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Three-dimensional characterization of an excavation-induced fracture network with gas tomography

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In the safety assessment of a nuclear waste repository, it is crucial to identify and isolate possible pathways for radionuclides from the waste canister to the biosphere and vice versa. Despite the potential self-sealing properties depending on the host rock and the decrease of the permeability over time, the migration depends on the presence of a fracture network, the connectivity of the fractures, and their connectivity to tunnels or drifts. To describe the initial state of said pathways, we demonstrate the inversion of transient pressure measurements to delineate the structural and pneumatic properties of an excavation-induced fracture network at the Meuse/Haute-Marne Underground Research Laboratory (URL) operated by the French radioactive waste management agency ANDRA.

The tomographic tests were carried out as sequential constant-rate injections of nitrogen and the resulting pressure perturbations were recorded in nearby borehole intervals. In total, nine boreholes with two injection/monitoring intervals each are available on a volume of approximately 3m times 3m times 5m. Therefore, the joint inversion of more than 300 signals allows unique insights into the excavation-induced fracture network.

A discrete fracture network (DFN) model is applied for the forward and inverse modeling. Thereby, the strong heterogeneity of the distribution of hydraulic or pneumatic properties caused by the fracture network can be described. A numerical model is used to simulate the transient pressure diffusion in the DFN. The structural properties and the permeability of the DFN model are characterized by solving the inverse problem. The inversion relies on a stochastic model of the DFN parameters based on the Bayesian equation. The posterior distribution, i.e., the distribution of the DFN parameters given the measured data, is the product of likelihood and prior distribution. The likelihood function compares the error between the measured data and the simulated outcome of the tomography experiments for a given DFN model. The prior distribution includes information about the fracture properties obtained in previous studies. The posterior distribution is characterized by generating samples from the posterior with Markov chain Monte Carlo (MCMC) methods. Due to the unknown number of fractures, the insertion and deletion of fractures are possible according to the reversible jump MCMC algorithm.

The inversion approach results in several DFN realizations that are approximately equally likely which is illustrated in a fracture probability map and a map of the permeability distribution. Thereby, preferential flow paths can be characterized.