THE BELGIAN DEMONSTRATION PROGRAMME FOR THE DISPOSAL OF HIGH-LEVEL AND LONG-LIVED RADIOACTIVE WASTE

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European Underground Research Infrastructure for Disposal of Nuclear Waste in Clay Environment

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ABSTRACT

The EIG EURIDICE is responsible for performing large-scale tests, technical demonstrations and experiments so as to assess the feasibility of a final disposal of vitrified radioactive waste in deep clay layers. This programme is part of the Belgian Research and Development programme managed by ONDRAF/NIRAS. The research infrastructure includes the Underground Research Facilities HADES (URF HADES) in the Boom Clay geological formation and surface facilities. The achievements of the demonstration programme are the demonstration of the construction of shafts and galleries at industrial scale, the characterisation of the hydro-mechanical response of the host rock, and the "OPHELIE mock-up" a large scale hydration test under thermal load of pre-fabricated bentonite blocks. The future works will consist mainly in the realisation of the “PRACLAY experiments” including a large scale heater test. The results of this test will constitute an important input for the Safety and Feasibility Cases 1 (SFC-1, 2013) and 2 (SFC-2, 2020).

1. Introduction

The Boom Clay layer, a tertiary plastic clay, was chosen as a study case for the geological disposal of high-level and long-lived radioactive waste. In Belgium, the R&D programme on this topic was initiated at the Belgian nuclear research centre (SCK•CEN) in 1974. The URF HADES was constructed at a depth of 223m for R&D purposes. The first construction phase started in 1980 and since the URF HADES has been expanded several times. Figure 1 shows the construction history. The primary purpose is conducting various in-situ experiments to study the feasibility of HLW disposal in the Boom Clay layer. HADES is currently managed by the Economic Interest Grouping EURIDICE, a joint venture between SCK•CEN and NIRAS/ONDRAF.

Since previous research yielded promising results, the R&D programme is more and more tending towards large scale and demonstration tests. The realisation of the demonstration programme “the PRACLAY project” is the main mission of EURIDICE. The PRACLAY project includes:

- The extension of **URF HADES** consisting in the construction of a second shaft, a connecting gallery between the second shaft and the existing laboratory, an experimental gallery perpendicular to the connecting gallery and the ventilation building leading to the demonstration of the industrial process for constructing the underground disposal infrastructure;
- The ***in-situ PRACLAY experiments*** aiming to demonstrate that Boom Clay is suitable, in terms of performance of the disposal system, to undergo the thermal load induced by the vitrified waste;
- The ***surface PRACLAY experiments*** to demonstrate the technical construction and placement of the engineered barriers, as well as researching the interaction of these with the host rock.

2. The extension of the URF HADES

The demonstration that we can construct a repository infrastructure, using an industrial technique, while controlling the disturbances at an acceptable level in terms of performance of the disposal system, is now well advanced with the experience gained with the construction of the HADES extension. The extension consists in the realisation of a second shaft (1997-1999) and the construction of a connecting gallery (2001-2002).

The hydro-mechanical behaviour of Boom Clay around the excavation and its evolution with time is now well characterised and the high sealing capacities of Boom Clay have been proven [1].

