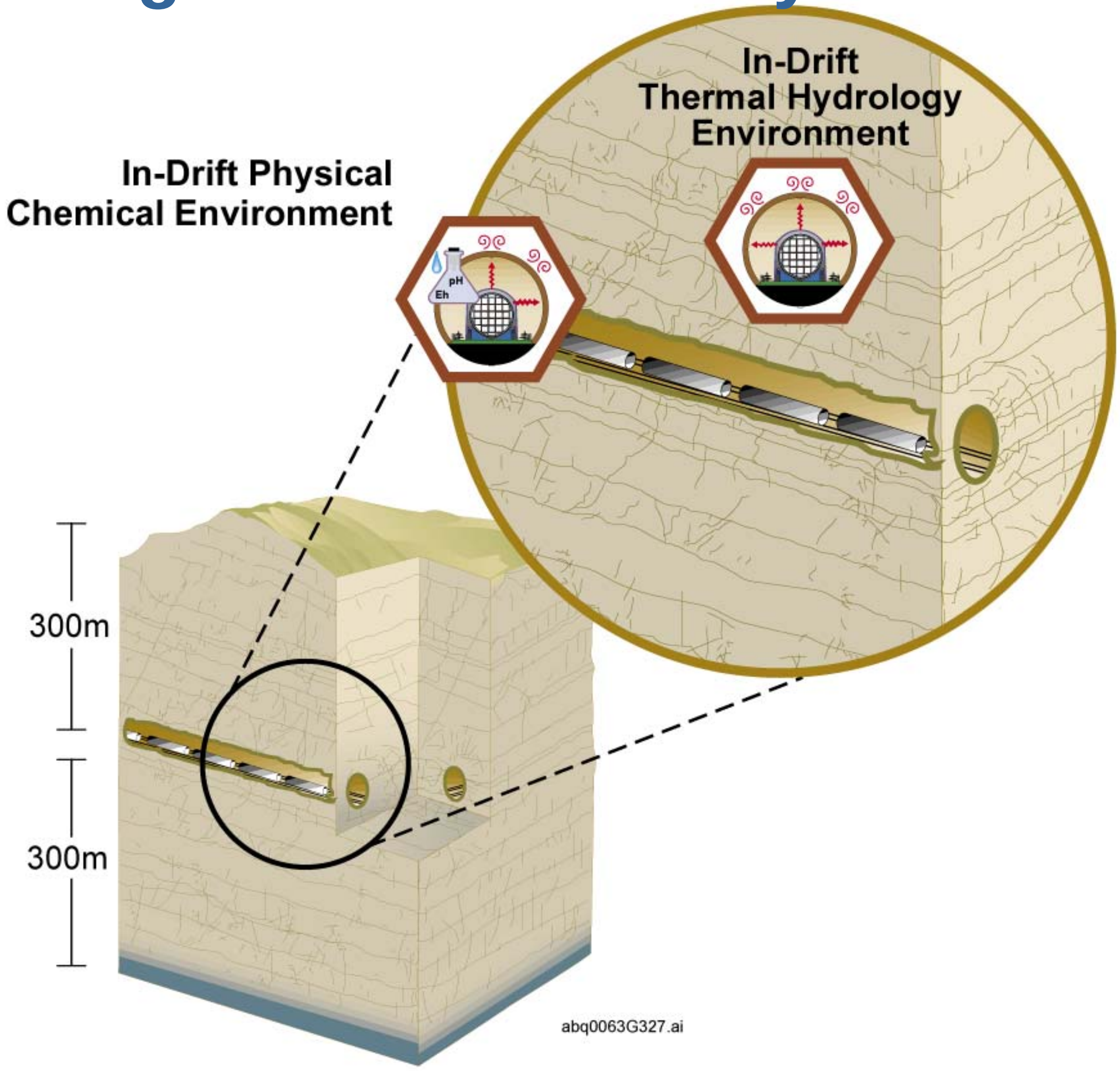
# TSPA-SR Nominal Scenario – Process Model Factors



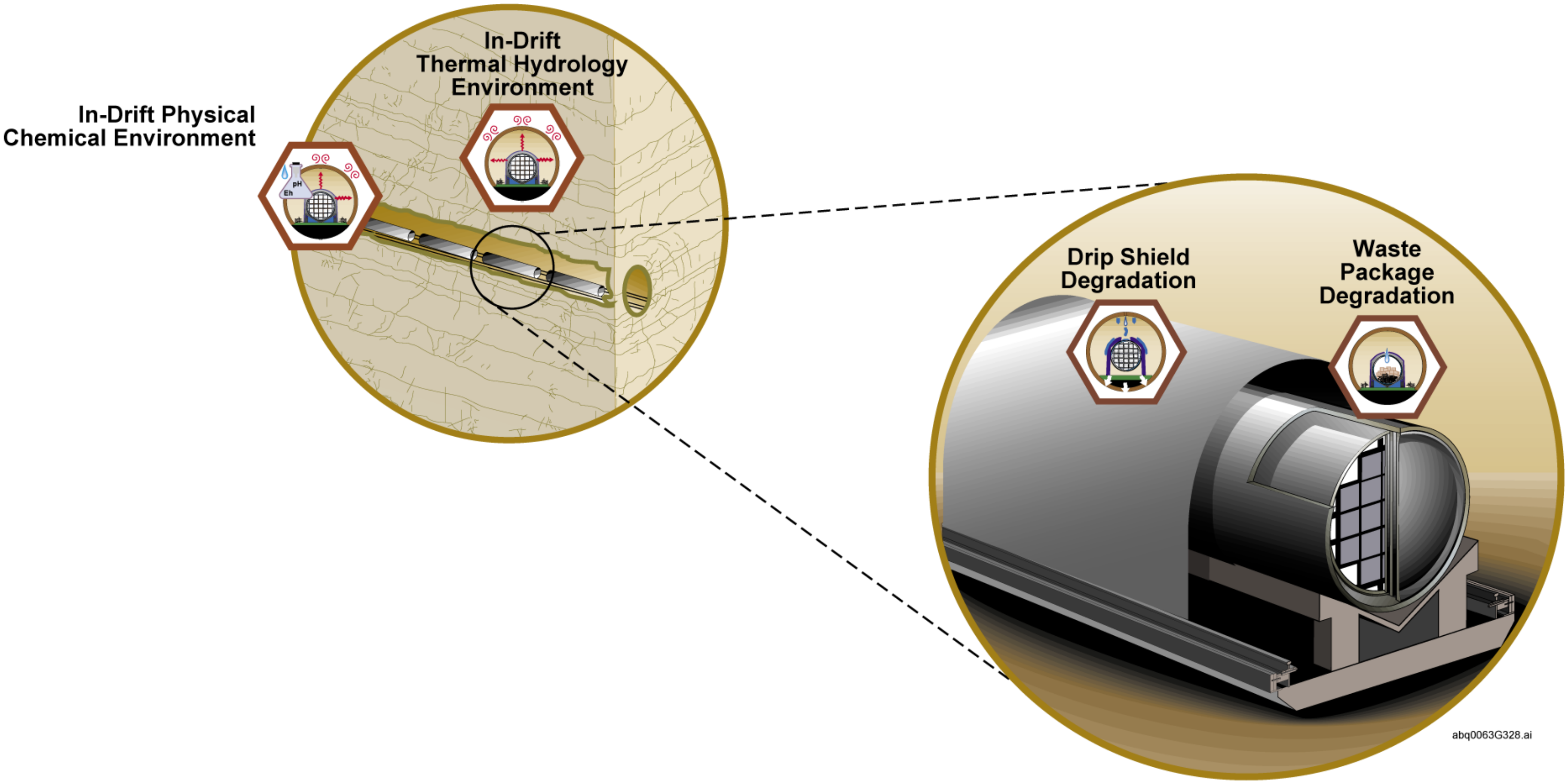
# Process Model Factors Affecting Water Contacting Waste Packages



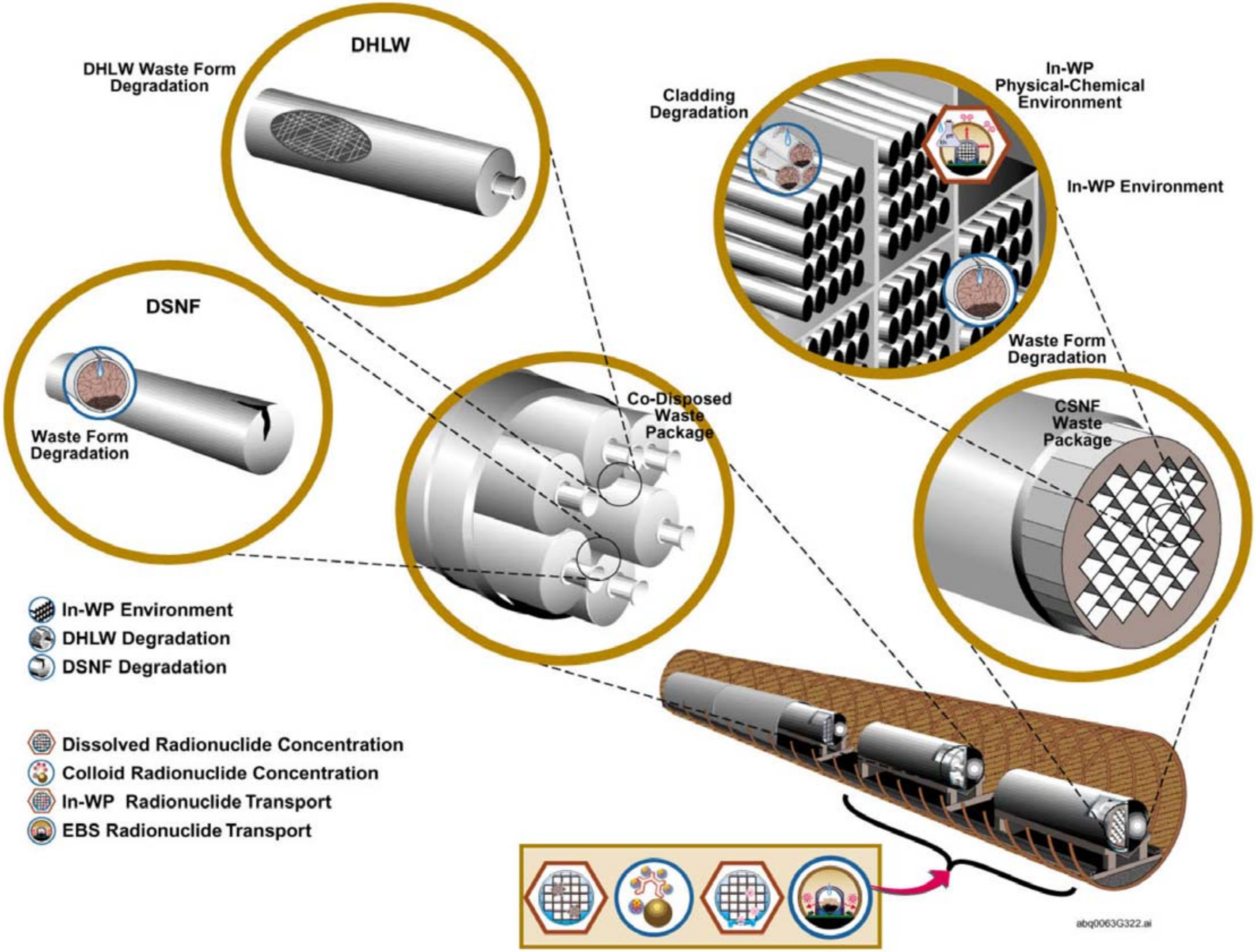
# Process Model Factors Affecting Waste Package Lifetime – Engineered Barrier System Environments



