SAND2015-6445PE

Deep Borehole Field Test:

Organization of Presentations

Description of FY15 DBFT Engineering Deliverable

Ernest Hardin

Sandia National Laboratories

Deep Borehole Field Test

Engineering Support Services Contract Kickoff Meeting

Las Vegas, NV

August 5, 2015

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

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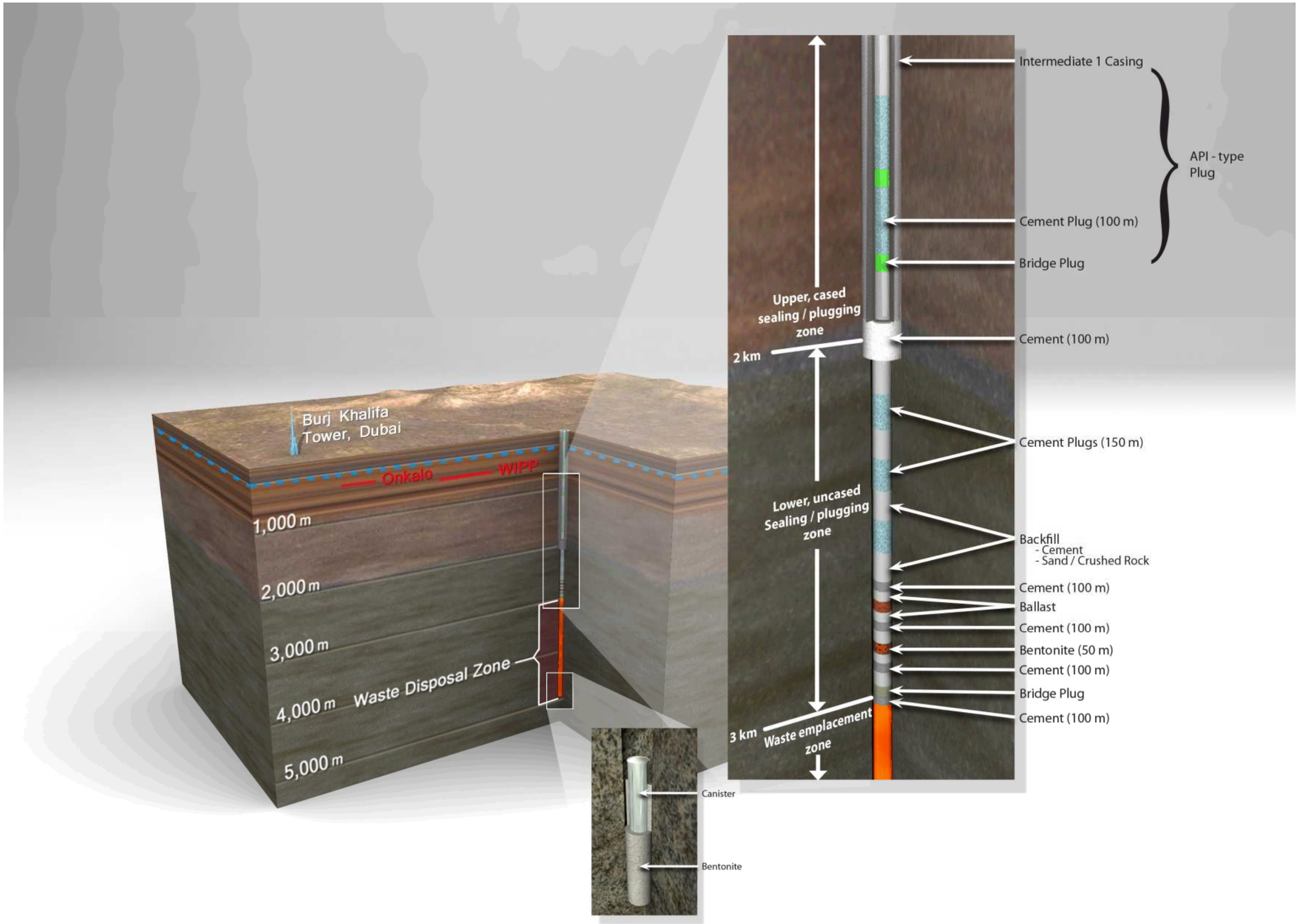
Deep Borehole Disposal Concept



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Objectives of the Deep Borehole Field Test

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

Evaluate site

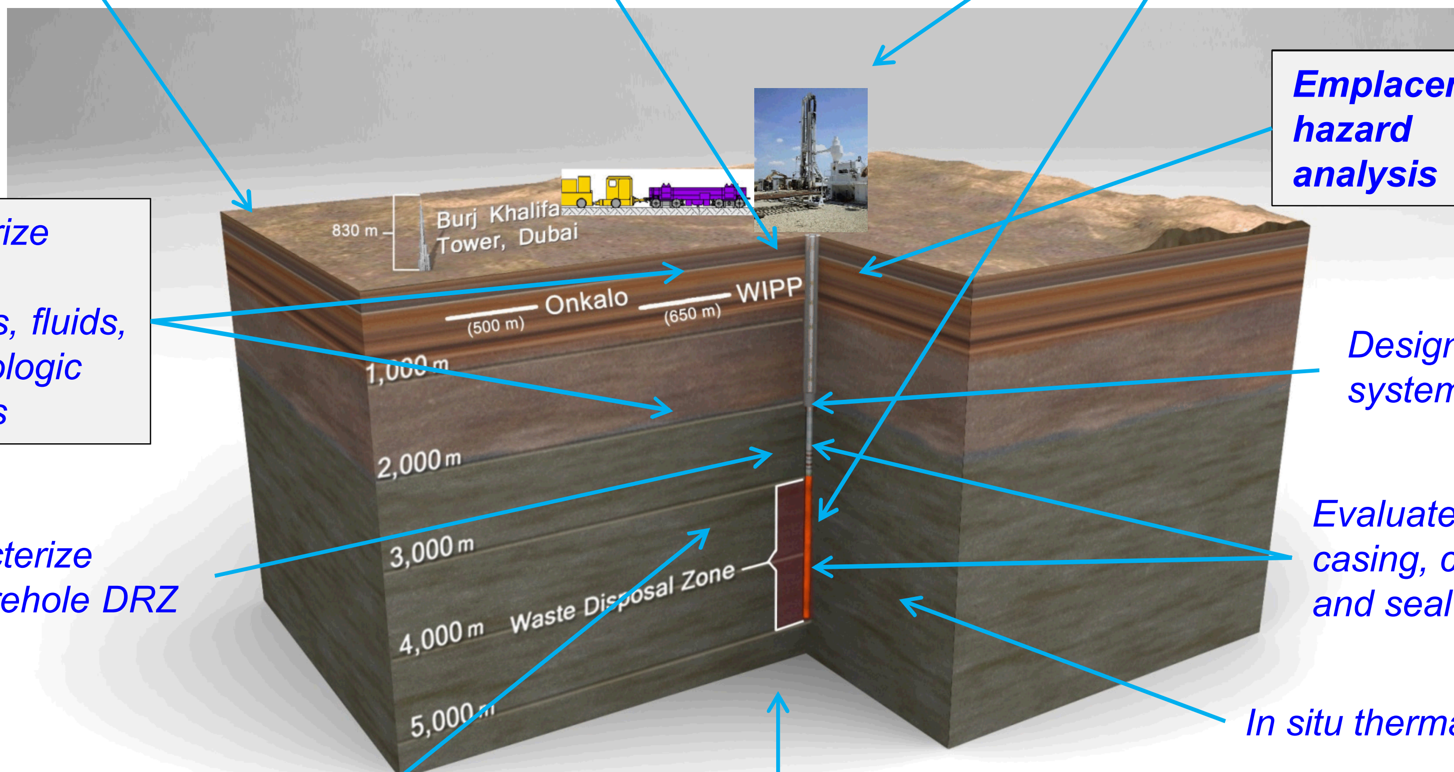
Design and construct characterization borehole then field test borehole

