Deep Borehole Field Test
Waste Packaging, Emplacement and Seals Testing

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Outline

- Borehole Emplacement Concepts of Operations
- Borehole Environment
- Waste Packaging Concepts
- Safety of Emplacement Operations
- Borehole and Overpack Tradeoffs
- Waste Canister – Overpack Interface for DOE-Owned Wastes
- DBD Requirements Flowdown and Assumptions
Spent Fuel Test – Climax (1978-1983)

Waste package containing irradiated PWR fuel assembly being lowered through shipping cask into borehole, leading to Climax Mine.
Wireline Emplacement Surface Layout

- BOP Shield (assume BOP in place)
- Packages lowered one at a time
- After up to 40 packages are emplaced, set a plug to carry the weight of more packages
**Rig capacities:**
- Triple pipe stands (90’)
- >500,000 lb working load
- Automatic pipe handling and joint makeup

**Shielded shipping cask:**
- Length ~22 ft, weight ~30 MT

**Upper and lower cask doors**

**Transfer carrier**

**Subgrade basement**
- Power slips/tongs
- Mud surge control
- Blowout preventer
Automated joint tender “iron roughneck” →

Power slips ↓
Drill-String Emplacement: Basement Detail

- Receiving Collar
- Basement Ceiling
- Concrete Liner
- Power Slips (remotely operated)
- Structural Frame
- Power Tongs (remotely operated)
- Mud Control
- Blowout Preventer
- Hanger
- Tieback Guidance Casing
- Surface Casing
- Conductor
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

- **Example Types of Emplacement 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
  - Waste package(s) stuck in collapse casing → Fishing operations
  - External hazards (seismic, extreme weather)
Deep Borehole Field Test Engineering Design Work Package

- **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., Costing
    - Transport Cask Integration

- **Fabrication/Testing FY17**

- **Field Implementation FY18-19**

- **Sealing Studies FY15-19**

**Engineering Services Contractor Support (AREVA)**

**Additional Procurements**
### Waste Disposal 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). |
## Controlled Design Assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Waste containment requirements for waste packages during operations are TBD.)</td>
<td>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.</td>
</tr>
<tr>
<td>(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.)</td>
<td>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).</td>
</tr>
<tr>
<td>(Maximum density of borehole fluid when loaded waste packages are present is TBD.)</td>
<td>Borehole Fluid Maximum Density – Borehole fluid density is assumed to be less than or equal to 1.3X the density of pure water at in situ conditions.</td>
</tr>
</tbody>
</table>
Borehole Environment for Waste Package/Overpack Conceptual Design

- **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

Canisters emplaced but guidance casing still in place above -3000 m, and seals not yet installed (not to scale).
Common concepts for wireline and drill-string emplacement

- Axial load ~150,000 lb (tensile, compressive)
- Bending stresses (minor)
- Provision for fishing

Requirement: factor of safety $\geq 2.0$

Terminology

- Canister $\equiv$ Thin-wall sealed (stainless) vessel
- Disposal Overpack $\equiv$ Heavy container for canistered wastes
- Waste Package $\equiv$ Heavy container for bulk wastes
- Examples (Cs/Sr capsules, DOE/EM bulk wastes, SNF)
Flask Type Waste Package for Bulk Waste
Reference size 10.75” max. OD

- Flask sealed with tapered threaded plug, with welded cover plate
- All weld heat mitigation done before waste loading, except cover plate (not shown)
- Minimal weld-heat effect on loaded waste
- API schedule tubulars and connections
- Factor of safety $\geq 2.0$

WELDED TOP BOX
WITH FILL PORT (4.75” DIA)
NC77 DRILL PIPE THREAD

FILL PLUG LENGTH 12” FOR SHIELDING, WELDED COVER PLATE

WELDED BOTTOM PIN
NC77 DRILL PIPE THREAD

10 3/4”

8 3/4”

