ESV EURIDICE GIE

Activity Report 2011

RESTRICTED

All intellectual property rights and copyright are reserved. Any communication or reproduction of this document, or any communication or use of its content, is strictly prohibited without explicit authorisation. Any infringement of this rule is illegal and shall entitle EIG EURIDICE to claim damages from the infringer, without prejudice to any other rights in the event of grant of a patent or registration in the field of intellectual property.

EIG EURIDICE
Boeretang 200
BE-2400 MOL
Tel. +32 14 33 27 84
euridice@sckcen.be
www.euridice.be

Activity Report - 2011

Doc. 12-118

Approved by:

Guy Collard
Board of Governors

Marc Demarche
Chairman of the Board

Contents

General foreword
Marc Demarche, Chairman of the Board of EIG EURIDICE

Dear reader,

This Activity Report 2011 gives an account of the main developments and achievements with respect to the statutory tasks and missions of EIG EURIDICE.

One of the main tasks is the development and realisation of the PRACLAY project. With the extension of the HADES Underground Research Facility (HADES URF) during the period 1997-2007, important steps have already been taken in this project, such as the excavation of the connecting gallery and the PRACLAY gallery, including the crossing of both galleries, using appropriate industrial techniques. All these achievements have contributed to demonstrating the feasibility of constructing an underground repository in a clay host rock in Belgium.

Since then EIG EURIDICE has largely focused its activities on preparing the large-scale Seal & Heater experiment. This experiment is a key element of the PRACLAY project, and aims to demonstrate and confirm our understanding of the combined excavation-induced and thermal disturbance of the clay host rock. The ultimate goal is to convincingly demonstrate that these repository-induced disturbances of the clay host rock do not jeopardize the containment and isolation capacity of the clay barrier.

At the end of 2010 the main components of the PRACLAY Seal & Heater experiment were installed in the PRACLAY gallery: the instrumentation devices in the Boom clay and in the PRACLAY gallery, the metallic seal structure with its ring of bentonite blocks, and the primary heater system.

During 2011 EIG EURIDICE completed almost all the installation work, backfilling the gallery with sand and closing the seal structure by welding the manhole plate. In December 2011 work began on saturating the backfilled gallery with water, bringing the part of the PRACLAY gallery that will be heated to its final configuration before the start of the heating phase.

The actual moment when the heater system can be switched on is determined by the swelling behaviour of the bentonite ring in the seal structure. Sufficient bentonite swelling is required to reach the experimental hydro-mechanical boundary conditions to be able to conduct the experiment in sufficiently severe conditions. In order to assess the status of the seal with respect to evolution of its swelling pressure, EIG EURIDICE organised a workshop in November 2011, bringing together international experts to discuss and advise on the timing of switching on the heater system. The main conclusion was that swelling behaviour was currently insufficient to allow a rapid switch-on and that a new assessment needed to be made around mid-2012. EIG EURIDICE will closely monitor developments in order to be able to determine the most appropriate timing.

EIG EURIDICE also contributes to the feasibility demonstration programme for the construction of a supercontainer for high-level waste. In 2011 EIG EURIDICE produced the final report covering the first phase of the test programme (first half-scale test (2009-2010)) and helped prepare for the second phase (2012-2013).

In May 2011 EIG EURIDICE, together with SCK•CEN and ONDRAF/NIRAS, organised a three-day international event to mark the 30th anniversary of the HADES URF. More than 100 experts gathered to discuss the role of underground research Facilities in national geological disposal programmes for radioactive waste.

With the participants' key conclusion that URFs play a central role in the development of geological disposal systems comes the important related challenge of managing all the knowledge and expertise acquired for long periods extending over many decades. EIG EURIDICE is therefore making continuous efforts to organise its expertise and know-how in its main fields of activity, both within the EURIDICE team itself and in collaborations with external partners.

EIG EURIDICE: history, tasks and fields of expertise

EIG EURIDICE (European Underground Research Infrastructure for Disposal of nuclear waste In Clay Environment) is an Economic Interest Grouping (EIG) involving the Belgian Nuclear Research Centre SCK•CEN and the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS). It manages the HADES underground research facility and carries out R&D, including feasibility studies for the disposal of high-level and long-lived radioactive waste in a clay host rock. In this way, EIG EURIDICE contributes to the national disposal programme for high-level and long-lived waste managed by ONDRAF/NIRAS, organised in a stepwise manner with major milestones at key decision points.

In 1974 SCK•CEN started research into the geological disposal of high-level and long-lived radioactive waste in a clay host rock. The Boom clay, a poorly indurated clay (or plastic clay) underneath the SCK•CEN research site in Mol at a depth of 180 to 280 metres, was and still is regarded as a potentially suitable host formation. In 1980 SCK•CEN began construction of the HADES (High-Activity Disposal Experimental Site) underground research facility (HADES URF - Figure 1), situated at a depth of about 225 metres. This was the first purpose-built underground research facility in plastic clay in Europe and worldwide. The facility was gradually extended, with the excavation of a second shaft (1997-1999) and a connecting gallery (2001-2002) linking the second shaft to the then existing underground facility. At each stage of excavation and construction, new techniques were used and new technological and engineering expertise was gained. The HADES URF has been fully managed by EIG EURIDICE since 2000.

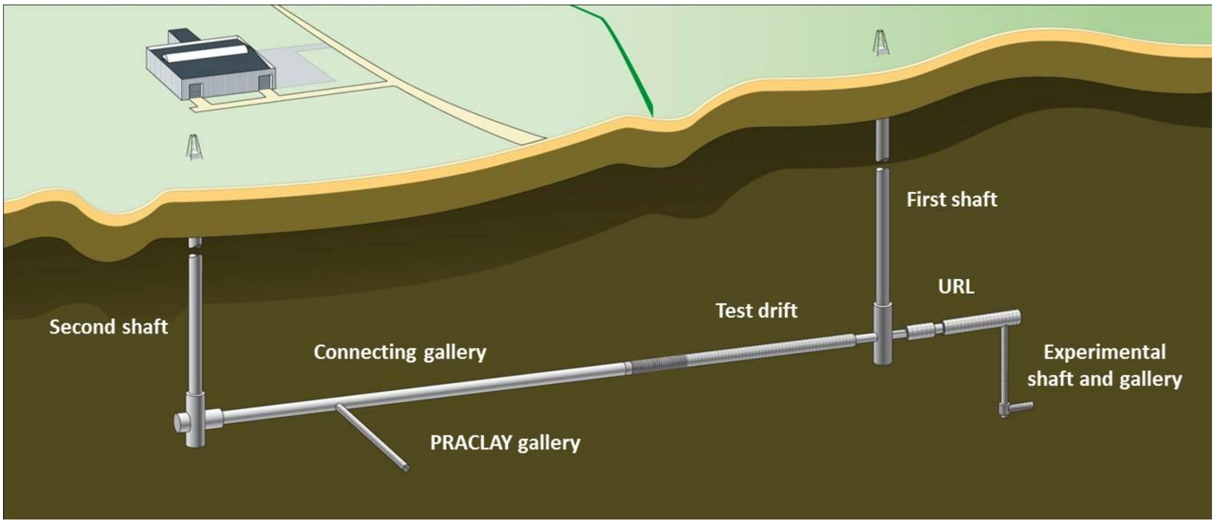


Figure 1 The underground research facility HADES (High-Activity Disposal Experimental Site)

The main statutory tasks of EIG EURIDICE entail a range of activities relating to the development and operation of an underground research facility with a view to developing and facilitating the activities of EURIDICE's constituent members:

- The management and operation of HADES and all the installations situated on the land for which EIG EURIDICE has a building lease.
- The development of the PRACLAY project, which aims to contribute to demonstrating the feasibility of disposal of radioactive waste in a clay host rock.

- The possible development, implementation and valorisation of other research projects and experiments with regard to the disposal of radioactive waste.
- The possible realisation, exploitation and valorisation of other research projects concerning the long-term management of radioactive waste in order to support the scientific programmes of its members using their resources.
- Communication about its own activities, in dialogue with its members, including the organisation of visits to the HADES URF.

After 30 years of research in and around the HADES URF, a lot of expertise and know-how has been acquired in different scientific and technological fields, of key importance for developing an underground radioactive waste disposal facility in poorly indurated clay formations such as the Boom clay. The scientific and technological expertise of EIG EURIDICE focuses on three areas:

1. excavation and construction techniques for an underground repository in a clay host rock;
2. the thermo-hydro-mechanical (THM) behaviour of the clay host rock (i.e. the Boom clay);
3. instrumentation & monitoring.

EIG EURIDICE's first area of expertise has changed significantly over the past 30 years, with excavation and construction of the HADES URF evolving from semi-manual and slow to industrial, using tailor-made tunnelling machines. The tunnelling techniques used for excavating in poorly indurated clay at great depth, including the crossing between galleries, have greatly reduced excavation-induced disturbance of the clay layer and have demonstrated that it is feasible to construct a disposal infrastructure, at a reasonable speed and cost. Since the natural clay layer will be the main barrier for radionuclide migration in a geological disposal system, reducing the excavation-damaged zone (EDZ) is a key objective and relates directly to the safety of a disposal system.

The second field of expertise of EIG EURIDICE involves understanding the THM behaviour and characterisation of a clay host rock, including all disturbance processes induced by the construction of the galleries and by the emplacement of heat-emitting radioactive waste. In low-permeability clays such as the Boom clay THM processes are strongly coupled. EIG EURIDICE's knowledge base is mainly built on the research activities in and around the HADES URF in the Boom clay. The intensive scientific instrumentation systems installed in the clay before, during and after the construction of galleries made it possible to create a valuable geotechnical knowledge and database to characterise and understand the hydro-mechanical response of Boom clay in the short and long term, including the generation and evolution of the EDZ. Proper understanding of the coupled THM processes in the Boom clay around the repository is essential to determine to what extent these processes could affect the containment and isolation capacity of the clay. The most important project in this area for the past few years has been the large-scale PRACLAY experiment. Here, the combination of the hydro-mechanical disturbances due to excavation of galleries and the further coupled thermo-hydro-mechanical disturbance due to heat production, as in the case of the disposal of high-level vitrified waste or spent fuel, are studied on a large scale. In this Activity Report 2011, you will find further details about progress made in 2011 and the status of this experiment at the end of 2011.

The R&D programme in and around the HADES URF relies heavily on the use of various instrumentation devices and techniques to measure and monitor the main THM characteristics of the clay; some of these have been developed in-house. This is the third main area of expertise of EIG EURIDICE. Experience has been gained on several aspects specific to this type of instrumentation and monitoring, such as the long-term management of sensors and their measurement data, reliability (e.g. how to implement field calibration and what the alternatives are when this is not possible) and robustness under adverse conditions, such as corrosion and mechanical strains. This extensive instrumentation experience will be an essential element in designing a monitoring programme for an underground repository for high-level and long-lived waste in a clay host rock.

With its R&D activities and fields of expertise, EIG EURIDICE contributes to the national programme for high-level and long-lived waste disposal managed by ONDRAF/NIRAS. In 2011 ONDRAF/NIRAS published its final waste plan for the long-term management of high-level and/or long-lived waste (NIROND 2011-02, September 2011), with a view to obtaining a policy decision on the long-term management of this waste. EIG EURIDICE contributed its knowledge and expertise to this report, in support of ONDRAF/NIRAS' reference solution of geological disposal in poorly indurated clay.

The next milestones of the ONDRAF/NIRAS geological disposal programme will largely depend on the timing and nature of the policy decision eventually made. For EIG EURIDICE, the execution of the PRACLAY project, including the start-up of the PRACLAY Heater experiment, will be key, with the objective of launching the heating phase of the experiment without delay. This will enable EIG EURIDICE to obtain and interpret the results and findings of the first few years of heating, during which important observations can already be made, and provide this valuable input for the safety and feasibility assessments of ONDRAF/NIRAS in the context of its next programme milestone, i.e. Safety and Feasibility Case 1 (planned for 2015 at the earliest).

Objectives for 2011 - Evaluation

The main objectives for 2011 formulated in the Activity Report 2010 were as follows:

1. Installation of the PRACLAY Seal and Heater experiment

Installation of the secondary heater, backfilling of the gallery, final closure of the seal and hydration of the backfill sand during the first half of 2011.

2. Technical and scientific follow up of the PRACLAY Seal and Heater experiment

- Follow up the hydration and swelling of the bentonite in order to be able to decide when the Heater test can be started;
- Conduct baseline measurements before starting the Heater test;
- Follow up measurements and observations after starting the Heater test.

3. Scientific tasks related to the THM behaviour of a disposal system in a clay host rock

- Start of the fourth phase of the ATLAS Heater test;
- Start of the laboratory creep test at high temperature;
- State-of-the-art report on the unsaturated behaviour of the Boom clay (CIMNE PhD);
- Laboratory investigation of the anisotropic THM behaviour of the Boom clay.

4. Supercontainer feasibility demonstration test (on surface)

Publication of the final report on the first half-scale test and start of the second half-scale test.

5. Specific support to ONDRAF/NIRAS on disposal technology and 6. Safety and Feasibility Case 1

Continued participation and contribution of EIG EURIDICE in/to the SATELITE working group meetings of ONDRAF/NIRAS, contribution to the investigation on disturbances of the clay host rock and to the reporting within the context of *Safety and Feasibility Case 1.*

6. Operation and management of EIG EURIDICE and its facilities

Operation and management of EIG EURIDICE and its facilities according to the Statutory Rules of the EIG and in line with ISO 9001-2008 standard (external audit February 2011).

More specifically, the status of the hoisting system of the two access shafts will be assessed and, if necessary, adjustments suggested.

7. European Commission's FP7 MoDeRn project

Participation in and contribution to the European Commission's FP7 MoDeRn project according to the agreed work programme, with implementation of specific measuring techniques for the PRACLAY Heater test and the large-scale supercontainer feasibility demonstration tests.

8. Communication

- Organisation of the international event "30 years HADES" (23-25 May, Antwerp);
- Organisation of one Exchange Meeting (autumn 2011);
- Public tender contract for communication support (including the creation of a new website).

9. Knowledge domains of EIG EURIDICE

Based on the strategic objectives that were defined during 2010 in relation to its main knowledge domains, EIG EURIDICE will continue working on the development of long-term partnerships (e.g. with universities), management of the expertise within the scientific team and communication with all stakeholders. This will be done in close consultation with both partners, SCK•CEN and ONDRAF/NIRAS.

10. Surface disposal project for category A waste

EIG EURIDICE will support ONDRAF/NIRAS in preparing the safety case for surface disposal of category A radioactive waste by undertaking well-defined, scheduled tasks.

On 31 December 2011 the status of these objectives was as follows:

1. Installation of the PRACLAY Seal and Heater experiment

By the end of 2011 nearly all the components of the seal and heater experiment were installed (sand backfill, welding of seal, saturation of backfilled sand with water), bringing the experimental set-up to its final configuration awaiting switch-on of the heater system. The exact timing of the heater switch-on will be determined by seal performance: swelling pressure and permeability evolution of the bentonite ring in the seal structure.

2. Technical and scientific follow-up of the PRACLAY Seal and Heater experiment

During 2011 the saturation of the bentonite ring in the seal structure and its subsequent swelling behaviour were monitored and both predictive and interpretative modelling were performed. A thorough assessment of the evolution of swelling behaviour was conducted in the light of assessing the timing of switch-on (two-day workshop with external experts).

All measurements to establish baseline conditions for the heater experiment were continued.

3. Scientific tasks related to the THM behaviour of a disposal system in a clay host rock

- The fourth phase of the ATLAS heating test has been started;
- The laboratory creep tests at high temperature have been started;
- A state-of-the-art report on the THM behaviour of Boom clay with aspects related to unsaturated behaviour of Boom clay and Ypresian clays has been written (PhD thesis at CIMNE, Spain);
- Laboratory research on the anisotropic THM behaviour of the Boom clay was started.

4. Supercontainer feasibility demonstration test (on surface)

The final report on the first half-scale test on construction feasibility of the supercontainer was published. Preparations for the second half-scale test, to be performed during 2012 and 2013, got underway as planned.

5. Specific support to ONDRAF/NIRAS on disposal technology and 6. Safety and Feasibility Case 1

Continued participation and contribution of EIG EURIDICE in/to the SATELITE working group meetings of ONDRAF/NIRAS, contribution to the investigation on disturbances of the clay host rock and to the reporting within the context of *Safety and Feasibility Case 1* (planned by ONDRAF/NIRAS for 2015 at the earliest).

