U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Deep Borehole Field Test
Waste Packaging, Emplacement and Seals Testing

Ernest Hardin

Sandia National Laboratories

U.S. Nuclear Waste Technical Review Board Visit

Albuquerque, NM

July 16, 2015

Unclassified, Unlimited Release (SAND2015-5628 PE)

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

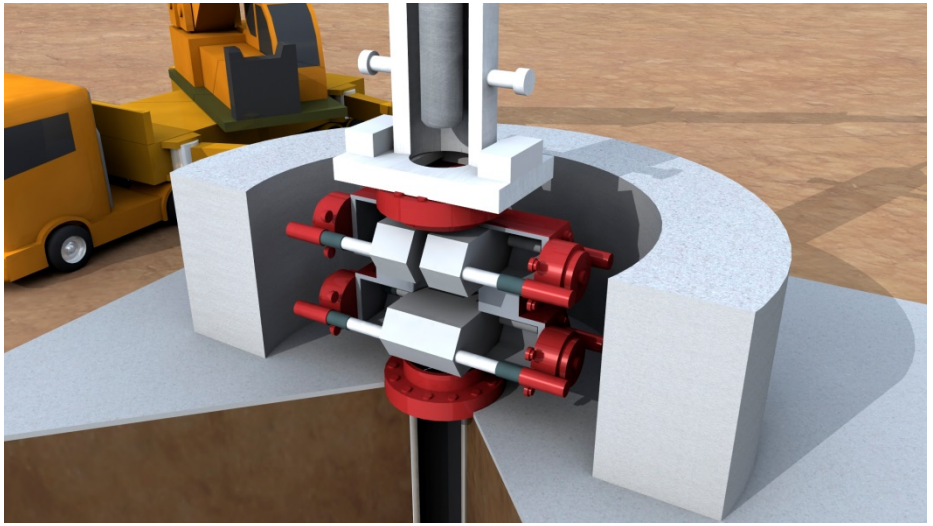
Spent Fuel Test – Climax (1978-1983)

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Wireline Emplacement Surface Layout

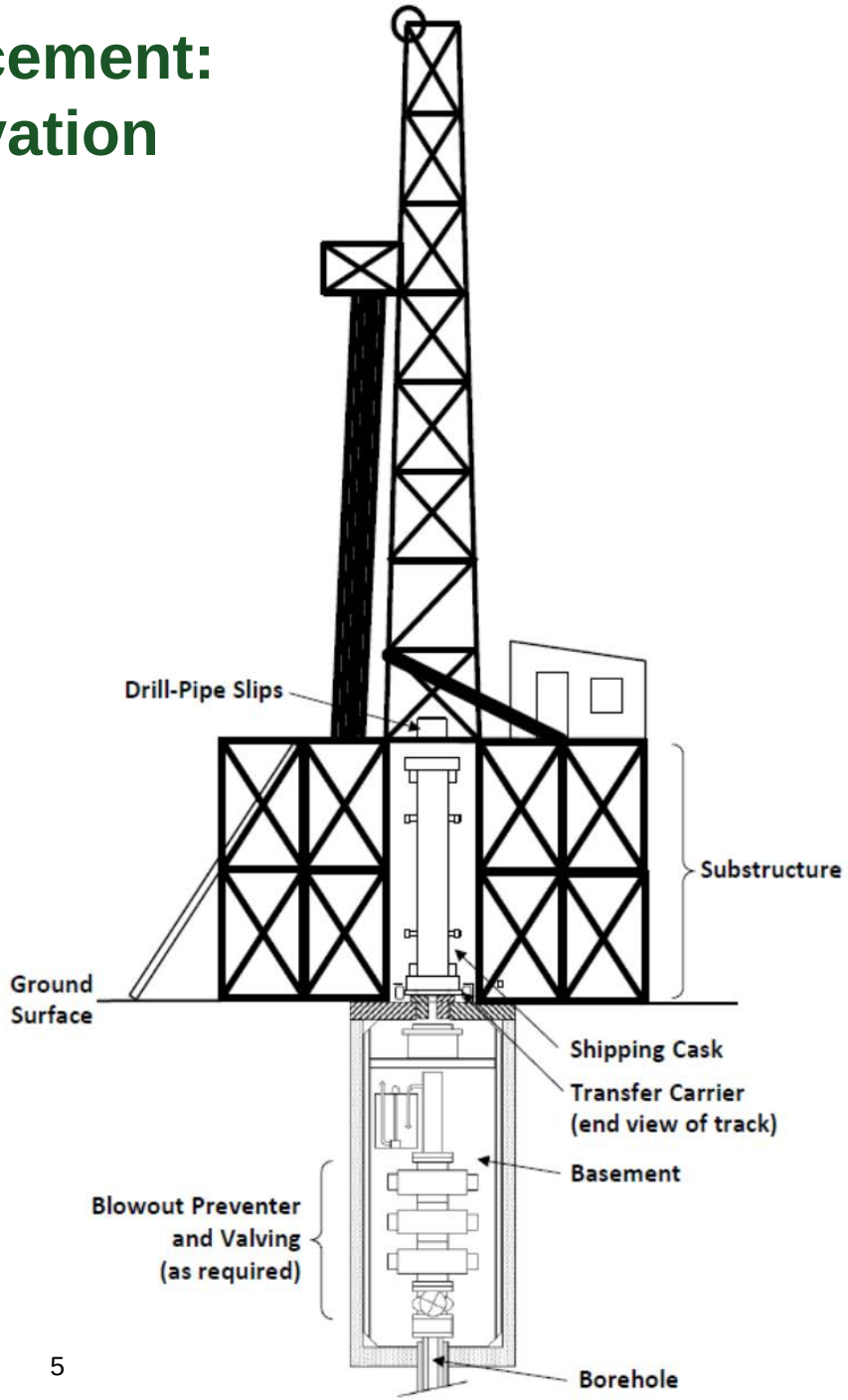
- BOP Shield (assume BOP in place)
- Packages lowered one at a time
- After up to 40 packages are emplaced, set a plug to carry the weight of more packages



