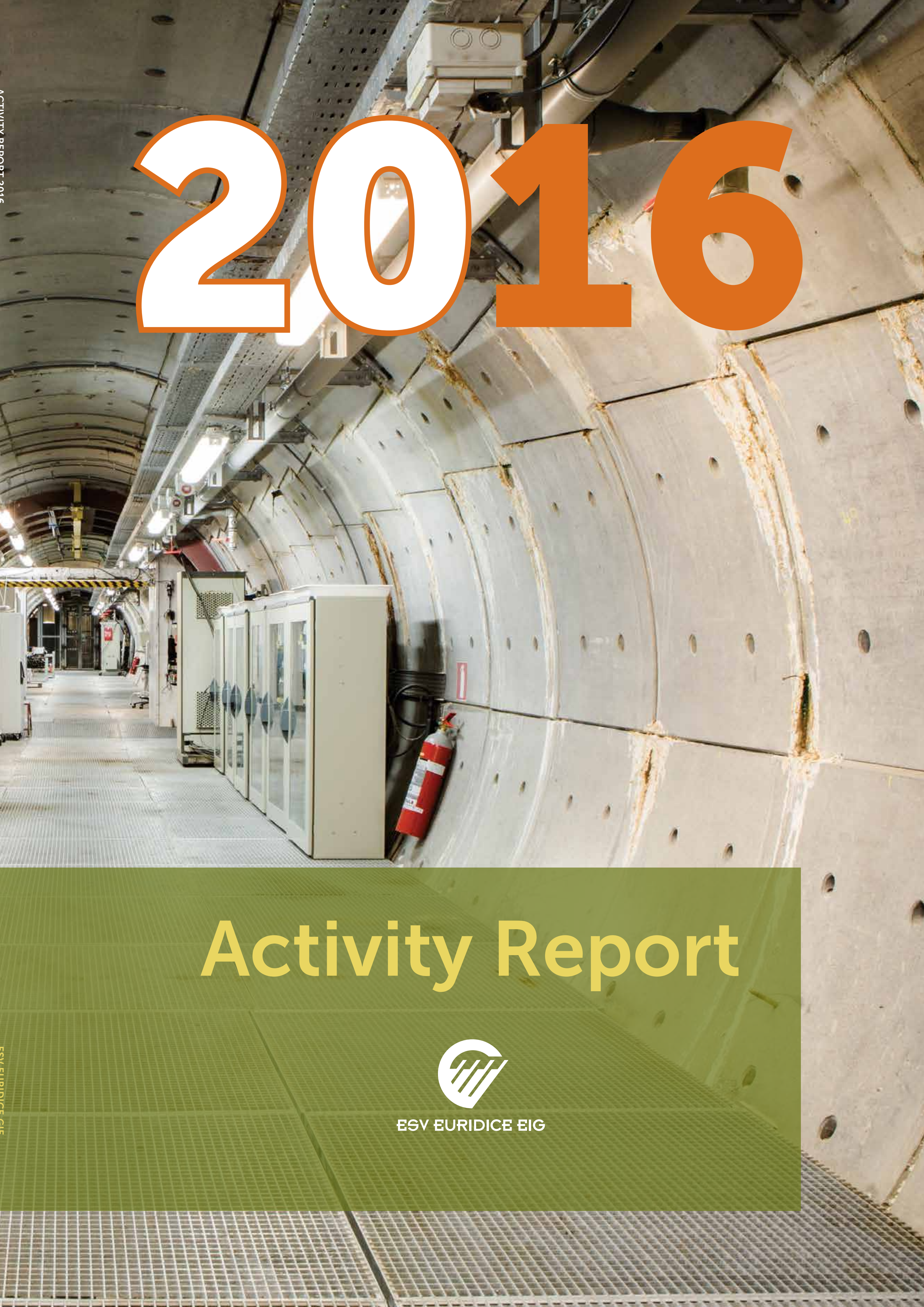

2016

Activity Report

ESV EURIDICE EIG

2016
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Activity Report 2016

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General foreword

Marc Demarche, Chairman of the Board of EIG EURIDICE

Dear reader,

EIG EURIDICE is the Economic Interest Grouping of ONDRAF/NIRAS and SCK•CEN, and is responsible for managing and operating the HADES underground research laboratory (URL), conducting research and development activities relating to the geological disposal of radioactive waste in deep clay formations, and communicating about its activities. This Activity Report provides a comprehensive overview of the main developments and achievements with respect to EIG EURIDICE's statutory tasks in 2016.

Since the late 1990s, the PRACLAY project has been a key priority for EIG EURIDICE. The large-scale PRACLAY Heater test, carried out in the PRACLAY gallery, is the final stage of this project. The heating phase of this experiment was successfully started in November 2014. In August 2015 the target temperature of 80°C was reached at the interface between the concrete gallery lining and the Boom Clay. This temperature will be kept constant for 10 years, after which the cooling phase and dismantling will follow. During 2016 the heating phase was successfully continued. The findings obtained during the first years of heating generally confirm the "blind predictions". These predictions were defined using numerical calculation models before the start of the heating phase, and are based on the results of small-scale in-situ heating tests. In 2016 EURIDICE published a first summary report about the start-up phase (November 2014 – August 2015).

Over the coming years the EURIDICE team will ensure scientific and technical follow-up of the experiment; this comprises maintenance of the experimental set-up, management of the instrumentation system and all measurement data, interpretation of the various measurements and observations, and systematic technical and scientific reporting during the experiment. The preparation of a first interim scientific and technical evaluation report on the 10-year experiment will be initiated in 2017. A number of scientific publications are also planned for 2017.

In 2016, besides focusing on the PRACLAY Heater test, EURIDICE also devoted a great deal of effort to the recording and optimal management of its knowledge and expertise in the area of measuring instruments and monitoring through a systematic evaluation of the performance of measurement sensors in earlier experiments in the HADES URL. The methodological approach was defined and described in detail in 2016. The initial results will be available and reported in 2017.

After a series of communication activities in 2015 related to the start of the PRACLAY Heater test (see the 2015 Activity Report), 2016 was business as usual in terms of communications. The scientific section of the EURIDICE website was developed further in collaboration with the scientific team.

With regard to the safety and operation of the facilities, important improvements have been made: in terms of organisation and responsibilities, by creating a EURIDICE – SCK•CEN – ONDRAF/NIRAS consultative committee for health and safety in the workplace, and in the area of technical facilities and operating procedures (such as fire safety, electrical installations and training). These efforts will be continued over the next few years. In 2016 preparations for the refurbishment of the shaft 1 hoisting system were also set in motion, with the publication of a tender for the appointment of an engineering firm. The award of the contract is planned for the spring of 2017.

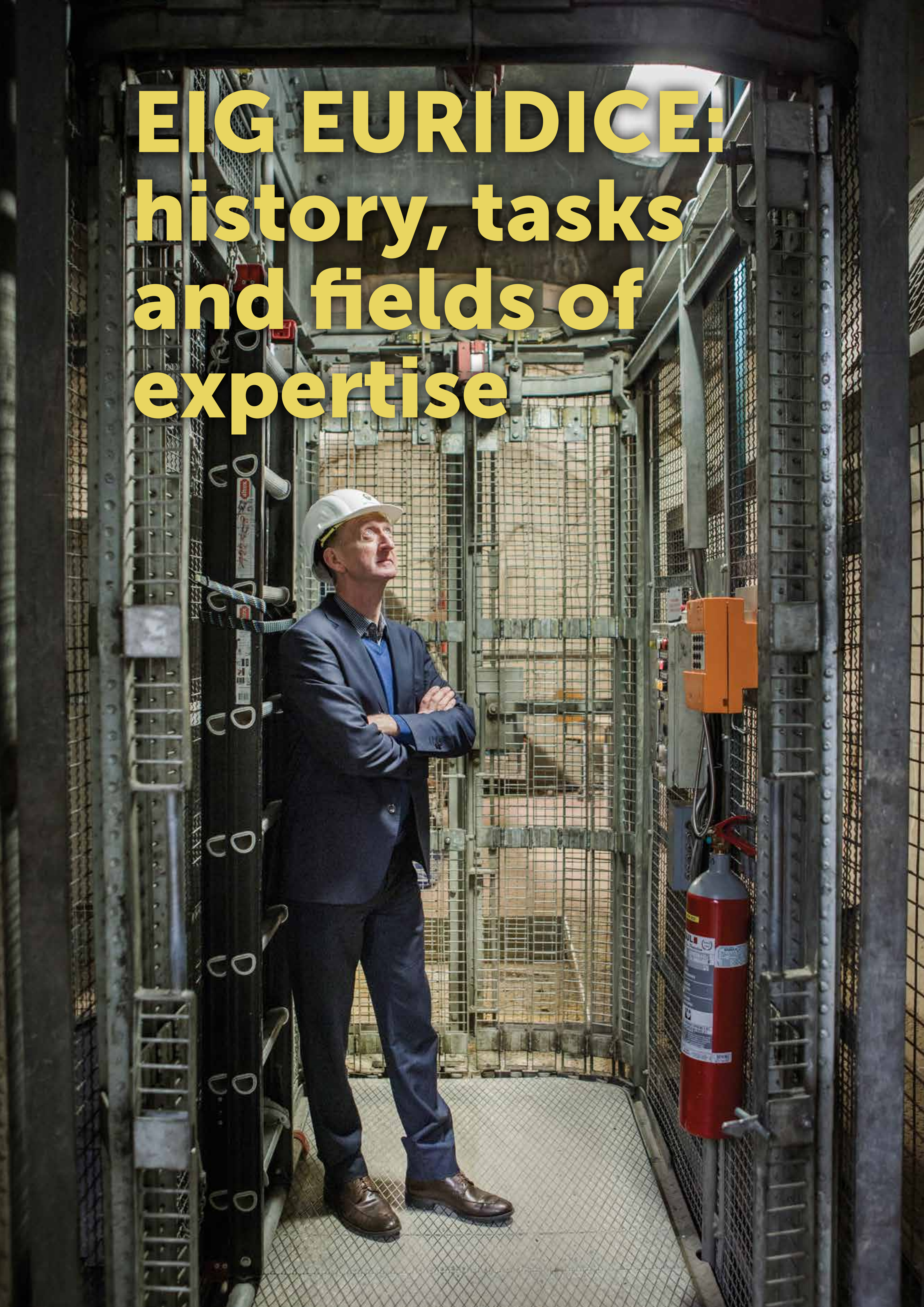
EURIDICE has also contributed to ONDRAF/NIRAS's surface disposal programme for low-level waste in the areas of safety assessments, hydrogeological studies and monitoring/instrumentation.

In the course of 2016, EIG EURIDICE, at the request of its constituent members SCK•CEN and ONDRAF/NIRAS, initiated a strategic review of the implementation of its tasks, today and in the future. To this end, EURIDICE's Management Board set up a Task Group, which submitted its findings and proposals to the Board at the end of 2016; the Board has since endorsed these findings and proposals. In April 2017 these findings and proposals will be submitted to the Joint Meeting of Members with a view to adopting the necessary decisions about the future objectives and operation of EURIDICE. 2017 will therefore be a defining year for the future of the Economic Interest Grouping.

Although 2016 was in many ways successful for EIG EURIDICE, it was also the year we lost one of its pioneers. Marc Buyens passed away on 24 August 2016. He was among those who were involved in the construction of the HADES URL right from the start back in the late 1970s, and was one of the driving forces behind EIG EURIDICE (EIG PRACLAY at the time). All those years, Marc worked tirelessly towards EIG EURIDICE's success, displaying great expertise, commitment and a good understanding of human nature. We are sincerely grateful for his extensive contributions.

Marc Demarche, Chairman of the Board of EIG EURIDICE

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 laboratory and carries out RD&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. EIG EURIDICE also contributes, to a more limited extent, to the surface disposal programme of ONDRAF/NIRAS for low-level waste.

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), was and still is regarded as a potentially suitable host formation. This clay layer is found at a depth of 190 to 290 metres below the SCK•CEN research site in Mol. In 1980 SCK•CEN began construction of the HADES (High-Activity Disposal Experimental Site) underground research laboratory (HADES URL 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 laboratory 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 laboratory. At each stage of excavation and construction, new techniques were used and new technological and engineering expertise was gained. The HADES URL has been managed and operated by the EIG since 1995.

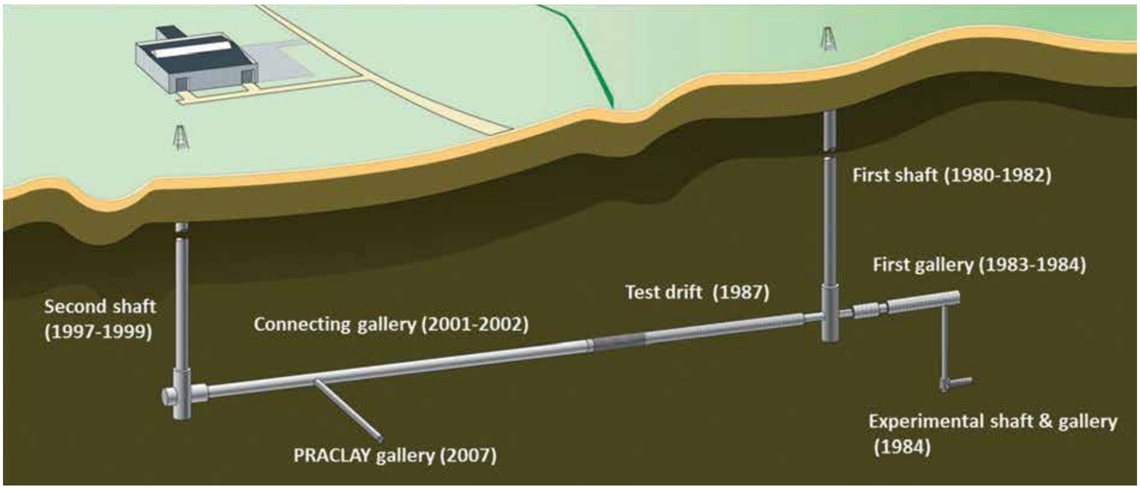


Figure 1 - The underground research laboratory HADES (High-Activity Disposal Experimental Site)

The main statutory tasks of EIG EURIDICE entail a range of activities with a view to developing and facilitating the activities of EIG EURIDICE's constituent members:

- The management and operation of the HADES URL 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 URL.

After 35 years of research in and around the HADES URL, 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 and Engineered Barrier System (EBS)
3. Instrumentation & monitoring.

EIG EURIDICE's first area of expertise has changed significantly over the past 35 years, with excavation and construction of the HADES URL 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) around the excavated galleries 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 thermo-hydro-mechanical (THM) behaviour and characterisation of a clay host rock and Engineered Barrier System (EBS) (concrete buffer comprising Supercontainer, concrete liner, clay-based seal materials such as bentonite, etc.), 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 URL as well as in surface laboratories in collaboration with geotechnical laboratories and institutes worldwide. The extensive scientific instrumentation systems installed in the clay before, during and after the construction of galleries made it possible to create a valuable geotechnical knowledge base 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 excavation-damaged zone (EDZ). Proper understanding of the coupled THM processes in a clay host rock around the repository is essential so as to determine to what extent these processes could affect the capacity of the clay to contain the radioactive substances and to isolate the radioactive waste. The most important project in this area is 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.

The RD&D programme in and around the HADES URL 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 in several aspects specific to this type of instrumentation and monitoring, such as the long-term operation (decades) 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 for good implementation of future in-situ experiments and in designing a monitoring programme for an underground repository for high-level and long-lived waste in a clay host rock.

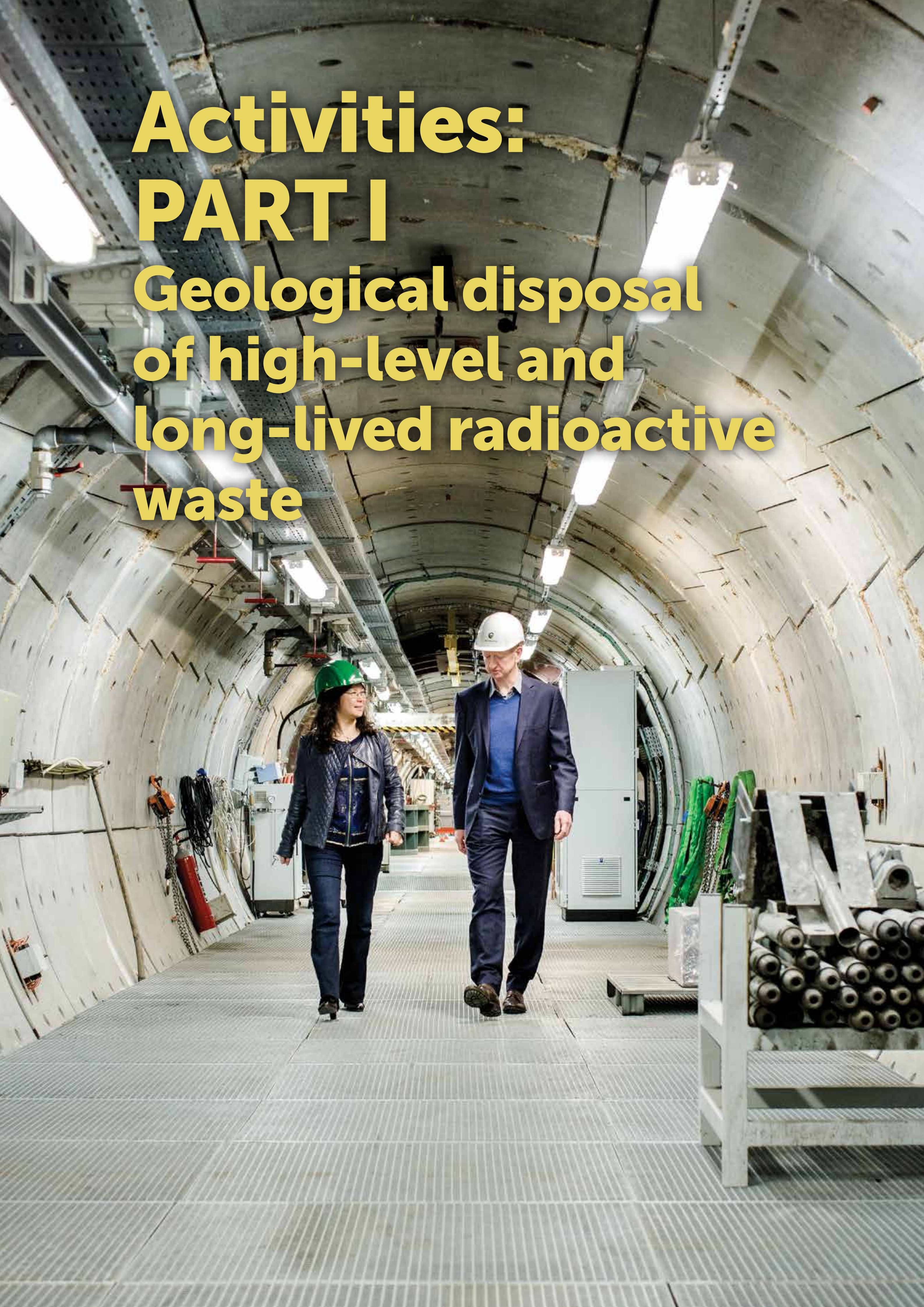
With its RD&D activities and fields of expertise, EIG EURIDICE contributes to the national programme for high-level and long-lived waste disposal managed by ONDRAF/NIRAS. In 2011 ONDRAF/NIRAS published its waste plan for the long-term management of high-level and/or long-lived waste (NIROND 2011-02, September 2011), with a view to obtaining a policy decision on the long-term management of this waste. In 2013 ONDRAF/NIRAS finalised its RD&D plan on geological disposal (NIROND-TR 2013-12 E), describing the main achievements and future challenges. The next milestones of this programme will largely depend on the timing and nature of the policy decision.

