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WASTE AND DISPOSAL: RESEARCH AND DEVELOPMENT

Background

The primary mission of the Waste and Disposal Department is to perform research in support of the development of safe and sustainable solutions for the management and geological disposal of radioactive waste. At the international level, consensus exists on geological disposal as an adequate long-term solution for the final disposal of high-level and long-lived radioactive waste. In Belgium, geological disposal in clay is the primary option for the final disposition of high-level waste (HLW) and spent fuel. The Boom Clay formation at the Mol site is studied as the reference host rock for methodological studies on the geological disposal of radioactive waste. We started investigations on the Boom Clay in 1975.

Within the Belgian R&D programme, performance assessment studies play a key role in the evaluation of the long-term safety of geological or shallow disposal systems. These studies contribute:

- to identify possible scenarios that might lead to the exposure of man to radioactivity or toxic substances;
- to analyse the consequences of the most relevant scenarios and
- to compare the estimated concentrations, fluxes, doses and risks with appropriate safety criteria.

Because aquifers are in Belgium key components of shallow or deep disposal systems, hydrogeological modelling is a critical element for assessing the long-term safety of a repository.

Other key factors in safety assessment are:

- the waste inventory;
- the short- and long-term behaviour of waste forms and engineered barriers and
- the barrier properties of the host formation.

The Waste and Disposal Department studies the different processes governing the return of radionuclides to the biosphere as well as the factors influencing these processes. Experiments on clay cores and field tests are performed to determine the values of the input parameters for modelling these processes. These investigations are complemented with large-scale in situ experiments in close to real conditions from underground research laboratories and with natural analogue studies.

At the beginning of 2002, the Belgian agency for radioactive waste and enriched fissile materials ONDRAF/NIRAS will present the SAFIR 2 report (Safety Assessment and Feasibility Interim Report) to the authorities. As a contribution to this report, SCK•CEN summarised the main results obtained during the last 10 years on the performance assessment of the geological disposal of high-level and long-lived radioactive waste at the Mol site.

As a contribution to improve the decision-making process, we are actively involved through PhD and postdoctoral theses in philosophical and ethical reflections on waste disposal and management, including the study of socio-psychological factors and cognitive dissonance mechanisms (see chapter "Integration of social sciences and humanities in research"). This approach is complemented by the observation of participation groups in local partnerships as Mona (Mol) and Stola (Dessel) for low-level waste disposal options in the vicinity of these two municipalities. We are following similar involvement practices in Europe in the frame of the European Concerted Action on Waste Management "COWAM".

Objectives

The overall objectives of R&D conducted at the Waste and Disposal Department are:

- to assess the performance and to identify the most influential elements of integrated repository systems for the final disposal of radioactive waste;
- to characterise in detail the source term and to assess the compatibility and the performance of the waste forms and other artificial barriers with the clay environment;
- to understand and determine the migration of radionuclides and gases through the host formation and engineered barriers and
- to understand the whole hydrogeological system in north-eastern Belgium governing the geosphere transport to the biosphere.

In addition to the general objectives, each of our projects in its field of expertise needs to meet the following detailed objectives:

- to develop methodologies and tools oriented to long-term safety, applicable to different waste types, host formations and disposal concepts;
- to determine or verify the various relevant physical and chemical characteristics of barriers or waste forms relevant to the Belgian programme;
- to provide reliable models and parameters, based on a sound scientific understanding and to collect laboratory and field data according to quality assurance requirements;

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- to test, verify and improve computer codes used in performance assessment calculations of waste disposal concepts or contaminated sites including e.g. processes like the water flow and transport of radionuclides in saturated and unsaturated engineered barriers, aquifers and soils.

The next sections describe the scientific programme and the main achievements of work performed by the Waste and Disposal Department in 2001. Progress and achievements in respectively performance assessments, waste forms and packages, near- and far-field studies are reported on.

Programme

Performance assessments

Performance assessments were conducted in the framework of the following contracts and research agreements:

- the performance assessment of the potential geological disposal of high-level and long-lived radioactive waste in the Boom Clay layer at the Mol site;
- the evaluation of the role and the harmonisation of the treatment of bentonite barriers in performance assessments of high-level waste disposal systems at European Community (EC) level: the BENIPA project (BENtonite barriers in Integrated Performance Assessment);
- the exploration of the applicability of various output variables (concentrations, fluxes) as performance and safety indicators: the SPIN project (testing of Safety and Performance INdicators);
- the assessment of the adequacy of data and samples from the Russian injection sites in order to better understand the chemical behaviour and migration of radionuclides in the geological environment: the BORIS project (BORehole Injection Sites at Krasnoyarsk-26 and Tomsk-7);
- the performance assessments for site-specific concepts regarding surface or deep disposal of low-level waste at the nuclear zones in the Mol-Dessel region (B);
- the contribution to the impact assessment studies of a radium storage facility at Olen (B);
- training in performance assessment methodology for East-European countries.

