Deep Borehole Disposal of Nuclear Waste: Science Needs

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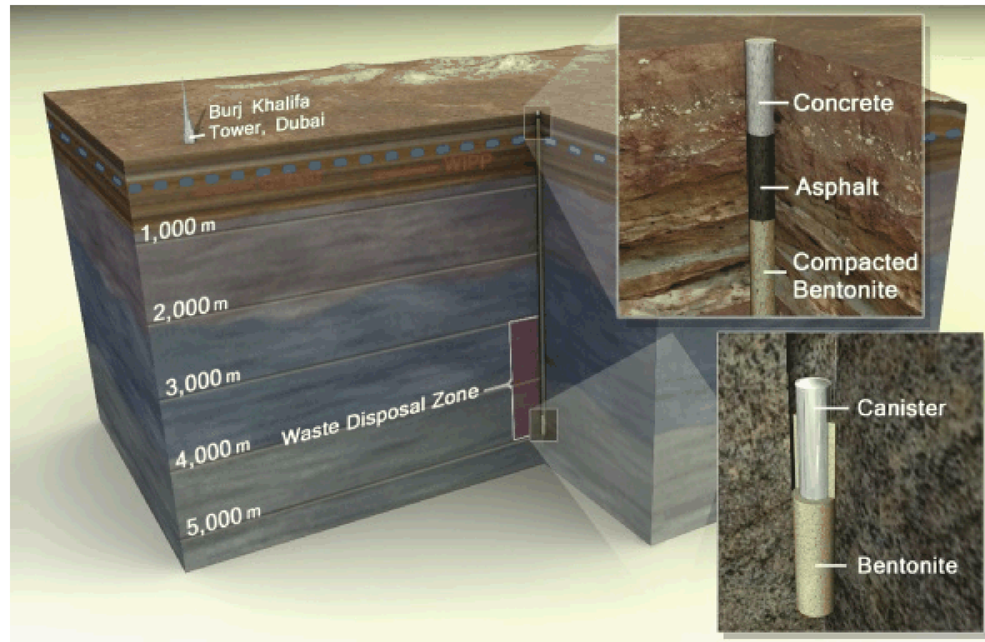
- Concept
- Siting
- Demonstration
- Science Needs



Materials Science and Technology
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Deep Borehole Disposal Concept

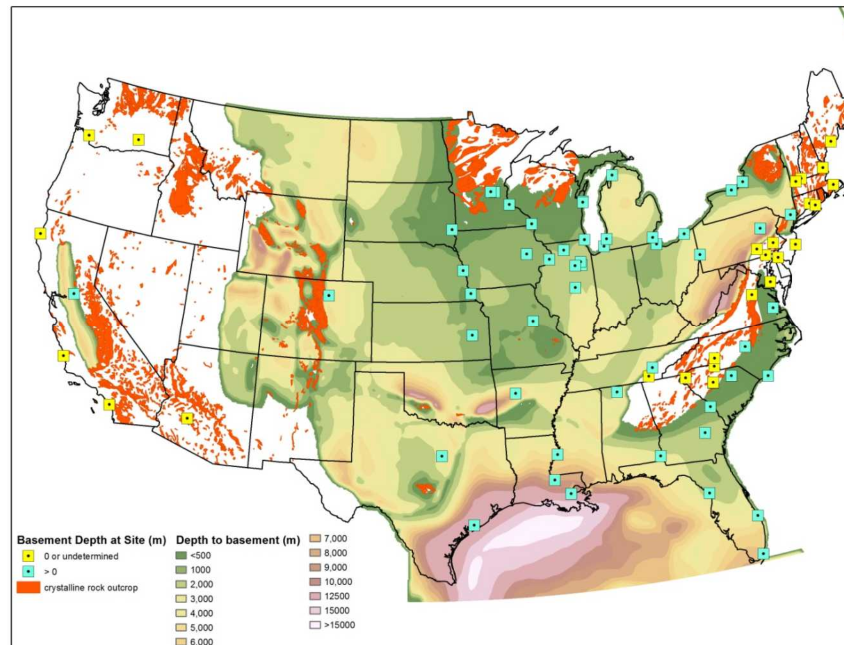
- **A borehole, or array of boreholes , will be drilled into crystalline basement rock to about 5,000 m depth**
- **Approximately 400 waste canisters would be emplaced in the lower 2,000 m of each borehole**
- **Upper borehole would be sealed with compacted bentonite clay and cement plugs**
- **Several factors suggest the disposal concept is viable and safe:**
  - **Crystalline basement rocks are common in many stable continental regions**
  - **Existing drilling technology permits 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 inhibit thermally induced groundwater convection**

