SAND2015-6972PE

Deep Borehole Field Test
FY15 DBFT Engineering Work Package

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Deep Borehole Field Test
Engineering Design Study Workshop
Albuquerque, NM
August 18-20, 2015

Unclassified, Unlimited Release (SAND2015-**)**

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Agenda – DBFT Engineering Workshop

- **Introduction and stage-setting (Day 1 AM; 2 to 4 hours)**
  - *Welcome (EH, 15 min)*
  - *Review of overall methodology and activities (KJ, 20 min)*
  - *Review of emplacement modes (EH and JS, 60 min)*
  - *Introduction to FT/ET analysis (AC, 15 min)*
  - Discussion (All)
- **Fault trees (Day 1 AM+PM; 4 to 8 hours; KJ)**
  - Failure modes (see Hazard Analysis report table)
  - Initial fault trees
  - Probabilities for basic events...(get thru one emplacement mode by Day 1)
- **Fault trees (Day 2 AM; 2 to 4 hours; KJ & EH)**
  - Complete fault tree basic event probabilities
- **Event trees and consequences (Day 2 AM+PM; 3 to 6 hours; KJ)**
  - Review top-level event tree
  - Branch by branch:
    - Possible consequences
    - Assess probabilities

Prepared presentations shown in italics.

Agenda – DBFT Engineering Workshop

- **Event trees (Day 3 AM; 2 to 4 hours; KJ & EH)**
  - Complete event tree event probabilities
- **Consequences (Day 3 AM; 2 to 4 hours)**
  - *Costs for normal operations (JF, 15 min)*
  - *Costing for off-normal outcomes (JC & JF, 20 min)*
  - Review cost estimates (KJ):
    - Uncertainty
    - Correlations and differences
    - Occupational risks
- **Roll-up calculations (Day 3 PM; 2 to 4 hours; KJ & AC)**
  - Presentation (AC)
  - Discussion (All)

Prepared presentations shown in italics.

Objectives of the Deep Borehole Field Test

Synthesize field test activities, test results, and analyses into a comprehensive evaluation of concept feasibility

Evaluate site

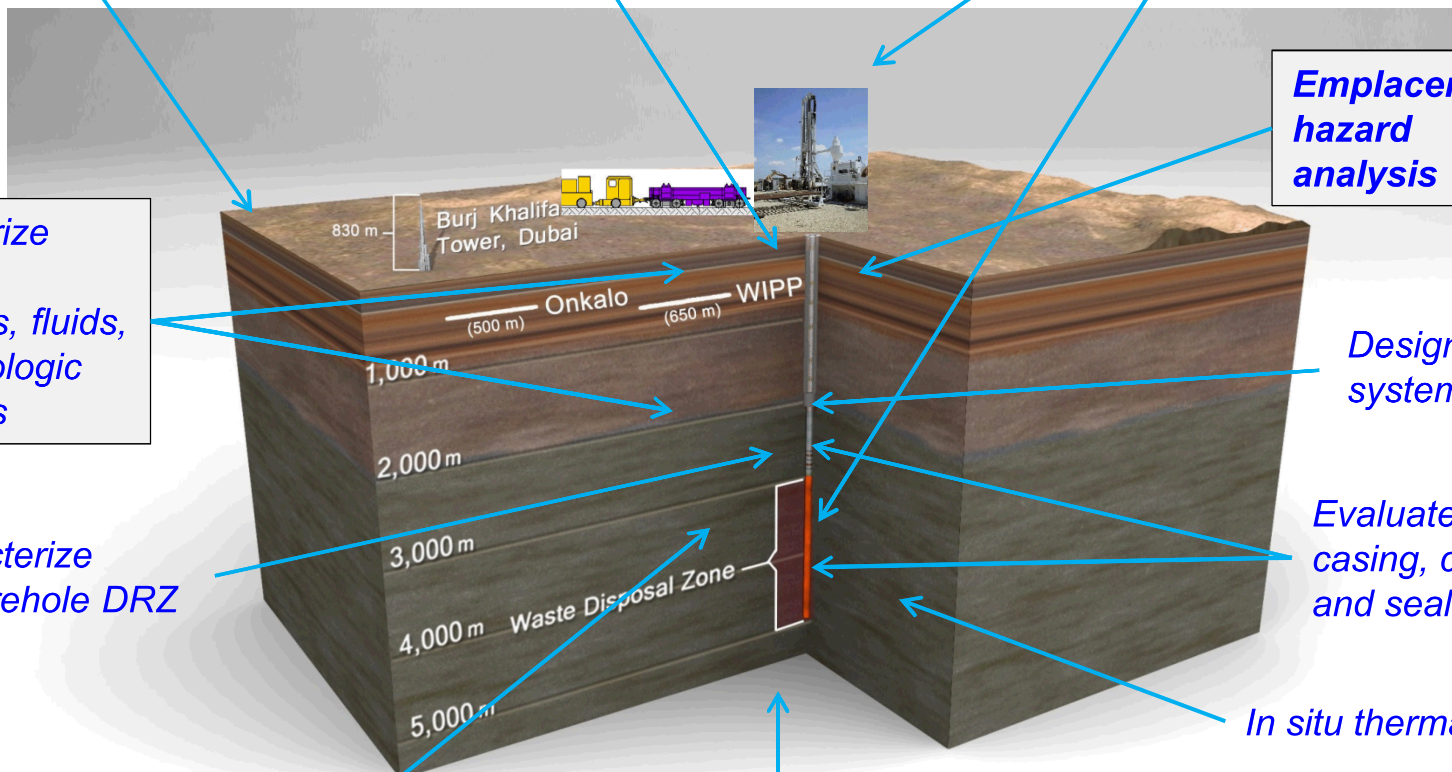
Design and construct characterization borehole then field test borehole