EIG EURIDICE's scientific activities in 2016 focused on following up the PRACLAY Heater test. After a successful switch-on of the heating system on 3 November 2014, the temperature at the interface between the concrete lining and the clay reached 80°C in August 2015, marking the end of the start-up phase. Since then, the power of the heating system has been systematically adjusted to keep the temperature constant at 80°C (steady heating phase). In May 2016 a first report was published on the experimental evolution during the start-up phase.

An overview of the main observations regarding the PRACLAY Heater test since switching on the heating up until the end of 2016 is given in this Activity Report, based on measurements from the numerous sensors that are installed in the PRACLAY gallery, the seal, the concrete lining and in instrumented boreholes around the PRACLAY gallery. In general, the experiment is evolving as expected and confirms the blind predictions that were made by modelling.

Activities: PART I

Geological disposal of high-level and long-lived radioactive waste



1. PRACLAY "Demonstration & confirmation experiments"

1.1. Introduction: the PRACLAY project

One of the aims of EIG EURIDICE is the development and execution 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 strata such as the 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 construction 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-hydro-mechanical-chemical behaviour of Boom Clay and the gallery lining.

With the PRACLAY experiments, EIG EURIDICE is making an important contribution to the Safety and Feasibility Cases, which are part of the ONDRAF/NIRAS 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

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. The **demonstration experiments** focused on excavation techniques and construction of a shaft and galleries. 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, making use of a reinforcement structure. Most of the PRACLAY demonstration experiments are now finished. The **confirmation tests** are focusing on confirming and improving existing knowledge about the thermo-hydro-mechanical-chemical behaviour of the Boom Clay surrounding a disposal infrastructure. The **Heater test** is the main experiment in this regard. The objective of this test is to confirm, on a large scale, that the thermal load generated by the heat-emitting waste will not jeopardise the safety functions of the host rock. In particular, the Heater test aims to assess the consequences of the coupled thermo-hydro-mechanical impact on the Boom Clay and the evolution of the excavation-damaged zone (EDZ) during the thermal transient in the case of disposal of heat-emitting waste. The status of the PRACLAY Heater test is discussed in Section 1.2.

For this purpose, part of the PRACLAY gallery (30 m) has been closed off with a seal structure and will be heated for a period of 10 years at a temperature of 80°C at the interface 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), installation of the heating system started in 2010 (primary heater) and was completed in 2014 (secondary heater). A detailed report about the design, preparation and installation of the PRACLAY experiment was published in 2013, upon conclusion of the installation phase of the experiment (EUR 13-129).

The heating system was switched on on 3 November 2014 to test all components of the experimental set-up, including the control systems of both the primary and secondary heating systems. After a successful test phase it was decided at the beginning of 2015 to continue heating. The target temperature of 80°C at the interface between the gallery lining and the clay was reached on 18 August 2015, marking the end of the start-up phase. A detailed report on the experimental evolution during the start-up phase was published in 2016 (EUR_PH_16_025).

Since August 2015, the power of the heating system has been systematically adjusted to maintain the temperature at the points of contact between the lining and the Boom Clay at a constant 80°C, marking the start of the stationary phase of the Heater test. A constant flow of data is generated by an extensive network of sensors installed in and around the PRACLAY gallery, and compared with the predictions made by modelling.

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. No on-surface experiments were performed in 2016.

1.2. PRACLAY IN-SITU: the Heater test

1.2.1. Test set-up

The different parts of the PRACLAY Seal & Heater experimental set-up are shown in Figure 2. The heating system is installed in a 30-metre-long section of the PRACLAY gallery. This section is backfilled with sand, closed from the accessible part of the PRACLAY gallery by a seal structure and saturated with water.

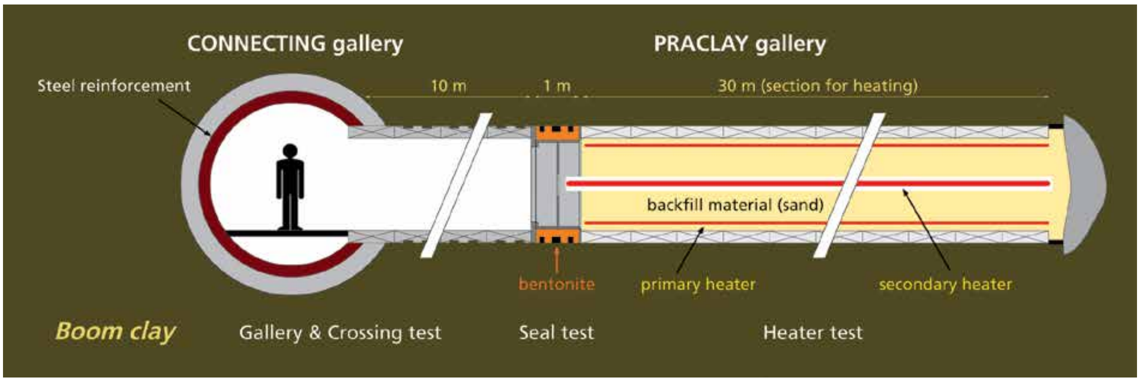


Figure 2 - Design of the PRACLAY experiment

HEATING SYSTEM

The **heating system** consists of a primary heater, attached to the gallery lining, and a secondary heater, which is placed in a central tube that rests on a support structure. Both of these are electrical heaters. Figure 3 shows the cables of the primary heater and the central tube for the secondary heater, before the gallery was closed and backfilled with sand.

Figure 3 - Cross-section of the central tube and view of the primary heating system

The **primary heater** was installed in the PRACLAY gallery in 2010. The gallery is divided into three zones (front-end, middle and far-end), each of which is subdivided into four sections (upper, lower, left, right) (Figure 4). Each section is equipped with two heater elements, ensuring 100% redundancy of the system.

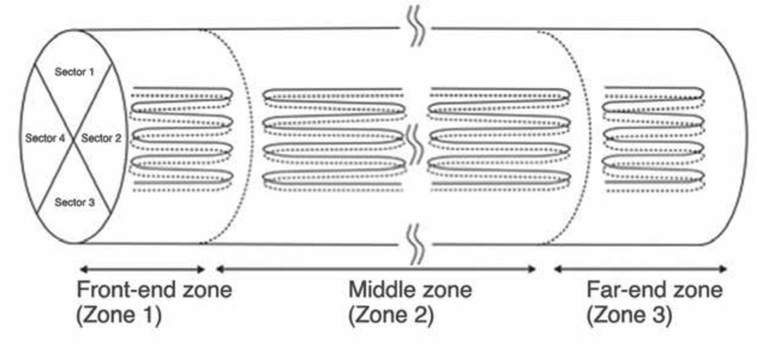


Figure 4 - The primary heating system is composed of three zones, each divided into four sections.

Installation of the **secondary heater** in the PRACLAY gallery began in 2012 and was completed in 2014. It consists of eight identical secondary heater assemblies that are inserted into the central tube. For four of the assemblies, replaceability is guaranteed at all times.

A control system regulating the heating power as a function of measured and target temperature is part of the heating system. The primary and secondary heating systems each have their own control system. The primary heater is regulated in different ways for the three different zones to ensure that the temperature is kept as constant and uniform as possible (80°C at the interface between the gallery lining and the Boom Clay) over the whole heated zone during the steady heating phase. The secondary heater can only deliver the same power output over its entire length, and this has to be regulated over time to ensure the same thermal boundary conditions (i.e. a constant temperature of 80°C at the interface between the gallery lining and the Boom Clay). The value of this power output will be set at the time of the switch-over.

HYDRAULIC SEAL

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 (Figure 5).

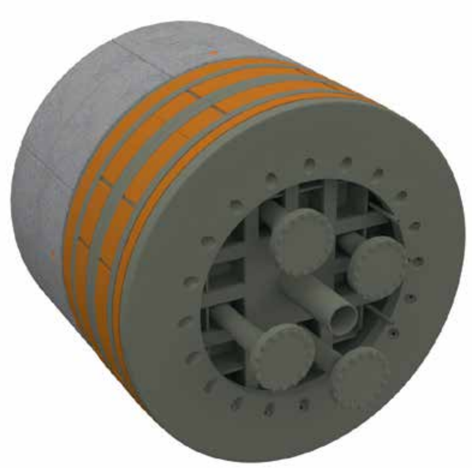


Figure 5 - 3D view of the seal with a central steel cylinder and an annular ring of bentonite (orange) against the clay

The hydraulic seal not only has to close off the PRACLAY gallery, it also has to hydraulically isolate the clay surrounding the heated part of the PRACLAY gallery, which can provide a preferential pathway for water towards the main gallery during the heating phase. Bentonite has a very low hydraulic conductivity (when compacted to a suitable dry density) and swells when it is hydrated. The swelling pressure exerted by the hydrated bentonite on the Boom Clay will lower the hydraulic conductivity of the Boom Clay around the seal, thus creating "undrained hydraulic boundary conditions" for the Heater test. The swelling behaviour of the bentonite ring in the seal is studied in the **Seal test**.

When designing the seal, two main criteria were defined. The maximum radial swelling pressure between the bentonite and the Boom Clay should be less than approx. 6.0 MPa (60 bar), so as not to re-damage the surrounding Boom Clay. The minimum swelling pressure before switch-on was set at 2.5 MPa (25 bar) to avoid creating negative effective stresses within and around the seal during the Heater test (the maximum pore water pressures in the gallery upstream of the seal and in the surrounding clay during the Heater test are estimated at 2.5 MPa by numerical prediction). The second criterion is that the hydraulic conductivity of the bentonite in saturated conditions should be lower than that of undisturbed Boom Clay (≈ 10-12 m/s).

To meet these specifications, firstly, the initial dry density of the bentonite was carefully determined, as this parameter determines its swelling pressure and its final saturated hydraulic conductivity. The desired initial dry density was determined by scoping calculations, taking into account the technological void and the interaction with the Boom Clay. An initial dry density of 1.8 t/m^3 was selected. Secondly, the bentonite needs to be sufficiently hydrated. The bentonite seal has been hydrated since its installation in January 2010 by pore water coming from the Boom Clay and by water injected through filters placed on the outer surface (extrados) of the steel cylinder since April 2010. Different kinds of instruments were incorporated into the bentonite rings during installation to monitor the water injection rate as well as stress (swelling pressure) and pore water pressure in the bentonite and in the Boom Clay around the seal. The instruments are grouped into sections A, B and C (Figure 6).

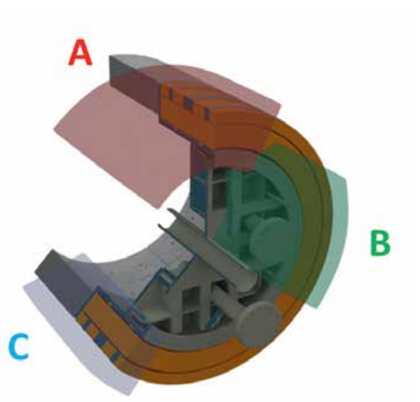


Figure 6 - Various instruments inside the bentonite, grouped into sections A, B and C

When the heating system was switched on on 3 November 2014 the radial pressures at the interface between the bentonite and the Boom Clay were around 3.3 MPa and thus higher than the required threshold value of 2.5 MPa (Figure 7). The pore water pressure in the PRACLAY backfill sand at that time had reached 1 MPa (10.0 bar) and no water leakage through the seal was observed. Hydraulic conductivity at the interface between the bentonite and the Boom Clay (at section C) was measured in September 2014 and the value obtained is similar to that of the undisturbed Boom Clay.

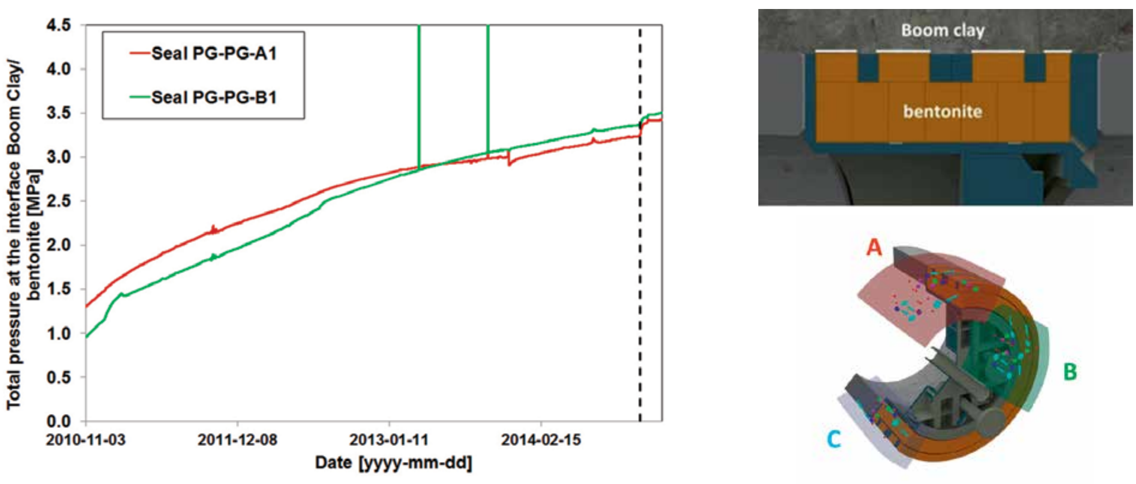


Figure 7 - Radial stresses measured at the interface between the bentonite and the Boom Clay sidewall (white line in insert), for sections A, B and C

BACKFILL SAND

The part of the PRACLAY gallery that is being heated is filled with sand (Mol sand M34) and saturated with water. The **water-saturated backfill** sand has to ensure efficient heat transfer from the heating elements to the surrounding clay and, together with the hydraulic seal, create homogeneous "undrained hydraulic boundary conditions" along the interface between the clay and the gallery lining. On 3 November 2014 the water pressure inside the gallery reached 1 MPa, and the PRACLAY gallery was estimated to be fully saturated.

MONITORING, INSTRUMENTATION AND DATA MANAGEMENT

The PRACLAY Seal and Heater tests are extensively instrumented to control the heating process and for the purpose of the experimental follow-up. To ensure convenient access to the sensor data, a user interface has been built into the database. This interface has several functionalities: a "dashboard" to give a quick overview of selected variables, the generation of a daily Safety Report, and an extensive graphical module to generate both time evolution and spatial profiles of measured variables.

INSULATION DOOR

On 2 March 2015, about four months after heater switch-on, an insulation door was installed in front of the seal (at a distance of about 1.5 m from the seal) to limit the cooling of the steel cylinder that closes off the heated section of the gallery and thereby to limit the end effect of the Heater test. It also provides an operational safety barrier. The door consists of an aluminium structure that is bolted against the lining, supporting a window to allow visual inspection of the seal.

1.2.2. CONTROL, FOLLOW-UP AND MANAGEMENT OF THE HEATER TEST

MANAGEMENT GUIDE

A management guide with a set of procedures was compiled in close collaboration with ONDRAF/NIRAS in 2014 to specify the follow-up of the test, define the action plan in case of unexpected events and clearly outline and assign the different responsibilities with respect to safety, scientific objectives and technical aspects, such as maintenance and checks. Based on the experience gained over more than one year of follow-up of the experiment, the management guide was completely reviewed and updated in 2016.

NUMERICAL MODELLING

Numerical modelling plays an important role in the PRACLAY Heater test both in terms of preparation of the test and as regards controlling and interpreting it.

Prior to the switch-on of the heating system, with a view to increasing the reliability of the numerical modelling of the expected evolution of the Heater test, significant efforts were devoted to understanding and then numerically reproducing past in-situ measurements. This exercise resulted in a set of reliable parameters that were used in predictive modelling of the PRACLAY Heater test, the so-called "blind predictions" that give an indication of how the Heater test is expected to evolve. Subsequently, different altered scenarios (i.e. deviating from the expected evolution) were studied numerically:

- To support in different ways the design and control of the various components (e.g. primary heater, secondary heater and thermal insulation door) of the PRACLAY Heater test.
- To obtain a possible range of experimental evolutions based on extensive parametric sensitivity analysis.
- To provide a clear basis for developing the procedures for the follow-up and/or management of the Heater test in the event of failure of the primary heater and/or in the event of seal or lining instability.

Since switch-on of the heating system, numerical modelling has received constant attention:

- to determine the primary heater power for the manual input in the heater control system during the stationary phase;
- to improve understanding of the measurements and observations of the Heater test: the predictive modelling of the PRACLAY Heater test is continuously updated by considering the actual heater power and by comparing the numerical results with the actual measurements obtained during the Heater test.

1.2.3 OBSERVATIONS REGARDING THE PRACLAY HEATER TEST 2014-2016

The primary heating system was switched on on 3 November 2014. The target temperature of 80°C at the interface between the gallery lining and the clay was reached on 18 August 2015, marking the end of the "start-up phase". Since August 2015, the temperature at the contact between the lining and the Boom Clay is maintained at a constant 80°C, marking the start of the stationary phase of the Heater test.

The main results from the Heater test since the switch-on in November 2014 up until the end of 2016 are presented in the next section.

EVOLUTION OF THE TEST-CONTROL PARAMETERS

Control of the Heater test is mainly based on the temperature evolution at the interface between the concrete lining and the Boom Clay with the objective of having a temperature profile that is as uniform as possible along the 30 m long heated part of the PRACLAY gallery.

