U.S. DEPARTMENT OF ENERGY | Nuclear Energy

SAND2014-19289PE

Deep Borehole Disposal Concept and Field Test

Timothy C. Gunter (DOE-NE)
Robert J. MacKinnon (SNL)

Used Fuel Disposition R&D Campaign

2014 Fuel Cycle Technologies Annual Meeting
November 4-6, 2014
Idaho Falls, ID

Sandia National Laboratories is a multiprogram 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. SAND2014-xxxx

Deep Borehole Disposal Outline

- Overview
  - Deep Borehole Disposal (DBH) Concept
  - DBH Field Test
  - DBH Field Test Request for Information
  - Subsurface Technology and Engineering RD&D (SubTER) Crosscut
- DBH Concept, Design and Field Test Project
  - DBH Concept
  - Geological Aspects of Siting
  - Reference Design and Operations
  - DBH Field Test Project
- Conclusions

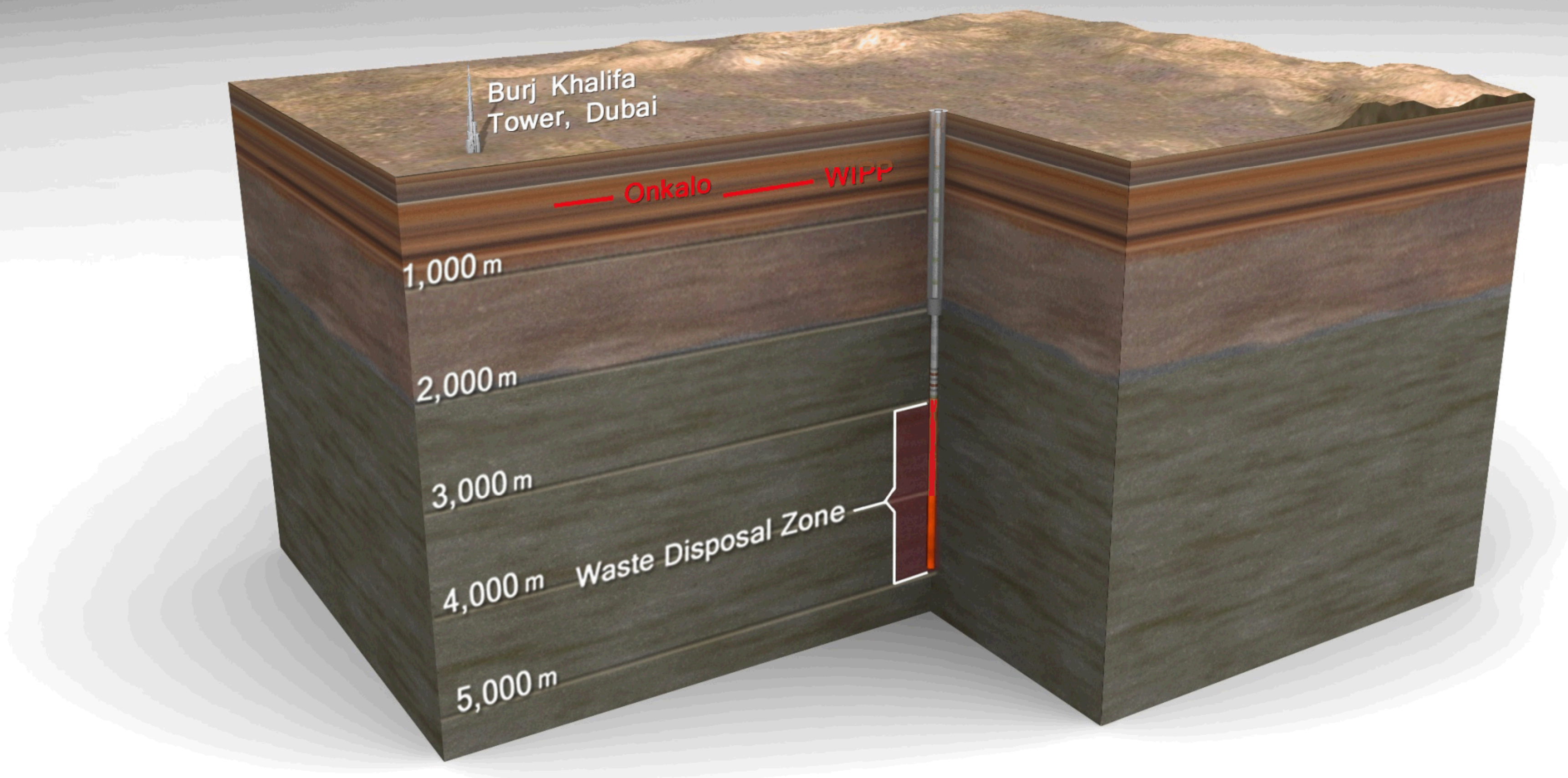
Deep Borehole Disposal Concept

- **Deep borehole disposal of high-level radioactive waste has been considered in the U.S. and elsewhere since the 1950s and has been periodically studied since the 1970s**
- **Disposal concept consists of drilling a borehole or array of boreholes into crystalline basement rock to about 5,000 m depth**
- **Waste could consist of DOE-managed waste forms, including some DOE spent nuclear fuel, high-level radioactive waste, or other specialized waste types**
- **Waste canisters would be emplaced in the lower 2,000 meters of the borehole**
- **Upper borehole would be sealed with compacted bentonite clay, cement plugs, and cemented backfill**

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Deep Borehole Disposal Concept



