

**INTERNATIONAL CO-OPERATION AND PARTNERSHIPS AT THE HADES  
UNDERGROUND RESEARCH FACILITY (MOL, BELGIUM)**

A. Sneyers, G. Volckaert, B. Neerdael  
Belgian Nuclear Research Centre SCK•CEN  
Boeretang 200, B-2400 Mol, Belgium

M. Demarche  
E.I.G. EURIDICE  
Boeretang 200, B-2400 Mol, Belgium

Ph. Lalieux  
NIRAS/ONDRAF  
Kunstlaan 14, B-1210 Brussels, Belgium

**ABSTRACT**

The HADES Underground Research Facility (URF) (Mol, Belgium) has played a central role in the establishing of a scientific and technical basis for deep disposal in clay formations. As part of the Belgian repository development program, the Boom Clay has been investigated as a potential host rock for the geological disposal of long-lived and high-level radioactive waste and spent fuel. Within the Belgian repository development plan, emphasis in R&D has progressively shifted from the study of basic phenomena to the investigation of complex and interacting processes. In line with this evolution, large-scale demonstration projects have become increasingly important. The Belgian URF is now being extended and this development opens up perspectives for planning new *in situ* experiments and intensifying international co-operation. This paper gives an overview of the objectives of international co-operation in the HADES facility and outlines a number of key areas where progress in repository development can be achieved through collaborative efforts.

**INTRODUCTION**

Within the Belgian waste management program, the Boom Clay is investigated as a reference formation for methodological studies on the geological disposal of long-lived and high-level radioactive waste and spent fuel. The Nuclear Research Centre SCK•CEN initiated the Belgian R&D program on radioactive waste disposal in 1974. Since 1980, these studies have included the construction and the operation of a dedicated Underground Research Facility (URF): the High Activity Disposal Experimental Site (HADES).

Recently, a number of initiatives have been taken to plan new *in situ* experiments and to facilitate world-wide co-operation in the HADES URF. Within this context, Belgium has offered to contribute actively to IAEA's Network of Centers of Excellence for Training in and Demonstration of Waste Disposal Technologies in Underground Research Facilities. This Network was formally initiated during a Technical Committee Meeting, held in Vienna from 8 to

10 October 2001 and provides a unique opportunity for international co-operation, demonstration and training activities in the HADES URF under the aegis of the Agency.

## THE HADES UNDERGROUND RESEARCH FACILITY

The HADES URF is the main research infrastructure for studies on geological disposal in Belgium. The Belgian URF is situated at the Mol nuclear area and is located in the Boom Clay Formation at a depth of approximately 225 meters below surface-level. A number of properties make this clay formation particularly appropriate as a host rock for radioactive waste disposal: the Boom Clay has a very low hydraulic conductivity (K-value of approximately  $2 \cdot 10^{-12} \text{ m} \cdot \text{s}^{-1}$ ), a high retention capacity for cations and a low diffusion constant for anions ( $D_{\text{app}}$  lower than  $10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$ ). As a result, all mass transport in the Boom Clay is limited to slow diffusion.

The construction of HADES started in 1980 and the underground facility was extended in 1986. The HADES URF is currently undergoing further expansion with the building of a second access shaft and the construction of an 80 meter long gallery (Figure 1). This gallery will connect the existing URF with the second access shaft.

