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SAND2015-5628PE

Deep Borehole Field Test
Waste Packaging, Emplacement and Seals Testing

Ernest Hardin

Sandia National Laboratories

U.S. Nuclear Waste Technical Review Board Visit

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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

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Spent Fuel Test – Climax (1978-1983)

Waste package containing irradiated PWR fuel assembly being lowered through shipping cask into borehole, leading to Climax Mine

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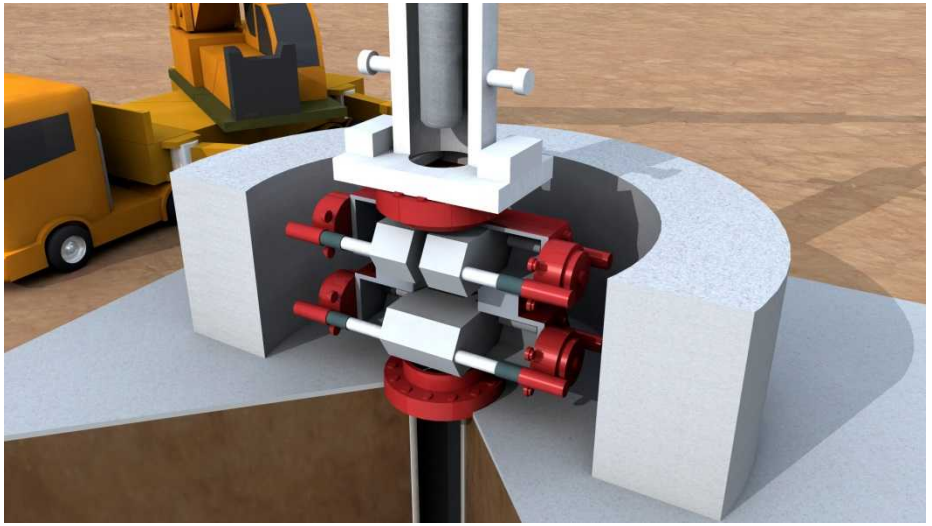
Wireline Emplacement Surface Layout

- 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



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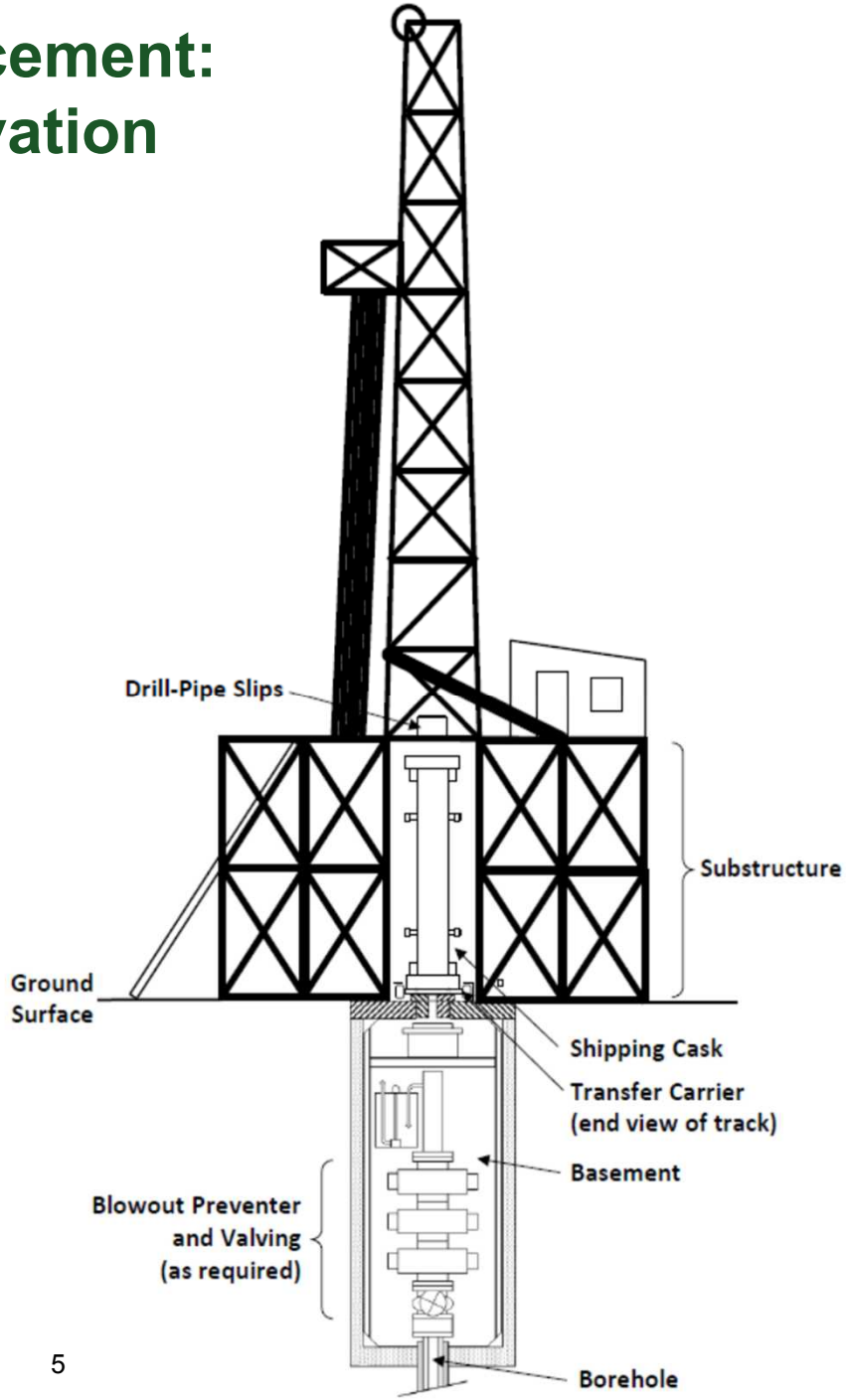
Drill-String Emplacement: Rig/Basement Elevation