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Drill-String Emplacement: Rig/Basement Elevation

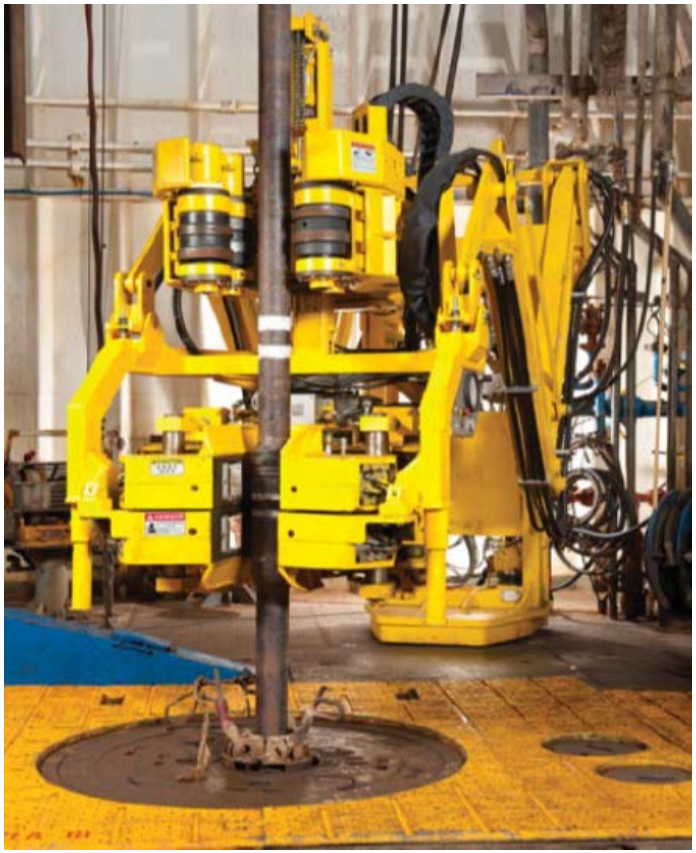
- **Rig capacities:**
  - Triple pipe stands (90')
  - >500,000 lb working load
  - Automatic pipe handling and joint makeup
- **Shielded shipping cask:**
  - Length ~22 ft, weight ~30 MT
- **Upper and lower cask doors**
- **Transfer carrier**
- **Subgrade basement**
  - Power slips/tongs
  - Mud surge control
  - Blowout preventer