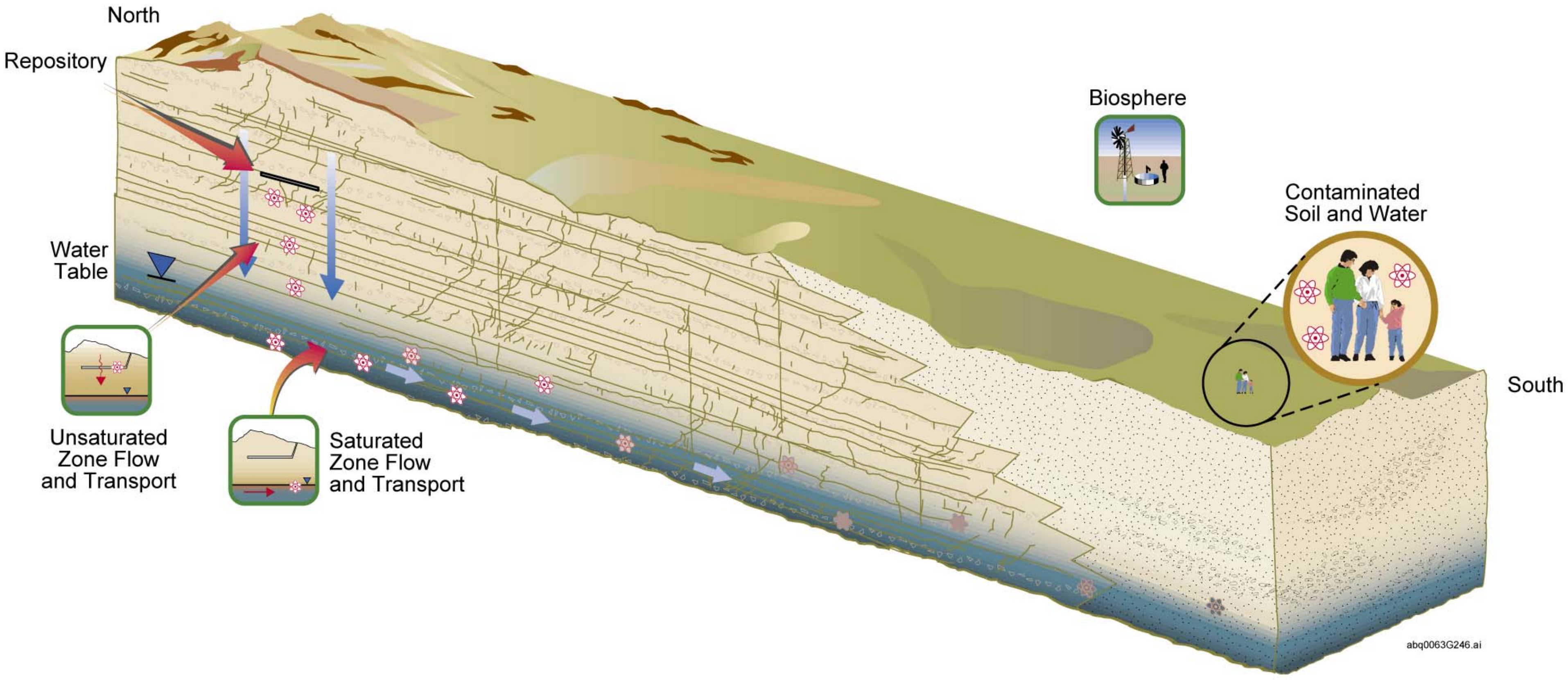
# Process Model Factors Affecting Waste Package Lifetime – Waste Package Degradation



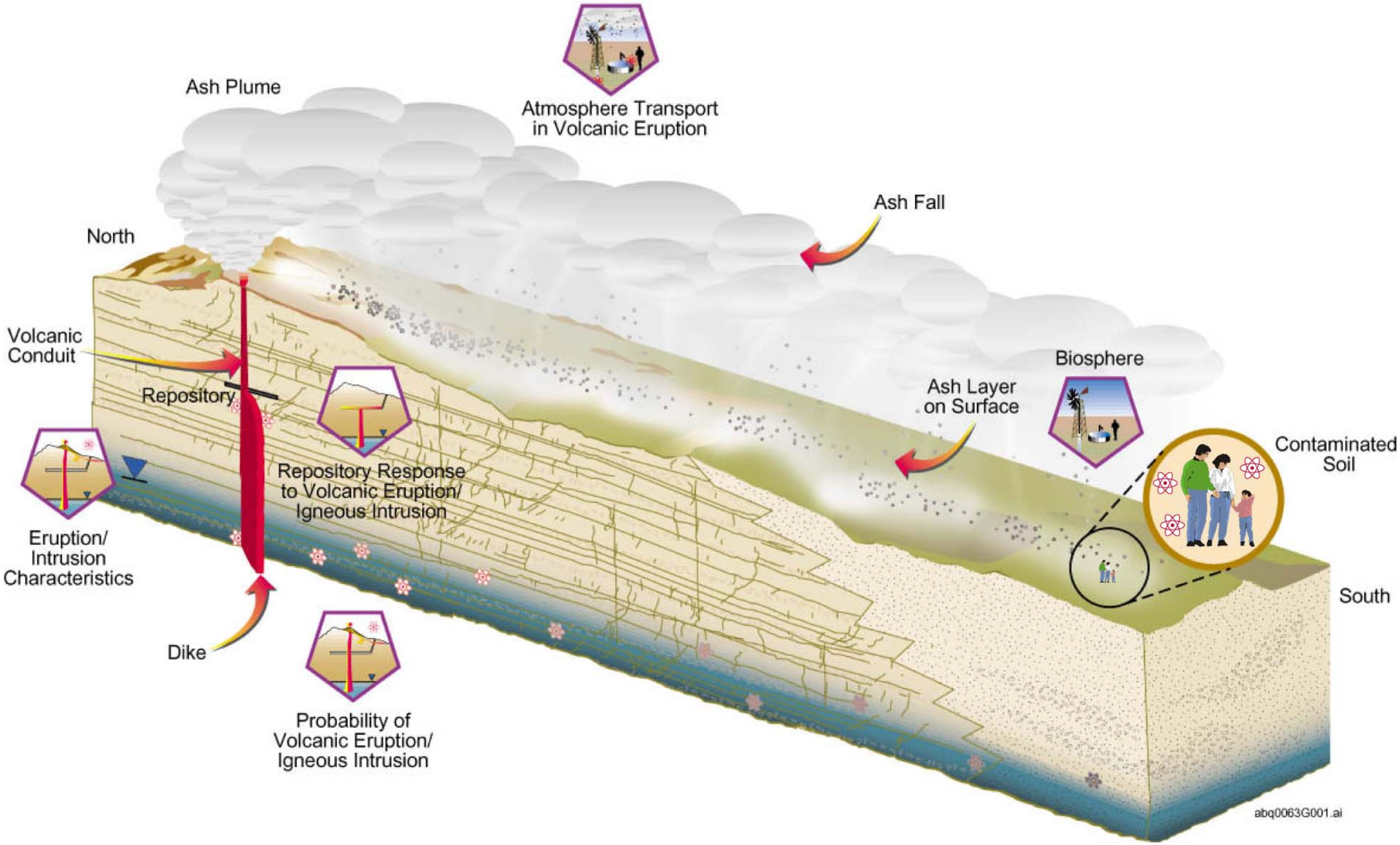
# Process Model Factors Affecting Radionuclide Release From the Engineered Barriers