- **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



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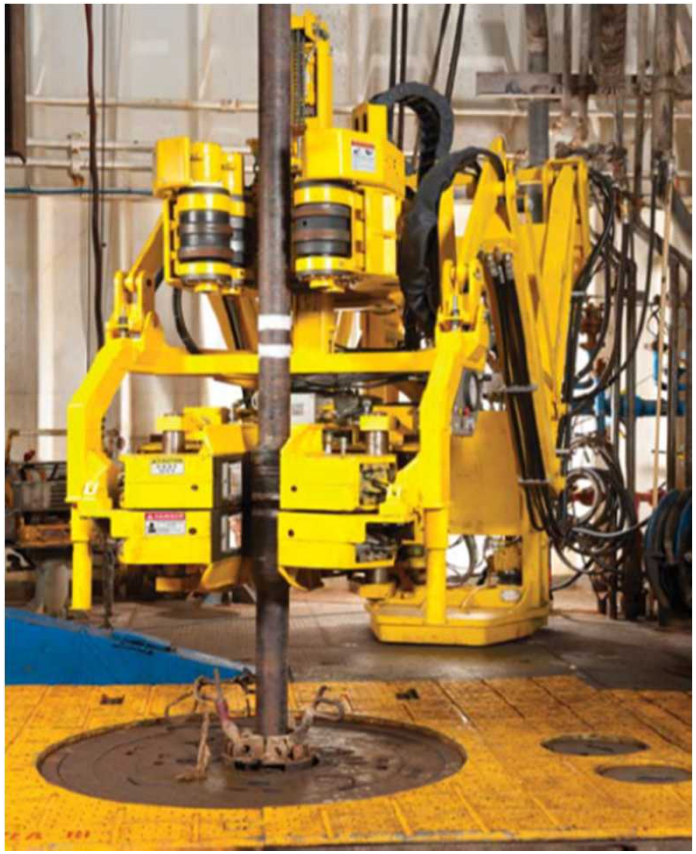
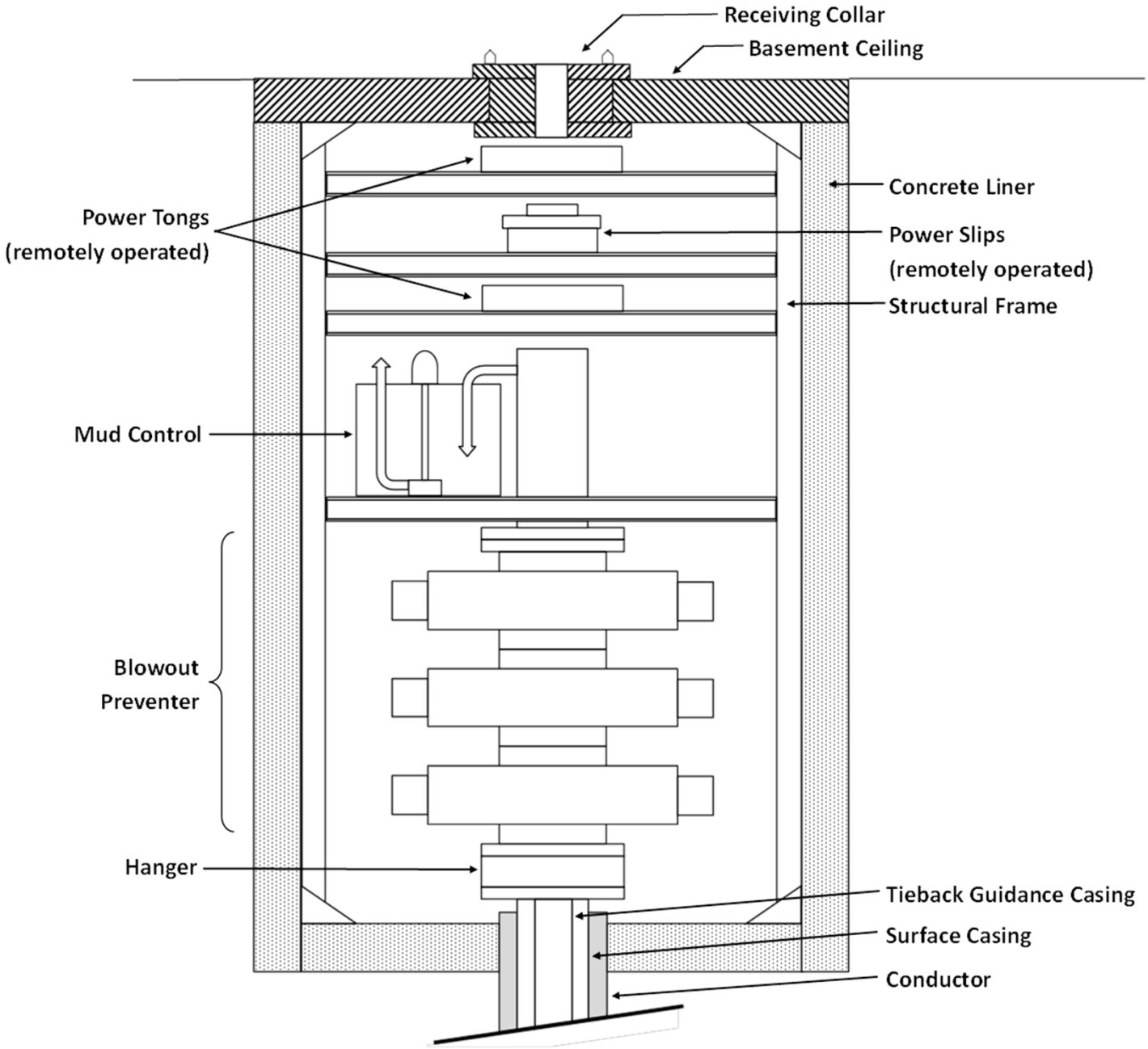
Drill-String Emplacement: Pipe Handling/Joint Makeup

