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Key Technologies Analyses to Develop a Deep Borehole Disposal Concept for HLW

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1. Introduction

A deep geological disposal system, the disposal depth is about 500 m below ground, is considered as the safest method to isolate the spent fuels(SF) or high-level radioactive waste(HLW) 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 these high-level radioactive wastes can be disposed of in deeper and more stable rock formation than 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 for deep borehole disposal of spent fuels or high level radioactive wastes which has been developed by some countries according to the rapid advance in the development of drilling technology, as an alternative method to the deep geological disposal method, was reviewed. And the key technologies and challenges in development of this disposal method with the nuclear environment were analyzed.

2. Concept of Deep Borehole Disposal

2.1 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].

Recently it has been mentioned as an alternative to disposing of SNF and HLW in a deep geological disposal concept. In 2012, the Blue Ribbon Commission on America's Nuclear Future recommended further research and development to help resolve some of the uncertainties associated with deep borehole disposal.5 The BRC particularly emphasized that deep borehole disposal might be considered for certain forms of waste that have essentially no potential for reuse.

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[2].

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 (Figure 1.)

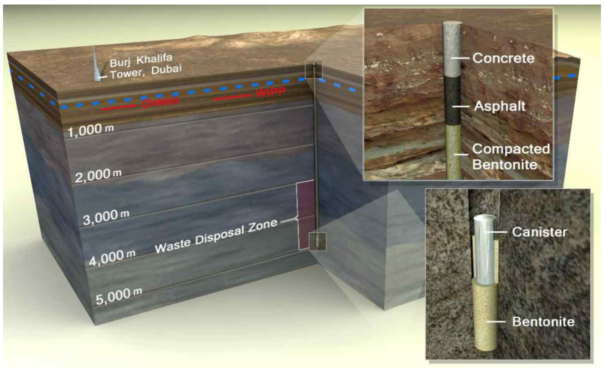

Figure 1. General concept of deep borehole sisposal [2]

2.2 Potential advantages

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

- 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.

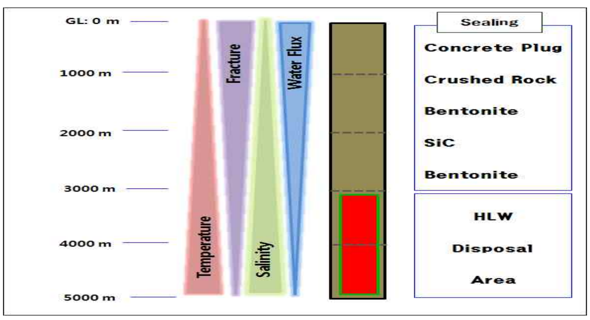

Figure 2. Deep borehole disposal environment.

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

3. Key Technologies and Technical Challenges

3.1 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.

3.2 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.

3.3 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 deep 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.

3.4 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 deep 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.

4. Concluding Remarks

In this paper, the general concept of deep borehole disposal for spent fuels or high level radioactive wastes which has been developed by some countries according to the rapid advance in the development of borehole drilling technology, as an alternative method to the deep geological disposal method, was reviewed. And the key technologies, such as drilling technology of large diameter borehole, packaging and emplacement technology, sealing technology and performance/safety analyses technologies, and their challenges in development of deep borehole disposal system were analyzed.

REFERENCES

[1] NIREX, A Review of the Deep Borehole Disposal Concept for Radioactive Waset, Nirex report no. N/108, Oxfordshire, UK, 2004.

[2] Bill W. Arnold, Patrick V. Brady, Stephen Pye, Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste, SAND2011-6749, Sandia National Laboratories, Albuquerque, NM. 2011.