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# Deep Borehole Disposal Engineering

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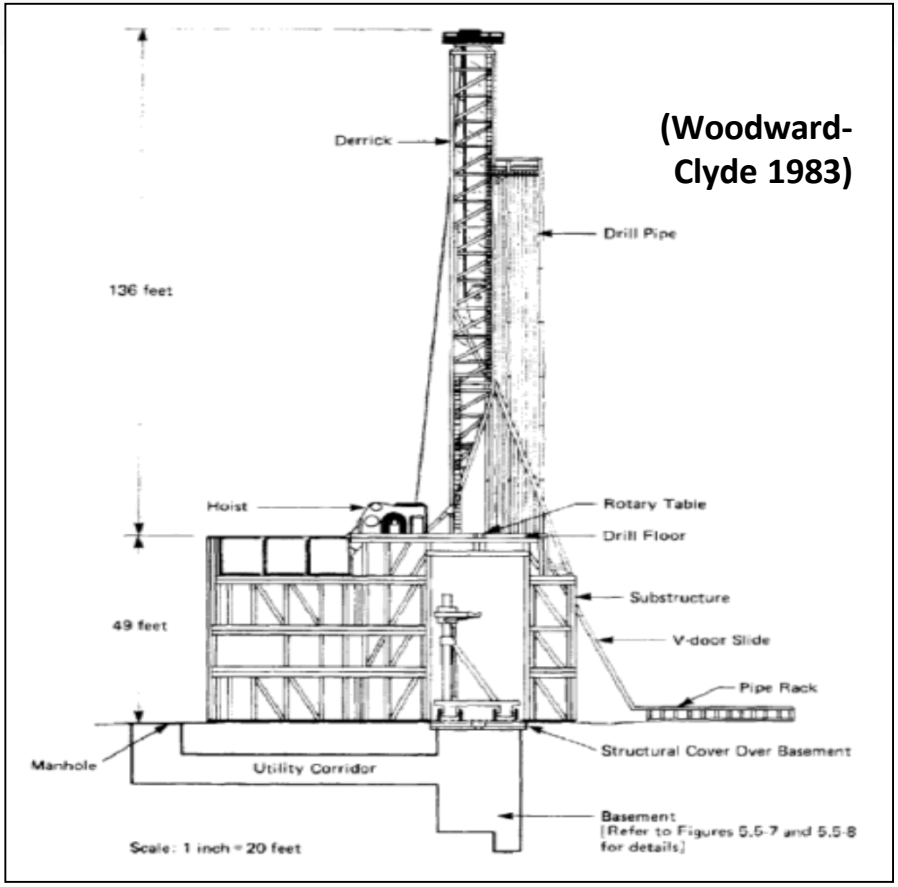
# Outline

- Borehole Emplacement Concepts
- Deep Borehole Field Test Engineering Design Study
- Borehole Environment
- Disposal Overpack/Waste Package Design Concepts
- Safety of Disposal Operations
- Disposal Borehole and Overpack Size Tradeoffs
- Waste Canister – Overpack Design Interface
- DBD Requirements Flowdown to DBFT
- Q&A

# Deep Borehole Disposal
# Alternative Emplacement Concepts*

## Drill-String Emplacement




## Wireline Emplacement



* Workover rig needed for borehole sealing and plugging

# Deep Borehole Field Test Engineering Design

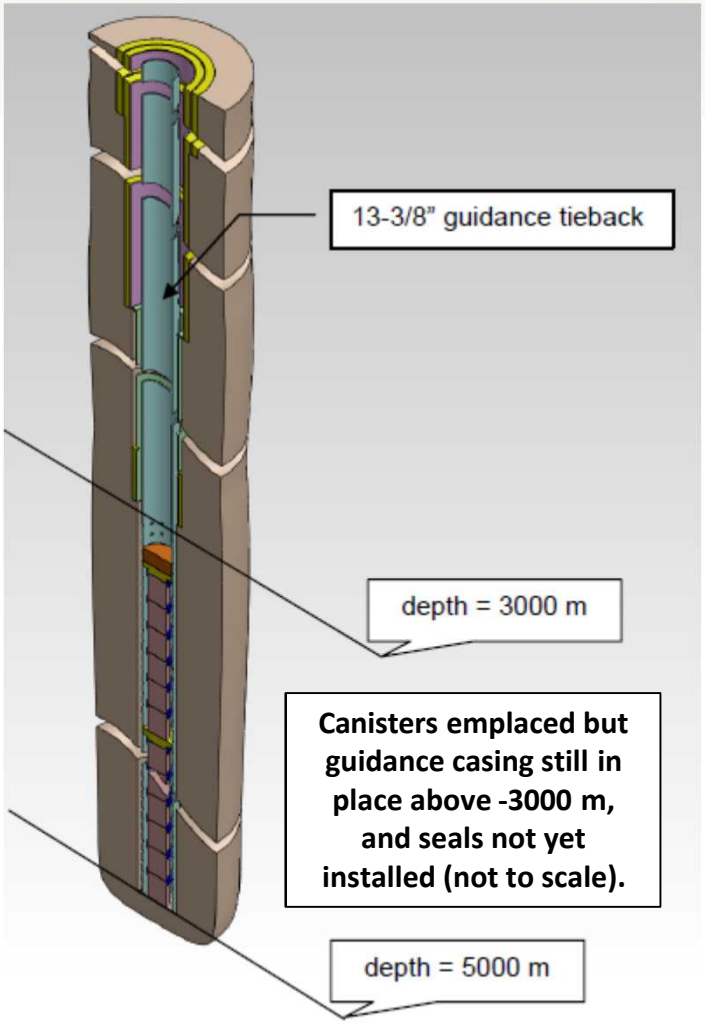
- **Conceptual Design FY15**
  - Conceptual Design Report
    - Emplacement Option Description
    - Hazard/Risk Analysis
    - Costing
    - Overpack/Package Concepts
    - Emplacement Mode Selection
- **Final Design FY16**
  - Design Package
    - Design, Fabrication Specs.
    - Safety Manual, Procedures, Testing
    - Transport Cask Integration
- **Fabrication/Testing FY17**
- **Field Implementation FY18-19**

