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Spent Fuel and Waste Science and Technology

Deep Borehole Disposal (DBD) Process Model Integration

Geoff Freeze

Sandia National Laboratories

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DBD Control Account (1.08.01.03.06) – Scope

- **Deep Borehole Field Test (DBFT) (DOE 2016)**
  - ~5-year project to evaluate feasibility of siting and operating a DBD facility
  - Ongoing planning, R&D, and DOE contractor support
    - Characterization Borehole (CB): 5,000 m deep, 8.5 in. diam., for downhole science
    - Field Test Borehole (FTB): 5,000 m deep, 17 in. diam., for engineering demonstration
    - DBFT will use surrogate waste packages (no radioactive waste)
- **FY16 M2 Technical Reports**
  - DBFT Project Plan, Rev. 1 (SNL 2016a)
  - DBFT Site Geoscience Guidelines and Data Evaluation (Sassani et al. 2016)
  - DBFT Conceptual Design (SNL 2016b)
  - DBFT Laboratory and Borehole Testing Strategy (SNL 2016c)
  - DBD Safety Analysis (Freeze et al. 2016) → Final DBD PA needed ~2020
- **Collaborating National Labs**
  - SNL, LANL, LBNL, ORNL, PNNL, INL

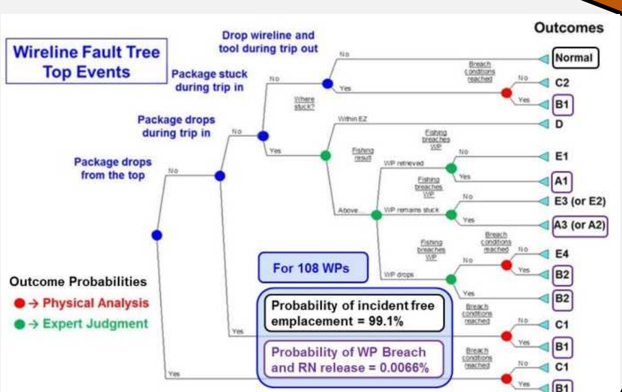
DBD Safety Case – Safety Assessment

Safety Assessment

Pre-Closure Safety Analysis	Post-Closure Performance Assessment	Confidence Enhancement
• Transportation safety analysis • Construction safety analysis • Operational safety analysis	• FEP analysis • Scenario development • Model development • Software/model validation • PA model analyses • Uncertainty and sensitivity analyses	• Independent evidence • Natural analogues • Technical arguments • Long-term extrapolation • Detailed process modeling

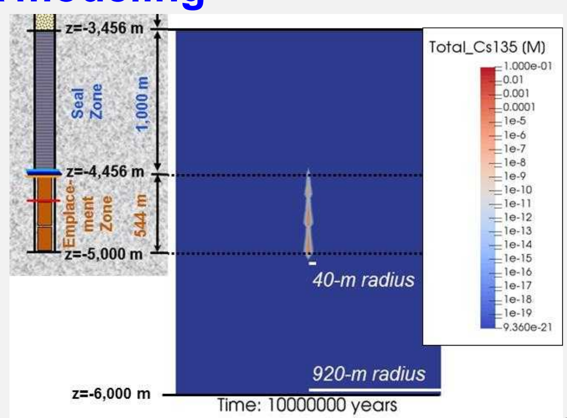
Pre-Closure Safety Analysis

- Hazards and Event Sequences



Post-Closure Performance Assessment

- FEP identification and screening
- Scenarios (undisturbed)
- PA modeling



Confidence Enhancement

- Independent evidence

Freeze et al. (2016)

SNL (2016b) Hardin and Su (2017)

