Main Features for the Conceptualization of the Post-Closure Evolution Scenario of the Cigéo LIL-HL Waste Repository - 13105

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ABSTRACT

In France, in order to commission the planned geological repository by 2025, a license application for the industrial project of this geological repository called Cigéo (Centre Industriel de Stockage Géologique) must be submitted and reviewed by the competent authorities by 2015. On the basis of its preliminary design set up in 2009 and on the associated reqirements for long-term safety, an overall conceptual model has been developed in order to prepare the performance and safety analysis.

The Cigéo repository makes use of the passive safety response characteristics of both the engineered and geological barriers that allow:

- resisting water ingress, with repository designs favoring the limitation of the water flows;
- limiting the release of radionuclides and chemical toxics;
- delaying and mitigating the spread of radionuclides and chemical toxics.

In order to evaluate the performance of the various elements, a conceptual model of the thermo-hydro-chemico-mechanical (THMC) evolution of the different components of the repository has been designed. It takes stock of a 20 years research effort which allowed data to be obtained from various surface geological campaigns, in-situ experiments in URLs and wastes characterization, and advances in numerical simulation to be utilised. Based on the best available knowledge to date, this conceptual model constitutes a robust basis for the definition and development of the long-term safety scenarios. It also helps identifying the residual uncertainties, and provides guidelines for additional research and system optimizations.

INTRODUCTION

In preparation for the choices of models and data supporting the safety assessments for the HLW and ILW French geological repository project Cigéo, the proposed scenario conceptualization is chiefly based on the phenomenological knowledge concerning waste, repository materials and the geological environment. Through research projects conducted in surface laboratories, experiments in the underground Laboratory of Meuse/Haute Marne (including the technological demonstrators) and the numerical simulation program, the R&D progresses made since 2005 help to strengthen and specify more accurately the phenomenological evolution considered, by attempting to reduce the identified residual uncertainties, and to more efficiently take into account the temporal and geometrical reality of the repository.

This conceptualization also takes into account:

- The more precise localization of the surface and underground architectures;
- The options of conception(design) which can be different from those already evaluated (in 2005), and that can lead to different modalities of representation (for example: sealings and heads of HLW vitrified waste vaults);
- The evolution of the inventory of waste (nature, quantities, radiological contents); and
- The evolution of the numerical methods and capacities allowing the improvement of the representation of components, processes, and scales of time and space of the repository, which are necessary for reporting the progress made in understanding and representing the THMC processes.

The phenomenological conceptualization of the Expected (i.e. normal) Evolution Scenario corresponds to the phenomenological evolution considered the most likely, when considering the the scientific and technological knowledge available. It aims at describing and quantifying the release and the transfer of radionuclides (and chemical toxics) from the waste packages to the biosphere, over the period of one million years.

It takes into account the possible variations compared to the most likely evolution (natural variability, industrial choices, and uncertainties). The quantification of the behavior of radionuclides through direct (concentrations and molar flows), and indirect indicators related to the functions of the components of the repository system (for example water flows and Peclet values).

The conceptualization is then characterized by:

- Mathematical models representing the processes and the components considered for representing the release and the transport of the radionuclides and,
- Values of parameters associated to these models. The domains of uncertainties or of variability are translated in the typology of the models and of the parameters (e.g. "phenomenological", conservative, pessimistic, alternate).

THE GENERAL GEOLOGICAL ENVIRONMENT

The conceptualization of the geological environment includes:

- The definition of a "realistic" geometry of the layers (or group of layers), with variable dips and thicknesses, in particular for the Callovo-Oxfordian formation. This is achieved through a representation of the roofs and walls of the formations by the superposition of sections of non-parallel and non-horizontal surfaces of variable orientation;

- Explicit representation of the porous horizons identified in the Oxfordian aquifer; and
- Grouping of the Oxfordian and Dogger hydrogeological models in a single model including the Callovo-Oxfordian layer. It would allow representing the natural variability of the hydrogeological gradient in the Callovo-Oxfordian in association with the flows directions in the Oxfordian. Thus, the potential effects of the relative positions of the repository zones, in particular vis-à-vis the surface-underground connections, could be estimated in terms of flow in the repository, in the perspective of the processing of the Altered Evolution Scenarios (e.g. seals failure).

