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YUCCA MOUNTAIN 2008 PERFORMANCE ASSESSMENT: MODELING THE ENGINEERED BARRIER SYSTEM

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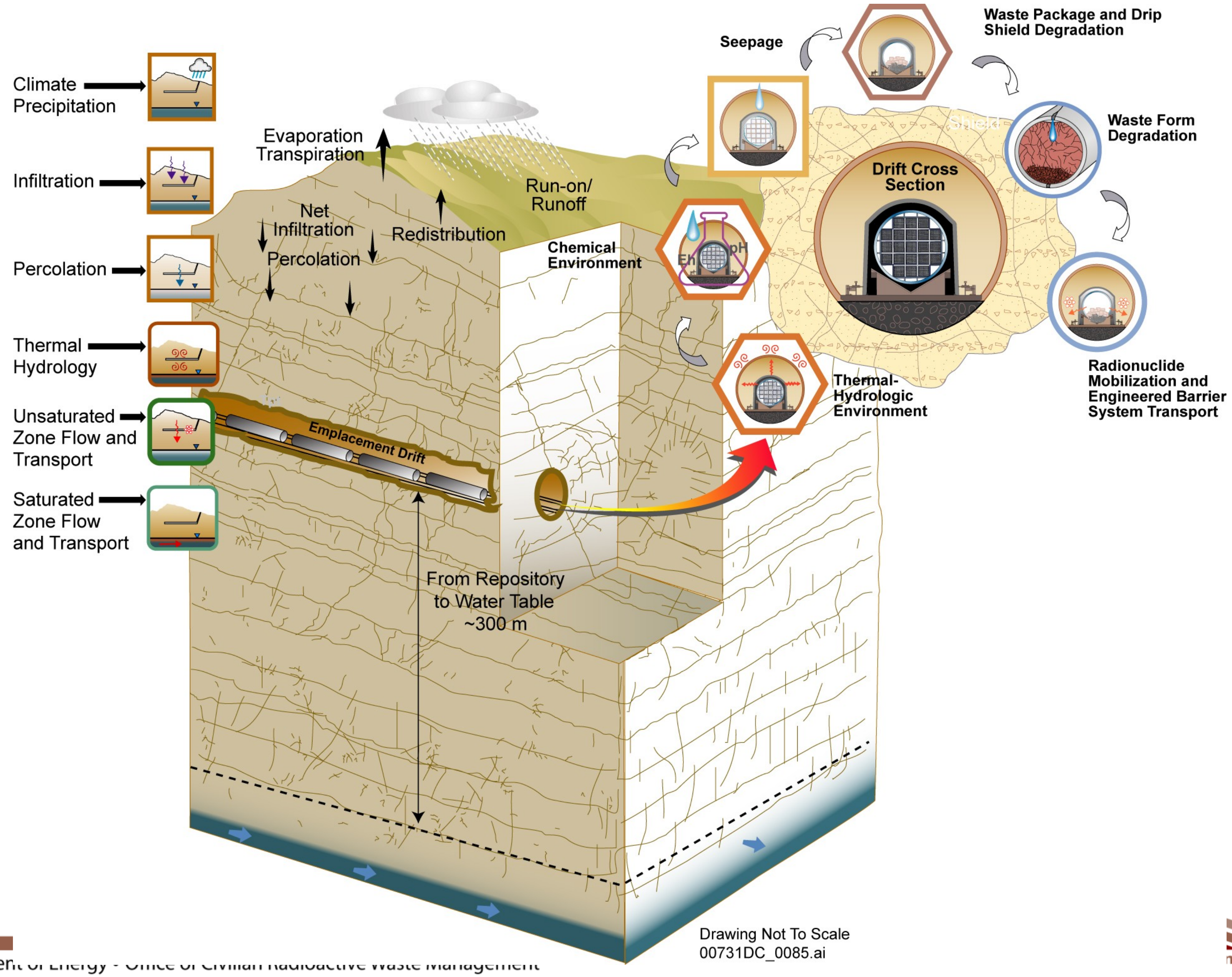
Outline

- Barrier definition and EBS barrier functions
- Description of EBS
  - Overview of processes and features of the EBS
  - Characteristics of the EBS
  - Drip Shield
  - Waste Package
  - Commercial SNF Cladding
- EBS Models
- Uncertainties
- Barrier Capability
- Conclusions

