Long-term Performance of Engineered Barrier Systems (PEBS) - An International EURATOM Project on the Study and Testing of Engineered Barriers for the Final Disposal of HAW Using PEBS as an Example – 13299

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ABSTRACT

The main aim of the PEBS project is to evaluate the sealing and barrier performance of the EBS over time, through development of a comprehensive approach involving experiments, model development, and consideration of the potential impacts on long-term safety functions. The experiments and models cover the full range of conditions, from initial emplacement of wastes (high heat generation and EBS resaturation) through to later stage establishment of near steady-state conditions, i.e. full resaturation and thermal equilibrium with the host rock. These aspects will be integrated in a manner that will lead to greater certainty and thus greater confidence regarding the development from the initial transient state of the EBS to its long-term state, which provides the required isolation of the wastes.

The work proposed within the project builds on existing knowledge and experience generated during recent years and supported by ongoing national and EC research programs. The project aims to provide a more complete description of the THM and THMC (thermo-hydro-mechanical-chemical) evolution of the EBS system, a more quantitative basis for relating the evolutionary behavior to the safety functions of the system, and a further clarification of the significance of residual uncertainties for long-term performance assessment. The importance of uncertainties arising from potential disagreement between the process models and the laboratory and in-situ experiments to be performed within PEBS, and their implications for an extrapolation of the results, will be reviewed, with particular emphasis on possible impacts on safety functions.

In addition to the scientific-technical aims, the consortium will disseminate the basic findings to the broad scientific community within the EU, China and Japan, use expertise gained for public information purposes, and promote knowledge and technology transfer through training.

INTRODUCTION

The evolution of the engineered barrier system (EBS) of geological repositories for radioactive waste has been the subject of many national and international research programs during the last decade. The emphasis of the research activities was on the elaboration of a detailed understanding of the complex THMC processes that are expected to develop in the early post-closure period in the near field. From the perspective of radiological long-term safety, an in-depth understanding of these coupled processes is of great significance, because the evolution of the EBS during the early post-closure phase may have a non-negligible impact on the radiological safety functions at the time when the canisters breach. Unexpected process interactions during the resaturation phase (heat pulse, gas generation, non-uniform water uptake from the host rock) could affect the homogeneity of the safety-relevant parameters used in the assessment of EBS (e.g. swelling pressure, hydraulic conductivity, diffusivity).

In previous EU-supported research projects, such as FEBEX, ESDRED and NF-PRO, remarkable advances were made in broadening the scientific understanding of THMC-related processes in the near field around waste canisters. The experimental data bases were extended on the laboratory and field scales, and numerical simulation tools developed. Less successful, however, was the attempt to use this in-depth process understanding for constraining the conceptual and parametric uncertainties in the context of long-term safety assessment. It was recognized that performance assessment (PA)-related uncertainties could not be reduced significantly with the newly developed THM-C codes, due to a lack of confidence in their predictive capabilities on time scales that are relevant for PA. To gain confidence in the modeling of coupled processes in the canister near field, a general need was stated for:

- Systematic and traceable validation procedures, which would make it possible to qualify the predictive capability of the THMC codes with quantitative performance indicators such as post-test evaluations (e.g. evaluations of blind predictions, dismantling of experiments and post-test analyses).
- Adaptations in the PA methodologies, which would allow the transfer of improved THMC-related process understanding to the corresponding safety function indicators for the EBS.

An integrated approach is required to set up the scientific validation procedures in a context that is relevant for PA purposes. Thus, validation experiments are to be conducted on a real scale (in-situ experiments, large scale mock-up experiments) to avoid scaling effects. Furthermore, the assessed THMC processes, the experimental conditions and the experimental times should be specified according to the needs of PA.

DETAILED DEFINITION OF PROJECT CONTENT AND PREPARATION WORK

Under its EURATOM call for proposals in 2007, the European Commission had defined specific work for testing and modeling THMC processes in backfill and in the near field of containers with heat-generating waste as eligible for funding. A strong consortium was formed, headed by BGR, which submitted a funding application and a detailed proposal of the necessary work in 2008. This application for funding was not successful for a number of reasons. In view of the assessment of the application, however, EURATOM recommended submitting a new proposal in 2009. This was successful.

