Feasibility Study of a Deep Geological Repository in France Dossier 2005

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ABSTRACT

To fulfill its obligations as stipulated in the 1991 French Waste Act, Andra submitted the Dossier 2005 to French Government on 30 June 2005. This Dossier reports on Andra's feasibility study pertaining to deep geological disposal of high level and long lived radioactive waste. It presents the result of a waste inventory and of site characterization, as well as the engineering, science, and safety studies, used to demonstrate technological feasibility, adequate scientific understanding of all relevant processes, reversibility, and operational and long term safety of the studied repository concept.
The Dossier 2005 Argile presents the outcome of this research program focused on:

- Site characterization, laboratory and in-situ experiments, URL with experiments in progress, site- and regional-scale, hydrogeologic, seismic and climate evolution studies;
- Data acquisition on waste forms, material behavior, understanding of long-term physical and chemical processes;
- Design of a repository system , its architecture and integration into a geological site, commensurate with long term safety and reversible management;
- Safety of construction, operation and closure of the underground facility;
- Repository behavior and evolution – detailed understanding of thermal, mechanical, chemical and hydraulic phenomena, their modeling and numerical simulation; and
- Long-term safety evaluation and repository performance assessment.

Main results of Dossier 2005 Argile are summarized in this paper.

INTRODUCTION

As requested by the law of 30 December, 1991, two files, Dossier 2005 Argile and Dossier 2005 Granite, were delivered to the French Government on 30 June 2005. Dossier 2005 Argile deals with the existing Meuse/Haute-Marne site near Bure. Dossier 2005 Granite is based on experiments and knowledge in foreign countries and deals with generic approaches for safe disposal of high-level and long-lived (HL-LLW) radioactive waste in a deep geological disposal system (repository) in granites in France. This paper focuses on Dossier 2005 Argile.
The iterative approach leading to the Dossier 2005 is presented as shown on Fig. 1.

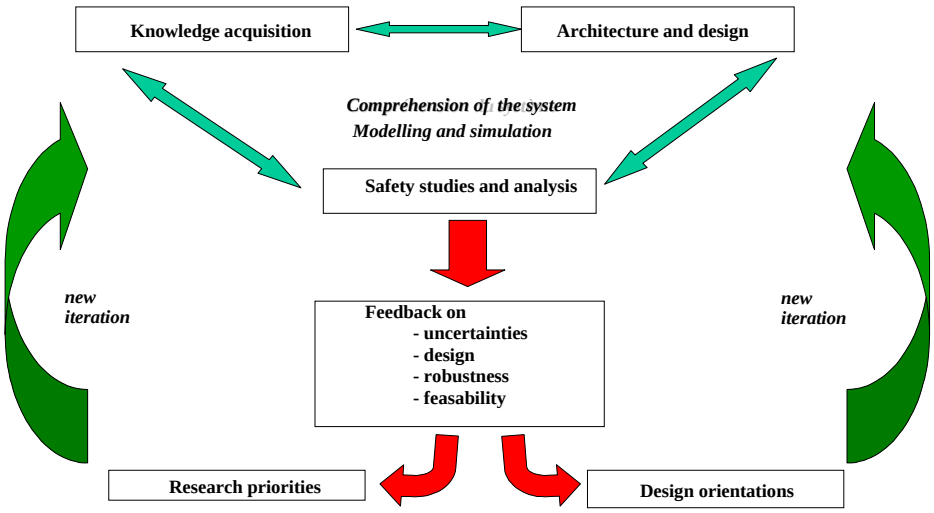

Fig.1. Iterative approach in Dossier 2005

Three iterations were carried out between 1994 and 2005 (construction and operation licence application of the underground research laboratory in 1996, Dossier 2001, Dossier 2005).
In the following sections, the design approach is presented. Then, main waste and site characteristics are given as input data to the repository design. Special emphasis is put on reversibility. Last, methods for analysis and performance assessment of the safe disposal are introduced and main results reported.

