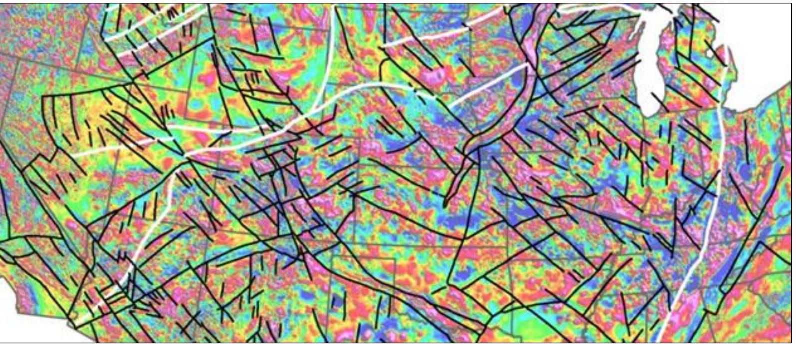
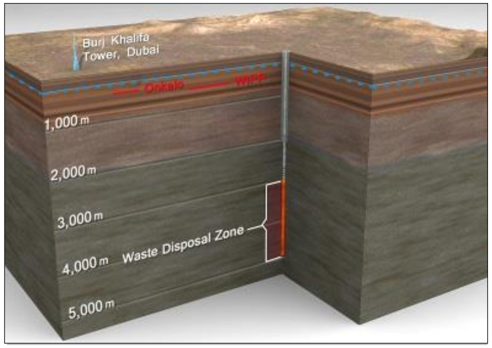
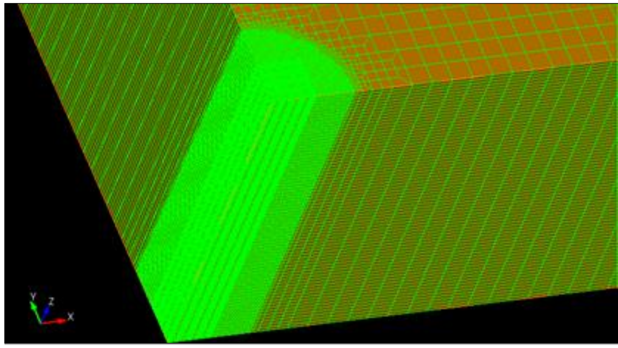
Exceptional service in the national interest

Sandia National Laboratories







The U.S. Deep Borehole Field Test

Patrick V. Brady, Kristopher L. Kuhlman, David L. Sassani, Geoffrey A. Freeze, Ernest L. Hardin, and Robert J. MacKinnon

Sandia National Laboratories

Applied System Analysis & Research Department

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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. SAND2015-3116 PE

Recent Motivating Events

- **Jan. 2012: Blue Ribbon Commission Report**
- **Jan. 2013: US Department of Energy (DOE) Strategy**

  Strategy for Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste
- **Oct. 2014: DOE Disposal Options**

  Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel
  1. **Dispose all HLW & SNF in common repository**
  2. **Dispose some DOE-managed HLW and SNF in separate mined repository**
  3. **Dispose of smaller waste forms in deep boreholes**
- **Oct. 2014: Deep Borehole Request for Information (RFI)**

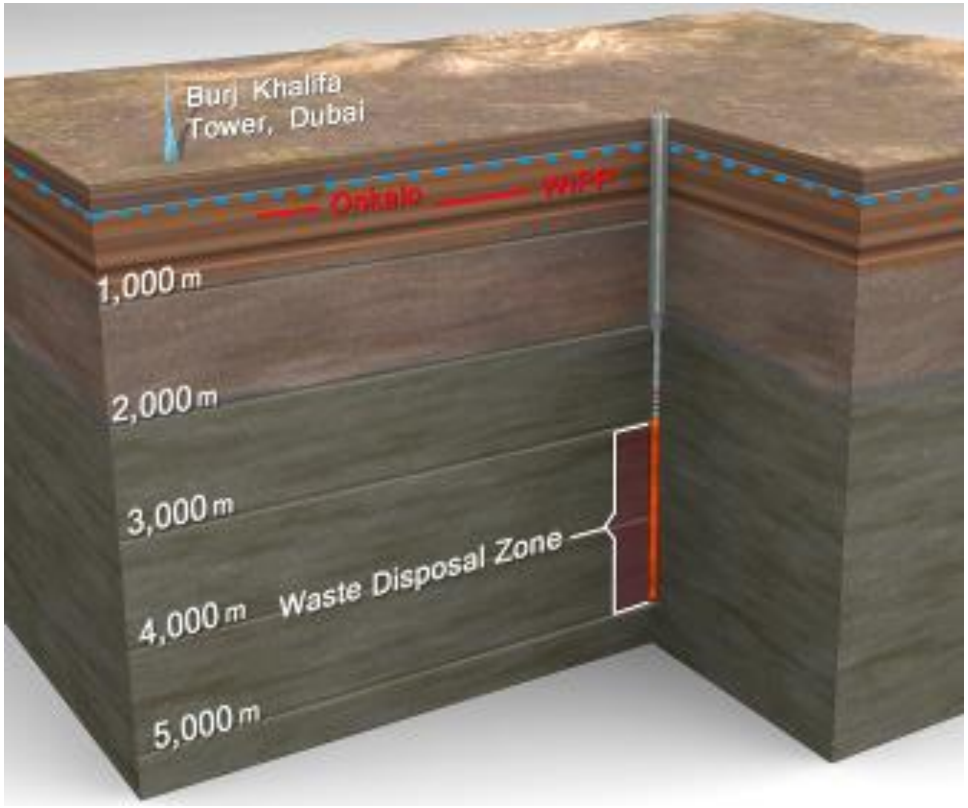
  Seeking Interest in siting a Deep Borehole Field Test
- **March 2015: Deep Borehole Draft Request for Proposals (RFP)**

  Seeking Site, Drilling & Management Proposals for Deep Borehole Field Test

Deep Borehole Disposal Concept

- 5,000 m deep borehole(s) in crystalline basement rock, well below fresh groundwater resources
  - Waste canisters in bottom 2,000 m
  - Seals in upper 3,000 m

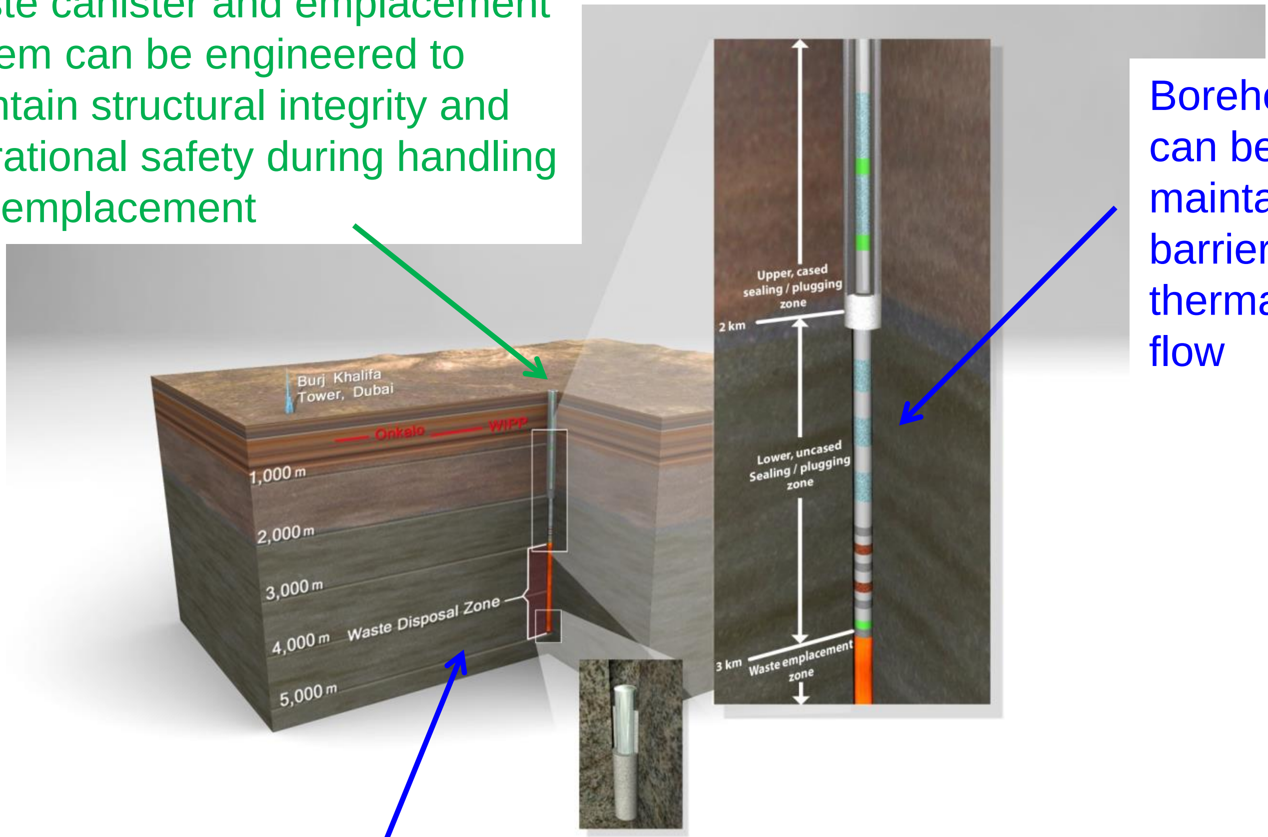
- Bottom hole diameter
  - 17 in. for bulk waste forms or SNF/HLW
  - 8.5 in. for smaller DOE-managed waste forms