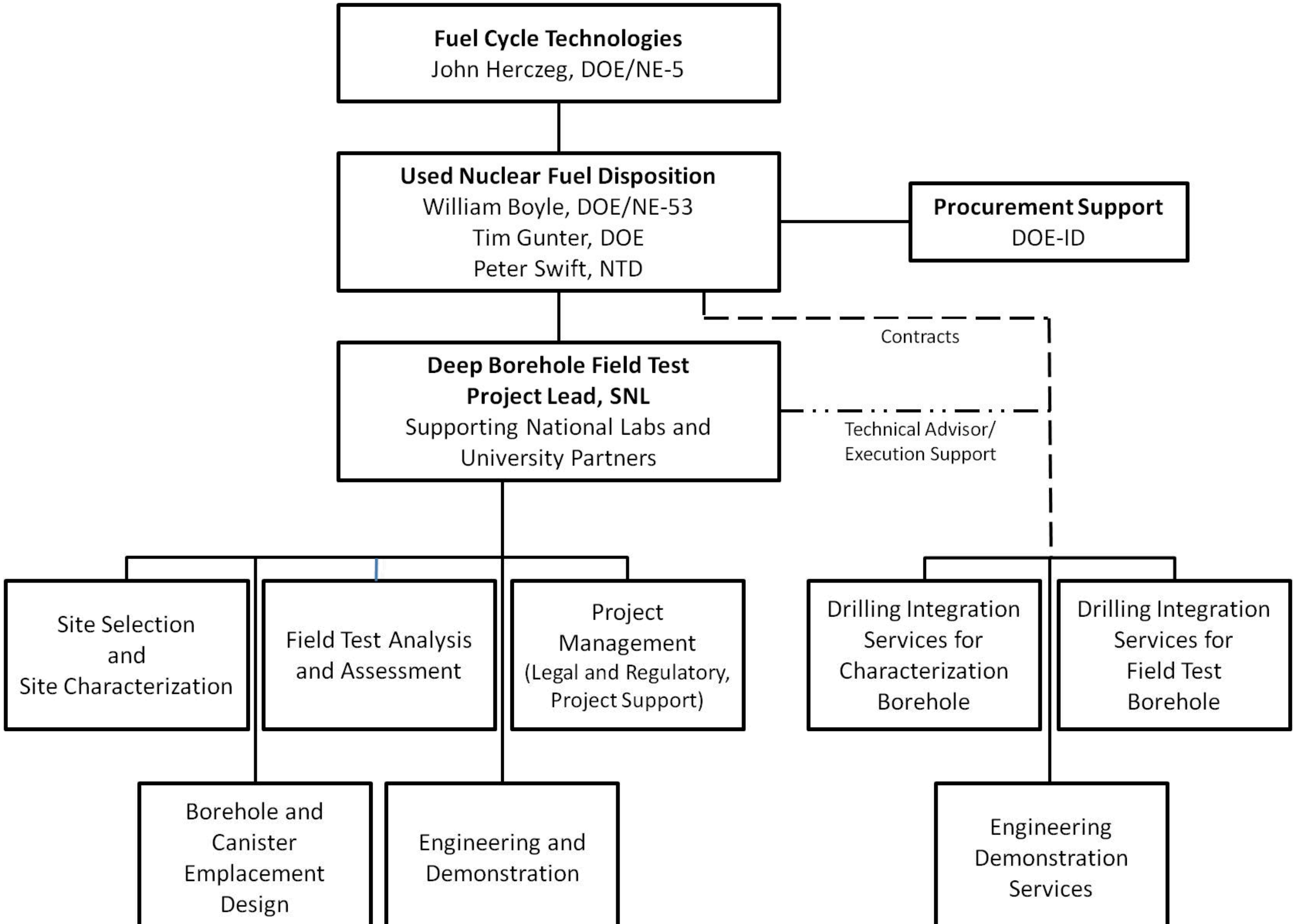
Deep Borehole Field Test

- **Additional research, development, and demonstration is necessary in several important areas for further consideration of deep borehole disposal of radioactive waste, including:**
  - Demonstration of drilling technology and borehole construction to 5 km depth with sufficient diameter for cost effective waste disposal
  - Verification of deep geological, geochemical, and hydrological conditions at a representative location
  - Evaluation of canister, waste, and seals materials at representative temperature, pressure, salinity, and geochemical conditions
  - Development and testing of engineering methods for waste canister loading, shielded surface operations, waste canister emplacement, and borehole seals deployment
- **The RD&D objectives for deep borehole disposal would be best met with a borehole field test that is conducted to a depth of 5 km in a representative location (without emplacement of radioactive wastes)**

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Deep Borehole Field Test Project Organization



Deep Borehole Field Test Request for Information

- **Deep Borehole Field Test Request for Information (RFI)**
  - RFI solicits input and interest from States, local communities, individuals, private groups, academia, or any other stakeholders who are willing to host a DBH Field Test
  - The RFI is now posted via Federal Business Opportunities (FedBizOpps, www.fbo.gov) under DE-SOL-0007705
  - Posted to on October 24, 2014, responses due December 8, 2014 (45 days)
  - Direct link: https://www.fbo.gov/index?s=opportunity&mode=form&id=d3ff93b06490ac4383e0ba41509dc46a&tab=core&_cview=0
- **DOE Idaho Operations Office (Procurement & Contracts)**

Deep Borehole Field Test
SubTER Crosscutting Initiative

- NE is one of several DOE offices participating in the Subsurface Technology and Engineering Research RD&D (SubTER) Crosscutting Initiative
- More effectively leverage funding through multi-office collaborations, and improve efficiency by avoiding overlapping or redundant research
- NE has proposed the deep borehole field test as an area for collaboration under SubTER, to leverage other DOE expertise in drilling technology, well construction and integrity, and subsurface characterization.
- Possible co-location of deep borehole experiments with EERE Enhanced Geothermal Systems Frontier Observatory for Research in Geothermal Energy (FORGE), a proposed R&D site for subsurface research (if rock conditions are suitable for both programs)

