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Waste Disposal

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THE PRIMARY MISSION of the Waste Disposal programme is to propose, develop, and assess solutions for a safe and acceptable disposal of radioactive waste. Geological disposal is considered a realistic solution for the final disposal of high-level and long-lived radioactive waste, whereas shallow-land burial is examined for the disposal of low-level radioactive waste. In Belgium, deep geological burial in clay is the primary option for the disposal of High-Level Waste (HLW) and spent fuel.

Performance assessment The Performance Assessment project focuses on assessing the long-term safety and the acceptability of disposal systems by developing and applying validated methods to the modelling of the various phenomena controlling the release and the migration of radionuclides from the repository to the biosphere. This assessment requires reliable data on the different components of the system and more particulary on the most critical elements of integrated repository systems. The programme is therefore divided into complementary projects dealing with particular aspects.

Programme Running performance assessments are elaborated in the framework of the following contracts and research agreements with NIRAS/ONDRAF and the EC:

- a multiyear research programme for elaborating the performance assessment of the potential geological disposal of radioactive waste in the Boom Clay layer at the Mol site;
- the SPent fuel Assessment (SPA) project, a performance assessment of the direct disposal of spent fuel at the Mol site;
- complementary concept assessments for shallow-land burial in Belgium and abroad.

Achievements We are elaborating a detailed performance assessment for the Mol site, following a strict quality-assurance procedure. The first step of this assessment consists in a systematic scenario study. All phenomena that are almost certain to take place will be treated in a normal-evolution scenario, but eight altered-evolution scenarios were also identified.

The PORFLOW code allows us to simulate the release of radionuclides from the near field and their migration through the host clay layer, in order to analyse the consequences of the disposal of vitrified HLW. An example of the calculated radionuclide fluxes into the Neogene aquifer is given in Figure 1 for the case of the normal-evolution scenario. The transport of radionuclides released from the host clay through the aquifer into the biosphere is simulated with the Groundwater Modelling System (GMS) package. Calculations of the flow paths allowed us to determine the area and the rivers that might be influenced by radionuclides released from the geological repository.

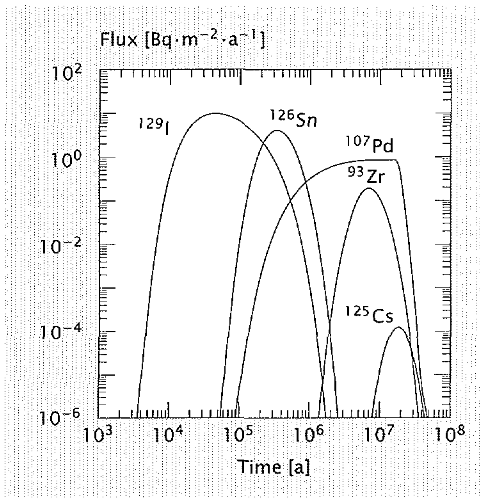


Figure 1 Calculated fluxes of selected radionuclides released from the host clay layer into the Neogene aquifer.

For the SPA project, we collected the basics for the assessment into a topical report covering the geology and hydrogeology of the site, the spent-fuel inventories, the packaging policy, and the repository design. The next step of this assessment will be to select and describe the scenarios to be analysed.

In the framework of an internal R&D project, we collected clay cores in clay pits and measured the vertical and horizontal hydraulic conductivity of the clay. The results of these measurements, together with those obtained from the measurements on clay cores taken during a data-acquisition campaign, are essential for defining the spatial variability of this parameter of the Boom Clay on a regional scale.

Perspectives for 1998 The performance assessments regarding the geological disposal of reprocessing waste in the Boom Clay layer at the Mol site are long-lasting and iterative processes which will have to continue for some more years. In particular in 1998, we will analyse in detail the normal-evolution scenario for the most important waste types. We will use these results in our contribution on environmental impact assessment to the SAFIR 2 report, to be presented in 1999 by NIRAS/ONDRAF to the Belgian authorities responsible for radioactive waste disposal.

From 1998 until 1999, we will perform the consequence analyses of spent-fuel disposal in clay in the framework of the EC's SPA project.

Characterization of the geosphere The host rock is the natural and the main barrier against the migration of radionuclides to the biosphere. Its characterization includes that of the confining layers and requires

- to characterize the Boom Clay formation adequately and to study its homogeneity;
- to collect the geological, piezometric, and hydraulic data required for studying the hydrogeological system in the Mol area and to develop a regional aquifer model for Northeastern Belgium;
- to test and validate computer codes used in the performance assessments for simulating water flow and transport of radionuclides in aquifers;
- to build confidence in long-term predictions by developing natural-analogue studies on the Boom Clay formation itself.

Programme The hydrogeological studies sponsored by NIRAS/ONDRAF are piezometric measurements in the boreholes of SCK•CEN's hydrogeological network and the elaboration of a data-acquisition campaign needed for further developing the multilayer regional aquifer model of Northeastern Belgium. This campaign is complemented by an internal R&D project that investigates the spatial variability of the hydraulic conductivity of the Boom Clay.

