2013 Activity Report

ESV EURIDICE EIG

ACTIVITY REPORT 2013
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General foreword

Marc Demarche, Chairman of the Board of EIG EURIDICE

Dear reader,

The Activity Report 2013 provides a comprehensive overview of the main developments and achievements with respect to EIG EURIDICE's statutory tasks. EIG EURIDICE is responsible for the management and exploitation of the HADES underground research laboratory, for research, demonstration and development into the disposal of radioactive waste and for communicating about its activities.

Much of 2013 was spent on further preparation of the large-scale PRACLAY Heater experiment. This will be the last stage of the PRACLAY project, which began back in 1997 with the expansion of the HADES laboratory. The goal of this experiment, in which the heating phase itself will last ten years, is to demonstrate that mechanical and thermal disturbances, resulting from the construction of a disposal infrastructure and the emplacement of heat-producing high-level radioactive waste, do not affect the containment and isolation capacity of the clay host rock. The effect of the temperature on the components of the disposal infrastructure itself, such as the stability of the concrete gallery lining, will also be studied. The entire step-by-step implementation of the PRACLAY project is and will remain the main task of EIG EURIDICE. The importance of the ten-year Heater experiment for the national RD&D programme requires very thorough preparation, with no detail overlooked.

The Heater experiment will be conducted in the PRACLAY gallery, which was excavated in 2007. EIG EURIDICE has been installing all the test components there since 2010. Many measuring instruments have been placed in and around the PRACLAY gallery to accurately monitor all major phenomena and processes in the clay and in the gallery itself.

At the beginning of 2010, the steel seal structure was installed with a ring of bentonite blocks in contact with the Boom Clay. As it swells, this bentonite-ring should create the required hydraulic boundary conditions for the Heater experiment, so that all the knowledge acquired can be applied in a real repository for high-level radioactive waste. Once the seal was in place, the primary heating system was installed against the gallery lining (2010), followed by the central tube for the secondary heating system (2011). The two heating systems will provide adequate redundancy during the ten-year experiment. The gallery was then backfilled with sand and the opening in the middle of the seal was welded shut (end of 2011). After closing off the backfilled gallery, it was saturated with water and the water pressure was slowly increased (2012 and 2013). This made it possible to check the seal structure's impermeability to water during the first phase of pressure build-up.

The swelling of the bentonite ring in the seal was closely monitored throughout this time, and a series of tests were carried out to investigate the hydraulic and mechanical properties of the seal.

At the end of 2013, EIG EURIDICE, in close cooperation with ONDRAF/NIRAS, carried out a systematic analysis and verification of all the elements needed for the actual start-up of the Heater experiment. For this purpose, a variety of risk analyses were performed. Based on this, it was decided in late 2013, inter alia,

to improve the design of the secondary heater and of the control systems for the primary and secondary heaters. Moreover, in December 2013, a workshop was organised with national and international experts to critically review all components of the experiment.

Two important conclusions could be formulated at the end of 2013. Firstly, it was found that the bentonite ring had swelled enough (i.e. a sufficiently high swelling pressure was observed) to meet the hydraulic boundary conditions required to be able to successfully start the Heater experiment. Secondly, the final preparations (installing and testing the secondary heating system and establishing all follow-up procedures for the experiment, including the alarm systems) can be made in the first half of 2014. The actual start-up of the Heater experiment is therefore scheduled for the second half of 2014.

EIG EURIDICE also contributes to the test programme for demonstrating the technical feasibility of the construction of a supercontainer as a disposal container for high-level radioactive waste (vitrified waste or irradiated fuel elements). In 2013 EIG EURIDICE supported the coordination and implementation of the second half-scale test (2012-2013), by preparing, developing and implementing the full instrumentation plan for this test. The test itself was performed according to schedule during the first half of 2013.

EIG EURIDICE also made available its expertise in the field of instrumentation and monitoring to the project for the surface disposal of low-level radioactive waste, including for the testing of the concrete test modules.

The management of acquired knowledge and expertise is and remains a key objective for EIG EURIDICE. To oversee the quality of the work carried out and the RD&D planned, the EIG can rely on its Scientific Advisory Committee (SAC), the composition of which was renewed in June 2013. EIG EURIDICE thanked the members who were leaving the SAC for their many years of much appreciated service: Prof. Noël Vandenberghe, Dr Piet Zuidema and Prof. Hans-Joachim Alheid, and welcomed the new members: Prof. Philippe Claeys, Prof. Jean-Marc Baele and Mr Tilmann Rothfuchs.

EIG EURIDICE also wants to use the start-up of the Heater experiment in 2014 as an opportunity to put the spotlight on its unique technical and scientific RD&D in and around the HADES underground laboratory and to attract the attention of universities and other scientific institutions or engineering organisations, with a view to strengthening the network of future collaborations. This is an ongoing challenge in terms of knowledge and information management for disposal programmes that span many decades.

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 EIG EURIDICE since 2000.

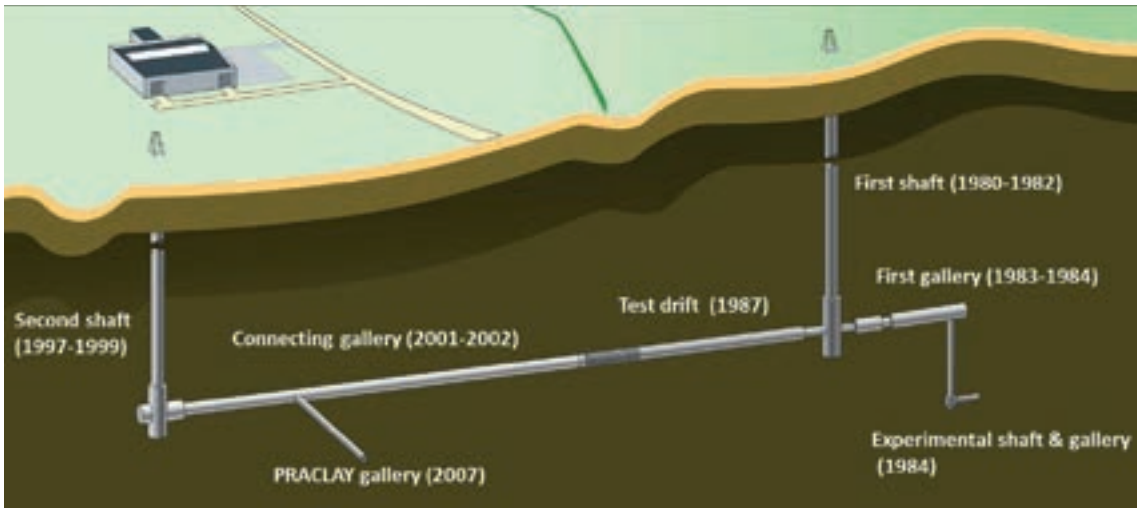


Figure 1 - The underground research laboratory HADES
(High Activity Disposal Experimental Site)

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 exploitation 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 30 years of research in and around the HADES URL, a lot of expertise and know-how have 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.
3. Instrumentation & monitoring.

EIG EURIDICE's first area of expertise has changed significantly over the past 30 years, with excavation and construction of the HADES 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) is a key objective and relates directly to the safety of a disposal system.

The second field of expertise of EIG EURIDICE involves understanding the THM behaviour and characterisation of a clay host rock, including all disturbance processes induced by the construction of the galleries and by the emplacement of heat-emitting radioactive waste. In low-permeability clays such as the Boom Clay, THM processes are strongly coupled. EIG EURIDICE's knowledge base is mainly built on the research activities in and around the HADES URL in the Boom Clay. 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 EDZ. Proper understanding of the coupled THM processes in a clay host rock around the repository is essential 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 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

final waste plan for the long-term management of high-level and/or long-lived waste (NIROND 2011-02, September 2011), with a view to obtaining a policy decision on the long-term management of this waste. 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. For EIG EURIDICE, the execution of the PRACLAY project, including the start-up of the PRACLAY Heater experiment in 2014, will be key. This will enable EIG EURIDICE to obtain and interpret the results and findings of the first few years of heating, during which important observations can already be made, and provide this valuable input for the safety and feasibility assessments of ONDRAF/NIRAS in the context of its next programme milestone, i.e. Safety and Feasibility Case 1.

Objectives for 2013 - Evaluation

The main objectives for 2013 formulated in the Activity Report 2012 were as follows:

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

- Follow up the hydration and swelling of the bentonite in order to be able to decide when the Heater test can be successfully started.
- Continue to test the seal performance (cold conditions) in different sections, at the Boom Clay/bentonite interface and inside the seal by means of gas tests, water tests, permeability measurements, etc.
- Enhance the risk analysis and the analysis of what associated consequences various scenarios will have for the Heater test, list all possible related actions and start preparing for these actions;
- Organise the second workshop on the heater switch-on at the end of 2013.
- Conduct baseline measurements before starting the Heater test.

2. Scientific tasks related to the thermo-hydro-mechanical behaviour of a disposal system in a clay host rock

- Follow-up, analysis, interpretation and numerical investigation of the fourth phase of the ATLAS test and, at the end of the cooling phase, preparation of the "heating pulse" test.
- Continue the laboratory creep tests at high temperature, the laboratory investigation of the anisotropic thermo-hydro-mechanical behaviour of Boom Clay and the thermo-hydro-mechanical-chemical behaviour of Boom Clay and Ypresian clays.
- Numerical investigation of the excavation-damaged zone (EDZ) in Boom Clay.
- Start the laboratory investigation of gas transport in Boom Clay.
- Establish the plan for a detailed investigation and follow-up of the stability of the liner in HADES. This will involve a systematic inspection plan, long-term monitoring programme, additional laboratory tests and numerical investigation, and a PhD project.
- Continue the development of the short-term and long-term hydro-mechanically coupled constitutive models and validate with long-term in-situ measurements.

3. Supercontainer feasibility demonstration test (on surface)

- Execution of the second half-scale test with the following specific objectives.
  - Test and optimise the concrete composition of the buffer.
  - Monitor the onset and evolution of cracks in the concrete buffer.
  - Measure corrosion of carbon steel in the buffer using different methods.
- First analysis/interpretation of the test results.

4. Specific support to ONDRAF/NIRAS on disposal technology and on the Safety and Feasibility Case 1

- Support ONDRAF/NIRAS in developing an approach to manage operational safety in the geological disposal concept using our expertise and experience in the operation of the HADES URL.
- Continue to contribute to the investigation of disturbances in the clay host rock and the thermo-

hydro-mechanical behaviour of repository components, and to the reporting within the context of *Safety and Feasibility Case 1*.

- Consolidate the large body of knowledge (and data) available on the hydro-mechanical and thermo-hydro-mechanical behaviour of Boom Clay (and to a lesser extent Ypresian clays). This will be done, in particular, through the finalisation of a geotechnical synthesis report for Boom Clay (update of the 2004 "state-of-the-art" report, EIG EURIDICE 04-251), which began to be drafted in 2012.
- Progressively introduce key Boom Clay (and Ypresian clay when available) parameters and their values into the data clearance system implemented by ONDRAF/NIRAS to ensure consistency within the whole RD&D programme.
- Support ONDRAF/NIRAS (provide samples, data, technical and scientific expertise) for the follow-up of PhD and post-doctoral research on the (thermo-)hydro-mechanical(-chemical) behaviour of Boom Clay and Ypresian clays and on gas transport through Boom Clay.

5. Management and exploitation of EIG EURIDICE and its installations

- Management and exploitation of EIG EURIDICE and its installations according to the Statutory Rules of the EIG and in line with the ISO 9001-2008 standard (recertification audit February 2013).
- Prepare for the replacement of the hoisting system of shaft 1. Due to some ambiguities concerning the applicable regulatory framework, replacement of the hoisting system will take longer than initially estimated. A preliminary design study will first explore the different options for renewing the hoisting system. This will give a clearer view of the possibilities and the related regulations that have to be complied with.
- In association with SCK•CEN, EIG EURIDICE will prepare all the documents needed to apply for an environmental licence. The goal is to submit the application in the first half of 2013.
- Concerning a possible separate visitors' entrance, all elements will be prepared to enable the constituent members to reach a decision.

6. European Commission projects

The MoDeRn project will end in 2013. Major activities therefore include final reporting on instrumentation performance in PRACLAY and in the supercontainer test programme.

As coordinator of the European Commission's TIMODAZ project, EIG EURIDICE, together with ENPC (France), will edit a special issue in "Rock Mechanics and Rock Engineering" (Springer, WoS referenced) on the topic of "Thermo-Hydro-Mechanical effects in clay host rocks", which will be published in March 2013.

7. Communication

- Go online with the new website.
- Update the programme for guided visits and develop a coherent new manual for the visitor guides.
- Prepare a communication after a decision in principle on the long-term management of B&C waste.
- Publication of the scientific report "The design and installation of the PRACLAY in-situ experiment".

8. Knowledge domains of EIG EURIDICE

- Take further steps to develop an integrated knowledge management system:
  - Draw up a complete and structured inventory of all information produced by EIG EURIDICE.
  - Efficiently integrate the information management of EIG EURIDICE with the knowledge management systems used by SCK•CEN (Alexandria) and ONDRAF/NIRAS (Vignette).
  - Launch a knowledge management project on excavation technology.
- Take further concerted action for collaboration with universities on Master's theses and PhDs, on the basis of the agreement between SCK•CEN and ONDRAF/NIRAS.
- Input all experiments into the GSIS system.

9. Surface disposal project for category A waste

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

EIG EURIDICE will provide the final report on the instrumentation of the demonstration test. Depending on how far advanced the test cover set-up is, EIG EURIDICE might also assist in the instrumentation work for this project.

On 31 December 2013 the status of these objectives was as follows:

1. Technical and scientific follow-up of the PRACLAY Seal and Heater experiment (PART I, 1.2.1)

- In the course of 2013, hydration and swelling of the bentonite were carefully monitored and analysed using numerical modelling to improve understanding of the controlling processes and factors.
- The seal performance was further tested by means of a series of gas breakthrough tests at the interface between the bentonite and the Boom Clay. These tests indicated the seal was performing well at the interface and, together with the measurements, confirmed that the radial pressures exerted by the bentonite on the Boom Clay are around 3 MPa and are thus higher than the threshold value of 2.5 MPa required for the heater switch-on.
- A series of permeability tests in the Boom Clay were conducted in the vicinity of the seal and around the PRACLAY gallery. The results indicated that the hydraulic conductivity in the vicinity of the seal is similar to that of undisturbed Boom Clay. Around the PRACLAY gallery, at the same distance from the gallery (50-75 cm), the hydraulic conductivity of the Boom Clay is 1.5 – 2 times higher. These observations indicate on the one hand the efficiency of the swelling of the seal and on the other that the excavation-damaged zone (EDZ) around the PRACLAY gallery has not yet completely sealed.
- Various altered evolution scenarios of the PRACLAY Heater experiment and associated consequences, as well as the efficiency of different possible related actions, were further analysed. The output of these analyses will be an important tool for the follow-up and management of the Heater test after switch-on. Meanwhile, a systematic risk analysis has been performed to identify a potential failure of the secondary heater.
- The second workshop with external experts on preparations for the heater switch-on, with the

objective of advising EIG EURIDICE on any outstanding work or issues that need to be addressed in the run-up to the switch-on, was successfully organised in collaboration with ONDRAF/NIRAS at the end of 2013. During the workshop, the EIG EURIDICE team and the ONDRAF/NIRAS experts described the current status of the test set-up and preparations for the test follow-up. In general, the experts confirmed that the seal on the bentonite ring has evolved to the point where the Heater experiment can be started; EIG EURIDICE is preparing all elements needed for successful follow-up of the experiment. No major uncertainties or concerns with respect to the switch-on of the heater were voiced.

- Finally, the in-situ measurements around PRACLAY were systematically reported and analysed, based on which the baseline measurements before starting the heater test can easily be updated.

2. Scientific tasks related to the thermo-hydro-mechanical behaviour of a disposal system in a clay host rock (PART I, 2)

- At the end of 2013, the cooling phase of the ATLAS IV test was not yet completely finished. The in-situ measurements of the ATLAS IV test were systematically analysed. Due to the priority given to the preparation of the PRACLAY Heater test, no numerical simulation was performed in 2013. This will be done in 2014 when the ATLAS cooling phase ends. The heater capacity was checked to ensure that the "heating pulse" test can be carried out at the end of the cooling phase, as planned.
- The laboratory creep tests at high temperature were run in 2013 as part of the PhD project underway at IRSM. The laboratory investigation of the anisotropic thermo-hydro-mechanical behaviour of Boom Clay and the thermo-hydro-mechanical-chemical behaviour of Boom Clay and Ypresian clays is progressing well within the PhD and post-doctoral programmes at CERMES.
- Numerical investigation of the EDZ in Boom Clay was studied within the framework of PhD projects at Ulg and DUT/EIG EURIDICE.
- Laboratory investigation of gas transport in Boom Clay has been started within the PhD programme at CIMNE (UPC).
- Preliminary studies on the stability of the liner in HADES have been conducted by Tractebel in cooperation with EIG EURIDICE. Some open issues were identified and will be further studied in 2014. A systematic inspection plan and long-term monitoring programme were established and launched in 2013. Additional laboratory tests and numerical investigations will be performed in 2014 as part of a PhD project. An assessment of the in-situ measurements with respect to the initial design for the liner will also be performed in 2014 in cooperation with Tractebel.
- The short-term and long-term hydro-mechanically coupled constitutive models were further developed within the framework of PhD/post-doctoral programmes at IRSM and CERMES. The elasto-visco-plastic-damage model, coupled with the self-sealing model, developed at IRSM is being validated by long-term in-situ measurements.

3. Supercontainer feasibility demonstration test (on surface) (PART I, 1.2.2)

- The second half scale test (HST2) was performed in 2013 to gain further insight into the feasibility of constructing the supercontainer (SC). This test incorporated new and innovative monitoring techniques to study the initiation and propagation of cracks in the concrete buffer. Different kinds of sensors were also installed to measure the corrosion potential of the carbon steel.
- An initial analysis/interpretation has been completed and an integration report will be delivered in 2014.

4. Specific support to ONDRAF/NIRAS on disposal technology and on the Safety and Feasibility Case 1 (PART I, 8 and 9)

- EIG EURIDICE provided information to ONDRAF/NIRAS on the expertise gained during the construction of HADES and the experience in the daily operation of the HADES URL, to support ONDRAF/NIRAS in developing an approach to manage the operational safety of a geological repository. EIG EURIDICE also supported ONDRAF/NIRAS in its RD&D technical feasibility programme on geological disposal by participating in research on the fabrication of the waste disposal packages through its contributions to the experimental programme on the supercontainer. Further support included participation in the research project meetings and review of the reports produced by the project partners.
- EIG EURIDICE provided scientific and technical input for the development of ONDRAF/NIRAS' first Safety and Feasibility Case (SFC-1) with its expertise in geomechanics of clay. In particular, EIG EURIDICE contributes to the integration of this scientific knowledge into the SFC-1 as the body responsible for drafting the "integration report" on the evolution of the disturbed zone around a deep repository for high-level and/or long-lived waste in a clay layer. This report will be part of the set of documents formally making up ONDRAF/NIRAS' SFC-1.
- EIG EURIDICE is preparing a state-of-the-art report on the geomechanical behaviour and properties of Boom Clay at Mol, in which a large body of knowledge (and data) available on the thermo-hydro-mechanical behaviour was analysed and consolidated. Key parameters of Boom Clay and their values are being introduced into the data clearance system of ONDRAF/NIRAS.
- In parallel, EIG EURIDICE was involved in the research program on the thermo-hydro-mechanical behaviour in Ypersian clays. The knowledge basis (and data) is obtained progressively.
- As agreed with ONDRAF/NIRAS, EIG EURIDICE supported ONDRAF/NIRAS for the follow-up of PhD and post-doctoral research on the (thermo-)hydro-mechanical(-chemical) behaviour of Boom Clay and Ypresian clays and on gas transport through Boom Clay.

5. Management and exploitation of EIG EURIDICE and its installations (PART I, 7)

- Management and exploitation of EIG EURIDICE and its installations proceeds according to the Statutory Rules of the EIG and in line with the ISO 9001-2008 standard.
- The preliminary design study for the replacement of the shaft 1 hoisting system has started and a draft version of the report was delivered at the end of 2013. The final version will be ready in March 2014.
- In November 2013 EIG EURIDICE was issued with an environmental licence. EIG EURIDICE acknowledges the support of SCK•CEN's environmental protection coordinator.
- A document (EUR 13/119) describing the different options for a visitors' entrance was submitted to the General Assembly (April 2013), which decided on the solution to be adopted.

6. European Commission projects (PART I, 4)

The European Commission MoDeRn project came to an end on 31 October 2013. EIG EURIDICE has delivered the due reports on Work Packages (WP) 2 and 3. WP2, containing the R&D on monitoring technologies, dealt mainly with the results of the innovative monitoring techniques applied in the supercontainer test set-up. WP3, the demonstration part, involved the results of the fibre optic sensors installed around PRACLAY, as well as the seismic sensors, including the tests with the new (prototype) seismic hammer.

In the course of 2012 and 2013, as coordinator of the European Commission TIMODAZ project, EIG EURIDICE, together with ENPC (France), edited a special issue in "Rock Mechanics and Rock Engineering" (Springer, WoS referenced) on the topic of "Thermo-Hydro-Mechanical effects in clay host rocks", which will be published in the first volume of 2014.

7. Communication

- At the end of 2013, a new version of the website was submitted to ONDRAF/NIRAS and SCK•CEN for approval.
- The programme for guided visits was updated to take into account the new modules that had been installed in the demonstration hall. The visitor guides have received relevant training but a new manual still needs to be developed.
- The scientific report entitled "The design and installation of the PRACLAY In-Situ Experiment" was published in November 2013.

8. Knowledge domains of EIG EURIDICE

- The first steps were taken towards introducing an integrated knowledge management system: the EIG EURIDICE team started drawing up the inventory of all information documents; the possibility of integrating EIG EURIDICE documents with the Alexandria (SCK•CEN) and Vignette (ONDRAF/NIRAS) systems was discussed. A project on excavation and construction technologies still has to be launched.
- An overview of collaboration with universities on PhD research is given later in this report.
- Some of the in-situ experiments were input into the GSIS system and EIG EURIDICE will continue this process during 2014.

9. Surface disposal project for category A waste (PART II)

- In 2013, additional documentation on the radiological long-term safety assessments was prepared and the results of these safety assessments have been documented in several scientific papers.
- Concerning the test cover, the instrumentation plan has been further refined and the field installation of the different sensors was tested.
- The make-shift wiring/layout of the data-acquisition system of the Demonstration Test is finished. The report including the measurement data still has to be delivered and is scheduled for 2014. The data-acquisition system continues to run – an agreement on the long-term follow-up of the monitoring data will also be reached.

Objectives for 2014

1. Switch-on of the PRACLAY heater system

EIG EURIDICE plans to switch on the PRACLAY heater in autumn 2014. In order to be fully prepared for the PRACLAY Heater experiment follow-up, the following objectives have to be met before the switch-on:

- Complete installation and testing of the experimental set-up. This concerns mainly the additional technical elements identified during 2013:
  - modification of the thermal control protocol in the control system for the primary heater;
  - installation of the secondary heater and its control system with the modified design;
  - installation of the thermal insulation door in front of the seal structure;
  - construction of the plugs to be used in the event of leakage through the seal feed-throughs.
- Install and test the data management tools for the test measurements. This includes the Data Acquisition System and "real-time" visualisation system, as well as all associated back-ups (hardware and software) and UPS (Uninterruptible Power Supply).
- Update the analysis of the experimental evolution (bentonite ring swelling, pressure build-up in the PRACLAY gallery, etc.) taking into account the actual planning of the heater switch-on in autumn 2014. This update also includes sensitivity analysis and analysis of various altered evolution scenarios.
- Prepare and complete the procedures necessary for the management and control of the experiment. These procedures also include the implementation of the alarm system and the monitoring and critical evaluation of the key parameters of the experiment in order to organize the scientific follow-up of the experiment.
- Report on the modelling results (expected evolutions, minor and major deviations) that will be used to support decision-making during the experimental follow-up.

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

- Continue to follow-up the hydration and swelling of the bentonite ring seal before and after the heater switch-on.
- Conduct baseline measurements before starting the Heater experiment and report on the "initial conditions" of the PRACLAY Heater experiment.
- Report on the seismic measurements obtained around the PRACLAY seal focusing on the response to the excavation and subsequent self-sealing of the Boom Clay. Quantitative interpretation of the mechanical properties of the Boom Clay will also be included in this report.
- Report on the numerical simulations made to prepare for the Heater experiment start-up (bentonite seal behaviour, experimental evolution, risk analyses, etc.).