Automated joint tender "iron roughneck" →



Power slips ↓

Drill-String Emplacement: Basement Detail



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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)

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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.*
    - *Safety Manual, Procedures, Testing*
    - *Transport Cask Integration*
- **Fabrication/Testing FY17**
- **Field Implementation FY18-19**
- **Sealing Studies FY15-19**

Engineering Services Contractor Support (AREVA)

Additional Procurements

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DBD Flowdown to DBFT Design Requirements, Example

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).
…	…

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DBD Flowdown to DBFT Design Assumptions, Example

Controlled Design Assumptions	
…	…
(Waste containment 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 1.3X the density of pure water at in situ conditions.
…	…

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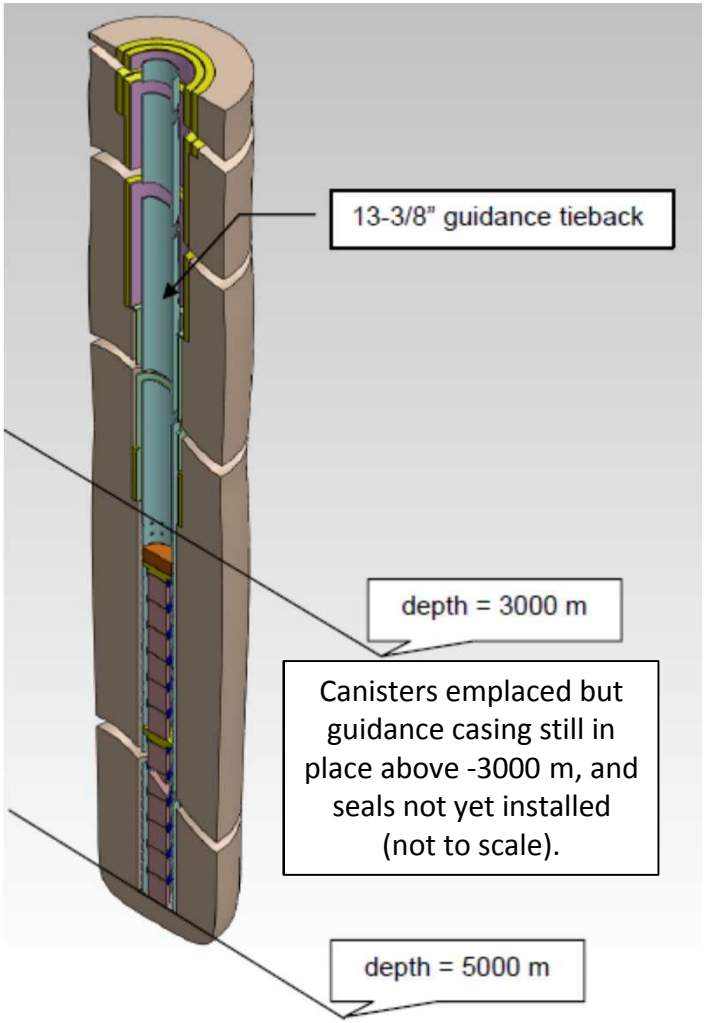
Borehole Environment for Waste Package/Overpack Conceptual Design