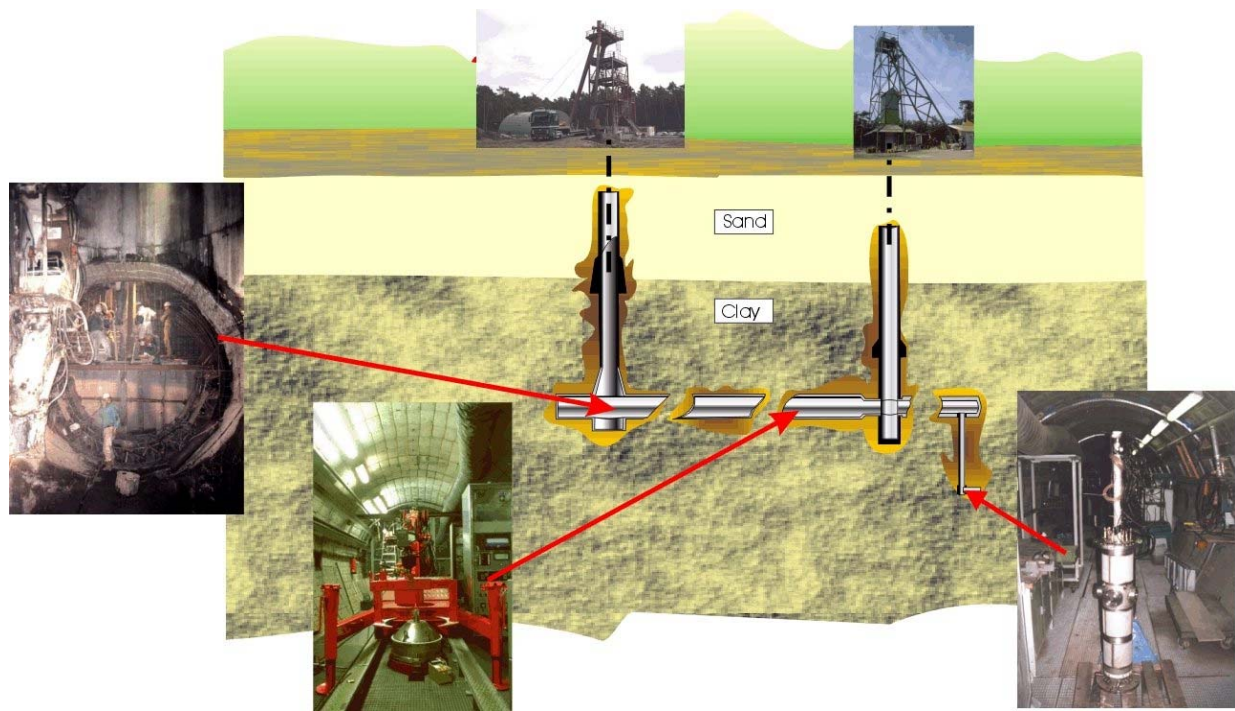


Fig. 1. The HADES URF after the completion of the construction of the second access shaft and connecting gallery

Today, the Economic Interest Grouping (E.I.G.) EURIDICE (formerly E.I.G. PRACLAY) is in charge of the management and the exploitation of the HADES URF. The E.I.G. EURIDICE is a joint undertaking between the Belgian Agency for Radioactive Waste Management NIRAS/ONDRAF and the Nuclear Research Centre SCK•CEN.

The HADES URF is one of the few underground research facilities world-wide where experiments with radioactive tracers as well as with alpha- and gamma-sources can be conducted. In addition to expertise directly linked to underground testing, extensive capabilities and infrastructure exist on-site to carry out complementary experiments in surface laboratories as well as modeling studies and performance assessments in support of *in situ* experiments in HADES. In particular, the Members of the E.I.G. EURIDICE dispose of:

- state-of-the-art surface laboratories to perform tests in support of *in situ* experiments;
- surface facilities and infrastructure (including hot-cells) to conduct experiments on radioactive materials;
- capabilities to plan, realize and manage large-scale underground constructions.

The availability of both surface laboratories and an underground research infrastructure as well as highly specialized skills allows for addressing a wide range of disposal-related issues.

For vitrified HLW, the Belgian radioactive waste management program foresees a cooling period of 50 to 60 years prior to disposal. Consistent with present expectations, it is anticipated that the HADES URF will continue to play a key role in repository development during the next two decades.

## **SAFIR 2 AND THE BELGIAN REPOSITORY DEVELOPMENT PROGRAM**

Ongoing studies in Belgium cover a broad spectrum of research activities including site characterization, the characterization of conditioned reprocessing waste, studies on the long-term behavior of waste packages and engineered barriers under geological disposal conditions, various engineering aspects such as repository construction, backfilling and sealing, the migration and transport of radionuclides under reducing conditions in clay, and the evaluation of the impact of the Excavation Disturbed Zone (EDZ). Over the years, large-scale demonstration experiments have become increasingly important. Within the Belgian R&D program, safety studies and performance assessments play an important role in the evaluation of the long-term radiological safety of disposal as well as in the definition of research priorities. In addition, these assessments are fundamental in the process of building confidence as well as for making recommendations for improving the repository design.

To a large extent, the scientific-technical content of the work performed in Belgium during the last decade has been based on the conclusions from the evaluation of the first Safety and Feasibility Interim Report (SAFIR) (1). This report was submitted to the Belgian Government in 1989 in order to provide all available information regarding the suitability of the Boom Clay Formation as a potential host rock for the geological disposal of long-lived and high-level radioactive waste arising from nuclear activities in Belgium. Ten years after the publication of the SAFIR report, the Belgian Radioactive Waste Management Agency NIRAS/ONDRAF was charged with the preparation for publication of the SAFIR 2 report. The SAFIR 2 report compiles all important scientific and technical information concerning the feasibility and safety of a geological repository for long-lived and high-level radioactive waste in a poorly indurated clay in Belgium. The report addresses the issue of geological disposal in clay from both a technical and a radiological safety viewpoint. Prior to publication in 2002, the SAFIR 2 report

will be presented to the authorities. The SAFIR 2 report will also be submitted for peer review to the NEA/OECD. It is expected that, equally as for SAFIR, the conclusions from the evaluation of SAFIR 2 will outline the overall direction and priorities in the Belgian R&D program beyond 2002.