3. Scientific tasks related to the thermo-hydro-mechanical behaviour of a disposal system in a clay host rock

- Carry out analysis, interpretation and numerical investigation of the fourth phase of the ATLAS test and, at the end of the cooling phase, make permeability measurements before performing a "heating pulse" test to investigate the ultimate temperature limit of the Boom Clay and possible thermally induced irreversible damage to the clay. After the heating pulse test, samples will be taken in the thermally affected zone to investigate the thermal effects on the key properties of the clay.
- PhD and post-doctoral research
  - Continue the laboratory creep tests at high temperature, the laboratory investigation of

the anisotropic thermo-hydro-mechanical behaviour of Boom Clay and the thermo-hydro-mechanical-chemical behaviour of Boom Clay and Ypresian clays;
  - Continue the laboratory investigation of gas transport in the Boom Clay;
  - Continue the numerical investigation of the excavation-damaged zone (EDZ) in the Boom Clay.
- Start the detailed investigation and follow-up of the stability of the liner in HADES in cooperation with Tractebel and embark on PhD research on this subject.
- Continue the development of the short-term and long-term thermo-hydro-mechanically coupled constitutive models and validate these models with the in-situ measurements.
- Define and conduct a new series of in-situ tests (hydro-fracturing and Self-Boring Pressure meter tests) in HADES to refine knowledge on the in-situ stress state of the Boom Clay at the HADES level.

4. Supercontainer feasibility demonstration test (on surface)

- Write the final report on the second half-scale test, including an overall analysis of all results and observations.
- Management and technical follow-up of the DEF test (Delayed Ettringite Formation).

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

- Support ONDRAF/NIRAS in developing an approach to the operational safety of a geological disposal facility on the basis of EIG EURIDICE's expertise and experience in the operation of the HADES URL.
- Continue to contribute to the investigation of disturbances in the clay host rock and the thermo-hydro-mechanical behaviour of repository components, and to reporting within the context of ONDRAF/NIRAS's "Safety and Feasibility Case 1".
- Consolidate the large body of knowledge (and data) available on the hydro-mechanical and thermo-hydro-mechanical behaviour of Boom Clay (and to a lesser extent Ypresian clays). In particular, this needs to be done by finalising a geotechnical synthesis report for Boom Clay (update of the 2004 "state-of-the-art" report, EIG EURIDICE 04-251)
- Introduce the key Boom Clay parameters (and Ypresian clay parameters when available) and their values into the data clearance system managed by ONDRAF/NIRAS to ensure consistency within the national RD&D programme.
- Support ONDRAF/NIRAS (provide samples, data, technical and scientific expertise) for the supervision of PhDs, post-doctoral studies and research carried out by third parties on the (thermo-)hydro-mechanical(-chemical) behaviour of Boom Clay and Ypresian clays and on gas transport.

6. Management and exploitation of EIG EURIDICE and its installations

- Management and exploitation of EIG EURIDICE and its installations according to the Statutory Rules of the EIG and in line with the ISO 9001-2008 standard.
- Prepare for the replacement of the shaft 1 hoisting system. A preliminary design study and cost estimate will be finalised in the first half of 2014, on the basis of which discussions with the authorities and inspection bodies will be held in order to decide on the applicable regulations.
- Prepare the EIG EURIDICE site for a new visitor entrance that will be built in 2014, including some modifications to technical infrastructure and roads on the site.

- Changes to the electrical infrastructure will be made, mainly in our workshop.
- Re-evaluation of some safety-related aspects, such as the fire-detection systems.

7. Monitoring

As has already been outlined in the new monitoring task, EIG EURIDICE will establish, in the first instance, an updated instrumentation review to summarise experience with the different monitoring techniques. This review will cover:

- The experimental set-up in HADES and at the surface.
- Experience with similar set-ups outside of EIG EURIDICE. The contacts that EIG EURIDICE maintains with other organisations (e.g. NAGRA) or consortia (e.g. Mont Terri) will allow us to obtain the information required for this type of study.

The second part of this task, in which the role of monitoring in the safety case will be developed, will probably not be started before 2015.

8. SAC (Scientific Advisory Committee of EIG EURIDICE)

- Continue to work with the SAC on the scientific aspects of the PRACLAY project.
- Expand the working scope of the scientific and technical remit of the SAC, in line with the scope of the main knowledge domains of EIG EURIDICE.
- Discuss and establish a set of research topics for future PhDs.
- Improve collaborative networking with the academic world.

9. POP (Programme committee for underground experiments)

- Draw up an inventory of all experimental set-ups (past and current) in HADES.
- Discuss and define, at a conceptual level, possible new tests for the period 2015-2020 in line with the RD&D plan of ONDRAF/NIRAS.

10. Communication

- Develop a document on the communication strategy for the period 2014-2020 in dialogue with the constituent members.
- Establish an access procedure for visitors in preparation for the new separate entrance.
- Develop a new manual for visitor guides.
- Go online with the new website.
- Prepare an event, planned for early 2015, to mark the start-up of the PRACLAY Heater experiment.

11. Knowledge domains of EIG EURIDICE

A knowledge management team will be created to develop an integrated knowledge management system. The following steps need to be taken:

- Continue to draw up a complete and structured inventory of all information produced by

EIG EURIDICE and input all experiments and instrumentation into the GSIS system.

- Start a project on excavation and construction technologies.
- Integrate the information management of EIG EURIDICE with the knowledge management systems used by SCK•CEN (Alexandria) and ONDRAF/NIRAS (Vignette).

12. Surface disposal project for category A waste

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

EIG EURIDICE will provide the final report on the instrumentation of the demonstration test. Depending on how far advanced the test cover set-up is, EIG EURIDICE may also assist in the instrumentation work for this project.

13. Establish an agreement with ONDRAF/NIRAS for 2015-2020

Conclude a contractual agreement with ONDRAF/NIRAS for the programme on geological disposal of high-level waste for the period after 2014.

Activities: PART I

High-level and long-lived waste disposal

1. PRACLAY "Demonstration & confirmation experiments"

1.1. Introduction: the PRACLAY project

One of the aims of EIG EURIDICE is the development of the PRACLAY project to demonstrate the feasibility of the disposal of high-level, heat-producing vitrified radioactive waste or spent fuel in deep clay layers such as 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 Safety and Feasibility Case 1 (SFC-1) and 2 (SFC-2), which are part of the ONDRAF/NIRAS research programme for long-term management of category B & C radioactive waste.

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

PRACLAY IN-SITU

DEMONSTRATION EXPERIMENTS

Second shaft
Connecting gallery
Gallery & Crossing test
PRACLAY gallery
Supporting studies: European Commission's CLIPEX project

CONFIRMATION TESTS

Heater test
Seal test
Supporting studies:
    EDZ test (European Commission's SELFRAC & TIMODAZ projects)
    PhD theses

PRACLAY ON-SURFACE

DEMONSTRATION EXPERIMENTS

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

PRACLAY IN-SITU experiments can be divided into demonstration experiments and confirmation tests. **Demonstration experiments** focused on excavation techniques and construction. 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 ring. Most of the PRACLAY demonstration experiments are now finished. **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 main 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.

For this purpose, part of the PRACLAY gallery (30 m) is closed and will be heated for a period of 10 years at a temperature of 80°C at the 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 heater system started in 2010 (primary heater) and will be completed in 2014 (secondary heater).

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

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

1.2. Achievements in 2013

1.2.1. PRACLAY IN-SITU

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

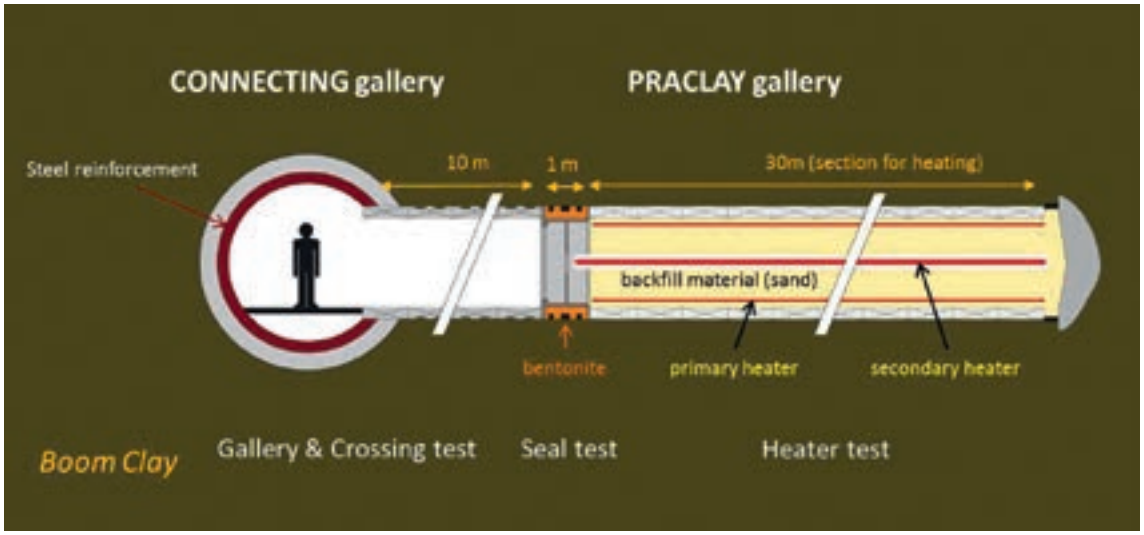


Figure 2 - Design of the PRACLAY Seal & Heater experiment

After the excavation of the PRACLAY gallery in 2007, the hydraulic seal was designed and installed in 2010. 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 3).

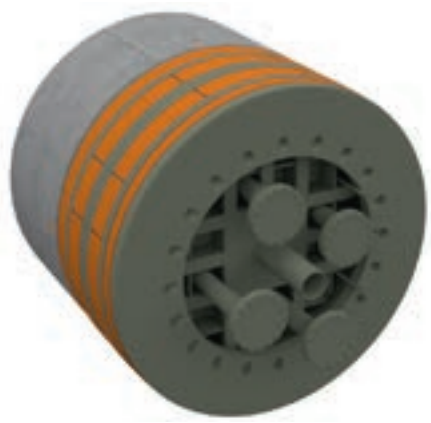


Figure 3 - 3D view of the seal with a central steel cylinder and an annular ring of bentonite (orange) against the clay

The hydraulic seal not only has to close the PRACLAY gallery; it also has to hydraulically isolate the EDZ around the gallery, which can provide a preferential pathway for water towards the main gallery. Bentonite has a very low hydraulic conductivity and swells when it is hydrated. The swelling pressure exerted by the hydrated bentonite on the clay will lower the hydraulic conductivity of the clay around the seal, thus creating "undrained hydraulic boundary conditions" for the Heater test. The swelling behaviour of the seal, and more specifically of the bentonite, is studied in the **Seal test**.

The placement of a heating system and water-saturated sand in the heated section of the PRACLAY gallery completes the experimental set-up. The water-saturated backfill sand has to ensure undrained hydraulic boundary conditions at the interface between the clay and the gallery lining.

The closed part of the PRACLAY gallery (30 m) will be heated for a period of 10 years at a temperature of 80°C at the interface between the gallery lining and the clay. A detailed report about the design, preparation and installation of the PRACLAY Seal & Heater experiment was published in 2013, at the conclusion of the installation phase of the experiment (EUR 13-129).

In this section of the Activity Report, you will find the most important research and installation activities conducted in 2013.

INSTALLATION OF THE 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. Since the primary heater is inaccessible during the Heater test, twice as many primary heater cables than were necessary are installed (100% redundancy). The secondary heater is a back-up and will remain accessible and replaceable at all times during the test.

A control system regulating the heating power as a function of measured and target temperatures is also part of the heating system. During the start-up phase the temperature will be increased slowly to limit the thermal gradient over the gallery lining during this phase.

The **primary heater** was installed in the PRACLAY gallery in 2010. The gallery is divided into three zones (front, middle and end), each of which is subdivided into four sections (upper, lower, left, right). Each section is equipped with two heater elements, ensuring 100% redundancy of the system. Systematic monitoring of the performance of the primary heater cables was continued in 2012 and 2013. Since 2011, one cable has been found to be damaged after backfilling the upstream part of the PRACLAY gallery with sand and closing the hydraulic seal. However, during the testing of the heating system, the cable functioned properly.

In 2013 the functionality of the user interface of the control system was re-evaluated. Subsequently, it was decided to replace this interface with a more user-friendly one. For this purpose, the desired functionalities were defined and will be implemented in 2014.

The modifications include:

- The use of different temperature setpoints and parameters for individual sections.
- Introduction of a notification level and an alarm level for the safety-related parameters, such as the maximum allowable temperature gradient in the concrete lining.
- Addition of a visualisation and settings screen that facilitates the visualisation of alarms and measurements and makes it easier to adjust the control system settings.
- More direct access to the Proportional Integral Derivative (PID) values of the heater control.
- A manual control mode that allows a constant power output.
- Monitoring of the sheath temperature of the primary heater cables.
- Introduction of the option of selecting which thermocouples are used to control which heater section.

The **secondary heater** was installed in the PRACLAY gallery in February 2012. This consists of four heater elements, which were inserted into the central tube inside the part of the PRACLAY gallery that will be heated. The central tube contains five guide tubes (four for heater cables and one for other purposes; see Figure 4) and remains accessible at all times so that the heater elements can be replaced if necessary. The secondary heater is a back-up and will only be used in the event of failure of the primary heater. Whereas the primary heater is regulated to provide a constant temperature during the steady heating phase (80°C at the interface between the gallery lining and the Boom Clay), the secondary heater will provide a constant power output, the value of which will be set at the time of the switch-over.

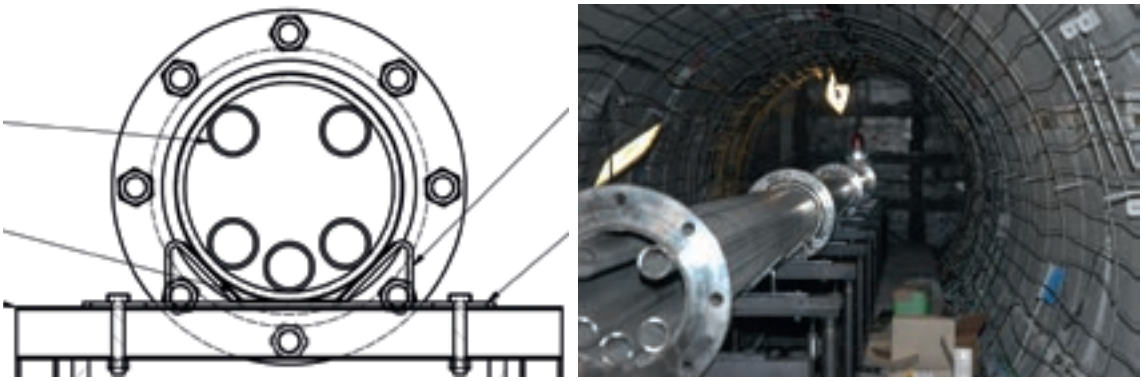


Figure 4 - Cross-section of the central tube

In 2013 detailed modelling showed that the secondary heater design was not optimal and that the heater elements could not be replaced if necessary. Various improvements were made to the design and these will be implemented in 2014.

- The secondary heater had no dedicated control system. The control system of the primary heater was to be used after rewiring the heater cables (disconnecting some of the primary cables to connect the secondaries). A decision was made to install a dedicated control system for the secondary heater.
- Longer heater cables will be installed, which will run the full length of the central tube.
- To limit sheath temperatures, individual cables will be replaced by heater assemblies. These consist of stainless steel rods, each equipped with four heater cables and four thermocouples. Eight assemblies will be installed in total, four in the original small tubes and four in another extra tube (Figure 5). This guarantees 200% availability of the required maximum heater output for the secondary heater.

Figure 5 - Eight heater assemblies of the secondary heater to be installed in the central tube

TEST OF THE HEATING SYSTEM

As in 2012, several short heating tests were performed in 2013. The tests consist of a brief power-up of the heater system. The effect on the test set-up was monitored.

SATURATION OF THE PRACLAY GALLERY

The part of the PRACLAY gallery that will be heated was backfilled with Mol sand (M34) before September 2011. About 38m^3 of tap water was injected into this part of gallery before January 2012. To increase the saturation of the backfilling in the PRACLAY gallery, an additional 4.8 m^3 of tap water was gradually injected into the gallery between January 2012 and May 2012, and as a result the pressure in the gallery increased from 0.13 MPa to 0.50 MPa (pressurisation phase). In June 2012 the artificial injection was stopped. With the water flowing from the host Boom Clay into the gallery, the pore water pressure (PWP) in the gallery has gradually increased since then. At the end of 2013, it reached 0.79 MPa. The water saturation of the PRACLAY gallery at the end of 2013 was estimated to be about 99%.

INSTRUMENTATION

No important new field installations were carried out in 2013 with respect to the PRACLAY Seal & Heater experiment. Most of the activities involved maintenance of installed sensors, including management of the data. Most sensors have been connected to the database. The remaining work is planned for 2014.

In addition, EIG EURIDICE started developing a “real-time” visualisation system to obtain faster access to the measurement data. This work was essential given the large number of sensors, with their associated datasets that already span many years. The visualisation will allow immediate assessment of the state of the experimental set-up, automated report generation on a regular basis, as well as advanced visualisation and follow-up possibilities from 1D (time series data), 2D (profiles and contours) and 3D plots.

The design of an alarm system to detect or warn of any deviating behaviour was also finalised.

THE SEAL TEST - EVOLUTION OF THE SEAL

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 ca. 6.0 MPa (60 bar), while the minimum pressure before switch-on was set at 2.5 MPa (25 bar). This target pressure is based on numerical studies on the interaction of the Heater test and the Seal test, taking into account the role that the seal should play (hydraulic isolation) and the requirement that the hydraulic conductivity of the bentonite in saturated conditions should be lower than that of undisturbed Boom Clay.

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 extrados (outer surface) of the cylinder since April 2010 (Figure 6).

Figure 6 - Water injection filters on the outer surface of the steel cylinder (light grey areas)

Changes in the following parameters are monitored during the hydration of the bentonite:

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

To measure these parameters, different kinds of instruments were incorporated into the bentonite rings during installation. The instruments are grouped into three sections: A, B and C (Figure 7). The evolution of the different parameters is discussed below.

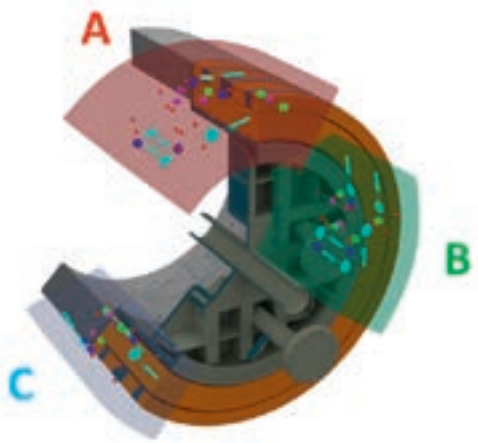


Figure 7 - Various instruments inside the bentonite, grouped into sections A, B and C

In February 2012 optical targets were installed on the seal structure, as well as on selected segments of the accessible part of the PRACLAY gallery, to detect any movement (mainly axial) due to the pressurisation and heating of the PRACLAY gallery. A total station (electronic theodolite) was set up at the front of the PRACLAY gallery to monitor these targets (Figure 8). The frequency of measurements can be adjusted according to the events in the PRACLAY gallery.

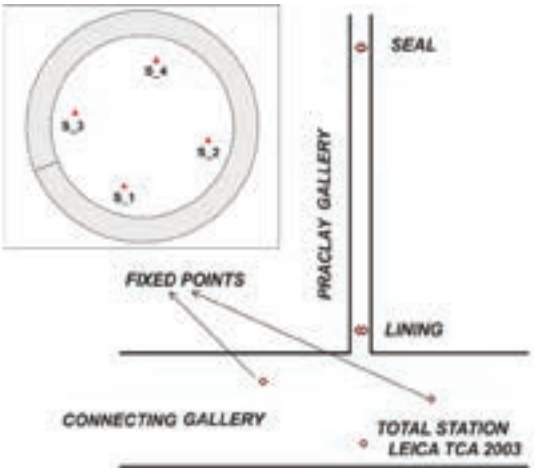


Figure 8 - Theodolite monitoring system for analysing the movement of the seal structure

Concerning the hydration of the bentonite seal, a total of 45 kg of water had been injected into the bentonite by the end of 2013. The **water injection rate** is 6 g/day (Figure 9), independent of the injection pressure, due to the high suction inside the bentonite. The formation of a volume of "bentonite gel" around the injection filters may have impeded further injection.

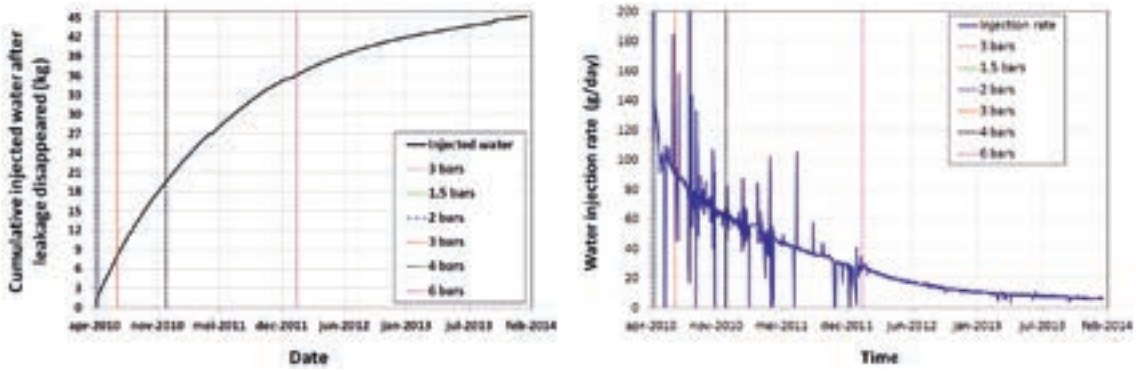


Figure 9 - Artificial water injection into the seal: total amount of water injected (left) and measured water injection rate (right)

The evolution of the **stresses** (radial, circumferential, axial, all stress values being relative) in the bentonite ring and the stresses exerted by the bentonite on the Boom Clay and the steel structure of the hydraulic seal are shown in Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14.

Although the rate of increase differs for the different sensors - especially at the beginning of the Seal test due to the complex configuration of the set-up (e.g. the presence of steel ribs) and the presence of the initial technological voids - most of the sensors show a clear increasing trend and the increasing rates converge for the sensors installed at the same position. The only exception is the radial stress measured at the bentonite/Boom Clay interface at section C (Figure 10). The stress began to increase a few days after the start of the artificial hydration, indicating that during the first few days of artificial hydration, closure of the voids was taking place. After all voids were closed, the stresses in the bentonite started to increase.