Geological Aspects of Borehole Siting

<u>Undesirable</u> Features at d > 3 km

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

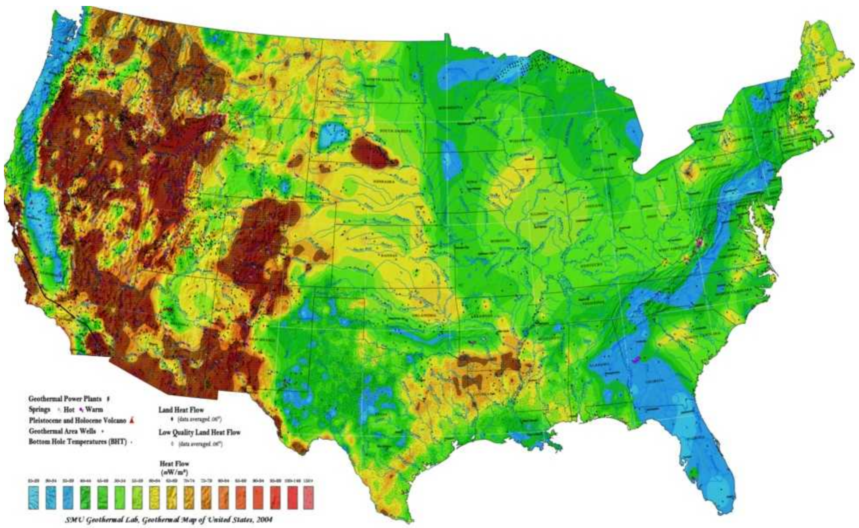
Depth to Crystalline Basement



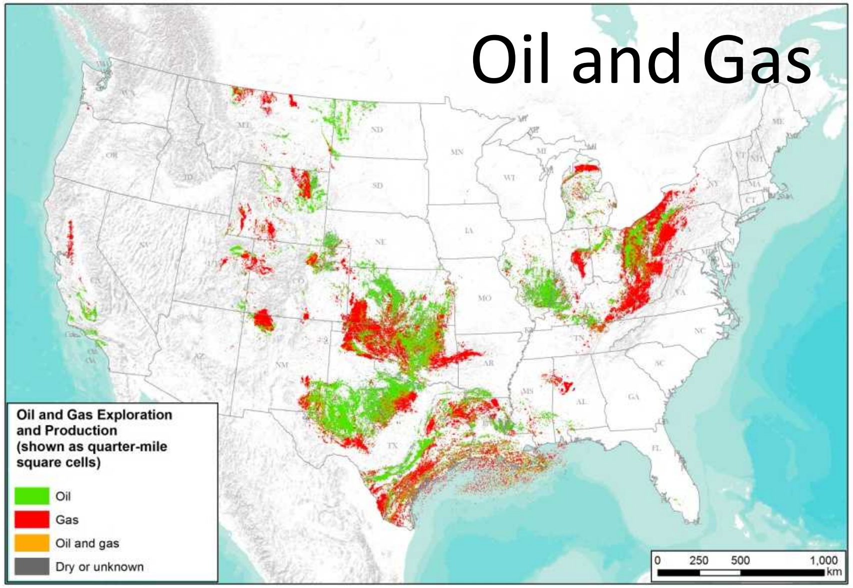
from Perry (2011) *GIS Map of Depth to Crystalline Basement*, personal communication, Los Alamos National Laboratory.

