An Analysis on the Borehole Spacing for Deep Borehole Disposal of HLW

Jongyoul LEE [*], Geonyoung KIM, Daeseok BAE, Heuijoo CHOI, Kyeongsoo KIM

Korea Atomic Energy Research Institute, 989-111, Daedeokdaero, Yuseong, Daejeon
[*]Corresponding author: njylee@kaeri.re.kr

ABSTRACT

A mined deep geological disposal system is considered as the safest method to isolate the spent fuels or high-level radioactive waste from the human environment with the best available technology at present time. However, if these high-level radioactive wastes can be disposed of in deeper and more stable rock formation than mined deep geological disposal depth, it has several advantages. Therefore, as an alternative disposal concept, i.e., deep borehole disposal technology is under consideration in number of countries in terms of its outstanding safety and cost effectiveness.

In this paper, the general concept and key technologies for deep borehole disposal of spent fuels or HLW, as an alternative method to the mined deep geological disposal method, were reviewed. After then an analysis on the distance between boreholes for the disposal of HLW was carried out. Based on the results, a disposal area was calculated approximately and compared with that of mined deep geological disposal.

I. INTRODUCTION

A mined deep geological disposal system, the disposal depth is about 500 m below ground, is considered as the safest method to isolate the spent fuels or high-level radioactive waste from the human environment with the best available technology at present time. The disposal safety of this system has been demonstrated with underground research laboratory and some advanced countries such as Finland and Sweden are implementing their disposal project on commercial stage. However, if the spent fuels or the high-level radioactive wastes can be disposed of in the depth of 3~5 km and more stable rock formation, it has several advantages. For example, (1) significant fluid flow through basement rock is prevented, in part, by low permeability, poorly connected transport pathways, and (2) overburden self-sealing. (3)Deep fluids also resist vertical movement because they are density stratified and reducing conditions will sharply limit solubility of most dose-critical radionuclides at the depth. Finally, (4) high ionic strengths of deep fluids will prevent colloidal transport. Therefore, as an alternative disposal concept to the mined deep geological disposal concept (DGD), very deep borehole disposal (DBD) technology is under consideration in number of countries in terms of its outstanding safety and cost effectiveness.

In this paper, the general concept and key technologies for deep borehole disposal of spent fuels or HLW, as an alternative method to the mined geological disposal method, were reviewed. After then an analysis on the distance between boreholes for the disposal of HLW was carried out. Based on the results, a disposal area were calculated approximately and compared with that of mined geological disposal. These results will be used as an input for the analyses of applicability for DBD in Korea.

II. A CONCEPT OF DEEP BOREHOLE DISPOAL

II.A General Concept

Deep borehole disposal of spent fuel from nuclear power plants or solidified high-level radioactive waste from the reprocessing of nuclear fuel is a concept that dates from the 1950s in USA as one of several disposal concepts. This concept was considered again in the 1990s and early 2000s in USA and some countries in Europe such as Sweden, Denmark and the UK [1].

A recent deep borehole disposal concept consists of drilling a borehole (or array of boreholes) into crystalline basement rock to a depth of about 5,000 m, emplacing waste canisters containing spent nuclear fuels or vitrified high-level waste in the lower 2,000 m of the borehole, and sealing the upper 3,000 m of the borehole.

The waste packages would be emplaced individually or as a string of 10-20 packages. A single borehole could contain up to 400 waste packages, each approximately 5 m in length. The sealing material for the borehole can be compacted bentonite, asphalt and concrete (Fig. 1.) [2].

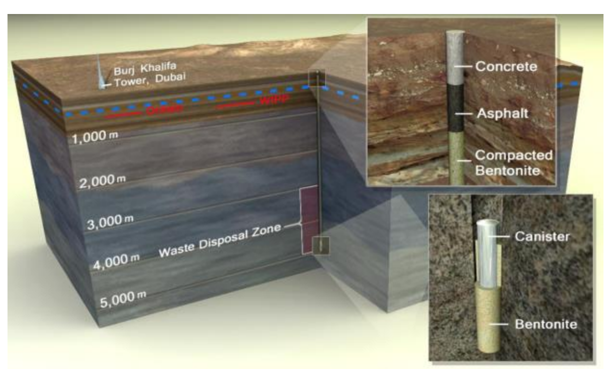

Figure 1. General concept of deep borehole disposal[2].

