

## Andra research on the geological disposal of high-level long-lived radioactive waste



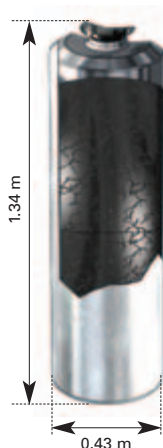
Experimental drift (-445 m) of the Meuse/Haute-Marne underground research laboratory

### A national mission

The high-level long-lived radioactive waste (HLLL) resulting from nuclear power plants, spent fuel reprocessing, research and defence activities is currently stored safely and temporarily in industrial facilities.

The French Waste Act dated 30<sup>th</sup> December 1991 initiated a research programme to define methods for the long-term management of this waste. It has entrusted Andra, the French National Radioactive Waste Management Agency, with the task of assessing the feasibility of deep geological disposal of this waste, a solution also considered by various other countries (Finland, Sweden, Belgium, Switzerland, United States) and deemed particularly robust with regard to safety by international authorities such as the IAEA<sup>1</sup>. The results of this research are regularly assessed by the French

National Review Board, an independent authority created by the December 30<sup>th</sup> 1991 Waste Act, and constitute the basis of the parliamentary debate scheduled for 2006.



Picture of an R7T7 vitrified C waste primary package

**> A repository system** consists of a series of elementary cavities (disposal cells) excavated in the rock (host formation). These disposal cells are grouped into large sets (modules) and receive the waste packages. The modules are connected by drifts, themselves serviced by access paths connected to the surface via shafts.

### > Detailed knowledge of the waste to be managed

Andra has compiled an inventory of the waste and assessed its future production by current facilities based on four scenarios defined with waste producers (EDF, AREVA, CEA) and representative of possible strategies for spent fuel reprocessing (from continuation to complete interruption).

There are two types of waste:

**> C waste:** high-level waste (1% of the total volume and 96% of the radioactivity) resulting from spent fuel reprocessing, confined in a glass matrix and poured into stainless steel drums. This type of waste gives off large amounts of heat.

**> B waste:** long-lived intermediate-level waste (the most abundant in terms of volume) compacted or conditioned in bitumen or concrete matrixes and then placed in concrete or steel drums.

The radioactivity of the waste decreases over time.

The studies have encompassed the possibility of the disposal of non-reprocessed spent fuel, although spent fuel is not today considered as waste and is planned for reprocessing in the next years.

<sup>1</sup> International Atomic Energy Agency

# Clay and granite: Two research programmes

## > Granite medium

Since Andra does not have available an underground laboratory in a French granite formation, its research teams have participated in experiments conducted in Sweden (Äspö), Switzerland (Grimmel), Canada (Lac du Bonnet) and Finland (Olkiluoto). These studies were not intended to assess the feasibility of a repository designed according to the specific characteristics of a particular site. Their purpose was to assess the interest of the granite medium and to propose generic concepts capable of meeting the long-term safety objectives within the French geological context. In the same manner, the safety analysis is not intended to produce specific conclusions regarding the performance of the system considered with respect to quantified radiological protection objectives. Its purpose is to identify and handle essential issues and to verify that none of the problem areas examined rules out feasibility.

Andra has studied the feasibility of an HLLL waste repository in French clay and granite formations. The results of this research are presented in the Dossier "2005 Argile" (clay) and Dossier "2005 Granite".

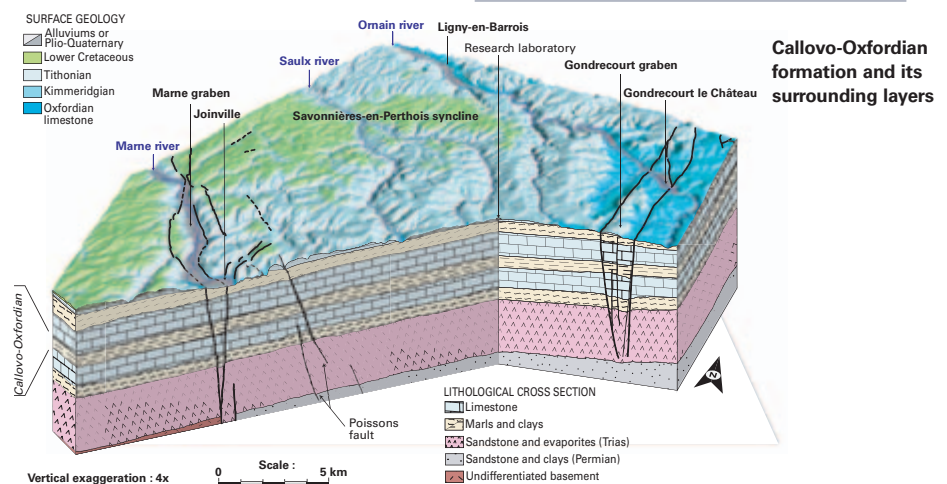
The studies covered four complementary aspects:

- > Acquisition of data concerning the waste packages, material behaviour and clay and granite mediums.
- > Repository design: waste conditioning, repository architecture and integration in a geological site, operating modes and reversibility.
- > Analysis of the long-term behaviour of the repository and modelling of its thermal, mechanical, chemical and hydraulic evolution.
- > Long-term safety analyses.

