Validation Tests for Thermal-Hydro-Mechanical Behaviors in the Engineered Barrier System of a HLW Repository -Experiences and Plans

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1. Introduction

The concept of a Korean high level waste (HLW) repository is based upon a multi barrier system composed of engineered barriers and the surrounding plutonic rock. The repository is constructed in a bed rock of several hundred meters in depth below the ground surface, and its engineered barrier system (EBS) consists of waste forms, disposal containers, and buffer/backfill. A reference disposal system was developed in 2002 by Korea Atomic Energy Research Institute (KAERI) [1].

The engineering performance of a HLW repository is dependent, to a large extent, upon the characteristics of the EBS, especially its thermal-hydro-mechanical (T-H-M) processes that may occur by the coupling of the influences of the heat generated by radioactive decay, of the ground water flowing in from the surrounding rock, and of the swelling pressure exerted by bentonitic buffer. Therefore, understanding the T-H-M processes in the engineered barrier system is one of major issues in the performance assessment of a HLW repository.

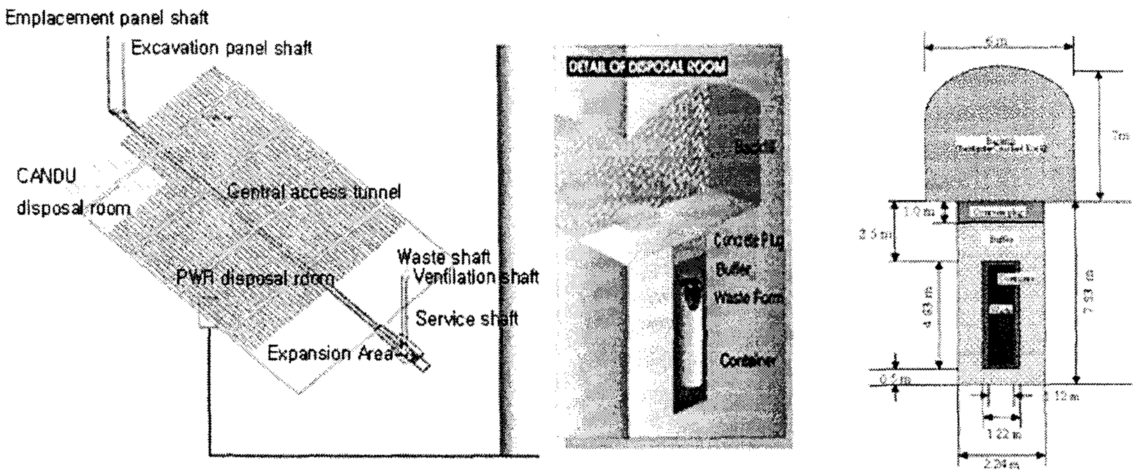
In this connection, the KAERI planed two stages of validation tests to investigate T-H-M behaviors in the engineered barrier system (EBS) of the reference disposal system: an engineering-scale test and then a full scale of "in-situ" test. This paper presents experiences in the engineering-scale test and further plans to be carried out in the 4th step (2007 ~ 2012) of R&D programs, at KAERI underground research tunnel (KURT) which was constructed at a mountainous area of the KAERI in Daejeon.

2. Reference Disposal System

A reference disposal system [2] developed by KAERI in the year 2002 is as shown in Figure 1. The reference disposal system includes the disposal area, the serve shaft complex, and the ventilation exhaust shaft complex. The disposal area in which CANDU wastes are emplaced separately from the

PWR wastes consists of 8 disposal panels. Based on 40m emplacement tunnel spacing, each panel for PWR consists normally of 42 emplacement tunnels. The CANDU panel, located at the lower left, consists of 38 emplacement tunnels. Each emplacement tunnel is 250 m long. In each emplacement tunnel the borehole spacing is allowed to be 6m for PWR and 3m for CANDU, to ensure neither the maximum container surface temperature nor the maximum buffer temperature of 100 ℃.

