WASTE DISPOSAL CONCEPT IN A TERTIARY CLAY FORMATION

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ABSTRACT

Investigations on the suitability of a tertiary clay layer as host formation for disposal of conditioned high-level and alpha bearing radioactive waste were started in Belgium in the mid seventies. On the basis of results obtained from preliminary field and laboratory research it was possible at the end of the seventies to elaborate a first rough outline of an underground facility for final emplacement of the waste concerned.

Excellent retention capacity for most of the long-lived radionuclides and low hydraulic conductivity are the two main trumps of the Boom clay formation in the investigated area. In the early stage of the program, however, uncertainties remained about the possibility of creating galleries at reasonable depth in clay at an acceptable cost price. Therefore, the decision was taken in 1978 to build an underground laboratory in order to investigate, among others, the geotechnical properties and the minability of the Boom clay.

A satisfactory reproduction of three years of in situ measurements was obtained by using an elasto-viscoplastic model with strain softening. The main conclusion of this R & D program, is that tunneling capabilities at reasonable cost prices in deep laying Boom clay have been demonstrated.

The latest research results, including those arising from further field and laboratory investigations and from various studies devoted more particularly to near future and long-term safety aspects, allow to reconsider and improve the first nearly ten years old disposal concept. The concept was updated particularly on the basis of :

- the progress made in the field of deep clay rheology ;
  the experimental thermal conductivity values obtained during near surface full scale dummy tests ;
- the volumes and characteristics of a realistic Belgian production program of various conditioned waste.

It was also considered that waste retrievibility will no longer be a must in the future and that a thick overpack for the vitrified waste canisters will seriously contribute to the handeling and short-term safety of the system.

In the present concept all the waste drums including the vitrified waste canisters are emplaced in the axis of disposal galleries. The axial configuration presents a number of advantages compared with the radial one :-lower construction cost price ;

- improved containment (extended multibarrier principle) ;
- better and homogeneous decay heat dissipation.

The future development of the facility passes through different stages including demonstration and pilot plant before operational phase.

INTRODUCTION

Since the mid seventies, an extensive Research and Development program has been carried out in Belgium regarding the deep disposal of long-lived high-level waste in geological formations.

These studies, which are partly supported by the Commission of the European Communities in Brussels, were performed by the Nuclear Study Centre in Mol (CEN/SCK) initially at its own expense and since 1983 financed by the concerned waste producers through the National Agency for Radioactive Waste and Fissile Materials (ONDRAF/NIRAS) which was created in the beginning of the eighties to ensure the overall management of radioactive waste produced in the country.

Ever since the studies were started, preference was given to a tertiary clay formation, extending at depth in the north-east of the country under the nuclear site of Mol-Dessel.

The first field and laboratory reconnaissance works were followed at the end of the seventies by a first feasibility study based on conservative hypotheses. This study has demonstrated the necessity to dispose of an experimental installation in clay liable to provide all missing experimental data.

This installation, which was excavated in the beginning of the eighties, has been fully operational for several years now and constitutes a precious tool for performing an integrated study program containing numerous research topics.

Thanks to the abundance and quality of the results obtained, the first feasibility study could be updated based

upon the actual quantities of the various types of waste to be managed in Belgium.

THE CHOICE OF A TERTIARY CLAY FORMATION AS HOST ROCK FOR DEEP DISPOSAL

Belgium is a small country (with a surface area of 30,521 km^2, i.e. 300 times less than the United States), densely populated (300 inhabitants/km^2, i.e. 14 times more than the United States), with a very complex geology composed of formations extending from early Cambrian to late Quaternary.

One of the first actions undertaken by Belgium in the framework of its Research and Development program consisted in making an inventory of the deep geological formations suitable for the disposal of high-level and alpha bearing waste on the domestic territory.

This inventory has shown that in Belgium only the pelitic formations from the Paleozoic Era (phillites and shales) or from the Cenozoic Era (clays) could be taken into consideration. The latter include the so-called "Boom clay" from the Oligocene (35 million years old), a formation which has the advantage of extending at moderate depth (-180 to -260 m) under the nuclear site of Mol-Dessel where the CEN/SCK is situated.

This is one of the reasons why the Boom clay formation has been chosen right from the start as potential host rock for the R & D program which for that reason has a much more marked site-specific character than in other countries.