**Engineering Services Contractor Support**

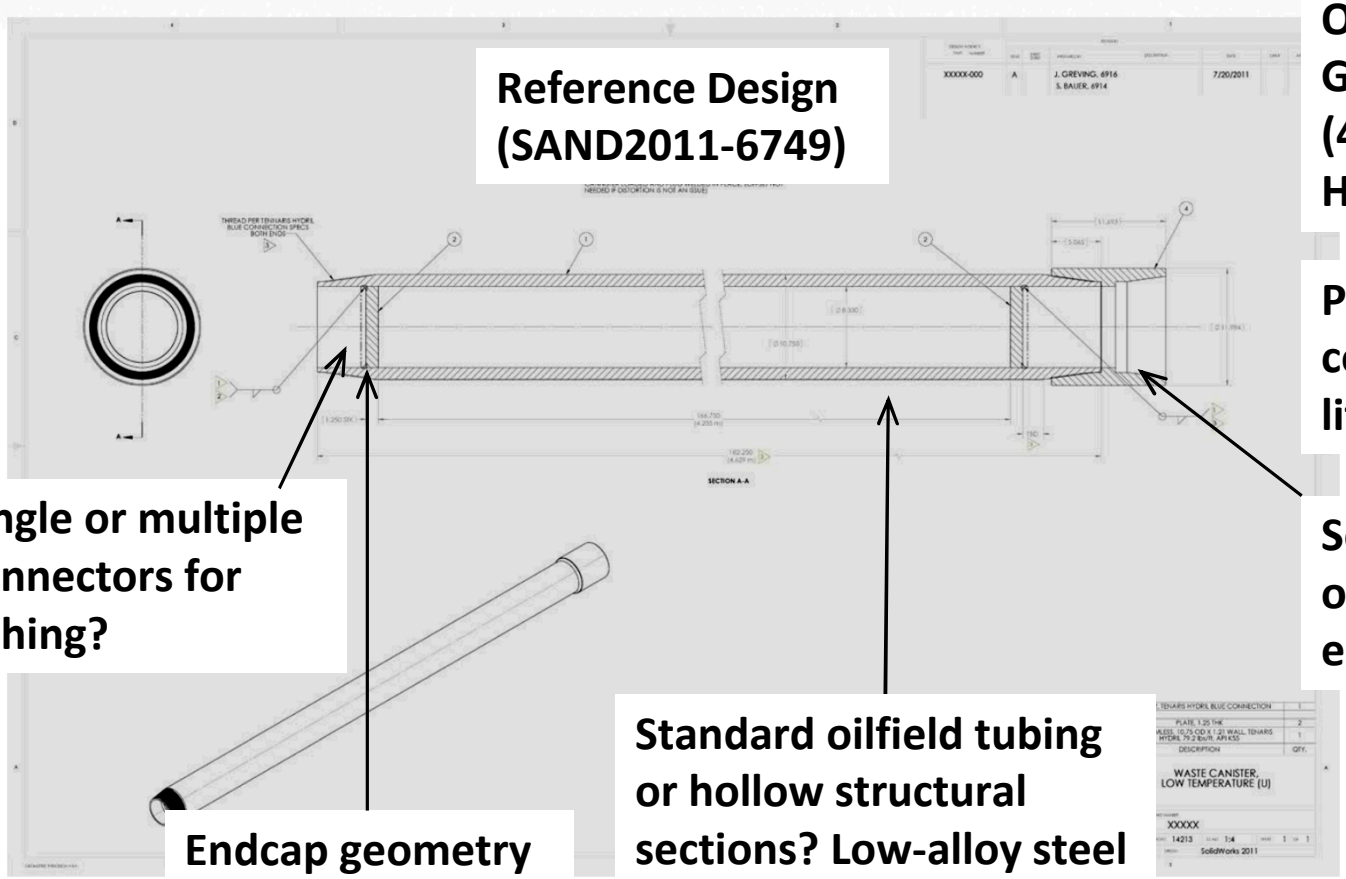
**Additional Procurement**

# Borehole Environment

- **Thermal**
  - 170°C background (+/-)
- **Hydrologic**
  - 9.6 ksi downhole pressure with 1.3× borehole fluid
- **Mechanical**
  - Steel liner from surface
- **Chemical**
  - Chloride brine
- **Longevity of Construction and Packaging Materials**
  - Nominally ≤ 10 years