- **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



Overpack/Package Conceptual Design

- **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 ≥ 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)

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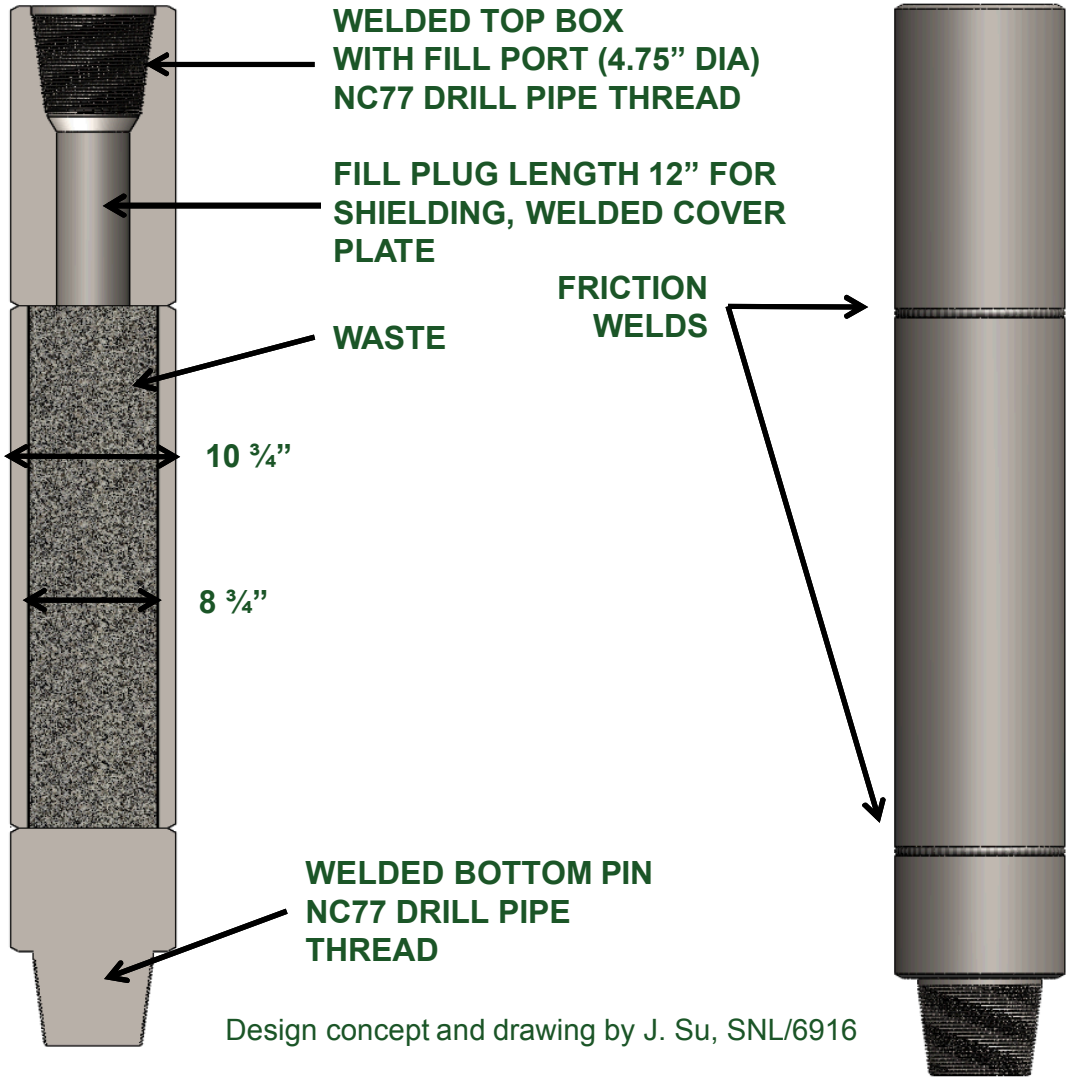
Option #1 Waste Package – Flask Type Reference size 10.75” max. OD



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

- All weld heat mitigation except cover plate, done before waste loading
- Minimal weld-heat effect on loaded waste
- API schedule tubulars
- Factor of safety ≥ 2.0