DBD Concept – R&D Needs

- **R&D is necessary in several important areas for further consideration of deep borehole disposal of radioactive waste, including:**
  - Evaluation of drilling technology and borehole construction to 5,000 m depth with sufficient diameter for cost effective waste disposal
  - Development and testing of engineering methods for waste package loading, shielded surface operations, waste package handling and emplacement, and borehole seals deployment
  - Evaluation of waste, packaging, and sealing materials at representative temperature, pressure, salinity, and geochemical conditions
  - Verification of deep geological, geochemical, and hydrological conditions at a representative location
- **The DBFT will provide R&D opportunities in these areas**

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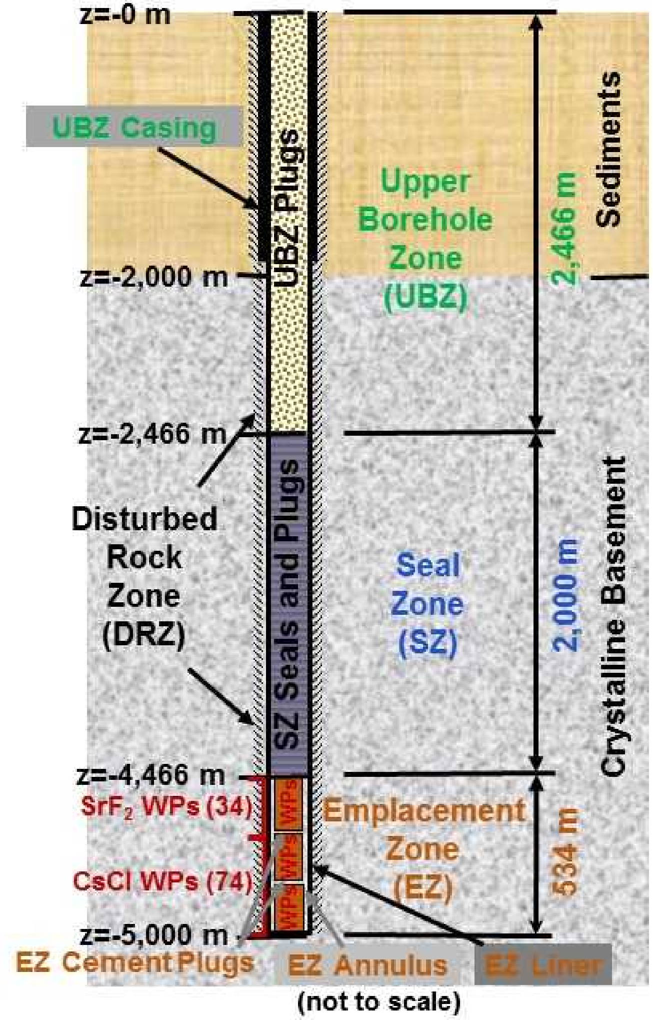
Post-Closure PA for DBD of Cs/Sr Capsules

- **All 1936 Cs/Sr capsules fit in a single borehole with a 534-m Emplacement Zone**
  - 108 WPs (4.76 m each)
    - *34 Sr WPs in upper EZ*
    - *74 Cs WPs in lower EZ*
    - *18 Cs or Sr capsules per WP*
  - 2 cement plugs (10 m each)
  - Bottom-hole diameter = 31.1 cm (12.25 in)
- **Seal Zone consists of alternating layers of cement plugs, bentonite seals, and crushed rock ballast**
- **Radionuclide transport pathways**
  - Up borehole through Seal Zone (seals/ DRZ)
  - To host rock surrounding Emplacement Zone
- **Biosphere**
  - Not currently modeled



UFD R&D Roadmap Appendix B – Deep Borehole FEP Prioritization (Waste, Seals, Crystalline Host Rock)

