EXTENSION OF THE UNDERGROUND RESEARCH FACILITY FOR REAL-SCALE DEMONSTRATION

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ABSTRACT

The research programme for disposal of High-Level radioactive Waste in Belgium (HLW) is reaching the demonstration stage. Designs are finalised for a large-scale demonstration of the current disposal concept. To this extent, the Economic Interest Grouping (EIG) EURIDICE, a joint venture between the Belgian Nuclear Research Centre SCK•CEN and the Belgian Waste Management Agency NIRAS/ONDRAF is managing the extension of the existing HADES underground research facility with a second shaft and connecting gallery to allow for the large-scale nature of the works. SCK•CEN started the construction of the existing facility 20 years ago, aiming at performing in situ research in the Boom Clay, a tertiary clay formation identified as a potential host rock for HLW disposal. The gallery construction in this clay allowed improving the excavation techniques in this type of rock, evolving from a feasibility test to a mechanised technique causing minimal damage to the surrounding host rock. The original freezing technique, adopted based on geotechnical characterisation of deep core samples taken from the surface, has been replaced by an excavation technique without prior ground conditioning. Also, the initially applied cast iron lining has been replaced by the more economical concrete segment lining. During its 20 years lifetime, the existing underground facility has seen many in situ investigations being performed, studying material properties, migration, (geo-)chemical interactions, geomechanical and hydraulic behaviour of clay and engineered backfill materials, in some cases at elevated temperatures. The unique nature of the HADES facility also raised the interest of external organisations. Sometimes we operated as a service provider, but usually joint projects have been set-up where the scientific and practical expertise of SCK•CEN complemented the experimental needs. The PRACLAY demonstration programme that is currently being developed aims at the construction and operation of a HLW disposal gallery, and contains a direct and an indirect demonstration. The direct demonstration consists of the feasibility of construction, operation and/or sealing of the underground infrastructure (linedgallery with backfill and disposal tube, gallery crossing with plugs,…) with industrial techniques that could also be applied in a real repository. The indirect demonstration refers to the validation of the models that describe the effects of these activities on the performance of the disposal site. The demonstration, planned to start within a few years, has required a second access shaft to cope with the large-scale underground works. The construction of the second shaft started in 1997 and has been finished in 1999. In addition to the shaft, a connecting gallery of almost 100 metres will be excavated in 2001 to locate the PRACLAY demonstration test in optimal conditions. Indeed, the current facility is well packed with experimental set-ups, so that a large-scale test would affect (and be affected) too much by the existing experiments. The PRACLAY test itself is scheduled to be installed in a purpose-built gallery in 2003, and will after an initial hydration consist of a 5-year heating period, followed by cooling and dismantling. During the test the performance of the engineered barriers of the actual disposal concept, and interactions between the different components of this concept will also be studied. As we want to gain a maximum of useful information for the future design of such structures in clay, the works being carried out during this extension should be representative. Through modelling, essential parameters such as excavation speed and lining support are determined. Extensive monitoring of the works will then validate or complement the current hypotheses on the response of the clay to the underground works. The extension further allows for other large-scale experiments in clay that are anticipated (spent fuel tests, alternative concepts,…). Considering the increased interest in clay as a disposal medium in several countries, the perspectives of this research can hardly be underestimated.
INTRODUCTION

The final disposal of High-Level radioactive Waste (HLW) is becoming the most challenging issue regarding the current and future applications of nuclear fission energy. The initial scientific and technical approach was based on the analysis of the safety and feasibility of the different concepts proposed. The Belgian research programme has always been concentrating on disposal in clay formations, as these are the only suitable host formations in Belgium. Based on an elaborate safety assessment methodology, a concept has been developed and adapted through the years, resulting in the current gallery network design. The safety of this concept is assessed by predictions based on modelling. Input data for these calculations are gathered mainly through laboratory and in situ tests (1) in the HADES underground research facility (URF), whose construction started in 1980 (2). During its 20 years lifetime, the existing URF has seen many in situ investigations being performed, studying material properties (such as corrosion), migration, (geo-)chemical interactions, geomechanical and hydraulic behaviour of clay and engineered backfill materials, in some cases at elevated temperatures. From small-scale tests, also some integrated tests at medium scale were performed to investigate interacting processes. The unique nature of the HADES underground research facility also raised the interest of external organisations. Sometimes we operated as a service provider (making the underground infrastructure available to our partners), but usually joint projects were set-up, in some cases financed by the European Commission, where the scientific and practical expertise of SCK•CEN complemented the experimental needs of the partner organisations.