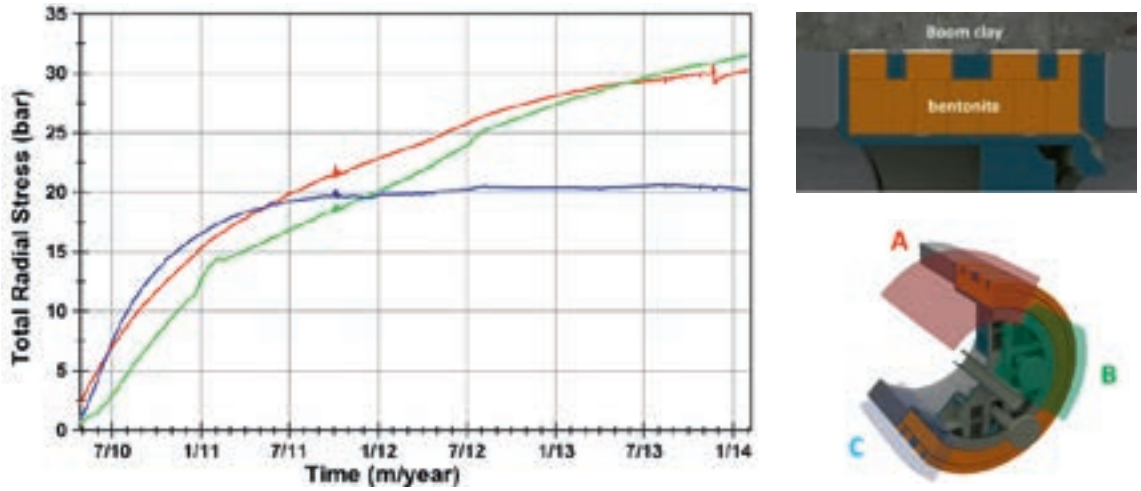


Figure 10 - Radial stresses measured at the interface between the bentonite and the Boom Clay sidewall (white line in insert), for sections A, B and C

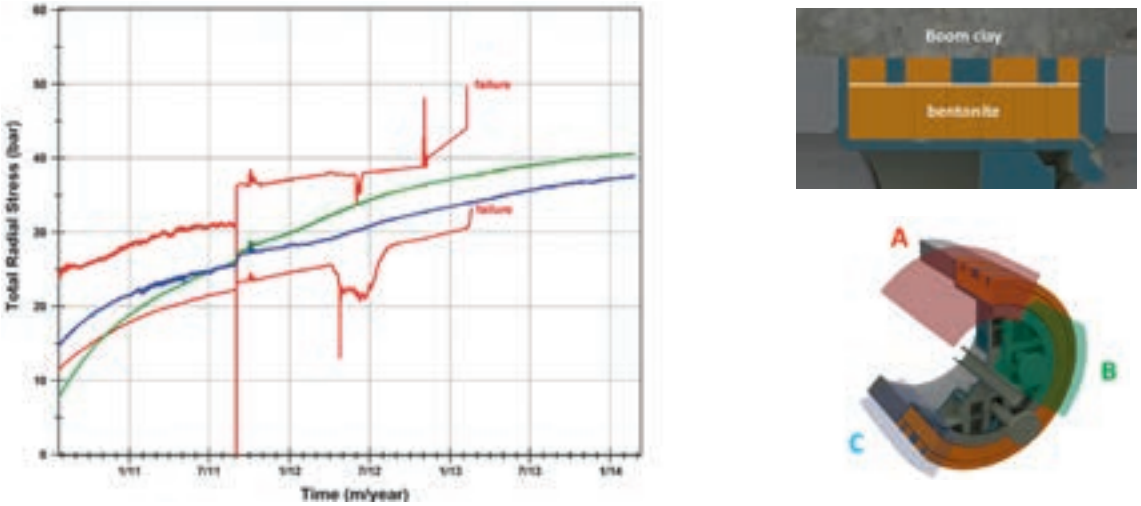


Figure 11 - Radial stresses measured in the void between the inner and outer bentonite rings (white line in insert), for sections A, B and C

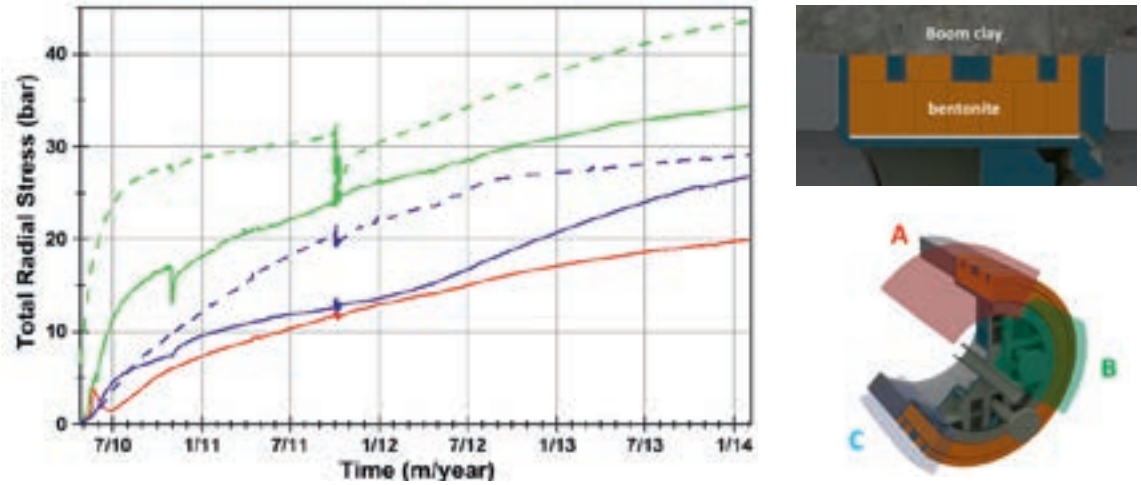


Figure 12 - Radial stresses measured at the interface between the bentonite and the steel cylinder (white line in insert), for sections A, B and C

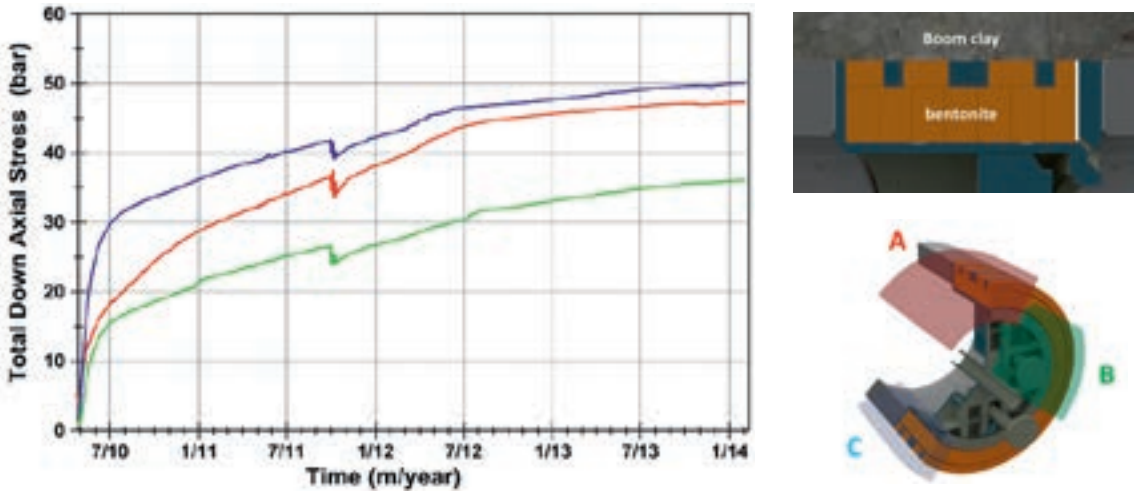


Figure 13 - Axial stress measured between the bentonite ring and the downstream steel flange (white line in insert), for sections A, B and C

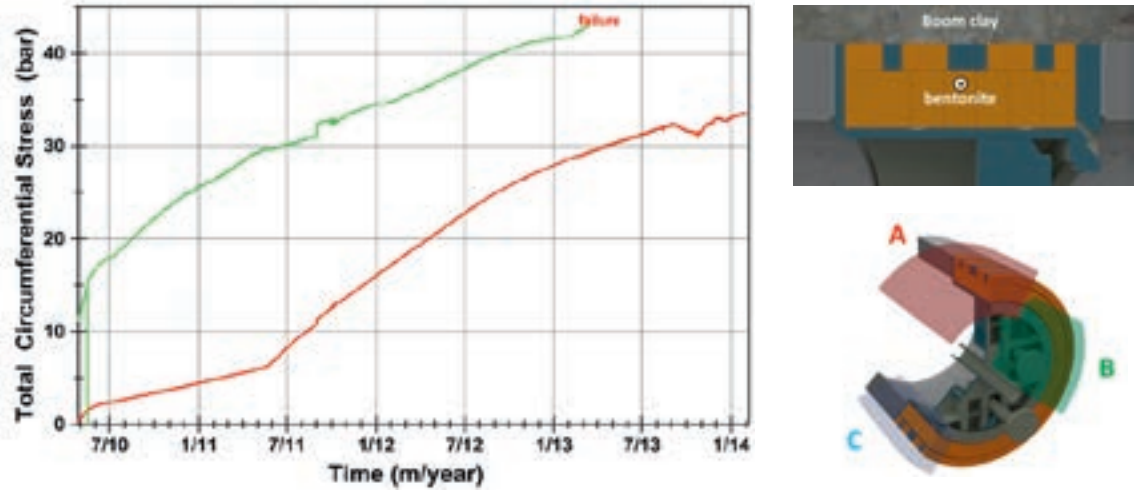


Figure 14 - Circumferential stresses measured in the inner bentonite ring (white point in insert), for sections A, B and C

Radial swelling stress at the interface with the Boom Clay at sections A and B was close to 3.0 MPa (30 bar) at the end of 2013 (the target swelling pressure for heater switch-on is 2.5 MPa (25 bar) based on the scoping calculations). The measurements at section C, however, show an evolution that has levelled off at about 2.0 MPa (20 bar) since mid-2011 (Figure 10).

The radial stresses measured in the void between the inner and outer rings of bentonite show a relatively homogeneous evolution. Two sensors at section A failed at the beginning of 2013 and the sensors installed at sections B and C measured the radial swelling pressure at between 3.8 MPa (38 bar) and 4.0 MPa (40 bar) at the end of 2013, indicating a good contact between the two bentonite rings (Figure 11).

However, the swelling pressure measured at the interface between the bentonite and the steel cylinder is still quite heterogeneous (Figure 12) due to the artificial injection filters that are installed in only two rings and do not cover the complete circumference.

The evolution of axial stress measured at the bentonite/steel flange interface also shows a homogeneous evolution, but the increasing rate seems to have been slowing down since 2013. Overall, section C has the

highest axial stress, followed by section A and section B (Figure 13).

Finally, the circumferential stress shows a continuous increase, indicating that the contact between the bentonite blocks is improving. The stress measured at section A reached 3.3 MPa (33 bar) at the end of 2013 (Figure 14). Unfortunately, sensors in sections B and C have failed, preventing us from having an overview of the circumferential stress.

The measured **pore water pressure** at the interface between the bentonite and the Boom Clay is evolving smoothly and shows a positive pore water pressure of between 0.35 MPa (3.5 bar) (downstream side of the seal) and 0.60 MPa (6.0 bar) (upstream side of the seal), indicating full saturation of the bentonite in the contact zone (Figure 15). The temporary jumps in pore water pressure at different filters were due to the seal performance tests (filter manipulations to check the saturation state), permeability tests (hydraulic water conductivity measurements) and gas tests that were performed on these filters to check the gas breakthrough pressure (see below). Considering the pore water pressure in the PRACLAY gallery is about 0.80 MPa (8.0 bar), the lower pore pressure on the downstream side also indicates good seal behaviour in the contact zone between the bentonite and the Boom Clay. The filters at the interface between the inner and outer bentonite rings and in the inner bentonite ring have not yet significantly deviated from atmospheric pressure, indicating the unsaturated state of the bentonite in these locations.

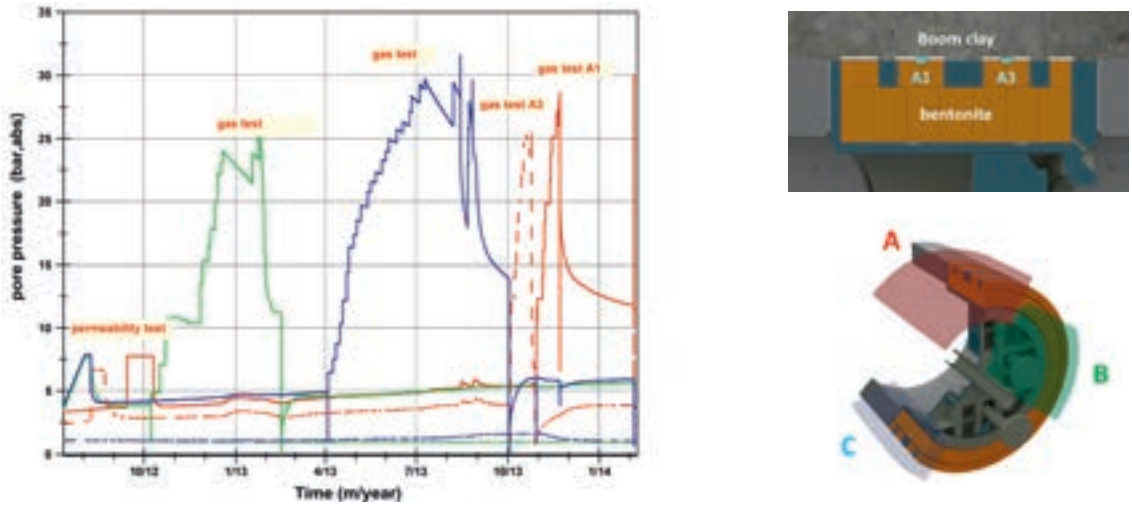


Figure 15 Pore water pressure at the interface between the bentonite and the Boom Clay (white line in insert), for sections A, B and C

Hydraulic conductivity was measured again in 2013 in the Boom Clay in the vicinity of the seal. The values obtained on two filters at a distance of 55 cm and 75 cm from the seal indicated that the hydraulic conductivity at these positions stayed stable and very close to that of the undisturbed Boom Clay with respect to the measurement conducted in 2012. Due to the gas tests, the hydraulic conductivity at the interface between the bentonite and the Boom Clay was not measured during 2013.

The **seal structure movement** is being carefully monitored by the total station (electronic theodolite) that has been installed. After more than a year and a half, the total measured displacement for each of the four target points on the seal structure is about 2.5 mm, due to the pressurisation of the PRACLAY gallery. Overall, the seal structure remains stable and the four target points have moved homogeneously in the same direction (Figure 16).

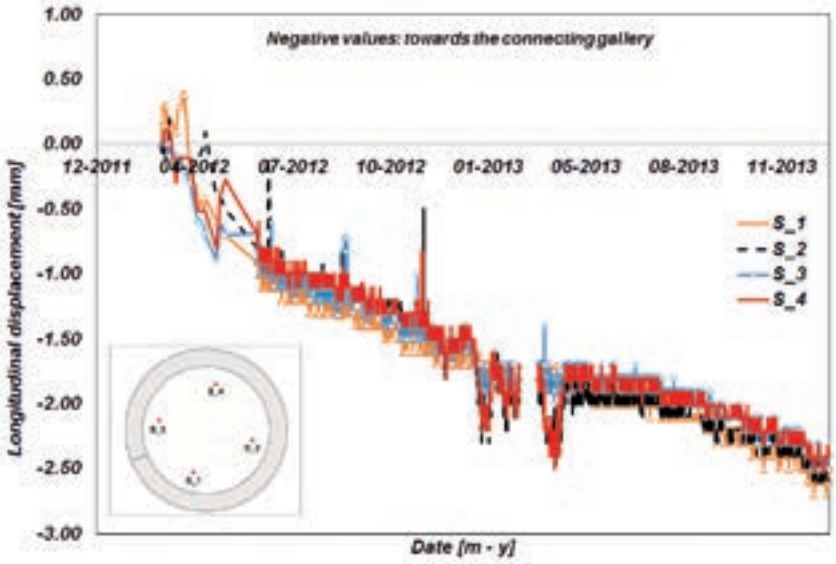


Figure 16 - Displacement of four target points on the seal structure and correlation with the evolution of the pressure inside the PRACLAY gallery

The strain gauges installed on the PRACLAY support beams are connected to the data-acquisition system and are taking regular, in-situ measurements. There have been no significant strain values measured to date, which indicates that there is no significant movement of the PRACLAY gallery lining.

In summary, the seal is behaving as expected, with the measured swelling pressures indicating that the seal is evolving more and more towards a homogeneous state albeit the hydration process is much slower than initially predicted, thereby delaying the swelling pressure conditions for the switch-on. Most of the sensors have measured a swelling pressure larger than the target heater switch-on pressure (2.5 MPa), with the exception of the radial swelling pressure at the bentonite/Boom Clay interface at section C, where the measured swelling pressure is levelling off at 2.0 MPa (20 bar). This target value of 2.5 MPa is mainly determined based on the numerical predictions taking into account the thermal-hydro-mechanical behaviour of both bentonite and Boom Clay as well as the interaction among different components of the experiment. The main criterion is to avoid the "negative" effective swelling pressure at the Bentonite/Boom Clay interface during the entire experiment. The constitutive laws used for the numerical predictions were firstly calibrated by the laboratory tests and then validated by in situ measurements on both bentonite and Boom Clay.

To assess the performance of the seal and to check the consistency of the measurements, especially the radial swelling pressure measured at the Bentonite/Boom Clay interface at section C, which is critical for the heater switch-on decision, a series of **gas breakthrough tests** at the Bentonite/Boom Clay interface have been conducted since the end of 2012.

The **gas breakthrough tests** consisted of injecting Ar gas into the system through a filter at the bentonite/Boom Clay interface. The gas pressure is increased stepwise and by monitoring the gas flow out of the filter into the environment, a gas breakthrough is detected as a sudden pressure drop. The pressure at which gas breakthrough occurs is representative of the minimum stress due to the bentonite swelling. Although the gas pressure at breakthrough is sensitive to various factors, the observation of the gas breakthrough at different filters provided us with an opportunity to check and confirm the measured swelling pressure at that location.

In total, four gas breakthrough tests were conducted: one at section B, one at section C and two at section A (on the A3 downstream filter and the A1 upstream filter, respectively) (Figure 15).

The first gas test at section B started on 8 October 2012. The initial pore water pressure before the start of the test was 0.39 MPa (3.9 bar). Breakthrough pressure was reached at 2.51 MPa (25.1 bar). The total pressure measured by the closest total pressure sensor (flat jack) at the time of the breakthrough was 2.79 MPa (27.9 bar) (Figure 10). Detailed analysis of the measurements of other sensors during and after the gas breakthrough test indicated that there are no direct hydraulic paths between the filter on which the gas test was conducted and other sensors.

The second gas test on section C started on 4 April 2013. The initial pore water pressure before the start of the test was 0.49 MPa (4.9 bar). The breakthrough pressure was reached at 3.15 MPa (31.5 bar), which was much higher than the total pressure measured at the closest sensor to this section, which has been levelling off at around 2.0 MPa (20 bar) since mid-2011. A global analysis by integrating the measurements from different sensors and the gas breakthrough test results indicated that the measurement at this critical sensor is unreliable. The swelling pressure measured at this location should match the breakthrough pressure of 3.15 MPa (31.5 bar). The second breakthrough occurred at about 3.0 MPa (30 bar) shortly after the first breakthrough, indicating that the seal has good and fast sealing capacity.

Finally, the gas breakthrough pressure obtained on the A3 (downstream) and A1 (upstream) filters at section A were about 2.5 MPa (25 bar) and 2.9 MPa (29 bar), respectively. The total pressure measured at the sensor close to the A1 filter at the time of breakthrough was about 3.0 MPa (30 bar), which matches closely with the breakthrough pressure. Unfortunately, the total pressure sensor installed at this section close to the A1 downstream filter failed. The difference in breakthrough pressure at the upstream and downstream filters suggested that the swelling pressure downstream is smaller than that upstream. This is mainly due to the saturation of the PRACLAY gallery.

In conclusion, gas breakthrough pressure is always close to the total radial pressure measured close to the filter location. The exception is section C, where the breakthrough pressure exceeds the total pressure as read from the sensor by 1.1 MPa (11 bar) and casts doubt on the reliability of this sensor.

The gas migration mechanism under such seal conditions still needs to be fully understood.

SEISMIC MONITORING

The seismic installation around the PRACLAY gallery consists of 23 transmitters (T) and 19 receivers (R). The sensors used are micro-seismic piezoelectric sensors that can both transmit and receive signals. They are installed in boreholes as well as at the interface between the gallery lining and the Boom Clay (Figure 17).

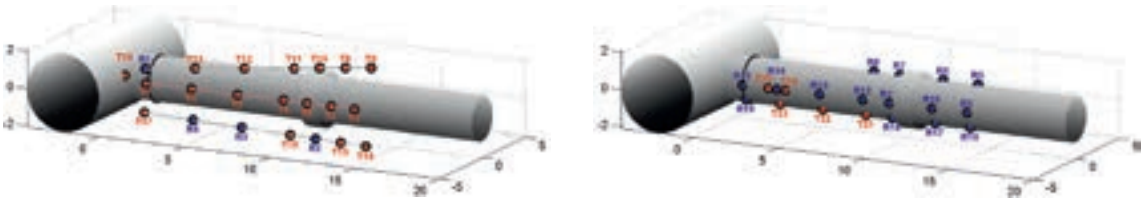


Figure 17 - Transmitters (T) and receivers (R) installed in boreholes [left] and at the extrados (outer surface of the PRACLAY gallery) [right]

The main objectives of the seismic installation are to:

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

Shear (S) waves in the Boom Clay are known to propagate predominantly in the frequency range between 1 and 1000 Hz (Figure 18). S-waves are sensitive to changes in physical properties of the clay and will help assess the mechanical response of the EDZ around the PRACLAY gallery during the Heater experiment. For this reason, attempts have been made to recover S-waves from the signals currently measured by the micro-seismic installation. This consisted mainly of filtering out the higher frequencies during post-signal analysis and installing low-pass filters in the data-acquisition (DAQ) system prior to recording the signals.

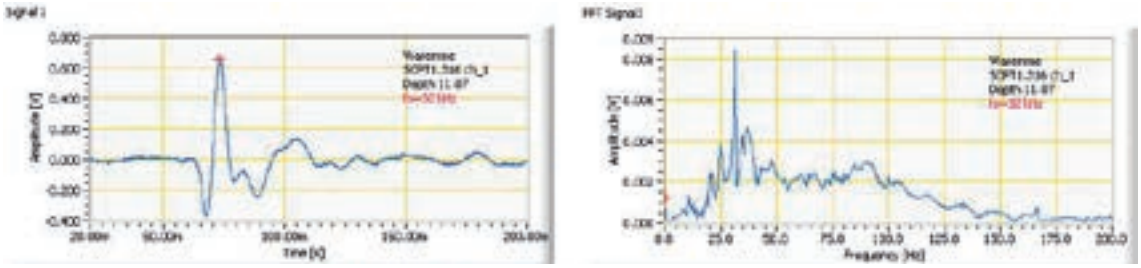


Figure 18 - Typical time series (left) and frequency spectra (right) obtained in the Boom Clay with an impact hammer similar to the one developed for the new S-wave hammer

Another attempt centred on the design of a new S-wave hammer to generate predominantly S-waves. A prototype of the hammer is shown in Figure 19. The hammer fits in a borehole with a minimum internal diameter of 95 mm, and can be installed in any direction in order to optimise the generation of S-wave signals. A built-in anvil and piston system generates predominantly low-frequency S-waves.

Figure 19 - (Left) 3D design model and (right) prototype of new seismic hammer designed to enhance the generation of S-waves

Analysis and interpretation methods for the existing micro-seismic installation data recorded in HADES have been modified to improve the detection of S-waves. Part of the improvement stems from lowering the

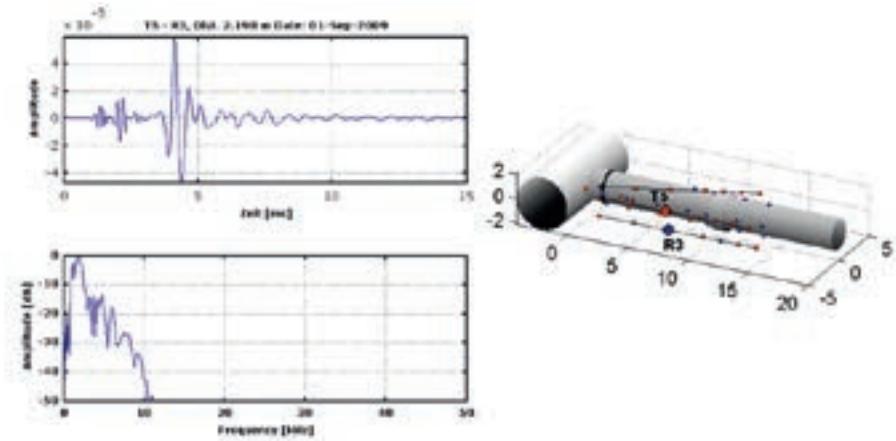


Figure 20 - S-wave signal (top) between T5 and R3 and reduced frequency spectrum from 2006 to 2009, after low-pass 5 kHz filter (bottom)

high pass frequency from 5000 to 1000 Hz during post signal analysis, which significantly improves the detection of S-waves. Another method that improved detection resulted from the installation of a low pass 5 kHz filter in the DAQ system. The results, shown in Figure 20 for transmitter T5 and receiver R3, clearly show the detection of S-waves after the installation of such a filter, which caused the cut-off of the frequencies higher than 10kHz.

The results of two tests performed in HADES with the prototype hammer can be seen in Figure 21. The prototype hammer was installed in a cased borehole, located next to the PRACLAY gallery. The first test campaign carried out on 20 August 2013 (Figure 21, left) shows a significant amount of noise in most of the signals. After this test, improvements to the hydraulic system of the hammer were made before repeating the tests on 29 August 2013. The signals generated during the second test (Figure 21, right) show a significant improvement in the S-wave signals in comparison with the results of the first test campaign. Besides improvements to the hydraulic system, the signals in the second test campaign have been stacked, which further reduces background noise and improves the quality of the signals.