We focused the hydrogeological studies supporting some of these assessments on the further development of the multi-layer regional aquifer model of north-eastern Belgium and the collection of the required data (piezometric measurements, spatial variability of the hydraulic conductivity for the Boom Clay, etc).

Waste forms and packages

The programme consists of the following activities:

- the investigation of the compatibility of bituminised radioactive waste (Eurobitum) with the disposal environment;
- the investigation of the effect of chemical degradation products of contaminated cellulose-based waste on the solubility and sorption of Am and Pu in Boom Clay;
- the study of the corrosion mechanisms of high-level waste glass in geological disposal media;
- the study of the effect of α-radiolysis on the corrosion of UO_2 doped with ^{233}U and ^{238}Pu;
- the study by electrochemical techniques of the sensitivity to localised (pitting) corrosion of stainless steel container materials in geological disposal media. Immersion corrosion tests are conducted to investigate the time dependence;
- the investigation and demonstration by *in situ* tests of the interaction behaviour between alpha-active vitrified waste samples and backfill materials: the CORALUS project (CORrosion of Active gLass in Underground Storage conditions).

Near- and far-fields

We developed further the characterisation activities of the backfill material (near-field) and the host formation (far-field) in the following directions:

- migration tests carried out to study the diffusion of actinides, fission products and the mobility of the dissolved organic matter in the interstitial clay water. We developed and applied electrokinetic methods as a complementary technique to reduce the very long time required for performing migration experiments and to study the speciation of the different radionuclides in the reducing clay sediment;
- large-scale 3-D experiments with tritiated water, with ^{14}C-labelled bicarbonate, and with ^{14}C-labelled organic matter, installed from the underground research facility. These experiments are aimed at confirming the anisotropy of the hydraulic parameters and at validating the migration model and the parameter values;

- experiments with labelled organic matter (OM) designed to deepen the understanding of the role of the organic matter on the transport of radionuclides by complexation in a reducing, organic rich clay sediment and to improve the conceptual model to be implemented in performance assessment: the TRANCOM-II project (TRAnsport of Nuclides by Compexation with Organic Matter);
- detailed characterisation of the organic matter and the study of its evolution with time, assumed to confirm the long term geochemical stability of the Boom Clay;
- the study of the influence of high pH alkaline fluids (concrete construction material or backfill) on the long time performance of a repository: the ECOCLAY-II project (Effect Of Cement on CLAY barrier performance);
- a large-scale *in situ* demonstration project developing and assessing backfill and sealing materials and methods. Beside the performance of the seal with regard to water and gas tightness, the test allows to validate models describing water and gas flow through the seal and the near field: the RESEAL project (REpository SEALing in argillaceous rock);
- the determination of the degree of homogeneity of the Boom Clay with regard to the migration of radionuclides, through detailed sampling and testing over the full thickness of the formation.

Achievements

Performance assessments

We are reviewing and testing within the SPIN project various performance and safety indicators.

A good indicator of the performance of the disposal system with respect to the "retardation/slow release" safety function, in combination with the "physical confinement", is the flux of activity that is released from each component of this system.

The following figure gives as an example the fluxes of ^{99}Tc released from each component in case of direct disposal of 2 000 tons of spent fuel.

Waste form

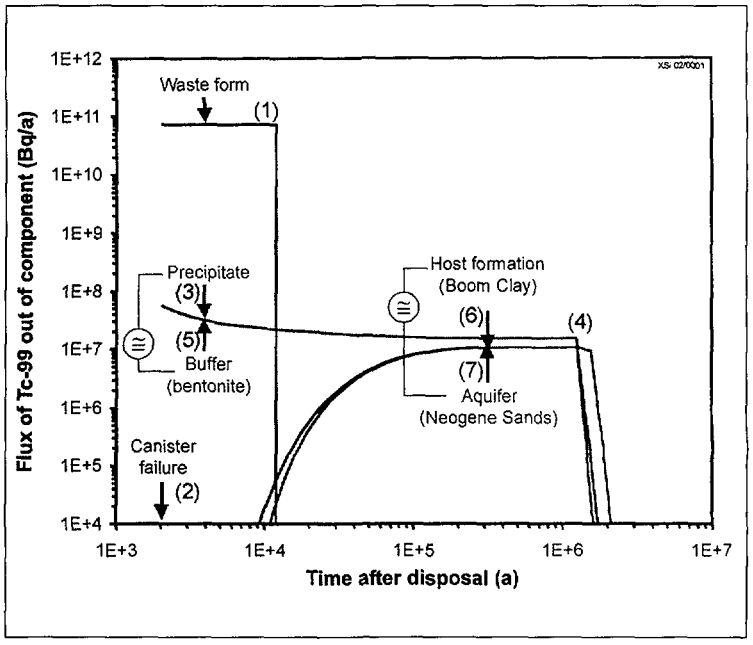
The release of the ^{99}Tc inventory from the degrading waste form (1) is conservatively assumed to be completed 10 000 years after canister failure (2). As the solubility limit of $TcO_2.nH_2O$ is quickly reached around the waste form under reducing conditions, a considerable fraction of ^{99}Tc released from the waste immediately precipitates (3). The figure indicates that the activity flux of nuclides leaving the precipitate (3) is more than 1 000 times lower than the maximum flux out of the waste (1). The precipitate only disappears after about 1.5 million years (4) and with a half-life of 213 000 years, a large fraction of the ^{99}Tc inventory decays even before migrating into the bentonite buffer.