Deep Borehole Disposal Concept – Safety Case (Preclosure and Postclosure)

Waste canister and emplacement system can be engineered to maintain structural integrity and operational safety during handling and emplacement

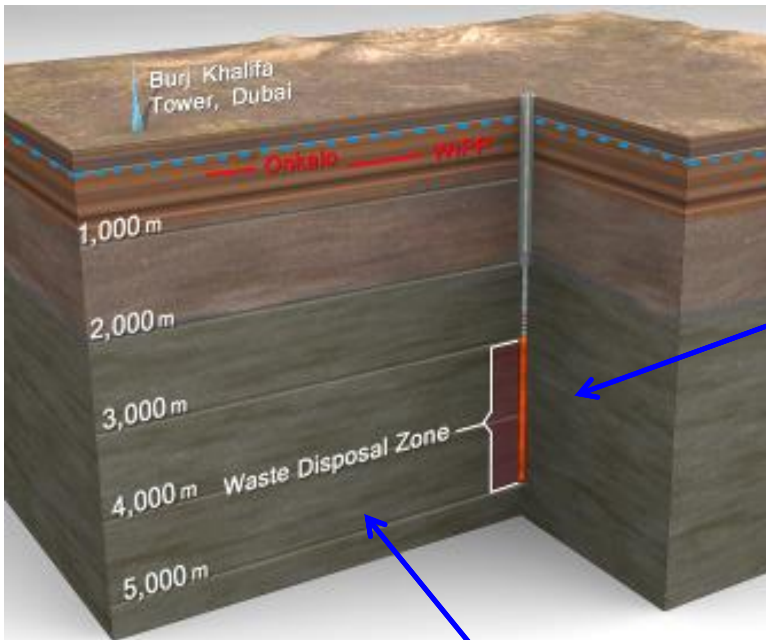
Borehole seals (and DRZ) can be engineered/evolve to maintain a low-permeability barrier over the period of thermally-induced upward flow



Deep crystalline rocks typically have low permeability and lack hydraulic connection to shallow groundwater

Deep Borehole Disposal Concept – Safety and Viability Considerations

Long-Term Waste Isolation (hydrogeochemical considerations)



Waste emplacement is deep in crystalline basement

- at least 1,000 m of crystalline rock (seal zone) overlying the waste disposal zone
- Crystalline basement within 2,000 m of the surface is common in many stable continental regions

Deep groundwater in the crystalline basement:

- has very long residence times – isolated from shallow groundwater
- has high salinity and is geochemically reducing – limits the solubility and enhances the sorption of many radionuclides in wastes
- exhibits density stratification (saline groundwater underlying fresh groundwater) – opposes thermally-induced upward groundwater convection

Deep Borehole Disposal Concept – Safety and Viability Considerations

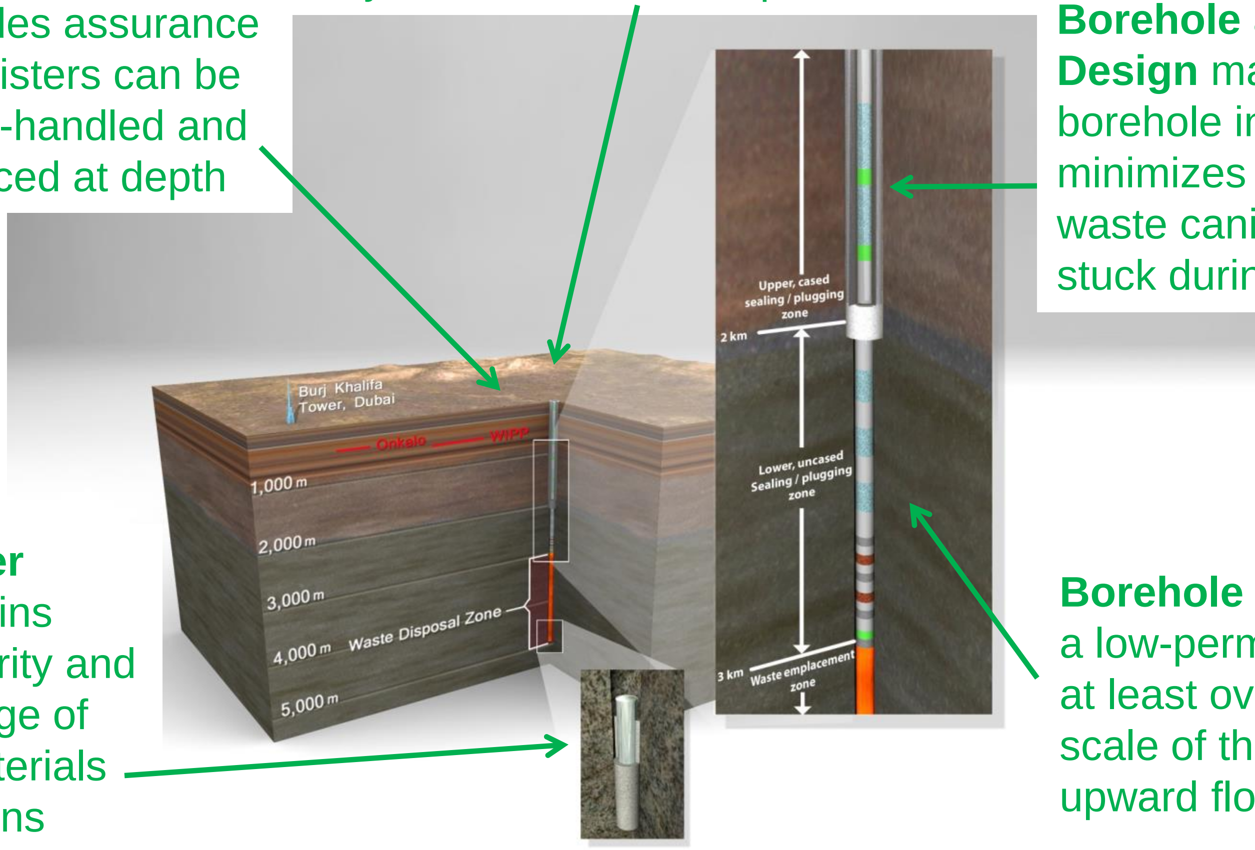
Sandia National Laboratories

Operational Safety and Feasibility (engineering considerations)

Drilling Technology exists to drill and case a large-diameter boreholes to 5,000 m depth in crystalline rock at acceptable cost

Emplacement System Design provides assurance the waste canisters can be safely surface-handled and can be emplaced at depth

Borehole and Casing Design maintains borehole integrity and minimizes probability of waste canisters becoming stuck during emplacement

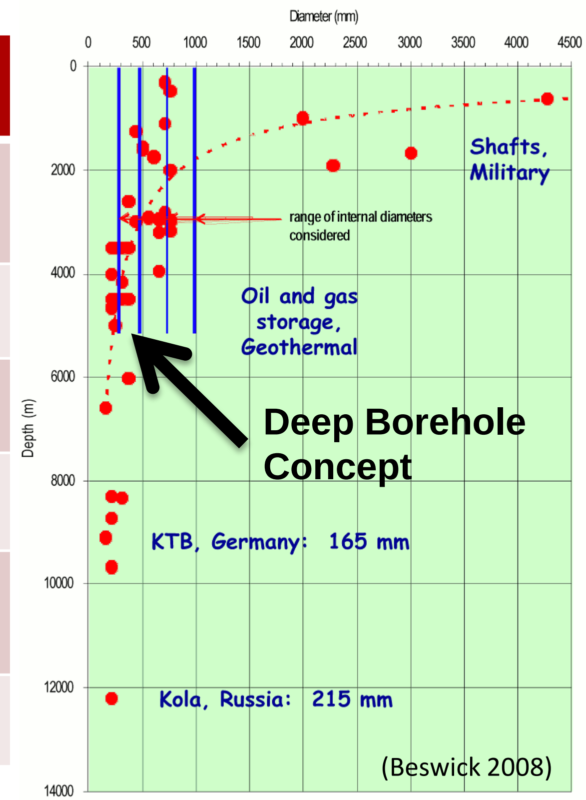


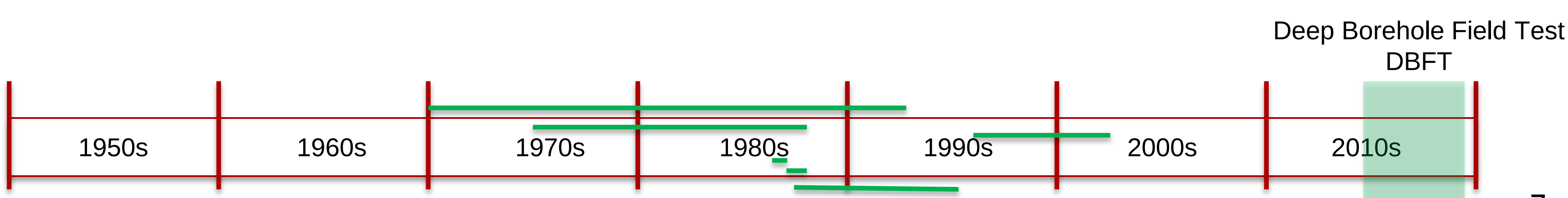
Waste Canister Design maintains structural integrity and prevents leakage of radioactive materials during operations

Borehole Seals maintain a low-permeability barrier, at least over the time scale of thermally-induced upward flow