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).

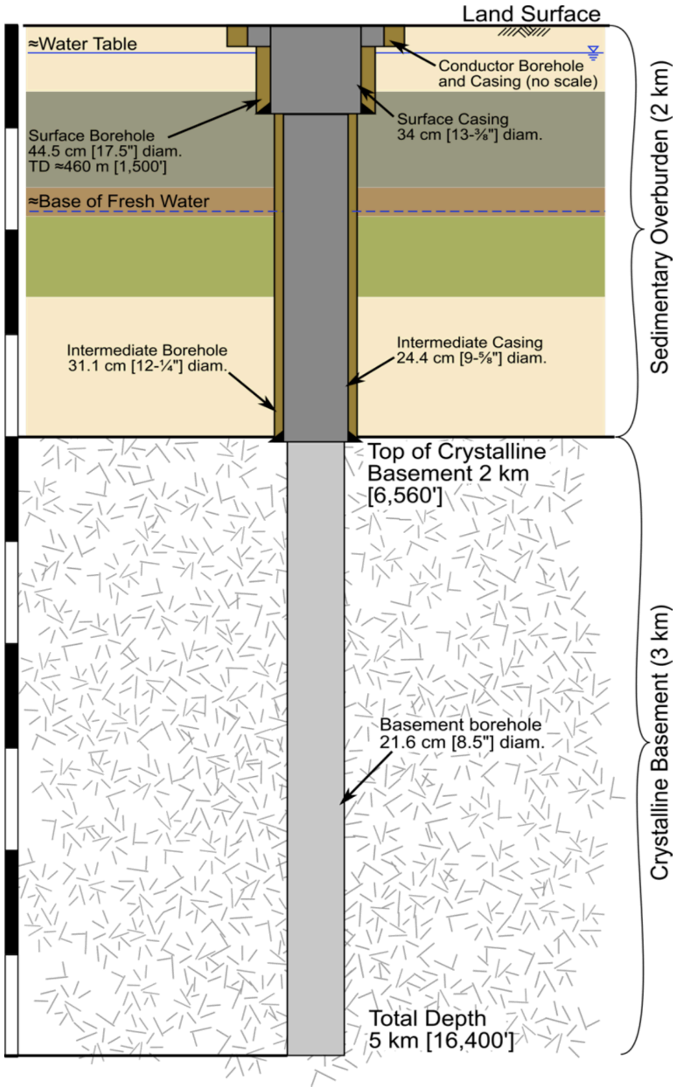
Deep Borehole Field Test

■ 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

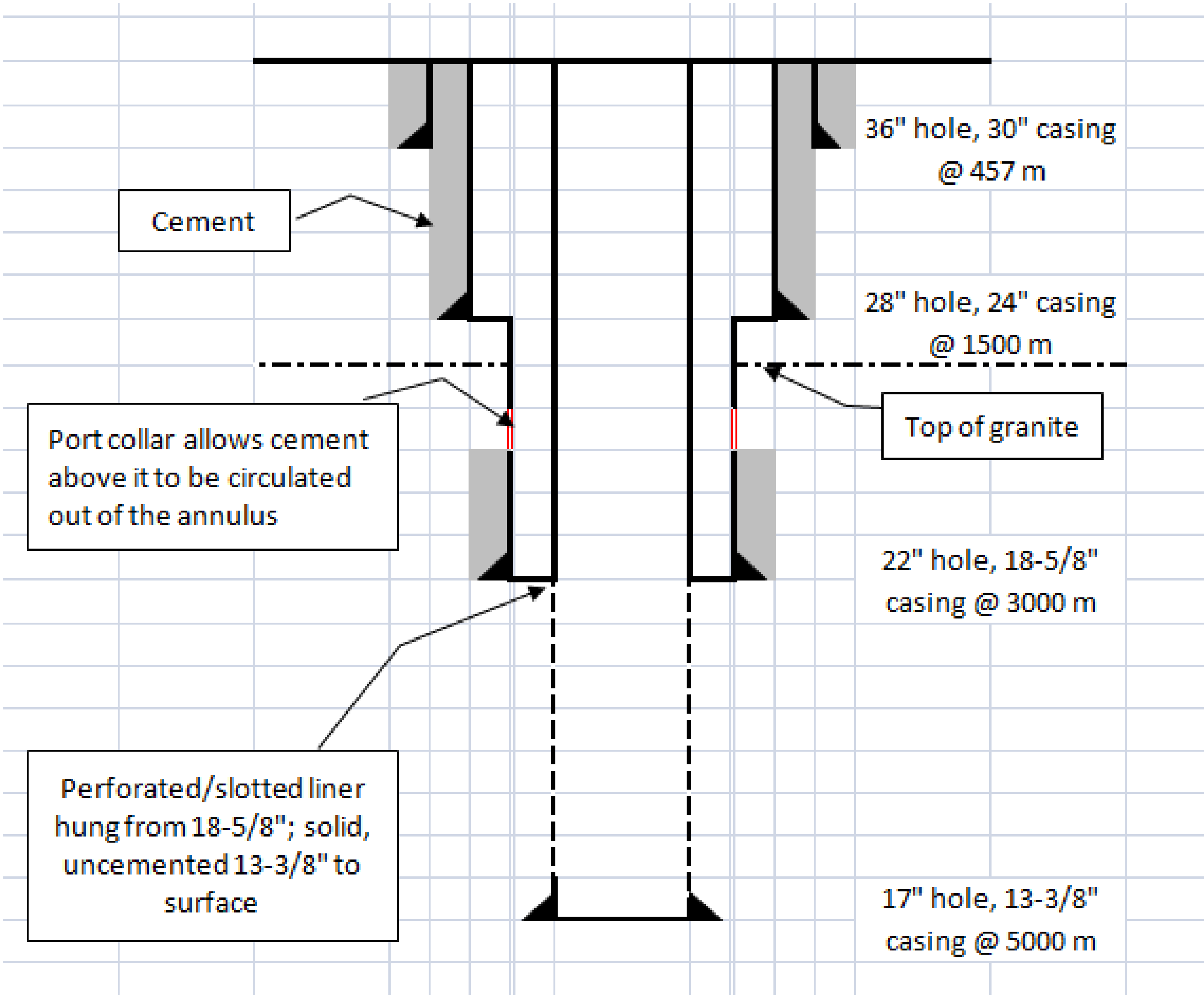
■ Field Test Demonstration Borehole

- Bottom-hole diameter 17 in
- Reference disposal borehole diameter/ casing plan
- Demonstration of emplacement system and test canisters
- Casing removal