Buffer/Clay

The figure indicates that for this nuclide conservatively assumed to be non-sorbed, the buffer only has a limited contribution: its output flux (5) is almost equal to its input flux (3). The maximum flux released from the host clay layer (6) is about a factor 1.5 lower than the flux released from the buffer (5).

Aquifer

The first radionuclides will reach the aquifer after about 10 000 years and the activity flux is equal to 50 % of its maximum value after about 60 000 years. Regarding the aquifer for which transport times of about 2 500 years are calculated, its impact on the activity flux discharged into the rivers is negligible for this example, *i.e.* the flux out of the aquifer (7) is practically equal to the flux coming out of the Boom Clay (6).



Evolution of the ^{99}Tc fluxes (Bq/a) released from each component

In 2001, the Waste and Disposal Department elaborated a compilation of 20 years of observations of hydraulic heads in various aquifers of north-east Belgium based on the data from 47 sites of SCK•CEN's piezometric network. The results of the measurements of hydraulic conductivity of the clay cores taken from boreholes at Zoersel, Mol and Weelde are now available. They show the lateral homogeneity of the Boom Clay formation in the considered area and confirm, as expected, a slight influence of the depth on the hydraulic conductivity. A new version of the regional hydrogeological model based on recent geological data, pumping rates and hydraulic characteristics is in preparation.

We also took part in an impact assessment study for the radium storage facility at Olen (Belgium). In this study, account was taken of one of the important pathways by which the contaminants can reach man, i.e., leaching to groundwater and use of groundwater for drinking and irrigation. The conceptual model to be considered in the impact assessment was derived and the waste form, the engineered barriers and the site were characterised. Waste characterisation focused on derivation of elemental concentrations under disposal conditions referring to a geochemical model. Properties of engineered barriers that govern the leaching of contaminants present in the waste, notably percolation of water, sorption and diffusion, were derived on the basis of literature and construction data. Measurements of hydraulic conductivity and sorption coefficients for radium, uranium, arsenic and lead using cores sampled from the field provided the data necessary for calculating the migration of contaminants in the aquifer. Leaching of radionuclides and non-radiological components towards groundwater was then calculated using state-of-the-art numerical models of water flow and contaminant transport in unsaturated layers. Results showed that leaching from the waste forms containing the highest concentration of contaminants present in the tailing and the radium sources, needles and salts, did not lead to unacceptable concentrations in the groundwater when a reasonable period of leaching is considered.

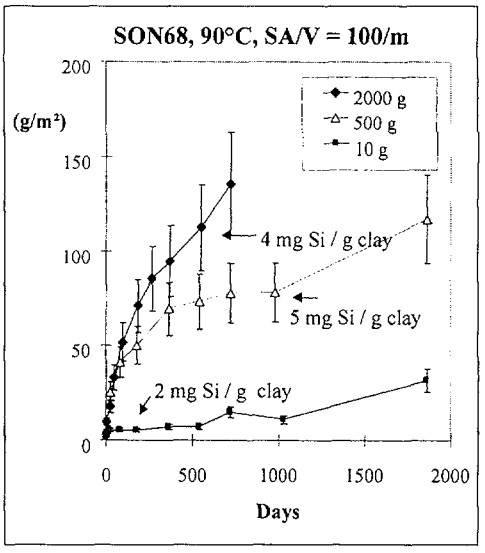
The Waste and Disposal Department provided training to Slovenian fellows on the performance assessment for low- and intermediate-level waste repository, in the frame of a Technical Co-operation (TC) project with the International Atomic Energy Agency (IAEA). We organise similar training activities on geological disposal of HLW and spent fuel for Slovak and Czech fellows in the framework of a grant from the Belgian Ministry of Economic Affairs concerning support to East European countries for enhancing nuclear safety.