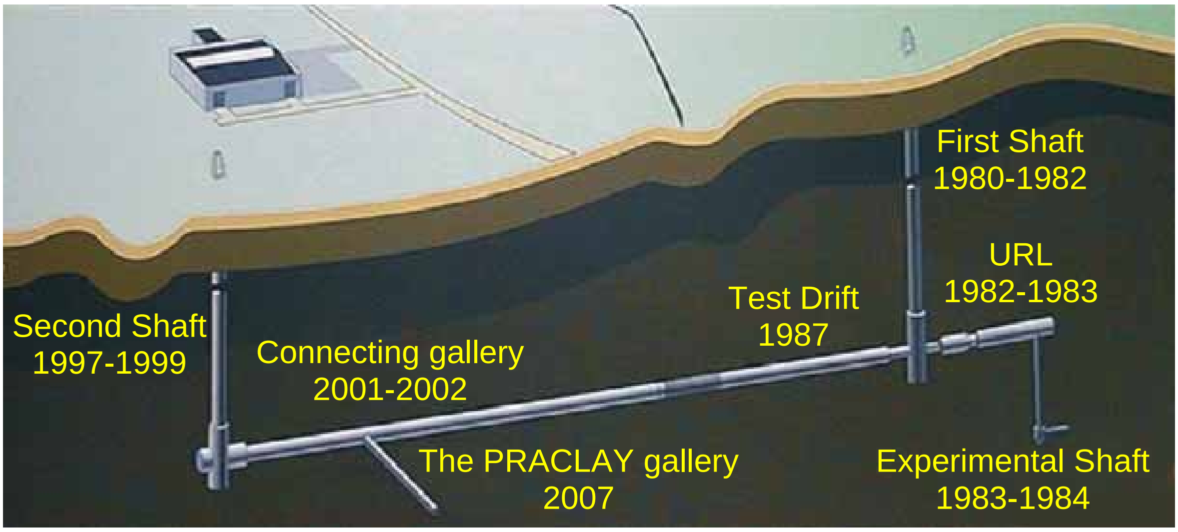

Fig 1. The construction history of HADES

2.1 The second shaft

The second shaft has an effective diameter of 3 m and widens out to an effective diameter of 5m at low level. The ground freezing technique was used to sink the shaft through the water-bearing sands. In this section the definitive lining consists of prefabricated concrete rings with an 8-mm thick outer steel casing. The gap between the preliminary lining and the definitive lining was filled with asphalt. The part in Boom Clay was realised without freezing [2]. In this section the definitive lining consists of poured concrete in direct contact with the Boom Clay.

The feasibility of digging in unfrozen Boom Clay from the top (-190 m) to the middle (250 m) of the Boom Clay layer has been demonstrated. During the excavation of the second shaft, the mechanical behaviour of the rock was quite homogeneous, irrespective of the depth. During the construction of the starting chambers, significant slip planes were observed. Their symmetry around the shaft axis indicated that the fractures were induced by the excavation work. Active support installed immediately after the excavation considerably reduced the opening of the fractures and the risk of detachment of blocks.

2.2 The connecting gallery

The construction of the connecting gallery by an industrial technique has been an important milestone in the demonstration programme for the disposal of high-level radioactive waste. Four main requirements were set to limit the extent of the zone disturbed by excavation: maximising the construction rate (minimum 2 meters a day), minimising the overexcavation, minimising the length of the unsupported zone, and choosing a stiff lining.

The construction of the connecting gallery required the prior construction of a mounting chamber, namely of a chamber that would be large enough to enable the tunnelling machine and the associated equipment to be assembled. The tunnelling machine (see figure 2) was composed of three main parts: a road header to excavate the rock, a 2.3 metre long shield to protect the workers and control the convergence, and a bird-wing erector to install the lining segments. The excavated diameter by the road-header was slightly smaller than that of the shield. It was therefore the shield that imposed the final, smooth excavation profile. The lining technique was the wedge block technique, an expandable-lining technique thought to be suitable for lining galleries in the Boom Clay at about 223 m depth while minimising convergence [3].

Fig 2**.** The tunnelling machine used for the construction of the connecting gallery

2.3 The EC CLIPEX project

The excavation of the connecting gallery from the second shaft towards the existing Test Drift provided a unique and original opportunity to monitor the hydro-mechanical parameters of Boom Clay ahead of an excavation front. The EC CLIPEX instrumentation programme (Clay Instrumentation Programme for the Extension of an Underground Research Laboratory) enabled the instantaneous hydro-mechanical response of the clay during excavation of the connecting gallery to be characterised with high reliability [4]. The host rock has been instrumented both in the zone to be excavated and around it.