DESIGN APPROACH FOR A SAFE AND REVERSIBLE DISPOSAL SYSTEM

Long term safety is a direct input to design. In an iterative approach between design and safety, Andra assigned safety functions to all the components of the repository having a significant role (host formation, waste packages, architecture elements) and this functional analysis defines then the technical specifications in terms of requirements for each component to be designed. These component characteristics (for example, materials and thickness of the disposal packages, cell dimensions, etc.) were determined with respect to safety by taking into account their interactions with the environment and the possible uncertainties. They were then integrated in the repository evolution scenarios and assessed with more or less penalising calculation values.
The design of a "multi-function" system completes the notion of a ″multi-barrier″ system. Some components contribute to fulfilling the same function (complementary) or maintaining the function in case one of them fails (redundancy).

The assessment of repository feasibility assumes that a sufficient knowledge of the behaviour of the repository components has been acquired. Over repository time scales, no feedback is available other than by means of natural and archaeological analogues. This does not mean, however, that these residual uncertainties related to the long duration and specific to the dossier, cannot be managed with a sufficient degree of confidence provided :

- Provisions are taken with regards to the repository conditions which would allow overcoming uncertainty consequences : choice of a very stable geological medium hardly affected since its deposition (155 million years ago), compartmentalisation of the repository into zones to prevent interactions between various kinds of waste, use of simple materials whose behaviour is well-known (for example, unalloyed steel, concrete), etc.
- Safety is integrated upstream from the design in order to orient the choices toward the most robust solutions with respect to a possible lack of knowledge, and

- Uncertainties are systematically investigated and their potential effects examined, particularly in qualitative safety analyses, and taken into account in the safety assessment.

Andra implemented three complementary approaches to synthesise the knowledge, describe the repository evolution and manage the uncertainties.
Knowledge reference documents were made up in order to have a complete view of the elements available on the studied components : geological medium, materials, packages, etc. They include a review of the state of knowledge, correlatively identified the lack of knowledge and thus contributed in determining the sources of uncertainty and orienting the actions to reduce them.
Once a good level of knowledge is reached on each of the components and the repository global architecture is defined, it is necessary to describe as precised as possible its evolution through space and time : this is the purpose of PARS (phenomenological analysis of repository situations), which describes the phenomena (thermal, mechanical, hydraulic, chemical, radiological) and their couplings throughout the repository evolution and specifies the phases of this evolution from construction up to 1 million years. However, the system has to be broken down into simple subsystems in order to analyse it and PARS splits the repository evolution into a set of situations, each corresponding to a specific part of the repository and a specific time period, as well as a homogeneous phenomenological state. The phenomena and their couplings, as well as the associated models, are assessed for each situation and this assessment establishes the limits of knowledge or understanding and determines the uncertainties. The systematic work accomplished with the PARS led to a list of uncertainties. This approach is completed by a more transversal view of the main processes governing the repository evolution.
Finally, in a conventional way, the calculation parameters, models or data are systematically listed in order to ensure their traceability and to progressively update them through knowledge acquisitions, for the safety calculations.

A normal evolution scenario complying with the objectives was designed in order to perform the various studies. Then, uncertainties were managed through a qualitative analysis of safety and altered evolution scenarios.

As required by the 1991 law, the reversibility of the disposal system was studied, and was shown possible without weakening its safe performance.

WASTE PACKAGES

The feasibility study of an HL-LL waste repository, its design and safety assessment relies on the following knowledge of waste packages:

- Quantity, types and characteristics of current and future packages; and
- Long-term phenomenological behaviour in a repository situation, particularly the possible release of radionuclides.

In close collaboration with the waste producers an inventory model of HLW-LL waste was drawn up. This inventory model accounts for both the waste already produced, that currently is stored in conditioned and unconditioned forms on the production sites, and the waste that will be produced in the future by the current nuclear power plants.

One of the main scenarios studied supposes that all the 45,000 metric tons of heavy metal (MTHM) spent nuclear fuel (SF) unloaded by EDF (Electricité de France) power plants currently operating will be reprocessed. The total volume of vitrified waste accounts for about 6300 m3, and that of intermediate LL radioactive waste for about 80,000 m3.

