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

Role of Different Barriers in Total System Performance Assessment - Examples from Nominal, Degraded, Neutralized and Early Waste Package Degradation Scenarios

Presented to:
Nuclear Waste Technical Review Board

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YUCCA MOUNTAIN PROJECT

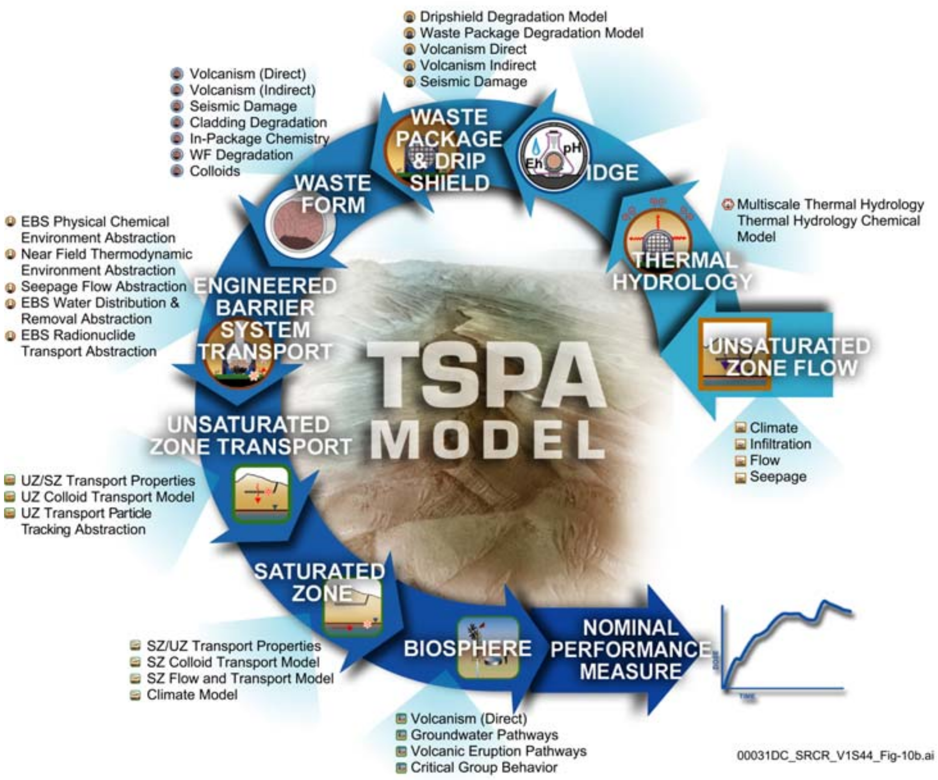
Outline

- NWTRB Question
- TSPA - the Tool
- Barriers in TSPA
- Approaches to Evaluating Barrier Contribution
- Barrier Contribution Results
  - Nominal Waste Package Scenario Class
  - Early Waste Package Failure Scenario
  - Degraded and Neutralized Waste Package Failure Scenarios
  - Igneous Intrusion Waste Package Failure Scenario
- Unquantified Uncertainty Analyses
- Summary and Conclusions

NWTRB Question

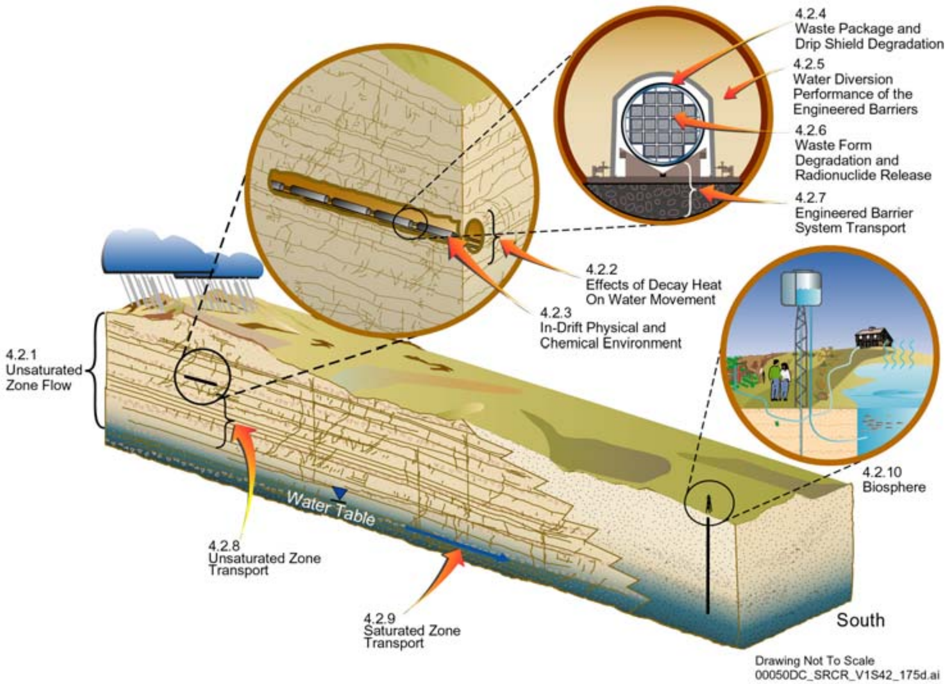
- Clarify roles played by the different natural and engineered barriers in the total system performance assessment
- Address over reliance on the waste package in the safety case
- In answering these questions:
  - compare nominal case TSPA with more rapid waste package degradation scenarios
  - address the mode and extent of each waste package failure scenario, the mechanisms for release and the roles of the different barriers
    - compare the dose due to a degraded and neutralized WP
    - evaluate dose when completely neutralized
  - evaluate how robust are the conclusions on defense-in-depth

Total System Performance Assessment
The Tool



- TSPA is a tool which integrates all aspects of the system affecting postclosure performance
- Consequently, TSPA is both comprehensive and complex
- Some barriers can mask the performance contribution of other barriers
- Therefore, clearly evaluating the role of each barrier requires alternative methods

Barriers Evaluated in TSPA



- **Surficial soils and topography**
- **Unsaturated rock layers overlying the repository**
- **Drip shield**
- **Waste Package**
- **Spent fuel cladding**
- **Waste form / concentration limits**
- **Drift invert**
- **Unsaturated rock layers below repository**
- **Tuff and alluvial aquifers**

Barriers Evaluated in TSPA-SR

Key Attributes of System	Process Model Factor	Barrier	Barrier Function
Limiting Water Contacting Waste Package	Climate	Surficial soils and topography	Reduce the amount of water entering the unsaturated zone by surficial processes (e.g., precipitation lost to runoff, evaporation, and plant uptake
	Net Infiltration		
	Unsaturated Zone Flow	Unsaturated rock layers overlying the repository and host unit	Reduce the amount of water reaching the repository by subsurface processes (e.g., lateral diversion and flow around emplacement drifts)
	Coupled Effects on Unsaturated Zone Flow		
	Seepage into Emplacement Drifts		
	Coupled Effects on Seepage		
Prolonging Waste Package Lifetime	In-Drift Physical and Chemical Environments	N/A	These factors provide conditions that affect performance, but are not barriers per se in the TSPA-SR.
	In-Drift Moisture Distribution		
	Drip Shield Degradation and Performance	Drip shield around the waste packages	Prevent water contacting the waste package and waste form by diverting water flow around the waste package; therefore limiting advective transport through the invert
	Waste Package Degradation and Performance	Waste package	Prevent water from contacting the waste form

Barriers Evaluated in TSPA-SR

Key Attributes of System	Process Model Factor	Barrier	Barrier Function
Limiting Radionuclide Mobilization and Release from the Engineered Barrier System	Radionuclide Inventory	N/A	These factors provide conditions that affect performance, but are not barriers per se in the TSPA-SR.
	In-Package Environments		
	Cladding Degradation and Performance	Spent fuel cladding	Delay and/or limit liquid water contacting spent nuclear fuel after waste packages have degraded
	CSNF Degradation and Performance		
	DSNF Degradation and Performance		
	DHLW Degradation and Performance		
	Dissolved Radionuclide Concentrations	Waste form	Limit radionuclide release rates as a result of low solubilities or low diffusion through degraded engineered barriers
	Colloid-Associated Radionuclide Concentrations		
	In-Package Radionuclide Transport		
	EBS (Invert) Degradation and Performance	Drift Invert	

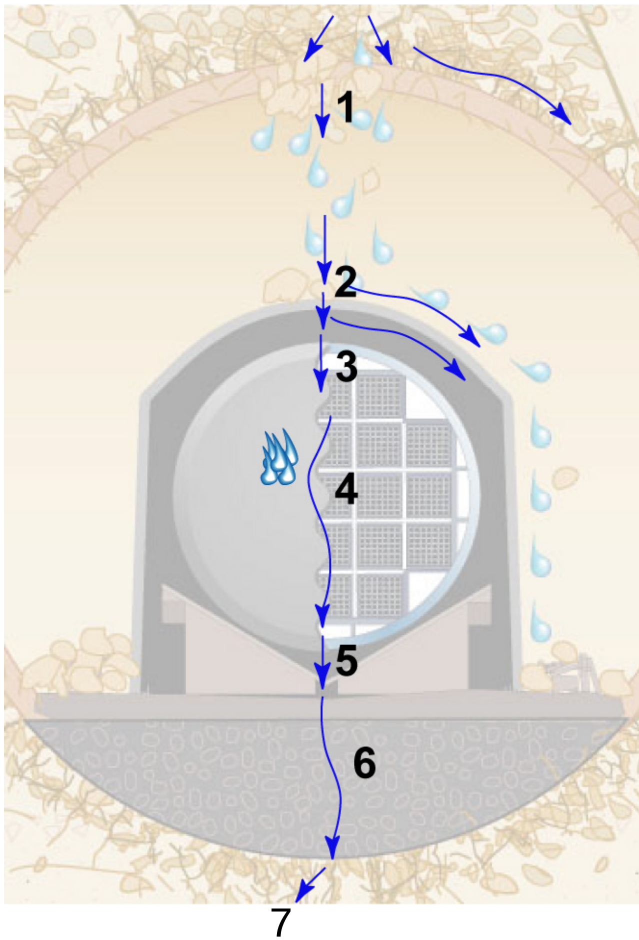
Barriers Evaluated in TSPA-SR

Key Attributes of System	Process Model Factor	Barrier	Barrier Function
Slow Transport Away from the Engineered Barrier System	Unsaturated Zone Radionuclide Transport (Advective Pathways; Retardation; Dispersion; Dilution)	Unsaturated rock layers below the repository	Delay radionuclide movement to the groundwater aquifer because of water residence time, matrix diffusion, and/or sorption
	Saturated Zone Radionuclide Transport	Tuff and alluvial aquifers (flow path extending from below the repository to point of compliance)	Delay radionuclide movement to the receptor location by water residence time, matrix diffusion, and/or sorption
	Wellhead Dilution	N/A	These factors provide conditions that affect performance but are not barriers per se.
	Biosphere Dose Conversion Factors		
Addressing Effects of Potentially Disruptive Processes and Events	Probability of Volcanic Eruption	N/A	These factors provide conditions that affect performance but are not barriers.
	Characteristics of Volcanic Eruption		
	Effects of Volcanic Eruption		
	Atmospheric Transport of Volcanic Eruption		
	Biosphere Dose Conversion for Volcanic Eruption		
	Probability of Igneous Intrusion		
	Characteristics of Igneous Intrusion		
	Effects of Igneous Intrusion		

Barrier Conceptual Models

- Barrier conceptual models (including key assumptions and conservatisms) affect the significance of the barrier to system performance
- Several key conceptual models have been presented in previous talks:
  - Waste package degradation models by Gerry Gordon
  - Unsaturated zone flow and transport conceptual models by Bo Bodvarsson
  - Saturated zone flow and transport conceptual models by Al Eddebbarh
- EBS thermal-hydrologic and transport conceptual models are presented in the following slides to assist in explaining these barriers contribution to system performance

Schematic of Conceptualizations for In-Drift Thermal-Hydrologic Processes - Dripping Environment