6. Operation and management of EIG EURIDICE and its facilities

Management and operation of EIG EURIDICE and its facilities was conducted according to the Statutory Rules of EIG and in line with ISO 9001-2008 standard (external audit on 10 February 2011).

The status of the two access shafts and the hoisting equipment was assessed. To conclude this assessment, EIG EURIDICE will proactively prepare the replacement of the hoisting system of shaft 1 (public tender procedure), in order to make the replacement in due time (2012-2013 timeframe).

7. European Commission’s FP7 MoDeRn project

EIG EURIDICE participated in and contributed to the European Commission’s FP7 MoDeRn project according to the agreed work programme. Its main contributions are the installation and use of specific measuring equipment in the PRACLAY Heater test and in the half-scale supercontainer feasibility demonstration tests (phases 1 and 2).

8. Communication

- EIG EURIDICE, together with its two constituent members, SCK•CEN and ONDRAF/NIRAS, organised an international event "30 years HADES" from 23-25 May 2011 in Antwerp;
- one Exchange Meeting was organised in December 2011 on the status of the ONDRAF/NIRAS disposal programmes (surface disposal project for category A waste, the waste plan for long-term management of category B&C waste and the R&D programme on geological disposal of category B&C waste);
- a public tender contract for supporting EIG EURIDICE in its communication activities (website and publications) was awarded through a public tender procedure.

9. Knowledge domains of EIG EURIDICE

Based on the definition of the strategic knowledge domains of EIG EURIDICE, decisions were taken to recruit additional scientific and technical staff in the fields of THM and instrumentation & monitoring. Discussions were launched to review the functioning of the advisory bodies (SAC – Scientific Advisory Committee and POP – Programming committee for underground testing) in order to make the necessary changes to the rules in 2012. Concerted action with SCK•CEN and ONDRAF/NIRAS directed at universities with a view to collaboration on Master's theses and PhDs is scheduled for 2012.

10. Surface disposal project for category A waste

As contractually stipulated, EIG EURIDICE supported ONDRAF/NIRAS in preparing the safety case for the nuclear licence application.

Objectives for 2012

1. Installation of the PRACLAY Seal and Heater experiment

- Installation of the secondary heater system to complete the set-up of the PRACLAY in-situ experiments;
- Positioning of the steel structure at the crossing of the connecting gallery with the PRACLAY gallery to avoid axial displacement of the PRACLAY gallery during heating phase (security);
- Installation of a permanent observation system in order to monitor the movement of the whole structure of the seal;
- Finalisation of the design of the structure to be used in the event of a leakage in the feed-throughs during the heating phase (security);
- Publication of the report on the 2^{nd} phase of the PRACLAY in-situ experiment, entitled "Installation of the PRACLAY seal and heater experiments".

2. Technical and scientific follow-up of the PRACLAY Seal and Heater experiment

- Testing the whole seal performance (cold condition) by slight pressurisation of the PRACLAY gallery;
- Follow-up of the hydration and swelling of the bentonite in order to be able to decide when the Heater test can be started. A second workshop on the heater switch-on is planned in the second half of 2012;
- Conducting baseline measurements before starting the Heater test;
- Follow up of the measurements and observations after starting the Heater test.

3. Scientific tasks related to the THM behaviour of a disposal system in a clay host rock

- Follow-up, analysis, interpretation and numerical investigation of the 4th phase of the ATLAS test;
- Continue the laboratory creep tests at high temperature;
- Continue the laboratory investigation of anisotropic THM behaviour of Boom clay;
- Numerical investigation of the excavation-damaged zone (EDZ) in Boom clay;
- Continue the laboratory investigation of THMC behaviour of Ypresian clays.

4. Supercontainer feasibility demonstration test (on surface)

Start the second half-scale test, perform corrosion tests and continue the numerical investigation of the first half-scale test.

5. Specific support to ONDRAF/NIRAS on disposal technology and 6. Safety and Feasibility Case 1

- Continued participation and contribution of EIG EURIDICE in/to the SATELITE working group meetings of ONDRAF/NIRAS, contribution to the investigation on disturbances of the clay host rock and to the reporting within the context of *Safety and Feasibility Case 1* (planned by ONDRAF/NIRAS for 2015 at the earliest).

- A state-of-the-art report on THM behaviour of the Boom clay, specifically a topic report on its "constitutive laws", with the focus on identifying the reference model of the Boom clay together with a range of associated reference parameters.

6. Operation and management of EIG EURIDICE and its facilities

Operation and management of EIG EURIDICE and its facilities according to the Statutory Rules of EIG and in line with ISO 9001-2008 standard (recertification audit February 2013).

Prepare the replacement of the hoisting system of shaft 1 (public tender procedure), in order to make the replacement in due time (2012-2013 timeframe).

7. European Commission FP7 projects

Participation in and contribution to the European Commission's FP7 MoDeRn project according to the agreed work programme, with implementation of specific measuring techniques for the PRACLAY Heater test and the large-scale supercontainer feasibility demonstration tests.

As coordinator of the European Commission's TIMODAZ project, EIG EURIDICE will organise an international post-TIMODAZ workshop in 2012, as defined and scheduled in the final dissemination plan of the project.

8. Communication

- Creation of a new website as part of the communication contract
- Communicate in different ways on the status of the PRACLAY experiment:
    - Scientific PRACLAY report: 2nd phase
    - A publication for a wide target audience on the PRACLAY experiment
    - News item about PRACLAY on the new website
- Organisation of an event on the occasion of the heater switch-on
- Organisation of an Exchange Meeting
- Implementation of changes to guided visits as planned (for example, new module on clay properties in the demo hall)

9. Knowledge domains of EIG EURIDICE

- Review the functioning of the advisory bodies (SAC – Scientific Advisory Committee and POP – Programming committee for underground testing) in order to make the necessary changes to the Rules in 2012.
- Take further concerted action for collaboration with universities on Master's theses and PhDs.

10. Surface disposal project for category A waste

EIG EURIDICE will support ONDRAF/NIRAS in the preparation and subsequent presentation and defence of the Safety Case for the near-surface disposal site for category A waste. This support concerns the tasks entrusted to EIG EURIDICE and will be provided as per the agreed planning.

Activities: PART I High-level and long-lived waste disposal

1. PRACLAY "Demonstration & confirmation experiments"

1.1. Introduction: the PRACLAY project

One of the aims of EIG EURIDICE is the development of the PRACLAY project to demonstrate the feasibility of the disposal of high-level, heat-producing vitrified radioactive waste or spent fuel in deep clay layers such as Boom clay.

The PRACLAY project consists of several sub-projects and experiments. Together, these are referred to as the PRACLAY "Demonstration & confirmation experiments". The aims of these experiments are:

- To demonstrate the feasibility of underground constructions in Boom clay;
- To demonstrate the feasibility of the disposal concept for high-level waste in Boom clay;
- To confirm and expand knowledge about the thermo-hydr o-mechanical (-chemical) behaviour of Boom clay and the gallery lining.

With the PRACLAY experiments, EIG EURIDICE is making an important contribution to Safety and Feasibility Case 1 (SFC 1) and 2 (SFC 2), which are part of the ONDRAF/NIRAS research programme for long-term management of category B&C radioactive waste.

In general, a distinction can be made between two groups of experiments: PRACLAY IN-SITU (meaning “in HADES”) and PRACLAY ON-SURFACE experiments:

PRACLAY IN-SITU

- **DEMONSTRATION EXPERIMENTS**
    - Second shaft
    - Connecting gallery
    - Gallery & Crossing test
    - PRACLAY gallery
    - Supporting studies: European Commission’s CLIPEX project
- **CONFIRMATION TESTS**
    - Heater test
    - Seal test
    - Supporting studies:
        - EDZ test (European Commission’s SELFRAC & TIMODAZ projects)
        - PhD theses (CIMNE, CERMES, ULG, IRSM)

PRACLAY ON-SURFACE

- **DEMONSTRATION EXPERIMENTS**
    - OPHELIE (SAFIR 2 repository design)
    - SUPERCONTAINER feasibility tests
        - Small-scale test
        - Half-scale tests
        - Annular backfill test in European Commission’s ESDRED project

PRACLAY IN-SITU experiments can be divided into demonstration experiments and confirmation tests. **Demonstration experiments** focused on excavation techniques and construction work. The excavation of the connecting gallery using a tunnelling machine, for example, demonstrated the feasibility of constructing galleries on an industrial scale. With the construction of the PRACLAY gallery in 2007, it was shown that it is possible to make perpendicular connections between a disposal gallery and a main gallery. Most of the demonstration experiments are now finished. **Confirmation tests** are focusing on confirming existing knowledge about the THM(C) behaviour of the Boom clay surrounding a disposal infrastructure. The Heater test is the main experiment in this regard. This test will be used to simulate the heat production of high-level vitrified waste or spent fuel on a large scale. In this way, researchers can observe and analyse the THM(C) behaviour of the Boom clay after excavation and subsequent large-scale heating. For this purpose, part of the PRACLAY gallery (30 m) is closed and will be heated for a period of 10 years at a temperature of 80°C at the point of contact between the gallery lining and the clay. After the construction of the PRACLAY gallery in 2007 and the design and installation of the seal (2007-2010), the heater system was installed in 2010 and 2011.

PRACLAY ON-SURFACE experiments are studying different components of a disposal system and comprise laboratory tests to characterise these different components and their interaction. Many of the aspects that are studied on the surface are based on a specific disposal system design.

The current Belgian reference design for heat-producing high-level radioactive waste is based on the supercontainer concept. Tests are performed on different scales to demonstrate the feasibility of the construction of a supercontainer.

1.2. Achievements in 2011

1.2.1. PRACLAY IN-SITU

The different parts of the PRACLAY Seal & Heater experimental set-up are shown in Figure 2.

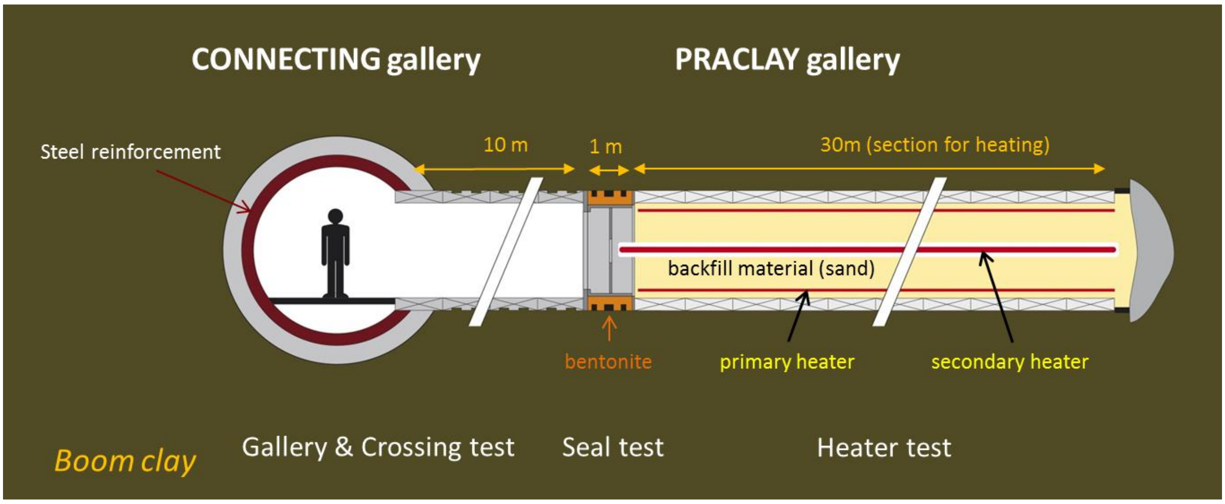


Figure 2 Design of the PRACLAY Seal & Heater experiment

After the excavation of the PRACLAY gallery in 2007, the hydraulic seal was designed and installed. The hydraulic seal consists of a stainless steel structure closing off the heated part of the gallery from the underground infrastructure and an annular ring of bentonite (MX80) placed against the clay. The hydraulic seal not only has to close the PRACLAY gallery; it also has to hydraulically cut off the excavation-disturbed zone around the gallery, which can provide a preferential pathway for water towards the main gallery. Bentonite has a very low hydraulic conductivity and swells when it is hydrated. The swelling pressure exerted by the hydrated bentonite on the clay will lower the hydraulic conductivity of the clay around the seal, thus creating the "undrained hydraulic boundary conditions" for the Heater test. The behaviour of the seal, and more specifically of the bentonite, is studied in the **Seal test**.

The closed part of the PRACLAY gallery (30 m) will be heated for a period of 10 years at a temperature of 80°C at the point of contact between the gallery lining and the clay. The PRACLAY **Heater test** studies the effect of this heat on the Boom clay on a representative scale in time and space. The aim is to confirm our understanding of the combined excavation-induced and thermal disturbance of the clay host rock and to demonstrate that these repository-induced thermal and mechanical disturbances of the clay host rock do not affect the containment and isolation capacity of the clay barrier.

A detailed report about the design, preparation and installation of the PRACLAY Seal & Heater experiment will be published in 2012, concluding the installation phase of the experiment.

In this section of the Activity Report, you will find the most important research and installation activities in 2011.

INSTALLATION OF THE HEATER

The primary heater was installed in the PRACLAY gallery in 2010. The gallery is divided into three sections (front, middle and end), each of which is subdivided into four zones (upper, lower, left, right). Each zone is equipped with two heater elements, ensuring 100% redundancy of the system.

Although no actual installation work concerning the primary heater took place in 2011, other activities were carried out. EURIDICE personnel received training on the heater control system. Furthermore, the performance of the heater cables was systematically monitored. After backfilling the upstream part of the PRACLAY gallery with sand and closing the hydraulic seal, one cable was found to be damaged. Due to the 100% redundant design, this will not affect heater performance.

BACKFILLING AND SATURATION OF THE PRACLAY GALLERY

After the installation of the heating system, the part of the PRACLAY gallery that will be heated was filled with Mol M34 sand. Backfilling was done in two phases: the first in May 2011, during which the gallery was backfilled except for the part just behind the hydraulic seal. Subsequently the last section of the central tube was installed. After this was done, the last section was backfilled in August and September 2011. In total, backfilling the gallery with approx. 100 m^3 of sand took 18 days.

Figure 3 Sand backfill operations

The backfill was delivered in big bags of 0.9 t (0.6 m^3) of sand. Three containers were used to transport the sand from the surface to the underground facility. There it was blown into the gallery using a shotcrete injection machine. The gallery was filled from the dead end towards the hydraulic seal by pulling back the injection tube. The injection was regularly stopped to inspect the sand front and to check that no cables (heating or instrumentation) were damaged.

The dry density of the backfilled sand is about 1.61 g/cm^3, which gives a saturated thermal conductivity of about 2.9 W/m.K and a saturated hydraulic conductivity of about 5.10^{-4}, thus meeting the requirements for PRACLAY backfill material.

On 28 November 2011 the process of saturating the backfill with water started. Ordinary tap water was injected through six filters placed at the bottom of the gallery. About 38 m^3 water was injected over 15 days. No water leakage through or around the seal was observed during the saturation phase. Several injection/venting loops were (and are still being) performed in order to achieve as near as possible full saturation of the PRACLAY gallery.

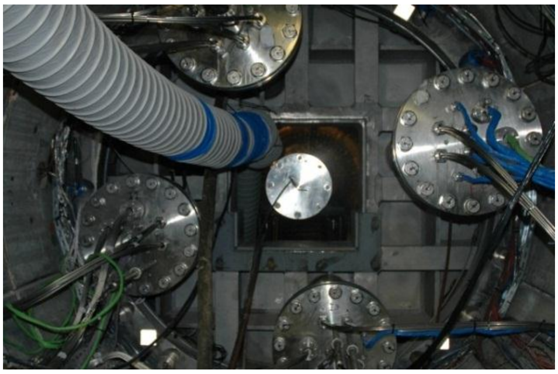
INSTRUMENTATION

Most monitoring equipment for the PRACLAY in-situ experiments was already installed, so no large-scale installation work was performed in 2011.