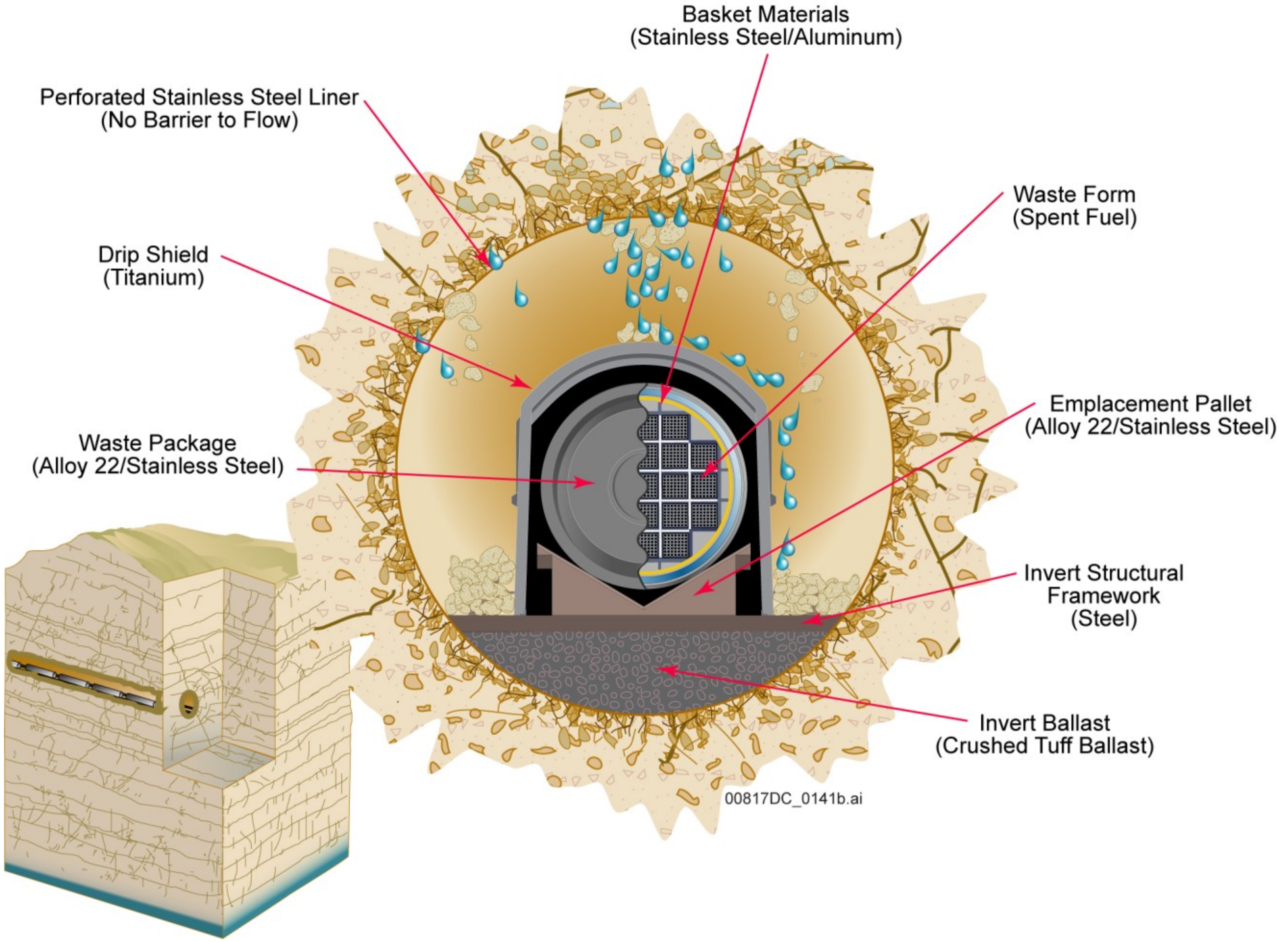
Repository System Barriers and EBS Functions

- A barrier is defined in 10 CFR 63.2 as any material, structure, or feature that prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain Repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste
- The repository system is composed of natural and engineered features that function together as the Upper Natural Barrier (UNB), the Lower Natural Barrier (LNB), and the Engineered Barrier System (EBS)
- The EBS prevents or substantially reduces:
  1. The rate of movement of water to the waste
  2. The rate of release of radionuclides from the waste
  3. The rate of movement of radionuclides from the EBS to the LNB