UFD FEP No. – FEP Name -- Media	Overall Priority Score
2.2.01.01 -- Evolution of DRZ -- Deep Boreholes	6.13
2.2.09.01 -- Chemical Characteristics of Groundwater in Host Rock -- Deep Boreholes	5.86
2.2.09.05 -- Radionuclide Speciation and Solubility in Host Rock -- Deep Boreholes	5.86
2.2.09.03 -- Chemical Interactions and Evolution of Groundwater in Host Rock -- Deep Boreholes	5.40
2.1.09.13 -- Radionuclide Speciation and Solubility in EBS	4.86
2.2.02.01 -- Stratigraphy and Properties of Host Rock -- Deep Boreholes	3.74
2.2.05.01 -- Fractures -- Host Rock -- Deep Boreholes	3.65
2.2.08.01 -- Flow Through the Host Rock -- Deep Boreholes	3.65
2.2.08.06 -- Flow Through DRZ -- Deep Boreholes	3.65
2.2.11.04 -- Thermal Effects on Chemistry and Microbial Activity in Geosphere -- Deep Boreholes	3.55
2.1.04.01 -- Evolution and Degradation of Backfill/Buffer	3.50
2.1.05.01 -- Degradation of Seals	3.50

Waste/Emplacement Zone
Seals/DRZ
Host Rock Crystalline Basement

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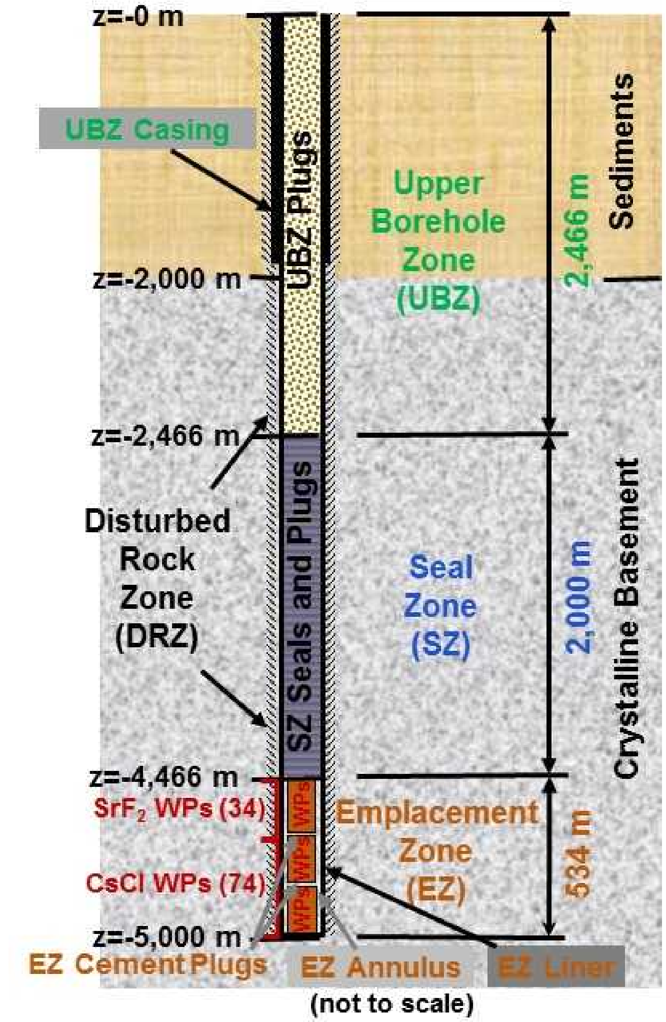
Post-Closure PA – Undisturbed Scenario

- **Emplacement Zone Key Processes**
  - Temperature effects (Task 28)
    - *Ambient = 125°C to 140°C in EZ*
    - *Max. due to heat from ^{90}Sr and ^{137}Cs decay = 240°C in EZ*
  - Thermally-induced upward fluid flux (Task 27)
    - *Short duration (days/years) fluid thermal expansion*
    - *Longer duration (10s-100s of years) buoyant convection*
    - *Most evident in brine-filled EZ annulus*
  - WF (solid CsCl, SrF_2) degradation
    - *assumed to be instantaneous*
    - *no solubility limits for Cs (reasonable) or Sr (conservative)*
  - WP (carbon steel) degradation
    - *breach assumed at 1 year after sealing/closure*
    - *PA is sensitive to slower breach (up to 100 years)*
  - Cement plug degradation (Task 29)
    - *alkaline chemistry*
  - Gas generation from WP and EZ liner corrosion
  - Colloid formation



