Muon detector developed for subsurface borehole imaging

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A research team, including Los Alamos National Laboratory, is examining how naturally occurring cosmic rays could precisely image the density distribution in the Earth's subsurface to provide a direct, real-time, and low-cost method for monitoring fluid displacement in subsurface reservoirs. Such technology could be used to observe the sequestration of the greenhouse gas carbon dioxide (CO_2) and track fluid migration during injection or hydrocarbon production. The journal *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* has published their developmental work.

Significance of the work

Muons are generated naturally in the upper atmosphere from cosmic ray interactions. Due to their widespread availability and highly penetrating nature, scientists are studying them for a variety of difficult imaging scenarios. Muons penetrate the Earth's surface. By measuring the muon flux at various depths in wells, the attenuation of the muon signal due to the different stratigraphic units, or the fluids contained within these units, can be determined. These measurements could identify and interpret variations in density and fluid content as a function of time. The information could be processed and interpreted jointly with other geophysical data to improve spatial resolution and reduce uncertainty.

This approach has the potential to become a direct, real-time, and low-cost method for monitoring fluid displacement in subsurface reservoirs. In the example of geological carbon storage, such a method would enable monitoring the CO_2 concentration by observing density changes over time as the CO_2 is injected and replaces brine.

Strict requirements of size, ability to withstand an underground environment, data transmission rate, background effects, and performance requirements guide the development of a miniaturized muon-tracking detector deployed in a borehole. The primary technical challenges for the design include: 1) a miniaturized detectors capable of fitting in standard 7-inch diameter boreholes and 2) resisting the harsh underground conditions (e.g., pressure, heat, water, corrosive chemicals) for long periods of time.

The team developed and tested a Borehole Muon Detector system that is considerably smaller, lighter, and more portable than the previous systems that they had created. Numerical modeling suggests that the Borehole Muon Detector would be able to detect small changes in densities, which are a proxy for fluid migration, as deep as 1,500 meters underground. The use of several muon detectors would enable researchers to build a tomographic image of the underground environment. The investigators have already developed a version is small enough to test in a typical 7-inch-diameter borehole environment. The new design concept could fit into a pressure vessel with an outside diameter of only 6 inches.

Achievements

To test the viability of this technique, researchers developed and tested a muon detector designed to function in boreholes. The inventors used the Monte Carlo code GEANT4 to simulate the anticipated detector response and tested the prototype Borehole Muon Detector in the Shallow Underground Laboratory at the Pacific Northwest National Laboratory and in the underground tunnel at Los Alamos's Technical Area 41. The Los Alamos tunnel is a decommissioned drift in the Bandelier Tuff units in Los Alamos Canyon, with a floor approximately 90 m below the mesa top above, and extending approximately 90 m into the side of the mesa.

Los Alamos investigators used their expertise in muon imaging and particle detectors to run the Borehole Muon Detector in comparison with the their well-characterized larger detector known as the Mini-Muon Tracker. The Borehole Muon Detector provided data acquisition sensitivity comparable with that of the Mini-Muon Tracker. This comparison proved the technical and economic feasibility of a Borehole Muon Detector system, which is considerably smaller, lighter, and more portable than the Mini-Muon Tracker.

The research team

Reference: "A Novel Muon Detector for Borehole Density Tomography,"*Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 108 (2017). doi: 10.1016/j.nima.2017.01.023.
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