# Deep-Borehole Disposal and Deep Isolation

**"Not a vestige could be seen, nor any indication of where we were going."**

**—Henry Lawson in "Journey to the Center of the Earth" by Jules Verne.**

# Deep boreholes

**Idea: Instead of (300 to 800 meter deep) geological repositories (such as Yucca Mountain), place wastes into deep, vertical wells.**

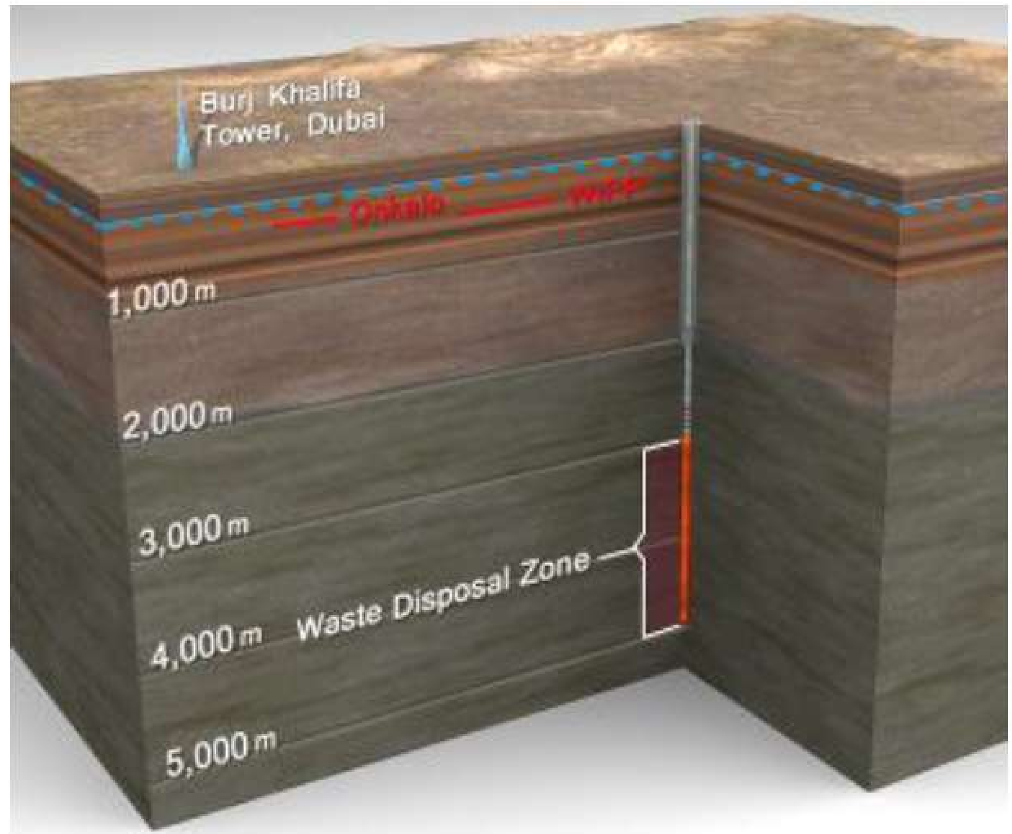
**Large-diameter boreholes drilled to depths of 4 to 5 km (2.5 to 3 miles) into the granitic basement. Relies on stable geological barriers instead of engineered barriers.**

