A Case for Disposal of Nuclear Waste in Deep Boreholes

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Conceptual Model for Very Deep Borehole Disposal

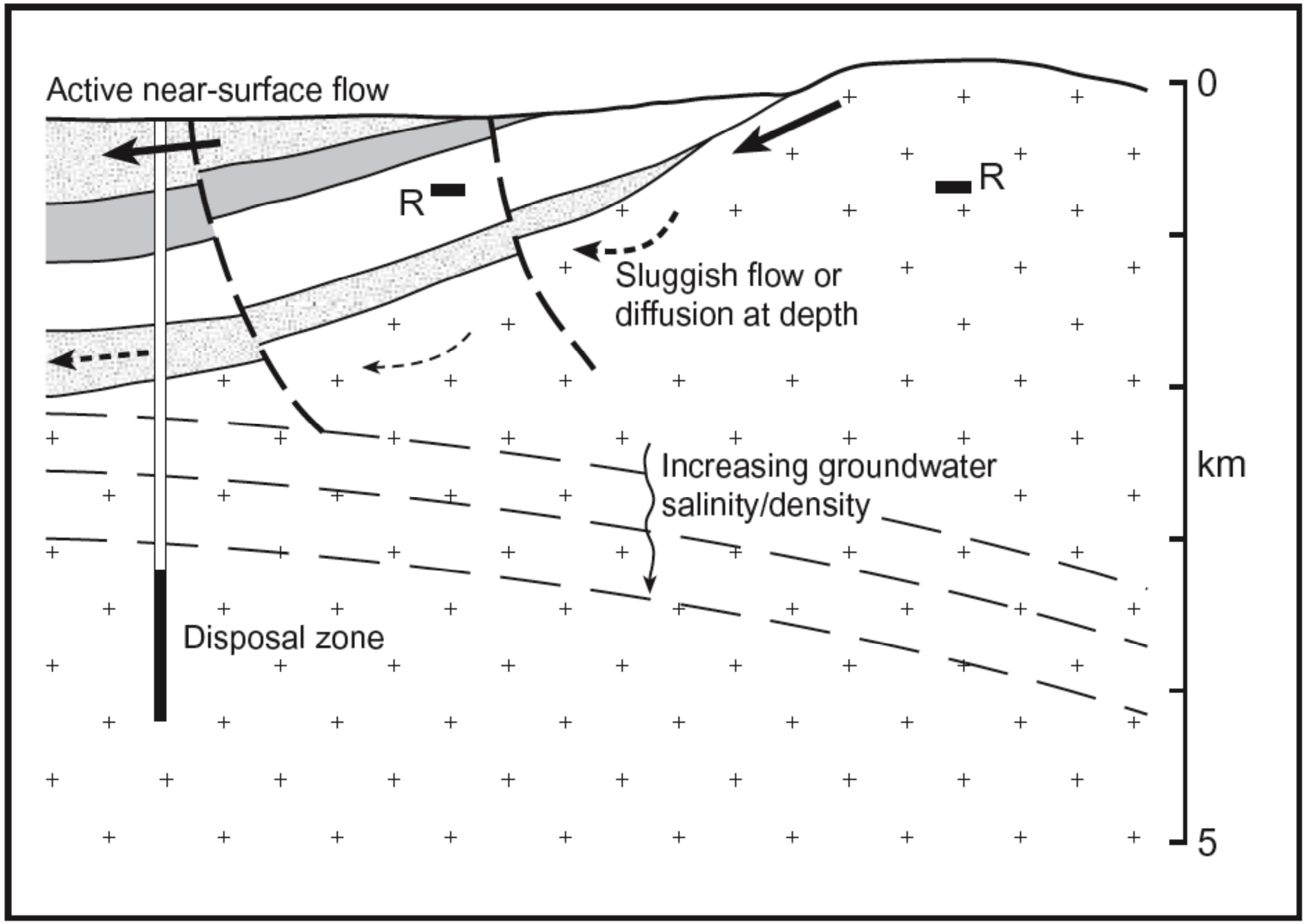
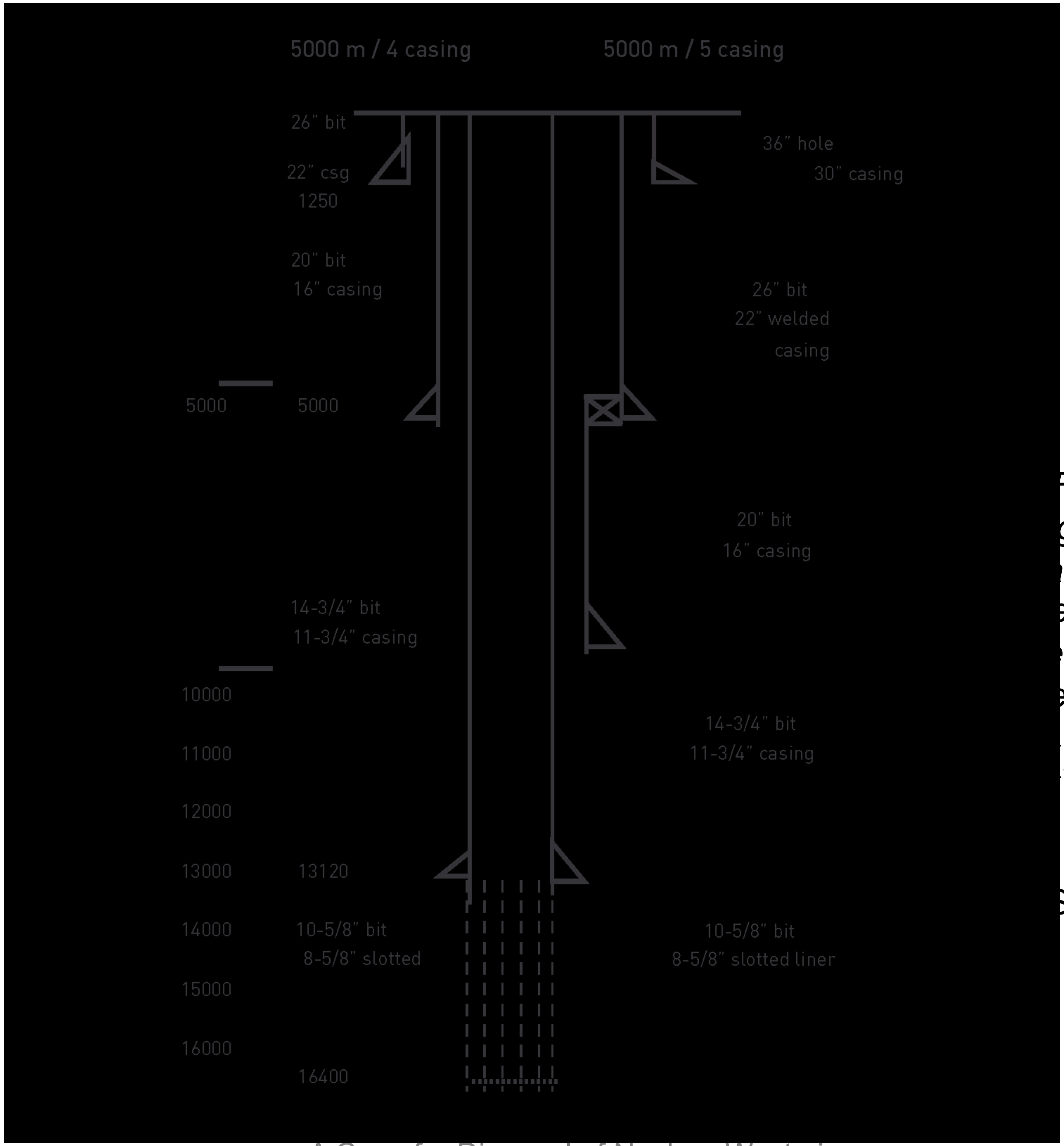