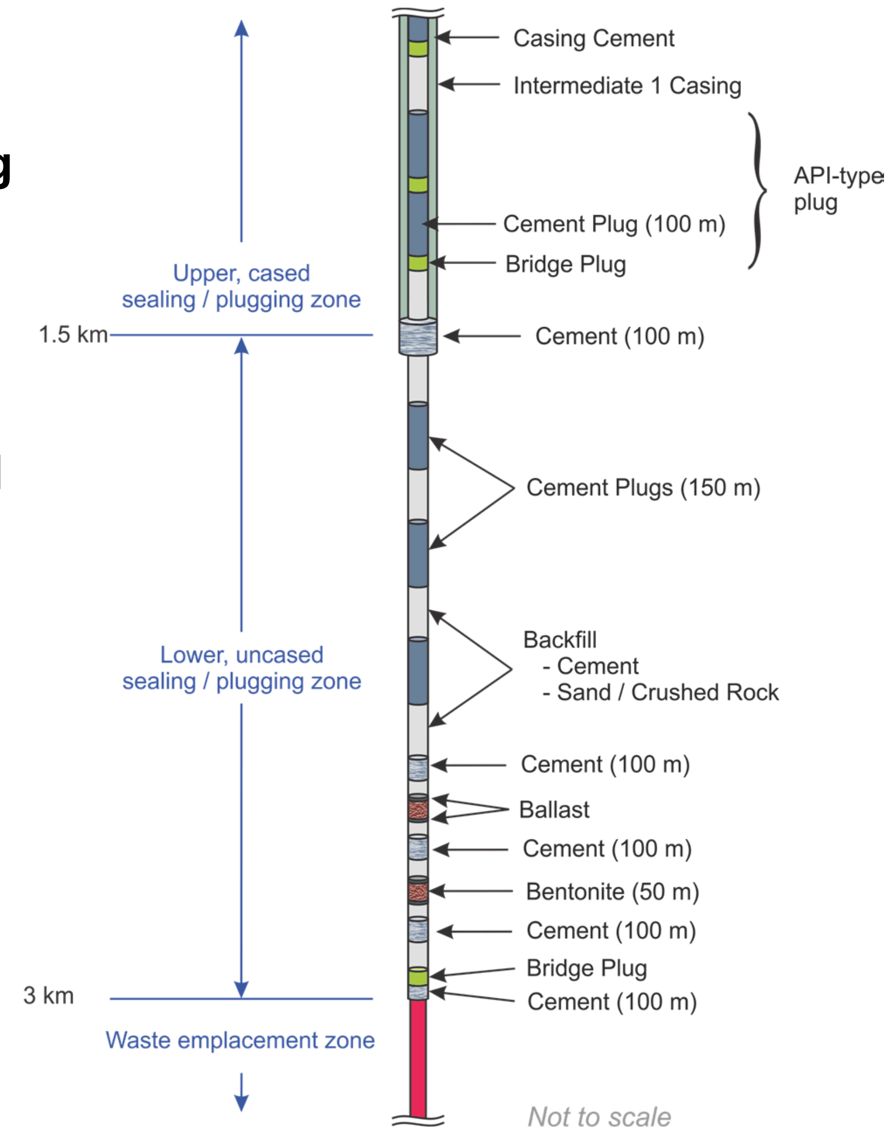
Field Test Borehole Casing Plan

- Drilling to 5 km depth at 17-inch diameter is not uncommon for geothermal development
- The perforated guidance liner will be left in place in the disposal zone, but will be removed in the seal zone, along with much of the 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 Performance 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
  10. Multi-Attribute (cost-risk) Conceptual Design Selection Analysis
  11. Supporting Engineering Analyses

Engineering Support Services Contract Kickoff – August, 2015

- **Presentations by Sandia Staff**
  - Emplacement Options
    - *Drill-string, wireline, and other emplacement options considered*
    - *Requirements and assumptions*
  - Packaging Options
    - *Flask-type vs. Internal-flush*
    - *Reference size and smaller size for Cs/Sr capsules*
  - Emplacement method hazard analysis
  - Cost estimation
  - Multi-Attribute Cost-Risk Utility Analysis
  - DBFT Engineering Project Planning

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Wireline and Drill-String Emplacement Concepts

Ernest Hardin

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Outline

- Spent Fuel Test – Climax
- Wireline Emplacement
- Drill-String Emplacement
- Borehole Environment
- Emplacement Safety
- Requirements and Assumptions
- Size Tradeoffs
- DOE-Owned Waste Management

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

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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

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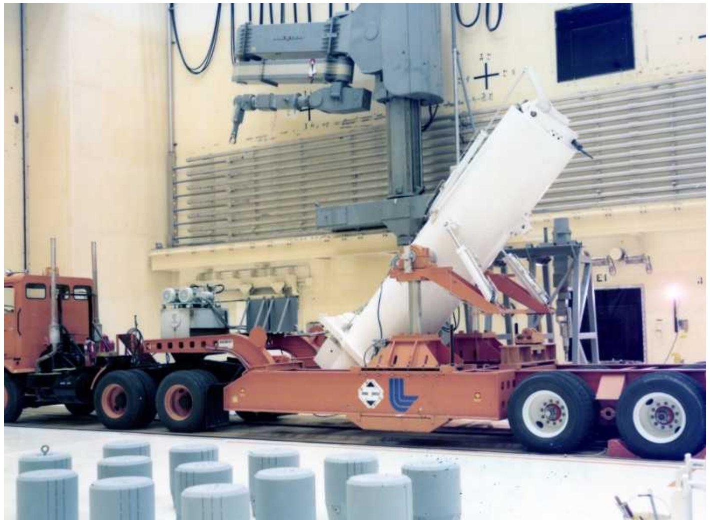
Spent Fuel Test–Climax:
Transportation and Storage (EMAD ↔ Climax)



← Cask Upending (EMAD*)

→ Dry Well Storage (EMAD)

← Hot-Cell Canister Storage (EMAD)