# Deep Borehole Disposal
# Disposal Overpack Design Questions



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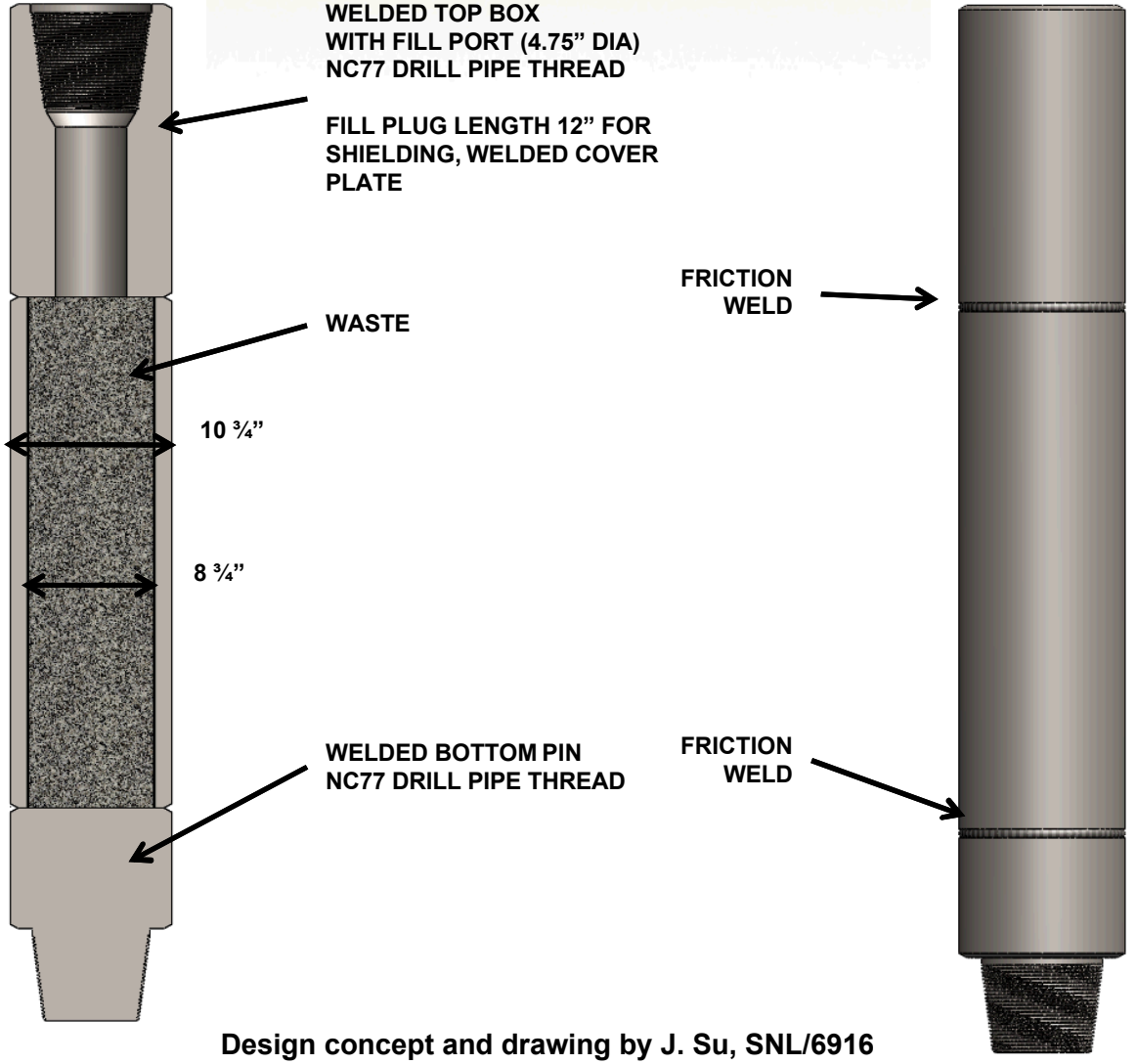
# Overpack/Package Conceptual Design

- **Same concepts for wireline and drill-string emplacement**
- **Axial load ~150,000 lb (tensile, compressive)**
- **Bending stresses**
- **Provision for fishing**
- **Requirement: factor of safety ≥ 2.0**
- **Terminology**
  - Canister – Thin-wall sealed (stainless) vessel
  - Disposal Overpack – Heavy container for canistered wastes
  - Waste Package – Heavy container for bulk wastes
  - Examples (Cs/Sr capsules, DOE/EM bulk wastes, SNF)

# Option #1 Waste Package – Flask Type
## Reference size 10.75” max. OD




All weld heat mitigation except cover plate, done before waste loading.