1 **Seepage into drift**
- function of percolation and fracture characteristics

2 **Flux through drip shield**
- function of drip shield failure fraction

3 **Flux into waste package**
- function of waste package failure fraction

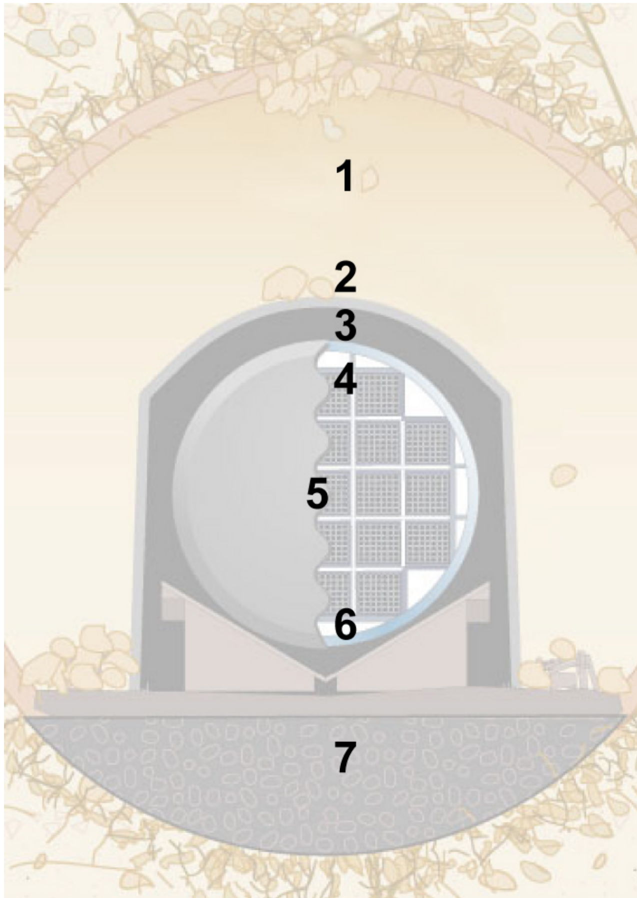
4 **Flux through waste package**
- *assumed to contact all exposed waste*

5 **Flux out of waste package**
- assume flux in = flux out (no "bathtub" effect)

6 **Flux through invert**
- assume flux in = flux out

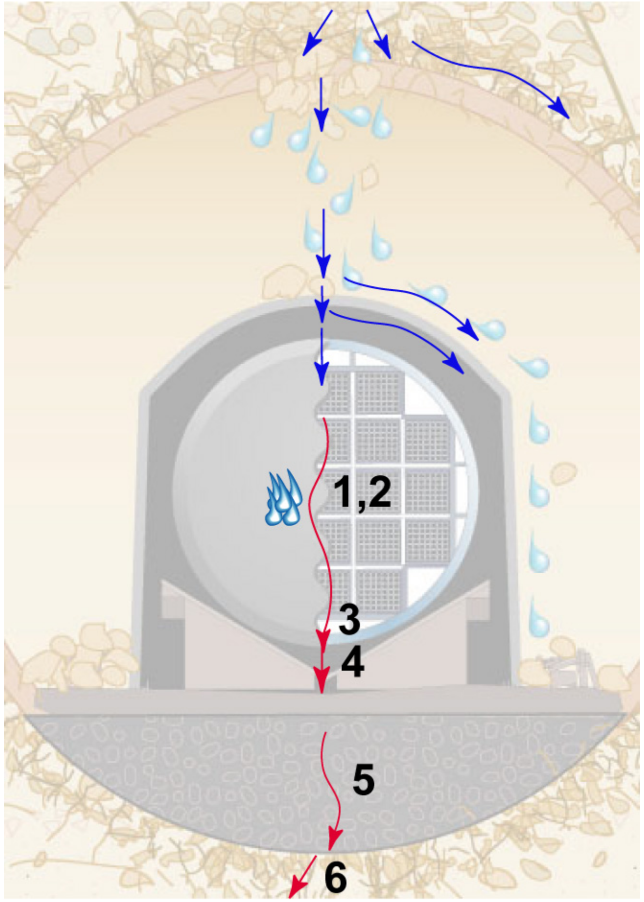
7 **Flux into rock**
- assume flux into fractures

Schematic of Conceptualizations for In-Drift Thermal-Hydrologic Processes - Non-dripping Environment



1. **Humidity in drift**
   - function of design and rock characteristics
2. **Salt/dust on drip shield and waste package surface affect critical RH for corrosion initiation**
3. **Moisture on waste package controlled by humidity under drip shield**
4. **Humidity inside and outside waste package equilibrate after waste package fails**
5. **Water film assumed to develop on exposed waste form**
6. ***<u>Cracks through failed waste packages assumed to be water saturated</u>***
7. **Water content in invert**
   - function of design and rock/invert characteristics

Schematic of Conceptualizations for In-Drift Chemical and Transport Processes - Dripping Environment



1 **Flux contacts all exposed waste**

2 **Exposed waste alters**
- radionuclide concentration in liquid phase limited by solubility
- radionuclides are released to liquid or colloid phase

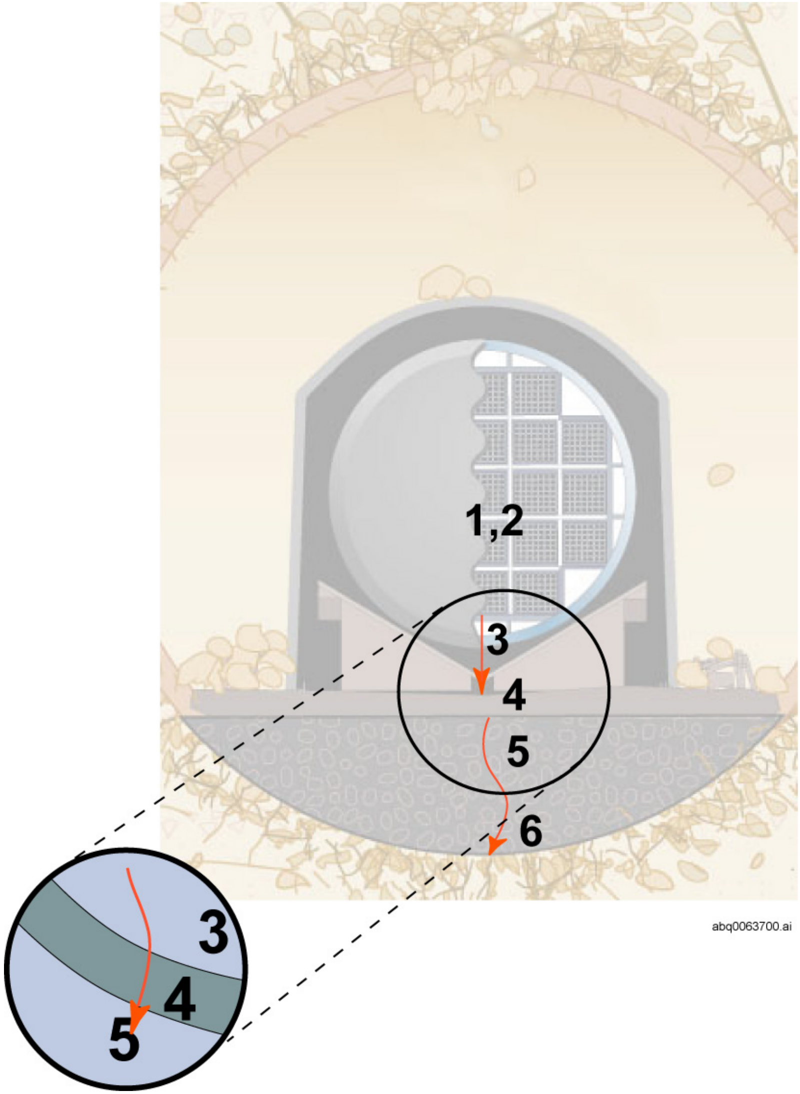
3 **Advective transport from waste package**
- function of flux and concentration (or alteration rate if very high solubility)

4 **Advective transport starts as soon as waste package is breached**
- *assume second breach is at bottom of waste package*

5 **Advective transport through invert**
- function of flux and concentration (solubility) in invert

6 **Advective transport from EBS enters fractures in rock**

Schematic of Conceptualizations for In-Drift Chemical and Transport Processes - Non-dripping Environment



1. **Exposed waste form alters in humid air**
2. **Radionuclide concentrations in water film on altered waste form limited by solubility**
3. **Dissolved radionuclides diffuse through water film**
   - *assume waste form is at base of waste package, i.e., no diffusion time to inner waste package barrier*
4. **Diffusive transport through degraded waste package**
   - *assume opening is in contact with invert*
   - diffusive transport a function of concentration/gradient, breach size, and diffusion characteristics
5. **Diffusive transport through invert function of water content**
6. ***Diffusive flux through invert assumed to enter fractures of host rock***

Waste Package Breach Scenarios Considered - Key Assumptions

- Nominal (base case) scenario class
  - uses nominal models, analyses and parameters (and associated uncertainty) to develop “expected” waste package failure rate and amount
  - rate and amount of waste package and drip shield failure vary with time and from realization to realization due to uncertainty
  - 1% probability of first waste package breach at about 11,000 years
- Early waste package breach scenario
  - assumes a breached waste package at emplacement
  - assumes one breach of one waste package (300 cm^2)
  - waste package randomly located in dripping or non-dripping environments
  - drip shield assumes nominal performance

Waste Package Breach Scenarios Considered - Key Assumptions

(Continued)

- **Neutralized waste package breach scenario**
  - assumes all (~12,000) waste packages are breached at emplacement
  - assumes the breached area remains constant
  - assumes one breach of each waste packages (300 cm^2)
  - drip shield assumes nominal performance
- **Degraded waste package barrier analysis**
  - fixes several key waste package degradation parameters at the near maximum (5th or 95th percentile) of their expected range within the nominal scenario
  - rate and amount of waste package degradation vary with time, but at a higher rate than nominal scenario class

Waste Package Breach Scenarios Considered - Key Assumptions

(Continued)

- **Igneous intrusion waste package breach scenario**
  - **assumes mean initiation probability of 1.6 x 10^{-8} $year^{-1}$**
  - **assumes ~ 200 packages are completely neutralized (~400 breaches each ~300 cm^2)**
  - **assumes ~ 200 dripshields and cladding also completely neutralized**
  - **assumes solubility controlled by in-rock chemistry**

NOTE: All other components of the TSPA are treated assuming the nominal performance scenario models and parameters (with their quantified uncertainty)

NOTE: Results presented illustrate quantified uncertainty in performance and statistical measures of that performance (i.e., mean, median, and 5th and 95th percentile)

Different Approaches to Quantifying Barrier Contributions

- **Subsystem performance for nominal scenario class**
  - key radionuclides
  - fluxes across different barriers
  - different release modes from EBS
    - diffusion
    - advection
- **Subsystem performance for early waste package failure scenario**
  - key radionuclides
  - fluxes across different barriers
  - different release modes from EBS
- **Degraded and neutralized waste package scenarios**

NOTE: Other degraded/enhanced barrier importance analyses are presented in TSPA-SR Rev 0, ICN 01. Other neutralized barrier importance analyses are presented in RSS Rev 4, ICN 01.