→ 50 km Route EMAD to/from Climax

* EMAD = Engine Maintenance and Disassembly

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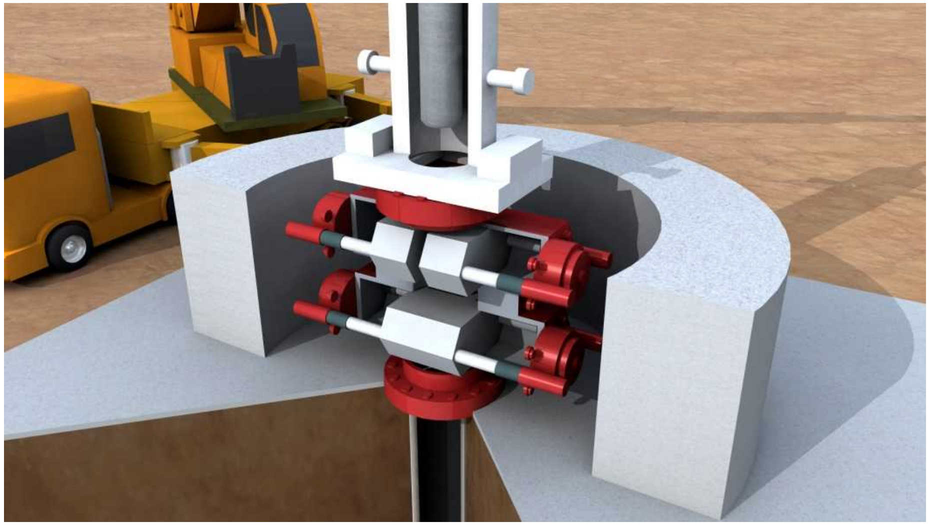
Wireline Emplacement Surface Layout

- **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**

VIDEO



Drill-String Emplacement: Rig & Basement Elevation

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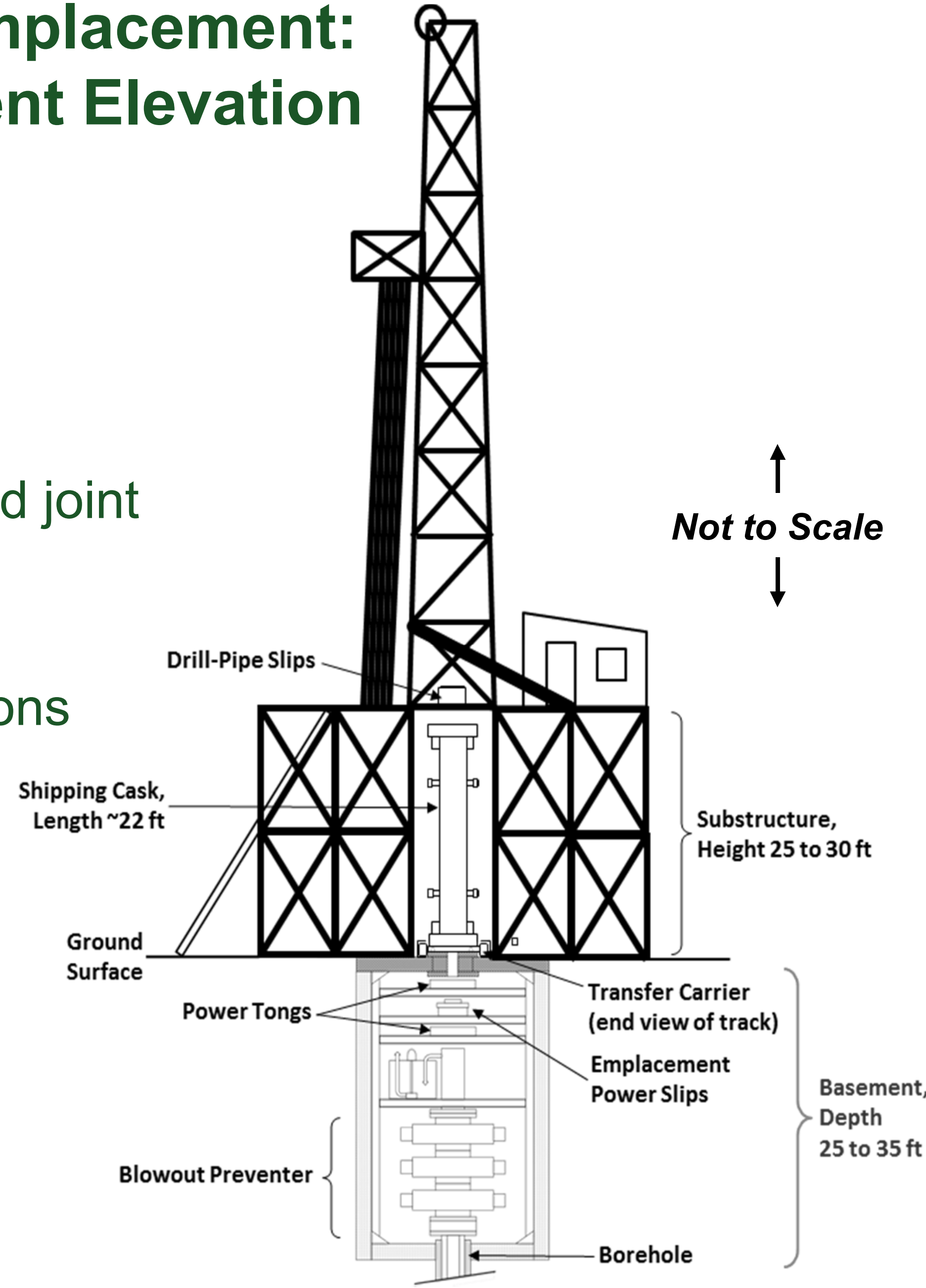
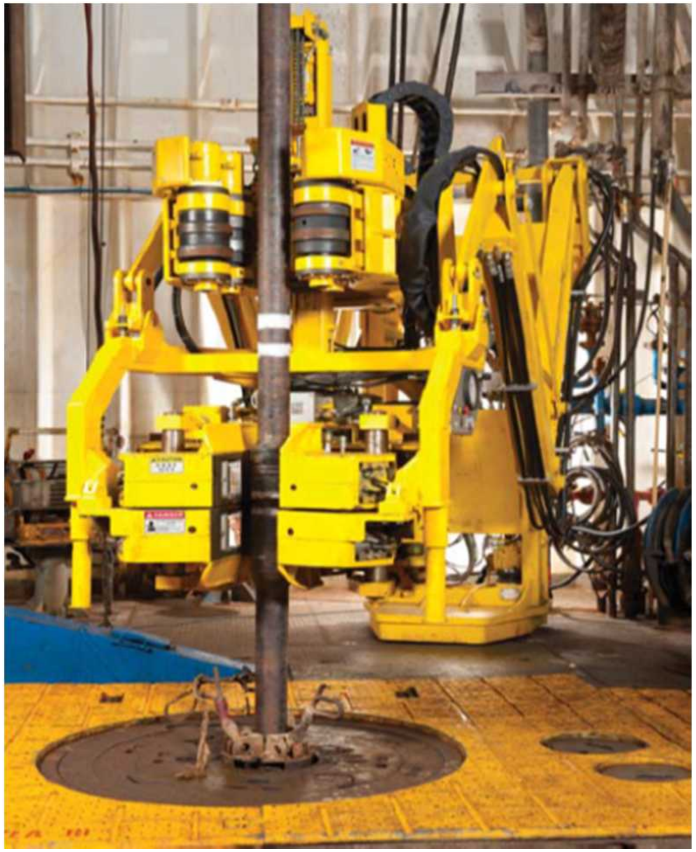
- **Rig capacities:**
  - Triple pipe stands (90’)
  - >500,000 lb working load
  - Automatic pipe handling and joint makeup
- **Shielded shipping cask:**
  - Length ~22 ft, weight ~30 tons
- **Upper and lower cask doors**
- **Transfer carrier**
- **Subgrade basement**
  - Power slips/tongs
  - Mud surge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