DBH Concept, Design and Field Test Project

Deep Borehole Disposal Feasibility

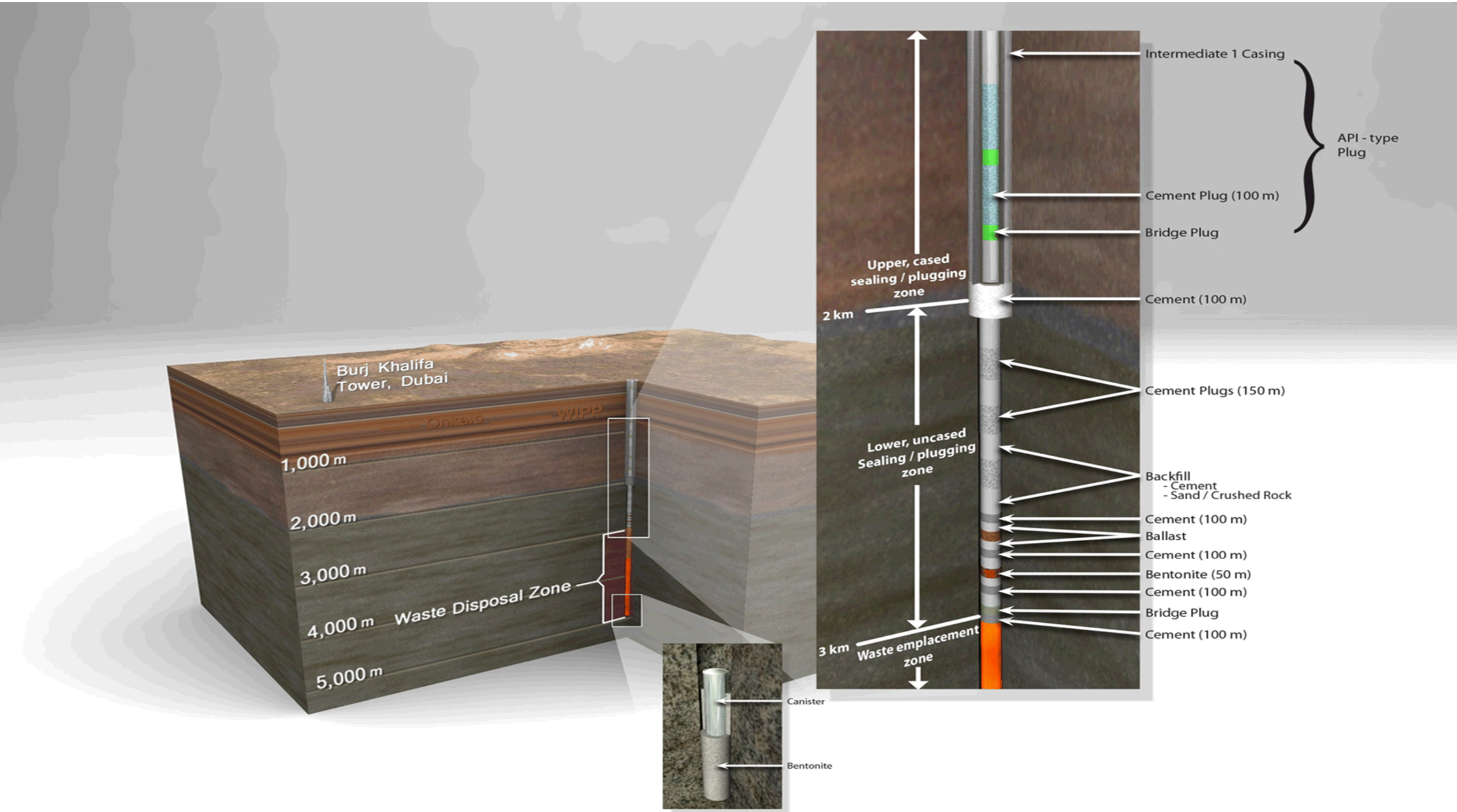
Several factors suggest that the disposal concept may provide a technically feasible and cost-effective alternative for safe disposal of some DOE-managed waste forms:

- Crystalline basement rocks are common in many stable continental regions
- Existing drilling technology should permit dependable construction at acceptable cost
- Low permeability and long residence time of high-salinity groundwater in deep continental crystalline basement at many locations suggests very limited interaction with shallow fresh groundwater resources
- Geochemically reducing conditions at depth limit the solubility and enhance the sorption of many radionuclides in the waste
- Density stratification of saline groundwater underlying fresh groundwater would oppose thermally induced groundwater convection

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Deep Borehole Disposal Concept



