BELGIAN CONCEPT FOR HLW DISPOSAL: DEVELOPMENT AND DEMONSTRATION

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ABSTRACT

The Belgian concept consists of an horizontal network of disposal galleries in a clay layer, the Boom Clay Formation. This tertiary clay formation is the subject of extensive research dealing with all phenomena that may possibly affect the performance of a potential disposal site, such as corrosion, migration, or climate changes. The safety assessment of the disposal concept is based on the results of this research. The uncertainty on these results may vary, due to the limitations of the laboratory research (e.g. scale effects in time and space), the spatial variation of properties in geological formations, or the identification of relevant phenomena.

The perception of the general public of HLW disposal is an important factor, as final decisions have to be taken by the public authorities. When this perception is distorted by a misunderstanding of the available information, the process of decision-taking may be disturbed. Confidence building can be achieved by safety assessment, but should also be complemented by a more tangible demonstration of the concept, because the "seeing is believing"-factor must not be neglected.

With this in mind, the Belgian Waste Agency NIRAS/ONDRAF and the Nuclear Energy Research Centre SCK•CEN have jointly set up the Economic Interest Grouping PRACLAY to manage the demonstration program for the Belgium concept for HLW disposal. This program consists essentially of the construction and operation of a real-scale disposal gallery. Additional construction works (extension of the current underground facility by a second shaft and connection gallery) and specification of technical concept details (materials, procedures for e.g. waste handling, instrumentation) are therefore required. The operation of a surface mock-up is going on as a main preparation test for e.g. instrumentation and buffer material. The construction works also give the opportunity to observe the response of the clay host rock to these operations. Where appropriate, demonstration activities are integrated in a permanent exhibition, which allows the general public to get a better idea about this aspect of nuclear energy.

With all the experience already gathered, we can state that demonstration is an essential phase in the development and implementation of a HLW concept. It gives valuable feedback, both on the scientific and technical aspects, as on the socio-political aspects. Scientific and technical questions can now be addressed more effectively. We also notice more awareness about HLW disposal when people (both decision-makers and local inhabitants) have visited the site. This will enhance the discussion not only on disposal in general, but also on actual topics such as reprocessing or the sense of retrievability. Eventually, this feedback will allow concept improvement to reach a consensus with all interested parties: scientists, waste producers and society in general.

INTRODUCTION

The final disposal of High-Level Radioactive Waste (HLW) is becoming the most challenging issue regarding the current and future applications of nuclear fission energy. The initial scientific and technical approach was based on the analysis of the safety and feasibility of the different concepts proposed. Some kind of consensus at international level on the main safety indicators currently exists; this has led to many concept proposals due to different policies regarding the source term (such direct disposal of spent fuel versus reprocessed waste) and the geological conditions (host formations, etc). The Belgian research program, initiated in 1974, has always been concentrating on clay layers as these are the only suitable host formations in Belgium. Based on an elaborate safety assessment methodology, a concept has been developed and adapted through the years, resulting in the current gallery network design. The safety of this concept is assessed by predictions based on modeling. Input data for these calculations are gathered mainly through laboratory and in situ tests (dealt with in the paper of Neerdael et al. at this conference).

To get a better idea of many technical and operational details related to the implementation of such concept, a demonstration program has been set-up jointly by the Belgian Waste Agency NIRAS/ONDRAF and the Nuclear Research Centre SCK•CEN. Through their Economic Interest Grouping named PRACLAY, they are currently preparing the construction and operation of a simulated disposal gallery on real scale. Preparations include both construction works (extension of the current underground facility) and test set-ups including a large scale surface mock-up and an underground instrumentation program.

The recent years have seen the increasing importance of society-related aspects due to the specific nature of HLW disposal, with large construction works and even larger time-scales. It has become clear that involvement of the public is a basic condition for any successful achievement in this area. As shown further, demonstration plays an important role in such policy.

CONCEPT DESIGN AND ASSESSMENT

Since its initiation, the Belgian research program and related concept on HLW disposal, as in any country, has been determined by the geological medium and the source term. The essential safety indicators (essentially risk of population due to release of radionuclides), with their calculation methods, have however been defined at an international scale and applied in many joint research programs such as PAGIS (1).

Apart from investigating the safety of any concept, also its feasibility needs to be demonstrated. This has been accomplished by the construction (1980-1987) of the HADES underground research facility (2), which has allowed us to refine the mining and operational aspects.