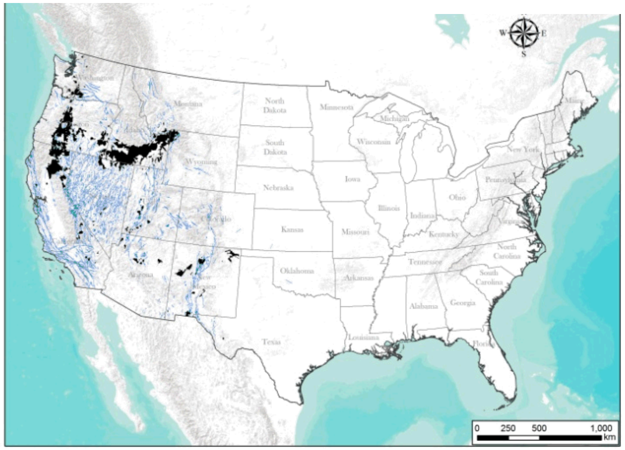
Geological Aspects of Borehole Siting

Heat Flow



Oil and Gas





Volcanoes and recent faults

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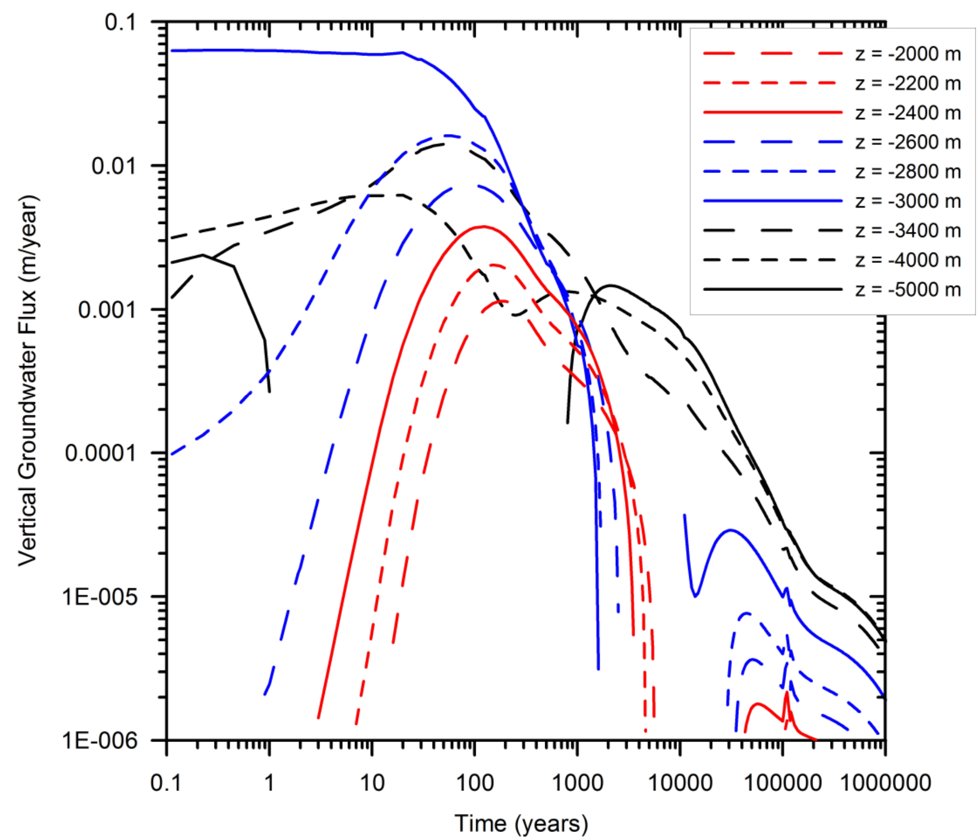
Geochemistry

- **Reducing conditions maintain spent fuel components in less soluble, lower valence states (Pu^{III} an exception)**
- **Reducing conditions favor greater sorption of radionuclides on seals, wall rock**
- **Highly saline deep fluids inhibit thermal convection and prevent colloidal transport**
- **^{129}I is the only radionuclide <u>not</u> predicted to be insoluble and/or strongly sorbed**