Deep Continental Drilling

Name	Location	Years	Depth [km]	Diam. [in]	Purpose
Kola SG-3	NW USSR	1970-1992	12.2	8½	Geologic Exploration + Technology Development
Fenton Hill (3)	New Mexico	1975-1987	3, 4.2, 4.6	8¾, 9⅞	Enhanced Geothermal
Gravberg	Central Sweden	1986-1987	6.6	6½	Gas Wildcat in Siljan Impact Structure
Cajon Pass	California	1987-1988	3.5	6¼	Geomechanics near San Andreas Fault
KTB (2)	SE Germany	1987-1994	4, 9.1	6, 6½	Geologic Exploration + Technology Development
Soultz-sous-Forêts GPK (3)	NE France	1995-2003	5.1, 5.1, 5.3	9⅝	Enhanced Geothermal





Deep Borehole Disposal

- **Hess et al. (1957) NAS Publication 519**

  The Disposal of Radioactive Waste on Land. Appendix C: Committee on Deep Disposal

- **Obrien et al. (1979) LBL-7089**

  The Very Deep Hole Concept: Evaluation of an Alternative for Nuclear Waste disposal

- **Woodward-Clyde (1983) ONWI-226**

  Very Deep Hole Systems Engineering Studies

- **Juhlin & Sandstedt (1989) SKB 89-39**

  Storage of Nuclear Waste in Very Deep Boreholes

- **Ferguson (1994) SRNL WSRC-TR-94-0266**

  Excess Plutonium Disposition: The Deep Borehole Option

- **Heiken et al. (1996) LANL LA-13168-MS**

  Disposition of Excess Weapon Plutonium in Deep Borehole: Site Selection Handbook

- **Harrison (2000) SKB-R-00-35**

  Very Deep Borehole – Deutag's Opinion on Boring, Canister Emplacement and Retreivability

- **Nirex (2004) N/108**

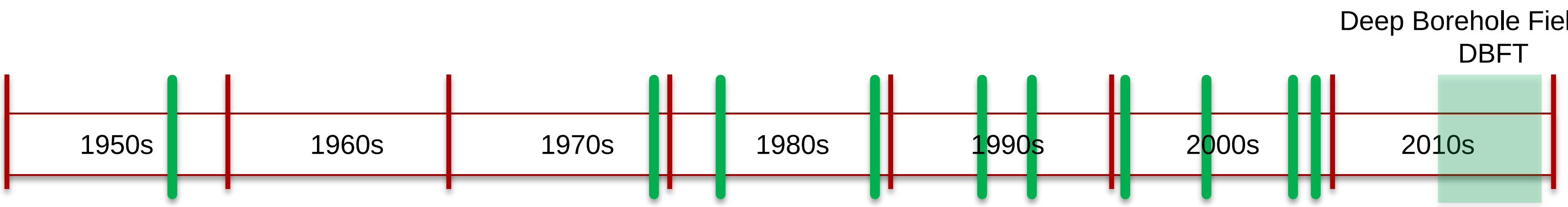
  A Review of the Deep Borehole Disposal Concept

- **Beswick (2008)**

  Status of Technology for Deep Borehole Disposal

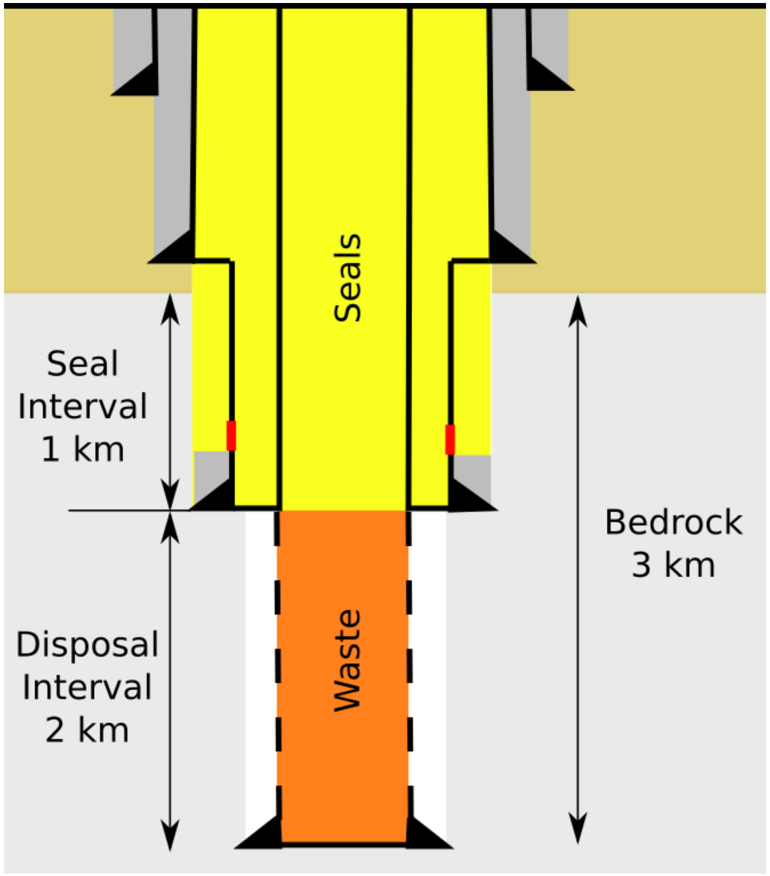
- **Brady et al. (2009) SNL SAND2009-4401**

  Deep Borehole Disposal of High-Level Radioactive Waste

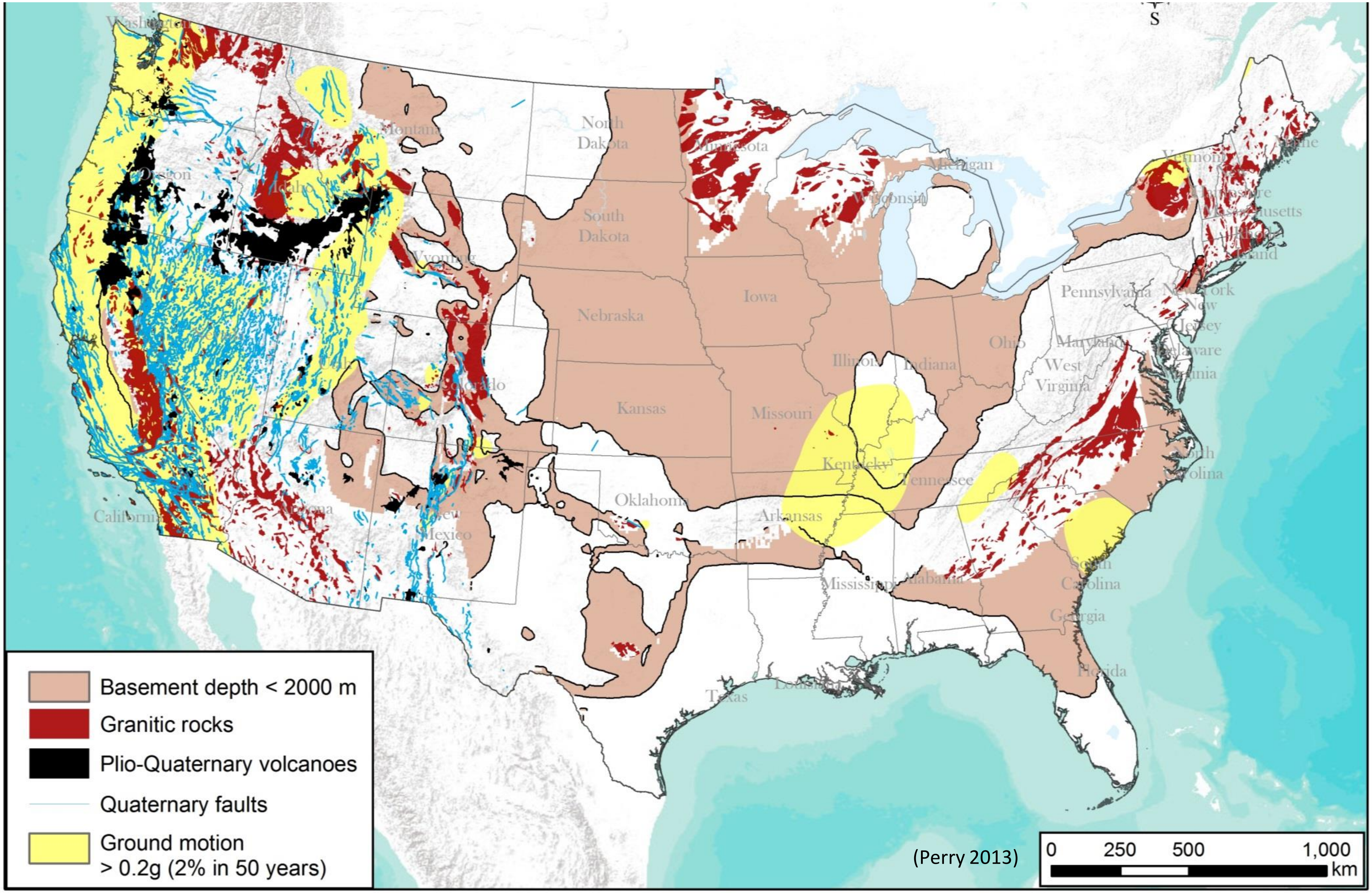


Deep Borehole Concept & Field Test

- **Deep Borehole Disposal (DBD)**
  - Boreholes in crystalline rock to 5 km TD
  - 3 km bedrock / 2 km overburden
  - 1 km bedrock seal
  - 2 km disposal zone
  - Single borehole or grid
- **Deep Borehole Field Test (DBFT)**
  - Department of Energy – Office of Nuclear Energy (DOE-NE)
  - FY 2015-2019 project
  - Two boreholes to 5 km TD
  - Science and engineering demonstration