The long-term waste packages behaviour was also investigated in detail in order to assess radionuclide releases when disposed of in a geological repository. After identification of the phenomena likely to first alter the matrices and the waste in the presence of water and then release the radionuclides into the solution, key phenomena were selected and their modelling provided a quantitative evaluation that demonstrated that glass-matrix lifetimes of at least several hundreds of millennia could be achieved in the conditions of the Callovo-Oxfordian clay environment. In the case of bituminised packages, a gradual radionuclide release over a period lasting from 10,000 years to several tens of thousands years resulted from the studies and the linked modelling. For hulls and caps, a simple corrosion model was applied, and releases were directly derived from corrosion rates.

THE GEOLOGICAL MEDIUM: THE MEUSE HAUTE-MARNE SITE

By the type and layout of their minerals and by their compactness and low permeability, deep argillaceous formations, such as the Callovo-Oxfordian formation of the Meuse Haute-Marne near Bure site which is approximately 155 million years old, have intrinsic properties that are valuable for the study of a geological repository of HL-LL waste: Water circulation is very low, thus reducing all effects induced by its presence and transport of radionuclides is mainly due to diffusive processes. The chemistry of the host medium remains stable over time no matter what disturbances occur due to the deterioration of the materials used for the installations, and this guarantees preservation of the argillites' confinement properties. With regards to geomechanics aspect, excellent rock stability allows for safe excavation and operations. The high content of clay minerals also governs interesting long-term deformability properties, and provides a high degree of radionuclides retention.

The surveys, measurements and analyses of the current state of the Meuse/Haute-Marne site and the properties of the Callovo-Oxfordian argillaceous layer have enabled a three-dimensional (3D) image of the site (commonly referred to as a conceptual model). This image, consistent with the sedimentological, structural, hydrogeological, geomechanical and geochemical data acquired, serves as a basis for the repository performance assessment.
Geological 3D section of the Meuse/Haute-Marne site is shown on Fig. 2.

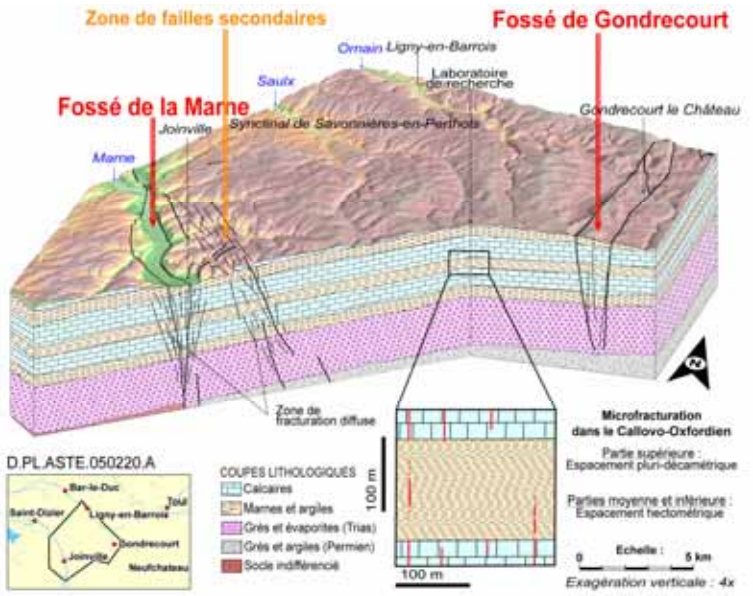

Fig.2. Geological 3D section of the Meuse/Haute-Marne site

The purpose of the experimental programme from 1999 to 2005 was to provide the data required for the modelling of phenomena identified as important for the design and safety assessment of a possible repository, including checking the favourable properties of the formation (extension of disturbances due to a repository, confinement capacity and radionuclides transfer processes in the Callovo-Oxfordian), constructability of a repository and the nature and extent of rock excavation damage.
Apart from full scale experiments and direct measurements on the argillites in the laboratory drifts, the excavation and construction of the two shafts between 2000 and 2005 were accompanied by numerous scientific works aimed at detailed observation of the Oxfordian and the Callovo-Oxfordian, the geology of the ground inside the rock, monitoring of the hydraulic and mechanical disturbances and assessment of the nature and extent of excavation-induced rock damage.
The research programme also included the drilling of bore-holes and seismic surveys designed to increase knowledge of the host layer and the surrounding formations that demonstrated continuity and homogeneity, as well as tectonic stability of the site and of the Callovo-Oxfordian Formation.

