Connecting gallery	The construction of the Connecting gallery	
Type of test Construction techniques Clay characterisation	**Collaborations:** BELGATOM	**Period:** 2001-2002

BACKGROUND

Research into geological disposal of radioactive waste in deep clay formations has been ongoing for more than 30 years in the HADES underground research laboratory (URL) at Mol. Work on the HADES URL started in 1980 with the construction of a first shaft, followed by the excavation, in frozen Boom Clay, of the first gallery in 1983. While working on this horizontal gallery, it was found that freezing the clay before excavation was not necessary and even detrimental. A small-diameter shaft and a small-diameter gallery were therefore dug – as a test case – in non-frozen clay in 1984. This led to the excavation of the first extension of the HADES URL in non-frozen clay: the second gallery or 'Test drift', which was completed in 1987. Due to the requirements of the mining regulatory body, it became mandatory to construct a second shaft before conducting any new large-scale work in the HADES URL, such as, for instance, construction of the PRACLAY gallery and installation of the PRACLAY experimental set-up. The decision was then made to extend the HADES URL with an 80 m long gallery, connecting the existing HADES URL with the newly built second shaft. The second shaft was dug between 1997 and 1999, and the Connecting gallery in 2001 and 2002 (Figure 1). The construction of the earlier parts of the HADES URL (exploratory phase of the RD&D programme) proceeded manually, achieving a relatively low progress rate (2 metres a week). It was clear that an actual waste repository would have to be built in a much faster and more industrial way. The feasibility of industrial excavation in the Boom Clay, however, had never before been demonstrated at such depth. It was therefore decided that this extension of the HADES URL could be regarded as helping to demonstrate the feasibility of deep disposal of radioactive waste (demonstration phase of RD&D programme). This was, in fact, the first time that industrial techniques would be used to excavate a gallery in the Boom Clay at such depth, making it an important milestone in the demonstration programme. Furthermore, a large instrumentation programme in and around the gallery was set up in order to improve understanding of the hydro-mechanical response of the rock during and after the construction work.

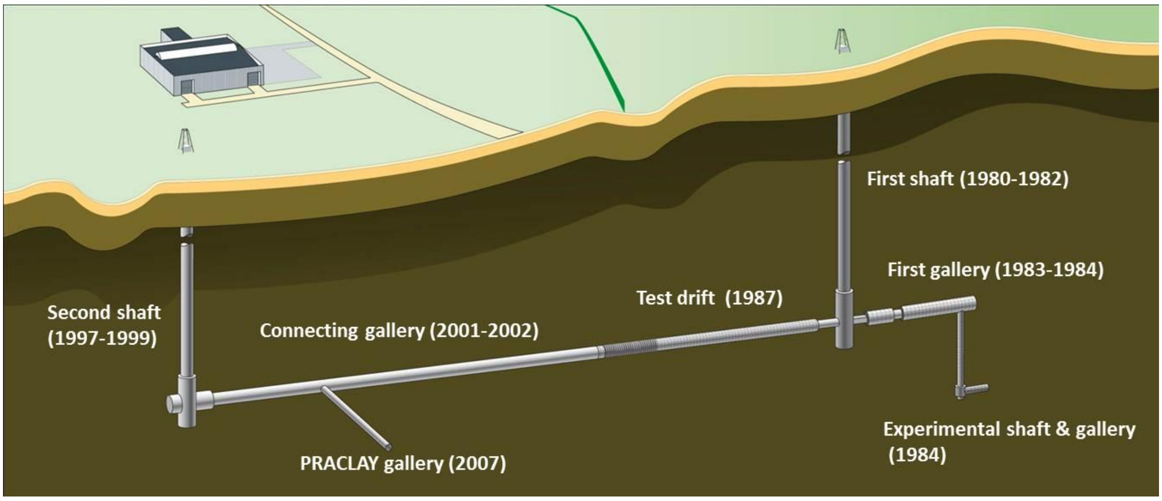

Figure 1 - Construction history of the HADES URL.

