

Geological Repository Layout for Radioactive High Level Long Lived Waste in Argillite

J.L. Gausson

Agence nationale pour la gestion des déchets radioactifs (ANDRA)
Parc de la Croix Blanche -1/7, rue Jean Monnet 92298 Châtenay-Malabry, Cedex
France

ABSTRACT

In the framework of the 1991 French radioactive waste act, Andra has studied the feasibility of a geological repository in the argillite layer of the Bure site for high-level long-lived waste. This presentation is focused on the underground facilities that constitute the specific component of this project. The preliminary underground layout, which has been elaborated, is based on four categories of data:

- the waste characteristics and inventory;
- the geological properties of the host argillite;
- the long term performance objectives of the repository;
- the specifications in term of operation and reversibility.

The underground facilities consist of two types of works: the access works (shafts and drifts) and the disposal cells.

The function of the access works is to permit the implementation of two concurrent activities: the nuclear operations (transfer and emplacement of the disposal packages into the disposal cells) and the construction of the next disposal cells. The design of the drifts network which matches up to this function is also influenced by two other specifications: the minimisation of the drift dimensions in order to limit their influence on the integrity of the geological formation and the necessity of a safe ventilation in case of fire. The resulting layout is a network of 4 parallel drifts (2 of them being dedicated to the operation, the other two being dedicated to the construction activities). The average diameter of these access drifts is 7 meters. 4 shafts ensure the link between the surface and the underground.

The most important function of the disposal cells is to contribute to the long-term performance of the repository. In this regard, the thermal and geotechnical considerations play an important role. The B wastes (intermediate level wastes) are not (or not very) exothermic. Consequently, the design of their disposal cells result mainly from geotechnical considerations. The disposal packages (made of concrete) are piled up in big cavities the diameter of which is about 10 meters and the length of which is about 250 meters. On the other hand, the design of the C waste disposal cells (vitrified waste) is mainly derived from their thermal power (about 500 W after a 60 year period of interim storage). The disposal cell is a tunnel the diameter of which is about 0,70 m and the length of which is about 40 m. The number of the disposal packages (made of steel) per cell, the spacing between two adjacent canisters within a given cell and the spacing between two adjacent cells are adjusted to limit the peak of temperature in the host formation at 100°C.

The disposal cells are also characterized by favourable design factors that would facilitate the potential retrieval of the wastes.

The whole underground layout would represent a surface area of several km².

INTRODUCTION

According to the 1991 French Radioactive Waste Act [1], Andra has studied the feasibility of a reversible geological repository in the argillite layer of the Meuse/Haute-Marne site (The underground laboratory is located in Bure) for high level long lived waste. This feasibility study is exposed in a report ("Dossier 2005" [2]) the draft version of which has been submitted to the French government in June 2005. The present paper is focused on the underground facilities design that constitutes the specific component of this project.

INPUT DATA

The preliminary underground layout, which has been elaborated, is based on two essential categories of input data: the waste inventory and the geological properties of the host rock.

Waste characteristics and Inventory

HLLL waste which are taken into account are divided into the following categories: -Class B waste has low to medium β - γ activity and therefore generates little or no heat. It constitutes the largest part of the inventory not only in term of volume but also in term of package number. Their total radioisotope inventory is relatively small compared to the other wastes. -Class C waste consists of fission products and minor actinides separated out during fuel reprocessing. Their high β - γ activity generates heat, which declines over time mainly due to the radioactive decay of the medium-lived fission products (cesium-137, strontium-90). This waste is incorporated in a glass matrix. Scenarios of direct disposal (without reprocessing) has also been examined in the framework of a comprehensive approach. Spent fuel is highly radioactive and generates also heat due to the presence of fission products as well as of plutonium and americium (stemming mainly from plutonium decay).

Input data: the Geology

As far as the geology is concerned, the Meuse/Haute-Marne site belongs to the eastern rim of the Paris Basin. In the zone studied, the Paris Basin consists of alternating layers of predominantly clay sediment and limestone. Within the sedimentary series, the clay formation studied is the Callovo-Oxfordian argillite formation.

In this zone, the Callovo-Oxfordian is a homogeneous layer of low permeability, the top of which is found at a depth ranging from 420 metres (corresponding to the laboratory site) to over 600 metres following the direction of the dip. Its thickness also varies gradually from 130 metres in the South to 160 metres in the North of the zone.

As far as short-term mechanical behaviour is concerned, the simple compressive strength of the argillites averages 21 megapascals (MPa) in the middle of the formation studied. The modulus of elastic deformation of Callovo-Oxfordien argillites ranges from 3 000 to 5 000 MPa.