The numerical simulations using Mohr-Coulomb and Modified Cam-Clay models gave reliable blind predictions in terms of displacement and pressure on the lining thus allowing an optimum design of the tunnel machine. One important finding of the project is the unpredicted observation of hydraulic perturbation deep inside the formation. Current model developments are made to explain the variation of pore water pressure in the far-field (about 60m from the excavated front) considering the delayed effects through the viscosity of the Clay skeleton.

2.4 The SELFRAC project

The creation of an excavation disturbed or damaged zone is expected for all geologic formations. Macro- and micro-fracturing, and in general a rearrangement of rock structures, will occur in this zone resulting in significant increases of permeability to flow. Implications of the higher permeability of the damaged zone and its time evolution under various repository scenarios need to be evaluated as part of waste repository safety assessment. Within the EC SELFRAC project, various issues, such as processes creating fractures in the excavation damaged zone, the degree of permeability increases, potential for sealing or healing (with permeability reduction) in the zone were investigated [5].

Laboratory tests were conducted to characterise the sealing process by monitoring the evolution of the flow properties along a fracture. Results of these tests show that for Boom Clay sealing occurs very quickly after the flooding of the fracture. During the sealing process the permeability decreases up to value close to the permeability of intact Boom Clay (about 10^{-12} m/s).

The in situ experiments in Boom Clay have allowed to follow the evolution with time of the hydro-mechanical behaviour of Boom Clay around a gallery excavated by industrial technique and to quantify the effect of the sealing processes on the hydraulic conductivity evolution. The radial extent of the fracture zone around the gallery was about 1 m. However a slight increase of the hydraulic conductivity was measured up to 6-8 m into the host-rock. It was shown that two years after the excavation the interconnected fractures zone was reduced from 1m to less than 60 cm around the gallery. The hydraulic conductivity in the sealed zone and beyond in the host-rock remains lower than 2.5 10^{-11}m/s. We can therefore conclude that the repository system would not be adversely affected by the excavation process of the repository infrastructure.

3. The in situ PRACLAY experiments

The main objective of the PRACLAY experiments is to verify that Boom Clay is suitable, in terms of performance of the disposal system, to undergo the thermal load induced by the vitrified waste. The test will focus on the study of the combined effect of the EDZ (Excavation Damaged Zone) and the thermal impact at repository scale. The influence of the temperature increase on the EDZ evolution as well as the possible additional damage created by the thermal load will be studied. The impact of the THMC (Thermo-Hydro-Mechanical and Chemical) response on the transport properties of the Boom Clay will also be assessed. A long term (more than 10 years) large scale heater test would be representative of the most penalizing conditions that could be encountered in the real disposal. The results of the test will constitute an important input for the SFC (Safety and Feasibility Case) -1, 2013 and -2, 2020.

The design of the PRACLAY experiments is now fixed based on numerical simulations. The design phase included the definition of the geometry, the boundary conditions and the instrumentation programme. We developed the PRACLAY in-situ experiments to be design-independent to overcome possible future changes in the reference disposal design. The PRACLAY experiments will be performed within “The PRACLAY Gallery”, which will be 45 m long with an internal diameter of 1.9 m, lined with concrete segments and perpendicular to the connecting gallery. The heated length will be about 30 m. The PRACLAY in-situ experiments regroups a set of three tests (see figure 3):

- The gallery and crossing test
- The heater test
- The plug test

The excavation will be performed under the protection of a shield and using the wedge block system for the lining. The method has to allow an excavation rate (excavation + installation of the lining) of minimum 2m/day. At the end of the gallery a stop test will be carried out in order to assess the difficulty to restart the tunnelling machine after a stopping period of one week. The construction of the PRACLAY gallery requires a steel reinforcement ring at the crossing with the connecting gallery. According the design of the connecting gallery the maximum possible diameter for the opening in the lining of the connecting gallery is 2.55 m. Consequently, the nominal diameter of the extrados of the PRACLAY gallery has been fixed to 2.5 m taking into account the convergence. A diameter about 2.5 m corresponds to the range of diameters considered for the repository designs.

The results of the gallery and crossing test will give additional information for the optimisation of the tunnel excavation and will demonstrate the feasibility to construct a crossing between an access gallery and a disposal gallery.