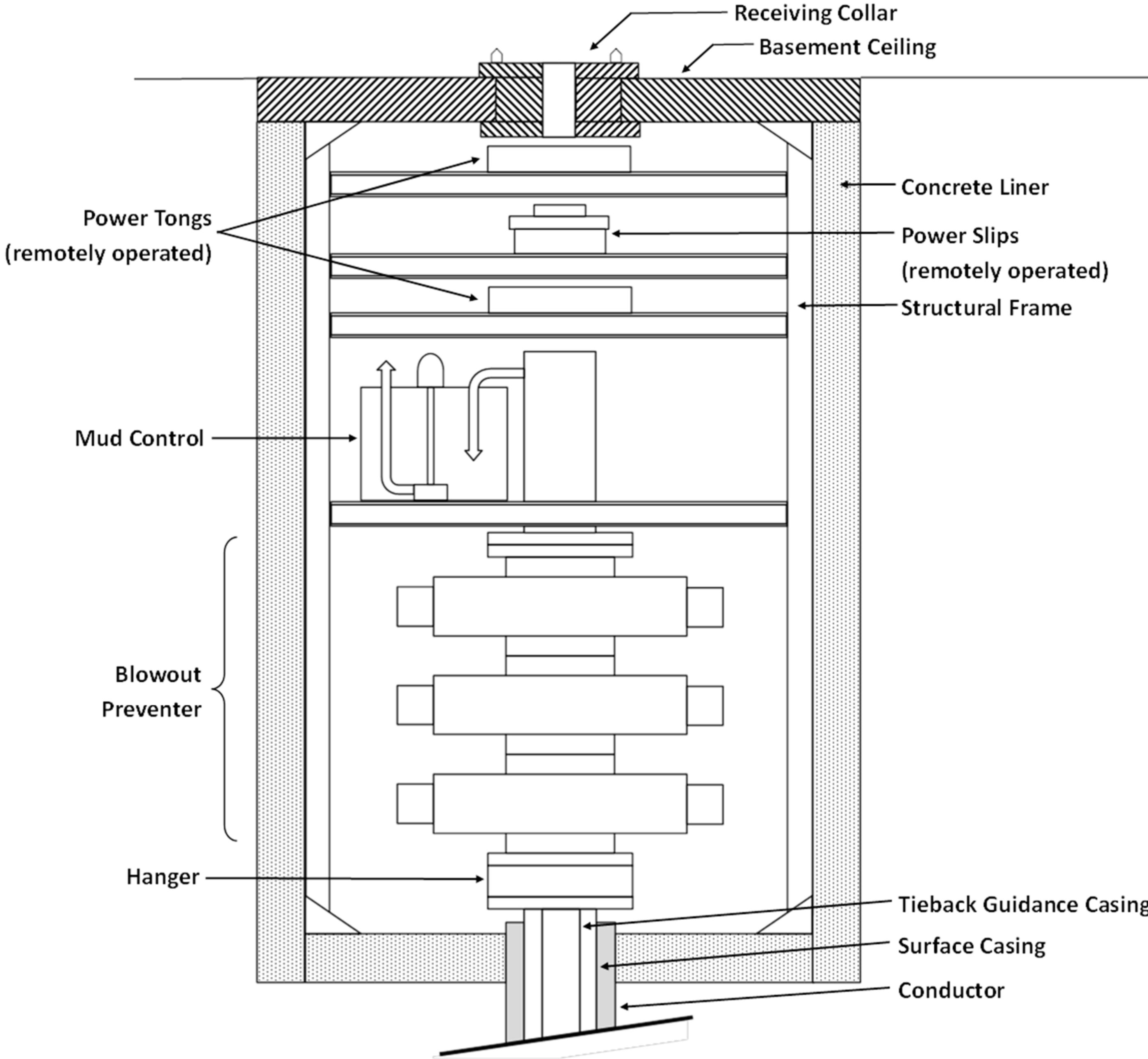
Drill-String Emplacement: Pipe Handling/Joint Makeup

Automated joint tender "iron roughneck" →



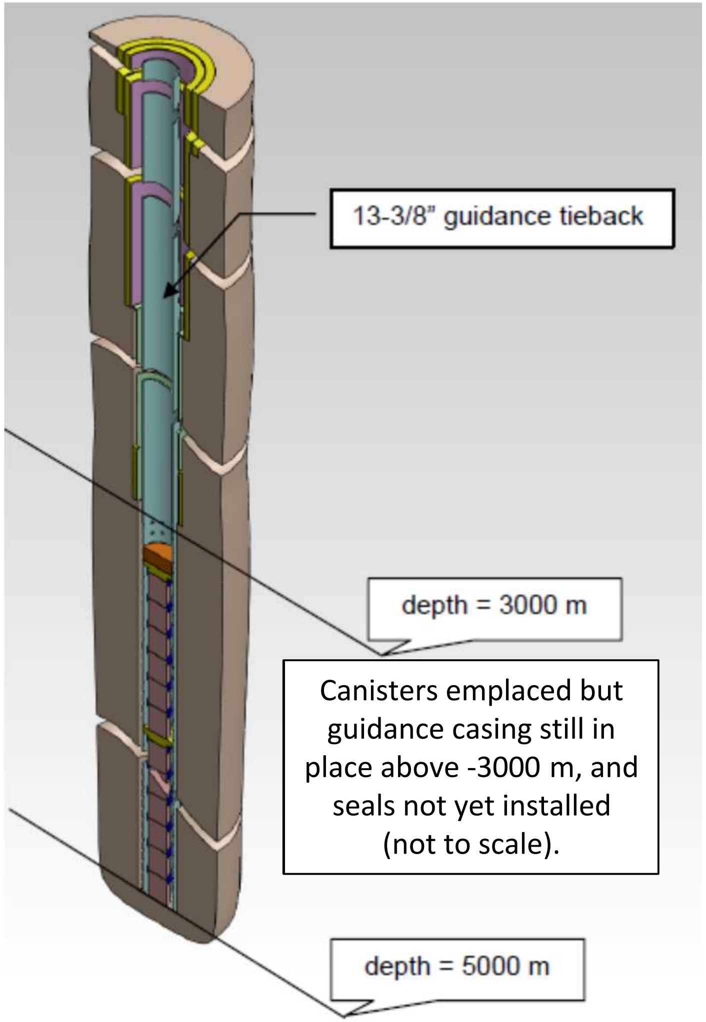
Power slips ↓

Drill-String Emplacement: Basement Detail



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)