The Callovo-Oxfordian argillites present anisotropic thermal conductivities, with the anisotropy resulting from the bedding corresponding to the deposit of sediments. Parallel to the stratification, the thermal conductivity varies from 1.9 to 2.7 watts per metre and per degree Celsius ($W/m \cdot ^\circ C$) depending on the carbonate content. It varies from 1.3 to 1.9 $W/m \cdot ^\circ C$ at right-angles to the stratification.

REQUIREMENTS

Long term performance objectives

For the post-closure period, Basic Safety Rule n° III.2.f states that the radiological impact of a repository shall not exceed $\frac{1}{4}$ millisievert per year (mSv p.a.) for a reference scenario covering a series of probable

natural events.

The Reversibility

The Act of 30 December 1991 makes provision for a study of a reversible repository. At the government's request, the National Review Board (CNE) submitted a report on reversibility in June 1998. In December 1998, the government published a declaration stressing that research should adhere to the reversibility paradigm.

LAYOUT DESCRIPTION

The underground disposal facility would consist of disposal cells (underground caverns), excavated in the argillite formation, containing waste disposal packages. These waste packages consist of primary waste packages, as conditioned by waste generators, supplemented by an over pack according to repository requirements. The layout studied contains disposal cells for the various categories of waste within specific disposal zones (B waste zone, C waste zone and, if applicable, spent fuel zone) physically distinct from each other. This arrangement is considered to offer independence in terms of management of the various types of waste as well as of phenomenological behaviour.

For cell construction, waste emplacement and reversible management of the disposal facilities, the access to the underground is ensured by four vertical shafts and connecting drifts.

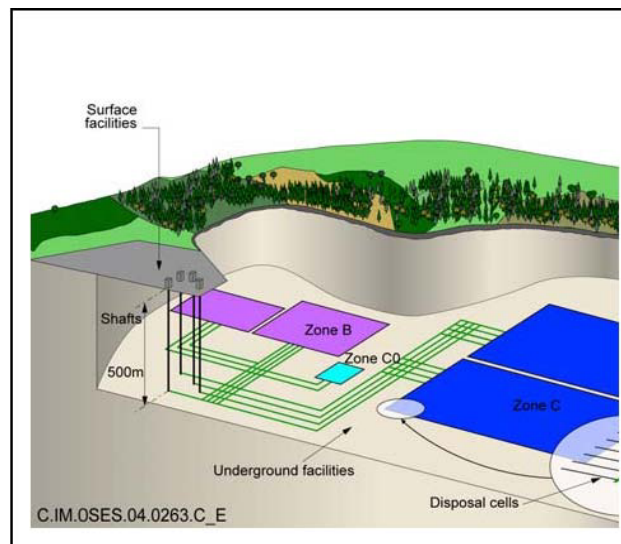


Fig. 1. View of a geological repository in operation

KEY FACTORS IN THE DESIGN OF THE UNDERGROUND FACILITIES

The technical options proposed for the design of the underground facilities are based on three main needs:

- the long-term safety functions;
- the reversibility;
- the operational safety. These needs are accompanied by a search for compactness.

Design and long-term safety

In order to control water flows, radionuclide migration to the environment, and the disturbance caused by the repository, several measures are adopted.

- In order to maximise the thickness of argillite located above and below the repository, the underground facilities are developed on a single level and located in the middle of the Callovo-Oxfordian layer.
- The geometric configuration of the underground facilities is designed to keep the temperature of the host rock in contact with the disposal cells below 100°C.
- The disposal cells are “blind” tunnels and the groups of cells have a “dead-end” topology. The overall layout itself is in a dead end configuration, all shafts being grouped together on a single side of the repository.
- The disposal zones are compartmentalised to reduce the quantity of waste and radionuclides that could be affected in the case of a failure or of an intrusion situation. In this respect, each module consisting of a cell or a group of cells is independent from the others by seals and a sufficient horizontal distance.

Design and reversibility

The meaning of the term “reversibility” is wider than the only ability to withdraw waste packages from the repository (“retrievability”). Reversibility is defined as the possibility of progressive and flexible management of the disposal process, leaving future generations free to make their own decisions.

In this regard, the modularity of the layout, adopted with regard to long term safety considerations, (consisting of independent modules) constitutes a favourable factor. Moreover, the dedication of distinct connecting drifts to the construction and operation activities permits the implementation of a step-by-step programme. Construction and operation of a small group of disposal cells can be carried out simultaneously and the feedback experience gained on the first steps can be used to improve the design and the operation method on the following ones.