The Engineered Barrier System (EBS) in the reference disposal system includes wastes, disposal containers, buffer/backfill, and a concrete plug. The HLWs are encapsulated in disposal containers, which are deposited into boreholes on the floor of the emplacement rooms. The gap between the container and the wall of a borehole is then filled with a buffer material and the inside space of the emplacement rooms with a backfill material. In the Figure 1(b) is specified the dimension of the components of the EBS.



(a) (b)

Figure 1. Schematic picture of a reference disposal system developed in 2002.

3. Engineering-scale Test (KENTEX)

The KAERI Engineering-scale T-H-M Experiment for Engineered Barrier System (KENTEX) was designed to be a third scale of the reference disposal system. In order to simulate the disposal conditions in the reference disposal system, it includes five major components: a heating system, a confining cylinder, a hydration tank, bentonite blocks, and sensors and instruments. The heating system was fabricated to simulate the heat generated from a high level waste (e.g., PWR or CANDU spent fuel) and then released through a disposal container. The confining cylinder plays a role of the wall of a borehole excavated in the host rock. The hydration tank is for the supply of ground water flowing in around the borehole. The bentonite blocks were prepared to have the same specification as those to be used for the buffer of the reference disposal system. And several kinds of sensors were installed to monitor the facility and measure the data of thermal-hydro-mechanical behaviors in the bentonite blocks. In the Figure 2 and Figure 3 are shown a picture of the "KENTEX" facility and the specification of bentonite blocks used for KENTEX test, respectively.

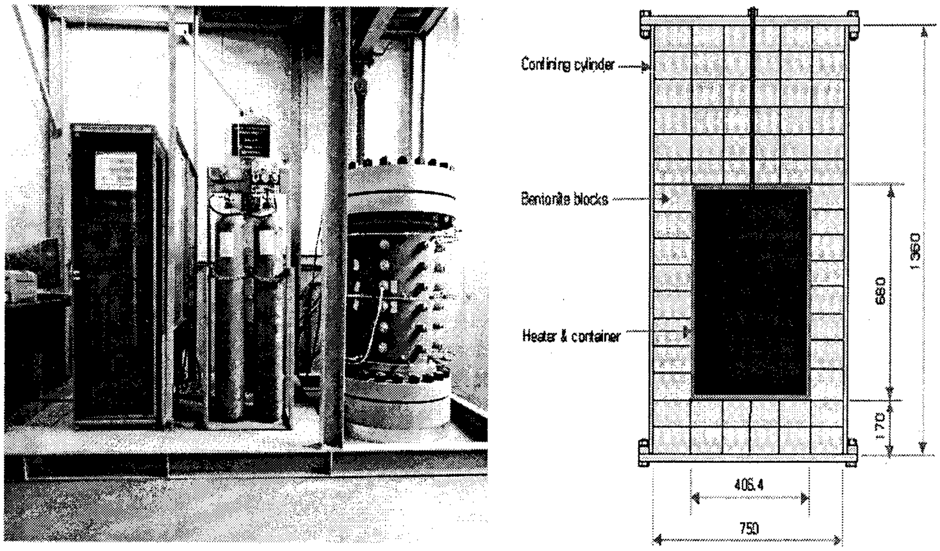
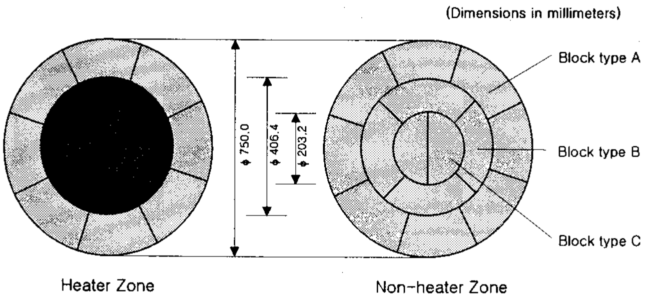


Figure 2. Picture and a schematic diagram of the "KENTEX" facility.



