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Deep Borehole Disposal of Spent Nuclear Fuel and High –Level Waste

U.S. Nuclear Waste Technical Review Board

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DEEP BOREHOLE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

Summary

Deep borehole disposal is a type of geologic disposal in which spent nuclear fuel (SNF) and solid high level radioactive waste (HLW) are isolated from the environment by emplacement in boreholes at depths from two to five kilometers (Km) beneath the land surface. Key aspects of deep borehole disposal addressed in this fact sheet are safety, capacity, technical feasibility and technical challenges. Safety results from the geologic isolation of the radioactive materials and depends strongly on the characteristics of the geologic environment. Many locations in the United States may have suitable geologic strata at appropriate depths and lithology is a critical factor in ensuring safe and reliable geologic isolation. Geographically-distributed deep borehole disposal can reduce transportation requirements and risk relative to centralized storage and disposal. Current research concepts suggest that each borehole could hold between 100 and 200 metric tons (MT) SNF, so 10 to 20 boreholes could contain the approximately 2,000 MT SNF discharged from U.S. nuclear power plants each year. Because of lower waste form density, the 7,000 MT HLW DOE needs to dispose would likely require more than 35 to 70 boreholes, and it may be impractical to emplace at depth some existing large-diameter canisters of vitrified waste. Advances in deep borehole drilling have demonstrated the technical feasibility of drilling boreholes to depths of two Km or more. Technical challenges arise from characterization and engineering of boreholes, including the development and demonstration of robust and reliable borehole seals. A significant operational concern is the possibility of a waste package becoming lodged in the borehole above the emplacement zone. After emplacement and sealing, attempts to retrieve SNF from deep boreholes would present significant technical and safety challenges. Prototypes demonstrating technical feasibility and reliability are required, and deep borehole disposal research and development can benefit significantly from international collaboration. Considering all known factors, deep borehole disposal is a credible approach to isolating radionuclides in SNF and HLW from the environment for very long periods of time.

Safety

Deep borehole disposal has the potential to provide very robust waste isolation. For example, calculations by Sandia National Laboratories estimate the peak dose from a hypothetical borehole containing 150 MT SNF to be approximately $1x10^{-10}$ mrem/yr, more than a billion times below current regulatory limits for releases from geologic repositories (1). Actual isolation performance will depend strongly on the geology of the borehole environment, and extraordinary performance of engineered systems should not be required.

Many locations throughout the U.S. are likely to have suitable geologic strata at depth, including sedimentary, igneous and metamorphic rock types (1, 2). Maximum isolation capability and reliability will be associated with geologic settings that have: low permeability; reducing geochemistry; a high capacity for retarding radionuclide migration; no natural resources (including geothermal resources); and negligible seismic and igneous activity.

Uncertainty is inherent in all natural and engineered systems. Confidence in waste isolation performance of deep borehole disposal can be enhanced through robust total system characterization, early and sustained monitoring, and quantitative risk assessment. All critical natural and engineered deep borehole system elements must be analyzable over geologic time scales, and poorly understood features or processes diminish confidence in performance estimates of deep borehole systems. Natural analogs can be of significant value in improving understanding and evaluating models. Confidence is enhanced when natural analogs and other lines of evidence are consistent with proposed interpretations and performance projections.

During the operational phase of deep borehole disposal there is a risk of a waste package becoming lodged out of place in the borehole. Process prototyping and contingency planning can significantly mitigate (but not completely eliminate) this risk.

Capacity

Borehole capacity depends partly on the thickness of suitable geologic strata at depth and on the diameter and depth of the borehole. A 2009 study investigated emplacement of 100 to 200 MT per borehole[1] at depths from 3- to 5-Km in 45 cm-wide boreholes (1). At those emplacement rates, between 650 and 1,300 boreholes would be needed to dispose of the 130,000 MT of U.S. commercial SNF expected to exist in 2070 (3). Borehole capacity may also be subject to thermal loading limits; Emplacement of hot waste can cause buoyant upwelling of groundwater at depth for hundreds of years or more (1).

Technical Feasibility

Drilling deep boreholes for disposal of SNF and HLW is feasible using proven available technology. Numerous boreholes greater than 2-Km deep have been drilled (2), including a 6-Km deep petroleum exploration borehole in Nevada (6) and a 12-Km deep borehole in Russia (7). Deep boreholes have also been used for geothermal energy production (4). For example, 17 production wells drilled in Japan's Okuaizu geothermal field ranged from 1.6 to 2.4-Km deep (8).

Although not a technical issue, economic cost could factor into the feasibility of borehole disposal. The cost of drilling and constructing deep boreholes depends upon rock type, depth and diameter of the borehole, and well casing design, among other factors. Cost estimates[2] for drilling deep boreholes, including some based on geothermal energy production wells, have ranged from $1-$4M/Km (2, 4). In general, for similar diameter and lithology drilling costs for deep borehole disposal are likely to be comparable to those for other deep oil, gas and geothermal boreholes.