As far as the retrievability is concerned, preference is given to materials and design arrangements promoting the durability of the structures and the disposal packages over a period of several centuries. Therefore, clearances (between waste packages and cell walls) for handling purposes can be durably maintained. Then, should the retrieval of the waste be decided, it would be possible to carry out this operation with the same equipment as the one used for the emplacement.

Design and operational safety

Operational safety considerations aim to ensure the safety of construction, waste transfer, waste emplacement and closure activities. Construction and nuclear operations implemented in the underground are characterized by specific flows in term of materials, vehicles, people and ventilation. To avoid any interference between these flows, specific drifts are dedicated to construction and nuclear activities. This physical separation permits to carry out these operations simultaneously and safely.

Quest for compactness for the underground facilities

The search of compactness consists in limiting the total excavated volume and the footprint of the underground layout. This objective is motivated by a reduction of the impact on the host rock (for long term safety reasons) but also by economical considerations.

As a result, the principle of irradiating waste repository chambers with simple geometry has been selected for B waste, while horizontal cells, in tunnels, are preferred for C waste and spent fuel. Nevertheless, the compactness results from a compromise between thermal, geotechnical and technological requirements.

WASTE OVERPACK AND DISPOSAL CELL CONSIDERED FOR B WASTE

Disposal package

The B waste category covers a highly diverse range of primary packages in terms of conditioning, geometry, radiological and chemical content. In order to standardize the handling operations, the disposal package adopted is a concrete container that regroups together four primary packages. The weight of this package varies from 6 to 25 tonnes and its dimensions from 1.2 to 3 metres. Radiological protection is not incorporated into the container as it would require an extra thickness of concrete and adversely affect the compactness target.

Disposal cell

The disposal cells are subhorizontal tunnels limited in length to approximately 270 m. As B waste packages are only slightly exothermic, if at all, the excavated diameter of the cells results essentially from the geotechnical design and the compactness target. It is limited to 12 metres at most.

The concrete drift liner gives the engineered structure mechanical stability. Selected first and foremost for its mechanical qualities and its durability favourable to reversibility, the concrete liner also provides chemical protection for the packages and contributes to radionuclide retention. Its inner section has a rectangular shape and delimits a repository chamber in which the packages are stacked over several levels.

The repository chamber forms an irradiating volume in which packages are handled by a remotely operated forklift. The head of the cells is equipped with a radiological airlock enabling the disposal packages to be extracted from the shielded transfer casks and protecting the operators liable to be present in the access drift.

During the closure process, the gaps between packages in the disposal cell are not backfilled to facilitate the operations. This provision would also facilitate a potential retrieval of the waste packages. The volume occupied by the radiological airlock is backfilled and the access drift is sealed with a swelling clay plug. Each B waste cell constitutes, in the long term, a module isolated from the others.

WASTE OVERPACK AND DISPOSAL CELL CONSIDERED FOR C WASTE

Disposal package

To prevent the inflow of water onto the waste during the thermal phase (during which the temperature exceeds 50°C), each primary package of vitrified waste is placed in a watertight overpack. This over-pack is made of non-alloy steel with an effective thickness of 55 millimetres, very conservatively designed to withstand corrosion for several thousand years. The mass of the standard disposal package is about 2 tonnes.

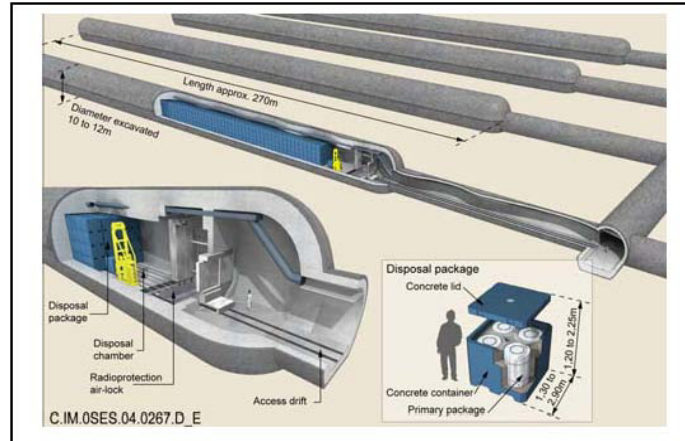


Fig. 2. B waste disposal cell in operation

Disposal cell

The design of C waste disposal cells results from the search for a physical and chemical environment suited to the packages. In this regard, steel is prioritized versus concrete since this latter material is not compatible with the glass matrix. The design is also influenced by thermal considerations. From this standpoint, the heat is to be dissipated by conduction through the rock only and not by ventilation. C waste disposal cells are dead-end, horizontal boreholes with an excavated diameter of approximately 0.7 metre. At this stage, their length has been limited to around 40 metres, a length considered reasonable in view of construction and handling techniques. They are equipped with a metallic sleeve that supports the argillites and enables package handling for their emplacement and possible future retrieval. They contain a single row of 5 to 18 disposal packages. Given the residual thermal power of the waste (after an interim storage period of 60 to 70 years) the disposal package require to be separated from each others by spacers to keep the temperature of the rock below 100°C. As far as the closure process is concerned, a swelling clay plug held mechanically by a concrete retaining plug seals the cell.