A thorough experimental programme has been performed on the Meuse/Haute-Marne site, from the underground facility (Fig. 3).

Fig.3. Schematic illustration of the Meuse/Haute-Marne Underground Research Laboratory near Bure.

The following experiments have been undertaken:

- Scientific surveys in excavation drifts, with EDZ observation, pressure and permeability measurement, gas permeability measurement, extensometers ;
- Response to shaft sinking by deformation measurements and sonic wave velocity recordings;
- Permeability and interstitial water measurements;
- Chemical sampling and analysis of water and gas;
- Radionuclide diffusion and retention experiments;
- KEY experiment aiming at excavating and testing a groove concept to cut off the EDZ (excavation damaged zone);

- Thermal conductivity experiments; and
- Measurement of the argillite creep over a period of several years;

THE REPOSITORY AND ITS INSTALLATIONS

Engineering studies have made it possible to design the various repository components, then to check their industrial feasibility (construction, operation, operational safety, etc.). The main components of the design have been studied based, as far as possible, on existing industrial experience feedback in the nuclear, mining and civil-engineering fields. The options proposed do not freeze the specific architecture of a repository. At this stage, they represent a technical vision of what a repository installation may look like, but which is likely to evolve. Indeed, major work remains to be performed concerning the project's industrial development in order to carry out more detailed engineering studies.

The architecture proposed for the underground installations (Fig. 4) is horizontal with little vertical extension. In order to optimise the thickness of the argillites located above and below the repository, the structures are placed in the middle of the formation on a single level.
The repository zones are separated from each other according to waste type, the repository is divided into sub-assemblies and the various categories of packages (B, C and, where applicable, SF) are emplaced in separate zones, which are subdivided into modules and disposal cells receiving the packages. In zone B, a module corresponds to a single disposal cell; in zones C and SF, it comprises between one and several hundred cells. The modules are constructed and filled progressively to meet the disposal requirements, and several modules may be under construction or operation simultaneously within the same zone.