Minimal weld-heat effect on loaded waste.

API schedule tubulars.

Design concept and drawing by J. Su, SNL/6916



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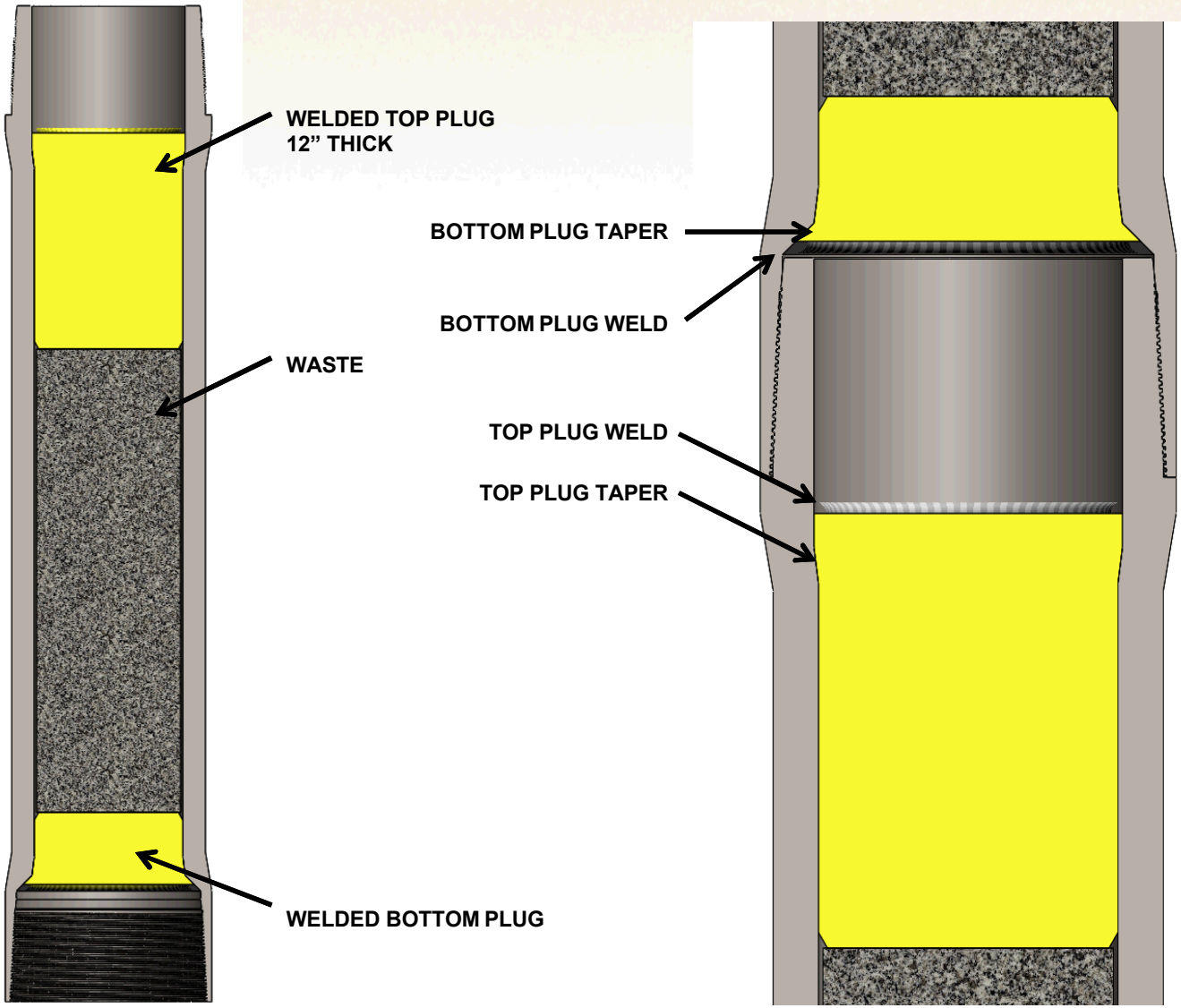
# Option #2 – Bulk Waste Overpack

## Reference size 11” max. OD




- Internal-flush design for canistered waste forms.
- No fabrication welds in axial load path.
- External upset (forged) connections.
- Possible weld-heat effect on loaded waste.
- Novel taper/weld sealing design.
- API schedule tubulars.