**Not a new idea: first proposed in the 1950s.**

# Deep Borehole Disposal Concept

Sandia National Laboratories

- 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



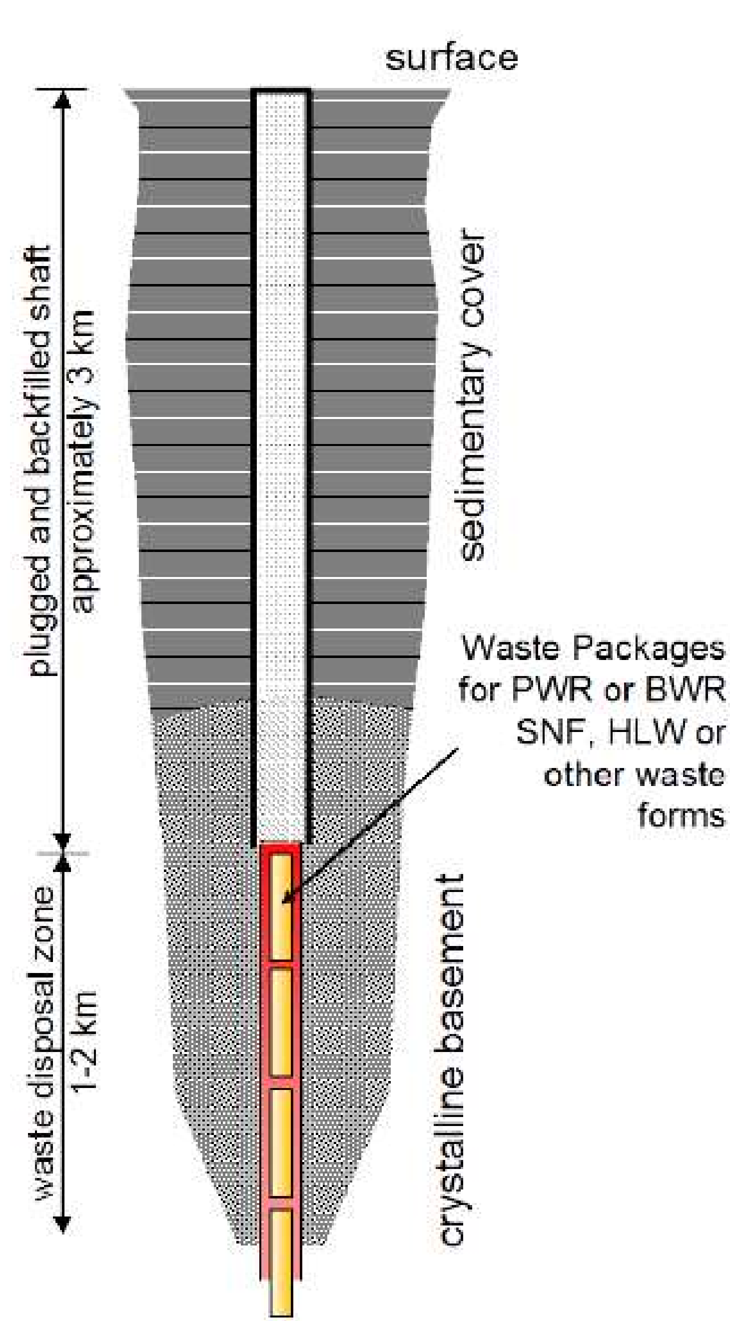
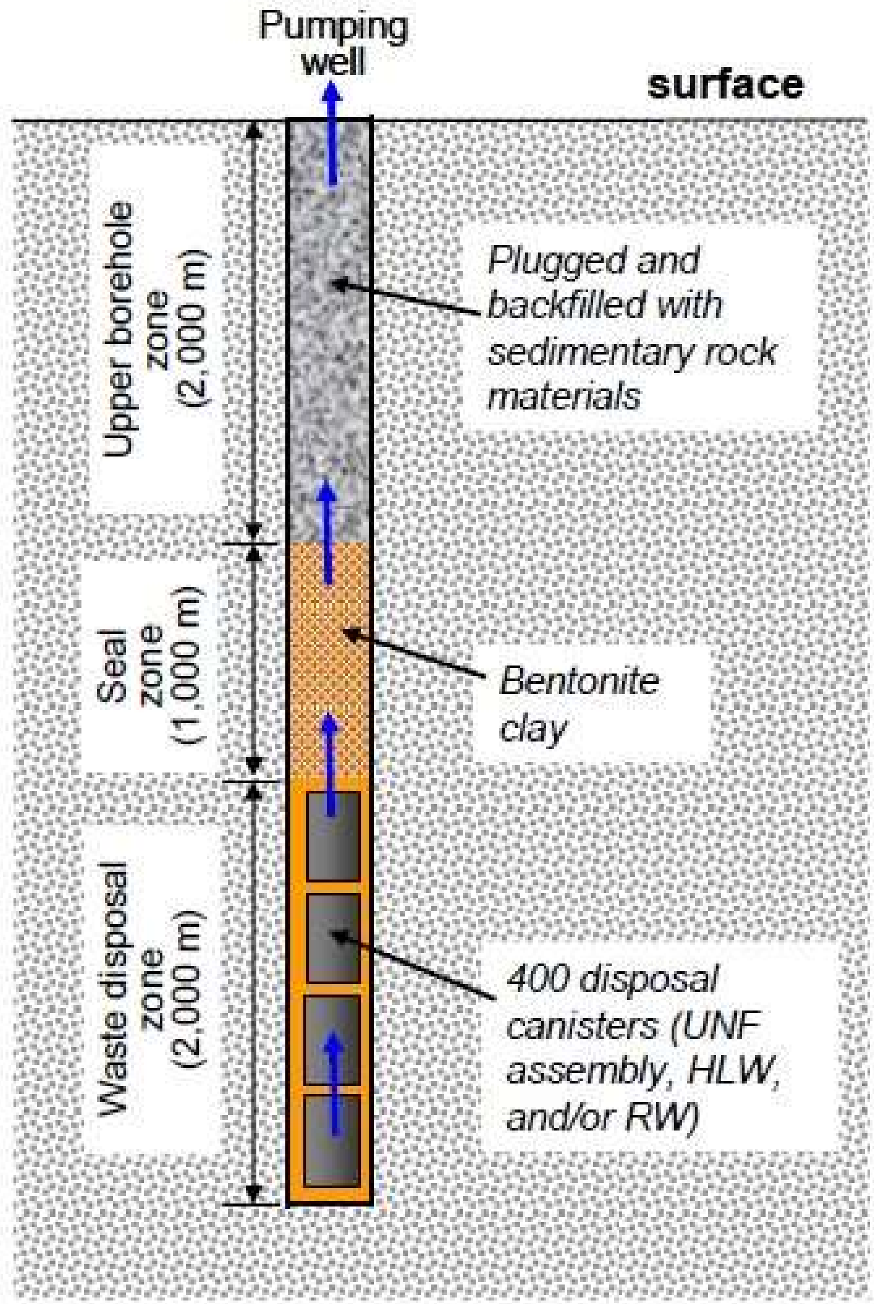