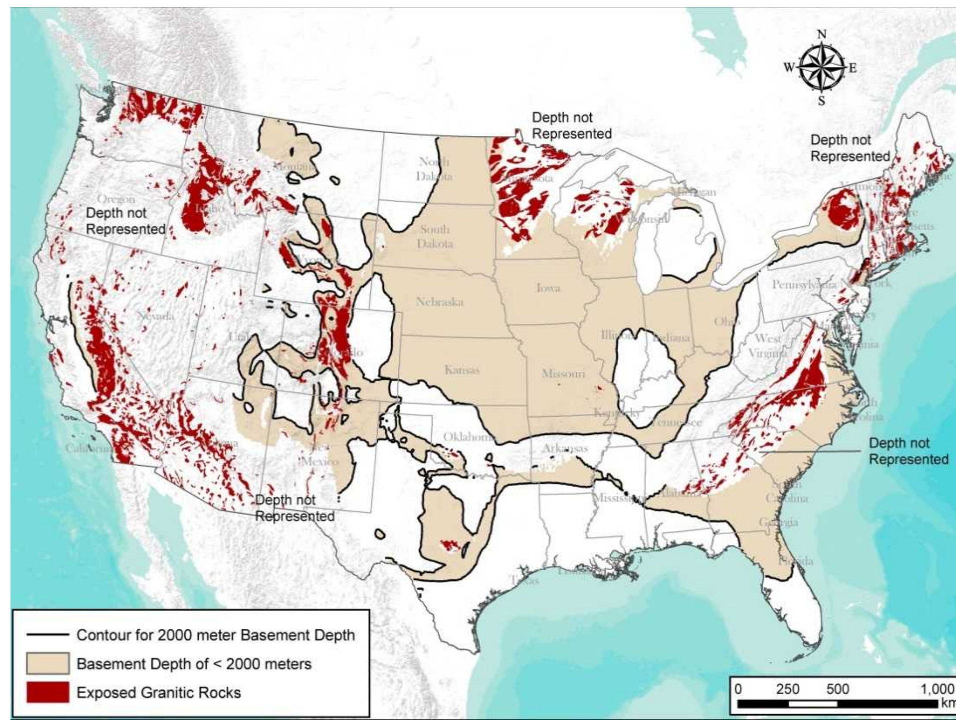
Geological Aspects of Borehole Siting

Site selection guidelines indicate that large areas with favorable geological characteristics exist in the U.S.

Undesirable Features at d > 3 km

- **Young meteoric groundwater**
- **Low-salinity, oxidizing groundwater**
- **Economic natural resources**
- **Upward hydraulic gradients**
- **Overpressuring**
- **High geothermal heat flow**
- **High permeability hydraulic connections to the subsurface**

Depth to Crystalline Basement

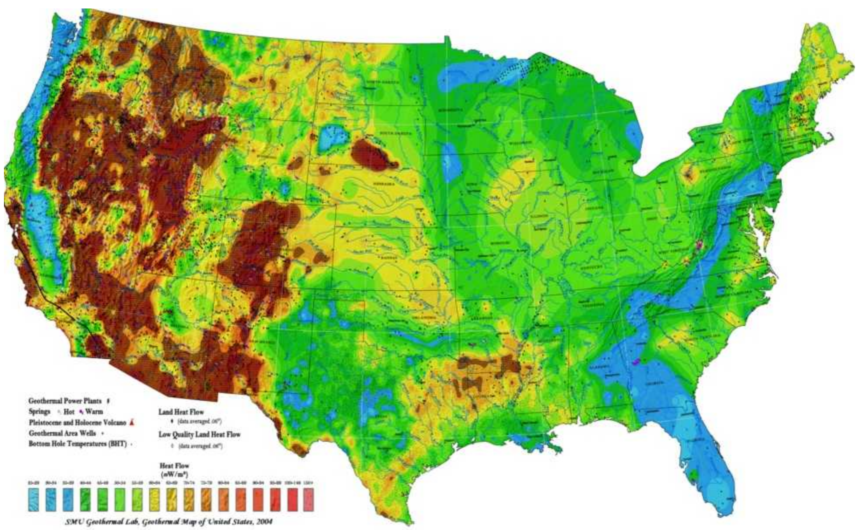


from Perry et al. (2014) Regional Geology: A GIS Database for Alternative Host Rocks and Potential Siting Guidelines, FCRD-UFD-2014-000068 .

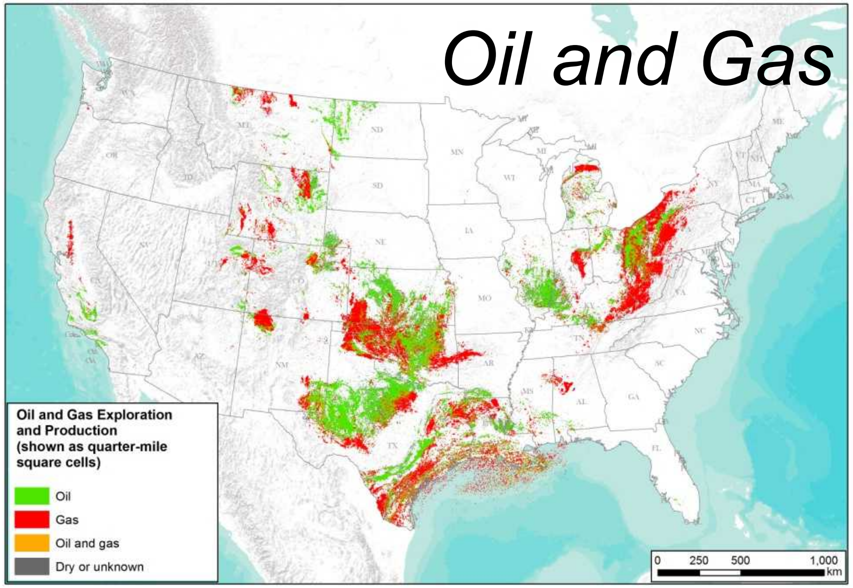
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