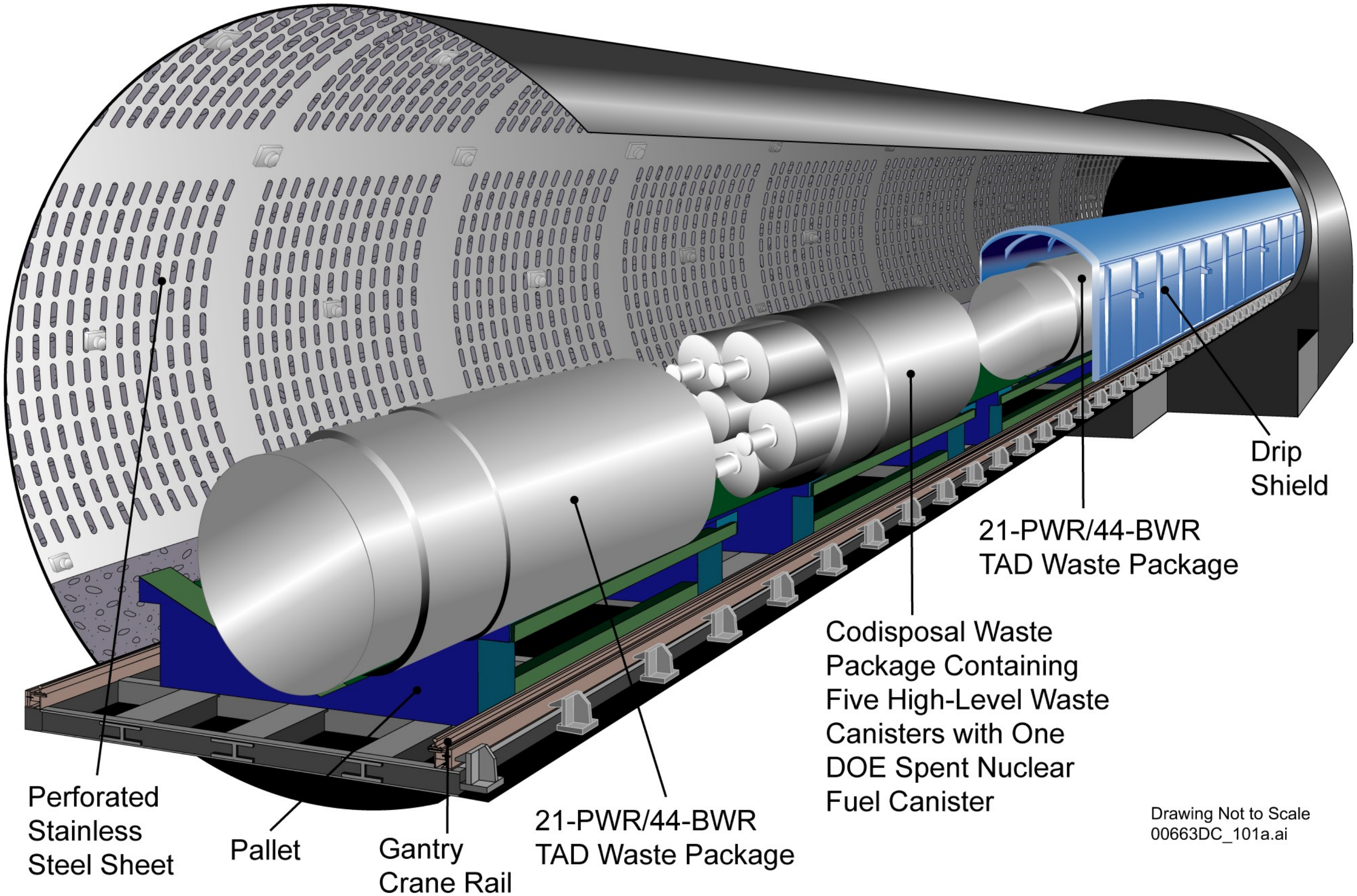
Components of Natural and Engineered Barrier Systems at Yucca Mountain



Schematic of the EBS



Engineered Barrier System



Drawing Not to Scale
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Characteristics of the EBS

- Thermal, mechanical, hydrologic (including isolation of waste from moisture), and chemical environments favorable to waste isolation and affected principally be thermal effects of radioactive decay and possible seismic events
- Corrosion-resistant metals designed and fabricated to perform and function in environments expected in emplacement drifts and prevent water from contacting waste for tens to hundreds of thousands of years
- Waste package (WP) stainless steel inner vessel and transport, aging, and disposal (TAD) canister that provide structural resistance to kinematic loading induced by seismic ground motion
- Generally low solubility and high sorption capacity of radionuclides, thus delaying or preventing their release in the event that waste packages are breached
- Delayed transport of radionuclides through the EBS due to insignificant advection and slow diffusion through EBS features for several hundreds of thousands of years

Drip Shield

- Placed over waste packages
- Fabricated from Titanium Grade 7
  - Nearly pure titanium alloy containing a small addition of palladium to provide a higher degree of corrosion resistance
- Structural components constructed using higher-strength Titanium Grade 29
  - Alloying elements aluminum and vanadium to provide the required strength, and ruthenium to provide corrosion resistance

Commercial SNF Waste Packages

- **Constitute ~70% of the waste packages that will be emplaced in the repository**
- **Consists of two concentric cylinders:**
  1. **Inner vessel of Stainless Steel Type 316 designed for structural support**
  2. **Corrosion-resistant outer barrier made of Alloy 22, a nickel-chromium-molybdenum alloy**
- **Waste package internal components**
  - **TAD canister and basket materials**

