Nr. 1 February 2002

EURIDICE News

NR. 1

Editorial

Dear reader,

We are delighted to present you the first issue of EURIDICE News. The purpose of this new initiative is to enable the EURIDICE team to keep you informed about its activities.
In this first issue, we will introduce the EURIDICE team members, its Management Committee, the Programme Committee on Underground Experiments and its Scientific Advisory Committee (SAC). You can also find out about the main objectives of the EIG EURIDICE and about the aims of the PRACLAY project, which will contribute to the demonstration of the feasability of disposal of nuclear waste in deep clay layers. The important role of the URF HADES has to be acknowledged of course. Furthermore, the location on the site of the Belgian Nuclear Research Centre at Mol (SCK·CEN) is a major advantage and offers the possibility to appeal to experts in different disciplines. You can also read more about OPHELIE, the 'On-surface Preliminary Heating simulation Experimenting Later Instruments and Equipment'. The significant progress made in constructing shafts in a clay environment since the first shaft was built in 1980 is also featured in this issue of EURIDICE News. Excavating galleries in deep clay layers and on an industrial scale will be demonstrated from January 2002 on.

We are keen to find out what you think about the topics covered in EURIDICE News. Please send any comments or suggestions to Brigitte Pitz, our project assistant, at bpitz@sckcen.be.

We hope that you enjoy reading EURIDICE News.

Jean-Paul Minon

EURIDICE News

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EIG EURIDICE

GIVING SHAPE TO THE LONG-TERM MANAGEMENT OF LONG-LIVED HIGH-LEVEL RADIOACTIVE WASTE

ONDRAF/NIRAS

ONDRAF/NIRAS is the Belgian Agency for Radioactive Waste and Enriched Fissile Materials. The Agency was created by law in 1980 and is responsible for managing all the radioactive waste produced within Belgian borders. The principal task of ONDRAF/NIRAS is to protect the public and the environment against the potential hazards arising from radioactive waste – not just in the short term, but also in the long term. In fact, one of the long-term tasks of ONDRAF/NIRAS is to study, prepare and eventually oversee construction of disposal facilities for radioactive waste.

SCK•CEN

The Belgian Nuclear Research Centre SCK•CEN was set up in 1952. One of its statutory tasks is to conduct research into the safe conditioning and disposal of radioactive waste. Over the years the SCK•CEN has developed an expertise in this field that has earned it a world-wide reputation. One of its research tools is a unique underground research facility constructed at a depth of about 230 metres, known as URF HADES. The SCK•CEN research is largely funded by ONDRAF/NIRAS, as well as through research contracts that are jointly funded by the European Commission.

EIG EURIDICE

In 1995 the SCK•CEN and ONDRAF/NIRAS founded the Economic Interest Grouping PRACLAY in order to develop and facilitate their activities. The most important objective of the EIG PRACLAY was to realise the PRACLAY project, which aims to contribute to the demonstration of the feasibility of disposal of radioactive waste in clay layers. The PRACLAY project mainly involves the extension of the existing URF HADES using industrial tunnelling techniques, the PRACLAY experiment (which consists of installation, follow-up and dismantling of a pilot gallery similar to a disposal gallery) and the OPHELIE mock-up (which is a surface simulation of the PRACLAY experiment).

On 18 December 2000 the articles of association were amended and the name of the EIG PRACLAY was changed to EIG EURIDICE (European Underground Research Infrastructure for Disposal of radioactive waste In a Clay Environment). The EIG EURIDICE is now responsible for the management and operation of the underground research facility URF HADES. The realisation of the PRACLAY project is still one of the main aims of the EIG EURIDICE, however.

The main objectives of the EIG EURIDICE are as follows:

- the management and operation of all facilities located on the site of the EIG EURIDICE, particularly the URF HADES;
- the development of all technical aspects of the PRACLAY project as well as co-ordination of the project;
- the possible development, implementation and valorisation of other research projects and experiments relating to the geological disposal of nuclear waste;
- communication about its own activities.

Since its creation, the EIG EURIDICE has played a key part in the iterative process of developing concepts for radioactive waste disposal. Indeed, the initial results of the OPHELIE mock-up and the preparation of the PRACLAY experiment gave rise to unresolved questions regarding the Belgian reference concept, leading to its review. This approach is very important to ensure that there is sufficient flexibility in the process of concept development to allow new insights and technical information to be taken into consideration. This is essential in order to enhance credibility and confidence in the concept.

STRUCTURE OF THE EIG EURIDICE

The EIG EURIDICE is made up of SCK•CEN and ONDRAF/NIRAS, each having two representatives on the EIG EURIDICE Board. The Chairman of the Board is appointed by ONDRAF/NIRAS.

The EIG EURIDICE Board is assisted in its decision-making by two advisory committees, the Scientific Advisory Committee (SAC) and the Programme Committee Underground Experiments (POP). The SAC consists of scientists (mostly associated to different Belgian universities) and advises the Board on scientific decisions. The POP is an advisory committee on which only members of the EIG EURIDICE are represented; it advises the Board on the acceptability of experiments in the URF HADES and suggests any improvements and collaborative ventures that might contribute to increasing the added value of a proposed experiment. The safety co-ordinator also sits on the POP.

Two members of the project management team manage the EIG EURIDICE on a daily basis. The Project Manager, who is appointed by ONDRAF/NIRAS, is in charge of the overall management of the EIG EURIDICE. He is assisted by a Deputy Project Manager, who is appointed by the SCK•CEN and is responsible for the scientific aspects of the EIG EURIDICE.

THE EIG EURIDICE does not have any staff of its own but, under the by-laws, members of staff of both SCK•CEN and ONDRAF/NIRAS are assigned to the EIG EURIDICE, forming part of the EIG EURIDICE team. Members of the EIG EURIDICE team are allocated specific tasks.

The EIG EURIDICE can also call on experts within both SCK•CEN and ONDRAF/NIRAS.

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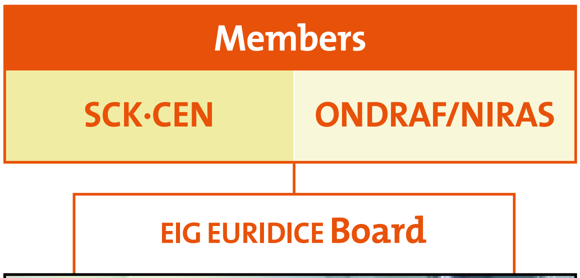
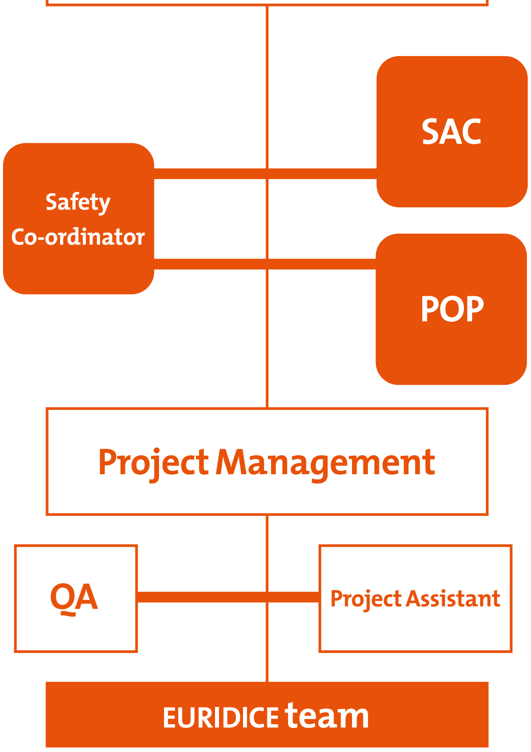


The EIG EURIDICE Board, from left to right: Ludo Veuchelen (Secretary), Jean-Paul Minon (Chairman), David Emmery, Paul Govaerts, Bernard Neerdael



The EURIDICE SAC, from left to right: Professors Antoine Pourbaix, Jan Wastiels, Noel Vandenberghe, Véronique Halloin, Jean-François Thimus. Etienne Vansant is not pictured.