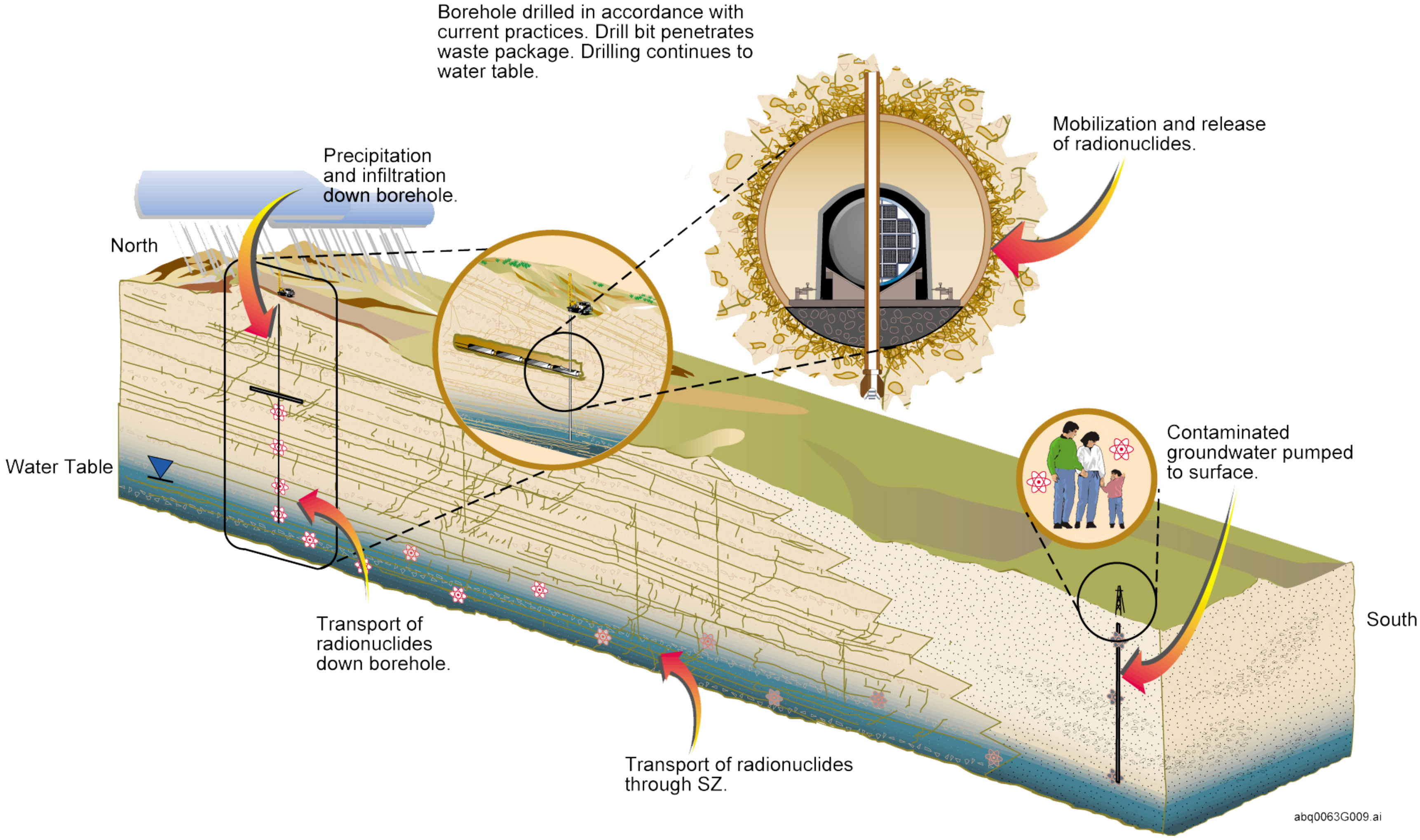
# Process Model Factors Affecting Radionuclide Transport Away from Engineered Barriers



# Process Model Factors for Disruptive Events Scenario



# Process Model Factors for Human Intrusion Scenario



# Uncertainty and Variability Incorporated in the TSPA-SR Models

- **The technical basis for each process model and the corresponding abstraction included in the TSPA-SR is contained in the family of Analysis/Model Reports (AMRs)**
- **Uncertainty and both spatial and temporal variability are included in each model as appropriate**
- **Where significant complexity or unquantified uncertainty was encountered a degree of conservatism was included in the AMR**
- **The subsequent process model talks will discuss the nature and extent of the uncertainty and conservatism included in the models**

## Overview of Quantified Uncertainty and Variability in Models Supporting TSPA-SR

| Key Attributes of System | Process Model | Quantified Uncertainty | Quantified Variability | Comments |
|---|---|---|---|---|
| | Climate | ✓ | ✓ | ▪ Uncertainty is captured by lower and upper bounds for climate.<br>▪ Variability is captured through timing of climates. |
| **Water Contacting Waste Package** | Net Infiltration | ✓ | ✓ | |
| | Unsaturated Zone Flow | ✓ | ✓ | ▪ 10% of flow through Calico Hills vitric unit (which is beneath about half the repository) is through the fractures. Results at Busted Butte indicate that 100% of flow through this unit should reside in the matrix. |
| | Coupled Effects on UZ Flow | ✓ | | ▪ Thermal effects of far-field UZ flow have been screened out. |
| | Seepage into Emplacement Drifts | ✓ | ✓ | • Seepage threshold possibly underestimated.<br>• Seep flux increased by 55% to account for effects of drift degradation & rock bolts. |
| | Coupled Effects on Seepage | | | • Percolation flux taken 5 m above drift crown during thermal period as input to seepage model.<br>▪ Thermal dry-out neglected, possible better performance of lower lithophysal unit neglected. |
| **Waste Package Lifetime** | In-Drift Physical and Chemical Environments | | ✓ | ▪ Laboratory A22 corrosion rates measured under extreme chemical environments. |
| | In-Drift Moisture Distribution | | ✓ | ▪ Threshold RH based on the deliquescence point of NaNO3 salt, and the same threshold RH for both drip and no-drip conditions. |
| | Drip Shield Degradation and Performance | ✓ | ✓ | ▪ Corrosion initiated at threshold RH. |
| | Waste Package Degradation and Performance | ✓ | ✓ | ▪ Corrosion initiated at threshold RH.<br>▪ Density and orientation of embedded defects/flaws.<br>▪ Highly aggressive water chemistry conditions are assumed for SCC Crack Initiation and Propagation.<br>▪ Laboratory A22 corrosion rates measured under extreme chemical environments. |

## OVERVIEW OF QUANTIFIED UNCERTAINTY AND VARIABILITY IN MODELS SUPPORTING TSPA-SR

| KEY ATTRIBUTES OF SYSTEM | PROCESS MODEL | QUANTIFIED UNCERTAINTY | QUANTIFIED VARIABILITY | COMMENTS |
|---|---|---|---|---|
| **Radionuclide Mobilization and Release from the Engineered Barrier System** | Radionuclide Inventory | | | ▪ C-14 included in inventory is transported entirely in the aqueous phase. |
| | In-Package Environments | | ✓ | ▪ Thermal dry-out effects during first 5-10,000 years neglected. (No effect on DSNF/DHLW), |
| | Cladding Degradation and Performance | ✓ | ✓ | ▪ Conservative estimate of perforation from creep rupture is used<br>▪ Wet unzipping has uncertainty added that is in addition to the uncertainty in the CSNF degradation rate |
| | CSNF Degradation and Performance | | | ▪ Degradation rates do not consider secondary phase formation. |
| | DSNF Degradation and Performance | | | ▪ No cladding credit is assumed<br>▪ A constant degradation rate is used that conservatively bounds degradation of metallic uranium present in N-reactor fuel<br>▪ Degradation rates do not consider secondary phase formation. |
| | DHLW Degradation and Performance | | | ▪ High degradation rates are assumed.<br>▪ Degradation rates do not consider secondary phase formation. |
| | Dissolved Radionuclide Concentrations | ✓ | | ▪ High Np solubility is predicted because $Np_2O_5$ is conservatively assumed to be the controlling solid phase<br>▪ Np or other radioisotopes are not incorporated into secondary phases of uranium are assumed |
| | Colloid-Associated Radionuclide Concentrations | ✓ | | ▪ Concentration of iron-(hydr)oxide corrosion-product colloids not linked to corrosion rates<br>▪ Stabilities of colloid types (waste-form, groundwater, and corrosion-product colloids) are treated independently.<br>▪ Assumption that groundwater colloids consist of montmorillonite (smectite) clay minerals |
| | In-Package Radionuclide Transport | | | ▪ Diffusion from altered waste form to inner wall of waste package neglected |
| | EBS (Invert) Degradation and Performance | | ✓ | ▪ The advective flow for radionuclide transport through the invert is a one-dimensional process and always vertically downward.<br>▪ The binary diffusion coefficient for all radionuclides is bounded by the self-diffusion coefficient of water.<br>▪ A zero concentration boundary condition at the invert/UZ interface is enforced during the post-closure simulation period. |

# Overview of Quantified Uncertainty and Variability in Models Supporting TSPA-SR

| Key Attributes of System | Process Model Factor | Quantified Uncertainty | Quantified Variability | Comments |
|---|---|---|---|---|
| Transport Away from the Engineered Barrier System | UZ Radionuclide Transport (Advective Pathways; Retardation; Dispersion; Dilution) | ✓ | ✓ | • The treatment of fracture/matrix diffusion assumes a stagnant matrix, which has been shown to be conservative.<br>• Colloid concentrations and $K_d$s used to calculate $K_c$ are conservative (i.e., high).<br>• Colloid retardation is neglected for all colloids in the UZ.<br>• Physical colloid filtration is neglected for transport in fractures. |
| | SZ Radionuclide Transport | ✓ | ✓ | • Sorption coefficients for alluvium is likely low.<br>• No sorption in fractures.<br>• No removal of colloids by mechanical filtration. |
| | Wellhead Dilution | ✓ | | |
| | Biosphere Dose Conversion Factors | ✓ | | ▪ Pessimistic DCF values for possible gastrointestinal absorption. |
| Effects of Potentially Disruptive Processes and Events | Probability of Volcanic Eruption | ✓ | ✓ | ▪ Spatial and temporal variability in igneous processes considered by PVHA panel. |
| | Characteristics of Volcanic Eruption | ✓ | | • Eruptive events assumed to be violent for full duration. |
| | Effects of Volcanic Eruption | ✓ | | ▪ Volcanic eruption assumed to degrade all waste packages, drip shields, and cladding that are intersected by eruptive conduit. |
| | Atmospheric Transport of Volcanic Eruption | ✓ | ✓ | ▪ Variability in Wind Speed with altitude and time included in cdf.<br>▪ Assume wind always blows toward critical group (south). (Conservative approach to compensate for not including surface redistribution processes). |
| | Biosphere Dose Conversion for Volcanic Eruption | ✓ | | • High air mass loading assumed to persist permanently following ashfall. |
| | Probability of Igneous Intrusion | ✓ | ✓ | ▪ Spatial and temporal variability in igneous processes considered by PVHA panel. |
| | Characteristics of Igneous Intrusion | | ✓ | ▪ Variability in location (length and orientation) affects extent of damage.<br>▪ Multiple dikes possible in a single event, assumed to be at least favorable spacing. |
| | Effects of Igneous Intrusion | ✓ | ✓ | • Variability in location (length and orientation) affects extent of damage.<br>• Igneous intrusion assumed to degrade all waste package drip shields and cladding in all drifts that are intersected by dike.<br>• Three waste packages on either side of the dike are assumed fully degraded. |