## > Clay medium

Andra has conducted studies in its Meuse/Haute-Marne underground research laboratory, created by the decree of August 1999 and located at a depth of 490 m in a stiff argillaceous rock (argillite) 155 million years old,

referred to as the Callovo-Oxfordian formation. Since 1994, Andra has drilled 27 deep boreholes meaning over 15 km of drilled formations, cored 2.3 km of argillite from these boreholes, and taken over 30 000 samples. Direct survey of the Callovo-Oxfordian and in situ experiments are pursued since 2004 in the shafts and in nearly 100 metres of drifts. The Mont Terri laboratory in Switzerland is also an essential resource, with clay similar to that of the Bure site.



## > International cooperation and review

Andra has conducted these two research programmes in collaboration with foreign counterparts (Nagra in Switzerland, Enresa in Spain, BGR in Germany, Ondraf in Belgium, etc.) and

with the scientific community in France (French Geological Survey BRGM, Atomic Energy Commission CEA, French National Centre for Scientific Research CNRS, French Petroleum Institute IFP, National Institute for Industrial Environment & Risks INERIS, National Polytechnic Institute of Lorraine INPL, School of Mines, etc.)

and abroad. Over 100 laboratories throughout the world have participated. In addition, Andra submits its research for international review. In 2003, a group of international experts under the aegis of the OECD/NEA examined the synthesis report on clay produced in 2001 and considered the results obtained as positive.

# Meuse/Haute-Marne site

## > An argillaceous formation favourable for waste disposal

After 10 years of research, Andra has acquired sufficient data to consider that the Callovo-Oxfordian formation of the Meuse/Haute-Marne site has favourable properties for an HLLL waste repository.

This argillaceous formation with very low permeability and homogeneous over a large area, located at an average depth of 500 metres, is unaffected by faults and presents very low seismic risk. Since deep enough, future climatic changes (erosion) will not impact it.

Other characteristics are: very low water flow, little deformation, good response to the perturbations due to mining excavation work and to the thermal and chemical impact of the waste and repository materials (thus preserving its confinement properties over very long periods of time), stable geological environment.

As well, surrounding formations presents low permeability and slow water flow. These favourable characteristics are found throughout a 200 km<sup>2</sup> area north and west of the laboratory.



Meuse/Haute-Marne research laboratory

# Repository architectures in an argillaceous formation

## > Robust options and modular system specialized according to waste type

In order to dispose of and manage the various types of waste packages (B, C, and possibly spent fuel) in a safe and reversible manner, Andra has adopted simple and robust options, proposing a modular and flexible architecture consisting of elementary components (repository modules).

In order to simplify operation and increase its robustness, the waste packages manufactured by waste producers are

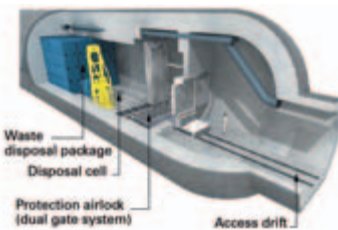
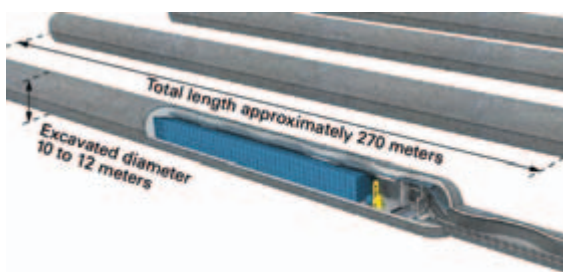
placed in concrete containers (B waste) or steel containers (C waste and spent fuel). The repository is located on a single level in the middle of the Callovo-Oxfordian and organised into distinct zones (according to package type) separated by 250 metres of argillite and subdivided into modules.

The generally circular profile of the engineered structures, their dead-end arrangement, their closure with low-permeability seals, the back-filling of the drifts at the end of the operating phase and the choice of materials (concrete, steel, clay) all contribute at first to reducing perturbations and minimising water flow in the geological

formation, then later to limiting and delaying the release and migration of radioactive elements.

## > Reversibility guaranteed for at least three centuries

Integrated as of the repository design phase, the reversibility requirement leads to privileging durable materials and to the implementation of systems for package retrieval. Waste package retrieval is possible through simple inversion of the emplacement process over various centuries.



The B waste disposal cell has a useful length of 250 m, an excavated diameter of 12 m, and is equipped with concrete lining. The waste disposal packages, which contain primary packages, are manufactured in concrete and stacked in several layers in the disposal cell.