Block type	Radius mm		Angle in degrees α	Dimensions mm			Thickness mm	Number of blocks(*)
	R	r		a	b	c		
A	375.0	203.2	45	287.4	155.5	172.3	85	128
B	203.2	101.6	90	287.4	143.7	101.6	85	32
C	101.6		180	203.2	203.2	0	85	16

Figure 3. Specification of bentonite blocks used for KENTEX test.

The KENTEX facility, after its installation and test-run, is carried out in three stages: heating phase, cooling phase, and dismantling and sampling phase. In the heating phase, the T-H-M behaviors (that is, changes in the temperature, humidity or water content, and total pressure of the bentonite blocks) are measured when the temperature at the heater/ bentonite blocks interface is maintained to be 90

℃. In the cooling phase with the heater turned off, the temperature is recovered into an initial state and the opposite T-H-M phenomena to the heating phase are observed. The sampling of the bentonite blocks is conducted after dismantling the experimental setup at the end of the heating and cooling phase, to identify the water content and to evaluate the material law of water content which is determined from the results of the laboratory tests. In addition, works are also done to verify hypotheses and to characterize the KENTEX components.

The heating phase test started on May 31, 2005 and is now in operation. Figures 5 to 7 are the typical examples of experimental results measured up to date for temperature, humidity, and total pressure, respectively. The temperature data were measured without any problem except for the shutdown period of the facility for a short-time repairing. The temperatures at the same radius in a section was nearly similar in their values, which indicated axial symmetry in the temperature distribution. As shown in the figure, the temperature rapidly reached a quasi-stationary state within about 2 weeks and, after the period, went up slowly toward a steady value.

The total pressure, which was dominant to the swelling pressure by the bentonite blocks, increased as the degree of saturation of bentonite blocks increased due to the inflow of water from the hydration surface. The total pressures of the bentonite blocks near the hydration surface were higher than those at the heater side, which was expected to be attributed to higher swelling pressure of the bentonite blocks in contact with the early in-flowed water. The heater-side bentonite blocks revealed that there was negligible change of the total pressure at early stage of operation and, after about 70 days, its pressure increased with a progressive advance as the water was in-flowed from the hydration surface through the outer bentonite blocks. In this evolution of the total pressure, two peaks at the early stage is thought to be a system-intrinsic behavior, occurring by the pressurized water in-flowed fast through the crevices among the bentonite blocks on start of the test.

The humidity data were measured only by one of 7 sensors installed, six of which were suspected to be in some trouble owing to the damage or technical limitation of the sensor. This technical trouble in the humidity sensor has been reported abroad. It was observed in Figure 7 that the humidity measured by the working sensor increased sharply on applying the pressurized water and then decreased gradually. However, from 80 days, it started to increase again. This is expected to occur by the following drying-wetting process: First, sharply increasing humidity is related to the water in-flowed through the crevices among bentonite blocks. Second, heat transfer from heaters produces drying of the blocks, this causing the humidity to decrease. The higher the distance to the hydration surface, the longer the duration of the drying phase. Third, after some time with almost a steady humidity value, hydration reaches the dried zone and overcomes the drying process, increasing the humidity values. Wetting returns. The greater the distance to the hydration surface, the smaller the wetting rate. The humidity data obtained from only one working sensor is not sufficient to explain the hydro process in the bentonite blocks. For supporting this lack of humidity data, preparation work is in progress for the direct measurement of water content using core sampling (Figure 8).

Anther main objective of the KENTEX is to improve and validate the T-H-M model for the performance assessment of the reference disposal system. The modeling program has been set up in three steps: preliminary modeling during the design of the test, concurrent modeling during the operational stage of the test, and final modeling following the dismantling and sampling. The phase of the preliminary modeling was completed, and concurrent modeling is now being performed based on the experimental data obtained up to date from the test.