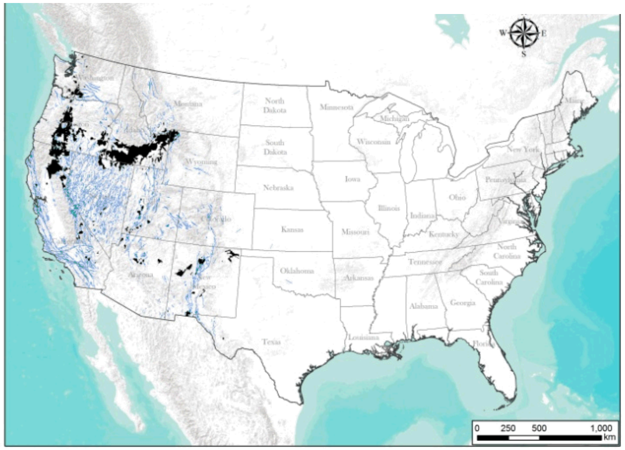
Geological Aspects of Borehole Siting

Heat Flow



Oil and Gas





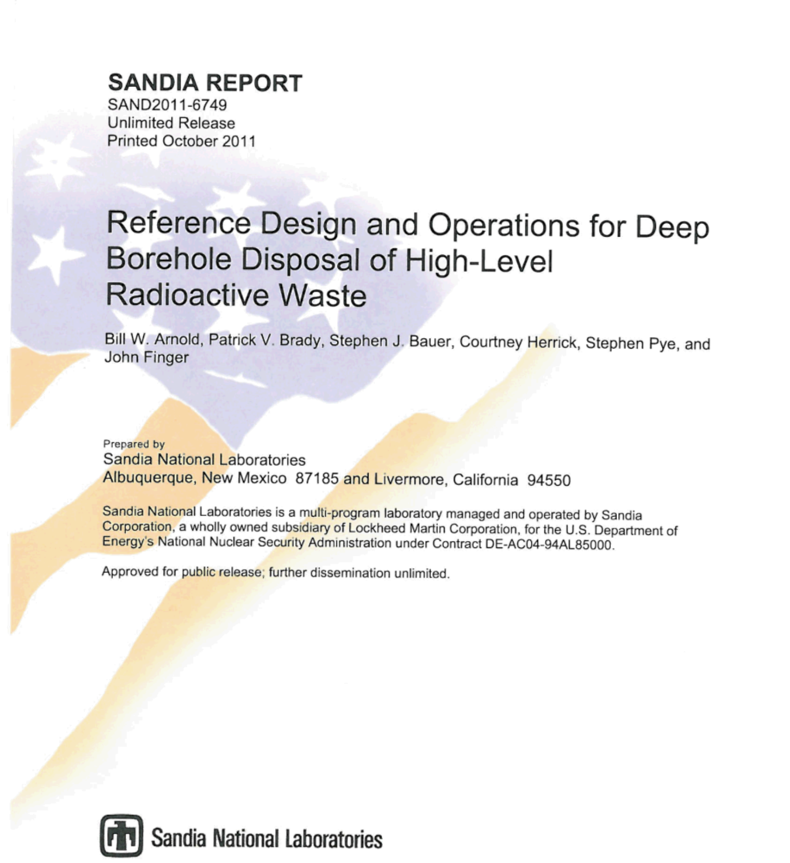
Volcanoes and recent faults

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Reference Design and Operations Objectives and Requirements

- <u>Overarching objective</u>: A simple and achievable, internally consistent system for waste disposal that meets regulatory requirements for operational and public safety
- Update and refine the conceptual design presented in Brady et al. (2009)
- Consider preliminary design alternatives
- Provide a reference design for performance assessment and risk analysis
- Provide a reference design for more accurate cost estimates
- Numerous viable design alternatives exist – this reference design is one choice that provides a basis for the objectives stated above


SANDIA REPORT
SAND2011-6749
Unlimited Release
Printed October 2011

Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste

Bill W. Arnold, Patrick V. Brady, Stephen J. Bauer, Courtney Herrick, Stephen Pye, and John Finger

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

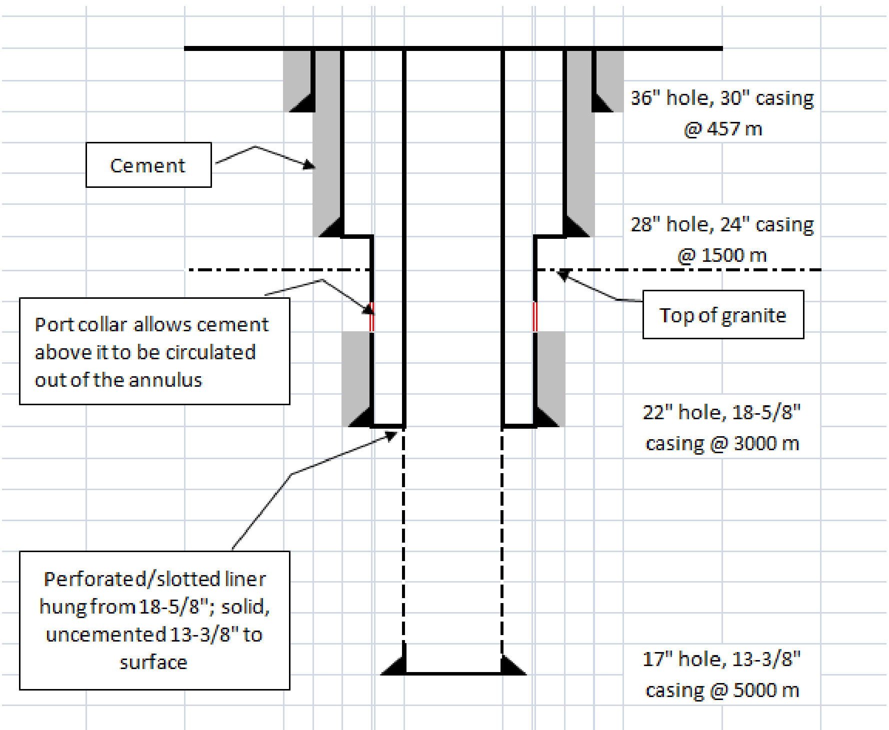
Arnold et al. (2011)

