Borehole Muon Detector for 4D Density Tomography of Subsurface Reservoirs

Award Number: FWP-66844

Project Summary:

This project worked to develop the basis of a new time-lapse 3D (i.e., 4D) method for monitoring fluid displacements in subsurface reservoirs based on the inversion of density-dependent attenuation of cosmic ray muon flux data. Monte Carlo modeling methods were used for detector simulations and to optimize the detector design. The robustness of the design comes primarily from the use of scintillating rods, as opposed to drift tubes that are used in many large muon detectors, where the polystyrene scintillating rods are arrayed in alternating layers to provide a coordinate scheme. Testing and measurements were performed using a prototype borehole muon detector (BMD) to test the performance of the scintillators, in both the laboratory and shallow underground facilities.

Prime Performer:
Pacific Northwest National Laboratory

Principal Investigator:
Alain Bonneville

Project Duration:
10/01/2014 – 08/31/2016

Performer Location:
Richland, Washington

Program:
Carbon Transport & Storage

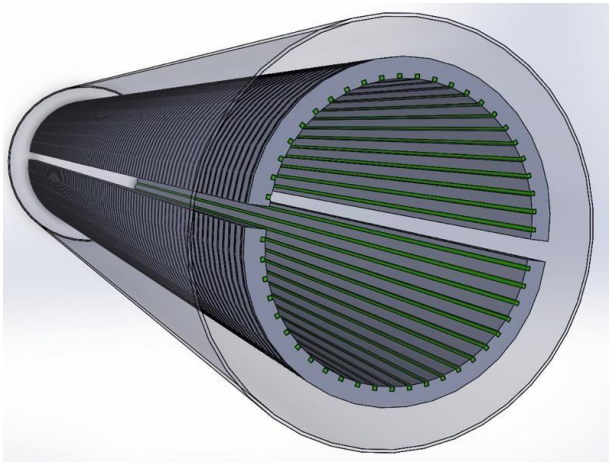

Figure 1: The concept for the next generation borehole muon detector design.

Project Outcomes:

This project developed a BMD to evaluate the density-dependent attenuation of the cosmic ray muon flux at depth. The detector is compact and robust enough for deployment in a large borehole. This muon detector can provide tomographic data to detect small changes in density at depths up to 1.5 kilometers. The BMD was successful in detecting muons above ground and in underground facilities at Pacific Northwest National Laboratory and Los Alamos National Laboratory. The results from the BMD compare well with those from the larger detector. While the prototype detector demonstrates the concept for a borehole detector, it is too large to fit in a 6-inch borehole. A new design concept has been developed for this next-generation muon detector. It will fit into a 6-inch outer diameter pressure vessel and could be deployed in wells cased with 7-inch casings.

Theoretical inferences and preliminary modeling suggest that the combination of seismic and muon observations can be valuable in estimating the density and elastic parameters in the subsurface. Three cases: seismic travel time, P wave reflection, and full waveform, were considered. An example using Monte Carlo inversion was tested to evaluate the potential of evaluating both density and elastic parameters. A better understanding of practical limits and errors is needed to further refine these estimates. Further developments involve the use of gravity data as an additional constraint in the data inversion process.

Presentations, Papers, and Publications

Final Report: A Novel Muon Detector for Borehole Density Tomography (2017) – Bonneville, Alain, Kouzes, Richard T., Yamaoka, Jared, Rowe, Charlotte, Guardincerri, Elena, Durham, J. Matthew, Morris, Christopher L., Poulson, Daniel C., Plaud-Ramos, Kenie, Morley, Deborah J., Bacon, Jeffrey D., Bynes, James, Cercillieux, Julien, Ketter, Chris, Le, Khanh, Mostafanezhad, Morley, Varner, Gary, Flygare, Joshua, Lintereur, Azaree T.