# TSPA Results

- TSPA-VA
- TSPA-SR Preliminary Nominal Scenario Class
  - 100 k-yr dose rate
  - 100 k-yr key radionuclides
  - 1,000 k-yr dose rate
  - 1,000 k-yr key radionuclides
- TSPA-SR Preliminary Igneous Activity Scenario Class
- Sensitivity Analysis

# TSPA-VA Results*

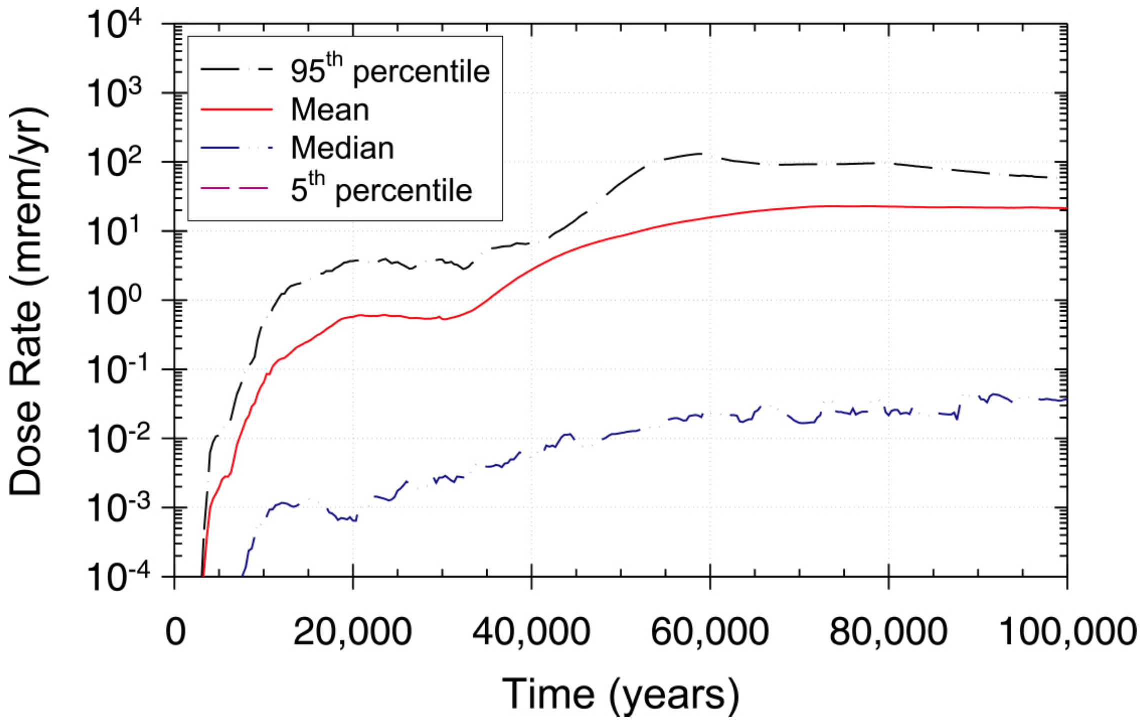
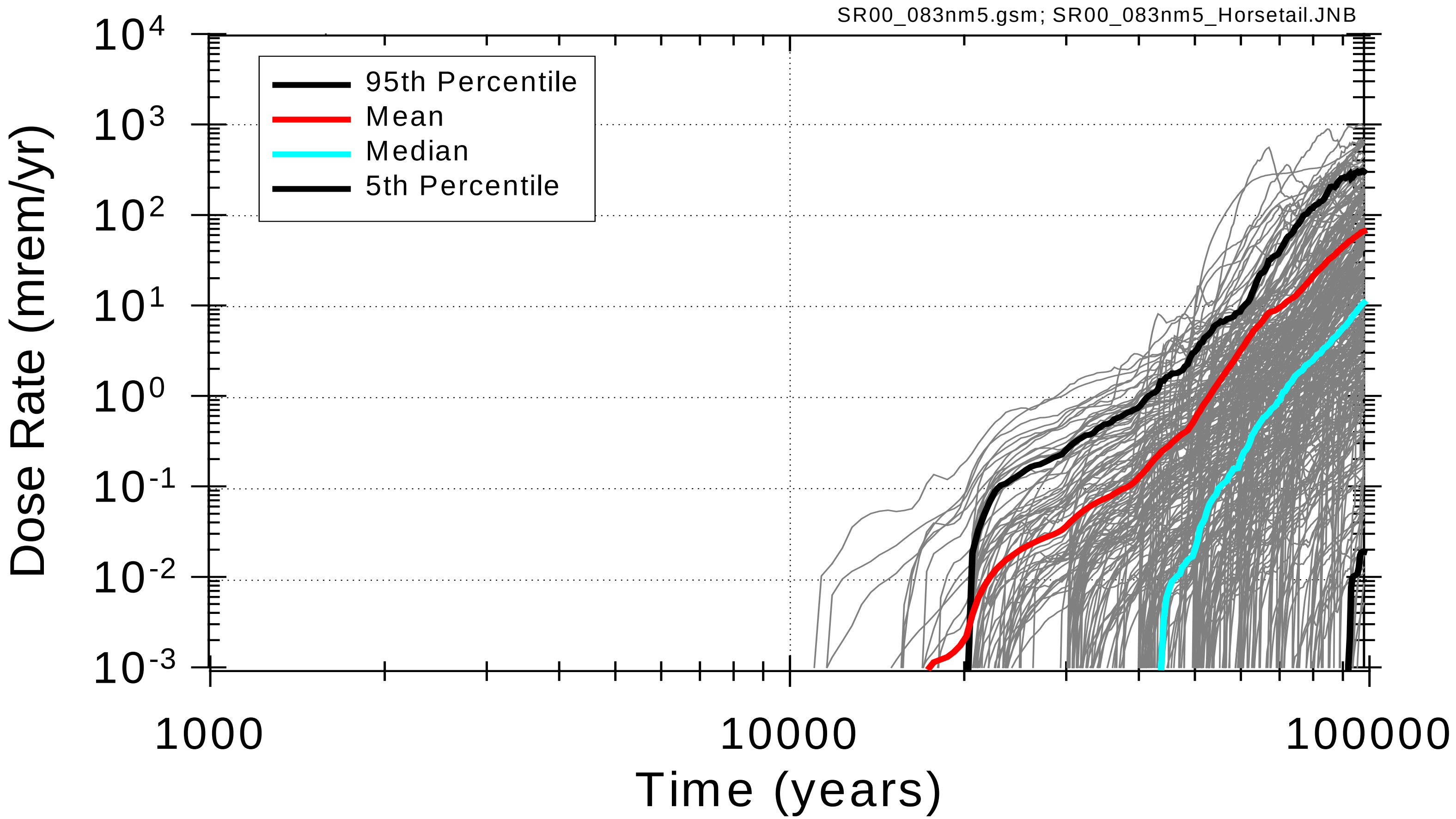



***Figure 4-28 of Viability Assessment of a Repository of Yucca Mountain, Volume 3 Total System Performance Assessment**

*This information was prepared for the 8/00 NWTRB meeting for illustrative purposes only and is subject to revision; not appropriate for assessing regulatory compliance.*

# TSPA-SR Preliminary Nominal Scenario Class – Individual Dose Results

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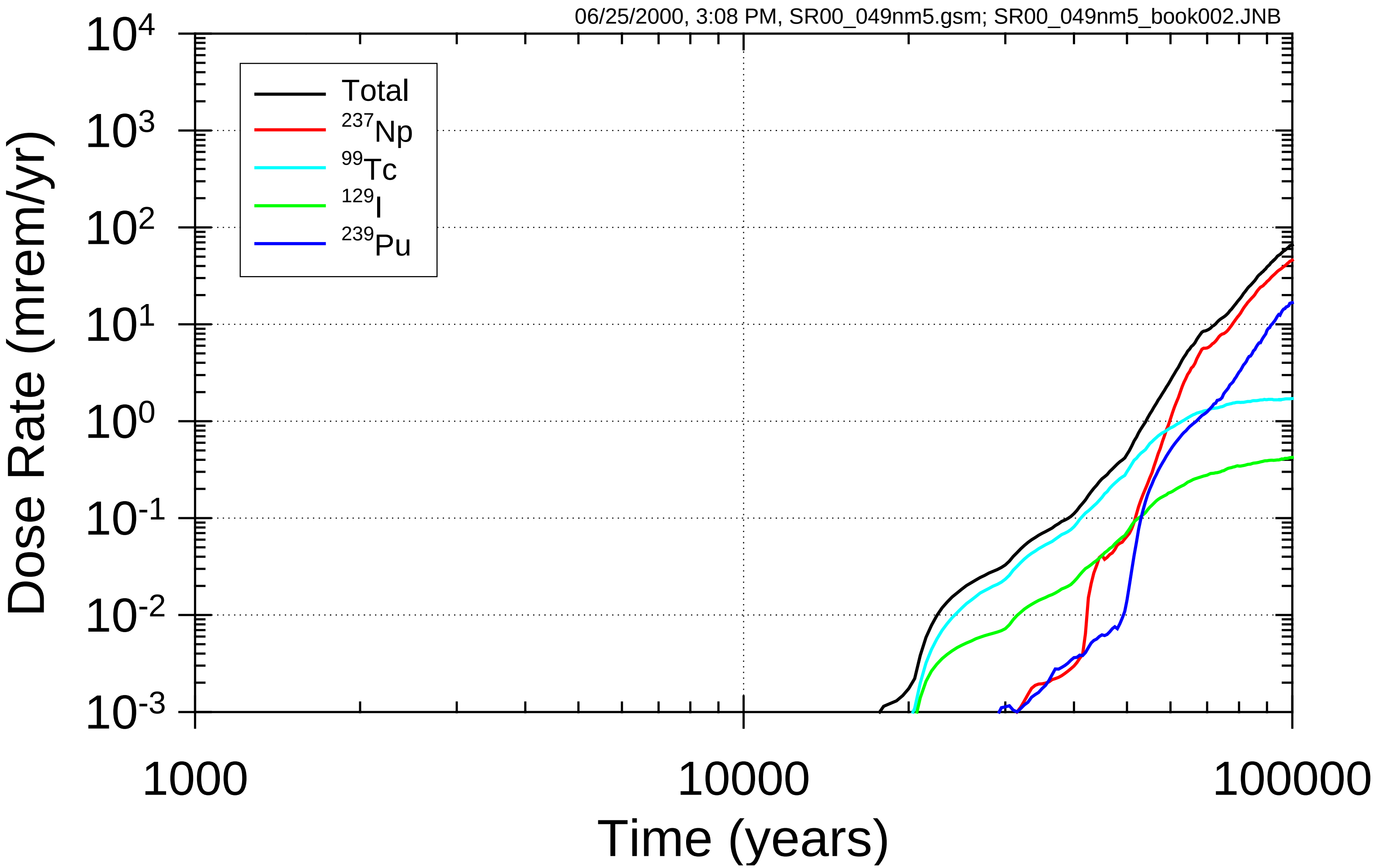
# TSPA-SR Preliminary Nominal Scenario Class – Key Radionuclides