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

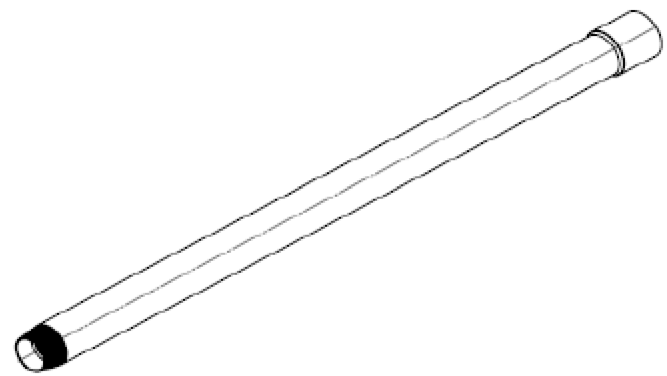
Reference Design and Operations Borehole Design

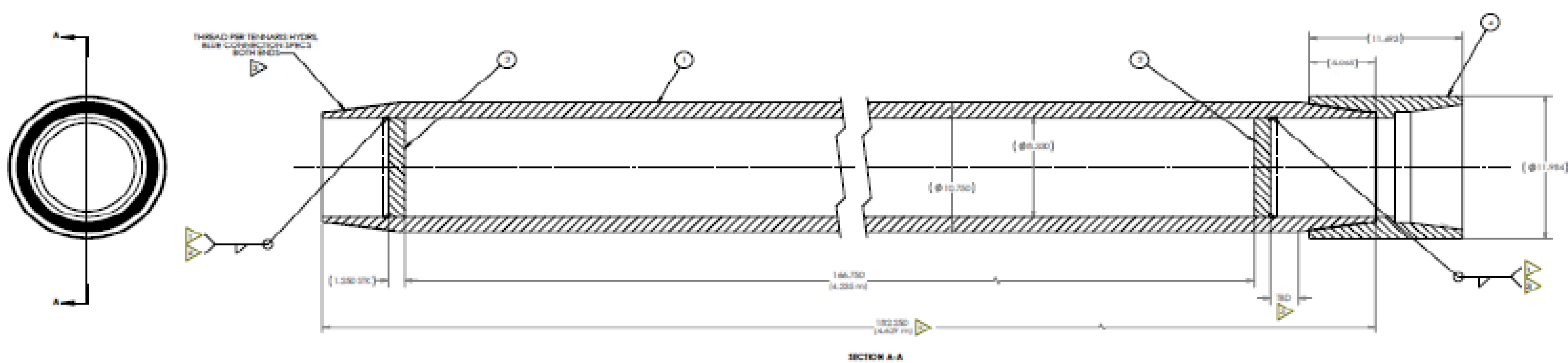
- Drilling to 5 km depth is not exceptional for geothermal development and 17 inches diameter should be feasible with current technology
- Longer rig time and challenges with testing and logging in the reference borehole, lead to consideration of a smaller characterization borehole
- A liner casing will be in place for the emplacement of waste canisters to assure against stuck canisters and facilitate potential retrieval (until the liner is pulled and seals set)
- The perforated liner will be left in place in the disposal zone, but will be removed in the seal zone, along with most of the intermediate casing



Reference Design and Operations
Waste Canister Design

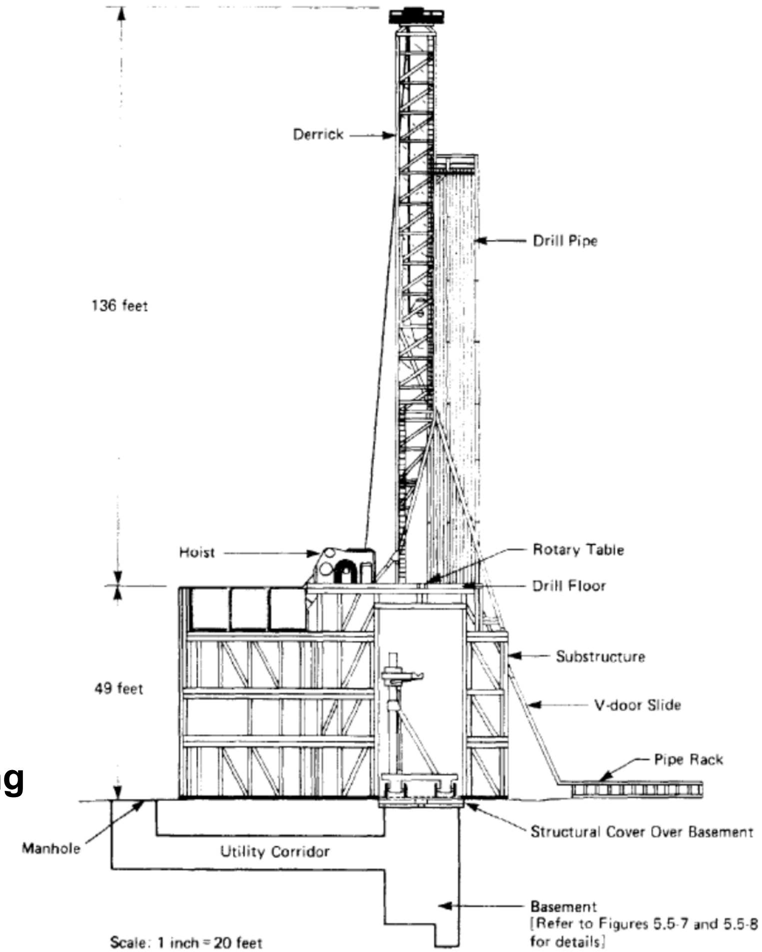
- **Waste canisters consist of carbon steel tubing with welded plugs and threaded connections**
- **Canisters are designed to withstand projected hydrostatic pressure and mechanical load of overlying canisters**
- **Waste canisters would retain their integrity until after the borehole is loaded and sealed**