FRICTION WELDS

Design concept and drawing by J. Su, SNL/6916
Internal-Flush Overpack for Canistered Waste
Reference size 11” max. OD

- Internal-flush design for canistered waste forms
- No fabrication welds in axial load path
- Uses external semi-flush casing
- External upset forged connections
- Possible weld-heat effect on loaded waste
- Novel tapered swage design with sealing weld
- API schedule tubulars
- Factor of safety $\geq 2.0$

Design concept and drawing by J. Su, SNL/6916
Cs/Sr Capsule Flask-Type Overpack
Reference package size ~5” OD

- For ~99% of capsules (2.6” OD)
- Flask sealed with tapered threaded plug, with welded cover plate
- All weld heat mitigation done before waste loading, except cover plate (not shown)
- Welded API NC38 connections
- 5.0” OD x 4.0” ID tubing
- 19,800 psi collapse pressure
- Use friction welding: https://www.youtube.com/watch?v=51Zs8iaydt0
- Factor of safety $\geq 2.0$

A 5-m long package may contain up to 8 Cs/Sr capsules end-to-end.

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

Not to scale; package shortened for analysis and plotting.
Wireline Emplacement – Upper and Lower Subs Attached to Each Waste Package

- BOX CONNECTOR
- CRUMPLE ZONE
- WIRELINE LATCH
- FISHING OVERSHOOT LATCH POINTS
- PIN CONNECTOR
<table>
<thead>
<tr>
<th>#</th>
<th>Application</th>
<th>Cost</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flask-type package for bulk waste forms, reference size</td>
<td>~$10k for body</td>
<td>- External flush</td>
<td>- Welds in axial load path</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- API threads</td>
<td>- Flask-type loading</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Weld heat treatment (before loading)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Internal-flush overpack for canistered bulk waste forms, reference size</td>
<td>TBD</td>
<td>- External semi-flush tubing (upset forged)</td>
<td>- Tubing hard to find (Tenaris)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- No welds in axial load path</td>
<td>- Sealing weld after loading</td>
</tr>
<tr>
<td>3</td>
<td>Internal-flush package for bulk waste or 3-capsule bundles</td>
<td>TBD</td>
<td>- External semi-flush tubing (upset forged)</td>
<td>- Lower collapse pressure (available tubing sizes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- No welds in axial load path</td>
<td>- Smaller OD, less volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Custom mill run</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Sealing weld after loading</td>
</tr>
<tr>
<td>4</td>
<td>Flask-type package for stacked Cs/Sr capsules (2.6” OD)</td>
<td>TBD</td>
<td>- External flush</td>
<td>- Welds in axial load path</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- API threads</td>
<td>- Flask-type loading</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Weld heat treatment (before loading)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Internal-flush overpack for stacked Cs/Sr capsules (up to 3.3” OD) in canister</td>
<td>TBD</td>
<td>- External flush</td>
<td>- Custom mill run</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- No welds in axial load path</td>
<td>- Sealing weld after loading</td>
</tr>
</tbody>
</table>
# Disposal Borehole and Overpack Size Tradeoffs