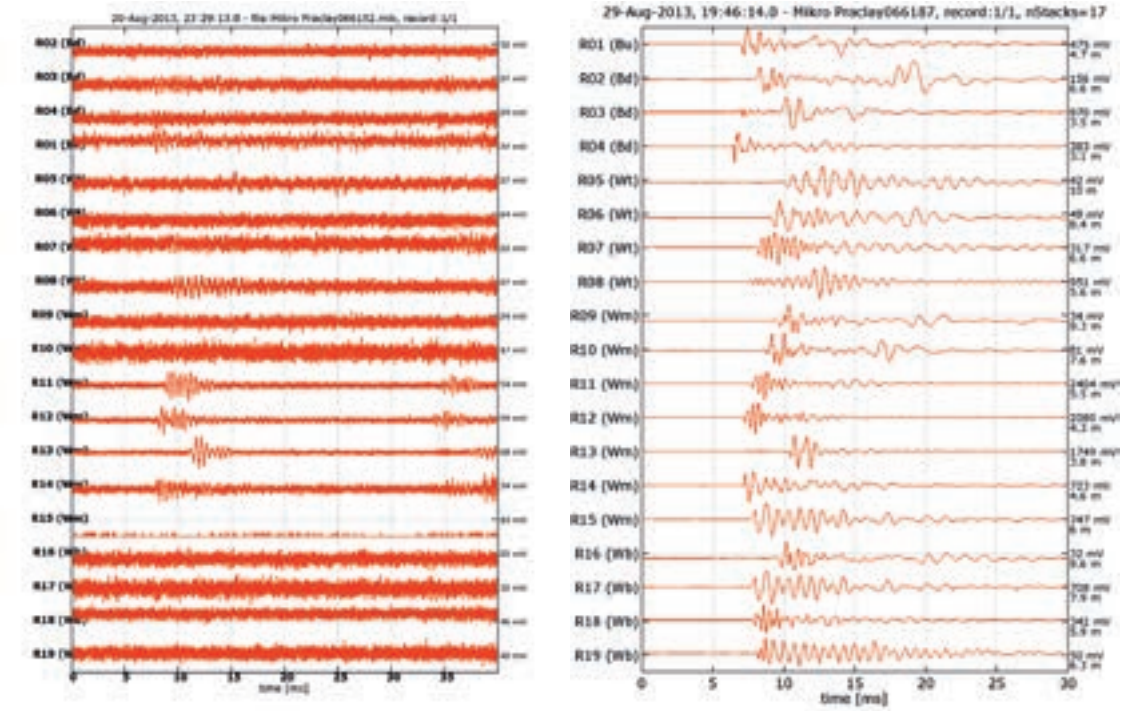


Figure 21 - Signals generated with prototype of new seismic hammer (left) showing first tests on 20 August 2013 and (right) after improvements to hydraulic system and stacking

Testing is ongoing to further improve the quality and performance of the new S-wave hammer. Once the tests are completed, the hammer should enhance the ability to generate S-wave signals and thereby improve S wave monitoring of the near field around the PRACLAY gallery during the Heater experiment.

NUMERICAL MODELLING OF THE PRACLAY SEAL AND HEATER TESTS

During 2013, numerical modelling work played an essential role in the preparation and decision-making process for the heater switch-on.

The follow-up and management of the PRACLAY Heater test should be supported by a good knowledge of the expected evolution of the experiment. This knowledge relies on two important tools that EIG EURIDICE

has prepared, based on the intensive numerical modelling program:

- Analysis of the expected evolution scenario, including a sensitivity analysis.
- Analysis of the altered evolution scenarios.

To increase the reliability of the expected evolution modelling results, significant efforts were devoted to understanding and then reproducing, numerically, past in-situ measurements (i.e. the evolution of the experimental conditions since the excavation of the PRACLAY gallery). Based on the in-situ measurements, the numerical simulations were further fine-tuned in the course of 2013 and used to predict the evolution of the bentonite and thermo-hydro-mechanical (THM) responses of Boom Clay during the Heater test. Figure 22 and Figure 23 show examples of the numerical modelling of seal hydration (Figure 22) and pore water pressure evolution around the PRACLAY gallery (Figure 23). A good agreement between the numerical results and in-situ measurements provided a set of reliable parameters that were then applied for the analysis of the expected and altered evolution scenarios.

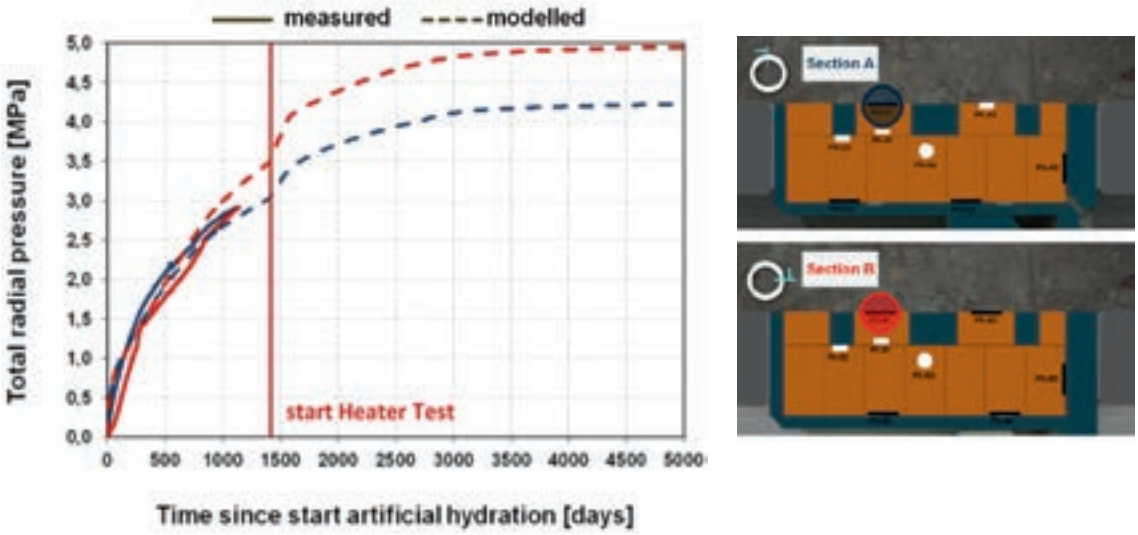


Figure 22 - Numerical modelling of seal hydration in terms of swelling pressure

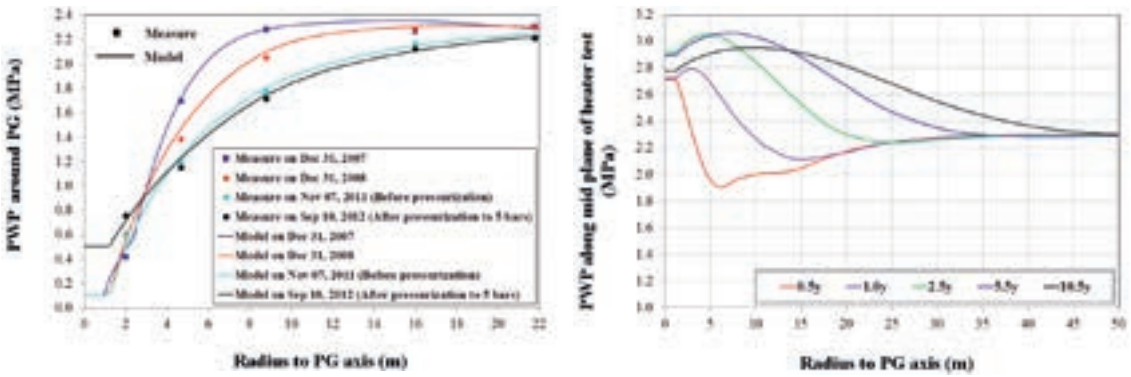


Figure 23 - Numerical modelling of the pore water pressure evolution around the PRACLAY gallery. On the left is a numerical simulation of the past evolution and on the right the expected evolution during the Heater test.

For the **expected evolution scenario**, a **sensitivity analysis** was conducted to obtain a possible range of experimental evolutions, taking into account uncertainties about, for example, the THM parameters, the timing for the switch-on and the heating control system.

In parallel with the analysis of the expected evolution scenario, various **altered evolution scenarios** were numerically modelled to assess their consequences and to check what can be done, including the efficiency of any action taken. Altered evolution scenarios that have been studied include:

- Water leakage along the cable feed-throughs in the seal (with different fluxes, durations and timing)
- Failures of different sections and zones of the primary heater (with different durations and timing)
- Damage to the Boom Clay (e.g. permeability increase) in the zone around the seal and/or heater, caused by heating the gallery

Finally, in order to be better prepared for the heater switch-on, a **risk analysis** was performed to ensure that all components in the experimental set-up will function as expected. As a consequence of this analysis, the initial design of the secondary heater needed to be optimised and the interface for the control system of the primary heater had to be improved.

To validate the modelling results, multiple independent codes were used and the modelling was performed by different people.

Another important part of the numerical work performed in 2013 focused on the **prediction of the THM response of Boom Clay in a real repository**, which will serve as a guide for assessing the PRACLAY objectives. This is because the PRACLAY Heater test was designed to be more conservative in terms of THM response of the Boom Clay compared to a real repository.

PLUG TO STOP POTENTIAL LEAKAGE IN THE SEAL FEED-THROUGHS

The seal steel structure contains four main conduits (Figure 24) through which are fed the numerous cables, water pressure tubing and wiring connecting the sensors inside the heater part of the experiment to their respective measurement and data-acquisition systems located outside the experimental gallery. The various feed-through components use Conax™-type sealing glands, which can withstand pressures of up to 30 MPa, depending on the applied torque. If one or more of these glands leak, immediate action is necessary to stop the leakage in order to limit possible disruption of the experiment. In 2012 a design was developed consisting of a pre-fabricated plug that can be placed over either an individual gland or a set of leaking glands to completely stop leakages (Figure 25). This plug design was slightly modified in 2013 to offer more flexibility to plug individual leaks. The construction of the plug will proceed in early 2014, before the heater is switched on.

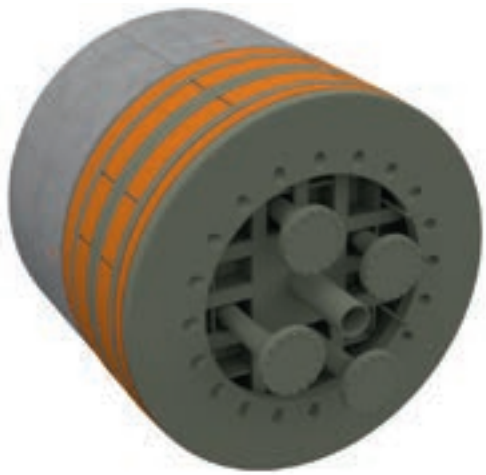


Figure 24 - Overview of the seal showing the four main feed-through conduits

Figure 25 - Proposed design for a plug to stop potential leakage in seal feed-throughs

TIMING FOR SWITCH-ON OF THE PRACLAY HEATER

Once all test components have been installed, the heater can be switched on when the status of the experimental set-up meets certain requirements and when EIG EURIDICE is ready to appropriately monitor the test.

In addition to the construction of the PRACLAY gallery, the Heater test set-up comprises mainly four components:

- The hydraulic seal
- The heating system
- The backfill sand
- The instrumentation and data-acquisition (DAQ) system.

The hydraulic seal has to meet the following specifications:

- The hydraulic conductivity of the seal in saturated state should be as low as possible (at most equal to or less than the hydraulic conductivity of undisturbed Boom Clay ($\approx 10^{-12}$ m/s)).
- The swelling pressure should be greater than 2.5 MPa 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).
- The swelling pressure should be less than 6.0 MPa so as not to fracture the clay.

At the present time, EIG EURIDICE considers the bentonite hydration and swelling to be sufficient for the heater switch-on because:

- The water pressure in the backfill sand is currently 0.8 MPa and no water leakage through the hydraulic seal has been observed.
- The local measurements of the hydraulic conductivity at the bentonite/clay interface are close to the hydraulic conductivity of undisturbed Boom Clay.
- The radial pressures exerted by the bentonite on the Boom Clay are around 3 MPa and are thus higher than the required threshold value of 2.5 MPa. This is confirmed by measurements and the gas breakthrough tests.
- EIG EURIDICE believes it has sufficient understanding of the seal behaviour and the measured data can be reasonably well reproduced by numerical simulations.

Concerning setting up the experiment, three remaining issues that need to be resolved before the switch-on were identified in the course of 2013:

- The most critical issue concerned the secondary heater. As mentioned above, a risk analysis by numerical simulation indicated that its initial design was not optimal with respect to heating

power and the risk of not being able to replace the secondary heater. Consequently, a series of improvements were made to the design and these will be implemented in the first half of 2014.

- For the management of the heating system, a more user-friendly interface for the control system of the primary heater will be installed with all the necessary functionalities.
- The instrumentation and DAQ system will be completed with the implementation of an alarm system and visualisation tools.

These improvements will be implemented in early 2014 and everything will be tested before July 2014.

With respect to the follow-up of the experiment, all procedures will be ready by the end of May 2014.

The above-mentioned points were presented and discussed during the second workshop on the start-up of the PRACLAY Heater experiment, held on 12 & 13 December 2013. In general, the experts agreed that:

- EIG EURIDICE has covered all relevant issues in preparing for the heater switch-on.
- Correct data management tools and organisational procedures are in place to ensure a good follow-up of the test.

No major uncertainties or problems concerning the switch-on of the heater were voiced during the workshop.

Based on all these elements, EIG EURIDICE is planning the actual switch-on in the autumn of 2014.

1.2.2. PRACLAY ON-SURFACE

HALF-SCALE TESTS: SUPERCONTAINER CONSTRUCTION FEASIBILITY TEST NO. 2

The second half scale test (HST2) was performed in 2013 to gain further insight into the feasibility of constructing the different components of the supercontainer (SC) conceptual design proposed by ONDRAF/NIRAS for the packaging of high-level radioactive waste.

An overview of the set-up used for the second SC half-scale test is shown in Figure 26. The so called half-scale test has a full-scale diameter, while its height is limited to approximately half of that of a real SC. As can be seen in Figure 26, the HST2 integrates two separate moulds: an outer mould for the construction of the concrete buffer and an inner mould to create the opening necessary for the installation of the heated overpack. Both moulds use a re& usable steel structure to reduce costs when repeating the test.

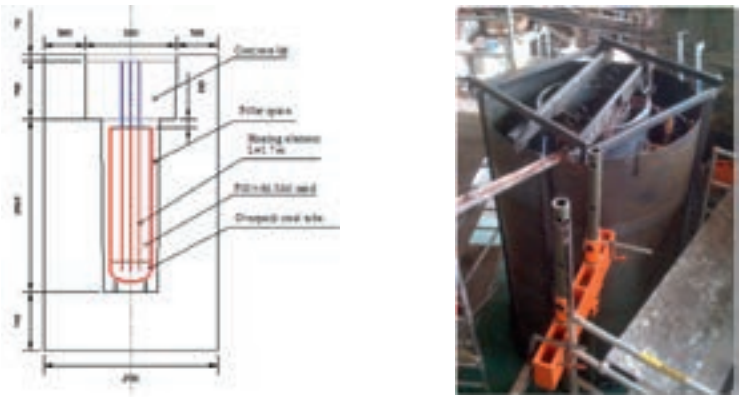


Figure 26 - Cross-sectional view of the HST2 (left) and test set-up showing the outer and inner metal moulds (right)

The test incorporated new and innovative monitoring techniques to study the initiation and propagation of cracks in the concrete buffer and to monitor active corrosion of the carbon steel overpack. These included the use of fibre optic sensors to measure semi-distributed temperature and strain in both axial and radial directions, Digital Image Correlation (DIC) and Acoustic Emission (AE) to monitor crack formation, and a new sensor to measure the evolution of corrosion of the carbon steel overpack. Many of the sensors were installed with a high degree of redundancy to allow direct comparison of the sensors and to evaluate their performance. The parameters monitored in the HST2 are listed in Table 1.

Instrumentation	Parameter
Thermocouple	Temperature
Strain gauges (including vibrating wire gauges)	Strain
LVDT (Linear Velocity Displacement Transducer)	Displacement
Anemometer	Wind velocity
Humidity TDR probe	Moisture content
DIC (Digital Image Correlation)	Onset and propagation of cracking
AE (Acoustic Emission)	Crack formation
Total pressure sensor	Total pressure
Fibre optics	Temperature, axial and radial strain
Oxygen sensor	Oxygen flux
Reference electrode	Corrosion potential
Corrosion sensor	Corrosion rate

Table 1 - Monitoring parameters and instrumentation in the second half-scale test

CRACK FORMATION

The DIC and AE monitoring systems successfully identified the time of initiation of the first micro-cracks formed on the surface of the concrete buffer. The cracks measured approximately 15 ± 5 microns in width and formed less than one day after the start of the heating phase. The DIC and AE results have been confirmed by both optical fibre and vibrating wire strain measurements. Figure 27 shows a typical set-up of the DIC method.

Preliminary laboratory tests performed to evaluate the application of DIC to detect the initiation of cracking in concrete showed that the DIC method can measure micro-cracks with a crack opening resolution of approximately 12.5 ± 5 microns. This is sufficiently sensitive to detect the formation of potential micro-cracks in the concrete buffer of the SC.

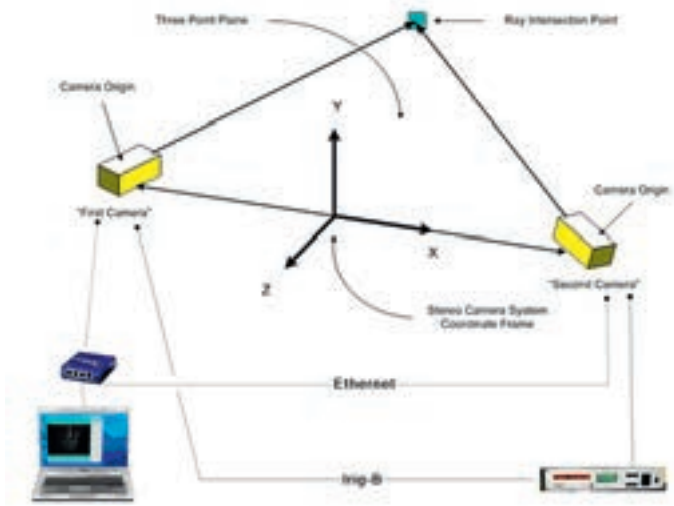


Figure 27 - Typical DIC set-up

AE utilises the transient elastic waves emitted by the tip of a crack during propagation. These waves are detected by piezoelectric sensors mounted on the surface of the concrete and are transformed into electric waveforms. AE provides information on the density of cracks, and the geometric location and depth of the cracking sources, while enabling the characterisation of the mode of cracking. A typical set-up is shown in Figure 28.

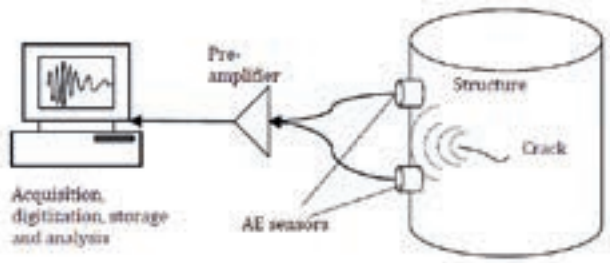


Figure 28 - Typical AE set-up to monitor cracking in a concrete structure

Generally, the DIC's grey digital image pattern is printed on a plastic film and then glued onto the surface of the area of interest of the object. This requires a dry surface for proper adherence of the glue. In the case of the HST2 experiment, it was important to start measurements as soon as possible after casting in order not to miss the first development of cracks. However, the presence of moisture on the concrete surface during the first few days following casting made it impossible to glue a plastic film on the concrete surface. In fact, the plastic film would have run the risk of peeling off as a result of pressure build-up due to the presence of moisture. To solve this problem, a technique was developed whereby the digital pattern was projected directly onto the concrete surface without the need to glue it. Doing so enabled the installation of the digital image only two days after casting.

As shown in Figure 29, the outer steel mould contains three windows. The windows are removable to provide access for the installation of the digital images as well as to take measurements during the test. The figure also shows the grey digital image installed in window 2, two days after casting, and four AE sensors installed at each corner of the window.

The DIC and AE measurements did not show any evidence of cracks during the first phase of the test. The first phase represents the first 56 days of testing, before the installation of the heated overpack. During this phase, the monitoring system measured only dilatation and shrinkage of the buffer generated by the hydration and hardening of the concrete. These results are in line with model predictions, which suggest

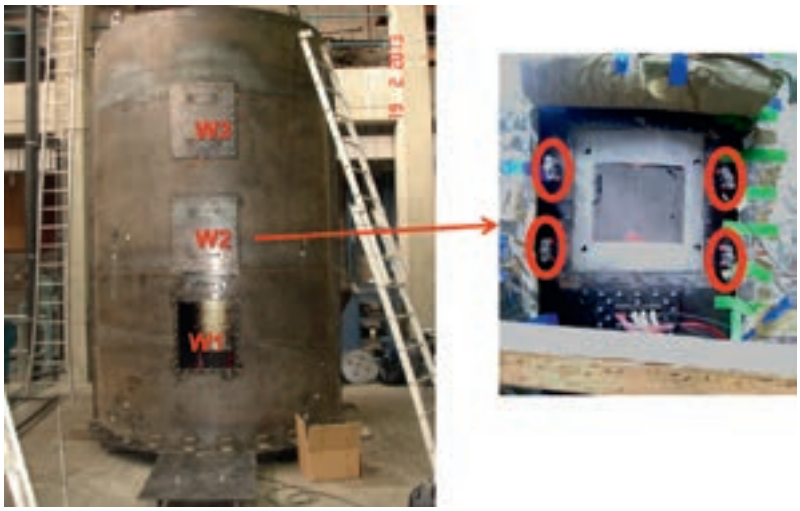


Figure 29 - Outer mould showing the three removable access windows for the DIC measurements (left) and printed digital image together with four AE receivers installed in window 2 (right)

a low probability of developing cracks during the first phase of the test. They also agree with both visual observations and physical measurements of strain obtained from Fibre Bragg Grating (FBG) optical fibres and vibrating wire (VW) sensors installed in the concrete buffer. In addition, the results also confirm observations made during the first half scale test performed in 2009, where no cracks developed in the concrete buffer during the first phase of the test.

The heated overpack was installed in the buffer on 10 June 2013. The day after, the concrete filler was cast to fill the void space left after the installation of the heated overpack. This marked the start of the second phase of the test. This phase lasted approximately 77 days, during which time the AE measurements successfully detected the onset of cracking in the buffer, as described in more detail below.

The first cracks detected by the AE and DIC systems appeared in window 2, just one day after the start of the heating phase. The initiation of the first cracks was marked by the sharp increase in AE hits shown in Figure 30 and confirmed by the visible image of the cracks shown in Figure 31.

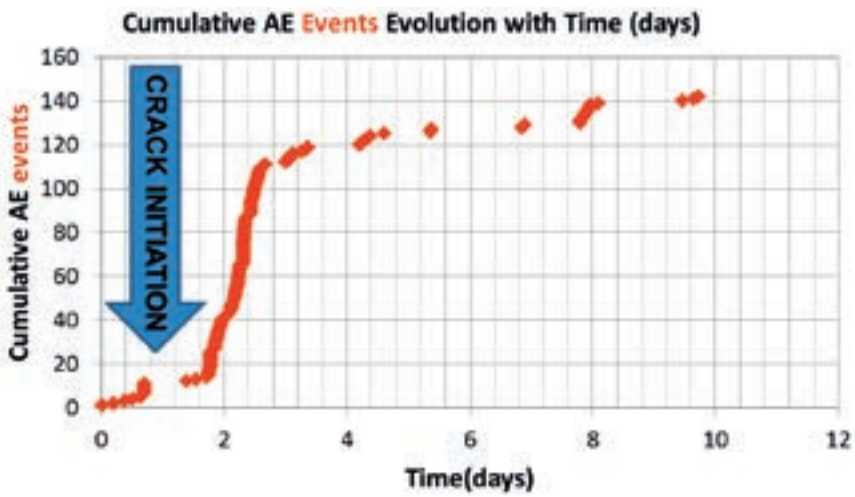


Figure 30 - Cumulative AE hits recorded in window 2 during the first few days following the start of the heated phase

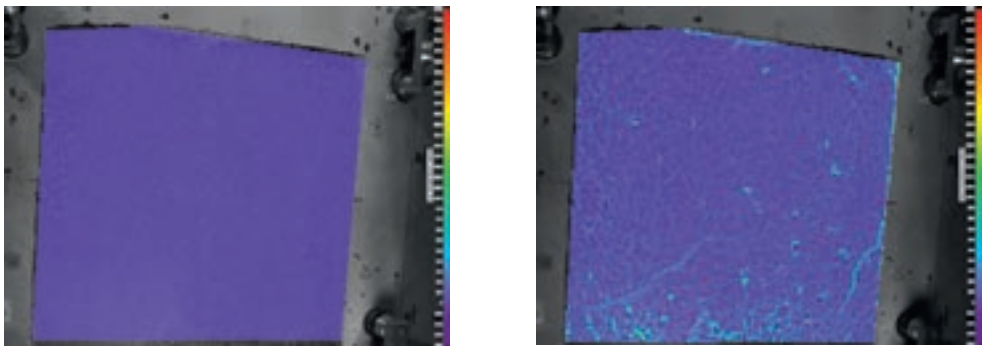


Figure 31 - DIC image taken at window 2 just prior to the start of the heating phase (left) without cracks; and the same image taken a day after the start of the heating phase showing the presence of micro-cracks (right)

The measurements of axial strain obtained from both FBG optical fibres and VW sensors installed in the concrete buffer provide additional confirmation of the DIC and AE measurements. These results appear in Figure 32 and Figure 33, respectively.