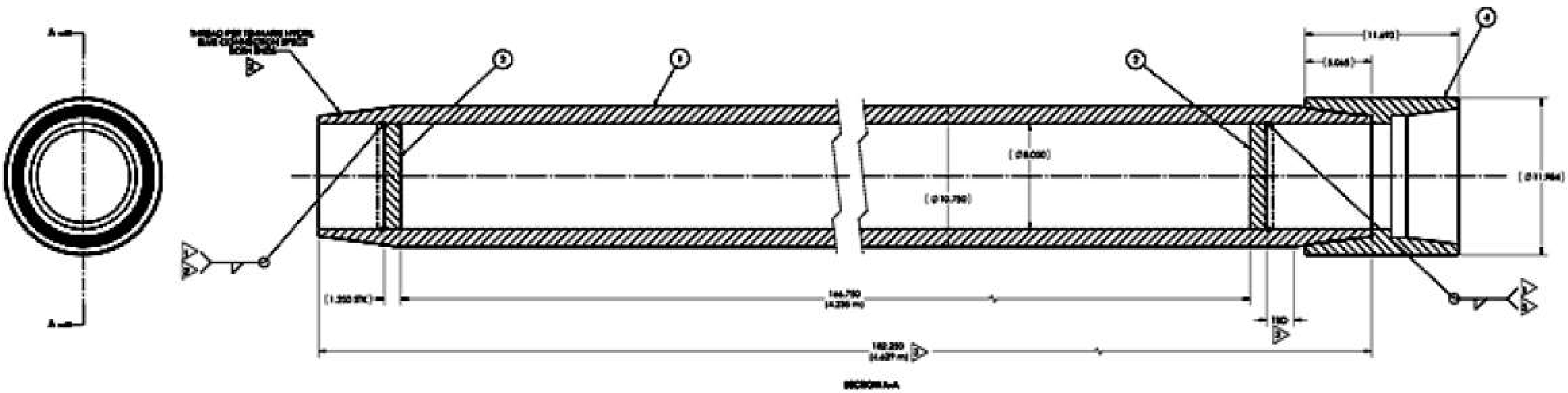

**Figure 1. Deep Borehole Disposal Schematic.**




(Arnold et al. 2013) SAND2013-9490P

# 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



# “Basement rocks”

**Basement rock: the oldest rocks in a given area; a complex of metamorphic and igneous rocks that underlies the sedimentary deposits. Usually Precambrian in age (older than 540 million years).**