In the PHYMOL (PalaeoHYdrogeology of the MOL site) project, sponsored by the EC, we will look for indications, on the basis of the geochemical distributions, regarding the ground-water flow in the Mol region during a glaciation.

Achievements The fourth borehole of the hydrogeological data-acquisition campaign has been drilled at Weelde in 1997. It reaches the top of the Ieper Clay and has allowed us to take cores and to carry out geophysical loggings. The hydraulic conductivity of clay cores taken at Zoersel and Mol is measured to study the variability of the hydraulic conductivity of the Boom Clay with depth and to look for correlation with the lithostratigraphy of the clay layer.

Perspectives for 1998 We will resume the regional hydrogeological modelling by taking into account the results obtained from the large 1996–1997 data-acquisition campaign. In this respect, we will also further determine the hydraulic conductivity on clay cores.

For the PHYMOL project, we will interpret the results of the first series of geochemical and isotope analyses on ground-water samples and develop models to explain the observed isotope distributions.

Characterization of the waste Characterizing the source term is of primary importance for assessing a waste disposal system. It requires

- to assess, through in situ and laboratory corrosion experiments, the performance of candidate overpack materials as physical engineered barrier;
- to determine or verify various chemical and physical characteristics of radioactive waste forms relevant to the Belgian waste management programme;
- to improve or develop tools and methods for characterizing radioactive waste;

- to assess experimentally or demonstrate in situ, in parallel with modelling works, the long-term behaviour of various waste forms with regard to their geological disposal in clay.

Programme The programme comprises the following activities:

- the nondestructive assay of real LLW packages, as part of a round-robin campaign, and the measurement of the leaching stability of cemented ion-exchange resins;
- the investigation of the effect of the radiolythic degradation of bituminised waste and of the degradation products of contaminated cellulose waste on the solubility of americium and plutonium in geological disposal situations (clay or bentonite environment);
- the study of the corrosion mechanisms of HLW glass in geological disposal media, with special emphasis on the leaching behaviour of neptunium and technetium, and on the geochemical and mathematical modelling of the corrosion; in complement to this, the characterization of neptunium complexes formed when neptunium-doped glass and clay water interact;
- the determination of the solubility of UO_2 in Boom Clay water, emphasizing the effect of humic acids and carbonates;
- the study by electrochemical techniques of the corrosion stability of stainless-steel container materials in geological disposal media, considering the influence of the most important parameters on pitting corrosion;
- the study by in situ tests of the interaction between cemented or vitrified waste and Boom Clay or backfill materials.

Achievements We had to expand considerably our laboratory infrastructure to accommodate the new R&D programmes started in 1997. We purchased three glove boxes to perform tests under anaerobic atmosphere (pure argon, occasionally with control of the CO_2 pressure). They are used for the plutonium and americium solubility study, the UO_2 solubility study, and the electrochemical corrosion study on container materials.

We proposed a final interpretation of the in situ corrosion tests on glasses started some ten years ago, focusing on the tests yielding contact with Boom Clay at 90°C. An extended programme of surface and profile analyses using Scanning Electron Microscopy – Energy-Dispersive Spectroscopy (SEM-EDS), Electron-Probe MicroAnalysis (EPMA) with X-rays, and Secondary-Ion Mass Spectroscopy (SIMS) on the corroded glass samples enabled us to interpret the measured mass losses. We demonstrated the meaningfulness of the in situ test data as compared with laboratory simulation tests. We obtained new information on the dissolution mechanisms from the longer experiments (until 7.5 years). The effect of the glass composition on its dissolution upon interaction with Boom Clay increases with time, the difference between the "best" and "worst" glass being about a factor of 30. We propose three types of dissolution behaviour: a matrix-controlled dissolution in case of the Cogéma glass SON68, a selective, diffusion-controlled dissolution in case of the DWK PAMELA glass SAN60, and a quite fast dissolution for the DWK PAMELA glass SM513 associated with secondary-phase formation. The total depletion depth of the glasses after 7.5 years ranges between a few hundred microns and some tenths of a micron. We also observed that the glass corrosion in contact with Boom Clay is very sensitive to temperature. We propose a dissolution rate of $0.3\,\mu m \cdot a^{-1}$ at the ambient temperature of 16°C, suggesting that the glass matrix is indeed a barrier in the geological disposal system.

We developed a geochemical model to describe the interactions between HLW glass and Boom Clay. This model, based on the combination of two submodels (glass/water and clay/water), uses the PHREEQC geochemical code and assumes that the cation concentration in solution is controlled by single minerals. Silicon, for instance, would be controlled by the chalcedony phase in Boom Clay. We obtained a good agreement between the calculated and measured composition of the interstitial clay water. So far, we only applied the model to the Cogéma glass SON68. The main finding is that the calculated soluble silica concentration in solution, $K_s = 10^{-3.7}$, remains below the saturation limit of amorphous silica, $K_s = 10^{-2.9}$ (representative for the glass). This explains the corrosion-enhancing effect of Boom Clay, which acts as a sink for silica released from the glass and thus prevents saturation of the solution. Further efforts will consider variations in glass composition and other glasses, to try to explain the different corrosion behaviours and the possible occurrence of secondary minerals.