Since the program was started some 15 years ago, no fundamental objections could be raised against this choice, which is the reason why waste disposal in clay formation has remained the sole option selected by Belgium ever since.

THE FIRST R & D WORKS AND THE MAIN RESULTS

The first field reconnaissance campaigns (boreholes and sismic reflexion - high-resolution 3D-campaign) have demonstrated that the Boom clay layer is very regular and homogeneous, with a constant thickness and not affected by tectonic features like faults or flexures liable to interrupt its geometric continuity.

Laboratory research performed on samples taken in boreholes and in the outcropping zone has also demonstrated the quality of the studied clay:

- good sorption and exchange capacities;
- very low permeability (no significant movement of water in the clay mass);
- plastic mechanical behaviour (ability of the clay to undergo unrecoverable but limited strains without cracking or crumbling).

Laboratory experiments and field heating tests have also shown the rather poor thermal characteristics concerning the heat dissipation within the Boom clay.

FEASIBILITY STUDY "HADES"

On the basis of this first set of results obtained, a first feasibility study known as "HADES"* study was performed at the end of the seventies to evaluate the possibility of building an industrial disposal installation in the Boom clay formation under the Mol-Dessel nuclear site and to identify the problems to be solved in the course of the R & D program. (1, 2, 3).

Basic hypotheses

In order to start from realistic and conservative conditions, a certain number of hypotheses were put forward :

- installled electronulcear program of 10,000MW (el) during 30 years of production with systematic reprocessing of all spent fuel, leading to a production of approximately 9,000 (vitrified) HLW canisters, 9,000 hulls canisters and 150,000 ILW drums ;
  - maximum heat capacity of 1.5 W/m^2, taking into account the selected area and the thermal properties of the clay ;
  - a surface interim storage for thermal decay of 50 to 75 years and a temperature increase of the clay after disposal of the waste limited to 100°C ;
  - necessity to maintain the possibility of retrieving the HLW during a sufficient period of time ; this requirement made it necessary to leave the disposal galleries and the access drifts and shafts open during the whole retrievability period.

Results

On the basis of the above-mentioned hypotheses and taking into account the mining and nuclear regulations to be simultaneously respected , the study has shown that such a disposal structure was perfectly achievable with the existing technologies. Because of the rather poor mechanical behaviour of the clay, special precautions had to be taken for the digging operations. For the main access shafts and galleries it was recommended to use the freezing technique while the secondary (disposal) galleries had to be dug by means of a tunnel boring machine. The shafts were classically lined with concrete whereas the linings of the galleries were made of cast-iron segments.

The lay-out of a possible disposal configuration is shown on Fig. 1 which represents :