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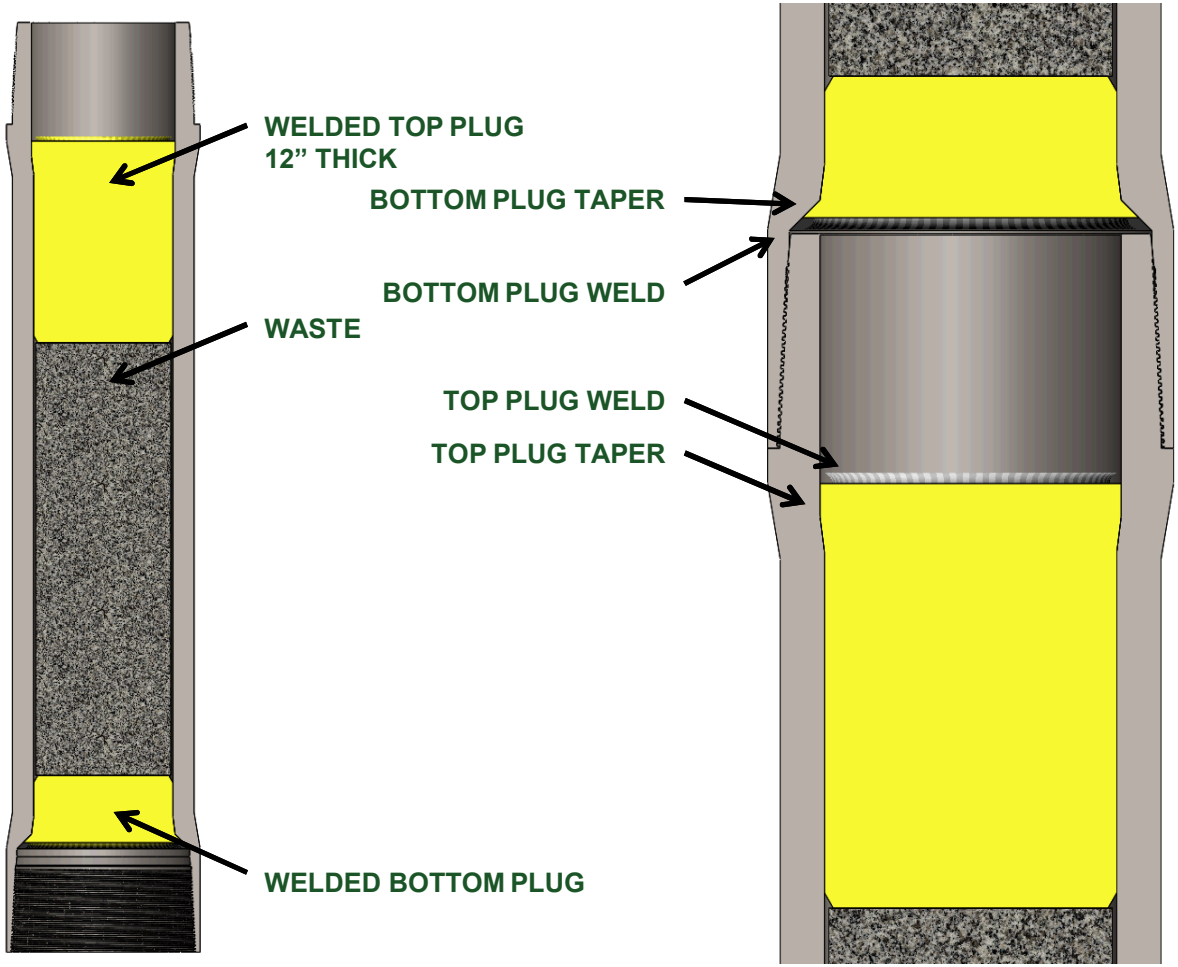
Option #2 – Bulk Waste Overpack
Reference size 11” max. OD