Develop and test systems for handling, emplacing, and retrieving WPs

Design and test WPs

Emplacement hazard analysis

Characterize overlying sediments, fluids, and hydrologic conditions



Design seal system

Characterize the borehole DRZ

Evaluate WP, WF, casing, cement, and seal materials

In situ thermal test

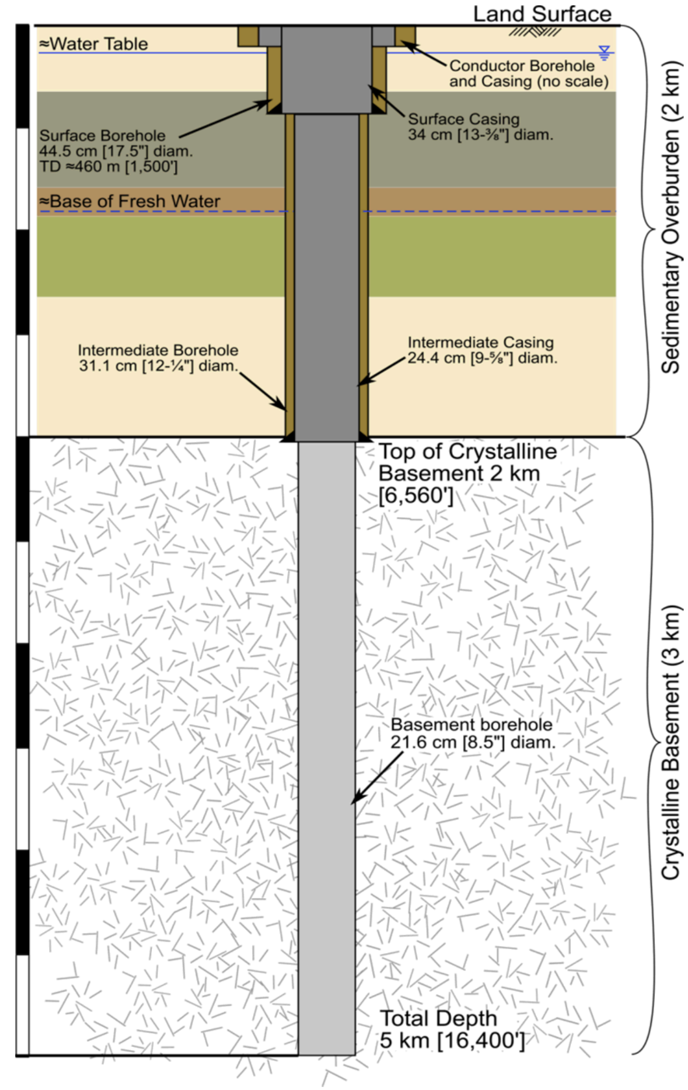
Characterize bedrock, fluids, and hydrologic conditions

Assess post-closure safety

In no case will the US Government place or otherwise have nuclear material, waste, or other waste disposal material on the property (RFP 2015).

Deep Borehole Field Test

- **Characterization Borehole** →
  - Bottom-hole diameter 8.5 in
  - Core and fluid sampling
  - Open-hole testing
  - Well logging and geophysical surveys
  - Predictions for field test borehole
  - RFP issued; proposals due Sept. 2015
- **Field Test Demonstration Borehole**