The first report to the Belgian authorities on safety and feasibility "SAFIR" (3) pointed out the importance of the clay layer and its thickness. The original concept with inclined disposal boreholes has therefore been replaced by a concept consisting of a horizontal network of galleries to preserve a maximum thickness of the clay layer. A lot of effort has since then been devoted to the performance of such gallery network and of the disposal gallery in particular. Fig. 1 shows an overall view of this concept, with a typical cross-section of such gallery.

After lining the excavated gallery (to limit the convergence), a central tube is placed and the remaining space backfilled with a clay-based material. The central, stainless steel tube will contain the waste canisters, which may be equipped with some form of overpack as an additional barrier. The lining, consisting of concrete segments, limits the convergence and hence damaging of the host clay layer, while the backfill material has swelling characteristics to provide a good sealing of this space. Addition of graphite further increases the thermal conductivity and limits the temperature of the waste canisters. We would like to mention that the final material choices have not yet been established. Concrete may affect the clay characteristics (alkaline plume), while some corrosion mechanisms need further study before e.g. the central tube material is selected. The role of the engineered barrier is not to provide the final safety, but to improve short-term aspects of disposal such as handling, retrievability and protection during the thermal phase. Alternatives based on microtunnelling techniques have not been retained due to technical issues (feasibility), although a smaller excavation diameter, with a smaller excavation damaged zone, could be more advantageous.

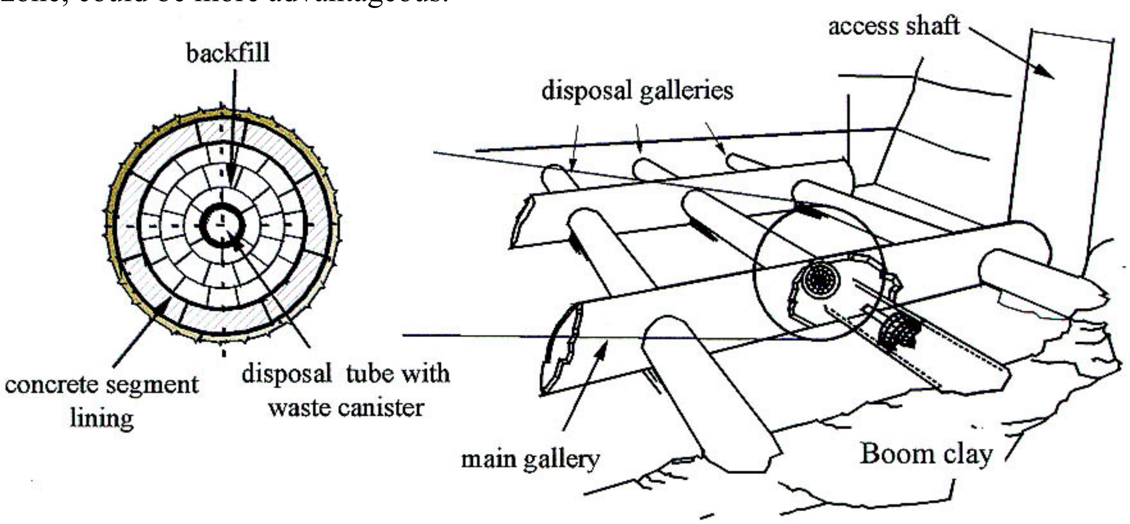

Fig. 1.: Concept with main and disposal galleries, and cross-section of a disposal gallery

The phenomena corresponding with the different disposal gallery parts have been structured into corrosion behavior of the waste glass and package materials, backfill characterization, performance of the host clay formation (both near and far field), ending with the optional release of nuclides in the aquifers surrounding the clay layer (hydrology).

The corrosion studies concentrate – in the framework on HLW disposal - on the leaching behavior of the glass waste matrix and the canister and overpack materials (mainly stainless steel).

The backfill surrounding the central tube is subject to hydration/saturation; this process may be further complicated by the thermal field due to the heat-generation of the HLW. Previous testing has made it clear that hydration may take longer time spans (up to several years), while a thermal gradient inside this backfill material may give way to phenomena such as evaporative processes causing increased electrolyte concentrations. Detailed investigations are currently being planned and carried out to get a more accurate view on the backfill performance under these conditions. Another research topic in this area deals with the sealing of the created openings: as the excavations have partly destroyed the isolation characteristic of the geological host formation, we must be able to show that the proposed sealing techniques will overcome this.

The main barrier is the geological clay layer. Migration of radionuclides with all the related parameters with regard to e.g. hydraulics and geochemistry was included in the first scientific activities after the underground research facility became operational. The hydrological studies in and around the clay layer further complete the characterization of the disposal system.

