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Full scale 3D-modelling of the coupled gas migration and heat dissipation in a planned repository for radioactive waste in the Callovo-Oxfordian clay

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ABSTRACT

An important question related to the long-term safety performance of a repository for long-lived medium and high-level radioactive waste in the Callovo-Oxfordian clay unit is the impact of heat and gas generated in the waste emplacement areas on the gas and water pressure and on the water saturation in the backfilled repository and in the host rock.

The current design of such a repository consists of a multitude of different underground structures, such as emplacement drifts for waste canisters and other types of waste packages, access and ventilation drifts, and access shafts in the central part of the repository. The individual underground structures exhibit different thermo-hydraulic and geometrical properties yielding a large and complex system for the flow and transport of gas, water and heat.

A detailed 3D modelling of the entire repository would require a tremendous computational effort, even when using high performance simulator codes. A newly developed method (Poller et al., 2011) allows for the 3D modelling of the two-phase gas–water flow and thermal evolution in the entire repository/host-rock system in a simplified manner. Besides accounting for both the detailed structures at local scale and the global geometry of the drift network, it also allows for an assessment of the gas phase pressure as well as the hydrogen and heat fluxes developing over the complete lifetime of the repository system.

In this paper, the results of a reference scenario are presented. The assessment focuses on the two dominant processes, i.e. the dissolution and diffusion of the generated hydrogen, and the advective migration of the forming hydrogen gas phase in space and time (up to 1 million years). Further, the main findings of a sensitivity analysis on different features, physical processes and parameter uncertainty are presented.

1. Introduction

The French agency for the management of radioactive waste (ANDRA) is planning a deep geological repository for long-lived medium and high-level radioactive waste in the low permeable Callovo-Oxfordian clay.

Several aspects are related to the long-term safety performance of this repository, such as, (i) the influence of the emitted heat and the gas on the evolution of the fluid pressures and the water saturation in the repository's drifts and shafts as well as in the host rock itself (ANDRA, 2005), (ii) the migration of the generated gases (e.g. hydrogen or methane) within and potentially outside the repository system, and (iii) the potential for overpressure in the near field of the repository as this could affect the mechanical integrity of geotechnical and geologic barriers.

For the performance assessment, a good understanding of the behaviour of the repository system over a large time scale of several hundreds of thousands of years is compulsory. This involves the assessment of the spectrum of the manifold and complex features, events and processes (FEP), which may influence the behaviour of the repository system. Numerical non-isothermal two-phase flow and transport modelling is a powerful tool to accomplish this task. However, besides the general range of uncertainty with respect to the FEPs, a detailed 3D modelling of the entire repository accounting for both the detailed structures at local scale and the global geometry of the drift network would require a tremendous computational effort, even when using a high-performance code like TOUGH2-MP (Zhang et al., 2008).

Based on a newly developed approach (Poller et al., 2011), in this paper, we present and discuss the results of a simulation case using a set of reference parameters and the currently envisaged repository architecture (Section 5). The assessment focuses on the two dominant processes, i.e. the dissolution and diffusion of the generated hydrogen, and the advective migration of the forming gas phase in space and time. In addition, the main conclusions of a sensitivity analysis based on a series of simulations with

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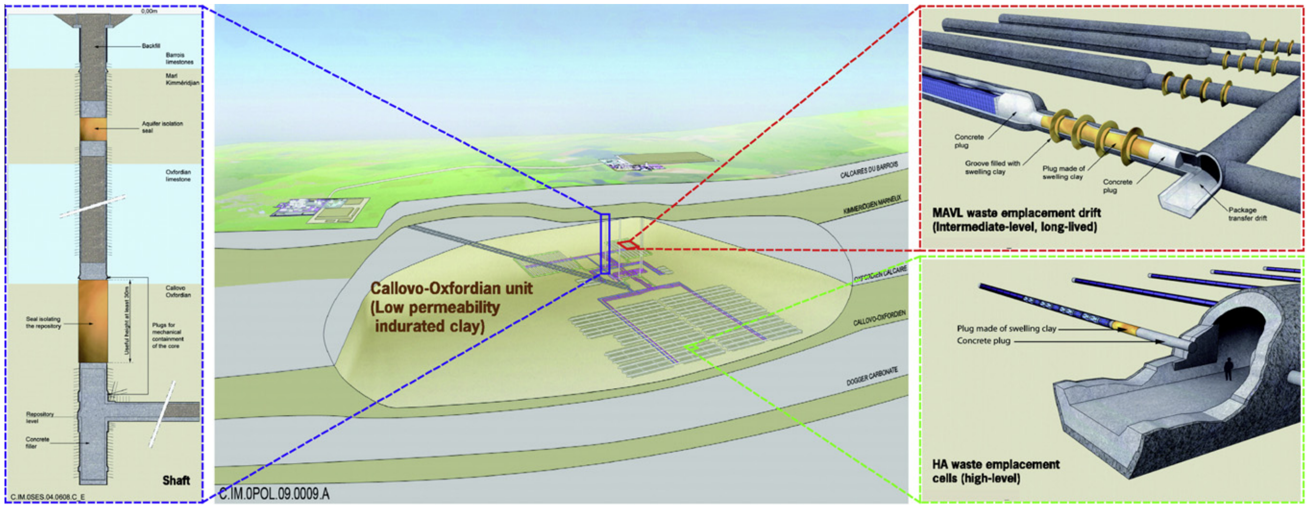

