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

YUCCA MOUNTAIN PROJECT

Barrier Capability Analyses

Presented to:
Nuclear Waste Technical Review Board

Presented by:

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Overview

- **Barrier Importance, Barrier Capability, and Part 63**
- **Brief summary of available analysis techniques**
- **Analyses currently being considered to support the License Application (LA)**
  - **Representative examples based on past work**
  - **All examples for nominal performance scenario**
  - **All examples are draft**
    - **All quantitative results will be updated for LA**
  - **Examples are shown as mean results for simplicity in illustration; full discussion in the LA will address uncertainty**

Regulatory Basis

- **"*Important to waste isolation*, with respect to design of the engineered barrier system and characterization of natural barriers, means those engineered and natural barriers whose function is to provide a reasonable expectation that high-level waste can be disposed of without exceeding the requirements of §63.113(b) and (c)" (10 CFR 63.2)**
- **"*Barrier* means any material, structure, or feature that, for a period of time to be determined by NRC, prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository… or… the release rate of radionuclides from the waste…" (10 CFR 63.2)**

Regulatory Basis
(Continued)

- "Describe the capability of barriers, identified as important to waste isolation, to isolate waste, taking into account uncertainties in characterizing and modeling the behavior of the barriers" (10 CFR 63.115(b))
- "Provide the technical basis for the description of the capability of barriers … based on and consistent with the technical basis for the performance assessments used to demonstrate compliance with §63.113(b) and (c)" (10 CFR 63.115(c))

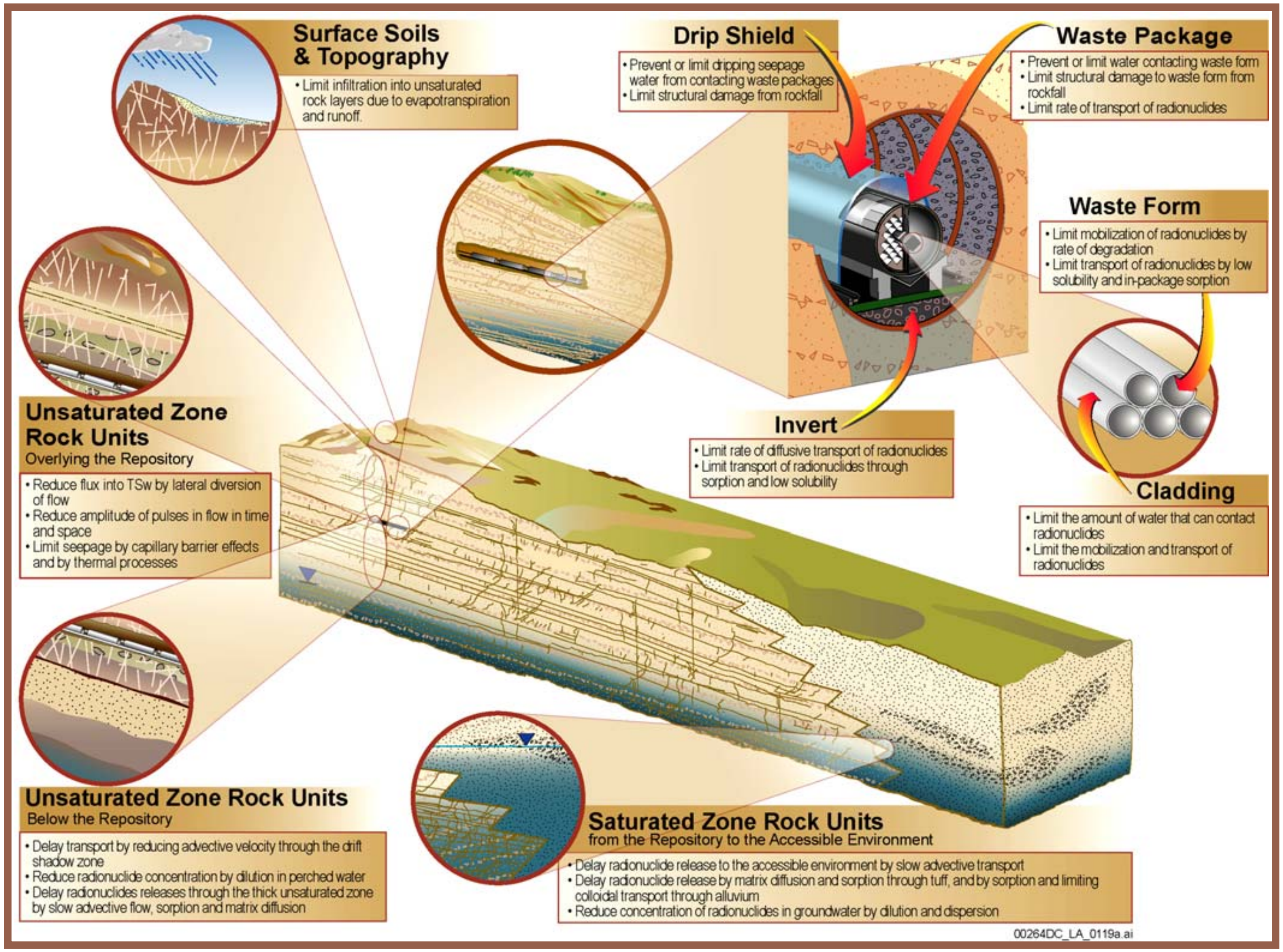
Summary of Barrier Analysis Approaches

- **System-level regression analysis**
  - **Provides insights into main contributors to uncertainty in total system performance**
  - **Emphasis on total system limits insights at component level**
- **One-on analyses**
  - **Good display of relative contributions of barriers**
    - **Strongly dependent on order**
    - **Not physically realistic (e.g., waste will not be emplaced without engineered barriers)**
- **One-off and neutralization analyses**
  - **Show individual barrier contribution independent of order, but**
    - **Redundant capabilities are difficult to characterize**
    - **Not physically realistic (i.e., all barriers are expected to contribute)**