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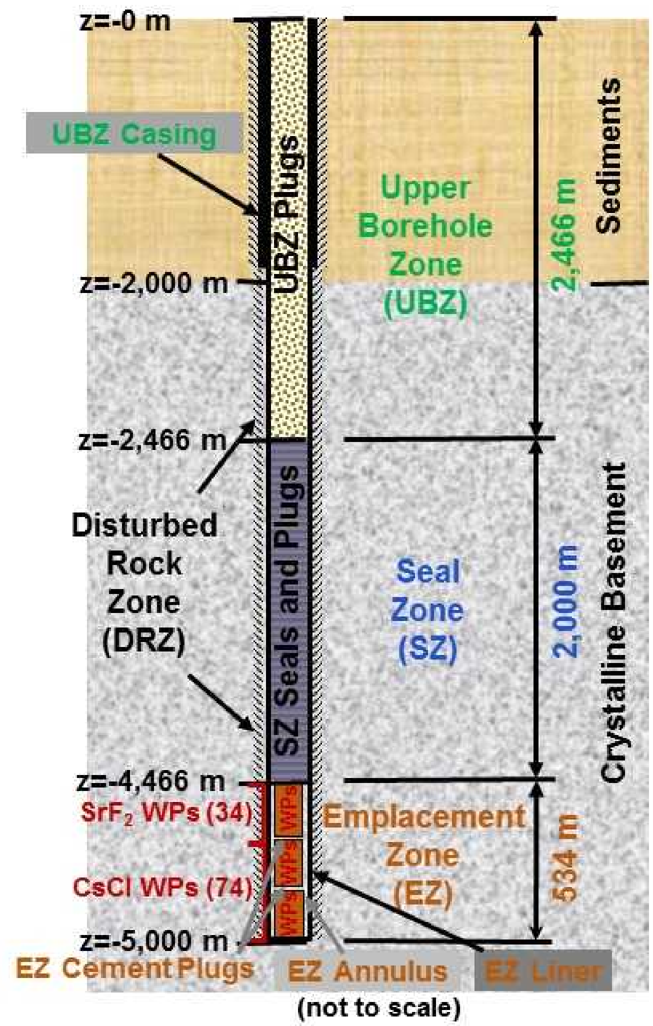
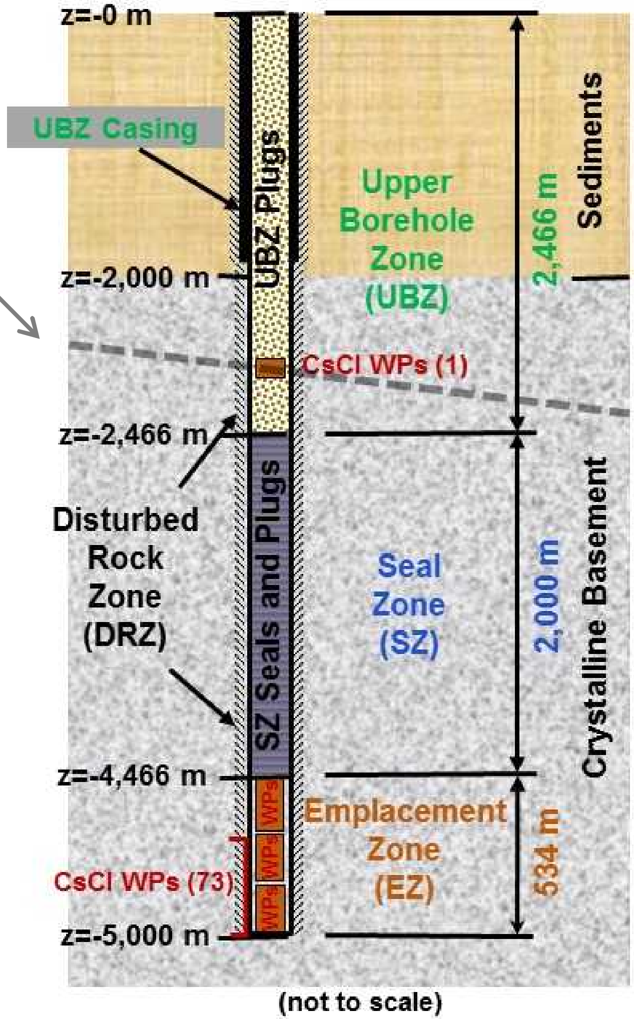
Post-Closure PA – Undisturbed Scenario