The EURIDICE team together with the experts, from left to right: Marc Demarche (Project Manager), Jean-Marie Linotte, Johan Bel, Frédéric Bernier (Deputy Project Manager), Jan Verstricht, Kris Moerkens, Brigitte Pitz, Alex Isenborghs, Bernard Dereeper, Pol Meynendonckx, Bert Vreys, Marc Buyens, Xavier Sillen, Johan Peters, Xiang Ling Li, Wim Bastiaens.
Valentine Vanhove, Geert Volckaert, Robert Gens, Pierre De Cannière, Bruno Kursten, Philippe Lalieux and Christian Lefèvre are not pictured.

The underground research facility

URF HADES

Research and testing concerning geological disposal of radwaste in clay layers has been carried out for over 20 years in the surface and underground research facilities in the URF (Underground Research Facility) HADES (High-Activity Disposal Experimental Site) at Mol. Work on URF HADES started in 1980 with the construction of a first shaft, followed by excavation, in frozen Boom Clay, of the URL (Underground Research Laboratory) in 1983 (see figure). During the excavation work, it was found that freezing the clay before excavation was not necessary and was even detrimental. A small-diameter shaft and a small-diameter gallery were therefore excavated – as a test case – in non-frozen clay in 1984. This led to the excavation in non-frozen clay of the first extension of the URF HADES: the Test Drift, which was completed in 1987. Due to requirements of the mining regulatory body it became mandatory to construct a second shaft before executing any new large-scale work in the URF HADES. Thus, a second shaft had to be sunk before starting the excavation of the PRACLAY gallery, in which the PRACLAY demonstration experiment is to be set up. The decision was made to use this opportunity to extend the URF HADES with an 80-metre long gallery, connecting the existing URF HADES with the second shaft. The second shaft was built between 1997 and 1999, and the construction of the 'connecting gallery' is scheduled for 2001-2002. The construction of this connecting gallery using an industrial technique, together with the PRACLAY experiment, are components of the PRACLAY project.

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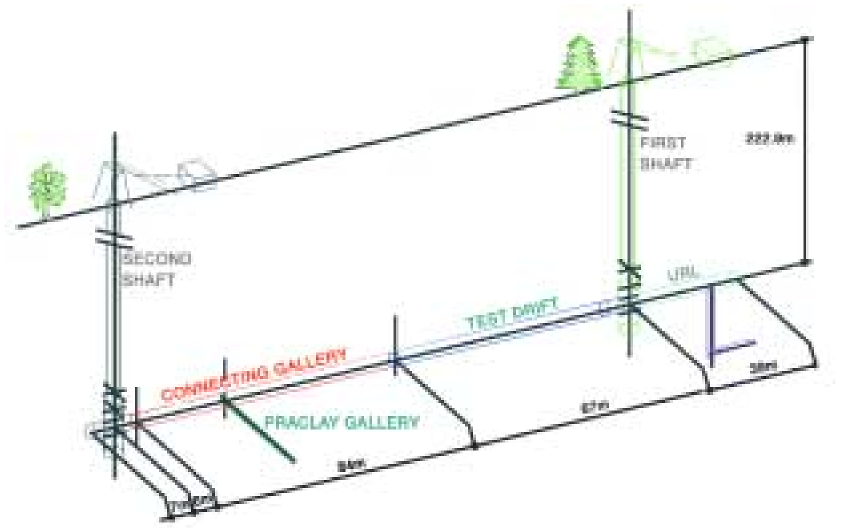
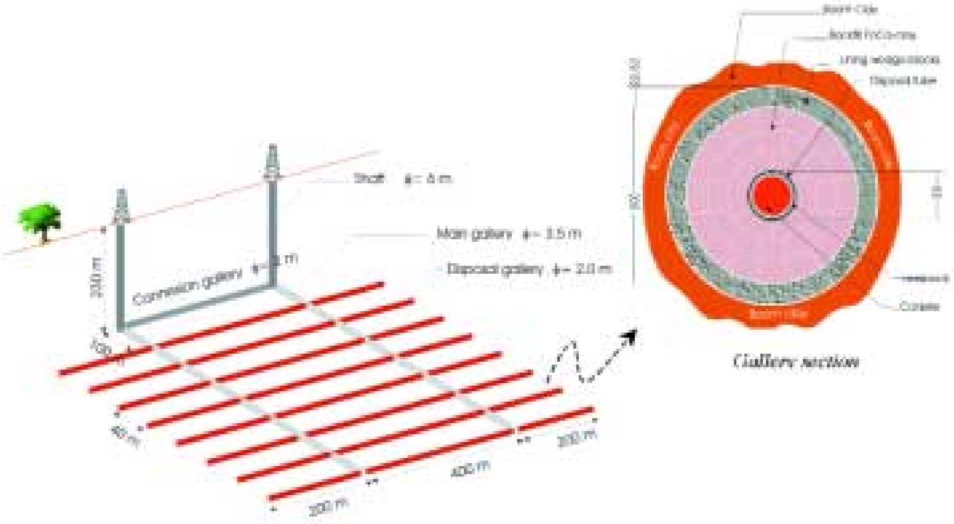


Overview of the URF HADES

The Belgian reference concept for disposal of heat-emitting high-level vitrified radwaste

Since 1978, different repository concepts have been considered for heat-emitting high-level vitrified radwaste in the Boom Clay formation (depth between approx. 190 and approx. 290 metres). The current Belgian reference concept is based on a ‘multi-barrier’ concept. Several ‘engineered barriers’ (overpack, backfill) are installed between the waste matrix itself (primary containment) and the host rock. Their purpose is to delay the release of activity from the repository structure into the geological environment. The figure shows the general layout of the present concept. Two connected shafts give access to two main galleries. Each of these main galleries gives access to 2-metre diameter disposal galleries in which the waste will be deposited. The gap between the central disposal tube and the concrete lining would be back-filled with pre-compacted bentonite blocks.

However, due to unresolved questions arising from the initial results of the OPHELIE mock-up, the preparation of the PRACLAY experiment and the drafting of the SAFIR II report, the present reference concept is currently under review.