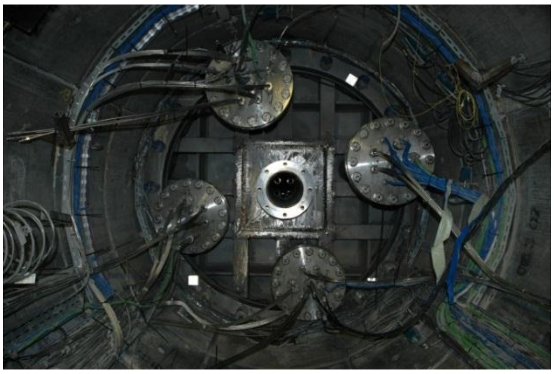
Prior to the final closure of the seal, the last feed-throughs were installed. Some non-standard cables were used: the coaxial signal cables for the seismic sensors and the extension cables for the fibre optic extensometers. The tubes for the seal injection system were also installed through the seal. Finally, a 55 m-long fibre optic cable for distributed temperature monitoring was blown inside an instrumentation tube and placed loop-wise inside the PRACLAY Gallery. The signals from the fibre are read using a rather experimental method (Rayleigh backscatter), a measurement technique investigated as part of the European Commission's MoDeRn project.

CLOSURE OF THE SEAL STRUCTURE

The hydraulic seal, installed in 2010, had a square manhole to keep the upstream part of the PRACLAY gallery accessible for the installation of the heating system and sand backfill material. After this work was completed, a plate was welded over the manhole in September 2011 to fully close the seal. This finalised the complete installation of the hydraulic seal.



(a)



(b)

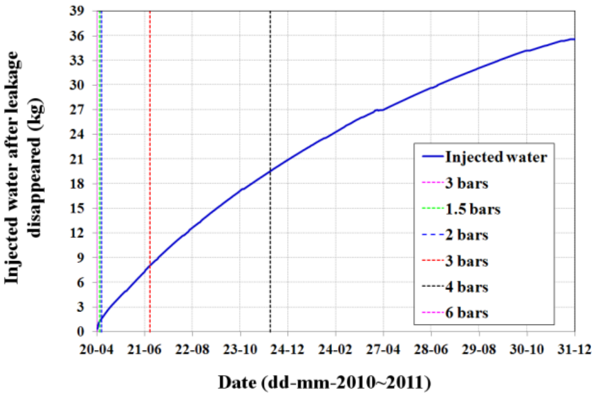
Figure 4 A central plate was welded onto the hydraulic seal and the central tube to close the manhole: (a) before welding; (b) after welding

THE SEAL TEST - EVOLUTION OF THE SEAL

The bentonite seal is hydrated by pore water coming from the Boom clay (since its installation in January 2010) and by water injected through filters placed on the extrados (outer surface) of the cylinder (since April 2010). Changes in the following **parameters** are monitored during the hydration of the bentonite:

- water injection rate
- relative humidity in the bentonite
- stress (swelling pressure) in the bentonite
- pore water pressure in the bentonite
- pore water pressure in the Boom clay around the seal
- displacement of the interface between the bentonite and the Boom clay

At the end of 2011, a total of about 35 kg of **water** was injected into the bentonite after the disappearance of a leakage that occurred at the beginning of the artificial injection phase (Figure **5**). There is no clear impact of the injection pressure on the injection rate, suggesting the persistence of high suction inside the bentonite.



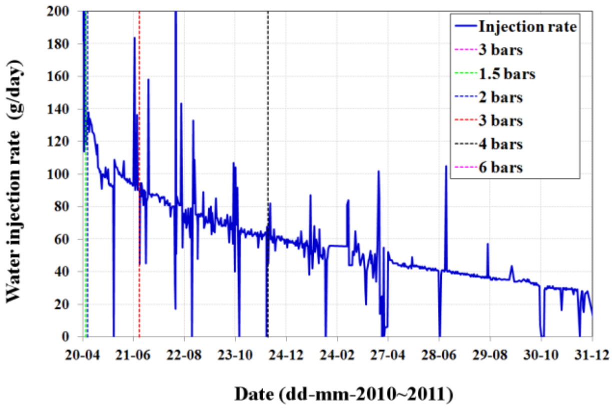


Figure 5 Artificial water injection of the seal:
total amount of water injected (left) and measured water injection rate (right)

Concerning **relative humidity**, all sensors failed once they came in contact with water, caused by artificial hydration of the seal. It is known that this kind of sensor is fragile once inundated with water. The interpretation of the measured data before failure is not straightforward. Probably the relative humidity sensors, which are placed along the technological void and the bentonite interfaces, rather measure the relative humidity of the air in the voids between the bentonite blocks than the relative humidity of the bentonite blocks themselves.

The evolution of the **stresses** (all stress values are relative) in the bentonite ring and the stresses exerted by the bentonite on the Boom clay and the steel structure of the hydraulic seal is shown in Figure 6, Figure 7, Figure 8 and Figure 9.

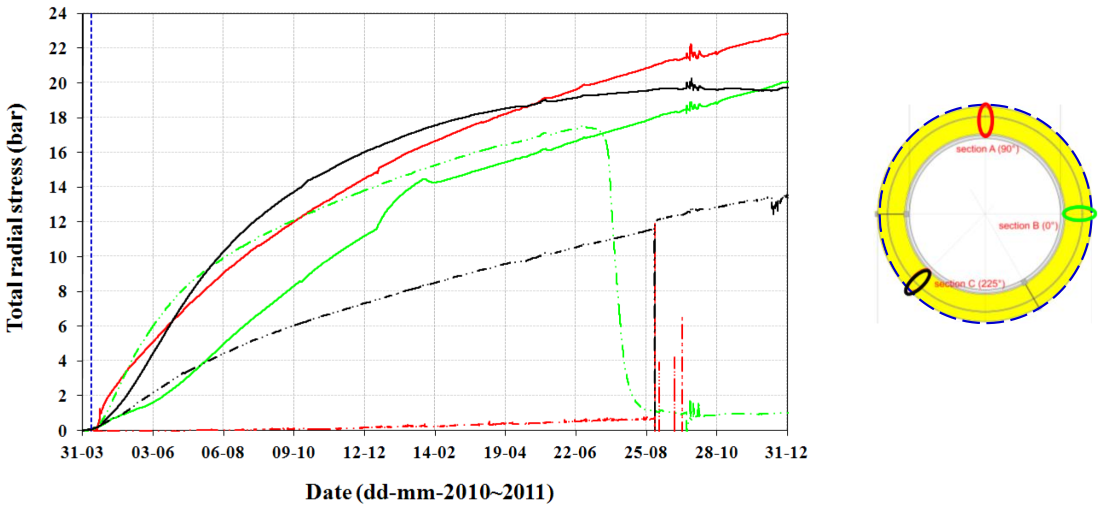


Figure 6 Radial stresses measured at the interface between the bentonite and the Boom clay sidewall

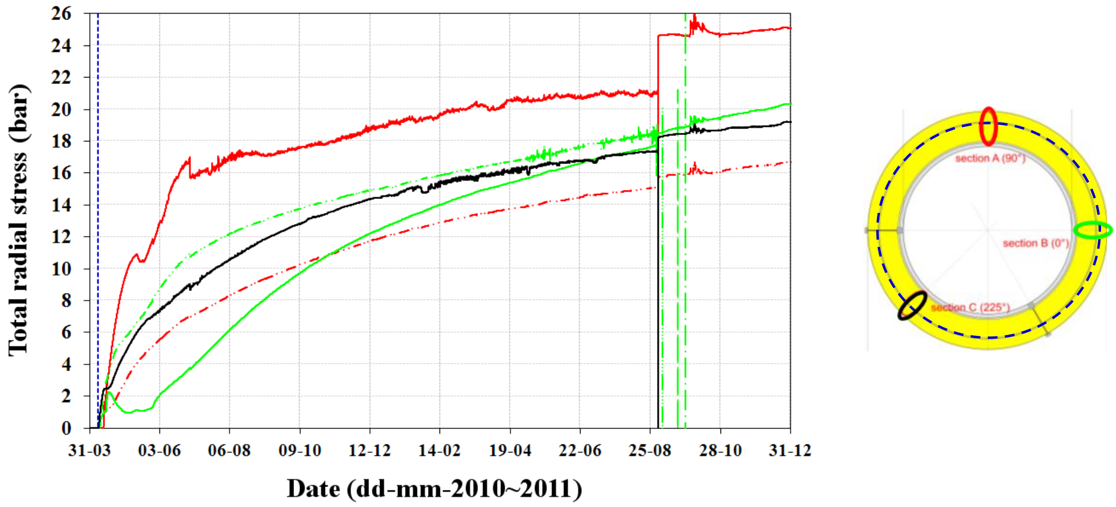


Figure 7 Radial stresses measured in the void between the inner and outer bentonite ring

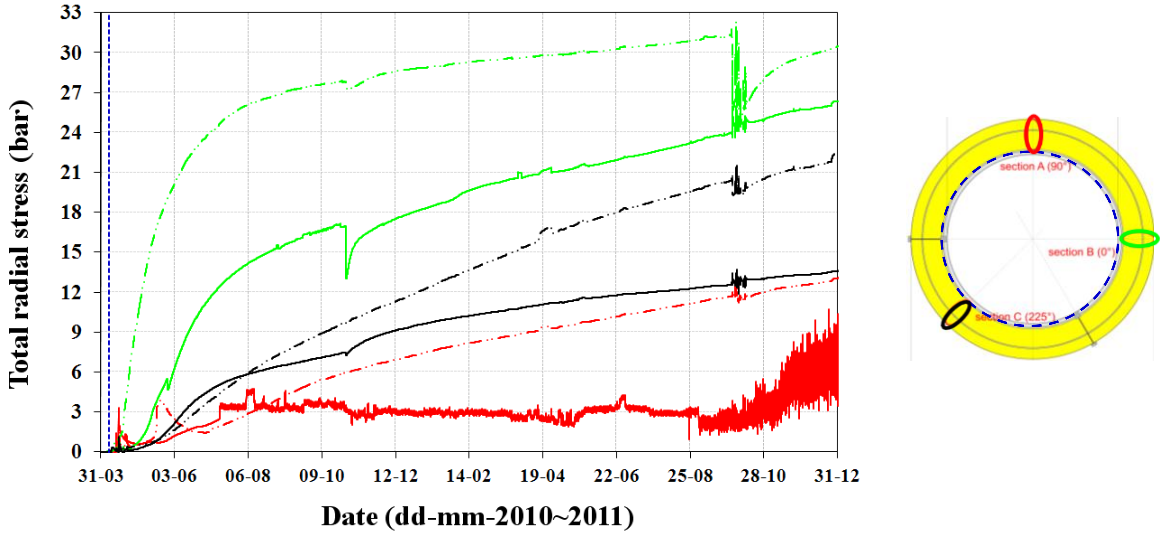


Figure 8 Radial stresses measured at the interface between the bentonite and the steel cylinder

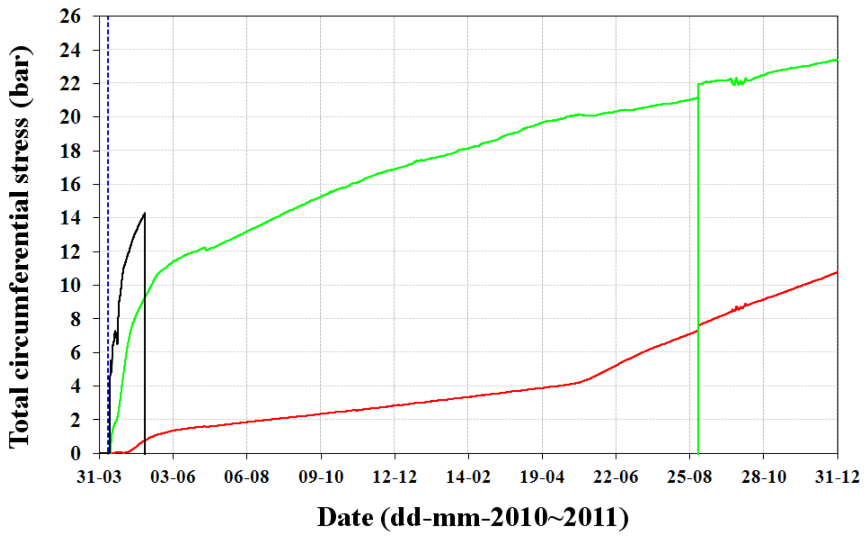


Figure 9 Circumferential stresses measured in the inner bentonite ring

Although the rate of increase differs for the different sensors, most of the sensors show a clear increasing trend. These stress increases started a few days after the start of the artificial hydration, indicating that during the first few days of artificial hydration, closure of the voids took place. After all voids closed, the stresses in the bentonite ring started to increase.

The stresses measured at the interface of the bentonite and the Boom clay and in the void between the inner and outer rings of bentonite show a relatively homogenous evolution. The former are mostly greater than 2 MPa (except for one sensor that shows a lower value) (

Figure 6), while the latter range from 1.7 MPa to 2.5 MPa (Figure 7). However, the swelling pressure measured at the interface between the bentonite and the steel cylinder is quite heterogeneous (Figure 8) due to the artificial injection filters that are installed in only two rings and do not cover the complete circumference.
The circumferential stress measured at section A (upper section) still shows a lower value, indicating the weak contact between the bentonite blocks, but is increasing more pronounced (Figure 9), which suggests the contact is improving.

The measured **pore water pressures** at the interface between the bentonite and the Boom clay are starting to show positive pore water pressures, indicating full saturation of the bentonite in the contact zone (Figure 10). However, the filters at the interface between the inner and outer bentonite rings and in the inner bentonite ring have not yet significantly deviated from atmospheric pressure, indicating the unsaturated state of the bentonite in these locations. This is confirmed by the results of manipulations performed on several filters to gain better insight into bentonite status since October 2010.

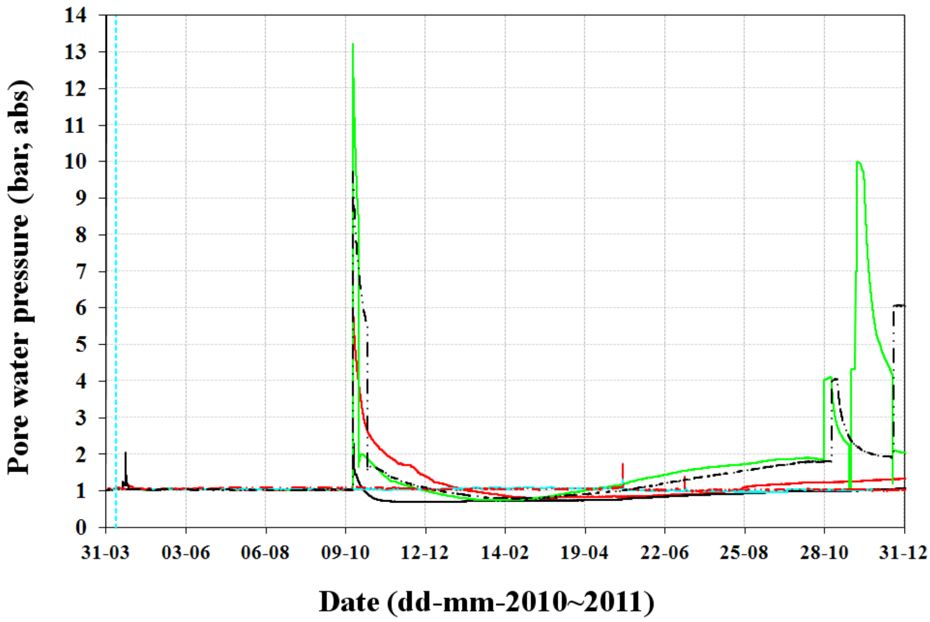


Figure 10 Pore water pressures measured at the interface of the bentonite and the Boom clay

Hydraulic conductivity was measured at the interface of the bentonite and the Boom clay (section C) and in the Boom clay in the vicinity of the seal. The values obtained on three filters in the Boom clay at a distance of 55 cm and 75 cm from the seal range from 3.5 to 4.1 x 10^{-12} m/s, which are very close to that of the undisturbed Boom clay. The value measured at the bentonite/Boom clay interface is less than 3 x 10^{-12} m/s, smaller than that measured in the Boom clay, indicating the seal's relatively good performance. Hydraulic conductivity will be systematically measured in and around the seal to test seal performance.

The **displacements** measured by the two extensometers in the bentonite ring are given in Figure 11. Both extensometers measured an outward displacement (swelling) of about 13 mm at the end of

2011, and show clear increasing trend. Unfortunately, both extensometers failed at the end of 2011 due to liquid water penetration when saturation of the gallery began.