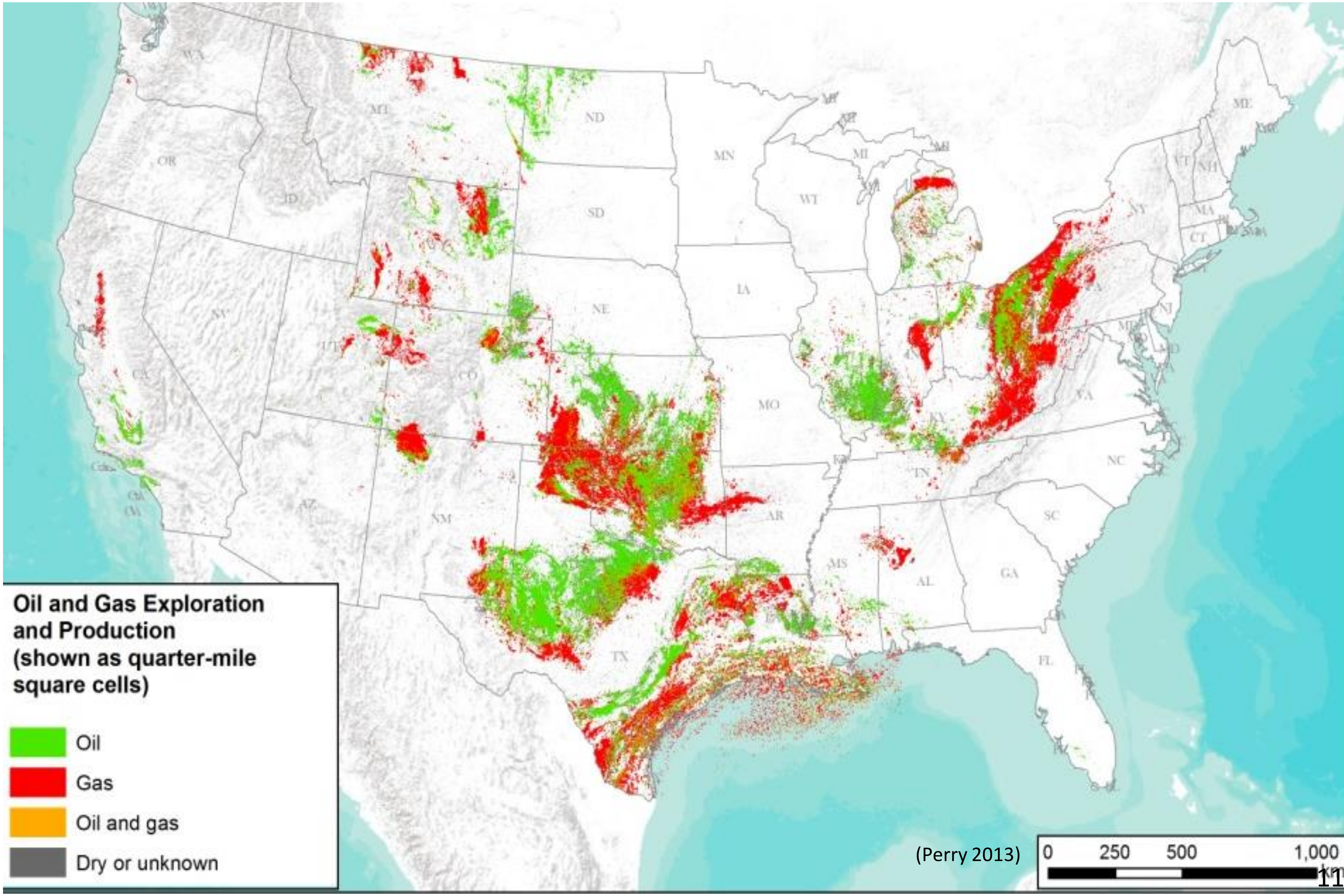


Siting: Bedrock + Hazards



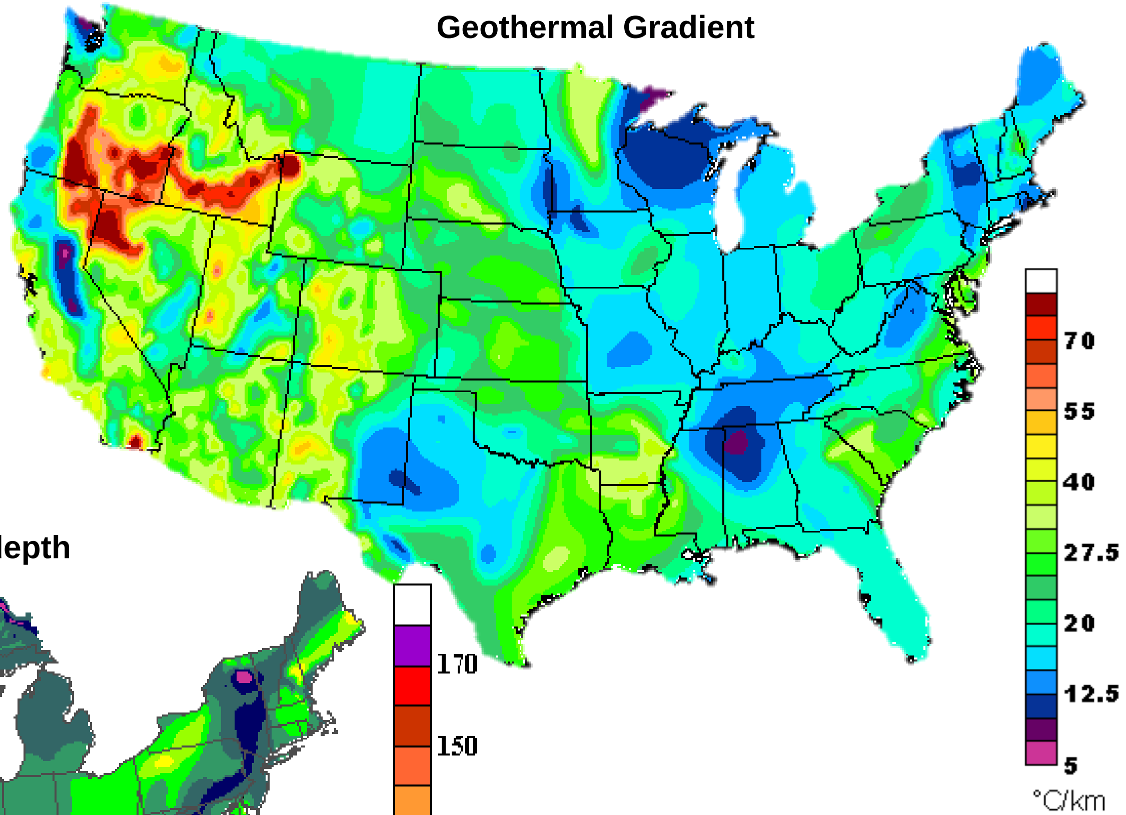
(Perry 2013)

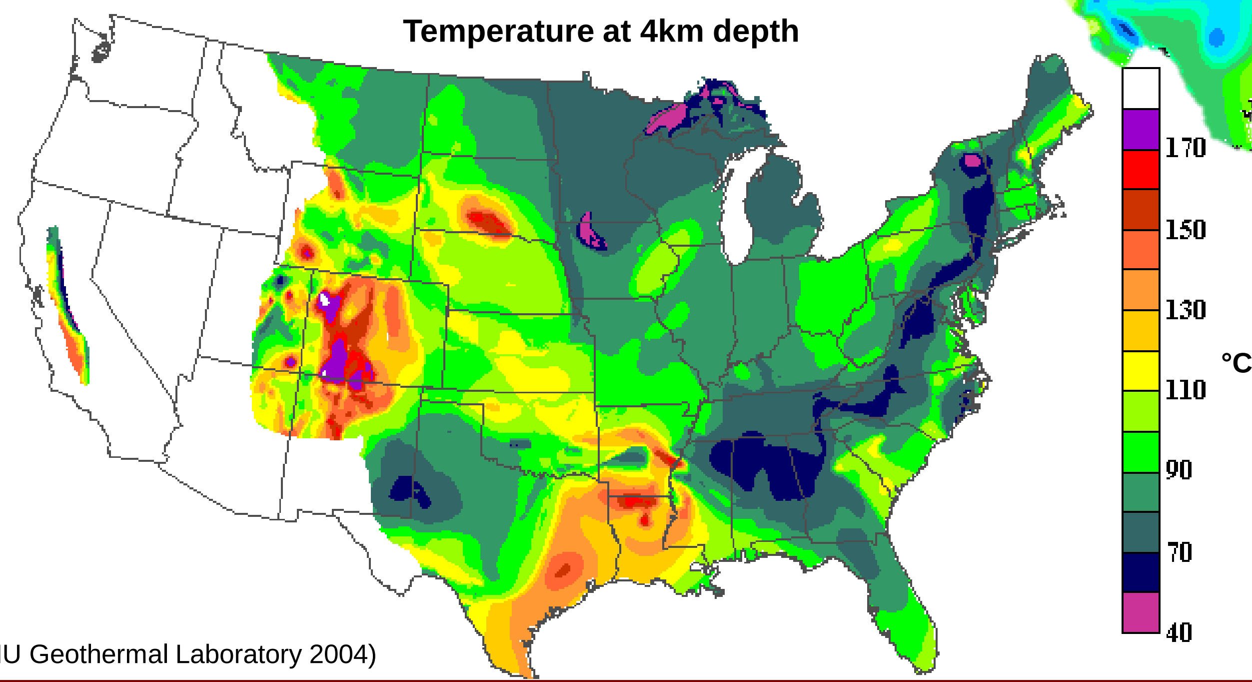
Siting: Oil/Gas Activity



(Perry 2013)