Several teams are investigating these aspects through desk studies, laboratory tests and in situ tests. The modeling range extends from corrosion of glass, through the backfill hydration up to the migration of different radionuclides through the clay layer into the biosphere. Laboratory tests allow to investigate under well-defined conditions the validity of these models, while in situ testing further allows to consider representative conditions. The latter test set-ups further allow to combine several aspects, such as excavation combined with backfilling, hydration and heating, or the corrosion in contact with clay under gamma-irradiation.

Although all these distinctive parts have been tested and modeled, a main integrated test at real scale was still lacking, and therefore SCK•CEN and NIRAS/ONDRAF have decided to design, construct and operate a representative simulation of a disposal gallery.

CONCEPT DEMONSTRATION

The Belgian Waste Agency NIRAS/ONDRAF, which is responsible for the concept development, has set-up, jointly with SCK•CEN, initiator of the research on HLW disposal, an Economic Interest Grouping PRACLAY to manage a large-scale demonstration program. This program consists basically on the construction, operation and analysis of a disposal gallery at real-scale (with limited but representative length). This requires the extension of the current infrastructure with a second access shaft and connection gallery (4,5). Currently, the second shaft has been completed. Preparations for the construction of the connecting gallery are currently going on. In contrast with the previous (manual) construction works, this excavation will be performed in a representative way. This requires excavation at a minimum rate and using a minimal overbreak to limit damage of the clay formation, and therefore only mechanized methods will be suitable. The list of specifications is currently being updated to take all these aspects into consideration.

A first objective of such demonstration is the validation of the current models describing the thermo-, hydro- and mechanical (THM) behavior of the clay (aimed at optimizing the excavation process). The properties of the clay formation should not be affected neither by the excavation nor by subsequent ventilation. A clear understanding also allows to elaborate a cost-effective design for the underground structures including minimum excavation advance, gallery lining thickness, and crossing chamber structures, where disposal galleries may exert forces on the main galleries. Complementary to the modeling of the clay, the modeling of the (clay-based) backfill behavior is an important task. Here the main questions are the evolution of the hydration and other hydraulic parameters (e.g. permeability), the swelling and the influence of a temperature gradient and the overall temperatures. It has become clear that not only the THM-modeling should be considered, but also the geochemical aspects, such as cementation phenomena or the possible concentration of solutes (such as corrosion-enhancing chlorides) towards the hot zone in an unsaturated medium.

Two experimental set-ups within EC shared-cost actions are currently dealing with these aspects: an underground instrumentation program "CLIPEX" (6) to monitor gallery excavation in deep clays, and a surface mock-up "Ophelie" (7) to investigate the backfill configuration and the related instrumentation.

The excavation of the connection gallery gives us an unique opportunity to monitor the clay response to the excavation. Due to the depth considered, surface monitoring, usually applied in shallow excavations, is not feasible, and therefore we have taken advantage of the current configuration (excavation towards the existing facilities) to monitor the zone that will be excavated, as well as the surrounding ones. Models predicting stress changes and displacement around the excavation front and the gallery can therefore be checked directly with the in situ observations. Initial predictions have been made by several modeling teams, and with the first (preliminary) results (Fig. 2), we were able to define the location and measurement ranges for the different sensor types.