Summary of Barrier Analysis Approaches
(Continued)

- **Intermediate results from full Total System Performance Assessment (TSPA)**
  - Show individual barrier contribution in context of full system, but
    - Redundant capabilities are difficult to characterize
    - Different types of results (e.g., water flux, radionuclide flux) for different barriers: total dose is not the primary metric
- **Proposed Approach for LA**
  - Intermediate metrics using component analysis, full-system analysis, and one-off/one-on techniques as appropriate
    - Capability in terms of limiting water or radionuclide movement
    - Provide insight on individual components
    - Will address 10 CFR 63.115 requirements

Nine Barriers Proposed for Consideration in the License Application



- **Surface soils and topography**
- **Unsaturated Zone (UZ) above (seepage, drift effects)**
- **Drip shield**
- **Waste Package**
- **Cladding**
- **Waste Form**
- **Invert**
- **UZ below (transport)**
- **Saturated Zone (SZ)**

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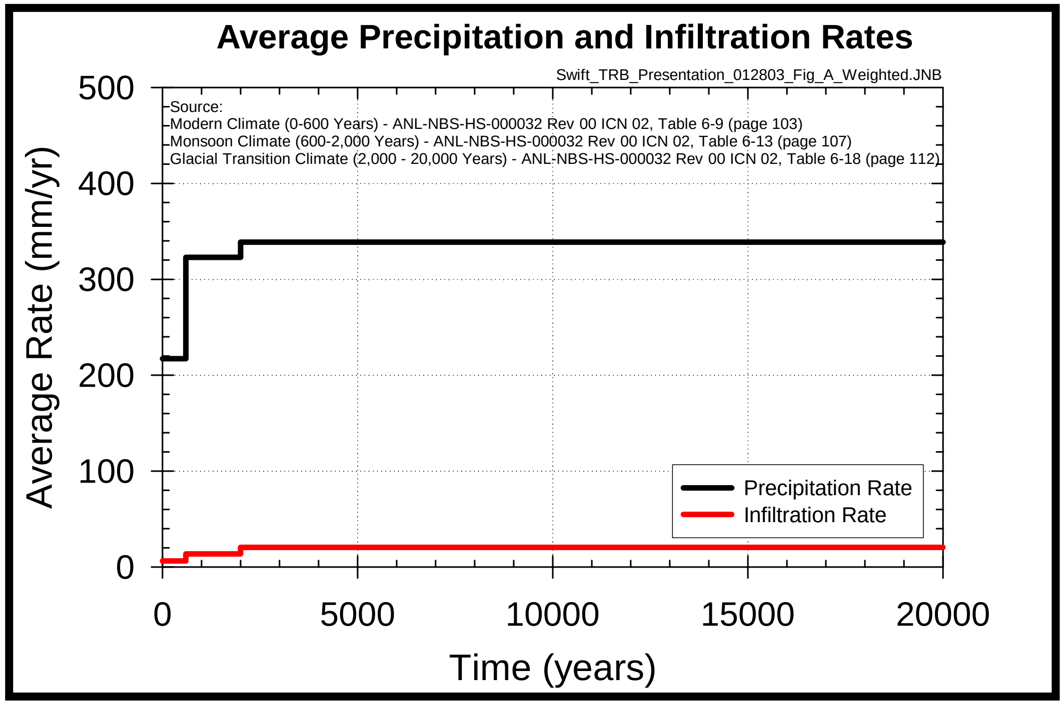
Surficial Soils and Topography Example Barrier Capability Description

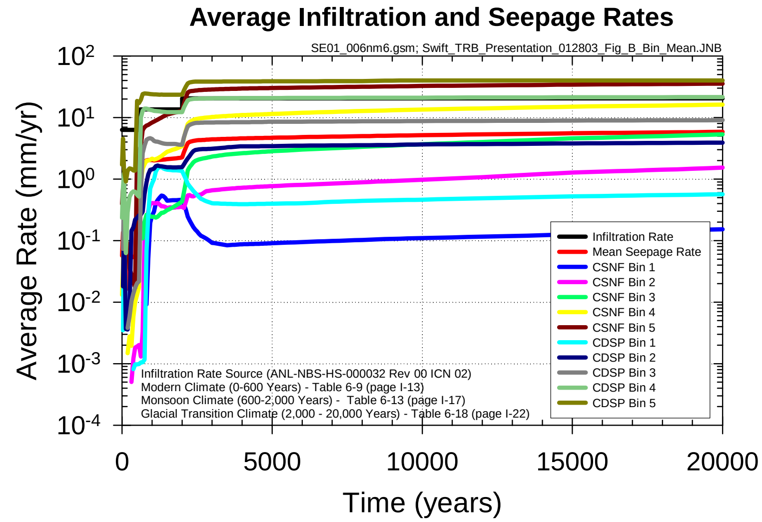
- **Capability: reduce the rate of movement of water**
- **Draft comparison of precipitation and infiltration**
  - **Precipitation and infiltration are shown as spatial averages for 38.7 km^2 domain**
  - **Curves are weighted averages for low, medium, and high infiltration conditions corresponding to uncertainty in climate states**
  - **Steps in time history correspond to climate changes**
- **Surficial soils and topography reduce spatially-averaged water movement at 10,000 years approximately 16x**