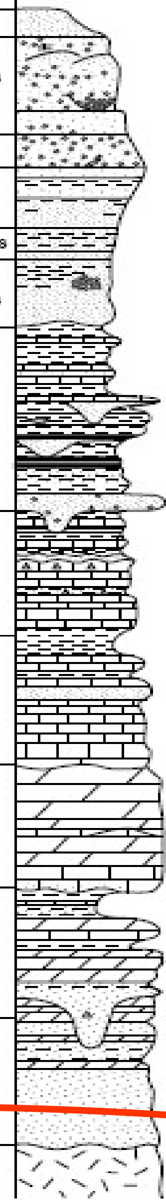
**For deep-bore disposal, we are interested in basement rocks made of granite (for now).**

# Granite

Granite is an igneous rock which formed by slowly cooling magma that was trapped beneath the earth's surface. Composed of quartz (silica) and various aluminosilicates.

# Generalized Illinois Geologic Column

| Era | | Period or System and Thickness | Epoch | Age (years ago) | General Types of Rocks |
|---|---|---|---|---|---|
| CENOZOIC "Recent Life" | Age of Mammals | Quaternary 0–500' | Holocene | 10,000 | Recent; alluvium in river valleys |
| | | | Pleistocene Glacial Age | 1.8 m | Glacial till, glacial outwash, gravel, sand, silt, lake deposits of clay and silt; wind deposits of loess and sand dunes. Deposits cover nearly all of state except northwest corner and southern tip |
| | | Tertiary 0–500' | Pliocene | 5.3 m | Chert gravel, present in northern, southern, and western Illinois |
| | | | Eocene | 33.7 m<br>54.8 m | Mostly micaceous sand with some silt and clay; present only in southern Illinois |
| | | | Paleocene | 65 m | Mostly clay, little sand; present only in southern Illinois |
| MESOZOIC "Middle Life" | Age of Reptiles | Cretaceous 0–300' | | 144 m<br>290 m | Mostly sand, some thin beds of clay, and, locally, gravel; present only in southern and western Illinois |
| PALEOZOIC "Ancient Life" | Age of Amphibians and Early Plants | Pennsylvanian 0–3,000' ("Coal Measures") | | 323 m | Largely shale and sandstone with beds of coal, limestone, and clay |
| | | Mississippian 0–3,500' | | 354 m | Black and gray shale at base, middle zone of thick limestone that grades to siltstone chert, and shale; upper zone of interbedded sandstone, shale, and limestone |
| | Age of Fishes | Devonian 0–1,500' | | 417 m | Thick limestone, minor sandstones, and shales; largely chert and cherty limestone in southern Illinois; black shale at top |
| | Age of Invertebrates | Silurian 0–1,000' | | 443 m | Principally dolomite and limestone |
| | | Ordovician 500–2,000' | | 490 m | Largely dolomite and limestone but contains sandstone, shale, and siltstone formations |
| | | Cambrian 1,500–3,000' | | 543 m | Chiefly sandstones with some dolomite and shale; exposed only in small areas in north-central Illinois |
| Precambrian | | | | | Igneous and metamorphic rocks; known in Illinois only from deep wells |