Design concept and drawing by J. Su, SNL/6916



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# Option #4 Cs/Sr Capsule Overpack

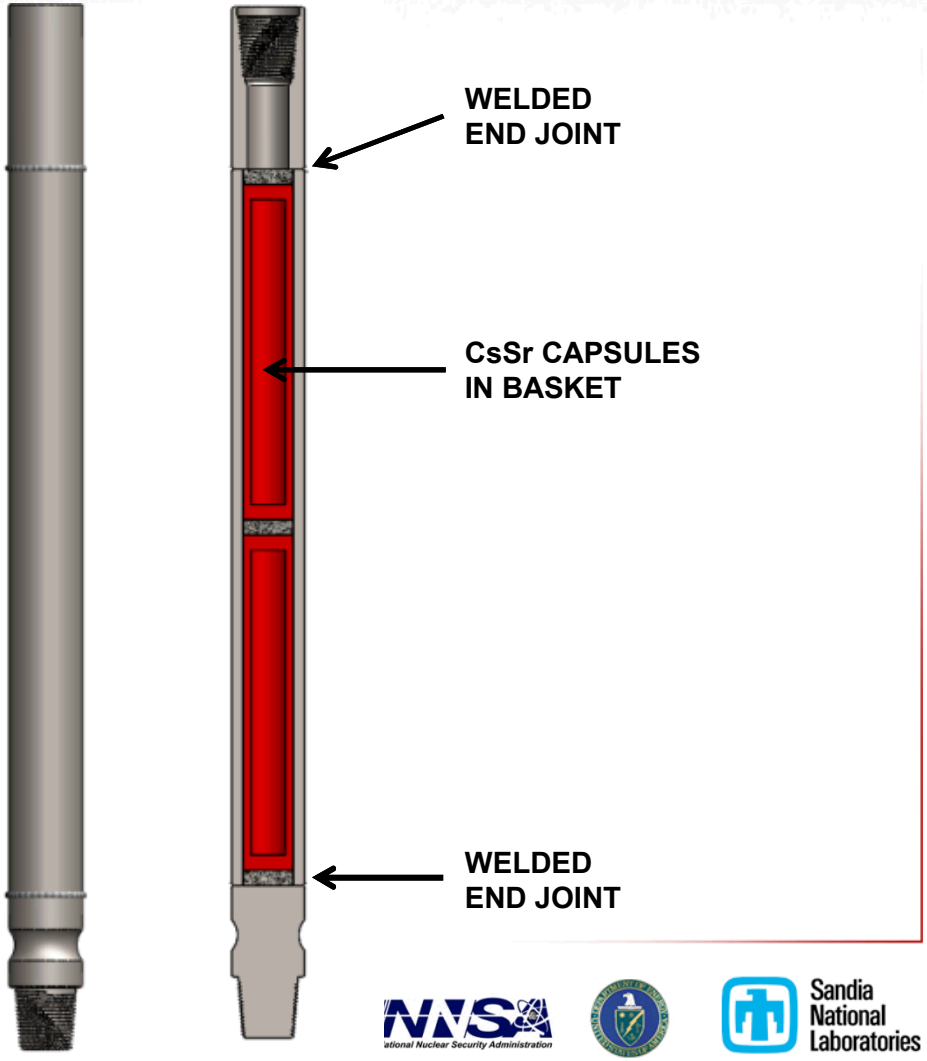
## Reference size ~5” OD

## Flask-type for loading the majority of capsules (2.6” OD)

- Welded API NC38 connections
- 5.0” OD x 4.0” ID
- 19,800 psi collapse pressure
- (Not to scale)

**Canister may contain up to 8 CsSr capsules end-to-end.**

Design concept and drawing by J. Su, SNL/6916



# Overpack/Package Design Concepts Summary

| # | Application | Cost | Pros | Cons |
|---|---|---|---|---|
| 1 | Large canister bulk waste (smaller version for 3-capsule bundles) | ~$10k for body | External flush<br>Standard API thread<br>Post-weld heat treatment | Welds in axial load path<br>Flask-type waste loading limitations |
| 2 | Large canister bulk waste (smaller version for 3-capsule bundles) | TBD | External upset (strong)<br>No welds in axial load path | External upset tubing hard to find (Tenaris)<br>Sealing weld after waste loading |
| 3 | Large canister bulk waste/3 capsule groups | TBD | External semi-flush<br>No welds in axial load path | Lower collapse pressure<br>Smaller OD, less waste volume<br>Custom mill run<br>Sealing weld after waste loading |
| 4 | Stacked Cs/Sr capsules (2.6” OD) in canister or basket | TBD | External flush<br>Standard API thread<br>Post-weld heat treatment | Welds in axial load path<br>Flask-type waste loading limitations |
| 5 | Stacked Cs/Sr capsules (2.6” or 3.3” OD) in canister or basket | TBD | External flush<br>No welds in axial load path | Custom mill run<br>Sealing weld after waste loading |

# Deep Borehole Disposal
# Waste Canister – Overpack Design Interface

- **Physical Environment for Waste Canisters (size, weight, temperature)**
- **Shielding Requirements for Waste Forms**
- **Transportation Effects (remote disposal locations)**
- **Overpack Closure Welding**
- **Other Possible Interface Specs.**
  - Canister handling features (e.g., grapple for loading)
  - Material compatibility
  - Waste heat generation
  - Canister fillers
- **Waste and Environment Data for Postclosure PA**

# Safety of Disposal Operations

- **DB Field Test vs. Potential Future Disposal System**
  - DBFT will have zero radiological risk
- **Accident Prevention During Emplacement Operations**
  - DBFT engineering: safety analysis of emplacement that discriminates between alternative emplacement concepts
- **Downhole Failure Modes/Accidents (disposal system)**
  - Single canister drop in borehole (zero consequence?)
  - Pipe string + waste packages drop in borehole
  - Pipe string drop onto canister(s)
  - Canister leak/crush
  - Fishing operations (pipe string or wireline)
  - External hazards (seismic, extreme weather; potentially significant to selection of emplacement mode?)

