Deep-Borehole Disposal

"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 shallow (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.
Figure 1. Deep Borehole Disposal Schematic.
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.
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 US 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).
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.

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
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(my prediction)

Experience with deep CO$_2$ injection wells such as that in Decatur may influence the future of deep boreholes.