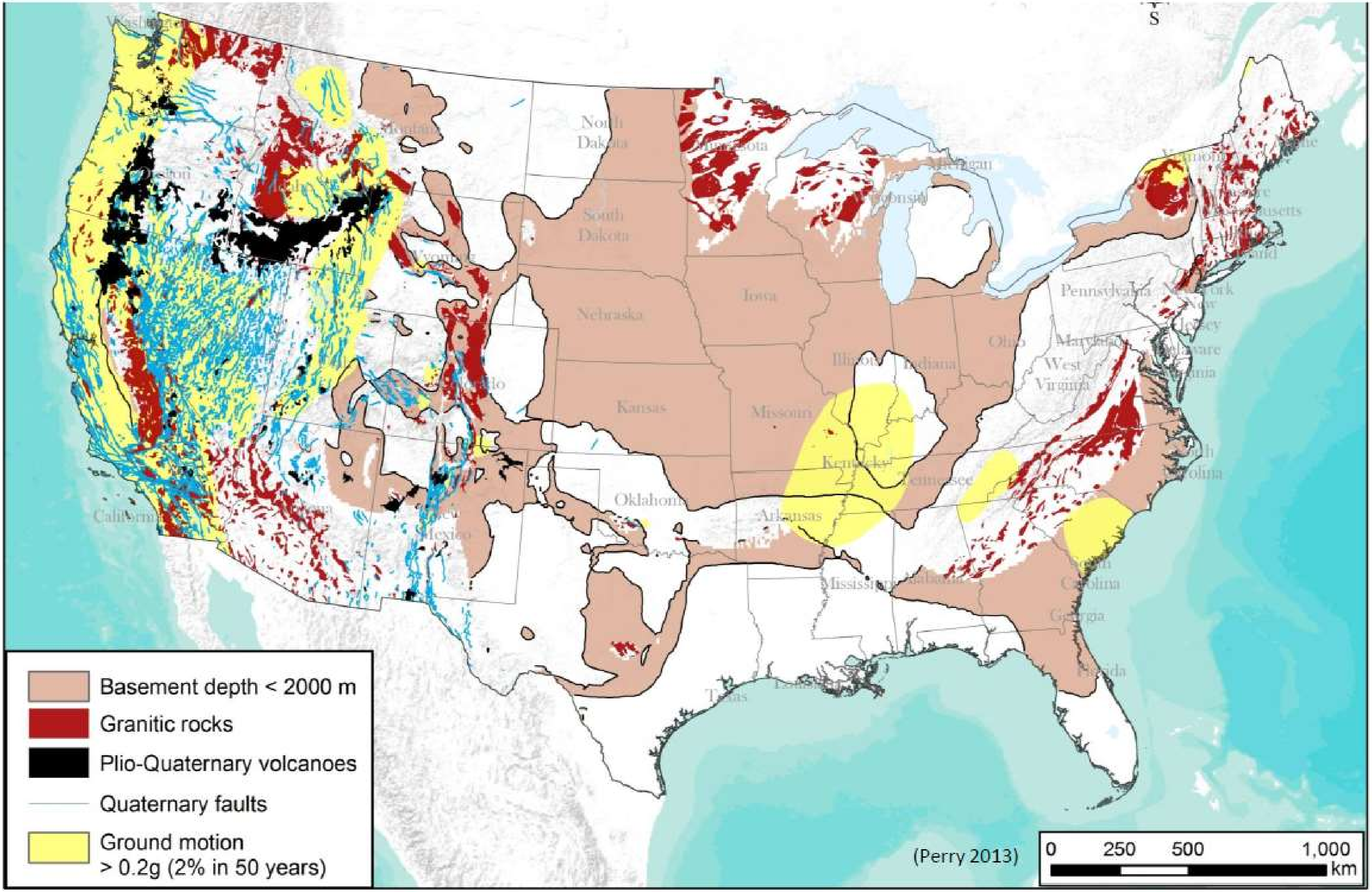
There are no surface outcrops of the basement rocks in Illinois. All we know about them are from core samples.

# Advantages of deep-bore hole disposal

1. Unlike volcanic rocks, salt layers, and remote locations, granitic basement rocks are common in the U.S. at depths of 2,000 to 5,000 m.

2. Long-transport pathways: the distance between the wastes and the biosphere is literally miles (kilometers).

# Siting: Bedrock + Hazards



# Advantages of deep-bore hole disposal

3. Very slow movement of groundwater. Basement rocks have little porosity or permeability. This groundwater is not part of the hydrologic cycle. May be thousands of years old.

4. Deep crystalline rocks typically have a low water content.

# Advantages of deep-bore hole disposal

5. Reducing (oxygen-poor) conditions which would limit metal corrosion of waste containers, and limit the mobility of radionuclides like Tc as Tc (IV).

6. Adsorption of radionuclides by bore-hole backfill materials and to a lesser extent, the granitic basement rocks. Anions such as $^{36}Cl^{-}$ will not move far anyway (will move with the groundwater).

# Advantages of deep-bore hole disposal

7. Not likely that radioactive gases will escape. Major overburden pressures contribute to sealing fractures that could allow gases (and liquids) to move away from the borehole.

8. Long-term stability: granitic basement rocks have been buried for millions of years. May be dense, and resistant to deformation.

# Advantages of deep-bore hole disposal

9. No heat-load limitations (heat might be useful to isolate wastes). A borehole team at Sandia calculated that the heat flux from a borehole in granite reached no further than about 10 to 100 meters.