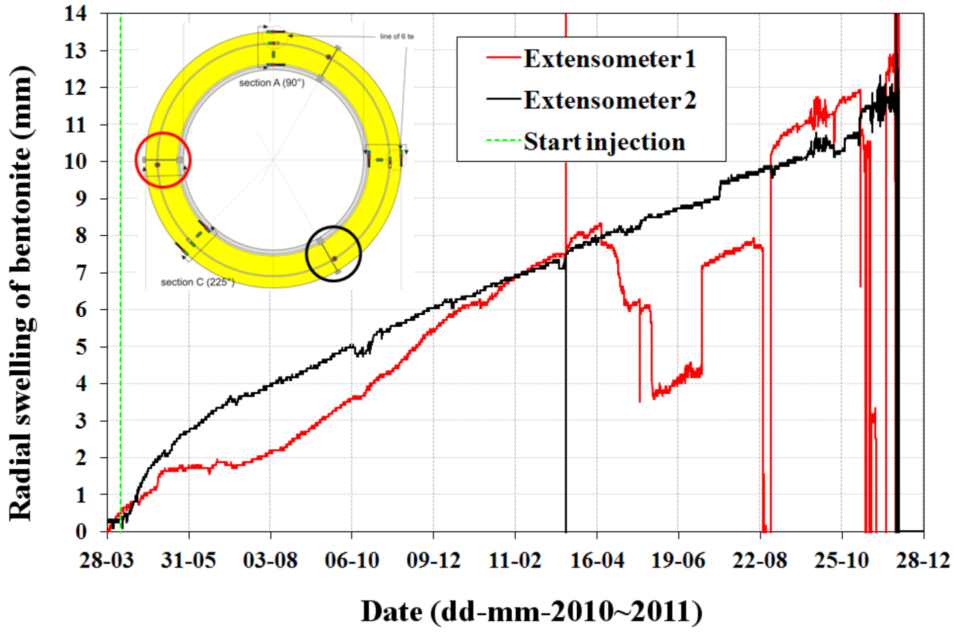


Figure 11 Measured radial displacement (an outward displacement is positive) of the bentonite ring

All together, these measurements indicate that bentonite hydration is evolving in the right direction. The bentonite has been swelling up to 13 mm towards the Boom clay, and most of the radial swelling pressures at the interface of the bentonite and the Boom clay are quite homogeneous and greater than 2 MPa. The stresses measured indicate that almost all the gaps in and around the seal were closed shortly after the start of the artificial injection. At the bentonite/Boom clay interface, pore water pressures higher than atmospheric pressure are measured, which indicates good saturation of this interface. Finally, the hydraulic conductivity measured at the bentonite/Boom clay interface is smaller than that measured in the Boom clay around the seal, which is similar (order of magnitude of 10^{-12} m/s) to hydraulic conductivities measured for undisturbed Boom clay.

NUMERICAL INVESTIGATION OF THE PRACLAY SEAL AND HEATER TESTS

Numerical simulations of bentonite hydration are made to get a better understanding of this hydration process. Modelling bentonite behaviour is difficult, however, as it involves a complex interplay of coupled THM processes.

First, a sensitivity analysis was carried out to determine the important factors affecting bentonite behaviour. This identified a series of questions and uncertainties. For example, what is the capability of the mechanical constitutive model used (BBM model) to simulate the behaviour of the compacted bentonite? Or how do the micro/macro-structures of the bentonite evolve and what is the evolution of bentonite permeability during the hydration/swelling phase? What can numerical simulations teach us about the interaction between the bentonite and the Boom clay?

By comparing numerical results with in-situ measurements, a set of "best parameters" and associated assumptions were then defined. Subsequently, this set was used to predict bentonite behaviour and the thermo-hydro-mechanical processes in the Boom clay during the Heater test. This predicted evolution was then evaluated (the bentonite should be sufficiently hydrated and swelled to create the most impermeable zone possible at the intersection of the heated and non-heated parts of the PRACLAY gallery to ensure the hydraulic boundary conditions of the PRACLAY Heater test).

A large number of scenarios were modelled. The prediction suggested that the heating phase can speed up the hydration process and the generation of swelling pressure. During heating, no negative stresses are predicted along the bentonite/Boom clay interface and the predicted pore water pressures around the heated section of the PRACLAY gallery correspond to the desired pore water pressure for the Heater test (as determined by the scoping calculation, assuming 1 metre of seal).

However, it is important to bear in mind that the numerical simulations are based on a set of assumptions and simplifications. Some additional laboratory tests are planned to gain better insight into bentonite hydration and, in particular, to verify the assumptions and simplifications made in the simulations.

WORKSHOP ON THE SWITCH-ON OF THE PRACLAY HEATER

A "PRACLAY Heater switch-on" workshop was held in Mol on 23-24 November 2011. The main objective was to discuss with some invited external experts the decision process to determine the appropriate moment for the PRACLAY heater to be switched on.

To substantiate a decision on switch-on, the following questions needed to be answered:

- Is bentonite behaviour in the seal sufficiently well understood?
- Can bentonite behaviour be predicted with sufficient confidence?
- Is there sufficient confidence that the bentonite will meet the requirements for the hydraulic seal by the proposed switch-on date?
- Is the test programme of the seal adequate and does it provide relevant indicators for deciding about switch-on?

The discussion was based on the evaluation of bentonite behaviour and the predicted evolution (see section on the numerical investigation) of the THM conditions in the Boom clay and hydraulic seal during the PRACLAY Heater test.

The findings of the workshop can be summarised as follow:

- The seal is evolving in the right direction, but still in a heterogeneous way. Total bentonite stresses (especially circumferential stress at section A) are still low. The technological voids have closed, but the hydro-mechanical properties of the closed voids need to be further investigated and monitored.
- Based on the **observations,** there is confidence that the seal can develop sufficient swelling pressures (with time). According to the **modelling**, the start of the heating process speeds up the hydration process and increases total stresses in the seal (sufficiently so that these stay above pore pressures), but modelling hypotheses still have to be further verified/confirmed.

As a result, the experts considered that, based on the current observations and **conservative** assumptions, there is **not yet** sufficient confidence that the seal will fulfil its role for switch-on, even though the modelling results suggested the contrary.

It was decided to start the saturation of the gallery as soon as possible and monitor the pressure evolution in gallery and seal behaviour and performance during saturation of the gallery. Pressurisation of the PRACLAY gallery could be one way to test overall seal performance. The experts suggested enhancing the risk analysis and further fine-tuning the models (hypotheses, constitutive law, etc.) to get more indicators for a new assessment of the switch-on in the course of 2012.

Expectations are that the switch-on can occur by the end of 2012, beginning of 2013.

SEISMIC MONITORING

The seismic installation in the HADES URF consists of 23 transmitters (T) and 19 receivers (R). The sensors used are micro-seismic piezoelectric sensors that can both transmit and receive signals. They are installed in boreholes as well as at the interface between the gallery lining and the Boom clay. (Figure 12)

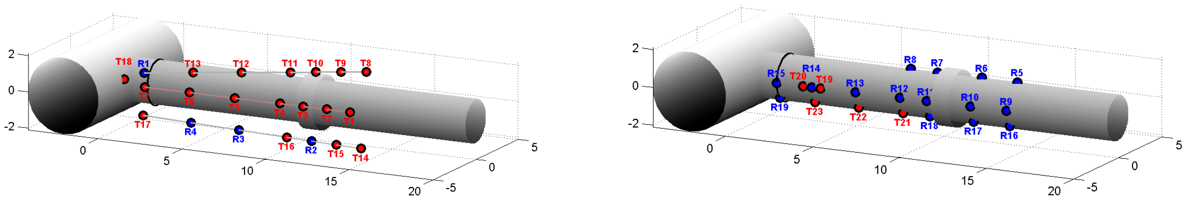


Figure 12 Transmitters (T) and receivers (R) installed in boreholes [left] and at the extrados (outer surface of the PRACLAY gallery [right].

The main objectives of the seismic installation are to:

- Determine both near- and far-field background seismic characteristics of the Boom clay;
- Monitor evolution of the excavation-damaged zone (EDZ) created around the PRACLAY gallery during and since its construction in 2007; and
- Provide seismic data on the Boom clay during the future PRACLAY heater experiment.

The seismic installation at HADES has continued to provide information in the near and far field around the PRACLAY gallery since the system was set up in 2006. The results of monitoring since construction of the PRACLAY gallery confirm the self-sealing properties of the Boom clay.

In 2011 efforts continued to recover S-wave signals from the recorded data by using windowing and filtering techniques during post-signal analyses. Due to the different frequency ranges observed for the P and S waves, both waves must be analysed separately. Measurements show that S waves contain frequencies mainly below 1 kHz, while P waves are detectable at all of the eight transmitted frequencies but show optimum resolution in the 7-23 kHz range. To improve overall signal-to-noise ratio and to optimise the detection of S waves, it is necessary to apply a strong low-pass filter (5 kHz or lower) that matches the S-wave frequency content.

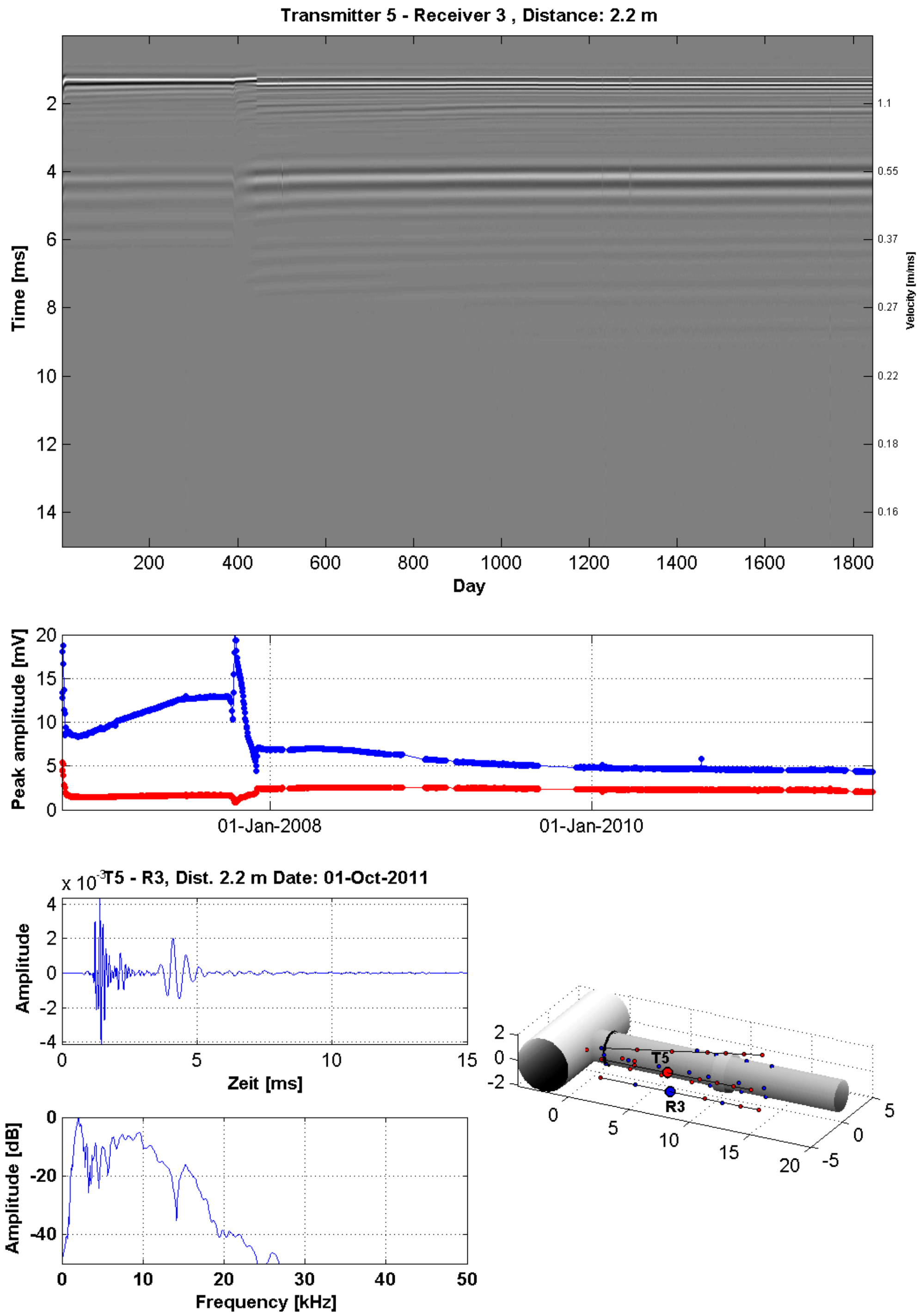


Figure 13 Evolution of P and S-wave signals between transmitter T5 and receiver R3 from 2006 to 2011 using a low-pass 5 kHz filter

Analysing the data with a low-pass filter now enables the detection of S waves in most of the recorded signals (
Figure **13**). In the future, it should be possible to enhance the generation and detection of S-wave rich signals using a special S-wave source. A design for such a source was finalised by EURIDICE in 2011 as part of final-year thesis work carried out by Maickel Spong during his training at SCK•CEN's DEO. A prototype of the source is being constructed at SCK•CEN and is partly financed by the European Commission's MoDeRn Project, for which a demonstration test is planned in 2012.

1.2.2. PRACLAY ON-SURFACE

HALF-SCALE TESTS

The half-scale tests are part of the ON-SURFACE experimental programme aimed at demonstrating the feasibility of constructing the different components of the supercontainer. The primary goal is to demonstrate the feasibility of constructing the supercontainer using currently available techniques. In addition, the tests contribute to the validation of finite element method (FEM) calculations performed to simulate the thermo-hydro-mechanical (THM) behaviour of the concrete materials and provide valuable practical experience for optimising the design, safety and construction procedures for the supercontainer.

Figure 14 Half-scale test set-up

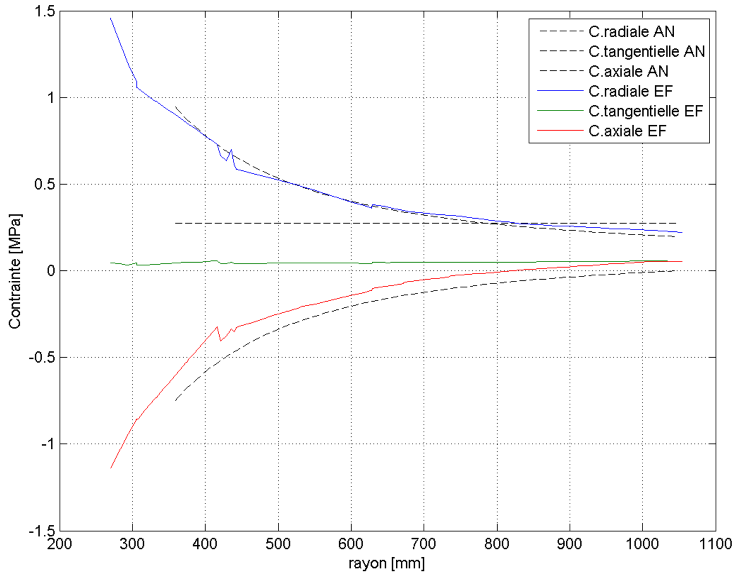
The first half-scale test was performed in 2009. The results highlighted a number of aspects that need further investigation in order to improve the construction quality of the supercontainer. These include:

- Possible cracking of the buffer caused by thermal and mechanical stresses
- Level of adhesion between concrete filler and metal overpack
- Challenges involved in providing a homogeneous concrete mixture
- Corrosion aspects of the overpack

In 2011 finite element analyses were started to gain further insight into the thermo-mechanical behaviour of the concrete buffer. These analyses are ongoing and focus primarily on the likelihood of the concrete buffer developing fractures under thermal load as well as the interaction between the overpack and filler during the heating phase. Where possible, input parameters obtained from the first half-scale test are used in the model in order to validate its results.

Analyses were also started in 2011 to re-evaluate the 2D axisymmetric heat transport calculations carried out previously by SCK•CEN (Thermal analysis of the supercontainer concept, E. Weetjens and X. Sillen). These thermal scoping calculations show a higher temperature than that observed in the first half-scale test. The new scoping calculations will use the new parameters obtained from the half-scale test in order to fine-tune the model.

