Panel #6 Multiple Barriers: Waste Forms and Canister Materials

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Deep Borehole Disposal Post-Closure Conceptual Model – Components

Robust Isolation from the Biosphere

**Natural System**
- Overlying Sediments
- Crystalline Basement
  - Low permeability and long residence time
  - Density stratification of brine opposes upward convection
  - Geochemically reducing conditions limit the solubility and enhance the sorption of many radionuclides

**Engineered Barriers**
- Borehole seals (and disturbed rock zone)
- Waste forms
- Waste packages

(from Freeze, 2015)

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Deep Borehole Disposal Conceptual Model
Overview: Single Borehole Undisturbed Scenario

- **Waste Package**
  - Provides structural integrity for emplacement/removal operational protection
    - assumed to rapidly degrade after emplacement seal

- **Inventory / Waste Form**
  - DOE-managed High Level Waste (HLW)
    - Cesium/Strontium (CsCl)/(SrF₂) Capsules
  - *Previous* - Commercial Spent Nuclear Fuel (SNF)

- **Post-Closure Release Pathways**
  - Undisturbed
    - Up borehole through seals/disturbed rock zone
      - Seals represent multiple barrier with geology
      - To host rock surrounding disposal zone
        - High-permeability pathway to shallow groundwater

- **Biosphere (Dose)**
  - Subsurface release to aquifer
  - Pumping from aquifer to surface receptor

- **Primary Barrier is Geologic System**
  - Isolated, reducing, low permeability
  - Long transport pathway, likely diffusive

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Canister/Package Materials and Performance Goals

- **Conceptual Test Packages for DBFT**
  - Direct use of drill pipe steel (e.g., small test package overpack)
    - Material: alloy steel; hardened/tempered, 110 ksi yield (API* P110)
  - Possible alternative - stronger material for larger safety factor
    - More difficult to work

- **Universal Canister Materials**
  - Stainless steel (316-L)
  - Overpack for disposal - perhaps like test canister

- **Performance Goals for Disposal**
  - Canister/package structural stability for safe emplacement of waste forms
    - Non crushing in higher-pressure environment
    - Strength to support package weights above (bridge plugs between multiple packages)
  - After emplacement and sealing
    - Lifetime assumed to be ~decade(s)
    - No postclosure performance credit taken in previous analyses

*American Petroleum Institute*
DOE-Managed Small Waste Forms are Potential Candidates for DBD (SNL 2014)

- Cesium (CsCl) and strontium (SrF₂) capsules stored at the Hanford Site
  - Reasonably well understood (straightforward) materials
- Untreated calcine HLW currently stored at INL in sets of stainless steel bins within concrete vaults
- Salt wastes from electrometallurgical treatment of sodium-bonded fuels could be packaged in small canisters as they are produced
- Some smaller DOE-managed SNF
  - Currently stored in pools at Idaho National Laboratory and Savannah River Site
- Vitrified HLW that has not yet been made
  - Would need to be packaged for deep borehole disposal

Performance Goals Driven Primarily by Natural System

- Degradation rates of waste forms are not primary barrier (package – no credit taken)
- Reliance more directly on geologic conditions in crystalline basement
  - Low solubility limits on radionuclide concentrations
  - Slow transport due to diffusive flux and interaction with seals materials
    - Transport along borehole retarded by seals retarding radionuclides
    - Low permeability and sorptive/reactive
DBD Conceptual Model – Undisturbed Scenario Waste Form Concepts

Inventory and Waste Form Degradation Rates

Previous Performance Assessment (PA) Work

- 400 assemblies stacked in a 2,000 m zone
  - Radionuclide inventory and thermal output (Carter et al. 2012)
  - Waste form fractional degradation rate
    - slower = $1 \times 10^{-7}$ yr$^{-1}$
      » mass release: 50% by 4,800,000 yrs; 76% by 10,000,000 yrs
    - faster = $2 \times 10^{-5}$ yr$^{-1}$
      » mass release: 50% by 35,000 yrs; 99.9% by 350,000 yrs

Current/Future PA Work

- 1936 CsCl/SrF$_2$ capsules stacked in 1,300 m zone
  - Radionuclide inventory and thermal output from 1335 CsCl capsules and 601 SrF$_2$ capsules (SNL, 2014)
  - Degradation rates appears to be rapid – CsCl (SrF$_2$ solubility limit)
  - Cs$^+$, Sr$^{2+}$ aqueous ions interaction with clays/zeolites (seals)

Solubility Limits – Low for Redox Sensitive Radioelements