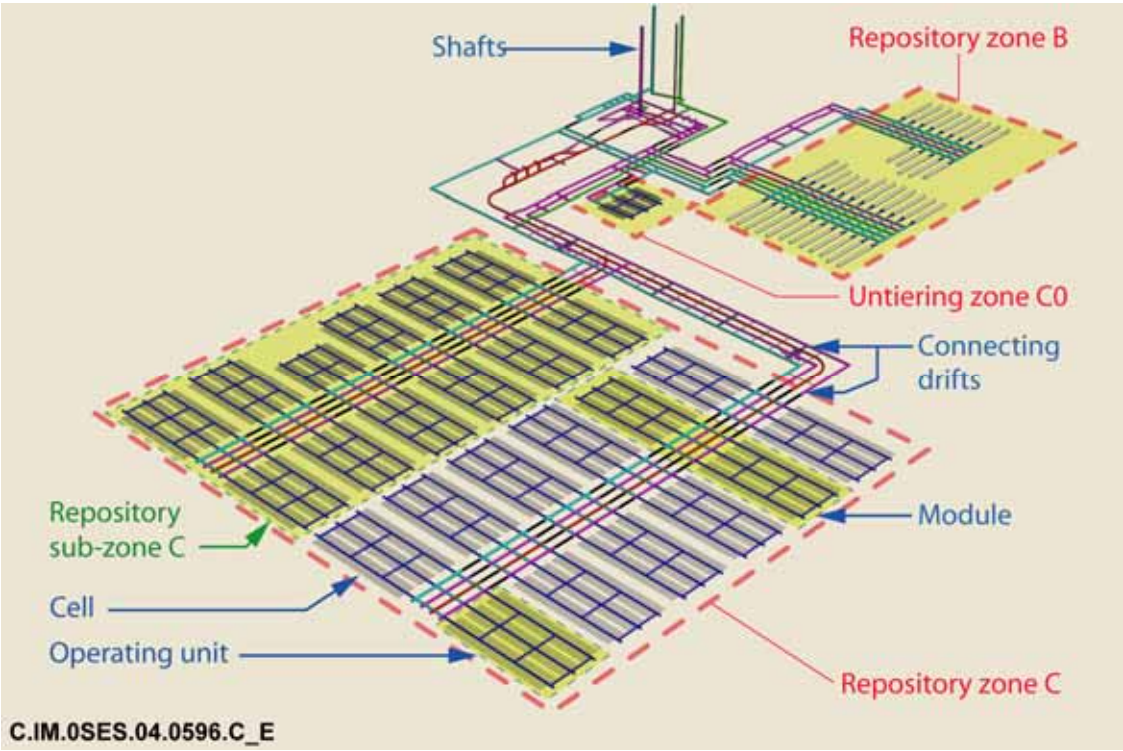

Fig.4. General lay-out of the IL and HL-LL waste repository

Type B waste primary packages represent more than 90 % in volume of HLLL waste. The disposal cell proposed is a dead-end horizontal tunnel with a useable length of 250 m and an excavated diameter of 12 m.
The option of steel over-packing type C vitrified waste has been favoured. The management of the heat released by the waste and the long-term safety requirements were the dimensioning factors. The structure of the disposal cells for type C waste is shown of Fig. 5.