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DBD Flowdown to DBFT Requirements (1/3)

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 (2/3)

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.
…	…

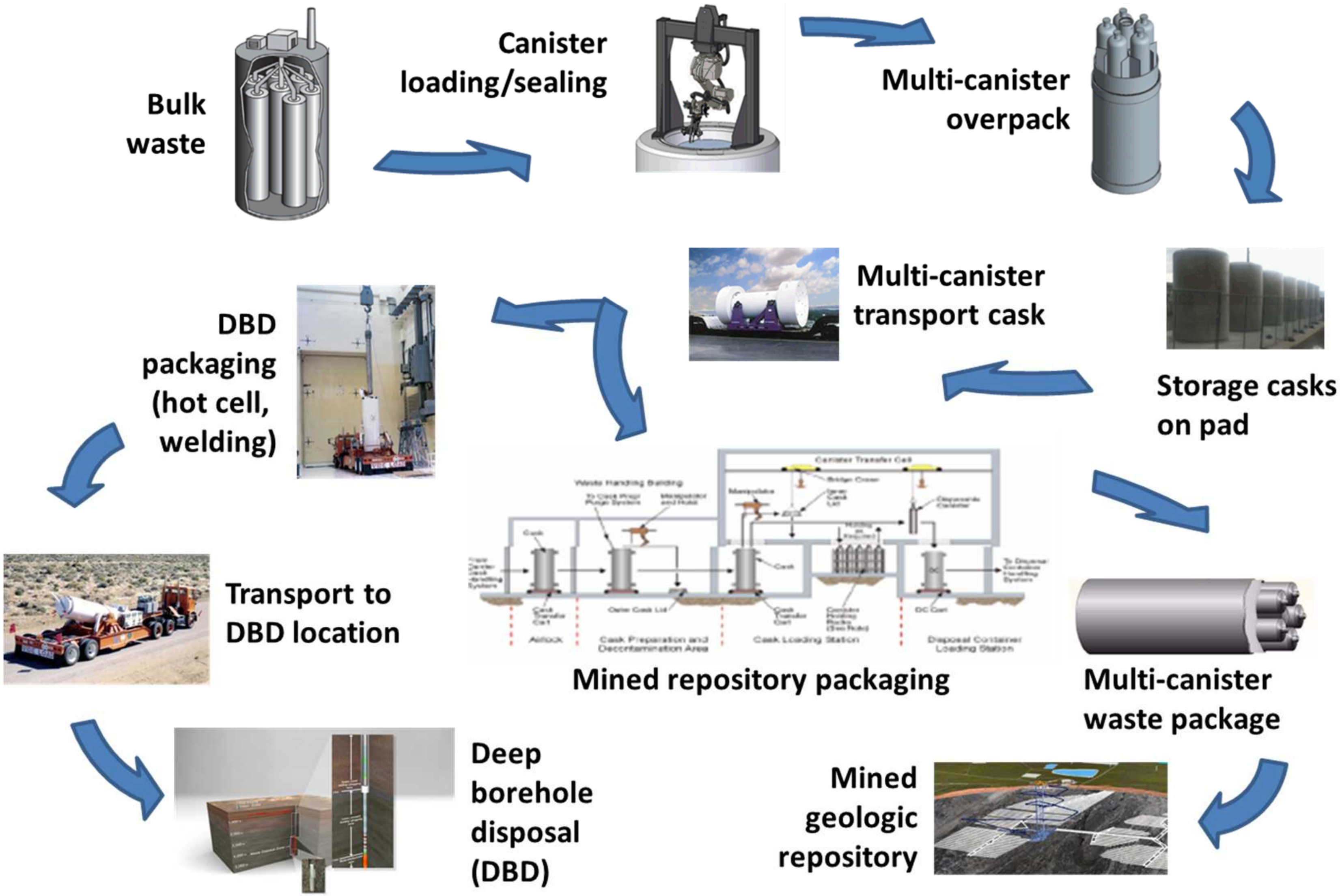
DBD Flowdown to DBFT Requirements (3/3)

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 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.
…	…

System Concept for Packaging, Storage, Transportation & Geologic Disposal



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Disposal Borehole and Overpack Size Tradeoffs

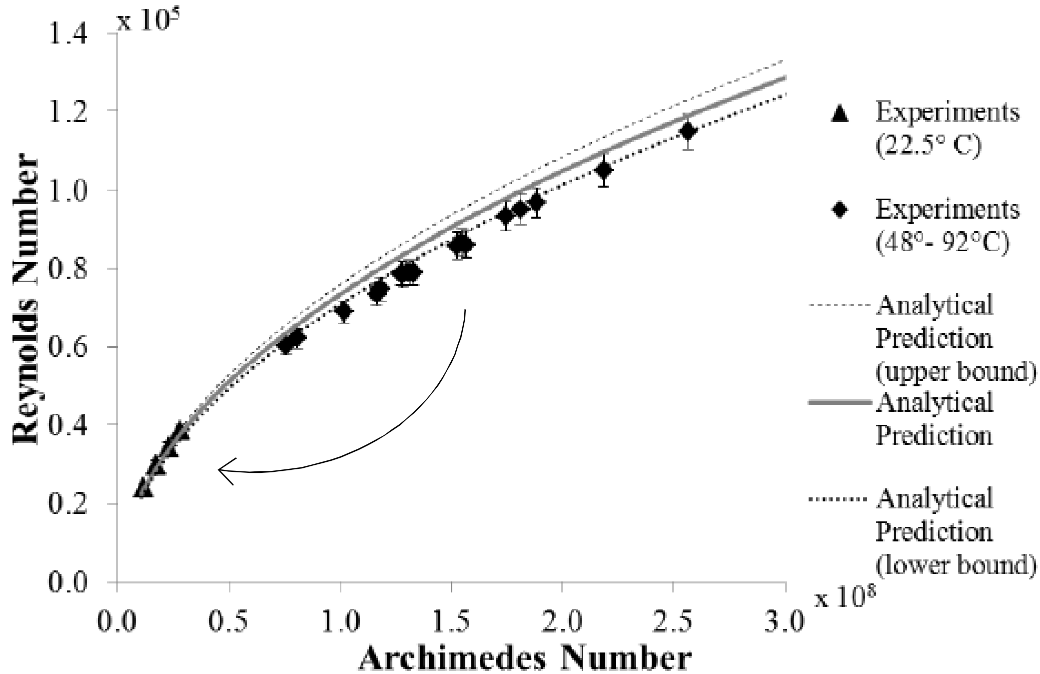
Borehole and Canister Sizes >>>>	Small	Medium	Reference	Large
Waste per Canister >>>>	2 to 8 capsules end-to-end	3-capsule groups stacked ≤ 8 high	Bulk	Bulk
Disposal Zone Hole Diameter	8.5”	12.3”	17”	22”
Disposal Zone Casing ID	6.4”	9.8”	12.6”	17.4”
Disposal Overpack OD	5”	8.5”	11”	16”
Disposal Overpack 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.