OBJECTIVES

The first objective was to demonstrate the feasibility – from both a technical and an economic point of view – of constructing galleries in poorly indurated clay, employing industrial techniques that could be used for the full-size repository.

The second objective was to gather as much data as possible regarding the characteristics of the host rock during and after excavation. To achieve the second objective, a large instrumentation programme in and around the Connecting gallery was set up as part of the **CLIPEX project** in order to obtain data on the hydro-mechanical response of the host rock during and after the construction work. As the clay host rock is the main barrier in the disposal system, this understanding is important to be able to assess the long-term safety of a repository.

DESIGN & INSTALLATION

The gallery was excavated starting from the bottom of the second shaft, working towards the Test drift. First, a 'mounting chamber' was constructed so that the tunnelling machine could be assembled underground. The technique used for the Connecting gallery was excavation of the clay rock under protection of a shield. The construction of the lining, using the 'wedge-block technique', proceeds behind the shield with a minimal unsupported zone during construction. A minimum progress rate of 2m/day, 24 hours a day and 7 days a week, was imposed. Figure 2 shows the tunnelling machine and the lining system.

The tunnelling machine

The tunnelling shield has a rear diameter of 4.82 m and is equipped with a cutting head at the front. The clay front is excavated by means of a roadheader and the shield is pushed into the clay by hydraulic jacks on a regular basis, thus enabling a smooth excavation profile thanks to the cutting head. A bird-wing erector (fixed at the end of the shield) applies the wedge-block system: 12 segments are used to build a lining ring, which has a nominal external diameter of 4.80 m, a wall thickness of 0.4 m and a length of 1 m. A total of 83 rings are installed; in the last few metres of the Connecting gallery, the tunnelling shield itself acts as lining.

The lining system

For the lining of the gallery a lining system using the wedge-block technique was considered. This involves the placement of lining segments in contact with the excavated host rock. By pushing in one or more wedges, the lining expands and presses itself against the excavated wall. Figure 2c explains the principle of the wedge-block system. The advantage of using this technique compared with other tunnelling techniques is that it causes minimal disturbance of the clay massif. To apply the wedge-block system, however, the 'immediate convergence' of the clay massif had to be known quite precisely. This was one of the experimental aspects of the execution of the Connecting gallery, because the 'immediate convergence' was only estimated by numerical analysis at that time, since digging in clay at that depth had never been done quickly and using industrial techniques. During the excavation of the Connecting gallery, a great deal of additional information – including on 'immediate convergence' – about the behaviour of the clay host rock was obtained.