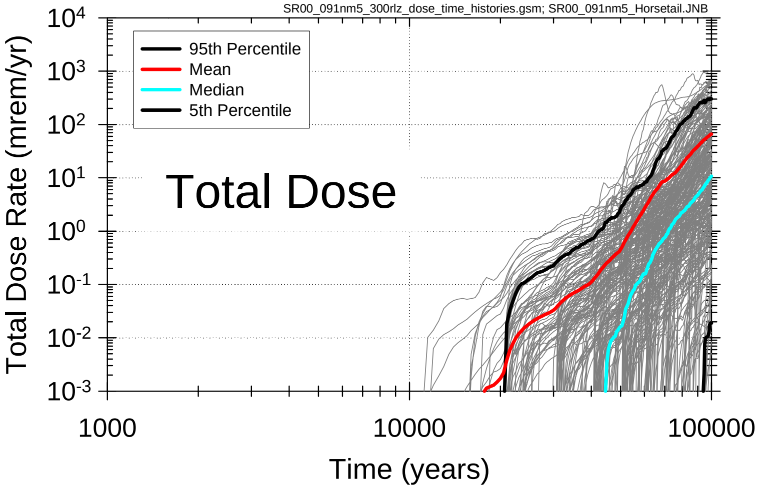
Subsystem Performance Results Used to Clarify Role of Different Barriers

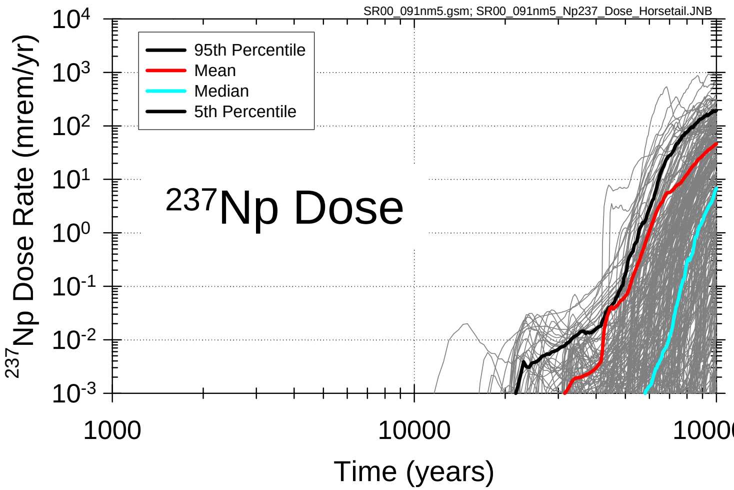
- **Individual radionuclide dose rates (mrem/yr)**
  - **high solubility radionuclides (^{99}Tc)**
  - **low solubility radionuclides (^{237}Np)**
- **Waste package and drip shield degradation**
- **Individual radionuclide release rates**
  - **across EBS (base of invert)**
  - **across base of Unsaturated Zone**
  - **across 20 km boundary of Saturated Zone**
- **Advective vs. diffusive release rates from EBS**

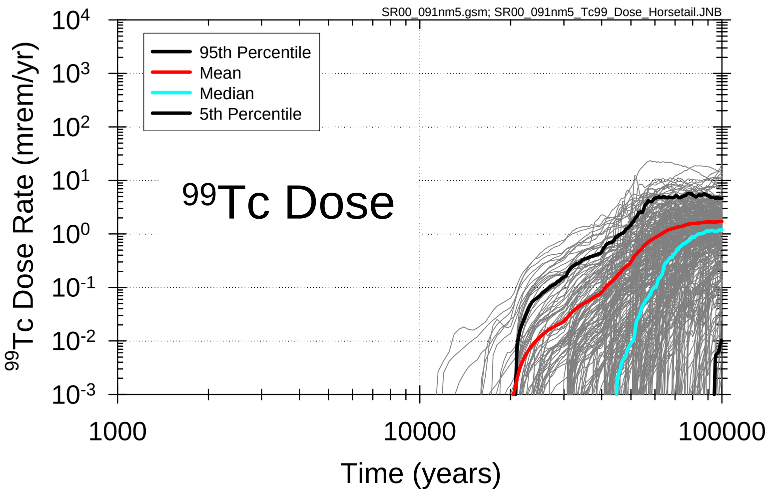
NOTE: Release rates are in mass release rates (gm/yr)

Nominal Performance Scenario Class
Total Dose Rate and Key Radionuclides

- **Total dose rate during the first 100,000 years is controlled primarily by ^{99}Tc, ^{237}Np, and ^{239}Pu**
- **Doses to ~40,000 years dominated by ^{99}Tc diffusive release through SCC cracks in the lid welds**
- **Doses of time greater than 40,000 years dominated by ^{237}Np diffusive and advective releases, with a small contribution from ^{239}Pu**

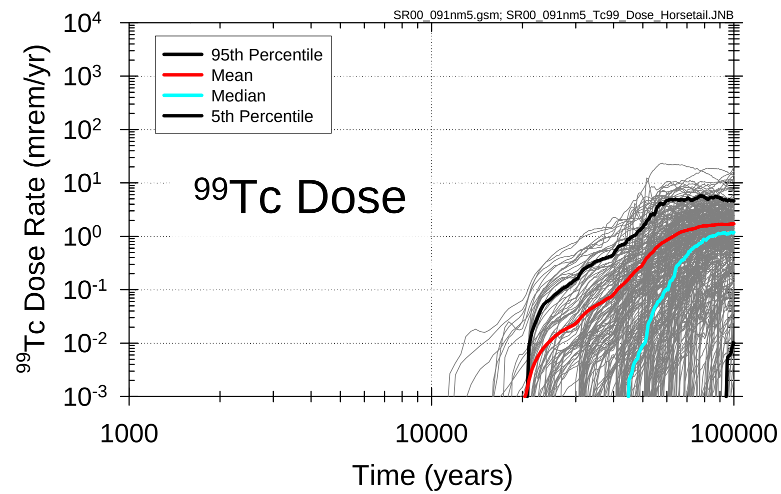


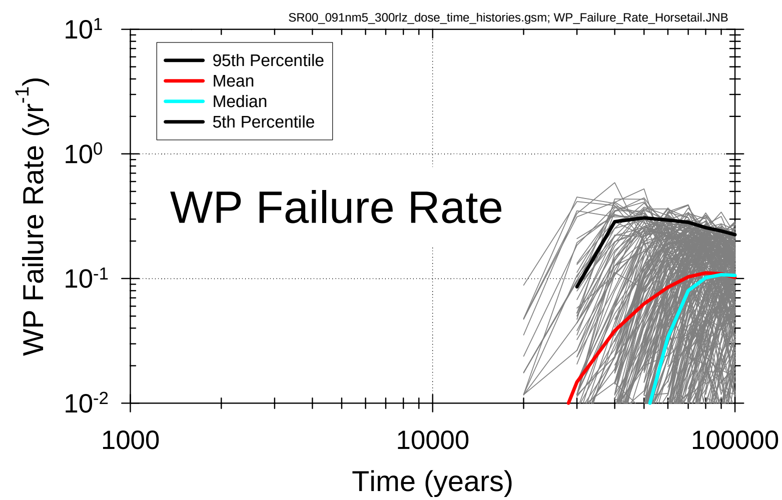




Nominal Performance Scenario Class
Waste Package Failure Rate versus ^{99}Tc Dose Rate

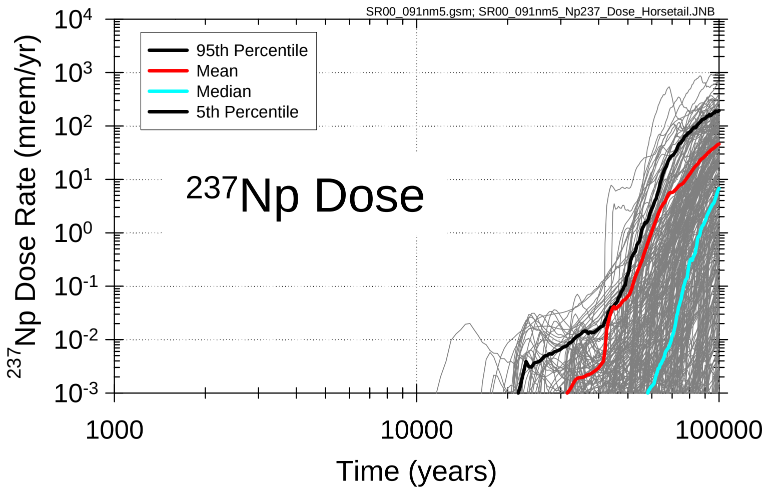
- **^{99}Tc dose rate mirrors the mean waste package failure rate**
  - **NOTE: when the waste package failure rate becomes constant (~ 70,000 years) the ^{99}Tc release (and dose) rate becomes constant also**
- **This applies to high solubility radionuclides which are assumed to diffuse through thin films**
- **This was also noted in TSPA-VA**

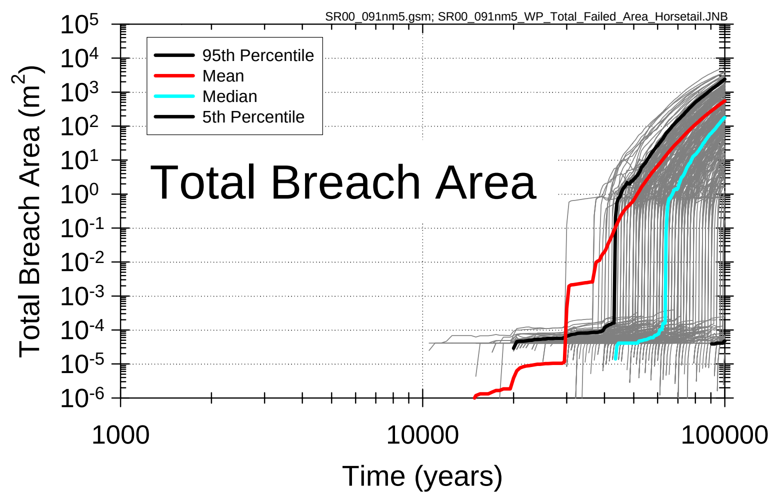




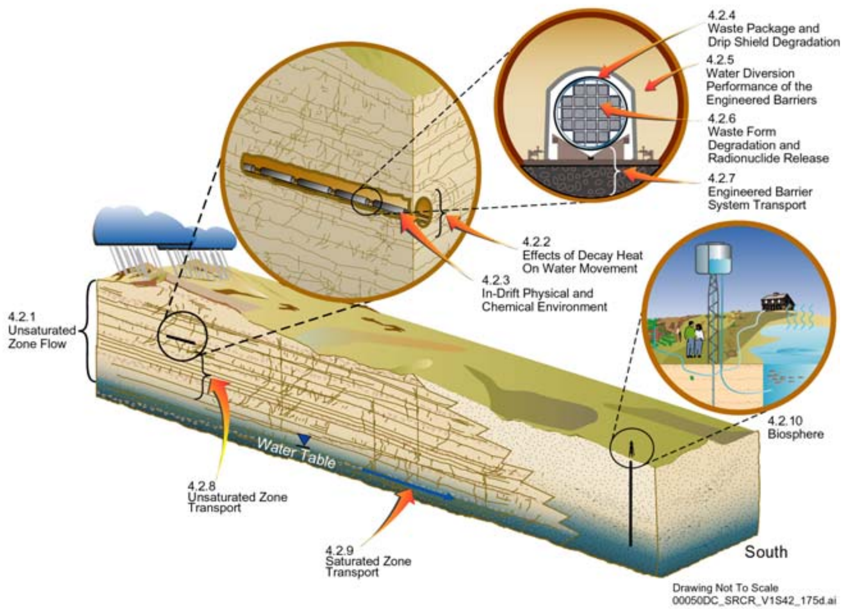
Nominal Performance Scenario Class
Cumulative WP Opening Area versus ^{237}Np Dose Rate

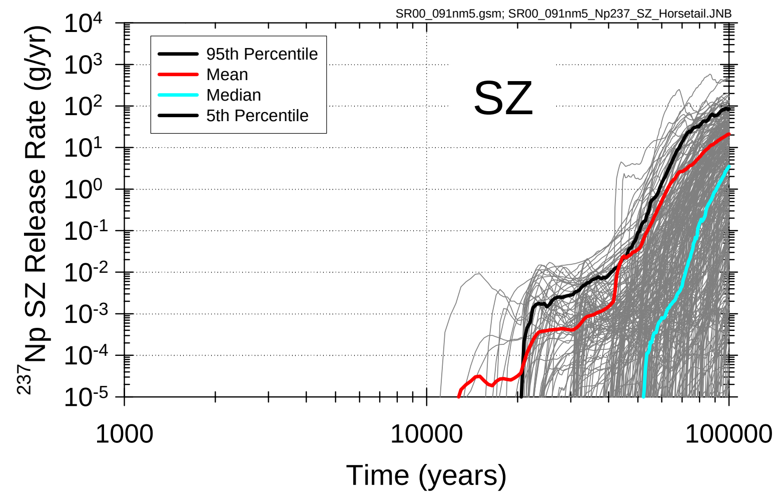
- **Doses (and releases) of solubility-limited radionuclides, such as ^{237}Np, mirror the cumulative waste package breach area (over all packages)**
- **Advective and diffusive releases from the waste package are both linearly proportional to the breach opening area for solubility limited radionuclide**
- **Small breach areas correspond to small crack penetrations (primarily stress corrosion cracks)**
- **Larger breach areas correspond to “patch” failures caused by general corrosion (times > 40,000 years)**
- **^{237}Np and ^{99}Tc behave differently, primarily because of their different solubilities**