## OVERALL FRAMEWORK FOR INTERNATIONAL CO-OPERATION

Although the accountability for radioactive waste management resides with each country generating the waste, issues related to the safe management of long-lived and high-level waste transcend national boundaries. Consequently, international programs supported by the European Commission (EC), the Nuclear Energy Agency (NEA/OECD) and the International Atomic Energy Agency (IAEA) have contributed considerably to the developing of a knowledge base and the establishing of consensus on key issues in radioactive waste management.

Belgium holds a long tradition in international co-operation. The HADES URF has played a pioneering role in R&D on disposal in clay formations and has hosted a large number of international projects. For example, the EC has supported the Belgian R&D program on radioactive waste disposal since 1976. Also in the future, efforts will continue to embed research performed in Belgium in an international context. With regard to the framework for international co-operation, various forms of collaboration are possible, in particular:

- co-operation across national boundaries on a bi- or multilateral basis;
- co-operations in the framework of programs supported by international organizations, notably the IAEA, NEA/OECD and the EC.

Co-operations on a bi- or multilateral basis allow for great flexibility in planning and budgeting. This mode of co-operation is particularly appropriate for conducting investigations requiring long testing durations, especially where experimental durations exceed the maximum acceptable contractual period granted by international organizations sponsoring R&D in waste disposal. *In situ* tests in HADES intended to study long-term effects in realistic disposal conditions indeed require long testing times and call for specific organizational and contractual arrangements. Bi-or multilateral agreements between project partners overcome these limitations and can be tailored to specific needs and requirements in R&D.

International organizations provide a framework for broad co-operation. The European Commission, the Nuclear Energy Agency and the International Atomic Energy Agency have played an important role in creating a framework for international co-operation in underground research facilities including HADES. Two recent initiatives and developments in programs supported by international organizations open up new and important opportunities for intensifying international collaboration.

The first initiative concerns the European Commission's proposal on research, technological development and demonstration activities (2002-2006). In particular, the Commission plans to introduce two main instruments in Framework Program 6: the creation of networks of excellence and the establishing of integrated projects (2). These instruments will be applied in carrying out activities in a limited number of priority thematic areas including research on radioactive waste

management. The initiative by the European Commission will contribute to an efficient organization of research, will provide a broad platform to benefit from synergies in R&D and opens interesting perspectives for achieving progress in repository development through co-operative work in large infrastructures including underground research facilities such as the HADES URF.

The second initiative involves the creation in October 2001 of IAEA's Network of Centers of Excellence for Training in and Demonstration of Waste Disposal Technologies in Underground Research Facilities (3). The focus of the Network is on the use of Underground Research Facilities to achieve progress in repository development. The main objectives of the Network are:

- To demonstrate waste disposal technologies and to contribute to the resolution of key technical issues;
- To encourage the transfer and the preservation of knowledge and technologies;
- To supplement national efforts and promote public confidence in geological disposal.

Belgium will contribute actively to the Network. To this end, the HADES URF has been made available to the Network for conducting *in situ* R&D work and demonstration tests in HADES under the aegis of the IAEA. Project partners with highly developed R&D programs on radioactive waste disposal can take advantage of synergies in research. Member States with less advanced repository development programs can benefit from the Network through active participation in experimental work in HADES or through dedicated programs for promoting the transfer and preservation of knowledge and technologies.

In the context of these international programs, Belgium is committed to plan and develop collaborative activities jointly and in close consultation with all project partners. These activities can include projects on training, knowledge and technology transfer as well as joint experimental work in HADES. Training activities will enable project partners to acquire hands-on experience, to build expertise and to develop or preserve knowledge. As regards joint activities in demonstrating waste disposal technologies, particular emphasis will be on projects where international co-operation can contribute to achieve progress and to establish consensus among experts on issues that are critical in repository development.

## **INTERNATIONAL CO-OPERATION AT THE HADES URF**

The role of underground research facilities in repository development has been highlighted in a number of recent publications (4-10). Experience derived from underground testing is fundamental in developing consensus on various scientific-technical issues and in building confidence in geological disposal.