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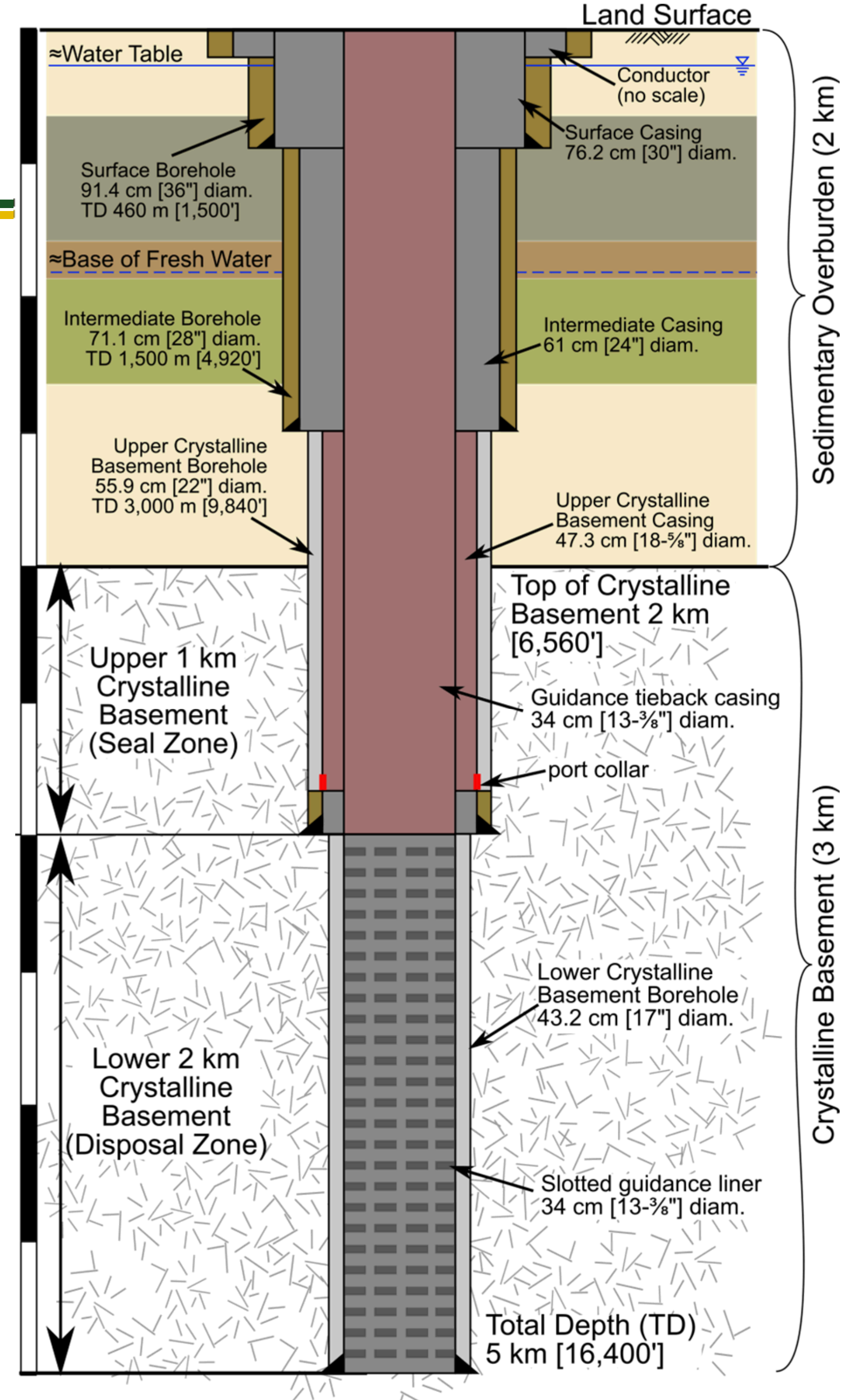
Field Test Borehole

- Disposal borehole diameter/plan
- Demonstrate emplacement and test canisters
- Casing removal
- 17-inch diameter at 5 km is not uncommon for geothermal

