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Statistical Analysis of Cased-Hole Monitoring Well Logs for the GeoCquest Field Validation Experiment based on a Time-Lapse Technique: Interpretation Example and Interpretation Accuracy

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The GeoCquest Field Validation (GFV) Experiment is a field-scale geological carbon sequestration research test conducted under the Otway Stage 4 program at the Otway International Test Centre, Victoria, Australia. The study involved the injection of approximately 10,000 tonnes of supercritical CO_2-rich gas (80 mol% CO_2 and 20 mol% CH_4) into the lithologically heterogeneous Paaratte Formation Parasequence 2 (PS-2) within the onshore Otway Basin at a depth of approximately 1.5 kilometers.

The GFV monitoring plan incorporated a strategically designed cased-hole pulsed-neutron logging (PNL) program, optimized for high temporal frequency and operational efficiency. This unique logging program was conducted in the newly drilled, dedicated passive monitoring well, CRC-8, over a period of 5 to 6 months. Data were collected with SLB's latest-generation pulsed-neutron instrument, the Pulsar service. Neutron-induced gamma ray counts are acquired as spectra in the energy and time domains, which are analyzed to yield Gas, Sigma, and Hydrogen-related measurements (GSH mode). For baseline runs, four passes of well logging were conducted in the eccentered configuration at a deliberately slow logging speed of approximately 200 ft/hr. The target Zone-of-Interest (ZoI) was an 80-meter interval within the freshwater aquifer that was initially saturated with brine. During the monitoring phase, up to three logging passes per day were performed under identical operational conditions.

The statistics of radiation counting were significantly improved by the slow logging speed and integration of daily passes, resulting in an excellent signal-to-noise ratio observed across both baseline and monitoring runs. This high-quality spatiotemporal PNL dataset enabled a rigorous statistical analysis of GSH measurements, examining their behavior on a depth-by-depth basis within the ZoI. The primary objective of the statistical study was to *detect* the presence of CO_2-rich gas at each depth point, sampled at 6-inch intervals, and to evaluate breakthrough times at CRC-8 with a *pre-defined confidence interval* (CI). Prior to analysis, PNL data were corrected for depth mismatches using automated depth alignment tools and in-house developed code to enhance precision in depth registration. An independent samples t-test was performed to compare the means of two independent groups: (1) the pre-injection baseline and (2) the daily monitoring data. The goal was to determine whether there was statistical evidence of a significant difference between the means of these groups, enabling the detection of CO_2-rich gas with a 95% CI at each sampling point. For depths where CO_2-rich gas was detected, saturation estimates were derived using a time-lapse interpretation technique. Furthermore, the uncertainty associated with these saturation estimates was quantified to improve the interpretation accuracy.

Our statistical analysis demonstrates a comprehensive evaluation of breakthrough times across multiple layers with a 95% CI. Breakthrough was observed as early as within a week, indicating the potential for gas migration through high-permeability streaks between the injector and monitoring wells, located nearly 100 meters apart. These findings highlight the effectiveness of the proposed methodologies in detecting and quantifying the migration of CO_2-rich gas in heterogeneous formations, providing valuable insights for advancing carbon sequestration monitoring technologies and improving the reliability of predictive models.

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References

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