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

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

Remaining Conceptual Design Questions

- **Deep Borehole Field Test**
  a) Occupational safety discriminators
  b) Factor of safety and need for heat treatment
  c) Waste package sinking velocity (disproportionate viscosity effect?) *
  d) Waste package drop resistance (dry, surface)
  e) Wireline releasable cable head re-design
  f) Make/break longevity on premium casing connections
  g) Leak detection/characterization
- **Disposal System (in addition to above)**
  h) Double-redundant string control during drill-string trips in/out
  i) Operability of pipe ram/slip ram for redundant gripping of strings
  j) Safety interlocks
  k) Final disposal zone cementing configuration and emplacement fluid
  l) Engineered measures to prevent packages getting stuck (e.g., downhole instrumentation and telemetry)
  m) Repair of basement equipment in radiation environment

*** Bates 2011 SM Thesis, MIT (http://dspace.mit.edu/handle/1721.1/76520#files-area)**

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References

- 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.
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Multi-Attribute Emplacement Concept Selection Study: Approach and Status

Ernest Hardin

Sandia National Laboratories

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Steps in the Deep Borehole Emplacement Mode Study

Define alternative emplacement modes

Drill-string or wireline — Options Letter Report, Rev. 9

Identify objectives and performance metrics

Objectives identify "ideal" alternatives; performance metrics focus on measuring achievement and differentiating the alternatives — Methodology Letter Report, Section 2.3

Evaluate the performance of each alternative using performance metrics

Key uncertainties that may affect performance — Hazard Analysis Letter Report

Identify and quantify key uncertainties affecting performance → **Evaluate alternatives under each outcome of the key uncertainties**

Combine multiple outcomes / metrics into single measures (as needed)

Consequences on multiple objectives can be combined based on tradeoffs by decision-makers — Consequences of normal and off-normal events can be combined through weighting — Methodology Letter Report, Section 2.6

Compare the alternatives based on their anticipated performance

Extensive sensitivity analyses — Methodology Letter Report, Section 2.7

Select an emplacement mode for the DBFT based on the disposal system

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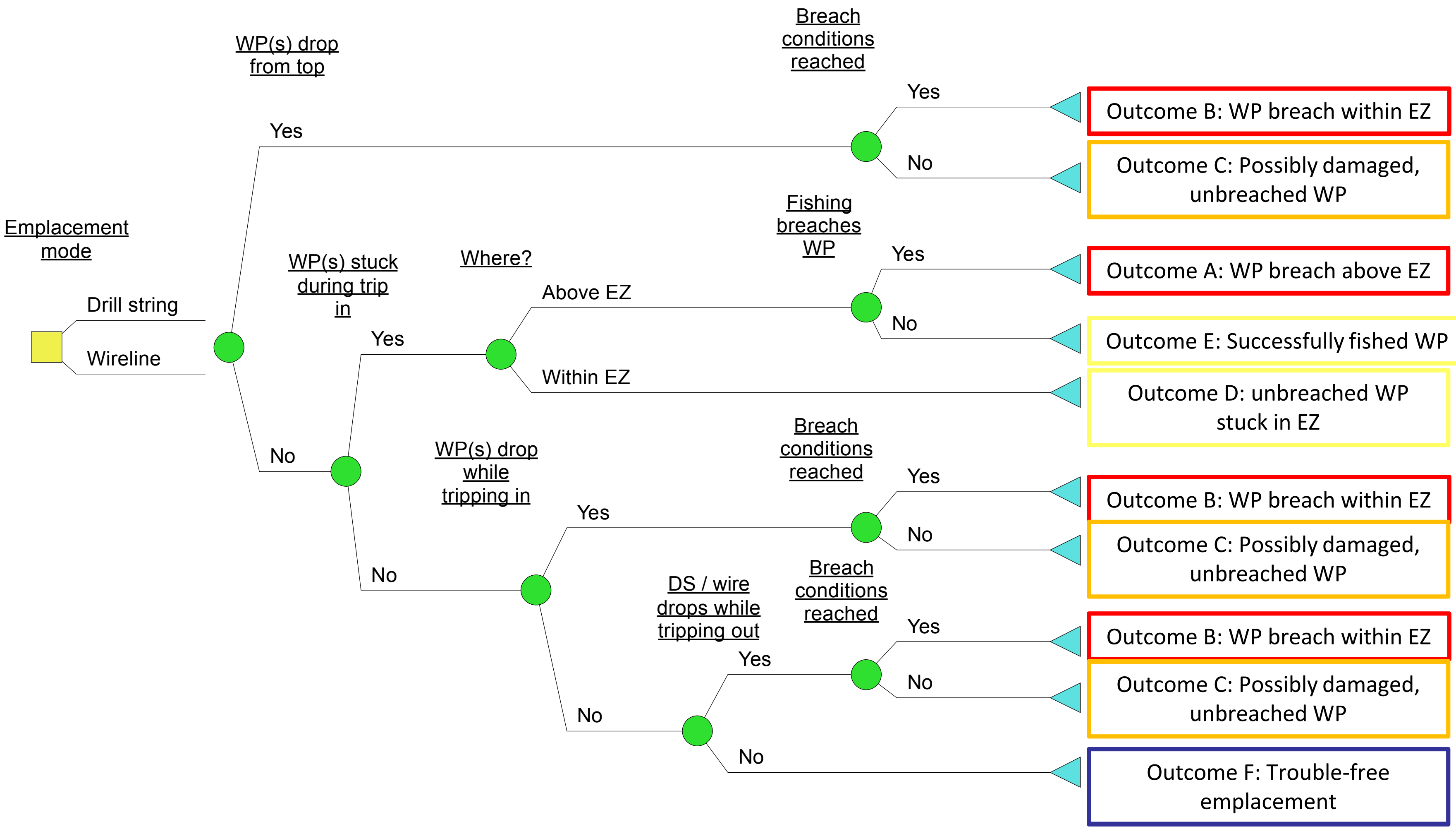
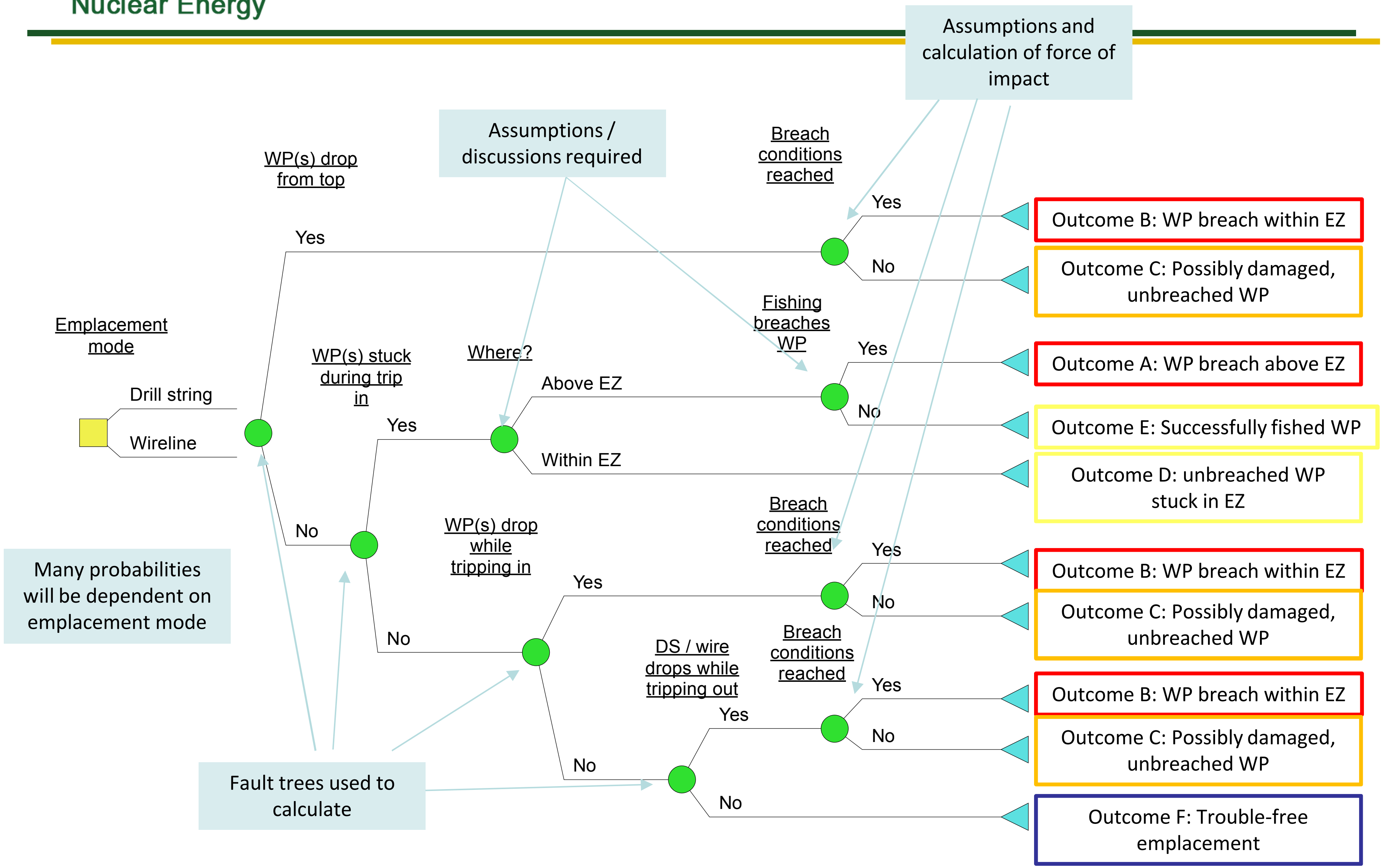
Top-level simplified event tree: what can go wrong during emplacement