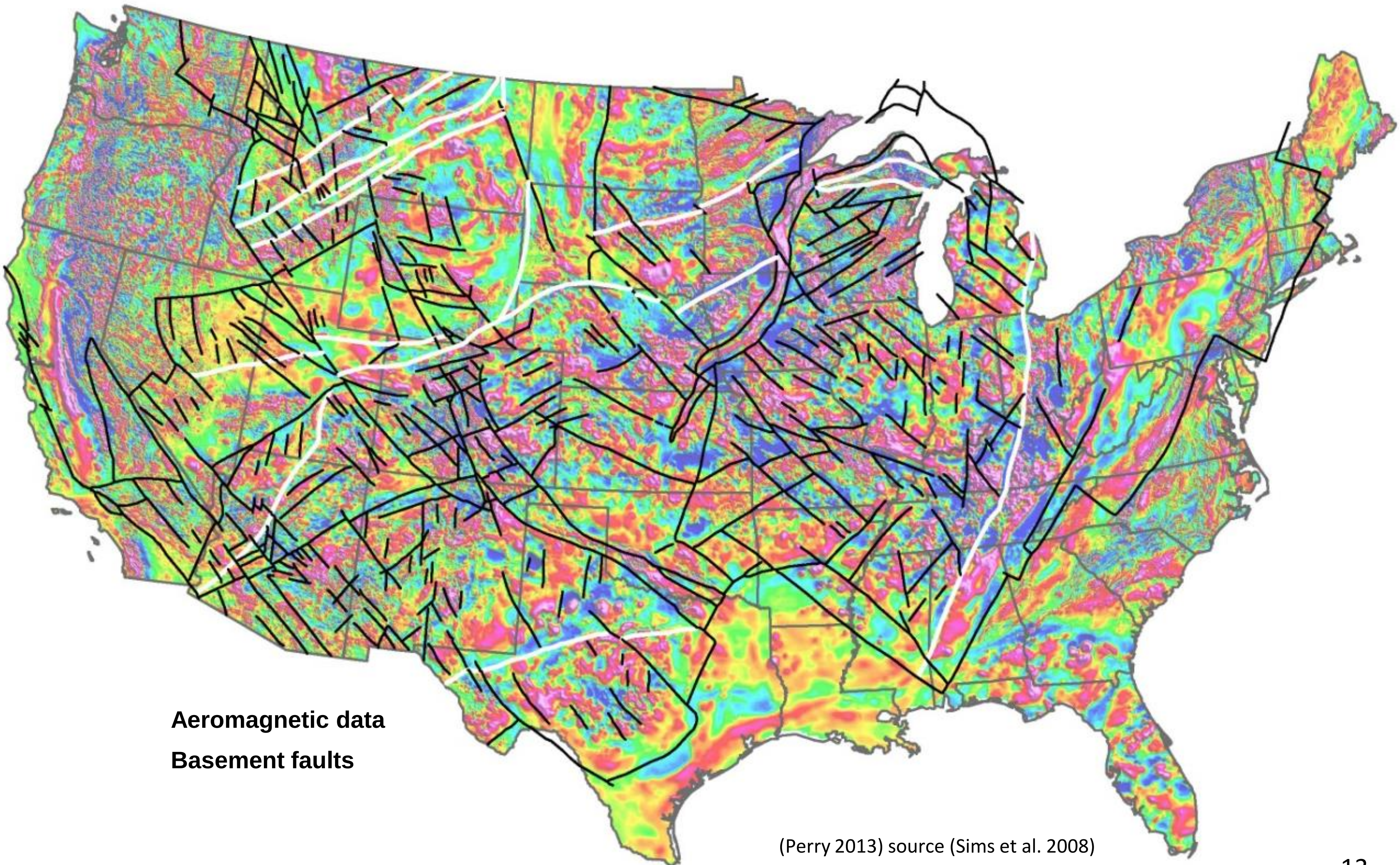
Siting: Geothermal





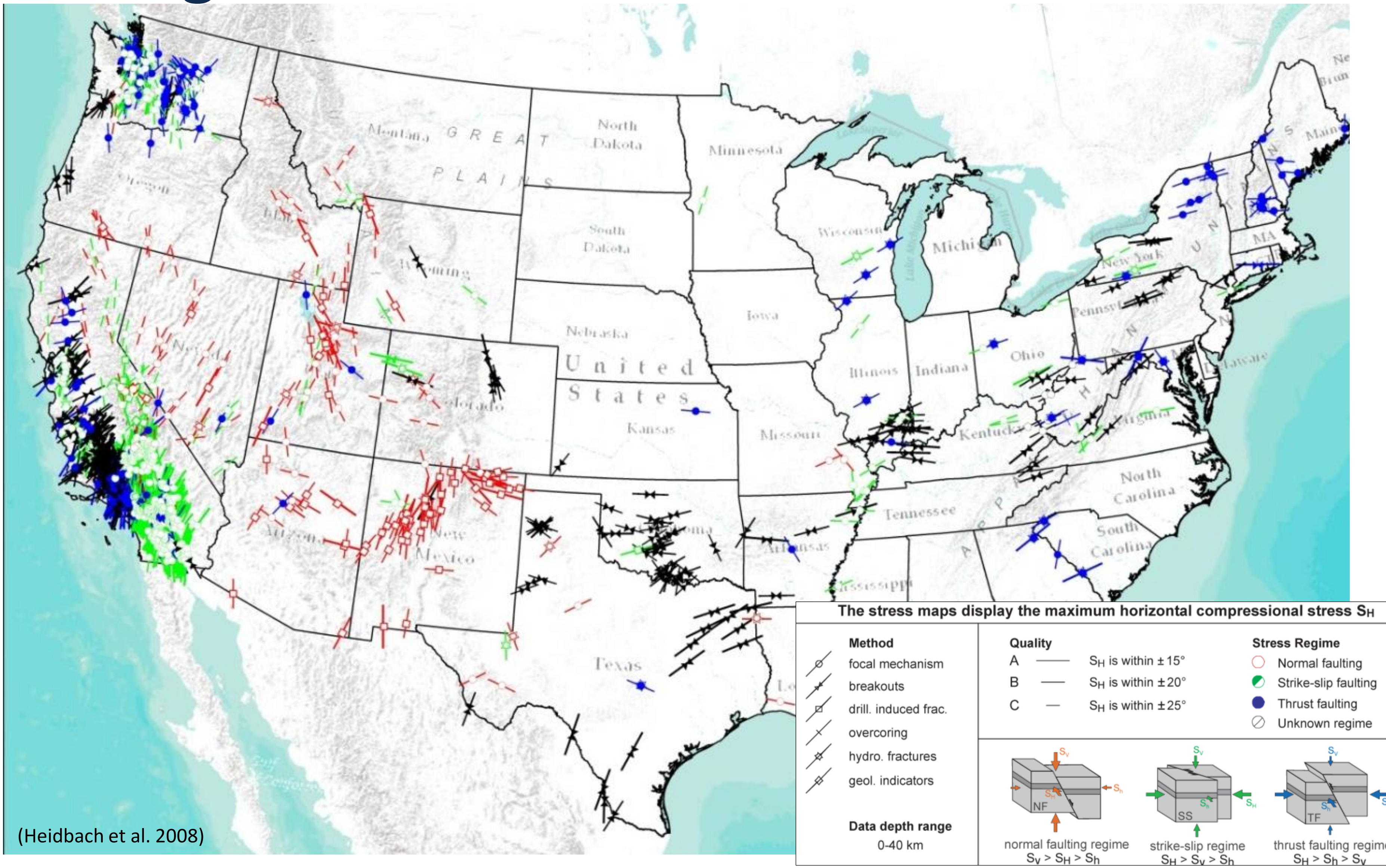
(SMU Geothermal Laboratory 2004)

Siting: Basement Structure



(Perry 2013) source (Sims et al. 2008)