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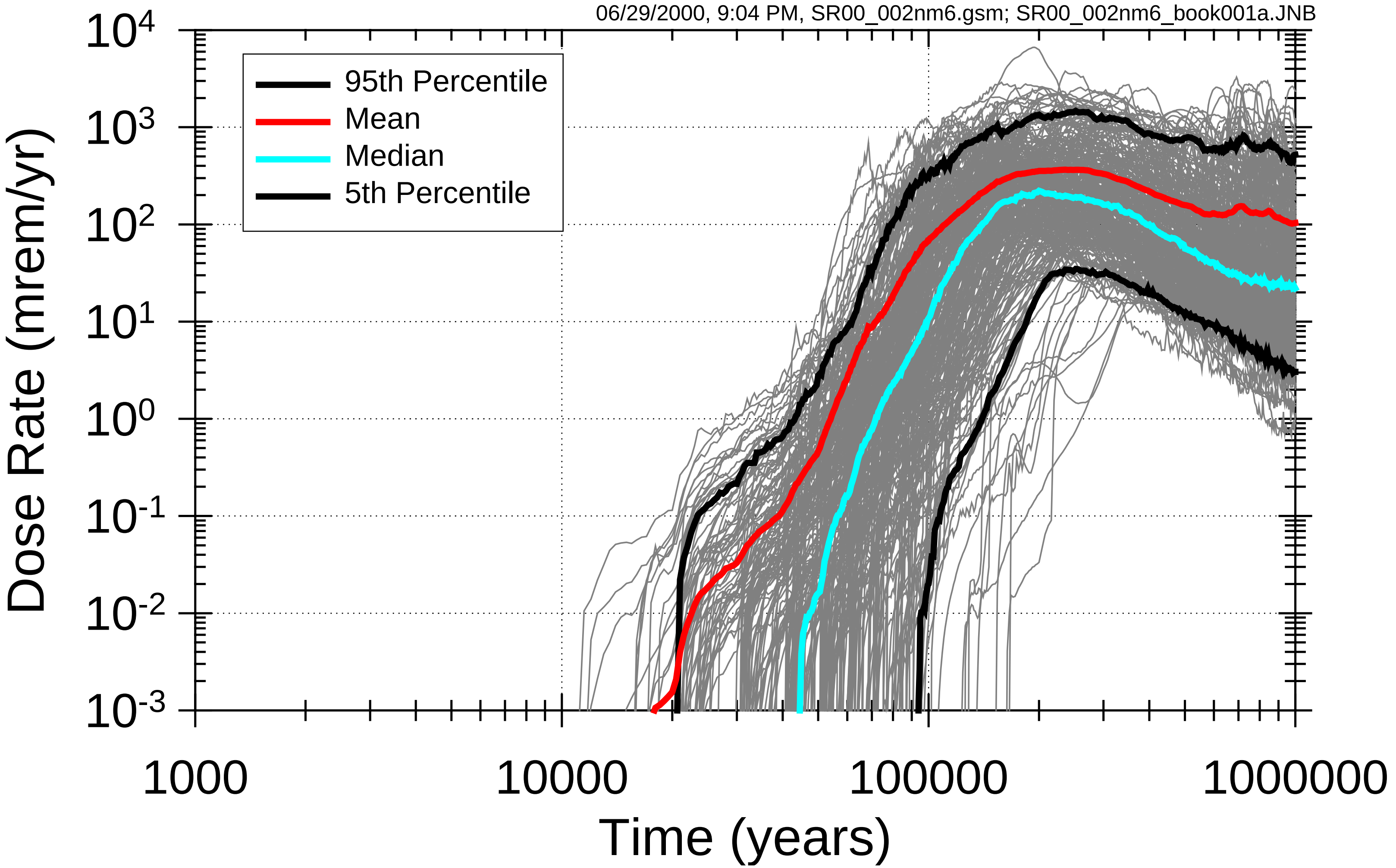
# TSPA-SR Preliminary Nominal Scenario Class – Individual Dose Results

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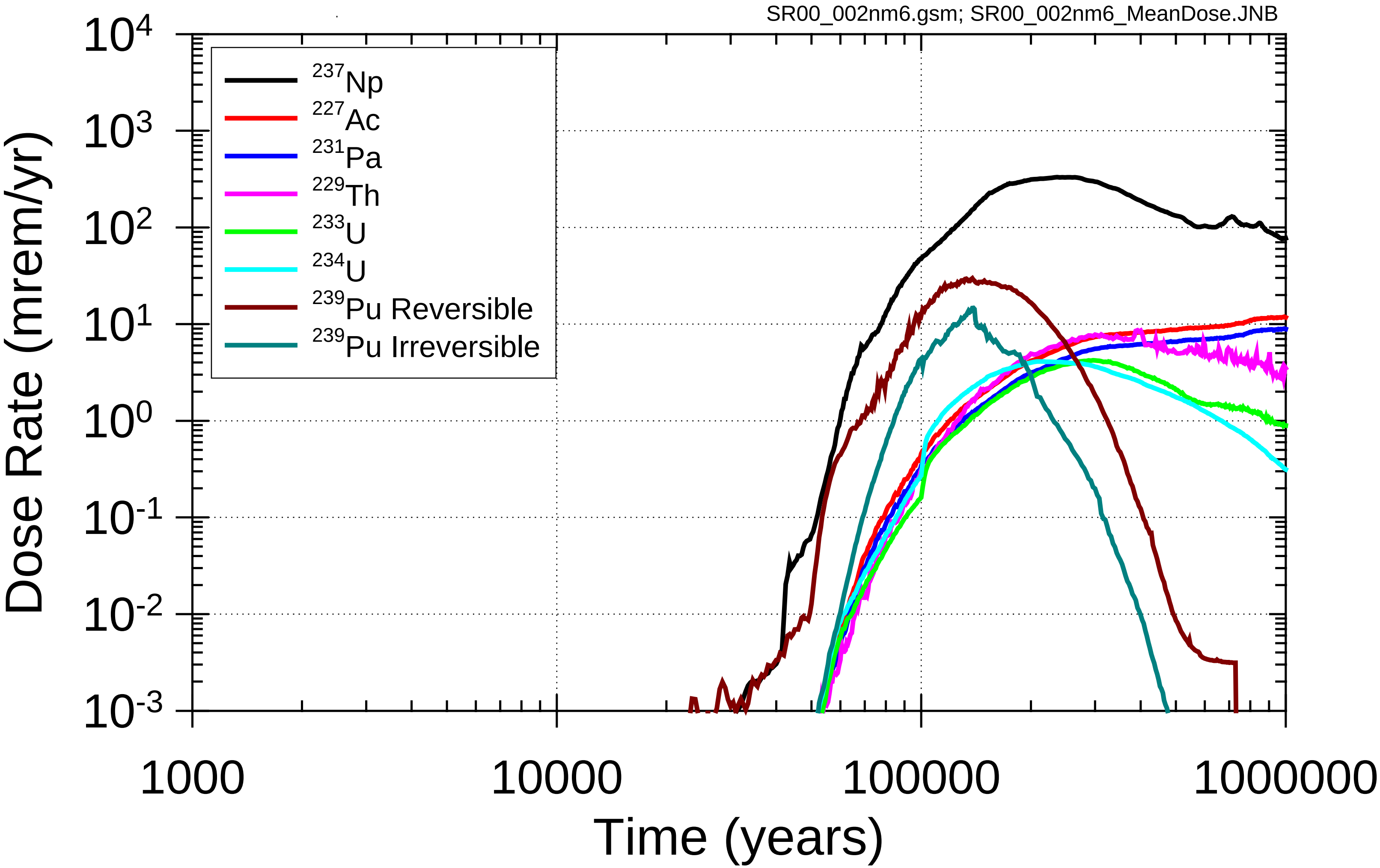
# TSPA-SR Preliminary Nominal Scenario Class – Key Radionuclides