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

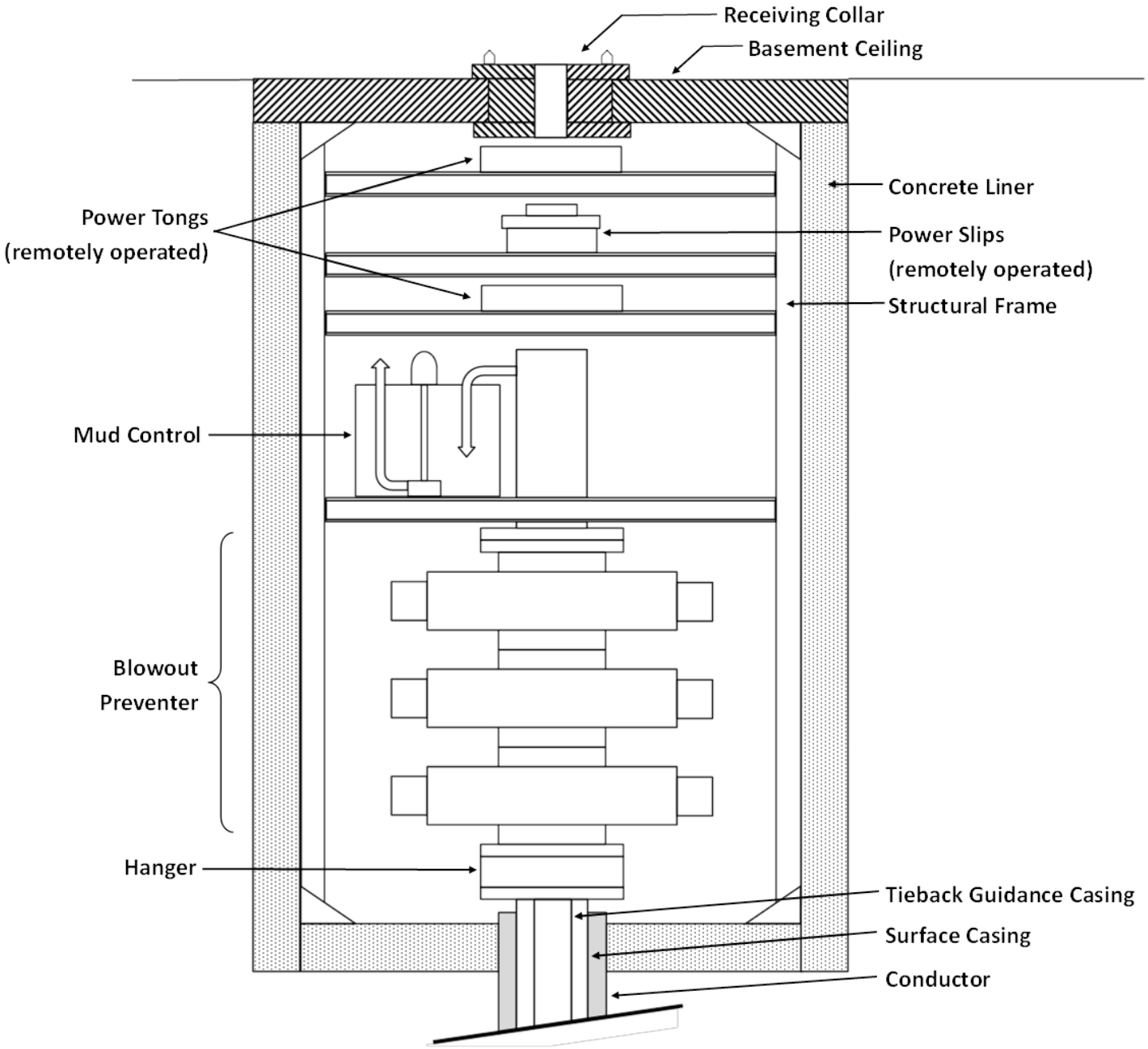
Drill-String Emplacement: Pipe Handling/Joint Makeup

Automated joint tender "iron roughneck" →



Power slips ↓

Drill-String Emplacement: Basement Detail



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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

Engineering Services Contractor Support (AREVA)

Additional Procurements

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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).
…	…

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

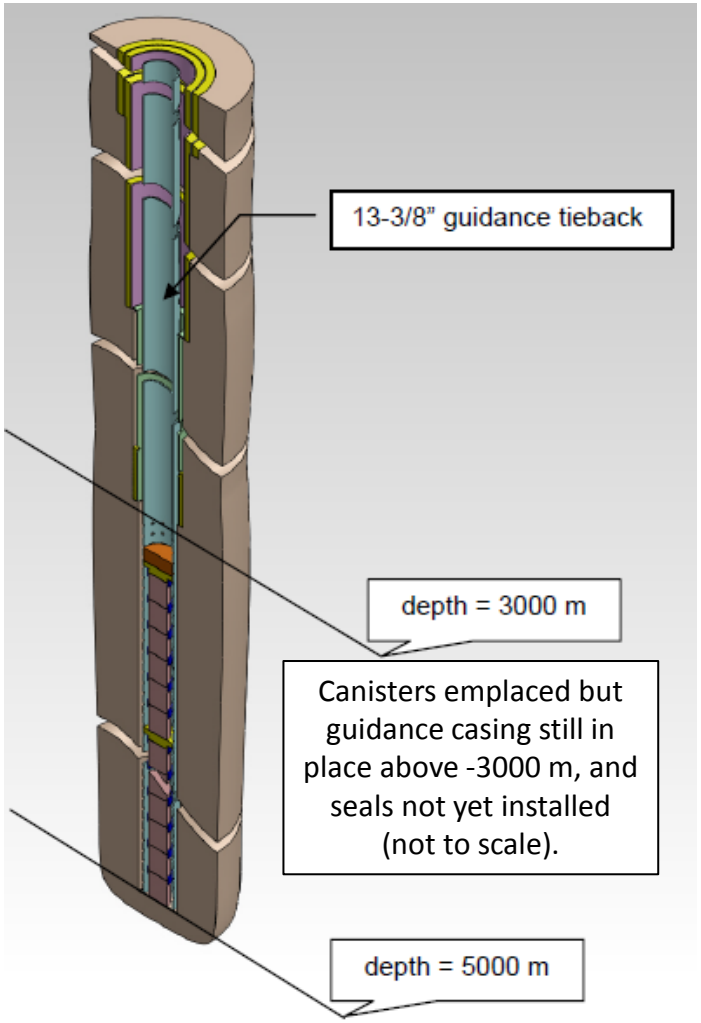
DBD Flowdown to DBFT Design Assumptions, Example