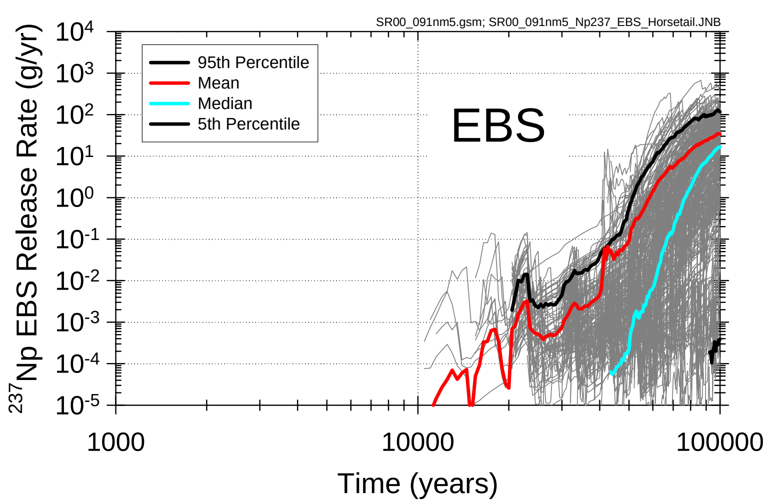


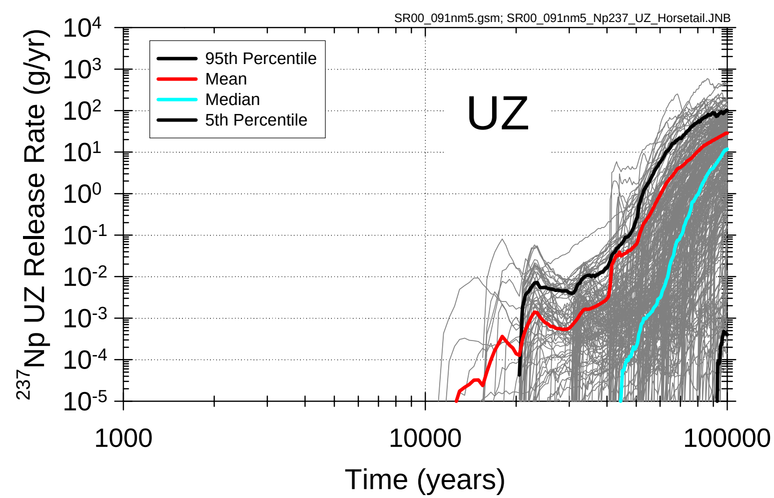


Nominal Performance Scenario Class
^{237}Np Release Rate From Various Barriers



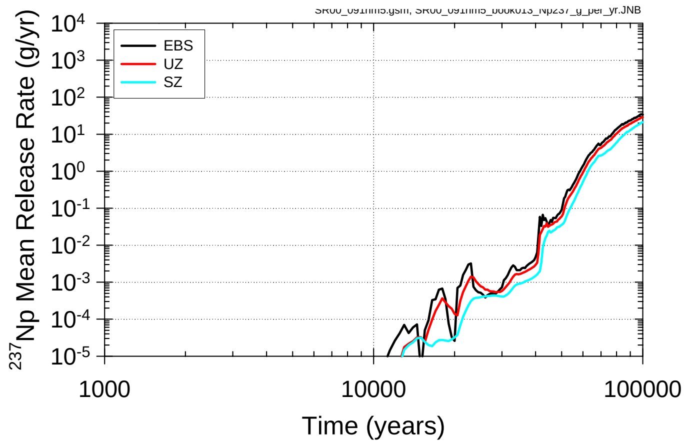




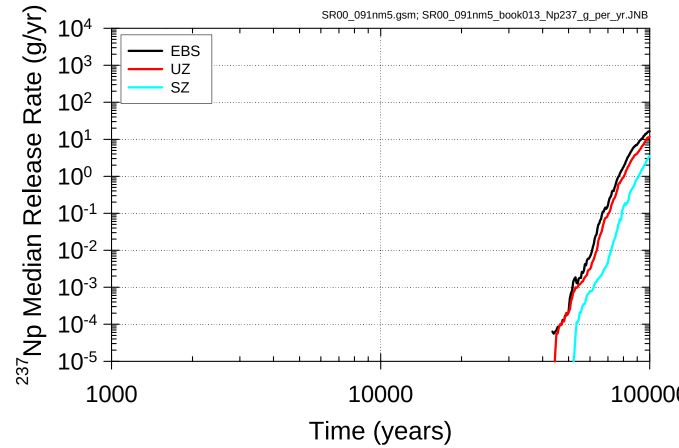


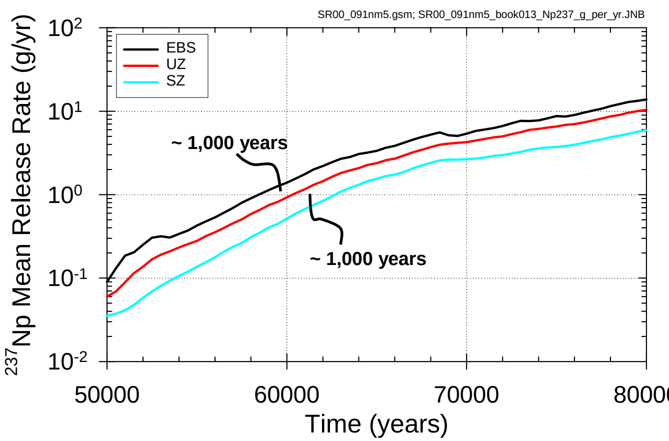
Nominal Performance Scenario Class Comparison of ^{237}Np Release Rate From Various Barriers

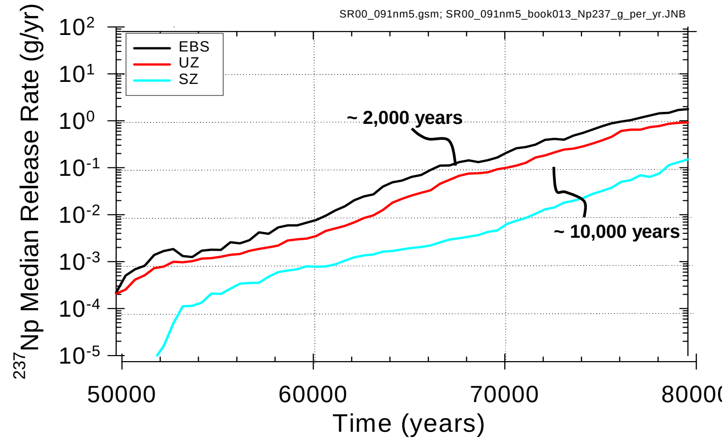
^{237}Np Mean Release Rate



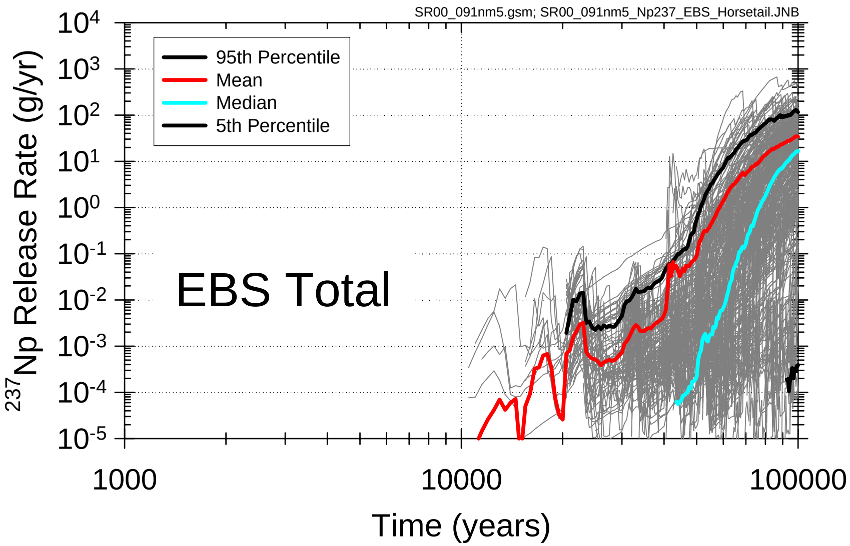
^{237}Np Median Release Rate

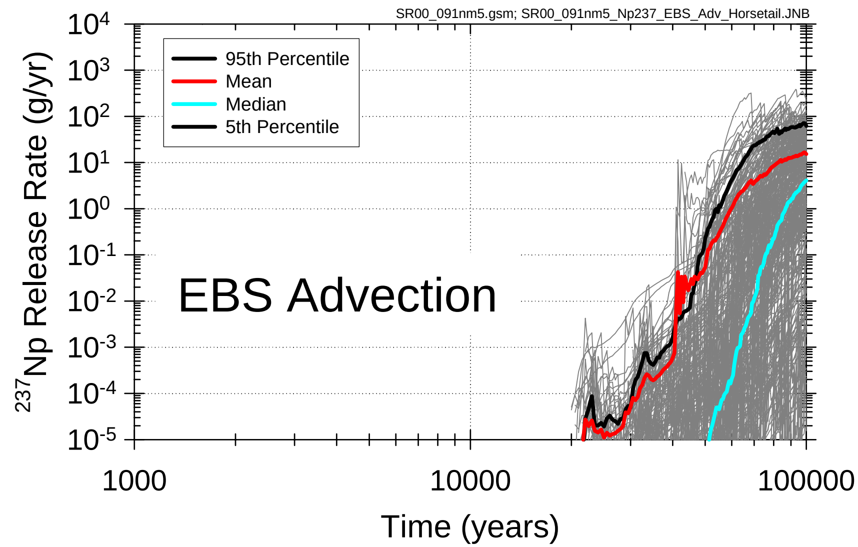


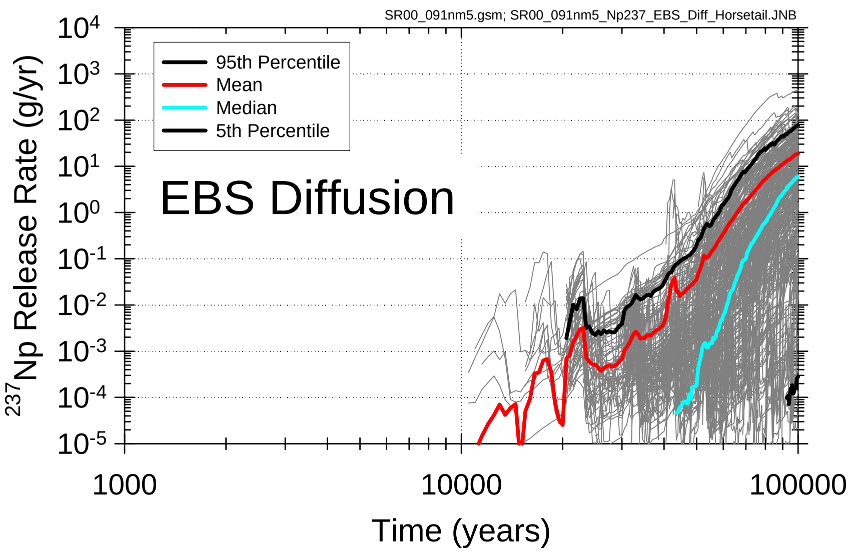




^{237}Np EBS Release Rates - Advection vs Diffusion



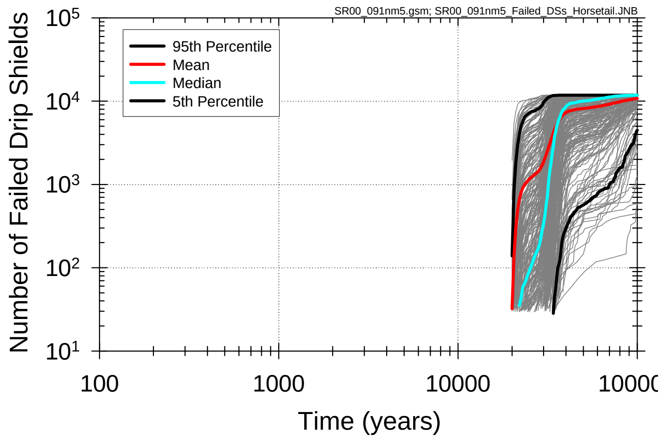




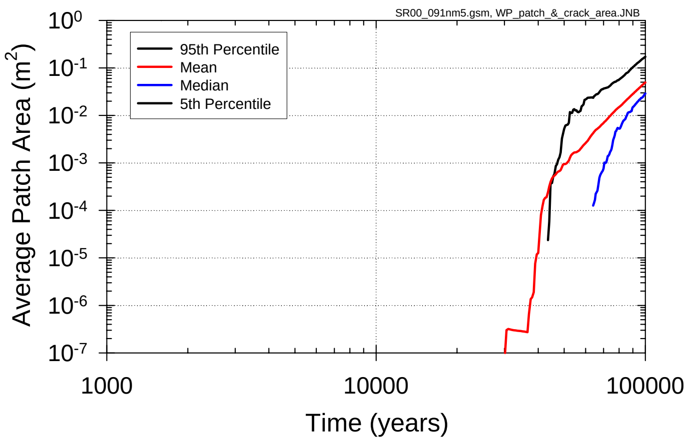
- **EBS diffusive releases dominate to ~ 40,000 years**
  - **< 40,000 years "patch" area is very small and drip shields are intact (see following slide)**
- **EBS advection ~ EBS diffusion after 40,000 years**
  - **15% of WPs have advection**