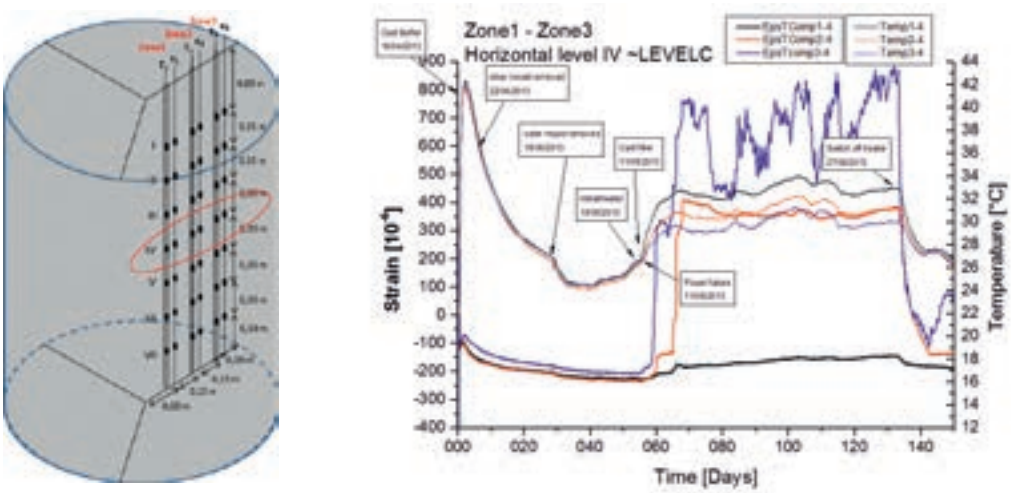


Figure 32 - Measurements of axial strain (lower curves) and temperature (upper curves) from three FBG sensors installed at the mid-level of the HST2, confirming onset of cracks in phase 2. Black = zone 1; red = zone 2; blue = zone 3

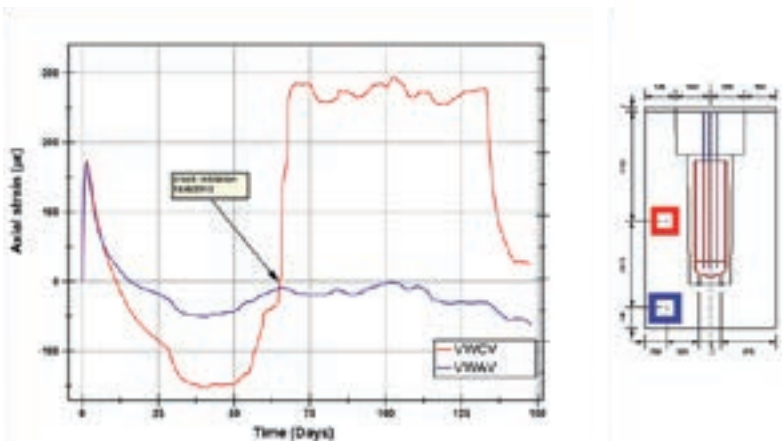


Figure 33 - Measurements of axial strain from two VW sensors installed at the mid and lower levels of the HST2, confirming onset of cracks in phase 2

OVERVIEW OF CORROSION MONITORING INSTALLATION

The major goal of the corrosion measurements was to measure the instantaneous uniform corrosion rate, representative of the initial oxic phase, in situ, in a real-size SC set-up. The corrosion rate of carbon steel was measured in four ways:

- Weight loss coupons. These were cut out of a carbon steel block having the same specifications as the reference carbon steel for the SC;
- A corrosion sensor developed at the Nuclear Research Centre of Argentina (CNEA) (Duffó and Farina, 2009) based on the Linear Polarisation Resistance technique (LPR, G. Duffó);
- A patented new sensor (PermaZEN) developed at the Vrije Universiteit Brussel (VUB) in Belgium (Kursten et al., 2013), based on the multisine Electrochemical Impedance Spectroscopy method (EIS). A special and unique in-house analytical method was developed to derive corrosion rates from the recorded EIS spectra;
- A corrosion sensor developed at CEA, France (Bataillon, 2011), based on the single sine EIS method.

A layout of the installation can be seen in Figure 34.

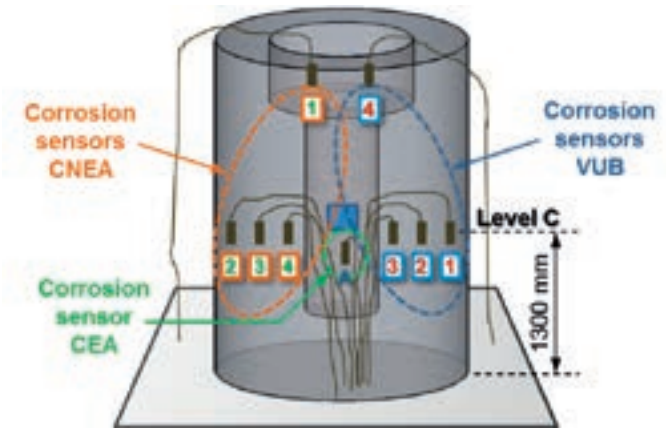


Figure 34 - Installation of corrosion sensors in the HST2

The measurements obtained with the different corrosion sensors embedded in the concrete buffer of the HST2 prototype provided insight into the behaviour of the P355 QL2-grade carbon steel overpack when exposed to the high pH of the concrete buffer. Since the test was performed at the surface, the measurements represent the initial oxic phase expected during the first period of disposal. The corrosion potential increased to values in the range between 100 mV_{SHE} and 0 mV_{SHE} after ~80 days of curing. This ennoblement of the corrosion potential is attributed to the formation of the passive film.

The corrosion rate showed a steep rise during the first few hours after casting, increasing to a value of ~90 µm/year. This increase was attributed to the formation of the passive film. After ~160 days of exposure, the corrosion rate decreased to ~4-5 µm/year. The impedance measurements confirmed the decrease in corrosion activity with time. The data measured with the CEA corrosion sensor still needs to be analysed in more detail.

Finally, an area that needs further development concerns the automation of the measurement procedure for the CNEA and CEA sensors. The procedure could be made similar to that used by the PermaZEN sensors, which can be operated fully automatically and provide continuous measurements via a remote internet connection.

2. Supporting studies

2.1. ATLAS

The small-scale in-situ ATLAS (Admissible Thermal Loading for Argillaceous Storage) tests are performed to assess the thermo-hydro-mechanical (THM) behaviour of the host Boom Clay at the HADES URL.

To broaden the THM characterisation of the Boom Clay on a larger scale and at different temperature levels, the ATLAS test set-up installed in 1993 and 1996 (ATLAS I & II) was extended in 2006 by drilling two additional instrumented boreholes (AT97E and AT98E) (Figure 35). The heater was switched on again from April 2007 to April 2008 with a stepwise power increase, followed by instantaneous shutdown. This phase is called ATLAS III. Three-dimensional coupled THM modelling of the ATLAS III test has been performed. The good agreement between measurements and numerical modelling of temperature and pore water pressure in the horizontal plane of the heater highlights the THM anisotropy of the Boom Clay and yields a set of THM parameters. By introducing mechanical anisotropy into the THM coupling model, the numerical simulation predicts an instantaneous but temporary pore water pressure decrease after increasing power, and a temporary pore water pressure increase after cooling in the horizontal plane, but not in the vertical plane. The former phenomenon has been confirmed by in-situ measurements from ATLAS III.

To gain better insight into the anisotropic THM behaviour of the Boom Clay, a new upward, instrumented borehole AT90IU was drilled above the ATLAS heater at the end of 2010 (Figure 36).

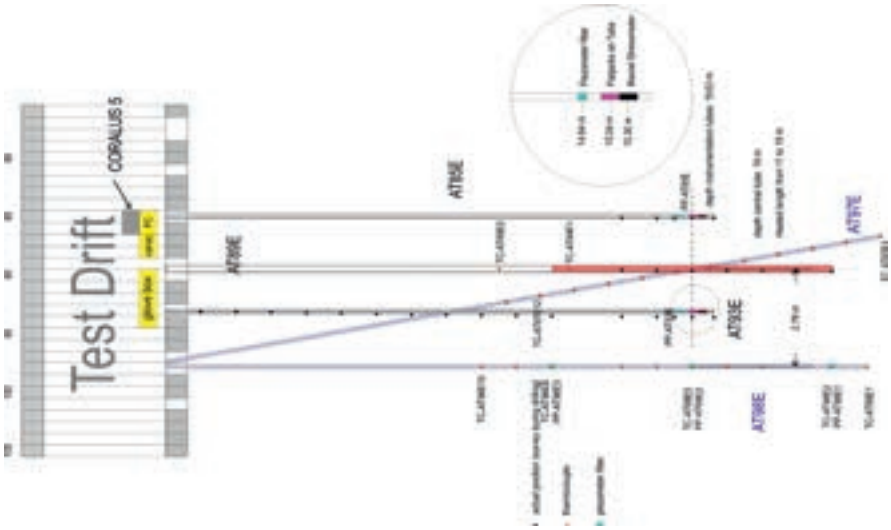


Figure 35 - Schematic view of the small-scale in-situ ATLAS test

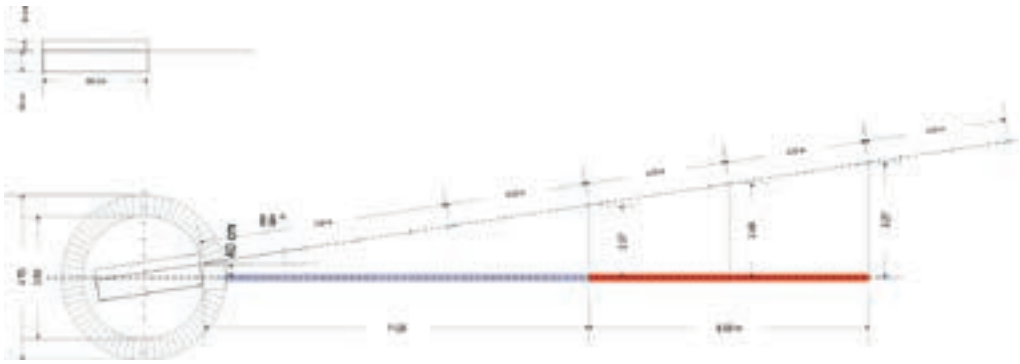


Figure 36 - Upward borehole AT90IU drilled above the heater for ATLAS IV

The new phase of the ATLAS heater test (ATLAS IV) started on 18 October 2011, using the same heating strategy as for ATLAS III to facilitate interpretation and comparison between the ATLAS III and ATLAS IV tests. As expected, the available measured variation in the pore water pressure from the new upward borehole was different from that measured from the borehole in the horizontal plane, which confirms the mechanical anisotropy of the Boom Clay. The heater was shut down on 29 November 2012 and the cooling phase started. By the end of 2013, the temperature, pore water pressure and stresses had almost recovered to the initial state before heating began (Figure 37).The extended picture of the temperature field provides clear evidence of the thermal anisotropy of the Boom Clay (Figure 38).

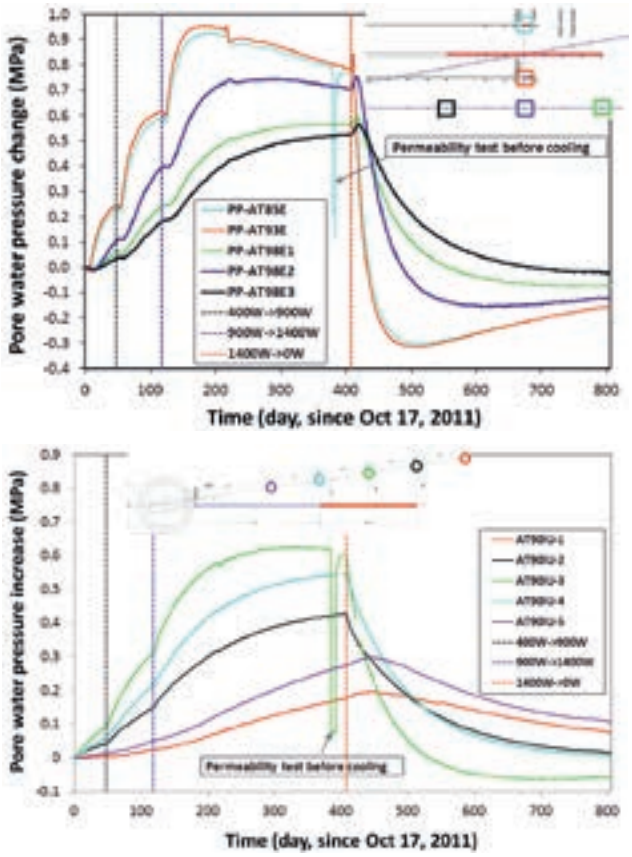


Figure 37 - Pore water pressure variation measured from boreholes in the horizontal plane (above) and from the upward borehole (below)

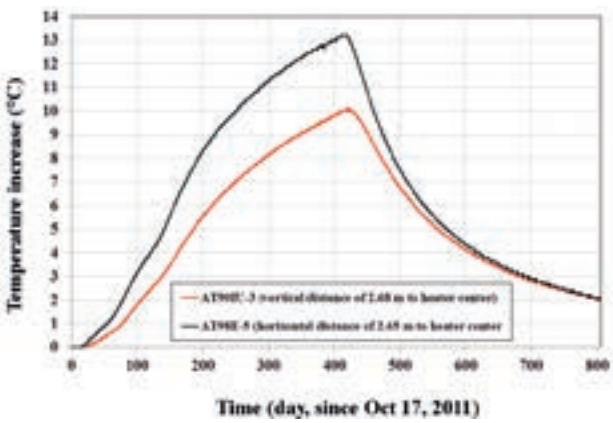


Figure 38 - Temperature measured by two sensors in the upward borehole and the horizontal borehole with almost the same distance to the heater centre

2.2. Stability of the Connecting gallery

Since the construction of the Connecting gallery in 2002, strain has been measured in three different rings of the Connecting gallery with the help of the strain gauges installed in the segments. The aim is to monitor the deformation process of the concrete segments in order to determine by back-analysis the pressure exerted by the clay on the liner and to estimate the stability of such a structure over a long period of time. This may be a critical issue during the operational phase of a nuclear waste repository, which can span several decades or even up to a century. Strain and stress analysis was performed by TRACTEBEL Engineering, with an initial interpretation of the stresses inside the lining segments. The estimated stresses were derived from the measured strains, taking into account a creep function of the concrete segments.

OBSERVATIONS

Figure 39 shows the strains observed (averaged to one inner and one outer strain value per segment) since the installation of the Connecting gallery lining segments. The strain evolution shows a rapid increase in the strain due to direct contact between the clay and the concrete lining, followed by a gradual and monotonous increase in the strain over time. This secondary monotonous increase is the result of different phenomena, including the increase in the pressure against the lining (consolidation of the clay) and the creep behaviour of both the concrete and the Boom Clay, neither of which is negligible. A comparative analysis of the measurements between the three rings shows consistent behaviour, confirming the reliability of the monitoring method and results.

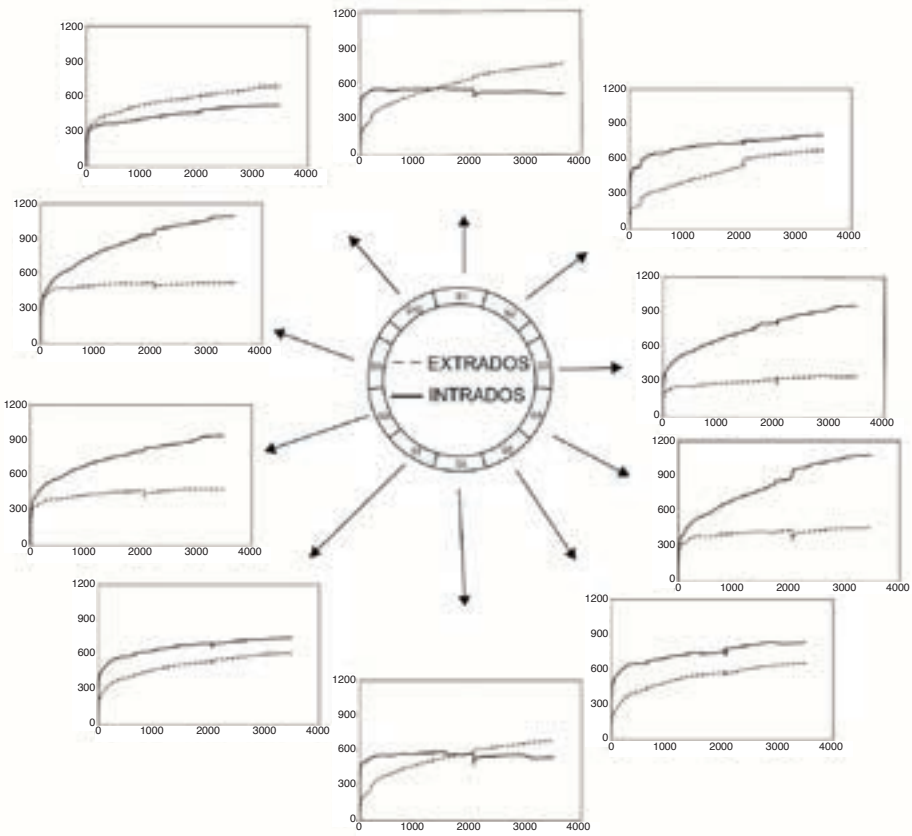


Figure 39 - Evolution of the strain in ring 30 (averaged by segment).
The horizontal axis of the different plots is the time from 0 to 4000 days and the vertical axis corresponds to micro-strain from 0 to 1200.

INTERPRETATION

To assess the stresses, and especially the circumferential stress, TRACTEBEL Engineering analysed the strains according to the relevant EUROCODE, and taking into account the creep behaviour of the concrete. Their technical report gives an initial interpretation of the stress in the lining and thus the pressure applied against the lining. Some comments were addressed to TRACTEBEL to improve the analysis, and a new interpretation will be delivered in the course of 2014. When deriving the actual stress state based on the strain measurements, several factors need to be considered: the non-circularity (eccentricity) of the segmental lining rings, the relative position of the different segments, the non-ideal contact (joint) between the segments, and other (secondary) phenomena that might modify the behaviour of the lining structure.

LOOKING AHEAD

Following the different recommendations and meetings with TRACTEBEL, several actions were defined. A systematic visual inspection of the cracks observed at the surface of the concrete segmental lining is already carried out on a regular basis. In addition, direct stress measurements by experimental methods are being considered. A first attempt was made during core drilling in the liner in late 2013 and early 2014 by installing strain gauges in and around the core using the principle of the stress relief method. Since the drilling was not performed specifically to test this method, and as the test procedures were being tried for the first time (application of strain gauges in combination with water cooling for the core drilling), the initial measurements were difficult to interpret. Other non-destructive methods are being studied and further experiments will follow.

The accuracy of the strain measurements should be estimated to determine the final error on the results by error propagation. An advanced investigation of the role of the creep behaviour of the concrete will also be conducted.

Finally, the real geometry of the rings should be determined to obtain a complete picture of the current state of the lining, so that the different imperfections of the structure (shifts between segments, diameter in different orientation, etc.) can be included in the assessment of the strains and stresses.

2.3. PhD research

A specific thermo-hydro-mechanical-chemical characterisation programme on Boom Clay was run in parallel with the PRACLAY experiments, in collaboration with different universities and laboratories through several PhD research projects. EIG EURIDICE is involved in the definition and supervision of these projects.

In the context of the ONDRAF/NIRAS research programme on geological disposal to examine other potential host formations for high-level waste disposal, several PhD theses are investigating the thermo-hydro-mechanical-chemical behaviour of Ypresian clays and are being co-supervised by EIG EURIDICE.

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

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

This research aims to study, on a laboratory scale, the gas transport mechanisms and breakthrough processes in Boom Clay.

The specific objectives of the research relate to the following aspects of the experimental behaviour of the Boom Clay during gas injection processes:

- Examine the effects of the stress state and stress history under isotropic conditions or with a deviatoric component.
- Investigate the volume change behaviour during gas tests and their impact on gas permeability.
- Check the role played by the orientation of natural discontinuities in rock or artificial interfaces.
- Study temperature effects on breakthrough processes.
- Estimate the influence of the gas injection rate.

After an extended review of gas migration processes through clays, an exhaustive experimental programme that will provide a better understanding of these processes has been launched. To this end, special oedometer and triaxial cells under controlled pneumatic, hydraulic, mechanical stress and deformation and thermal boundary conditions will be designed, updated and used. Furthermore, different techniques - such as electrical resistivity tomography or, alternatively, chemical tracers - will be investigated to track the paths followed by gas during the injection process in a complementary set-up.

In the first stage of the research, a special high-pressure oedometer cell was designed and used to perform air injection experiments at elevated pressures on intact clay core samples.

The Boom Clay was firstly characterised to evaluate mechanical compressibility and two phase flow properties (water retention and water permeability). In these preliminary tests, boundary conditions - vertical stress, inlet and outlet pressures and volumes of air/water and temperature - were carefully controlled. Special emphasis was placed on measuring sample vertical displacements throughout the gas injection process. The anisotropy of the clay was taken into account by carrying out tests at both orientations: with a bedding plane parallel and orthogonal to the flow. To this end, three preliminary tests at elevated air pressures and vertical stresses were performed at room temperature, at different orientations and using a fast (volumetric) air injection rate to minimise unwanted rate effects (some lateral stress relaxation under oedometer conditions). Compressibility of the samples during drained loading and water permeability at different stress states, gradients and orientations was also determined. Air injections were conducted starting from two initial gas pressures, lower and higher than the air entry value, to evaluate possible desaturation effects on the material before the fast air injection. Finally, the dissipation stages after shut-in were also analysed to evaluate air intrinsic permeability changes (Figure 40).

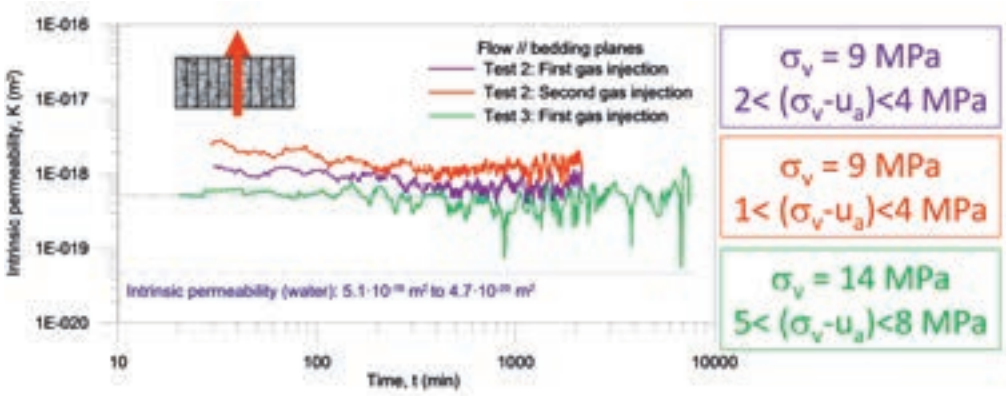


Figure 40 - Intrinsic permeability to air in samples with bedding planes, parallel to flow at different constitutive stresses

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 at the end of 2011.

The research project is in three parts:

A. Laboratory tests

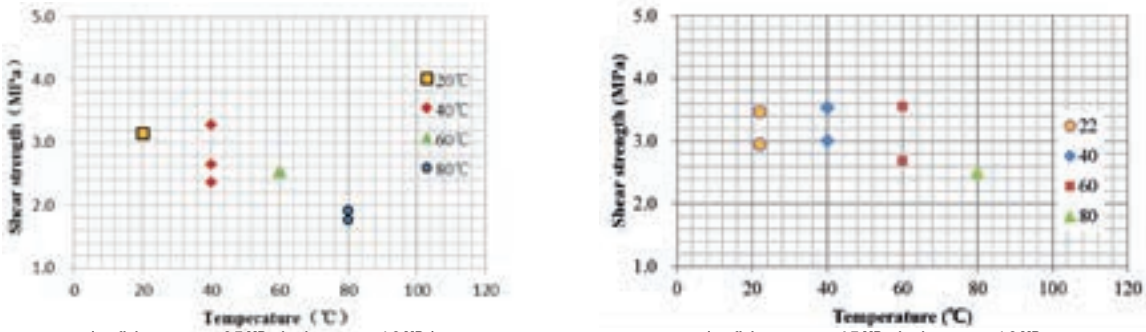
B. Constitutive law development, taking into account long-term behaviour and thermo-hydro-mechanical coupling, including damage and self-sealing processes.