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.
…	…

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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



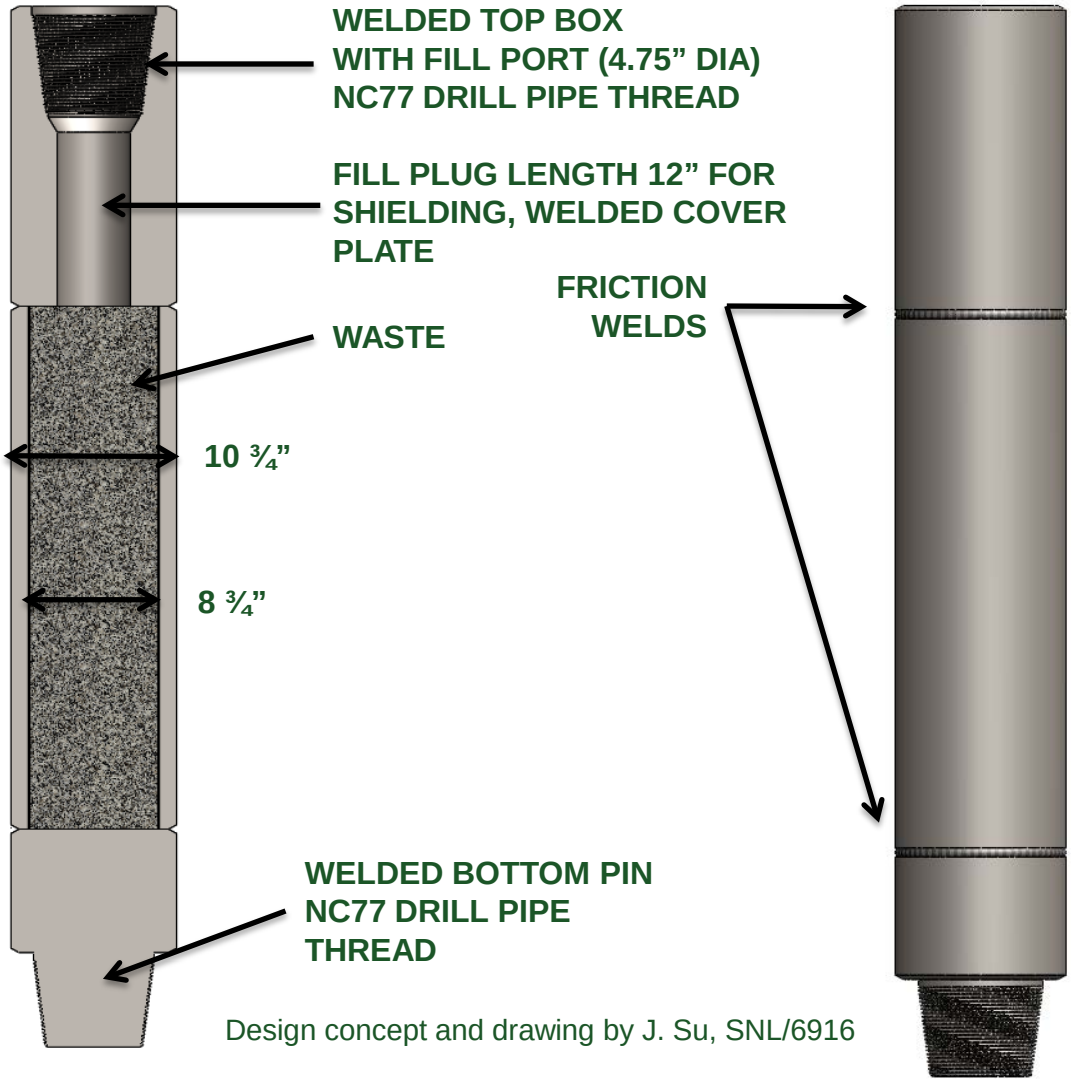
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Flask Type Waste Package for Bulk Waste Reference size 10.75” max. OD