The large scale heater test is considered as a generic issue for all repository design actually considered by ONDRAF/NIRAS since at a distance larger than a few metres from the waste, the influence of the specific design on the temperature profile is limited. It has to demonstrate that the damaged zone due to thermal load of the host rock remains acceptable in terms of long term performance of the repository. It will be important to verify that fracturing remains acceptable and that the decrease of effective stress due to the increase of pore water pressure will not lead to the liquefaction of Boom Clay. The impact of the chemical processes on the transport properties of the Boom Clay will also be investigated. It has been chosen for the PRACLAY In Situ Experiment, to use a heater system imposing a as constant as possible temperature of about 80°C at the extrados gallery wall. However a second heater working at constant flux will also be installed as a back up of the first heater in case of failure. This back-up heater can be retrieved during the PRACLAY Heater Test.

Plugs (within disposal galleries, between disposal and main galleries, between main galleries and shafts) are considered, at least as a conservative measure, in the overall repository design in order to e.g., limit interactions between various repository zones (compartimentalisation through cutting the hydraulic connection along the gallery lining and EDZ), increase the resilience of the repository to intrusion, and avoid gas migration. The “PRACLAY Plug Test” aims at demonstrating that it is possible to cut-off hydraulically the EDZ and the engineered barriers of the disposal galleries with a horizontal plug.

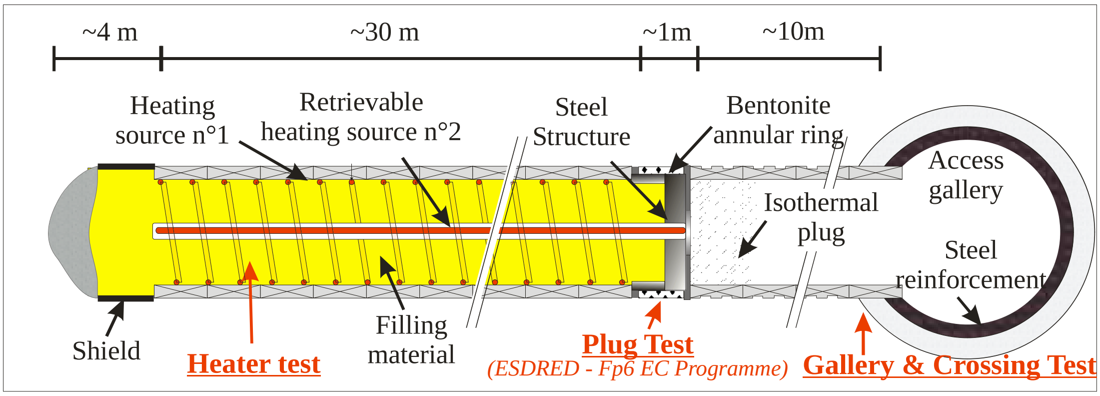

Fig 3. The PRACLAY experiments

The PRACLAY gallery will be constructed in 2007 so that the experiments can be installed in 2008. The start of the heating phase is planned in the first semester of 2009. The EC project TIMODAZ (Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks) has been introduced in the frame of the 6th Framework Programme and is now under contract negotiations. The project includes lab and field experiments, modelling and model validation through benchmarking. After such an independent validation, the codes will be applied to perform predictive simulations of the PRACLAY experiments. In total 8 countries are represented (BE, FR, CH, DE, NL, ES, CZ, UK).

3. The Surface PRACLAY Experiments

The PRACLAY Surface Experiments include the feasibility study of the construction and the handling of the engineered barriers. For these tests, it is currently understood that in situ conditions are not required, i.e., that the influence of, and the interactions with, the host formation do not condition the short term performances of the engineered barriers. Hence, it is not primordial to test these elements in situ. It was therefore decided to test them on surface which should enable better control of the experimental conditions and be more cost-effective.