- **Seal Zone Key Processes**
  - Cement plug degradation (Task 29)
    - *alkaline chemistry*
  - Bentonite evolution/degradation
    - *radionuclide sorption*
  - DRZ evolution
  - Preferential flow and transport pathways
    - *Vertical connected fracture/damage pathways through seals and/or DRZ*
  - Re-equilibration of ambient salinity gradient / density stratification (Task 26)
    - *opposes upward fluid flux*
    - *defines time after which seal performance is less important*



Post-Closure PA – Disturbed Scenarios

- **"Stuck" Waste Package**
  - High-permeability fracture pathway to shallow groundwater
    - *FCM and DFN representations of fracture network*
- **Seismic / Igneous**
- **Human Intrusion**



DBD Process Models and Testing – Key Models for Integration

- **Salinity-dependent density (Task 26)**
  - For prediction of re-establishment of ambient conditions
    - FEPs: 2.2.09.03 (5.40), 2.2.08.01 (3.65)
- **High temperature (T ≤ 250°C) behavior (Task 28)**
  - Material degradation, geochemistry and solubility, Pitzer at high-T
    - FEPs: 2.2.09.01 (5.86), 2.2.09.05 (5.86), 2.2.11.04 (3.55)
- **Flow and transport in EZ annulus region (Task 27)**
  - Thermally-induced upward flux
    - FEPs: 2.1.09.13 (4.86), 2.1.04.01 (3.50)

- **Ongoing Modeling and Laboratory Experiments:**
  - Swedish COSC borehole core studies (LBNL)
  - Local/regional THC models of geochemistry, flow, and transport (SNL, LBNL)
  - Borehole testing strategy (SNL)
  - Develop CFD model for flow in EZ annulus?

DBD Process Models and Testing – Key Models for Integration

- **Seals**
  - Bentonite degradation
  - Cement chemistry / alkaline plume (Task 29)
    - FEPs: 2.2.01.01 (6.13), 2.2.08.06 (3.65), 2.1.05.01 (3.50)
- **Fracture representation (FCM, DFN)**
  - DRZ and host rock evolution
    - FEPs: 2.2.02.01 (3.74), 2.2.05.01 (3.65)

- **Ongoing Modeling and Laboratory Experiments:**
  - Sealing methods and materials (SNL / U of Sheffield)
  - Seal / DRZ modeling and lab experiments (LBNL)
  - Geomechanical models of borehole breakout and DRZ (SNL, LBNL)
  - Geologic framework model (LANL, SNL, LBNL)
  - DBD PA model (SNL)

DBD Concept – Summary and Conclusions

- **Recent studies have identified no fundamental flaws regarding safety or implementation of the DBD concept**
  - Preliminary DBD safety case analyses suggest:
    - *Pre-closure – low probability of operational failures*
    - *Post-closure – robust waste isolation for 1,000,000 years (^{135}Cs)*
  - DOE has made no decision to dispose of any waste in deep boreholes
- **Additional R&D is necessary in several important areas**
  - The DBFT will provide further insights into the feasibility of the DBD concept
- **Open issues (Freeze et al. 2016, NWTRB 2016):**
  - Drilling feasibility and borehole breakout
  - Operational feasibility and pre-closure safety – additional hazard analyses needed for: transportation, worker exposure, surface handling, and external events (e.g., seismic, flooding, sabotage)
  - Waste form and waste package degradation / longevity
  - Colloidal transport
  - Effects of gas generation (from metal corrosion), microbes, and/or radiolysis
  - Seal (and DRZ) characteristics and evolution
  - Deep subsurface characterization