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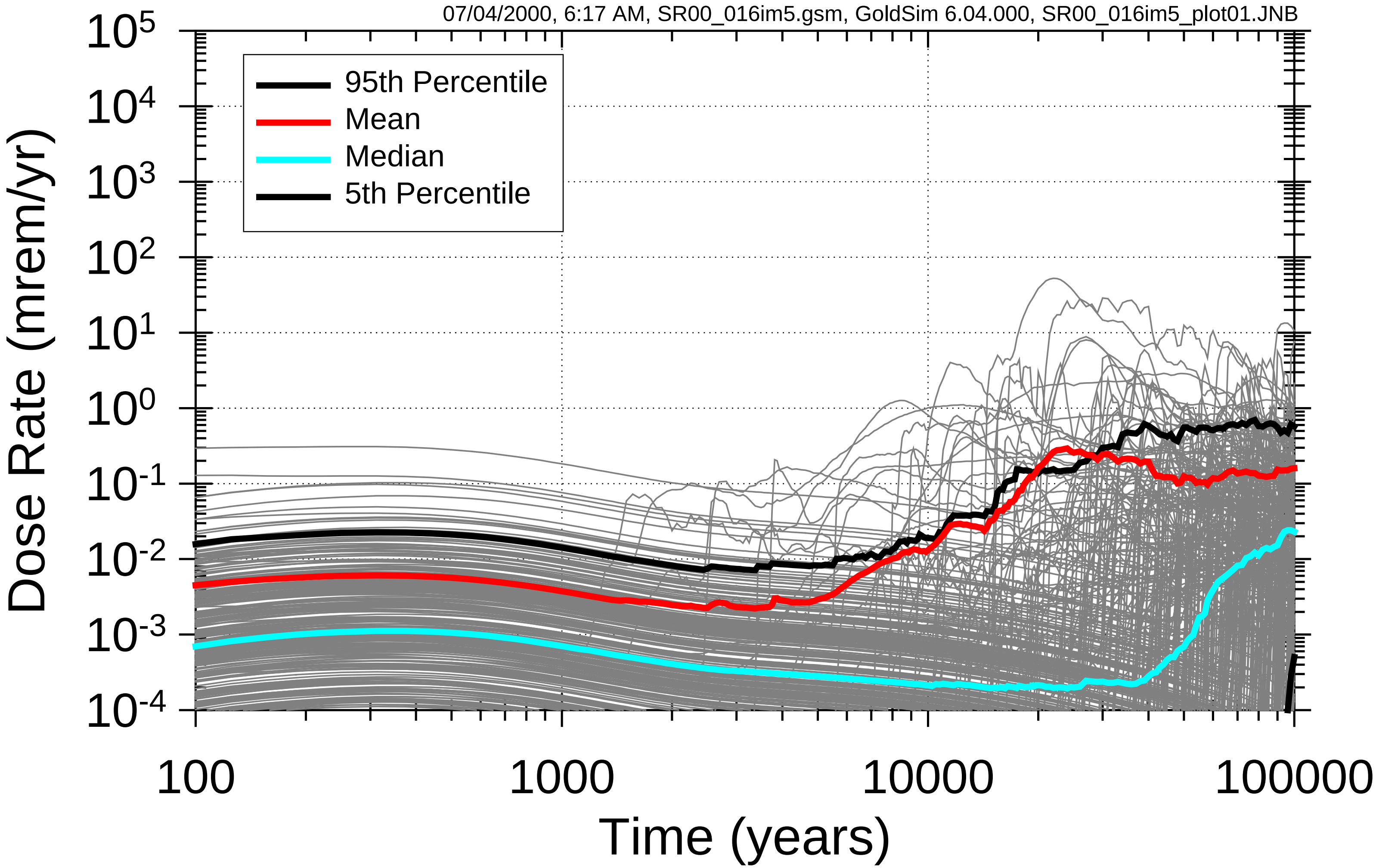
# TSPA-SR Preliminary Igneous Activity Scenario Class – Individual Dose Results

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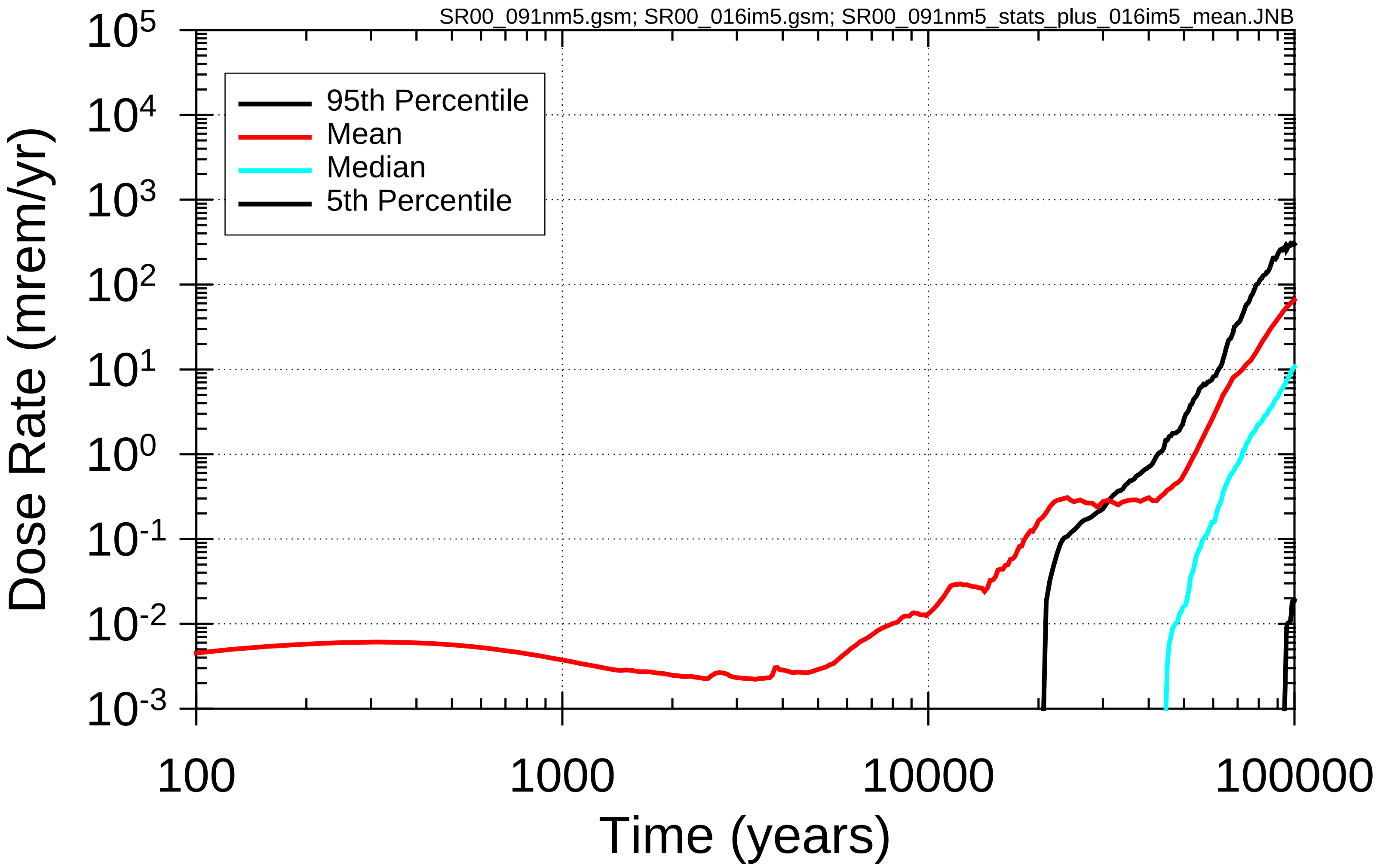
# TSPA-SR Preliminary Combined Nominal and Igneous Activity Scenario Classes – Individual Dose Results

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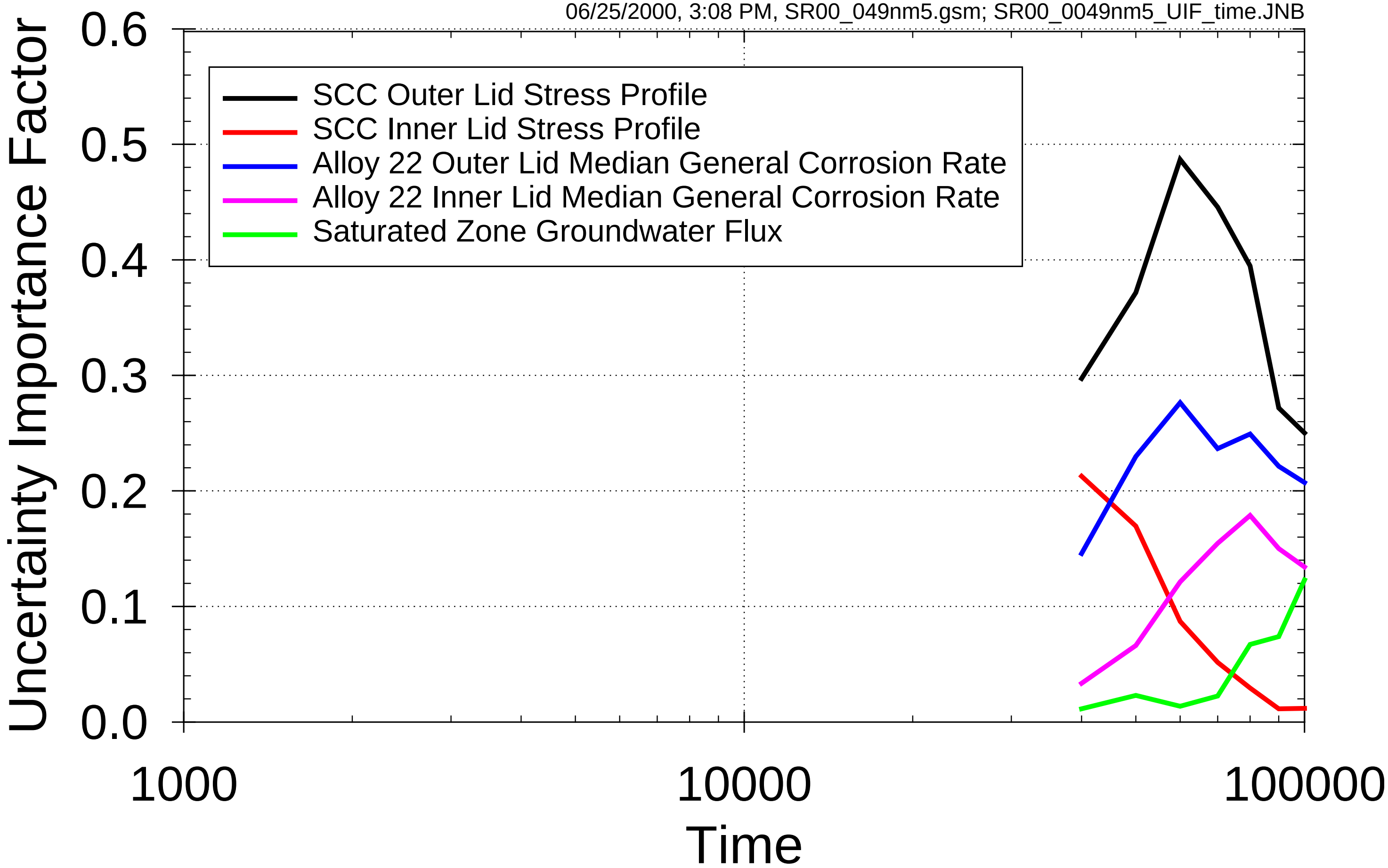
# Summary of TSPA-SR Preliminary Sensitivity Analyses