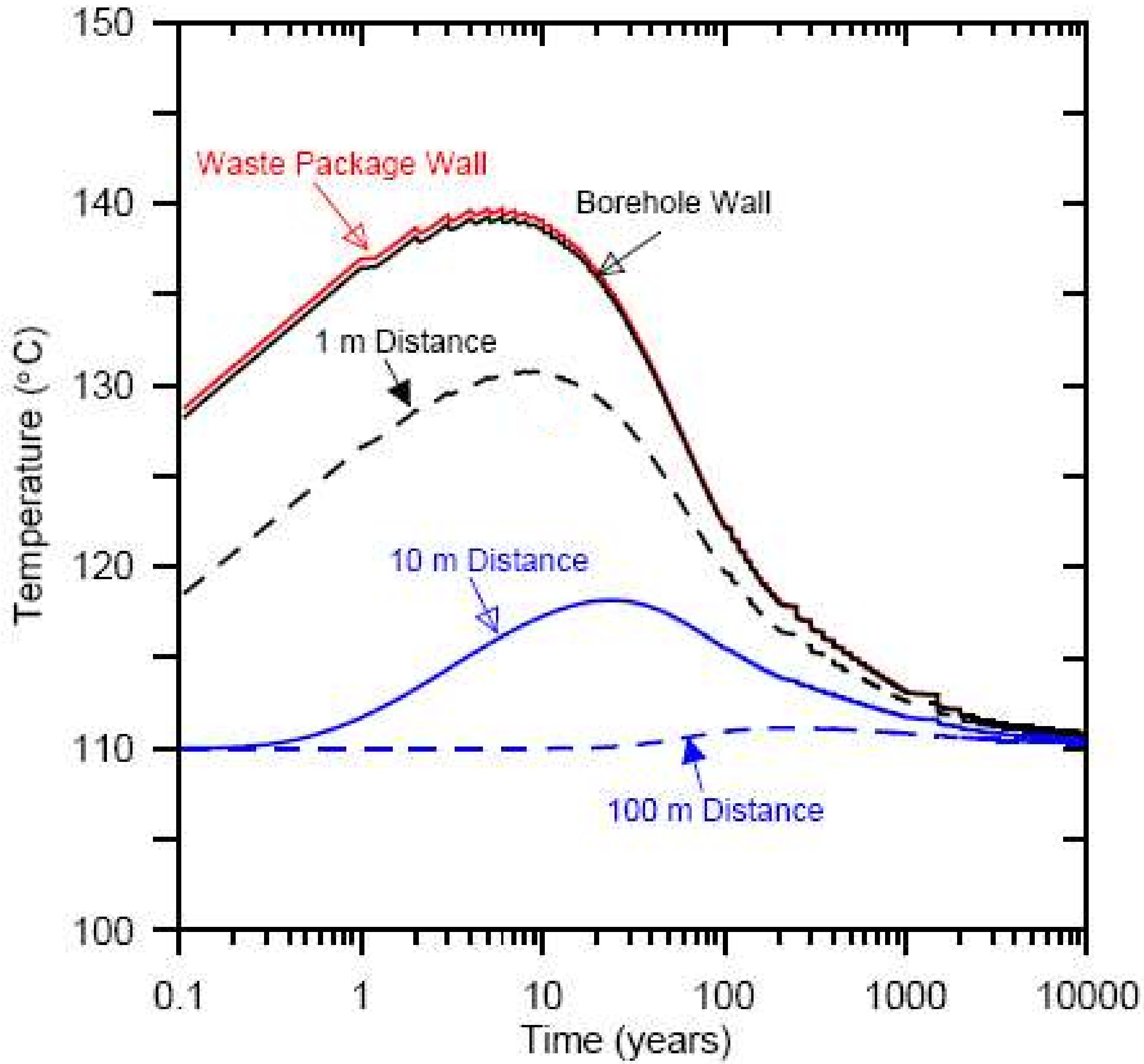



**Figure 5. Temperature as a Function of Time and Distance from the Borehole for PWR Spent Fuel Assembly Disposal**

# Advantages of deep-bore hole disposal

10. Drill as needed. Capacity: 160 metric tons/borehole. More wastes, more drill holes. One estimate is that 950 boreholes will store all the SNF through 2030 with a total cost that is less than the Yucca Mountain repository.

# Design need of deep-bore hole disposal

Waste canister design may need study because of the static load on the lowest canisters in the disposal zone because of the weight of the SNF above it. It is assumed that, after closure, the canisters will corrode.