C. Back-analysis of long-term in-situ measurements and prediction of the PRACLAY experiment.

A. LABORATORY TESTS

SHORT-TERM BEHAVIOUR OF BOOM CLAY

Before dealing with the temperature effect on the long-term behaviour of Boom Clay (creep), an intensive test programme to investigate firstly the temperature effect on its short-term behaviour was run. A series of undrained triaxial tests under well-defined THM loading paths have been performed since the project started. The test results obtained indicate clearly that the shear strength of Boom Clay decreases as the temperature increases (Figure 41). By analysing the test results using the Mohr-Coulomb criterion, it can clearly be seen that the effective cohesion of Boom Clay decreases with temperature, but the temperature effect on the effective internal friction angle is not so apparent (Figure 42). More tests are needed to investigate this aspect.



(confining pressure: 3.7 MPa, back pressure: 1.2 MPa)

(confining pressure: 4.7 MPa; back pressure: 1.2 MPa

Figure 41 - Evolution of the shear strength with temperature

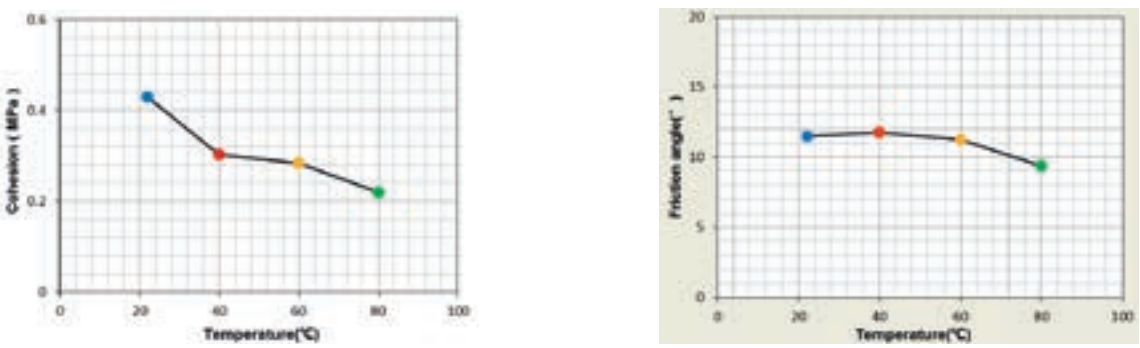


Figure 42 - Evolution of the effective cohesion and internal friction angle with temperature

Moreover, in the course of 2013, more undrained triaxial tests with several loading/unloading cycles under different confining pressures and at different temperatures were performed in order to investigate the damage process of the natural Boom Clay at different temperatures (Figure 43). Detailed interpretations of these tests are still ongoing. Preliminary analysis shows that:

- Boom Clay shows a very low plastic yield stress (very low elastic limit): the strain cannot fully recover during the unloading process even after a very low strain. The elasto-plastic transition is progressive.
- The elastic modulus is very high at low strain but decreases as irreversible deformation accumulates.
- Softening occurs at large deformations.
- Hysteresis develops with accumulated deformation: the hysteresis loop becomes bigger with each increment of axial strain. This is probably the result of kinematic hardening, which causes the plastic strain to accumulate during both the loading and the unloading process.

Further tests are needed to verify the temperature effect on the Young's modulus evolution (damage) and hardening law of the Boom Clay.

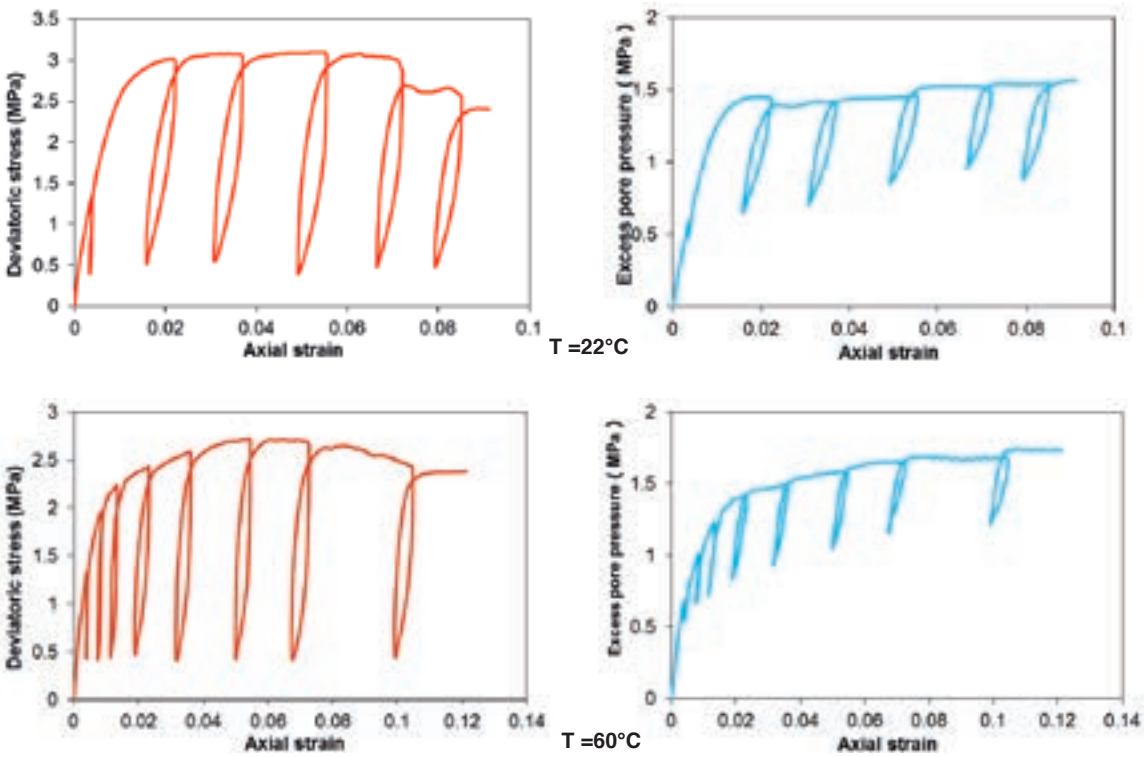


Figure 43 - Undrained loading-unloading triaxial tests (σ_3= 4.7 MPa, pw = 1.2 MPa)

LONG-TERM BEHAVIOUR (CREEP) OF BOOM CLAY

In order to investigate the temperature effect on the creep behaviour of the natural Boom Clay, drained triaxial creep tests with heating/cooling cycles were started and are still ongoing. To date, creep tests have been performed with deviatoric stresses of 1 MPa and 1.5 MPa. The first results obtained indicate that no obvious creep occurs when the deviatoric stress is less than 1 MPa. Above 1.5 MPa, obvious creep was observed. There are not yet enough test results to describe the temperature effect on the creep rate.

B. CONSTITUTIVE LAW DEVELOPMENT

During 2011-2013, a so-called "super-subloading surface Modified Cam-Clay model" was first developed (Figure 44). This model makes it possible to represent the elasto-plastic behaviour of clays in a different loading history (structured, normal consolidated and overconsolidated) by introducing the concepts of superloading and subloading surface, proposed by Asaoka et al. (2000). This model was then extended to consider the creep behaviour of clays. The elasto-visco-plastic model developed was calibrated by short-term laboratory simulations and creep tests in both oedometer and triaxial cells on Boom Clay, and finally validated by simulation of short-term and long-term observation around the HADES URL, including all construction stages of HADES (Yuan Kekuo, 2013).

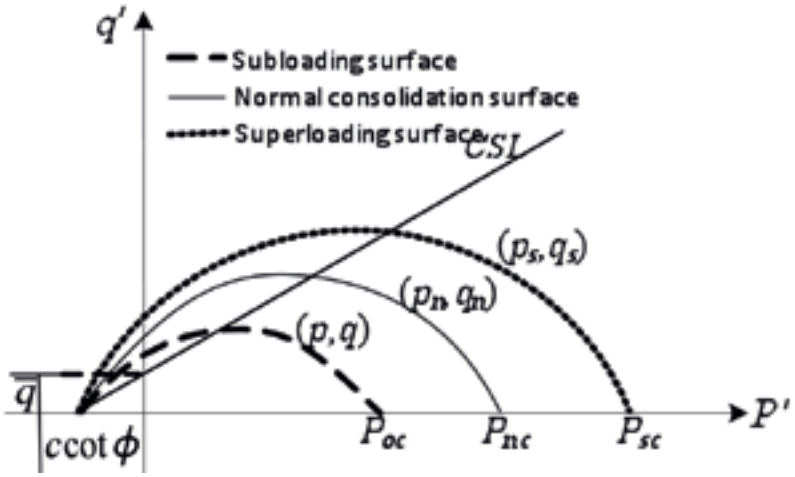


Figure 44 - Super-subloading surface Modified Cam-Clay model

C. PREDICTION OF THE PRACLAY HEATER TEST

Based on the established elasto-plastic-damage mechanical constitutive model and self-sealing model, a large 3D numerical simulation of the in-situ PRACLAY Heater test has been carried out. As shown in Figure 45, the Connecting gallery was included in the numerical model. The anisotropy of Young's modulus, permeability and thermal conductivity as well as the in-situ stress were considered. The simulation results provide us with some initial insight into the long-term influence of the Connecting gallery on the PRACLAY Heater test. Figure 46 shows how the hydraulic boundary condition of the Connecting gallery influences the pore water pressure distribution over the long term.

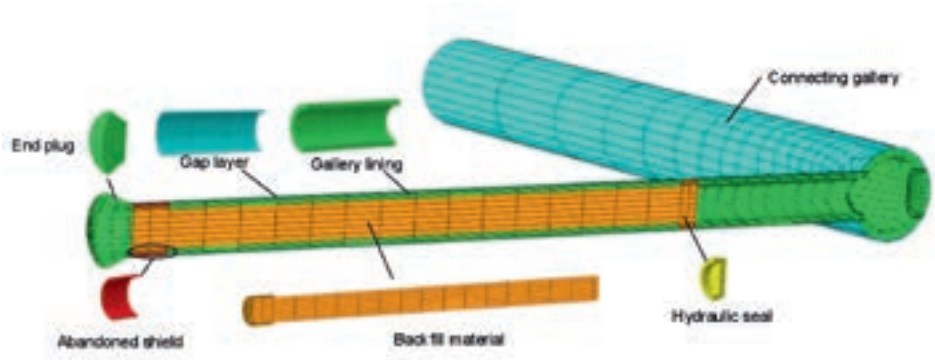
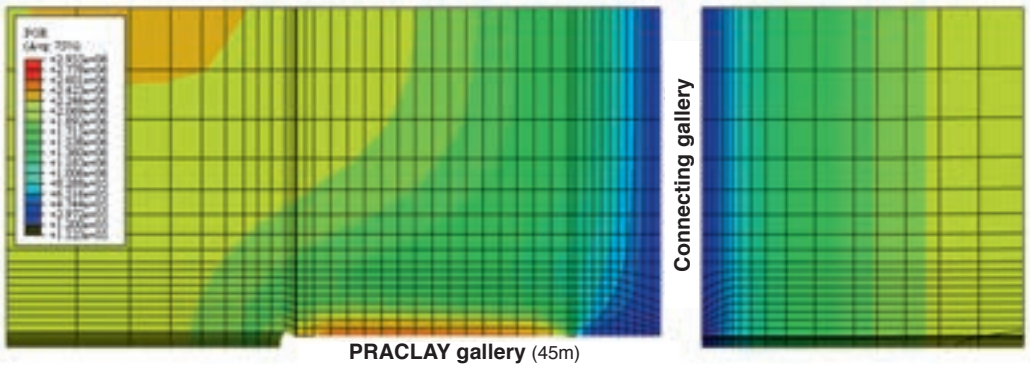
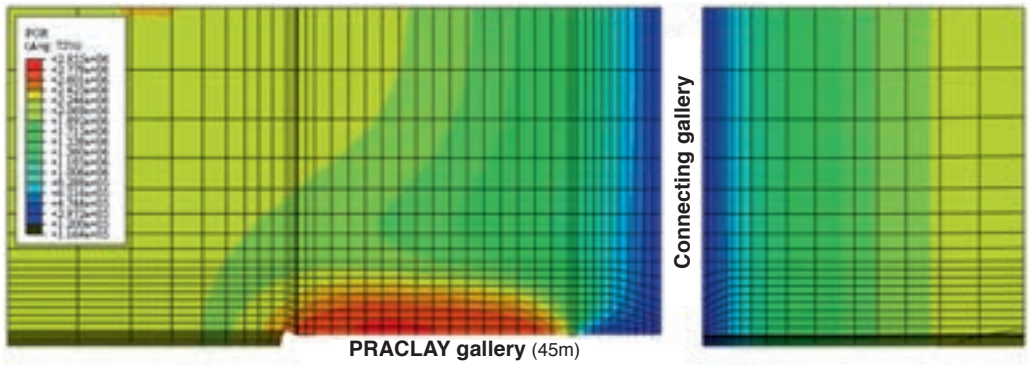


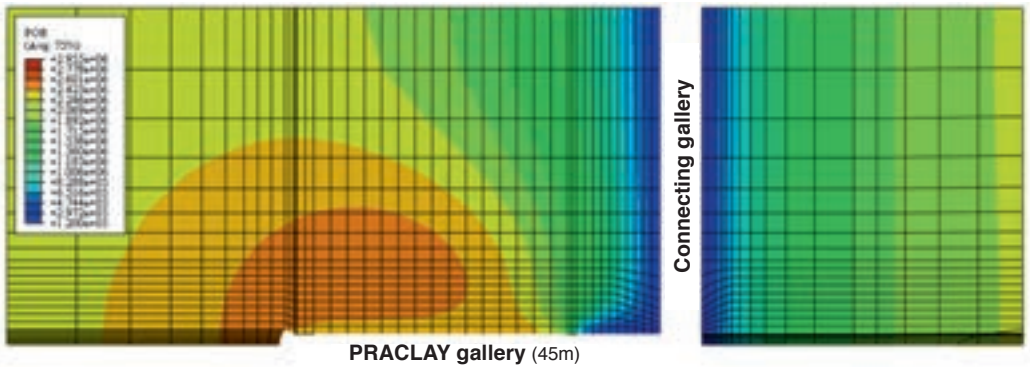
Figure 45 - Finite element model of PRACLAY gallery



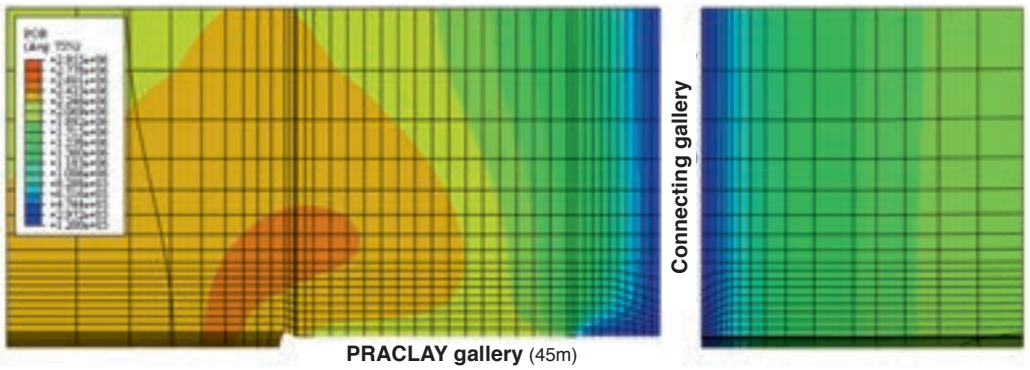
(a) After heating for 0.5 years (values in Pa)



(b) After heating for 1 year (values in Pa)



(c) After heating for 5 years (values in Pa)



(d) After heating for 10 years (values in Pa)

Figure 46 - Distribution of pore water pressure around the PRACLAY gallery (horizontal plane)

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

In 2013 the research activities at CERMES involved three research programmes:

- Investigation of the anisotropic behaviour of Boom Clay (PhD project 2011-2014)
- Investigation of the shear behaviour of Boom Clay and Ypresian clays (6-month post-doctoral project)
- Modelling the mechanical behaviour of Boom Clay in the context of the bounding surface concept (1-year post-doctoral project)

INVESTIGATION OF THE ANISOTROPIC BEHAVIOUR OF BOOM CLAY

A PhD research project entitled "Investigation of anisotropic behaviour of Boom Clay" started at CERMES at the end of 2011 and comprises three parts:

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

During 2013, the research focused on the characterisation of the mechanical anisotropy of Boom Clay.

The anisotropy of the shear modulus G_{max} of natural Boom Clay was examined through the measurements of shear wave V_s by bender element. Measurements were made on the samples taken from a borehole drilled in a horizontal direction, at several distances r from the centre of the Connecting gallery in HADES. Three measurements (V_{hh}, V_{hv}, V_{h45}) were performed for each sample (Figure 47a). As for several other stiff clays, the shear modulus in the direction parallel to the bedding plane (G_{hh}) is higher than that in the direction perpendicular to the bedding plane (G_{hv}). The ratio G_{hh}/G_{hv} determined for the far field is around 1.26. However, more measurements on the samples taken from the far field are needed to refine the results. As far as the evolution of G_{max} with distance r is concerned, an increase followed by stabilisation is observed, suggesting an extension of the EDZ about 1.6 m from the gallery extrados, which is quite consistent with the in-situ observations and investigations. After the G_{max} measurements, some soil specimens were studied with a Scanning Electron Microscope (SEM) and Mercury Intrusion Porosimetry (MIP) in order to identify the microstructure of different samples. Based on the observations, a semi-empirical model with a parameter for damage that is related to the void ratio of macro-pores (diameter ≥ 1 µm) was developed. This model was applied to the results obtained and agrees well with the measurements (see Figure 47b). It will be fine-tuned in the near future by more data on the far field.

The shear test on Boom Clay samples (D = 38mm, H = 76mm) under no lateral strain conditions was carried out too in order to identify the ratio between the horizontal and vertical stresses, i.e. σ'_h/σ'_v. A final value of σ'_h/σ'_v is about 0.85 and is larger than that obtained by the oedometer test (D = 50 mm, H = 20 mm), which is about 0.7. The test results indicated that the ratio between the horizontal and vertical stresses evolves with the stress paths and also depends on the anisotropy of the materials. Extrapolation to the in-situ stress state is not straightforward. Further investigation is thus necessary.

Moreover, an anisotropic model accounting for the initial structure (inherent anisotropy) has also been developed and applied to model the triaxial test data under no lateral strain conditions (Figure 48).

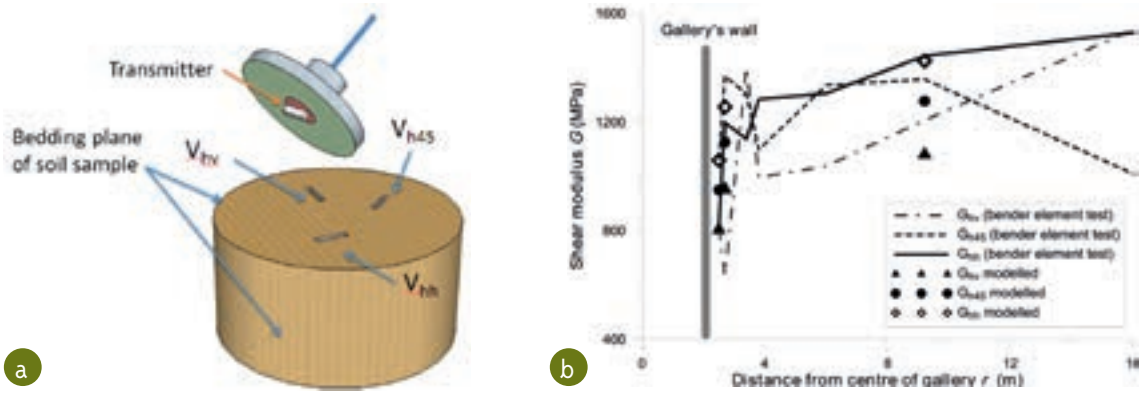


Figure 47 - Shear modulus G_{max} of Boom Clay at Mol: (a) experimental set-up;
(b) comparison of shear modulus between measurement and model (horizontal plane)

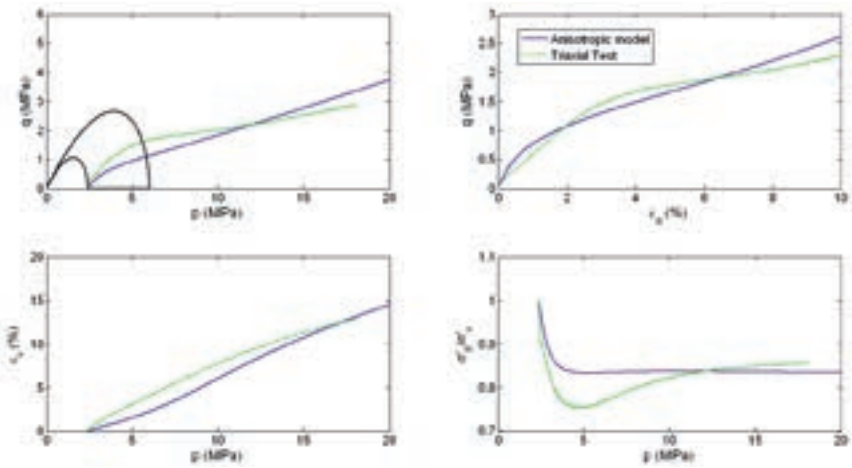


Figure 48 - Comparison between experimental data and
model simulationmodulus between measurement and model (horizontal plane)

INVESTIGATION OF SHEAR BEHAVIOUR OF BOOM CLAY AND YPRESIAN CLAYS

In 2010 a three-year PhD research project on "THMC behaviour of Ypresian clays", financed directly by ONDRAF/NIRAS and co-supervised by EIG EURIDICE, was started at CERMES. This project is part of the ONDRAF/NIRAS research programme to examine other potential host formations for high-level waste disposal. The focus lies on the characterisation of fundamental THM behaviour by means of laboratory tests. Close attention was paid to the pore water chemistry effects on the THM behaviour. In order to provide input for the knowledge transferability study of different clay formations, comparative tests on Boom Clay (on the samples taken from HADES and from the Essen borehole) were also performed as part of this PhD project. The PhD thesis entitled "Study of the chemo-hydro-mechanical behaviour of stiff clays in the context of radioactive waste disposal", written by Xuan Phu NGUYEN, was successfully defended in March 2013.

At the end of this PhD project, it was agreed jointly with ONDRAF/NIRAS to prolong the research to further investigate the interaction between the physico-chemical and mechanical effects identified by the oedometer loading/unloading/reloading tests (see Activity Report 2012) under triaxial conditions. To this end, a series of drained triaxial compression tests with loading/unloading/reloading cycles were

performed on both Boom Clay and Ypresian clays. Another objective of these tests is to compare the test results obtained by a similar test programme run in different laboratories (see research programme at IRSM).

The shear behaviour of Boom Clay at Mol (core R 66-67 around the HADES URL) and Ypresian clays at Kallo (core number 76 from ON-Kallo-1 borehole) was characterised on samples 38 mm in diameter and 76 mm in height, with the axial direction perpendicular to the bedding plane. Local (in axial ε_{al} and radial ε_{rl} directions, at the mid-height of the sample) and global axial ε_{ag} (outside the cell) displacements and volumetric strains ε_{vg} were all measured (Figure 49).