Future work in HADES will focus on thematic priority areas in repository development. In particular, co-operative projects in HADES will be developed to meet the following objectives:

- Resolving outstanding scientific-technical issues;
- Demonstrating waste disposal technologies;

- Supporting training and knowledge and technology transfer;
- Promoting public confidence in geological disposal.

After the completion of the extension of underground research facility in 2002-2003, various activities will be developed and implemented.

## **RESOLVING OUTSTANDING SCIENTIFIC-TECHNICAL ISSUES**

Like in other countries pursuing the geological disposal option, the development of a geological repository for radioactive waste in Belgium is a gradual and stepwise process. In general terms, key elements in the stepwise development process of a geological repository include, among others, site selection, waste characterization, the development of a repository design, the establishment of a scientific-technical basis for geological disposal, the delivery of mature disposal technologies for repository construction, operation, sealing, closure, and, if appropriate, post-closure monitoring and the implementation of technologies for waste retrieval (11). The successful accomplishment of each of these steps implies the resolution of a wide variety of scientific and technical key issues.

### **Studies related to the behavior of the waste packages**

#### *Investigations on the geological disposal of bituminized radioactive waste*

Since the late 1960's, bitumen has been commonly used by the nuclear industry as a matrix for the immobilization of low and intermediate level waste including evaporator sludge, ion-exchange resins, liquid concentrates, incinerator ashes, and filter materials. Bituminized waste forms arising in the Belgian waste disposal program are considered for geological disposal in clay. Accordingly, the understanding of the long-term properties and behavior of organic waste forms under geological disposal conditions in clay is fundamental to the Belgian R&D program.

Various coupled processes affect the long-term behavior of disposed bituminized waste (12). These processes include the swelling of the bituminized waste product due to gas generation and the uptake of water; the release of soluble salts embedded in the waste (in particular  $\text{NaNO}_3$ ); and the production of water-soluble organic complexing agents as a result of radiolytic, chemical and microbial degradation. In addition, the intrinsic properties of bituminized waste will evolve due to the physico-chemical ageing, in turn affecting the extent of the cited processes. Future studies in Belgium will concentrate on the detailed assessment of various processes affecting the long-term behavior of organic waste forms under geological disposal conditions. Detailed information on these processes is essential for providing scientifically sound recommendations on the acceptability of bituminized waste for disposal in a clay formation.

#### *Investigations on the long-term behavior of cement materials in clay*

Cement-based materials are important in radioactive waste isolation. Besides being applied as a matrix for the conditioning of low- and intermediate-level radioactive waste, concrete is extensively used in geological repositories for construction purposes (lining) or as a backfill. In various repository designs, cements provide an effective physical and chemical barrier for the

immobilization of radioactive and toxic pollutants. In disposal conditions however, cementitious materials interact with the host rock and repository groundwater. These interactions may influence the long-term stability of cement-based materials. To investigate the impact of potential alteration processes on the long-term safety of disposal, SCK•CEN has initiated an experimental program in the HADES Underground Research Laboratory. Data derived from this study have indicated significant interaction between the Boom Clay and cementitious materials, resulting in the development of newly formed phases (13). Redox and carbonation reactions can explain these interactions and lead to an increase in porosity of the cement matrix. Future research is however needed to extrapolate data obtained from short-term *in situ* experiments as well as to assess the impact of complex and interacting processes on the long-term safety of disposal.

#### *Investigations on the geological disposal of vitrified waste*

Within the Belgian waste management program, various types of high-level vitrified waste are considered for geological disposal. The corrosion rate of vitrified waste is one of the key parameters in performance assessment studies. Accordingly, considerable efforts have been spent over the years to investigate the long-term behavior of various types of vitrified radioactive waste in representative geological disposal conditions of a clay formation. The experimental program has been focussed on laboratory tests to study the influence of inactive components of the disposal system (clay and engineered barriers) on the corrosion mechanisms and kinetics as well as the sorption and diffusion of leached silica in a clay host rock. *In situ* experiments in the HADES URF have been complemented with investigations in surface laboratories and modeling studies.

In a geological repository for high-level vitrified waste, several repository components (e.g. backfill, overpack, host rock) may interact with the glass matrix and, by consequence, will have an impact on glass corrosion mechanisms and kinetics. Despite extensive research, a number of scientific issues require further and detailed investigation. In particular, the impact of clay on the dissolution of nuclear waste glass is not yet completely understood (14). Existing studies indicate that the glass dissolution rate strongly depends on the fate and the speciation of released inactive components. However, data on the sorption and precipitation kinetics of released glass components are presently inadequate. Future research is needed to provide these data and elucidate underlying processes.