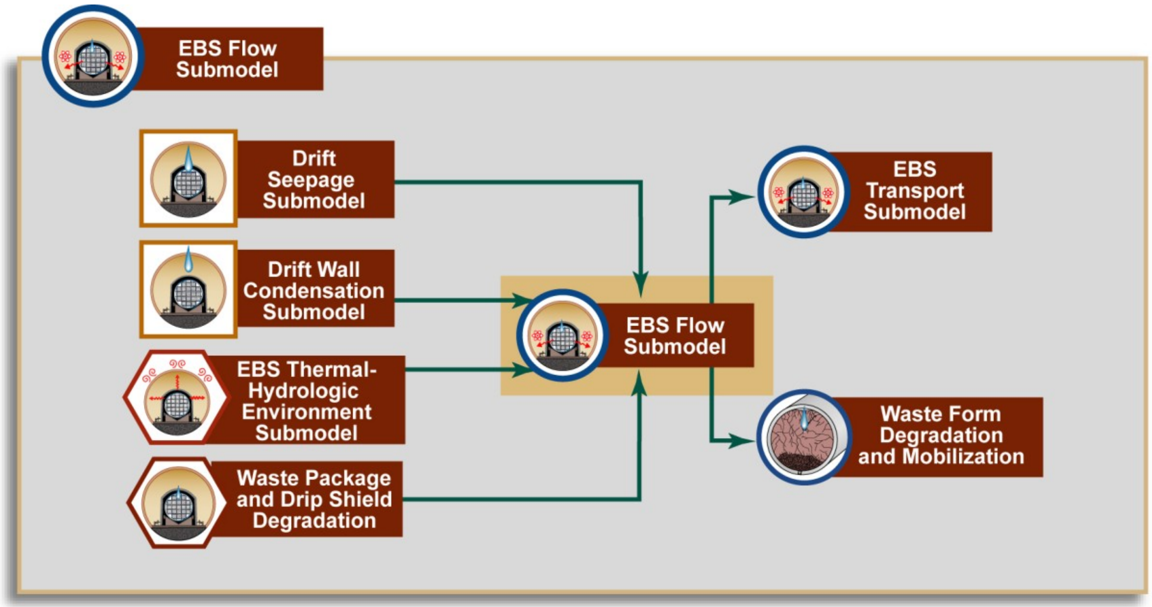
Codisposal Waste Packages

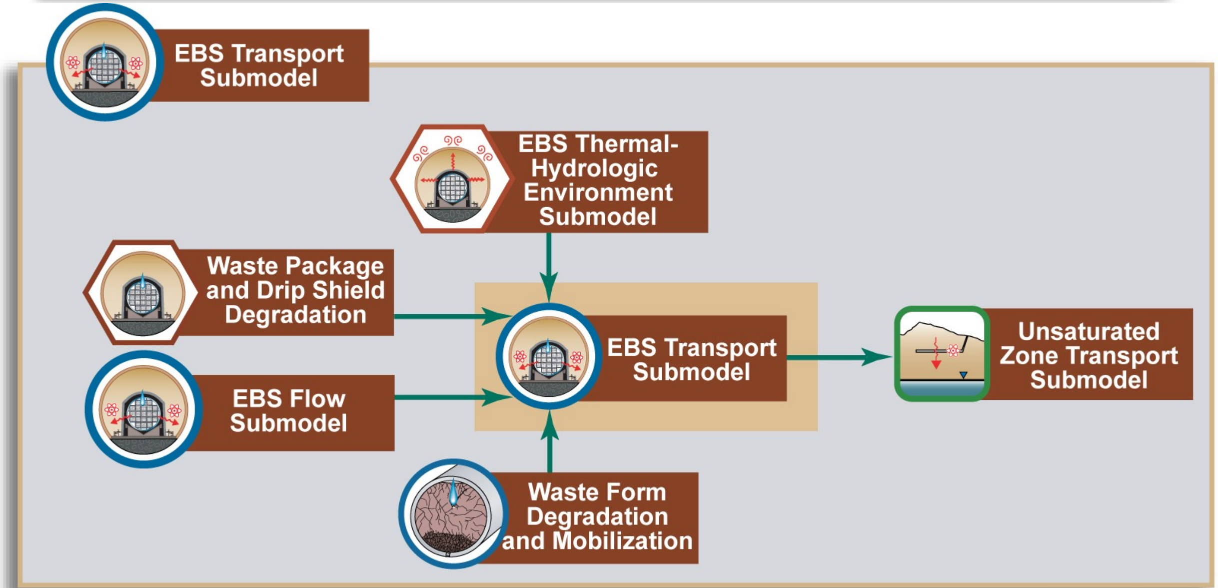
- Constitute ~30% of the waste packages that will be emplaced in the repository
- Corrosion-resistant outer barrier and inner vessel same as commercial SNF WPs
- Contain both HLW canisters and DOE SNF canisters
- HLW is composed of a borosilicate glass waste form
- DOE SNF is composed of uranium metal (N Reactor) fuel and other DOE SNF waste forms
- WP internal components