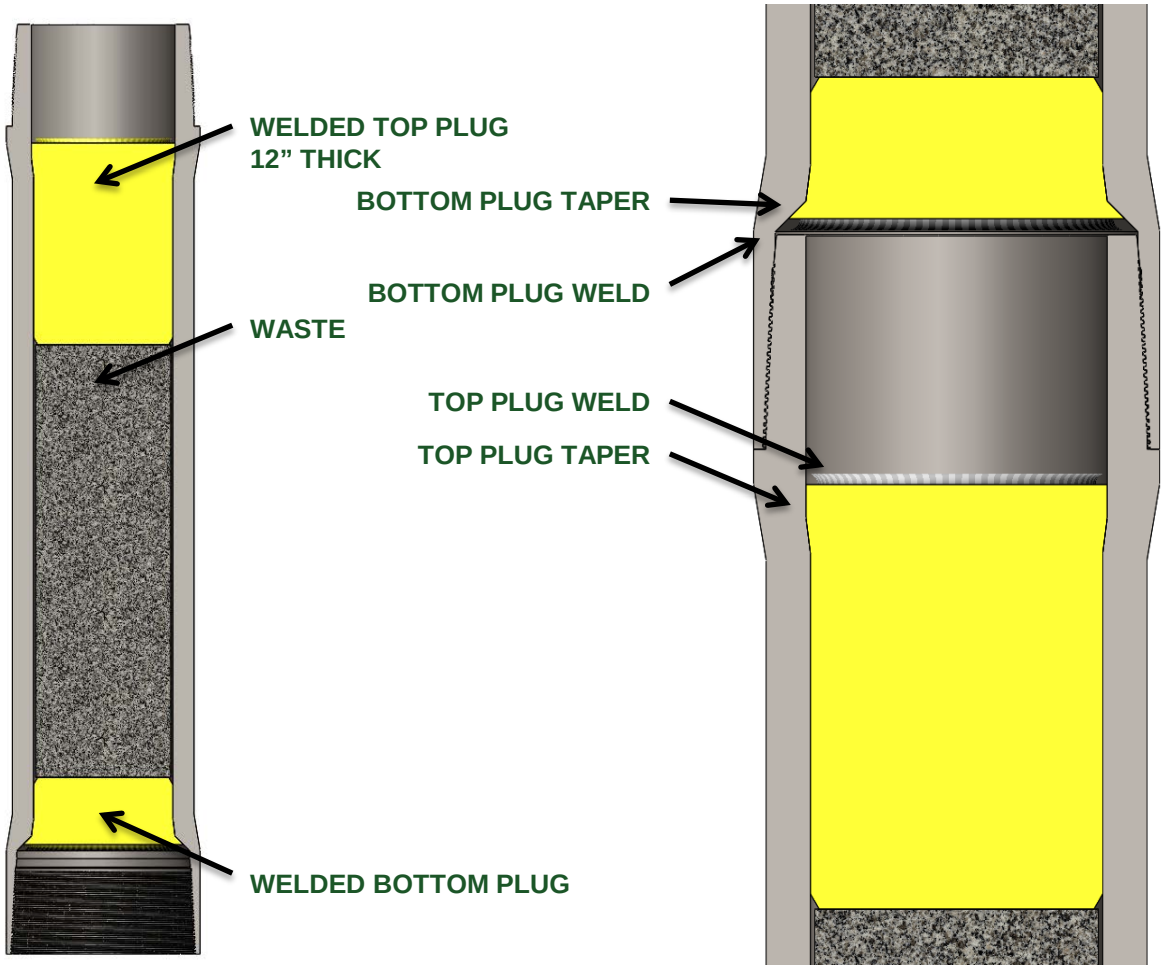


Design concept and drawing by J. Su, SNL/6916

- 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 ≥ 2.0

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Internal-Flush Overpack for Canistered Waste Reference size 11” max. OD



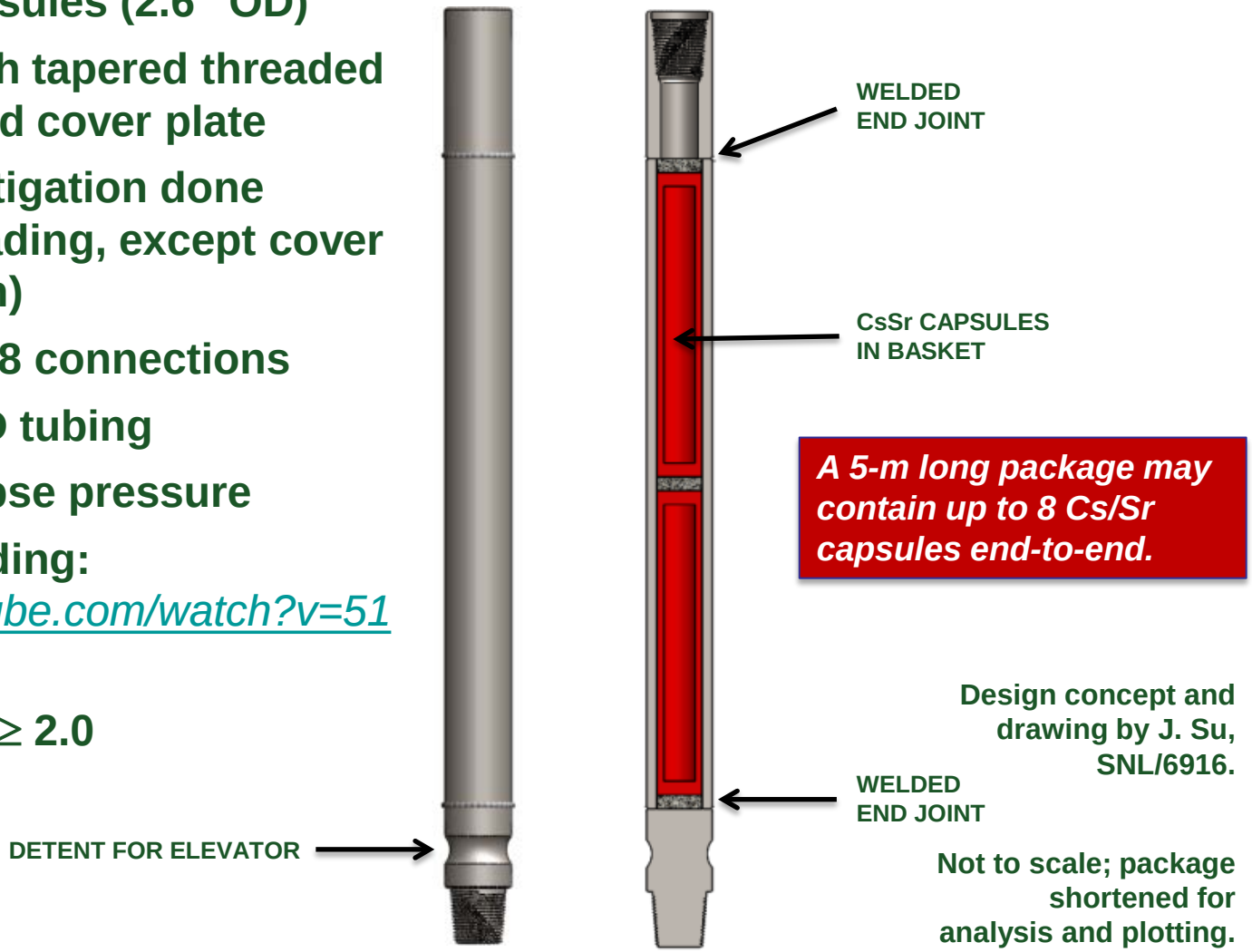
- Internal-flush design for canistered waste forms
- No fabrication welds in axial load path
- Uses external semi-flush casing
- External upset forged connections
- Possible weld-heat effect on loaded waste
- Novel tapered swage design with sealing weld
- API schedule tubulars
- Factor of safety ≥ 2.0