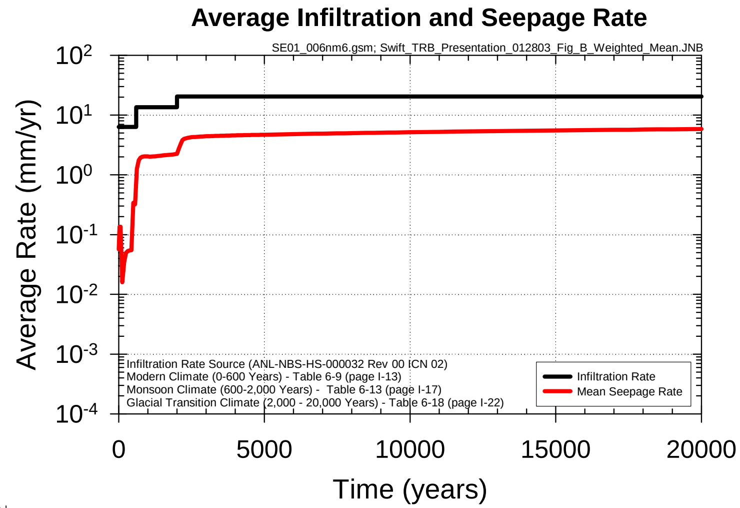


Draft precipitation and infiltration based on spatially-averaged results from ANL-NBS-HS-000032, Rev. 00 ICN 02 [FEIS/SSPA Infiltration Model AMR) for three infiltration maps, weighted by the relative frequency of occurrence of these maps in TSPA-FEIS

Unsaturated Zone above the Repository Example Barrier Capability Description

- **Capability: reduce the rate of movement of water**
- **Draft comparison of mean seepage flux for seeping environments to average infiltration flux**
  - **Mean seepage shown for 10 waste package bins (upper plot) and for overall mean weighted by bin frequency in 300 realizations (lower plot)**
  - **Infiltration shown as spatial average for 38.7 km ^{2} model domain (see previous slide)**
- **UZ flow and drift effects reduce total water flux onto drip shields at 10,000 years ~ 4x relative to infiltration**





Draft seepage results show mean performance from 300 realizations. Source: calculations performed for SL986M3 Rev. 00, figure 6-5 (TSPA-FEIS).

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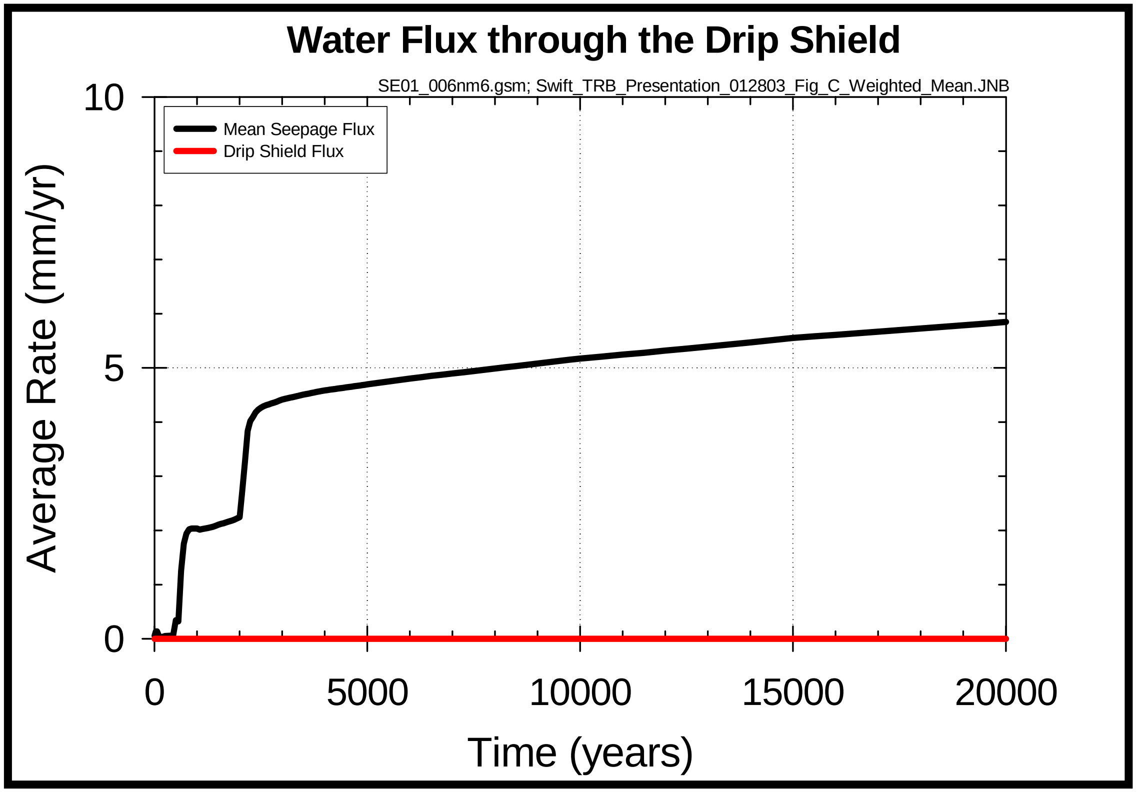
Drip Shield
Example Barrier Capability Description