Waste forms and packages

Investigations on the geological disposal of cellulose-containing waste were focused this year on the effect of cellulose degradation products on Pu and Am solubility and sorption in the Boom Clay affected by alkaline fluids, released e.g. from a concrete gallery liner (see also section near-field). This complements previous studies investigating Pu and Am solubility in *undisturbed* Boom Clay. Earlier studies have shown that α-ISA (iso-saccharinic acid, *i.e* the most important cellulose degradation product) is removed from solution when brought in contact with undisturbed Boom Clay. Accordingly, a R&D project to measure the sorption capacity of Boom Clay for α-ISA was launched.

Concerning studies on vitrified waste, results from previous R&D programmes were reviewed and new experiments were initiated after interpretation of the 5-year experimental programme 1996-2000.

It is generally accepted that the dissolution of glass depends on the amount of silica sorbed on the clay. To assess the influence of silica sorption on the glass dissolution rate, we carried out leach experiments using clay slurries with different concentrations of



Cumulative mass losses for SON68 glass for tests at 90°C in mixtures of different Boom Clay concentrations, at a glass surface area/solution volume (SA/V) of 100 m^{-1}, with indication of the estimated amount of silica released by the glass and immobilised by the clay (mg Si/g clay). The 95% confidence interval on the mass losses is estimated at 20%.

Boom Clay per liter clay water (varying from 10 to 2000 gram clay per liter).

The figure refering to SON 68 Glas at 90°C, shows that for low Boom Clay concentrations (10 and 500 gram clay per liter), the glass dissolution rate decreases with time. The amount of silica sorbed on the clay corresponds respectively to 2 and 5 mg silica per gram clay. Relatively high dissolution rates were observed for tests at high Boom Clay concentrations (2000 gram clay per liter). In the latter case, the amount of silica immobilised per gram clay equals 4 mg silica per gram clay.

The high glass dissolution rate at relatively high amounts of silica sorbed on the clay (approaching saturation) suggests that, apart from silica sorption, an additional process may take place.

This process may include the precipitation of silica into secondary phases. Both mechanisms, silica sorption on the clay and silica precipitation into secondary phases, may be the driving forces for glass dissolution as they provide sinks for silica released from the glass. Future work will focus on the detailed assessment of the impact of these mechanisms on the long term glass dissolution.

Furthermore, experiments were started to study other important aspects of glass dissolution. One can mention:

- the diffusion of silica in the clay can have an important impact on glass dissolution, because it leads to removal of silica from the glass. To study this, we designed new tests to measure simultaneously the glass dissolution behaviour and the diffusion of Si from the glass into the clay.

- It has been observed previously that the addition of glass frit to the leaching medium decreases the glass dissolution. Experiments have been started to verify this in conditions representative for the Belgian disposal concept.

- ^{237}Np, ^{99}Tc, ^{79}Se, ^{126}Sn, ^{93}Zr, and ^{107}Pd are considered as potential critical nuclides in performance assessment. The maximum mobile concentration in the liquid (in a clay environment) is used as input parameter in performance assessment studies. Experiments have started to measure these concentrations in near field clay conditions after contact with simulated waste glass, doped with these elements.

In 2001, we completed a project to investigate the release of Np from vitrified waste as well as its speciation and mobility. The main objective of this study was to gain insight in the speciation of the released Np under the site specific disposal conditions of the Boom Clay Formation.

It was found that two dominant species of tetravalent Np form in Boom Clay porewater. Most of the Np(IV) is associated with humic substances but Np(IV) is also present as a a mixed hydroxohumate complex, $Np(OH)_3HA(I)$. The complexation constant of this species varies with pH, ionic strength and humic acid solution. The value of this constant under conditions relevant for the Boom Clay was determined and will serve as a basic input parameter for speciation calculations in support of performance and safety assessments.

As part of a project supported by the European Commission, SCK•CEN investigates the compatibility of spent fuel with disposal in clay. In particular, experimental work is focused on the effect of alpha dose (rate) on the dissolution rate of UO_2 in disposal conditions as well as the influence of potential surrounding materials on the dissolution rate of this alpha-doped UO_2. The Institute for TransUranium elements (ITU) is in charge of the preparation of the alpha-doped UO_2 (^{233}U and ^{238}Pu).

The experimental programme is now progressing after preliminary actions like:

- the construction of experimental devices for static and dynamic dissolution tests with powdered UO_2 (200-300 µm) in presence (or not) e.g. of Boom Clay or bentonite.;

- the testing of preparation procedures using depleted UO_2. Annealing UO_2 at 1 000°C in Ar/H2 atmosphere proved to be successful in reducing the oxidised surface layer, prior to dissolution.

SCK•CEN completed an extensive parametric study on the two Belgian candidate container materials (stainless steels AISI 316L hMo and UHB 904L) for geological disposal in Boom Clay and compared their corrosion behaviour with some other alloys (Ni- and Ti- alloys). We studied more in detail the susceptibility to localised corrosion (pitting) of the candidate container materials by Cyclic Potentiodynamic Polarisation (CPP) measurements.