Finally, a Master's thesis was completed in 2011 by Nordhal Mallinus at ECAM under the supervision of EIG EURIDICE: *Étude du Comportement Thermomécanique du supercontainer destiné à l'Emballage de Déchets Hautement Radioactifs pour l'Entreposage dans un Dépôt Géologique Profond* (Mallinus, 2011). The main objective of the thesis was to verify the thermo-mechanical behaviour of the supercontainer. In particular, emphasis was placed on the dilation of the overpack after casting of the filler, the evolution of temperature in the supercontainer and the likelihood of these two factors causing micro-fissuring of the concrete buffer. The results obtained using both finite element and analytical analyses indicate maximum stresses at the surface of the supercontainer of approximately 0.2 MPa due to dilation of the overpack and 3.3 MPa due to thermal gradient. Given the concrete's tensile strength of 4.1 MPa, the results suggest that neither the thermal nor the dilation stresses generated in the supercontainer are sufficient to cause fracturing of the concrete buffer.



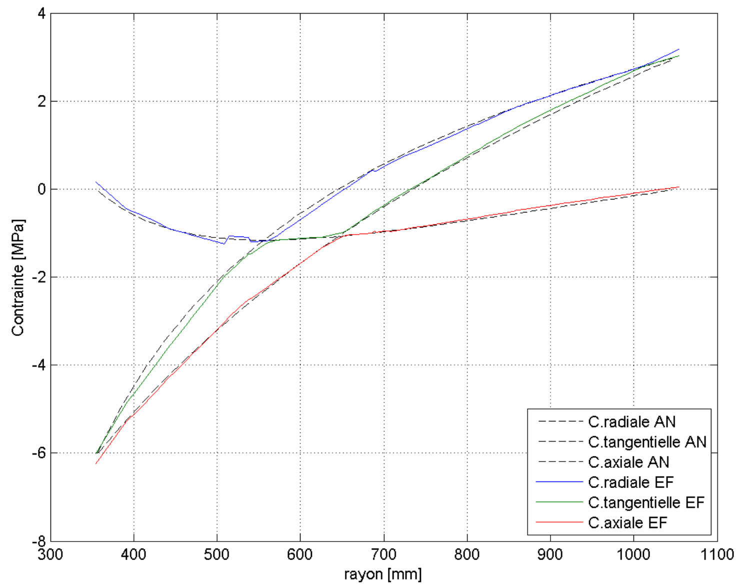


Figure 15 Simulated stresses due to dilation of the overpack [top] and due to thermal gradient [bottom] (positive: traction, negative : compression)

The second half-scale test is planned for 2012 and will mainly address the following aspects:

- thermal gradients and their potential for crack development in the concrete buffer;
- interface adhesion between overpack, concrete and filler;
- test of new low-modulus concrete filler to absorb tensile stresses due to dilation of the overpack; and
- corrosion development of the overpack.

2. Supporting studies

2.1. ATLAS

The small-scale in-situ ATLAS (**A**dmissible **T**hermal **L**oading for **A**rgillaceous **S**torage) tests are performed to assess the thermo-hydro-mechanical behaviour of the host Boom clay at the HADES underground research facility.

From July 1993 to June 1996, a constant heat source of 900 W was used in the first phase of the ATLAS heating test programme, later named ATLAS I. During the second phase (ATLAS II), the power was increased to 1800 W and kept constant from June 1996 to May 1997. This was followed by shutdown and natural cooling, starting in June 1997.

To broaden the THM characterisation of the Boom clay on a larger scale and at different temperature levels, the test set-up was extended in 2006 by drilling two additional instrumented boreholes (AT97E and AT98E) (Figure 16). The heater was switched on again from April 2007 to April 2008 with a stepwise power increase, followed by instantaneous shutdown. This phase is called ATLAS III. The extended picture of the temperature field provides clear evidence of the thermal anisotropy. Moreover, the pattern of the thermally induced pore pressure evolution measured in the bedding plane can be numerically interpreted by mechanical anisotropy.

To gain better insight into the anisotropic THM behaviour of the Boom clay, a new upward, instrumented borehole AT90IU was drilled above the ATLAS heater at the end of 2010 (Figure 17). The new cycle of heating and cooling (ATLAS IV test) started on 18 October 2011, and the same heating strategy as for ATLAS III was used to facilitate interpretation. The available measured variation of the pore water pressure from the upward borehole was as expected, which confirms the mechanical anisotropy of Boom clay. A heating-pulse test is also planned at the end of the ATLAS IV test to determine the "ultimate" heating limit the Boom clay can sustain.

The ATLAS test described above provides a large set of good-quality, well-documented data on temperature, pore water pressure and total stress, and many interesting observations can be made. The set-up of the tests has a simple geometry, essentially depending on a single material (Boom clay), and it has well-defined boundary conditions, which facilitates comparison between measurement and numerical modelling. This test also serves as preparation for a full-scale PRACLAY Heater test.

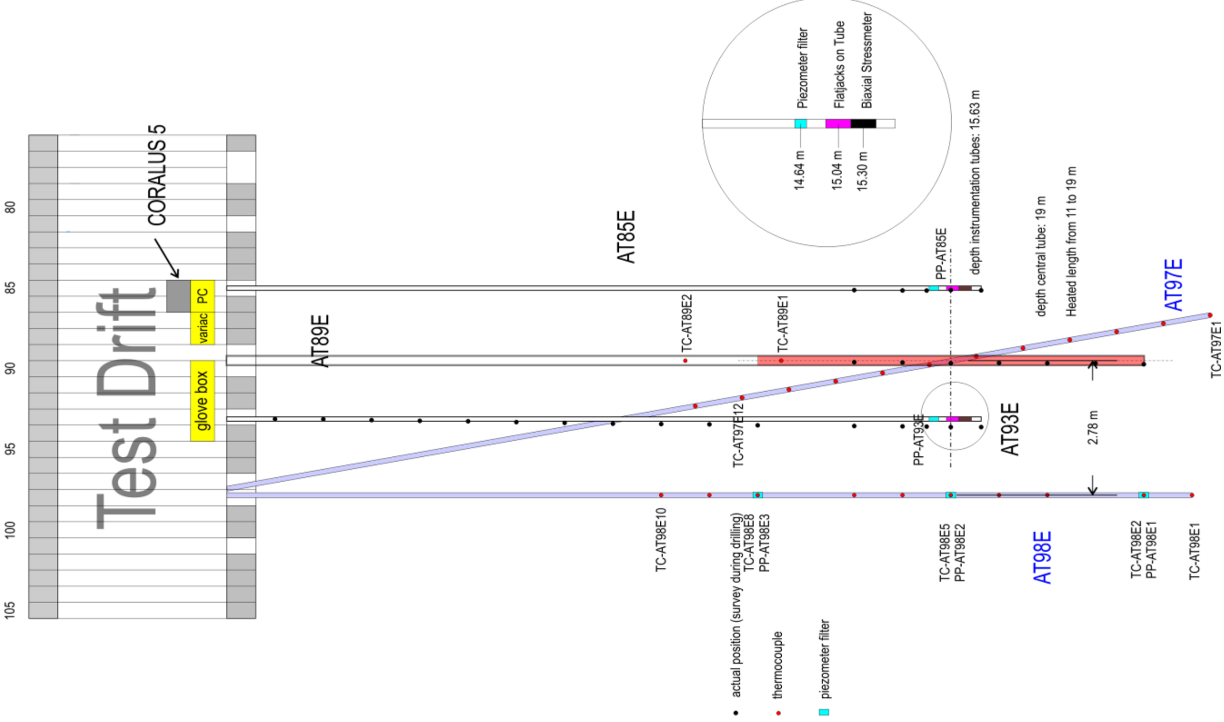


Figure 16 Schematic view of the small-scale in-situ ATLAS test

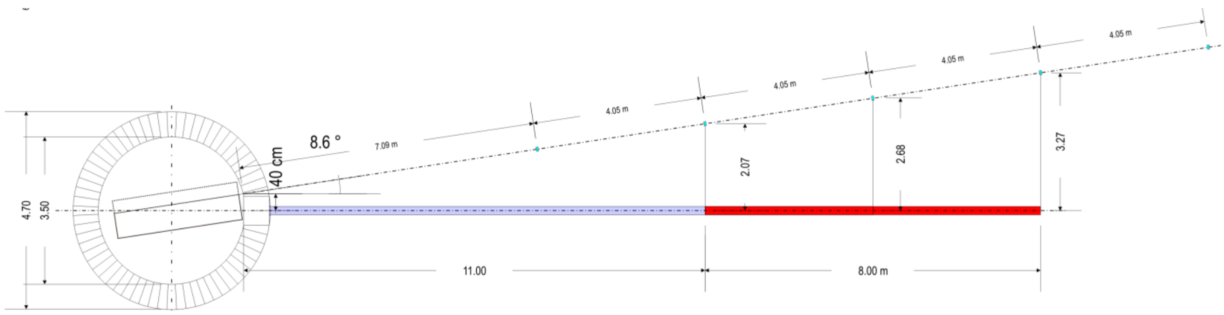


Figure 17 Upward borehole AT90IU drilled above the heater for ATLAS IV

2.2. PhDs

As part of research activities, especially the PRACLAY in-situ experiments, a specific THMC (thermo-hydro-mechanical-chemical) characterisation programme on Boom clay was run in parallel with the design and installation of the PRACLAY experiments in cooperation with different universities and laboratories through a PhD programme. EIG EURIDICE is involved in the definition and follow-up of the PhD research programme.

Meanwhile, in the context of the ONDRAF/NIRAS research programme for geological disposal to examine alternative host formations for HLW disposal, several PhD programmes investigating the THMC behaviour of Ypresian clays are underway and are being monitored and supervised by EIG EURIDICE.

CIMNE (Universitat Politècnica de Catalunya. BarcelonaTech (UPC), Spain)

A PhD thesis entitled "Thermo-hydro-mechanical behaviour of two deep Belgian clay formations: Boom and Ypresian clays" was submitted and successfully defended by Analice Lima. As part of research for the thesis, Boom clay and Ypresian clay samples were thoroughly studied from an experimental point of view using advanced techniques to analyse their coupled behavioural response along thermo-hydro-mechanical paths. Besides hydraulic and mechanical paths at different temperatures, other aspects considered included sensitivity to heating pulse tests, anisotropy effects and stress paths involving partially saturated states. To perform these tests, special equipment and set-ups were developed and adapted. Oedometer cells were specifically adapted to control vapour pressure at different temperatures, isotropic cells with local axial and radial measurements were specially adapted for vapour transfer, and constant volume cells in thermal baths were adapted to capture the thermal sensitivity of water permeability. The constant volume and fully instrumented heating cell – with several thermocouples and pressure transducers – was updated to analyse the impact of relatively fast thermal pulses on the pore pressure build-up and dissipation features of these low permeability materials. Thermal pulses were analysed by numerical simulations performed with the finite element code CODE_BRIGHT.

The results of this PhD research improve understanding of the THM behaviour of the Boom clay; the THM parameters obtained in heating pulse tests are consistent with those deduced from the in-situ ATLAS III test. The test results on Ypresian clays and their comparison with those for Boom clay constitute important input for the knowledge transferability study of different clay formations.

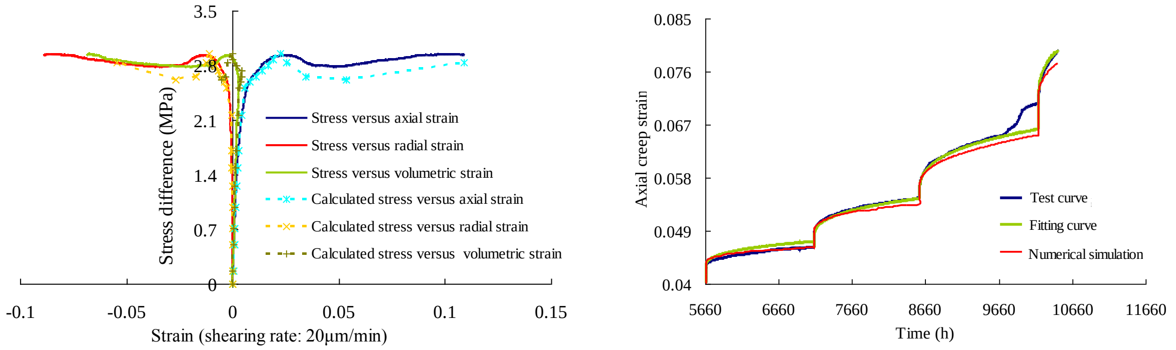
IRSM (Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China)

The main objectives of the cooperation with IRSM are to study the long-term hydro-mechanical behaviour of the Boom clay by performing laboratory creep tests at a very low loading rate for a very long time and back-analysing the long-term field measurements obtained around HADES in order to gain a deeper understanding of the creep mechanism of the Boom clay and acquire knowledge and information that can be used to simulate the “PRACLAY Experiment”.

Activities during 2011 focused on:

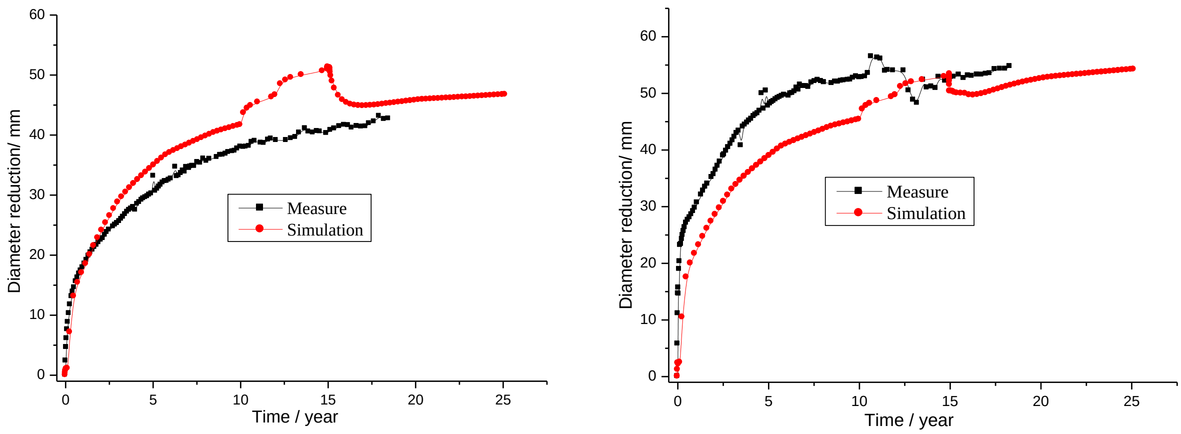
Further development and validation of the elasto-visco-plastic-damage coupled with the self-sealing constitutive model.

Figure 18 shows the validation of the constitutive model by simulating the laboratory tests on Boom clay. Figure 19 shows the application of the constitutive model by simulating the long-term HM measurements around HADES. Figure 20 illustrates the improvement in the developed model by comparing modelled and measured pore pressures around the connecting gallery. Figure 21 illustrates the numerical investigation of self-sealing of the Boom clay around the connecting gallery. For comparison purposes, in-situ measurements of the hydraulic conductivity around the connecting gallery are also given, which show the model can reproduce the self-sealing process around the connecting gallery fairly well.



a) triaxial test b) triaxial creep test

Figure 18 Validation of the elasto-visco-plastic-damage model: simulation of the laboratory tests on Boom clay



a) ring 43 b) ring 105

Figure 19 Simulation of long-term behaviour of HADES: long-term convergence in different rings of Test Drift

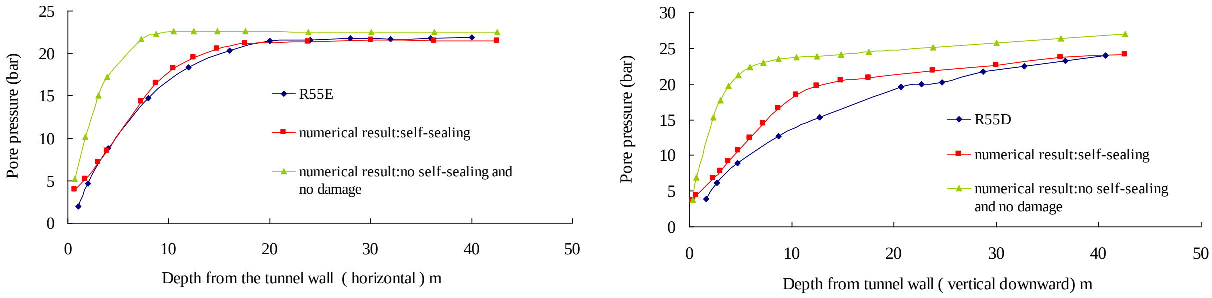


Figure 20 Comparison of numerical/in-situ measurement: pore water pressure profile nine months (left) and two years (right) after excavation of the connecting gallery

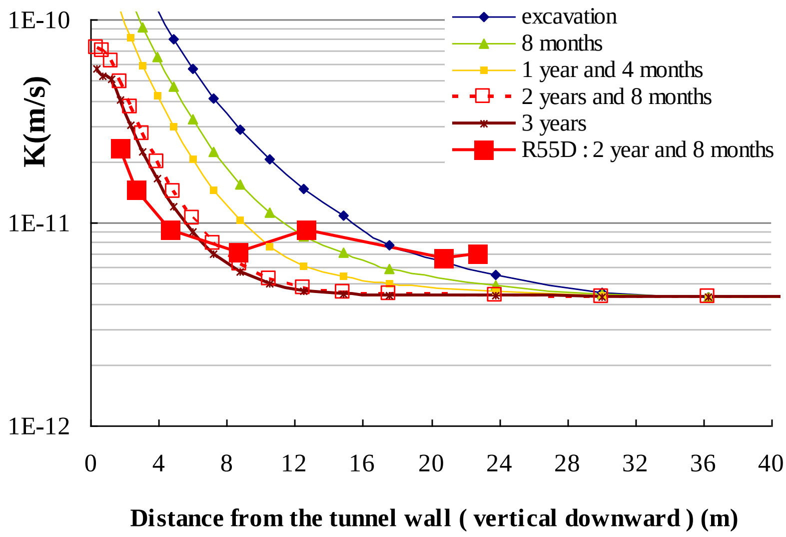


Figure 21 Investigation of self-sealing of Boom clay: predicted and measured horizontal hydraulic conductivity evolution around connecting gallery (R55D :in situ measurement)

Laboratory creep tests

During 2011, laboratory activities consisted mainly in updating the triaxial creep cells to a high-temperature environment. The updated cells were then first tested on the local (China) clay samples and poorly preserved Boom clay samples. At the end of 2011, new laboratory creep tests on Boom clay samples at high temperature were started with the aim of studying the temperature effect on the creep rate of the Boom clay.