Reference Design and Operations Waste Canister Emplacement

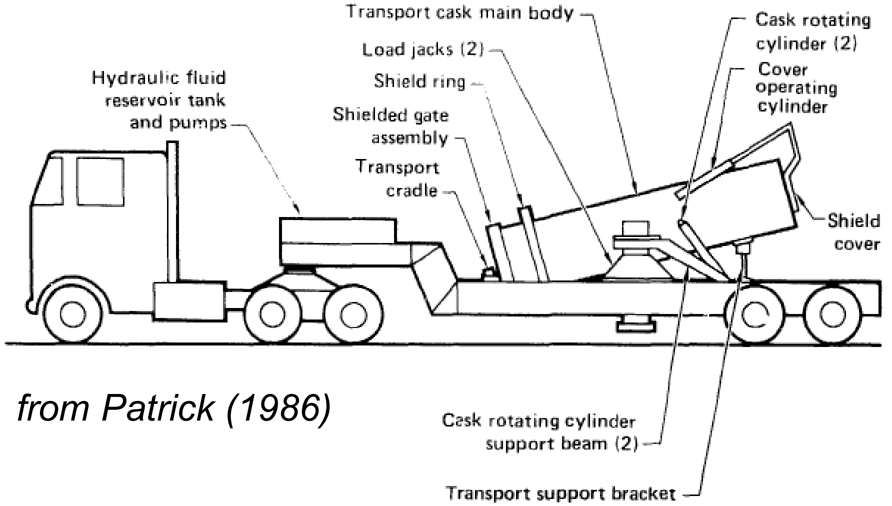
- Loaded waste canisters would be transported to the site by tractor trailer using shipping casks
- Surface handling would rotate the shipping cask to a vertical position, move the cask by a short rail system over the borehole, attach the canister to the canister string and lower it into the borehole by remote operation
- Strings of 40 canisters (about 200 m) would be attached to the pipe string with a J-slot assembly and lowered to the disposal zone
- A synthetic oil-base mud with a high bentonite concentration would be present in the disposal zone, forming a grout around the waste canisters
- Each canister string would be separated from overlying canister strings by a bridge plug and cement plug



from Woodward-Clyde Consultants (1983)

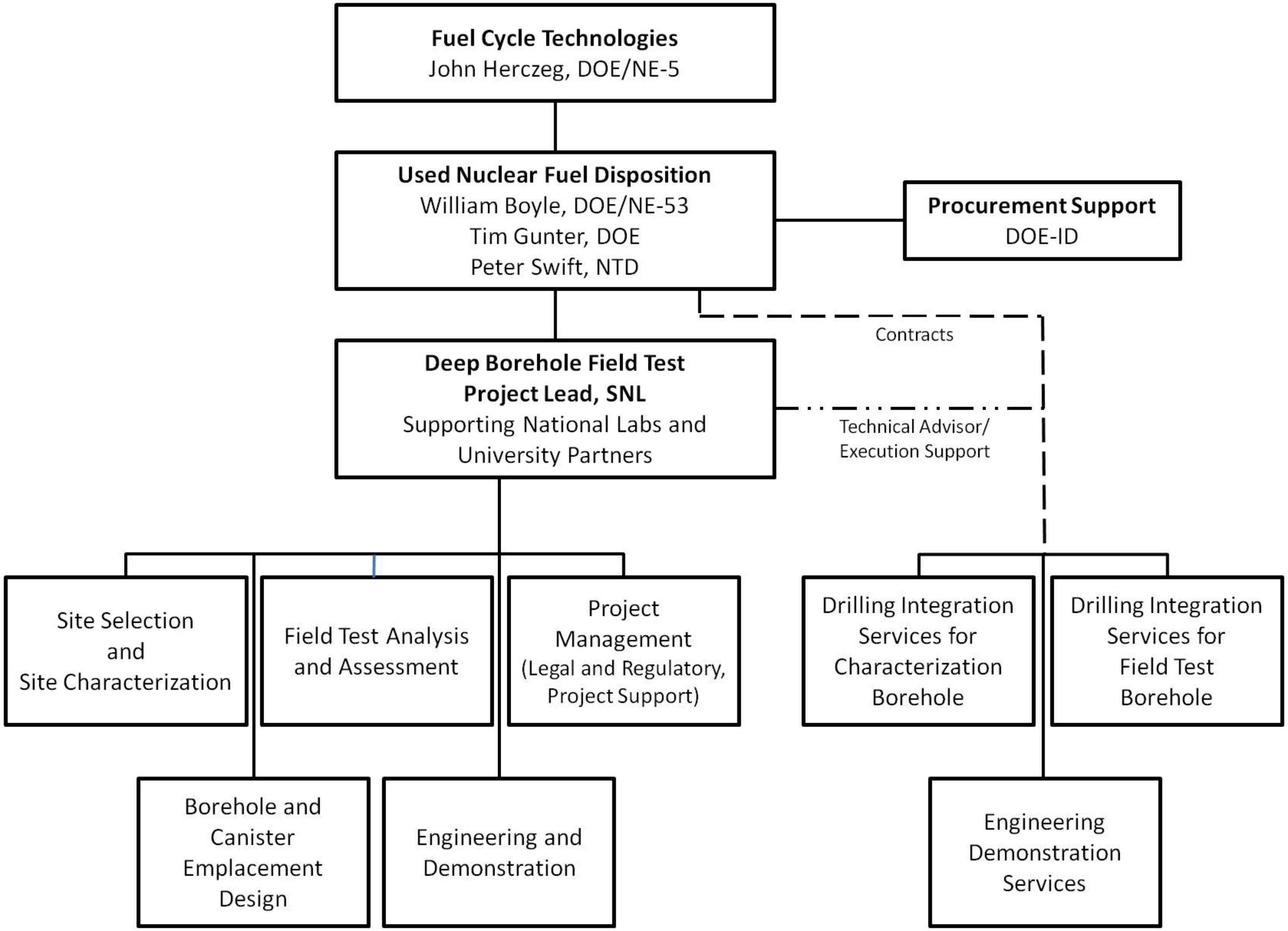
Reference Design and Operations Waste Canister Emplacement

