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NUCLIDE MIGRATION FIELD EXPERIMENTS IN TUFF, G TUNNEL, NEVADA TEST SITE*

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ABSTRACT

A project to begin to address the phenomena of flow and element migration in fractured porous rock has recently been started by the Los Alamos National Laboratory, Sandia National Laboratories, and Argonne National Laboratory. The work has three objectives: 1) to develop the experimental, instrumental, and safety techniques necessary to conduct controlled, small-scale, radionuclide migration, field experiments; 2) to use these techniques to define radionuclide migration through rock by performing generic, at-depth experiments under closely controlled conditions in a single fracture in porous rock; and 3) to determine whether available lithologic, geochemical, and hydraulic properties together with existing or developed transport models are sufficient and appropriate to describe real field conditions (i.e., to scale from small-scale laboratory studies to bench-size studies to field studies). The detailed scope of this project and its current status are described.

INTRODUCTION

The intrinsic appeal of deep burial as a means for safe disposal of nuclear reactor waste is the concept that the rock surrounding the repository will provide a significant barrier between the radioactive waste and man's environment. Because the host rock provides the first natural barrier of radionuclide migration and strongly influences the detailed design of the engineered repository within it, an understanding of the properties of the host rock is of considerable importance. Such an understanding will also be the basis for predicting the performance of a repository and for identifying potential deficiencies in the models used for the predictions. Clearly, such information will also be essential in the process of selecting and licensing a repository and indeed in convincing the general public of the ultimate safety of such disposal.

In order to estimate the concentrations and travel times for radionuclides that may leave a repository, one must develop predictive models based on the understanding of the dynamic processes that occur at each location in the total repository-rock system. These models must include appropriate equilibrium and rate expressions that adequately describe the various dominant chemical phenomena involved, i.e., diffusion, dissolution, complexation, precipitation, ion exchange, surface adsorption, hydrolysis, coprecipitation,

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formation of solid solutions, colloid and polymer formation, etc., for each of the waste elements involved. The knowledge of the regional hydrologic regime must then be superimposed on the chemistry. This includes effects such as hydrodynamic dispersion, distance, pore-fluid velocity, and saturated or unsaturated flow. For many rocks, including tuff (volcanic pyroclastic rock), one has the additional complication of having flow that is dominated by the hydrology and mineralogy of a fracture system. Tuff also has a significant amount of connected porosity (15-40%), which means that diffusion into the matrix away from fractures is an additional retardation process. Mathematical methods must be developed that will handle the dominant processes that occur in systems of this type. These models must be verified by selected field tests specifically designed to address this

When considering groundwater flow and radionuclide retention in the complex flow systems that can occur in rock, one also has a serious problem in determining if laboratory studies are being performed under conditions appropriate to natural systems and if models of nuclide transport derived from laboratory results correctly handle nuclide movement under natural conditions. Indeed, there is even concern [1] that there is a problem with understanding fluid flow itself as function of the size of the sample studied. These questions can only be answered by increasingly more complex laboratory and field tests.

A multiyear project to begin to address these problems has recently been started [2]. The project is being performed jointly by the Los Alamos National Laboratory, Sandia National Laboratories, and Argonne National Laboratory. The work has three principal objectives: 1) to develop the experimental, instrumental, and safety techniques necessary to conduct controlled, small-scale, radionuclide migration, field experiments; 2) to use these techniques to define radionuclide migration through rock by performing generic, at-depth experiments under closely controlled conditions in a single fracture in a porous rock (tuff); and 3) to determine whether available lithologic, geochemical, and hydraulic properties together with existing or developed transport models are sufficient and appropriate to describe real field conditions (i.e., to scale from small-scale laboratory studies to bench-size studies to field studies). The techniques developed for the field experiment may also be used to screen potential repository sites and will be helpful in planning the large-scale field tests that may be required for site licensing by the Nuclear Regulatory Commission.

PROJECT SCOPE

Two migration experiments will be performed in the field. Stable or short-lived nuclides will be used in the first experiment, in part to demonstrate that the newly developed experimental methods are proper for the objectives of the project and are safe before conducting the second experiment, which will have actinides and long-lived nuclides as tracers. Study of the migration rates of actinides is one of the prime goals of this project because the possible release of actinides to the accessible environment is of appreciable concern. Both experiments include detailed, post-flow analyses of the entire spatial distributions of the migrating elements along the fracture and into the rock matrix, using techniques developed in the initial stages of the project. These data for the entire flow path are essential for correlating the migration of nuclides under actual field conditions with laboratory and modeling studies.