Observations from the Praclay mock-up suggest the presence of high chloride concentrations in the porewater (see section Waste and Disposal – Demonstration). Accordingly, we paid particular

attention to the influence of the choride content on the corrosion susceptibility. At a Cl- concentration of 20000 $mg.l^{-1}$, we observed signs of pitting for AISI 316L and 316Ti solutions (16°C, anaerobic conditions). These metals could suffer from long-term corrosion problems under such conditions, as repassivation will not occur once a localised attack is initiated. Similar conclusions are drawn on the susceptibility to pitting at 90°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 °C and for aerobic conditions (autoclave), the pitting susceptibility of UHB 904L increases with increasing chloride content but decreases with increasing sulphate content.

The CORALUS (CORrosion of Active gLass in Underground Storage conditions) experiment was designed to study the influence of complex and combined processes on the corrosion of vitrified HLW in repository conditions. The experimental programme foresees the installation of four modular test tubes in the Boom Clay, These test tubes contain inactive and alpha-active SON68 glass samples, three different backfill materials and, for two of the test tubes, ^{60}Co sources aiming to simulate the gamma field. Planned tests will run at 30 or 90 °C.

In 2001, significant progress was achieved. After saturation of the backfill materials of the second test tube, which was installed in April 2000, the tube was slowly heated to 30 °C. On the piezometer solutions, we measured the ionic composition and the type and amount of dissolved gases. By means of flow-through cells, we monitored the pH and redox potential of solutions in contact with the backfill interstitial solutions. Two additional test tubes were installed. After saturation of the backfill materials, these tubes will be heated to 90 °C, followed by the insertion of the ^{60}Co sources.

We further report progress in the following areas:

- the extension of the accreditation by BELTEST for our R&D projects on high-level waste glass, radioactive cellulose waste and bituminised waste;
- the initiation of R&D on the destructive radiochemical analysis of high-level waste glass, in particular the inventory of long-living nuclides like Se-79, Sn-126, Zr-93 and Pd-107.
- the further development of a reliable and reproducible methodology for measuring the redox potential in clay water to be used in the laboratory tests.

Near- and far-fields

We still developed the experimental work in surface and underground laboratories to investigate radionuclide migration, to refine the value of the main transport parameters and to check the good agreement with model predictions.

From the water of the percolation type experiments, we obtained concentration limits corresponding to an "operational solubility" in the interstitial Boom Clay water for different radionuclides. We observed that, after a few renewals of the pore water in the clay core, the concentration of the introduced radionuclide reaches a steady state. Such steady concentrations are used as an "operational solubility" in performance assessment calculations as well as to test the geochemical modelling for solubility calculations.

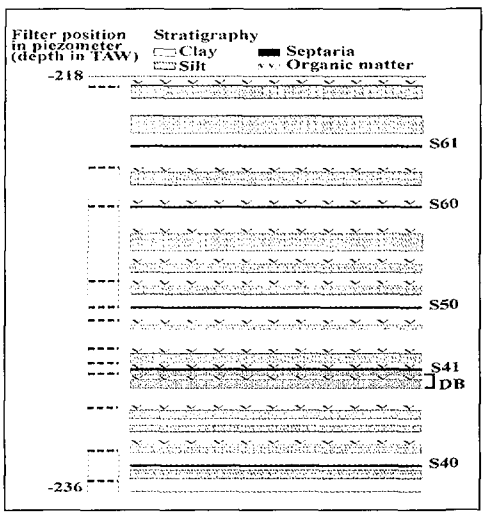
Regarding the migration behaviour of redox-sensitive radionuclides, the electromigration technique has proved to be extremely useful to acquire knowledge on the speciation of the migrating species, by separating the species on the basis of their valence. Information on the speciation of the migrating species is essential since both the solubility limited $U(OH)_4$ and the non solubility limited $UO_2(CO_3)_3^{4-}$ species can be stable under *in situ* Boom Clay conditions. The electromigration experiments indicate, in support of the speciation calculations, that the dominant U-species in solution is the solubility limited $U(OH)_4$.

One key issue in the disposal of spent fuel is the presence and release of the long-lived ^{129}I mainly present as iodide (I^-). Geological formations considered for nuclear waste disposal are unable to retard most of anionic species. As ^{129}I is considered as one of the most important radionuclides, its confinement must be based on a robust engineered barrier. In a first step, we investigated active carbon as a possible additive in this engineered barrier but the results did not reach the minimum requirements put forward by the performance assessors. After promising preliminary tests, we therefore decided to investigate organobentonites.