The Callovo-Oxfordian representation is based on:

- A vertical distribution of the Callovo-Oxfordian in two macro units, the first one (UC: carbonated unit) showing higher carbonates contents and the second one (UA: argillaceous unit) higher clay minerals contents.
- Vertically, an homogeneous and constant (over time) distribution of the hydro-dispersive properties of every macro unit and horizontally, a division of every macro unit into a set of sub-units with homogeneous and constant hydro-dispersive properties.

This representation should take stock of the results obtained through the different exploration tools used for characterizing the geology of the sector (boreholes and 3D seismic survey). Then, it allows a probabilistic and detailed analysis of uncertainties to be carried out by allocating the lateral variabilities of hydro-dispersive properties and the uncertainties detected only on every macro-unit and not on the overall thickness of the Callovo-Oxfordian layer.

THE REPOSITORY

As indicated previously, the envisaged conceptualization aims at an approach that provides the best fit to the actual conditions of the repository. It associates the representation of the complete repository in a single model including the different zones (districts, vaults and drifts), the central zone and the surface-underground connections and a precise localization of the repository works in the Callovo-Oxfordian layer.

THE NEAR-FIELD ARGILITES

The damaged zone

The characterization of the damaged zone generated during the excavation process (nature, geometry, hydro-dispersive properties) conducted since 2005, in particular on different work elements in the Underground Laboratory (various sizes and excavation techniques) from now on of the following:

- At the level of the argillaceous unit of the Callovo-Oxfordian, a damaged zone constituted by two successive zones showing an almost-elliptic and iso–centered shape;
- A connected fractured zone, characterized by a network of strongly interconnected shear and extension fractures. They are chevron-shaped fractures which are created during the excavation and onion skin-shaped fractures related to the radial discharge; and
- A "discreet" fractured zone, beyond the connected fractured zone, characterized by fractures mainly not interconnected, which are approximately parallel to the walls of the excavated drifts and delimitate blocks of non-damaged argilites.

The hydraulic "self-healing" of fractures both in the connected-fractured zone and in the "discreet" fractured zone by both swelling of illite-smectite type minerals and mechanical compression. In the absence of major deformation, the EDZ (excavation damaged zone) recovers permeability lower than 10^{-9} m/s in the connected-fractured zone, and to that similar of the undisturbed argilites in the "discreet" fractured zone.

The phenomenological evolution of the damaged zone through time must be considered case by case. For example, for a drift seal, the hydromechanical interaction between the core and the argilites (swelling pressure of the bentonite core) should help to maintain a low permeability (less than 10^{-9} m/s).

Hence, the reference conceptualization proposed for the damaged zone considers (Fig. 1):

- A 'relatively' higher permeability zone (10^{-9} m/s), defined as being the EDZ, the extension of which is that of the connected fractured zone (thickness of about 0.35 times the excavated diameter),
- A zone of lower permeability (10^{-11} m/s) with thickness approximately of 0.8 times the excavated diameter.

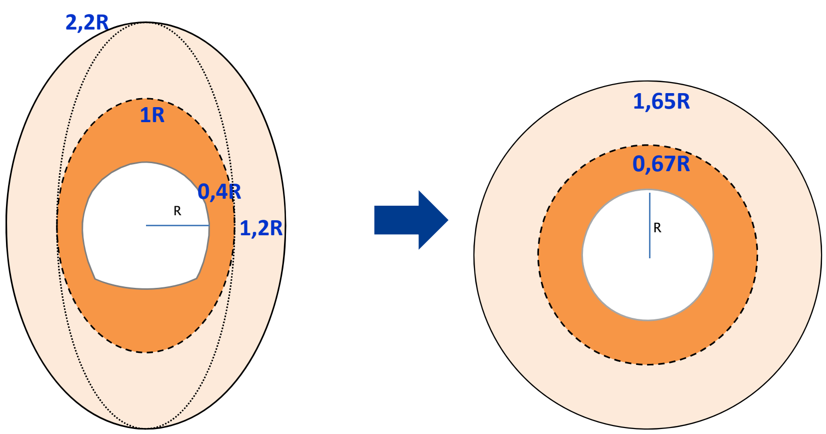

Fig. 1: Schematic of the Callovo-Oxfordian near-field representation of the excavation damaged zone.