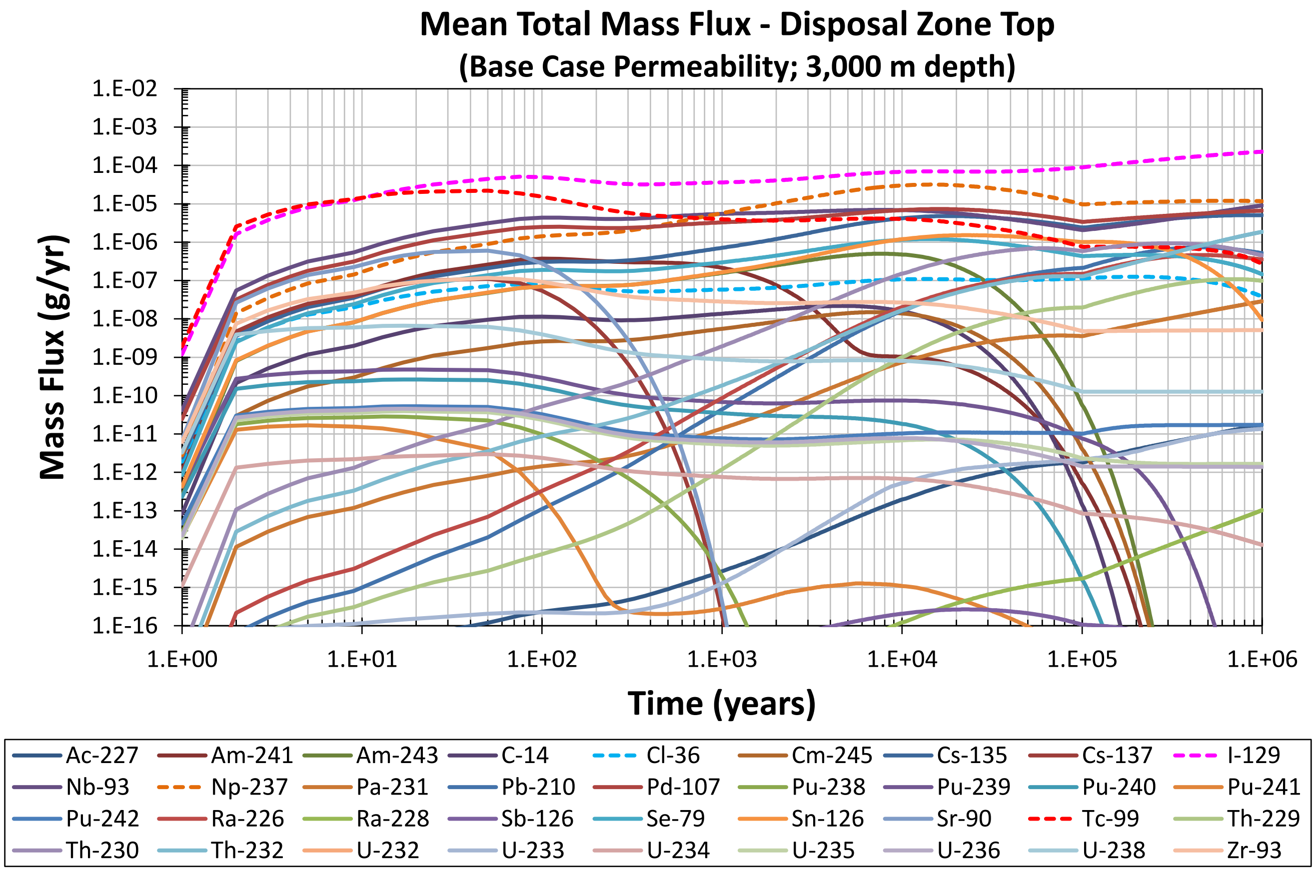
Siting: Stress State

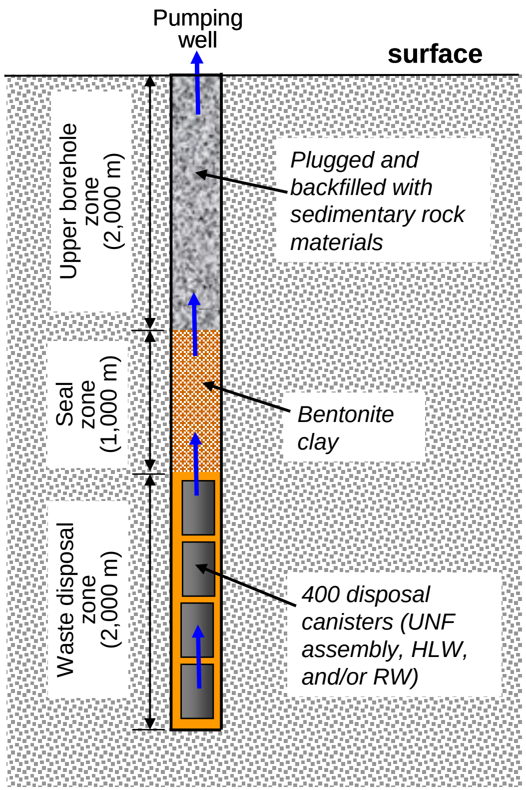


(Heidbach et al. 2008)

Deep Borehole PA Models

- **No Radionuclide Release in 10^6 Years**





(Arnold et al. 2013) SAND2013-9490P

Deep Borehole Field Test (DBFT)

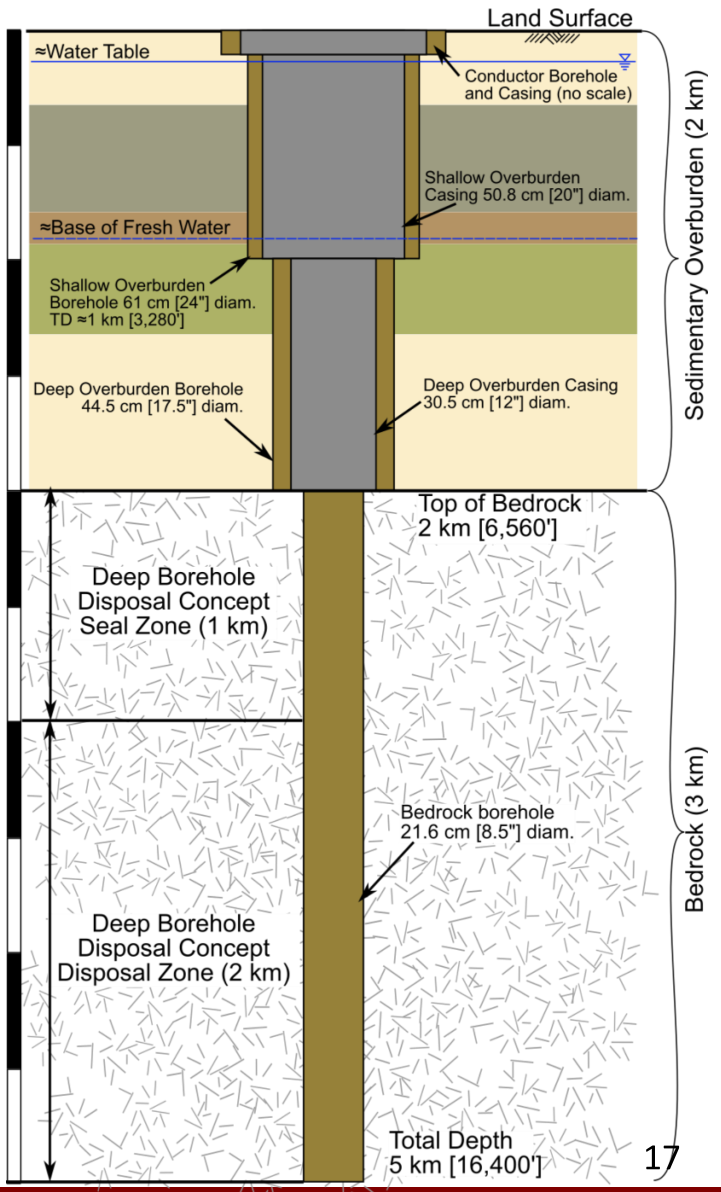
- **Drill Two 5-km Boreholes**
  - **Characterization Borehole (CB): 21.6 cm [8.5”] @ TD**
  - **Field Test Borehole (FTB): 43.2 cm [17”] @ TD**

- **Prove Ability to:**
  - **Drill deep, wide, straight borehole safely (CB + FTB)**
  - **Characterize bedrock (CB)**
  - **Test formations in situ (CB)**
  - **Collect geochemical profiles (CB)**
  - **Emplace/retrieve surrogate canisters (FTB)**

Characterization Borehole (CB)

- **Medium-Diameter Borehole**
  - **Within current drilling experience**
- **Drill/Case Sedimentary Section**
  - **Minimal testing (not DBFT focus)**
- **Drill Bedrock Section**
  - **Core (5%) and sample bedrock**
- **Testing/Sampling After Completion**
  - **Packer tool via work-over rig**
  - **At limits of current technology**

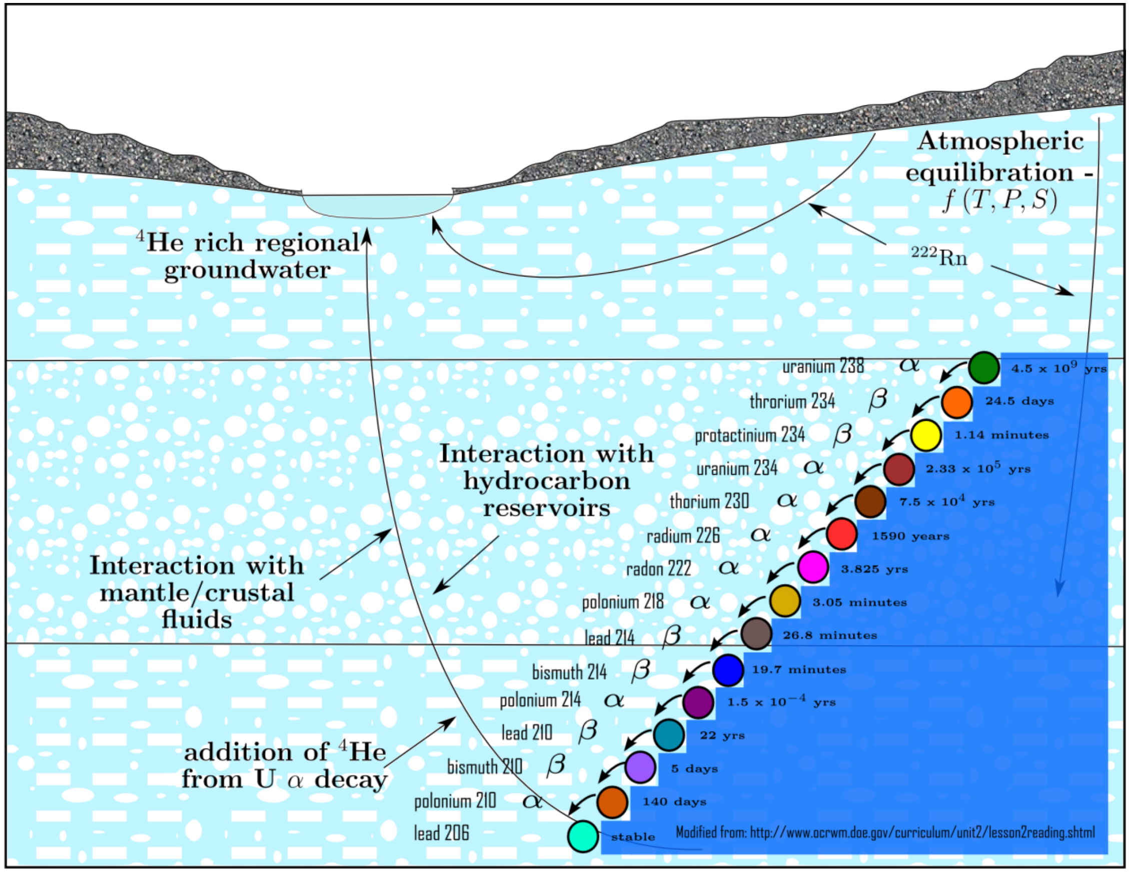
Borehole designed to maximize likelihood of good samples