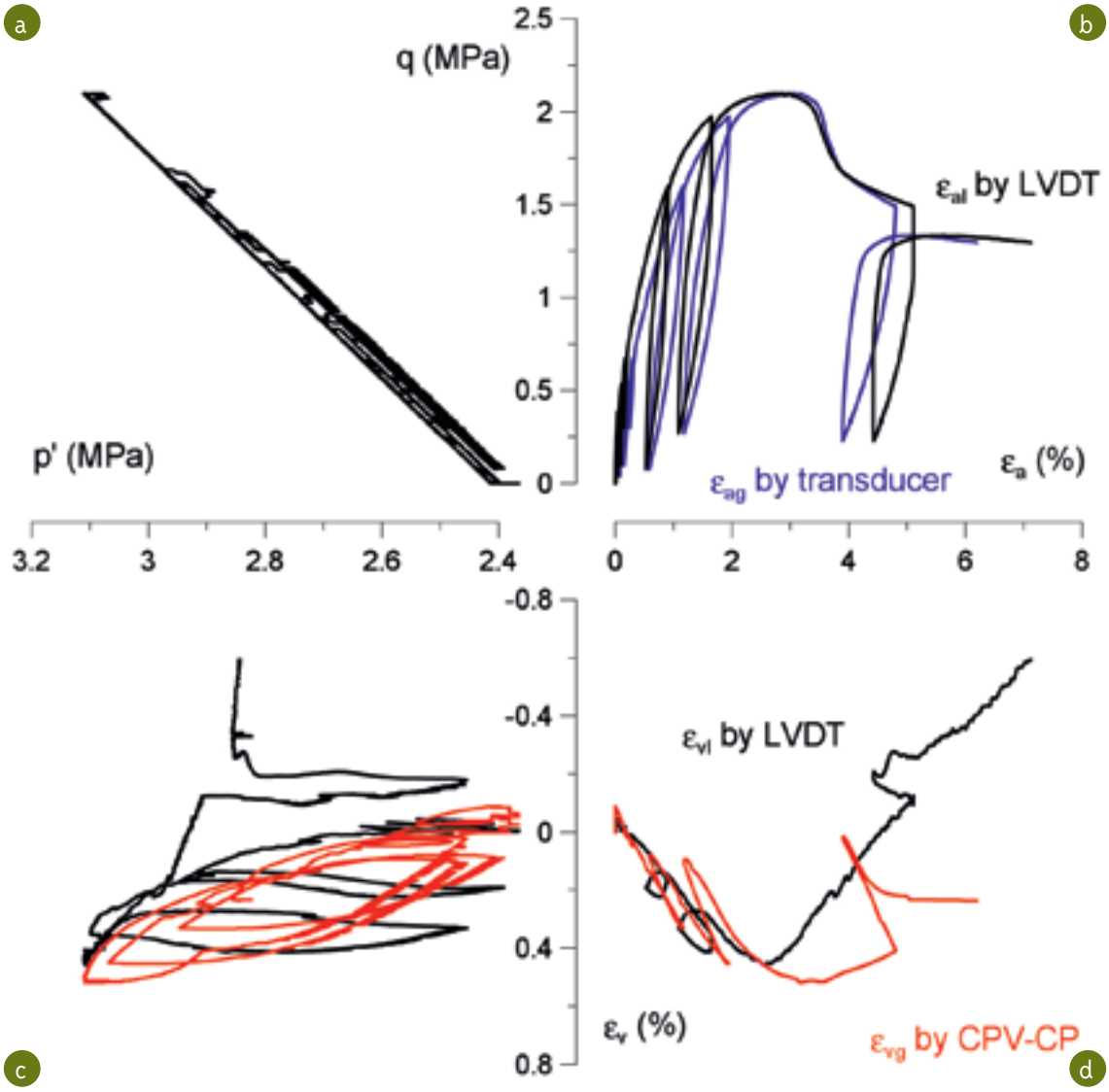


Figure 49 - Triaxial test on Boom Clay with unloading - reloading loops
(ε_v: volumetric strain, ε_{vl}: local volumetric strain obtained by local axial and radial strains,
q: deviatoric stress, P': effective mean stress)

The anisotropic local strain responses were clearly evidenced upon isotropic consolidation on both clays, being related to the stratification of these deep deposits.

Clear unloading - reloading hysteresis on the curves of deviatoric stress versus axial strains (Figure 49 b) and compression curve (Figure 49 c) was observed, even at the beginning of shearing. However, the loop

becomes bigger with the shearing process, which is consistent with the observation by the undrained triaxial tests with loading/unloading cycles performed at IRSM (see above Figure 43).

The confrontation between local and global volumetric strains shows different, even contrasting, local and global shearing behaviour of Boom Clay during the softening and dilatation phases (Figure 49-d). This difference can be explained by the shear band that developed in two stages: an initiation stage with strain concentration and a sliding stage with a clear relative displacement of the two blocks. These triaxial tests with pre- and post-peak unloading - reloading loops on both Boom Clay and Ypresian Clays enable the damage process to be identified, represented by the decrease in Young's modulus and Poisson ratio with accumulated plastic strain. Compared to the literature, significantly higher values, especially at low axial strains, were obtained for Young's modulus. This observation is also consistent with that by IRSM. Detailed quantitative comparison and interpretation of all these test results obtained by the two laboratories (IRSM and CERMES) will be done in the course of 2014.

MODELLING THE MECHANICAL BEHAVIOUR OF BOOM CLAY AND YPRESIAN CLAYS

A sophisticated thermo-mechanical constitutive law for Boom Clay was developed in the PhD thesis of P.Y. Hong within CERMES's own PhD programme. This constitutive law (bounding surface model ACC-2) makes it possible to take into account the smooth transition of elasto-plasticity and to correctly model both volumetric and shearing behaviour at the same time.

In March 2013 EIG EURIDICE entrusted CERMES with a one-year post-doctoral research project on "Modelling the mechanical behaviour of Boom Clay in the framework of the bounding surface concept" and is also financing it.

The objectives of this research are:

- to explore the potential of the ACC-2 model to better model hydro-mechanical (HM) perturbations in both the near and the far field during excavation and thus to better assess the Excavation-Damaged Zone (EDZ) and Excavation-disturbed Zone (EdZ), including the large extent of the hydraulic disturbance zone observed during the excavation of the Connecting and the PRACLAY gallery; and
- to further develop the ACC-2 model to better describe the loading/unloading/reloading behaviour of Boom Clay (especially the hysteresis).

During 2013, the ACC-2 model was firstly modified to improve the description of strain-softening behaviour. This improvement was then examined by simulating a series of tests on natural Boom Clay. Secondly, the model was further developed and improved to better produce the unloading/reloading hysteresis. Finally, a constitutive model, taking into account the kinematic hardening mechanism, together with the elements of two-surface plasticity and the mechanical-physico-chemical coupling, was developed (Figure 50). All parameters in this model have a clear physical meaning and can be determined by conventional laboratory testing such as isotropic tests and drained triaxial tests. Various strain-driven standard triaxial tests have been simulated to demonstrate the performance of this model.

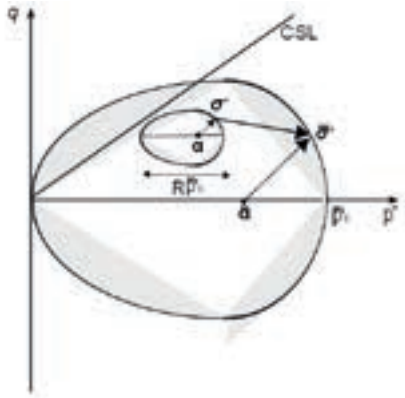


Figure 50 - Kinematic hardening model: schematic representation of yield surface and the translation rule

Figure 51 shows the numerical simulation of the oedometer compression test with loading/unloading cycles on natural Boom Clay, using this model. The simulation curve corresponds quite well with the smooth cyclic experimental curve.

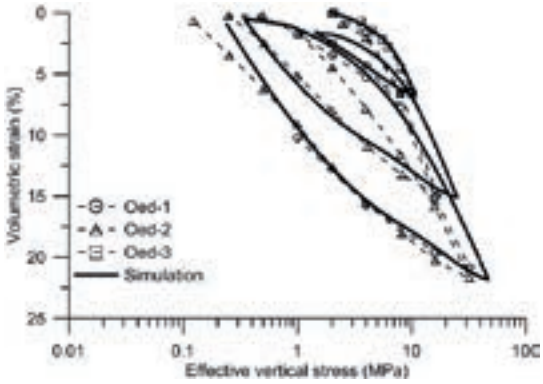


Figure 51 - Numerical simulation of oedometer tests

ULg (University of Liège, Belgium)

A PhD research project on the EDZ started at the end of 2011 at ULg, focusing on the numerical simulation of EDZ structure and fractures, based on the strain localisation concept and using the second gradient finite element tool and considering short-term hydro-mechanical coupling behaviour. This thesis is financed directly by ONDRAF/NIRAS and is supervised jointly by EIG EURIDICE and ONDRAF/NIRAS.

During 2013, a parametric study was conducted to better define the key parameters for the numerical modelling of strain localisation, such as the elastic parameter of the second gradient and those linked to the cohesion softening which is a prerequisite for initiating the strain localisation and thus the development of a fracture network. In this study, the unsaturated state of the clay was taken into account to improve the hydro-mechanical coupling modelling.

The role of the concrete lining on the development of the fractures in the clay was emphasised by modelling the excavation of the Connecting gallery with and without the lining. The effects of the localised shearing bands on the pattern of the pore water pressure evolution during the excavation were also affected by the lining. The contact between the concrete lining and the clay during excavation was also analysed by considering the hydro-mechanical interface elements.

Finally, a comparison with the in situ measurements before, during and after excavation of the Connecting gallery was started. This revealed that considering a cross-anisotropic elasto-plastic constitutive law enables better reproduction of numerical in-situ measurements. Moreover, a modelling considering the anisotropy of the mechanical and hydraulic properties as well as the initial stress anisotropy was performed to highlight the effect of the anisotropic properties of the clay.

A more in-depth analysis of the soil-structure interaction from a general point of view will be carried out during the coming year. Moreover, existing triaxial test results will be re-analysed in order to refine the hydro-mechanical parameters of Boom Clay.

DUT (Dalian University of Technology)

EIG EURIDICE established a scientific cooperation programme with DUT (Dalian University of Technology, China) in 2012 on the "experimental and numerical investigation of the effect of anisotropy of Boom Clay in the EDZ process". The experimental work will be performed in the DUT laboratory, while the numerical part will mainly be carried out by the DUT PhD student (Liu ShiYi) who has received a scholarship from the Chinese government to work at EIG EURIDICE for two years (June 2012 - June 2014). This PhD research is being carried out with financial support from DUT. EIG EURIDICE provides the Boom Clay samples and supervises the research.

In the course of 2013, the hardening/softening Drucker-Prager model considering elastic and plastic cross-anisotropy (developed and implemented in 2012) was further refined by introducing a new hardening and softening law to better describe the failure of Boom Clay. The model was firstly validated by simulating the laboratory triaxial tests performed by IRSM and the hollow cylinder triaxial experiment performed by EPFL (Ecole Polytechnique Fédérale de Lausanne) as part of the European Commission's TIMODAZ project, and then applied to the modelling of the Connecting gallery excavation using the finite element method. Moreover, a method combining a finite element stress analysis with searching for slip lines was proposed to predict fractures in the EDZ based on the strain-softening zone. The slip lines may present the anticipated patterns of failure surfaces in the clay due to the excavation. Figure 52 shows an example of the predicted slip lines in the strain-softening zone after excavation of the Connecting gallery, which corresponds to in-situ observations.

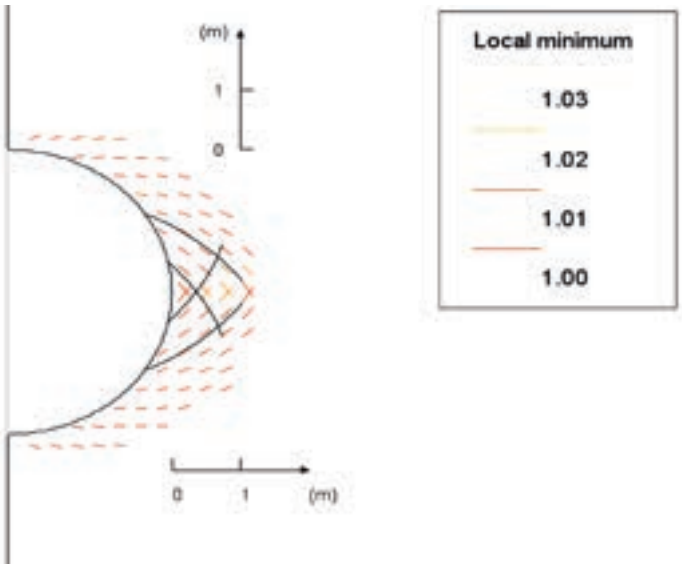


Figure 52 - Slip lines in the strain softening zone (black lines) and the local minimum of the objective function (the closer to one, the closer to the failure condition)

2.4. GeoScientific Information System GSIS

As part of the GSIS project, which is being developed under a joint agreement between ONDRAF/NIRAS and SCK•CEN within the Geosynthesis programme, EIG EURIDICE has taken on responsibility for the information regarding the HADES infrastructure, the experimental set-ups run by EIG EURIDICE, and the associated data (validated data should also be included in the GSIS, as this will become the sole data source for external stakeholders).

During 2013, a review was performed on the construction-related data of HADES that had already been input into the current GSIS. Some data has been updated based on discussions with the surveyor (Geomodus), who also conducted additional surveys. Furthermore, EIG EURIDICE suggested some ways of improving the way HADES is modelled in GSIS.

Another important aspect of the GSIS project is the management of the clay cores by integrating the data about them into the GSIS. EIG EURIDICE has contributed to establishing a procedure for the management of the cores in GSIS. This is fairly essential in order to keep track of the many cores (with the test results) that are sent to laboratories worldwide.

3. Monitoring approach

With the objective of developing the monitoring approach in the safety case, a specific agreement was reached between ONDRAF/NIRAS and EIG EURIDICE, including a specific monitoring task.

The first part of this task concerns an updated instrumentation review, in which the different monitoring techniques used at EIG EURIDICE (HADES and surface set-ups) and outside of EIG EURIDICE – mostly at similar organisations and URLs – will be assessed in the context of a possible application in repository conditions. The knowledge gathered through international cooperation (in particular the European Commission's MoDeRn project, but also other bilateral or multilateral contacts) will be incorporated into this review.

The second part deals with the development of a monitoring strategy in which, starting from the safety statements, a detailed monitoring programme will be developed.

The first part (instrumentation review) will be covered mainly in 2014, while the second part (development of monitoring strategy) will probably not start before 2015.

4. Participation in international research projects

4.1. European Commission (EC) projects

TIMODAZ

The TIMODAZ project (Thermal Impact on the Damaged Zone around a Radioactive Waste Disposal in Clay Host Rock) officially ended in 2010.

In the course of 2012 and 2013, as coordinator of this project, EIG EURIDICE, together with ENPC (France),

edited a special issue in "Rock Mechanics and Rock Engineering" (Springer, WoS referenced) on the topic of "Thermo-Hydro-Mechanical effects in clay host rocks", which will be published in the first volume of 2014 of the journal (Rock Mech Rock Eng (2014) 47:1DOI 10.1007/s00603-013-0445-0).

FORGE

EIG EURIDICE is not itself a partner in the EC project FORGE (Fate of Repository Gases), but provides support to SCK•CEN.

In 2013 EIG EURIDICE continued to follow up the FORGE instrumented megapackers, which were installed in the HADES URL in 2011. This consisted mainly of gathering and storing monitoring data for both the megapackers and the piezometers installed in the immediate vicinity of the megapackers.

EIG EURIDICE finalised the following reports in 2013 on the installation of the FORGE megapacker system:

- FORGE packers installation report - FORGE deliverable D4.4;
- FORGE packers installation executive summary report - FORGE deliverable 4-18 (Chapter 3)

MoDeRn

EIG EURIDICE participated in the EC MoDeRn project (Monitoring Developments for safe Repository operation and staged closure), which came to an end on 31 October 2013 after running for 54 months.

There was a great deal of reporting during 2013 on Work Packages (WP) 2 and 3. WP2, containing the R&D on monitoring technologies, dealt mainly with the results of the innovative monitoring techniques applied in the supercontainer test set-up (such as the different fibre optic sensor types, and the corrosion monitoring techniques – see section 1.2.2.). WP3, the demonstration part, involved the results of the fibre optic sensors installed around the PRACLAY seal and heater, as well as the seismic sensors, including the tests with the new (prototype) seismic hammer.

The final MoDeRn conference was held in March 2013 (Luxembourg).

With regard to continuing research on monitoring, networking with the project partners and new organisations is currently going on in the IGD-TP (Implementing Geological Disposal – Technical Platform), in which "monitoring" is an important topic. EIG EURIDICE attended the IGD-TP workshop in October 2013 in Prague (CZ), where future actions in the field of repository monitoring were discussed in a preparatory way.

4.2. Other International collaborations

NAGRA (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle)

EIG EURIDICE has been contacted by NAGRA, which is also preparing a large-scale Heater Experiment (FE) in the Mont Terri Research Facility, with a request to review its Instrumentation Plan. For 2013, this concerned mainly the borehole instrumentation around the main tunnel. A further review is planned for 2014.

LUCOEX (Large Underground Concept Experiments)

EIG EURIDICE has become involved in the EC LUCOEX project, which brings together the real-scale experiments at Mont Terri, Bure, Aspö and Onkalo. For this project, a technical expert group has been appointed, with representatives from non-project partners to ensure independent review and feedback to the project. EIG EURIDICE represents SCK•CEN, which is the original official participant in this group.

ENPC (l'Ecole nationale des ponts et chaussées)

In September 2013 a EIG EURIDICE staff member (Xiangling Li) was appointed (by order of the French Ministry of the Ecology, Sustainable Development and Energy) as member of the ENPC Scientific Council.

IRMM (Institute for Reference Materials and Measurements)

Since 1999, EIG EURIDICE has delivered services for IRMM's long-standing operation of an ultra-low-level radioactivity lab in support of European Commission policies in the fields of, for example, international standardisation, radioactive waste management and radiation protection. For this purpose, part of the HADES underground research laboratory has been leased to IRMM. The contract is a Service Agreement that can be extended on a yearly basis.

At the end of 2011 this contract was amended to include the lease of extra space in the underground laboratory, on the southern side of shaft 2. During 2012 and 2013 this extra space was used by IRMM specifically for the testing of high-purity germanium detectors for the GERDA double beta decay experiment (the "Heroica" project).

5. Scientific Advisory Committee (SAC)

In June 2013 the composition of the Scientific Advisory Committee (SAC) of EIG EURIDICE was amended due to the expiry of the term of office of all previous members.

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)
- Mr 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)

The new SAC regulations, approved by the General Assembly of EIG EURIDICE on 23 April 2012, extend the scope of the committee's remit to all scientific and technological activities of EIG EURIDICE.

Two SAC meetings were convened during 2013: one specific SAC meeting on 7 June 2013, another during the second workshop on the preparation of the PRACLAY heater switch-on (12-13 December 2013).

The topics discussed with the SAC in 2013 focused mainly on the PRACLAY Seal & Heater experiment, especially the PRACLAY bentonite seal evolution and the link with the start-up of the PRACLAY Heater experiment:

- The evolution of the bentonite seal hydration and swelling and the assessment of its performance as a hydraulic boundary for the PRACLAY Heater experiment;
- Predictive modelling of the expected evolution of the bentonite seal and the Boom Clay during the heating test, taking into account the uncertainty of certain parameters by using sensitivity analysis;
- Predictive assessment of possible altered evolution scenarios, i.e. assessment of possible deviations from the expected behaviour of the various components of the heater and seal.

In parallel with the presentations on the above "scientific aspects", the EIG EURIDICE team also presented the preparatory work on the following technical and management aspects:

- Data management tools to display , archive, analyse and report the test measurements;
- Procedures for the follow-up of the Heater experiment.

The chair of the SAC reported to the Management Board of EIG EURIDICE in November 2013, formulating the following main observations and conclusions:

- It will be important to properly inform the new SAC members about EIG EURIDICE's objectives, context, past achievements and future challenges;
- The SAC appreciates the quality of EIG EURIDICE's work in preparing for the Heater experiment (including a comprehensive risk analysis);
- The hydraulic and mechanical behaviour of a complex bentonite structure (as in the seal) requires further RD&D efforts, but important lessons can be learnt from the Seal experiment;
- The SAC can play a role in enhancing interactions with the academic and scientific world for future PhD projects.

6. Programme committee for underground experiments (POP)

The regulations of the POP (Programme committee for underground experiments) were reviewed and updated in the course of 2013, and were approved by the General Assembly on 23 April 2013.

In the course of 2013, on the basis of the RD&D plan of ONDRAF/NIRAS (to be published), the POP launched an initiative to draw up a complete inventory of all past and ongoing in-situ experiments, and to evaluate opportunities for new experiments. The inventory of in-situ experiments (both ongoing and finished) will be input into the GSIS system (GeoScientific Information System).

Moreover, the need for a drilling core management procedure and database was discussed by the POP. A procedure has been established to ensure tracking of all clay samples sent to third parties and to maintain a link between core samples and research results through the GSIS system.

7. Management & exploitation of installations

GENERAL

The Statutory Rules define the tasks of EIG EURIDICE concerning the management and exploitation of the installations on the land for which EIG EURIDICE holds a building lease. In 2013 these tasks were performed in accordance with applicable regulations.

The exploitation team continually supported RD&D activities in different projects:

- Connection of monitoring devices to the data-logging system in HADES;
- Renewal of the data-acquisition system of older experiments such as CLIPEX;
- Some technical adaptations to PRACLAY (e.g. temporary flexible tubes have been replaced with stainless steel tubes (injection into the seal); modifications to the gas injection system for gas breakthrough tests; changes to optimise the measurement of the displacement of the seal, etc.);
- Development and testing of a seismic hammer measurement device;

The exploitation team delivered services related to experiments for the supercontainer project (see section 1.2.2.), both in-house preparatory work and on-site (i.e. at MAGNEL, Ghent) instrument installation. All required maintenance on machinery, site and infrastructure was performed in accordance with the operating licence and applicable legal and regulatory requirements and in line with the ISO 9001:2008 standard. Finally, the necessary support for providing visitors with guided tours through the underground laboratory was provided throughout 2013.

The work initiated on updating the operation manual and developing maintenance logs was not finished in 2013, and will be an objective for 2014.

UNDERGROUND INSTALLATIONS AND ASSOCIATED HOISTING SYSTEMS

The exploitation team and/or AIB Vinçotte carried out the necessary controls and checks on the shafts, cables, hoisting equipment, etc. There were some interruptions in, for instance, the hoisting systems and shafts, but these were resolved within a reasonable period of time and without any major problems.

A mechanical problem occurred on the shaft 1 hoisting system, which caused an unplanned downtime of about a week. The shaft 2 hoisting system was shut down for a few weeks because there was some uncertainty concerning the inspection of a specific component. For a period of about two months, work underground and organised visits had to be limited due to some planned maintenance work by ELIA, Belgium's electricity transmission system operator, on the electrical power supply lines outside the EIG EURIDICE site. A few more minor problems that occurred during operation were all rectified within an acceptable period of time.

As explained in the Activity Report 2012, EIG EURIDICE proactively launched a study on the various options and corresponding regulations for the refurbishment of the shaft 1 hoisting system. DBE (Germany) performed this study during 2013 and delivered a first draft report on the main options. This document will be finalised at the beginning of 2014. During 2014 we will initiate discussions with the competent authorities (Federal Public Service for Employment, Labour and Social Dialogue) and with the external inspection body AIB Vinçotte on the applicable regulations.

By the end of 2012 we had replaced the shaft 1 ventilation system. The new unit was brought into service at

the beginning of 2013. Some problems that arose were resolved by the contractor. Remaining actions will be completed during the first few months of 2014.

Other standard maintenance and repair work on the hoisting systems, shafts and galleries was performed by the exploitation team in 2013.

ABOVE-GROUND INSTALLATIONS AND BUILDINGS

The exploitation team carried out standard maintenance and necessary repairs on installations, buildings and infrastructure in 2013.

Some specific actions were taken and modifications made in order to meet the requirements to obtain an environmental licence, such as a new gas storage unit, new storage facilities for oil and chemical products, demolition and removal of the old fuel tank, etc.

Concerning the planned new visitor entrance for EIG EURIDICE, the General Assembly of EIG EURIDICE eventually decided in favour of an access road coming from Boeretang. The draft design includes the new entrance road leading to EIG EURIDICE and the necessary road works on site. Some specific actions were taken, including surveyor measurements and verification of exact positions of underground pipes and cables. The project will be the subject of a public tender in 2014 and will also be implemented the same year.

LICENCES

The operating licence is valid until 2024. Nothing changed in this respect in 2013.

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.

In June 2013 EIG EURIDICE applied to the Province of Antwerp for an environmental licence, which was granted in November 2013 for a period of 20 years.

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

EEIG EURIDICE supports ONDRAF/NIRAS in its RD&D technical feasibility programme of geological disposal. This programme aims to demonstrate the construction and operational feasibility of the proposed concept for geological disposal and the repository design. The next programme milestone is the Safety and Feasibility Case (SFC-1), which is scheduled for 2015.

The repository technology studies cover the following topics:

- fabrication of the waste disposal packages
- construction of the underground repository
- operation and closure of the underground repository

EIG EURIDICE is involved in research on the fabrication of the waste disposal packages through its

contributions to the experimental programme on the supercontainer (see 1.2.2), including participation in the research project meetings and review of the reports produced by the project partners.

