TITLE: FRACTURE FLOW, TRANSPORT, AND DUAL PERMEABILITY MODELS AT YUCCA MOUNTAIN, NEVADA

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Yucca Mountain is a potential site for the US high-level nuclear waste repository. The site was chosen in part because of the very dry environment and the relatively large distance (500 m) to the water table. Fractures play an important role in both flow and transport at Yucca Mountain. Hydrogeologic units contain both non-welded tuffs, with low fracture densities, and welded tuffs, with large fracture densities. In the numerical models of the site, the fractured rock is often represented as an equivalent continuum, dual porosity, or a dual permeability model. In the equivalent continuum formulation, the properties of the fracture and matrix portions on the continuum are combined using the volume fractions of each media type. This provides an effective tool in some of the steady-state flow and some transient thermal calculations. In the dual porosity method, the matrix material is considered only to be storage for the fracture system and is not available for communication with other matrix material. Only the fracture system is allowed to communicate globally. This allows for considerable mathematical simplification (leading to CPU times only slightly longer than the equivalent continuum model), but is usually inappropriate for unsaturated zone simulations, where flow often occurs in the matrix material because of capillary suction. The dual porosity method will not be described further. In the dual permeability method, each computational cell is subdivided into a fracture and a matrix portion. The fracture portion can communicate with all other fracture volumes in the numerical grid. Likewise, the matrix portion can communicate with all other matrix volumes in the numerical grid. In addition, the matrix portion is allowed to communicate only with the fracture portion in the same computational cell. This is the most computationally intensive of the fracture models. For transient flow, there are often large differences between the equivalent continuum and dual permeability methods. For transport, the results from the two fracture models are usually significantly different. This is because the fractures and matrix are in approximate capillary equilibrium and thus have little fluid driving force; the transported species will tend to remain in the fractures if they started there. Thus, while the equivalent continuum model will mix the transported species instantaneously, the dual permeability methods allow for fracture matrix exchange primarily through diffusion.

This presentation will describe the numerical formulation of the equivalent continuum and dual permeability models and it addresses the appropriateness of the fracture models through a series of simulations ranging from simple to complex; the most complex simulation is represented by a model of Yucca Mountain. The connection to realistic fracture simulation will be made by describing a related task to take field-derived fracture networks and produce numerical simulations on very realistic grids, which represent the fracture networks. For all of the simulations we consider only unsaturated zone flow and transport. The first test simulation used for comparison is a model of a homogeneous system with low-capillary pressures. In this simulation, the two fracture models (dual permeability and equivalent continuum) provide close results even with large fracture densities. The transport results show differences. The results suggest that the transport properties (such as Kds) of the fracture are important. Without this information, matrix diffusivity values are critical. The next level of sophistication involves a multiple layered system. The results are similar to the homogeneous system. The big change is the magnitude of the difference in the results for transport. For the last simulation, we use a heterogeneous data set from Yucca Mountain. This set represents a cross section across the mountain near Antler Ridge. The model is very heterogeneous and, in particular, the hydrogeologic units are dipping. Travel times for both sorbing and non-sorbing radionuclides are presented for both fracture models. The results demonstrate the need for dual permeability methods. The dual permeability model predicts break-through times a factor of 100 sooner than the equivalent continuum model. When diffusivities of the matrix are used in the model, the break-through times are increased, relative to the dual permeability model without diffusivities, but not up to the times obtained with equivalent continuum model. In the fracture network modeling effort, the realistic fracture network model is generated using the FRACMAN code from Golder, Inc. This task will be done by Yucca Mountain participants at Sandia National Laboratory and will produce fracture networks that match networks found in the USGS fracture block experiments. The FRACMAN numerical grid is made up of planes of 2-d triangles in 3-d space. An example of such a grid is shown in Figure 1. The Los Alamos grid generation software, GEOMESH, is then used to improve the mesh for computations in the unsaturated region (see the summary on Grid Generation) and fill in the matrix material with a tetrahedral mesh. With realistic fracture geometry and associated mesh, we will explore the

relationships between realistic models and fracture abstractions, such as dual permeability and equivalent continuum models.

Significance:

A prediction of the flux of radionuclides to the accessible environment is a major requirement for any licensing or site suitability activity at Yucca Mountain. As fracture flow is potentially the most critical flow mechanism, a through understanding of the abstraction process is necessary for a defensible assessment of radionuclide flux to the environment. The transport aspects of radionuclide diffusion from fractures to matrix rock and the retardation of radionuclides on fracture minerals are dependent on the realistic representation of fracture flow. Our work will establish the level of detail necessary for the site-suitability calculations.

External Reviews.

The Nuclear Waste Technical Review Board (NWTRB), a body appointed by the President, reviewed this project on July 17, 1994.

Collaborators:

Mike Nicholl, Sandia National Laboratory (SNL) and Larry Anna of the USGS will produce the FRACMAN grids for the realistic fracture models. Susan Altman, Cliff Ho, and Bill Arnold, SNL, will run some of the dual permeability simulations.

Publications:

Rosenberg, N.D., W.E. Soll, B.A. Robinson and G.A. Zyvoloski, ÒMicroscale and Macroscale Modeling of Flow in Unsaturated Fractured Rock,Ó American Geophysical Union , Chapman Conference on Aqueous Phase and Multiphase Transport in Fractured Rock, Burlington, VT, September 1994.