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

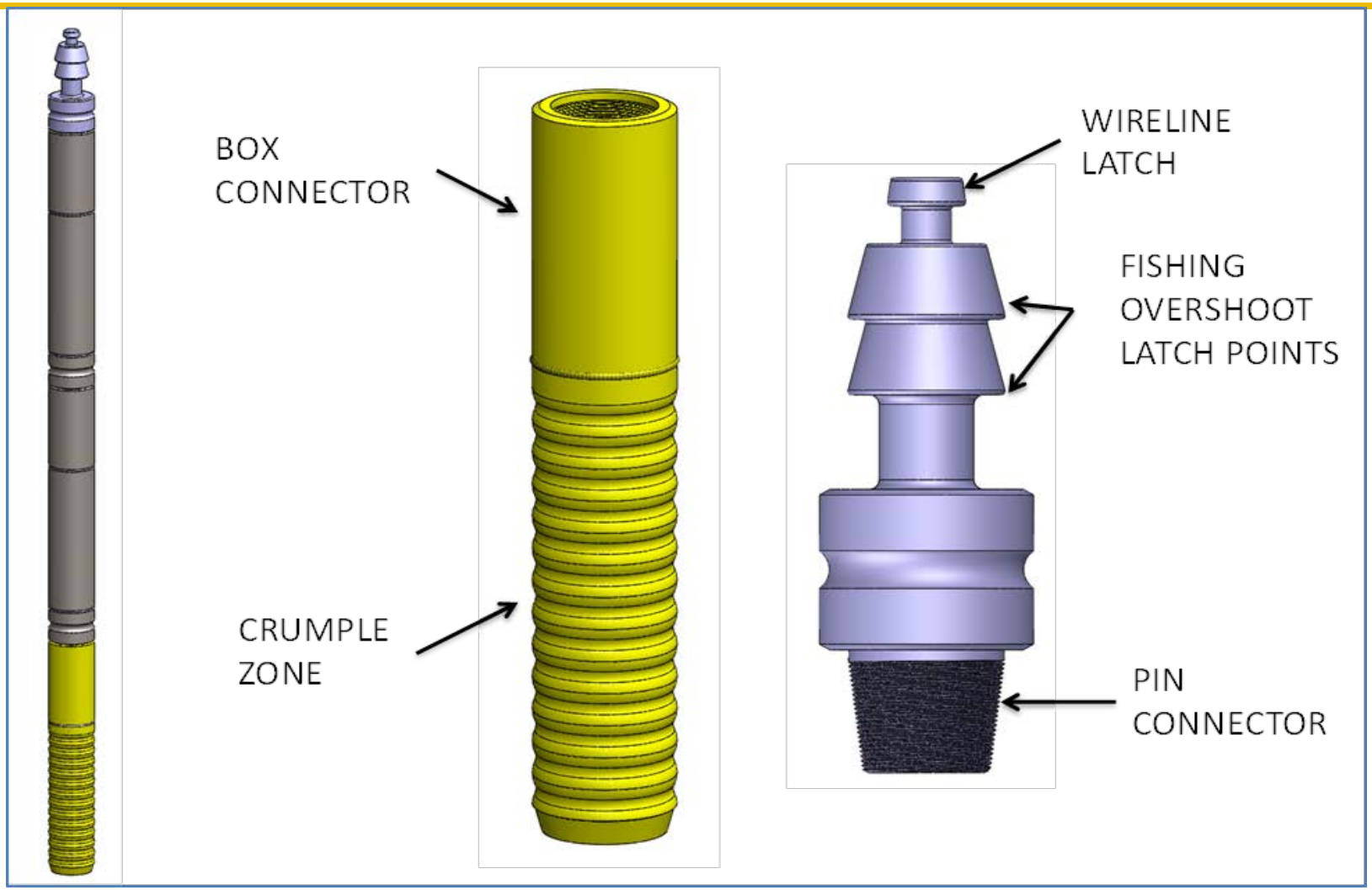
Cs/Sr Capsule Flask-Type Overpack Reference package size ~5” OD

