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Dear Mr. Conti:

This is in response to your letter of June 15 in which you requested an informal letter report containing my views on the characterization of the hydrologic system surrounding a HL waste repository in tuff. Specifically you asked for my thoughts regarding information, measurements and data needed to describe such a hydrologic system.

The system of concern is assumed to have the repository in the unsaturated zone at some distance above a regional water table. The tuff is stratified, with nearly horizontal layers of different physical properties relative to water flow and contaminant retardation, and the tuff extends to a large depth below the regional water table. The primary reason for describing the hydrologic system is to assess the effectiveness of the surrounding geologic medium in isolating contaminants from the accessible environment over a long time span. It is also assumed that the site is located in a desert environment and a portion of the small amount of precipitation enters the surface and percolates downward forming the principal input to the water flow system surrounding the repository. The unsaturated zone between the surface and the regional water table contains water under negative pressure except perhaps at geologic interfaces where a perched water table may exist.

The most likely pathway for contaminants is from the repository downward with the percolating water to the regional water table, then through the saturated zone to the accessible environment. However, lateral flow through perched saturated zones may alter the downward pathway. A second pathway that requires evaluating is through the air-filled primary and secondary pores of the unsaturated rock. In this case, the contaminant would need to be in the vapor state or included within aerosol particles.

The stored radioactive waste will cause nonisothermal conditions surrounding the repository, drying of the rock in the immediate vicinity of the repository, and a wetting of the rock at some distance from the repository. The dried zone surrounding the repository should enhance waste isolation, while the wetted zone may increase downward percolation under this zone.

In considering the hydrologic system for a repository located in an unsaturated zone, we have found it useful to consider three separate but interacting fields: near-field, meso-field, and far-field, mainly because assessment techniques and computer models will be somewhat different for the three fields. The near-field is the zone which is directly influenced by the emplacement of the repository, including the thermally influenced zone and the evaporation/condensation zone. The meso-field is the remainder of the unsaturated zone to the water table, while the far-field is the zone below the regional water table. Each of these fields will be discussed separately, with emphasis on the near-and meso-field.

Under the present state-of-the-art for characterizing the hydrologic system of a stratified tuff, several integrated approaches will be necessary to provide reliable conclusions, including detailed geologic descriptions of each stratum, measurements of relevant physical/chemical properties by different methods and on different scales, and theoretical treatments with appropriate computer modeling on different scales. The combined knowledge from the different approaches will likely be necessary to make reliable estimates of travel times and release rates for critical radionuclides.

Considerable research has been done on methods for predicting water flow and contaminant transport through saturated fractured rock of the far-field. The major problems are associated with scale of measurements, obtaining sufficient spatial distribution of hydrologic and geochemical data, and the prediction of flow and transport over long time spans. The characterization of the far-field in a tuff is not unlike that for other geologic media, such as basalt. However, the source of contaminants for the far-field will be over an area of the water table instead of within the saturated zone as it would be if the repository is at depth below the water table.

The meso-field may be considered isothermal, except for near the land surface and for the normal geothermal temperature gradients. The zone between the land surface and the water table is critical to waste isolation, since transport velocities would be expected to be extremely low. As you well know, prior to a couple of years ago there was little interest in evaluating the hydrologic characteristics of unsaturated rock systems. Therefore, the informational data bank for such systems is quite limited. During the past few years, studies have been made to assess the applicability to unsaturated rock of theories, measurement techniques and computer models developed for unsaturated unconsolidated porous media and for saturated consolidated media. Again, no single approach will suffice for the hydrologic characterization of this zone; several approaches will need to be followed and the results integrated.

In the following discussion, I am assuming that a shaft will be excavated using techniques which minimize the alteration of the geologic environment, including the water status, surrounding the shaft. If this is the case, a detailed description of the rock matrix and fracture pattern should be made at all depths as excavation proceeds. Samples of the rock matrix should be taken for measurements, such as total porosity, pore-size distribution, moisture release curves and hydraulic conductivity as a function of water content and potential. Methods for these measurements are available and the results will give evaluations as to the water conducting properties and times of travel for solutes for the rock matrix at different depths. This type of information can be coupled later with information on the fracture system to give flow and transport through the combined matrix and fracture flow system.