Thermal Hydrology

- Groundwater flow induced by waste heat occurs by thermal expansion at earlier times and is dominated by buoyant free convection at later times
- Upward flow rates will be smaller because salinity stratification is not included in this model

Simulated specific discharge in the borehole/disturbed zone for 9 boreholes containing used fuel with 200 m spacing



Bill W. Arnold (2012) Presentation to NWTRB, March 7, 2012

Practical Aspects of Deep Borehole Disposal

- **Costs are dominated by borehole drilling and construction**
- **There is significant uncertainty about drill rig time and cost associated with testing and logging of the borehole**
- **The estimated $27M cost shown here is for boreholes following the more intensively characterized initial borehole at a site**
- **Aside from transportation costs, estimated disposal costs are $158/kg heavy metal (HM) (compared to nuclear waste fund fee of roughly $400/kg HM (Gibbs, 2010))**
- **Estimated time for drilling, borehole completion, waste emplacement, and sealing is about 186 days**

	Cost per Borehole
Drilling, Casing, and Borehole Completion	$27,296,587
Waste Canisters and Loading	$7,629,600
Waste Canister Emplacement	$2,775,000
Borehole Sealing	$2,450,146
Total	**$40,151,333**

Note: All costs are in 2011 $US and approximately for 2011 expenses.

from Arnold et al. (2011)

Deep Borehole Demonstration

- **Will demonstrate:**
  - **Site selection and characterization**
  - **Drilling**
  - **Canister emplacement**
  - **Surface handling**
- **Will not involve radioactive waste**
- **Parallel science thrusts**
- **Parallel seals research**
- **5 years, 72M$; 8M$ in Proposed FY15 Budget**

	FY-1	FY-2	FY-3	FY-4	FY-5
Site Selection Guidelines	▲				
List of Candidate Sites	▲				
Prioritize Engineering & Science Needs		▲			
Permits & Licensing of Site for Demonstration		▲			
Drilling Contractor Selection		▲			
Design & Fabricate Canister			▲		
Borehole Construction				▲	
Canister Emplacement Test					▲
Science & Engineering Demonstrations					▲
Finalize Documentation					▲

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Science Needs

Table 5.1-1 Overlapping enhanced geothermal technology and deep borehole needs

Wellbore integrity and drilling technology

- Novel materials for well completions
- Real-time, in situ data acquisition and transmission systems
- Diagnostics and remediation tools and techniques
- Quantification of seal material and failure
- Advanced drilling and completion tools
- Well abandonment analysis

Subsurface Stress

- Sensing stress state beyond the borehole

Fracture & Fluid Flow Control

- Physicochemical controls and responses
- Manipulating (enhancing, reducing and eliminating) fluid flow

New Subsurface Signals

- New Sensors and Monitoring Approaches
- Next Generation Integration Approaches
- Diagnostic signatures of critical transitions
- Autonomous acquisition, processing and assimilation

After: Hubbard S. and Walck, M. C. Adaptive Control of Fractures and Fluids. Subsurface Crosscut National Lab Team. Presented to USEA (2014).