Project Structure

After the completion of contractual negotiations, project work started in 2010. A consortium of 17 partners from 7 countries was formed to meet the project requirements mentioned. Since many partners already knew each other from the earlier EURATOM projects, they were quickly able to agree on a division of tasks that would meet requirements, into 5 technical and 2 organizational work packages. Moreover, they were able to include some tests pending from NF-

PRO. The technical work comprised the definition of relevant scenarios as a basis for all further testing and modeling (WP-1, responsibility assigned to SKB), and the verification of modeling results based on the findings from the Underground Research Lab and from the technical laboratories (WP-4, responsibility assigned to NAGRA). ENRESA is the overall coordinator for work carried out underground at Mont Terri in Switzerland and at the technical laboratories (WP-2). GRS assumes the general management of the necessary modeling calculations for the various interlinked processes (THMC processes, thermal, hydraulic, mechanical and chemical processes, WP-3). The participation of BRIUG as the Chinese partner institute was secured for the PEBS consortium based on an existing MoU between the People's Republic of China and Germany. BRIUG is responsible for the exchange of experiences between China and Europe, contributing findings from its own mock-up tests to the EU research community (WP-B). BGR as the project coordinator has also taken on the tasks project management (WP-6) and dissemination of findings (WP-5).

The full results of the PEBS project as well as findings from other projects related to engineered barriers will be presented at the PEBS Final Conference to be held in February 2014 (BGR, Germany).

International Links

What international links exist between the work carried out under this project, and what results are the partners and the European Commission expecting? Both BRIUG (China) and JAEA (Japan) are our partners for global information sharing. BRIUG is an important partner for scientific exchange, for instance, with partners from Scandinavia, firstly because of its work in crystalline rock (Beishan site), and secondly because of its studies of bentonite as backfill. In 2011, the exchange between PEBS and Japan was greatly affected by the aftermath of the Fukushima event.

At the European level, exchange is planned particularly between Spain, Switzerland, Sweden and Germany. In-situ tests were carried out predominantly at Mont Terri in Switzerland (HE-E - heater experiment, operated by NAGRA) and laboratory experiments were performed in Spain (by CIEMAT). These involve both tests running over several years and entailing considerable use of equipment, and tests using small test pieces that are observed over several months.
The necessary models for the various interlinked processes (THMC processes, thermal, hydraulic, mechanical and chemical processes) were defined by GRS (Germany), and the modeling calculations performed by GRS and the Spanish partners CIMNE-Barcelona and the University of La Coruna.

In the following paragraphs, an example of typical laboratory work is presented in more detail.

EXPERIMENTS

NAGRA Heater Experiment at the Mont Terri Underground Research Laboratory

The heater test [1] at Mont Terri (HE-E) involves observation of THMC processes with two different backfills (bentonite and a bentonite-sand mixture) using more than 250 sensors (see Fig. 1). A 1:2 scale mock-up on blocks of bentonite was placed in a borehole; this was filled completely with backfill up to the wall of the surrounding host rock, sealed and heated to 140 °C at pre-defined intervals.

