
**The Influence of Repository Thermal Load on Multiphase Flow
and Heat Transfer in the Unsaturated Zone of Yucca Mountain**

MOL.20050412.0195

Yu-Shu Wu, S. Mukhopadhyay, K. Zhang, and G. S. Bodvarsson

Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley CA 94720 USA

2/14/05

Abstract

The 500-700 m thick Yucca Mountain unsaturated zone (UZ) is under extensive investigation as a subsurface repository for the permanent disposal of high-level nuclear wastes. The site characterization has been mostly carried out for analyzing unsaturated flow and radionuclide transport under ambient, isothermal conditions. However, significant research effort has also been devoted to understand the nature of flow and transport processes under non-isothermal conditions. In particular, substantial repository heating from radioactive waste decay has motivated investigations of the coupled thermo-hydrologic (TH) behavior of the UZ under repository heating and its potential impact on repository performance. Significant progress has been made in quantitative coupled TH studies in the last decade. Despite the significant advances made so far in modeling and understanding TH processes, the previous studies have been in general limited to modeling in 1-D and 2-D (instead of the full 3-D representation), and/or small spatial and temporal scale analysis. In addition to these limited modeling exercises, multidimensional modeling has been carried out for large-scale (at the scale of the entire mountain) TH analyses. However, these previous large, mountain-scale TH models utilized the effective continuum model (ECM), rather than the more rigorous dual-continuum model (DKM). This is primarily due to numerical difficulties and computational burden involved with simulating highly non-linear coupled two-phase fluid flow and heat transfer in the fractured unsaturated rock with over one hundred thousand grid blocks (required for mountain-scale simulations). In general, 3-D, mountain-scale, DKM investigations of

coupled TH processes in the fractured rock of Yucca Mountain is lacking in the literature..

In parallel to the TH modeling studies, significant progress has also been made in site characterization of UZ flow and transport processes. For example, field and modeling studies conducted over the past few years have updated and enhanced our understanding, and revealed many new insights into how the UZ system works under the natural, ambient conditions. As a result, both geological and conceptual models have been updated by model calibration and verification efforts, and fracture-matrix properties and model parameters are better estimated. In addition, the repository design and drift layout plan, which are different from the ones used in previous modeling studies, are also revised. These advances in site characterization, data collection and parameter estimates motivate this work for updated TH modeling efforts.

Emplacement of heat-generating, high-level nuclear wastes in the system of unsaturated welded and unwelded fractured tuff will disturb the ambient condition and create complex multiphase fluid flow and heat transfer processes. The physical phenomena associated with repository heating include conductive and convective heat transfer, phase change (boiling and condensation), two-phase flow of liquid and gas phases under variably saturated conditions, enhanced fracture-matrix interaction due to rapid matrix drying and imbibition, diffusion and dispersion of vapor and gas, vapor sorption, and vapor pressure lowering effects. These TH processes will last over hundreds and thousands of years after waste emplacement and significantly redistribute the in-situ moisture and alter the ambient flux above and below the repository. In particular, these processes are expected to affect the water flow or seepage into and around the emplacement drifts, which will have a direct impact on the corrosion rate of waste emplacement canisters and on the potential for the transport of radionuclides away from the drifts, carried by the liquid phase to the water table.

This paper presents the results of our latest effort to develop a representative 3-D, mountain-scale TH model to investigate the coupled TH processes for the repository under thermal load. More specifically, the TH model implements the current geological framework and hydrogeological UZ flow conceptual models, and incorporates the most updated, best-estimated input parameters from the 3-D model calibration (Wu et. al., 2003). Using the more rigorous DKM approach, the TH model consists of (1) a 2-D north-south cross section modeling studies with refined meshes near and around the repository block and (2) a full 3-D representation of the repository and UZ system, which explicitly includes every waste emplacement drift of the repository. For better description of the ambient geothermal condition of the UZ system, the TH model is first calibrated against measured borehole temperature data. The temperature calibration provides the needed surface and water table boundary and initial conditions for the TH model.

A multidimensional, mountain-scale, TH model is presented for investigating unsaturated flow behavior in response to the thermal load from radioactive decay from the potential nuclear waste repository in the unsaturated zone (UZ) at Yucca Mountain, Nevada. The TH model, consisting of 2-D and 3-D representations of the UZ repository system, is based on the current repository design, drift layout, thermal loading scenario, and estimated current and future climatic conditions. In particular, this mountain-scale TH model is developed to evaluate the coupled TH processes on mountain-scale UZ flow and simulate the impact of nuclear waste heat release on the natural hydrogeological system, including heat-driven processes occurring in the areas near and far away from repository drifts. The model simulations provide predictions for thermally affected liquid saturation, gas- and liquid-phase fluxes, and elevated water and rock temperature to predict the changes in water flux driven by evaporation/condensation processes, and drainage between drifts. These simulations provide mountain-scale thermally perturbed flow fields for assessing the repository performance under thermal loading condition.

The mountain-scale TH model is used to obtain scientific understanding of TH processes in the UZ of Yucca Mountain under the designed schedule of repository thermal load and comparing the UZ responses with and without ventilation operation in the first 50 years

after waste emplacement. The current and future climate conditions are represented using a time-dependent net infiltration map with three-step increases, i.e., the present-day climate lasts to 600 years and the monsoon covers from 600–2,000 years, which is followed by the glacial transition for the remaining duration of 10,000 year regulatory period. The model simulations predict the future TH processes of the UZ system under repository thermal load and reveal better insight into moisture conditions and percolation fluxes in the UZ system.