Belgian concept for vitrified HLW

Marc Demarche, Frédéric Bernier

THE PRACLAY PROJECT

Objectives of the PRACLAY project

The PRACLAY (Preliminary demonstration test for Clay disposal of highly radioactive waste) project is a milestone in the development of a possible repository for radwaste in clay layers, essentially in the case of vitrified waste, as it aims to demonstrate the feasibility of some important elements of such a repository.

This demonstration is based on two fundamental aspects. The first consists of demonstrating the technical feasibility of the repository, taking into account the real and practical nature of the operations. This is attempted by demonstrating the construction, operation and sealing, at an acceptable cost, of a safe disposal system. The second aspect contributes to the long-term safety and performance of the disposal system through a better understanding of the processes involved in the disposal system and an attempt to validate mathematical models.

The objectives of the PRACLAY project, of which the PRACLAY experiment is part, are defined as follows:

① To demonstrate the feasibility – from a technical and economic point of view – of excavating a gallery (PRACLAY gallery) similar, except in length, to the proposed disposal galleries, using the industrial techniques that would have to be employed for the full-size repository.

② To study and achieve the intersection between main and disposal galleries.

③ To set up a pilot gallery geometrically identical, except in length, to a disposal gallery, as defined in the reference concept. Except for the vitrified waste, for which electrical heaters will be substituted, the materials and techniques used in the PRACLAY experiment will, as far as possible, be similar to the real ones.

④ To confirm and improve our knowledge of different aspects of the current reference concept, mainly through the PRACLAY experiment.

These objectives will be met as follows:

① By excavating the connecting gallery using an industrial technique. The technique will involve the use of a tunnelling machine consisting of a shield equipped with an excavator (roadheader) for digging the rock and a segment erector for installing the lining (wedge block system). If the construction of the connecting gallery already meets the objective, a fully mechanised technique for the excavation of the PRACLAY gallery will no longer be required.

② By building the intersection between the PRACLAY gallery and the connecting gallery, and studying its behaviour during the experimental and dismantling phases of the test.

③ By setting up the PRACLAY experiment (lining, backfill material, central tube, gallery plugs, etc.).

④ By carrying out any other study required to understand the long-term behaviour of the different components of the disposal system and their interaction.

Planning of the PRACLAY project

Due to the fact that studies carried out during the preparation of the PRACLAY experiment, interim results of the OPHELIE mock-up and studies conducted during the drafting of the ONDRAF/NIRAS Safety and Feasibility Interim Report (SAFIR II) have given rise to unresolved questions regarding the engineered barriers of the current reference concept, ONDRAF/NIRAS has decided to review – with the help of the EIG EURIDICE – the current reference concept for the disposal of heat-emitting high-level vitrified waste. ONDRAF/NIRAS is currently aiming to have the concept reviewed by mid-2003. Since the PRACLAY project is meant to demonstrate the feasibility of this reference concept, it is obvious that this review period will affect the planning of the PRACLAY project. However, work on some parts of the PRACLAY project, which are less dependent on the concept, will be continued.

The connecting gallery, which serves to demonstrate the feasibility of constructing a gallery in the Boom Clay using industrial techniques, will be completed in 2001-2002. In 2003 a ventilation building will be built on top of the second shaft in order to ventilate the complete URF HADES.

Before constructing the PRACLAY gallery in which the PRACLAY experiment will be set up, a Reinforcing Ring (RR) has to be installed at the intersection of the connecting gallery and the future PRACLAY gallery. Instrumentation also has to be installed in the host rock around the site of the future PRACLAY gallery. Both the design of the RR and the instrumentation are concept-dependent. The design of the RR depends on the forces that will be exerted by the PRACLAY gallery/experiment on the connecting gallery, and will be finalised in 2004. The instrumentation will be placed in the host rock after the installation of the RR and will be installed in 2005. Once the instrumentation is in place, the host rock needs a stabilisation period of six months before excavation work on the PRACLAY gallery can start. The construction of the PRACLAY gallery is concept-dependent and will start in 2006. Once the experiment itself has been set up (to be completed in 2007), there follows a five-year heating phase, due to end in 2012. After a cooling period of one year (2013) the experiment will be dismantled (2014).

The final report describing the implementation and results of the PRACLAY project will be issued by the end of 2015, based on the review of the current reference concept and the 5-year duration of the heating phase.

Objectives of the PRACLAY experiment

The PRACLAY experiment will, as far as possible, be an in situ verification and confirmation of the present state of scientific and conceptual knowledge. It will contribute to a better understanding of the disposal system and the interactions (thermo-hydro-mechanical phenomena and possible geochemical coupling) between its different components. The desired output of the PRACLAY experiment, as indicated below, is the information that EURIDICE wants to gain from the experiment, taking into account the actual reference concept and its future evolution. Nevertheless, similar outputs will probably be requested in case the reference concept changes.

For this purpose, as much data as possible will be gathered concerning the behaviour of the different components of the disposal system in conditions similar to actual disposal conditions. Most of the measurements will have to be conducted right from the beginning of the excavation works and all the way through the heating and post-heating phases. This implies that a significant proportion of the instrumentation will be installed at an early stage. The instrumentation must be redundant to guarantee that a sufficient fraction of the instruments will withstand the in situ conditions (such as corrosion) over the long term. However, the introduction of external devices (instruments, samples, etc.) within the disposal system should never alter the demonstration character of the PRACLAY experiment.

The information gathered will be used to validate existing mathematical models by comparing in situ measurements with theoretical model predictions. The need to further update these models will also be assessed based on the interpretation of the data collected. This will enable proper long-term predictions to be made for the actual repository and optimisation of its design. It will also make it possible to select materials that are better suited.

The desired output of the PRACLAY experiment is as follows:

- Observation of the behaviour of the whole disposal system and its interaction with the access gallery and the host rock, and in particular the behaviour of the gallery plugs.
- Characterisation of the disturbed zone in the host rock (e.g. changes in permeability) due to the excavation process (EDZ) and the thermal load (TDZ), in particular its scale and its evolution over time. This is important in order to verify the hypotheses considered in the performance assessment studies after the start of the hydration process.
- Verification of the hydration process through the backfill material, before the heating phase, and the interaction of the backfill material with the host rock. This information will be useful in determining the precise optimum time to install the canister in the repository galleries.
- A study of the geochemistry of the interstitial water to verify the phenomena occurring inside the backfill material, the concrete and the host rock lining during the hydration process and thermal phase. The formation of saline fronts and alkaline plume through the backfill materials and the host rock is particularly important.
- A study of the thermo-hydro-mechanical phenomena occurring inside the backfill material (possible effects of geochemical coupling, e.g. heat and water transport process, swelling capacity of the backfill) and its interaction with the host rock, the lining and the central tube. This is essential in order to verify the swelling behaviour of the backfill material.

Although the following points are outside the scope of the initial objectives of the PRACLAY experiment, they will also be studied to take advantage of the experimental conditions mirroring those conditions encountered in a real disposal situation:

- A study of the migration parameters after thermal loading to verify the hypotheses considered in the performance assessment studies.
- Verification on a large scale of the corrosion behaviour of the metallic components of the system. Up to now corrosion experiments have been performed on 30 mm x 30 mm samples. Since the corrosion is a stochastic phenomenon, the scale effect can be important for the interpretation. In particular, the influence of temperature, the interaction between the backfill material and potential candidate overpack materials, the corrosion resistance of the welding, and the determination of the corrosion potential in real disposal conditions will be studied.