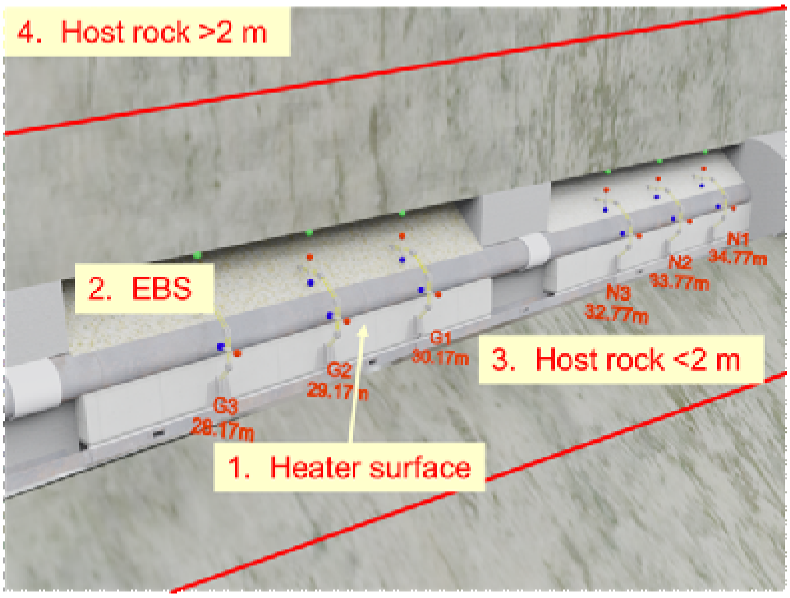

Fig. 1. Selection of humidity and temperature sensors

Humidity and temperature data are collected at all four levels. The focus here is on storing these very extensive data. They can be accessed by the partners online via the internet and in real time. For example, the measured temperature at location “12” (Fig. 2) shows the increase in temperature of the host rock (black) and bentonite (middle and near center, green and red) from June 2011 until July 2012. The left (front) section of the tunnel is backfilled with a sand-bentonite mixture, the right (rear) section is backfilled with pure bentonite (see Fig. 1). The dotted line indicates the temperatures in the sand-bentonite mixture, and the full line the temperatures in the pure bentonite (Fig. 2)).

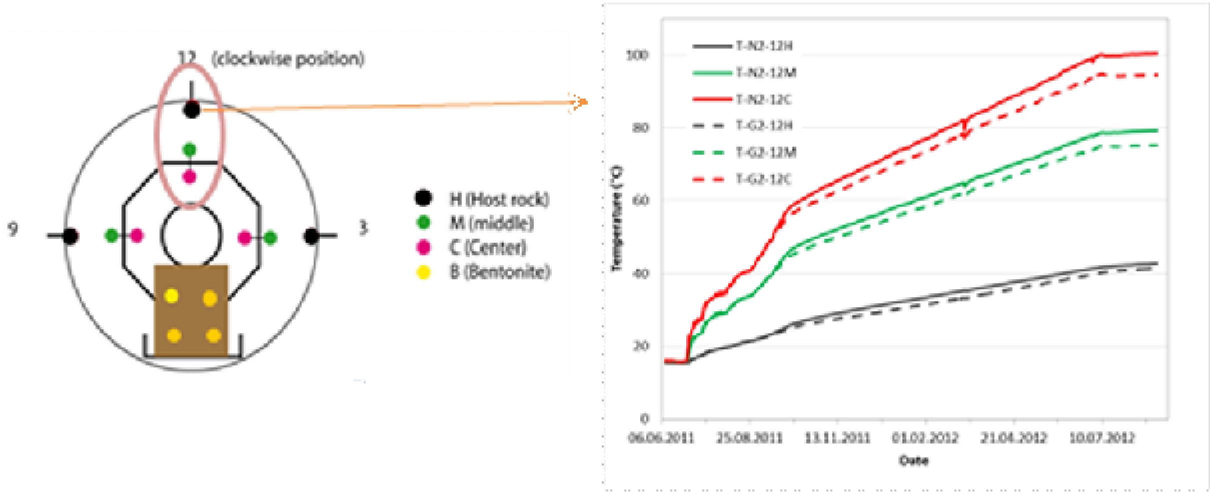

Fig. 2. Left side: Clockface arrangement of sensors. Right side: Comparison of temperatures of sand/bentonite (dotted lines) and bentonite (full lines) at twelve o'clock position

Seismic and geo-electrical monitoring of the heater experiment by BGR

A few months before the start of the heater experiment at Mont Terri in June 2011, BGR started seismic and geo-electrical monitoring of the Opalinus Clay (OPA, host rock of the heater experiment) at three different distances (10, 20 and 30 cm) from the interface between the sand-bentonite mixture and the OPA (SB-OPA). Fig 3 indicates the curve progressions of velocities and amplitudes from the monitoring period from March until winter 2011.