The chemical perturbations

The quantification of the various chemical perturbations affecting the Callovo-Oxfordien near-field (alkaline plume, iron / argilites interaction, oxidation, effects of salt migration) allowed to strengthen the evaluations previously carried out, to specify the phenomenology, in particular over a longer time period, to characterize the nature of solids and fluids in the disturbed argilites and finally to more precisely evaluate the modifications of their hydro-dispersive properties.

In connection with the representation of the damaged zone, such knowledge acquisition enables all the concerned work elements (ILW tunnels, drifts, HLW cells) an explicit representation of the chemically perturbed zones of argilites, according to a {Kd, Csat} approach for the radionuclides of interest. This representation includes different zones of homogeneous and constant properties or variables with time, determined on the basis of the extended perturbation evolutions.

THE HYDROGEOLOGICAL EVOLUTION OVER THE NEXT MILLION YEARS

The more recent hydrogeological modeling indicates from now on a less penalizing (or pessimistic) evolution of the flows than that considered in the previous studies. In particular significant results should be mentioned:

- the absence of significant evolution of trajectories (and associated transfer times) in the Oxfordian and Dogger aquifers, as well as the absence of natural outlets even when considering the potential influence of the geodynamic evolution over the next million years;
- Transfer times widely superior to hundred of thousand years, and the limited evolution of the hydraulic gradient within the Callovo-Oxfordian formation during this period.

This leads to envisage the definition of a single geometrical and hydrogeological model, applied from the closure of the repository up to a million years, or the succession of models (through time) taking into account the limited variations due to geodynamic evolutions.

THE (THERMO)-HYDRAULIC-GAS TRANSIENT

In 2005, the performance of the simulation tools of and the available global representation of the hydraulic-gas transient, led to consider a fully-saturated state of the repository as soon as its closure. This implied to take into account an instantaneous release of radionuclides in solution (when a labile source-term was considered). This was based on an analysis of the neutral or conservative character of this hypothesis and on a penalizing representation of the release of the gaseous radionuclides (C-14) during this period

While taking into account of the residual uncertainties, the combination of advances in knowledge on the behavior of ILW and HLW in unsaturated conditions and progresses made in the characterization of the (thermo)-hydraulic-gas transient and of the concomitant transfer of radionuclides in liquid and gas phases (Fig. 2), now allows a more realistic representation of the transient. while its evaluation would be conducted in saturated conditions, adjustments are made for i) hydro-dispersive parameters as a function of the saturation level; ii) source terms for different waste packages through preparatory simulations taking into account the unsaturated conditions.

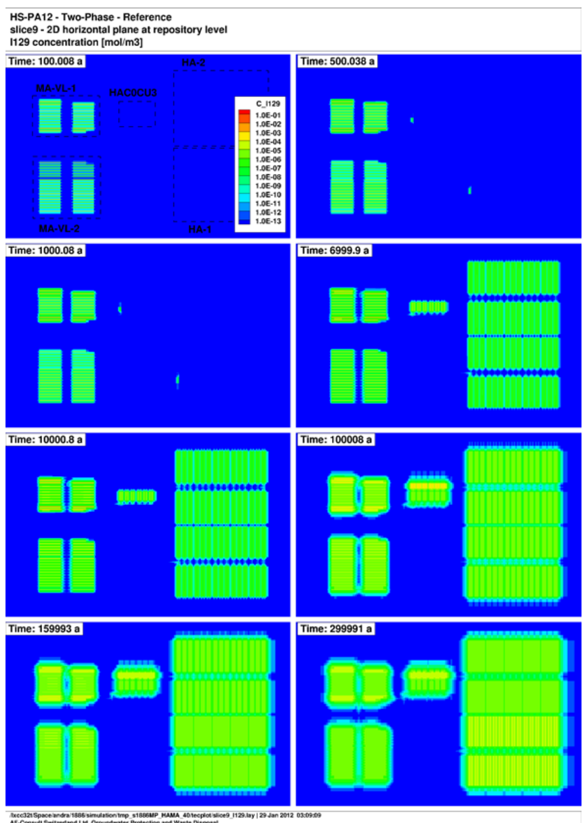

Fig. 2: Concentration mapping of I-129 during the thermo-hydraulic-gas transient.