Nominal Performance Scenario Results Waste Package and Drip Shield Failures

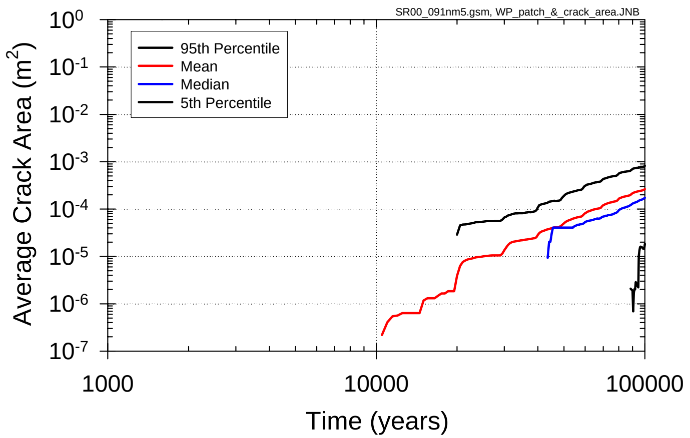
Drip Shield Failures



Average Patch Area



Average Crack Area



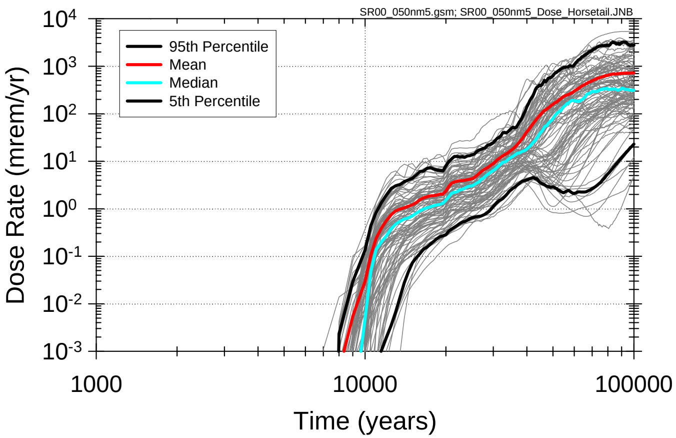
- **Most drip shields fail by 30,000 - 40,000 years**
- **“Patch” area dominates crack area at ~40,000 years**

Summary of Nominal Performance Scenario Results

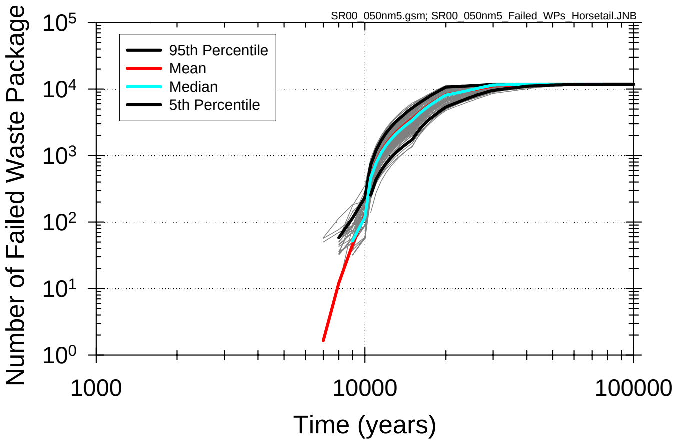
- **Waste package failure dominates time of occurrence of EBS release**
- **Waste package failure uncertainty and variability dominates spread of dose rates**
- **EBS releases are dominated by diffusion until “patches” form on the waste package (due to general corrosion) and drip shields fail**
- **Delay of transport in UZ and SZ is several thousand years**

Degraded Waste Package Scenario Results

Total Dose Rate



WP Failure Rate



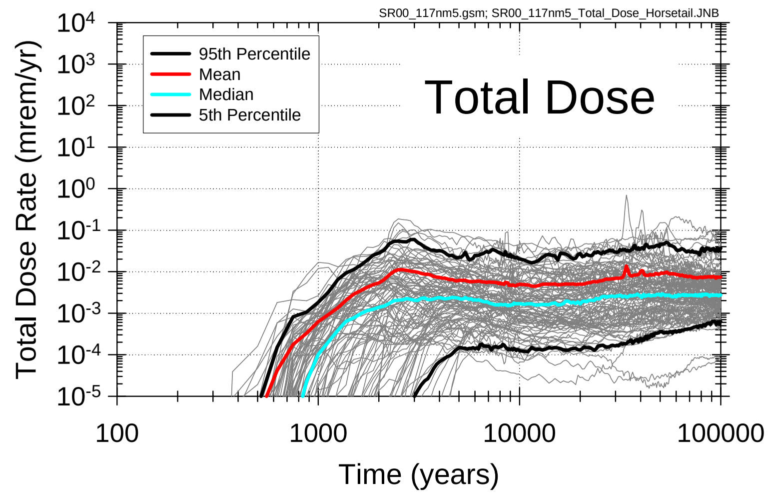
- **Degraded scenario assumed several waste package degradation model parameters simultaneously set at near maximum (95% percentile)**
  - **this sequence of events has a very low probability (<<10^{-4}) of occurring**
- **Initial failures occur before 10,000 years**
- **Uncertainty in waste package failure rate (and dose rates) reduced**

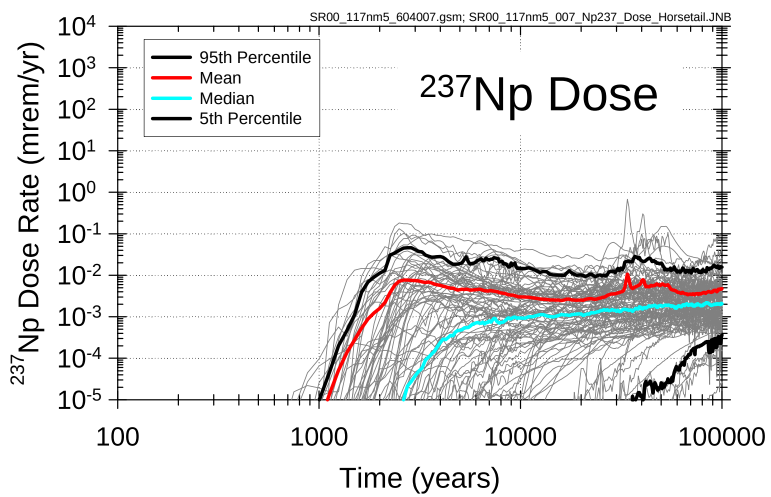
Early Waste Package Failure Scenario

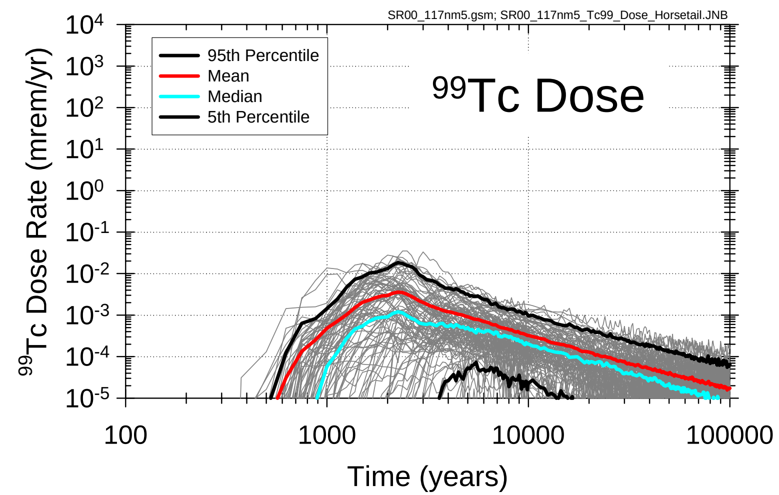
- Single CSNF waste package failure
- Impose 300 cm^2 breach 100 years after emplacement
- Assume package randomly located
  - ~15% in dripping environment
  - ~85% in non dripping environment
- Drip shield performs as in nominal case

Early Waste Package Failure Scenario Dose Rate

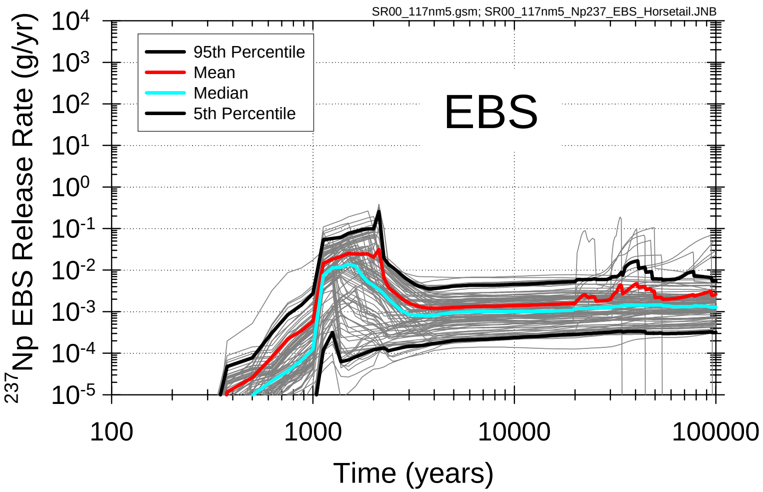
- **Total dose rate during the first 100,000 years is controlled primarily by ^{99}Tc, ^{237}Np, and ^{239}Pu**
- **^{99}Tc is less important for the early waste package failure scenario because the relatively large area of a juvenile patch failure (300 cm^2 at 100 years) releases the ^{99}Tc inventory very rapidly**