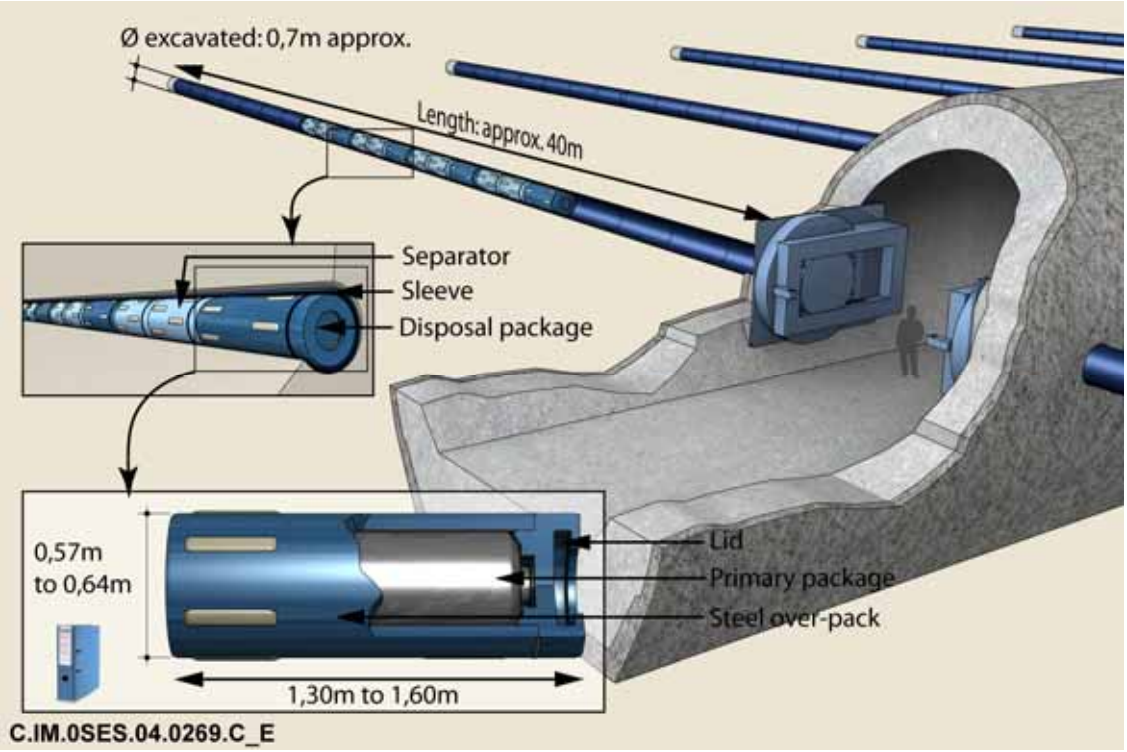

Fig.5. Type C waste disposal cell while in operating configuration

REVERSIBILITY

Special emphasis has been put on reversibility as it was a major concern from the public and a specific request of the 1991 law. The reversible operation has been defined as the possibility of progressive and flexible management of the repository that leaves future generations with freedom of decision. For this purpose, the disposal process is broken down into successive stages that allow, starting from the creation of the first modules up to the possible closure of a module or repository zone, a waiting and observation period, before deciding to pass to the next stage or to return to the previous one. Passing from one stage to another is not a final choice, like a page being turned, but a reasoned decision made in the full knowledge of the scientific, technical, economic, social and environmental parameters and of the consequences implied by the passage from one stage to another.
Reversibility has been made possible by knowledge of the evolution of the condition of the structures and the definition of the means of action, over a time scale of at least a century. This has led to research concerning the operational arrangements for managing the repository, particularly package retrievability, as well as the monitoring equipment that could be fitted within the structures.
As examples of the Phenomenological analysis, the physics of the behaviour of a type B waste cell shown on Fig. 6. The evolution of the structures is a determining factor for taking action on the disposal process. The Phenomenological analysis shows that the structures will remain in good condition for a period of

one or more centuries and that, over that period of time, the conditions in the repository will remain close to those of a surface storage unit. Andra has integrated into the structural design the possibility of package retrieval, which could be decided upon by future generations, to make it easier.

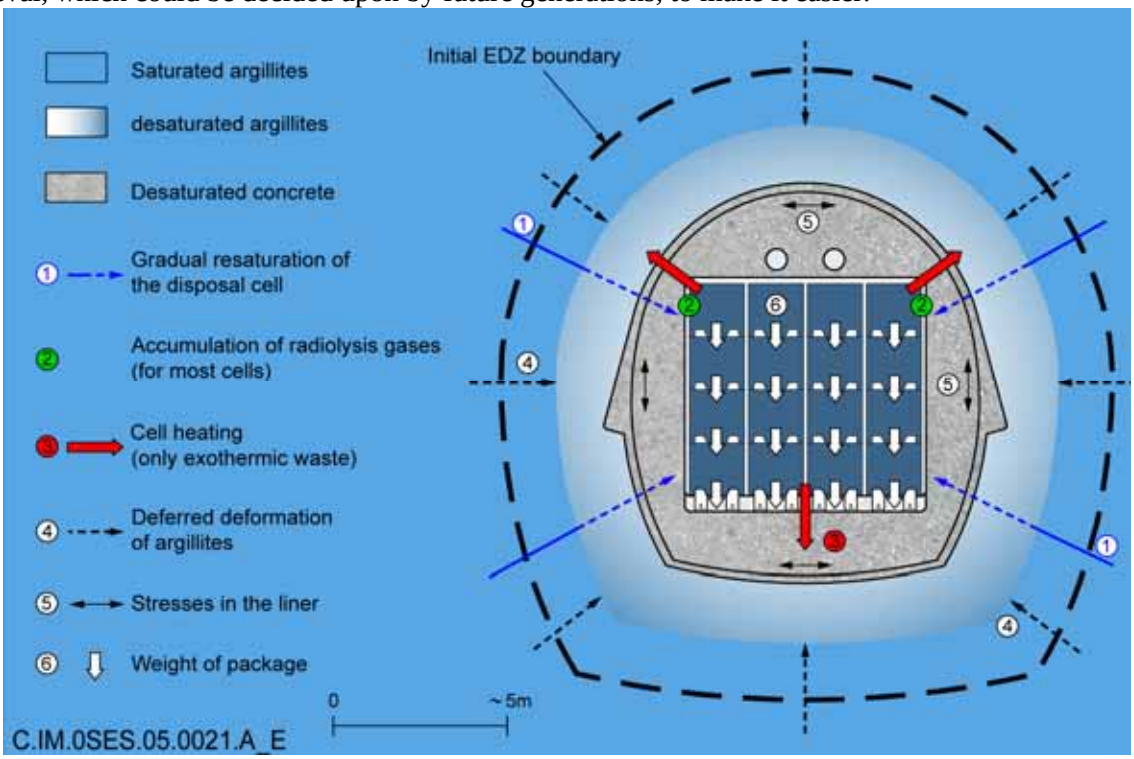

Fig.6. Schematic representation of the main phenomena inside a type B waste cell after closure

The design of type B waste cell linings as well as type C waste cell sleeves ensures their mechanical stability for 200 to 300 years without any particular maintenance almost independent of the closure phases carried out.

