



U.S. DEPARTMENT OF
ENERGY

SAND2015-8752PE
Nuclear Energy

Panel #6 Multiple Barriers: Waste Forms and Canister Materials

David Sassani

Principal Member of Technical Staff,

Sandia National Laboratories

DOE Office of Nuclear Energy Used Nuclear Fuel Disposition R&D Campaign

International Technical Workshop on Deep Borehole Disposal of Radioactive Waste

U.S. Nuclear Waste Technical Review Board

Washington, D.C., October 20-21, 2015

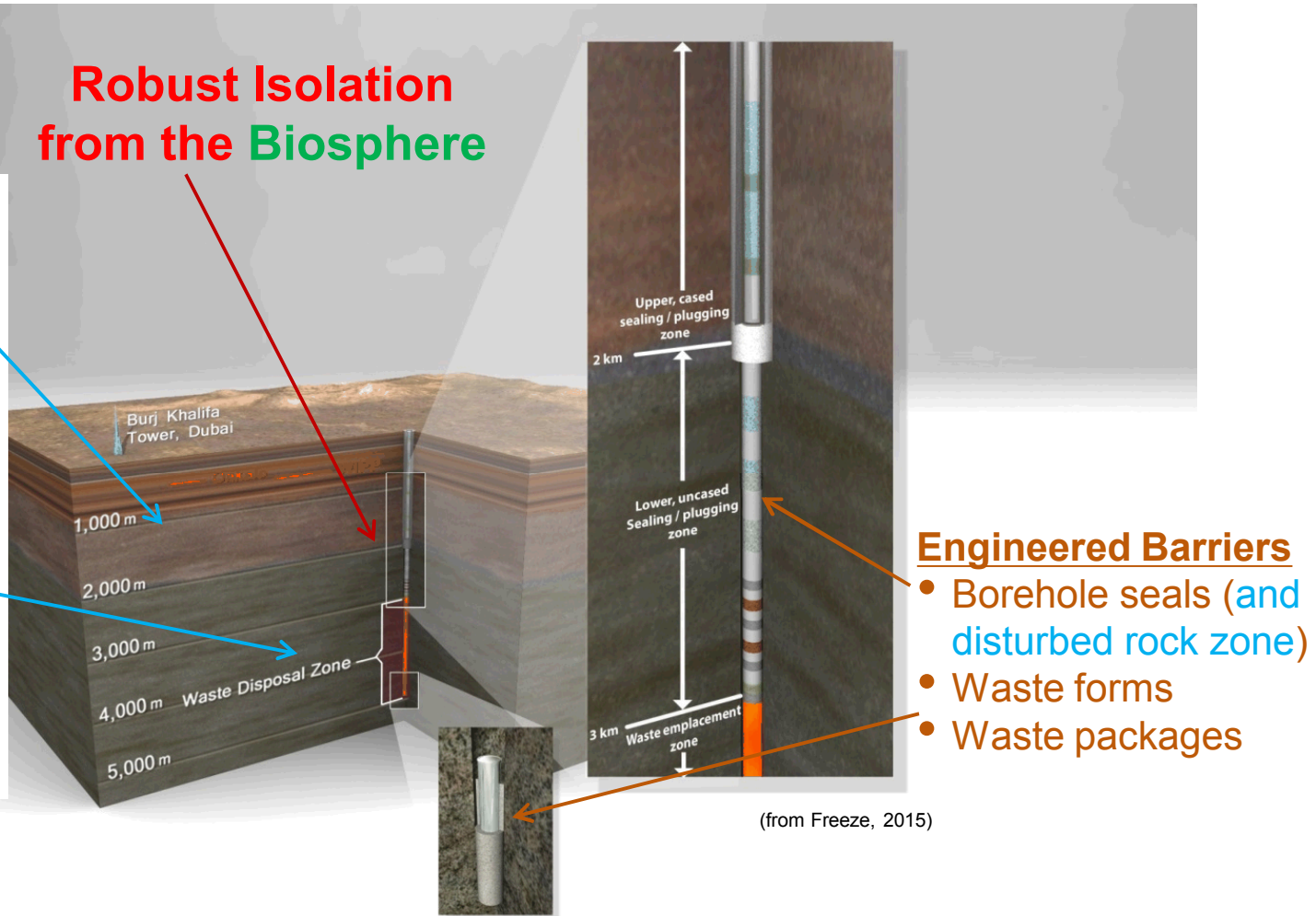


Deep Borehole Disposal Post-Closure Conceptual Model – Components

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)