The site for the field experiments is in tuff exposed in G Tunnel at the Nevada Test Site. A single fracture (parting plane) will be used because the emphasis of the project is on flow and element migration in fractured porous rock. The bedding/parting plane was selected for use because a horizontal flow system was preferred for these initial experiments. It was felt that the flow could be better controlled in a horizontal than in a vertical system. Furthermore, these zeolitized tuffs are relatively easy to mine and, therefore, the removal of the entire flow path for detailed characterization should be much easier. G Tunnel is not a potential nuclear waste repository site. Each of the field tests will be performed in the same fracture but at a different location.

A potential configuration for the field experiments is shown in Figure 1. The maximum length of the flow path will be less than 1.5 m. Prior to injection of tracers, groundwater will be injected for some time to fully saturate the rock and establish steady state flow. The elements to be studied will then be injected from as near a single point as possible because this will allow data to be obtained on dispersion and channeling along the flow path. The tracers will be injected somewhat downstream from the water injection region so that "sheet" flow will be reasonably well established. There will be multiple sampling points for the collection of groundwater because it is desirable to obtain information on flow and dispersion on a real-time basis.

The site will be characterized in detail in order to determine the parameters necessary to perform the experiments and interpret the results. The emphasis is on the characterization of the flow and geochemical properties of the site. Obviously, these are needed in order to design the water and tracer-injection systems and water collection system.

The studies of the hydraulic environment that occurs in the selected site will concentrate on developing a better understanding of the role of diffusion in pyroclastic rock. This is necessary since diffusion in fractured porous tuff is potentially a very significant factor in retarding the migration of radionuclides. The principal data needs include matrix porosity, diffusion coefficients, equilibrium sorption data, pore shape, pore size distribution, ratio of connected pores to total porosity, and mineralogy of the coating of pores.

It is desirable to use water in field and laboratory studies that has a composition as close to equilibrium with the rock surfaces involved in the experiments as is reasonably possible. Non-equilibrium reactions between the natural components of the waste and the rock must not complete with the sorption-desorption reactions of the nuclides being studied. We will use a rock-pretreated natural groundwater since the chemical species in solution are most likely to be in an equilibrium state. The actual flow paths will be pretreated for some weeks prior to tracer injection. The inlet and outlet groundwater composition will be monitored during the experiments.

In order to gain information in a single experiment on a variety of elements having greatly differing retardation properties, "staged" injections of water movement tracer and migrating element(s) may be used. That is, several injections of groundwater containing one or more tracers would be made at different times during the course of the experiment. The earliest injections would be for those elements with the lowest migration rates, while later injections would be for those elements with the highest migration rates. The concentration of the migrating element in the groundwater will always be significantly below the solubility limit in the water. The length of the injection period will be optimized in the laboratory and modeling studies (see Reference 3, for example). The migration rate information used to select the sequence of injection will also be obtained from the laboratory studies. This procedure would localize most of the migrating elements somewhere along the flow path and give the maximum time for migration of those elements with strong retardation characteristics. A mass balance will be attempted for all tracers used in the study.