- Engineering feasibility has been demonstrated for surface handling and borehole emplacement of waste canisters with the Spent Fuel Test – Climax (SFT-C) at the Nevada Test Site (NTS) (Patrick, 1986)
- Spent fuel assemblies from Turkey Point reactor were transported to NTS, packaged in canisters, lowered down a 420-m borehole, emplaced in the underground granite thermal test facility for 3 years, and removed to the surface via the borehole
- Waste handling and emplacement operations were conducted within operational safety requirements and without incident



from Patrick (1986)

Deep Borehole Field Test Project Organization



Deep Borehole Field Test Project WBS (to Project Level 3)

1.0 Deep Borehole Field Test

1.1 Field Test Siting
1.1.1 Site Solicitation
1.1.2 Site Selection
1.1.3 Site Characterization

1.2 Procurements for Drilling and Engineering Services
1.2.1 Drilling Integration Services Contract for Characterization Borehole
1.2.2 Drilling Integration Services Contract for Field Test Borehole
1.2.3 Engineering Demonstration Services Contract

1.4 Characterization Borehole
1.4.1 Conceptual Design and Requirements
1.4.2 Construction Specifications
1.4.3 Borehole Construction

1.5 Scientific Testing and Analysis
1.5.1 Test Design and Tool Construction
1.5.2 Geology
1.5.3 Hydrogeology
1.5.4 Geomechanics
1.5.5 Geochemistry
1.5.6 Heat Transfer
1.5.7 Borehole Seals
1.5.8 System and Subsystem Modeling

1.6 Field Test Borehole
1.6.1 Conceptual Design and Requirements
1.6.2 Construction Specifications
1.6.3 Borehole Construction

1.7 Engineering and Demonstration
1.7.1 Canister and Canister Handling Equipment
1.7.2 Canister Emplacement Demonstration

1.8 Field Test Assessment
1.8.1 Safety Analyses
1.8.2 Field Test Evaluation

Project Management/Support

1.3 Legal and Regulatory Requirements
- Permitting and NEPA Compliance

1.9 Project Management
- Projects Controls and Configuration Management
- Risk Management
- Quality Assurance
- Safety (ES&H)

Deep Borehole Field Test Estimated Costs ($Million)

Project WBS	Activity	FY15	FY16	FY17	FY18	FY19	Total
1.1	Field Test Siting	3.4	2.0				**5.4**
1.2	Procurements for Drilling and Engineering Services[1]						
1.3	Legal and Regulatory Requirements	0.6	2.0				**2.6**
1.4	Characterization Borehole (Design, Drilling, and Construction)	1.6	16.0	3.0			**20.6**
1.5	Scientific Testing and Analysis	0.5	1.0	5.0	3.0		**9.5**
1.6	Field Test Borehole (Design, Drilling, and Construction)			11.0	18.0		**29.0**
1.7	Engineering and Demonstration		0.75	2.0	3.0		**5.75**
1.8	Field Test Assessment				2.0	3.0	**5.0**
1.9	Project Management	0.4	0.5	0.5	0.5	0.5	**2.4**
Total		**6.50**	**22.25**	**21.50**	**26.50**	**3.50**	**80.25**

[1] Procurement costs are included in other WBS elements.

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Deep Borehole Field Test Project Key Milestones

Siting RFI Issued 10/24/14

	FY15	FY16	FY17	FY18	FY19
Field Test – Award Engineering Services Contract	04/01/15				
Site Selection – Decision	05/04/15				
Documentation – Borehole and Field Test Design	09/15/15				
Characterization Borehole – Award Drilling Integration Services Contract		11/30/15			
Characterization Borehole – Start Drilling		06/01/16			
Characterization Borehole – Complete Construction			11/16/16		
Field Test Borehole – Award Drilling Integration Services Contract			01/13/17		
Field Test Borehole – Start Drilling			07/07/17		
Field Test Borehole – Complete Construction				12/01/17	
Field Test – Start Emplacement Demonstration				01/17/18	
Field Test – Complete Emplacement Demonstration					05/29/19
Documentation – Field Test Analyses and Evaluation					09/30/19

Deep Borehole Disposal Conclusions

- Multiple factors have indicated that the deep borehole disposal concept provides alternative to safe disposal of radioactive waste for widely available locations with favorable geological and hydrological characteristics
- Implementation of deep borehole disposal with a simple reference design and operations could be feasible, cost effective, and have sufficient capacity
- A deep borehole field test (without emplacement of radioactive wastes) is the next logical step in evaluating this waste disposal option
- Field Test duration of 5 years, ~80M$; 8M$ in Proposed FY15 Budget
- NE has proposed the deep borehole field test as an area for collaboration under SubTER, to leverage other DOE expertise in drilling technology, well construction and integrity, and subsurface characterization