Commercial SNF Cladding

- Provides protection for commercial SNF from the surrounding environment
- May fail by mechanical action from seismic or igneous activity and/or by long-term chemical degradation
- Modeled in the TSPA as being failed upon emplacement of the waste packages in the repository

Identification and Linkages of Abstractions





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EBS Transport: Inputs and Outputs

EBS Thermal-Hydrologic Environment Submodel
- Liquid Saturation in Invert
- Temperature and Relative Humidity at Waste Package
- Imbibition Flux in Invert

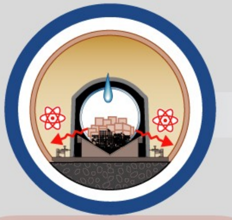
Waste Package and Drip Shield Degradation
- Time of Failure
- Number of Patch Breaches/Failed WP
- Number of SCC Breaches/Failed WP
- Number of Early Failed WPs
- Number of LC Failed WPs
- Number of GC and SCC Failed WPs

EBS Flow Submodel
- Flow Through the Waste Package and Invert

Waste Form Degradation and Mobilization
- Dissolved Concentration Limits
- Dissolution Rates
- Irreversibly Sorbed Radionuclide Mass on Colloid
- Reversibly Sorbed Radionuclide Mass on Colloid

Invert Material Properties
- Porosity and Diffusion Coefficients in Crushed Tuff

EBS Transport Submodel
- *One-Dimensional Advective and Diffusive Transport Through the EBS*
  - *Retardation of Dissolved Species*
  - *Colloid Transport Included*
  - *Liquid Films Always Allow Diffusion Through WP Stress Corrosion Cracks*

Inputs →  → Outputs

Unsaturated Zone Transport Submodel
- Radionuclide Mass Release Rate to the Unsaturated Zone

- Laboratory Data for Diffusivity of Unsaturated Crushed Tuff
- Process-Level Modeling of EBS Response

Model Confidence Foundation

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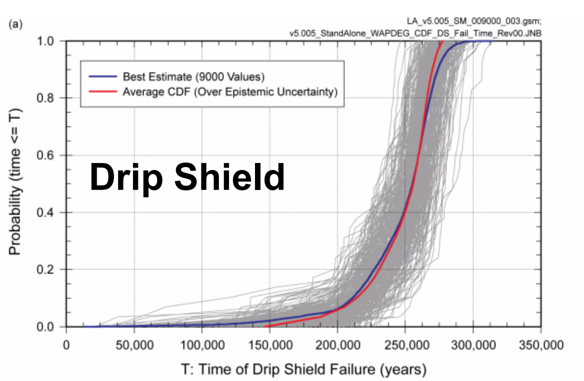
Representative Uncertainties in the EBS

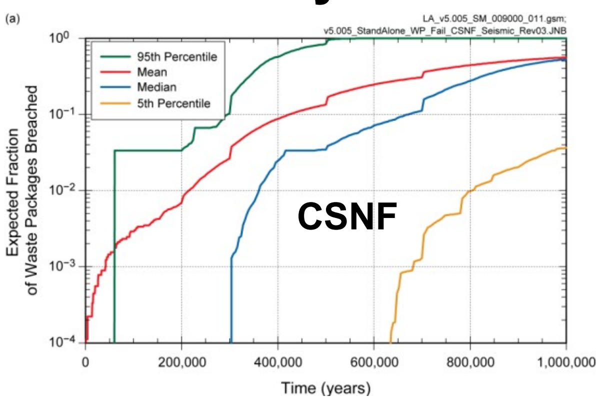
- Seepage/Thermal seepage
  - Bulk permeability and capillary strength (uncertainty distributions on mean values)
  - Hydrologic conditions in the invert (low/high invert)
- Environmental conditions
  - Host rock thermal conductivity and percolation flux
  - In situ (“starting”) pore waters
  - Pitzer model uncertainty
- WP and DS Degradation processes
  - WP general corrosion (GC) and drip shield GC rates temperature dependence
  - WP stress corrosion cracking growth model parameters
- Waste Form Degradation
  - In-package chemistry, degradation rates, solubilities
- Transport
  - Diffusion coefficient (invert), steel corrosion rates for WP internals
  - Equilibrium and kinetic rate constants for sorption
- Incorporated probabilistically in the models by sampling across uncertainty ranges in the inputs and analyzed directly in the TSPA model with multiple realizations