- 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
- Factor of safety ≥ 2.0

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

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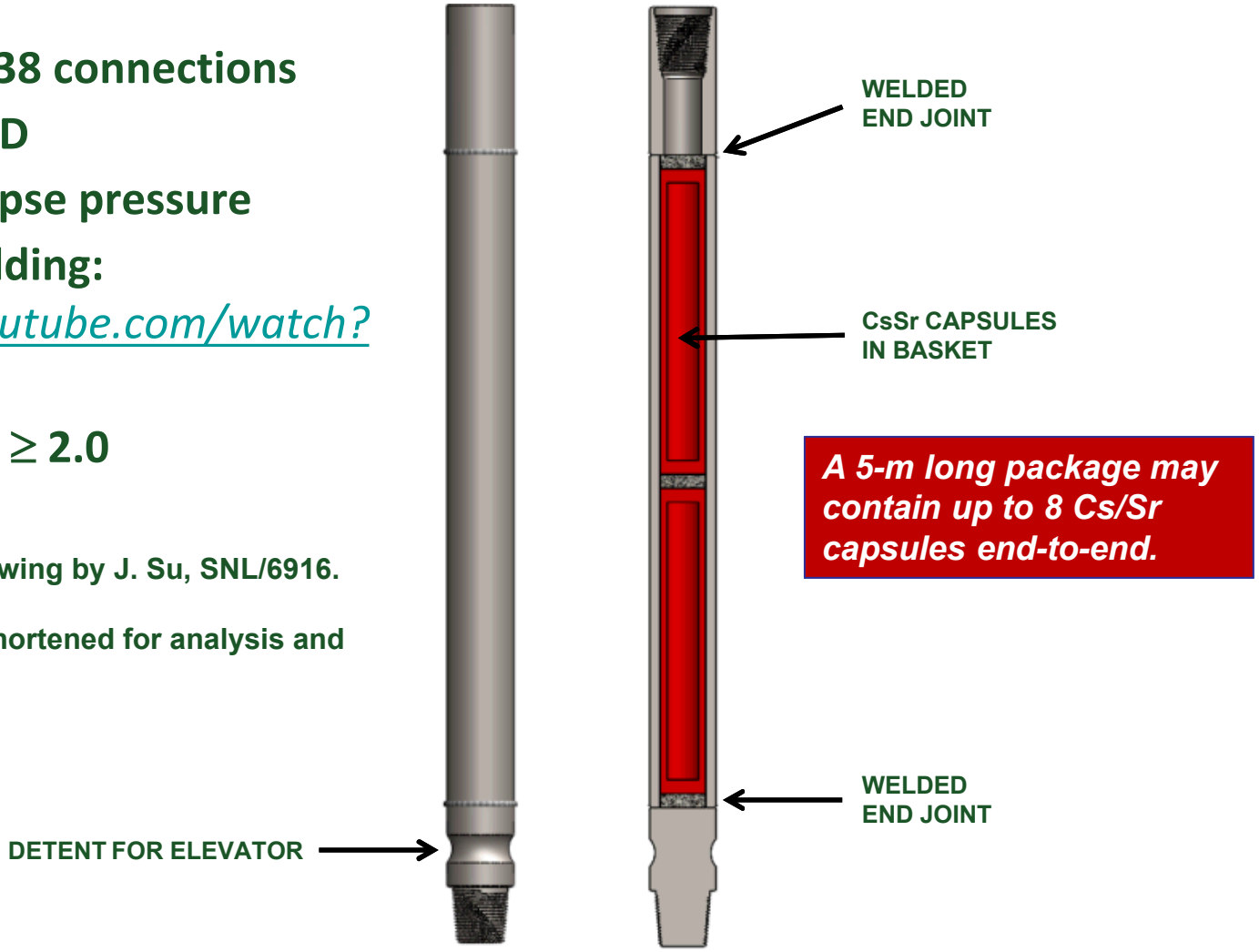
Option #4 Cs/Sr Capsule Overpack
Reference package size ~5” OD
Flask-type for loading ~99% of capsules (2.6” OD)

- Welded API NC38 connections
- 5.0” OD x 4.0” ID
- 19,800 psi collapse pressure
- Use friction welding: https://www.youtube.com/watch?v=51Zs8iaydt0
- Factor of safety ≥ 2.0

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

Not to scale; package shortened for analysis and plotting.