Furthermore, physico-chemical conditions in the near field of a geological repository for vitrified high-level waste will change with time due to, among others, the cooling of the waste packages,  $\gamma$ -irradiation and radiolysis of the backfill, corrosion of container materials. To study these complex and interacting processes under representative disposal conditions, SCK•CEN has developed a dedicated and integrated *in situ* test: the CORALUS experiment (15). The experimental design of one of the test tubes of the CORALUS experiment is shown in figure 2 and allows for performing *in situ* corrosion tests at on  $\alpha$ -doped glass specimens in the presence of various types of backfill materials.

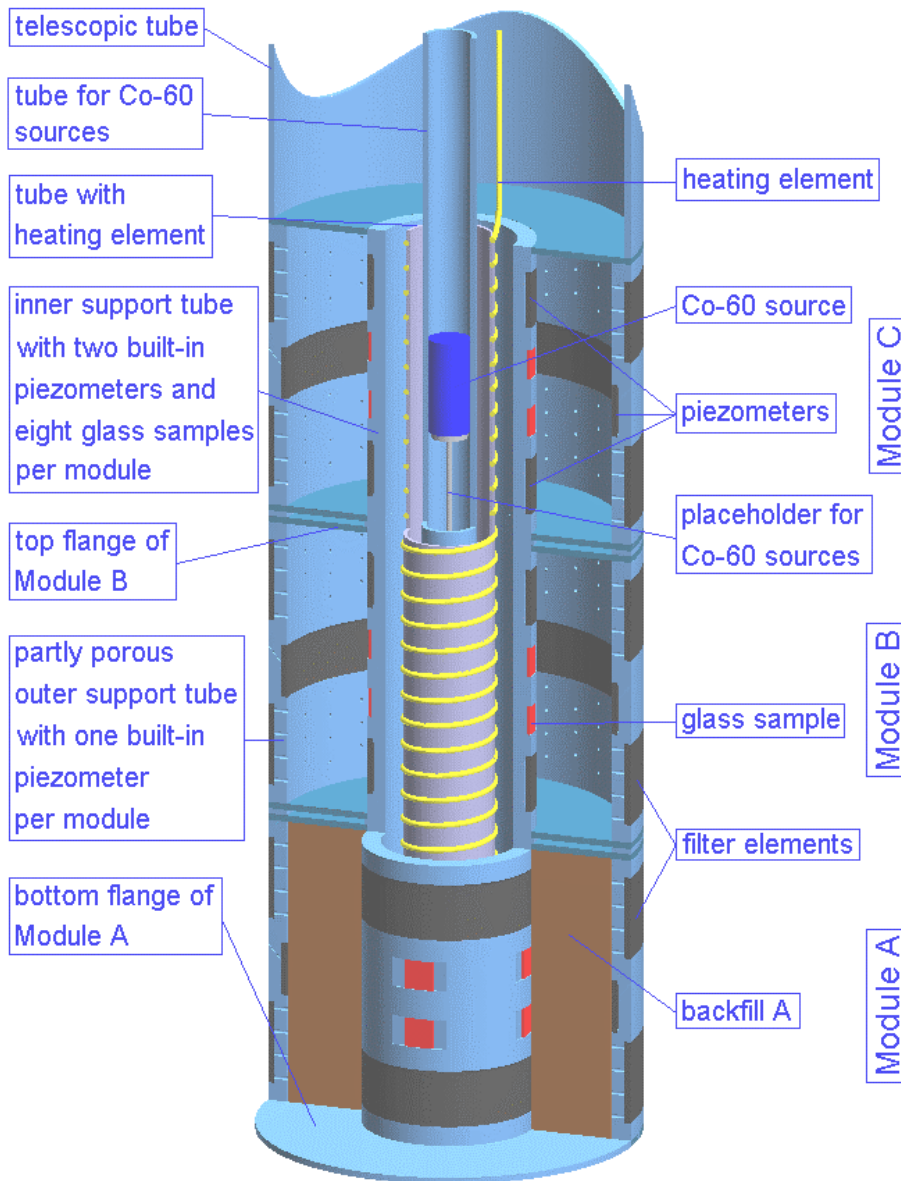


Fig. 2: Modeling image of a CORALUS test tube

The tests are conducted at elevated temperature and in presence of  $\gamma$ -radiation in order to study the time-dependence of glass corrosion as well as the combined effect of heat and radiation. Experimental data derived from the CORALUS experiment will allow to verify long-term predictions on the performance of vitrified waste based on conventional laboratory experiments and modeling studies.