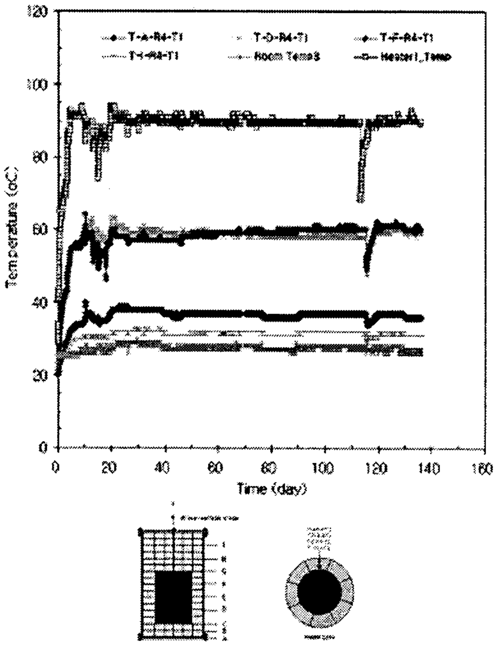


Figure 5 Temerature change as a function of time

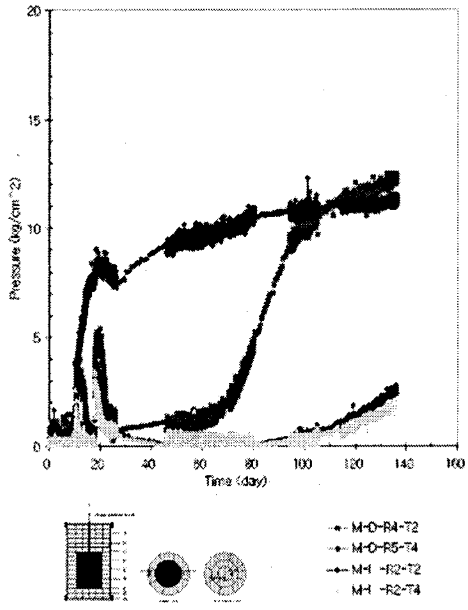


Figure 6 Total pressure change as a function of time

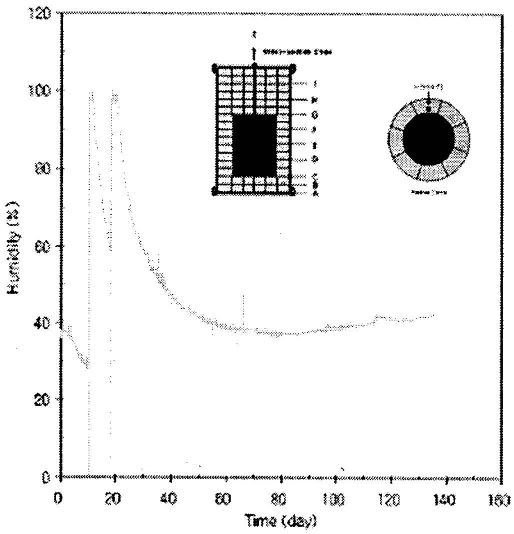


Figure 7 Humidity change as a function of time

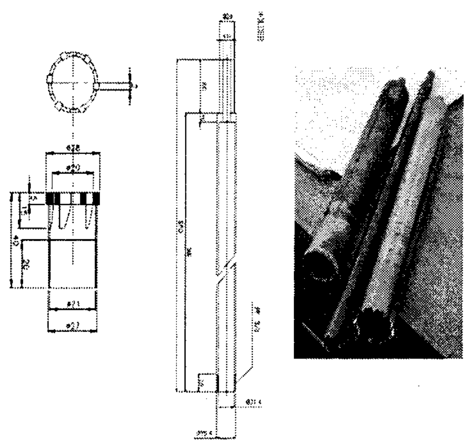


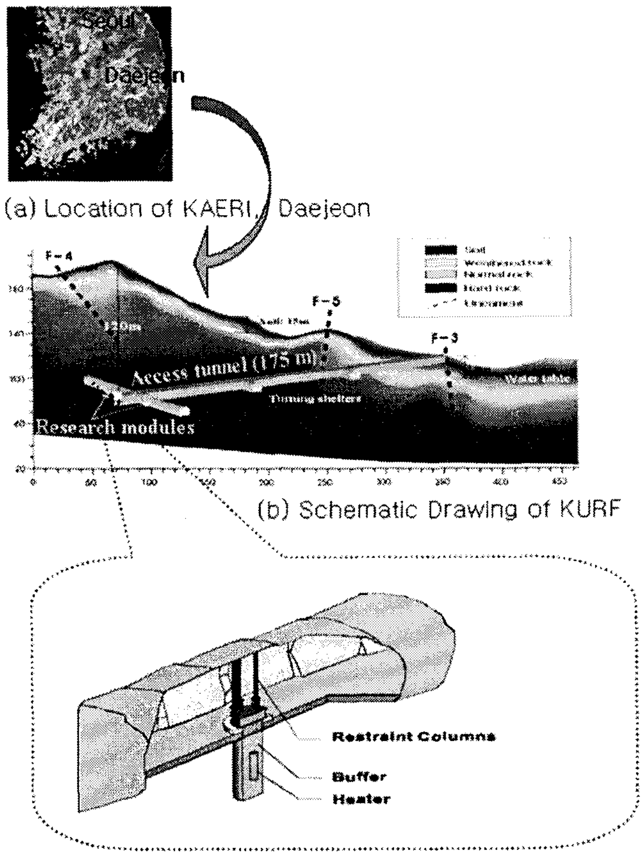
Figure 8 Core-drilling device for water content measurement in case of RH sensor failure.

4. "In-situ" Test (BUFINURF)

The "in-situ" test (thereafter called BUFINURF) intends to be carried out in the 4th step (2007 ~ 2011) of R&D programs, at KAERI underground research Tunnel (KURT) which was constructed at a mountainous area of the KAERI. in Daejeon.

The KURT, as shown in Figure 9 (b), consists of two main parts: the access tunnel and the research modules where major R&D will be carried out. The tunnel portal is at the end point of the site valley. The access tunnel is linear and 175 m in length. It has the slope of -10 % to obtain the maximum depth of research modules. The research modules are located each at the left and right sides of the access tunnel end. The lengths of the research modules are 27 m and 43 m, respectively. The access tunnel and research modules are all in horseshoe shape, and their height and width are both 6 m.

The test zone for the BUFINURF (Figure 9 (c)) is located at the dead side of the right research module. It has the dimension of 6 m x 10 m in square and 6 m in height. A test pit is constructed at an area in the test zone where the fractures cross it. All the electrical and electronic equipments for data acquisition and heater control as well as air conditioning systems are placed on a service area which is located in the corner side of the test zone.



(c) Schematic Drawing of BUFINURF Test Zone

Figure 9. KAERI Underground Research Tunnel.

The BUFINURF is an almost full scale of in-situ test facility to simulate the engineered barrier system of a Korean Reference HLW Disposal System (KRS) which will be proposed as a result of the 3rd step of R&D program. It includes five major components: a test pit, a heating system, bentonite blocks, sensors and instruments, and DAS (data acquisition system) and HCS (heater control system).

A test pit represents a borehole at which a spent fuel is emplaced in the KRS. It is located at the central area of the test zone, as shown in Figure 10. The dimension is 2.24 m in diameter and 5 m in height. In this pit, a heater and bentonite blocks are emplaced and then a restraint cover and restraint columns are finally installed in order to suppress the rise of bentonite blocks due to their swelling.