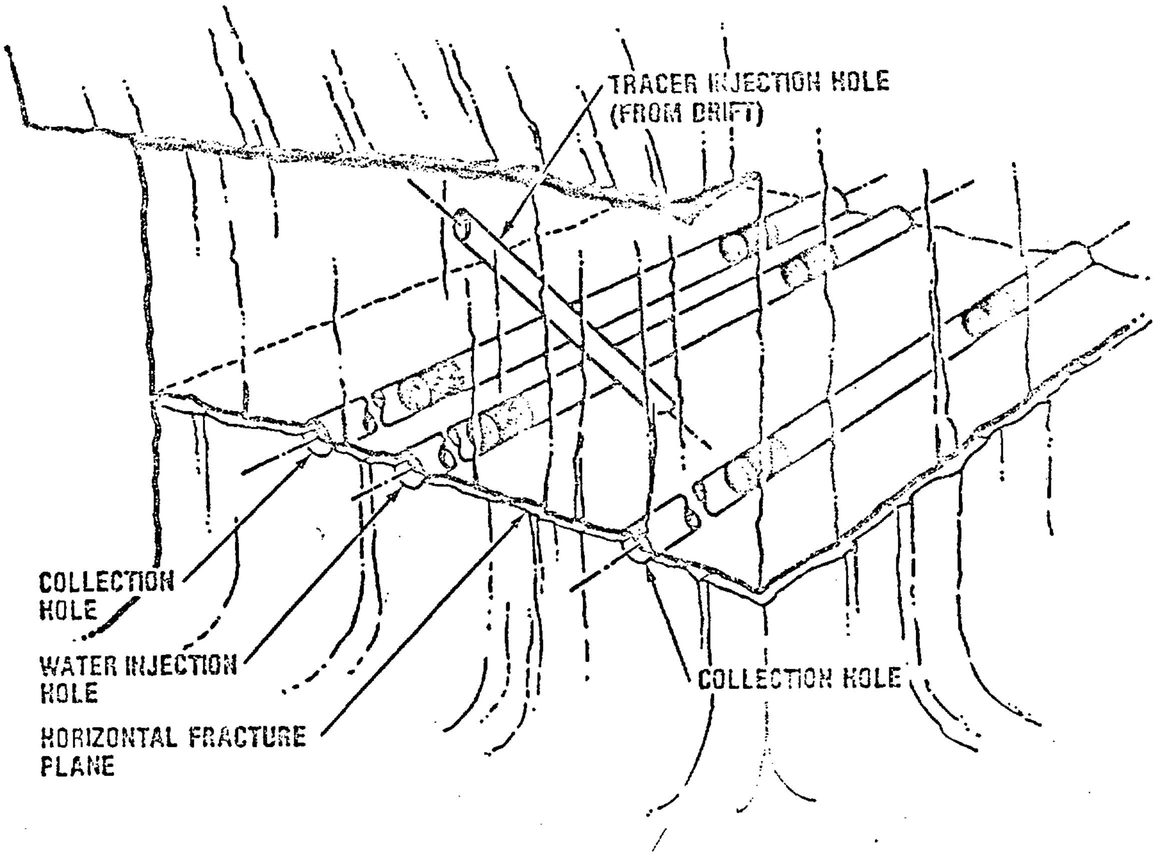

Fig. 1. Potential field experiment configuration.

The total duration of the experiment, from initiation to termination of groundwater flow, will be about 18 weeks. This will then be followed by application of post-experiment analysis methods to the actual flow path, which will be removed in its entirety, if possible. The experimental techniques to be used to detect the locations of the tracers among the flow path may include radiation mapping using an automated scanning system, autoradiography, counting of tracers in small samples removed for analyses, and chemical dissolution of such samples.

It would be most beneficial to the field and laboratory experiments if a tracer were found which could be used to locate the actual flow paths through the rock. The tracer should sorb on the tuff but not otherwise interfere with the transport processes. Therefore, it should be easily and efficiently detectable so that low concentrations can be used. It will be measured during the post-experiment analysis for each field and large-scale laboratory experiment.

Comprehensive laboratory studies of the sorptive and migration properties of the same materials will be performed using existing (core) and newly developed techniques. The latter include the development of laboratory techniques using large cores or blocks of material to better simulate the field experiment, but under controlled conditions. An example of such an experiment is shown in Figure 2. Ultimately blocks of sufficient size to provide flow paths of 0.5 m may be used. The initial tests of water movement tracers and post-experiment analysis techniques will be done using these samples.