### *Corrosion research*

An extensive parametric study to investigate the corrosion behaviour of two Belgian candidate container materials (stainless steels AISI 316L hMo and UHB 904L) for geological disposal in Boom Clay has been completed recently. The corrosion behaviour of these materials was



compared with Ni- and Ti- alloys. Particular attention was paid to the investigation of localised corrosion (pitting) of the candidate container materials by Cyclic Potentiodynamic Polarisation (CPP) measurements.

New data derived from the OPHELIE mock-up suggest the possible presence of high chloride concentrations in repository porewater. A study to investigate the influence of the chloride content will contribute to assess the impact on corrosion susceptibility. At a  $\text{Cl}^-$  concentration of  $20,000 \text{ mg.L}^{-1}$ , signs of pitting were observed for AISI 316L and 316Ti (tests at  $16^\circ\text{C}$ ) indicating that these metals could suffer from long-term corrosion problems, as repassivation will not occur once a localised attack is initiated. Similar conclusions are drawn on the susceptibility to pitting at  $90^\circ\text{C}$  (anaerobic conditions) for Ni-alloys Hastelloy C-4 and C-22. For stainless steel UHB 904L, pitting is easier initiated at high temperature. At  $140^\circ\text{C}$  and for aerobic conditions, the pitting susceptibility of UHB 904L increases with increasing chloride content but decreases with increasing sulphate content.

#### *Investigations on the geological disposal of spent fuel*

As a consequence of the decision not to continue reprocessing of spent fuel from Belgian nuclear power plants, studies on the direct geological disposal of spent nuclear fuel in a clay formation have gained increased interest during the last few years.

Predictive models and accurate data on the source term of critical radionuclides released from spent nuclear fuel are fundamental for the assessment of the long-term safety of disposal. At present, various models describing the dissolution of spent fuel or  $\text{UO}_2$  under oxidizing conditions are available. The application of existing models to the site specific reducing repository conditions of the Boom Clay Formation is however not straightforward. As a result, an experimental program has been set up to provide data for confirmation of the source model used in performance assessments. In addition, these experiments intend to elucidate spent fuel dissolution mechanisms and to provide data on the impact of dissolved natural organic matter and carbonate on  $\text{UO}_2$  solubility. To this end, dissolution tests are carried out on  $\text{UO}_2$  in complex media representative for the Boom Clay (16).

#### **Studies related to the migration of radionuclides and gases in the geosphere**

Within the Belgian repository design, the Boom Clay Formation is an important natural barrier preventing the release of radionuclides from a geological repository to the biosphere. Its low permeability and excellent sorption characteristics favor the barrier performance of the Boom Clay. Accordingly, data on the migration of radionuclides and gases are key parameters in the assessment of the overall safety of disposal.

Transport models require detailed information on the near- and far-field properties of the repository environment. Within the Belgian R&D program, special attention has been paid to the influence of organic matter dissolved in the interstitial clay water on radionuclide mobility. In addition, conceptual and mathematical models have been developed for the migration of radionuclides in clay as well as models for the thermohydrromechanical and chemical behavior of unsaturated clay-based backfill materials.

As a complement to standard migration experiments, which are very lengthy for retarded elements, SCK•CEN has developed electrokinetic methods. These methods have proved to be extremely effective in determining key-migration parameters for these elements in a much faster way (17).

Migration experiments in laboratory conditions as well as large-scale *in situ* experiments in the HADES URF have significantly improved understanding of radionuclide and gas transport in clay. The extrapolation of data and processes, derived from short-term laboratory experiments, to the extremely long time periods pertinent for geological disposal remains however one of the major concerns in safety assessments. Future work will therefore aim at improving knowledge on the processes influencing radionuclide migration and retardation. In addition, particular emphasis will be on the study of the long-term evolution of the Boom Clay as a host rock for radioactive waste disposal. Co-operative work in the HADES facility will contribute to resolving these scientific issues.

## **DEMONSTRATING WASTE DISPOSAL TECHNOLOGIES**

Demonstration tests have become increasingly important in the Belgian R&D program as an effective means to demonstrate the technical feasibility of HLW disposal in clay and to improve disposal technologies. Ongoing and planned demonstration experiments include the RESEAL and the PRACLAY experiment.

### **RESEAL: demonstrating the sealing of a repository**

An important factor affecting the long-term safety of disposal is associated with the sealing of the repository. Within the RESEAL project, SCK•CEN investigates various aspects of repository sealing (18). The RESEAL project is a large-scale *in situ* experiment to demonstrate the feasibility and effectiveness of the sealing of a repository in a clay formation.