CB: Environmental Tracer Profiles

- **Vertical Profiles**
  - Fluid density
  - Temperature
  - Noble gases
  - Stable water isotopes
  - Atmospheric radioisotope tracers (e.g., Xe)
- **Long-Term Data**
  - Water provenance
  - Flow mechanisms

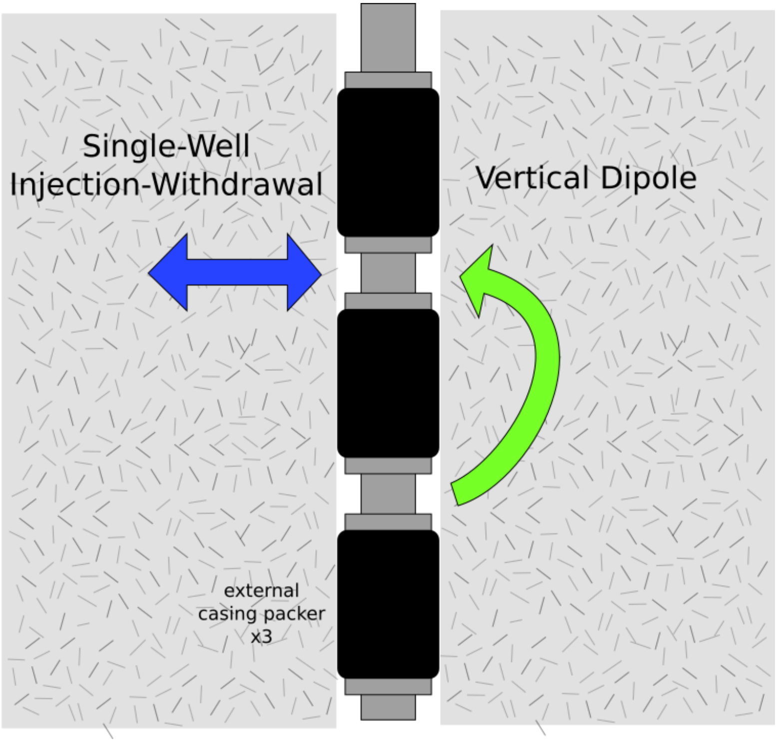
Minerals → pores → fractures



Fluid Sample Quality + Quantity *Very Important!*

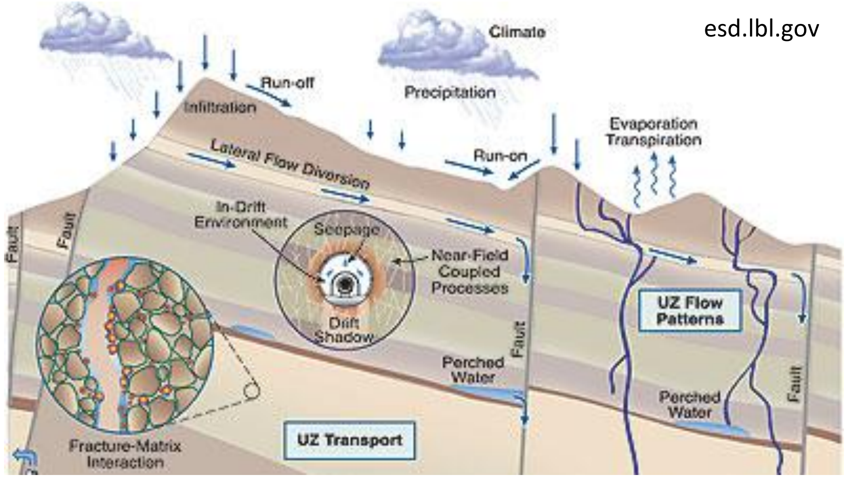
CB: Hydrogeologic Testing

- **Hydrologic Property Profiles**
  - **Static formation pressure**
  - **Permeability / compressibility**
    - **Pumping/sampling in high K**
    - **Pulse testing in low K**
- **Borehole Tracer Tests**
  - **Single-well injection-withdrawal**
  - **Vertical dipole**
  - **Understand transport pathways**
- **Hydraulic Fracturing Tests**
  - **σ_h magnitude**
- **Borehole Heater Test**
  - **Surrogate canister with heater**



Characterization Difference

- Borehole Characterization & Siting vs.
  - Mined waste repositories
    - Less "site mapping"
    - Go/no go decision point
    - Single-phase fluid flow
    - Less steep pressure gradients
  - Oil/gas or mineral exploration
    - Crystalline basement vs sedimentary rocks
    - Low-permeability
    - Minimal mineralization
    - Avoid overpressure
  - Geothermal exploration
    - Low geothermal gradient



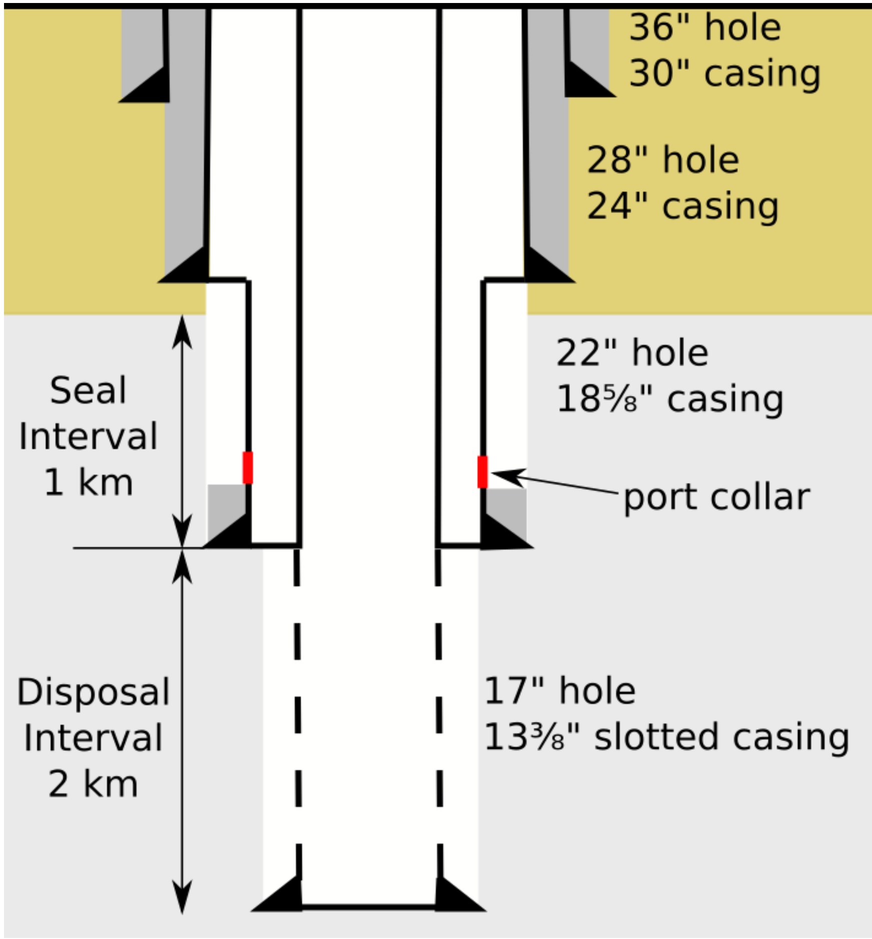
esd.lbl.gov

SAND2010-6048

DBFT: Field Test Borehole (FTB)

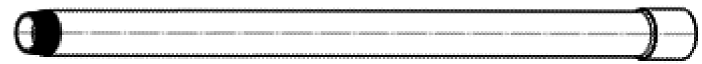
- **Large-Diameter Borehole**
  - **Push envelope of drilling tech**
- **Casing Schedule**
  - **Continuous 13 ⅜” pathway to TD**
    - **Slotted & permanent in disposal interval**
    - **Removable in seal and overburden intervals**
- **Demonstrate**
  - **Emplacing canisters**
  - **Removing canisters**
  - **Surface handling operations**