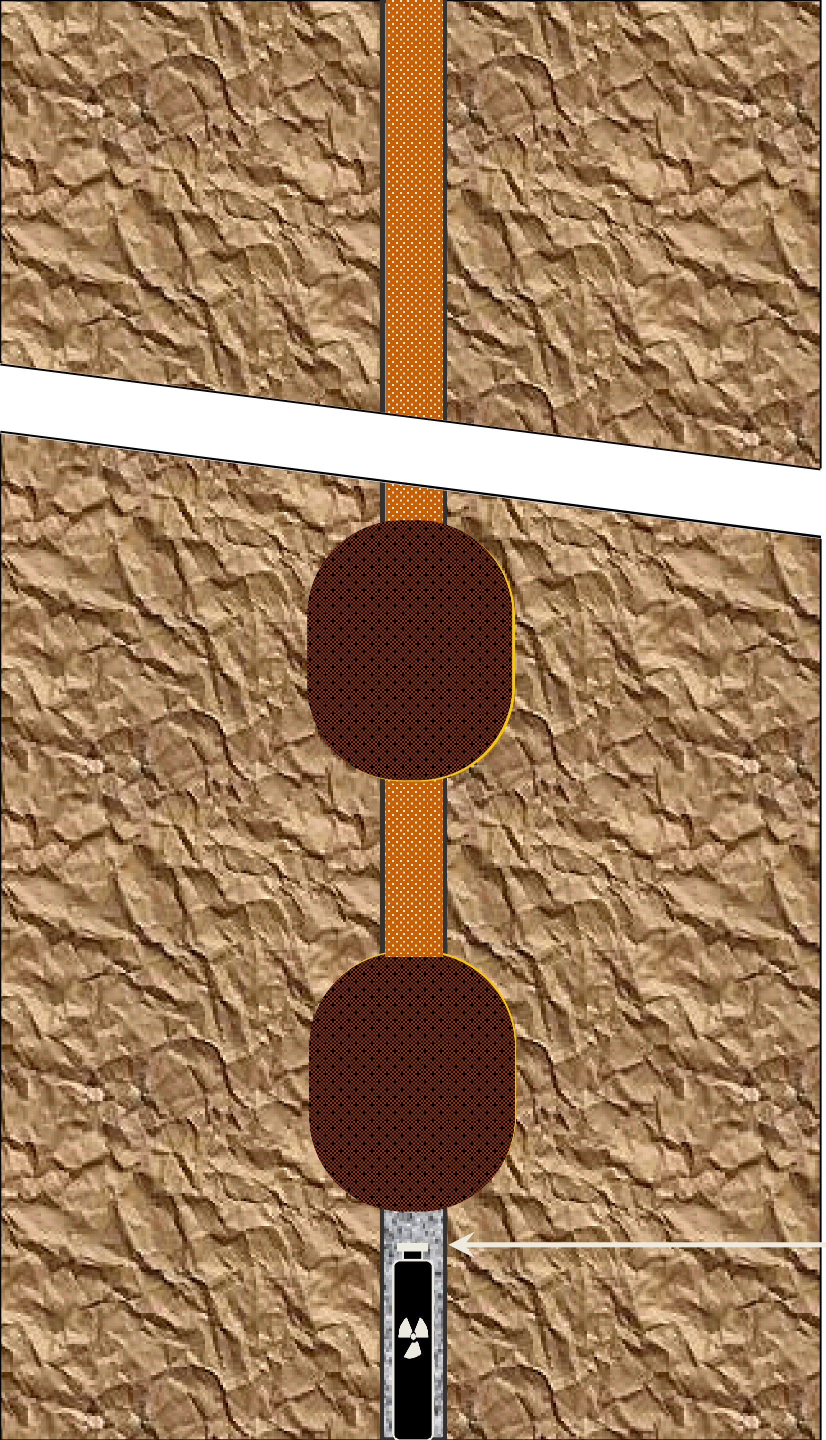
Science of Borehole Sealing

- **Need to predict long-term performance of bentonite and cement – effect of high salinity fluids on bentonite expansion, long-term degradation modes of cement.**
- **Need to predict impacts of steel/wasteform corrosion (e.g. H_2 generation) impacts on seals.**
- **How to monitor long-term seal performance?**

Novel Seals

- **Rock Welding – melt a sarcophagous above/around the waste.**
- **Reactive barrier/chemical sorbents to sequester any radionuclide leakoff.**

Rock welding to seal the borehole (F. Gibb/Sheffield)