<table>
<thead>
<tr>
<th>Borehole and Canister Sizes &gt;&gt;&gt;&gt;&gt;</th>
<th>Small</th>
<th>Medium</th>
<th>Reference</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste per Canister &gt;&gt;&gt;&gt;&gt;</td>
<td>2 to 8 capsules end-to-end</td>
<td>3-capsule groups stacked ≤ 8 high</td>
<td>Bulk</td>
<td>Bulk</td>
</tr>
<tr>
<td>Disposal Zone Hole Diameter</td>
<td>8.5”</td>
<td>12.3”</td>
<td>17”</td>
<td>22”</td>
</tr>
<tr>
<td>Disposal Zone Casing ID</td>
<td>6.4”</td>
<td>9.8”</td>
<td>12.6”</td>
<td>17.4”</td>
</tr>
<tr>
<td>Disposal Overpack OD</td>
<td>5”</td>
<td>8.5”</td>
<td>11”</td>
<td>16”</td>
</tr>
<tr>
<td>Disposal Overpack ID</td>
<td>4”</td>
<td>6.5”</td>
<td>8.5”</td>
<td>12”</td>
</tr>
<tr>
<td>Avail. Disposal Volume/Borehole (ft³)</td>
<td>460</td>
<td>1220</td>
<td>2,090</td>
<td>4,170</td>
</tr>
<tr>
<td>Disposal Canister Length (ft)</td>
<td>3.9 to 15.6</td>
<td>3.9 to 15.6</td>
<td>16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Canister Capacity</td>
<td>2 to 8 capsules</td>
<td>6 to 24 capsules</td>
<td>5.2 ft.³</td>
<td>10.4 ft.³</td>
</tr>
<tr>
<td># Waste Packages/Disposal Zone</td>
<td>968 to 242</td>
<td>323 to 81</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Capsule Disposal Interval Height</td>
<td>~4,500 ft *</td>
<td>~1,500 ft *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling/Completion Costs ($M)</td>
<td>&lt; 20 *</td>
<td>&lt; 25 *</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Borehole Cost/Disposal Vol.</td>
<td>($/ft³)</td>
<td>($/ft³)</td>
<td>($/ft³)</td>
<td>($/ft³)</td>
</tr>
<tr>
<td>($/in³)</td>
<td>&lt; 40 *</td>
<td>&lt; 26 *</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>&lt; 23 *</td>
<td>&lt; 15 *</td>
<td>11</td>
<td>8</td>
</tr>
</tbody>
</table>

* 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.
System Concept for Packaging, Storage, Transportation & Geologic Disposal

Bulk waste → Canister loading/sealing → Multi-canister overpack → Multi-canister transport cask → Storage casks on pad → Mined repository packaging → Multi-canister waste package

DBD packaging (hot cell, welding) → Transport to DBD location → Mined geologic repository

Deep borehole disposal (DBD)
Sealing Objectives

- **Encapsulate Waste Packages**
  - Emplacement fluid

- **Wellbore Sealing**
  - Barrier to impede advective movement and chemical diffusion
  - Sorbent for cationic radionuclides
  - Controlled interface at borehole wall

- **Disturbed Rock Zone**
  - No explicit objective to seal DRZ
  - Long-term R&D interest for rock melting studies (developmental)

- **Performance Longevity**
  - Stable geologic materials (e.g., clays)
  - Long-lived engineered materials (e.g., cement for mechanical support)

- **Performance Benchmarks**
  - Oil-and-gas well plug/abandon procedures
  - Deep underground waste injection well plugging/sealing
General Sealing Concept
Sealing Materials and Methods

General Outline

- **Clay**
  - Smectites, illites, zeolites
  - Emplacement Methods

- **Cement**
  - Material Properties and Longevity
  - Emplacement Methods and Setting Times

- **Fused Borehole Plug**

- **Rock Melting**
  - Low Permeability Plug
  - Controlled Annealing of Host Rock

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(Pusch, R. *Borehole sealing with highly compacted Na bentonite.* SKB TR-81-09)
Sealing Studies Underway

- **Collaborative studies in Sweden, Finland, Belgium, France, Rep. of Korea, and elsewhere**

- **DOE SBIR/STTR (small business)**
  - OLYMPIC RESEARCH: Development of thermally formed plugs for deep borehole waste disposal applications – Thermite formula heat source and sealant (2013-2016)
  - CIMENTUM: Unique cimentum cement for cementing & grout in deep boreholes for radioactive waste disposal (2015-2016)

- **SNL Partner Labs and Subcontracts**
  - UNIVERSITY OF SHEFFIELD: Deep borehole field test and borehole seal design and performance criteria (2015-2016; award pending)
  - KAERI: Borehole sealing investigations collaboration (2015+)
  - LANL: High-T, high-P investigations of smectite stability
References