Fig. 1. Conceptual model for very deep borehole disposal. In this scenario, wastes are emplaced in the lower 1000 m of a borehole, deep within crystalline basement rocks in a region that is hydraulically effectively decoupled from more active regions of groundwater flow in the upper part of the crust. At these depths, pore fluids in the rock might be expected to be stagnant, stable, and density stratified, with progressively increasing salinity with depth. "R" denotes typical depths of conventional mined repositories for long-lived wastes.

Chapman and Gibb: July/August 2003 **Radwaste Solutions** 29

4- and 5-Interval 5,000 m Casing



Future of Geothermal
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New Technical Factors Favoring Re-evaluation of Deep Boreholes

- Improved oil/gas/geothermal drilling technology especially for enhanced geothermal systems: same rock, same depth
- Successful Swedish & Finnish repository siting – same type of rock but in shallower (~500 m) mined repositories. Deep boreholes are slimmer, deeper (3 – 4 km) versions. Rock properties improve with depth (e.g., lower permeability)
- Improved host rock characterization methods: Again oil & gas developments. Both wide-field & downhole, e.g. seismic imaging, well logging

Favorable Aspects of Deep Boreholes

- Reducing chemistry: guarantees low solubility
- Extremely low rock permeability and water content/mobility
- Not heat load limited
- Inherently modular: Drill as needed, pay as you go
- Widespread applicability – can share international RD&D experience
- Simpler (but not trivial) to analyze: easier to understand case for safety assurance
- May be possible to separately license borehole technology and siting – analogous to process for standardized reactors
- Synergism with engineered geothermal systems (EGS)

Disadvantages of Deep Boreholes

- Harder to retrieve waste after final repository closure (but not impossible) (Advantageous for some waste classes)
- Cannot use for disposal of large intact contaminated components (not a pertinent goal?)
- Somewhat larger diameter than most other applications (i.e., 0.5 vs. 0.25 m); but can use smaller diameter for consolidated fuel or reprocessing waste forms

Worth mentioning is a possible factor inhibiting research in this area – the prohibition in the US Nuclear Waste Policy Act of 1982, as amended in 1987, of the evaluation of disposal into granite; to quote Sec. 161:

> (c) TERMINATION OF GRANITE RESEARCH. – Not later than 6 months after the date of the enactment of the Nuclear Waste Policy Amendments Act of 1987, the Secretary shall phase out in an orderly manner funding for all research programs in existence on such date of enactment designated to evaluate the suitability of crystalline rock as a potential repository host medium.