II.B Potential Advantages

Because the proposed disposal zone in a deep borehole disposal concept is significantly deeper than that of a mined geological disposal, waste isolation from the biosphere and ground water systems could be enhanced by several factors (Figure 2).

- The greater depth of emplacement
- The low permeability of the host rock at depth, as well as longer distances to the surface, which would result in very long travel times
- Deep fluids also resist vertical movement because they are density stratified.
- The reducing conditions (i.e., low concentrations of oxygen), which would result in greater geochemical isolation of the waste due to the lower solubility and mobility of some radionuclides, such as the actinides.

And also, multiple disposal sites could be located near nuclear power plants with suitable geologies, thus reducing the need to transport spent fuels.

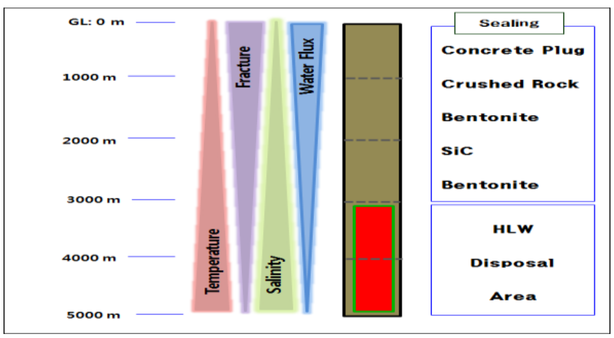

Figure 2. Deep borehole disposal environment.

III. KEY TECHNOLOGIES AND TECHNICAL CHALLENGES

III. A Drilling & Casing Technology

The completion of a deep borehole with a diameter of up to 0.6 m to a depth of 5,000 m has never been demonstrated. Drilling a deep borehole with large diameter in crystalline rock body would require the development of technologies well beyond the experience and practice of the oil industry. Deep boreholes in crystalline rock with smaller diameters drilled for scientific investigations have been in difficulties by complications related to spontaneous deformation of the borehole wall caused by anisotropic stress fields at depth.

The emplacement of casing at such depth in a potentially deformed borehole and sealing of the metal casing-rock interfaces are significant technological challenges. The potential for inadequate sealing between the casing and surrounding rock is a major concern for the deep borehole concept. An insufficient seal might be difficult to detect by well logging and could provide a hydraulic pathway to the surface.

III. B Packaging and Emplacement Technology

To reduce the size of the waste package and diameter of boreholes, dismantling commercial SF assemblies that are in dry storage at nuclear utility sites would be necessary. Repackaging SF involves extensive fuel handling that could lead to fuel rod breakage and potential radiation exposure to workers. The criticality and thermal implications of consolidating the SF rods also must be considered. Further, there are many types of SF of various sizes that might be problematic for consolidation.

During the emplacement of hundreds of waste packages, the possibility of some packages becoming stuck in a borehole must be considered. Normal operation for dealing with downhole obstacles, such as drilling through the obstructions or forcing the packages down the borehole, could not be used when emplacing highly radioactive waste packages.

III. C Sealing and Retrieval Technology

Effective, long-term performing sealing materials would have to be developed and demonstrated for sealing the deep bore hole above the emplaced waste. A number of approaches have been proposed, such as backfilling with materials like concrete and bentonite or taking advantage of the heat produced by the waste to encapsulate waste packages in melted rock. However these approaches have not been subjected to in situ demonstration, underground testing.