* High Activity Disposal Experimental Site

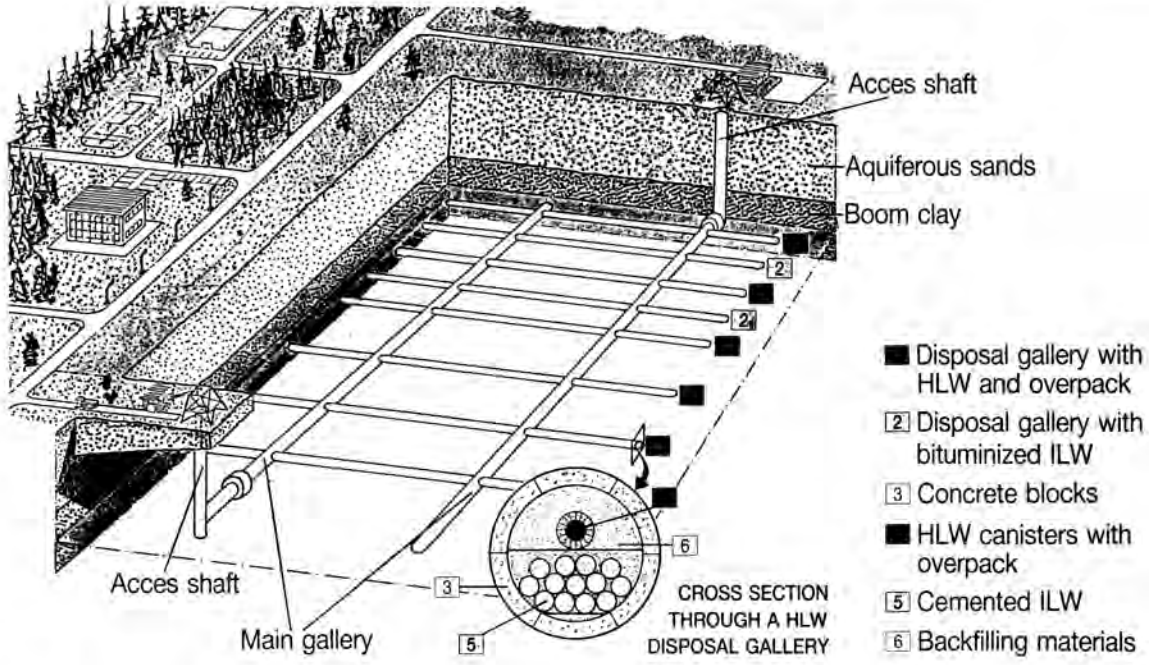

Fig. 1. General Layout of Underground Facility for Radial Disposal Concept.

- two access shafts with a usefull diameter of 4,5 m,
- a main (access) gallery with a usefull diameter of 4,5 m,
- seven disposal galleries with a usefull diameter of 3,5 m
- HLW canisters in radial steel-cased disposal pits (retrievable) in three galleries with a total length of 7,500 m
- Hulls canisters in radial disposal pits in a 1,800 m length gallery (retrievable) and,
- ILW in full section of three galleries (non-retrievable) with a total length of 7,000 m

The total costs of the whole plant, comprising the construction of the underground and surface facilities and the operation works, has been estimated at approximately 625 millions US dollars. The adoption of a non-retrievable option could lead to a strong reduction of this price. The main part of the underground works costs was devoted to the precautions to be taken because of a lack of knowledge on the geomechanical response of the clay.

It was therefore decided to build an experimental installation on the site of the CEN/SCK which would allow among others to acquire knowledge on the rheology of the clay under "in situ" conditions in order to better evaluate the digging and lining aspects, as well as the thermal phenomena taking place in the clay environment.

EXPERIMENTAL IN SITU PROGRAM

At the beginning of the eighties, the CEN/SCK started construction of an experimental underground installation with the support of the Commission of the European Communities.

In order to avoid any risk of mining incident or accident which would jeopardize the whole project, special care was taken during the construction of the experimental galery using the freezing technique for the digging operations and over-dimensioned cast-iron segments as lining system.

These precautions fortunately proved to be useless, as the clay appeared easy to dig and presented a great rheological stability. The experimental installation could thus be completed by less expensive test cavities, excavated with the help of conventional means and lined with concrete blocks.

The results obtained in the course of construction with regard to the clay behaviour in depth during digging have been confirmed by long-term results ever since the experimental installation was put into service in 1984. The subsequent excavation of a gallery with an effective section of 3.5 m and a length of approximately 60 m reinforced the conviction that it is possible to excavate long portions of gallery in clay at the considered depth with conventional

means and hence at reasonable prices without major problems (4).

Besides the research efforts made for geomechanical purposes, an ambitious multidisciplinary program is being carried out in the experimental facility. This study program, which will last many more years, bears upon all aspects requiring the acquisition of knowledge on the phenomena occurring in direct contact with clay, such as corrosion, migration, heat dissipation, local hydrology, etc..

Simultaneously with these studies, all aspects not requiring in situ conditions have been studied in surface laboratories, whereas the desk studies related to the safety of waste disposal in clay formation have been going on for several years and integrated in global studies performed in this field at European level (5).

UPDATING OF THE FEASIBILITY STUDY "HADES"

After some ten years of continuous R & D, it appeared appropriate to resume the feasibility study HADES published in 1979 and to update it on the basis of new hypotheses, on technical and scientific data obtained in the meantime, and especially on the basis of the actual waste quantities corresponding to the Belgian electronuclear program.

