THERMAL LOADING STUDIES USING THE UNSATURATED ZONE MODEL

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Research Objectives

Several factors will affect Thermal-Hydrological (TH) response of the Unsaturated Zone (UZ) to thermal load at the potential repository. These factors include small and large-scale heterogeneity, the thermal load within the repository drifts and presence of lithophysal cavities. The objective of this study is to quantify these effects.

Approach

Numerical modeling was used to investigate the effects of heat on UZ flow, temperature and liquid saturation on two spatial scales, for a range of potential repository operating modes. The TH simulations were conducted on two dual-permeability numerical grids. The first grid is a refined North-South Mountain-scale 2D model with layer-wise constant fracture permeability. The second grid is a refined half-drift (1-m grid near drift) 2D model with several realizations of spatially variable fracture permeability in the Topopah Spring welded unit (TSw). In the TSw lithophysal units, the thermal capacity and thermal conductivity of the lithophysal units were scaled using the lithophysal porosity. The second model includes both small-scale (less than 1-meter correlation length) heterogeneity in the fracture permeability and discrete high permeability fractures. Monte Carlo methods were used to generate several realizations of spatially variable fracture permeability (up to 4 orders of magnitude) in the TSw, based on the measured distribution of fracture permeability within the exploration drifts. Above boiling and below boiling repository operating modes are investigated by varying the initial thermal load and the amount of heat removed by ventilation. The simulations of coupled heat and mass flow were conducted using TOUGH2 (EOS3 module) over a simulated period of 100,000 years.

Accomplishments

The TH models provide insight into how decay heat from emplaced waste will affect the magnitude and spatial distribution of temperature, liquid saturation and percolation flux reaching the potential waste emplacement drifts, which in turn affects the potential for seepage into the drifts.

Significance of findings

The TH numerical studies provide an analysis of the range of predicted UZ response to heat generated by emplaced high-level radioactive waste that accounts for the uncertainty in repository heat load, the effectiveness of the ventilation process, spatial heterogeneity in flow properties and the effect of lithophysal cavities. For both the above boiling and below boiling cases the drift and the zone below (drift shadow) are dry (Figure 1a), but liquid saturation increases above drifts and within the drift pillars. Therefore, although liquid flux up to 5 meters above the drifts and within the pillars may be enhanced by condensation, the liquid flux below drifts, is zero (Figure 1b) or significantly reduced by a combination of thermal and capillary barrier effects for over 1000 years. Spatial heterogeneity in fracture permeability and even the presence of highly permeable features does not substantially alter the predicted liquid percolation flux. Reduced liquid percolation below the drift means that there is little potential for transport of radionuclides away from the drifts for thousands of years, and these results should be used in TSPA abstraction of the effects of heat on radionuclide transport. However, the above boiling operating mode may result in higher than desired temperatures in the waste emplacement drifts, at the base of Paintbrush non-welded unit (above the repository), and at the top of Calico Hills non-welded unit (below the repository).

Related Publications

C. B. Haukwa, S. Mukhopadhay, Y.W. Tsang and G.S. Bodvarsson: Liquid seepage at the repository horizon under thermal loading. Water Resources Research (in review).

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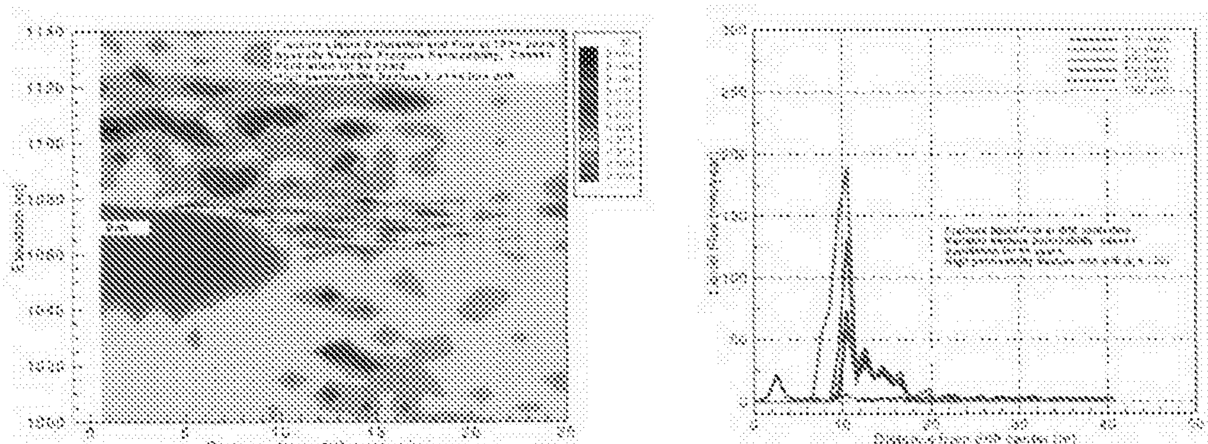

(a) (b)

Figure 1. Spatially variable TSw fracture permeability, above boiling repository (1.45 kW/m, 50 years 70% ventilation), high-permeability fracture into drift (k_f*100): (a) Fracture liquid saturation after 1000 years; (b) Fracture liquid flux at drift centerline