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Reviews of the In-situ Demonstration Test of the Engineered Barrier System in Many Countries

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1. Introduction

The deep geologic disposal of HLW (High level radioactive waste) has been researched in many nations as one of the reliable options to protect human life from the fatal threat of HLW. The engineering goal of deep geologic disposal is the establishment of solid engineering barriers against the dispersion of radionuclide into a natural barrier such as rock for more thousands or even millions of years.

Therefore, many nations considering the deep geologic disposal of HLW are now planning or executing in-situ demonstration experiments on their regional EBS (engineering barrier system) at their deep underground research facilities. The main purpose of the in-situ EBS test is the experimental confirmation of its performance, and the prediction of its long-term evolution through the modeling of EBS based on the experimental data. Additionally, the engineering feasibility for the construction of an engineering barrier system can also be checked through full scale construction of an in-situ test.

KAERI is currently preparing an in-situ test at a large 1/3 scale, called IN-DEBS (In-situ Demonstration of EBS) at KURT (KAERI Underground Research Tunnel) for the generic EBS suggested in A-KRS (Advanced KAERI Reference System), which was developed to treat the HLW from pyroprocessing. As the first step for the design of IN-DEBS, the foreign in-situ demonstrations of EBS were reviewed in this paper.

The demonstration projects, which were completed or are still being executed in some countries such as Sweden, France, Finland, Canada, Belgium, Switzerland, Spain, and Japan, were surveyed and summarized. In particular, hardware constitutions such as the heating element or compact bentonite, and the experimental procedures, have focused more on reviews than on experimental results in this survey, since their hardware information is very important for the design of the IN-DEBS.

2. Foreign EBS In-situ Demonstrations

One of the oldest demonstration projects was the BCE (Buffer/Container experiment, Nov., 1991 through May, 1994) project performed by AECL at the Bonnet URL (Underground Research Laboratory) in Canada [1]. The Bonnet project was a real-scale experiment simulating an in-floor borehole emplacement. The next older one was the TBT (Temperature buffer test, Mar., 2003 ~ Oct., 2009) project, which was executed by both Andra in France and SKB in Sweden to understand and simulate the THM behavior of a bentonite buffer material [2]. The above two projects are already completed after a 3–7 year heating test, but the actual project periods took nearly 10 years considering their preparation time (2–3 years) and dismantling time (1–2 years).

Figure 1. Illustration of TBT structure in Aspo URL

The FEBEX (Full-scale Engineered Barrier Experiment) project performed by ENRESA of Spain at the Nagra site in Switzerland was an international cooperative project, which was started in Feb., 1997 and ended in 2007. However, the FEBEX facility is still on suspended state for another experiment instead of its dismantling [3].

HE-E (Heating & Engineered Barrier experiment, June, 2011 to the present) is a rather young project installed at the Mont-Terri Clay URL in Switzerland [4]. In addition, the PRACLAY (PReliminAry demonstration test for CLAY disposal of HLW, 2011 to the present) is also a young on-going project, which is based on a boom clay medium, and thus does not have an artificial bentonite buffer, unlike other demonstrations [5]. The last one is the HORONOBE project in Japan, which is still in the planning status, but its detailed design was completed, and it is ready for a field installation [6].

3. Discussion

The above-mentioned demonstrations are almost real-scale tests except for the HE-E at Mont Terri, which was at a 1/2 scale. However, the IN-DEBS under planning by KAERI is at the 1/3 scale. The EBS dimensions for various projects are summarized in Table 1. The directions of the boreholes were equally mixed with horizontal and vertical types. In addition, the underground media were also granite or sedimentary rock equally, as shown in Table 1. The borehole in IN-DEBS was planned to be excavated horizontally in granite rock. IN-DBES will be mainly focused on the monitoring and modeling of THM (thermo-hydro-mechanical) behavior of a bentonite buffer rather than the engineering feasibility test since it is not at the real scale.

Table 1. Comparison of EBS dimensions in worldwide field demonstrations.

Project	Scale/ Direction	Borehole (buffer) (m)	Heater (m)	Rock Bed
Äspö-TBT	Full / Ver.	D1.8 H8.0	D0.6 H 3.0 x 2	Hard rock
Äspö-LOT	1:4 / Ver.	D0.3 H4.0	D0.1 H 4.7	Hard rock
*Mont Terri-HE-E	1:2 / Hor.	D1.3 L10	D0.22 H 4.0 x 2	Sediment
*Hades-PRACLAY	Full / Hor.	D1.9(2.5) L30		Boom Clay
NAGRA-FEBEX	Full / Hor.	D2.3 L17	D0.9 L 4.5	Granite
*Horonobe	Full / Ver.	D2.4 H 4.2	D0.82 H 1.73	Sediment
Bonnet-BCE	Full / Ver	D1.24 H 5.0	D0.64 H 2.2	Granite
IN-DEBS	**1/3 / Hor.**	**D0.8 L 3.0**	**D0.4 H 1.4**	**Granite**

The borehole is filled with a bentonite buffer and heating canister in most of the projects. The characteristics of the heating canisters used in the projects are summarized in Table 2. The heating canisters were mainly constituted by inserting a slightly smaller tube wound by a heating line helically. In the case of the PRACLAY test, a heating rod was installed additionally at the centerline of the heating tube as a spare unit, with sand filled in the tube as a heat transfer medium. The shell material of the heating canisters in most of the projects was carbon steel. As exceptions, the Äspö LOT test used a copper tube [7], and the old BCE test used an aluminum pipe. Copper coating on carbon steel is being considered in the IN-DEBS project as a part of a feasibility test of disposal canister manufacturing.

Table 2. Comparison of heating canister size, capacity, shell material, and operation temperature in field demonstrations worldwide.

Project	size	Capacity	Shell Material	Temperature (°C)
Äspö-TBT	D0.6 H 3.0 x 2	0.98 x 3	Carbon steel	CP 1.0-2.0 kW
Äspö-LOT	D0.1 H 4.7	2.0 kW	Cu pipe	CP 850 W
*Mont Terri-HE-E	D0.22 H 4.0 x 2	1.2 kW x 2	Stainless	CT 140
*Hades-PRACLAY	D1.9(2.5) L30		Concrete	CT 80
NAGRA-FEBEX	D0.9 L 4.5	4.3 kW	Carbon steel	CT 100
*Horonobe	D0.82 H 1.73		Carbon steel	Max. 100
Bonnet-BCE	D0.64 H 2.2	5 kW x 3	Aluminum	CT 85 (Max.175)
IN-DEBS	**D0.4 H 1.3**		**Copper**	**CT 80**

4. Summary

In this paper, the in-situ demonstrations of an EBS being performed or set to start were reviewed as a preliminary action before the design of IN-DBES at KURT. The borehole dimension, heating canister capacity, heating mode and maximum temperature, kind of buffer, and its arrangement, gap filling material, water supply system, etc. were surveyed for previous demonstrations. Consequently, it is hoped that through this study the key design factors for the IN-DEBS will be determined to be suitable for the KURT underground environment.

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