The RESEAL experiment is conducted in an experimental shaft within the HADES underground research laboratory. This experimental shaft has been backfilled with a sealing material consisting of a mixture of pre-compacted bentonite pellets and bentonite powder. An extensive instrumentation and monitoring program was set up to measure various parameters within the seal and the adjacent Boom Clay such as water pressure, axial and radial stress and displacement. Data obtained from the monitoring program yield invaluable information on the saturated and unsaturated hydro-mechanical behavior as well as the water and gas tightness of the sealing material and the EDZ in the host rock. These data will be applied for model calibration and validation.

### **PRACLAY: demonstration of the feasibility of HLW disposal in clay**

The PRACLAY project is a large-scale *in situ* demonstration experiment, which aims to demonstrate the technical feasibility of HLW disposal in a clay formation and to contribute to the assessment of the performance of the HLW disposal system. To this end, a second access shaft to the URF has been constructed, the existing HADES Underground Research Facility is being extended and a full-scale disposal gallery, which will host the PRACLAY experiment, will be

built. In addition to activities planned in the underground research laboratory, a surface mock-up (OPHELIE) has been constructed. The mock-up simulates a disposal gallery and will be used for the detailed investigation of the thermo-hydro-mechanical behavior of a HLW disposal repository (including the hydration of the bentonite-based backfill) prior to investigation in the underground research laboratory. The mock-up consists of a steel liner confining the reference backfill material, sensors and heating devices allowing to obtain thermal conditions similar to those expected to prevail for the *in situ* test. The mock-up will be dismantled in 2002.

The concept of the PRACLAY experiment will be based on the Belgian reference design for the disposal of high-level vitrified waste. This design is presently under review and will be updated where necessary taking into account state-of-the-art scientific and technical information. Conclusions from the SAFIR 2 report as well as data derived from the OPHELIE mock-up will be supportive in the process of optimizing the Belgian reference design for a repository for vitrified HLW.

The PRACLAY project will contribute to extend knowledge on deep excavations in plastic clay formations as well as to demonstrate the construction and the operation of a repository for the geological disposal of high-level radioactive waste in a clay formation. During the excavation of the connecting gallery, an extensive monitoring program (CLIPLEX project) will examine the hydro-mechanical behavior of the Boom Clay.

According to the present planning, the reference design will be available by 2003. In 2005, instrumentation to monitor various relevant parameters in the host rock will be installed. Subsequently, the PRACLAY gallery will be constructed taking into account the revised repository design. The PRACLAY experiment will be installed in 2007. The starting of the heating phase is also foreseen for 2007 and will continue until 2012. The PRACLAY experiment will be dismantled in 2014 after a one-year cooling period.

### **R&D on the development and the testing of instruments for various measurements in URFs**

Various types of measuring instruments and sensors are used for data collection in underground research laboratories. Data derived from these devices are critical for the understanding of processes affecting the long-term safety of disposal as well as for the validation of models. Accordingly, these devices have to comply with a set of stringent criteria with regard to their robustness and capability to operate over extended periods of time under harsh physical or chemical underground conditions.

Within the Belgian R&D program, extensive expertise exists in the development, the application and the testing (including validation and calibration) of instruments for underground measurements in clay. This expertise will be complemented with information derived from the dismantling of the OPHELIE mock-up. The acquired experience provides an excellent starting point for the evaluation of instrumentation for underground measurements as well as for developing new and reliable technologies. The SOMOS project aims at developing robust optical sensors for underground measurements. The testing, benchmarking, development and improvement of instruments for underground measurements is of broad interest to the international waste management community, and therefore provides attractive perspectives for broad international co-operation.

### **In situ test for the development of repository designs such as 'micro-tunnel' or borehole emplacement**

Besides the PRACLAY test, which will be based on the Belgian reference design, other *in situ* tests can be developed to demonstrate the feasibility of alternative designs. An example of such a design is the disposal in so-called micro-tunnels, i.e. tunnels with a diameter of about one meter. For this type of tunnels, SCK•CEN has developed a dedicated lining system, the so-called PRETEL (Pre-tension Lining) system. An *in situ* test could be performed to demonstrate the feasibility of micro-tunnel construction, waste emplacement and backfilling. The backfilling could be based on the use of high-density bentonite pellets and pneumatic transport techniques. Another concept is the emplacement of HLW in relative short lined boreholes (3.5 meters deep with a diameter of about 0.5 meters) with or without backfill. These boreholes could either be horizontal, inclined or vertical. An *in situ* test could be performed to test the drilling and the lining of such boreholes, waste emplacement, heat transfer and waste retrieval.

