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Fluid Flow, Heat Transfer, and Solute Transport at Nuclear Waste Storage Tanks in the Hanford Vadose Zone

Vadose Zone Journal

This article in VZJ

Vol. 1 No. 1, p. 68-88

Received: Dec 3, 2001
Published: Aug, 2002

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doi:10.2136/vzj2002.6800

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Abstract

At the Hanford Site, highly radioactive and chemically aggressive waste fluids have leaked from underground storage tanks into the vadose zone. This paper addresses hydrogeological issues at the 241-SX tank farm, especially focusing on Tank SX-108, which is one of the highest heat load, supernate density and ionic strength tanks at Hanford and a known leaker. The behavior of contaminants in the unsaturated zone near SX-108 is determined by an interplay of multiphase fluid flow and heat transfer processes with reactive chemical transport in a complex geological setting. Numerical simulation studies were performed to obtain a better understanding of mass and energy transport in the unique hydrogeologic system created by the SX tank farm. Problem parameters are patterned after conditions at Tank SX-108, and measured data were used whenever possible. Borrowing from techniques developed in geothermal and petroleum reservoir engineering, our simulations feature a comprehensive description of multiphase processes, including boiling and condensation phenomena, and precipitation and dissolution of solids. We find that the thermal perturbation from the tank causes large-scale redistribution of moisture and alters water seepage patterns. During periods of high heat load, fluid and heat flow near the tank are dominated by vapor–liquid counterflow (heat pipe), which provides a much more efficient mechanism than heat conduction for dissipating tank heat. The heat pipe mechanism is also very effective in concentrating dissolved solids near the heat source, where salts may precipitate even if they were only present in small concentrations in ambient fluids. Tank leaks that released aqueous fluids of high ionic strength into the vadose zone were also modeled. The heat load causes formation dry-out beneath the tank, which is accompanied by precipitation of solutes. These may become remobilized at a later time when tank temperatures decline and previously dried out regions are rewetted. Simulated temperature and moisture distributions compare well with borehole measurements performed in 2000. The temperature maximum observed beneath Tank SX-108 can be explained from past thermal history of the tank; it is not necessary to invoke heat generation from leaked radioactive contaminants. A novel composite medium model is used to explore effects of moisture tension–dependent anisotropy, which is shown to have important impacts on fluid flow and solute transport in the Hanford sediments.

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