# Costs and Barriers

$20 million per borehole

$10 billion for site characterization and license application.

$20 billion for operations, monitoring, and decommissioning.

$10 billion for transporting SNF

(from Brady et al., 2009)

The current Nuclear Waste Policy Act restricts geological repositories to only Yucca Mountain: deep boreholes would require an amendment.

# Disadvantages of deep-bore hole disposal

1. The wastes would **not** be easily retrievable. If future generations decided to reprocess UNF, it would be difficult to bring the wastes back to the surface because of the miles of sealing material.

2. The waste forms must fit into the well. Large containers would not go down the well. Wells could be 0.5-m diameter.

# “High-temperature” design

**Idea: dispose a waste with enough decay heat (> 700° C) to partially melt the enclosing rock (aqueous slurry of crushed granite), backfill grout (cement + sand), or a lead alloy.**

**Followed by vitrification and re-crystallization in 10 to 30 years.**

**Waste candidates: undiluted reprocessing wastes or SNF after less than 5 years of post-reactor cooling.**

# “High-temperature” design

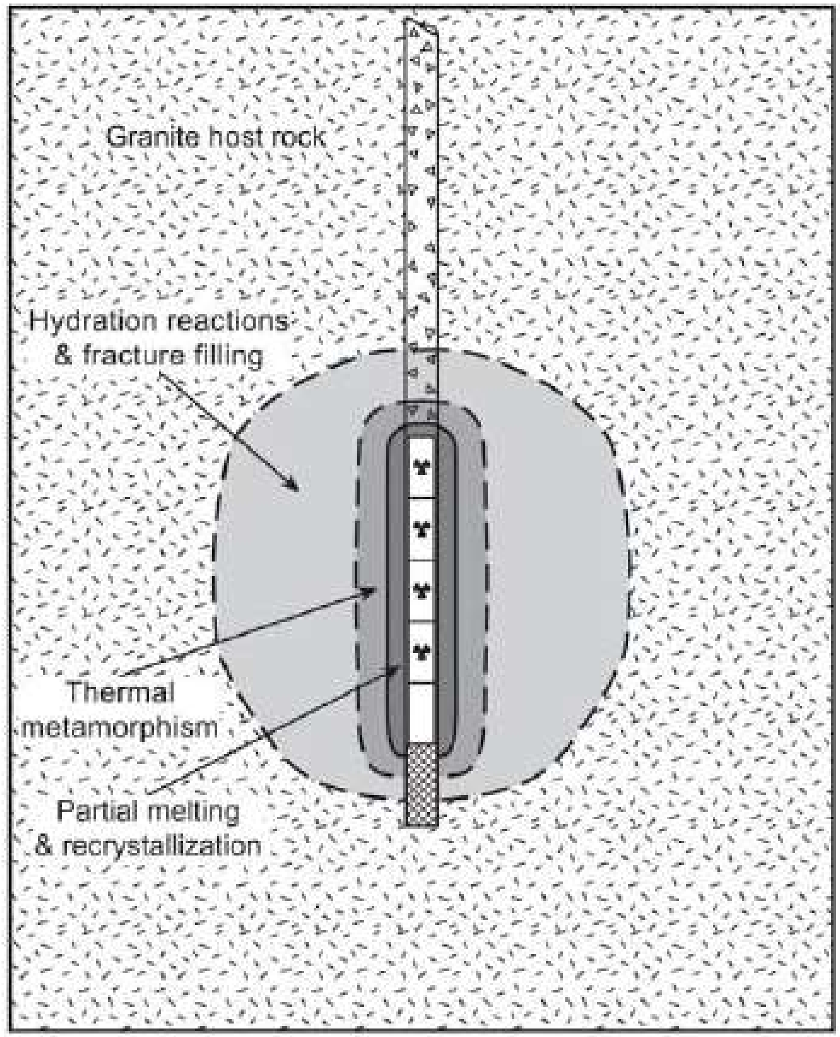



**Figure 2.** Schematic of high-temperature very deep disposal (HTVDD). Zones not to scale.

# Current Status of Deep Boreholes

**At the discussion-modeling stage.**

**Strong advocate: Prof. Fergus Gibb**

**Professor of Petrology & Geochemistry at the University of Sheffield, UK**

**(my prediction)**

**Experience with deep $CO_2$ injection wells such as that in Decatur may influence the future of deep boreholes.**

# Deep Boreholes at NPRE

**2014-2016. Robert Geringer. M.S. Thesis. "Preliminary Design and Analysis for Selected Problems in Deep Borehole Disposal of Spent Nuclear Fuel."**