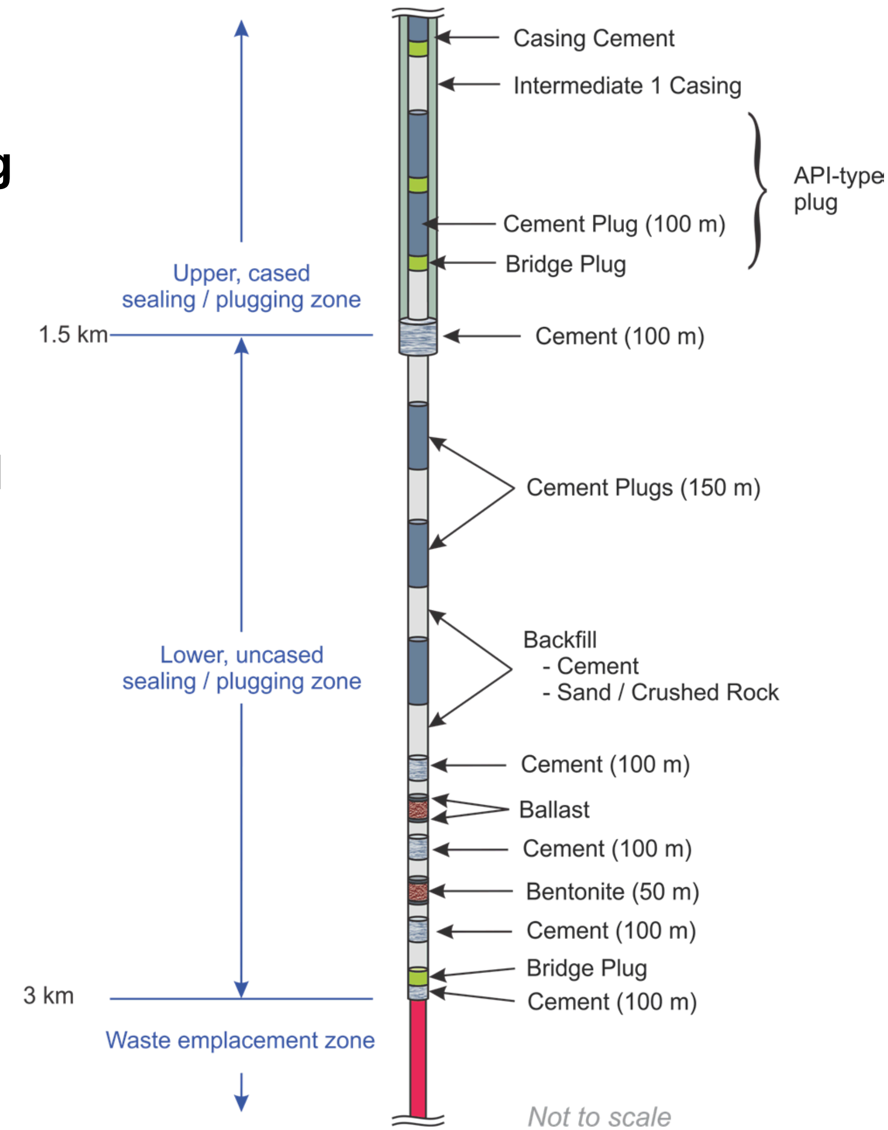
Disposal zone completion TBD

- Perforations
- Cementing
- Emplacement fluid
- Perforated guidance liner will be left in place in the disposal zone, but removed in the seal zone, along with intermediate casing



Reference Disposal Borehole Completion and Sealing Plan

- **Waste packages can withstand hydrostatic pressure and mechanical loading from overlying packages at *in situ* temperature**
- **The borehole above the waste disposal zone is sealed with alternating compacted bentonite clay, cement plugs, and cemented backfill**
- **Removal of casing from the seal zone in crystalline rock prior assures low-permeability and bonding with the borehole wall**



Source: Arnold et al. (2011)

FY15 Deliverable M2FT-15SN0817091 (SNL): *Deep Borehole Field Test Specifications*

- **Report Outline**
  1. DBFT Performance Objectives
  2. Disposal System Architecture
  3. Requirements, Assumptions and Criteria
  4. Available Technologies
  5. Borehole Environment
  6. Handling and Emplacement System Design Options
  7. Test Canister Concepts and Analysis
  8. Emplacement Hazard Analysis
  9. Emplacement Option Costs (normal and off-normal)
  10. Multi-Attribute (cost-risk) Conceptual Design Selection Analysis
  11. Supporting Engineering Analyses

Deep Borehole Field Test Engineering Design Work Package (SNL)

- **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

Deep Borehole Field Test Schedule

	FY15	FY16	FY17	FY18	FY19
Site Management and Drilling Integration Services (SM&D) Draft RFP – Issued	◆04/07/15				
Field Test – Award Engineering Services Contract	◆06/25/15				
SM&D Final RFP – Issue	◆07/09/15				
SM&D RFP – Proposals Due	◆09/09/15				
SM&D – Award Contract		◆02/05/16			
Field Test Borehole Services – RFP Issued		◆06/03/16			
Field Test Borehole Services – Proposals Due		◆08/05/16			
Characterization Borehole – Start Drilling		◆09/01/16			
Field Test Borehole Services – Award Contract			◆01/13/17		
Characterization Borehole – Completed			◆02/27/17		
Field Test Borehole – Start Drilling			◆07/07/17		
Field Test Borehole – Completed				◆01/05/18	
Field Test – Start Emplacement Demonstration				◆01/17/18	
Field Test – Complete Emplacement Demonstration					01/17/19 ◆
Documentation – Field Test Analyses and Evaluation					09/30/19 ◆

Wireline and Drill-String Emplacement Concepts

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Deep Borehole Field Test
Engineering Support Services Contract Kickoff Meeting
Las Vegas, NV
August 5, 2015

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Outline

- Spent Fuel Test – Climax
- Wireline Emplacement
- Drill-String Emplacement
- Borehole Environment
- Emplacement Safety
- Requirements and Assumptions
- Size Tradeoffs
- Some Design Questions

Spent Fuel Test – Climax (1978-1983)

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

VIDEO

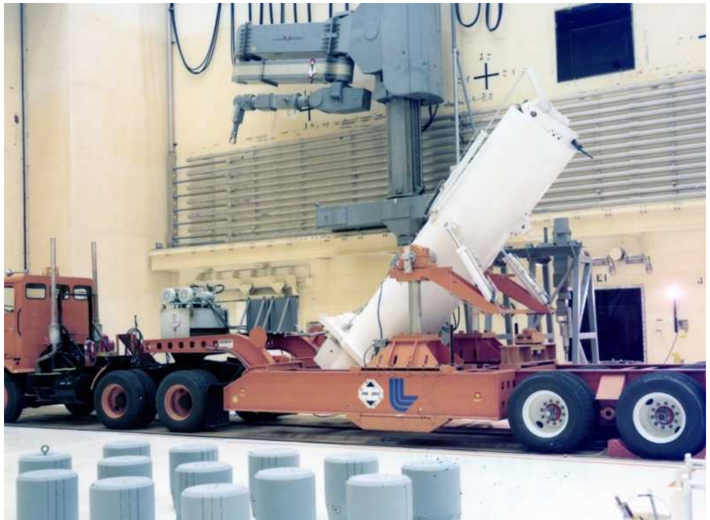
Spent Fuel Test–Climax: Underground Research Laboratory

- ~420 m depth, Climax granite stock, Nevada Test Site
- 11 PWR assemblies, Turkey Point NPP (one per canister)
- Lawrence Livermore National Lab (LLNL) lead

Rail-mounted Underground Transfer Vehicle
(in receive position under waste handling borehole)