Sources of probability estimates



Six Unique Outcomes To Be Evaluated

Outcome		Key Assumptions	Occupational Safety	Detectable Radiation Leakage	Incremental Cost (> normal wireline ops)
A	WP(s) breached above disposal zone (e.g. by fishing)	Fishing successful; borehole decon, sealing, plugging	TBD (primary risk may be radiological exposure during repair of critical equipment)	Yes	Fishing and remediation; delay; decon; loss of hole
B	WP(s) breached in emplacement zone	No fishing; borehole decon, sealing, plugging		Yes	Remediation; delay; decon; loss of hole
C	WP(s) dropped into disposal zone (or something dropped onto WPs); no breach	Fishing successful; WP(s) retrieved, inspected, replaced; borehole useable		No	Fishing (incl. string); delay; WP transport, inspection and replacement
D	WP(s) stuck in disposal zone; no breach	No fishing or further emplacement; cementing, sealing, plugging per plan		No	Delay; loss of disposal capacity
E	WP(s) stuck above disposal zone; no breach	Fishing successful; WP(s) retrieved; no further emplacement; cementing, sealing, plugging per plan		No	Fishing; delay; loss of disposal capacity
Normal operations; emplace 400 WPs					
F1	Drill-string	None	See above	No	See cost memo
F2	Wireline			No	Zero

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**

Expert Panel Will Develop Remaining Analysis Inputs During a 3-Day Workshop

- Review and refine, as necessary, the fault trees identifying the off-normal events of concern for each emplacement mode
- Review and/or develop probabilities for the fault trees, enabling calculation of the likelihood of each off-normal event for each mode
- Review and refine, as necessary, the events subsequent to an off-normal initiating event that would lead to adverse consequences
- Review and provide comments on the consequences assessment

Expert Panel Participants

- **External panelists:**
  - John Finger – Drilling consultant
  - Mark MacGlashan – Wireline consultant
  - Nelson Tusberg – Head of Engineering for Leitner-Poma.
  - Frank Spane – Geoscientist with PNNL
  - Sven Bader – AREVA engineer
  - Scott Bear – AREVA engineer
- **SNL staff panelists:**
  - Doug Blankenship – Manager of Geothermal Dept.
  - Courtney Herrick – WIPP engineer.
  - Tim Wheeler or Susan Stevens-Adams – Reliability Dept.
- **Supporting resources:**
  - Ernest Hardin/SNL (project lead)
  - Steve Pye – Drilling consultant
  - John Cochran/SNL (emplacement concepts; available as needed)
  - Jiann Su/SNL (waste packaging concepts; available as needed)
  - Paul Eslinger/PNNL (SAPHIRE)
- **Observers:**
  - Allen Croff/NWTRB Member

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DBFT Engineering: Objectives, Schedule and Technical Direction Overview

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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

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Contributions of DBFT Engineering Activities to Feasibility Demonstration

- **Design, develop, and demonstrate test packages, surface handling and emplacement systems, and operational methods for safe waste package emplacement and retrieval**
- **Verify through hazard analysis that handling and emplacement operations have acceptably low risk**
- **Provide reliable estimates of packaging and emplacement costs**