New hypotheses

Non-retrievability. During the past ten years, the philosophy with regard to this matter has strongly evolved. Whereas it was originally considered necessary to allow a retrieval procedure during a certain period of time after disposal, it now appears that both for safety and for economic reasons such a requirement is no longer envisaged at international level. This change of attitude has very important consequences for the waste disposal configuration. It is indeed no longer necessary to place the waste in radial disposal pits outside the galleries, they can now be placed parallel to the axis of the galleries. This central (axial) position of the HLW canisters in the centre of the disposal galleries offers several advantages compared to the orginally selected configuration :

- a more homogeneous (symmetric) heat dissipation in the surrounding clay body;
- a real effectiveness of the multibarrier concept ;
- a limitation on the radiological impact on the clay which is in this configuration protected by backfilling materials placed between the waste and the lining of the gallery ;
- a more effective use of the whole thickness of the clay layer as a migration barrier owing to the reduced height of the disposal configuration ;
- a less extended disturbed zone around the galleries thanks to a drastic reduction of the interfaces between the clay and the cavities (much less cavities dug in the clay) ;
- the use of a simple technique for digging and lining the galleries (no more openings to be foreseen for the radial disposal pits, no special and complicated devices for digging and lining operations) ;
- more effective performances or backfilling materials owing to an enhanced accessibility during placement operations.

Use of overpacks for HLW

The adoption of the axial disposal configuration for High Level waste canisters requires the use of a thick overpack for protection against radiation.

The purpose of such an overpack is to avoid the use of a shielded and cumbersome handling device in the confined disposal gallery for placing the waste and for the backfilling operations.

One of the undeniable advantages of an overpack is that it limits strongly any possibility of radiolysis in the surrounding backfilling materials after emplacement. An overpack that is thick enough (approximately 0,25 m carbon steel) absorbs the radiation emitted by the canisters, so that only the residual heat remains. In addition to its short-term protective functions during the operational stage, the overpack constitutes an additional protection for the clay barrier as it considerably delays the release of radionuclides in the host formation.

The waste

Unlike the previous study which started from an hypothetic electronuclear program of 10,000 MW(el), the new feasibility study is based on the actual electronuclear program, i.e. 5,600 MW(el), which is assumed to be carried on for the next 30 years.

The age of the fission products contained in the HLW at the moment of disposal was chosen to be equal to 50 years, which will require intermediate surface storage of the glass canisters during approximately 40 years.

Moreover, allowance is made for waste existing on the Belgian territory and originating from nuclear activities other than the generation of electricity, such as research, application of radioisotopes, manufacture of fuel, as well as for waste produced by an experimental reprocessing plant still to be dismantled.

The global quantities of waste thus available are given in the table below

TABLE I

Global Quantities of Waste Available

NATURE OF THE WASTE	NATURE OF THE MATRIX	VOLUME (m3)	PERCENTAGE OF THE TOTAL (%)
HLW	glass	850	6
Hulls	cement	2 200	15
MLW	cement	6 560	44
MLW	bitumen	5 200	35
Total		14 810	100

Thermal aspect

The thermal aspect is the decisive dimensioning factor.

Taking into account the thermal characteristics of the host rock and of the waste at the moment of disposal, the following criteria have been adopted:

a) a temperature rise of 5°C in the overlaying aquifer is considered acceptable,

b) the temperature rise on the surface may not exceed 0,5°C,

c) the temperature of the glass matrix may not exceed 500°C, and

d) the temperature of the clay in the near field of the disposal gallery may not exceed 1000°C,

The first criterion is quite severe and determines the dimensions of the disposal area, as well as the distance between the axis of the disposal galleries.

Disposal configuration and length estimates of disposal galleries (Fig. 2).

The underground installation, adapted to the above-mentioned waste quantities and meeting the proposed hypotheses, has been dimensioned for various disposal scenarios spread over time. These scenarios are based on two main options:

- disposal of all waste types when the interim storage of the HLW is completed, or
- early disposal of non-heating waste and late disposal of heat emitting waste when they become available after their interim storage period (40 years).

It is this last management scenario that will be described hereafter. In order to reduce the volumes of underground cavities required, the option was taken to fill the galleries with both waste types by placing first the non-heating waste drums and afterwards the heat emitting canisters in their overpacks.

Under these conditions and on the basis of the aforementioned hypotheses, the study departed from a total length of 7,300 m for the disposal galleries and 3,300 m for the main access galleries.