- 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 ≥ 2.0



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Overpack/Package Concepts Summary

#	Application	Cost	Pros	Cons
1	Flask-type package for bulk waste forms, reference size	~$10k for body	▪ External flush ▪ API threads ▪ Weld heat treatment (before loading)	▪ Welds in axial load path ▪ Flask-type loading
2	Internal-flush overpack for canistered bulk waste forms, reference size	TBD	▪ External semi-flush tubing (upset forged) ▪ No welds in axial load path	▪ Tubing hard to find (Tenaris) ▪ Sealing weld after loading
3	Internal-flush package for bulk waste or 3-capsule bundles	TBD	▪ External semi-flush tubing (upset forged) ▪ No welds in axial load path	▪ Lower collapse pressure (available tubing sizes) ▪ Smaller OD, less volume ▪ Custom mill run ▪ Sealing weld after loading
4	Flask-type package for stacked Cs/Sr capsules (2.6” OD)	TBD	▪ External flush ▪ API threads ▪ Weld heat treatment (before loading)	▪ Welds in axial load path ▪ Flask-type loading
5	Internal-flush overpack for stacked Cs/Sr capsules (up to 3.3” OD) in canister	TBD	▪ External flush ▪ No welds in axial load path	▪ Custom mill run ▪ Sealing weld after loading

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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

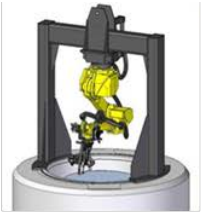
*** Capsule disposal intervals are less than the length of 2 km (6,560 ft) used for borehole cost estimation, so borehole costs would be less.**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

System Concept for Packaging, Storage, Transportation & Geologic Disposal

Bulk waste

Canister loading/sealing

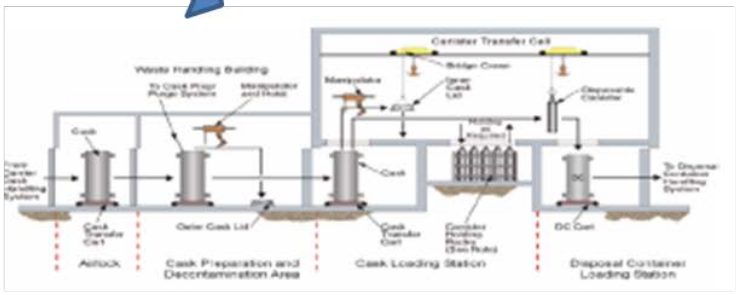


Multi-canister overpack

Multi-canister transport cask

Storage casks on pad

DBD packaging (hot cell, welding)

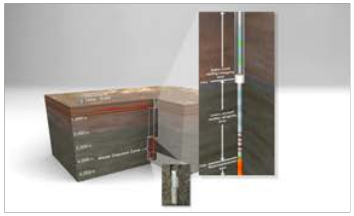


Mined repository packaging

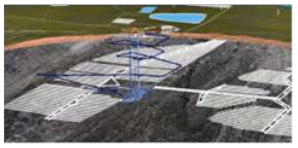
Multi-canister waste package

Transport to DBD location

Deep borehole disposal (DBD)