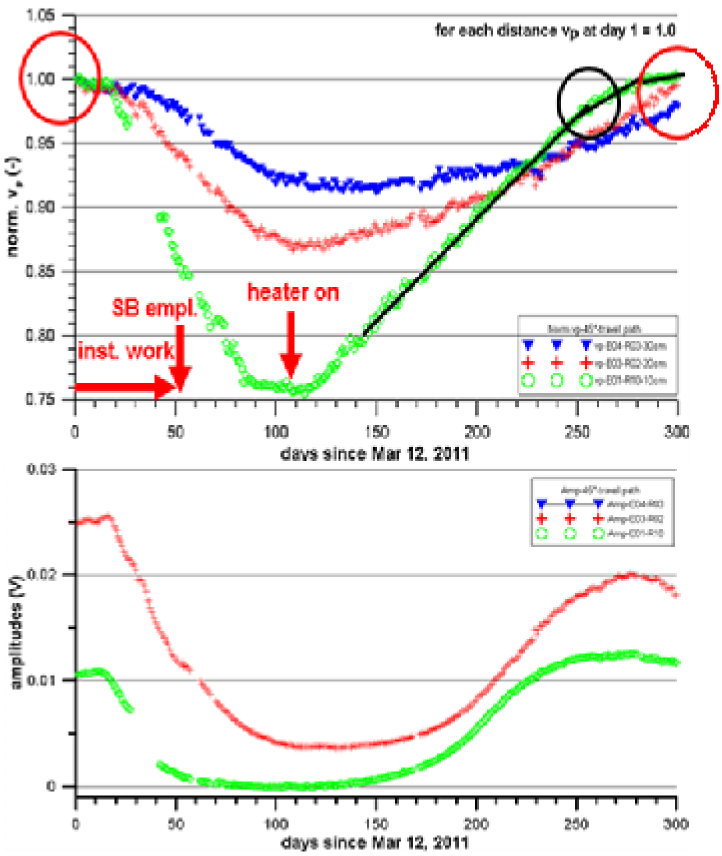

Fig. 3. Both X-axis: Operation days of experiment in, Y-axis: Seismic parameters: velocities of p-waves (top) and amplitudes (bottom) at distances of 10 (green), 20 (red) and 30 cm (blue) from SB-OPA interface

The devices were installed in three boreholes 86 mm in diameter and 1 m long. Two boreholes were set up with emitters and receivers, one borehole with receivers only. The complete system includes five emitters and ten receivers. One emitter and two receivers are placed in the front section of the experiment (embedded in the sand-bentonite mixture). The other devices are installed in the boreholes within the host rock.

NAGRA and BGR Engineered Barrier Experiment at the Mont Terri Underground Research Laboratory

For the already finished Engineered Barrier Experiment at Mont Terri URL (EB experiment, about eight years ago), BGR had installed some micro-seismic sensors that are still in operation. In line with the work schedule, the dismantling of the backfill in the tunnel for the EB experiment (see Fig. 4) started some weeks ago. The dismantling of the concrete seal started quite slowly, but is now making progress. The monitoring program of dismantling (unloading of host rock) complements the geo-electrical and micro-seismic program of the heater experiment (loading of host rock).

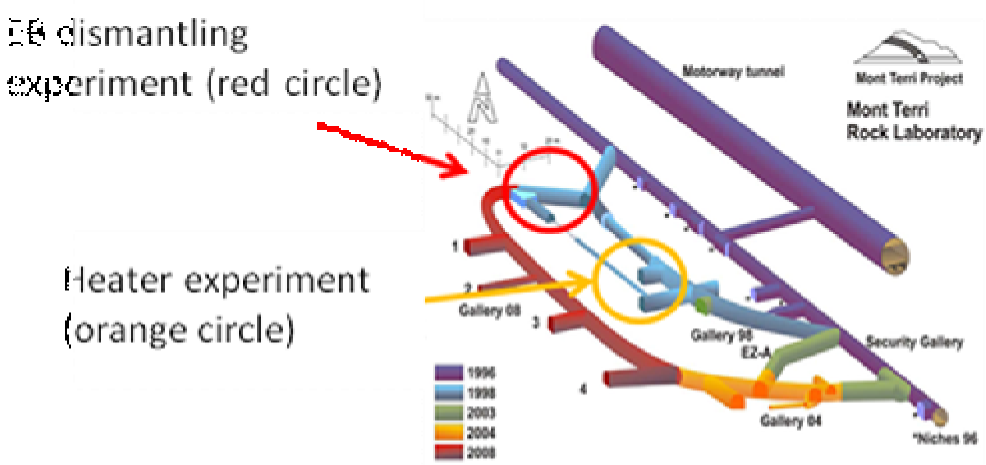

Fig. 4. Galleries of the Mont Terri URL, showing positions of the PEBS-EB dismantling experiment and heater experiment

Laboratory Tests

Laboratory Tests were performed by CIEMAT [2] and the Autonomous University of Madrid (UAM).

