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Investigation of two-phase flow phenomena associated with corrosion in an SF/HLW repository in Opalinus Clay, Switzerland

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ABSTRACT

Gas generation from corrosion of the waste canisters and gas accumulation in the backfilled emplacement tunnels is a key issue in the assessment of long-term radiological safety of the proposed repository for spent fuel and high-level waste (SF/HLW) sited in the Opalinus Clay formation of Northern Switzerland. Previous modeling studies indicated a significant pressure buildup in the backfilled emplacement tunnels for those sensitivity runs, where corrosion rates were high and the permeability of the Opalinus Clay was very low. As an extension to those studies, a refined process model of the canister corrosion phenomena has been developed, which accounts not only for the gas generation but also for the water consumption associated with the chemical reaction of corrosion of steel under anaerobic conditions. The simulations with the new process model indicate, that with increasing corrosion rates and decreasing host-rock permeability, pressure buildup increased, as expected. However, the simulations taking into account water consumption show that the pressure buildup is reduced compared to the simulation considering only gas generation. The pressure reduction is enhanced for lower permeability of the Opalinus Clay and for higher corrosion rates, which correspond to higher gas generations rates and higher water consumption rates. Moreover, the simulated two-phase flow patterns in the engineered barrier system (EBS) and surrounding Opalinus Clay show important differences at late time of the gas production phase as the generated gas continues to migrate outward into the surrounding host rock. For the case without water consumption, the water flow indicates overall downward flow due to a change in the overall density of the gas–fluid mixture from that based on the initially prescribed hydrostatic pressure gradient. For the case with water consumption, water flow converges toward the waste canister at a rate corresponding to the water consumption rate associated with the corrosion reaction. The water flow toward the canister is maintained even for very low permeabilities of the Opalinus clay sustaining the anaerobic corrosion of the steel canister.

0. Introduction

In deep geological repositories for spent fuel and high-level waste (SF/HLW), hydrogen will be produced by anaerobic corrosion of metals. The generation, accumulation and release of gases from the disposal system may affect a number of processes that influence long-term radiological safety of the repository (NEA, 2001). This issue has become a focus in many national radioactive waste isolation programs, such as in Switzerland (Nagra, 2002a,b,2004), France (Andra, 2005), and Belgium (Ortiz et al., 2002) among others. The safety relevant features, events and processes (FEPs) associated with waste generated gas include (a) excess gas/water pressures could affect the mechanical integrity of the engineered barrier system (EBS), (b) expulsion of contaminated water from the waste package due to the gas buildup, and (c) transport of volatile radionuclides through the EBS and surrounding geological barriers.

A comprehensive study of gas release was accomplished in the context of Nagra's Geosynthesis study (Nagra, 2002a), comprising a detailed assessment of both the relevant gas transport mechanisms and the gas release paths. Fig. 1 shows a schematic representation of Nagra's concept for a SF/HLW/ILW repository in Opalinus Clay with the possible gas pathways from the emplacement tunnels through the EBS and the host rock. Scoping calculations were conducted to simulate gas pressure buildup in a gallery of parallel SF/HLW tunnels. The assumption was made that the gas flow along the backfilled tunnel can be neglected, which allowed the use of a 2-D model geometry in a vertical cross section perpendicular to

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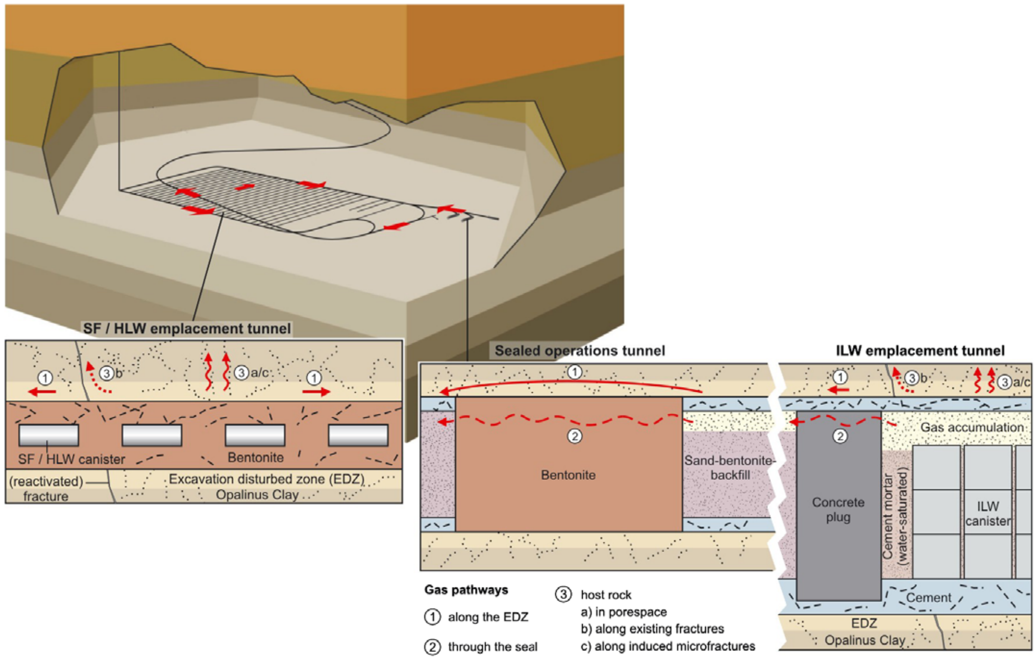