The waste packages cells and tunnels

For the ILW tunnels, the representation of release of radionuclides in solution according to the hydraulic environment is modeled by considering fractions of the inventory (labile release and matrix-related release) which can be mobilized through time during the progressive re-saturation of the tunnel.

For HLW cells, the hydraulic consequences of the gas generation (hydrogen production due to steel corrosion in reducing conditions) are taken into account as well as the overpressure of thermal origin in order to better quantify convective transfers through the repository architectures.

The repository and the Callovo-Oxfordian

For radionuclides in solution, the localized "piston effect" due to gas overpressures, is implicitly represented by adjusting the transport parameters (permeability, diffusion coefficient, retention) and the flow velocity in drifts during the transient on the basis of the phenomenological evaluations. The release and transfer of gaseous radionuclides (chiefly C14), in the repository and their migration to the Oxfordian aquifer through the repository drifts and shafts is represented by successive released fractions of the inventories determined on the basis of phenomenological evaluations coupling the hydraulics-gas transient and the transfer of gaseous radionuclides at the repository scale.

THE CHEMICAL DEGRADATION OF ILW TUNNELS

The detailed chemistry-transport evaluations coupled with the studies on transfer of radionuclides undertaken since 2005 provide a more precise evaluation of the kinetics of the degradation processes by taking into account the specific reactions kinetics, couplings between the chemical reactions and the hydro-dispersive properties with transport of solutes, and with complex degradation processes (for example the release of nitrates or organic compounds from bituminized wastes). The research on the behavior of radionuclides in these complex environments allows a better representation of the transport mechanisms involved (for example effects of complexing organic molecules or high ionic strength fluids). It is thus intended to implicitly take into account the chemical evolution of most of the components of the ILW tunnels by a decomposition of the tunnel in space/time sub-domains to which will be allocated the appropriate retention and solubility properties.

MAIN REMAINING UNCERTAINTIES

The overpressure in the Callovo-Oxfordian formation

At this stage, the interstitial overpressure in the Callovo-Oxfordian formation is not completely understood and its potential lateral variation is not known. Although there is no problem on the conceptualization of the initial hydraulic flow model (say up to 100,000 years), significant uncertainties remains in the specification of the longer term (e.g. the next million years) hydraulic heads in the Oxfordian and Dogger aquifers (overlying and underlying the Callovo-Oxfordian formation)

The hydraulic-gas transient

The quantification of the hydraulic-gas transient and its impact on the transfer of radionuclides relies on the numerical simulations that exploit the best conceptual models and parameters values obtained since 2005. However, uncertainties still remain, in particular regarding the kinetics of anoxic corrosion and the subsequent production of hydrogen.

CONCLUSIONS

The post-closure evolution scenario represents an "interpretation" of the expected functioning of the repository after its closure. It is proposed that a robust basis for the conceptualization of such scenario may be based on the most likely phenomenological evolution when considering the best knowledge available and the general design of the repository (the design requirements taking into account the safety functions assigned to each component).
This proposed conceptualization aims at:

- representing the evolution of the repository and the surrounding geological environment, mainly for facilitating the evaluation of the release and the transfer of radionuclides and chemical toxics quantifying the toxic and radiological impacts and ensuring that the regulatory limits in terms of radiation protection and toxicity are well respected;
- Verifying the performance of various components of the repository (e.g. waste packages, engineered barriers, geological formation) that contribute to the safety functions of the repository system;
- Understanding the functioning of the repository at different scales, more specifically with regard to the fluid flow and the transfer of solutes; and
- Identifying and prioritizing the various important physical phenomena.