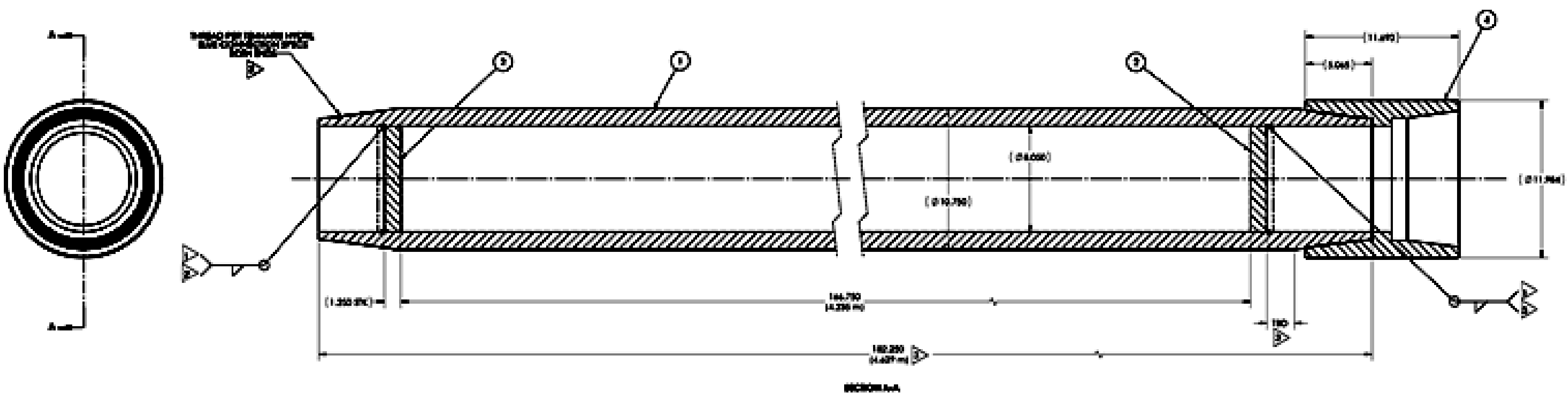
Borehole designed to maximize emplacement safety



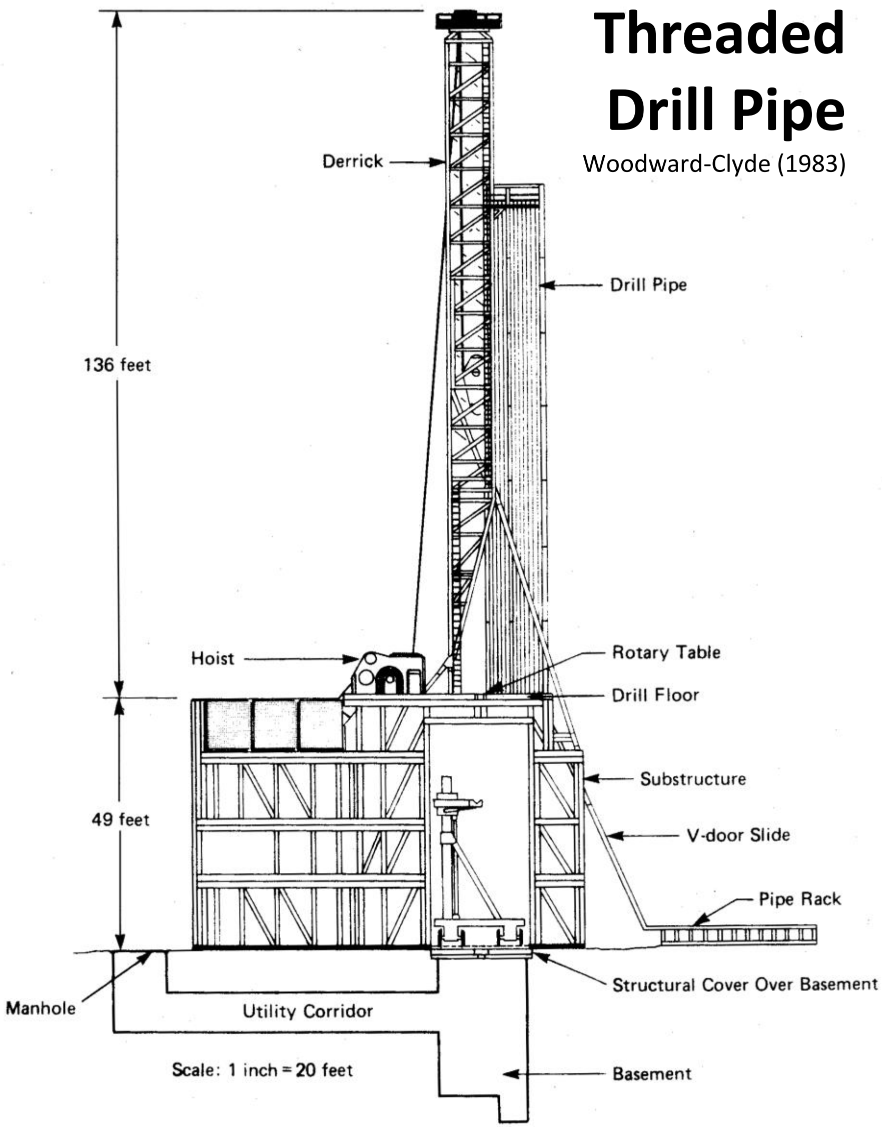
Waste Package Design

- **Structural Integrity**
  - **Hydrostatic pressure and canister string load**
  - **Integrity through emplacement, sealing, and closure**
- **Waste Loading**
  - **Transport and dispose in same canister**
  - **Transfer from shipping casks onsite**





FTB: Emplacement Methods



FTB: Operational Safety

- **Zero Radiological Risk**
- **Focus on Downhole Safety**
- **Downhole Failure Modes**
  - **Pipe string + canister(s) drop in borehole**
  - **Pipe string drop onto canister(s)**
  - **Single canister drop in borehole (consequence?)**
  - **Canister leak/crush**
  - **Fishing operations**
  - **Seismic events**

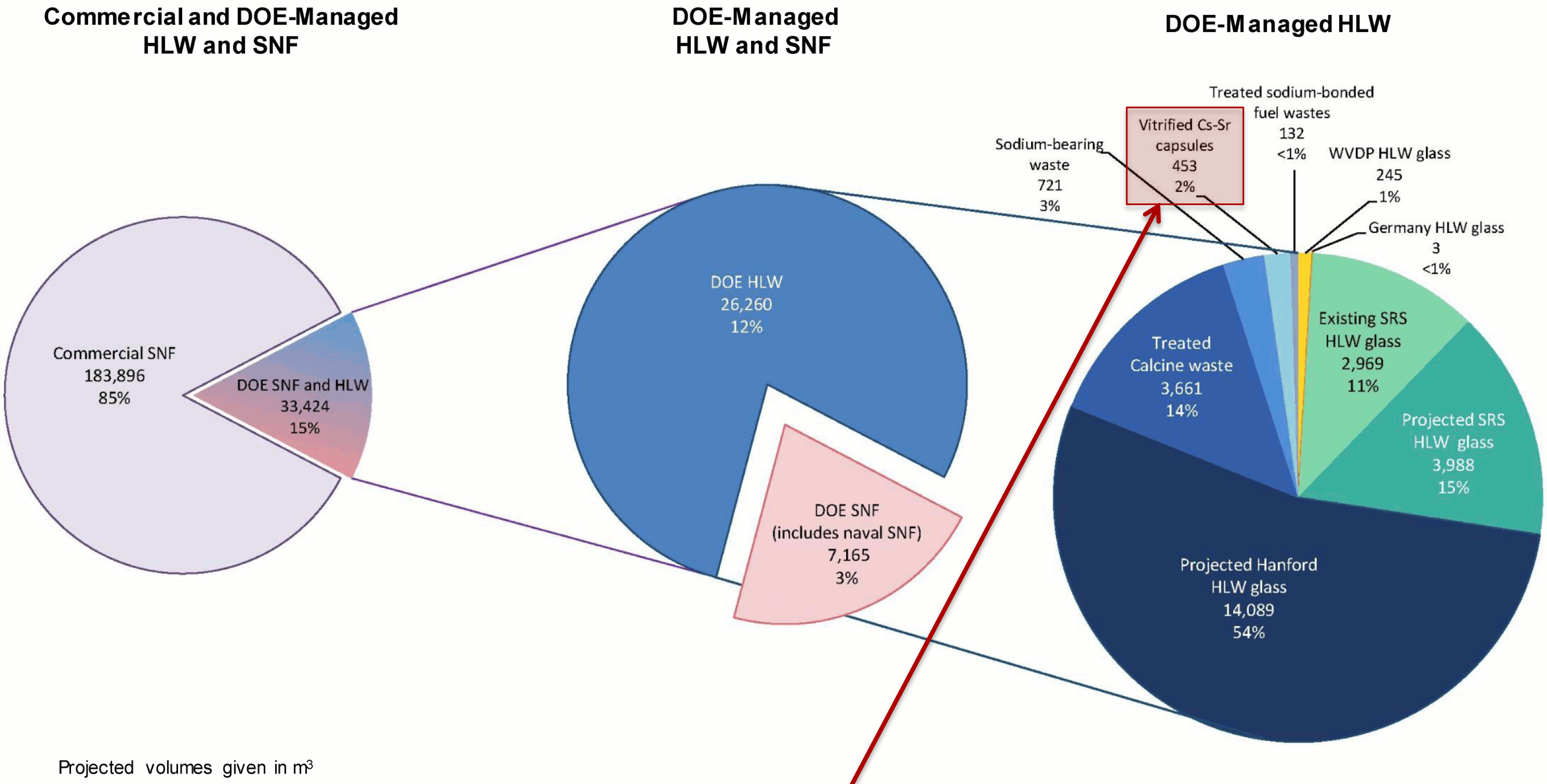
NTS Climax Spent Fuel Test (1978-1983)

Summary

- **Deep Borehole Disposal Concept**
  - 10 × geologic isolation of mined repository
  - Seals only pathway for release
  - Simple construction (for few boreholes)
  - Wide site availability
  - Single-Phase, Diffusion Dominated
  - Geological Issues?
    - Drill elsewhere vs. Engineer away
- **Deep Borehole Field Test (FY15-19)**
  - Drill two 5-km large-diameter boreholes
  - Demonstrate ability to
    - Characterize bedrock system (CB)
    - Emplace/retrieve surrogate canisters (FTB)

SAND2010-6048

Radioactive Waste Volumes



HLW = High-Level Waste
SNF = Spent Nuclear Fuel

≈ 40% total curies of radioactivity at Hanford