Considering the crossing between disposal galleries and main galleries, the two access shafts, the waste emplacement operations, the backfilling and sealing operations and the surface facilities, the total disposal costs for the waste

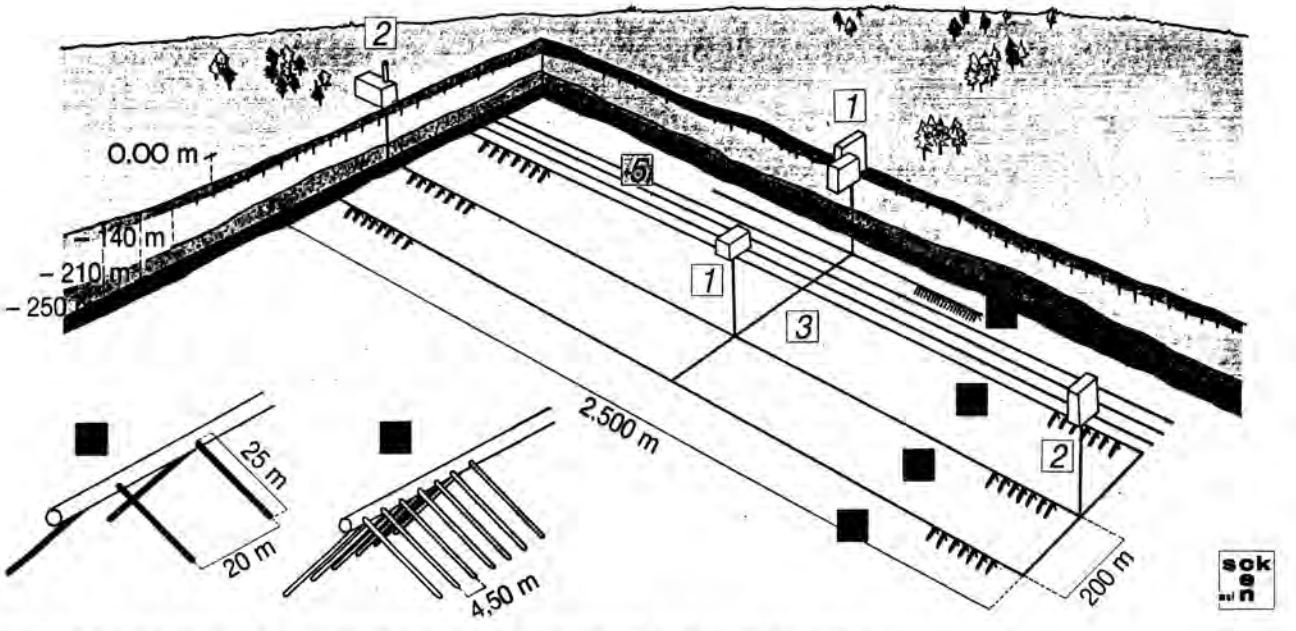

Fig. 2. General Layout of Underground Facility for Axial Disposal Concept.

quantities considered were assessed at about 450 million US dollars i.e. the same order of magnitude as the costs which were initially assessed for the HADES study. One can roughly say that the precautions taken with regard to the retrievability requirement in the first feasibility study are compensated by the use of a thick overpack in the second one. However, the main results of this last feasibility study was the considerable simplication of the mining works due to the adoption of the axial disposal configuration.

CONCLUSIONS

Performing a feasibility study of high- and intermediate-level waste disposal based on the scientific knowledge acquired during approximately 15 years of R & D on waste disposal in clay formation has boosted confidence in the qualities of such a formation as host rock.

Thanks to its favourable geomechanical characteristics, digging and lining in clay can be performed at reasonable prices and using well-tried techniques.

Because of its optimal retention and sorption qualities for most of the critical radionuclides, clay can be considered an ultimate barrier against the migration of radioelements towards the biosphere.

The systematic use of overpacks for the high-level (heat and radiation emitting) waste and the axial placement mode in the disposal galleries considerably reinforce the multibarrier nature of the disposal configuration and also facilitate the long-term behaviour modelization by simplifying the source term.

The R & D efforts should, however, be intensified on two fundamental aspects of the disposal mode:

- the thermal aspects, both from the point of view of geomechanics (stress-strains state, alterations, migration of pore water) and from the point of view of heat dissipation in the clay body ;
- the backfilling and sealing aspects of the underground cavities, as far as the performance of the materials and the placement techniques are concerned.

As for the modelling of the long-term phenomena occurring in the installation after its closure, it is envisaged to unlink as much as possible the behaviour of the system barriers and to maximize both independently and conservatively the performances to be expected from each of these barriers.

Finally, all potentially occurring phenomena should be observed on a full scale and in "in situ" conditions in a demonstration facility where the performances of the different barriers can be tested over long periods of time, as well as all mining and technological aspects such as handling and transportation of actual loads.

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