When developing the HLW disposal concept into a real implementation plan, the actors involved at the Belgian level NIRAS/ONDRAF (Belgian Waste Agency) and SCK•CEN (Nuclear Research Centre) felt the need to get a closer insight in many technical and operational details. They have therefore joined forces in the Economic Interest Grouping (EIG) EURIDICE (founded in 1995 as EIG PRACLAY) to develop and manage a demonstration programme to gather this knowledge, in addition of validating scientific hypotheses and models, in an integrated test. The demonstration will be performed at real scale to simulate several aspects of the concept, and the main part will consist of a gallery that will be built and operated within conditions according to the conceptual design.

The intended demonstration involves large underground construction works (3), and for reasons of operational safety, the Belgian Mining Authorities required a second access shaft to the URF. Also the impact that such a demonstration would have on the surrounding clay host rock through the excavation, heating and water flow, indicated the need for an extension of the current facility. This would avoid that the current experimental set-ups would be disturbed, and it offers also a clear reference (initial) condition for the demonstration itself. It was finally decided to position the second shaft at some 100 m from the current URF, and to connect both structures after completion of the shaft by a new gallery, from which also the demonstration test would be installed (4). Figure 1 shows the final structure upon completion of the works, which is scheduled for end 2003.
Fig. 1. Underground infrastructure upon completion of the extension works in 2003; the bold lines represent instrumented boreholes to monitor the excavation of the connecting gallery.

**SINKING OF THE SECOND SHAFT**

The design of the shaft could take advantage of the experiences obtained during the construction and operation of the first shaft. It has a total depth of almost 230 m, of which the upper 180 m are located in water bearing sands. Therefore, ground freezing has been applied to condition the sandy aquifers, with 16 freezing pipes - arranged on a 7-m diameter circle around the future shaft - reaching a depth of 192 m to cover also the transition zone between sand and clay. When the freezing wall was closed and thick enough, excavation started with semi-mechanical means. After each excavation pass of some 2 m, a shotcrete layer of 20 cm thick secured the freeze wall. The excavation continued upon reaching the top of the clay layer, where a foundation has been poured to support the secondary (final) lining. This lining consists of prefabricated reinforced concrete rings with an outer steel casing of 8 mm thick. The 30-cm thick rings are 2.85 m high and are welded together to obtain an impermeable lining with a final internal diameter of 3 m. The gap between the two linings has finally been filled with melted asphalt to give additional protection to the watertight steel liner and to obtain a uniform horizontal pressure distribution on the secondary lining.

Considering the good mechanical behaviour of the clay during the excavation of the foundation, the contractor proposed excavating the unfrozen clay down to the bottom of the shaft (230 m)
with a preliminary support consisting of sliding ribs, followed by the final lining of cast-in-place concrete, from the bottom up to the foundation. At the bottom part of the shaft, two starting rooms have also been prepared to accommodate the construction of galleries. Only the North-sided room (oriented towards existing facilities) will be used in the immediate future for the construction of the connecting gallery. The shaft has further been equipped with the appropriate hoisting equipment, able to deal with the heavy loads that we expect to occur in anticipation of the future underground works (200 kN versus 8 kN of first shaft), and the works have been completed in November 1999 (5).

In addition to the monitoring of the construction itself (dimensional stability, convergence...), some observations have been made that give indications on the influence of the shaft construction on the surrounding clay. These observations are still going on. The main parameters are the total pressure exerted by the clay on the lining, discontinuities in the clay during excavation, and additional observations (geophysical and hydraulic).