The PRACLAY experiment therefore calls for multidisciplinary areas of research.

Jan Verstricht, Marc Demarche, Bernard Dereeper

THE OPHELIE MOCK-UP

Introduction

Since several technical aspects of the in situ testing of the concept for the disposal of high-level radioactive waste had not yet been worked out in detail, ONDRAF/NIRAS decided in the early 1990s to first design and construct a large-scale surface mock-up called OPHELIE (On-surface Preliminary Heating simulation Experimenting Later Instruments and Equipment). During the follow-up period the use of the mock-up made it possible to review the chosen options for the design and in situ testing of the disposal system, such as the backfill material (specifications, manufacture, installation, hydration), the central tube and the monitoring equipment. This review will continue during the dismantling phase, which is planned for the latter half of 2002. The mock-up also enables the thermo-hydro-mechanical (THM) behaviour of the clay-based backfill material to be studied on a large scale.

Although the principal aim of OPHELIE is to optimise the in situ test, known as the PRACLAY experiment, it should also contribute to the design of the disposal concept. It must be pointed out that the design and experimental conditions of OPHELIE are based on the reference concept of the early 1990s and – as mentioned before – this concept is currently being reviewed.

Aside from these technical and scientific considerations, the experimental set-up is also featured in the permanent exhibition on HLW disposal. This provides a tool to communicate directly with both the scientific community and the general public about the research work that is under way.

The different milestones in the history of the mock-up are described below.

Set-up and instrumentation of mock-up

Design of the experiment

Figure 1 shows a general view of the mock-up during assembly.

Based on the design of the disposal gallery, the confining steel cylinder (simulating the concrete gallery lining) has an internal diameter of 2 m. Its length has been limited to 5 m. Centrally, a tube with dimensions similar to the waste disposal tube (outer diameter 508 mm) has been installed. This tube contains heating elements that dissipate heat at a power of 450 W/m. To obtain temperatures up to 120°C on the outside of the backfill, external thermal insulation with an integrated temperature control system has been added to the confining structure. All surfaces in contact with the backfill material are made from stainless steel.

Development of backfill material

An important part of the concept is the backfill material between the disposal tube and the gallery lining. Due to the horizontal nature of the concept, precompacted blocks were considered to be the most appropriate form. These have been engineered by CEA (F) taking into account design specifications regarding swelling pressure, thermal conductivity and handling. The design resulted in a mixture of 60 mass% FoCa clay, 35 mass% sand and 5 mass% graphite.

Swelling is achieved through the use of FoCa clay, which has a high Ca-smectite content. The swelling pressure depends on the dry density of the clay, which is partly determined by the compaction load applied during manufacture, and partly by the swelling volume and the initial water content of the clay. To limit the maximum swelling pressure, which should not exceed the stress conditions in the host rock (total stress of 4.5 MPa), sand has been added as an inert material. This allowed high compaction pressures (61 MPa) in order to obtain robust blocks, with very good dimensional characteristics (tolerances less than 1 mm). The thermal conductivity was increased by the addition of graphite.

Installation and instrumentation

Upon delivery of the confining structure we began assembling the set-up. The backfill blocks had excellent dimensional characteristics, which meant that we could complete one section (13 cm thick) in less than half an hour. The blocks were placed in three concentric rings around the central tube. Most of the time, however, was spent on installing the instrumentation.

The mock-up was instrumented to monitor the thermo-hydro-mechanical behaviour of the backfill material. The temperature field is monitored by 100 thermocouples, most of them arranged in radial and longitudinal configurations in the backfill. Some of them are installed on the heating elements, and 15 of them on the exterior of the structure. Piezometers and humidity sensors monitor the hydration of the backfill material. Pressure and level sensors on the external hydration system complement these measurements. From a mechanical point of view, the swelling of the backfill is the most significant phenomenon to occur in the mock-up. We therefore installed total-pressure sensors inside the backfill, complemented by strain gauges on the central tube and the external jacket; their deformation also gives an indirect idea of the internal pressures developing. To check the performance of concrete-segment instruments (load cells and pressure cells), a complete concrete-segment ring has also been integrated into the backfill.

Fig. 1: Mock-up during assembly, with the backfill blocks, hydration tubes and sensor cabling

Evolution of the experiment

Hydration

After assembly of the set-up, hydration began in December 1997. The water used for hydration is based on demineralised water, with $NaHCO_3$ added (1.17 kg/m³) to approximate the composition of the natural Boom Clay water. First the voids around the blocks were filled (some 1.5 m³), which took approximately 20 minutes. After this phase, we gradually increased the water pressure to reach 1 MPa after two weeks. The water flow rate decreased rapidly to less than half a litre a day after six months. The pressure sensors only indicated some swelling in the outer backfill region. The sensors near the central tube did not even register the 1 MPa externally applied pressure.

Heating

Six months after the hydration started, we switched on the heating elements. To test the thermal-hydraulic interaction, the pressure control system was disconnected, and the pressure increased quickly due to the expansion of the water. This generated a water pressure increase of approximately 1.5 MPa. After two months of heating, a first maximum was reached, with temperatures at the central tube reaching 105°C. Later in the experiment, the external heating was switched on to increase the overall temperature level. This was done gradually, and on one occasion (January 2000), the hydration system was disconnected again. This increased the water pressure by approximately 3 MPa. In June 2000 maximum temperatures were obtained, ranging from 117°C on the outside of the backfill to about 140°C near the central tube. Figure 2 shows the overall evolution in temperature of the horizontal radial profile in the middle section of the mock-up, while figure 3 shows the evolution in pressure recorded by the backfill total pressure sensors.

Observations: THM, geochemical, corrosion

The total temperature gradient over the backfill is a mere 20°C, which is lower than expected. The thermal conductivity derived from these measurements should be higher than 4 W/mK. This is difficult to explain for a porous material, and other phenomena may be of significance here.

In December 1998, a water leak detected at one of the cable sheaths of the internal strain gauges instigated what would become a major investigation programme on the chemical state of the backfill material. Samples of the water indicated a high content of Cl^- (up to 1 kg/m^3), which, after checking the rather unusual sampling conditions, was found to be most likely due to the backfill material itself. Unexpected values were also obtained for the NO_3^-, DOC (dissolved organic carbon), Si and pH values. A mass transport process could be at work in the mock-up, concentrating salts towards the central tube. This may be due to one or a combination of the following three processes:

- advective transport of soluble salts by a water front migrating through an unsaturated material during the hydration phase;
- advection/evaporation cycles (heat pipe) leaving the non-volatile salts in the hot zone;
- migration of salts due to thermo-osmosis or thermo-diffusion in the water-saturated region, i.e. diffusion of a solute under the influence of a temperature gradient if the chemical potential of the considered species varies with temperature.

Independent laboratory experiments at room temperature have confirmed that soluble salts are transported and concentrated by the water front migrating through the unsaturated material during the hydration process. Additional laboratory tests on the components of the backfill mixture showed that the FoCa clay itself was the main source of the chlorides.