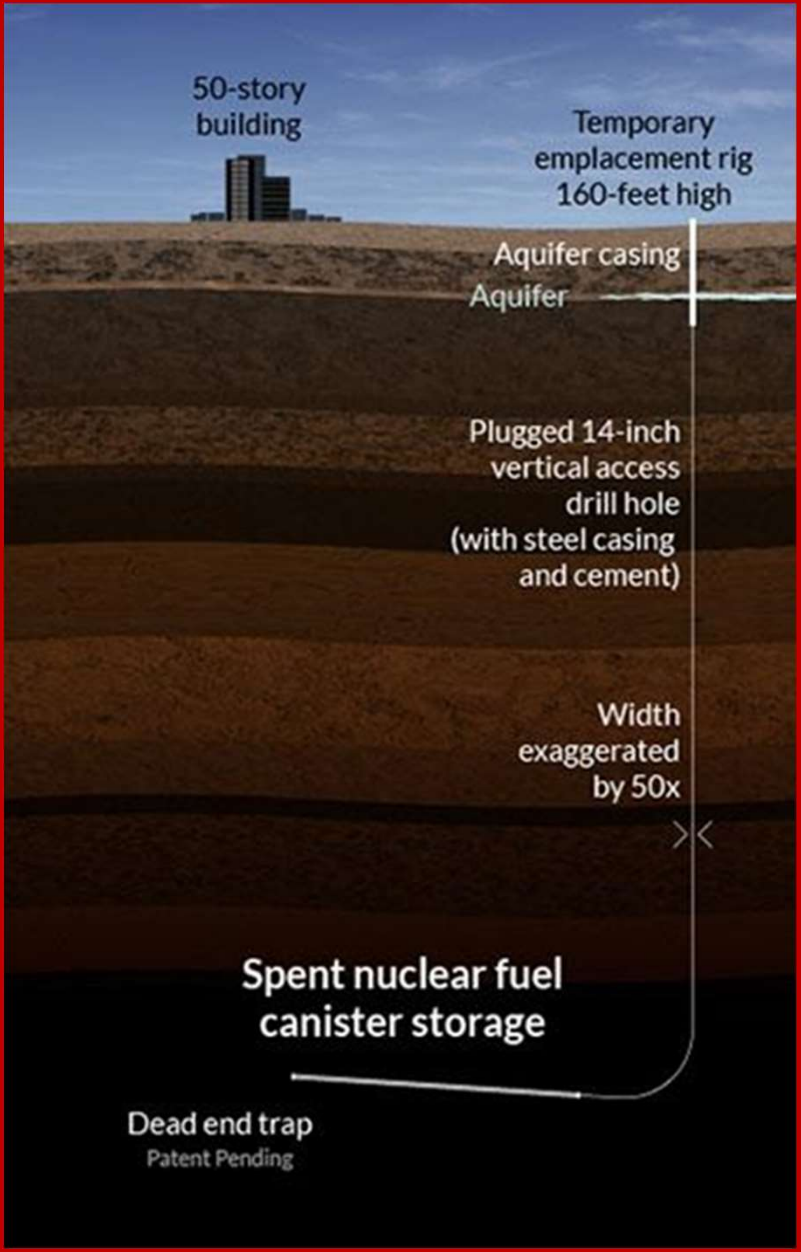
**Bae, J. W., W. R. Roy, and K. Huff. 2017. Benefits of Siting a Borehole Repository on Non-Operating Nuclear Facility. Proceedings of the 16th International High-Level Radioactive Waste Management Conference**

# Deep Boreholes at NPRE

**2018. NPRE 458. Design in NPRE. Advisor. Borehole approach for nuclear-waste disposal. Mateusz Lopez, Rebecca Herr, and Ben Junkroski.**

**2019. NPRE 458. Design in NPRE. Advisor. Deep borehole disposal of raffinate waste. Kerrick Klancnik, Heyuan Huang, and Demetrio Velazco.**

# The Deep Isolation concept



# The Deep Isolation concept

https://www.deepisolation.com/technology-demonstration/

https://www.youtube.com/watch?v=WeCc2RYbEQM (4:47)