Horizontal tunnels should be excavated in the proposed repository zone and into at least one tuff member above and another one below the repository zone where fracturing is minimal. The latter two levels can be considered as control zones and can be characterized for flow and transport using available methods without the complication of an extensive fracture system.

From the tunnels at each level, small diameter boreholes should be core drilled at different angles and to specified depths for examining spatial variability. Some of the boreholes should be in parallel with a spacing of approximately one meter for flow tests. Cores should be logged in detail and samples used for measurements as discussed above for the rock matrix.

At the upper and lower tunnel levels, the pre-emplacement flow conditions should be determined. This would entail the measurement of hydraulic gradients and hydraulic conductivities as a function of water potential. The hydraulic gradient may be close to unity and the vertical percolation rate equal to the hydraulic conductivity at the existing water potential, and the average downward velocity is the percolation rate divided by the effective water content (not including deadend pores containing water). The hydraulic gradient can be evaluated by using common tensiometers and psychrometers with adapted emplacement techniques for the minimally fractured tuff. The hydraulic conductivity of the medium as a function of potential can be determined using undisturbed cores by several techniques, one of which is by calculation from the measured saturated hydraulic conductivity and the moisture release curve. The laboratory determined saturated hydraulic conductivity should be checked by an <u>in situ</u> method such as outflow tests from packed off sections of boreholes. Other approaches to confirm the hydraulic results may become apparent after preliminary testing. The tunnel level below the repository level should be evaluated for radionuclide retardation properties as well as for water conductance properties.

If the percolation rates above and below the repository are nearly the same, long term steady state conditions may be assumed, and the percolation rate through the repository zone may be considered to be similar to that at the other levels.

If the percolation rate through the repository zone can be approximated by the above approach, further studies should be made within the more complex repository zone to further define the combined matrix/fracture flow system.

Characterization of the fracture system in the repository zone for liquid and vapor conductance is considered critical. The most promising approach for the scale required appears to be through a computer simulation model, as the 3-dimensional model developed by Dr. Huang of our staff. The model requires the probability distribution for several fracture parameters pertaining to location, orientation, aperture, density, shape and length. Fracture distribution and orientation can be obtained from borehole observations. We are assessing the approach of determining aperture size distributions by air flow measurements for a number of individual fractures intersecting two boreholes, and the approach appears promising. Fracture density, length and shape combine to form a fracture surface area per unit volume, a measurable quantity in the field. For a range of rock masses, surface area/volume, aperture distribution and orientation distribution appear sufficient to reasonably model a rock mass of interest.

After the simulated fracture system is generated, numerical experiments can be run to show hydraulic and solute transport characteristics. At present, the model can only be applied to a water saturated fracture system and where the permeability of the rock matrix is zero. We are extending the model to handle unsaturated conditions and finite permeability rock matrices.

Numerical experiments using the extended model should give estimates of flow pattern, hydraulic conductivities as a function of water potential, combined heat, vapor and liquid transport in the near-field, and dispersion and travel times for contaminants from the repository zone to the regional water table. The model is complex and requires considerable computer time for even a relatively small fracture system. However, given the expressed need to characterize the hydrologic and contaminant transport properties of a proposed repository site, the construction of a simulation model appears to be the most promising approach.

Additional components of an assessment program I consider important are:

(1) The recharge characteristics at the land surface. This is an important characterization not only for defining present conditions but also for predicting possible effects of future climatic changes. We are presently measuring recharge rates for individual fractures in welded tuff exposed at the land surface. These data will define the infiltration component of a rainfall-runoff model. The model will allow the examination of different rainfall characteristics on recharge to a fracture system.

(2) An assessment of contaminant transport as vapor through the air-filled pore space. Analyses may show that vapor transport is not significant but this is important to know.

(3) Borehole/shaft sealing. Sealing requirements in an unsaturated rock may be different from those for saturated conditions and the degree of sealing may influence water flow and contaminant transport significantly. An assessment of this seems necessary.

I hope the above comments can be combined with those from other contractors to assist you and your colleagues in evaluating the environmental assessment statements.

Sincerely yours,

Daniel D. Evans
Professor

DDE/kb