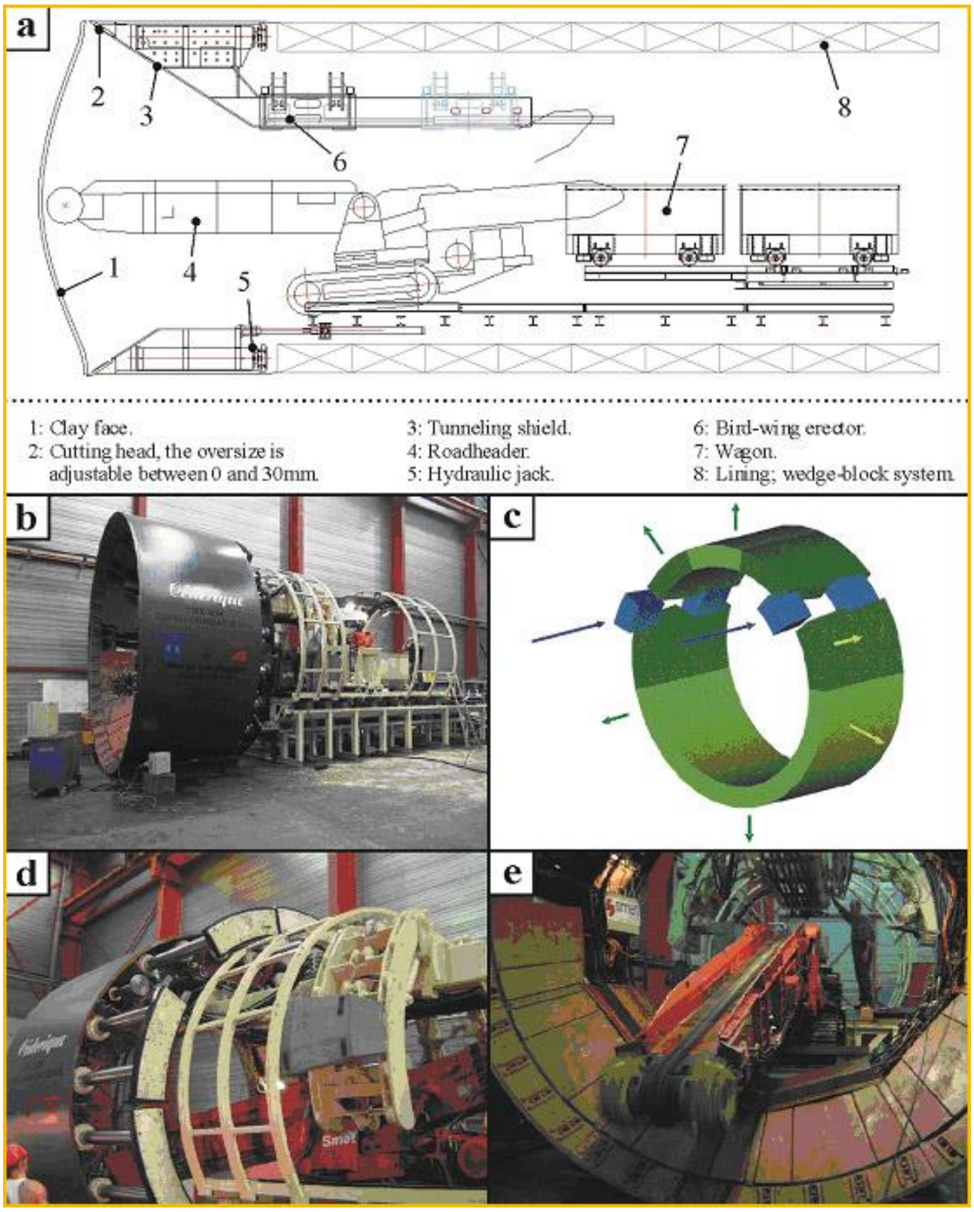

Figure 2 - General design of the excavation technique; a) schematic view of the tunnelling equipment, b) the same equipment during an on-surface test assembly, c) the wedge-block principle, d) hydraulic jacks and bird-wing erector, e) adjustable cutting head and roadheader.

TIMING

- Preparation and site installation: January - June 2001
- Construction of the mounting chamber and assembly of the tunnelling machine: July 2001 - January 2002
- Construction of the Connecting gallery: January - April 2002

RESULTS

The major results and conclusions are listed below. A complete report on the construction of the Connecting gallery is available on the website of EIG EURIDICE.

Tunnelling shield

The shield design proved to be appropriate: the shield diameter and the oversize (= difference between the excavation and shield diameters to cope with convergence of the clay before lining installation) were adequate for the placement of the segments and the steering of the shield. Indeed, it was important to have an adequate contact length between shield and clay. Too short a contact length would have entailed the risk of the shield 'floating' in the gallery; too long a contact length, on the other hand, would have made steering of the shield more difficult and would have increased the risk of the shield getting trapped. The elasto-plastic models used in the numerical simulations were therefore sufficient for determining the shield geometry.

Overall, **the construction work** was successful. The accuracy of the numerical predictions of the displacements by the clay host rock and of the pressures on the lining allowed the design and the dimensions of the tunnelling machine and of the lining segments to be appropriately defined. The two major challenges were therefore met:

- optimising the overexcavation and the shield diameter with respect to the dimensions of the lining, so as to minimise convergence while avoiding the shield getting trapped in the clay;
- achieving the target progress rate of 2 metres per 24 hours. (The excavation rate could be increased up to 10 metres a day with minor adaptations to the excavation technique and provided the access shaft was larger.)