Emplacement Gallery

Spent Fuel Test–Climax:
Transportation and Storage (EMAD ↔ Climax)



← **Cask Upending (EMAD*)**

→ **Dry Well Storage (EMAD)**

← **Hot-Cell Canister Storage (EMAD)**

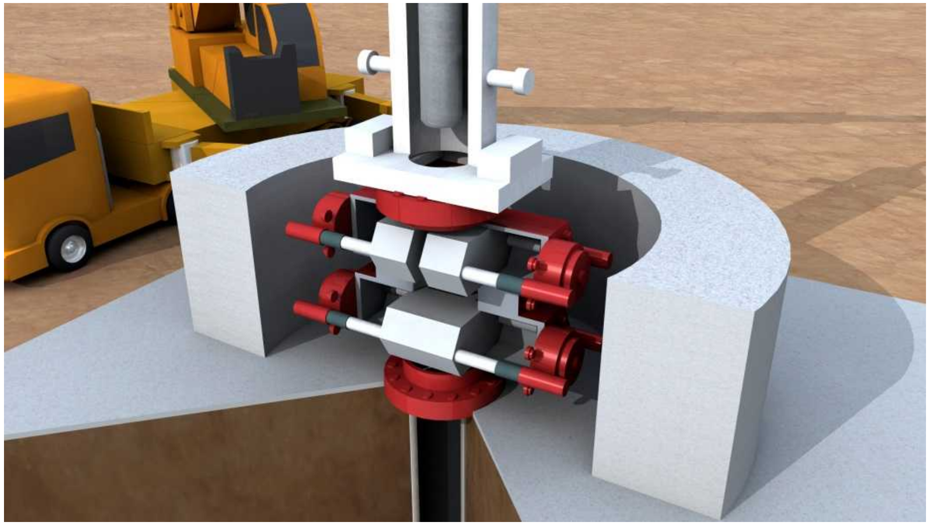
→ **50 km Route EMAD to/from Climax**