Due to the end effects, the direction of the heat flows over the gallery varies. In Zone 2, the most representative zone of the Heater test, the heat flux vector is almost perpendicular to the gallery surface, while in Zones 3 and 1, this is not the case. This implies that if the heating system delivers the same power output in the three zones, the rate of the temperature increase will be different. In order to ensure better control of the heater test with respect to a uniform target temperature of 80°C, intensive modelling taking into account the end effects and also the capacity of the heating system was performed to determine the heating strategy throughout the entire experiment. In the end, it was decided to control Zone 2 and Zone 3 using two different temperature indicators. Indicator 1 (T_{int_1}) is the average temperature measured at the outer surface of the liner in Zone 2 using the thermocouples embedded in the concrete liner in rings R37, R50 and R55. Indicator 2 (T_{int_2}) uses the average temperature measured by the sensors at the extrados of Ring 81 to control the temperature in Zone 3 (Figure 8 and Figure 9). It was also decided that the power for Zone 1 would mirror that for Zone 2 in spite of the end effect of heat dissipation so as to avoid overheating of the seal structure (safety precaution).

The power and associated temperature evolution in the three zones are illustrated in Figure 8 and Figure 9. In order to attain the target temperature of 80°C, the power in the three zones of the primary heating system was increased stepwise. As expected, the target temperature in Zone 2 (measured by T_{int_1}) was reached first in mid-August 2015; the power in Zone 2 (and therefore in Zone 1) was decreased accordingly to keep this target temperature constant (measured by T_{int_1}). The beginning of this power decrease was considered to be the start of the stationary phase. Once the target temperature in Zone 3 (measured by T_{int_2}) was reached in early June 2016, the power in this zone was decreased accordingly to keep it constant.

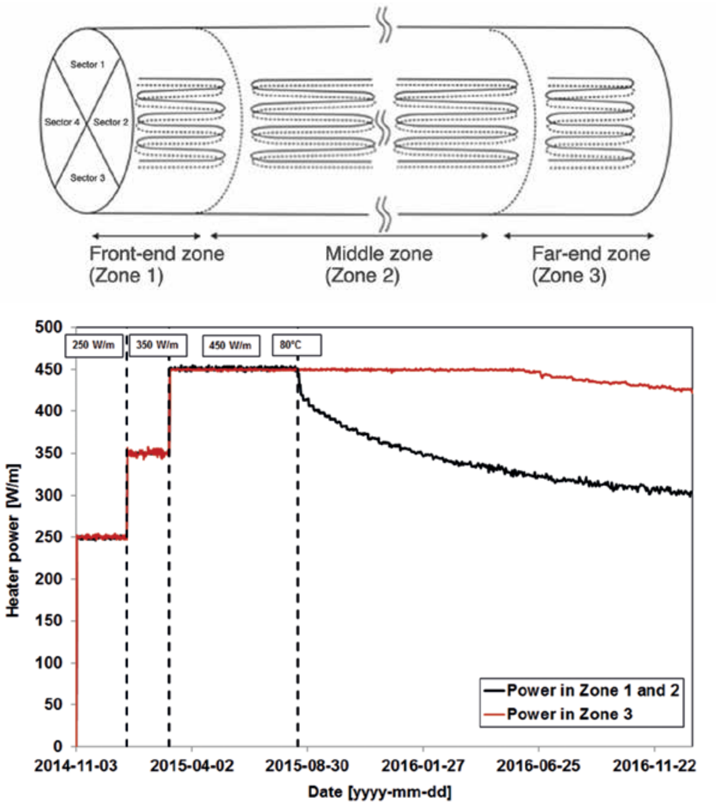


Figure 8 - Evolution of the power in watts per metre (W/m) in the three zones. The power in Zones 1 and 2 was decreased once the temperature in Zone 2 reached 80°C (measured by T_{int_1}). The power in Zone 3 was decreased with a delay of a couple of months once Zone 3 reached 80°C (measured by T_{int_2}).

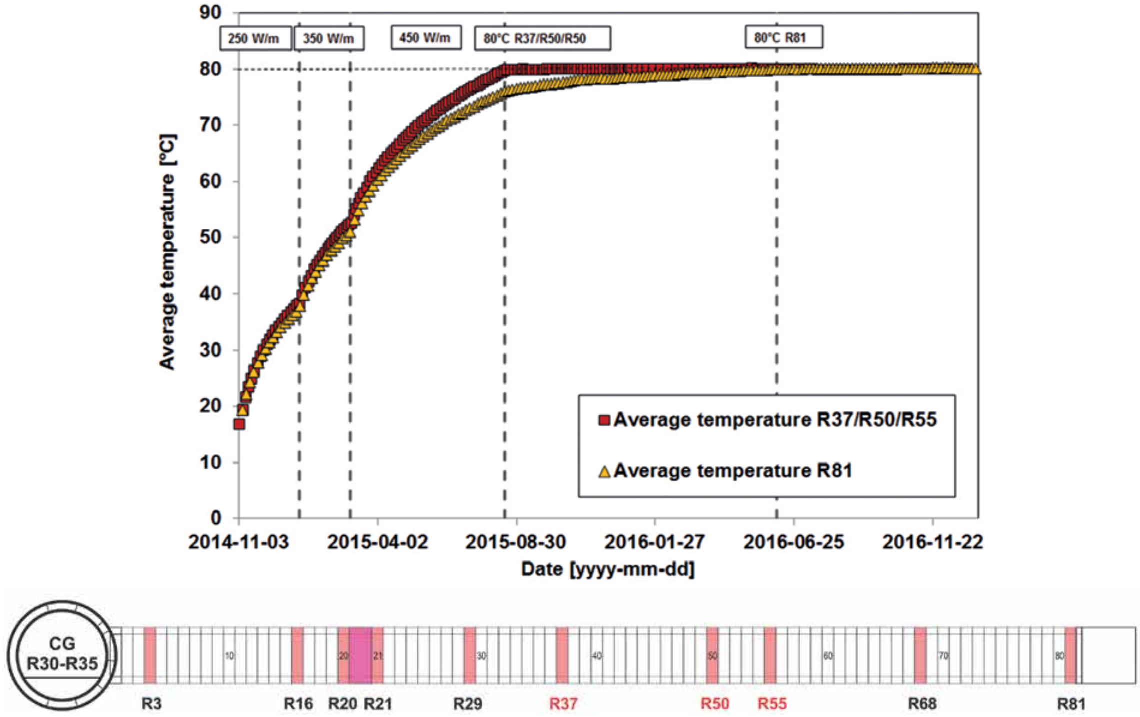


Figure 9 - Average temperature evolution measured using the extrados sensors in R37, R50 and R55 (T_{int_1}) and R81 (T_{int_2})

This heating strategy made it possible to obtain a reasonably homogenous temperature distribution at the extrados of the lining along the heated part of the gallery, as illustrated in Figure 10, though with some heterogeneities. This means that the target temperature of 80°C might be reached at some specific locations, while the rest might be slightly below or above this target temperature. This is one of the reasons that an "average" temperature over the selected thermocouple sensors at the extrados of lining rings was used as the temperature indicator for controlling the experiment.

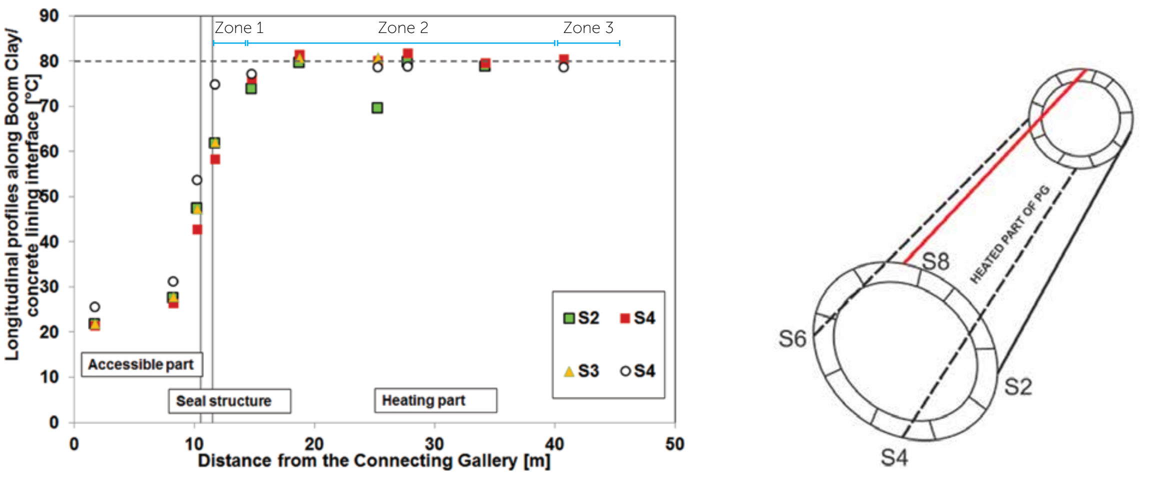


Figure 10 - Longitudinal profiles of the temperature along the extrados of the PRACLAY gallery (end 2016)

Due to the heating process and the difference in the thermal dilatation coefficient between the solid and the fluid part of the water-saturated sand, an excess pore water pressure is induced inside the PRACLAY gallery. This rise in pore water pressure in the backfilled part of the PRACLAY gallery is shown in Figure 11. During the start-up phase of the Heater test, the pore water pressure rose quickly at the beginning of each heating step, followed by a more gradual increase, due to progressive dissipation of water pressure in the surrounding clay. After the target temperature in Zone 2 was reached in August 2015, the pore water pressure fell briefly then levelled off. It is noted that, due to the fairly high hydraulic conductivity of the backfill material, the pore water pressure inside the backfilled part of the PRACLAY gallery is quite uniform.

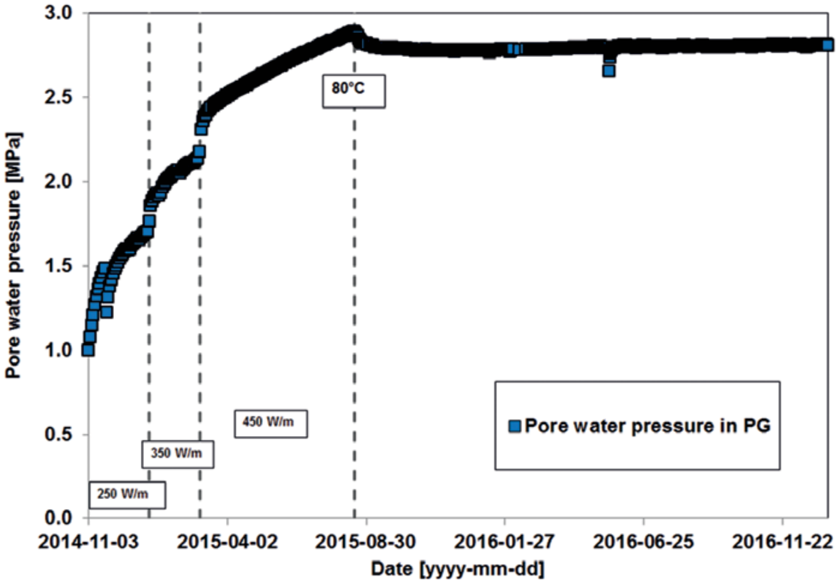


Figure 11 - Pore water pressure evolution in the backfilled part of the PRACLAY gallery

BOOM CLAY RESPONSES

The rise in temperature in the Boom Clay upon heating results in excess pore water pressure due to the differential thermal dilatation coefficient between the solid (skeleton) and the liquid phase (mainly water) in the clay (thermal-hydro-mechanical coupling behaviour).

The variation in the temperature and pore water pressure inside the Boom Clay is monitored using instrumented boreholes in different directions from the PRACLAY gallery and from the Connecting gallery (Figure 12).

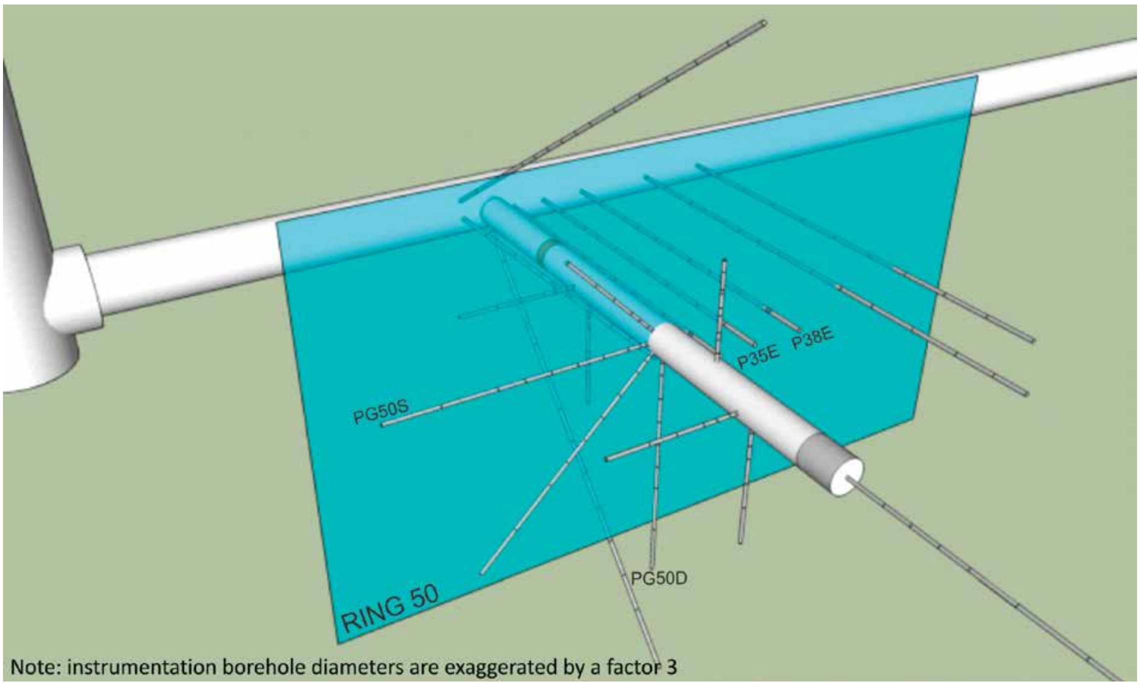


Figure 12 - 3D view of the instrumented boreholes from the PRACLAY gallery and the Connecting gallery

The evolution of the temperature and pore water pressure profiles in the vertical direction (monitored from the downward borehole PG50D in the middle section of the heated gallery) is shown in Figure 13. The evolution of the temperature and pore water pressure profiles in the horizontal direction (measured from the boreholes, drilled from the Connecting gallery and parallel to the PRACLAY gallery, with the sensors located at the middle section of the heated gallery, as shown in Figure 12) is shown in Figure 14.

Taking as the criterion a ΔT (rise in temperature) >1°C, it is observed that, at the end of 2016, the thermally affected zone had extended to a depth of about 12 m into the Boom Clay in the vertical direction (Figure 13a) and 15 m into the Boom Clay in the horizontal direction (Figure 14a). At a given time and at the same distance from the heater, the temperature rise in the horizontal direction is larger than that in the vertical direction. These observations clearly indicate an anisotropic heat transfer mechanism through the Boom Clay, as already observed in small-scale in-situ heater tests.

Concerning the evolution of the pore water pressure, close to the lining, the pore water pressure increased as expected from its initial value of 1 MPa before heating to a value close to 3 MPa at the end of the start-up phase (August 2015). Since the beginning of the stationary phase, the pore water pressure has remained nearly constant close to the lining but continues to increase in the clay. Over time the peak in pore water pressure has gradually shifted away from the gallery into the Boom Clay (Figure 13b and Figure 14).

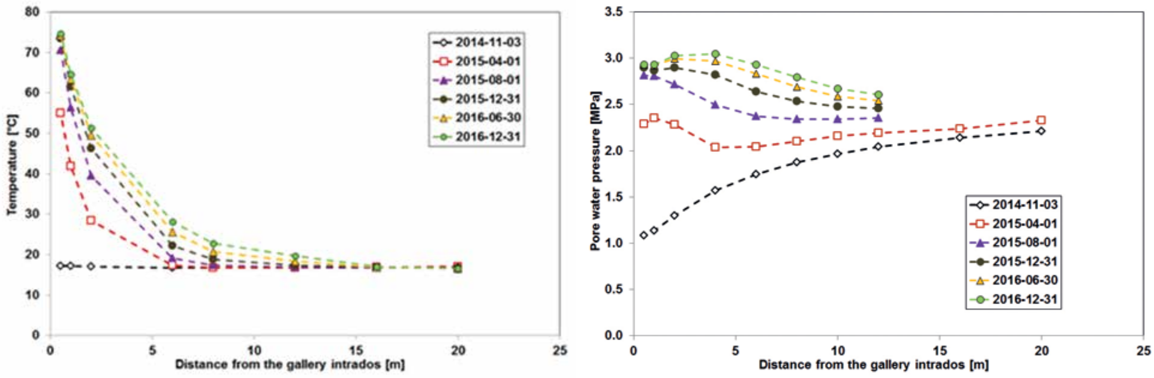


Figure 13 - Temperature and pore water pressure profiles in the vertical direction at the middle section of the heated part of the PRACLAY gallery (along borehole PG50D)

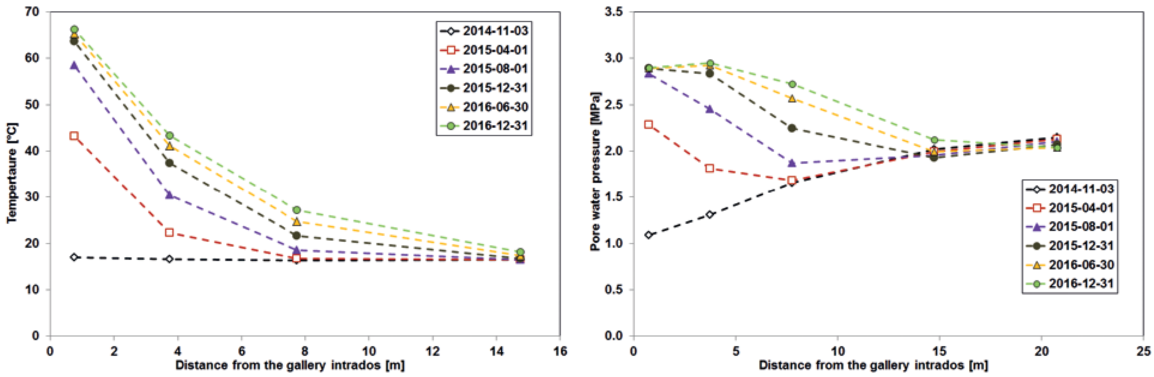


Figure 14 - Temperature and pore water pressure profiles in the horizontal direction at the middle section of the heated part of the PRACLAY gallery (measured from boreholes drilled from the Connecting gallery)

Spatial distribution of the temperature and pore water pressure around the PRACLAY gallery is illustrated in Figure 15 and Figure 16. Figure 15 shows the temperature and pore water pressure profiles along P35E, located approximately 0.75 m from the extrados of the gallery lining. The pore water pressure profile is almost uniform along the gallery, while the temperature profile shows a slight temperature gradient from the seal to the end part of the PRACLAY gallery. The pore water pressure profile in Figure 15 (b) clearly shows the hydraulic cut-off by the seal.

