

A Darcy scale coupled fluid-thermal framework to model radionuclide transport from a deep disposal borehole

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Abstract

Waste packages for disposal of radioactive waste originating from reprocessing of spent nuclear fuel typically include a stainless steel canister inside which the waste is immobilised in a (borosilicate) glass matrix. A potential disposal pathway for such wastes is in conventional mined geological disposal facilities (GDF) [1] or in deep boreholes [2]. In the latter concept, the packages are stacked in a disposal zone at a depth of several kilometres [3]. However, deep borehole disposal is still in its infancy requiring considerable Research, Development and Demonstration (RD&D) to bring the science to a similar level as for GDFs [4].

It is estimated that the total global inventory of radioactivity confined within (borosilicate) glass from reprocessing is on the order of 10^{20} Bq, with an approximate weight of 15,000 metric tonnes [5, 6]. The half-life of some of the radionuclides in nuclear waste is from the order of 10^5 - 10^9 y (e.g. ^{135}Cs , ^{79}Se , ^{238}U , etc) [6]. This waste will also generate heat for several hundred years [7, 8]. Any disposal container should have a lifetime long enough to survive (i.e. no breach therefore zero radionuclide release) the heat-production period.

For clay sediments, a porous medium-type pore network is the path through which transport occurs [9]. For crystalline rocks on the other hand, transport is typically through a fracture network with concomitant matrix diffusion [1]. The nonlinear interaction between different transport phenomena and the very long time scales of the processes involved, necessitates modelling as the most realistic tool to assess the risks to humans and the environment [10]. Given the much greater disposal depth of a deep borehole concept compared to conventional GDFs, and the heat-generating feature of the disposed waste, temperature evolution and its potential impact on radionuclide migration has to be accounted for in post-closure safety assessments.

For conventional GDFs, several studies have been conducted to model the thermal, hydraulic and mechanical interactions within the near field of the disposal environment [11]. The majority of these post-closure safety assessments consider isothermal transport of dissolved radionuclides, using simulation codes such as FRAC and PORFLOW [10, 12]. Some studies have also used TOUGH and TOUGHREACT to couple other transport phenomena [13]. However, few modelling studies exist for deep borehole disposal which include a proper linkage between the natural hydrostatic and temperature profiles to heat and solute mass transport at the Darcy scale [14, 15].

Here we present a coupled heat and solute mass transport modelling framework, subjected to depth-dependent temperature, pressure and viscosity profiles - assuming an instantaneous release of all radionuclides. This is a very conservative assumption but is consistent with typical “what if?” scenarios undertaken in post-closure safety assessments [16]. The TOUGHREACT code [17, 18] was used in an axi-symmetrical domain with a total depth of 3200 m. Several scenarios of heat-generation were investigated to test if the additional heat produced by the waste containers affects radionuclide migration, e.g. by generating convection-driven mass transport. Results show that the heat generation does not significantly affect the extent of the solute mass plume.

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