*** EMAD = Engine Maintenance and Disassembly**

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**

VIDEO



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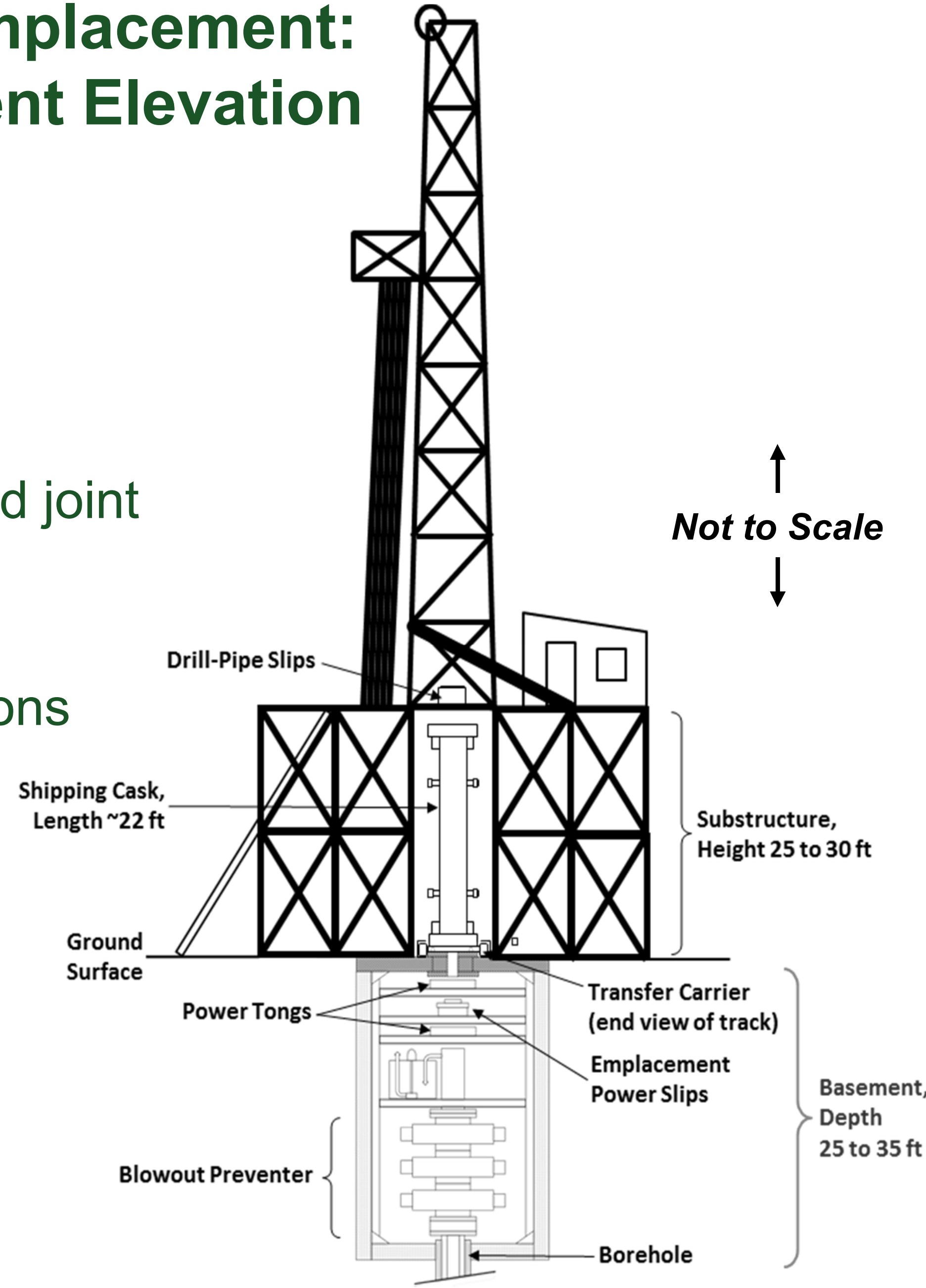
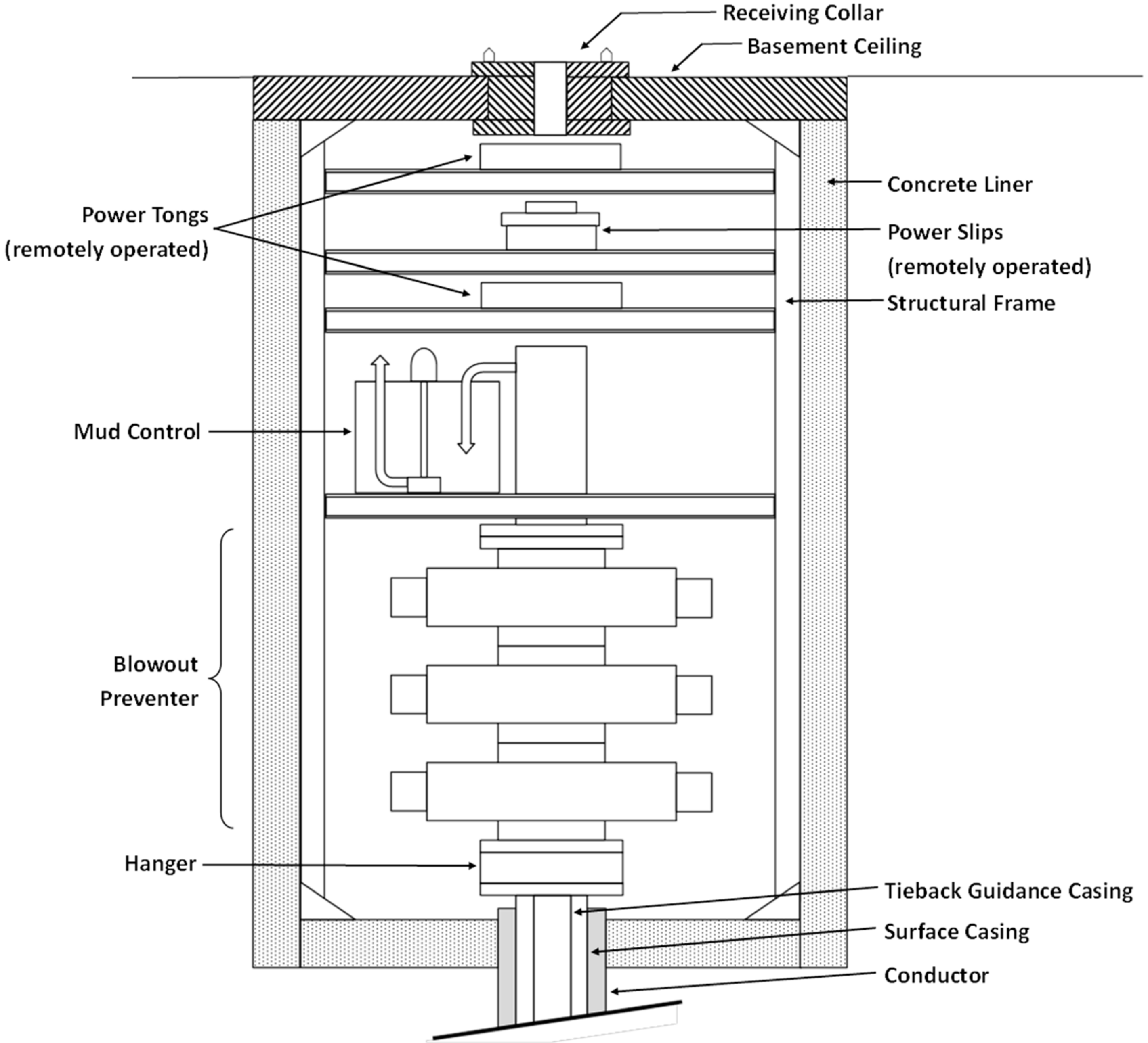
Drill-String Emplacement: Rig & Basement Elevation