Mined geologic repository



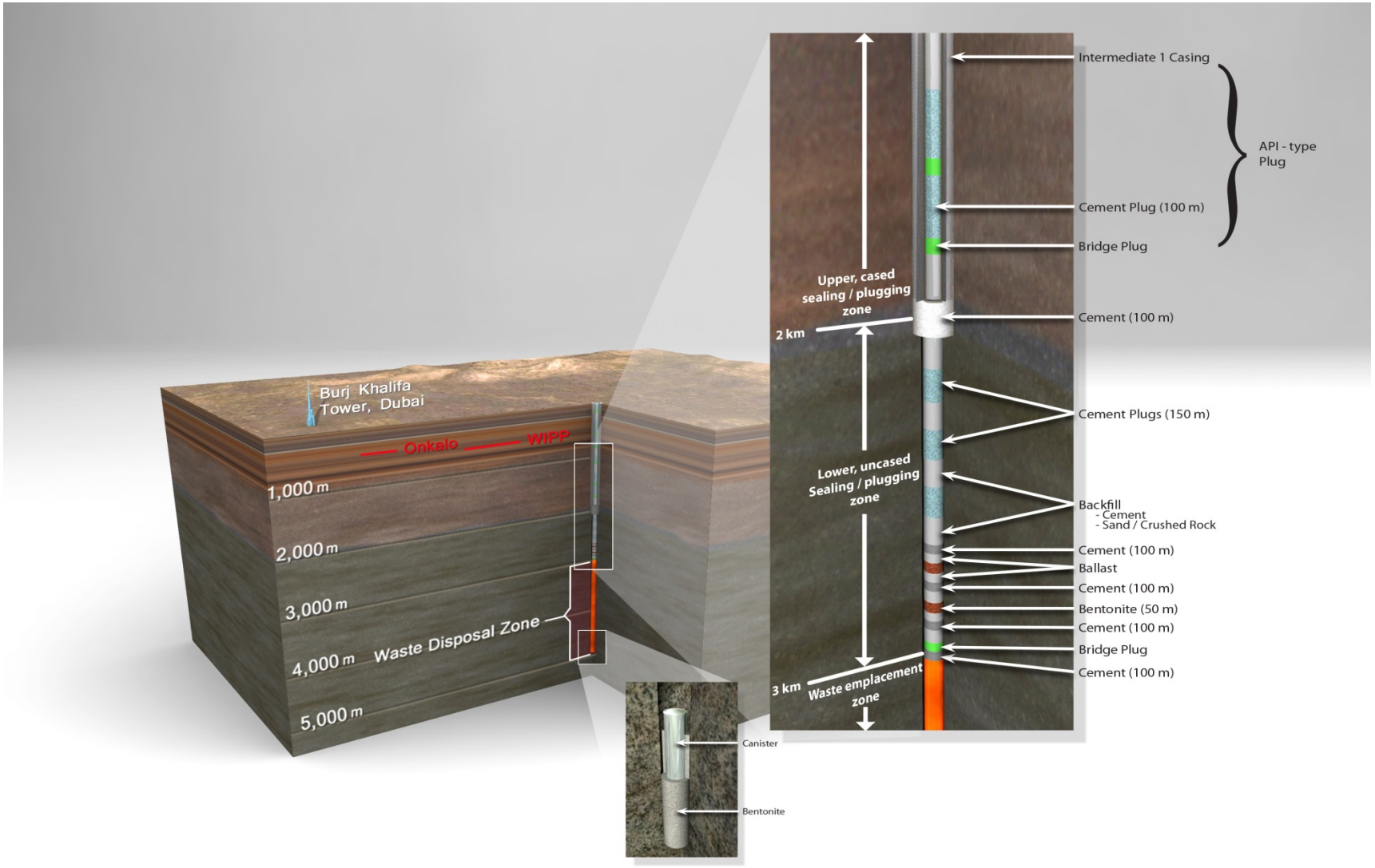
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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

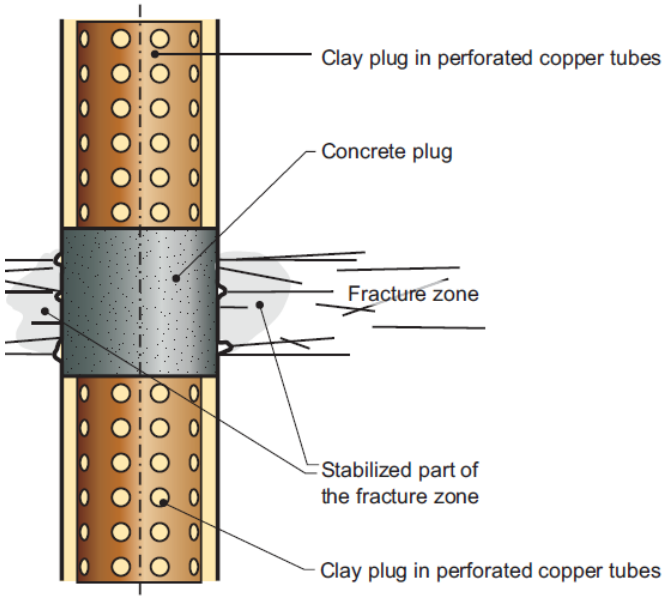
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

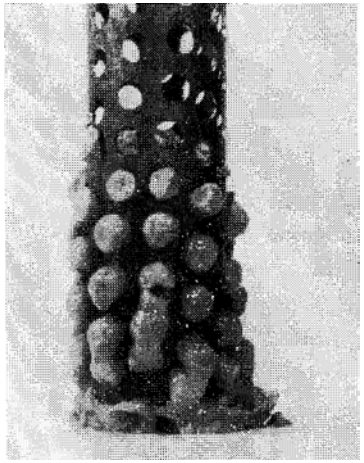
General Sealing Concept



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





Laboratory immersion 24 hr

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

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.