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

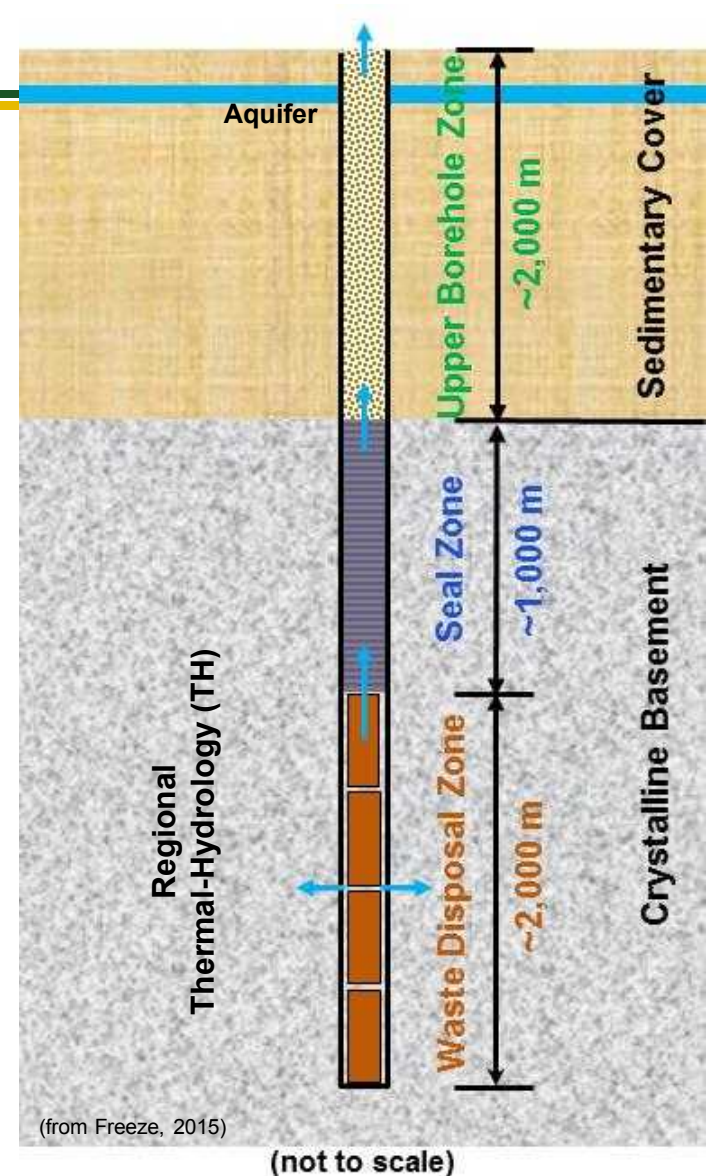
- Undisturbed
 - Up borehole through seals/disturbed rock zone
 - Seals represent multiple barrier with geology
 - To host rock surrounding disposal zone
 - High-permeability pathway to shallow groundwater

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





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

**American Petroleum Institute*

■ 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



Wastes Being Considered for Deep Borehole Disposal and Performance Goals

■ 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

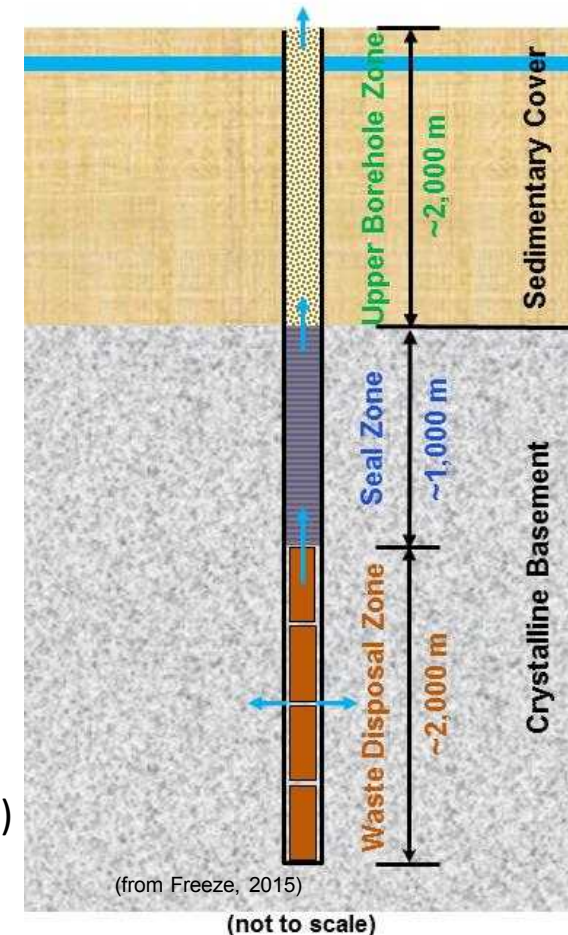
Previous Performance Assessment (PA) Work

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

Current/Future PA Work

- 1936 CsCl/SrF₂ capsules stacked in 1,300 m zone
 - Radionuclide inventory and thermal output from 1335 CsCl capsules and 601 SrF₂ capsules (SNL, 2014)
 - Degradation rates appears to be rapid – CsCl (SrF₂ solubility limit)
 - Cs⁺, Sr²⁺ aqueous ions interaction with clays/zeolites (seals)

Solubility Limits – Low for Redox Sensitive Radioelements





Nuclear Energy

- Carter, J.T., A.J. Luptak, J. Gastelum, C. Stockman, and A. Miller 2012. Fuel Cycle Potential Waste Inventory for Disposition. FCRD-USED-2010-000031, Rev. 5. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, Washington, DC.
- Freeze, G., Deep Borehole Disposal (DBD): Licensing and Post-Closure Safety Assessment. SAND2015-5637PE, U.S. Nuclear Waste Technical Review Board Briefing, Sandia National Laboratories, Albuquerque, NM, July 2015.
- SNL (Sandia National Laboratories) 2014. Evaluation of Options for Permanent Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste. FCRD-UFD-2013-000371 Rev. 1, SAND2014-0187P (Vol. I) and SAND2014-0189P (Vol. II). U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, Washington, DC.