# Disposal Borehole and Overpack Size Tradeoffs

| Borehole and Canister Sizes >>>> | Small | Medium | Reference | Large |
|---|---|---|---|---|
| Waste per Canister >>>> | 2 to 8 capsules end-to-end | 3-capsule groups stacked ≤ 8 high | Bulk | Bulk |
| Disposal Zone Hole Diameter | 8.5” | 12.3” | 17” | 22” |
| Disposal Zone Casing ID | 6.4” | 9.8” | 12.6” | 17.4” |
| Disposal Overpack OD | 5” | 8.5” | 11” | 16” |
| Disposal Overpack ID | 4” | 6.5” | 8.5” | 12” |
| Avail. Disposal Volume/Borehole ($ft^3$) | 460 | 1220 | 2,090 | 4,170 |
| Disposal Canister Length (ft) | 3.9 to 15.6 | 3.9 to 15.6 | 16.7 | 16.7 |
| Canister Capacity | 2 to 8 capsules | 6 to 24 capsules | 5.2 $ft.^3$ | 10.4 $ft.^3$ |
| # Waste Packages/Disposal Zone | 968 to 242 | 323 to 81 | 400 | 400 |
| Capsule Disposal Interval Height | ~4,500 ft * | ~1,500 ft * | | |
| Drilling/Completion Costs ($M) | < 20 * | < 25 * | 40 | 60 |
| Borehole Cost/Disposal Vol. ($k/$ft^3$) | < 40 * | < 26 * | 19 | 15 |
| ($/$in^3$) | < 23 * | < 15 * | 11 | 8 |

* Capsule disposal intervals are less than the length of 2 km (6,560 ft) used for borehole cost estimation, so borehole costs would be less.

# DBD Flowdown to DBFT Requirements (1/6)

<table>
<tr><th>Waste Disposal Requirement</th><th>Deep Borehole Field Test Requirement</th></tr>
<tr><td colspan="2">1.1 Industrial Safety and Health</td></tr>
<tr><td colspan="2">1.2 Radiological Protection</td></tr>
<tr><td rowspan="2">Radiation Exposure to Workers and the Public – Waste package loading, welding/sealing, handling, transport, emplacement, and retrieval equipment and operations shall comply with applicable radiological dose standards (e.g., 10CFR20). Engineered systems shall maintain exposures ALARA.</td><td>Radioactive Materials – Radioactive sealed sources used for well logging shall be removed from the site. No other designated radioactive materials or wastes will be used in the DBFT.</td></tr>
<tr><td>Test Design to Demonstrate Radiological Protection Capability – DBFT waste package handling, emplacement, and retrieval shall demonstrate that radiation exposure to workers could be effectively limited.</td></tr>
<tr><td colspan="2">1.3 Safeguards and Security Requirements</td></tr>
<tr><td colspan="2">1.4 Quality Assurance Requirements</td></tr>
</table>

# DBD Flowdown to DBFT Requirements (2/6)

| Waste Disposal Requirement | Deep Borehole Field Test Requirement |
|---|---|
| **1.5 Other Statutory and Regulatory Requirements** | |
| **1.6 Functional Requirements** | |
| **1.7 Operating Requirements** | |
| | **…** |
| | **Material Control** – Materials used in the Characterization and Field Test Boreholes shall be restricted to those on a list maintained by the Project Manager. |
| | **Material Inventory** – Materials used in the boreholes shall be logged, recording type, quantity, date of use, location of use, and manner of introduction. |
| | **Water Tracer** – All water (including makeup water for mud or cement) that is used in subsurface operations or otherwise introduced to the DBFT boreholes, will be tagged with a conservative tracer that is selected so that the presence of such water can be appropriately quantified in any fluid samples recovered for analysis. |
| | **…** |