Retrieving waste after it has been emplaced and sealed in a deep borehole would present significant technical and safety challenges. Current normal mined geological disposal concept would require that a retrieval option be maintained after emplacement of waste. That requirement would be difficult to meet in deep borehole concept for permanent disposal of spent fuels or high level wastes.

III. D Site Characterization and PA/SA

In feasibility analyses of deep borehole disposal, the assumptions are that less site characterization would be needed at great depth because conditions would be more homogeneous and that potentially advantageous conditions such as a reducing environment, low permeability, highly saline, and density-stratified groundwater would be found everywhere. However, deeply buried basement rock can have considerable variability in chemical and physical properties, and there are too few well-characterized scientific deep boreholes to make these generalizations. The characterization of deep, heterogeneous crustal rocks will require the development of new geophysical techniques that can map rock properties tens of meters away from the borehole, particularly fracture zones that could channelize flow.

The environment of the disposal zone in the deep bore hole of 5000 m depth is also quite different from that of mined geological disposal zone of 500 m depth. This environment must be considered in developing the performance assessment technology of the component of the disposal system like disposal packages, engineered barriers. And scenarios and FEPs for safety assessment of the disposal system should be developed with this environment.

IV. ANALYSES OF KEY FACTORS FOR BOREHOLES SPACING

In deep borehole concept, the distance between boreholes is very important in determining the disposal efficiency. So, the distance between boreholes for HLW should be optimized. The key factors to set the disposal hole spacing are thermal effect between boreholes and verticality of borehole.

IV.A Thermal Effect

In deep borehole disposal system, boreholes should have spacing not to thermally affect another borehole. So minimum spacing of the boreholes at the depth of 5 km, disposal zone, should be more than 50 m.

And, in the waste emplacement procedure of deep borehole disposal system, bridge plugs will be constructed to support the weight of canister strings. One of the issues related to the bridge plug is the maximum temperature for commercially available bridge plugs and the temperature increases from the radioactive waste. Several standard designs for bridge plugs in the disposal zone are rated up to 400 ºF (204 ºC)[3]

Figure 3 shows the temperature related to the time and distance from the borehole for PWR spent fuel assembly for the array of multi boreholes. Figure 4 shows the temperature at the depth of 5 km in the case of 50 meter distance between boreholes.

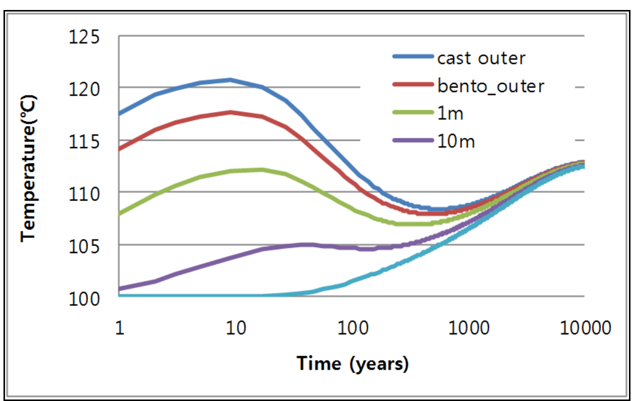

Figure 3. Temperature as a function of time and distance from boreholes.

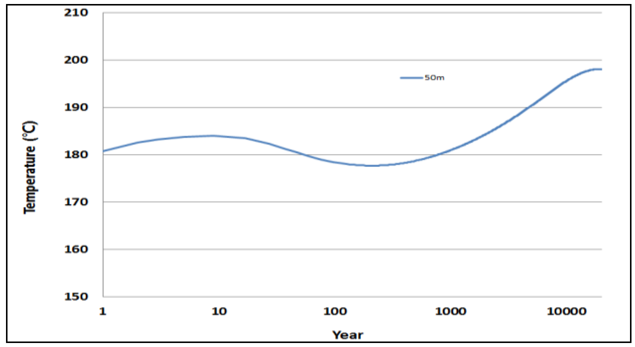

Figure 4. Temperature of 5 km depth of borehole (Distance between boreholes :50 m).