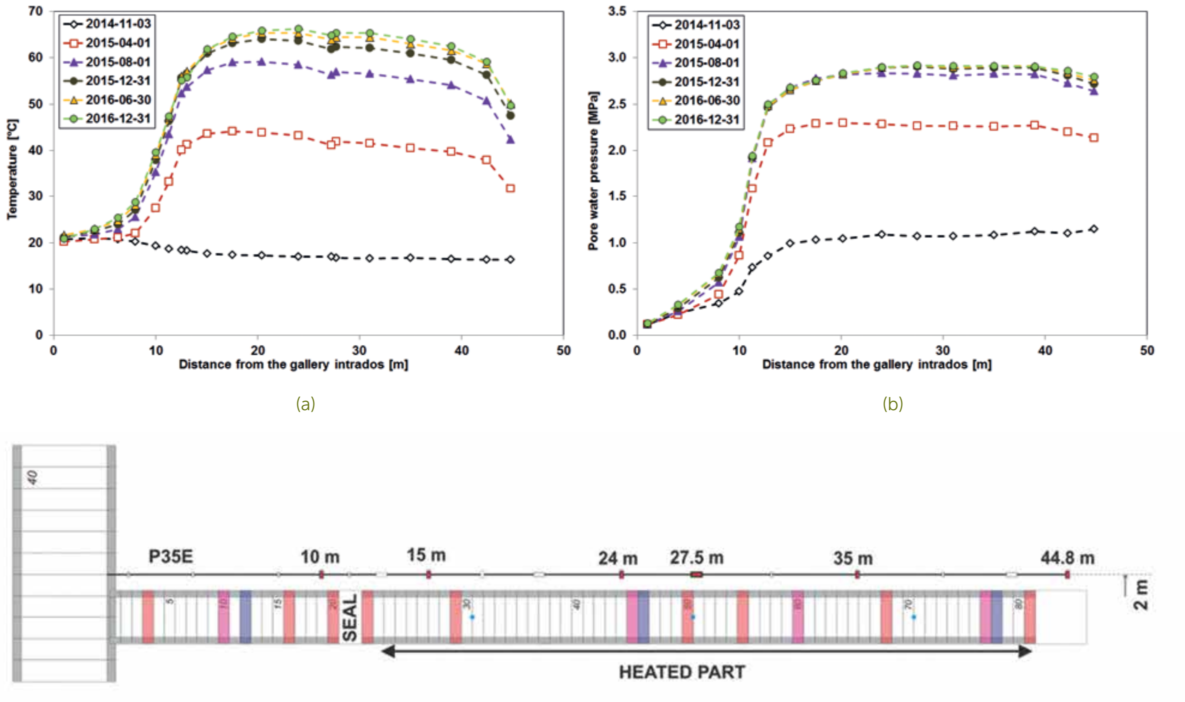


Figure 15 - Temperature and pore water pressure profiles in P35E

The temperature and pore water pressure at a distance of 5 m from the axis of the PRACLAY gallery can be seen in Figure 16. The pressure in this borehole reached almost 2.8 MPa in the deepest part of the boreholes, which is also closest to the PRACLAY gallery.

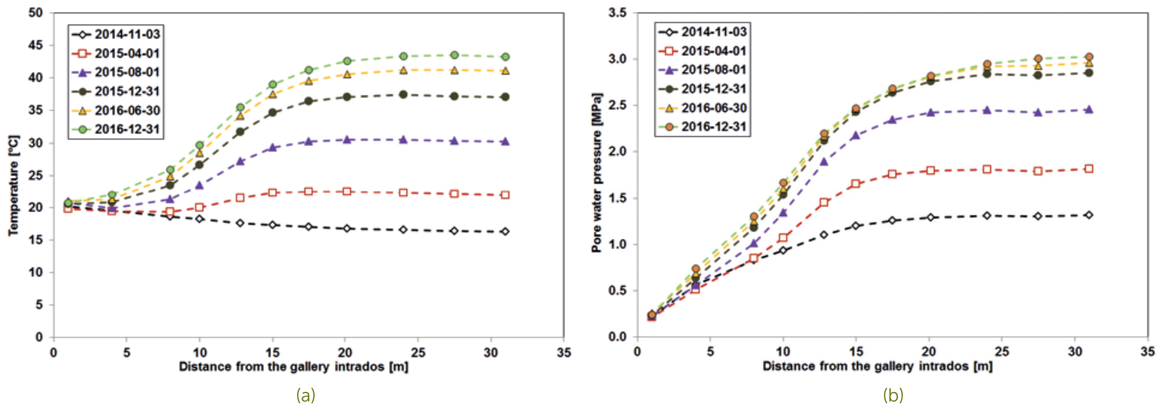


Figure 16 - Temperature and pore water pressure profiles in P38E

EVOLUTION OF THE HYDRAULIC SEAL

The hydration of the bentonite and the total pressure resulting from the pressure of the Boom Clay, on the one hand, and the swelling of the bentonite, on the other hand, were continuously monitored during the heating phase. Figure 17, for example, shows an increase in the pore water pressure at the Boom Clay/bentonite interface with the different heating steps. The pore water pressure in the bentonite ring evolves in the same way for the three sections A, B and C. One of the main purposes of the seal structure is to provide a hydraulic cut-off between the heated and the non-heated part of the experiment. The effect can be observed in the different evolution of the pore water pressure in sensors Seal-PP-A1 and Seal-PP-A3 in section A. The first is located close to the heated part, while the second is close to the accessible, non-heated part of the PRACLAY gallery. A significant difference of nearly 1 MPa can be observed between both sensors, indicating that the seal is functioning well. Moreover, the pore water pressure inside the PRACLAY gallery is maintained as expected due to the seal performing well.

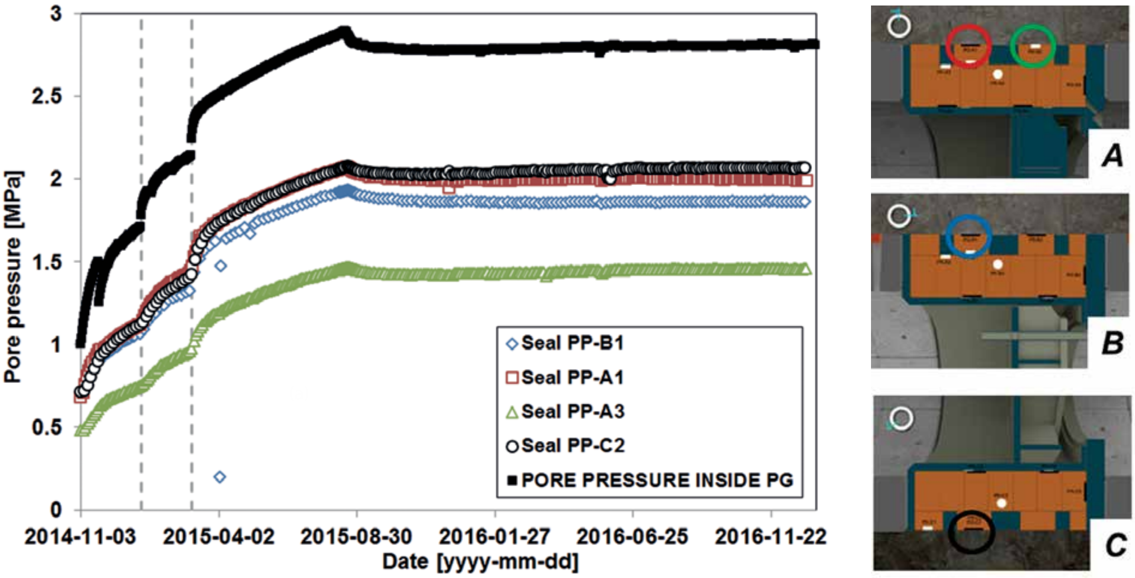


Figure 17 - Evolution of the pore water pressure at the Boom Clay/bentonite interface

In order to highlight the effect of the seal, Figure 18 shows the evolution of the pore water pressure at the Boom Clay/bentonite interface for different positions in section A, and at the Boom Clay/concrete lining interface close to section A. It is worth noting that between the non-heated and heated parts of the gallery, a big difference in pore water pressure of almost 2 MPa occurs over a distance of 1.5 m. This significant gradient is clear proof of the good hydraulic cut-off created by the seal.

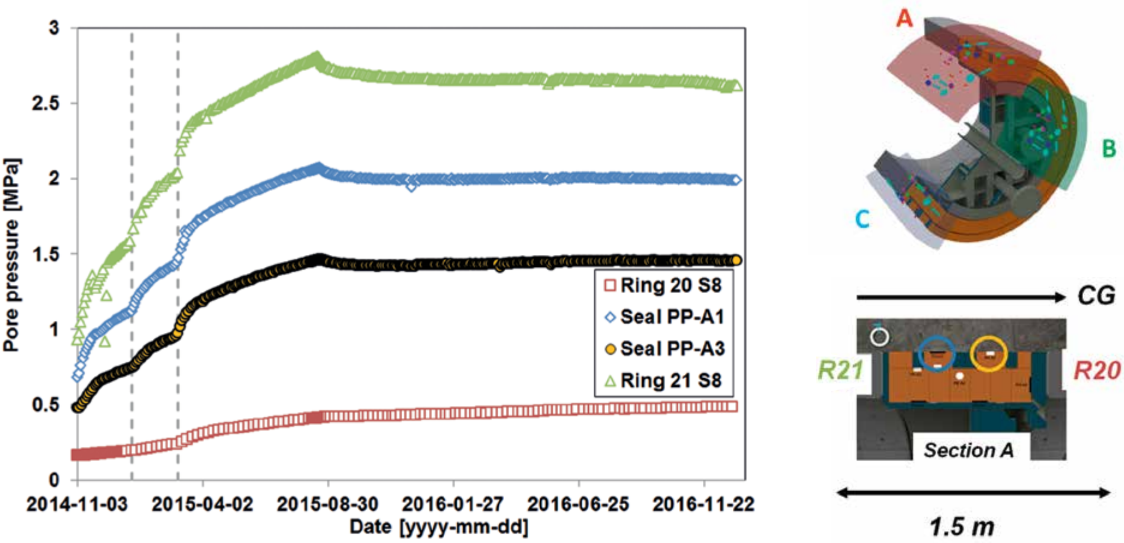


Figure 18 - Pore water pressure evolution at the Boom Clay/concrete lining interface and Boom Clay/bentonite interface

The evolution of the total pressure at the Boom Clay/bentonite interface can be seen in Figure 19. A slow increase is observed during the start-up heating phase. This increase seems to be steady. A variation in total pressure of about 1 MPa has been observed since heating was first applied, indicating a slow hydration and swelling process. The small increase in total pressure at the beginning of the second heating step is linked to the installation of the thermal insulation door in front of the seal, which temporarily caused a rapid increase in temperature. Indeed, the purpose of the door is to limit the heat loss in the accessible part of the PRACLAY gallery. As a consequence, the temperature of the seal increased and the total pressure at the Boom Clay/bentonite interface rose slightly

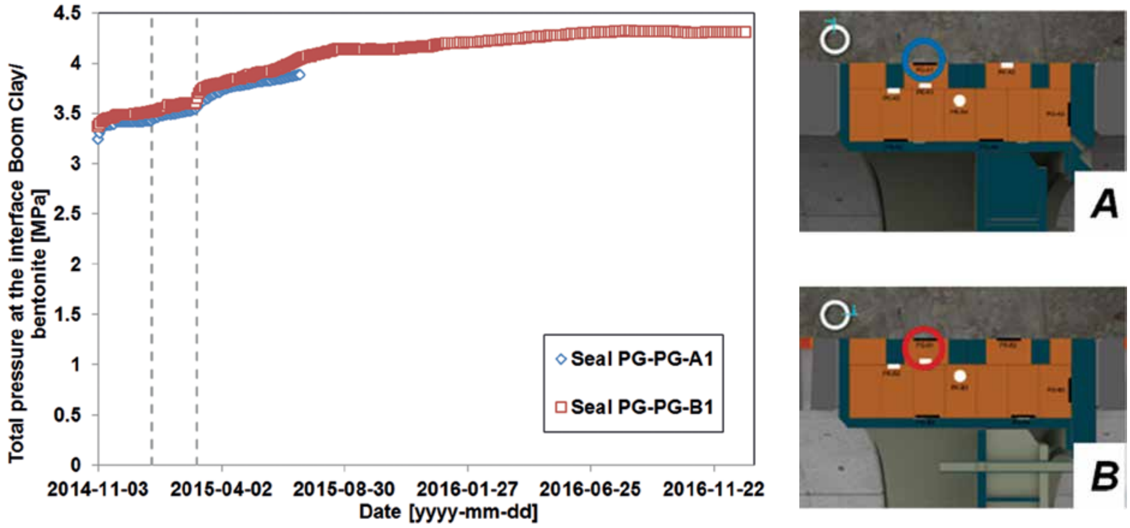


Figure 19 - Total pressure at the Boom Clay/bentonite interface in sections A and B

The movement of the seal structure towards the Connecting gallery was monitored by a total station and prisms attached to this structure, as can be seen in Figure 20. A significant increase in displacement during the start-up phase can be observed, but this has tended to be steady since the beginning of the stationary phase.

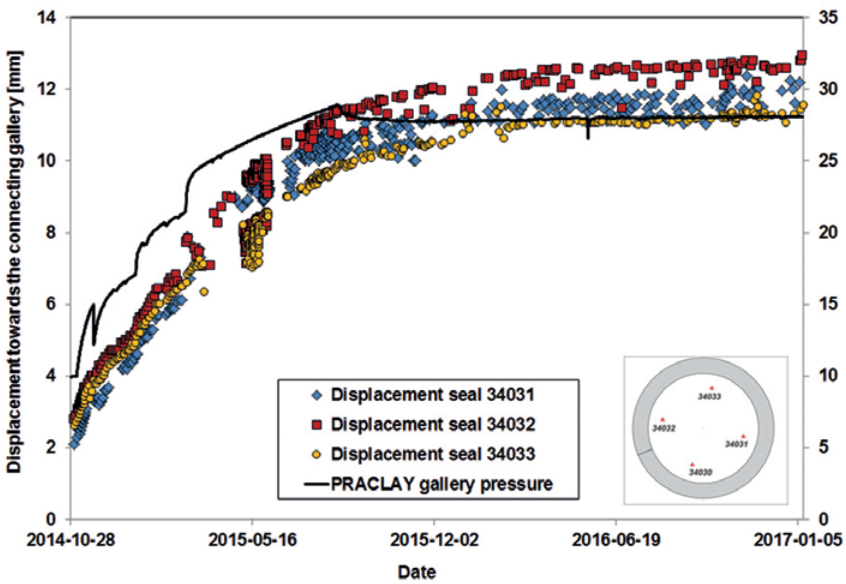
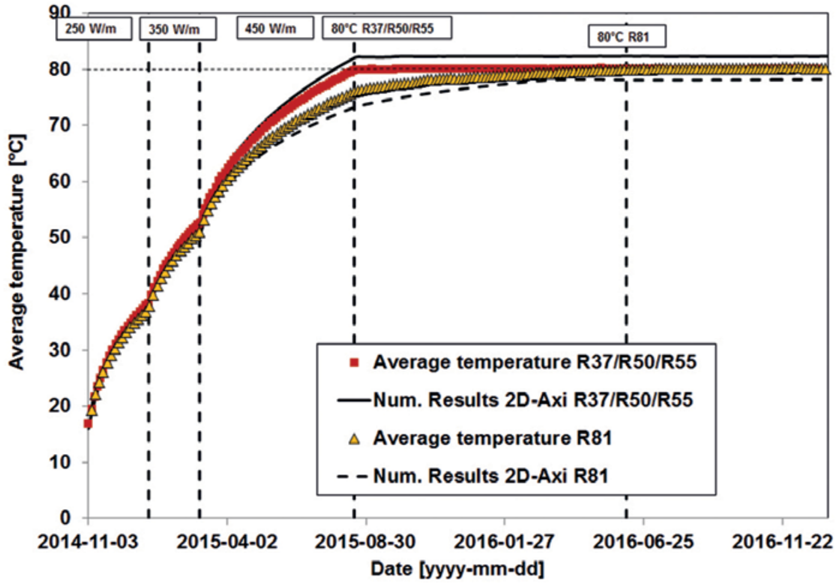


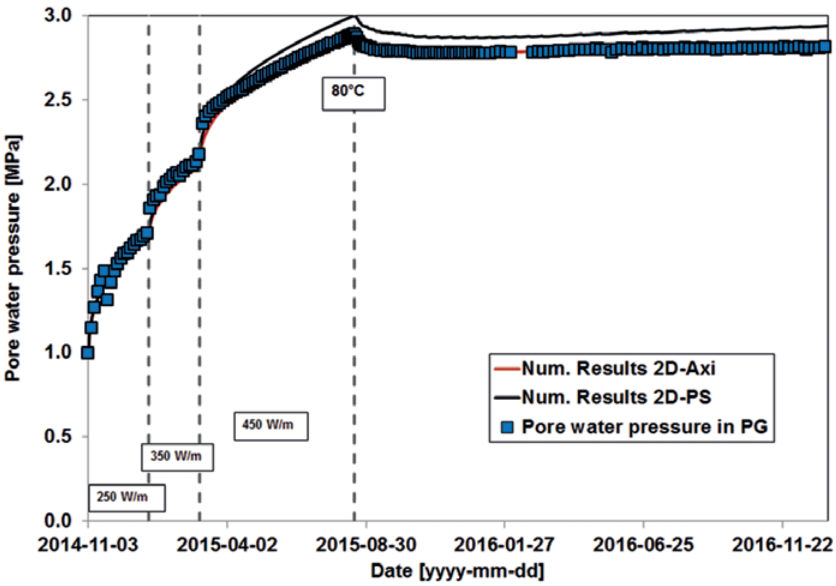
Figure 20 – Evolution of the movement of the seal structure towards the Connecting gallery since the beginning of the heating phase

COMPARISON BETWEEN MEASUREMENTS AND BLIND PREDICTIONS

As already mentioned, intensive predictive modelling was performed before the start of the experiment and during the heating phase. The aim of this work was, firstly, to provide input for the control of the experiment, mainly by managing the power input. A second very important aim was to enable comparison between the experimental measurements and the so-called "blind predictions" from the modelling. Figure 21 shows the evolution of the temperature at the interface of the lining and the Boom Clay and pore water pressure in the backfilled part of the PRACLAY gallery compared with the modelling results. Good agreement can be observed for both parameters. Regarding temperature, it can be stated that the modelling predictions correspond well with the actual (i.e. measured) evolution of the temperature inside all the components of the experiment (Figure 22 a). The pore water pressure evolution can also be modelled, but with a different level of agreement depending on the distance from the PRACLAY gallery (Figure 22 b).