On samples (Mol-1 drilling campaign) taken from the glauconite sand layers (Formations of Diest, Berchem and Voort) above the Boom Clay Formation, we studied the sorption behaviour of the following elements: Cl, I, Se, Sn and U. The Formations of Diest and Voort showed a low but significant sorption for Sn whereas the Formation of Berchem showed some sorption for uranium.

In the frame of the natural analogue study on Boom Clay, we drilled from the underground research facility (URF), a new 40 m deep borehole vertically. The borehole was cored over its entire depth, cutting organic-rich layers, the double band -the most silty layer of the Boom Clay and therefore a potential zone of higher permeability and pore water mobility-, the U-rich interval at the base of the Putte Member, and, the upper levels of the Terhagen Member. The clay cores are used for a detailed mineralogical, geochemical and radiochemical study of the Boom Clay and its interstitial water.

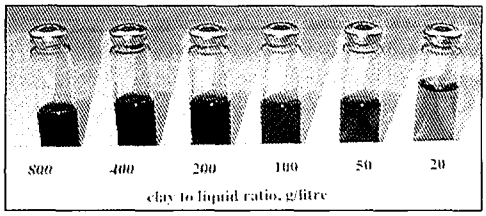
We installed a piezometer in this borehole for the TRANCOM-II project for the collection of pore water at 12 levels with specific characteristics (see figure below) to study the spatial variability of pore water in the Boom Clay and to get a detailed characterisation of the organic matter.

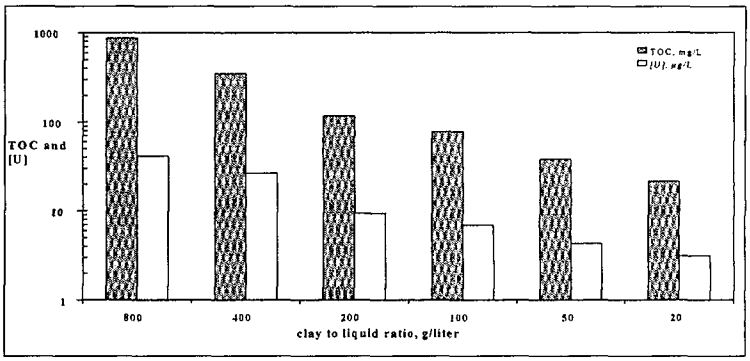


Sampling piezometer and sampled layers

For this purpose, we will analyse the molecular composition of the organic matter present in the water and compare it with the organic matter present as solid phase. Attention will be paid to the origin by studying the biological precursors, to the diagenetic evolution by investigation of the instable components and to the migration of the organic matter.

The natural uranium distribution in Boom Clay slurry was investigated to gain a better understanding of uranium retention mechanisms. Uranium is mainly associated with organic colloids, as generally indicated by the brown colour of samples. The graph presented below highlights very well the relationship between the Total Organic Carbon (TOC) and the uranium concentration. Because these colloids are not mobile in compact Boom Clay, values measured through batch distribution coefficients (K_d) are not representative for the *in situ* Boom Clay.





Association of uranium with colloids

Performance assessment studies on the direct disposal of spent fuels clearly indicate that uranium isotopes and their daughters would be the main contributors to the total dose rate at very long term. Both the tri-carbonate anion $UO_2(CO_3)_3^{4-}$ and the neutral species $U(OH)_4(aq)$ might coexist under the reducing conditions prevailing in the Boom Formation. We performed complexation experiments under *in situ* conditions ($pCO_2 = 10^{-2.39}$ atm and pH ~ 8.5) with uranium(VI) and various concentrations of different dissolved humic acids. A weak complexation is observed indicating that the uranium(VI) speciation in the Boom Clay interstitial water with a Dissolved Organic Carbon (DOC) of about 200 $mg.dm^{-3}$ is dominated by the carbonate complexes.

Monitoring of the *in situ* geochemical conditions is a key issue for the long term prediction of the chemical behaviour of radionuclides in the Boom Clay. Therefore we developed and installed *an in situ* monitoring system for Eh and pH measurement under pressure. The project is referred as "ORPHEUS" for "Oxidation Reduction Potential and pH Experimental Underground Station".

A generic coupled geochemical transport model, developed in collaboration with the United States Salinity Laboratory (Riverside, CA), is able to reproduce key processes of radionuclide behaviour in the soil (and other substrates) and the soil-plant environ-

ment, the groundwater and the engineered and geological components of repositories of radioactive waste.

In the frame of a post-doctoral research project, multi-component transport simulations have been performed for transient unsaturated flow conditions in heterogeneous soil profiles. Furthermore, the new code has been tested on well-selected cases (i.e., data sets) dealing with waste disposal issues, including the effect of an alkaline plume on the behaviour of Boom Clay. Migration experiments are planned on Boom Clay samples conditioned with young and evolved cement water in the frame of the EC ECO-CLAY project.

