A new multi-scale approach to modelling the fully coupled hydraulic and thermal evolution of a whole repository throughout its lifetime

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1. Introduction

Understanding the evolution of a whole radioactive waste disposal facility in terms of its hydraulic and thermal performance is a key input to the demonstration of post-closure safety. Representations of such systems become more complex in low-permeability, diffusive dominated host rocks where the process couplings can be significant to safety performance over extended periods of time, for example in the detailed behaviour of gas generation through metal corrosion and other processes. As such, major aspects of the performance of a facility can become dependent on the representation of these key features and associated coupled processes, which often operate only at very small spatial scales in comparison with the whole facility. The challenge therefore is to represent key, potentially coupled, processes at spatial scales ranging from cm to km.

The ANDRA reference design (Figure 1) considers the disposal of a range of different wastes (French MA-VL, ‘HA’ and ‘CO-CU3’ waste). The wastes have different heat sources and hydrogen gas generation rates, with the gas generation rates being coupled to fluid saturation and temperature. The objective was to develop a model which captures, as well as possible, all relevant hydraulic and thermal behaviours at all relevant spatial scales within a single model until the system returns to equilibrium. Thus the approach adopted had to minimise the impacts of errors arising due to spatial homogenisation and had to avoid any attempt to separate the domain into distinct models that are not fully coupled.

The system to be modelled also had to include an appropriate representation of the geology below the facility and up to the ground surface. Explicit treatment of the access engineering (shaft, ventilation wells etc.) and EDZs associated with all subsurface features was required.

2. System of Interest

![Diagram of interest](image)

Full Repository (km)

HA1 shown as example only – detailed structures for HA2, CO-CU3, and MA-VL1,2 also required

Access Drift

Main Drift Plug

Whole Repository (m)

Waste

Interface (1cm)

C0-CU3/HA Cells

Well

HA1 shown 

HA2

Range of spatial scales to be considered in a single model

‘Module’ (100m)

‘Cell’ (m)

3. Approach

A novel modelling approach was developed using the Quintessa code QPAC, which involved embedding detailed sub-models of individual MA-VL vaults and HA cells within a model of the entire repository. This approach enabled very small (cm) scale features, such as voids and interfaces around waste packages / containers that significantly influence the coupled thermo-hydraulic evolution to be represented explicitly in a model with a >50 km² areal domain. These sub-models were fully coupled using a monolithic approach, and did not rely on a split-operator or partially decoupled techniques. The approach relies on the expectation that many of the MA-VL vaults and HA cells will behave similarly, and therefore their behaviour can be approximated by representation of a small number of individual vaults or cells. This approach results in a small loss of information through spatial averaging, however when performed carefully (via thorough sensitivity testing), this was considered to be insignificant when compared with the additional detailed information retained at the vault and cell scale compared with conventional upscaling techniques (Figure 2).

4. Key Results

The expected diffusion domination of gas migration away from the facility was observed (with resulting pressurisation, see Figure 3), with only minor movement of gas to surface via the shaft, ventilation well and associated EDZs. Of key interest was the relative performance of the sub-modelled approach versus conventional homogenisation techniques. Investigations showed that while the conventional homogenisation approaches reflected the broad features of the system consistently with the sub-modelled approach, the sub-modelled approach was able to capture the higher pressures, fluid movements and fluid saturation changes close to the wastes that the homogenized approaches could not, with a consequent benefit on processing coupling.

Fig. 2. Scaling of fluxes from one sub-model (HA in this case) to represent many equivalent HA cells, see [1,2] for more detail

5. Conclusions

This method provides a better representation of the disposal system than conventional approaches. It has been successfully applied to a complex repository system and allowed a coherent representation of multi-phase flow, thermal transport and coupled gas generation, on a desktop computer with no need for high performance computing.

This sub-modelling approach could also be applied to other key components of the repository within the whole repository model, for example detailed sub-models of individual vault seals. However, the new approach is most advantageous in a large number of repeat features need to modelled in detail. Nested sub-models could also potentially be developed and more complex interactions between sub-models are also a possibility for future applications.

6. References


Fig. 3. Gas pressure in the MA vaults and HA cells for the 2009 Andra reference repository design