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Publication Date

2003-10-30

(ENTRY Workshop 2003, October 22-24, JNC Tokai, Japan)

MODELING OF COUPLED THC PROCESSES AND ROCK-FLUID INTERACTIONS AT THE PROPOSED NUCLEAR-WASTE REPOSITORY AT YUCCA MOUNTAIN, NEVADA

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ABSTRACT

Assessing the long-term performance of geologic nuclear waste repositories necessitates evaluating the effects of coupled thermal, hydrological, and chemical (THC) processes for time periods lasting thousands of years. To reach this goal and gain confidence in our predictive ability, an integrated modeling approach was developed consisting of: (1) process model development, (2) conceptual and numerical model development, (3) design of field and laboratory tests for model validation, (4) predictive analyses of test results, (5) test implementation, (6) comparisons of experimental results with predictive analyses, (7) model refinement and validation, and (8) model implementation for long-term predictive analyses. As part of this approach, an existing reactive transport numerical simulator (TOUGHREACT; Xu and Pruess, 2001) was refined and validated for applications specific to nuclear waste disposal (e.g., Xu et al., 2001; Spycher et al., 2003a). The simulator considers water, vapor, air, and heat transport; reactive gas, mineral, and aqueous phases; porosity-permeability-capillary pressure coupling; and dual (fracture/matrix) permeability. The simulator and modeling approach were applied to the proposed high-level nuclear waste repository at Yucca Mountain, Nevada, to evaluate the chemistry of waters that could seep into drifts and the effect of water-gas-rock interactions on the long-term hydrological behavior around the repository.

The proposed repository at Yucca Mountain is located in fractured, welded volcanic tuffs, several hundred meters above the regional water table. The fracture permeability (10^{-13}–10^{-12} m^2) is several orders of magnitude higher than the rock matrix permeability (10^{-17}– 10^{-19} m^2). In these unsaturated tuffs, water is held mostly in pores of the rock matrix (liquid saturation ~0.8–0.9). Upon waste emplacement and subsequent heating (due to radioactive decay), the matrix water would boil and travel as vapor in the fractures. In cooler regions above the repository, it would condense and drain back towards the boiling zone. This continuous boiling and refluxing of water is anticipated to induce mineral dissolution and precipitation, and alter the chemical composition of pore waters surrounding emplacement drifts.

These coupled processes were investigated using underground thermal tests and laboratory experiments. THC simulations of the Drift Scale Test (Sonnenthal, 2003; Xu et al., 2001) and of plug-flow reactor and fracture sealing experiments (Kneafsey et al., 2001; Dobson et al., 2003) provided the basis for model validation. Long-term (100,000 years) predictive analyses were then carried out to evaluate the effects of coupled THC processes around a typical nuclear-waste emplacement drift (Spycher et al., 2003a and b).

The long-term simulations indicate that fracture water in the area of highest liquid saturation above the modeled drift undergoes three distinct stages. First, dilution occurs as matrix water boils and condenses in fractures (from ~50 to 150 years). Because of capillary forces, the boiling front in the matrix stops expanding earlier than in fractures. Evaporative concentration then takes place (from ~150 to 600 years) under near-constant (boiling) temperatures as continuous boiling, condensation and refluxing take place in fractures. Finally, water compositions slowly return to original concentrations as the boiling front collapses towards the drift. While liquid saturations are significantly larger than residual, no extreme pH or salinity values are predicted. The dominant mineral to precipitate is amorphous silica, which forms in a thin zone within fractures around the drift (Figure 1) as the result of evaporative concentration at the boiling front. Depending on initial fracture porosity, this precipitation can lead to permeability reductions sufficient to deflect the bulk of percolating water around the drift. Investigations are under way to assess the model uncertainty and implications for long-term evaluation of repository performance.

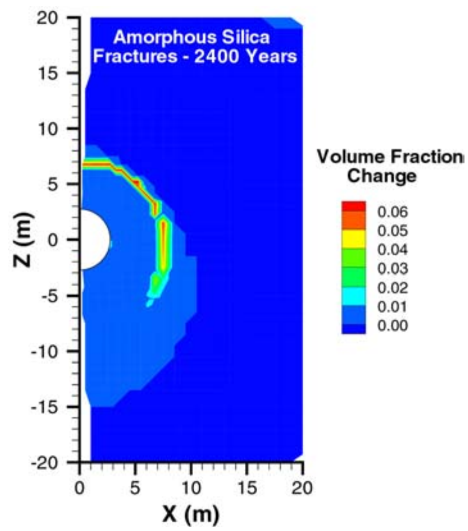

Figure 1. Predicted silica precipitation

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