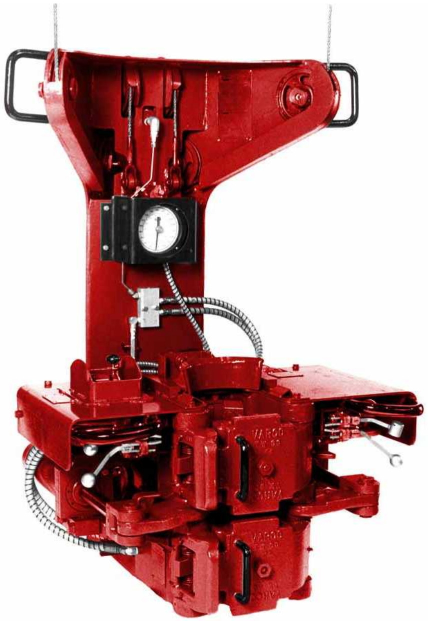
- **Rig capacities:**
  - Triple pipe stands (90')
  - >500,000 lb working load
  - Automatic pipe handling and joint makeup
- **Shielded shipping cask:**
  - Length ~22 ft, weight ~30 tons
- **Upper and lower cask doors**
- **Transfer carrier**
- **Subgrade basement**
  - Power slips/tongs
  - Mud surge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



Drill-String Emplacement: Basement Detail



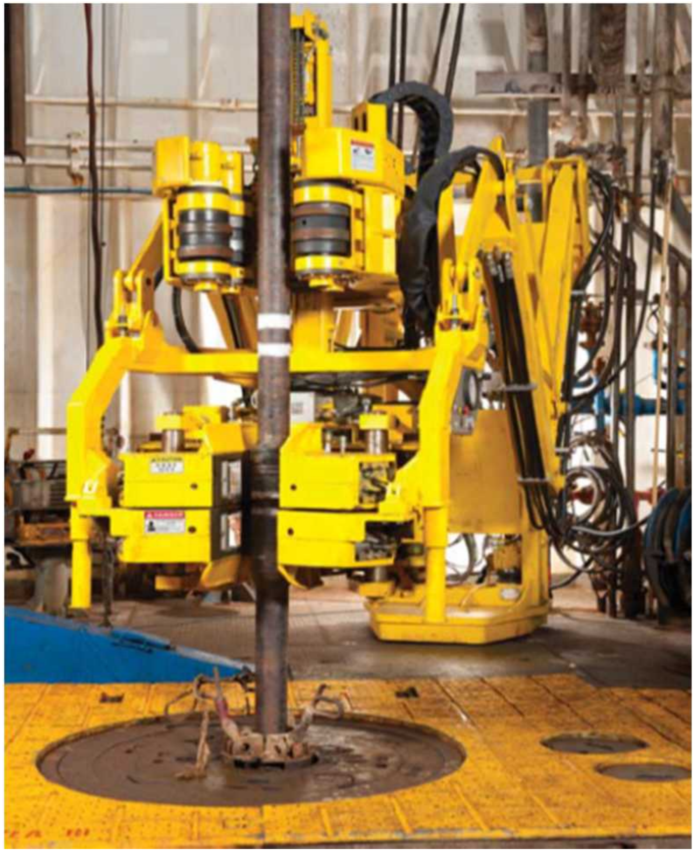
Drill-String Emplacement: Pipe Handling/Joint Makeup



Automated joint tender "iron roughneck" →

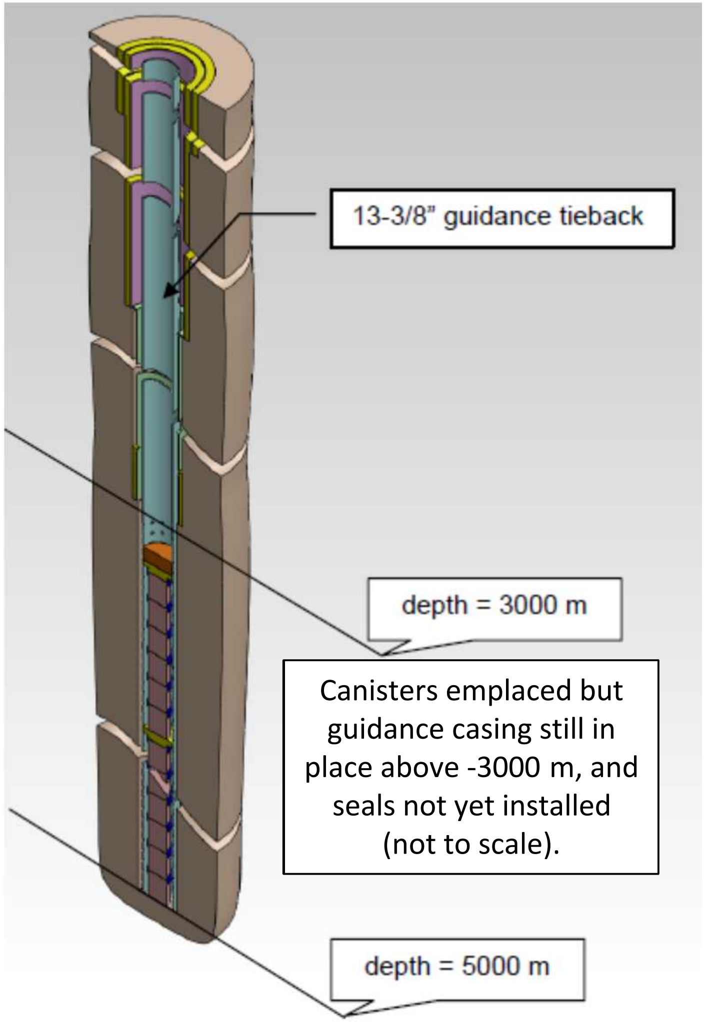
← Power tongs

Power slips ↓



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



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)