The wedge-block technique was preferred to a technique using bolted segments, on the one hand because the lining could be quickly installed and could be expanded against the clay host rock, causing less disturbance, and on the other hand for economic reasons. It could be improved through a few simple modifications and remains a priority option for future underground construction work in the Boom Clay.

Concrete-concrete contact between adjacent lining rings led to spoiling when the shield was pushed forward. The damage was probably due to small misalignments during placement. The spoiling was immediately noticed and from that point onwards, high-density polyethylene plates (3 mm thick) were inserted between the rings and the problem ceased.

Although the technical problems encountered throughout the construction process, relating to design aspects, were only minor, there was one major, unexpected problem: the extent of the detachment of clay blocks from the front and from the unsupported sidewalls. This was both a safety and a construction issue.

The measurement and research programmes carried out before and during the construction of the mounting chamber and during and after the construction of the Connecting gallery led to very comprehensive characterisation of the fracture pattern and to an equally comprehensive understanding of the instantaneous hydro-mechanical response of the Boom Clay to excavation using an industrial tunnelling technique.

The intensive characterisation of the fracturing resulted in a description, in terms of orientation and shape, of the fractures around the gallery and in a better understanding of how these fractures are formed. All the fractures observed at the HADES URL were induced by excavation. They originated some 6 metres ahead of the excavation front. Cored borings performed after the completion of the gallery indicated that the macro-fractures extend up to about 0.5 metres in the radial direction. It is worth mentioning that the construction of the PRACLAY gallery in 2007, at right angles to the Connecting gallery, provided similar information on the fracture pattern induced by excavation. Natural, pre-existing fractures were not observed, though it is impossible to prove their absence. The impact that fractures can have on the long-term performance of geological repositories will probably be limited by the sealing mechanisms that have already been identified qualitatively in various ways.

The conclusions regarding the **CLIPEX programme** are discussed in the CLIPEX report.

The total radial convergence of the Boom Clay was about 9 cm on the radius, which is considered acceptable in terms of hydro-mechanical disturbances. The total radial convergence is the sum of the instantaneous convergence of the Boom Clay measured through the holes in the tunnelling shield, which was about 45 mm on the radius, and the radial convergence ahead of the excavation front, which was also about 45 mm on the radius, according to the displacement sensors and the modelling results.

As the tunnel was constructed starting from the second shaft that was excavated several years earlier, the first few metres were excavated in the EdZ (excavation-disturbed zone) of the Second shaft. A **petrographic study** of this zone has shown that the Boom Clay only oxidises within fracture planes: the only evidence of pyrite oxidation, in the form of newly formed minerals, is within fracture planes, microfractures and discontinuities. Such oxidation effects are the visual print of the geomechanical disturbances caused by excavation. They are important within the framework of radionuclide migration studies and for performance assessment of the disposal system.

CONCLUSION AND IMPLICATIONS

In general, the tunnelling technique performed adequately and the successful construction of the Connecting gallery using this industrial technique makes an important contribution to demonstrating the feasibility of the disposal of nuclear waste in the Boom Clay. The main problems were caused by fracturing of the host rock and the subsequent falling of blocks out of the face. The gallery itself was excavated in less than six weeks. Except for the first and last few metres of the gallery, the minimum excavation rate of 2 m/day was maintained and sometimes even doubled. Higher excavation rates are feasible in future construction projects, provided that a larger access shaft is used than the one in the HADES URL (for clay transport to the surface) . One feature that caused some problems was the presence of pyrite concretions. Chunks up to 30 cm in diameter were found, causing damage to the teeth of the roadheader, since the head was designed to excavate soft rock only. The teeth had to be replaced several times.

PUBLICATIONS

The Connecting gallery. The extension of the HADES underground research facility at Mol, Belgium. Bastiaens W., Bernier F., Buyens M., Demarche M., Li X., Linotte J-M., Verstricht J. EURIDICE report 03-294, Mol, Belgium, 2003, 98pp.