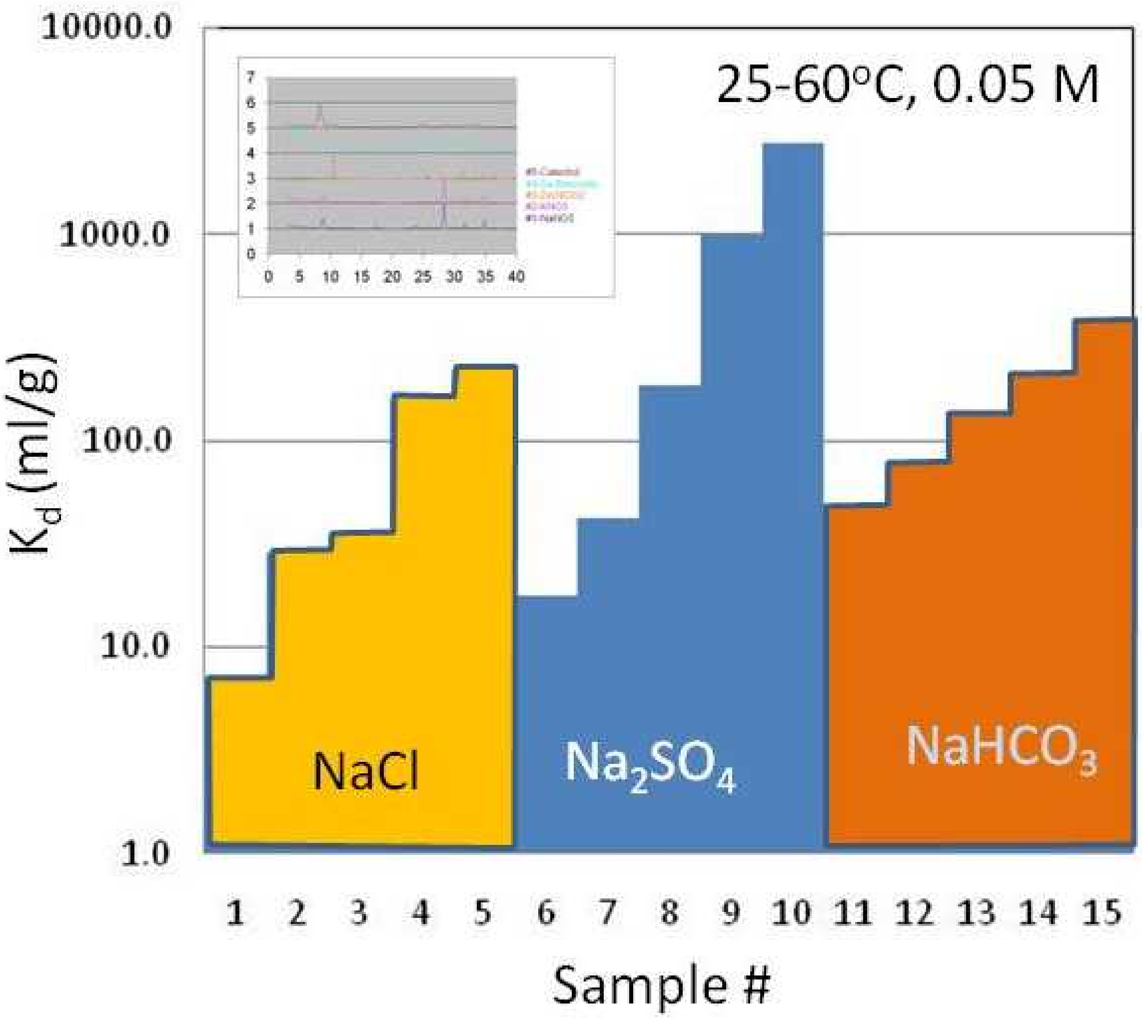


- Pour in backfill (crushed granite)
- Insert heater and melt backfill & wall-rock to seal the borehole
- Pour in more backfill and seal the borehole again
- Repeat as often as required then fill the rest of the borehole with backfill

3 km deep (topmost canister)

(Courtesy F. Gibb)

Iodine sorption on bismuth oxides and bismuth-doped bentonite.



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Summary

- Deep borehole disposal appears to be a safe, relatively inexpensive, and implementable option for nuclear wastes,

- Key science questions include:
  - The long-term behavior of traditional seals of cement and bentonite,
  - The ability to perform rock welding,
  - The design of chemically active seals that retain radionuclides, particularly ^{129}I.
  - How to monitor long-term seals performance.