SKB Study of Deep Borehole Disposal Operations

- ***Radiological consequences of accidents during disposal of spent nuclear fuel in a deep borehole*. SKB P-13-13. July, 2013.**
- **Off-normal events:**
  - The canister string is dropped from the drill stem before the canisters have reached their intended position in the hole (i.e., Outcomes B & C)
  - An incomplete canister string is dropped before all 40 canisters have been connected (i.e., Outcomes B & C)
  - Failure to release the canister string when it has reached its intended position (considered insignificant)
  - The canister string gets stuck above the disposal zone and cannot be released (i.e., Outcomes A & E)
  - The canister string is stuck in the disposal zone before reaching its intended position (i.e., Outcomes B & D)
- **Swedish regulatory Best-Available-Technology constraint**

DBD Flowdown to DBFT Requirements (Examples)

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 Design Assumptions (Examples)

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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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.

Some Remaining Conceptual Design Questions

Deep Borehole Field Test

a) Factor of safety, and need for heat treatment of welded packages
b) Waste package sinking velocity (Viscosity effect? Radial gap? Perforations?) *
c) Wireline releasable cable head re-design
d) Repeated make/break longevity on premium casing connections
e) Leak detection/characterization (prototype packages in borehole fluid)

Disposal System (in addition to above)

h) Occupational safety discriminators (repairs in radiological environments?)
i) Rotary table vs. top-head drive for drill-string operations
j) Operability of double-redundant string controls
k) Repair of basement equipment in radiation environments
l) Safety interlocks
m) Engineered measures to prevent packages getting stuck (e.g., lead packages, downhole instrumentation, wireless telemetry)
n) Final disposal zone cementing configuration and emplacement fluid
o) Waste package drop resistance (dry, surface)

Sinking Velocity Very Slow?
($\mu_f > \mu_{water}$ *in guidance casing)*

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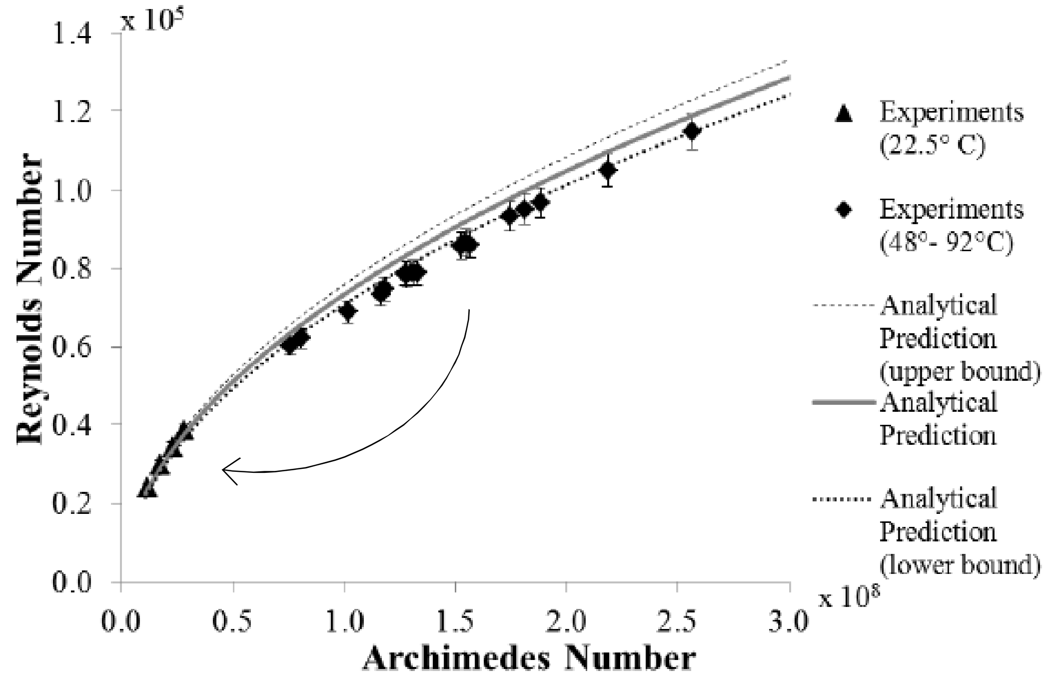
Velocity decrease….

$$Re = \frac{\rho_f V_f D_h}{\mu}$$

Abbreviation	Description of Variable	Dimensions
D_c	Diameter of Canister	L
t	Gap Thickness	L
D_h	Hydraulic Diameter*	L
l	Length of Canister	L
ρ_c	Density of Canister	$M/(L^3)$
ρ_f	Density of Fluid	$M/(L^3)$
μ	Viscosity of Fluid	$M/(LT)$
g	Gravitational Constant	L/T^2
ε	Surface Roughness	L
V_f	Velocity of Fluid	L/T



$$Ar = \frac{\rho_f(\rho_c - \rho_f) g {D_h}^3}{\mu^2}$$

Viscosity increase….

From Bates 2011 SM Thesis
Nominal result: reference package sinking velocity ~2.5 m/sec in water

References

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