The related PEBS tests included the following individual laboratory tests:

- Infiltration tests with EB FEBEX pellets (see Fig. 5), which included online measurement of swelling pressure, water intake and hydraulic conductivity
- Upon dismantling: determination of dry density, water content, basal spacings, porosity distribution, specific surface area
- Permeability tests on samples from EB in situ
- Infiltration tests with the sand-bentonite mixture from the heater experiment
- Long-term infiltration tests with measurement of hydraulic conductivity at low hydraulic gradients: FEBEX and MX-80
- Laboratory THM tests in cells
    - 40-cm long cells (FEBEX)
    - 50-cm long cells (HE-E)
- FEBEX mock-up

These experiments aim to provide support for the modeling of the EB in-situ test, to check the long-term hydro-mechanical behavior of a pellet barrier, and compare the HM behavior of pellets and compacted bentonite. The properties of the FEBEX bentonite pellets are:

– Initial dry density ρ_d 1.36 g/cm^3 and water content *w*=4.7%
– Bentonite height: 5 / 9 cm, diameter: 10 / 7 cm
– De-ionized water injected at 0.15 / 2 bar

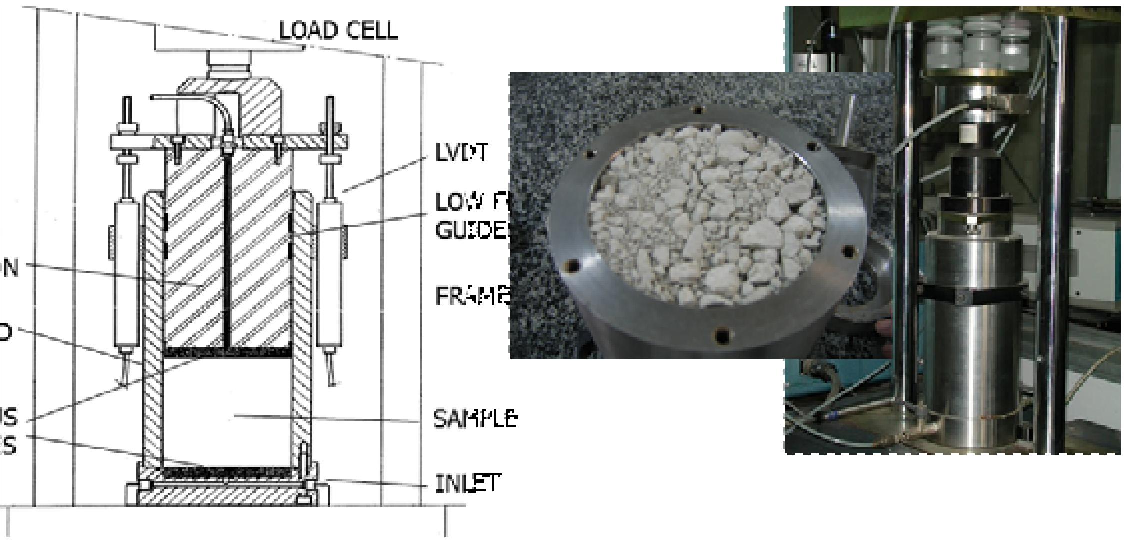

Fig. 5. Infiltration tests with FEBEX pellets, technical concept

MODELING

Particularly GRS (Germany), CIMNE (Spain) and the University of La Coruna (Spain) are currently developing concepts (for cases) and models for long-term predictions. The aim here is above all the ability to make reliable and safe predictions, thus also creating a stronger basis of trust in the dialog with all stakeholders.

