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First applications of a small-animal-PET scanner for process monitoring in rocks and soils

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In the past, process parameters of transport processes in fluid-containing geomaterials were derived from input-output measurements, where the sample had to be regarded as black box, or it had to be cut for spatial observations after the experiments without possibility to repeat the experiments. With tomographic methods, now enabling non-destructive spatiotemporal quantitative process observation, these limitations have been overcome. Therefore, the importance of tomographic laboratory methods for non-destructive imaging of the structure of soils and rocks, and for observation and quantification of processes within these materials is increasing.

Some of them are miniaturised geophysical field methods, like electrical resistivity tomography (ERT) and ultrasonic tomography, others have been originally developed for medical use, like x-ray tomography (XCT) and nuclear-magnetic imaging (MRI). In the past twenty years, positron emission tomography (PET) became a very effective diagnostic method of nuclear medicine, but its applications in material sciences and earth sciences are very rare, probably because the spatial resolution was rather weak (5 mm). The recent development of small animal PET scanners for biomedical research, reaching the physical limit of resolution of this method (around 1 mm), allows high-resolution measurements on rock cores and soil columns.

A positron-emitting radio tracer, for example a solution containing ^{18}F or ^{124}I, is injected into the sample for tracking the solution during transport and reaction within the sample. Sequential PET-measurements during the experiment yield the spatiotemporal

evolution of the tracer concentration quantitatively. The solid matrix, which strongly interferes most other tomographic methods, has minor effect on PET. This rectifiable effect is caused by attenuation of the 511 keV annihilation radiation.

A ClearPET®-scanner (raytest GmbH, Straubenhardt) has been installed and successfully tested on phantoms, rocks and soil samples in our laboratory. The improvement in resolution and sensitivity is enormous with respect to the medical PET scanner that had been used before. Thus, this new system enables to visualise and quantify transport processes in geological material with a high volume resolution of 1.5 μl (1,3 mm) and extreme high sensitivity for tracer concentrations (10^{-12} to 10^{-15} moles/ml; peak sensitivity in complete detector configuration = 4,5%). Because of its rotating gantry the unique feature of partial detector configuration, starting with 8, to 12, to 16 to the maximum of 20 detectors is possible. Furthermore, two adjustable detector diameters of 125 and 220 mm make possible to investigate small and big size samples on a single instrument. It is an ideal instrument for laboratory observation of slow transport of small quantities, but with a maximum frame rate of 1 tomogram/minute also suited for monitoring fast processes, like propagation of solutions in saturated fractured rocks.