# DBD Flowdown to DBFT Requirements (3/6)

| Waste Disposal Requirement | Deep Borehole Field Test Requirement |
|---|---|
| **1.8 Performance Criteria** | |
| … | … |
| **Disposal Borehole Service Life** – Borehole construction and completion shall be designed with service lifetime of 10 years, for safe disposal operations and sealing. | **Field Test Borehole Service Life** – Design service lifetime of the Characterization and Field Test Boreholes shall be 10 years, considering casing corrosion, creep, and other significant degradation processes. |
| … | … |
| **1.9 Borehole Design and Construction** | |
| … | … |
| **Borehole Deviation –** Waste disposal borehole(s) shall be constructed so that: 1) horizontal lineal deviation does not exceed 50 m; and 2) maximum dogleg severity specifications are met (Table 2). | **Borehole Deviation –** The Characterization Borehole and Field Test Borehole shall be constructed so that: 1) horizontal lineal deviation does not exceed 50 m; and 2) maximum dogleg severity specifications are met (Table 2). |
| … | … |

# DBD Flowdown to DBFT Requirements (4/6)

| Waste Disposal Requirement | Deep Borehole Field Test Requirement |
|---|---|
| **1.10 Waste Packaging Requirements** | |
| … | … |
| **Disposal Zone Pressure** – Waste packages shall perform in borehole fluid with minimum pressure from pure water and borehole depth, and maximum pressure TBD. | **Test Disposal Zone Pressure** – Test waste packages shall perform in borehole fluid with minimum pressure from pure water and borehole depth and maximum pressure for with maximum fluid density (Table 2). |
| **Waste Package Factor of Safety** – Minimum FoS for mechanical integrity calculations will be based in part on DBFT results and is TBD. | **Test Waste Package Factor of Safety** – Minimum FoS for mechanical analysis shall be 2.0 with respect to elastic/plastic analysis with idealized geometry. |
| … | … |

# DBD Flowdown to DBFT Requirements (5/6)

| 1.11 Waste Package Emplacement and Retrieval | |
|---|---|
| … | … |
| (The need for wellhead blowout prevention equipment in waste disposal boreholes is TBD.) | **Field Test Wellhead Preventer** – Test waste package emplacement and retrieval shall be configured so these operations can be performed with a blowout preventer stack. |
| **Emplacement System Redundancy** – Emplacement system shall have redundant means for holding packages and/or drill pipe so that single-point failures cannot result in drops. | **Emplacement System Redundancy** – Emplacement system shall have redundant means for holding packages and/or drill pipe so that single-point failures cannot result in drops. |
| … | … |

# DBD Flowdown to DBFT Requirements (6/6)

<table>
<tr><th colspan="2">1.12 Borehole Sealing</th></tr>
<tr><th colspan="2">1.13 Characterization Testing</th></tr>
<tr><th>…</th><th>…</th></tr>
<tr><td rowspan="3">(Testing, logging, sampling, and other data collection requirements for disposal boreholes are TBD.)</td><td>Safety Basis for Testing – Testing, logging, sampling, and other data collection shall be directly linked to the deep borehole disposal safety case.</td></tr>
<tr><td>Testing Baseline – Testing, logging, sampling, and other data collection, and the disposition of samples, shall be specified in a testing baseline.</td></tr>
<tr><td>Test Interference – Surface and subsurface testing activities shall be evaluated prior to deployment to determine whether they may significantly interfere with other testing activities.</td></tr>
</table>