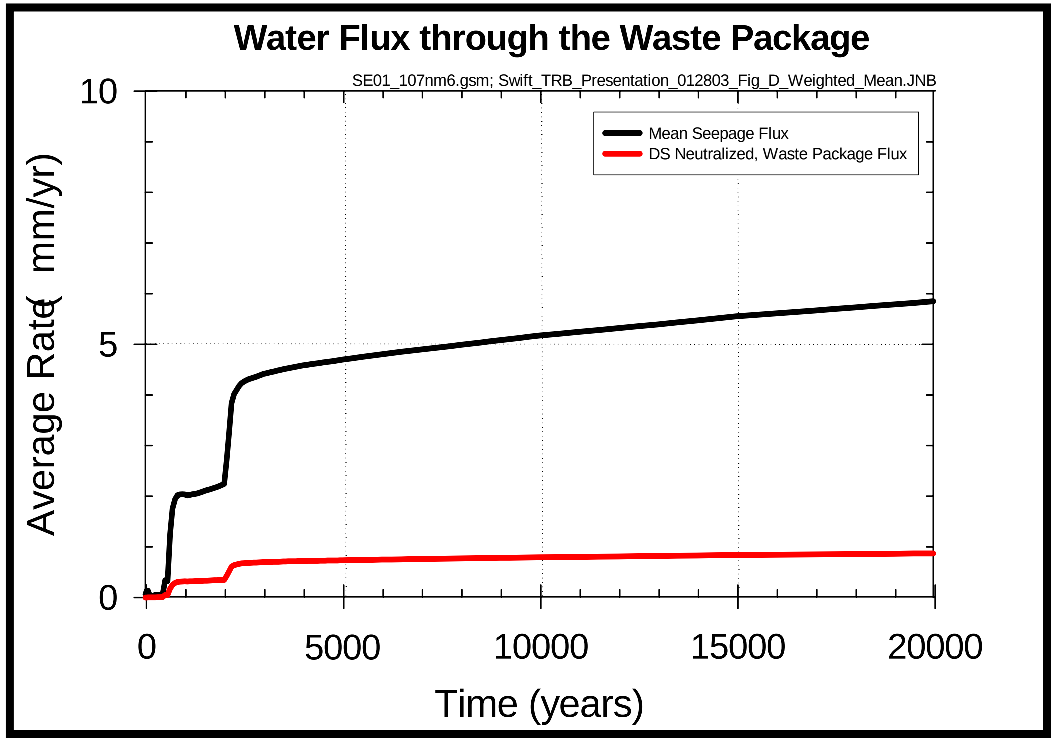
- **Capability: reduce the rate of movement of water**
- **Draft comparison of spatially-averaged mean seepage flux to mean water flux reaching waste package**
- **Drip shields reduce water flux at 10,000 years to zero (no drip shield failures during first 20,000 years)**



Draft results show mean performance from 300 realizations. Note linear scale rather than logarithmic scale shown for same information on figure 9. Source: calculations performed for SL986M3 Rev. 00, figure 6-5 (TSPA-FEIS).

Waste Package
Example Barrier Capability Description

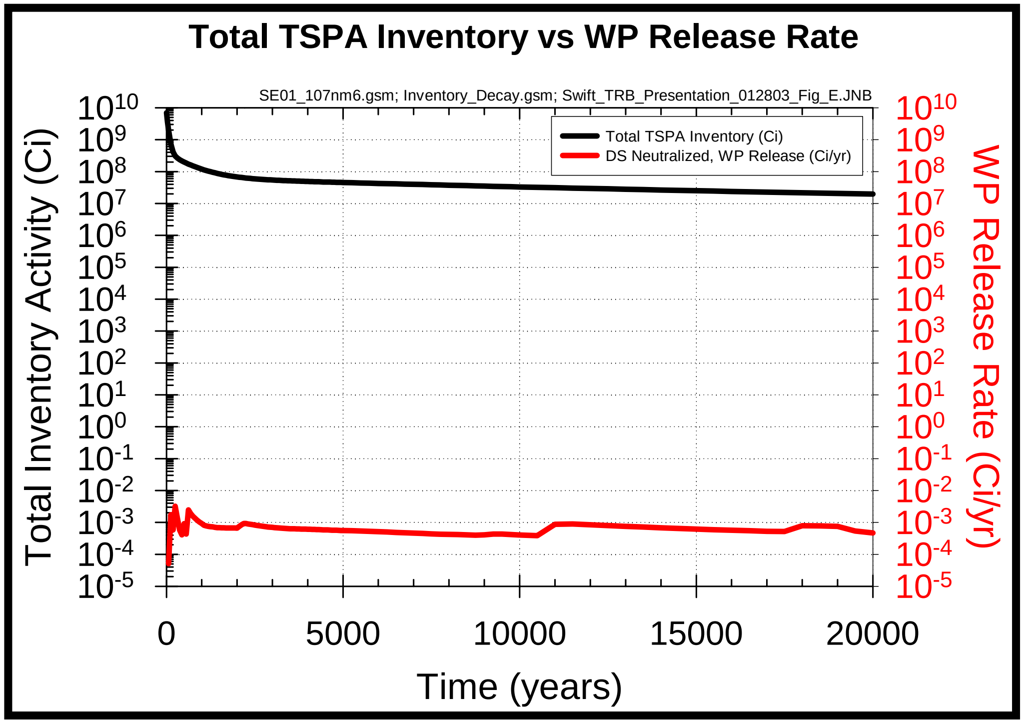
- **Capability: reduce the rate of movement of water**
- **Draft comparison of spatially-averaged mean seepage flux to mean water flux through waste packages with early failures and without a drip shield**
- **Waste packages alone (independent of drip shields) can reduce water flux to less than 1 mm/yr for packages with early failures and to zero for all other packages**



Draft results show mean performance from 300 realizations. Source: draft mean seepage calculations prepared for figure 9 of this presentation, scaled by area fraction of early package failure opening.

Waste Package
Example Barrier Capability Description
(Continued)

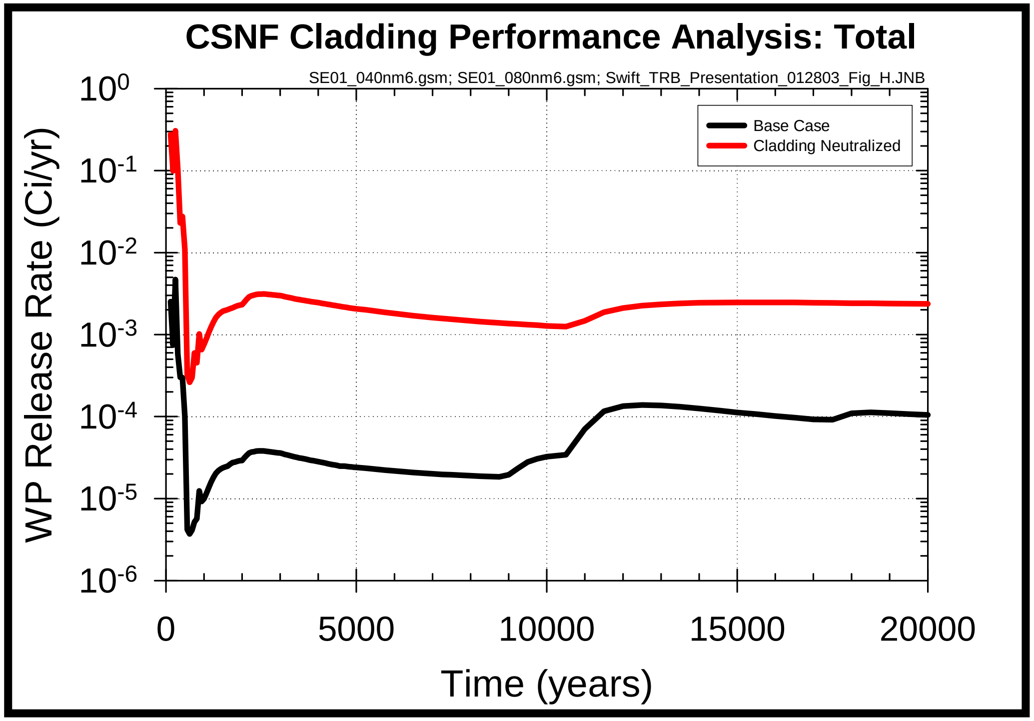
- **Capability: reduce the rate of radionuclide movement**
- **Draft comparison of total activity leaving waste package to total activity in TSPA inventory shows capability of barrier to limit radionuclide movement**
  - **Drip shield removed**
  - **Releases result from one early waste package failure in each realization**
- **Waste packages alone limit annual releases to less than one ten-billionth of the total inventory**