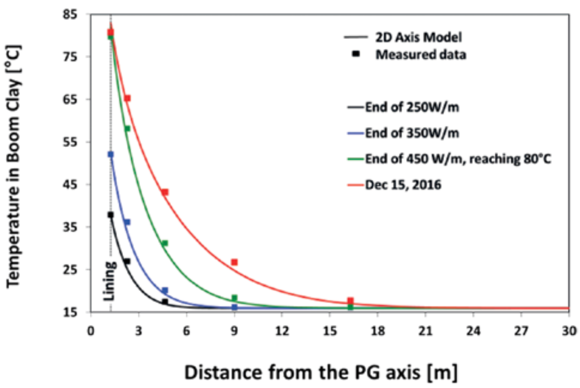


(a)

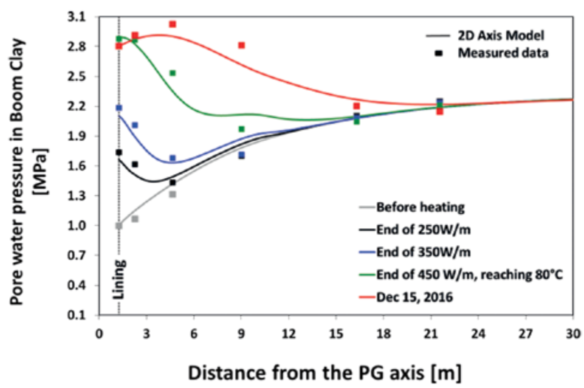


(b)

Figure 21 - Evolution of the temperature at the extrados of the lining and pore water pressure inside the PRACLAY gallery, compared with the numerical results



(a)



(b)

Figure 22 - Comparison between the measured and modelled temperature and pore water pressure (horizontal profiles)

2015 and 2016 were mainly devoted to controlling the experimental set-up and managing all the generated data. During 2017, preparation will start on a general report containing a complete evaluation of the experimental results and set-up and a more detailed analysis of the observations in the clay surrounding the PRACLAY gallery.

PERMEABILITY TEST AROUND THE CONNECTING GALLERY AND PRACLAY GALLERY

In order to study the excavation-induced permeability variation and the self-sealing capacity of the Boom Clay, a series of permeability tests have been conducted around HADES. During 2015 EIG EURIDICE compiled a summary of all the in-situ permeability tests performed around the Connecting gallery and the PRACLAY gallery between 2004 and 2012. In 2016 a new series of permeability tests were carried out around these two galleries. The purpose of the tests around the Connecting gallery was to study the permeability evolution of the Boom Clay in relation to the excavation, consolidation and creep of the clay. Around the PRACLAY gallery, the impact on the Boom Clay permeability of excavation, consolidation, seal installation and pressurisation of the backfilled part of the gallery, and heating was studied. The permeability evolution of the Boom Clay is important for the interpretation of the PRACLAY Heater test and has to be taken into account in the numerical modelling.

New series of permeability tests around the Connecting gallery were carried out again in 2016 on the reference filters installed from Ring 55, where the Boom Clay is not much disturbed yet by the PRACLAY Heater test. New test results were compared with the results obtained in 2004, 2005 and 2012. Evolution of the permeability shows that the self-sealing process around the Connecting gallery occurred rather quickly after excavation, but seems to slow down with time, as shown in Figure 23. There seems to have been no further decrease in permeability since 2012.

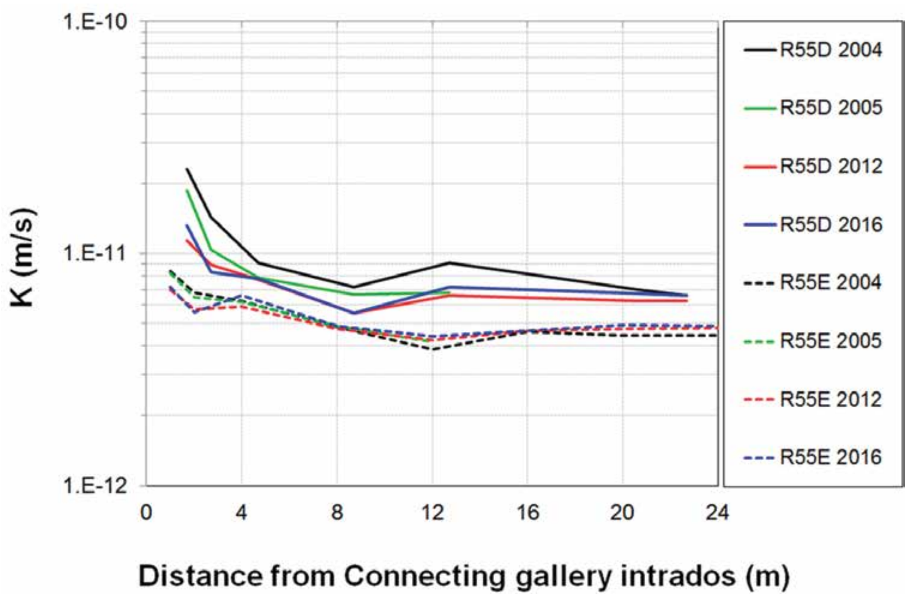


Figure 23 - Evolution of the hydraulic conductivity (coefficient of permeability) along boreholes R55D and R55E from 2004 to 2016

In addition, new permeability tests were also performed on the filters installed in vertical boreholes around Ring 13 of the Connecting gallery (R13U and R13D). Although the permeability measurement was never done on these filters before 2016, water samples were taken from them for geochemical analysis in 2004, 2005 and 2007. The permeability could be estimated from the data obtained during the sampling (pore water pressure variation and water outflow weight). The comparison between the permeability measured in 2016 and the permeability estimated from the geochemical sampling campaigns in 2004, 2005 and 2007 is shown in Figure 24, which demonstrates the effect of the excavation of the Connecting gallery and the subsequent self-sealing process of the Boom Clay, and also shows the non-homogeneity of the Boom Clay permeability above and below the Connecting gallery due to the presence of the more sandy clay layers.

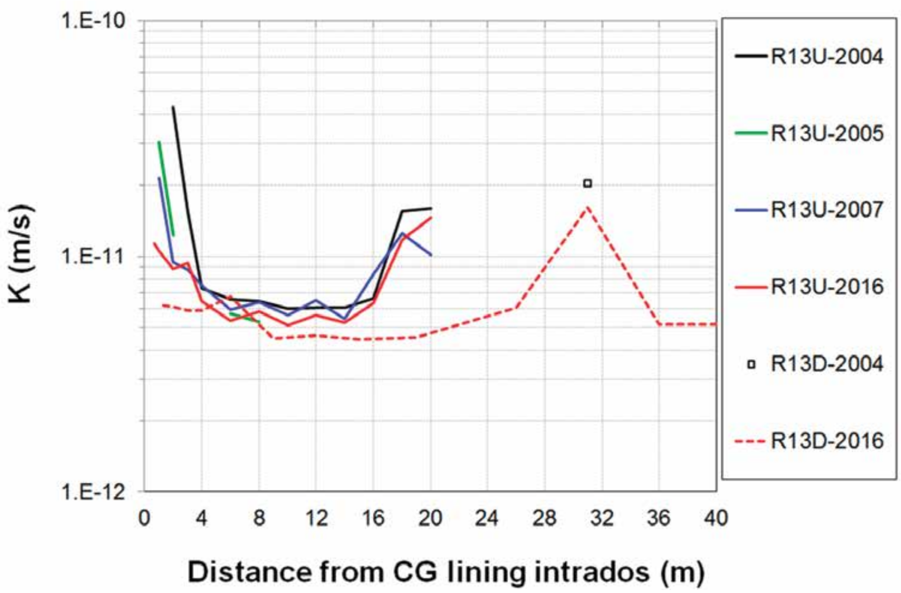


Figure 24 - Evolution of the hydraulic conductivity (coefficient of permeability) along boreholes R13U and R13D from 2004 to 2016

Around the PRACLAY gallery, systematic permeability tests on the selected filters before switch-on of the heater provided insight into the evolution of permeability after excavation. Most importantly, an initial value of the Boom Clay permeability before starting the PRACLAY Heater test was obtained.

The PRACLAY Heater test has now been running for more than two years with the maximum temperature in the Boom Clay having reached 80°C more than a year ago. In 2016 a limited number of permeability tests were performed in the Boom Clay close to the heated part of the PRACLAY gallery to check the effect of heating on Boom Clay permeability. Comparison of the test results before and after switch-on of the heater indicates that even on a large scale the increase in Boom Clay hydraulic conductivity with the increase in temperature is mainly due to the decrease in liquid viscosity, meaning that no significant change in the intrinsic permeability can be noted with temperature. This confirms the laboratory investigations on the Boom Clay and also the results from the smaller-scale in-situ ATLAS heating tests.

More in-situ permeability tests will be performed in 2017.

PRELIMINARY CONCLUSIONS

The PRACLAY Heater test has been running for more than two years and the target temperature of 80°C was reached on 19 August 2015. In general terms, the status of the experiment is satisfactory from the scientific, technical and safety point of view. The experimental set-up is evolving as expected. The PRACLAY seal is fulfilling its function, i.e. ensuring "hydraulic boundary conditions" for the Heater test. The thermo-hydro-mechanical responses of the Boom Clay are very much as predicted and there are no observations/measurements showing signs of "liquefaction" (e.g. large displacements, hydraulic fracturing or drastic changes in properties), confirming - to a large extent - the existing scientific knowledge on the thermo-hydro-mechanical properties and behaviour of the Boom Clay. This is also confirmed by in-situ permeability tests around the PRACLAY gallery, indicating no significant change in the intrinsic permeability of the Boom Clay in response to being heated.

EURIDICE plans a first evaluation of the objectives and the succes criteria of the PRACLAY Seal and Heater tests (ONDRAF/NIRAS note ref. 2007-1144) by the end of 2017. The results of this evaluation will be broadly communicated.

2. Supporting studies

2.1. Stability of the Connecting gallery

The convergence of the lining of the Connecting gallery has been monitored since the construction of the gallery in 2002.

The measurements indicate that convergence (diagonal reduction) can reach a value of around 10 mm for different diagonals of the rings, as can be seen in Figure 25. An ovalisation (lying egg shape) of the gallery is clearly demonstrated. Since the end of 2014 the measurements have shown the first signs of stabilisation, which was confirmed in 2016.

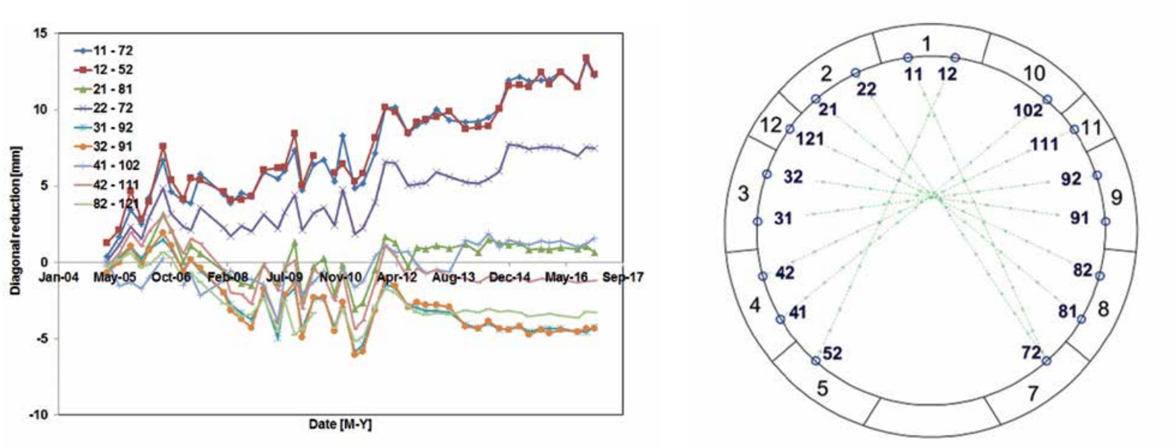


Figure 25 - Diagonal reduction measurement of Ring 50 in the Connecting gallery (positive values for reduction, negative for elongation)

2.2. Micro-seismic monitoring programme

The micro-seismic system around the PRACLAY gallery was installed in two phases between September 2006 and January 2008 and consists of 23 transmitters and 19 receivers (Figure 26 & Figure 27). The system has been operating continuously since 2006.

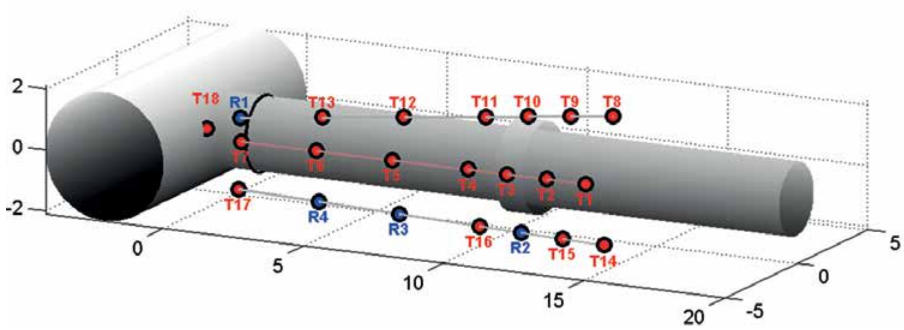


Figure 26 - [Red] transmitters (T) and [blue] receivers (R) installed in September 2006

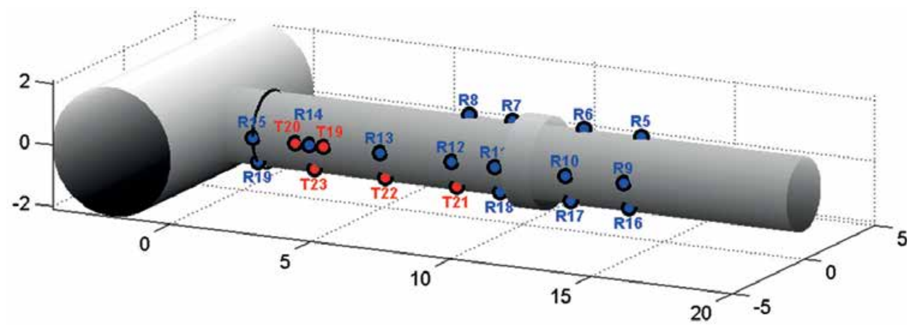


Figure 27 - [Red] transmitters (T) and [blue] receivers (R) installed in January 2008

As can be seen, the transmitters and receivers are located at various points along the PRACLAY gallery, both in the Boom Clay and at the interface between the concrete lining and the clay. This enables micro-seismic signals to be generated along different travel paths and transmitter-receiver combinations. This in turn makes it possible to monitor the evolution of compressive (P) and shear (S) wave velocities around the PRACLAY gallery and to provide valuable data to assess the very small strain dynamic moduli (E_{max} or G_{max}) and their evolution in the clay.

An example of typical P and S wave signals measured with the set-up is shown in Figure 28. The first signal shown in the time series plot corresponds to the P wave, while the second signal is the S wave, confirming that the set-up can measure both of these parameters.

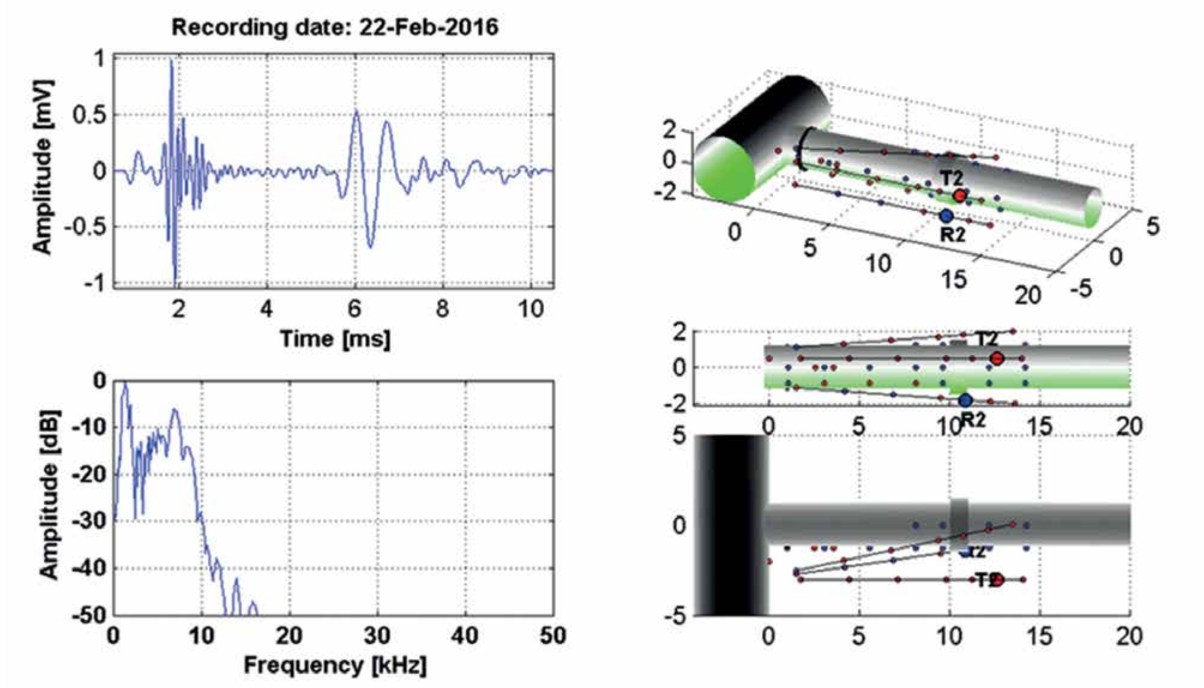


Figure 28 - Example of measurements obtained with the micro-seismic set-up, showing time series and frequency spectrum recordings of P and S waves for Transmitter 2 and Receiver 2 measured on 22 February 2016

One of the promising uses of the micro-seismic measurements is the possibility of monitoring the evolution of the seismic parameters in the clay during the PRACLAY Heater test.