The figure below illustrates, as an example, the results of calculations of possible processes interacting at a concrete-clay interface when an alkaline plume (pH 13,1 – high Na and K content) is flowing (1 mm d^{-1}) through a Boom clay core.

These simulations show the propagation after about one year time of an alkaline plume through the core with the occurrence of complementary reactions such as dissolution of primary minerals as kaolinite and precipitation of secondary phases (e.g. analcime). In case of absence of chemical reactions, the alkaline plume would reach the outlet after 32 days.

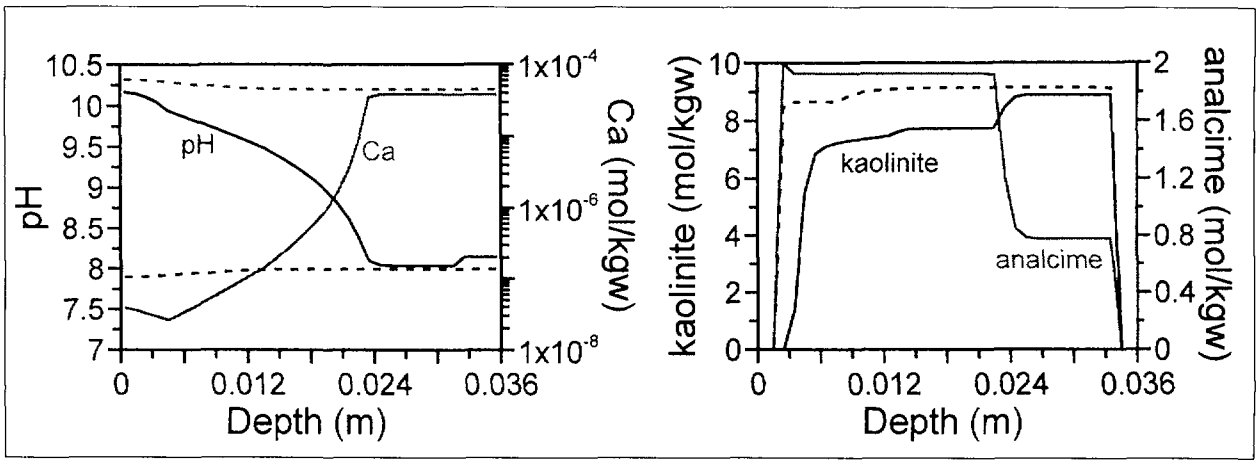
Dissolution of primary kaolinite indicates that the Boom Clay mineralogy is not in equilibrium with the infiltrating alkaline plume. Furthermore, secondary minerals (for example the zeolite analcime) are formed due to the break-up of primary phases, the dissolution of Si and Al and to the availability of cations in the alkaline plume (mainly Na and K in this example). The observed alterations influence the composition of the fluid in the clay core (e.g. the decrease in Ca-concentration). This indicates the importance of using a transport model incorporating different chemical processes to analyse the performance of a waste disposal concept.

In the frame of the RESEAL-II project, the hydration of the seal plug is not yet completed. We installed a mixture of FoCa clay pellets and powder in September 1999. We observed now that the hydro-mechanical perturbation around the plug, including the host clay fracturation in the near-field caused by the seal installation, is not yet restored. The migration and hydro-mechanical tests started in parallel in the surface laboratories on samples of powder/pellets mixture of FoCa Clay will provide complementary information on hydration mechanisms and on the diffusion parameters of this mixture. The partners started the first numerical simulations for the hydration phase of the shaft seal.

Perspectives

The performance assessments of the geological disposal of reprocessing waste in the Boom Clay layer at the Mol site will continue in 2002. Main emphasis will be on the scenario development. A systematic, transparent and well-documented approach will be applied to identify and to define the most relevant evolution scenarios. The assessments for the EC project BENIPA will be mainly carried out next year. Running the updated version of the regional hydrogeological model will allow to evaluate the necessity of performing an additional data acquisition campaign.

Our collaborations with East-European countries will continue in the next years, especially with Slovenia and Slovakia for the performance assess-



Simulation of the propagation of an alkaline plume into a 32-mm-long clay core after 333 days. (dotted line refers to the initial profile).

ments of designed facilities for the disposal of low-level radioactive waste.

In the framework of the programme for the disposal of low-level radioactive waste in Belgium, we will continue the performance assessment studies for the site-specific disposal concepts for the nuclear zones in the Mol-Dessel region. These studies include detailed mathematical modelling of radionuclide migration in the engineered barriers and the surrounding aquifers. The issue of gas generation owing to anaerobic corrosion of steel and the concomitant gas transport in disposal galleries, Boom Clay and aquifers for the deep disposal concept will also be investigated.