Draft results show mean performance from 300 realizations. Source: calculations performed for TDR-WIS-PA-000009, rev. 01, ICN 01, figure 10.

Cladding
Example Barrier Capability Description

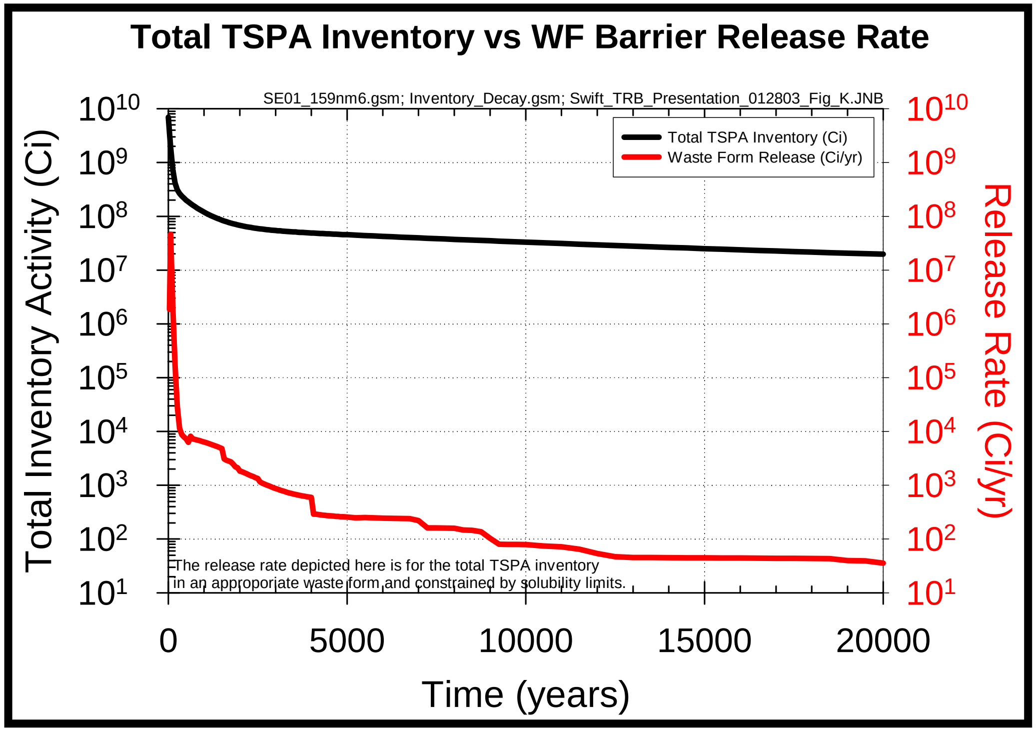
- **Capability: reduce the rate of radionuclide movement**
- **Draft comparison of total activity leaving waste package with and without cladding present on commercial spent nuclear fuel (CSNF)**
  - **Other barriers (e.g., drip shield and waste package) perform as expected**
- **Cladding has the potential to reduce total activity flux leaving the CSNF waste packages at 10,000 years ~40x**



Draft results show mean performance from 201 realizations, which represent the CSNF fraction early waste package failures in the the total of 300 realizations. Source: calculations performed for TDR-WIS-PA-000009, rev. 01, ICN 01, figure 19.