Another important observation is the presence of sulphides in the mock-up water, which was discovered when purging the accumulator of the hydration system. This could be indicative of some sulphate-reducing mechanism (thermal or microbial) present in the backfill.

The high Cl^- concentration and the presence of sulphides increase the risk of pitting and other forms of corrosion. A proper understanding of these chemical phenomena, which occur during the hydration of the backfill, is therefore essential to obtain a clear picture of the performance of steel and stainless steel barriers. Even if hydration is only a fairly short-term process, the pitting that could result is a self-sustaining process and could therefore affect the metal components over a long period of time.

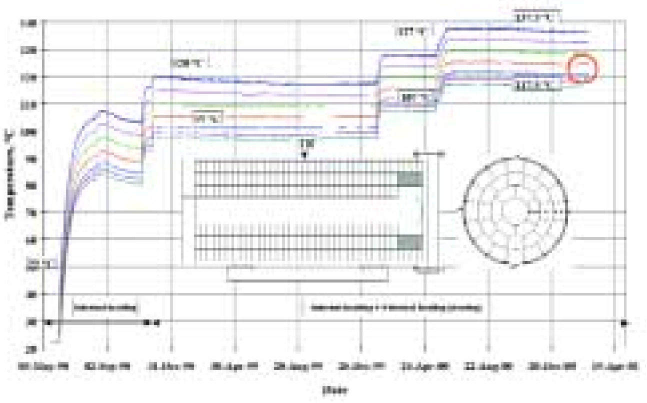


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Fig. 2: Evolution in the temperature of a radial profile in the middle of the mock-up.

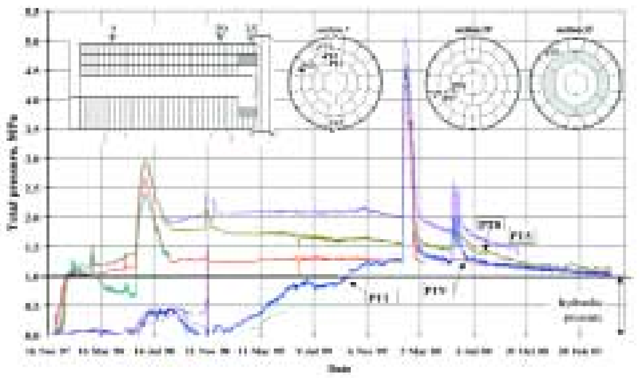

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Fig. 3: The total pressure inside the backfill is highly sensitive to temperature transients, but the swelling pressure has decreased to low values.

Sensor performance (thermocouples, strain gauges, moisture content)

Failures were observed in some types of sensors; the internal strain gauges showed a systematic failure, probably due to the corrosion of the sensor head, where the soldering may prove to be a weak point. In contrast, the external strain gauges did not experience any failure. However, their measurement characteristics are more geared towards short-term applications, whereas accurate measurements of long-term phenomena are more difficult to interpret, mainly due to drift phenomena.

Only a few humidity sensors failed, but the others became saturated. Some backfill pressure cells did not survive the experimental conditions (probably due to the high water pressure), and were also corroded. The sensors based on the hydraulic flat jack (pressure-on and load-in the concrete segment ring) also failed, probably due to a broken compensating valve. Many sensors did, of course, perform satisfactorily. The fact that no significant problems occurred with the thermocouples puts the corrosion aspects into a more realistic context. Retrieval and thorough analysis of the sensors is one of the key issues in the dismantling programme, which will now be discussed.

Dismantling programme

According to the current planning schedule, the heating in the mock-up will be switched off in mid-August 2002 and the set-up will be dismantled after cooling.

Cooling will be done as quickly as possible; in fact, a slow decrease in temperature might alter many characteristics (such as a redistribution of chemical elements), whereas our prime objective is to preserve the mock-up state as it was during the heated phase.

The main objective of the mock-up dismantling is to better characterise and understand the phenomena occurring inside the backfill material during both the hydration and the thermal phase of the experiment, their causes and their consequences on the integrity and performance of the mock-up components.

Recalibration of the functioning sensors will give us an idea of the long-term performance of the instrumentation and allow for a correction – if necessary – of the measurement data. Furthermore, the metallic components of the mock-up will give us the opportunity to assess corrosion susceptibility in conditions that are representative for an HLW disposal site.

Based on these objectives, an extensive sampling and analysis programme is being developed. This programme, which is based on current observations and related questions, covers:

- the hydration process (overall saturation degree, homogeneity),
- the thermal transfer characteristics in the backfill,
- corrosion (by investigating geochemical and microbiological phenomena, as they could affect the corrosion resistance of metal components, and by direct analysis of the metal surfaces),
- the THM properties of the backfill material (swelling, permeability, water retention, etc.),
- the mechanical properties of the central tube (tube dimensions, quality of weldings, etc.),
- the sensor performance (with recalibration or analysis of failure mode where applicable).

A detailed planning schedule has been drawn up to carry out the dismantling within a minimum period of time. Once the mock-up has been opened up, we will put the dismantling plan into effect non-stop (24-hour, 7-day schedule) to ensure that we obtain samples that have been disturbed as little as possible.

Conclusion and future prospects

The mock-up experiment is the first step in the demonstration of the disposal of HLW. The mock-up has generated a large measurement database and has already yielded important observations on the THM and chemical behaviour of the backfill material. Moreover, the dismantling process itself will provide us with unique 'hands-on' experience of the engineered barriers by giving direct access to these components after they have been subjected to hydration and heating over a period of several years, and will enable us to check the validity of several hypotheses in realistic conditions, as far as the engineered barriers are concerned. The mock-up test will provide additional data for the optimisation of the in situ experimental set-up from both a scientific point of view (e.g. which processes should be monitored) and a technical point of view (e.g. how to monitor these processes, which sensors will give the most reliable measurement results). Although not the primary goal of the mock-up experiment, valuable input for a critical review of the current HLW disposal concept has also been provided.

More generally, the development of the demonstration programme will interact closely with the optimisation of the concept (safe and economical), the fine-tuning of the concept parameters (e.g. thermal loading), the adaptation to a particular geological situation, the design and installation of engineered barriers, and the monitoring philosophy and technology.

On a larger international scale, EIG EURIDICE also participates in the second phase of the FEBEX project. Co-ordinated by the Spanish waste management agency ENRESA, this project comprises both an in situ and a mock-up simulation. The collaborative venture allows us to exchange both scientific and technical information, ranging from backfill phenomena at high temperatures to sampling techniques in preparation for the dismantling operations.

The demonstration activities that have been performed up to now have clearly shown that they are essential in assessing the feasibility and safety of a concept. Although the term 'demonstration' mainly refers to showing something, this particular case proves that it has a significant interaction with the waste disposal concept in general. This concept can never be considered to be completely comprehensive based on desk studies and laboratory experiments alone; a full-scale test in close-to-real conditions will be a necessary phase in the acceptance procedure.