Capability of the EBS to Prevent or Substantially Reduce Water Contacting the Waste

- **Depends on the integrity of the drip shields and waste packages**
- **TSPA results:**
  - **Drip shields will remain intact for hundreds of thousands of years**
  - **Majority of waste packages will remain intact for tens of thousands to hundreds of thousands of years**



Seismic Ground Motion (includes general corrosion)



Seismic and nominal processes

Capability of the EBS to Prevent or Reduce the Rate of Radionuclide Release From the Waste

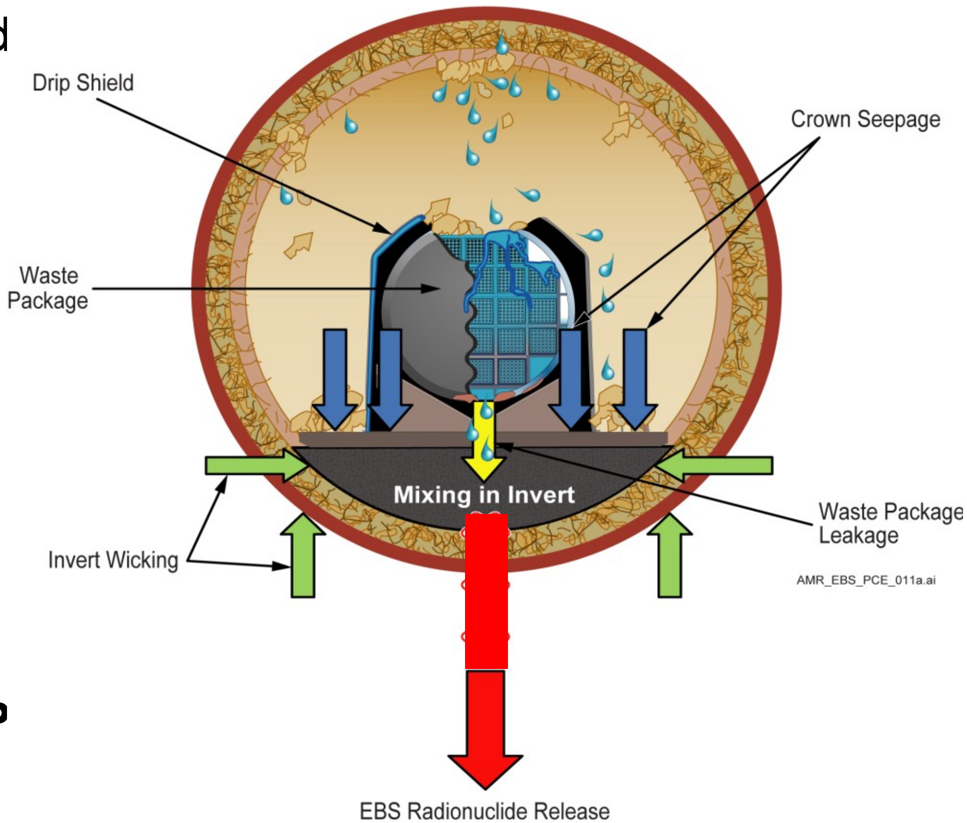
- **After a waste package is breached, radionuclides are not available for release and transport until the following processes have occurred:**
  - **Oxygen, liquid water, or water vapor enters the waste package, enabling degradation of the waste form and formation of a liquid pathway for radionuclide transport**
  - **Fuel cladding or canisters (HLW, TAD, DOE SNF) degrade and fail and allow water to contact the waste**
  - **Solid waste form degrades**
  - **Radionuclides are mobilized into aqueous solution or aqueous colloidal suspension**

Capability of the EBS to Prevent or Reduce the Movement of Radionuclides From the EBS to the LNB

- **Transport by advection when there is a liquid water flux through the waste package**
  - **Only after drip shield has failed**
  - **Only through corrosion patches, where seepage flux occurs**
- **Transport by diffusion through continuous liquid pathways in the waste package, including thin films of adsorbed water**
  - **Continuous thin film cannot form until the waste package temperature falls below 100°C and the relative humidity reaches 95%**
  - **Depends on the water saturation, porosity, temperature, and relative humidity in the waste package**
  - **Through stress corrosion cracks or through general corrosion patches in the waste package, both with and without liquid flux**
- **Retardation of radionuclide movement from the EBS**
  - **Due to sorption of radionuclides onto the waste package corrosion products and invert ballast material (crushed tuff)**
  - **Sorption is radionuclide-specific (e.g., ^{99}Tc is not sorbed; Pu is strongly sorbed)**
  - **Sorption dependent on EBS environment (pH, P_{CO2}, corrosion products composition)**