Location of Surface Exposures of Crystalline Basement Rocks in the US

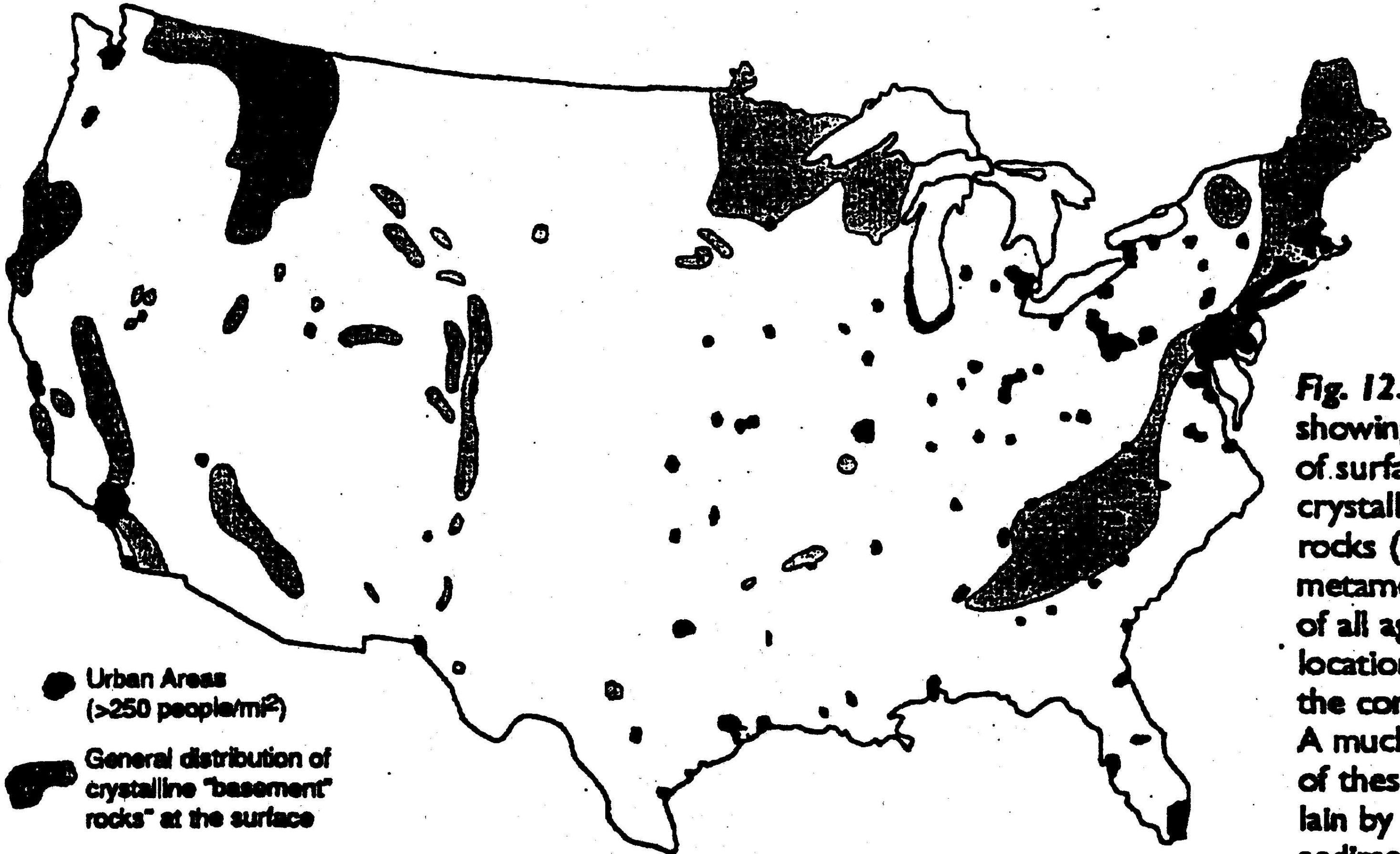

Fig. 12. **General map showing the distribution of surface exposures of crystalline basement rocks (predominantly metamorphic and plutonic) of all ages as well as the location of urban areas in the conterminous US. A much larger distribution of these rock types is overlain by less than 1 km of sedimentary rocks. (Adapted from Flawn, 1967.)**

Target Downhole Properties

An important goal is setting specifications for necessary and sufficient rock and water properties for deep borehole HLW disposal applications. They should be adequate to ensure the high level of sequestration required and at the same time be widely prevalent.

Candidate Properties Include:

Feature	Specification	Comment
Dominant Criterion:		
Permeability	$< 10^{-6}$ Darcy	To ensure low water movement velocity
Ancillary Goals:		
Porosity	< 1% by volume	% interconnected, and hydraulic diameter are also important, as contributors to low permeability
Water Content	< 1% by volume	Follows from low porosity
Downhole Pressure	Close to lithostatic or hydrostatic	To avoid excessive gradients
Salinity Density Increase	> 40 g/kg	Thwarts buoyant vertical convection in uppermost one km.
E_h (potential relative to hydrogen electrode)	< -0.1 volt	Characterizes reducing nature of environment; assures low solubility
pH (acid/base characteristics)	> 6; < 9	Also helps reduce corrosion and maintain low solubility
Retardation Factor	> 100 for most species	Adsorption on rock reduces rate of transport by this factor

MIT Findings over Past 20 Years

- Confirmative of work by others
- Prospects are good for <u>very</u> effective sequestration
- The main escape threat is by transport in water
  - Most challenging radionuclide is I-129
  - Weakest link may be borehole plug
- The approach appears to be cost-effective: <100 $/kg HM for ready-to-use hole (1 mill/kWhre fee is equivalent to ~400 $/kg HM)
- The thermal loading is quite tolerable – local max. rock temperature increase can be kept to 20° to 30°C

Summary/Conclusions/Recommendations

- Deep boreholes are worth reconsideration – especially as an alternative to transmutation