## Two basic guidelines Three major functions

### Long-term safety and reversibility are the guiding principles for repository design

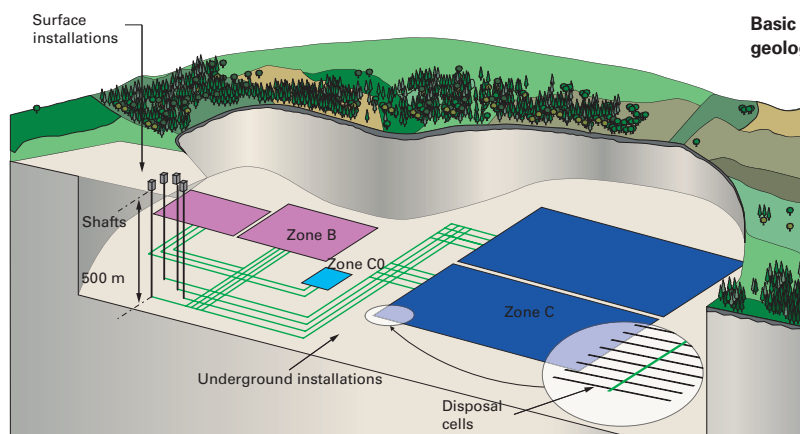
The purpose of a geological repository is to protect man and environment from the possible impact of radioactive waste by interposing various barriers capable of confining the radioactivity for several hundreds of thousands of years (packages containing the waste, repository installations, geological medium).

The safety approach adopted therefore takes into account very long periods of time and privileges the most robust solutions so as to ensure the three major functions of the repository:

> Limiting the release of radioactive elements and immobilising them in the repository

> Delaying and reducing the migration of radioactive elements beyond the repository

> Preventing water circulation (which can degrade the waste packages and favour the migration of the radionuclides contained therein)



Basic layout of the geological repository

These functions are ensured by barriers and various redundant components.

The approach to reversibility proposed by Andra consists of allowing the flexible and step-wise management of the repository. The objective is to leave future generations the freedom to make decisions concerning repository management. The modular repository design is intended to offer the widest possible range of choices. Reversibility means the possibility to retrieve emplaced

packages and as well to intervene in the disposal process and to modify the repository design. An observation programme has been developed to ensure the technical feasibility of the backward process. The studies have shown that reversibility could be ensured for a minimum period of two to three centuries, with no intervention other than standard maintenance and monitoring operations.



Åspö laboratory (Sweden)

## Safety assessment

### > Demonstration of the robustness of the repository concept in an argillaceous formation

To verify the robustness of the solutions proposed, Andra has simulated the repository evolution in the very long term through a phenomenological analysis of repository situations (PARS) and then tested the limits of validity of this representation via a safety analysis. This safety analysis defines the simplified history of repository evolution (normal evolution scenario). It covers the full range of possible situations through very cautious choices. Andra has also examined scenarios entailing highly unlikely events (intrusion, failure of safety functions).

### > Calculations projected over a period of 1 million years

According to the methodological guide published by the Nuclear Safety Authority (Basic Safety Rule RFS.III.2.f), the impact of the repository on man and the environment must amount to less than 0.25

millisievert in normal situations (i.e., 1/4 the dose due to non-natural exposure currently admitted for the public and approximately 1/10 the annual dose due to natural radioactivity). This impact has been subsequently calculated based on models. Andra has extended its calculations to one million years, in accordance with international practice.

The analysis shows that for all the situations considered, normal or altered, the proposed system ensures the three main safety functions without excessively depending on any of its components (each component contributes to the overall safety of the system in a significant but non-preponderant manner). The Callovo-Oxfordian formation plays a major role in immobilising the radionuclides and in delaying and limiting their migration into the environment in all situations.

The repository performance meets the dose objectives recommended by Basic safety rule III.2.f in all the scenarios considered, whether accidental or altered, and with significant margins. The repository represents therefore a robust disposal concept, including in rather unlikely situations with concurrent penalizing circumstances.

### > Granite medium: Interesting properties

*In the absence of a specifically site, the design principles adopted by Andra are based on research conducted in foreign laboratories and on a typological analysis of 78 granitic zones of over 20 km<sup>2</sup> located in the Massif Central and Massif Armoricain formations, quite apart from large faults.*

*The architectures proposed are adapted to granite fracturing and rely on the very low permeability and high resistance of the non-fractured rock. Various options have been transposed from the repository studies concerning the clay medium: overpacking, separation of packages into specialized zones and modules, modular operation and closure, sealing and backfilling of engineered structures, measures favouring reversibility.*

*In the absence of a specific site, the safety analysis has not estimated the impact of the repository in terms of the dose to which the public may be exposed. It has been used to determine the role and performance of the repository components with regard to the safety functions, and to identify and handle uncertainties. It stresses the relevance of the architecture adopted (adapted to granite fracturing) and the efficiency of the engineered components. A strong uncertainty remains regarding the possibility of finding sites with sound granite blocks of sufficient size outside the fracture network.*

### > Conclusion

Based on the research completed, the basic feasibility of geological disposal in an argillaceous formation appears to be achieved.



Agence nationale  
pour la gestion des déchets radioactifs