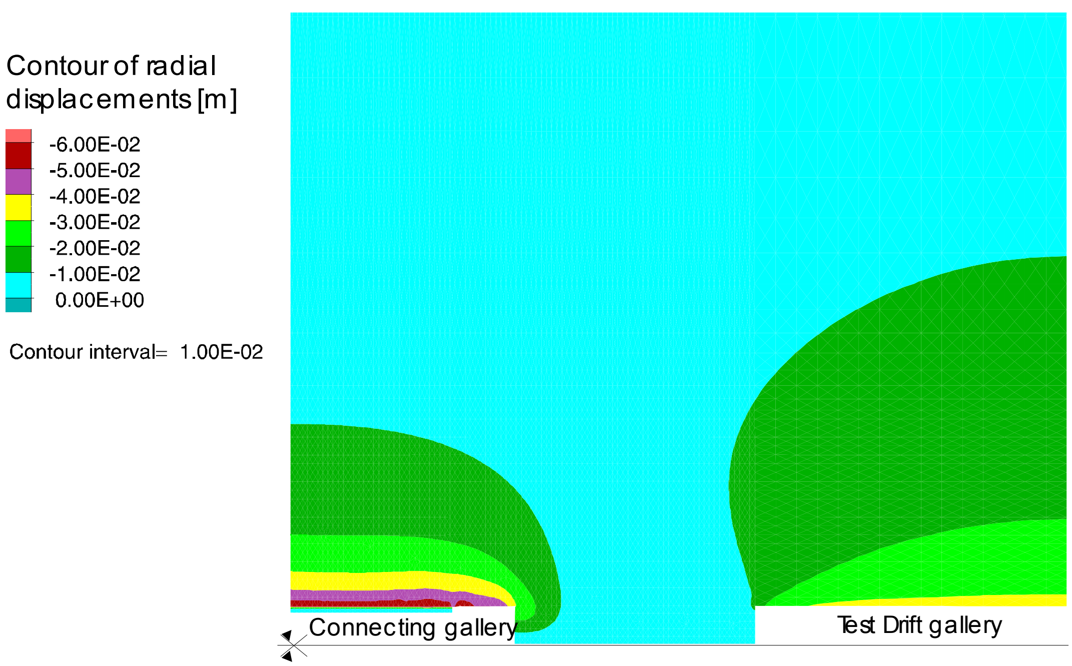

Fig. 2: Displacements around the underground gallery excavation

The current configuration is shown in Fig. 3, and consists of 4 boreholes for pressure measurements and 4 boreholes for displacement measurements (with extenso-, inclino- and deflectometers). The configuration will be extended with sensing equipment to be installed from the second shaft.

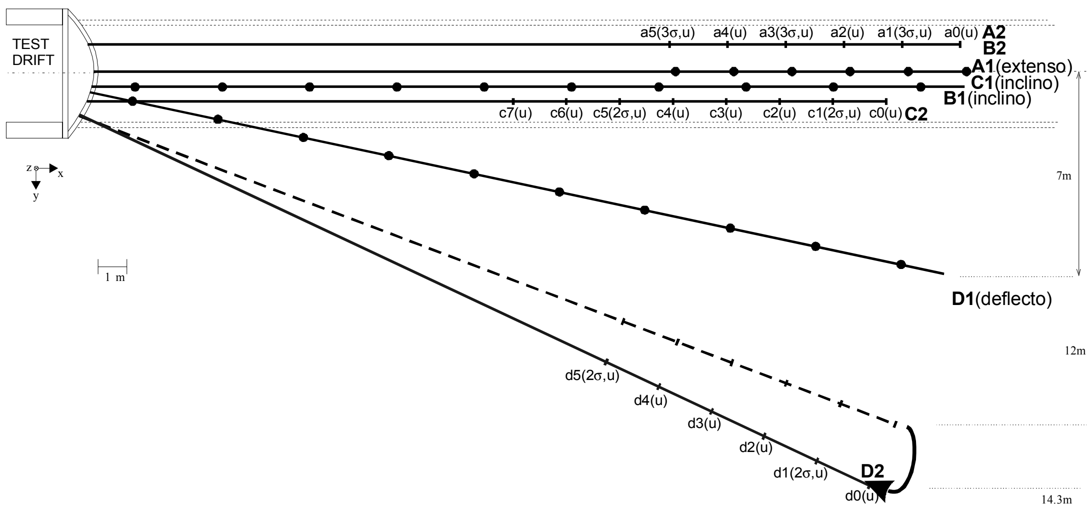

Fig. 3: Measurement configuration installed from the Test Drift front

The backfill buffer around the central tube determines largely the behavior of a disposal gallery. Many efforts are therefore devoted to the development and application of the backfill material. To test the current gallery design, a surface test set-up simulating a disposal gallery ("mock-up") has been constructed. It consists of a steel tube (replacing the gallery lining), 5 m long and 2 m inner diameter, with a inner central tube (0.5 m diameter). The backfill is placed by means of precompacted blocks in a 3-ring configuration. The central tube contains further a heating system to deliver some 450 W/m. This linear power is slightly increased with respect to the actual waste canister output to obtain in a shorter time the maximal temperatures. Sixteen hydration tubes provide the water needed for hydration and saturation of the backfill material. Fig. 4 shows a view of the mock-up during construction. Apart from the backfill blocks, arranged in three concentric rings, we also observe the cabling coming from the internal instrumentation. An important objective is indeed to test the instrumentation assumed to be used in the in situ test.