CERMES (Centre d'Enseignement et de Recherche en Mécanique des Sols, France)

THMC behaviour of Ypresian clays

In 2010 a three-year PhD research programme on "THMC behaviour of Ypresian Clay", financed directly by ONDRAF/NIRAS and monitored/supervised by EURIDICE, was started at CERMES. This PhD thesis will be completed as part of the ONDRAF/NIRAS research programme to examine alternative host formations for high-level waste disposal. The focus is on fundamental THM behaviour characterisation by means of laboratory tests. More attention is paid to the pore water chemistry effects on THM behaviour. In order to provide input for the knowledge transferability study of different clay formations, comparative tests on Boom clay will also be performed for this PhD thesis.

THM behaviour of Boom clay

A new PhD research programme entitled "Investigation of anisotropic behaviour of Boom clay" was started at CERMES. The European Commission’s TIMODAZ project has already highlighted the important anisotropic THM behaviour of Boom clay and revealed the necessity for further investigation. The newly launched PhD programme is in three parts:

1. Literature review
2. Experimental study
   - anisotropic hydraulic conductivity determination
   - anisotropic thermal conductivity determination
   - K0 determination
   - mechanical anisotropy in triaxial cells equipped with bender elements and/or ultrasonic sensors
   - microstructure investigation: initial state and its evolution under different loading paths
3. Constitutive modelling

ULG (University of Liège, Belgium)

A new PhD research programme on the EDZ started at the end of 2011 at ULG, focusing on the **numerical simulation of the EDZ** structure and fractures, based on the strain localisation concept and on short-term behaviour. The challenge will be to reproduce, at least partly, the in-situ observations – displacements, pore pressure evolution, fractures – around recent galleries in the HADES URF. This thesis is financed directly by ONDRAF/NIRAS and will be supervised jointly by EIG EURIDICE and SCK•CEN.

3. Participation in international research projects

3.1. European Commission projects

TIMODAZ

TIMODAZ officially ended in 2010. As coordinator of the project, EIG EURIDICE is preparing to organise an international post-TIMODAZ workshop, as defined in the "final dissemination plan" in the "final activity report of the TIMODAZ project".

FORGE

EIG EURIDICE provided design and installation support to SCK•CEN for the FORGE (Fate of Repository Gases) European Project FP7 Work Package 4, which deals with gas transport in-situ tests. The aim of these tests is to simulate on a relatively large scale the expected sequence of phenomena in a medium-level waste (MLW) repository that could lead to gas-driven radionuclide transport. To this end, a dual-packer system and two multi-filter piezometers were installed in the HADES URF. The large packers simulate in a controlled way the action of a swelling clay seal on the host rock and especially on the sealing of the excavation-damaged zone (EDZ). The packers are instrumented with displacement sensors covering the radial directions. There are two different filter sections in the packers: one for injection and the other for detection. The injection filters enable injection of different tracer solutions and are designed such that the dead volume of the injection chamber is kept to a minimum.

For this main experimental set-up, EIG EURIDICE provided the design and installation of:

- An instrumented large-diameter (355.6 mm) dual-packer system;
- Two multi-filter monitoring piezometers.

As part of the FORGE project, EIG EURIDICE was also responsible for the design and installation of:

- Dual-tube pore water filters in the seal of the PRACLAY gallery;

The FORGE dual-packer system was installed in HADES in June 2011, opposite the PRACLAY gallery. (Figure 22, Figure 23 and Figure 24)

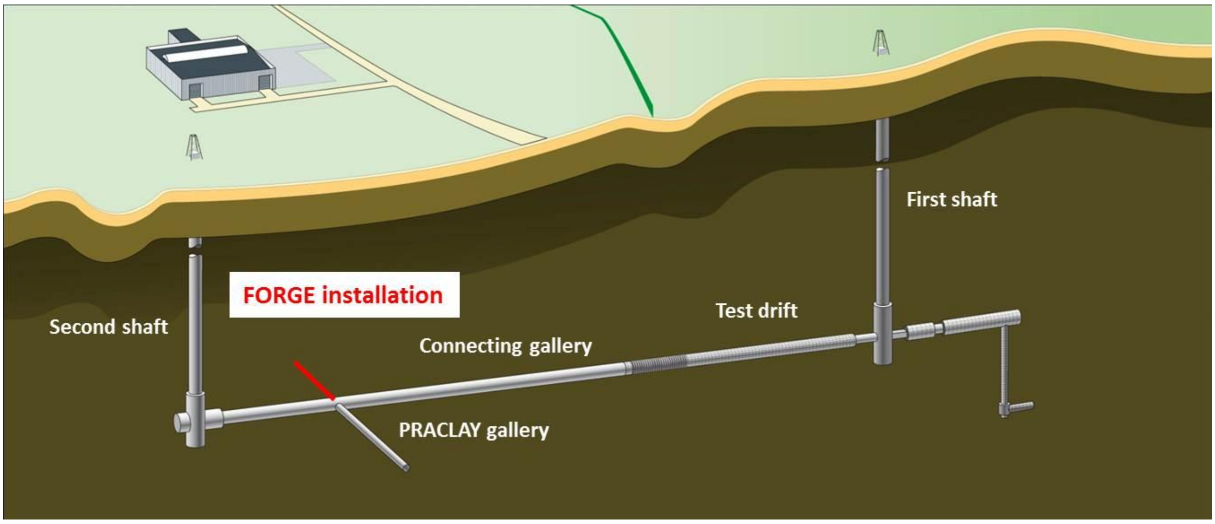


Figure 22 Installation of FORGE, opposite the PRACLAY gallery.

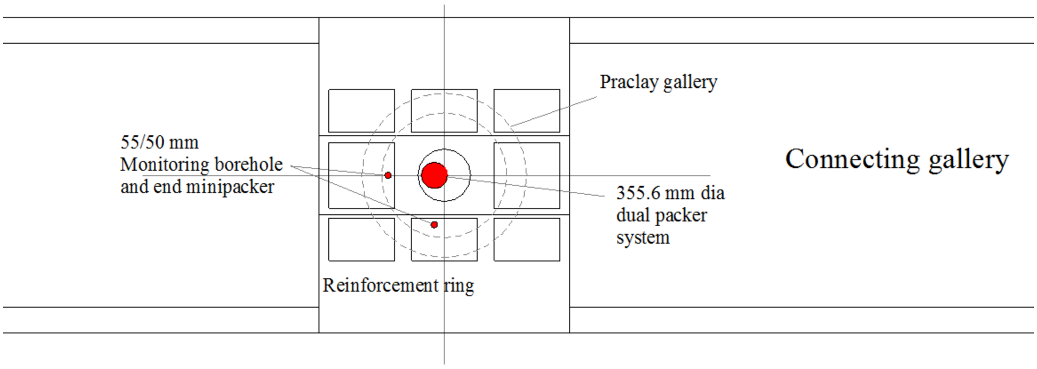


Figure 23 Location of the FORGE dual packers and monitoring piezometers in HADES

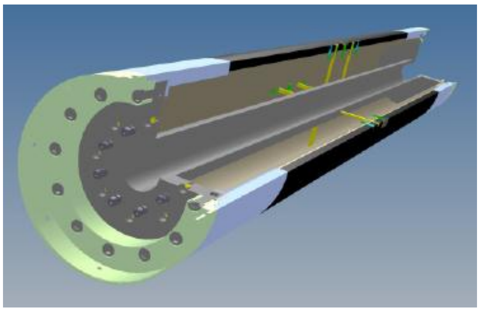
Detection filters located in the large packers and in the multi-piezometer observation boreholes allow monitoring of the diffusion of contaminants both parallel and perpendicular to the bedding plane. Filter sections located between the packers are used for injection of gas and anionic tracers. Combined use of both active and non-active tracers is possible. The two multi-filter piezometers surrounding the large packers measure the water pressure profiles in the Boom clay and monitor the evolution of the tracer concentrations as a function of time.

The large packer system has the following characteristics:

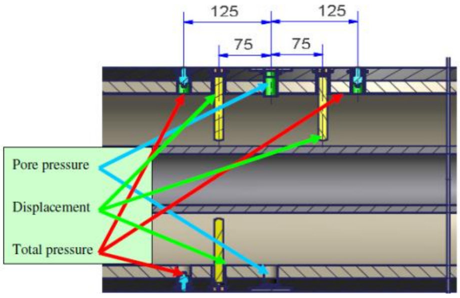
- Nominal diameter: 355.6 mm;
- Inflatable diameter: 340-440 mm;
- Max. working pressure: 120 bar; and
- Depth of installation in the clay (distance from gallery lining): 18.5 m.

The packer system is fully instrumented to measure:

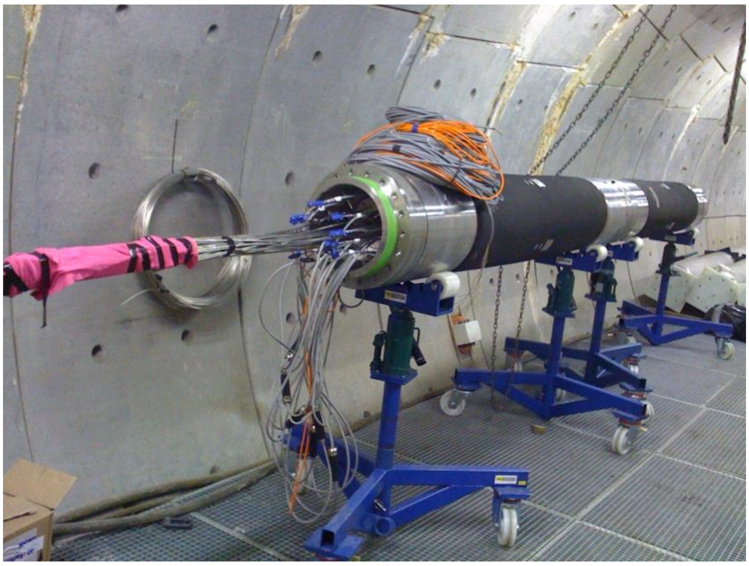
- Gas injection and detection pressure;
- Packer inflation pressure;
- Packer displacement;
- Pore water pressure; and
- Total stress.



3-D view and section through packer



Cross-section showing instrumentation



FORGE packers being assembled in HADES

Packers ready for installation

Figure 24 Installation of FORGE packer system

MoDeRn

MoDeRn (Monitoring Developments for Safe Repository Operation and Staged Closure) is a collaborative 7th Framework Programme (FP7) Euratom project. Started on 1 May 2009, it involves 18 partner organisations drawn from across Europe, Japan and the United States of America. The French Radioactive Waste Management Agency ANDRA is project coordinator. The original project duration of 48 months was extended by six months in 2011, so that the project will now run until 1 November 2013.

The MoDeRn project aims to provide a reference framework for the development and possible implementation of monitoring activities and associated stakeholder engagement during relevant phases of radioactive waste disposal, i.e. during site characterisation, construction, operation and staged closure, as well as during a post-closure institutional control phase. Activities within the MoDeRn project consider a range of strategic, technical and social issues associated with monitoring geological disposal and are split into a number of work packages (WPs):

- WP1: Monitoring objectives and strategies.
- WP2: State of the art, and research and technological development (RTD) of relevant monitoring technologies.
- WP3: *In situ* demonstration of innovative monitoring techniques.
- WP4: Case study of monitoring during all stages of the disposal process.
- WP5: Synthesis and dissemination of MoDeRn project results.
- WP6: Reference framework for repository monitoring.
- WP0: Consortium management and progress assessment.

EIG EURIDICE is involved in all relevant WPs. The work on WP1 and WP4 mainly involves desk studies, while WP2 and WP3 entail field work. Regarding the latter, an effort was made – when defining our contribution to the overall project – to incorporate the work being done within the PRACLAY experiment into this project.

The work performed under WP1 consisted of contributions to the monitoring framework, which is a general document at a strategic level ("Monitoring Objectives and Strategies"). The social aspects of monitoring are also part of this WP, and EURIDICE assists the University of Antwerp in a national exercise where the attitude of "lay stakeholders" towards monitoring in the context of an HLW disposal programme is investigated.

WP2 deals with sensor technology. EURIDICE has contributed towards the state-of-the-art report, drawing on its expertise gained over the years running different experimental set-ups in HADES and at the surface, complemented by a literature review. The sensor techniques EURIDICE is concentrating on are fibre optic sensor technologies, monitoring of cement-based materials (playing an important part in the supercontainer concept), and seismic techniques.

The demonstration of sensor technologies is the subject of WP3. In the framework of fibre optic sensor technology, we installed a fibre optic extensometer inside the PRACLAY Gallery, as well as an optical fibre for distributed temperature measurements. The latter has been installed in an instrumentation tube more than 50 m long to allow for optional replacement of the fibre for maintenance or research purposes.

Demonstration of monitoring of cement-based materials will be implemented mainly as part of the supercontainer instrumentation programme. No field work was carried out in 2011, but is planned for 2012. Concrete monitoring has been performed on an extensive scale, however, as part of the cAt demonstration test (see Part 2 of the 2011 Activity Report) – the experience gained will provide important input for the planned field work.

The seismic monitoring technology demonstration draws on the seismic set-up installed around the PRACLAY Gallery. The original signal processing – based on the analysis of amplitude and speed of the seismic waves in general – is being optimised to unlock much more information that is contained in these signals. Work has been done on the frequency content of the signals – which also allowed a more detailed analysis of the shear waves.

As a partner in the MoDeRn consortium, NRG also performed some tests in HADES with their system for wireless transmission from below ground to the surface – through the overlying clay and sand layers. This system is based on transmission by magnetic induction based on ultra-low frequencies (around 1 kHz).

The results of the previous WPs are then incorporated into WP4, where a case study of monitoring at all stages of the disposal process is worked out. This is intended to tackle all relevant monitoring aspects by going through a system based on different monitoring concepts and adapted to the different host rocks and engineered barrier designs. In practical terms, three case studies are being developed, one for each main type of host rock (clay, granite and salt). The clay case study, in which EURIDICE is also involved, is based on the indurated clay types considered by ANDRA (coordinator of this case study) and NAGRA. The study starts by mapping all processes and parameters to be monitored using the methodology (MoDeRn monitoring workflow) developed in WP1. This is followed by a proposal on how this monitoring could be done in terms of designing monitoring systems, to provide an evaluation of the reliability of sensor results and to develop scenarios for an unexpected repository evolution in order to discuss consequences of monitoring results. In general, it provides a route map for the analysis of monitoring covering all phases of the disposal process and a basis for discussing how technical and social considerations of monitoring results might influence the decision-making process.

Actual work on WP4 started in late 2011 with an initial overview of the parameters/processes. The main part of WP4 is expected to be completed in 2012.

Two progress meetings were held in 2011 (Prague in May and Amsterdam in November) to discuss project progress.