An internal report is being prepared to evaluate the quality of the micro-seismic set-up in HADES, as well as its long term performance. The final report will include an overview of the data and its quality recorded so far, an analysis of waveforms and material properties based on measurements of compressive (P) and shear (S) wave velocities obtained on a selected number of data sets, possible suggestions for increasing the added value of the micro-seismic set-up and general recommendations for future continuation of the system.

2.3. PhD research

For the past couple of years, a specific thermo-hydro-mechanical-chemical (THMC) characterisation programme on the Boom Clay has been run in parallel with the PRACLAY experiment, in collaboration with different universities and laboratories through several PhD research projects. EIG EURIDICE is involved in the definition and supervision of these projects. Concerning the chemical part of this THMC characterisation program, the research focused on the effect of the pore-water chemistry composition (salinity) on the hydro-mechanical behaviour of the Boom Clay.

A specific research project was initiated in 2014 to further study the anisotropy features of the thermal conductivity of Ypresian clays, the other potential host formation for high-level waste disposal in ONDRAF/NIRAS' geological disposal programme. EURIDICE's involvement is to offer its relevant expertise for the follow-up of the project and review of the related scientific papers.

Late 2015 marked the end of one phase of this THM-C characterisation programme: most of the contractual PhD research projects for the period 2010-2015 terminated at the end of 2015, except the cooperation project with the Institute of Rock and Soil Mechanics (IRSM) of the Chinese Academy of Science (CAS) on the long-term THM behaviour of the Boom Clay, which needs to be extended to be able to finish the initially planned long-term creep tests under well-defined THM boundary conditions.

The PhD project in collaboration with the International Center for Numerical Models in Engineering (CIMNE), Spain, on the laboratory investigation of the gas transport in the Boom Clay has also been extended for one year to enhance the laboratory evidence and to improve the interpretation through numerical modelling.

In 2016, EURIDICE has introduced together with the Expert Group "Waste & Disposal" of SCK•CEN, a joint PhD research project within the PhD program for Young Potentials of SCK•CEN's Academy. This project, entitled "A Multiscale Approach to Model Early Age Thermo-Hydro-Mechanical Behaviour of non-reinforced Concrete", was approved and awarded to the candidate Mr. Saeid BABAEI, who started in January 2017. It is financed by SCK•CEN's Academy and is performed in cooperation with the Antwerp University.

CIMNE (Universitat Politècnica de Catalunya, Barcelona (UPC), Spain)

A. "Laboratory investigation of gas transport processes in Boom Clay"

Financed directly by ONDRAF/NIRAS, the PhD research on the "Laboratory investigation of gas transport processes in Boom Clay" started at the end of 2012 by the candidate Laura Gonzalez-Blanco. Together with ONDRAF/NIRAS, EIG EURIDICE is involved in supervising and following up the project.

This research aims to study the gas transport mechanisms and breakthrough processes in the Boom Clay through an exhaustive laboratory experimental programme. Indeed, one of the important issues in the long-term performance of a geological repository concerns the generation and migration of gases that can be produced as a result of the anaerobic corrosion of metal canisters, radiolysis, microbial degradation of organic waste, etc.

Special cells have been developed to perform the gas injection tests under well-controlled pneumatic, hydraulic, mechanical and thermal boundary conditions.

The specific objectives of the project are:

- To investigate volume change behaviour during gas tests and its impact on gas permeability.
- To check the role played by the orientations of the bedding planes of rock using triaxial and oedometer cells, applying different boundary conditions.
- To estimate the influence of the gas injection rate.
- To study microstructural changes during gas injection and the role played by the opening of fissures.

It is worth underlining that the main focus of this study is the coupled hydro-mechanical behaviour of the clay in case of gas flow through preferential pathways. Consequently, relative high gas injection rates were used to give priority to dominant single phase air flow mechanisms associated with the opening of stress-dependent discontinuities, rather than on slower two-phase flow and air diffusion mechanisms though the matrix of the tested samples.

The experimental work continued in 2016. A substantial effort was made to analyse the experimental results obtained, focusing on volume change behaviour during gas injection and dissipation and on the microstructural changes after the gas migration process, which revealed the opening of fissures due to gas passage. Moreover, micro-focus computed tomography (μ-CT) scans were performed on intact samples and on samples that were used for gas tests. This information, combined with MIP (mercury intrusion porosimetry), not only makes it possible to quantify the fissured volume after gas passage, but also to visualise its distribution and connectivity.

To gain a better understanding of the gas transport mechanisms, numerical simulations of the gas tests were performed. The experimental results were simulated using a fully coupled hydro-mechanical finite element code. Different numerical approaches were used, one of which involved incorporating an embedded fracture permeability model to account for the gas flow along preferential pathways. This approach assumes that the clay's intrinsic permeability and its retention curve depend on strains through fracture aperture changes. Numerical analysis accounted for not only the correct simulation of the recorded upstream pressures and outflow volumes and pressures, but also the volume change behaviour of the gas tests. Numerical work continued in 2016, with a new approach involving incorporation of a random porosity field into the modelling based on the μ-CT data, which takes into account the heterogeneity of the material. The heterogeneity in the model provides a more realistic approach to automatically developing fracture patterns without the need to pre-define the fractured zone.

The experimental and numerical information offers good insight into the mechanisms of gas transport in deep clay formations and highlights the role played by the deformational response on the air transport properties of the sedimentary formation of the Boom Clay.

The annual meeting between ONDRAF/NIRAS, EIG EURIDICE and CIMNE/UPC was held in Brussels on 26 February 2016. The yearly progress report was delivered to ONDRAF/NIRAS and EIG EURIDICE in October 2016. The thesis defense is foreseen in May 2017.

The progress of the project in 2016 led to several publications (see Scientific output).

B. Tests on the thermal anisotropy of Ypresian clays
A specific project agreement between ONDRAF/NIRAS, EIG EURIDICE and CIMNE/UPC was drawn up for the period July 2014 - October 2015 to investigate in depth the thermal conductivity of Ypresian clays.

In 2016 an effort was made to finish the final report and disseminate the test results, which led to several publications in 2016 (see Scientific output).

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

The project "Research on long-term coupled thermo-hydro-mechanical (THM) behaviour of the Boom Clay" aims to investigate the effect of temperature on the creep and self-sealing capacity of the Boom Clay and to gain knowledge and information for simulating the PRACLAY Heater test. This project started in late 2011 and was concluded at the end of 2015.

A complete test programme has been established within the context of this collaboration agreement. This programme covers a set of short-term tests (odometer tests, triaxial tests at different temperatures, permeability tests, etc.) and long-term (creep) tests (odometer and triaxial). The long-term creep tests were aimed at investigating the deviatoric stress threshold for creep and temperature effects on the creep behaviour; particular attention was also devoted to creep behaviour during the heating/cooling cycle, which mimics the thermal path around an HLW repository.

Due to the low permeability of the Boom Clay, the laboratory tests, especially the creep tests on the Boom Clay, are extremely time-consuming. It was decided together with ONDRAF/NIRAS to continue the experimental study of the Boom Clay with IRSM. This study mainly aims to finish the planned experimental programme and especially the creep tests to fill some of the knowledge gaps identified regarding creep behaviour and provide more data to calibrate the parameters of the EVP-Damage model of the Boom Clay developed at IRSM based on laboratory tests.

A new THM-coupled triaxial testing machine, as shown in Figure 29, was specially designed and updated for the THM-coupled triaxial compression and creep tests on the Boom Clay. The new experimental system allows four triaxial cells to work together to improve test efficiency.

Figure 29 - New THM-coupled triaxial test machine for investigating short- and long-term THM behaviour (IRSM, China)

After careful calibration of the test machine against temperature variation and loading paths at the beginning of 2016, two short-term triaxial tests at different temperatures were first conducted. The stress-strain curves and pore water pressure-strain curves of THM-2.7-40-1 (under the confining pressure of 2.7 MPa, back pressure of 1.2 MPa and temperature 40°C) and THM-2.7-80-2 (under the confining pressure of 2.7 MPa, back pressure of 1.2 MPa and temperature 80°C) are shown in Figure 30. The test results were interpreted together with previous test results, as illustrated in Figure 31 and Figure 32, which clearly indicate the temperature effect on the shear strength of the Boom Clay.

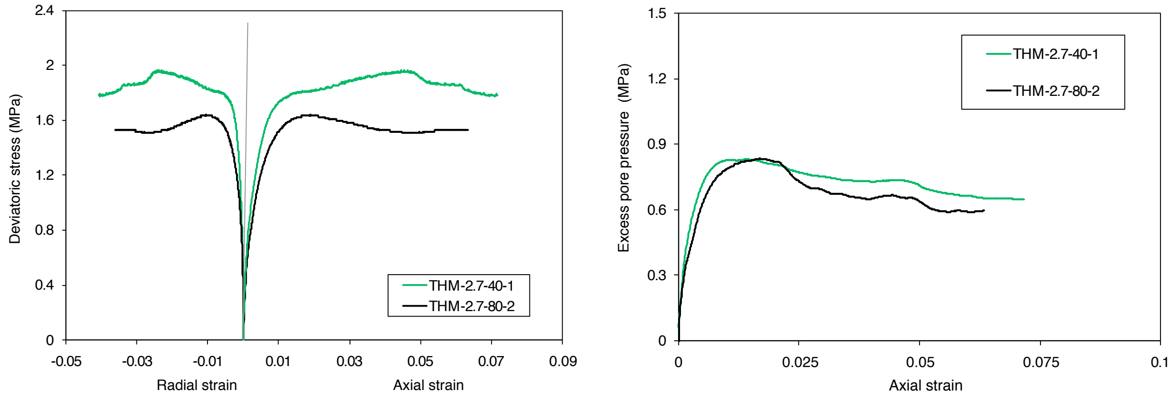


Figure 30 - The stress-strain curves and pore water pressure-strain curves of two short-term tests THM-2.7-40-1 and THM-2.7-80-2

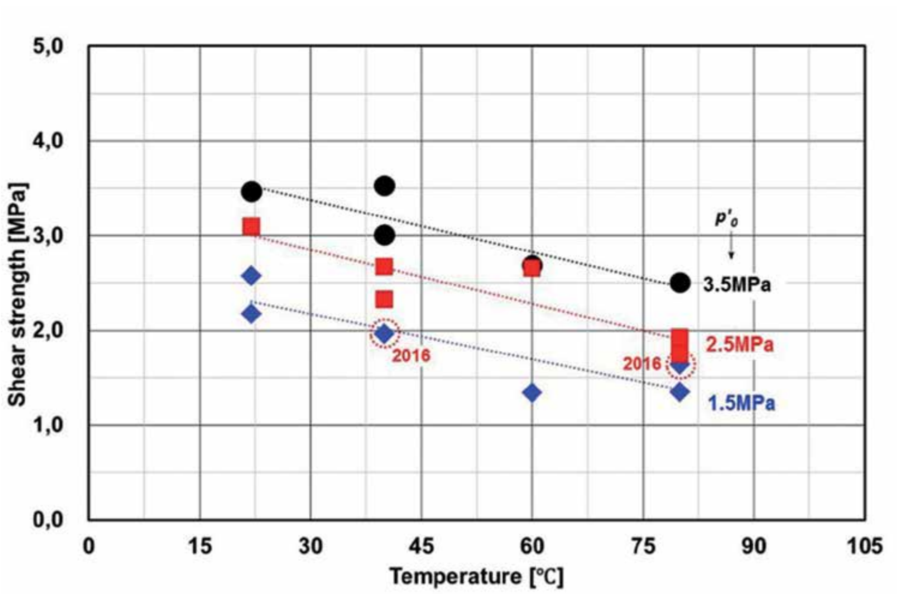


Figure 31 - Peak stress as a function of temperature at different initial mean effective stress p'0

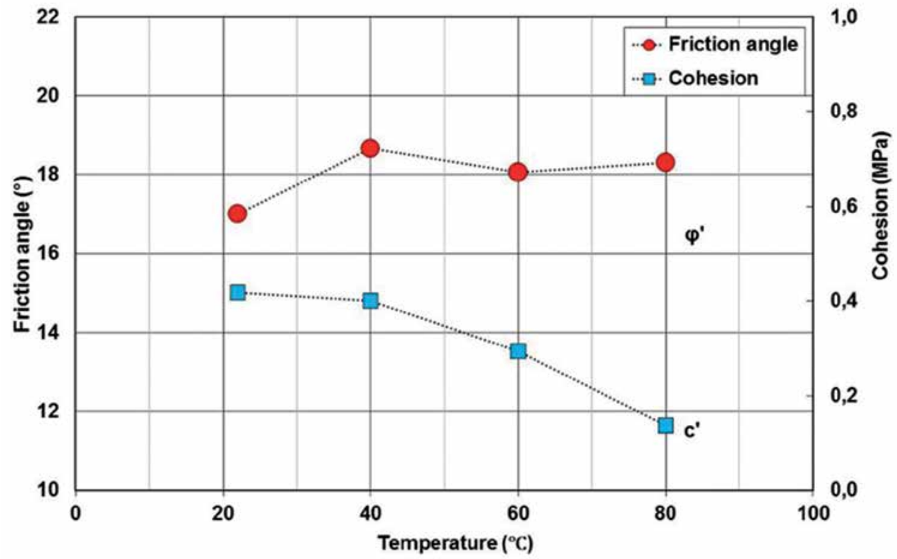


Figure 32 - Evolution of cohesion and friction angle with temperature

Meanwhile, two creep tests at different temperatures and under low deviatoric stress (< 1 MPa) have been initiated and are still ongoing. The main objectives are to determine the stress threshold (if it exists) of the creep under different temperatures.

2.4. GeoScientific Information System (GSIS)

As manager of the HADES URL, EIG EURIDICE supports the GSIS (GeoScientific Information System) project being developed by SCK•CEN and ONDRAF/NIRAS. The GSIS structures all field information in a geographical way, and contains elements ranging from shafts to analysis results from specific water samples obtained at a particular piezometer filter. EIG EURIDICE's contribution consists in adding and validating the elements (constructive components like shafts and galleries, boreholes, etc.). It will also use this database as an inventory for all geographically related information on equipment and instrumentation, and for the validated data series of selected sensors to be published for external users.

In 2016 the GSIS was ported to a new database server outside the SCK•CEN network to allow better access by external users. It is, however, still maintained (e.g. security and backups) by SCK•CEN's IT department. Further activity during the reporting year was limited to a review of some geographical data (e.g. borehole coordinates based on survey data) and development of the data management procedures. The latter should enable formal validation of measurement data, which will eventually be input into the GSIS after being cleared for external use.

3. Instrumentation & Monitoring

The issue of repository monitoring has attracted a great deal of international attention in recent years – mainly due to the more detailed requirements of the regulatory bodies in countries with advanced programmes (e.g. Finland), and also because of growing awareness of the societal role of monitoring. EIG EURIDICE has therefore set out a programme to investigate this in more detail, comprising a technical part and a more strategic part. In addition, EURIDICE also participates in a European project on repository monitoring (Modern2020). This project is discussed in the next section (4.1).

For the technical part, EIG EURIDICE can draw on more than 30 years' monitoring experience in underground conditions (relevant to a repository environment). Since the installation of the first experimental set-ups in HADES in the 1980s, a lot of monitoring experience has been gained on the long-term performance of sensors in repository-like conditions. This is very valuable as input for the development of a repository monitoring programme. To preserve this knowledge for a future programme over the longer term (decades), a more systematic and formal approach has been adopted to record the monitoring data from selected experimental set-ups, focusing in particular on the performance of the sensors in field conditions and in the long term.

For the strategic part of the programme, EIG EURIDICE will start by assessing which safety statements can be substantiated by specific monitoring parameters. In 2016 it did not undertake any work on this aspect for the Belgian case, but keeps abreast of international developments through its involvement in the Modern2020 project (see 4.1.).

The whole programme on monitoring has been formalised through the Monitoring Task Package agreement with ONDRAF/NIRAS. In this programme, five studies have been defined, four of which were started or continued in 2016.

The first study deals with the review of the instrumentation installed as part of the CLIPEX project. The aim of this project, which ran from 1997 to 2002, was to assess and characterise the hydro-mechanical disturbance of the Boom Clay and, more specifically, the EDZ during the excavation of the Connecting gallery (early 2002). The monitoring system consisted of instrumented boreholes installed from the Test Drift front and from the second shaft prior to the excavation of the Connecting gallery. In addition, the instrumented lining segments were part of the CLIPEX monitoring programme. The monitoring data included pore water pressure, total pressure, displacement and deformation. Initiated in 2015, the actual assessment methodology – being applied here for the first case – consisted mainly of a systematic description in an overview table of the actual performance of each individual sensor. Performance was assessed by considering various criteria, ranging from installation issues and sensor reliability with time to actual accuracy and signal quality.

The second study deals with data analysis and interpretation of the micro-seismic set-up. Further details can be found in Section 2.3.

The third study deals with diagnostic techniques that can be applied to non-accessible sensors. Many sensors that are installed in the (geotechnical) context of a repository (such as in URLs) are no longer accessible for maintenance, replacement or calibration. This makes it more difficult to interpret the sensor signal in the event of deviating or unexpected measurement data. For some sensor types, diagnostic techniques have been developed to check the functionality of the sensor when installed in the field. We first proposed a high-level approach to this issue in 2016. Following exploratory lab tests with thermocouples and vibrating wire strain gauges in 2016, in-situ tests will be carried out in HADES in 2017.

The fourth study tackles the data management issue. The PRACLAY experiment, as well as other experimental set-ups, has made it clear that data management in a repository context requires a specific approach, which should take into account aspects ranging from technical issues (e.g. non-accessible sensors and long-term reliability) and specific organisational matters (long-term follow-up, distributed and varying monitoring configurations, etc.) to strategic considerations such as the use of the data by different stakeholders (scientists, decision-makers, local citizen stakeholders, etc.). This study was initially aimed at developing a methodology for the management of repository data, based on the experience acquired to date. It covers a range of topics, from planning a monitoring system to follow-up and data validation. At the start of the study, it became clear that the initial focus on repository monitoring should be replaced by a more concrete objective relating to data management for demonstration tests, which could be put to use for, for example, PRACLAY and the generation of validated data sets for the GSIS.