References

- DOE (U.S. Department of Energy) 2016. *Request for Proposal (RFP) – Deep Borehole Field Test: Characterization Borehole Investigations*. Solicitation Number DE-SOL-0010181, US Department of Energy Idaho Operations Office, Idaho Falls, ID.
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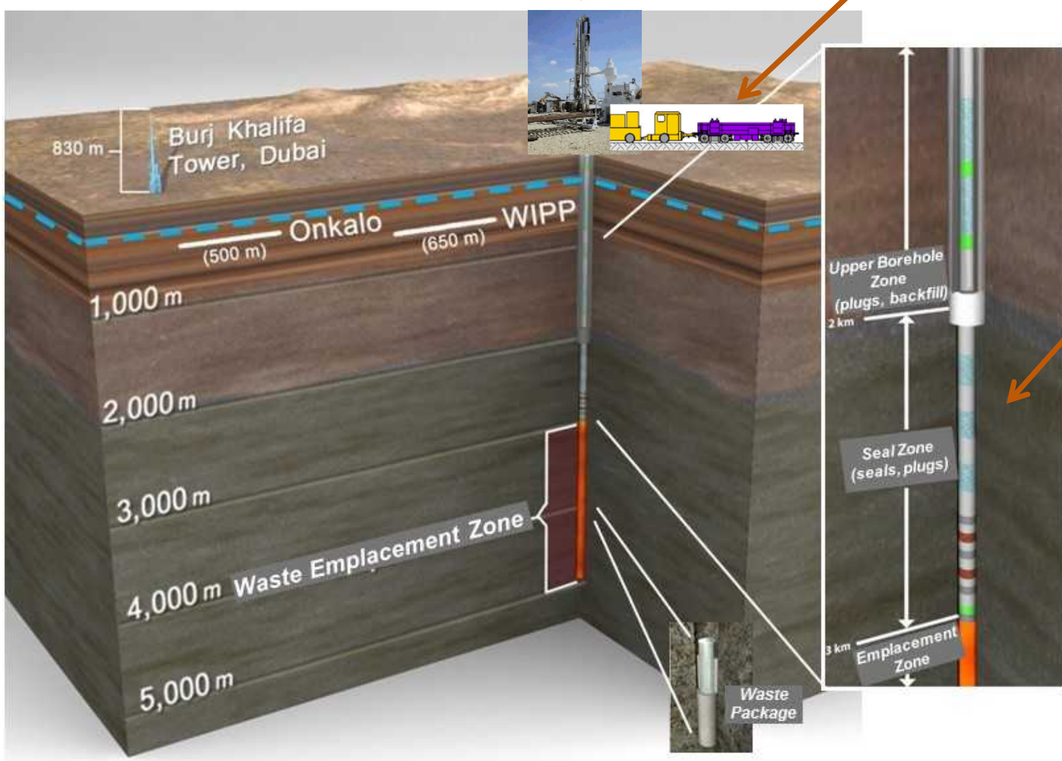
Backup Slides