EBS Transport Conceptual Model

- After the waste form starts degrading, mass can be mobilized and released through the breached WP into the invert and to the UZ
- Advective and diffusive transport, including radioactive decay and (equilibrium and kinetic) sorption
- Both dissolved and colloid-facilitated transport included
- Effect of continued degradation of WP internals included (metal corrosion products) and sorption onto corrosion products
- Chemical conditions inside the WP and invert determined separately (for solubility and colloid stability calculations)



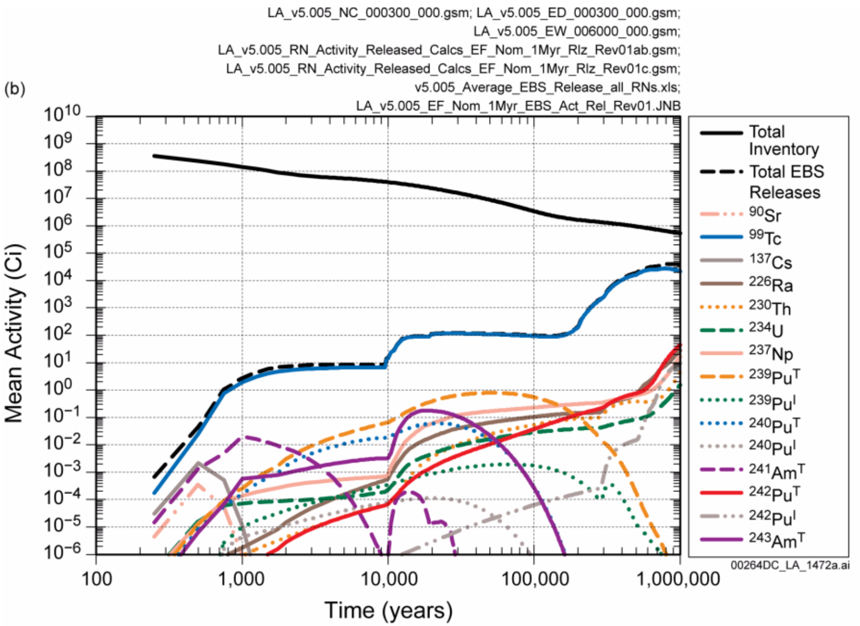
Quantification of EBS Barrier Capability

- **Two modeling cases considered for demonstrating barrier capability**
  - **Combined nominal/early failure modeling case**
    - **Drip shield and waste package early failure modeling cases and the nominal modeling case are combined into one modeling case**
    - **Representation of repository futures in which disruptive events do not occur**
    - **Provides a projection of a reference capability**
  - **Seismic ground motion modeling case**
    - **Addresses barrier capability as a function of disruptive conditions**
    - **Important to demonstration of compliance with the regulatory standards**

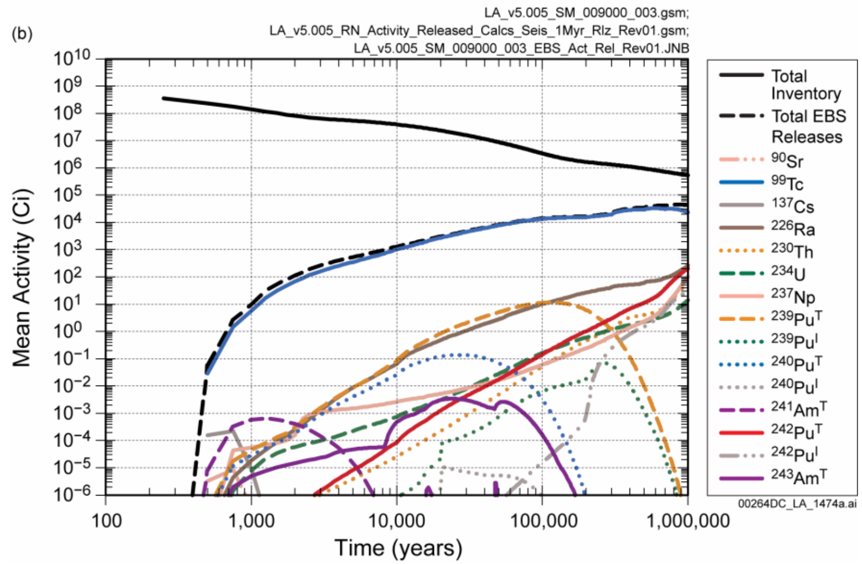
Mean Activity Released from the EBS

- Activity values account for radioactive decay and ingrowth
  - Total inventory curve drops through time as radioactive decay reduces the overall radioactivity of the waste
- Release curves show characteristic pattern:
  - Climbing as releases occur from the EBS
  - Eventual decline as radioactive decay removes the species from the overall inventory of material released
  - Radionuclides for which released activity is still climbing at 1,000,000 years are those that have very long half lives (^{242}Pu, ^{237}Np, ^{234}U), and ^{226}Ra, for which the release rate is determined by the concentration of their precursor species ^{230}Th and ^{234}U
- Releases from EBS to the UZ limited to small fraction of available inventory
- Large majority of released activity is in the form of ^{99}Tc, which transports through the EBS essentially without retardation