Technical Challenges

A deep borehole disposal system will include the following major elements: well casing and grout, waste packages, emplacement machinery, borehole seals, and monitoring systems. Technical challenges of deep borehole disposal include: characterization of the geologic, hydrogeologic, and geochemical environment; emplacement of waste packages at depth; development of robust monitoring technology; and development of reliable borehole seals. The relative difficulties that each of these challenges present will vary depending on the geologic setting and on the deep borehole design. Deep borehole seal technology has been investigated, and simple and elaborate approaches have been proposed (9). Very large thermal loads that significantly perturb the natural environment for long time periods will create additional challenges to establishing confidence in waste isolation predictions. Furthermore, after waste packages are sealed in place, retrieval is likely to be very problematic and deep borehole disposal of SNF is not desirable if the need for retrieval is foreseen.

A waste package may be subject to significant pressure and a risk of rupture due to crushing from the cumulative weight of the overlying packages. Although isolation performance does not depend on

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[1]Two hundred 5 m-long packages per kilometer, each package containing one 0.5 MT spent fuel assembly.

[2]Cost estimates do not include expenses arising from regulation, characterization, operations or monitoring. If 70,000 MTU SNF and HLW could be emplaced in 700 boreholes drilled for $20M each, the drilling costs would be approximately $14B, about 14 percent of the disposal cost estimates for an equivalent amount at Yucca Mountain.

waste package integrity, researchers have proposed to address this issue by limiting continuous waste emplacement strings to 1 Km and by emplacing stress-diffusing plugs between waste packages (2).

Development and testing of prototype deep borehole disposal systems would be of significant value in demonstrating existing concepts and enhancing confidence in deep borehole performance. It would also potentially allow currently unforeseen factors to be identified and their impact to be investigated as part of a phased research and development program into deep borehole disposal systems.

International Investigations

Deep borehole disposal is an area of ongoing investigation by the international community. The International Atomic Energy Agency has identified safety requirements for deep borehole disposal (10), and Sweden (11, 12) and the UK (13) are among the other nations that have investigated deep borehole disposal. Deep borehole disposal may be a preferred option for nations such as Mexico whose relatively small inventories of SNF may not merit development of a mined geologic repository. In any event, like other types of geologic disposal, deep borehole disposal research and development can benefit significantly from international collaboration.

References

1. Brady, Patrick V., Bill W. Arnold, Geoff A. Freeze, Peter N. Swift, Stephen J. Bauer, Joseph L. Kanney, Robert P. Rechard, Joshua S. Stein, 2009. Deep Borehole Disposal of High-Level Radioactive Waste. Sandia Report, SAND2009-4401.

2. Sapiie, B., and M. J. Driscol, 2009. A Review of Geology-Related Aspects of Deep Borehole Disposal of Nuclear Waste. MIT Nuclear Fuel Cycle (NFC) Technology and Policy Program, MIT-NFC-TR-109.

3. DOE, 2008. The Report To The President And The Congress By The Secretary Of Energy On The Need For A Second Repository, December 2008. DOE/RW-0595.

4. Polsky, Y., L. Capuano, et al. (2008). Enhanced Geothermal Systems (EGS) Well Construction Technology Evaluation Report, Sandia Report SAND2008-7866.

5. DOE, 2008. Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007, DOE/RW-0591.

6. Halsey, W.G., L.J. Jardine, C.E. Walter, 1995. Disposition of Plutonium in Deep Boreholes, paper prepared for submittal to the NATO International Scientific Exchange Program Advanced Research Workshop, Disposal of Weapons Plutonium-Approaches and Prospects, St. Petersburg, Russia, May 14-17, 1995. Lawrence Livermore National Laboratory, UCRL-JC-120995 Rev 1.

7. International Continental Scientific Drilling Program, http://www.icdp-online.org/front_content.php?idcat=695. Accessed 09/10/10.

8. Garg, S., and J. Combs, 2002. A Study of Production/Injection Data from Slim Holes and Large-Diameter Wells at the Okuaizu Geothermal Field, Tohoku, Japan. Idaho National Engineering and Environmental Laboratory, Bechtel BWXT Idaho, LLC, INEEL/EXT-02-01429.

9. F.G.F. Gibb, K.J. Taylor & B.E. Burakov. 2008. The ‘granite encapsulation’ route to the safe disposal of Pu and other actinides. Journal of Nuclear Materials, 374, 364-369.

10. International Atomic Energy Agency, 2006. “Geological Disposal of Radioactive Waste: Safety Requirements,” IAEA Safety Standards Series No. WS-R-4, Jointly sponsored by the International Atomic Energy Agency and the Organisation for Economic Cooperation and Development Nuclear Energy Agency, Vienna.

11. SKB, 1989. Storage of Nuclear Waste in Very Deep Boreholes: Feasibility Study and Assessment of Economic Potential. Part I: Geological Considerations. Part II: Overall Facility Plan and Cost Analysis. SKB Technical Report 89-39.

12. SKB, 1998. The Very Deep Hole Concept – Geoscientific appraisal of conditions at great depth. SKB Technical Report 98-05.

13. Nirex, 2004. A Review of the Deep Borehole Disposal Concept, Report N/108. United Kingdom Nirex Limited, June 2004.