We made significant progress in modelling the glass corrosion with a Monte Carlo transport code used to solve the mathematics of the transition state theory. This model assumes that the glass consists of two kinds of particles: a network former (silicon) and a network modifier (sodium), arranged on a diamond lattice in contact with water. Our Monte Carlo model so far assumes three processes: silica dissolution, ion exchange, and diffusion of silicon or sodium in water. We choose the model parameters, the probabilities and thermodynamic constants of the various processes, and the time step. The model calculations show two types of dissolution behaviour. For small concentrations of the network modifier (sodium), dissolution is congruent and the dissolution of the network former (silicon) dominates the dissolution process. For higher concentrations of the network modifier, the dissolution is not congruent and large surface layers form. Typical results from geochemical and Monte Carlo modelling are shown in Figures 2 and 3.

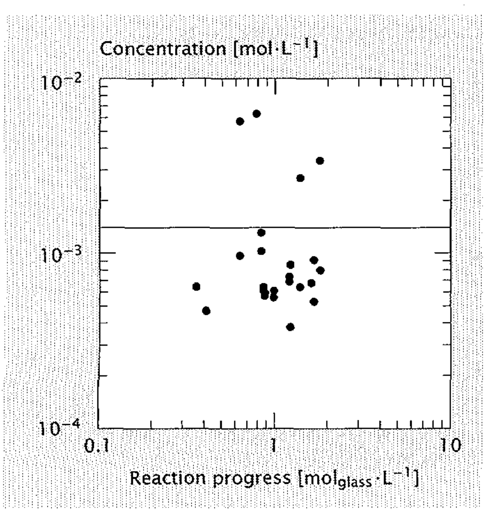
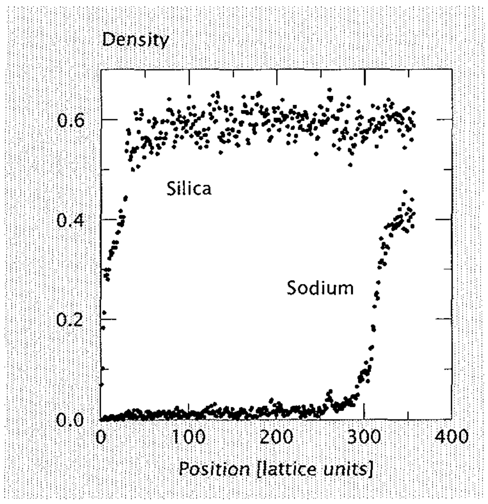


Figure 2 Measured (points) and calculated (line) concentrations of silicon released from the SON68 glass in a Boom Clay / clay-water slurry, at 90°C.

Figure 3 Surface layer profile calculated by Monte Carlo modelling for a Na/Si ratio of 0.4 after 0.2 days of leaching.



The electrochemical corrosion tests on candidate overpack materials were started. We focus on the AISI 316L stainless steel recently proposed by NIRAS/ONDRAF and investigate to a minor extent other materials such as other stainless steels, carbon steel, and nickel and titanium alloys, using a standard corrosion cell. The environmental conditions selected include Boom Clay and bentonite media, aerobic and anaerobic conditions, various concentrations of agressive agents (Cl^- and $S_2O_3^{2-}$), and temperatures of 16, 90, and 140°C. Polarization curves allow us to determine the characteristic potentials, for instance the critical potential for pit nucleation E_{np}.

The new electrochemical corrosion programme started by establishing a procedure to fabricate crevice-free working electrodes. A method using a double epoxy-resin system for embedding the metal yields good results. Preliminary results in clay water under aerobic conditions show that only carbon steel corrodes (by uniform corrosion) at 16°C, whereas more materials show signs of pitting corrosion at 90°C, for certain concentrations of Cl^- and $S_2O_3^{2-}$.

Progress on new projects includes the following achievements.

- Five full-size LLW packages were assayed by (nondestructive) gamma spectroscopy or passive neutron counting.

- We started to qualify some real cemented ion-exchange resins produced by the Doel power plant regarding homogeneity and leaching.
- We performed radiolythic degradation tests on inactive Eurobitum samples, by irradiating them for a total absorbed dose of 4.3 MGy in the BRIGITTE facility in BR2. The degradation products were fully analysed and their effect on the americium and plutonium solubility studied. The project on alpha-contaminated cellulose waste follows a similar rationale.
- New solubility tests on UO_2 in various types of clay waters aim to investigate the effect of humic acids and carbonate. Within two months, we obtained uranium solubility data between 2 and 8×10^{-7} M. The real solubility might be slightly higher.
- We started to investigate the neptunium complexes formed when HLW glass interacts with Boom Clay water. This study involves leach tests with neptunium-doped glass, the determination of the complexation constant for Np(IV) with humic acids, and the characterization of the complexes formed by means of laser-induced photoacoustic spectroscopy.
- We prepared new tests on cemented waste, with a view to investigating its long-term behaviour in disposal conditions in Boom Clay (in situ corrosion test tubes). Among the cement formulations used, one incorporates the reprocessed BR2 fuel.
- Another new in situ project, the CORALUS experiment, investigates the interaction between alpha-doped waste glass and bentonite backfill or Boom Clay. As a special feature, it includes ^{60}Co gamma-radiation sources and instrumentation allowing solution and gas sampling and analysis. The first test—a blank tube—will start during the first semester of 1998 (Fig. 4).