Acknowledgements

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Frédéric Bernier

THE EXCAVATION OF THE SECOND SHAFT

Geology

During the Lower Oligocene period, the North Sea covered large areas of northern Europe. In the deeper part of the North Sea basin, a clay deposit was formed. In Belgium, this clay formation is known as Boom Clay. At Mol, Boom Clay is present at a depth of 190-290 m. The Boom Clay layer is covered by a succession of layers of water-bearing sand (Neogene).

Boom Clay is characterised by a fairly constant chemical and mineralogical composition. There are variations in grain size, organic matter and carbonate content, resulting in the typical layering of Boom Clay. The variations reflect changes in local tectonics and climate, and are associated with Milankovitch cyclicity.

Experience gained from the first shaft

The excavation of the access shaft (1980-1982) through the water-bearing sands was carried out using the ground freezing technique. The effective diameter of the shaft is about 2.65 m. Since, at that time, non-frozen Boom Clay was expected to creep quickly at a depth of 200 m, the contractor also chose to use the ground freezing method to excavate in the Boom Clay. A polyethylene film was used to prevent water entering from the water-bearing sands. While the rock was thawing, we observed a lot of water leaking in, so we injected the joints of the concrete lining with watertight resin.

The main conclusions that have been drawn from the construction of the first shaft are:

- a large number of injections were needed to ensure satisfactory watertightness of the polyethylene film sandwiched between the two layers of concrete that form the shaft lining;
- freezing the Boom Clay increases the stresses in the rock resulting in rapid convergence and greater stresses in the linings, without really improving the mining capabilities.

The construction of the second shaft

The second shaft has an effective diameter of 3 m and widens out to an effective diameter of 5 m at low level (see figure 1).

The ground freezing technique was used to sink the shaft through the water-bearing sands. Sixteen freezing holes arranged around a 7-metre diameter circle centred on the axis of the shaft. The freezing pipes were anchored into the top of the clay layer at a depth of 194 m. The freezing tubes were fitted with a 50-mm diameter polyethylene tube through which $CaCl_2$ brine was injected. The brine circulated in a closed circuit and was cooled by two refrigeration sets rated at 250 kW each, using NH_3 as the cryogen.

Excavation began as soon as it was certain that the icewall was closed. The frozen sand was excavated with a jackhammer mounted on the hydraulic arm and with

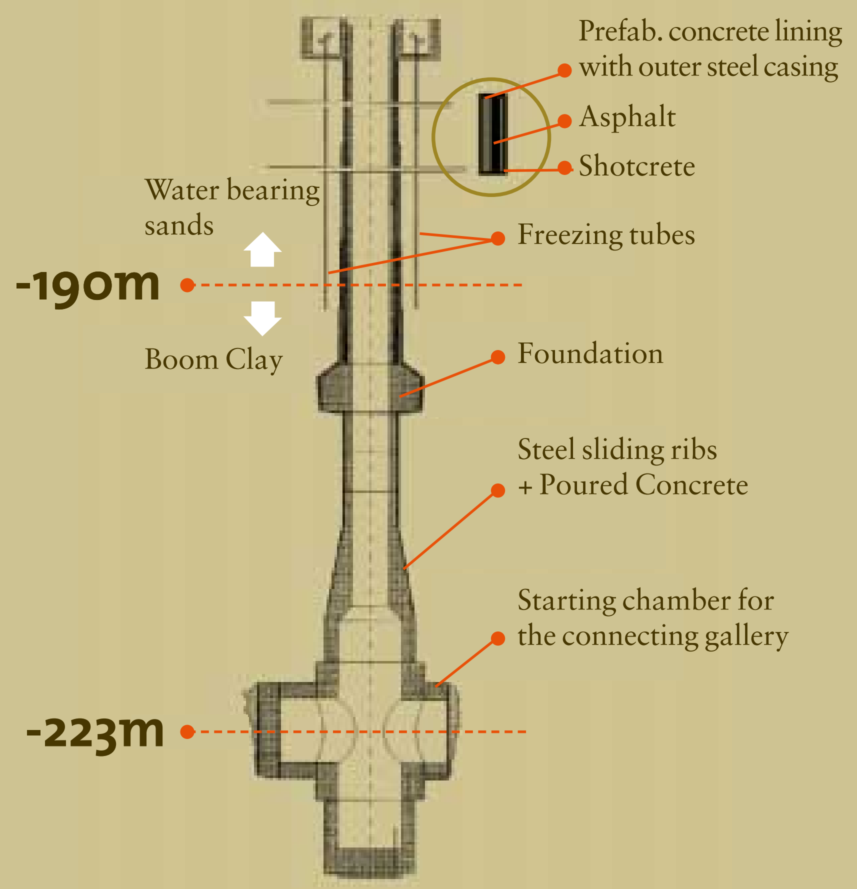

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Fig. 1: Design of the second shaft

manual air hammers (see picture 1). The mean rate of excavation was about 6 m per week. The blocks were loaded by hand into the kibbles. Tests were carried out to blast the frozen sand but the quantities of explosive required to achieve satisfactory removal proved to be excessive. This option was abandoned as it posed a risk to the lining above and to the freezing tubes. The frozen wall was secured by a primary lining, placed progressively as excavation proceeded, and composed of a 20-cm thick layer of shotcrete. In the Eigenbilzen sand (lower section), the thickness of the shotcrete was increased to 36 cm (because of the increase in the levels of silt and clay in the soil), the reinforcing mats being replaced by reinforcing cages prepared on the surface. In the transition zone a compressible lining was provided by the addition of radial panels made from a compressible material. At the top of the clay layer, a reinforced foundation was constructed in unfrozen clay to support the secondary lining. This lining consists of

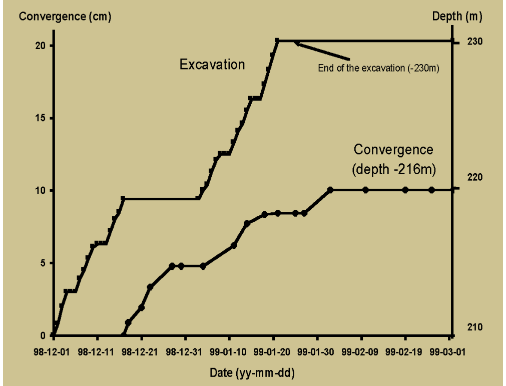

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Fig. 2: Convergence of the diameter of the sliding ribs at 216 m depth

prefabricated reinforced concrete rings with an 8-mm thick outer steel casing (see picture 2). The gap between the two linings is filled with asphalt.

Taking into account 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) using steel sliding ribs as the primary lining. Excavation was carried out primarily using the hydraulic arm, as well as manually with air hammers to shape the perimeter (see picture 3). Concrete was then poured from the bottom up to the foundation. This proceeded successfully although significant convergence was measured. Taking into account a mean over-excavation of 5 cm, we can estimate a convergence of about 25 cm on the diameter (this value does not include the convergence occurring ahead of the excavation front). This led to significant decompression of the rock, which was confirmed by the low total pressures recorded on the lining (less than 0.5 MPa). Convergence measurements are shown in figure 2. The influence of the excavation phases can be clearly observed.