DISPOSAL PACKAGE AND LAYOUT CONSIDERED FOR SPENT FUEL

Disposal package

The disposal packages designed for spent fuel comprise a cylindrical envelope of non-alloy steel. The thickness of this envelope must guarantee watertightness during the thermal phase. For fuel types (UOX and MOX) discharged from electricity generating pressurised water reactors (PWR), a lifetime of 10 000 years has been adopted. The thickness has been conservatively determined (approximately 110 mm for UOX container).

The number of assemblies in each package depends on the type of spent fuel. The packages studied contain one assembly in the case of MOX and four assemblies in the case of UOX. Moreover, the disposal package design ensures that the risk of criticality is controlled over the various time scales.

Disposal cell

The design of disposal cells for spent fuel is similar to that for C waste. Nevertheless, the insertion of a swelling clay buffer (engineered barrier) between the packages and the geological formation has been adopted. The aim is to safeguard against uncertainties in the thermomechanical behaviour of the cell, caused by a relatively slow decrease in the heat released from the spent fuel.

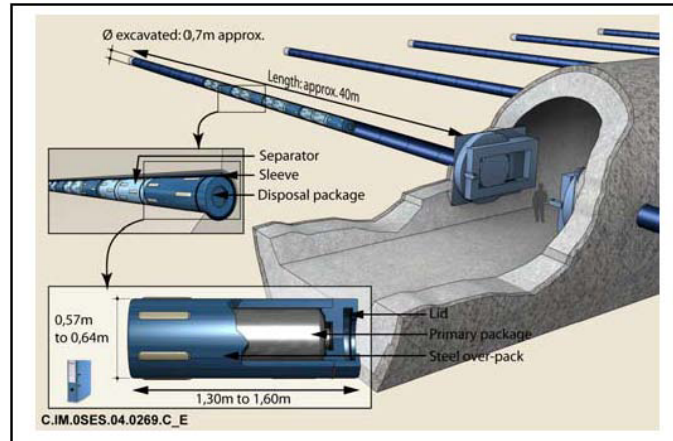


Fig. 3. Vitrified C waste disposal cell

OVERALL UNDERGROUND LAYOUT

The overall underground layout is composed of three components: the shafts, the connecting drifts and the disposal zones.

Shafts and connecting drifts

A series of four shafts links the surface facilities to the repository level:

- a shaft dedicated to the transfer of personnel and small equipment ; this shaft is also used for air intake;
- a shaft dedicated to the transfer of crushed rock, backfill, other materials and equipment; this shaft is also used for air intake;
- a shaft specifically dedicated to the transfer of disposal packages;
- an air exhaust shaft.

The disposal zones can be accessed from the shafts via a set of connecting drifts. To enable waste package emplacement activities and new module construction activities to coexist safely, the connecting drifts are allocated to specific functions:

- some connecting drifts serve the construction worksites and are equipped with railway lines or tracks for plant mounted on tyres. They are designed for the transfer of worksite personnel, mining equipment, broken rocks and construction materials;
- other drifts are dedicated to the transfer of disposal packages ; -finally, some drifts are specifically dedicated to ventilation air return. If and when a decision is taken to close the repository modules, the connecting drifts and shafts are sealed.

Disposal zones

The B waste disposal area is divided into two zones. One is dedicated to packages containing organic materials and the other to those that don't have some. This separation limits the impact of chemical disturbance that may be caused by alteration of the organic materials in the long term. The Fig. 4 illustrates the possibility of separating the repository zone into two sub-zones according to whether they contain organic matter or not.

The disposal area for vitrified C waste or spent fuel consists of a series of modules. Each module contains

several dozen disposal cells. The cells are served by access drifts, oriented at right angles to the cells. The space between the cells, essentially resulting from thermal considerations, is designed to ensure adequate heat dissipation.

An example of a possible overall layout developed on a footprint of 15 km² (for a scenario in which the spent fuel is entirely reprocessed) is illustrated by the Fig. 4.