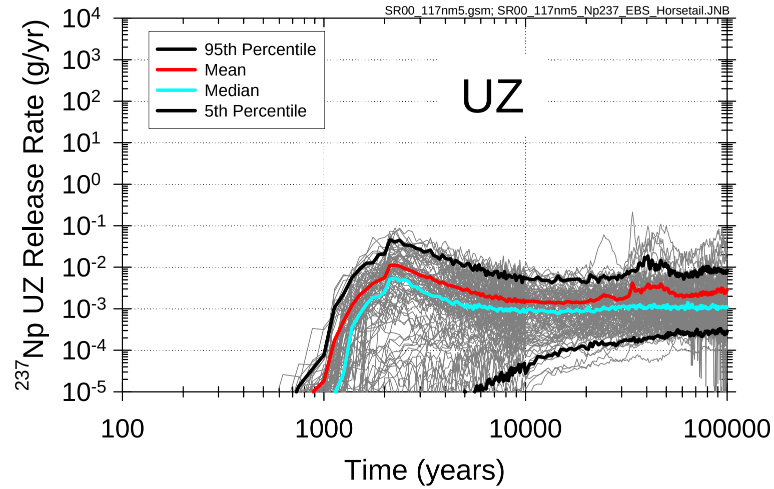


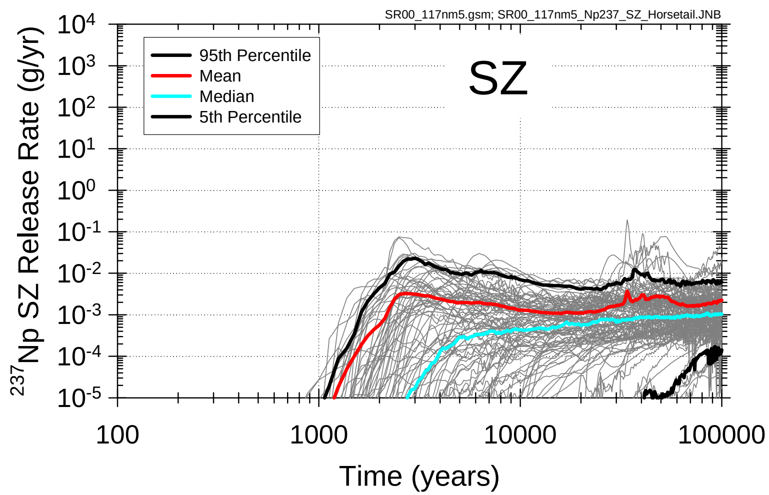




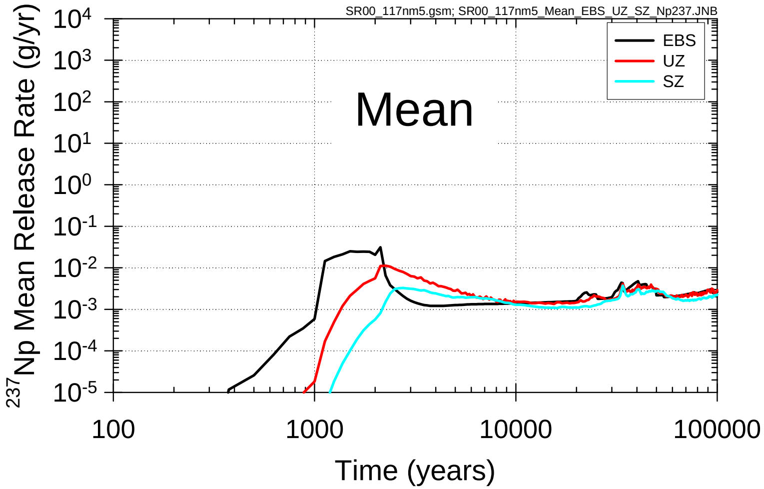
Early Waste Package Failure Scenario
^{237}Np Release Rate From Various Barriers

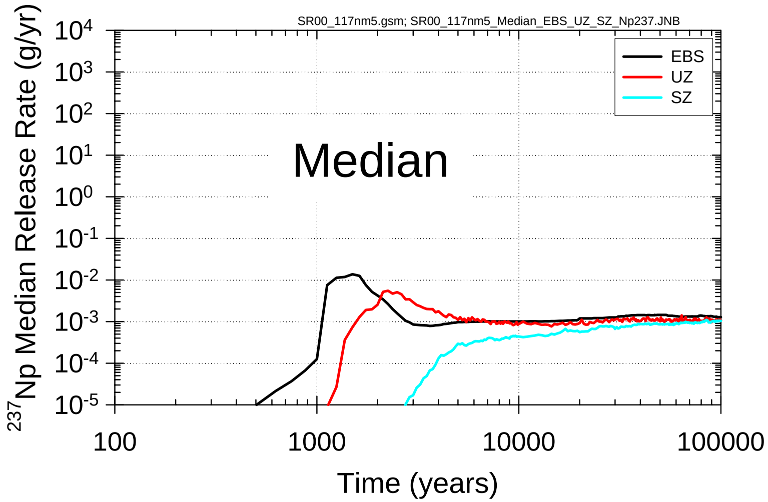






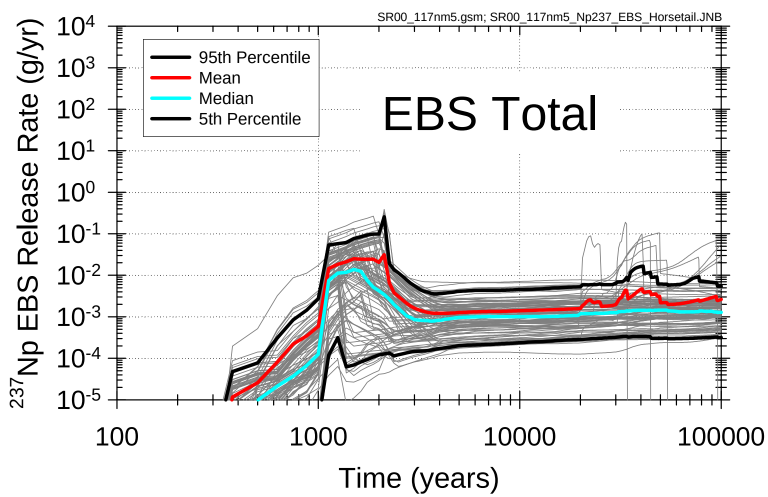
Early Waste Package Failure Scenario Comparison of ^{237}Np Release Rate for Various Barriers

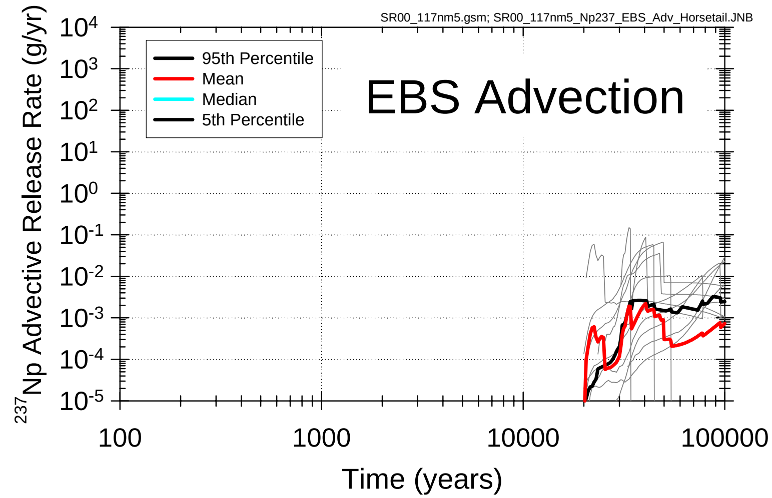


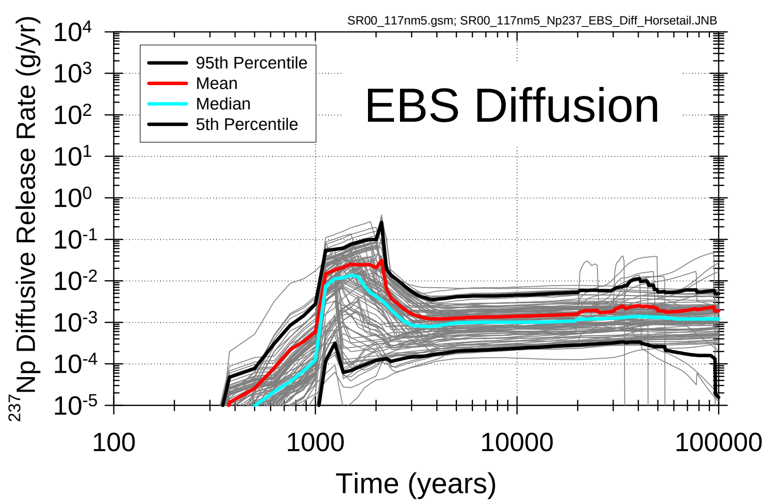


- **Delay in mean (and median) breakthrough time across UZ ~ 1,000 years**
- **Delay in mean breakthrough time across SZ to 20 km ~ 1,000 years**
  - **median breakthrough time (~5,000 yrs) difficult to discern due to dispersive effects in SZ**

Early Waste Package Failure Scenario
^{237}Np Advective vs. Diffusive EBS Release Rate







- **EBS diffusion dominates until drip shield failure at ~ 30,000 years**
- **Initial peak caused by high solubility (low pH) pulse inside the package during basket degradation**

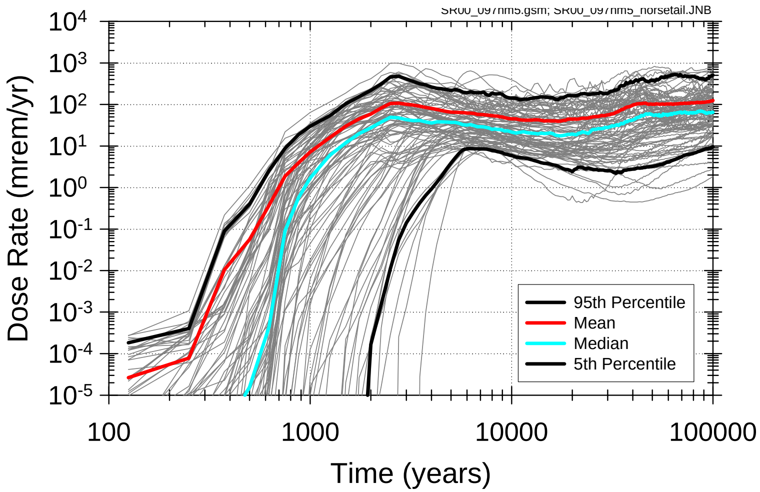
Summary of Early Waste Package Failure Scenario Results

- A single waste package failure results in ~ 0.01 mrem/yr, based on conservative assumptions of in-package and EBS transport
- Subsystem results show significance of drip shield performance and limited seepage (i.e., limited advective release)
- Results corroborate observations about subsystem performance in the nominal scenario
- Several unquantified uncertainties need to be addressed

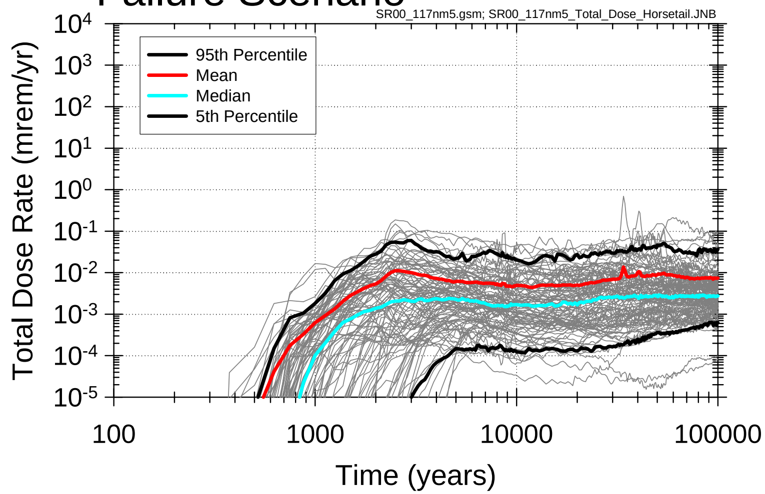
Neutralized Waste-Package Scenario Results

- **Assumes all waste packages are breached at emplacement**
- **One breach of <u>all</u> waste packages (300 cm²) occurs at emplacement**
- **Drip shield and all other barriers perform as in the nominal scenario**
- **Dose response is approximately equal to 11,770 (i.e., the total number of emplaced packages) times the CSNF early waste package failure scenario dose response**

WP Neutralization Scenario

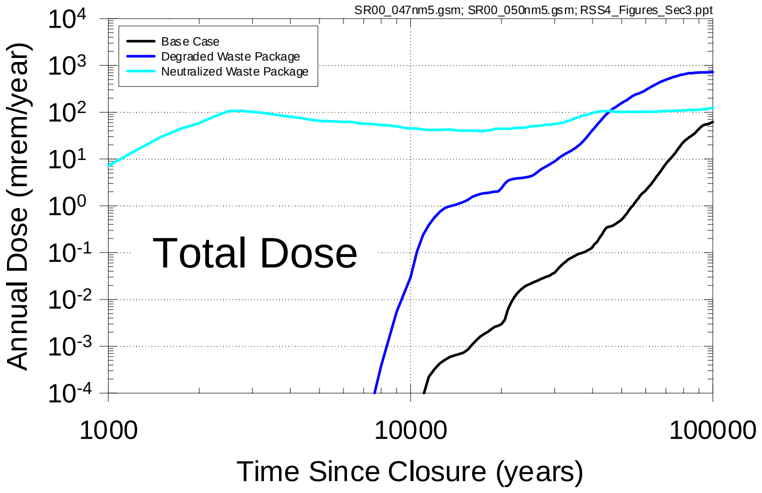


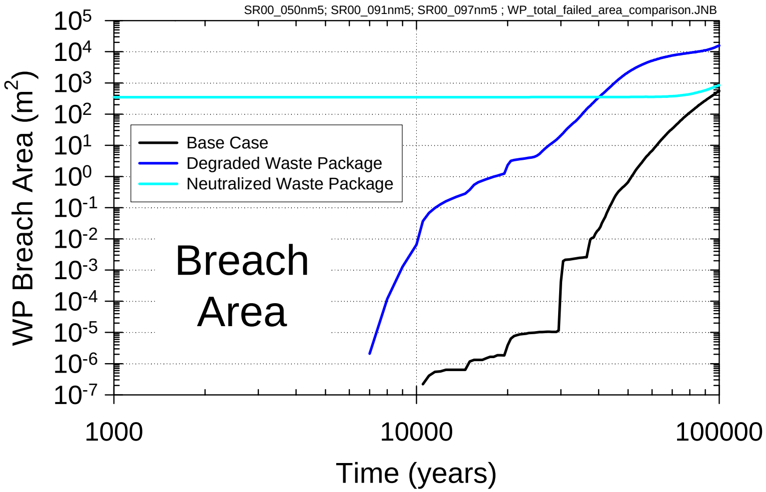
CSNF Early Waste Package Failure Scenario