Waste Form Degradation and Dissolution Example Barrier Capability Description

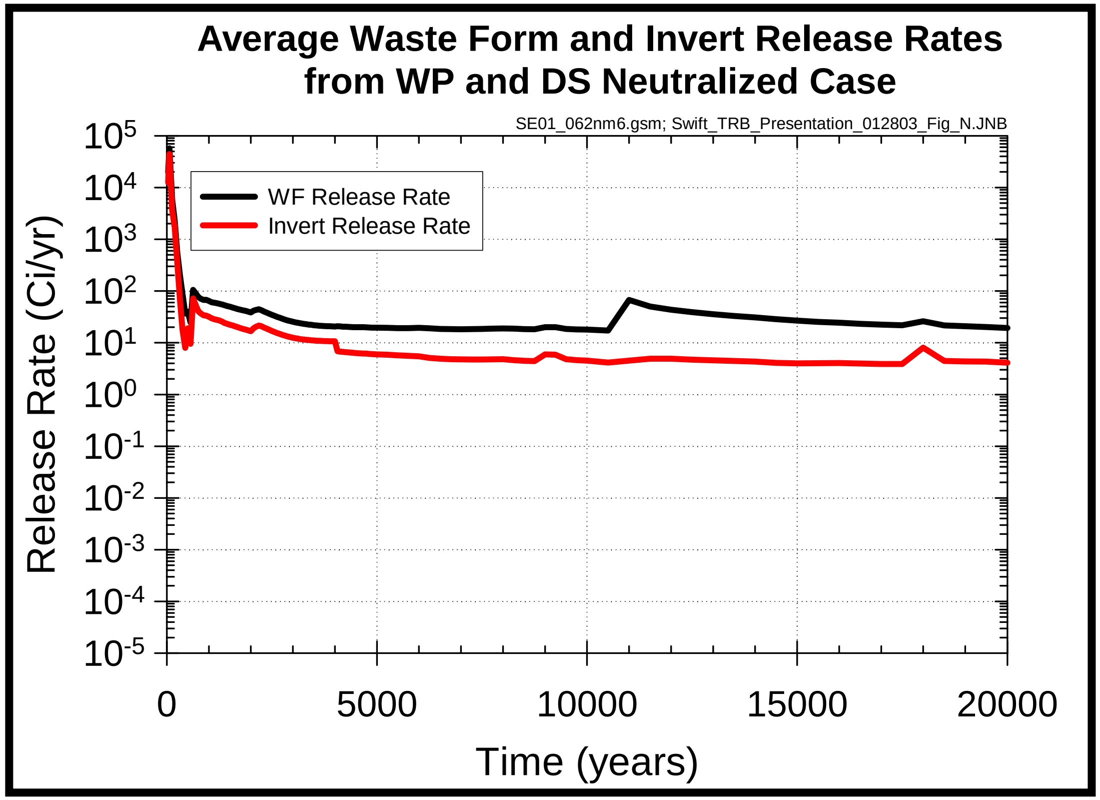
- **Capability: reduce the rate of radionuclide release from waste**
- **Draft comparison of total activity in TSPA inventory and total activity mobilized from waste form exposed to precipitation flux**
  - **Drip shield, Waste Package, and Cladding removed**
- **At 10,000 years, waste form alone has the potential to reduce annual radionuclide mobilization to approx. 1/400,000 of total inventory**



Draft results show mean performance from 300 realizations. Source: calculations performed for TDR-WIS-PA-000011, rev. 00, ICN 01, figure 7-3 (one-on analysis case 3).

Invert
Example Barrier Capability Description

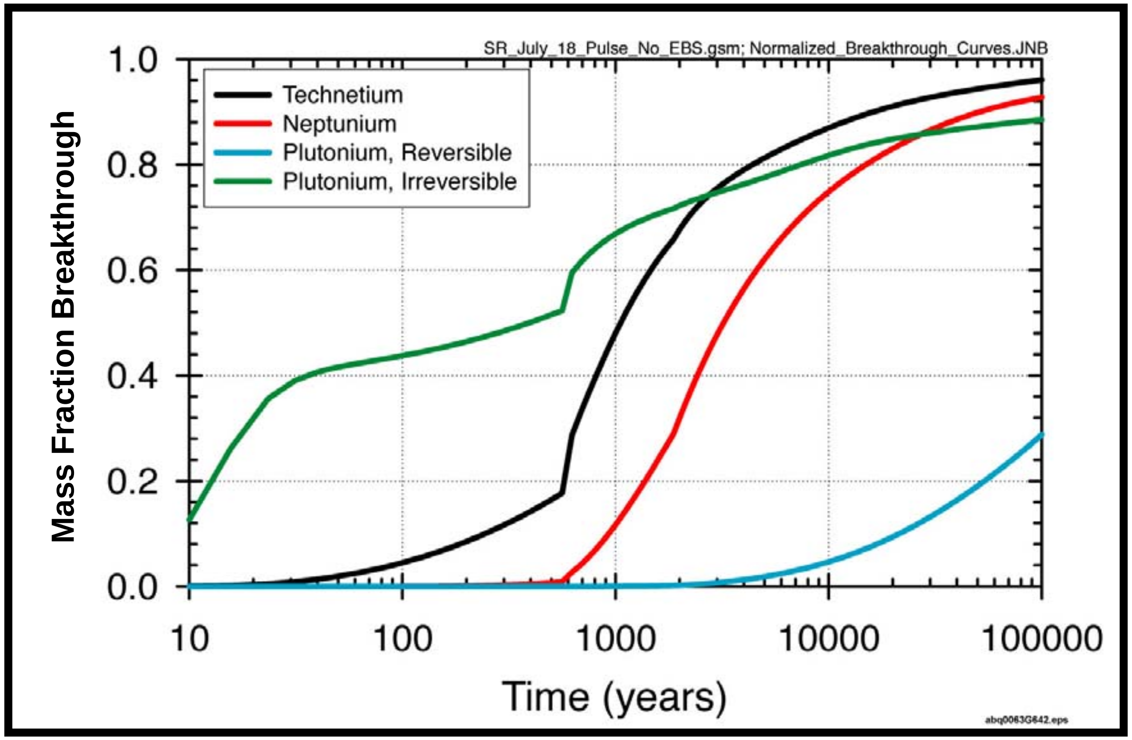
- **Capability: reduce the rate of radionuclide movement**
- **Draft comparison of total activity entering and exiting the invert**
  - **Waste package and drip shield removed**
- **At 10,000 years, invert has the potential to reduce total activity in groundwater approximately 4x**



Draft results show mean performance from 300 realizations. Source: unpublished calculations performed for TDR-WIS-PA-000009, rev. 01, ICN 01.