Perspectives for 1998 Since many experiments developed within the programme on waste packages, such as the CORALUS experiment, are rather time-consuming, they will continue in 1998.

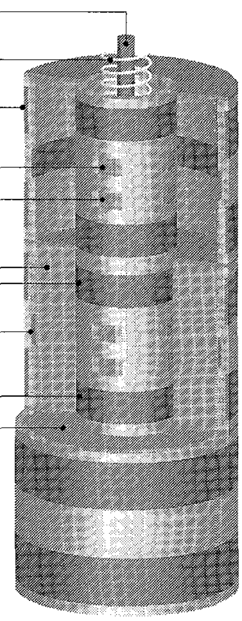


Figure 4 Three-dimensional view of a CORALUS test tube. Backfill and outer porous support tube of modules B and C are cross-sectioned to show details of the inner support tube.

Important milestones will however be achieved in 1998. In particular, we will submit our internal quality-assurance system to an external audit for accreditation and we will complete the round-robin campaign for nondestructive assay of full-size waste packages.

For the waste forms relevant to the Belgian programme, we can further mention

- the laser-induced photoacoustic spectroscopy analyses to be performed on the neptunium complexes from the leach tests on the neptunium-doped glass, in collaboration with Belgian and German institutions;
- the electrochemical and immersion tests to be started in the framework of the corrosion programme on canister materials;
- the new in situ corrosion tests to be installed with cement specimens and leach tests to be carried out on fully active cemented reprocessed BR2 fuel;
- the solubility and sorption tests with americium and plutonium to be performed for the bitumen and cellulose project.

Processes taking place (on the way) from the repository to the biosphere Assessing the performance of geological disposal systems requires knowledge of the source term and the near field, but also understanding and forecast of the migration of radionuclides in clay, their transport in the aquifers, and their potential release into the biosphere, as well as any process which might lead to the creation of migration paths. Therefore the following four objectives are of primary importance:

- to develop, test, and validate a conceptual and a mathematical model for the migration of radionuclides in clay, resorting to both laboratory and large-scale in situ migration experiments;
- to develop, test, and validate a model for the thermohydromechanical and chemical behaviour of an unsaturated clay-based backfill material;
- to study the generation of hydrogen gas due to anaerobic corrosion of metals and its subsequent migration through the clay by diffusion and gas breakthrough;
- to investigate the reaction of a clay environment to the temperature increase and the radiation dose in case of disposal of reprocessed HLW in the Boom Clay layer.

Programme As regards the far field, we extended a few years ago the part of the programme related to the clay host rock from the migration of radionuclides in the Boom Clay formation to the study of gas migration. With regard to gas generation, we also performed anaerobic corrosion experiments in clay slurries to study the corrosion rate of stainless and carbon steel in contact with Boom Clay.

More recently, the study of the influence of the organic matter present in the clay water contributed substantially to the migration programme. Migration tests study the diffusion of actinides and fission products, and the mobility of the dissolved organic matter in the interstitial clay water. Experiments with labelled organic matter are also performed.

Large-scale three-dimensional validation experiments are in progress. Installed from the underground research facility, they use tritiated water and ^{14}C-labelled bicarbonate.

In the framework of doctoral and postdoctoral theses, we develop electrokinetic methods to accelerate the time-consuming migration experiments (Fig. 5) and we study the Boom Clay formation as a natural analogue to increase the confidence in the modelling results for very long time spans.

Regarding the near field, the first phases of the CERBERUS project quantified the medium effects (E_h, pH, hydrogen production) induced by a HLW canister simulated with heating elements and ^{60}Co sources. After retrieval of the sources and hydration of the backfill, we are presently analysing the near-field effects on clay samples cored in the surrounding clay. The programme investigates further the performance of selected clay-based materials in different experimental conditions and configurations.