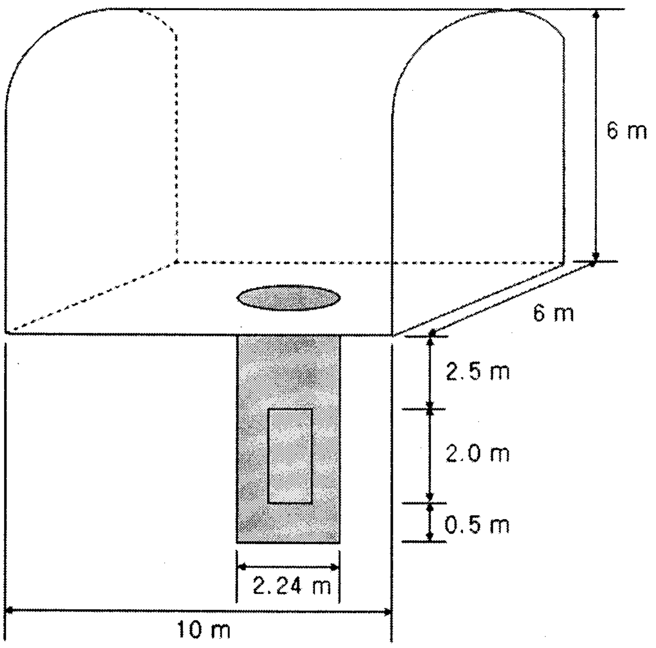


Figure 10 Layout of the test zone and pit

The BUFIINURF aims at investigating the T-H-M behaviors in the EBS under "in-situ" condition close to a realistic repository, making validation of computer codes for the T-H-M performance assessment of the EBS, and demonstrating the engineering feasibility for the fabrication and emplacement of bentonite blocks as the buffer of repository.

The program is divided into four major phases:

- Test zone characterization
- Excavation of a test pit
- Fabrication of test components and installation
- T-H-M test and modeling

Figure 11 represents the time schedule of the BUFIINURF which will be carried out in the 4th step of R&D programs.

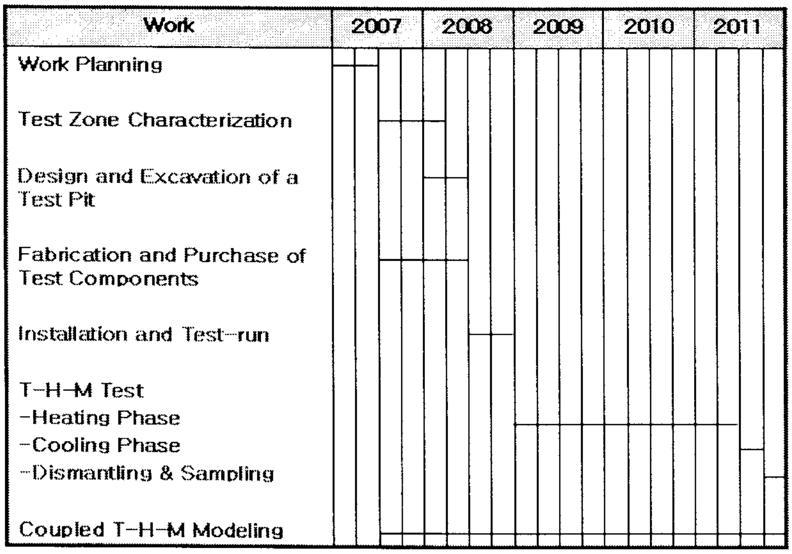


Figure 11 Time schedule of the BUFINURF

5. Conclusions

The KAERI developed a reference disposal system in 2002, and then planned two stages of validation tests to investigate T-H-M behaviors in the engineered barrier system (EBS) of the reference disposal system: an engineering-scale test (KENTEX) and a nearly full-scale of "in-situ" test (BUFINURF). This paper presented experiences in the installation and operation of the KENTEX as well as the results obtained up to date from the experiment and numerical modeling. For the BUFINURF, which will be carried out in the 4th step (2007 ~ 2012) of R&D programs to investigate the T-H-M behaviors in the EBS under "in-situ" condition close to a realistic repository, the following works were introduced: test zone characterization, excavation of a test pit, fabrication of test components and their installation, and T-H-M test and modeling.

Acknowledgement

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▒ References ▒

1. AECL, "Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste," AECL-10711, Atomic Energy of Canada Limited Report, (1994).