3.1 The OPHELIE mock-up

The OPHELIE mock-up (see Figure 4) deals with the reference design valid in the middle of the 90s. It simulated a section of a waste disposal gallery, in order to prepare the in situ PRACLAY Experiment and to review several technical aspects of its design. The mock-up focused on the engineered barriers of the disposal system: the buffer material, a mixture of FoCa Clay (60 wt %), sand (35 wt %) and graphite (5 wt %), the metallic disposal tube and the hydration system. The mock-up also allowed a large-scale investigation of the THM behaviour of the buffer material as well as of its interactions with the other barriers.

Globally, regarding its thermo-hydro-mechanical properties, the buffer material fulfilled its role: after four years of hydration and heating, it kept a low permeability and a high thermal conductivity. Although it swelled and filled all the technological voids, the swelling pressure remained low and the swelling process was not homogeneous.

The OPHELIE mock-up highlighted the complexity to determine and to understand the main processes (THM, chemical, corrosion …) controlling the behaviour of the engineered barriers in a saturated environment at temperatures exceeding 100 °C [6]. Associated with the presence of chlorides observed in the buffer, these observations were at the origin of the decision taken by ONDRAF/NIRAS to re-examine in-depth the Belgian reference design for the disposal of vitrified HLW and to develop the concept of a "Supercontainer" [7].

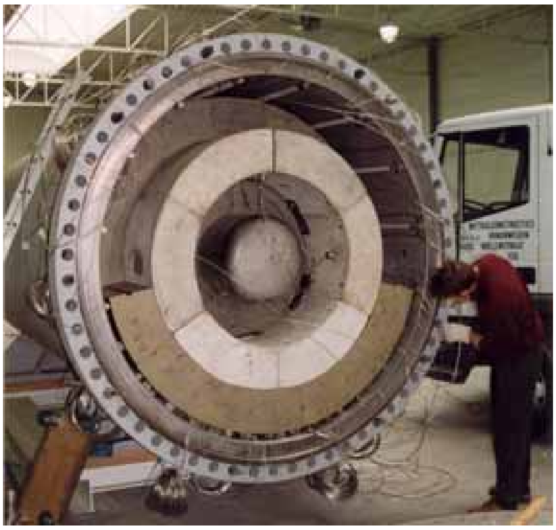

Fig 4. The OPHELIE mock-up

3.2 The demonstration of the “Supercontainer design”

ONDRAF/NIRAS selected “the Supercontainer design” as the new reference design. A more homogeneous cement-based material offers, amongst others, the advantage to create long-term chemical conditions much more favourable for the lifetime of the metallic barriers. Moreover, cement-based materials are well known because of the large number of applications and existing studies. The new reference design also considers a lower linear thermal power resulting in temperatures below 100 °C in the engineered barriers. Although some aspects related to feasibility and technological issues were already, implicitly, considered during this selection process, the technological feasibility to construct the engineered barriers system (EBS) and its different components remains, to a large extent, still to be demonstrated. This demonstration programme will start in 2007.

4 Conclusions

At this time, the study of the feasibility for Boom Clay is well advanced. The effect of a large scale thermal load on the behaviour of Boom Clay is an important key issue remaining to be studied. Indeed the impact of the thermal load generated by the waste is particularly important since it will significantly affect the temperature and the stress profiles on the whole thickness of Boom Clay in the short term after the disposal. Therefore the early transient THM perturbation might be the most severe impact that the repository system will undergo on a large spatial scale and in a relatively short period of time. In order to demonstrate that Boom Clay will behave as predicted under a thermal load a large scale heater test within "The PRACLAY experiments" is planned. The performance of a horizontal plug will be tested in the same experimental drift. The results of these large scale tests will be a milestone in the choice by the Belgian government of a disposal strategy for radioactive waste. Parallel to the in-situ PRACLAY experiments, the feasibility of the new reference design, the "Supercontainer" will be studied.

Acknowledgement

Some results presented in the paper were obtained in the frame of the CLIPEX and SELFRAC projects. These projects were co-funded by the European Commission within the fourth and the fifth framework programme, key action Nuclear Fission. This support is acknowledged.

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