4. Participation in international research projects

4.1. European Commission (EC) projects

Modern2020

Within the framework of the Horizon 2020 Euratom Work Programme NFRP6-2014 "Supporting the implementation of the first-of-the-kind geological repositories", a new proposal on monitoring of geological radioactive waste repositories, called "Modern2020", was approved by the EC early in 2015. The contract started on 1 June 2015 for a period of 48 months. In the project summary of the Modern2020 project, the general objective is stated as follows:

"The Modern2020 project aims at providing the means for developing and implementing an effective and efficient repository operational monitoring programme, taking into account the requirements of specific national programmes."

The project consists of four technical work packages (WPs), and EURIDICE is participating in two of these: WP3 (Monitoring Technology) as coordinator/advisor and WP4 (Demonstration and Practical Implementation) as Work Package Leader. The other two WPs are Strategy (WP2) and Societal Concerns and Stakeholder Involvement (WP5). The project consortium is made up of 28 partners from 12 countries. For EURIDICE, the project will involve nine person-months of staff time and a total budget of approximately EUR 227,000 (over a total for four years).

In WP3, EIG EURIDICE is contributing to four tasks, where it mainly has an advisory and coordinating role on the development of new fibre-optic sensors, the integration of these sensors with wireless transmission, and the testing and validation of the devices in repository-like conditions. In 2016 EURIDICE attended several technical meetings to discuss progress on the sensor technology. Our contribution deals with integration of novel fibre-optic techniques (mainly Fibre Bragg Grating-type sensors) with wireless read-out and transmission techniques. EURIDICE has also played a coordinating role in the sensor irradiation tests that are planned at SCK•CEN's facilities.

WP4, in which EURIDICE is the Work Package leader, brings together demonstrator set-ups that are being developed and are or will be operated in foreign URLs: Finland (Olkiluoto), France (Bure and Tournemire), and Switzerland (Mont Terri). In addition, this WP also revisits some existing cases, which will be re-assessed with the focus on monitoring experience that is relevant for repository operation, such as the use of monitoring data for decision-making, or the involvement of local stakeholders in the field set-up. As this WP partly builds on the results of WP2 and WP3, the actual work did not start at the beginning of the project. To assess the current situation and to start planning the actual work, EURIDICE organised a kick-off meeting in Turku (Finland) in May 2016. The current status of the four demonstrators, ranging from desk studies to functional set-ups, was presented. An initial exchange of thoughts on the fifth task, where existing cases will be "revisited" to look in particular for repository monitoring-related experience and which was not necessarily documented, has also taken place. Interaction with the other WPs has been limited; this is a point to consider during the next workshop (to be held in May 2017).

At the end of 2016, we also contributed to the reporting for the first 18-month period (from 1 June 2015 to 30 November 2016).

4.2. Other international collaborations

As part of the first International Conference on Energy Geotechnics ICEGT 2016, a mini-symposium entitled "Geotechnics for Nuclear Waste Disposal" was jointly organised by Enrique Romero (UPC), Xiangling Li (EIG EURIDICE) and Paul Marschall (NAGRA).

Xiangling Li was invited to edit a special issue on "rock mechanics and nuclear waste disposal" for the **"Journal of Rock Mechanics and Geotechnical Engineering"**, to be published in the first half of 2017. More than 10 papers have been submitted, including contributions from URL Mont Terri, URL Bure and FANC.

Xiangling Li has participated in the IAEA topical Technical Meeting of the Underground Research Facilities Network for Geological Disposal from 18-22 April 2016. The objectives of this Technical Meeting were :

- to provide an opportunity to discuss and agree on a generic framework that describes how a geological disposal solution is developed and to identify the key phases and activities that contribute to repository development;
- to draft a generic **roadmap** for geological disposal development.

Two Chinese visitors : Dr. Hongdan Yu and Dr. Haifeng Lu, sponsored by the Chinese Academy of Science (CAS), have started their scientific visit to EURIDICE since May 2016 for a period of one year. During their scientific stay, they work on the two following topics:

- "Knowledge consolidation on the laboratory test results related to the thermal-hydro-mechanical behaviour of Boom Clay " (by Dr. Hongdan Yu)
- "Knowledge consolidation on the in situ test results related to the hydro-mechanical behaviour of Boom Clay " (by Dr. Haifeng Lu)

IRMM (Institute for Reference Materials and Measurements), as of 1 July 2016 called "JRC-Geel"

Since 1999 EIG EURIDICE has delivered services for JRC-Geel's long-standing operation of an ultra-low-level radioactivity laboratory in support of European Commission policies in such fields as international standardisation, radioactive waste management and radioprotection. Some key projects in 2016 included: characterisation of reference materials for food safety and nuclear decommissioning, radiotracer studies of water from the Pacific Ocean to map ocean currents and study uptake in the food chain, and support to international research groups performing studies on rare nuclear decays and fusion research. The latter projects were carried out within JRC-Geel's Transnational Access Programme.

For this purpose, part of the HADES underground research laboratory has been leased to JRC-Geel. The contract is a Service Agreement that can be extended on a yearly basis.

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

EIG EURIDICE supports ONDRAF/NIRAS in its RD&D on the technical feasibility programme of geological disposal. This programme aims to demonstrate the construction and operational feasibility of the proposed concept for geological disposal. The next programme milestone is the first Safety and Feasibility Case (SFC-1), which is scheduled for 2020.

The repository technology studies cover the following topics:

- fabrication of the waste disposal packages;
- construction techniques and support for the design of the underground repository;
- operation and closure of the underground repository.

6. Support for Safety and Feasibility Case 1 of ONDRAF/NIRAS

EIG EURIDICE provides scientific and technical input for the development of ONDRAF/NIRAS's first Safety and Feasibility Case (SFC-1) with its expertise in the geomechanics of clays. In particular, it supports ONDRAF/NIRAS by writing documents on the geomechanical behaviour and properties of clays and provides a state-of-the-art report with an overview of the thermo-hydro-mechanical studies carried out on the Boom Clay by EURIDICE partners and within the HADES URL. EURIDICE is also in charge of the daily management, follow-up and scientific operation of the long-term, large-scale PRACLAY Heater test; the results from the first few years of this experiment (2016-2018) will constitute a significant element of the SFC.

EIG EURIDICE also supports ONDRAF/NIRAS by providing samples, data and technical and scientific expertise for studies carried out in collaboration with third parties on the (thermo-)hydro-mechanical (-chemical) behaviour of the Boom Clay and Ypresian clays and on gas transport.

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 programme – 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, respectively.

An important step in the successful completion of this project has been the licence application that ONDRAF/NIRAS submitted on 31 January 2013 to the Belgian nuclear regulator, the Federal Agency for Nuclear Control (FANC), for the surface disposal facility.

EIG EURIDICE supports the cAt project in the following areas:
- Calculations of the long-term radiological impact of the planned disposal facility;
- Calculations and validation tests of the hydrogeological models used in the licence application of the planned disposal facility;
- Preparation and instrumentation of the planned test cover;
- 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, prepared and documented during the period 2010-2012, are a key part of the safety arguments presented in the licence application.

After examining the licence application, FANC asked several questions on the phenomenological basis of the radiological long-term safety assessments and on the safety assessments themselves. In 2015 this resulted in a revision of the expected evolution of the disposal facility after its closure. Subsequently, the changed expected evolution needed to be reflected in changes to the assessment cases, which had to be re-calculated.

In 2016 the changed expected evolution assessment cases were defined and re-calculated. Reporting on this will be finalised early in 2017. These new calculations will be the basis for answering FANC's questions on this topic.

A final set of questions from FANC on safety assessments deals with the elaboration of altered evolution scenarios and new calculations for these scenarios. This topic will be addressed in 2017 with planned calculations and reporting.

2. Hydrogeological models

FANC's analysis of the licence application also led to questions on additional validation of the hydrogeological models. In order to comply with FANC's demand to validate the local groundwater model, field tests were performed in order to determine the groundwater flux (velocity). The dilution test methodology was refined and seasonally applied on six selected piezometers. For this purpose, two new drilling campaigns were carried out to the south and southeast of the future tumulus (two yellow triangles in the Figure). In addition, to determine the groundwater flow direction, the local piezometric network was measured on a monthly basis. Because the piezometers were installed during different drilling campaigns (time frame 2002-2016), their XYZ coordinates were also measured by different individuals/companies and using different techniques. In order to harmonise the data, a new topographical survey was conducted. Differences in height between former and latter measurements range mainly between 2 and 10 cm.

Figure 33 - Additional experimental programme for validation of the hydrogeological models

3. Test cover

As the construction of the test cover has been postponed, work focused on prototype testing in 2016. Two prototypes were tested: an infiltrometer and a sediment trap. Tests conducted with two types of infiltrometer on the test site for the test cover were conclusive. The sediment trap test showed that the screen fouled up fairly quickly. The choice of the mesh of the screen is paramount: a fine mesh will capture most of the sediment (also the finer fractions) but will be prone to fouling, leading to a loss of sediment by overflow. However, a coarser mesh will miss the finer fractions, which are predominantly the run-off sediments during severe rainfall. The design will have to be adapted.

Figure 34 - Prototype of the sediment trap

4. 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 for the cAt project has been underway since 2011 (See Figure 35).

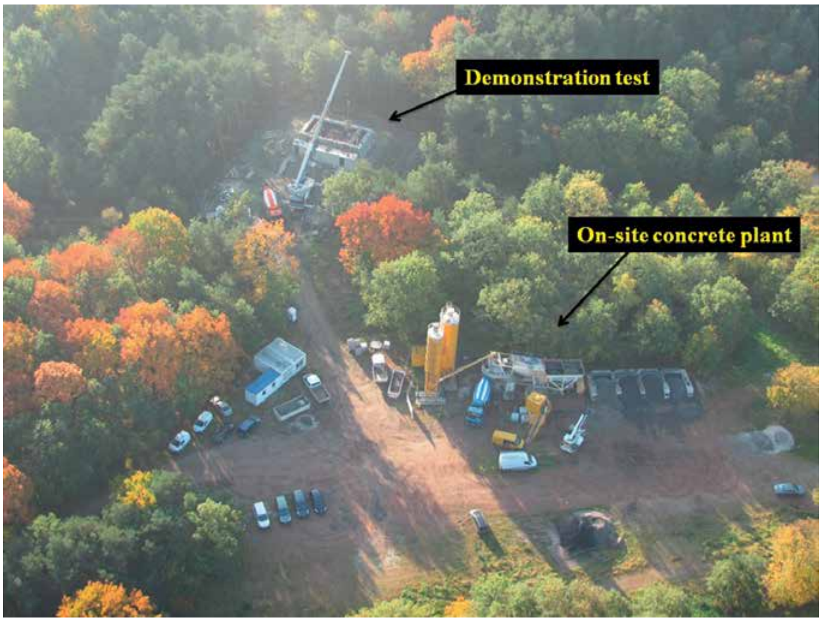
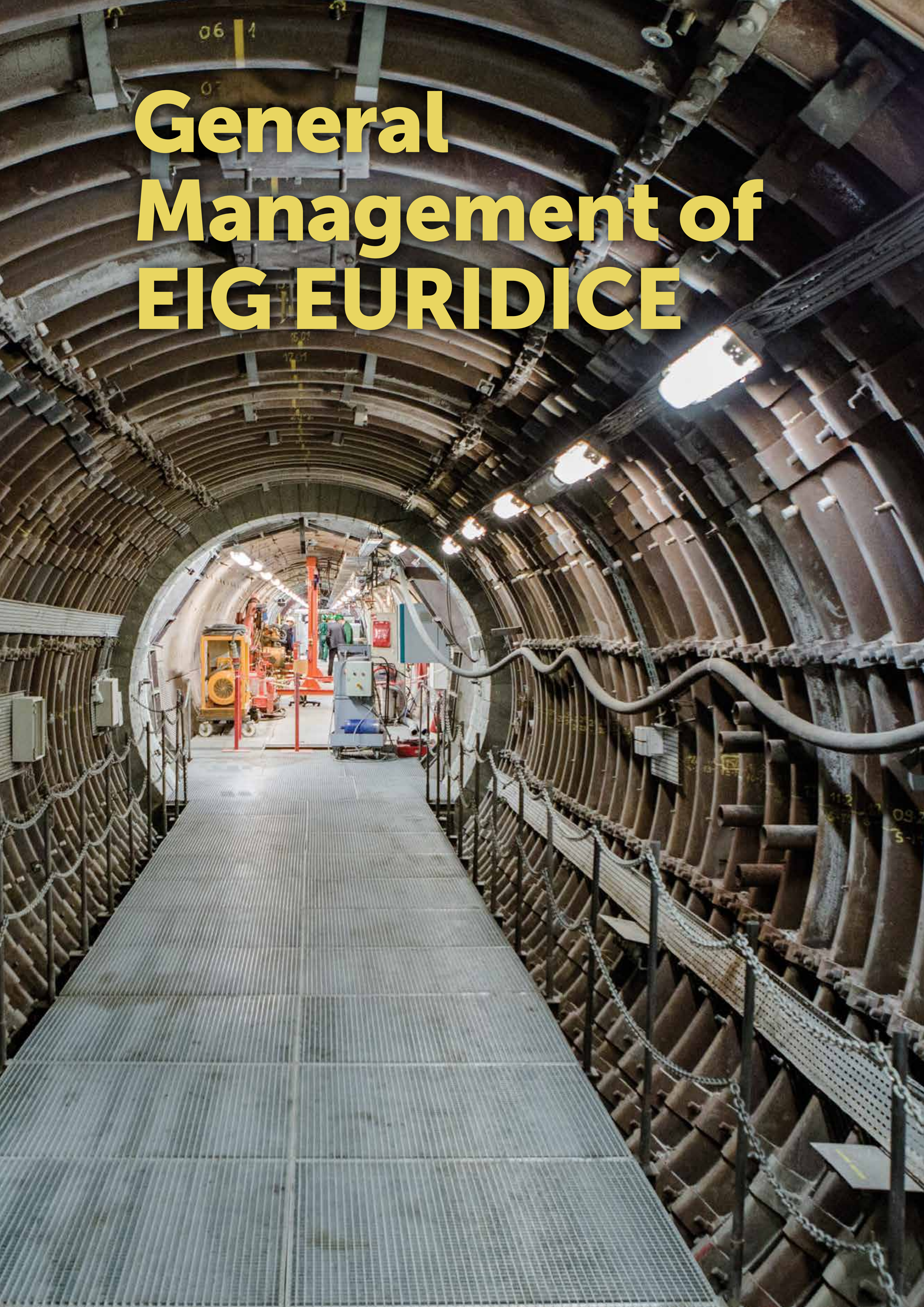


Figure 35 - Overview of the demonstration test

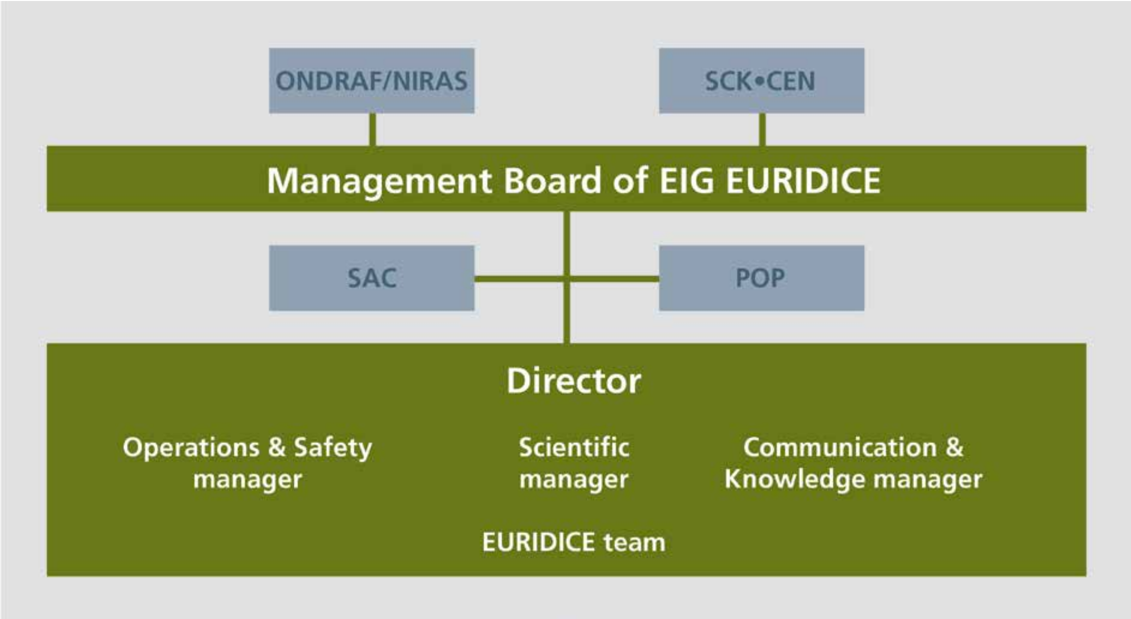
EIG EURIDICE, together with ONDRAF/NIRAS and Tractebel Engineering, has devised an instrumentation plan for assessing the temperature and stress conditions within the concrete used in the demonstration test.

Between 2011 and 2014 the test module and several test panels were built by ONDRAF/NIRAS and instrumented by EIG EURIDICE. There was no on-site construction work in 2015 and 2016. Data collection continued, however.

General Management of EIG EURIDICE



1. Organisation



EIG EURIDICE is governed by a four-person **Management Board**. ONDRAF/NIRAS and SCK•CEN each appoint two board members for a period of three years. The Chairman of the Board is appointed by ONDRAF/NIRAS. The Secretary of the Board and the Director of EURIDICE attend meetings in an advisory capacity.

The board members as at the end of 2016 are as follows (June 2016 - June 2019):

- Marc Demarche, Chairman, Deputy Director-General of ONDRAF/NIRAS
- Philippe Lalieux, Director long-term management ONDRAF/NIRAS
- Eric van Walle, Director-General of SCK•CEN
- Hildegarde Vandenhove, Director of the Environment, Health and Safety Institute of SCK•CEN

Responsibility for the day-to-day management of EURIDICE lies with the Director and the Scientific Manager, who are appointed by ONDRAF/NIRAS and SCK•CEN, respectively. They are supported in their task by the Operations & Safety manager and the Communication, Quality & Knowledge manager.