Unsaturated Zone Below the Repository Example Barrier Capability Description

- **Capability: reduce the rate of radionuclide movement**
- **Draft breakthrough curves for Tc, Np, Pu**
  - **Breakthrough based on unit release into UZ at time zero, effectively removes all engineered barriers**
  - **No radioactive decay**
- **Median UZ transport times for mean breakthroughs vary for different species**
  - **Tc-99: ~ 1000 yr**
  - **Np-237: ~ 3000 yr**
  - **Pu (dissolved and reversible colloids): > 100,00 yr**
  - **Irreversible Pu colloids: ~ 300 yr**

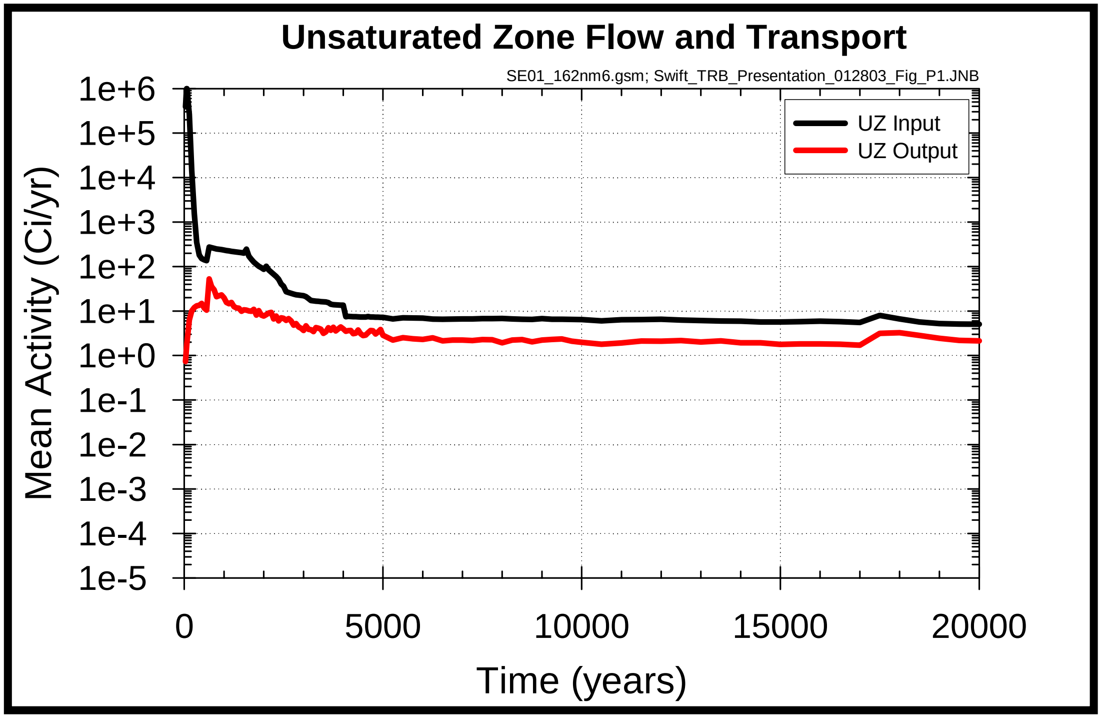


TSPA-SR Rev. 00, ICN 01, figure 3.7-12

Unsaturated Zone below the Repository Example Barrier Capability Description

(Continued)

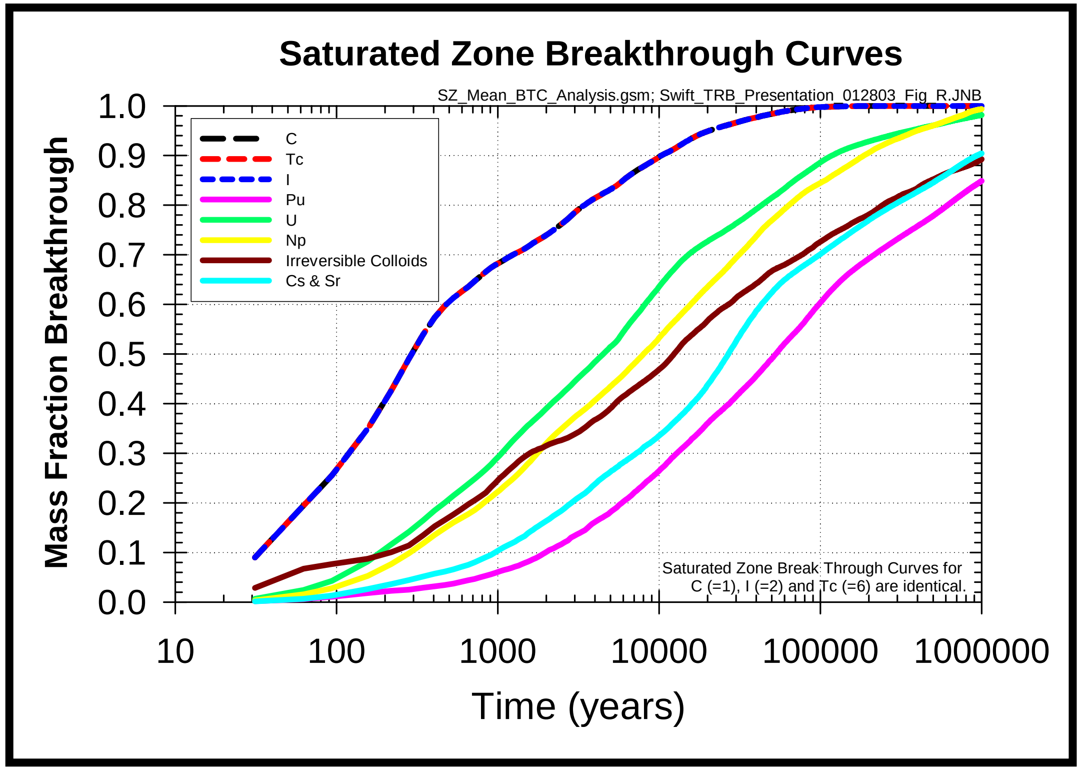
- **Capability: reduce the rate of radionuclide movement**
- **Draft comparison of total activity entering and exiting the unsaturated zone**
  - **Results shown with seepage effects, drip shield, waste package, and invert removed**
- **Potential activity reduction at 1000 years is > 10x, due to strong retardation of Am-241, Cs-137, Sr-90**



Draft results show mean performance from 300 realizations. Source: calculations performed for TDR-WIS-PA-000011, rev. 00, ICN 01, figure 7-6 (one-on analysis case 6).