- **Uncertainty analyses**
  - **> 200 parameters in nominal performance scenario are represented with an uncertainty range**
  - **Regression analysis, discriminant analysis, partial correlations and regression trees are used to identify the most significant parameters (an example follows)**
- **Sensitivity analyses**
  - **Specific analyses fixing individual key parameters at their 5th and/or 95th percentile used to illustrate contribution to performance of individual process model factors**
- **Barrier Importance analyses**
  - **Barrier analysis - Specific analyses fixing groups of key parameters at their 5th or 95th percentile used to illustrate contribution to performance of combined process model factors or barriers (an example for waste package degradation follows - additional examples are discussed in individual process model talks)**
  - **Barrier Neutralization Analyses - Specific Analyses removing the function of a particular barrier to gain insights to system performance (will be presented tomorrow in the RSS Rev 4 talk)**

# TSPA-SR Preliminary Nominal Scenario Class – Example Regression Analysis

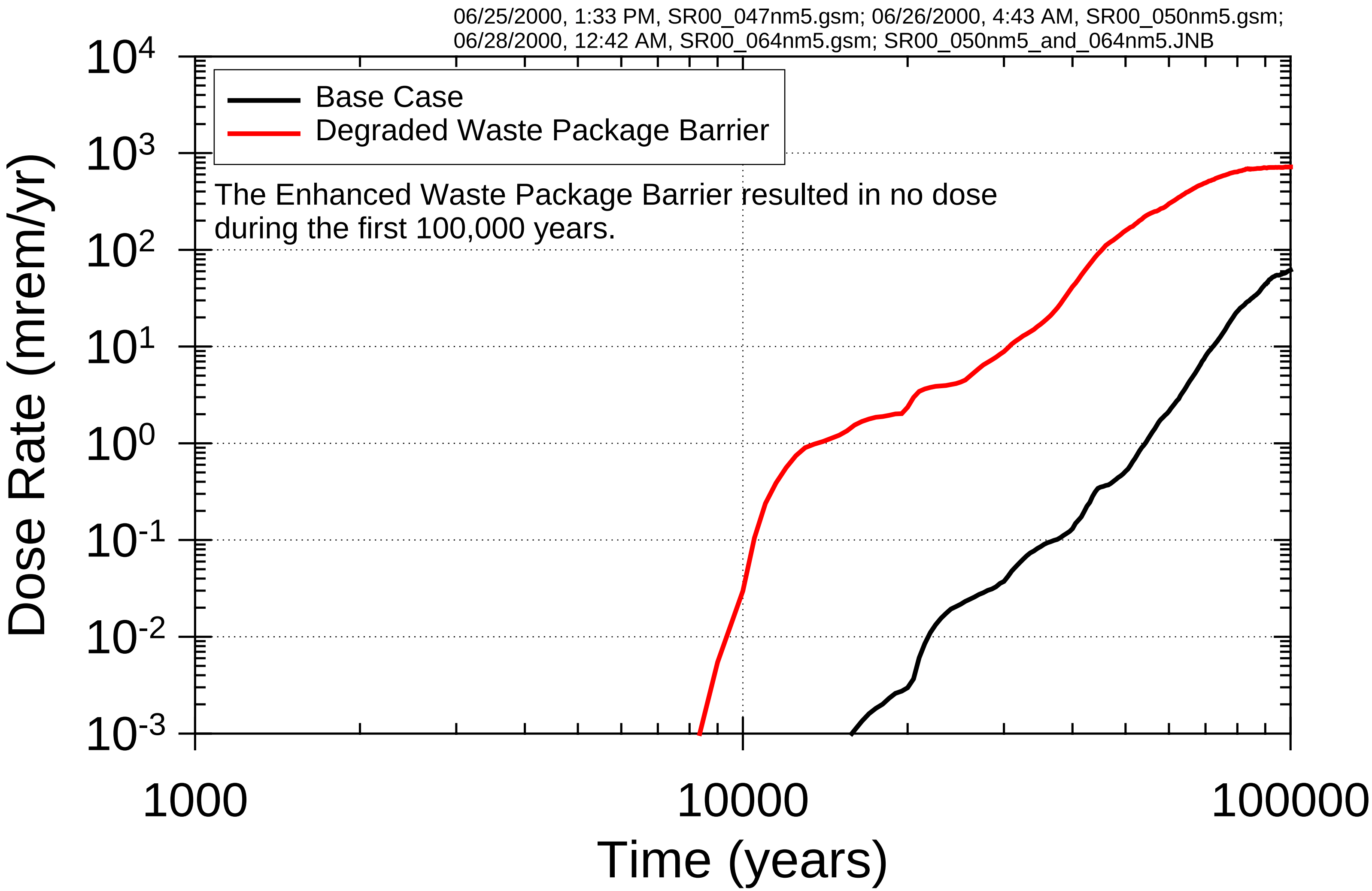



***NOTE: Insufficient statistics prior to 40k years to provide representative results**

# Example of Barrier Importance Analyses

- Based on regression analyses, several waste package degradation parameters have been identified as significantly affecting the dose rate
- The following waste package degradation parameters were fixed at their 95th and/or 5th percentile to provide an estimate of the possible pessimistic (degraded) or optimistic (enhanced) performance:
  - Outer and inner lid weld stress profiles
  - Median Alloy 22 corrosion rate for outer and inner lids
  - Aging and MIC factors for corrosion rate
  - Defect probability

# TSPA-SR Preliminary Nominal Scenario Class – Example of Waste Package Barrier Importance

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# Summary of Barrier Importance Analyses to be Presented in Subsequent Talks

- **Unsaturated zone flow and transport**
  - **Infiltration barrier**
  - **Seepage barrier**
  - **Unsaturated zone transport barrier**
- **Engineered Barrier System transport**
  - **Invert diffusion barrier**
- **Drip shield and waste package degradation**
  - **Drip shield barrier**
  - **Waste package barrier**

# Summary of Barrier Importance Analyses to be Presented in Subsequent Talks

- **Waste form degradation**
  - **Cladding barrier**
- **Saturated zone flow and transport**
  - **Saturated zone barrier**
- **Biosphere - none**
- **Disruptive events**
  - **Volcanic activity sensitivity analysis**
- **Neutralization**

# Summary of Technical Improvements for TSPA-SR

- **TSPA-SR has benefited from comments received from reviewers of TSPA-VA**
  - DOE Peer Review, NWTRB, NRC, USGS TSPA-VA Peer Review, Clark County
- **Major process model revisions include:**
  - Climate and seepage
  - Coupled thermal-hydro-chemical processes and in-drift environments
  - Waste package degradation (esp. stress corrosion cracking)
  - In-package chemistry and radionuclide mobilization (esp. colloids)
  - Saturated zone transport
  - Igneous activity
- **TSPA approach modified to address NRC and EPA requirements:**
  - Explicit screening of features, events and processes
  - “Expected” annual dose to member of critical group
  - Groundwater protection of representative volume of aquifer
  - Stylized human intrusion scenario

# Summary of Process Improvements for TSPA-SR

- All process models, abstraction models, analyses and calculations used to support TSPA-SR are controlled under a set of QA procedures common to all participants
- All data sets, parameters and models/analyses inputs and outputs are being tracked and controlled to ensure traceability
- TSPA-SR model developed to ensure all data used as input are traceable
- All data are tracked to verify quality status

# Summary of Remaining Work for TSPA-SR

- Complete analyses and check/review
- Complete uncertainty, sensitivity, and barrier importance analyses
- Complete analysis of results
- Complete documentation

# Backup

# Process Model Factors Affecting Water Contacting Waste Packages

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

# Process Model Factors Affecting Waste Package Lifetime – Engineered Barrier System Environments

| Key Attributes of Performance | Process Model Factor | TSPA-SR Input Parameters |
|---|---|---|
| Waste Package Lifetime | In-Drift Physical and Chemical Environments | • Rock volume and mass distribution<br>• Temperature and RH on the drip shield and waste package surface – f (multiple locations, waste type, time, climate)<br>• Fugacity of $CO_2$<br>• pH – f (region, time)<br>• Chloride – f (region, time)<br>• Mass of microbes |
| | In-Drift Thermal-Hydrologic Environment | • Seepage flux through the drip shield<br>• Fraction of drip shield and waste package surface that is wet |