Fig. 1. Schematic representation of Nagra's concept for a SF/HLW/ILW repository in Opalinus Clay with the possible gas pathways from the emplacement tunnels through the EBS and the host rock (after Nagra, 2004).

the axis of the emplacement tunnels. The calculations were based on robust assumptions with regard to the gas generation rates (termed "pessimistic" and "over-conservative" gas generation rates of 0.04 m^3/a and 0.4 m^3/a, respectively, corresponding to corrosion rates of 3.6 and 36 μm/a), gas generation scenarios (immediate/delayed onset of gas generation), and the site-specific conditions (variation of intrinsic permeability and gas entry pressure). Furthermore, the simulations included both isothermal and non-isothermal modeling runs (heat production by the SF/HLW). A multitude of sensitivity runs confirmed that it is very unlikely that excessive gas pressures are reached in the emplacement tunnels. In this context, the term "excessive" means that gas pressure reaches the magnitude of minimum stress (around 15 MPa at repository level), which is seen as indicative for the onset of irreversible deformation of the intact host rock (Fig. 2; cf. Nagra, 2002a, 2004). Only in the extreme case RGH5K with "over-conservative" gas generation rate, horizontal intrinsic permeability as low as 2.0E−21 m^2 and with a gas entry pressure of 21 MPa, did the simulated gas pressure in the emplacement tunnel reach 15 MPa after about 16,000 yrs. In all other cases the gas pressure did not exceed 10 MPa, corresponding to an overpressure of 3.5 MPa above hydrostatic conditions.

Even though most of the aforementioned sensitivity runs revealed moderate gas overpressures in the backfilled SF/HLW emplacement tunnels, there was yet a low likelihood of producing excessive pressures, when unfavorable input parameters were assumed. It is obvious that such rare, yet possible parameter combinations could occur in probabilistic safety assessments. Hence, the need was seen for refined process and system models of gas release, which are able to better constrain the degree of conservatism in the basic conceptual assumptions. Among other aspects, the following conservatisms of the previous modeling approach were further investigated in recent studies: (i) the 2-D model geometry does not account for gas release along the backfilled tunnels

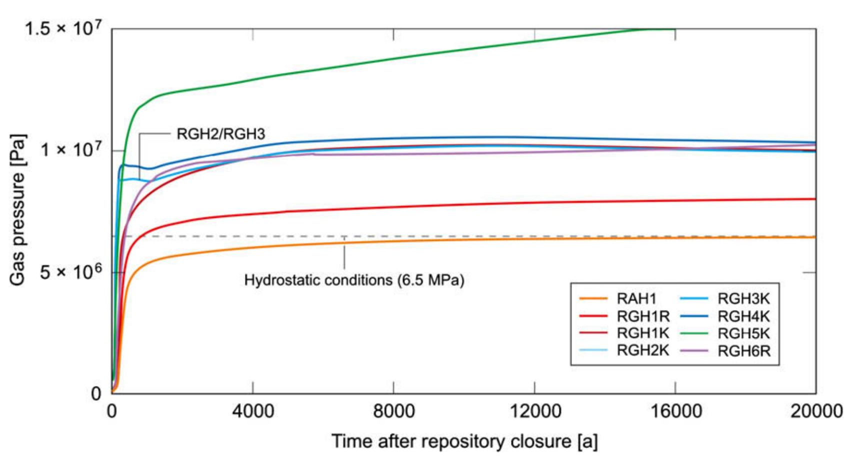

Fig. 2. Two-phase flow simulations of pressure buildup in the SF/HLW emplacement tunnels after Nagra (2002a). Modelling runs indicated with "R" (e.g. RGL2R, RGH1R) are assuming gas generation rates, which correspond to a corrosion rate of 3.6 μm/a. The runs marked with "K" (RGL1K, RGH1K) correspond to a corrosion rate of 36 μm/a. Runs RGH3K – RGH6R are non-isothermal simulations. A detailed description of the model parameters is given in Nagra (2002a).