Saturated Zone
Example Barrier Capability Description

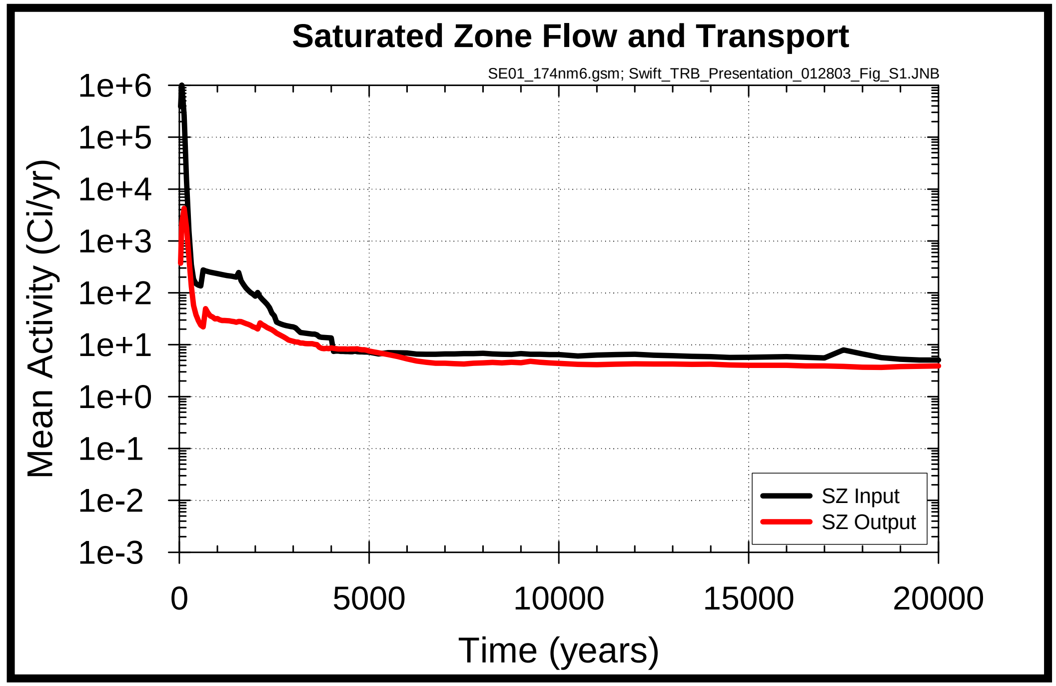
- **Capability: reduce the rate of radionuclide movement**
- **Draft mean breakthrough curves for SZ**
  - **Breakthrough based on unit release into SZ at time zero, effectively removes all engineered barriers**
  - **Present climate, scaled for wetter conditions**
  - **No radioactive decay**
- **Median SZ transport times for mean breakthroughs vary for different species**
  - **Tc-99: ~ 300 yr**
  - **Np-237: ~ 8,000 yr**
  - **Pu (dissolved and reversible colloids): ~ 53,000 yr**
  - **Cs-137, Sr-90: ~ 27,000 yr**
  - **Irreversible colloid species ~ 12,500 yr**



Draft results show mean performance from 100 realizations. Source: calculations performed for this presentation using models developed for SL986M3 Rev. 00, figure 6-5 (TSPA-FEIS).

Saturated Zone
Example Barrier Capability Description
(Continued)

- **Capability: reduce the rate of radionuclide movement**
- **Draft comparison of activity entering and exiting the SZ**
  - **Results shown with the unsaturated zone removed**
  - **For comparison with UZ results on page 17, seepage effects, drip shield, waste package, and invert also removed**
- **Potential activity reduction at 1000 years ~ 7x, due to strong retardation of Am-241, Cs-137, Sr-90**



Draft results show mean performance from 300 realizations.
Source: calculations performed for TDR-WIS-PA-000011, rev. 00, ICN 01, figure 7-13 (one-on analysis case 13).

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Summary of Draft Barrier Capabilities

Barrier	Limits Water Movement	Limits Radionuclide Release or Movement
Surficial Soils and Topography	Reduces spatially averaged mean annual precipitation ~ 16x at 10,000 years	-
Unsaturated Zone above the Repository (including seepage and drift effects)	Large spatial variability in water flux onto drip shield, spatial average reduced ~ 4x from average infiltration at 10,000 years	-
Drip shield	Reduces water flux onto waste packages throughout 10,000 years to zero	-
Waste Package	Independent of drip shield, can reduce water flux at 10,000 years more than 10x for early failure packages, to zero for other packages.	Reduces annual radioactivity release at 10,000 years to less than $1/10^{10}$ of total inventory

Summary of Draft Barrier Capabilities

(Continued)

Barrier	Limits Water Movement	Limits Radionuclide Release or Movement
Cladding	Independent of drip shield or waste package, prevents water from reaching CSNF until failure	Potential at 10,000 years to reduce CSNF radioactivity release rate ~40x
Waste Form	-	Independent of all other barriers, potential to reduce annual radionuclide release at 10,000 years to ~ 1/400,000 of total inventory
Invert	-	Independent of drip shield and waste package, potential to reduce radioactivity flux at 10,000 years ~4x

Summary of Draft Barrier Capabilities

(Continued)

Barrier	Limits Water Movement	Limits Radionuclide Release or Movement
Unsaturated zone below the repository	-	Transport times vary for different species; median breakthrough times range from ~300 years (colloidal species) to > 100,000 years (dissolved Pu). Potential to reduce radioactivity flux at 1000 years > 10x
Saturated zone	-	Transport times vary for different species: median breakthrough times range from ~300 yr (Tc-99) to ~ 50,000 years (dissolved Pu). Independent of UZ, potential to reduce radionuclide flux at 1000 years ~7x

Conclusions

- **Draft work to date confirms that each of the nine barriers has a capability to reduce movement of water or radionuclides**
- **Capabilities can be quantified using subsystem model and TSPA results**
- **Capability description analyses provide valuable insights into TSPA**