At the time of shotcreting, seven total pressure cells were mounted on the clay – shotcrete interface. Since then, the pressure has only very slowly increased, which might indicate that large deformations, and consequently a significant decompression of the surrounding host rock, have occurred during excavation. Very significant were the observations of large slip surfaces (Fig. 2) made during the excavation of the starting chambers, which also led to the detachment of some blocks. The geometry of these planes, together with visible slickenslides, indicates a movement towards the centre of the shaft being excavated. A first analysis has indicated that the larger movements were caused by the lack of active support at the beginning of the excavation works of the starting rooms; only protective support for the miners was present, so convergence was not limited, and this was also aggravated by the low excavation rate. The installation of an active support in the last excavation phase considerably improved the behaviour of the rock.

Fig. 2. A slip plane observed during the excavation of the starting room
To get a better look on the influence on the host rock, a geophysical characterisation programme is performed. Given the difficult nature of clay with respect to geophysical methods – clay is characterised by large losses when seismic or electro-magnetic methods are applied, an micro-seismic method has been adapted to image possible damaged zones around the excavation by single-borehole and cross-borehole techniques. This is further complemented by hydraulic measurements through a multi-piezometer installed in the affected zone to monitor the evolution of the pore water pressures and of the hydraulic permeability.

EXCAVATION OF THE CONNECTING GALLERY

From the North-sided starting room, a connecting gallery with the existing facilities will be excavated. Since this gallery will give access to the large-scale demonstration experiment and to other set-ups, we want the clay host rock to be as undisturbed as possible. Based on our experience with the previous shaft and gallery excavations, we have specified a maximal over-excavation of five centimetres and a minimal excavation rate of two metres/day. This will require the application of a semi-mechanised excavation technique to have a better control of these parameters.

Based on an extensive list of specifications, including the detailed design of the connecting gallery, several offers have been obtained. The contract has been awarded begin 2001, so that the construction works will be performed in 2001.

Within the demonstration programme, the opportunity offered by the gallery excavation is being used to benchmark to the different models that describe the geomechanical behaviour of the Boom Clay, and to compare them with field measurements. The influence of gallery excavation on the host rock is an essential part of our knowledge. Stimulated by the advantageous geometry, we have set up, with international partners, an extensive research programme, called CLIPEX, incorporating field instrumentation, modelling and characterisation of the clay. The main objective of the CLIPEX programme is to obtain an accurate model of mechanised gallery excavation in deep clay formations. Although field data were available, they were up to now related to manual excavations, where parameters such as overexcavation and progress rate were not very well known in advance. Also several deformation parameters could only be partially determined (after the excavation had passed); the initial convergence (radial movement towards gallery axis before the excavation front has passed) remained therefore largely unknown, although it is an essential parameter in geotechnical models. We have therefore designed an instrumentation programme, with sensors installed in boreholes that originate from the existing Test Drift (6,7). The sensors will measure the deformations and pressure (water and total) variations caused by the excavation works in and around the future connecting gallery. Location and measuring range of the sensors have been determined based on the results of the first modelling. In addition, the same instrument types have been installed from the second shaft to monitor the start of the excavation and to compare the readings between both extremities. The bold lines in Fig. 1 represent the instrumented boreholes around the future connecting gallery. When all the details of the excavation technique will be known, a more sophisticated blind modelling will be performed. The results of this benchmarking exercise will then be compared between each other, and later also with the field measurements. A characterisation programme has also been included in CLIPEX to obtain more reliable input data for the mechanical
behaviour of the Boom Clay by means of dilatometer, (self-boring) pressuremeter, and hydrofrac in situ tests. A more accurate modelling will allow us to optimise the design and construction of deep underground gallery structures in terms of safety (operational and longer-term) and cost.