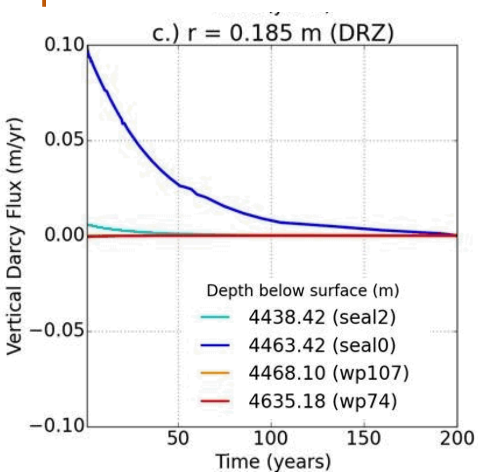
DBD Concept – Operational Feasibility and Pre-Closure Safety

Existing drilling technology should permit dependable construction at acceptable cost

Waste package emplacement system can be engineered to maintain structural integrity and operational safety during surface handling and downhole emplacement



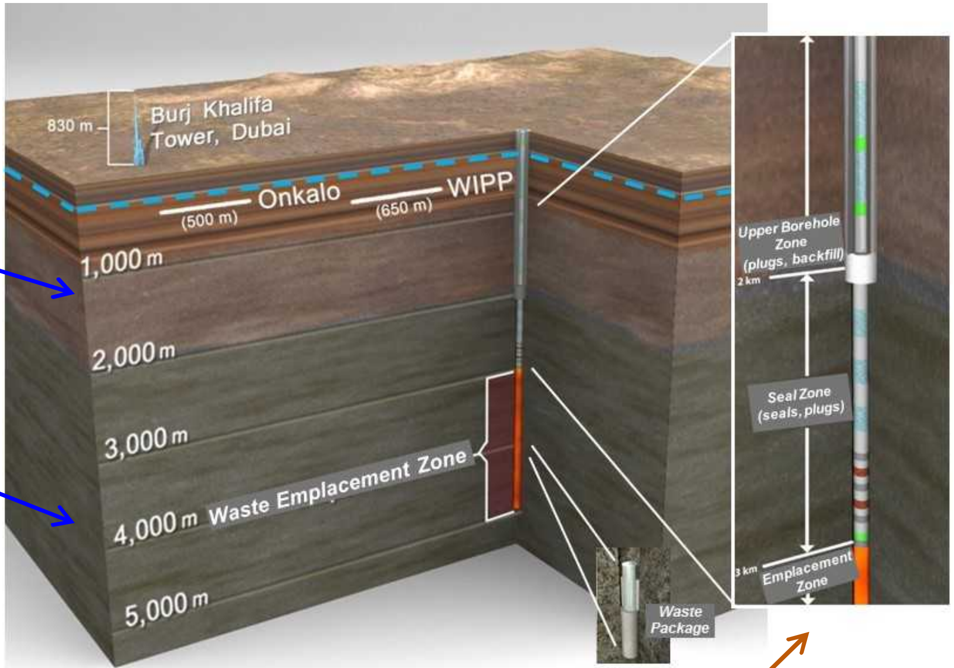
Borehole seals can be engineered and emplaced adjacent to the disturbed rock zone (DRZ) to maintain a low-permeability barrier over the period of thermally-induced upward flow



(Freeze et al. 2016)

DBD Concept – Long-Term Performance and Post-Closure Safety

Robust Multiple-Barrier Isolation of Waste from the Biosphere
- Waste disposal is deep in crystalline basement rock
- Crystalline basement within 2,000 m of the surface is common in many stable geologic regions
- At least 1,000 m of crystalline rock (seal zone) overlying the waste emplacement zone



Natural Barriers
- Overlying Sediments
- Crystalline Basement
  - Hydrologically isolated from shallow groundwater (typically low permeability and long groundwater residence time in deep crystalline rocks)
  - Deep groundwater typically exhibits density stratification (saline groundwater underlying fresh groundwater) that opposes upward convection
  - Geochemically reducing conditions limit the solubility and enhance the sorption of many radionuclides