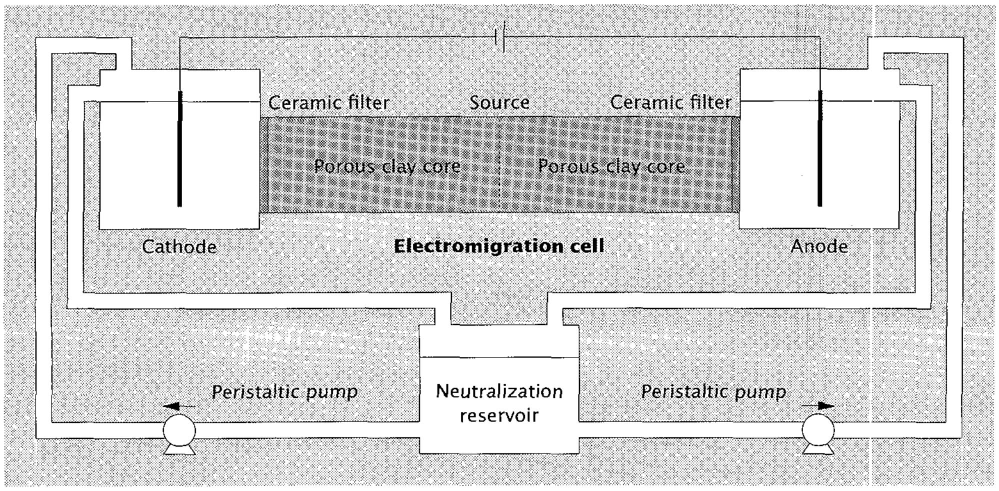


Figure 5
Experimental setup of the electrokinetic migration experiments.

The RESEAL project aims at the large-scale in situ demonstration of the feasibility of sealing a repository in a clay formation. In co-operation with European partners, we will seal an experimental shaft and test it for water and gas tightness. This experiment will also help us validate models for the calculation of water and gas flow through both clay seal and near-field clay.

The CATSIUS CLAY project is another validation and benchmark exercise for codes dealing with the hydromechanical and thermomechanical behaviour of unsaturated clays. To support code development, we continue to study different clay-based backfill materials with European partners. In particular, for model validation, we propose the representative set of reference field data obtained through the in situ test BACCHUS 2.

Achievements We continued the time-consuming experiment allowing us to determine the migration parameters in Boom Clay of the radionuclides of major concern.

We demonstrated and validated the applicability of the electrokinetic methods to determine diffusion coefficients in porous media (Fig. 6):

- diffusion coefficients can be obtained by independent calculation methods;
- the experimental time for diffusion studies reduces markedly;

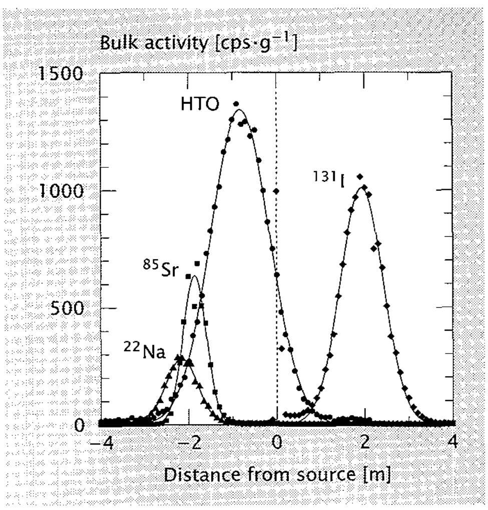


Figure 6 Distribution profiles after electromigration of ^{85}Sr ($72\,V\cdot m^{-1}$, 71 hrs), ^{22}Na ($84\,V\cdot m^{-1}$, 20 hrs), HTO ($79\,V\cdot m^{-1}$, 20 hrs), ^{131}I ($81\,V\cdot m^{-1}$, 20 hrs).

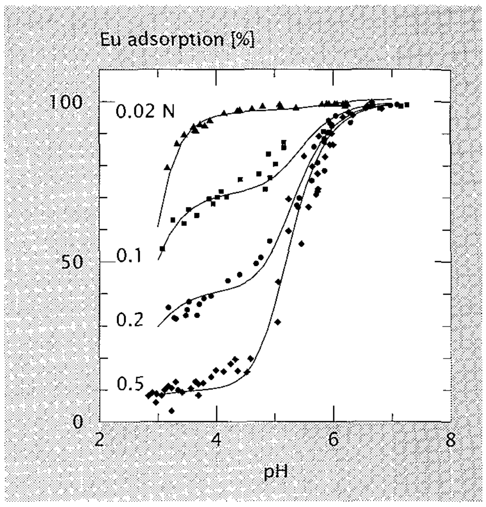


Figure 7 Europium sorption on illite as a function of pH and $NaClO_4$ concentration.

- the statistical reliability of the migration parameters increases markedly;
- soil characteristics such as the dispersion length and electro-osmotic mobility were determined;
- retardation coefficients for cationic species can also be obtained.

To increase the confidence in the long-term model predictions of the radionuclides migration, we characterized in detail the mineralogy and the geochemistry of the Boom Clay on samples of the Zoersel and Mol-1 drillings. We paid special attention to the distribution and mobility of the trace elements (lanthanides, uranium, and thorium) naturally occurring in the Boom Clay; these can be considered as natural analogues of critical elements for the long-term safety of a radioactive-waste disposal site. We are presently characterizing the radiochemistry of the Boom Clay.