Comparison of Nominal, Degraded, and Neutralized Waste Package Scenarios

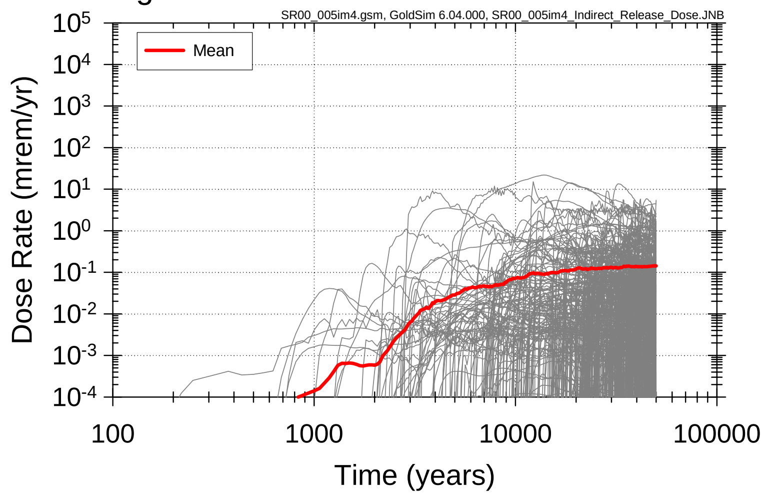
- **The cumulative waste package breach area is linearly proportional to the release rate and dose rate for solubility-limited radionuclides**
- **The cumulative breach area increases with time for the degraded and nominal ("base") cases, while it is fixed for the neutralized case**



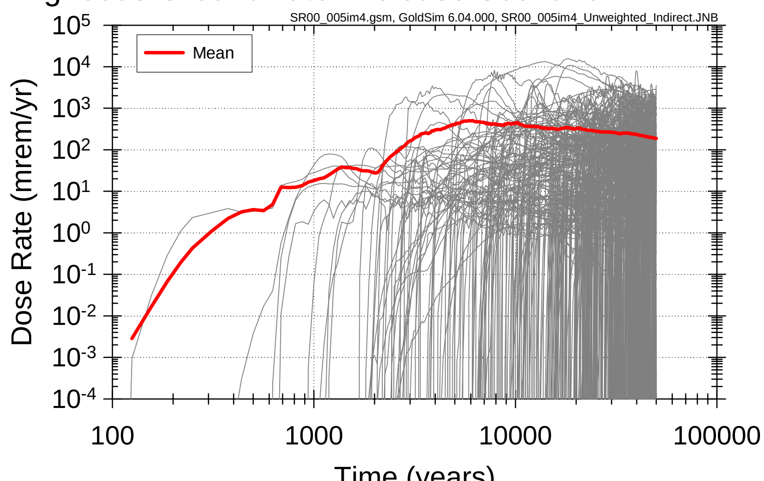


Igneous Intrusion Waste Package Breach Scenario

Probability-Weighted Dose for
Igneous Groundwater Release Scenario

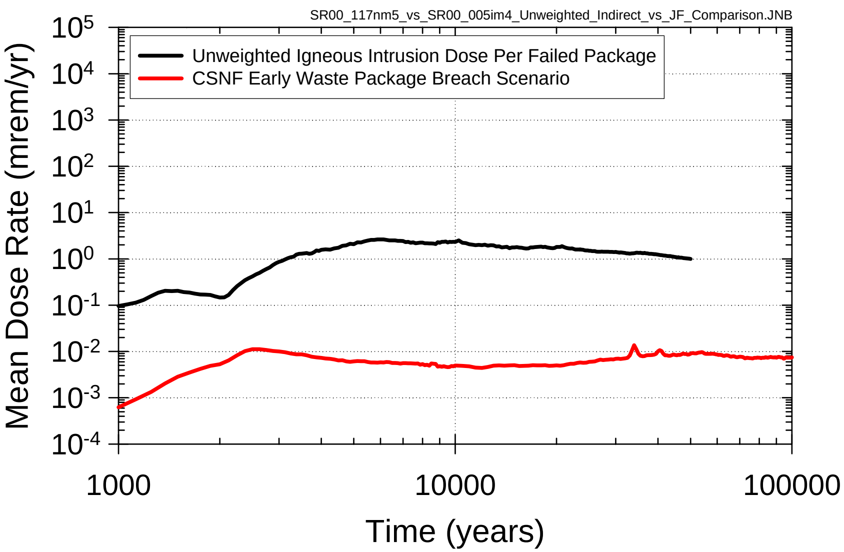


Unweighted Dose for
Igneous Groundwater Release Scenario



- **Probability - weighted doses include probability of occurrence**
  - **~1.6 x 10^{-8} yr^{-1}**
  - **~8 x 10^{-4} over 50,000 year simulation**
- **Unweighted doses remove the probability**
  - **i.e., assume event occurs within 50,000 year simulation**
- **Unweighted dose peaks at ~500 mrem/yr**
- **~200 waste packages completely neutralized**

Igneous Intrusion Waste Package Breach Scenario - Comparison to Early Waste Package Breach Scenario



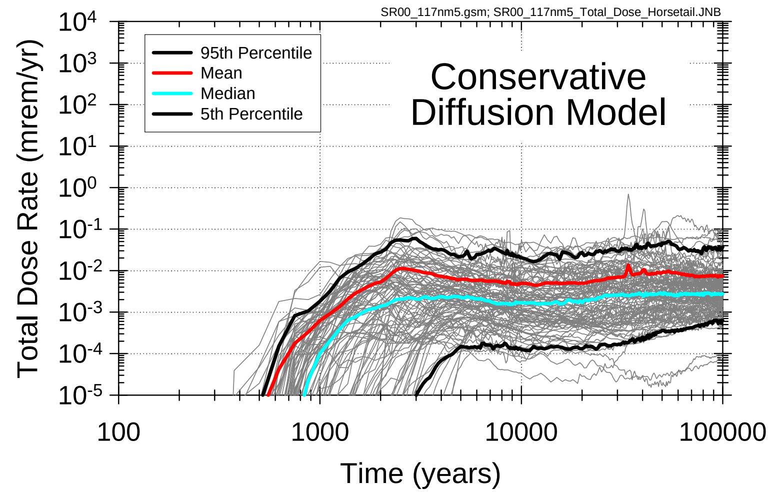
- **Unweighted igneous intrusion doses normalized to one package by dividing total dose rate by ~200**
- **Normalized igneous intrusion peak dose rate (~3 mrem/yr) is ~300 x the peak from early waste package breach scenarios because:**
  - **area exposed is greater**
  - **drip shield is removed**
- **Conclusion: Differences in "completely neutralized" and early waste package breach explainable primarily by breach area difference**

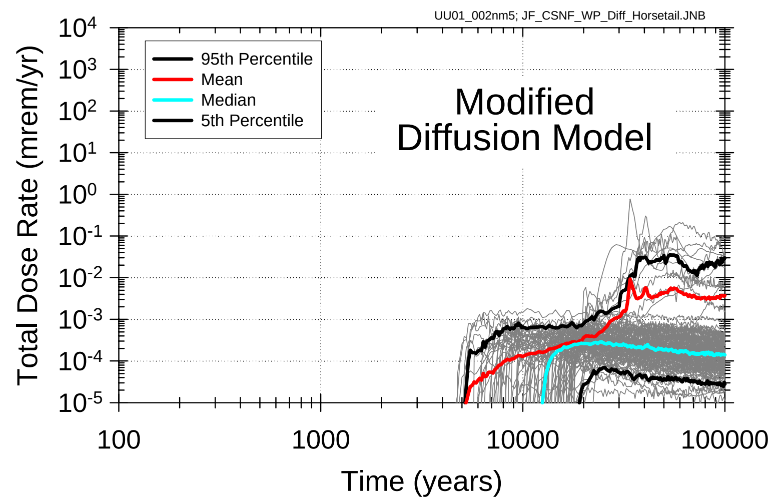
Unquantified Uncertainties

- Results and conclusions are predicated on considered models and their uncertainty
- Unquantified uncertainty exists in:
  - Diffusive release mechanism from waste package
  - Diffusive release across invert
  - Diffusive release from invert to fractured rock
  - Solubility of key radionuclides
- Ongoing efforts are evaluating the potential significance of these unquantified uncertainties (an example follows for the diffusive release from the waste package)

Comparison of Early Waste Package Failure Scenario with Preliminary Unquantified Uncertainties - In-Package and Ex-Package Diffusion Model

- **Use a more realistic conceptual model for diffusive transport along the pathway from the waste package interior, out through the SCC cracks, along the waste package surface, down the pedestal, and to the invert**
- **Relative humidity and temperature used to determine the in-package and ex-package diffusion coefficient, based on water film adsorption**
- **Corrosion product assumed to be Fe_2O_3 (adsorption isotherm for Fe_2O_3 used)**
- **Probability distribution used for the waste form basket lifetime (uniform distribution from 4,300 to 18,000 years)**





Summary and Conclusions

- Detailed explanation of results provided insights to barrier importance
  - insights are enhanced by conducting multiple analyses
- Interpretations require consideration of assumptions
- Additional insights possible for barrier importance and neutralization analyses
- On-going work to address unquantified uncertainties should provide additional perspectives

Backup Slides

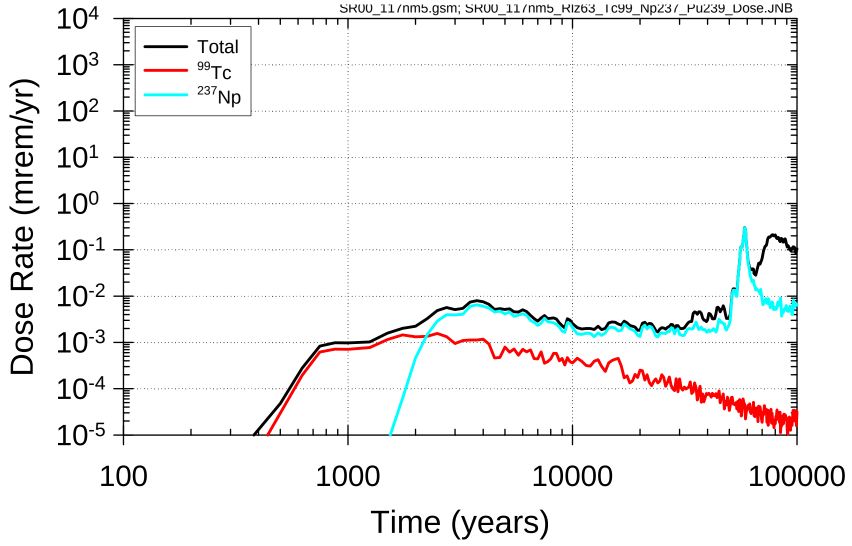
Early Waste Package Failure Scenario Realization 63 Dose Rate of Various Radionuclides

- **Direct causal relationship between mean histories, e.g., between mean dose rate and mean EBS release rate, is not rigorous**

- **Need to look at individual realizations to more rigorously trace cause-effect relationships**