Engineered Barriers
- Waste Forms
- Waste Packages
- Borehole Seals

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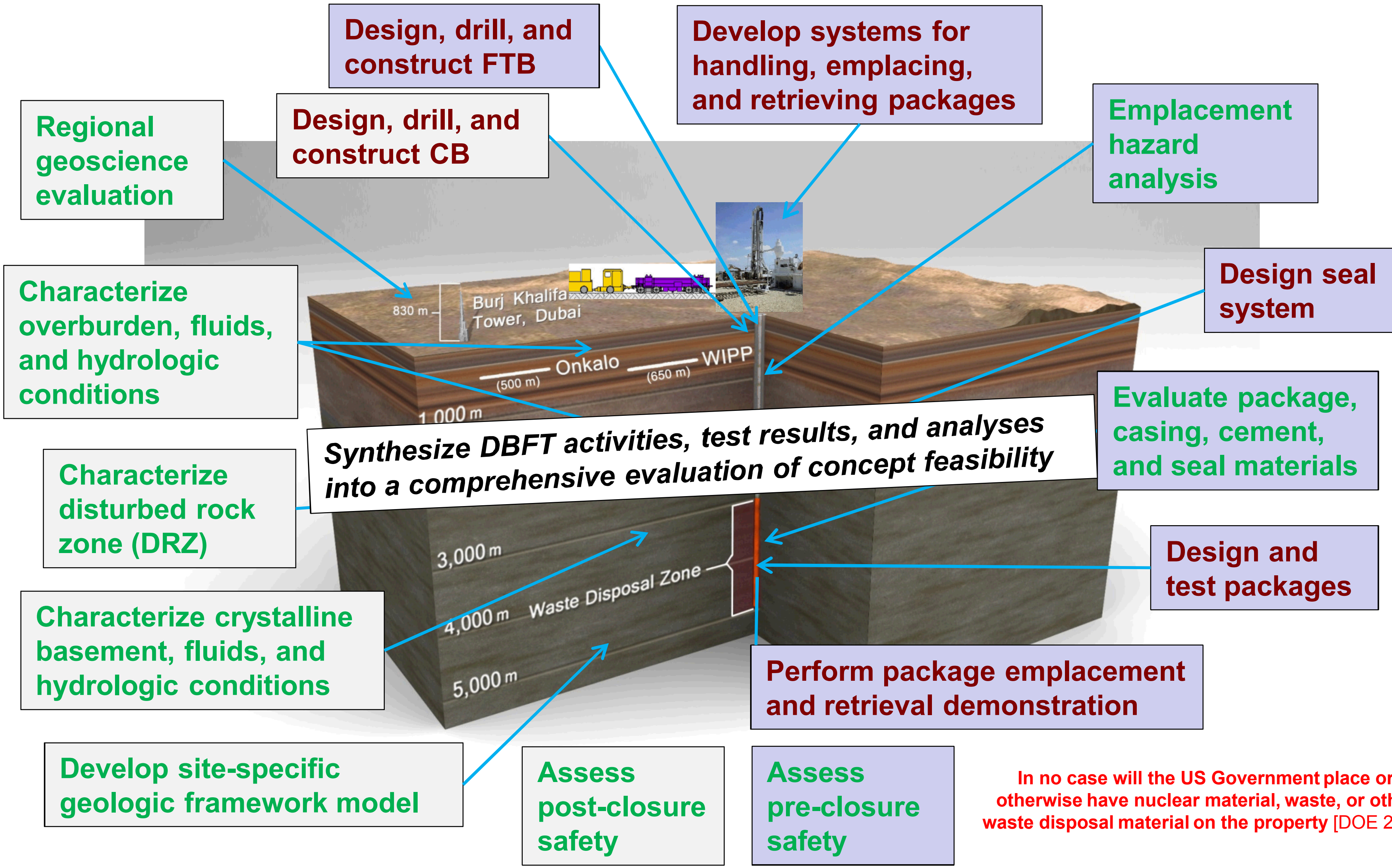
Deep Borehole Field Test (DBFT)



In no case will the US Government place or otherwise have nuclear material, waste, or other waste disposal material on the property [DOE 2016]