THE LONG-TERM BEHAVIOUR AND SAFETY OF THE GEOLOGICAL REPOSITORY AND ITS ENVIRONMENT

One of the main purposes of the deep geological waste repository is to provide a facility that, eventually, will not require human intervention and will be able to evolve passively in complete safety. In order to accomplish this, a body of knowledge is required describing the long term behaviour of the repository with a high degree of confidence and providing a basis for safety analysis.
The safety approach depends on several principles.

- First and foremost on a thorough knowledge of phenomena likely to evolve in the repository and an understanding of the long term behaviour of the repository and its environment; and
- The safety analysis, on the basis of in-depth knowledge of these phenomena, determines priorities by identifying key issues. The analysis draws on a rich and complex phenomenology, a prudent framework, which is represented in the form of simplified models and numerical simulations.

Based on this scheme, it tests the relevancy of the safety functions attributed to the various components and assesses the overall performance of the passive repository system. The safety assessment takes into account uncertainties regarding the repository evolution, the validity boundaries of the models, and possible variations of the parameters. It deals with uncertainties, as well as situations that deviate from the expected evolution, in the form of incidents that are independent of the intention of the designer (for example, intrusion into the repository) or failure of certain components. It culminates in a body of calculations and analyses, the purpose of which is to assess the compliance of the calculated impact of the repository with radiological protection regulations. It also produces safety indicators, parameters, that used to assess repository safety in a quantified form that sets forth the various safety margins of the disposal system.
Finally, the safety assessment facilitates an evaluation of the concept robustness of deep geological disposal.

Long-term behaviour was first studied in detail through the PARS, illustration of which has been given on Fig. 6. In order to facilitate comprehension of the complexity of the repository, Andra has broken down its evolution into different situations. Each of these situations corresponds to the phenomenological state of part of the repository or its environment at a given time in the repository lifetime and reflects the thermal, hydraulic, chemical and mechanical phenomena involved with their chronology and coupling. Together, these PARS define the complete and continuous phenomenological evolution of the repository and its geological environment.
Indeed, the PARS provided all integrated phenomenological information used for the design, for analyzing operations, as well as retrievability, and input data for modelling and performing safety analyses. Another example of the PARS is given for thermics at the scale of the repository and at different time horizons on Fig. 7.