# Process Model Factors Affecting Waste Package Lifetime – Waste Package Degradation

| Key Attributes of Performance | Process Model Factor | TSPA-SR Input Parameters |
|---|---|---|
| Waste Package Lifetime | Drip Shield Degradation and Performance | • Probability of material and manufacturing defect flaws in drip shield<br>• Size of material and manufacturing defect flaws in drip shield<br>• Probability and size of rockfall induced by seismic activity<br>• Threshold for general corrosion initiation<br>▪ General corrosion rate under drip and no-drip conditions<br>• Crevice corrosion initiation threshold<br>• Probability (or area) of crevice formation on drip shield<br>• Stress and stress intensity factor profile in drip shield<br>• SCC initiation threshold<br>• SCC crack growth rate<br>• Effect of material and manufacturing defects on SCC initiation and crack growth rate<br>• Effect of rockfall damage on SCC initiation and crack growth rate<br>• Hydrogen concentration profile in drip shield<br>• HIC initiation threshold<br>• Penetration opening size by general corrosion, localized corrosion and SC |
| | Waste Package Degradation and Performance | • Probability of material and manufacturing defect flaws in waste package<br>• Size of material and manufacturing defect flaws in waste package<br>• Threshold RH for general corrosion initiation under drip and no-drip conditions<br>• General corrosion rate under drip and no-drip conditions<br>• Crevice corrosion initiation threshold of WP outer barrier<br>• Penetration opening size by general corrosion, localized corrosion and SCC<br>• Stress and stress intensity factor profile at closure welds<br>• SCC initiation threshold<br>• SCC crack growth rate<br>• Effect of material and manufacturing defect on SCC initial and crack growth rate<br>• MIC factor on corrosion rate<br>• Kinetics phase instability processes in base metal and weld<br>• Aging factor on corrosion rate |

# Process Model Factors Affecting Radionuclide Release From the Engineered Barriers

| Key Attributes of System | Process Model Factor | TSPA-SR Input Parameters |
|---|---|---|
| Radionuclide Mobilization and Release from the Engineered Barrier System | In Package Environments | • pH – f (region, time)<br>• Total dissolved carbonate ($CO_3^{2}$) – f (region, time)<br>• Oxygen fugacity – f (region, time)<br>• Ionic strength – f (region, time)<br>• Fluoride – f(region, time)<br>• $CO_2$ fugacity<br>• Volume of water in the waste package/waste form cell |
| | Cladding Degradation and Performance | • Fraction of surface area of Zircaloy-clad CSNF exposed as a function of time |
| | CSNF Degradation and Performance | • CSNF intrinsic dissolution rate |
| | DSNF Degradation and Performance | • DSNF intrinsic dissolution rate |
| | HLW Degradation and Performance | • HLW intrinsic dissolution rate<br>• Specific surface area |
| | Dissolved Radionuclide Concentration | • Concentration limits (solubilities) for all isotopes |
| | Colloid-Associated Radionuclide Concentrations | • Types of waste form colloids<br>• Concentration of colloids<br>• $K_d$ and/or $K_c$ for various colloid types<br>• Fraction of inventory that travels as irreversibly attached onto colloids |
| | In-Package Radionuclide Transport | • Porosity of corrosion products – f (time)<br>• Saturation of corrosion products – f (time)<br>• Evaporation – f (temperature, relative humidity, composition) |
| | EBS (Invert) Degradation and Performance | • Thermally perturbed saturation in the invert – f (waste type, region, time, climate)<br>• Porosity of the invert<br>• Diffusion coefficient<br>• Volumetric flux through the invert – f (climate, time)<br>• Saturation in the invert after thermal pulse – f (time) |

# Process Model Factors Affecting Radionuclide Transport Away from Engineered Barriers

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

# Process Model Factors for Disruptive Events Scenario

| Key Attributes of Performance | Process Model Factor | TSPA-SR Input Parameters |
|---|---|---|
| Effects of Potentially Disruptive Processes and Events | Seismic Activity | • Probability of seismicity/structural deformation |
| | Volcanic Direct Release | • Annual probability of igneous intrusion<br>• Atmospheric transport parameters<br>• Probability that an intrusion will result in one or more eruptive vents<br>• Number of vents through the waste<br>• Wind direction factor<br>• Wind speed<br>• Biosphere dose conversion factors - f (radionuclide)<br>• Factor to account for radionuclide removal from soil |
| | Intrusive Indirect Release | • Annual probability of igneous intrusion<br>• Number of Waste Packages damaged by intrusion (for groundwater transport source term) |

# Examples of Possible Sensitivity and Barrier Importance Analyses to Evaluate Significance of Process Model Factors

| Key Attributes of System | Process Model Factor | Possible Sensitivity Analyses | Possible Barrier Importance Analyses |
|---|---|---|---|
| Water Contacting Waste Package | Climate | • Vary timing of climate change<br>• Vary magnitude of precipitation | • Combine maximum precipitation and maximum infiltration to maximize infiltration rate |
| | Net Infiltration | • Vary magnitude of infiltration | |
| | Unsaturated Zone Flow | • Vary magnitude of flux | • Combine 95$^{th}$ %ile on flow focussing factor and fracture properties to maximize seepage fraction and amount |
| | Coupled Effects on UZ Flow | • Vary timing/amount of dryout/reflux | |
| | Seepage into Emplacement Drifts | • Vary degree of flow focusing<br>• Vary percent of repository with seeps<br>• Vary fracture properties<br>• Vary episodicity | |
| | Coupled Effects on Seepage | • Vary changes to UZ flow | |
| Waste Package Lifetime | In-Drift Physical and Chemical Environments | • Vary T/RH<br>• Vary rockfall/location of rockfall<br>• Vary chemistry on DS (salt/dust)<br>• Vary chemistry on WP without DS present | • Combine 95$^{th}$ %ile on flow focussing factor and fracture properties to maximize seepage fraction and amount |
| | In-Drift Moisture Distribution | • Vary range of moisture on DS<br>• Vary condensation under DS<br>• Vary range of moisture on WP | |
| | Drip Shield Degradation and Performance | • Vary corrosion rate<br>• Evaluate drip shield separation<br>• Evaluate leakage through drip shield joints | • Combine 95$^{th}$ %ile on rockfall, Titanium degradation rate, indrift chemistry and HIC to minimize dripshield lifetime |
| | Waste Package Degradation and Performance | • Evaluate phase stability/aging<br>• Evaluate effect of phase stability on local/crevice corrosion<br>• Vary stress and stress intensity at closure weld<br>• Vary threshold stress<br>• Vary corrosion rate<br>• Vary initial defect size and probability<br>• Vary heat sensitization near welds<br>• Evaluate stainless steel barrier credit<br>• Evaluate co-dependence of DS/WP failure<br>• Vary MIC | • Combine 95$^{th}$ %ile on initial defects, stress state, threshold stress, corrosion rate, MIC, and aging to minimize waste package lifetime |

# Examples of Possible Sensitivity and Barrier Importance Analyses to Evaluate Significance of Process Model Factors

| Key Attributes of System | Process Model Factor | Possible Sensitivity Analyses | Possible Barrier Importance Analyses |
|---|---|---|---|
| Radionuclide Mobilization and Release from the Engineered Barrier System | Radionuclide Inventory | • Vary burn-up/age variability across repository | • N/A |
| | In-Package Environments | • Vary water chemistry<br>• Evaluate evaporation from breached waste packages during thermal period | |
| | Cladding Degradation and Performance | • Vary degradation rate<br>• Vary perforations | • Combine 95th %ile on initial defects, unzipping rate, and Fluoride content to minimize cladding lifetime |
| | CSNF Degradation and Performance | • Vary degradation rate | • N/A |
| | DSNF Degradation and Performance | • Vary degradation rate | |
| | DHLW Degradation and Performance | • Vary degradation rate | |
| | Dissolved Radionuclide Concentrations | • Vary Pu, Np solubility<br>• Evaluate secondary phases | • Combine 95th %ile colloids, pH, solubility, diffusion coefficient to maximize radionuclide mobilization and release |
| | Colloid-Associated Radionuclide Concentrations | • Vary fraction of irreversible colloids | |
| | In-Package Radionuclide Transport | • Vary Fraction of water removed from waste package | |
| | EBS (Invert) Degradation and Performance | • Vary sorption in invert<br>• Vary diffusion coefficient in invert<br>• Vary saturation of invert | |

# Examples of Possible Sensitivity and Barrier Importance Analyses to Evaluate Significance of Process Model Factors

| Key Attributes of System | Process Model Factor | Possible Sensitivity Analyses | Possible Barrier Importance Analyses |
|---|---|---|---|
| Transport Away from the Engineered Barrier System | UZ Radionuclide Transport (Advective Pathways; Retardation; Dispersion; Dilution) | • Vary matrix diffusion<br>• Vary colloid filtration<br>• Evaluate spatial variation of properties<br>• Vary sorption | • Combine 95th %ile on $K_d$, matrix diffusion, flow rates to minimize transport times in the unsaturated zone |
| | SZ Radionuclide Transport | • Evaluate effect of climate change on pathways and flux<br>• Evaluate water table rise<br>• Vary flux<br>• Evaluate flowing interval spacing<br>• Vary amount of alluvium<br>• Vary Kd in alluvium<br>• Vary colloid filtration in alluvium | • Combine 95th %ile on $K_d$, matrix diffusion, percent alluvium, flow rate to minimize transport times in the saturated zone |
| | Wellhead Dilution | • Vary volume of water used by critical group | • N/A |
| | Biosphere Dose Conversion Factors | • Vary BCDFs | |
| Effects of Potentially Disruptive Processes and Events | Probability of Volcanic Eruption | • Vary probability | • N/A |
| | Characteristics of Volcanic Eruption | • Vary event eruption volume | |
| | Effects of Volcanic Eruption | • Vary waste particle diameter | |
| | Atmospheric Transport of Volcanic Eruption | • Vary wind speed and direction | |
| | Biosphere Dose Conversion for Volcanic Eruption | • Vary BDCF | |
| | Probability of Igneous Intrusion | • Vary probability | |
| | Characteristics of Igneous Intrusion | • Vary number of packages affected | |
| | Effects of Igneous Intrusion | • Vary degree of degradation of waste package | |