Fig. 1. General repository layout with shafts, high-level radioactive waste disposal cells (HA) and medium-level long-lived radioactive waste disposal drifts (MAVL) (ANDRA, 2005).

varying physical parameters, different boundary conditions and different degrees of the spatial discretisation are presented (Section 6). The results are discussed and compared with respect to different measures such as (i) the maximum pressure in the repository, (ii) the resaturation time and (iii) the distribution of the generated hydrogen mass in the backfilled repository structures and in the host rock. A description of the foreseen architecture and operation of the repository is given in Section 2, The modelling approach, its underlying assumptions and the considered processes are outlined in Section 3. The model setup is explained in Section 4.

2. Repository system

The general layout of the repository is presented in Fig. 1. The repository system consists of three major zones: A large zone for high-level radioactive waste (zone HA), a zone for long-lived medium radioactive waste (zone MAVL) and a zone for infrastructure facilities and access shafts. The individual zones are connected by access and ventilation drifts. The horizontal extent of the complete repository is several kilometres in width and length; the thickness of the very low permeable host rock (Callovo-Oxfordian clay) is around 130 m. The repository is located in the vertical mid of the host rock unit, at around 500 m below ground level.

During the operational period of the repository (about 100 years), the complex network of drifts and disposal cells is ventilated under conditions of low relative humidity, leading to a drawdown of hydraulic pressure in the near field of the repository, as well as to a slight desaturation of the host rock in the vicinity of the drifts and caverns. At the end of the operational period, all repository structures are backfilled with specifically designed geomaterials. A set of hydraulic barriers (seals) is foreseen at the end of the emplacement drifts, at specific locations within and between the major zones, as well as in the upper part of the access shafts, to hinder the transport of potentially contaminated water or gas along the backfilled drifts and shafts.

During the post-operational period, the waste containers (in particular those with high-level waste) emit considerable amounts of heat, generated as a consequence of radioactive decay. Moreover, the corrosion and degradation of some waste components produces large amounts of gases (mostly hydrogen). Both processes have a strong impact on the resaturation of the repository and the geologic environment. The expected time scales of the major transient thermal and hydraulic phenomena were presented by ANDRA in 2005. The thermal transient is expected to last at most a few thousands of years, whereas the hydraulic transient is expected to last much longer (100,000 years).

3. Modelling approach

The complete lifetime of the repository is considered, i.e. the construction of the repository, the operational period and the post-closure period until the original natural hydraulic and thermal conditions in the host rock are retrieved.

3.1. Modelled processes

During the operational phase of the repository, the disposal and access drifts, as well as the access and ventilation shafts, are ventilated, and the low permeable clay host rock is progressively depressurized and even desaturated in the vicinity of the drifts. The gas–water flow is modelled as two-phase flow using the generalized Darcy's law and the relative permeability/capillary pressure concept. All the materials in the repository and the host rock are considered as porous media.

As soon as the drifts are backfilled and sealed, the post-operational period begins, and the principle processes modelled are:

- Thermal dissipation into the host rock, mainly by conduction, and an induced pore-water pressure increase by thermal expansion of the water.[1]
- Resaturation of the backfill materials, due to the drainage towards the drifts and the capillary suction of the backfill materials (at early times)
- Hydrogen gas generation and gas pressure build-up in the backfilled repository.[1]
- Displacement of water into the host rock due to the gas pressure buildup.[1]
- Dissolution of hydrogen into the pore water and transport by diffusion/advection.[1]

[1] This process begins as soon as the waste packages are inserted into the emplacement drifts.