EIG EURIDICE's main activities in relation to geological disposal RD&D and the management and operation of all EURIDICE facilities for the period 2015-2020 are defined in a contractual agreement with ONDRAF/NIRAS (ESV EURIDICE CO2015_RA_EUR_15-116). This agreement also specifies the total budget available.

The **Scientific Advisory Committee (SAC)** advises the EURIDICE Management Board on all scientific aspects of EURIDICE's work and comprises experts from various universities and from organisations working in the field of radioactive waste management.

The **Programme Committee for Underground Experiments (POP)** analyses the safety of proposed underground experiments and their potential interference with other experiments, and advises the EURIDICE Management Board on this matter. POP comprises representatives from both of the EIG's constituent members (ONDRAF/NIRAS and SCK•CEN) and from EURIDICE.

In the course of 2016, EIG EURIDICE, at the request of its constituent members SCK•CEN and ONDRAF/NIRAS, initiated a strategic review of the implementation of its tasks, today and in the future. To this end, EURIDICE's Management Board set up a Task Group, which submitted its findings and proposals to the Board at the end of 2016; the Board has since endorsed these findings and proposals. In April 2017 they will be submitted to the Joint Meeting of Members with a view to adopting the necessary decisions about the future objectives and operation of EURIDICE. 2017 will therefore be a defining year for the future of the Economic Interest Grouping.

2. EIG EURIDICE team

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

Director:
Peter De Preter

Scientific team:
Xiangling Li - Scientific manager
Lou Areias - Scientific collaborator
Arnaud Dizier - Scientific collaborator
Guangjing Chen - Scientific collaborator
Ioannis Troullinos - Scientific collaborator
Jan Verstricht - Scientific collaborator
Wim Bastiaens – Scientific collaborator

Technical team:
Jef Leysen - Operations & Safety manager
Luc Mariën – Project engineer
Hendrik Huysmans - Operation technician
Christian Lefèvre - Operation technician
Johan Peters - Operation technician
Bert Vreys - Operation technician

Office manager:
Caroline Poortmans

Organisation of visits:
Els Van Musscher

Communication, Quality & Knowledge manager:
Jan Rypens

Scientific Visitors
Hongdan Yu - Associate professor at IRSM•CAS, China
Haifeng Lu - Associate professor at Wuhan University, China

3. Scientific Advisory Committee (SAC)

The two constituent members of EIG EURIDICE each appoint three external experts for a period of four years.

The members appointed by SCK•CEN for the period June 2013 – June 2017 are:
- Prof. Robert Charlier, Professor of Geotechnical Engineering and Soil and Rock Mechanics at Liège University (Belgium)
- Prof. Geert De Schutter, Professor of Concrete Technology at Ghent University and Technical Director of the Magnel Laboratory for Concrete Research (Belgium)
- Prof. Tilmann Rothfuchs, Retired Head of GRS (Gesellschaft für Anlagen und Reaktorsicherheit) -division of Repository Safety Research (Germany)

The members appointed by ONDRAF/NIRAS for the same period are:
- Dr Gilles Armand, Head of the Fluid and Solid Mechanics Department at the French National Agency for Radioactive Waste Management - ANDRA (France)
- Prof. Jean-Marc Baele, Professor of Geology and Applied Geology, University of Mons (Belgium)
- Prof. Philippe Claeys, Head of the interdisciplinary research unit Earth System Sciences, Vrije Universiteit Brussel (Belgium)

EURIDICE organised one SAC meeting in 2016, on 30 May, during which the initial results of the heating phase after the successful switch-on were presented and discussed. The past performance of SAC was also evaluated and ways to improve its future operation as a EURIDICE scientific advisory committee were discussed. SAC presented its findings and recommendations to the EURIDICE Management Board at its meeting on 22 November 2016.

4. Programme Committee for Underground Experiments (POP)

In 2016 one POP meeting was held, on 10 May.

The joint SCK•CEN – ONDRAF/NIRAS – EURIDICE procedure on clay core management was implemented after a trial period. This procedure enables a complete inventory of clay cores used for RD&D purposes to be kept.

5. Management, operation & safety of installations

GENERAL

The Statutory Rules define the responsibilities and tasks of EIG EURIDICE concerning the management and operation of the installations on the land for which EIG EURIDICE holds a building lease. In 2016 these tasks were performed in accordance with applicable regulations, ensuring safe operations.

A new agreement between EURIDICE, SCK•CEN and ONDRAF/NIRAS was signed, which defines the safety structure of EIG EURIDICE and organises support by the two constituent members in the fields of safety, health and environmental protection. A committee comprising representatives from the three parties is responsible for implementing the agreement and for monitoring the safety of EURIDICE activities and installations. The committee meets on a monthly basis.

Besides all routine activities relating to maintenance, checks and inspections of machinery and installations, a general and systematic safety evaluation of all EURIDICE's activities is ongoing. The main priorities are:

- Fire safety: a fire safety study by an external company (FPC) was finalised in 2016, focusing mainly on the HADES URL. Based on the outcome, a series of recommendations for improvement were proposed:
  - reliable communication between the underground lab and above-ground installations in the event of a fire emergency;
  - fire compartments;
  - review of evacuation and emergency plans.

  Preparations for these actions got under way in 2016 and will be completed in 2017.
- Training programme: an overview matrix with the required training courses for all safety-related functions was established. On the basis of this matrix, a training path was defined for the function of "green helmet" and implementation started in 2016.

- Electrical installations: in the course of 2016 electrical installation relating to the shaft 2 distribution was completely mapped in an electrical e-mapping software program and all calculations were performed. This mapping and the calculations are being reviewed by AIB Vinçotte and on the basis of the outcome, expected in 2017, the necessary modifications to the electrical installation will be made. The evaluation and renewal of the shaft 1-related electrical distribution will be part of the shaft 1 refurbishment project.

The operation team gave technical support to RD&D activities in different projects and also to communication activities:
- Connection of monitoring devices to the data-logging system in HADES;
- Technical support to the PRACLAY seal and heater experiment;
- Operation of hoisting system and technical assistance during visits;
- Core sampling campaigns were performed.

In April 2016 Luc Mariën joined the EIG EURIDICE team. As a project engineer, he will manage technical projects and will interact with users and subcontractors.

UNDERGROUND INSTALLATIONS AND ASSOCIATED HOISTING SYSTEMS
The operation team and/or AIB Vinçotte carried out the necessary checks and inspections on the shafts, cables and hoisting equipment of shaft 1 and shaft 2. Operational interruptions in the two hoisting systems were very limited and did not affect the normal, safe operation of the HADES URL. The floor of the Test Drift was renewed.

With the new ONDRAF/NIRAS financing agreement covering the period 2016-2020, a budget for the replacement of the shaft 1 hoisting system is now in place. EURIDICE started preparing for this project in 2016 by adding a project engineer to the team. Preparations for the start of the study phase were made by launching the public tendering procedure at the end of 2016 to appoint an engineering firm.

ABOVE-GROUND INSTALLATIONS AND BUILDINGS
The operation team carried out standard maintenance and necessary repairs on the installations, buildings and infrastructure in 2016.

The replacement of the roof on the visitors' building, initially planned for 2016, was postponed due to the priority given to the public tendering procedure for appointment of an engineering firm for the refurbishment of shaft 1. The public tendering procedure for the roof of the visitors' building will be launched early in 2017.

For the renewal of the small water treatment facilities on the EURIDICE site, the public tender was being prepared and will be launched early in 2017.

LICENCES
The operating licence is valid until 2024. Nothing changed in this respect in 2016.

The nuclear licence of EIG EURIDICE (issued in August 2006) is valid until 2021. All inspections and checks under this licence were carried out by BEL V.

The environmental licence of EIG EURIDICE (granted in November 2013) is valid for 20 years.

6. Quality Management

Since 2007, EIG EURIDICE has been ISO-certified according to the ISO 9001:2008 standard for Quality Management. An external audit took place on 23 February 2016. There were no major or minor non-conformities.

A new certificate was granted for the period from 22/04/2016 to 15/9/2018. Before this period expires, the Quality Management System needs to be adapted to meet the new ISO 9001:2015 standard. To prepare for this transition, a half-day Readiness Review was completed by SGS, at the request of EIG EURIDICE, to identify any gaps between the current QM System and the requirements of the new standard. Based on this report, an external company will be commissioned in 2017 to help EIG EURIDICE adapt the current system.

7. Knowledge Management

EURIDICE is focusing a great deal on reporting activities in 2016 and the next few years, covering the PRACLAY Heater test and an ongoing project that involves making evaluations (based on lessons learnt) of measurement sensors used in past experimental set-ups in the HADES URL.

The report "The start-up phase of the PRACLAY Heater test" was finalised and published in 2016.

In the context of the strategic review on the future of EURIDICE, knowledge management and knowledge transfer were identified as key objectives for EURIDICE, and organisational structures have been proposed for discussing and defining the KM strategy for EURIDICE in consultation with ONDRAF/NIRAS and SCK•CEN.

Communication

Communication about its activities is one of EIG EURIDICE's statutory tasks. The HADES underground research laboratory (URL) and the above-ground exhibition are powerful tools for explaining the concept of geological disposal and are the ideal way to present and explain the research that has been going on for the past 36 years. In addition to arranging visits to the exhibition and the URL, EURIDICE has its own website, events and publications to inform a wide audience about its activities within the context of the ONDRAF/NIRAS's research programme on geological disposal.

EVENTS

On Wednesday 4 May 2016, the 20th Exchange Meeting was organised to present the initial results of the PRACLAY Heater test. The presentations are available on EURIDICE's website.

The 20th Exchange Meeting at the Lakehouse, Mol

VISITS

Anyone over the age of 18 can visit EIG EURIDICE and the underground research laboratory in small groups. Sociocultural organisations are looked after by trained guides, who also lead visits at ISOTOPOLIS, ONDRAF/NIRAS's information centre on radioactive waste. Geological disposal experts, journalists, university students with a scientific background and key political and economic figures are given a guided tour by scientific personnel, the Communication Manager and/or the Director of EIG EURIDICE, sometimes accompanied by ONDRAF/NIRAS or SCK•CEN management.

Visit to the HADES URL

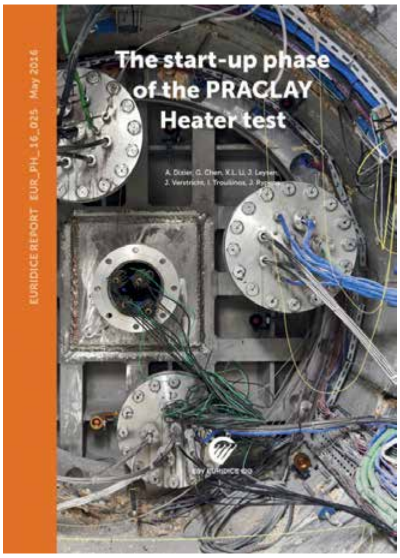
In 2016 EIG EURIDICE welcomed 2,155 visitors in the course of 143 visits to the HADES URL and the above-ground exhibition on geological disposal; 89 of these visits were led by trained tour guides. Of the 143 visits, 63 were for training and educational purposes and 32 involved sociocultural organisations. The remaining 48 concerned direct stakeholders of EIG EURIDICE or were arranged at the request of SCK•CEN or ONDRAF/NIRAS. Sixty-nine were Dutch-speaking, 54 English-speaking and 20 French-speaking.

PERMANENT EXHIBITION

The exhibition on geological disposal was updated in 2016. A new module was added to the Supercontainer demonstration test. The so-called supercontainer consists of a number of engineered barriers that must ensure the containment of high-level, heat-emitting radioactive waste for several thousand years. The focus of the demonstration test is the construction of an almost 4 metre high and 2 metre wide hollow concrete cylinder. In the current disposal concept of ONDRAF/NIRAS, this concrete cylinder will surround a carbon steel envelope that contains the waste canisters. The test was performed in a concrete laboratory at Ghent University. After the test, the concrete cylinder was transported to Mol and is now part of the permanent exhibition. During visits, the importance of this kind of demonstration test is stressed and the set-up of the experiment is explained.

PUBLICATIONS

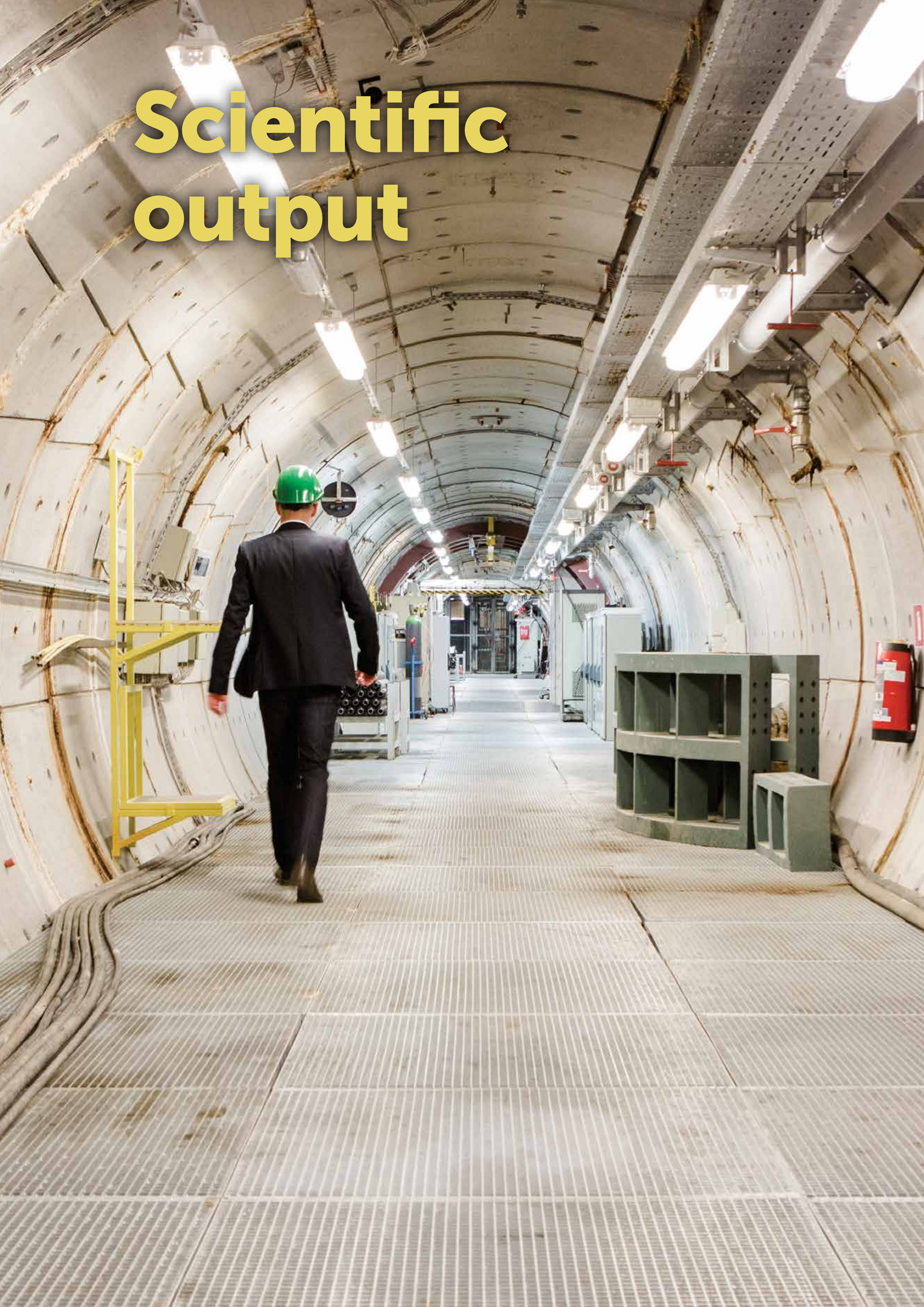
The most important measurement results of the start-up phase of PRACLAY Heater test have been gathered together in a first scientific report entitled "The start-up phase of the PRACLAY Heater test", which was published in 2016. Besides the main observations, the report contains an initial comparison with the predictive calculations on the evolution of temperature and pressure in the clay. The report can be downloaded from the EURIDICE website.



A new leaflet on the Supercontainer demonstration test was produced in 2016 and will be available from the beginning of 2017. It explains how the construction feasibility of the concrete cylinder is tested and studied.

Concerning scientific communication, the EURIDICE team contributed to 14 scientific papers in various journals and proceedings published in 2016; The list of papers is given in the next section "scientfic output".

Scientific output



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List of accronyms

ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs (FR)
CAS	Chinese Academy of Science
CIMNE	Centro Internacional de Métodos Numéricos en Ingeniería (ES)
CLIPEX	CLay Instrumentation Programme for the EXtension of an underground research laboratory
EBS	Engineered Barrier System
EC	European Commission
EDZ	Excavation-damaged zone
ESDRED	Engineering Studies and Demonstration of Repository Designs
FANC	Federal Agency for Nuclear Control (BE)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (DE)
GSIS	GeoScientific Information System
HADES	High-Activity Disposal Experimental Site
IRMM	Institute for Reference Materials and Measurements (BE)
IRSM	Institute of Rock and Soil Mechanics (China)
ISOTOPOLIS	ONDRAF/NIRAS' information centre about radioactive waste management, located in Dessel
Modern 2020	Development and Demonstration of monitoring strategies and technologies for geological disposal (within the frame of the Horizon 2020 Euratom Work Programme)
MONA	Mols Overleg Nucleair Afval (Local citizen platform on Nuclear Waste issues in Mol)
NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (CH)
ONDRAF/NIRAS	Belgian Agency for Radioactive Waste and Enriched Fissile Materials (BE)
OPHELIE	On surface Preliminary Heating simulation Experimenting Later Instruments and Equipments
POP	Programme Committee for Underground Experiments
SAC	Scientific Advisory Committee
SCK•CEN	Belgian Nuclear Research Centre (BE)
SELFRAC	Fractures and self-healing within the excavation disturbed zone in clays
STORA	Studie en Overleggroep Radioactief Afval in Dessel (study and consulting group Radioactive waste in Dessel: Local citizen platform on Nuclear Waste issues in Dessel)
THM	Thermo-hydro-mechanical
THMC	Thermo-hydro-mechanical-chemical
TIMODAZ	Thermal impact on the damaged zone around a radioactive waste disposal in clay host rocks
UPC	Universitat Politècnica de Catalunya (ES)
URL	Underground Research Laboratory

ESV EURIDICE EIG

EIG EURIDICE is an Economic Interest Grouping 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 safety and feasibility studies for the disposal of high-level and/or long-lived radioactive waste in a clay host rock.

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