During the construction of the starting chambers (see picture 4) at the bottom of the shaft, large slip surfaces were observed on both the north and the south side (see picture 5). This led to the detachment of some blocks, causing a lot of problems during excavation. The slip surfaces consist of an interconnected network of conjugated planes inclining at 35° towards the centre of the shaft. The circular shape of the slip surfaces indicates clearly that they are symmetric around the shaft axis. Slickensides, visible on the slip surfaces, clearly indicated a movement towards the centre of the shaft, which can be associated with the sinking operations.

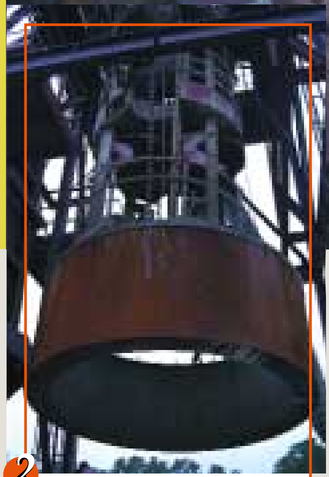
No active support was installed from the beginning of the excavation work on the starting chambers. In fact, support was installed during the first excavation phase mainly to protect the miners and not to limit convergence. This lack of active support and the low excavation rate have certainly favoured the opening of the fractures and aggravated the difficulties encountered. The installation of active support in the last excavation phase considerably improved the behaviour of the rock.

Conclusions and future studies

The feasibility of digging in unfrozen Boom Clay from the top to the middle 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 probably induced by the excavation work. Active temporary support installed immediately after excavation considerably reduced the opening of the fractures and the risk of detachment of blocks.

The study of the disturbed zone around the excavation and of the self-healing effect within the context of a repository for nuclear waste is of particular importance. This will be investigated in more detail within the framework of the EU SELFRAC project.

Picture 1: Excavation by freezing technique in the water-bearing sands



Picture 2: Installation of the first prefabricated reinforced concrete rings

Picture 5: A slip plane observed during the excavation of the starting chambers

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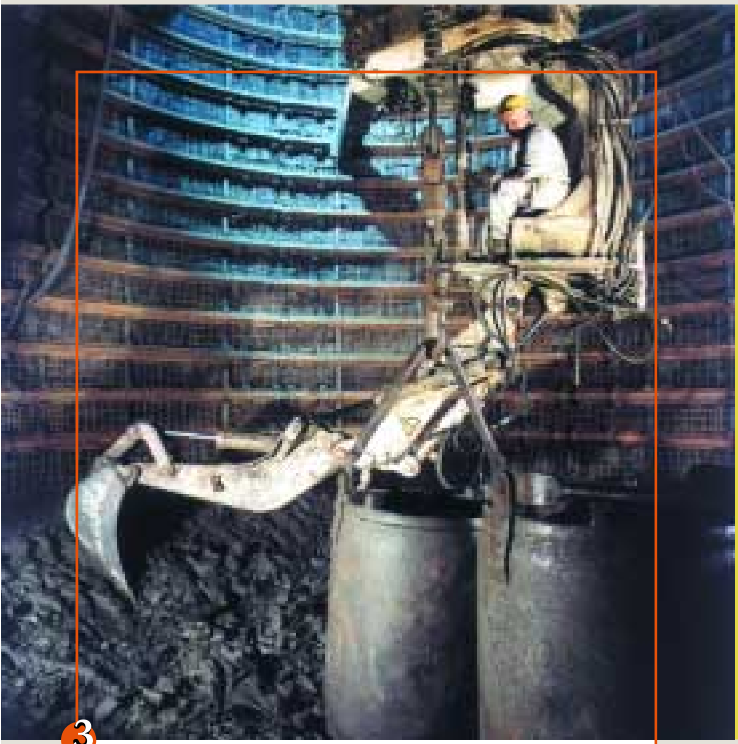

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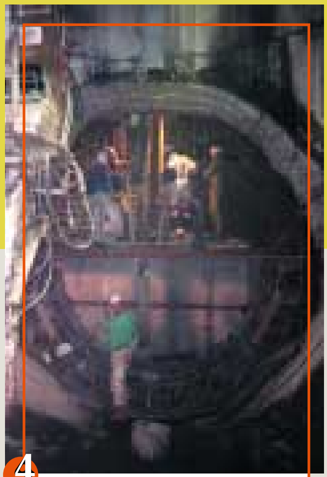
Picture 3: Excavation in unfrozen clay with steel sliding ribs as the primary lining



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Picture 4: Realisation of the south starting chamber

Frédéric Bernier

THE CONSTRUCTION OF THE CONNECTING GALLERY

AN EXPERIMENT IN ITSELF

The construction of the connecting gallery is an experiment in and of itself because it is the first time that an industrial excavation technique will be used for the construction of a gallery in Boom Clay at a depth of more than 200 m. The construction of this connecting gallery will provide important information about the excavation technique, and will also contribute to our understanding of the hydro-mechanical response of the clay mass during and after excavation.

The construction of the connecting gallery will be conducted using a tunnelling machine consisting of a 2.3-metre long shield, a roadheader for the excavation of the rock and a bird-wing erector system for the installation of the lining. The shield is equipped with a cutting head to ensure a smooth excavated profile.

The wedge block system, which is an expanded lining system, is used for the lining of the connecting gallery. In order to reduce the plastic zone created by the tunnelling process, a fast advancement rate of about two metres a day is required. Over-excavation is then reduced to a minimum (about 2 to 3 cm), and the lining is installed as soon as practically possible in order to minimise radial movement of the clay wall. The tunnelling machine will be fully instrumented (for forces exerted by the hydraulic jacks, convergence of the wall, etc.). This will ensure excellent control of the excavation parameters, and measurement of the instantaneous convergence for the first time. The EC CLIPEX project comprises an instrumentation programme to acquire experimental data, which can be used directly to test and refine hydro-mechanical models. A substantial part of the project is also devoted to blind predictions. Partners of the project are ANDRA, G3S, UPM and GEOCONTROL.

Since the connecting gallery will be excavated from the second shaft to the existing URF HADES, a unique and original opportunity arises to monitor hydro-mechanical parameters ahead of the front, as excavation of the connecting gallery advances. The instrumentation is located in three zones around the connecting gallery: from the Test Drift, from the bottom part of the second shaft, and in three lining sections of

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Fig. 1: The wedge block system