9. 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 geomechanics of clays. In particular, it is preparing a state-of-the-art report on the geomechanical behaviour and properties of Boom Clay, with emphasis on the results from the HADES URL. In the context of the research and development programme on the thermo-hydro-mechanical behaviour of Boom Clay and Ypresian clays, EIG EURIDICE also supervises and/or provides support for several PhD research projects (see 2.3).

EIG EURIDICE also contributes to the integration of this scientific knowledge into the Safety and Feasibility Case as the body responsible for drafting the "integration report" on the evolution of the disturbed zone around a deep repository for high-level and/or long-lived waste in a clay layer. This report will be part of the set of documents formally making up ONDRAF/NIRAS's SFC-1.

Activities: PART II

The surface disposal programme for category A waste - cAt Project

Introduction

On 23 June 2006 the Belgian federal government decided that the long-term management of category A waste should take the form of a surface disposal facility within the municipality of Dessel, situated in the northern, Flemish part of Belgium in the Province of Antwerp. The government commissioned ONDRAF/NIRAS to carry out this integrated project – i.e. the cAt project. To fulfil its appointed task, ONDRAF/NIRAS works in close collaboration with the STORA and MONA partnerships it has with the municipalities of Dessel and Mol.

An important step in the successful completion of this project 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 repository;
- Preparation and instrumentation of the planned test cover; and
- Instrumentation of the demonstration test for construction of concrete modules.

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

Radiological long-term safety assessments, prepared and documented in the course of 2010-2012, are a key part of the safety arguments presented in the licence application.

Additional documentation on these safety assessments was prepared in 2013:

- The report on FEP (feature, event, process) management, which demonstrates that systematic completeness checks have been performed in order to ensure that the scientific assessment basis has been correctly and completely considered during the development of the safety assessment models.
- The report on uncertainty management, which documents a new systematic methodology for the management and treatment of uncertainties and documents the application of this methodology in the category A safety case. The documentation of the safety assessment uncertainty and sensitivity analyses provided new insights into the disposal system performance behaviour, and more importantly enabled a two-fold conclusion:
  - The remaining uncertainties do not jeopardise safety;
  - The remaining uncertainties can be classified into more significant and less significant uncertainties, such that future research, development and demonstration can focus on the more significant uncertainties.

In order to prepare for future questions from FANC on the licence application, emphasis has been placed on:

- QA/QC procedures for preservation of the safety assessment results and references used in the safety case reports;
- preservation of modelling capacity so that new calculations can be performed quickly, if needed.

Furthermore, results from the safety assessments have been documented in scientific papers:

- J. Perko, S.C. Seetharam, D. Jacques, D. Mallants, W. Cool, E. Vermariën, Influence of cracks in cementitious engineered barriers in a near-surface disposal system: Assessment analysis of the Belgian case, in: ICEM2013, Proceedings of the ASME 2013 15th International Conference on Environmental Remediation and Radioactive Waste Management, 8-12 September 2013, Brussels, Belgium, 2013, pp. ICEM2013-96226 (Oral presentation and conference proceedings article).
- S.C. Seetharam, D. Mallants, J. Perko, D. Jacques, A consistent approach for the development of a comprehensive data base of time-dependent parameters for concrete engineered barriers, in: ICEM2013, Proceedings of the ASME 2013 15th International Conference on Environmental Remediation and Radioactive Waste Management, 8-12 September 2013, Brussels, Belgium, 2013, pp. ICEM2013-96219 (Oral presentation and conference proceedings article).
- S.C. Seetharam, J. Perko, D. Jacques, D. Mallants, 2014. Influence of fracture networks on radionuclide transport from solidified waste forms. Nuclear Engineering and Design (accepted for publication).
- D. Jacques, J. Perko, S.C. Seetharam, D. Mallants. Geochemical leaching model as a basis for determining time dependent sorption and physical properties of cementitious materials, Applied Geochemistry (submitted).
- J. Perko, S.C. Seetharam, D. Jacques, W. Cool, E. Vermariën, D. Mallants, Assessment of crack influence in cementitious components of a near-surface disposal of radioactive waste (under internal review).

2. Test cover

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

In 2012 an instrumentation plan for the future test cover was devised by EIG EURIDICE, together with ONDRAF/NIRAS and Tractebel Engineering. A programme subsequently got under way to test the robustness and reliability of the instrumentation under the expected conditions in the test cover.

The design of the test cover as well as the instrumentation plan have since been further refined, including some new aspects on, for instance, concrete monitoring. Based on a 3D model (Figure 53), the

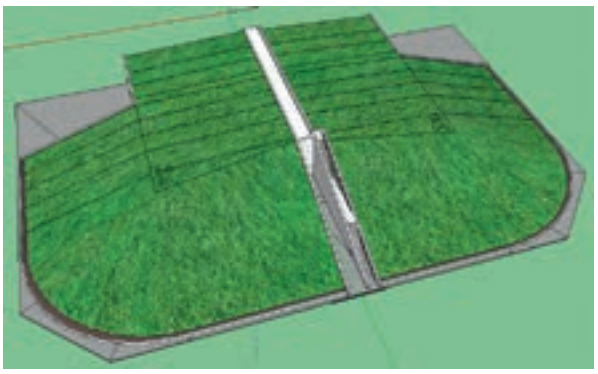


Figure 53 - 3D model of the test cover showing the first layer

instrumentation plan was optimised, in particular the drainage system. The drainage water collectors were designed in order to build a prototype in early 2014. CO2-gas samplers to operate under buried unsaturated conditions were designed. Currently, a prototype is being tested under laboratory and field conditions.

An experimental programme was set up to evaluate the possibility of measuring detailed water content profiles by spatial time domain reflectometry (TDR), i.e. full inversion of the wave along long TDR probes resulting in water contents with a spatial resolution of 1 cm. An innovative inversion scheme was developed for this purpose. The methodology was tested both in the laboratory and in the field. Figure 54 shows a vertically installed 70 cm-long TDR probe in a field soil, together with the derived water content profile, which is compared with depth-specific measurements taken close to (but not at exactly the same location as) the probe installation.

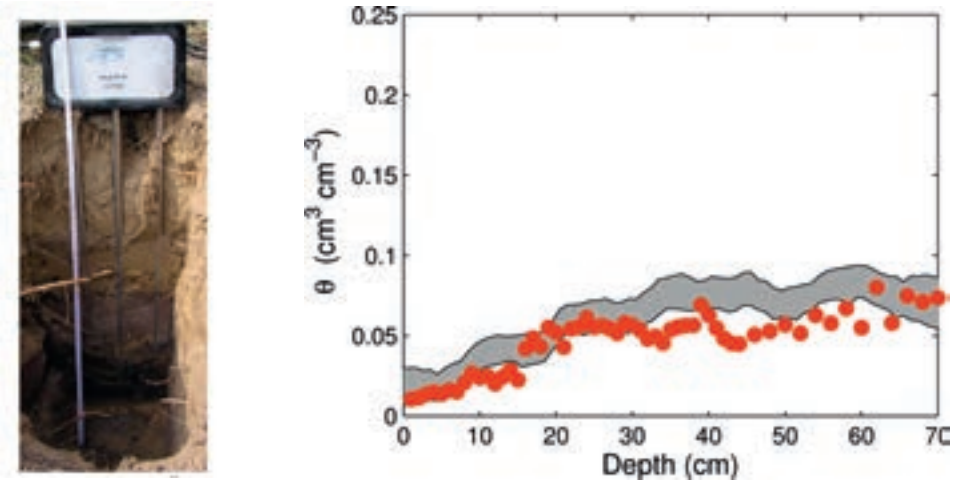


Figure 54 - (left) Vertically installed long TDR probe;
(right) derived water contents and uncertainty from inversion of the full wave form, together with measured water contents (red dots) measured close to the TDR probe

In 2013 field installation of the different sensors was tested. The main objectives were to test whether the sensors would survive tamping during the construction of the test cover, and to evaluate whether the sensors are compatible with the cover materials under field conditions. Two small heaps were constructed, one of sand and one of Boom Clay, and tamped with machinery similar to that which will be used when constructing the test cover, i.e. a vibrating roller and a sheepsfoot roller for the sand and clay, respectively (Figure 55).

Figure 55 - V2 vibrating roller for tamping the sand (top left), and V2 sheepsfoot roller (top right) for compacting the clay. In the bottom image, the vibrating roller was driven forwards and backwards over the sand tumulus during installation of a second sand layer.

During the process of forming the different layers and tamping, a number of sensors were installed: TDR probes, temperature probes, pF meters, pore water sampler, optic fibres (for distributed temperature sensing, DTS), and PVC tubes for performing ground-penetrating radar (GPR) measurements. All sensors and cables survived the tamping of the layers. The field test enabled us to improve the sensor installation procedures, especially in the clay layer. Successful measurements were obtained with TDR, temperature and pF meters. The pore water samplers were not successful and further action will be taken during 2014 to obtain reliable samplers. The DTS system was tested together with Olivier Hoes (Delft University of Technology, the Netherlands) and provided reliable measurements of the spatial distribution of temperature (Figure 56).

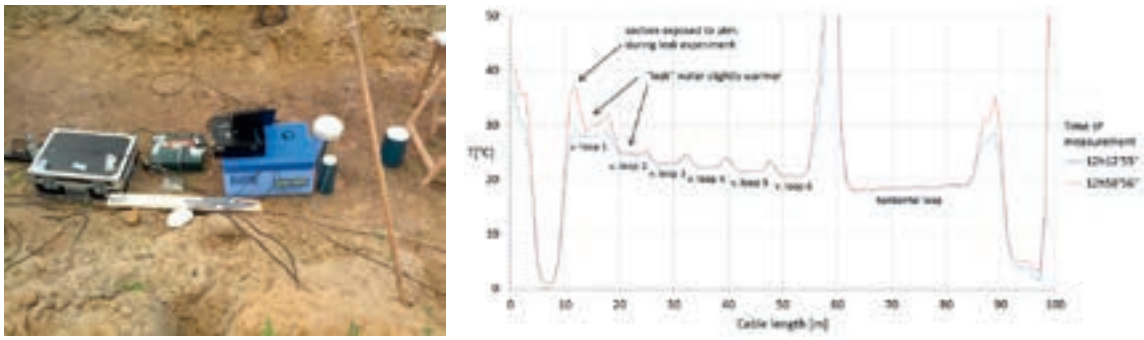


Figure 56 - (left) Field test of DTS measurements with fibre splicing equipment; (right) temperature distribution along the optic fibre for two given measurement times

The compatibility of GPR with the sand layers was tested in cooperation with Jan van der Kruk, Anja Klotzsche and Nils Güting (Forschungszentrum Jülich, Agrosphere, Germany). Four PVC tubes were installed

in which GPR measurements in six planes are possible (two vertical, two horizontal and two diagonal). Measurements were performed with two types of antennas (250 and 500 MHz, left picture in Figure 57) by simultaneously shifting the source and receiver in the boreholes with a spatial discretisation of 0.05 m (right picture in Figure 57).

Figure 57 - (left) GPR 500 MHz antenna; (right) pushing source and receiver into the borehole to measure a horizontal plane

A simplified interpretation of the data gathered made it possible to reconstruct the two-dimensional planes of permittivity and to derive water content with a non-site-specific calibration curve (Figure 58). Although more enhanced water profiles can be obtained by a more innovative interpretation of the data and by using a site-specific calibration curve, it was demonstrated that the GPR technique is compatible with the materials used in the test cover.

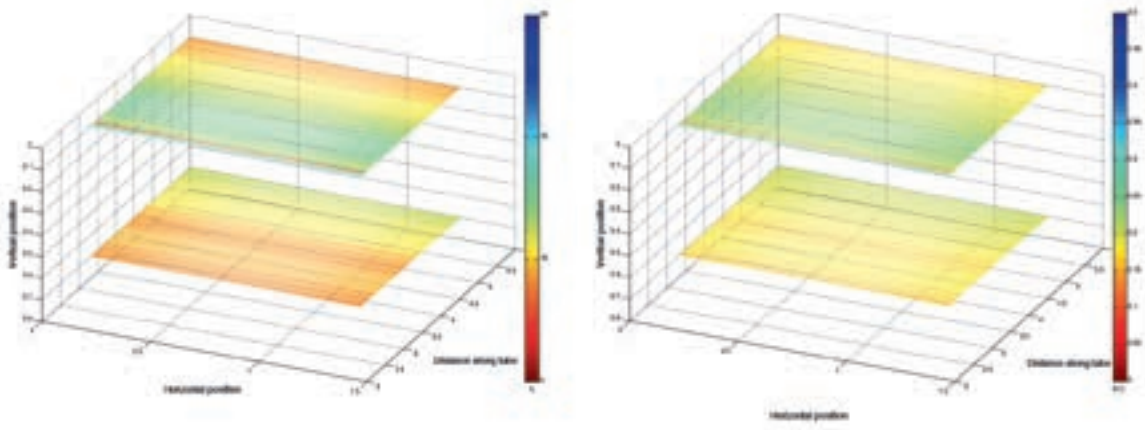


Figure 58 - (left) Relative permittivity; (right) derived volumetric water content in two horizontal planes

3. Demonstration test

In order to assess the technical feasibility of the module construction techniques and the industrial feasibility of the concrete that has been optimised for long-term safety and has been tested on a laboratory scale, a demonstration module construction test for the cAt project was set up and carried out (Figure 59).

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

In 2011 the test module and two test panels were built by ONDRAF/NIRAS and instrumented by EIG EURIDICE. A third panel was built in 2013 and was also instrumented by EIG EURIDICE. Vibrating wire strain gauges and formwork pressure sensors were installed. Monitoring of the instrument's readings continued in 2013 and will continue in 2014.

Figure 59 - Overview of the demonstration test

Scientific output

PUBLICATIONS

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Communication & general management

1. Communication

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

To ensure consistency in communication messages and strategies, it is important for all communication activities to be discussed with and agreed upon by both SCK•CEN and ONDRAF/NIRAS. This is mainly managed through the Communication Committee's meetings with ONDRAF/NIRAS and SCK•CEN communication managers.

MEDIA COVERAGE

During 2013 several journalists visited the HADES URL to report on the activities of EIG EURIDICE.

- The scientific journal EOS published a series by Senne Starckx on the nuclear legacy, with a first article on 5 May that dealt with the Belgian concept for geological disposal and covered, in particular, the research in HADES and the PRACLAY experiment.
- On 21 May an article written by Sophie Devillers, including an interview with Peter de Preter, appeared in La Libre Belgique with a focus on the research activities in HADES and the status of the research programme in Belgium. The reason for this article was a possible policy decision to be taken by the Belgian government.
- On 1 June De Tijd published a full-page article by Samuel Hanegreefs on radioactive waste and geological disposal.
- Finally, on 23 April, Marc Lens of Radio 2 Limburg interviewed Peter De Preter about the research on geological disposal in HADES and the use of the underground for multiple reasons.

PUBLICATIONS FOR A WIDE AUDIENCE

A special report on the design and installation of the PRACLAY In-Situ Experiment has been available since December 2013, dealing with all preparatory steps before starting the heater phase of the experiment (Figure 60). This technical and scientific report provides a good overview of the entire installation of the experiment and is available to anyone who is interested in the goals and set-up of the PRACLAY experiment.

Figure 60 - Report on the design and installation of the PRACLAY experiment

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, the information centre of ONDRAF/NIRAS on radioactive waste. Experts on geological disposal, 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.

In 2013 EIG EURIDICE welcomed 1,821 visitors to the HADES URL and the above-ground exhibition on geological disposal; 47 of the 114 visits were led by trained tour guides. Of the 114 visits, 44 were visits for training and educational purposes, 41 for VIPs and 29 for sociocultural organisations. Sixty-six were Dutch-speaking, 33 English-speaking and 15 French-speaking. At the end of their visit, visitors are asked to give feedback by means of an electronic questionnaire. Overall, people are very positive about their visit to EIG EURIDICE, the quality of the guides and the high standard of the research. They are especially impressed by the tour of the HADES URL. After going underground, they have a more realistic view of the scope and effort of the RD&D work and of what an actual repository might look like.

Besides continual interest from universities offering geological or engineering courses, there was marked interest from politicians. Both the Dutch Minister of Economic Affairs, Henk Kamp, and the Minister-President of the German-speaking Community of Belgium, Karl-Heinz Lambertz, visited EIG EURIDICE on 6 May and 14 October, respectively (Figure 61).

Figure 61 - Visit by the Dutch Minister of Economic Affairs, Henk Kamp (left), and the Minister-President of the German-speaking Community of Belgium, Karl-Heinz Lambertz (right)

WEBSITE

EIG EURIDICE is preparing a new website, in consultation with its constituent members, ONDRAF/NIRAS and SCK•CEN. The structure was discussed and modified on 1 February 2013. Based on feedback on the proposed changes, a new version of the website was presented to the management of both members at the end of 2013.

EVENTS

On 24 January EIG EURIDICE organised the 18th Exchange Meeting on the theme of **"Instrumentation and monitoring in radioactive waste repository research"**, with presentations on both the technical and the societal aspects of monitoring for a repository. The presentations will be made available on the new website.

2. Personnel

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 have operated as the EIG EURIDICE team since 2000, based at the EIG EURIDICE site.

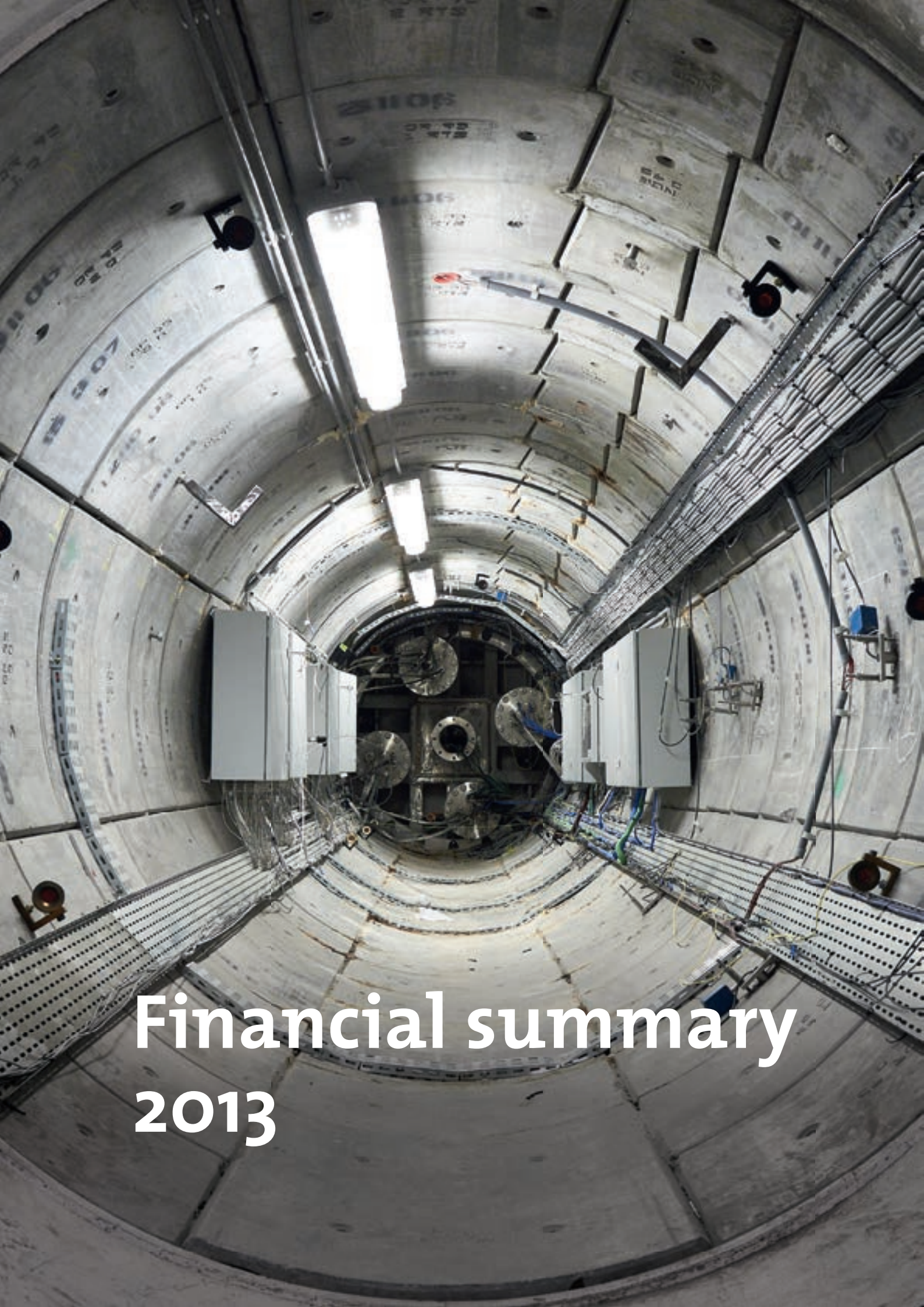
As of 1 January 2013, the EIG EURIDICE team consisted of 17 members. Kris Moerkens, former HADES Exploitation leader, retired in 2013. His tasks and responsibilities were taken over by Jef Leysen, the Operations & Safety Manager of EIG EURIDICE. SCK•CEN recruited one new staff member for EIG EURIDICE during 2013. Hendrik Huysmans took up his post at EIG EURIDICE in April. He is an experienced electrotechnician, who will support the team for instrumentation & monitoring on a technical level.

During 2013, SCK•CEN started a recruitment process seeking an engineer or scientist with expertise in the mechanical behaviour of structural components. The profile will be determined in 2014 according to the new agreement with ONDRAF/NIRAS that will define the priorities for the coming years. The profile will also take into account the need to reinforce the project management within the team.

3. Quality Management

Since 2007, EIG EURIDICE has been ISO-certified according to the ISO 9001:2008 standard for Quality Management. Jan Rypens, communication manager of the EIG EURIDICE, is responsible for keeping the quality management system up to date.

An external audit took place on 25 February 2013. There were no major or minor non-conformities. A new certificate was granted for the period from 22/04/2013 to 21/04/2016.



Financial summary 2013

Balance sheet (EUR)

	2013	2012	2011
Amounts receivables within 1 year	1,293,933	1,105,754	1,317,039
Commercial debts receivable	*1,125,317*	*996,860*	*1,237,924*
Other debts receivable	*168,616*	*108,894*	*79,115*
Cash at bank and in hand	218,657	1,018,142	984,557
Current assets	377	1,144	2,531
Total assets	**1,512,967**	**2,125,040**	**2,304,127**
Liabilities due within 1 year	1,512,967	2,125,040	2,304,111
Suppliers	*1,505,198*	*2,114,223*	*2,056,971*
Payments in advance	*0*	*5,849*	*247,140*
Additional amounts payable	*7,769*	*4,968*	*0*
Other tangible assets	0	0	16
Total liabilities	**1,512,967**	**2,125,040**	**2,304,127**
Company revenu	3,995,600	3,460,264	3,569,270
Turnover	*3,988,163*	*3,452,620*	*3,553,612*
Other operation income	*7,437*	*7,644*	*15,658*
Operating costs	3,994,592	3,461,414	3,571,602
Cost of services and various goods	*3,991,559*	*3,457,071*	*3,567,251*
Other operating charges	*3,033*	*4,343*	*4,351*
Financial revenu	352	1,733	3,351
Financial charges	572	223	516
Profit or loss on ordinary operation	**788**	**360**	**503**
Exceptional revenu	0	0	0
Exceptional charges	700	0	0
Pre-tax Profit and loss	**88**	**360**	**503**
Taxes	88	360	503
Profit or loss for the financial year	**0**	**0**	**0**

Lexicon

ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs (FR)
CERMES	Centre d'Enseignement et de Recherche en Mécanique des Sols (FR)
CIMNE	Centro Internacional de Métodos Numéricos en Ingeniería (ES)
EC	European Commission (BE)
ENPC	Ecole Nationale des Ponts et Chaussées (FR)
EPFL	Ecole Polytechnique Fédérale de Lausanne (CH)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (DE)
IRMM	Institute for Reference Materials and Measurements (BE)
IRSM	Institute of Rock and Soil Mechanics (China)
ITC	School of Underground Waste Storage and Disposal (CH)
NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (CH)
ONDRAF/NIRAS	Belgian Agency for Radioactive Waste and Enriched Fissile Materials (BE)
NRG	Nuclear Research & Consultancy Group (NL)
SCK•CEN	Belgian Nuclear Research Centre (BE)
ULg	Université de Liège (BE)
UPC	Universitat Politècnica de Catalunya (ES)
URL	Underground Research Laboratory (BE)
VUB	Vrije Universiteit Brussel (BE)

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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