CONSTRUCTION OF THE DEMONSTRATION GALLERY

Another essential aspect in the demonstration is the interaction between main and disposal galleries. This aspect has to be investigated from the construction (design of crossing structure), up to the long-term behaviour after the disposal gallery has been filled and closed. A cost-effective design of the crossing structure requires a good knowledge of the external pressures that will develop on the structure. Also here, modelling will help in obtaining more accurate predictions. Due to its experimental nature, this structure will also be instrumented (mainly strains and stresses) to verify the design against its hypotheses. In addition to the external pressures, this structure will also be subject to forces from the disposal gallery; these forces are caused by the swelling of the backfill material, thermal expansion of the long tubes etc. The internal side of the central tube should remain accessible throughout the experiment time span – also in the real concept, such accessibility will be required to have convenient access to the waste forms during at least some decades for monitoring and - optional - retrievability purposes. All these phenomena make the design of the plug, which has to isolate the waste canisters and the backfill surrounding the disposal tube from the main gallery, quite challenging. Figure 3 shows the current design of the plug.

![Fig. 3. Plug design to connect disposal gallery to main (connecting) gallery](image)

After construction of the 30 m long gallery, the central disposal tube will be installed, together with the backfill material to fill the remaining space between the gallery lining and the central tube. After the installation of the plug has been finished, the hydration of the backfill material will start, followed by the heating, which will last for five years. We intend to obtain similar thermal conditions as in the real repository, both at the engineered barriers and in the clay. After this period and some cooling, a dismantling of the set-up will allow complementing the field measurements that will have been performed during all stages of the test itself.
The excavation and subsequent heating will significantly influence the surrounding clay. This is also the subject of a part of the instrumentation. On the other hand, we expect this influence to be limited, so that experimental set-up’s are still possible in other parts of the connecting gallery.

FUTURE PERSPECTIVES

The underground research facility and the current extension works have allowed us to become the expert for construction in deep plastic clay formations. This expertise is highly valued in other exploration works that are currently performed in clay formations, as we observe an increasing interest in geological disposal options in clay all over the world.

This extended infrastructure offers many opportunities for joint test programmes, especially at larger scale. The different models that have been developed over the years, together with the in situ testing experience, have resulted in a toolbox that is of help for prospective research teams. The new part of the Boom Clay formation that will be made accessible will further allow to implement the demonstration of alternative concepts, e.g. with a different source term (spent fuel) or where retrievability should be considered.

In addition to the scientific and technical results obtained at large-scale demonstration tests, its significance for the public (both specialised as general) perception of HLW disposal (and radwaste disposal in general) cannot be underestimated. It is now generally agreed that political decisions depend on societal acceptance, and this in turn requires a realistic perception and confidence in the solutions proposed by the scientific community.

CONCLUSION

With the extension of the current underground research facility, we are fulfilling the necessary condition to implement the demonstration programme. A large new part of clay host rock will be made accessible, without interacting with the existing experimental set-ups. The configuration of the second shaft and the connecting gallery also allow for further extending the URF later on if necessary.

The current demonstration test is a logical step following other integrated tests. This integration is essential to assess the possible interactions (coupled mechanisms) between individual phenomena. Such coupled effects have been well studied between thermal, hydraulic and mechanical effects (THM-models), but also the interaction with e.g. chemical conditions is now increasingly investigated. Through demonstration tests, almost all the lacking pieces of knowledge, from purely scientific to operational, will be addressed. Such method has a strong convincing nature, not only to the scientific community, but also to the general public, to which a clearer picture of HLW disposal in general is given through demonstration.

Finally, many experiences that are being gathered, often not on purpose, during these real scale demonstration tests will give valuable input to desk studies that deal with operational issues and long-term strategies. Operational aspects include licensing, in which safety (during construction and operation) and conformity will play an important role. Another actual topic is monitoring during the different stages of the disposal site. The experience that is currently gathered with field
instrumentation will give sensible answers to questions about the feasibility of institutional, long-term and post-closure monitoring, and about the relevant parameters to monitor.

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REFERENCES