To study the fundamental interactions of radionuclides and Boom Clay, we developed a multisite sorption model for clay minerals. This model allows us to integrate a sorption database into a thermodynamics-based geochemical equilibrium calculation. Figure 7 shows the good agreement between the measured and the modelled sorption data for an europium-illite system. The lines are calculated by the multisite model considering both cation exchange and surface complexation sorption.

We continued to monitor and sample the large-scale in situ injection experiment with tritiated water, started in January 1988. After 10 years, the measured tritium concentrations in the interstitial water still agree very well with the results of the MICOF computer code simulation.

Regarding our large-scale three-dimensional in situ migration experiment started in 1995, we detected tritium in the filters located at one metre from the injection point, but the ^{14}C level is still below the detection limit.

We continued our research on the mobility of the dissolved organic matter (humic acids) in the interstitial clay water using labelled organic matter in the framework of an EC contract (TRANCOM-CLAY project). Two labels were tested for their stability in contact with Boom Clay: the ^{125}I label proved to be unstable, whereas the experiments with the ^{14}C one showed a good stability.

Percolation experiments through clay cores and a new large-scale in situ injection experiment are being performed with ^{14}C-labelled organic matter.

The pH and E_h of the Boom Clay are measured under real in situ physicochemical conditions: clay water, at a hydraulic pressure of 11 bar, in equilibrium with its inorganic carbon species (CO_2 equilibrium partial pressure). We measured an in situ pH value of 8.2.

As part of the study of the homogeneity of the Boom Clay layer, the hydraulic conductivity and migration parameters for tritiated water and iodine were measured for clay cores sampled over the whole thickness of the formation.

In the near field, we investigated the influence of both temperature and radiation on the migration properties of the Boom Clay through the results of an in situ migration experiment with ^{241}Am and ^{99}Tc, in the surroundings of the CERBERUS demonstration test. The influence of these parameters on the migration properties appears to be negligible, confirming previous direct measurements.

After the hydration phase of the backfill of CERBERUS, we launched a detailed campaign regarding the composition (mineralogy, geochemistry) of clay cores taken from the backfill material and drilled from the host clay in close contact with the canister wall. We also retrieved the waste glass and container material samples embedded in the surroundings. Their analysis is in progress.

The study of the gas generation caused by anaerobic corrosion and the gas migration in Boom Clay is in progress. Stainless steel 316L shows almost no anaerobic corrosion in contact with a Boom Clay slurry.

In co-operation with different European partners, we developed and tested computer codes for the hydromechanical and thermomechanical behaviour of unsaturated clay-based backfill material; these codes were applied to the results of support laboratory experiments and large-scale in situ tests, one of which is the BACCHUS 2 test, already running successfully for four years.

After full hydration of the backfill, we measured the hydraulic and gas transport parameters and confirmed the homogeneity and the tightness of the hydrated backfill.

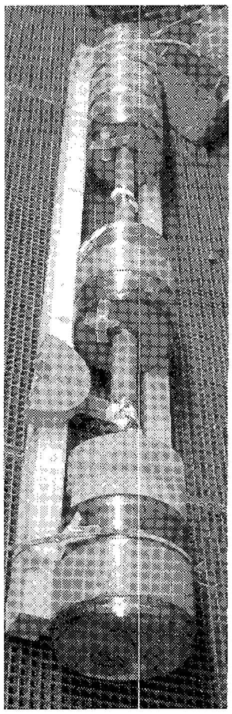
We obtained within the CATSIUS CLAY project the first simulations of the hydraulic pressure and the stress evolution inside and around the BACCHUS 2 test.

We also continued two previous actions:

- confirming the first indication of desaturation recorded in clay around the PHEBUS test; this will require some more months of ventilation through the large filter element embedded in clay;
- pursuing the long-term monitoring (water pressure, displacement, and radial, axial, and total stresses) around the underground facility to control its stability and provide long-term geotechnical measurements for the modelling of the clay behaviour.

We developed a borehole-sealing test, as a preliminary action within the large-scale sealing experiment of the exploratory shaft in the HADES infrastructure (Fig. 8). This test aims at following the hydration process of two swelling

Figure 8
Experimental setup during the mounting of the clay blocks for the borehole-sealing test.



clay seals and at testing their water and gas tightness after saturation. The experimental setup, installed in a 15-metre-long borehole with a diameter of 25 cm, includes the two following seals: one with FoCa clay (a French bentonite) and one with Serrata clay (a Spanish bentonite). We will finalize the design of the shaft-sealing test on the basis of our results. The design of the host-rock instrumentation, including sensors for water pressure, ground stress, and displacement, is finished; the construction is in progress.

We performed a series of support laboratory experiments to measure the hydromechanical and gas flow parameters of the sealing materials and of unsaturated Boom Clay. These parameters are used for design calculations and blind predictions of the behaviour of the borehole and shaft seals. The simulations show the sensitive influence of the unsaturated hydraulic parameters and boundary conditions on the saturation time.