# DBD Flowdown to DBFT Requirements (6/6)

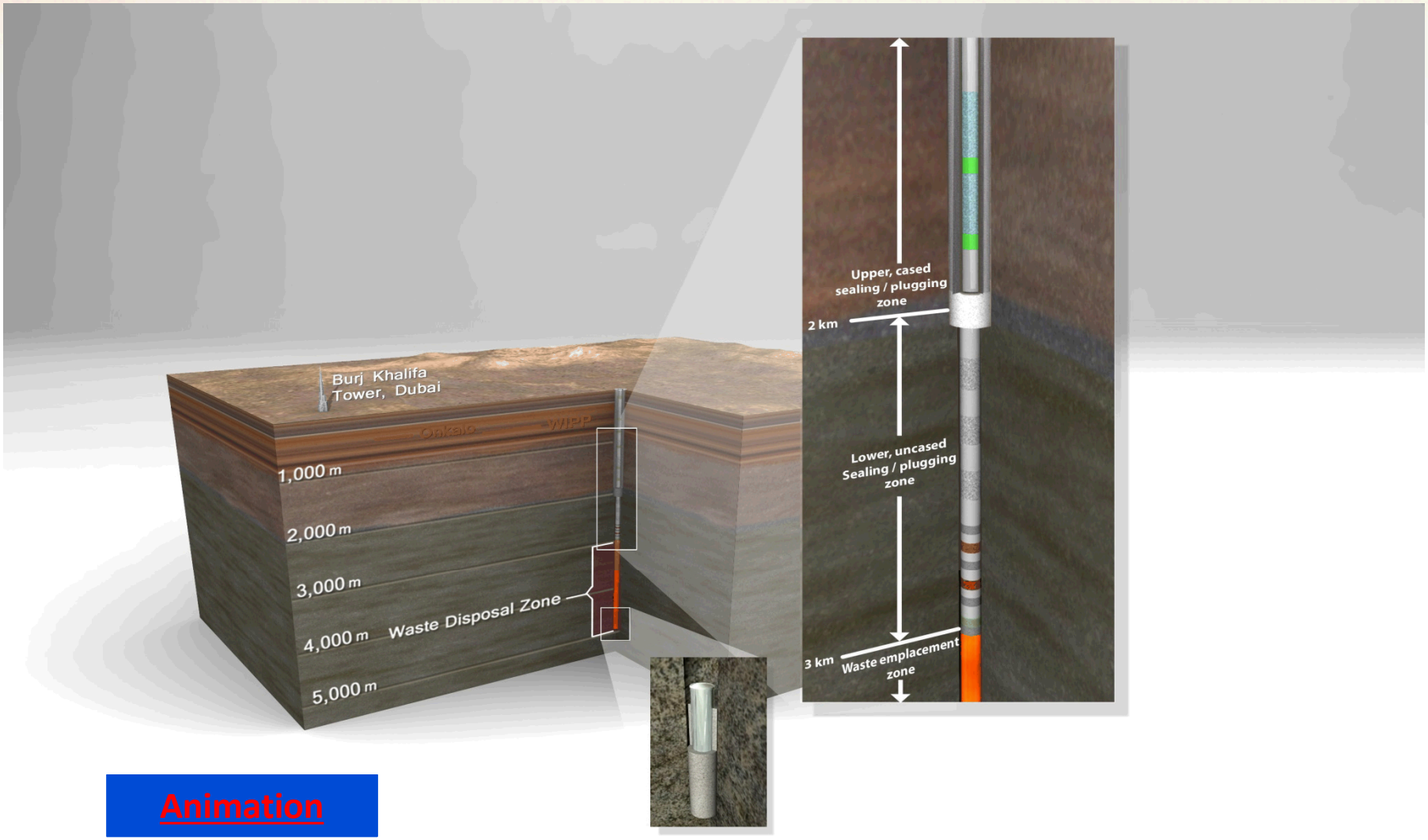
| Controlled Design Assumptions | |
|---|---|
| … | … |
| (Leakage control requirements for waste packages during operations are TBD.) | **Test Waste Package Failure** – For testing, package failure is defined as loss of control (e.g., dropping) of package(s) in the borehole, or dropping of drill pipe on one or more packages in the borehole. |
| (The need for directional drilling for disposal boreholes is TBD, and could be based on experience with drilling and construction of characterization borehole(s) at a future disposal site. | **Dogleg Severity/Directional Drilling** – Dogleg severity will be limited to 2°/100 ft in the top 1,000 m of the Characterization and Field Test Boreholes, and to 3°/100 ft below that (see deviation requirement). |
| (Maximum density of borehole fluid when loaded waste packages are present is TBD.) | **Borehole Fluid Maximum Density** – Borehole fluid density is assumed to be less than or equal to 1.3 the density of pure water at in situ conditions. |
| … | … |

# Backup

# Cs/Sr Capsules

| | | | | | Capsule heat (2025) | |
|---|---|---|---|---|---|---|
| | Count | Outer Dia. (in.) | Length (in.) | Outer Matl. | Avg. (W) | Max. (W) |
| **Cs Capsules** | 1312 | 2.6 | 20.8 | 316L SS | 95 | 129 |
| **Cs Capsules (overpacked)** | 23 | 3.3 | 21.8 | 316L SS | 78 | 105 |
| **Sr Capsules** | 600 | 2.6 | 20.1 | 316L SS or C-276 | 127 | 333 |

# Deep Borehole Disposal Concept




Animation



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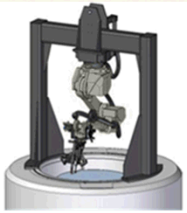
# System Concept for Packaging, Storage, Transportation & Geologic Disposal

Bulk waste

Canister loading/sealing

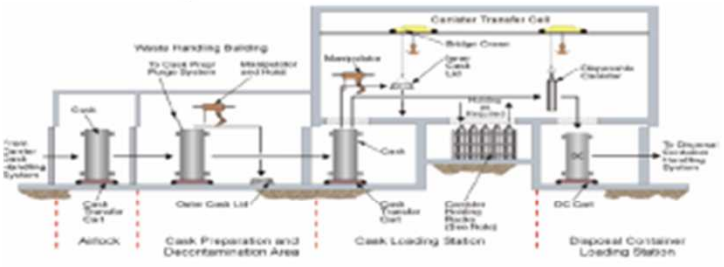


Multi-canister overpack

Multi-canister transport cask

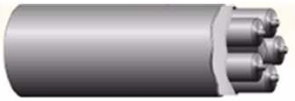
Storage casks on pad

DBD packaging (hot cell, welding)

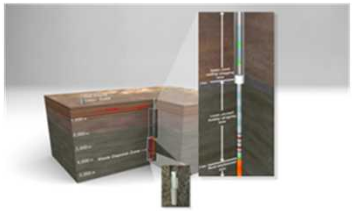



Mined repository packaging

Transport to DBD location



Multi-canister waste package



Deep borehole disposal (DBD)

Mined geologic repository