3.2. Other International collaborations

NAGRA (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle)

On several occasions NAGRA called on EURIDICE's expertise on large-scale experimental set-ups. Prior to the Mont Terri meeting (15 February 2011), EURIDICE presented the PRACLAY Seal and Heater tests at a meeting at NAGRA's offices on their planned "FE" (Full-scale Emplacement) experiment. The experiment will be a full-scale, long-term heated test at Mont Terri, with a design based on NAGRA's HLW emplacement concept. The aim of the FE experiment is the investigation of thermo-hydro-mechanical coupled effects, which could be induced on the host rock by the repository; the experiment therefore resembles the PRACLAY Heater test to a large extent.

In September 2011 EIG EURIDICE also participated in a review meeting on the "GAST" (Gas Permeable Seal test). In this set-up at the Grimsel Test Site, a 10 m-long seal prototype will be tested. We made several comments on the scope of the test, and made some suggestions on alternative measurement techniques and implementation details for a successful measurement set-up.

In November 2011 EIG EURIDICE also took part in the international workshop organised by NAGRA on behalf of NUMO (Japan) on the role of URFs in national geological disposal programmes.

NRG (Nuclear Research & Consultancy Group)

The NRG-EURIDICE-SCK•CEN cooperation agreement was terminated by EURIDICE and SCK•CEN at the beginning of 2011.

IRMM (Institute for Reference Materials and Measurements)

Since 1999 part of the HADES URF has been leased by IRMM (Institute for Reference Materials and Measurements). IRMM is performing gamma measurements in HADES because the background radiation is significantly lower underground than above ground. The contract is a Service Agreement that can be extended every year, as was done in 2011.

At the end of 2011 this contract was amended to include the lease of extra space in the underground facility, on the southern side of shaft 2. IRMM will start a new project in 2012 that will last for 10 months. EURIDICE is not planning to use this space during 2012, which is why it is available for IRMM to lease.

CNCC (China National Nuclear Corporation)

In October 2011 Xiangling Li was invited to deliver a one-day lecture at the Bejing Research Institute of Uranium Geology (BRIUG) on research associated with the THM behaviour of the host formation and the Engineered Barrier System (EBS - bentonite).

4. Scientific Advisory Committee

During 2011, three meetings with the Scientific Advisory Committee were organised, which focused on the PRACLAY in-situ experiments. The EURIDICE scientific team presented an update on the PRACLAY project at each of these.

Discussions mainly focused on the following aspects:

- Risk analysis of the PRACLAY seal and possible contingency plans;
- Investigation of the "septaria layer" present 10 m above HADES and its potential impact on the PRACLAY Heater test;
- Importance of knowledge management for the PRACLAY experiments: reporting, use of the logbook, etc.

At the last SAC meeting, EURIDICE presented the draft version of the PRACLAY report on the 2nd phase of the PRACLAY project: the setting up of the PRACLAY in-situ experiments.

The SAC members also emphasised the importance of a critical mass of researchers in all EURIDICE R&D fields and underlined the fact that it is necessary to enhance the manpower of the scientific team in specific areas, taking into account the scale and complexity of the project.

5. Management & exploitation of installations

General

The Statutory Rules define the tasks of EIG EURIDICE concerning the management and exploitation of the installations on the land for which EIG EURIDICE holds a building lease. In 2011 these tasks were properly performed.

In 2011 the exploitation team focused its efforts mainly on the final stages of the PRACLAY seal and heater installation, including installing and connecting some additional measuring instruments, installing the central tube with its support structure, backfilling with sand, closing the seal by welding and proceeding with saturation with water.

Other main activities were the recuperation of the CORALUS IV project, which involved the exploitation team having to perform overcoring of the experiment to retrieve it from the clay.

Drilling and installation of the FORGE project were also performed in 2011. This is the largest borehole ever made by the exploitation team, with a diameter of 405mm.

Besides these installation and recuperation activities, necessary maintenance on machinery, site and infrastructure was performed according to the exploitation license and applicable regulations requirements and in line with the ISO 9001:2008 standard.

Finally, the necessary support for guiding visitors through the underground facility was provided throughout 2011.

In order to improve reliability and ensure that knowledge is shared in-house, the operation manual is continually updated. This manual contains instructions on how to operate the installations, how to deal with problems, how to solve breakdowns, how to replace parts, etc.

Underground installations and associated hoisting systems

The exploitation team and/or AIB Vinçotte carried out the necessary checks on the shafts, cables, hoisting equipment, etc. There were no major defects found. Some minor interruptions in the hoisting system at shaft 2 were resolved without creating major problems.

After decades of operational use, the hoisting system of shaft 1 shows more and more signs of ageing. Before this installation was set up at EIG EURIDICE, it had already been in use for about 30 years as a mining hoisting system. It is increasingly difficult to find spare parts for a machine that is around 60 years old. To achieve better reliability, it was decided to investigate the possibility of replacing/renewing the system. This will continue in 2012, with the aim of launching a public tender procedure.

The ventilation system of shaft 1 is also worn. The pre-engineering work and the compilation of technical and administrative specifications were completed in 2011. The system will be replaced in 2012.

Other standard maintenance and repair work on the hoisting systems, shafts and galleries was performed by the exploitation team in 2011. At the end of the year, after the closure of the PRACLAY gallery, a clean-up was undertaken in the HADES URF.

Above-ground installations and buildings

During 2011 some changes were made to the demo hall to update the information about the PRACLAY project and the research programmes on geological disposal.

The operations team carried out standard maintenance and the necessary repair work on installations, buildings and infrastructure in 2011.

A clean-up operation was initiated not only underground, but also in the above-ground installations. The old site infrastructure at shaft 1 was demolished and removed. Unusable parts of old experiments were removed from the site. This is partly in preparation for the future renewal work on the hoisting system at this shaft.

LICENCES

The exploitation licence is valid until 2024. Nothing changed during 2011. Jef Leysen was appointed the new head of HADES, taking over from Philippe van Marcke, who left EIG EURIDICE at the end of 2011.

The nuclear licence of EIG EURIDICE, remains valid until 2021 (in effect from August 2006). All inspections and controls with respect to this licence were done by BEL V.

In 2011 EIG EURIDICE began preparations to apply for an environmental licence if required under the new protocol agreement between the Federal nuclear authority (FANC) and the Flemish authorities competent for environmental protection.

6. Specific support for the repository technology study of ONDRAF/NIRAS

EURIDICE also supports ONDRAF/NIRAS in its R&D technical feasibility programme of geological disposal. This programme aims to demonstrate the construction and operation feasibility of the proposed concept for geological disposal and the repository design. The next programme milestone is the Safety and Feasibility Case (SFC-1) (2015 at the earliest).

The studies under the R&D feasibility programme are subdivided into the following topics:
- fabrication of the waste disposal packages
- construction of the underground repository
- operation of the underground repository

EIG EURIDICE is involved in research on the fabrication of the waste disposal packages through its experimental programme on the supercontainer (see 1.2.2. PRACLAY ON-SURFACE).

Further support included participation in the research project's meetings and review of the reports produced by the project partners. EURIDICE also prepared a note on the assessment of deep borehole disposal of high-level and/or long-lived radioactive waste in Belgium.

7. Participation in the "SATELITE" meetings of ONDRAF/NIRAS

EIG EURIDICE supports the development of ONDRAF/NIRAS' first Safety and Feasibility Case (SFC-1) with its expertise in the thermo-hydro-mechanical behaviour of Boom clay. This mainly involves participating in SATELITE meetings organised by ONDRAF/NIRAS.

EIG EURIDICE is also responsible for the synthesis report on the evolution of the disturbed zone around a deep repository for high-level and/or long-lived waste in a clay layer. This report is part of the set of documents supporting ONDRAF/NIRAS' SFC-1.

Activities in this area in 2011 were very limited. ONDRAF/NIRAS organised one SATELITE meeting and a workshop on evolving conditions in a geological disposal system. EURIDICE participated in both meetings. No further developments for the report on the evolution of the disturbed zone were required in 2011.

Activities: PART II The surface disposal programme for category A waste - cAt Project

Introduction

On 23 June 2006 the Belgian federal government decided that the long-term management of category A waste should take the form of a surface disposal facility within the municipality of Dessel, situated in the northern, Flemish part of Belgium in the province of Antwerp. The government commissioned ONDRAF/NIRAS to carry out this integrated project – i.e. the cAt project. To fulfil its appointed task, ONDRAF/NIRAS works in close collaboration with the STORA and MONA partnerships it has with the municipalities of Dessel and Mol. An important step in the successful completion of this project is the construction and operating licence application that ONDRAF/NIRAS plans to submit in 2012 to the Belgian nuclear regulator, the Federal Agency for Nuclear Control (FANC).

EIG EURIDICE supports the cAt project in the following areas:

- The preparatory modelling work and calculations of the long-term radiological impact of the planned repository;
- Preparation and instrumentation of the planned test cover; and
- Instrumentation of the demonstration test for construction of concrete modules.

1. Radiological long-term safety assessments and quality assurance of models and codes

Radiological long-term safety assessments are a key part of the safety arguments presented in the ONDRAF/NIRAS safety case supporting the application for a construction and operating licence.

The safety case is structured as follows:

- Safety Report Level 1 — This is composed of a non-technical and a technical synthesis providing an overview of the key safety arguments for the safety of the repository.
- Safety Report Level 2 — This contains the safety arguments and the key elements substantiating these. By the end of 2011, the sections on concrete phenomenology, design and construction, and long-term safety had been submitted to an international peer review team under the aegis of the Nuclear Energy Agency (NEA). The results of this review are expected by mid-2012.
- Level 3 and 4 documents — These are composed of technical reports that have been prepared by and/or on behalf of ONDRAF/NIRAS and that bear out the safety arguments put forward in Safety Report Level 2.

Radiological long-term safety assessments contain two types of scenarios:

- *Inadvertent human intrusion scenarios* in which radiological impacts are calculated resulting from stylised inadvertent human intrusions into the repository after nuclear regulatory control has been lifted, and
- *Gradual leaching scenarios* in which first the gradual radionuclide release from the waste and disposal facility is modelled (near-field model), and subsequently the spreading of these releases into the geosphere and biosphere leading to calculated radiological impacts on human and non-human biota.

EIG EURIDICE supports the long-term safety assessments mainly by developing and implementing gradual leaching scenarios.

In 2011 conceptual models and computer models for the near-field and the hydrogeology were further tested and finally defined in discussions between EIG EURIDICE and ONDRAF/NIRAS for different scenarios and assessment cases.

- For the near-field, around 20 assessment cases were defined and subsequently calculated for 40 long-term safety-relevant radionuclides and approximately 10 safety and performance indicators. During analysis of the near-field results, specific attention was drawn to a systematisation of specific model checks such as mass balances and fluxes in and out of the key components. This systematisation was subsequently implemented for all of the assessment cases, before finalising the results. The documentation on these checks is due to be published in 2012, together with an overview of all efforts relating to qualification, verification and validation of the different models and calculations used for the radiological impact calculations.
- For the hydrogeology, assessments in 2011 focused on documentation of the reference model for the dilution factor, support with defining a groundwater monitoring programme in the environment of the category A waste repository and an assessment of solid-phase contamination and its spatial spreading as a function of time. The level 4 documentation of these aspects is planned for the first half of 2012.
- For the biosphere models, final verifications of models were made, calculations of radiological impact on humans were documented and radiological impact on non-human biota for the category A waste disposal facility was assessed.
- The combination of the results of these three models (near-field, hydrogeology, biosphere) led to radionuclide-specific disposal limits and other operational conditions for the emplacement of waste in the repository. These conditions are a key result for the level 2 report, and will be translated into operational limits and conditions in the construction and operating licence.
- Finally, at the request of FANC, a specific, stylised worst-case groundwater scenario was developed by ONDRAF/NIRAS and EIG EURIDICE, and subsequently implemented and analysed by EIG EURIDICE. Worst-case scenarios assume stylised conditions of loss of disposal facility performance and are developed for timeframes in which uncertainties about disposal facility performance are high.

The support work of EIG EURIDICE on the safety report consisted of reviewing the text of the long-term radiological safety assessment in the level 2 report drawn up by ONDRAF/NIRAS. Its contribution towards the environmental impact assessment report consisted of the calculations of the long-term chemical impact of the disposal facility as a supporting reference of the environmental impact assessment report.

The documentation, developed in 2011, focused on the synthesis information for the level 2 safety report, which was submitted to international peer review. The level 4 documentation of the long-term radiological impact calculations will be finalised by EIG EURIDICE in the first half of 2012. The documentation and assessments will be further amended to take account of the peer review. The application for a construction and operating licence for the surface repository for category A waste will then be submitted to FANC in the second half of 2012.

2. Test cover

After placing waste in surface-type disposal facilities for several decades, a multi-layer cover is installed on top of the disposal facility, aiming at reducing water infiltration into the facility so as to limit degradation through leaching of the underlying components and to limit leaching of radionuclides from the facility. In the meantime, a long-term test cover programme has been developed to gather information on the technical aspects and the dynamics of a multi-layer cover; the experience gained will form a solid basis for building confidence and experience with multi-layer cover systems to be used in the design, construction and monitoring of the final tumulus.

In 2010 a general lay-out of the test cover and of the reference to be used in the safety case supporting the licence application was developed by ONDRAF/NIRAS, supported by Tractebel Engineering for the design aspects and by EIG EURIDICE for the long-term evolution aspects and instrumentation needs and objectives. Before finalising this work, it was also subjected to critical review by an international team composed of experts from Switzerland, Germany, Bulgaria and France. The reference profile of the cover and the description of the long-term evolution of this reference profile were subsequently used for the scenario and model development for the radiological safety assessments. Since the priority of the category A project was to prepare the level 2 safety report in 2011, the next steps in the development of the test cover are planned for 2012: the technical specifications for the construction of the test cover will be drawn up by the end of 2012, with support from EIG EURIDICE in preparing the specifications for the test cover and its instrumentation.

3. Demonstration test

In order to assess the technical feasibility of the module construction techniques and the industrial feasibility of the concrete that has been optimised for long-term safety and has been tested on a laboratory scale, a demonstration module construction test was set up and carried out in 2011. (Figure **25**)

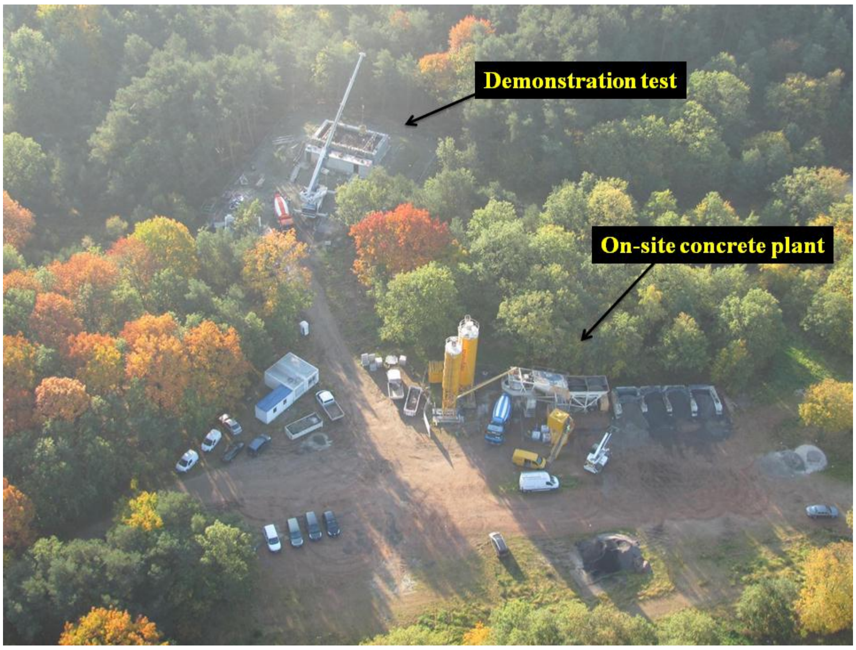


Figure 25 Overview of the demonstration test

EIG EURIDICE, together with ONDRAF/NIRAS and Tractebel Engineering, devised an instrumentation plan for assessing the temperature and stress conditions within the concrete used in the demonstration test. EIG EURIDICE placed the requisite instrumentation in the test set-up (Figure 26) and will report on the results in 2012. A key result of the tests in 2011 concerned the temperature measurements inside the concrete: temperatures were always below 70°C, leading to the conclusion that the concrete degradation mechanism “delayed ettringite formation” can be disregarded in this case. After developing a 1/8 demonstration module, additional test panels were constructed to further test concrete compaction; further concrete compaction tests are planned in 2012. These test panels will also be instrumented by EIG EURIDICE.