Objectives of Modeling and Selection of Cases for Modeling

The various THMC processes of concern will be assessed regarding their implications for different time and spatial scales. This includes identification of significant processes in the resaturation phase and beyond, and development or modification of available formulations to incorporate phenomena and processes deemed to be relevant for long-term predictions. It also involves assessment of coupled numerical analysis for long-term evolution of the engineered barrier system in the repository, with an evaluation of the model uncertainty and its implications for long-term predictions, and the compilation and evaluation of the usefulness of natural analogs for providing support, testing and validation of long-term predictions produced by the current

THMC models.

Decisions on modeling cases are made based on these criteria:

- Cases will be selected on the basis that processes exhibiting uncertainties are the most suitable candidates for extrapolation.
- Substantial data to improve the above process descriptions need to be provided.
- The modeling cases to be considered should be of general interest (e.g. of interest to more than one PEBS partner).

Table I shows the cases considered including: (i) variants and (ii) input cases.

Table I. Modeling Cases for Long-Term Extrapolation

Case no.	Description of case, conditions
1.	Water uptake in the buffer (T < 100 °C)
1.1	Isothermal saturation (extrapolation to sealing performance)
1.2	Long-term FEBEX in situ with constant T at 100°C
1.3	Long-term extrapolation using a realistic thermal source term
2.	Thermal evolution of the buffer (T > 100 °C)
2.1	Long-term extrapolation using a real thermal source term
3.	Hydro-mechanical evolution of the buffer
3.1	Uncertainty in HM evolution of buffer (pellets)
3.2	Impact of increased temperature or other factors linked to heat on the HM properties
3.3	Hydromechanical impact of corrosion processes (feedback from Case 4)
4.	Geochemical evolution, especially at interfaces (canister-bentonite and bentonite-concrete)
4.1	Study of the canister/bentonite interfaces
4.2	Study of the concrete/bentonite interfaces
4.3	Long-term evolution in the granite

DISSEMINATION OF RESULTS

The project includes exploitation and dissemination of the results on national, European and international levels, using the internet, specific communication with stakeholders, as well as training and education activities.

- A website has been set up to provide information to the consortium partners on matters such as objectives and content of the project.
- The website also includes links to all unclassified deliverables for download.

- The website also provides information about the latest developments (e.g. events, specific links, changes).
- A workshop has been organized specifically and exclusively for the regulatory authorities, to provide information on subjects such as the scenarios studied. Towards the end of the project a second workshop, exclusively proposed for the regulators, will be offered to discuss subject matters such as different cases (scenarios) in relation to the THMC processes, their preconditions and results.
- To foster communication and provide up-to-date information about the progress of the project, a newsletter is published (so far a total of 6 newsletters have been published).
- Moreover, a training event and workshop were held to present modern laboratory methods for analyzing bentonites.
- To complement these events, two field trips have been organized to show modern industrial-scale mining and production methods for various qualities of bentonite.

CONCLUSIONS

The PEBS project integrates European, Chinese and Japanese expertise to answer questions related to the disposal of heat-generating nuclear waste. The focus is on the characteristics of the buffer material under the influence of the canister and the host rock. Laboratory and underground in-situ tests are performed to generate various data to provide input for model calculations relating to short-, mid- and long-term processes, to help answer pressing questions concerning policy, science and the affected general public.

An interpretation of current and future results will be published in the final report. It will also be presented at the PEBS final conference.

REFERENCES

1. Irina Gaus, Oliver Czaikowski, Benoit Garitte, Uli Kuhlmann, Juan Carlos Mayor , Kristof Schuster, José-Luis Garcià Siñeriz, Thomas Trick, Klaus Wieczorek (2012). HE-E heater experiment at Mont Terri URL, EBS behavior immediately after repository closure in a clay host rock, ANDRA 5th International Meeting on Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, October 22-24, 2012, Montpellier, France.

2. M.V. Villar, P.L. Martín, I. Bárcena, J.L. García-Siñeriz, R. Gómez-Espina, A. Lloret (2012). Long-term experimental evidences of saturation of compacted bentonite under repository conditions, Engineering Geology 148-150 (2012), ELSEVIER.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme (FP7/2007-2011) under grant agreement number°249681.