- Should exploit synergism with enhanced/engineered geothermal systems (EGS)

Some Priority Questions on Deep Borehole HLW Disposal

1) Is (nearly) all igneous continental bedrock (i.e., “granite”) similar with respect to key parameters (permeability, porosity, E_h, pH, salinity)?
2) Are oil well logging methods currently adequate to measure these parameters in the range of interest of deep boreholes for HLW disposal?
3) Are current remote survey methods (seismic, ground penetrating radar, gravimetric, EM) adequate for initial site screening?
4) What is the practical current limit on borehole diameter (e.g. ~ 0.5m?) and the cost vs. diameter dependence?
5) Can we do without borehole liners in deep high-integrity granite?
6) Is the higher reliance on geology and geochemistry and the lesser role of engineered defense in depth (e.g. canister materials), compared to shallower mind repositories, an acceptable strategy?
7) How much emphasis should be placed on retrievability?
8) Is there significant commonality with boreholes drilled for enhanced geothermal systems?
9) Are there any unique socio-political/licensing issues compared to shallower mined repositories?
10) What factors could complicate emplacement of seals (e.g. of concrete, clay, and asphalt) that have long-term permeability comparable to the host rock?
11) What, in your opinion, is the biggest obstacle to pursuing deep boreholes as a HLW disposal option?

Bibliography of MIT Work

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- B. Sapiie, M. J. Driscoll and K. G. Jensen, "Regional Examples of Geological Settings for Nuclear Waste Disposal in Deep Boreholes," MIT-NFC-TR-113, Jan. 2010
- K. G. Jensen and M. J. Driscoll, "A Framework for Performance Assessment and Licensing of Deep Borehole Repositories," MIT-NFC-PR-ZZZ, Jan. 2010

There are also three theses underway:

- Jonathan Gibbs: "Feasibility of Horizontal Emplacement in Very Deep Borehole Disposal of Nuclear Waste"
- Ethan Bates, "Conceptual Design and Experimental Analysis of Canister Emplacement for Deep Borehole Waste Disposal"
- Kristoffer Jensen: "A Framework for Performance Assessment and Licensing of Deep Borehole Disposal of Nuclear High Level Wastes"