Annual Report
Influences of Flow Transients and Porous Medium Heterogeneity on
Colloid-Associated Contaminant Transport in the Vadose Zone

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Research Goals

We are investigating the role of colloids in the movement of radionuclides through water-unsaturated porous media. This research is guided by a key objective of the Environmental Management Science Program (EMSP), which is to improve conceptual and predictive models for contaminant movement in complex vadose zone environments. In the report entitled *National Roadmap for Vadose Zone Science and Technology* [DOE, 2001], increases in the understanding of colloid-contaminant interactions, colloid mobilization, and colloid deposition within unsaturated soils are cited as requisite needs for predicting contaminant fate and distribution in the vadose zone. We seek to address these needs by pursuing three overarching goals:

- (1) identify the mechanisms that govern colloid mobilization, transport, and deposition within unsaturated porous media;
- (2) quantify the role of colloids in scavenging and facilitating the transport of radionuclides; and
- (3) develop and test a mathematical model suitable for simulating the movement of colloid-associated radionuclides through variably saturated porous media.

Research Progress

This report summarizes work after eight months of a three-year project that began in September 2003. This is a collaborative effort between PIs at Yale University and the University of Colorado, and it involves a recently hired postdoctoral associate and two Ph.D. students. Our research plan calls for laboratory-scale experiments on colloid and radionuclide migration and on the development of mathematical models that are capable of describing the experimental observations. Progress has been made on both the laboratory and theoretical components of the study.

We have designed and constructed large columns appropriate for conducting experiments on the movement of inorganic colloids (silica and clay particles) and colloid-associated

radionuclides (cesium and strontium) through variably saturated geologic materials. These columns are instrumented with an array of probes for measuring and recording spatiotemporal variations in volumetric moisture content and capillary pressure head. Experiments thus far have focused on measuring colloid transport through columns packed homogeneously with quartz sand. The results of these experiments show that colloid attachment to the quartz-sand surfaces and at air-water interfaces is sensitive to changes in moisture content, as well as to variations in porewater ionic strength. While most of our experiments have been carried out under conditions of steady porewater flow, we also have performed experiments under transient-flow conditions. Analysis of these experiments demonstrates that large concentrations of colloids are mobilized not only during the passage of a wetting front, but also during passage of drying fronts.

We are in the process of using data from these laboratory experiments to test mathematical models. These models solve coupled partial differential equations for porewater flow, colloid transport, and colloid mass-transfer reactions that occur at solid-water and air-water interfaces. Important recent accomplishments include the verification of a model that describes rate-limited colloid mobilization induced by moving air-water interfaces. We anticipate submitting a manuscript that describes this model and its evaluation against experimental data this summer.

Planned Activities

Our results to date have succeeded in illuminating relationships between measurable system properties and colloid-transport characteristics within idealized systems. We will extend this work to examine how colloid transport influences the mobility of radionuclides within unsaturated porous media. The colloid effect on the migration of cesium and strontium will be measured first in columns packed homogeneously with quartz sand and then in intact cores that we will collect from DOE sites (Figure 1). The column experiments will be carried out concomitantly with batch experiments designed to measure the kinetics of radionuclide adsorption to (and desorption from) the mineral colloids. In addition to column and batch experiments, part of year 2 will be devoted to the fabrication of micromodels. These transparent representations of a porous medium will be used to identify the mechanisms that govern the mobilization of colloids during transient-flow periods, such as those caused by rainfall events. This information on colloid-release mechanisms will be used in coordination with the batch and

column data to parameterize and refine a mathematical for colloid-facilitated contaminant transport in partially saturated porous media (Figure 1).

Figure 1. Approximate time line for planned research activities