Perspectives for 1998 With regard to migration, the electrokinetic method will be applied to sorbed species, but some other developments are awaited in the framework of new R&D proposals on site remediation.

To study the exchange between mobile and immobile organic matter, we will perform migration experiments with doubly labelled matter.

Underground infrastructure SCK•CEN has constructed and operates a unique underground research facility, called HADES, located in the Boom Clay layer at a depth of 225 metres. In this facility, it carries out in situ experiments, studies the disturbances due to the construction of infrastructures in clay, and optimizes the design and the construction of a final repository. Indeed, the infrastructure must be adapted to its geological environment and plays an important role in the global performance of the near field. It is therefore also necessary

- to improve the knowledge about digging large excavations in deep clay in order to select the most appropriate techniques for building a final repository and to get experienced in safely operating such facilities;

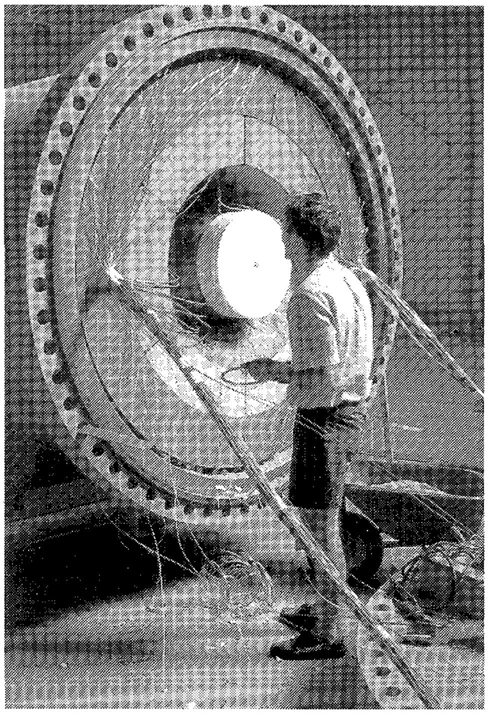


Figure 9 The PRACLAY mock-up before installation of the cover flange.

- to provide infrastructure and technical assistance to the experimenters, from the installation phase to the follow-up of any demonstration or validation test.

Programme The daily and medium-term operation of the underground research facility under safe conditions requires maintenance and assistance works. Maintenance ensures and improves the safety and stability of the facility and its technical equipment, whereas assistance means support to experimenters for drilling activities, access to the experimental areas in representative conditions, and reliable and traceable data acquisition.

The real-scale simulation of a disposal gallery (PRACLAY experiment) follows the current concept of a concrete-lined gallery with a central stainless-steel tube containing the waste forms. Bentonite-based backfill blocks fill the gap between the central tube (diameter of 0.5 metre) and the lining (inner diameter of 2 metres). Whereas the actual disposal galleries will be several hundred metres long, the PRACLAY demonstration gallery will be restricted to 30 metres. Electrical heaters will simulate the generation of heat by the waste forms, since the experiment will not use active ones. The construction of the PRACLAY gallery requires that of a second shaft and of a gallery connecting it to the current infrastructure.

We built a five-metre-long surface mock-up having a cross-section similar to that of the disposal gallery as far as central tube and backfill are concerned (Fig. 9). A steel liner will keep the backfill under pressure when the latter starts to swell due to water uptake.

Achievements The activities of the support team were mainly core sampling, drilling and overcoring, preparation or installation of new experiments, and follow-up of running ones.

We provided assistance to the EIG PRACLAY, in charge of the extension of the underground facility, for such actions as defining the technical specifications for the construction of the second shaft, analysing the corresponding tenders, and, presently, following up the construction works. In November, after such preliminary works as the freezing of the water-bearing sands down to a depth of 190 metres, the contractor started to excavate the second shaft (Fig. 10). This shaft and its equipment should be put in operation in early 1999. We are now providing similar assistance for drafting the specifications for the excavation of the connecting gallery.

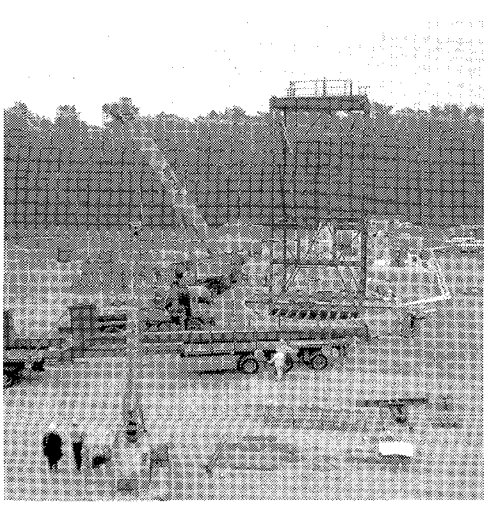


Figure 10 Construction of the hoisting equipment for shaft sinking.