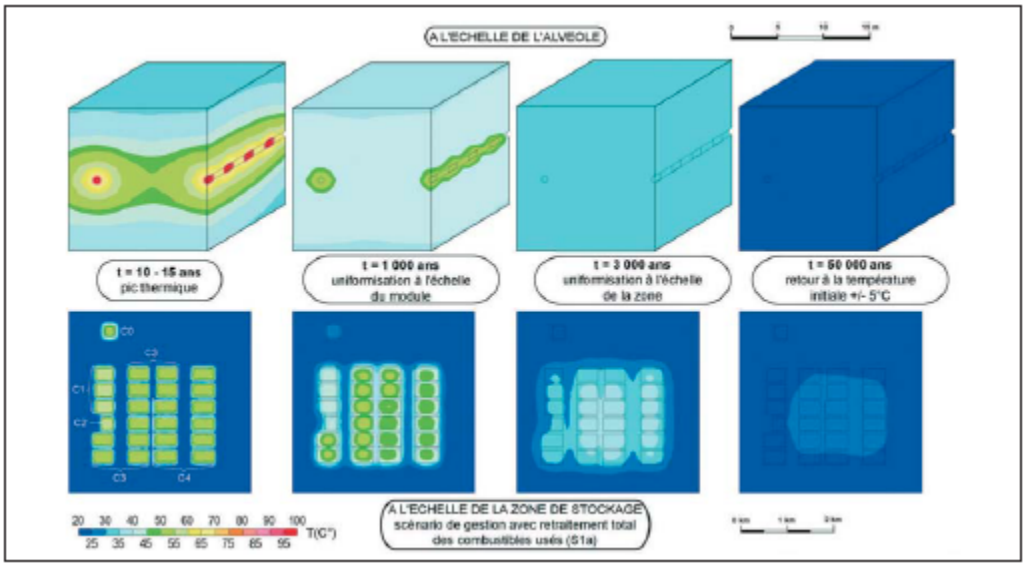

Fig.7. Temperature evolution in a type C waste repository zone at cell and repository zone scale

THE LONG-TERM REPOSITORY SAFETY ASSESSMENT

The long-term repository safety assessment consists of a thorough analysis of all possible features, processes and events (FEPs) affecting the repository. This assumes simplified but cautious representation of the phenomena and their development over time, and testing the validity boundaries of this

representation. For the purpose of the analysis, scenarios are developed and studied in details. The normal evolution scenario is the base case. Then, all types and combinations of FEPs can be tested through modified scenarios. The interest of scenarios is also to test the weight and consequences of different types of residual uncertainties on the long-term behaviour of the overall repository system.

A synthetic view of the dose at the outlet for the normal evolution scenario is shown on Fig. 8 for type B waste and type C waste.

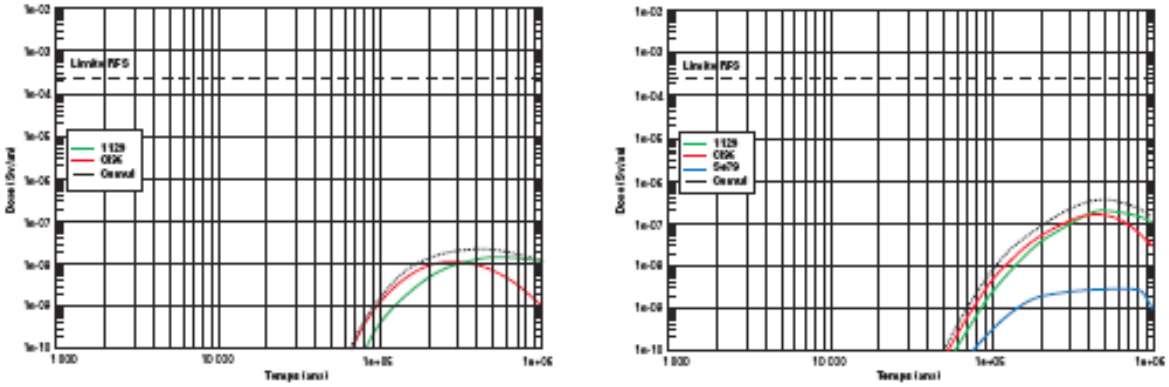

Fig.8. (left side): dose evolution at outlet (Saulx) versus time – type B reference package
(right side): dose evolution at outlet (Saulx) versus time – type C reference package

Maximum doses remain orders of magnitude lower than the regulation limit. Even for altered scenarios, including failure of the waste packages, similar results are achieved.

CONCLUSION

Studies performed by Andra during the last fifteen years have resulted in a considerable progress in research and understandings of HL-LL repository performance. The advantage of the Bure URl at Meuse / Haute-Marne site has been demonstrated and the basic feasibility of disposal in a French clay formation has been established. The main results to date are:

- The Meuse Haute-Marne site offers favorable geological conditions ;
- Architectures have been prepared to take advantage of the favourable geological conditions;
- Reversibility could be translated into concrete practical terms, and can be achieved without penalising safety margins; and
- The safety overview demonstrates the absence of significant impact on the environment.

Moreover, transferability of results over a region of 200 km^2 around the Meuse/Haute-Marne site has been shown.

As a result, after various types of assessments and reviews, and after a Public Debate, on June 2006 the French Parliament published a new Planning Act which requests an application in 2015 for the construction of a repository, and the beginning of disposal operations in 2025.