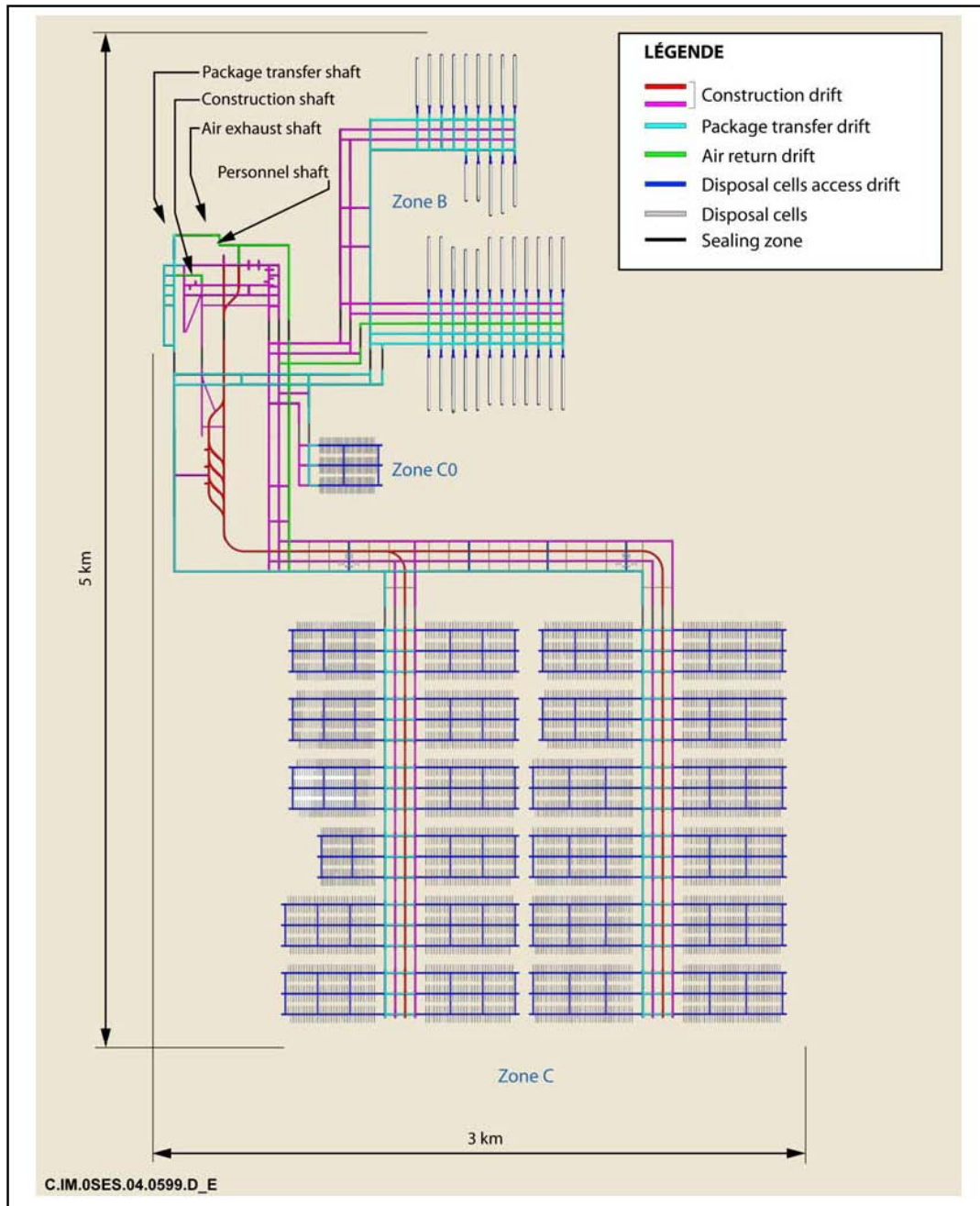


Fig. 4. Example of an overall layout for a scenario in which the spent fuel is entirely reprocessed

CONCLUSION

The repository design elaborated by Andra is characterized by its robustness. It is based on the findings of a comprehensive research program in term of science and engineering, on the feed back from industrial experience in the field of nuclear and mining activities, on the results of a technological prototypes demonstration program and on international benchmarking. In this last regard, the operational experience build up on the WIPP site, the only geologic repository existing in the world, has been a source of valuable information.

Nevertheless this design is not yet optimized. According to the French government's decision, a phase of development and optimization will be necessary.

REFERENCES

1. Act of 30 December 1991 – n° 91-1381
2. Dossier 2005 Agile – June and December 2005