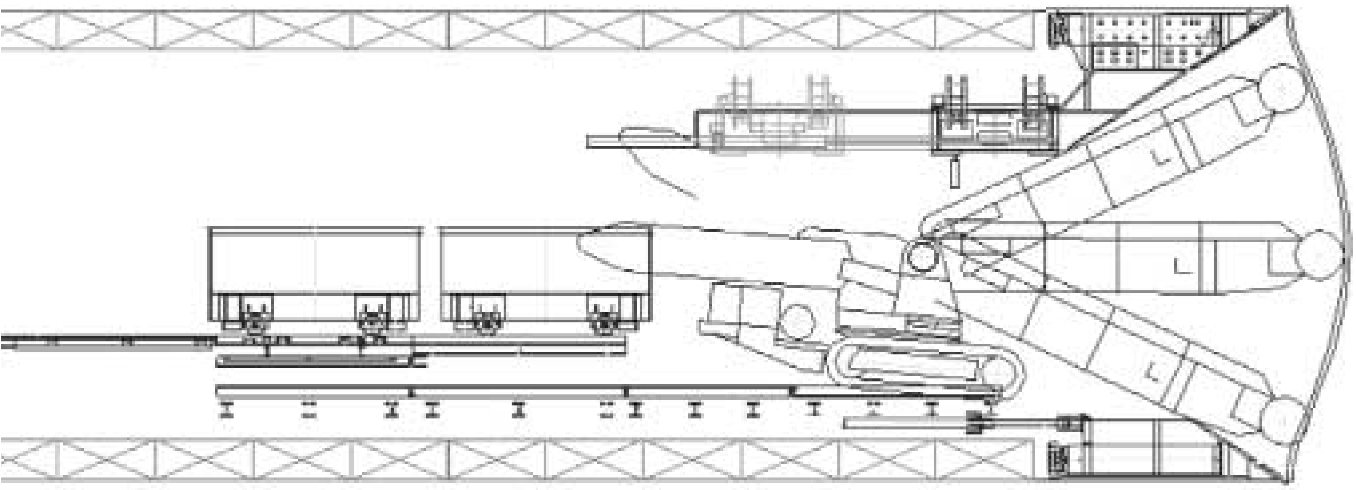

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Fig.2: The tunnelling machine for the construction of the connecting gallery

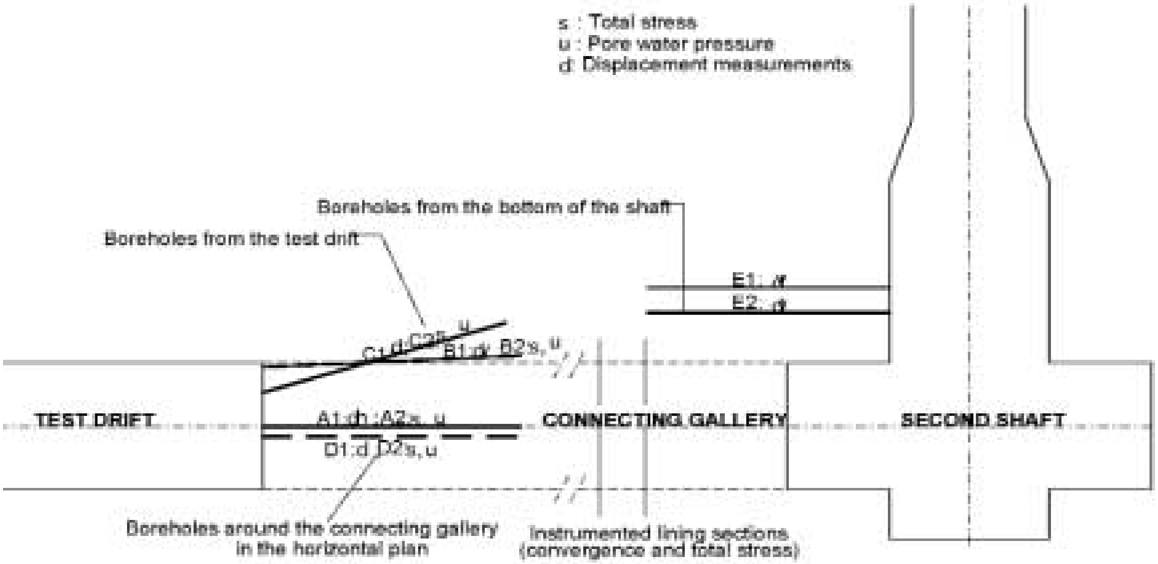

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Fig. 3: Convergence of the diameter of the sliding ribs at 216 m depth

the connecting gallery. Some interesting results have already been obtained:

- For the first time in URF HADES a pore water pressure of about 2.2 MPa has been recorded showing that the perturbation of the Test Drift is limited.
- During the construction of the second shaft a pressure drop about 0.2 MPa in the pore water pressure was recorded at a distance of about 60 m from the shaft. Simple poroplastic models that predict a maximum extent of perturbation of the shaft of 25 m under full deconfinement cannot explain these observations. Skeleton viscosity and fracturing in the near field have to be taken into account.

The blind predictions of the CLIPEX project are as follows:

- case studies to compare the predictions of the different codes for problems relating to the excavation of underground structures. In these calculations, all the data is imposed: geometry, boundary conditions, constitutive model, geotechnical characteristics and construction sequence;
- the hydro-mechanical behaviour of the clay mass during and after the construction of the connecting gallery. The predictions will quantify the evolution over time of pore pressures, stresses and displacements in the medium as well as pressures on the gallery lining. Based on their experience, the modelling teams will be free to use the data and the constitutive model they consider the most appropriate.

The first stage has now been completed (see figures). During this stage, a 2-D axisymmetric problem was identified, which accounts for the decompression of the clay mass ahead of the excavation face, the support-laying distance and the sequential tunnelling process studied in two different constitutive models (Mohr-Coulomb and Cam-Clay). The results from the different modelling were in good agreement. Except in the Cam-Clay model, discrepancies were found for the prediction of the hydro-mechanical parameters ahead of the tunnel face. A difference in integration rule for the Cam-Clay model seems the most probable explanation. The second stage will be completed by the end of 2001.

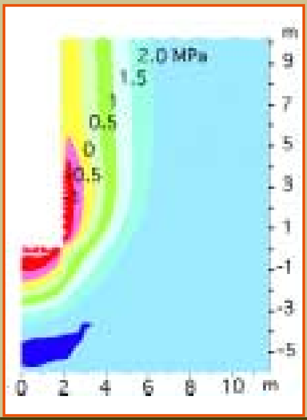

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Fig. 4: Excavation of the connecting gallery: contour plot of the pore water pressure

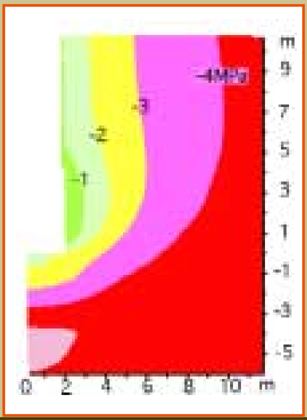

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Fig. 5: Contour plot of the radial stress

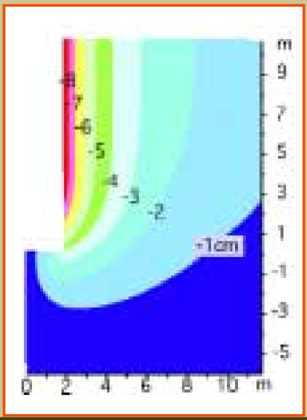

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Fig. 6: Contour plot of the radial displacement

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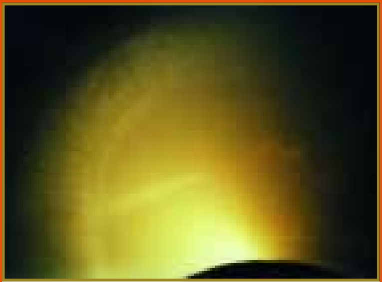

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