Mean Activity Released from the EBS



Combined Nominal/EF



Seismic Ground Motion

Key Points:

- **At 10^4 yrs, mean activity released from EBS is less than 4 x 10^{-5} % of the inventory**
- **By 10^6 yrs, mean activity released from EBS is about 7% of total decayed inventory and ~0.01% initial emplaced inventory**

Key Points:

- **At 10^4 yrs, mean activity released from EBS is about a factor of 100 higher (4 x 10^{-3} %) than Nominal/EF**
- **By 10^6 yrs, mean activity released from EBS is about the same as Nominal/EF**

CONCLUSIONS

- **EBS performs barrier capability functions by virtue of the materials and design of the emplacement drifts, drip shields, waste packages and waste forms, and waste package internal components**
- **EBS provides for chemical and thermal-hydrologic environments that lead to low solubilities for the radionuclides that make up the greatest fraction of the inventory activity**
- **EBS environments are such that radionuclide transport from the waste to the unsaturated zone is limited to a small fraction of the available inventory, even under the wide range of likely and unlikely seismic ground motion events**

Backup Slides

Waste Package and Drip Shield Degradation: Inputs and Outputs

Waste Package and Drip Shield Degradation

- *Alloy 22 Degradation*
  - *General Corrosion (GC) and MIC*
  - *Stress Corrosion Cracking (SCC)*
  - *WP Early Failure*
  - *Localized Corrosion*
- *Titanium Grade 7 Degradation*
  - *General Corrosion*

Inputs

EBS Chemical Environment
- pH, Cl, NO_3

EBS Thermal-Hydrologic Environment Submodel
- Temperature
- Relative Humidity

Alloy 22 General Corrosion Rate

Alloy 22 Stress Profiles

Alloy 22 Stress Intensity Factor Profiles

Alloy 22 Closure Weld Defects Data

Titanium Grade 7 General Corrosion Rate
- Topside of Drip Shield
- Underside of Drip Shield

Outputs

EBS Flow Submodel
- Number of Patch Breaches/Failed WP
- Number of SCC Breaches/Failed WP
- Number of Patch Breaches/Failed DS

Waste Form Degradation and Mobilization
- WP and DS Breach Ratio
- Fraction of Failed WPs

EBS Transport Submodel
- Number of Patch Breaches/Failed WP
- Number of SCC Breaches/Failed WP
- Number of Early Failed WPs
- Fraction of GC and SCC Failed WPs

Model Confidence Foundation

- Short- and Long-Term Corrosion Testing
- Standard Approaches to Corrosion Modeling
- Nuclear Industry Experience
- Materials Science Literature
- Field Data

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Waste Form Degradation and Mobilization: Inputs and Outputs

Waste Form Degradation and Mobilization

- *Radioisotope Inventory*
- *In-Package Chemistry (Including Inner Container Support and Corrosion)*
- *Cladding Failure Degradation*
- *Commercial Spent Nuclear Fuel (CSNF) Degradation*
- *DOE Spent Nuclear Fuel (DSNF) Degradation*
- *High-Level Waste (HLW) Degradation*
- *Dissolved Radionuclide Concentration Limits*
- *Colloidal Radionuclide Concentration*
- *Waste Form Rind Water Volume*

EBS Thermal-Hydrologic Environment Submodel

- Temperature and Relative Humidity at Waste Package

EBS Chemical Environment Submodel

- Ionic Strength in Invert
- pH in Invert
- P_{CO_2} in Invert and WP

Waste Package Degradation

- Time of Failure
- Number of Failed WPs

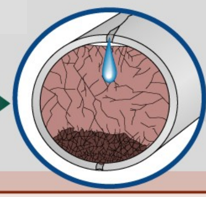
EBS Flow Submodel

- Flow Through Waste Package

Parameter Input:

- Colloid Sorption Coefficients
- Corrosion Rates of Container and Basket Material
- Specific Surface Areas of Waste Types
- Thermodynamic Data for Element Solubilities
- Predisposal Cladding Damage

Inputs



Outputs

EBS Transport Submodel

- Aqueous Radioisotope Concentration
- Dissolution Rates
- Irreversible Colloid Fraction
- Reversible Colloid Fraction

- Dissolution Tests on CSNF
- Dissolution Tests on HLW
- Dissolution Tests on DSNF
- Literature and Data on Cladding Failure
- Colloid Measurements
- Solubility Tests and Literature
- Comparison with Laboratory Experiments and Man-Made Analogue Materials on Chemistry

Model Confidence Foundation

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