In addition to the safety calculations, we will contribute to the dissemination of the results to the public through the local partnerships, which have been established in Dessel and Mol.

We also apply our expertise in site characterisation and flow and transport modelling in aquifer systems and variably saturated soils to the SCK•CEN programme on environmental restoration and site remediation. In collaboration with Vito, we contribute to the evaluation of permeable reactive barrier media for remediation of uranium plumes in groundwater.

Studies related to waste forms and packages will continue with a special focus on the compatibility of bituminised radioactive waste with Boom Clay. Areas of future R&D are the swelling behaviour due to the uptake of water, its effect on the near-field in the disposal concept and the effect of physico-chemical ageing (mainly due to radiolysis processes). We also intend to study in more detail the biodegradation of bituminised radioactive waste upon geological disposal.

Through our co-ordinating role for two new EC projects, we will contribute actively to the state-of-the-art at international level on glass dissolution mechanisms and container corrosion. The first one, the GLAMOR concerted action, will achieve a common understanding of the processes controlling the long-term dissolution of nuclear waste glasses in geological media. The second one, the COBECOMA (COrrosion BEhaviour of COntainer MAterials) thematic network, will review the R&D on container corrosion and identify the needs for future R&D in this area.

The time consuming migration programme including newly designed experimental set-ups, large scale *in situ* migration experiments and electromigration tests are continuing for some more years.

We will be in a position soon to start the first migration experiments in the frame of the ECOCLAY-II project, aimed at studying the influence of cement water on the geochemical behaviour of the host formation. For the natural analogue study of the Boom Clay, the final results of the analysis of the solid and the liquid phases will allow the detailed global interpretation.

After full saturation (RESEAL-II project), we will evaluate the efficiency of the seal at saturation (water and gas permeability tests) including the realisation of tracer diffusion tests. Modelling work will be carried out to assist in the interpretation of the seal behaviour and for validation purposes.

In preparation of the upcoming 6th Framework Research Programme of the European Commission, SCK•CEN intends to start discussions with potential research partners to develop joint projects using the same research infrastructure, to promote the exchange of scientific personnel and to organise joint workshops, conferences and training courses. The establishing of the European Research Area will offer unique opportunities to foster the creation of networks of excellence in radioactive waste management.

Partners

-	Tractebel (Brussels, Belgium)
AEA	AEA Technology (Harwell, UK)
ANDRA	Agence National pour la gestion des Déchets Radio-Actifs (Châtenay-Malabry, France)
ARMINES	Association pour la Recherche et le Développement des Méthodes et Processus Industriels (Paris, France)
BGD/SGB	Belgische Geologische Dienst / Service Géologique de Belgique (Brussels, Belgium)
BRGM	Bureau de Recherches Géologiques et Minières (Orleans, France)
CEA	Commissariat à l'Energie Atomique (Saclay, France)
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Madrid, Spain)
CSIC	Consejo Superior de Investigaciones Cientìficas (Madrid, Spain)

CT	Clay Technology AB (Lund, Sweden)
ENRESA	Empresa Nacional de Residuos Radiactivos, S.A. (Madrid, Spain)
Galson	Galson Sciences Ltd. (Oakham, UK)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Braunschweig, Germany)
IPSN	Institut de Protection et de Sûreté Nucléaire (Fontenay-aux-Roses, France)
KULeuven	Katholieke Universiteit Leuven (Leuven, Belgium)
LU	Loughborough University (Loughborough, UK)
NAGRA	National Cooperation for the Disposal of Radioactive Waste (Wettingen, Switzerland)
NERC	Natural Environment Research Council (Swindon, UK)
NRG	Nuclear Research & consultancy Group (Petten, the Netherlands)
POSIVA	Posiva Oy (Helsinki, Finland)
PSI	Paul Scherrer Institute (Villigen, Switzerland)
SKB	Svensk Kärnbränslehantering AB (Stockholm, Sweden)
UAM	Universidad Autónoma de Madrid (Madrid, Spain)
UBERN	Universitaet Bern (Bern, Switzerland)
UH	University of Helsinki (Helsinki, Finland)
ULB	Université Libre de Bruxelles (Brussels, Belgium)
UPC	Universitat Politecnica de Catalunya (Barcelona, Spain)
Vito	Vlaamse instelling voor technologisch onderzoek (Mol, Belgium)
VTT	Technical Research Centre of Finland (Epoo, Finland)

EC	European Commission (Brussels, Belgium)
IAEA	International Atomic Energy Agency (Vienna, Austria)
MEZ	Ministry of Economic Affaires (Brussels, Belgium)
ONDRAF/NIRAS	Belgian Agency for Radioactive Waste and Enriched Fissile Materials (Brussels, Belgium)
UMICORE	Former Union Minière (Olen, Belgium)

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