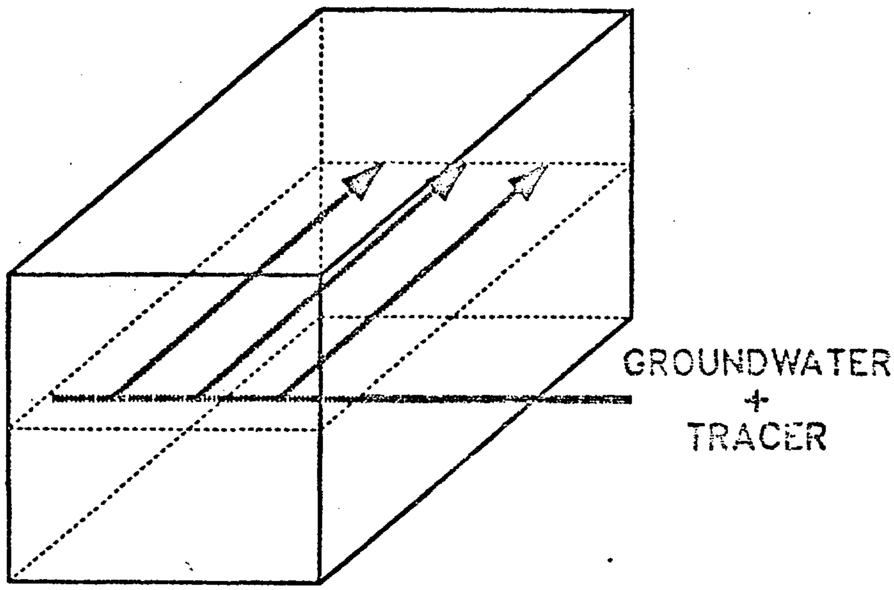

Fig. 2. Configuration of the experiments using blocks of tuff.

The suitability of various water movement tracers for use in fractured porous rock will be assessed. The one(s) selected must make it possible to determine the groundwater velocity but must not interfere in any way with chemistry that occurs in the fracture-flow experiments. The diffusion properties of these tracers will also be determined; they must function properly in a porous rock environment with the associated high tendency for diffusion into the matrix.

Concurrently with the field program, an extensive laboratory program will include determination of the necessary chemical adsorption and kinetic parameters, reaction mechanisms, chemical behavior in the groundwater, and sorption isotherms, in addition to the transport studies in blocks, development of water movement tracers, etc., already mentioned. Many of the techniques needed to obtain data have already been developed, and such studies are in progress [4,5].

Mathematical models will be needed that describe the chemical, geochemical, and hydraulic processes that are dominant in the laboratory and field experiments. Existing transport models will be used whenever possible. Three-dimensional numeric transport models must be developed that include the effects of diffusion into the matrix, velocity dispersion and channeling, sorption mechanisms, kinetics, and flow field. The data from the field and laboratory experiments will be compared with analogous data calculated using the available mathematical models. The adequacy of the models and laboratory techniques used to evaluate parameters will thereby be assessed. Refinements to the models and laboratory techniques will be made as necessary. The field experiments and accompanying analyses will hopefully provide the data and means to evaluate the adequacy of existing models under realistic conditions and, where appropriate, will provide a supplementary data capability.

CURRENT STATUS

One-dimensional analytical models for predicting radionuclide transport through fractured porous rock have been developed [3,6] or implemented [7]. Quantitative design criteria for the water and tracer injection and water sampling equipment have been generated and preliminary design requirements for experiment site selection were established. Based on these criteria, conceptual and detailed designs for water and tracer injection systems and a water and tracer collection system were completed. Design, fabrication, and field testing of a system for measuring <u>in situ</u> permeabilities ranging from tens of darcies to tenths of microdarcies have been completed.

Experiment site selection has in part depended on the definition of the geometrical, physical, and geochemical properties of fractures and intact beds of tuff that are required to meet the experiment objectives. Site selection started with a systematic survey (shallow cores) of bedding planes in G Tunnel, initiation of an exploratory drilling program to evaluate bed structure at depth, and a coring operation to provide arrays of test holes for field permeability measurements and cores for laboratory studies of permeability, mineralogy, petrography, bulk properties, sorption, diffusion, and other retardation properties. Data from these tasks are currently being collected and evaluated; characterization of the most promising sites for the field experiments will soon be completed.

The natural groundwater for use in the experiments has been selected. Studies of water movement tracers, rock and groundwater diffusion characteristics, and chemical retardation processes and kinetics, as well as radionuclide transport experiments in whole cores and cores containing natural fractures, have been initiated [5,8]. Development of the large-scale laboratory studies has also begun [8]. The use of ^{222}Rn as a water flow path tracer appears to be promising [9].

Development of a first-generation three-dimensional transport model for these experiments has also begun.

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