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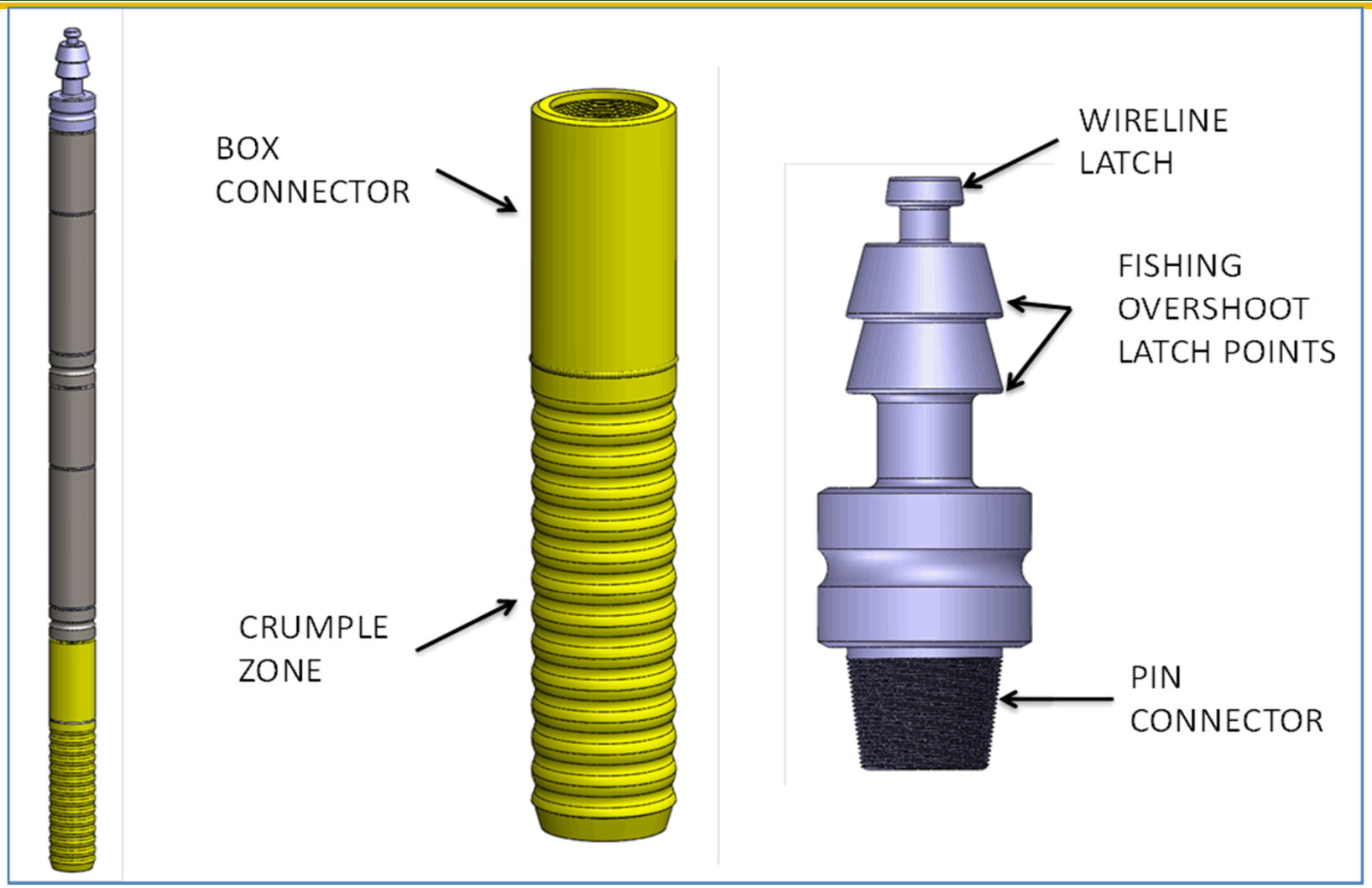
Wireline Emplacement – Upper and Lower Subs Attached to Each Waste Package



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Overpack/Package Concepts Summary

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

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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.

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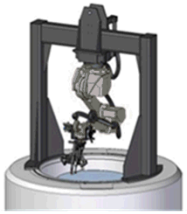
System Concept for Packaging, Storage, Transportation & Geologic Disposal

Bulk waste

Canister loading/sealing

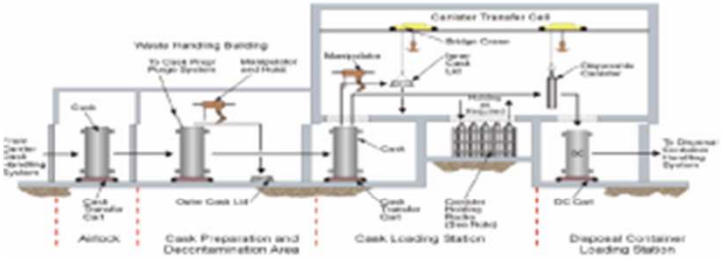


Multi-canister overpack

Multi-canister transport cask

Storage casks on pad

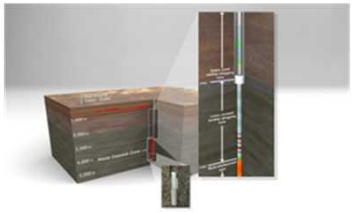
DBD packaging (hot cell, welding)



Mined repository packaging

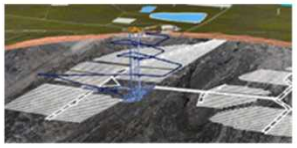
Transport to DBD location

Multi-canister waste package



Deep borehole disposal (DBD)