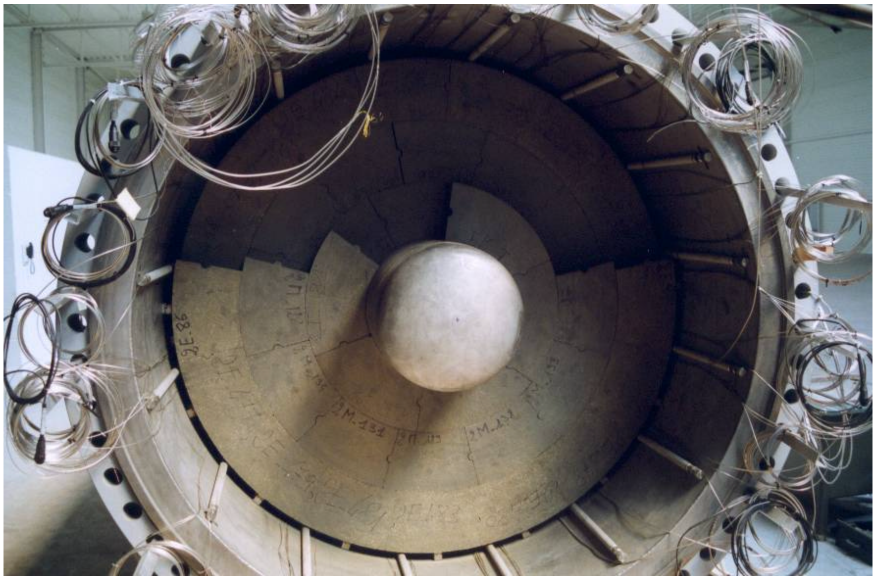

Fig. 4: The mock-up during construction

The test set-up was completed in the autumn of 1997. The flooding (filling of the void volume) took place at the beginning of Dec 1997, followed by a hydration at increasing pressure up to 1 MPa. After 6 months, the internal heating elements have been switched on for a heating duration of 3 years. Complementary to the internal heating system, an external system with isolation allows to obtain temperatures at the outer boundary that are representative for the in situ case. Currently, the temperature gradient in the backfill ranges from 97 °C (outer boundary) to almost 120 °C on the central tube.

After the 3-year heating period, we plan an extensive analysis of all the relevant components of the mock-up (backfill material, instrumentation) during and after the dismantling of the set-up.

The results that are available today indicate that complete saturation needs quite some time (up to several years), and that a thermal gradient in unsaturated media may cause physico-chemical phenomena that might influence the performance of the disposal system. This can also explain the higher than expected thermal conductivity, which would reach almost 4.5 W/mK, compared with the required 2.5 W/mK in case the heat transfer is purely conductive.

The demonstration at real scale of the proposed concept not only serves scientific purposes, but plays also a major role in involving the political world and the public in a broad sense with the issue of radioactive waste disposal. It further allows to tackle many engineering issues arising from the upscaling to real dimensions, such as the mechanized gallery excavation and lining, or backfill production, handling and installation. The scope of monitoring further extends from a purely scientific one to a broader data source applied towards operational and longer-term safety, licensing requirements, or even linked to retrievability. The topic of operational and post-closure monitoring is currently being discussed at several levels, but it is clear that this will differ from instrumentation for purely scientific reasons. The drop out rate observed sometimes with inaccessible geotechnical instrumentation cannot be allowed in operational disposal sites.

The demonstration project should finally result in a complete data set to allow the construction of a pilot plant. A demonstration site will then also serve as a proven way to maintain all the knowledge gathered, something that must not be overlooked as we are considering time spans of several decades.

PLANNING OF THE DEMONSTRATION AND IMPLEMENTATION PHASES OF A HLW REPOSITORY

The large-scale in situ demonstration test is scheduled to start in the year 2003. Infrastructure works for this test include the construction of the second shaft (completed), excavation of the connecting gallery (2001) and the test gallery (2002). The in situ test consists of a hydration phase (expected between 6 months and 1 year), a heating phase (3 years), and a cooling phase, with final results available around 2010. The repository is assumed to be operational the earliest in 2035. In the meantime and before the construction of the repository itself, several important phases will have to be performed starting from further demonstration tests based on concept improvement to the siting procedure and further characterization of a selected site, possibly including pilot tests.

CONCLUSION

The demonstration at real scale of a disposal concept is a necessary step in any implementation plan for HLW disposal. It first allows to confirm and to validate to some extent the short-term predictions. It contributes further to the technical development or optimization of the different components of the system, including their installation, the handling of waste canisters, the control and monitoring program.

A very important benefit is also the involvement of the general public. Their perception will determine the future policies on licensing or retrievability; a clear picture of the concept through demonstration will more likely result in realistic and feasible decisions when implementing the HLW disposal.

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