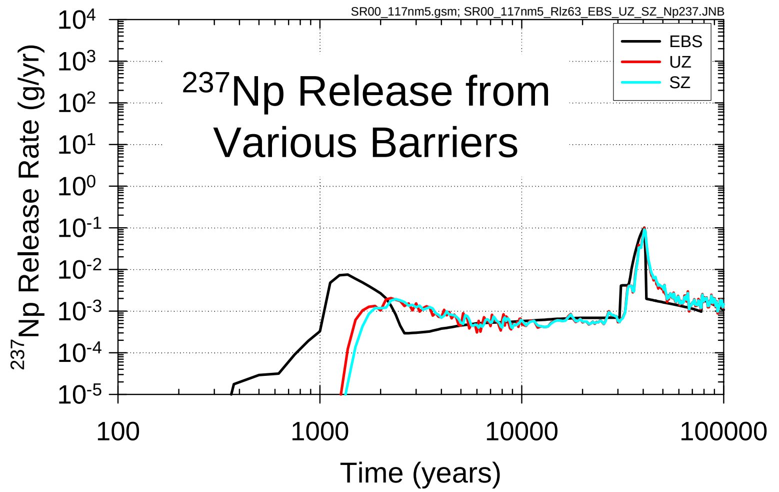
- **Use realization 63 (always drip) to examine relative contribution of advection/diffusion and the effect of in-drift chemistry on releases**

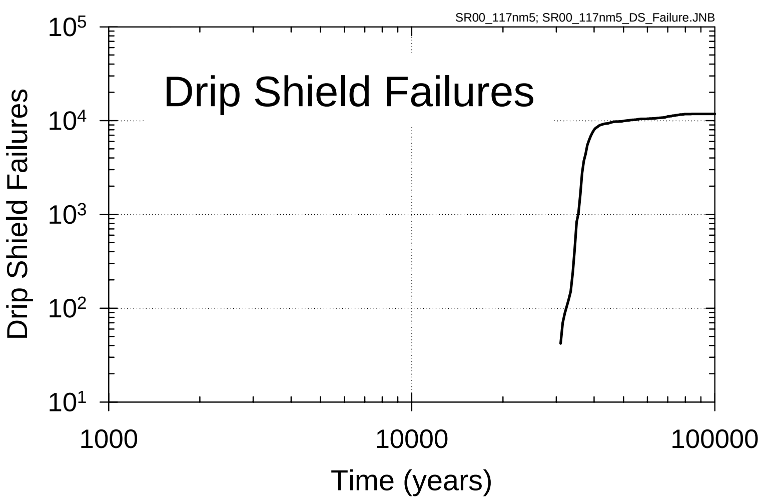
Dose Rate for Realization 63

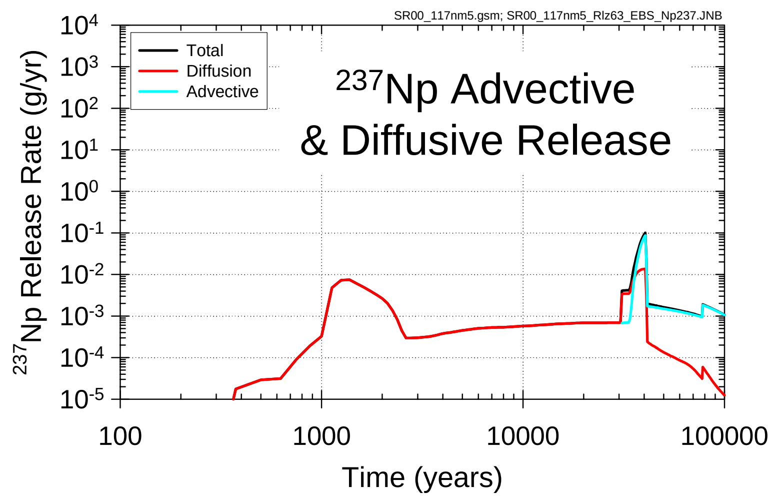


Early Waste Package Failure Scenario Realization 63
^{237}Np Release Rate from Various Barriers

- **Indicates delay in the natural system**
- **Shows ^{237}Np advective release when the drip shields begin to fail at about 30,000 years**

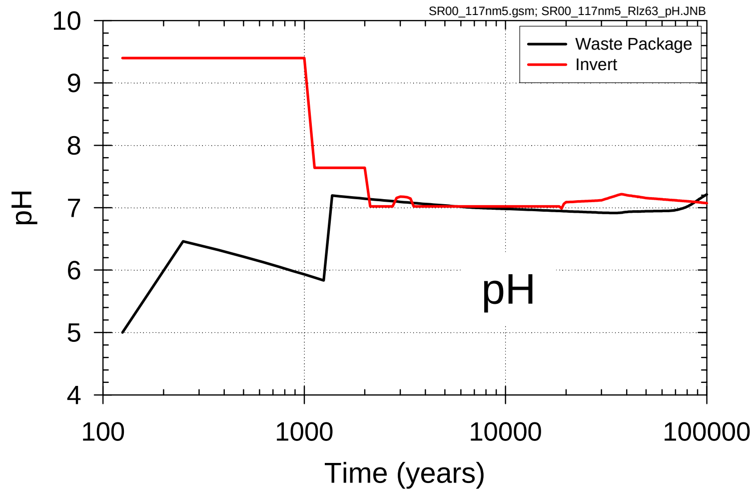


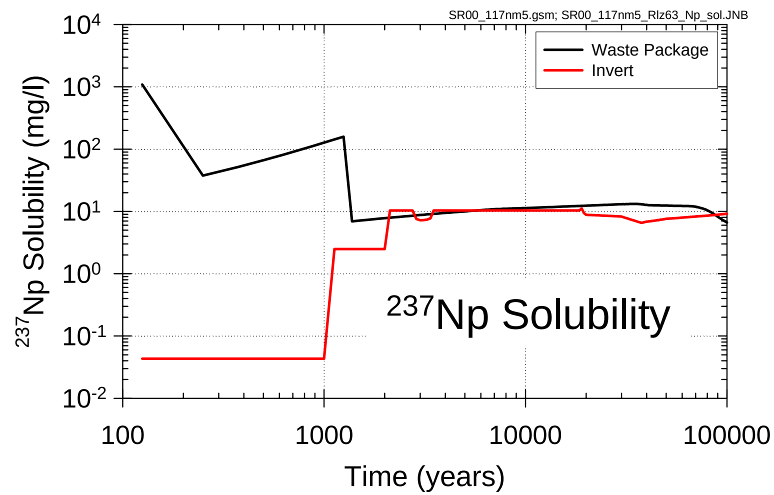




Early Waste Package Failure Scenario <u>Realization 63</u> Effect of EBS Chemical Environment

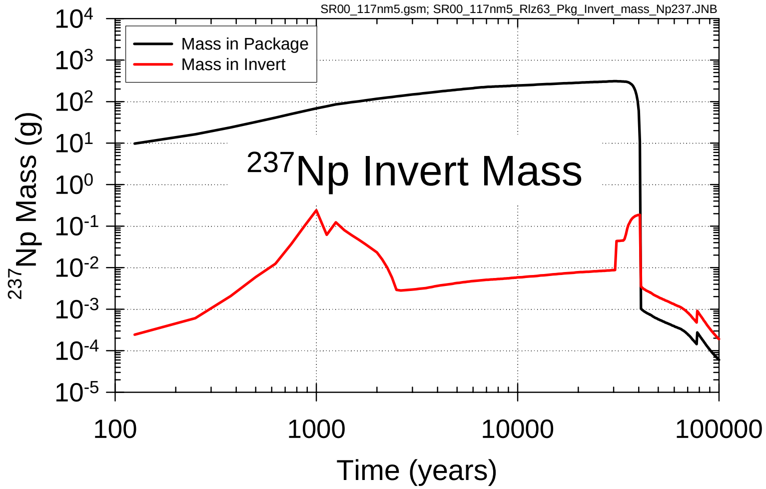
- **In-package pH and invert pH have opposite trends over early times; similarly for in-package Np solubility and in-drift Np solubility**
- **Low in-package pH during the first 1000 years causes high in-package Np solubility during this time**
- **High in-package Np solubility during the first 1000 years causes a large release of Np to the invert where it precipitates because of low in-drift Np solubility**

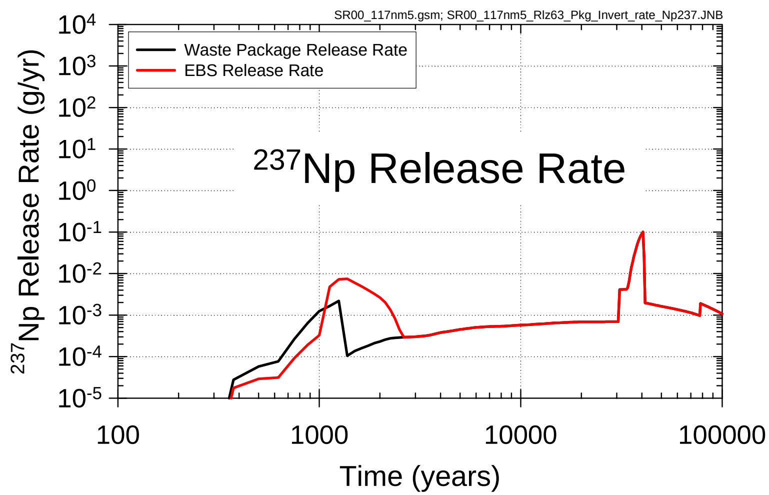




Early Waste Package Failure Scenario Realization 63 Effect of EBS Chemical Environment

- **Initially high Np release rate from the EBS decreases when the precipitated mass of Np in the invert is depleted at about 2500 years**
- **Afterwards the invert pH and in-package pH remain approximately equal and the waste-package and EBS release rates reach a steady state with equal release rates**





Summary of Key Thermal Hydrologic Assumptions Affecting EBS Release Rates

Component		Current Treatment	Key Unquantified Uncertainty	Addressing Significance
Thermal-Hydrologic Environment	▪ Above drip shield	▪ Thermally - perturbed seepage	▪ Effect of "dry out" zone	4
		▪ Humidity and temperature spatial distribution	▪ Effect of rock heterogeneity and uncertainty	4
	▪ On drip shield	▪ Hygroscopic salts control corrosion	▪ Salt/dust characteristics	
	▪ Under drip shield	▪ Humidity and temperature spatial distribution	▪ Convection cells and condensation	4
	▪ On waste package	▪ Hygroscopic salts control corrosion	▪ Salt/dust characteristics	4
		▪ Humidity and flux equilibrate	▪ Local chemical conditions	4
			▪ Moisture removed by evaporation	4
	▪ In waste package	▪ Moisture film continuous on waste form	▪ Moisture film not continuous on waste form	4
		▪ Moisture contacts all waste	▪ Flux does not contact all exposed waste	
		▪ Flux in = flux out	▪ Time delay before flux in = flux out (i.e., "bathtub" effect)	
	▪ Invert	▪ Saturation depends on design and rock/invert characteristics	▪ Uncertainty in water/invert characteristics	
			▪ Uncertainty in moisture removal	4
		▪ Flux considers: 2-d effects	▪ 3-d effects	4
	▪ Rock	▪ Advective flux go rates fractures	▪ Drift "shadow" effect	4

Summary of Key Chemical and Transport Assumptions Affecting EBS Release Rates

COMPONENT	CURRENT TREATMENT	KEY UNQUANTIFIED UNCERTAINTY	ADDRESSING SIGNIFICANCE
Waste form alteration	▪ Cladding degradation rate varies with initial state and localized zircaloy corrosion	▪ Alternative degradation modes and rates of Zircaloy	4
	▪ Cladding degraded by seismic effects		
	▪ Alteration rate considers environment (pH)		
Radionuclide concentration	▪ Solubility a function of environment for single controlling phase	▪ Uncertainty in controlling phases	4
	▪ Colloids fraction and amount	▪ Uncertainty in colloid stability and transport characteristic	4
	▪ Secondary phases considered as sensitivity		
In-Waste package transport	▪ Once waste package degrades, environments equilibrate	▪ Consider in waste package dry out	4
	▪ Water contacts all exposed waste	▪	
	▪ For diffusion, waste is placed at bottom of waste package	▪ Time delay for in-waste package diffusion	4
	▪ Water film is continuous	▪ Water film is discontinuous	4
Through waste package transport	▪ Advection occurs instantly with first breach	▪ Consider "bathtub effect	
	▪ Advection and diffusion considers area of waste package degraded	▪ Limit area to thickness of film	4
	▪ Difusion length limited to 2 cm to invert	▪ Use diffusion length considering varying lengths to invert	4
Through invert transport	▪ Advection considers through waste package flux	▪ Consider 3-d effects	4
	▪ Diffusive coefficient a function of saturation	▪ Diffusion coefficient uncertainty	
	▪ Diffusive transport released to host rock fractures	▪ Diffusive transport released to rock matrix	4