Mined geologic repository



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

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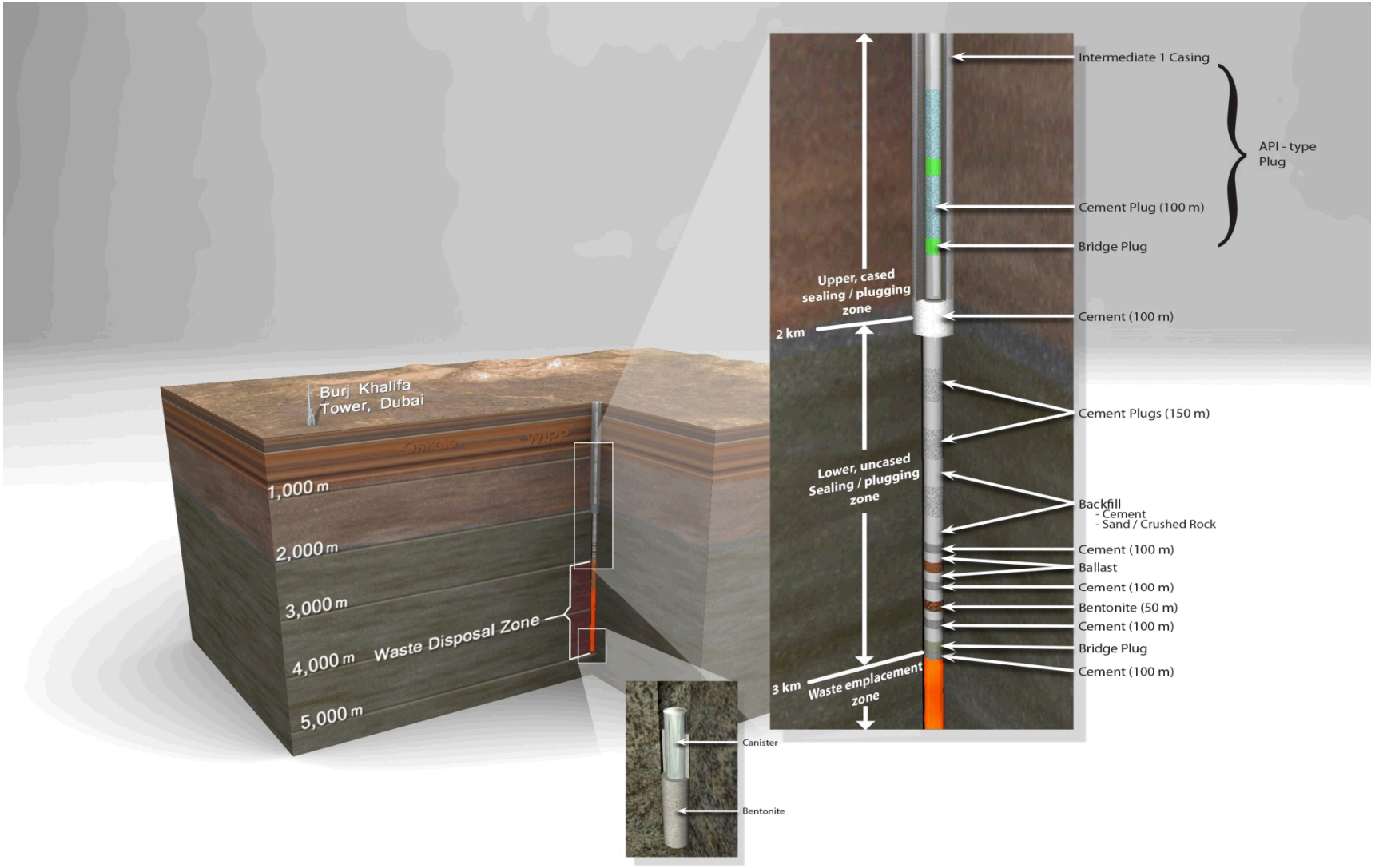
General Sealing Concept



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Sealing Materials and Methods General Outline

- **Clay**
  - Materials
    - *Na- or Ca-smectite, illites*
    - *Response to saline groundwater*
  - Emplacement Methods
    - *Container (block or pellet), perforated tube*
- **Cement**
  - Materials
    - *Many types of downhole cements are available*
  - Emplacement Methods
    - *Balanced plug, squeeze, two-plug method*
- **Fused Borehole Plug**
- **Rock Melting**

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Sealing Studies Underway

- **Collaborative studies in Sweden, Finland, Belgium, France, Rep. of Korea, and elsewhere**
- **DOE SBIR/STTR (small business)**
  - RESPEC: Rock melt borehole sealing system – Electric heater (2015-2017)
  - OLYMPIC RESEARCH: Development of thermally formed plugs for deep borehole waste disposal applications – Thermite formula heat source and sealant (2013-2016)
  - IMPACT TECHNOLOGIES/MIT/DoD AFRL: Deep bore storage of nuclear waste using millimeter wave technology (2014-2016)
  - 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

- SNL (Sandia National Laboratories) 2015 (in prep.). *Deep Borehole Field Test Specifications*. FCRD-UFD-2015-000132. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, Las Vegas, NV. September, 2015.
- SNL (Sandia National Laboratories) 2013. *Deep Borehole Disposal Research: Demonstration Site Selection Guidelines, Borehole Seals Design, and RD&D Needs*. FCRD-USED-2013-000409. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, Las Vegas, NV. October, 2013.
- SNL (Sandia National Laboratories) 2012. *Research, Development, and Demonstration Roadmap for Deep Borehole Disposal*. FCRD-USED-2012-000269. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, Las Vegas, NV. August, 2012.
- Arnold, B.W., P.V. Brady, S.J. Bauer, C. Herrick, S. Pye and J. Finger 2011. *Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste*. SAND2011-6749. Sandia National Laboratories, Albuquerque, NM. October, 2011.

Backup Slides

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Cs/Sr Capsules

	Count	Outer Dia. (in.)	Length (in.)	Outer Matl.	Capsule heat (2025)	
					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
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**