Figure 26 Example of instrumentation placed in the test set-up

Scientific output

PUBLICATIONS

Chen G., Li X.- *Numerical Study of PRACLAY Seal Test in Mol, Belgium*.- In: 2nd Int. Symposium on Computational Geomechanics (CD-ROM), Cavtat-Dubrovnik, Croatia (local Name: Hrvatska), 27-29 April 2011, Rhodes, Greece, IC2E International Centre for Computational Engineering, 2011, p. 640-649

Chen G., Sillen X., Verstricht J., Li X.- *ATLAS III in situ heating test in boom clay: Field data, observation and interpretation*.- In: Computers and Geotechnics, 38:5(2011), p. 683-696.- ISSN 0266-352X

Craeye B., De Schutter G., Areias L., Wacquier W., Van Humbeeck H., Van Cotthem A.- *Validation of the early-age thermo-mechanical behaviour of SCC Supercontainers for the disposal of High Level radioactive Waste*.- In: Design, Production and Placement of Self-Consolidating Concrete, Montréal, Canada, 26-29 September 2010 / RILEM, United States, Springer RILEM Bookseries, 2011, p. 851-861

Craeye B., De Schutter G., Wacquier W., Van Humbeeck H., Van Cotthem A., Areias L.- *Closure of the concrete supercontainer in hot cell under thermal load*.- In: Nuclear Engineering and Design, 241:5(2011), p. 1352-1359.- ISSN 0029-5493

Deng Y., Cui Y., Tang A., Nguyen X., Li X., Van Geet M.- *Investigating the pore-water chemistry effects on the volume change behaviour of Boom clay: Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, Nantes, France, 28 March - 2 April 2010*.- In: Physics and Chemistry of the Earth, 36:17-18(2011), p. 1905-1912.- ISSN 1474-7065

Deng Y., Tang A., Cui Y., Li X.- *Study on the hydraulic conductivity of Boom clay*.- In: Canadian Geotechnical Journal, 48:10(2011), p. 1461-1470.- ISSN 0008-3674

Deng Y., Tang A., Cui Y., Nguyen X., Li X., Wouters L.- *Laboratory hydro-mechanical characterisation of Boom Clay at Essen and Mol: Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, Nantes, France, 28 March - 2 April 2010*.- In: Physics and Chemistry of the Earth, 36:17-18(2011), p. 1878-1890.- ISSN 1474-7065

Jia S., Chen W., Yu H., Li X.- *Study of hydro-mechanical-damage coupled creep constitutive model of mudstone, Part I: Theoretical model*.- In: Rock and Soil Mechanics, 32:9(2011), p. 2596-2602.- ISSN 0080-9004

Jia S., Chen W., Yu H., Li X.- *Study of the hydro-mechanical-damage coupled creep constitutive model of mudstone, Part II: Numerical algorithm and parameter inversion*.- In: Rock and Soil Mechanics, 32:10(2011), p. 3163-3170.- ISSN 0080-9004

Le T., Cui Y., Munoz J., Delage P., Tang A., Li X.- *Studying the stress-suction coupling in soils using an oedometer equipped with a high capacity tensiometer*.- In: Frontiers of Architecture and Civil Engineering in China, 5:2(2011), p. 160-170.- ISSN 1673-7407

Li X. [edit.], et al. .- *TIMODAZ. Final activity report*.- Brussels, Belgium: European Commission, 2011.- 62 p.- (European Commission; Timodaz reports; FI6W-CT-2007-036449)

Lima Amorim A.- *Thermo-hydro-mechanical behaviour of two deep Belgian clay formations: Boom and Ypresian Clays*.- Barcelona, Spain: UNIVERSITAT POLITÈCNICA DE CATALUNYA, 2011.- 253 p.- PhD thesis

Mokni N., Olivella S., Valcke E., Mariën A., Smets S., Li X.- *Deformation and flow driven by osmotic processes in porous materials: application to bituminised waste materials*.- In: Transport in Porous Media, 86(2011), p. 665-692.- ISSN 0169-3913

Vaunat J., Gens A., de Vasconcelos R., Li X.- *Analysis of the excavation of a deep drift in a tertiary clay*.- In: 2nd Int. Symposium on Computational Geomechanics (CD-ROM), Cavtat-Dubrovnik, Croatia (local Name: Hrvatska), 27-29 April 2011, Rhodes, Greece, IC2E International Centre for Computational Engineering, Rhodes, Greece , 2011, p. 587-598

Wacquier W., Van Humbeeck H., Gens R., Wickham S., Harvey L., Areias L., e.a.- *Feasibility assessment of the Belgian Supercontainer disposal concept*.- In: Proceedings of the 2011 International High-Level Radioactive Waste Management Conference, Albuquerque, NM, United States, 10-14 April 2011 / American Nuclear Society, Red Hook, NY, United States, Curran Associates, Inc, 2011, p. 54-63

Wouters L., Li X.- *Radioactive Waste Management in Belgium. With particular emphasis on activities around clay as disposal host formation*.- Paris, France: NEA, 2011.- 8 p.- (NEA; NEA Clay Club Country report; CR-2011.BE)

POSTERS & PRESENTATIONS

Areias L., Volckaert G., Maes N., Bergmans G., Jacops E., Moerkens K., e.a.- *WP4.2.2 Gas Transport in the EDZ. Design and installation of in-situ mega packer experiment in Boom Clay (HADES URF, Mol)*.- FORGE General assembly.- Solothurn, Switzerland, 29 November - 1 December 2011.- [Poster]

Bastiaens W.- *1980 - 2010: Evolution of excavation techniques in HADES*.- HADES, 30 years of underground research laboratory - The changing role of URLs in radioactive waste disposal research.- Antwerp, Belgium, 23-25 May 2011.- [Presentation]

Chen G., Li X.- *PRACLAY Heater switch-on — Modeling of the Seal Test & Heater Test*.- Workshop on PRACLAY heater test switch-on .- Mol, Belgium, 23-24 November 2011.- [Presentation]

Chen G., Li X.- *Numerical Study of PRACLAY Seal Test in Mol, Belgium*.- 2nd Int. Symposium on Computational Geomechanics.- Cavtat-Dubrovnik, Croatia (local Name: Hrvatska), 27-29 April 2011.- [Presentation]

Cui Y., Deng Y., Tang A., Li X.- *Hydro-mechanical behaviour of Boom clay*.- International Workshop on Radioactive Waste Disposal, in the frame of " ISRM12th International Congress on Rock Mechanics ".- Beijing, China, 16-21 October 2011.- [Presentation]

Li X.- *Design and status of the PRACLAY Seal & Heater experiment*.- HADES, 30 years of underground research laboratory.- Antwerp, Belgium, 23-25 May 2011.- [Presentation]

Li X.- *PRACLAY Heater switch-on. Introduction*.- Workshop on PRACLAY heater test switch-on .- Mol, Belgium, 23-24 November 2011.- [Presentation]

Li X.- *The PRACLAY experiment and its role in the Belgian RD&D programme for geologic disposal in clay of high-level and long- lived radioactive waste*.- International Workshop on Radioactive Waste Disposal.- Beijing, China, 16-21 October 2011.- [Keynote]

Li X., Lalieux P., Van Geet M.- *The roles of the URL HADES in the Belgian RD&D program on radwaste geological disposal*.- International Workshop on "Networks of Underground Research Laboratories for International, Inter-disciplinary Innovations" .- Beijing, China, 17-17 October 2011.- [Keynote]

Van Marcke Ph.- Installation of the *PRACLAY Seal & Heater experiment*.- HADES, 30 years of underground research laboratory.- Antwerp, Belgium, 23-25 May 2011.- [Presentation]

Van Marcke Ph.- *PRACLAY Heater switch-on Experiment installation – day 1*.- Workshop on PRACLAY heater test switch-on .- Mol, Belgium, 23-24 November 2011.- [Presentation]

Van Marcke Ph.- *PRACLAY Heater switch-on Experiment installation – day 2*.- Workshop on PRACLAY heater test switch-on .- Mol, Belgium, 23-24 November 2011.- [Presentation]

Verstricht J.- *Seal Hydration & Testing. Monitoring results and first interpretations*.- Workshop on PRACLAY heater test switch-on.- Mol, Belgium, 23-24 November 2011.- [Presentation]

Communication & general management

1. Communication

Communicating about its activities is one of EIG EURIDICE's main tasks. The HADES Underground Research Facility (URF) is a powerful tool for explaining the concept of geological disposal and is a perfect starting point to present and explain the research that has been going on for the past 30 years.

To ensure consistency in communication messages and strategies, it is important for all communication activities to be discussed with and agreed upon by both SCK•CEN and ONDRAF/NIRAS. This is done every month during the Communication Committee's meetings with ONDRAF/NIRAS and SCK•CEN communication managers. During 2011, a public tender procedure was launched for a three-year contract with a communication partner for the production of a variety of publications and a new website. The Communication Committee kept a close eye on the various steps in the procedure and also made or confirmed important decisions. Finally, in October 2011, the contract was awarded to Bailleul Ontwerpbureau.

Website

A public contract with a communication partner for the creation of a new website was tendered and awarded during 2011. For this reason, only necessary updates were made to the existing website. During December 2011, two meetings were organised with Bailleul Ontwerpbureau and its subcontractor, One Agency, to start work on the new website, which will become operational in 2012.

Media Coverage

The publication of the first version of the Waste Plan in 2010 and the European Directive on geological disposal in 2011 generated greater demand for information on activities in and around the HADES URF, especially from the Netherlands, where there is renewed interest in research on geological disposal.

On 22 February 2011 there was a documentary on Dutch television (Labyrinth – VPRO), partly on HADES research activities.

EVENTS

To mark the 30th anniversary of the HADES Underground Research Facility, EIG EURIDICE, with support from SCK•CEN and ONDRAF/NIRAS, organised an international event on 23-25 May 2011 in the Radisson Blu Astrid Hotel, Antwerp. Experts from Belgium, Finland, France, Sweden and Switzerland came together to discuss the main achievements of the research work in and around underground research laboratories and the role of these facilities in national geological disposal programmes. About 140 people from 12 different countries participated in this successful event.

During his closing remarks, Peter De Preter, Director of EIG EURIDICE, commented that the event clearly showed that URFs make a significant contribution to the quality of the scientific and technological work of national research programmes. "Even when the final steps towards implementation of geological disposal are taken, research and development in underground facilities remains important." During the event, it also became clear that to take these steps, a decision-oriented research programme is required. "These decisions can be made if sound scientific and technological expertise is available and also if there is public support. In this regard, URFs can be very useful to make apparent to people the research efforts devoted to developing geological disposal."

Marc Demarche, Chairman of the Board of EIG EURIDICE

Eric Van Walle, Director-General SCK•CEN, and Jean-Paul Minon, General manager ONDRAF/NIRAS

Due to the international event, there was no Exchange Meeting during the spring of 2011.

The 17th Exchange Meeting was organised on Wednesday 7 December 2011 on the theme of:

"STATUS OF THE LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE IN BELGIUM:
THE CAT PROJECT IN DESSEL AND THE WASTE PLAN FOR B&C WASTE"

The presentations from both events are available on the EURIDICE website.

VISITS

Anyone over the age of 18 can visit EURIDICE and the underground research facility in small groups. Sociocultural organisations are looked after by trained guides, who also lead visits to ISOTOPOLIS. Experts on geological disposal, journalists, VIPs and university students with a scientific background are given a guided tour by scientific personnel, the Communication Manager and/or the director of EURIDICE, sometimes accompanied by ONDRAF/NIRAS or SCK•CEN management.

In 2011 EIG EURIDICE welcomed 1,778 visitors to the HADES URF and the above-ground exhibition on geological disposal; 65 of the 125 visits (1,200 of the 1,778 visitors) were led by trained tour guides. Of the 125 visits, 75 were Dutch-speaking, 28 English-speaking and 22 French-speaking. Besides continual interest from universities offering geological or engineering courses, there was increased interest from the Netherlands, more specifically from water companies, the Ministry of Economic Affairs, Agriculture and Innovation, and universities that are involved in the reactivated Dutch research programmes on geological disposal.

At the end of their visit, visitors are asked to give feedback by means of an electronic questionnaire. Overall, people are very positive about their visit to the HADES URF.

During 2011 the exhibition in the demo hall was upgraded. The most important new feature is a module on the PRACLAY experiment; in a series of short videos, visitors can now see the installation of the reinforcement ring, the excavation of the PRACLAY gallery and the installation of the seal and the heater system. (
Figure **27**)

Figure 27 Upgrade of the demo hall

2. Personnel

Under its Statutory Rules, EIG EURIDICE has no employees of its own. Personnel working for EURIDICE are under contract to either SCK•CEN or ONDRAF/NIRAS and have operated as the EURIDICE team since 2000, based at the EURIDICE location.

As of 1 January 2011, the EURIDICE team consisted of 16 members. At the end of 2011, Philippe Van Marcke left the team. During 2011, there were no additional secondments from de the members. EIG EURIDICE asked the member SCK•CEN to start a recruitment process seeking personnel with expertise in THM and in instrumentation & monitoring. One person in each of these two fields will be recruited in 2012.

3. Quality Management

Since 2007, EIG EURIDICE has been ISO-certified according to the ISO 9001:2008 standard for Quality Management.

During February 2011, an external audit took place. There were no major or minor comments.

Following this audit, simplification and reorganisation of the QMS on Vignette started as planned. During 2012, Jan Rypens took over responsibility as Quality Manager from Xiangling Li.

On 21 December 2011 Amelior performed a yearly internal audit. No major comments were made.

Financial summary 2011

BALANCE SHEET (EUR)

	2010	2011
Amounts receivables within 1 year	2.152.228	1.317.039
Commercial debts receivable	*2.031.664*	*1.237.924*
Other debts receivable	*120.564*	*79.115*
Cash at bank and in hand	360.763	984.557
Current assets	5.386	2.531
Total assets	**2.518.377**	**2.304.127**
Liabilities due within 1 year	2.518.295	2.304.111
Suppliers	*2.283.156*	*2.056.971*
Payments in advance	*230.171*	*247.140*
Additional amounts payable	*4.968*	*0*
Other tangible assets	82	16
Total liabilities	**2.518.377**	**2.304.127**
Company revenu	3.881.290	3.569.270
Turnover	*3.880.692*	*3.553.612*
Other operation income	*598*	*15.658*
Operating costs	3.883.514	3.571.602
Cost of services and various goods	*3.880.350*	*3.567.251*
Other operating charges	*3.164*	*4.351*
Financial revenu	2.414	3.351
Financial charges	493	516
Profit or loss on ordinary operation	**-303**	**503**
Exceptional revenu	659	0
Exceptional charges	0	0
Pre-tax Profit and loss	**356**	**503**
Taxes	356	503
Profit or loss for the financial year	**0**	**0**

Lexicon

ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs (FR)
ASC	Applied Seismology Consultants (UK)
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (DE)
BRIUG	Beijing Research Institute of Uranium Geology (China)
CERMES	Centre d'Enseignement et de Recherche en Mécanique des Sols (FR)
CIMNE	Centro Internacional de Métodos Numéricos en Ingeniería (ES)
CNNC	China National Nuclear Corporation (China)
CTU	Czech Technical University (CZ)
EC	European Commission (BE)
ENPC	Ecole Nationale des Ponts et Chaussées (FR)
EPFL	Ecole Polytechnique Fédérale de Lausanne (CH)
GRS	Gesellschaf für anlagen- und ReaktorSicherheit (DE)
IRMM	Institute for Reference Materials and Measurements (BE)
IRSM	Institute of Rock and Soil Mechanics (China)
ITC	School of Underground Waste Storage and Disposal (CH)
K.U.Leuven	Catholic University Leuven (BE)
NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (CH)
NSFC	Natural Science Foundation of China (China)
ONDRAF/NIRAS	The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (BE)
NRG	Nuclear Research & Consultancy Group (NL)
RAWRA	RAdioactive Waste Repository Authority (CZ)
SCK•CEN	Belgian Nuclear Research Centre (BE)
UGent	University of Gent (BE)
UJF	Université Joseph Fournier Grenoble (FR)
ULB	Université Libre de Bruxelles (BE)
ULg	Université de Liège (BE)
UPC	Universitat Politecnica de Catalunya (ES)
URL	Underground Research Laboratory (BE)