### **PROMOTING TRAINING AND KNOWLEDGE & TECHNOLOGY TRANSFER**

The HADES URF provides a unique testbed for promoting training, knowledge and technology transfer. Future activities in this field can be planned in the context of programmes supported by the European Commission or the IAEA, for example through IAEA Network of Centres of Excellence.

### **PROMOTING PUBLIC CONFIDENCE IN GEOLOGICAL DISPOSAL**

Accumulated experience from various national waste management programmes has shown that both technical and societal challenges are decisive in repository development. In particular, public acceptance and involvement have proved critical factors in advancing repository implementation. Appropriately, different countries have developed new approaches to address societal concerns and have established dedicated programs to endorse communication with and involvement of the public. Moreover, waste management organizations have adopted phased and flexible implementation programs and have structured R&D programmes in support of the societal decision-making process. These developments also have lead to new orientations in national scientific programmes: R&D projects have been set up on the long-term monitoring of repositories and the introduction of measures to ensure reversibility of steps - including retrieval of disposed waste. These projects have a strong institutional component and can contribute to promote public confidence in the concept of geological disposal.

### **The demonstration of technical feasibility of retrieving vitrified waste and/or spent fuel from a geological repository in clay**

In a number of countries, retrievability - or more generally reversibility - forms part of a stepwise repository implementation plan. Until now, no specific requirements apply to the Belgian repository development program with regard to the retrieval of emplaced wastes. In the current Belgian disposal design for long-lived and high-level radioactive waste however, waste retrieval is technically feasible in principle.

In most studies performed until now, the issue of retrievability - reversibility has been treated on a conceptual basis. So far, the technical feasibility of retrieving heat-generating long-lived waste from a geological repository has not yet been demonstrated and various technical issues relating to the retrievable emplacement of radioactive waste have not yet been addressed. Within this context, a full-scale *in situ* test in the HADES URF to demonstrate the technical feasibility of retrieval of heat-producing waste from a repository in clay could contribute to resolve various outstanding technical issues. These issues mainly pertain to the repository concept (repository design, choice of an appropriate overpack and backfill, repository sealing) as well as to diverse engineering aspects (drilling in plastic clay or hydrated backfill). Information derived from such a demonstration project can be applied to introduce the concept of retrievability-reversibility without adverse impacts on repository safety. A retrievability test in HADES would imply the emplacement of a number of electrically heated, remote handled canisters in a dedicated gallery, the monitoring of relevant parameters and the retrieval of the canisters after predefined test durations.

In addition to scientific-technical aspects, the implications of the retrievability concept can be evaluated in terms of operational safety, cost and institutional consequences. Finally, a demonstration project on retrieval of heat-producing HLW from a geological repository in clay is considered imperative for public information purposes.

### **Long-term monitoring**

Although a robust geological repository system is designed to be safe without relying on an active control, monitoring or maintenance, monitoring can play a role in the decision process. To address public concerns and to assure that the repository evolution is as expected, it may be desirable to keep a geological repository for radioactive waste under close surveillance during repository operation, including a potential period of enhanced retrievability, and/or for some period after repository sealing. To this end, it is essential to work out methodologies and to develop instrumentation for the periodic or continuous measuring of all parameters required for observing the evolution of the repository system (e.g. geomechanical, hydraulic, radiological, geochemical parameters). The objective of the proposed project is to develop and test strategies, methodologies, techniques and robust instrumentation for the long-term environmental monitoring of a geological repository in clay.

### **The application of safeguards standards during the operational phase and during partial closure of a geological repository in clay**

Until now, only few investigations have been conducted on the application of safeguards standards during the operational phase, partial closure and closure of a geological repository for radioactive waste. Within this context, it is proposed to use HADES as a testbed to evaluate impacts of safeguards systems on repository systems. The scope of this study would be to identify interfaces between safeguards and repository operations as well as to outline strategies and to develop technologies for safeguards to minimize adverse impacts on operations. The project would include various activities focusing on the development of sensors and measurement devices, the development of information and communication systems as well as analytical tools and the assessment of human factors, in particular in relation to data comprehension and credibility.

## FUTURE DEVELOPMENTS

It is anticipated that the results of the evaluation of the SAFIR 2 report will influence to a large extent the orientation and content of the future Belgian RD&D program on geological disposal. The extension of the HADES URF will allow to plan and implement new *in situ* experiments as well as to foster international co-operation in a number of thematic priority areas.

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