As shown in the figure 3 and 4, the spacing of waste disposal holes at sites with multiple boreholes can meet thermal management requirements for disposal.

IV.B Verticality of Borehole

Drilling of multiple boreholes in an array must preclude the possibility of intercepting another borehole in which waste has already been emplaced. Deviation of the borehole from its designed trajectory must be controlled such that the distance between any two boreholes is greater than 50 m at a bottom depth of 5 km.

The requirement that the minimum distance between storage intervals of separate holes should be 50 m implies that directional drilling will be necessary to control or correct deviation[3]. There are several ways to accomplish this with standard technology. Verticality can now be controlled accurately with liquid mud systems using vertical drilling systems.

Table 1 shows departures for different average deviation for 5 km borehole [4].

TABLE 1 Departures for different average inclinations for 5 km borehole

Average deviation (deg)	Departure (m)	Average deviation (deg)	Departure (m)
0.5	45	2.5	220
1.0	90	3.0	165
1.5	135	3.5	310
2.0	180	4.0	350

IV.C Disposal Area Analyses with the Borehole Spacing

With consideration of key factors for borehole spacing, the distance between deep boreholes can be set to 150 m. This distance comes from the average deviation of 0.5 degree and the minimum spacing of the boreholes at the depth of 5 km.

From this result, disposal area of a deep borehole disposal system is calculated approximately and compared with that of a mined geological disposal system in Korea [5]. As shown in the table, the disposal area can be reduced from 4.1 km^2 of DGD to 2.25 km^2 of DBD.

Table 2. Disposal area comparison between DGD & DBD

Direct disposal (total spent fuels : PWR 20,000 tHM, 45,000 Ass.)			
Deep Geological Disposal (DGD)		Deep Borehole Disposal (DBD)	
Length of D.T.	250 m	No. of DB	112
No. of D.T. in a pannel	54 개	Array	11 x 11
No. of Pannel	6	spacing	150 m
Disposal Area (km^2)	**4.1**	**D. Area (km^2)**	**2.25** 1.5 x 1.5 (km)

V. CONCLUSIONS

Even though a mined geological disposal system is considered as the safest method to isolate the spent fuels or HLW from the human environment at present time, if these high-level radioactive wastes can be disposed of in deeper and more stable rock formation than mined geological disposal depth, it has several advantages. Therefore, as an alternative disposal concept of mined geological disposal concept, deep borehole disposal technology is under consideration in number of countries in terms of its outstanding safety and cost effectiveness.

In this paper, the general concept and key technologies for deep borehole disposal of spent fuels or HLW, as an alternative method to the mined geological disposal method, were reviewed. After then an analysis on the distance between boreholes for the disposal of HLW was carried out. Based on the results, a disposal area was calculated approximately and compared with that of mined geological disposal. These results will be used as an input for the analyses of applicability for DBD in Korea.

REFERENCES

1. NIREX, A Review of the Deep Borehole Disposal Concept for Radioactive Waste, Nirex report no. N/108, Oxfordshire, UK, 2004.
2. Patrick V. Brady, Bill W. Arnold, Geoff A. Freeze, Peter N. Swift, Stephen J. Bauer, Joseph L. Kanney, Robert P. Rechard, Joshua S. Stein., Deep Borehole Disposal of High-Level Radioactive Waste, SAND2009-4401, SNL, Albuquerque, NM, 2009
3. Bill W. Arnold, Patrick V. Brady, Stephen J. Bauer, Courtney Herrick, Stephen Pye, and John Finger, Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste, SAND2011-6749, Sandia National Laboratories, Albuquerque, NM. 2011.
4. John Beswick, STATUS OF TECHNOLOGY FOR DEEP BOREHOLE DISPOSAL, EPS International Contract No NP 01185 April 2008
5. Lee, J.Y., Cho, D., Choi, H., Choi, J., Concept of a Korean reference disposal system for spent fuels. J. Nucl. Sci. Technol. 44 (12), 2007.