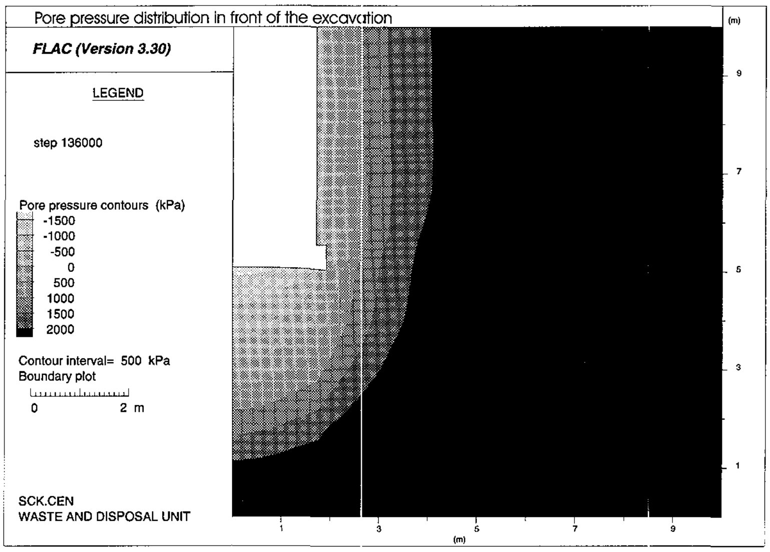


Figure 11 Calculations of pore pressures in clay during gallery excavation.

The monitoring and modelling related to the excavation of the connecting gallery resulted in the European project CLIPEX, with French and Spanish partners, and co-ordinated by the EIG PRACLAY. The project, started at the beginning of 1997, will run until the end of 1999.

First estimates of the displacements and stress variations around the excavation (Fig. 11) allowed us to draft the final specifications for the instrumentation, such as the location and measuring range of the proposed instruments and sensors, of which some are already ordered (stress, displacement). We devoted special attention to the compatibility of the instrumentation with the future excavation works.

In April 1997, we started to install the backfill and the instrumentation of the mock-up, after acceptance of the mock-up structure in January and after final acceptance of the demonstration building. After installation of the cover and installation and connection of the instrumentation racks, we flooded the mock-up at the beginning of December. We expect a sufficient hydration of the backfill by early 1998 to switch on the heating elements.

Perspectives for 1998 To optimize the planning and execution of drilling works, we will purchase a new coring equipment at the beginning of 1998.

The excavation of the second shaft will extend over the whole of 1998. In parallel, we will finalize the specifications for the excavation of the connecting gallery and of the PRACLAY gallery, and analyse tenders.

The installation of the CLIPEX instrumentation related to the connecting gallery will take place in the first quarter of 1998, from the existing underground structure (test drift); this will guarantee sufficient time for restoration of the ground conditions around the measuring devices before the start of the digging works, scheduled for the second semester of 1999. A characterization and monitoring programme will be developed prior to this installation to get more accurate data on some essential geomechanical parameters. This programme and the associated interpretation will enable us to improve the current models on the hydromechanical behaviour of the clay.

The heating of the PRACLAY surface mock-up will most likely be launched during the first quarter of 1998, depending on the evolution of the current hydration phase of the backfill material.

Partners, sponsors, and customers

Scientific partners Atomic Energy Authority (AEA Technology) — Association pour la recherche et le développement des méthodes et processus industriels (ARMINES) — Belgische Geologische Dienst/Service géologique de Belgique (BGD/SGB) — British Geological Survey (BGS) — Commissariat à l'énergie atomique (CEA) — Centre belge d'étude de la corrosion (CEBELCOR) — Chinese Institute for Atomic Energy (CIAE) — Chalmers University of Technology — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) — Centro Internacional de Métodos Numéricos en Ingeniería (CIMNE) — Clay Technology Lund AB — Energieonderzoek Centrum Nederland (ECN) — Etudes-recherches-matériaux (ERM) — Forschungszentrum Karlsruhe (FZK) — University of Aberdeen — Groupement pour l'étude des structures souterraines de stockage (G3S) — GEOCONTROL — Stockage souterrain (GEOSTOCK) — Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) — Institut de protection et de sûreté nucléaire (CEA-IPSN) — Institute for Reference Materials and Measurements (IRMM) — Instituto Sperimentale Modelli E Strutture (ISMES) — KEMA Nuclear — Katholieke Universiteit Leuven (KUL) — University of Loughborough — Université de Liège (ULg) — QuantiSci Ltd — Technical University of Delft — Tractebel — Teollisuuden Voima Oy, Development Office (TVO) — Université catholique de Louvain (UCL) — University of Coruna — Université Libre de Bruxelles (ULB) — University of Roma — University of Birmingham — University of Exeter — Polytechnic University of Madrid (UPM) — Polytechnic University of Cataluña (UPC) — Université de Paris-Sud (UPS) — University of Wales, College of Cardiff (UWCC) — Vlaamse Instelling voor Technologisch Onderzoek (VITO) — Vrije Universiteit Brussel (VUB) — Technical Research Centre of Finland (VTT)

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