Geophysical Applications in Vadose Zone Characterization

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Introduction

From 1943 to 1989, the Hanford Site in southeastern Washington produced plutonium for the United States nuclear weapons program. Approximately 54 million gallons of high-level radioactive waste generated from plutonium and uranium processing operations are currently stored in 177 underground tanks. 149 of the 177 tanks in twelve tank farms are of single-shell construction (SST's). Of these 149 SST's, 67 are known to have leaked or have been designated as "assumed leakers." About 760 cased boreholes (drywells) have been installed in the vicinity of the SST's.

Hanford's waste tanks are located on the site's central plateau, approximately 7 miles from the Columbia River. The drywells are typically 100 to 150 feet deep. Groundwater is intercepted at 200 to 250 feet below surface grade. The overlying vadose zone is comprised of complex sequences of boulder, gravel, and sand deposits; intercolated silt lenses; caliche lenses; and random clastic dikes. These sediment sequences are poorly consolidated and incompetent; steel casings are required.

Original geophysical methodology incorporated the use of Geiger-Mueller (GM) or sodium iodide (NaI) detectors for detection and measurement of gross gamma activity in the drywells. By the 1990's, it became apparent that more sophisticated logging would be required to adequately characterize, evaluate, and assess the nature and extent of subsurface contamination in the vicinity of the single-shell tanks. The Department of Energy Richland Office (DOE-RL) requested the DOE Grand Junction Office (DOE-GJO) to provide a baseline characterization of the vadose zone using high-resolution gamma spectroscopy in existing boreholes.

A geophysical method to detect and quantify anthropogenic radionuclides in the vadose zone embraces a suite of unique challenges for spectral gamma logging. These include a calibration methodology to detect and quantify a variety of gamma-emitting radionuclides through steel cased boreholes, measurements of activity in zones of extremely high gamma flux, and the ability to discriminate between contamination distributed within the formation and contamination localized to the borehole casing.

Technical Approach

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Two geophysical logging systems were specially designed for the baseline-logging project. The spectral gamma logging system (SGLS) uses a high-purity germanium (HPGe) detector with 35% relative efficiency. The SGLS provides reliable results for radionuclide concentrations from background levels up to several thousand picocuries per gram. The high rate logging system (HRLS) sonde is a very small, low efficiency HPGe detector that was developed to run with SGLS processors. With supplemental shielding, the high rate logging system (HRLS) is capable of measurements up to about 10^9 picocuries per gram.

Initial calibration of the SGLS and the HRLS was performed at the DOE-GJO Borehole Calibration Facility, which had been developed for the National Uranium Resource Evaluation program. Calibration for Hanford's geophysical program activities is performed at the DOE-RL borehole calibration facility. Each calibration standard contains known uniform test zones with gamma intensities related to known concentrations of potassium, and the decay progeny of uranium and thorium. The Hanford geophysical calibration standards are calibrated to the DOE-GJO Borehole Calibration Facility.

The dead time correction function and calibration constants for potassium, uranium, and thorium could be determined by relatively straightforward measurements in the calibration models. However, it was necessary to develop a calibration function for man-made radionuclides not present in the calibration models. A calibration function that related detector efficiency to energy level was developed by fitting a curve to data from 10 peaks associated with potassium, and uranium and thorium decay progeny over the range of 186 to 2614 keV. Using this function, the concentration (specific activity) could then be calculated for any radionuclide when the yield of the gamma ray was known.

Calibration of the high rate logging system (HRLS) was particularly difficult. Within tank farms, vadose zone radionuclides could be expected to range in concentrations between 10^6 to 10^8 picocuries per gram. Construction of test zones with uniformly distributed gamma-emitting radionuclides at these activity levels was not practical for reasons of personnel exposure (safety), prohibitive near-term construction costs, and regulatory requirements for long-term surveillance and subsequent disposal. Thus, the calibration required the use of the existing calibration models. Only a few of the calibration models were “hot” enough to provide discernable peaks and measurements were highly variable. Curve fitting was performed by inversely weighting individual data points by relative uncertainty. Recently, the HRLS was run in a slant borehole that was drilled to investigate contamination under tank 241-SX-108. A comparison of geophysical log data with laboratory measurements indicated excellent agreement with activity levels above 10^8 picocuries per gram. In response to the need to discriminate between contamination associated with a remote source, such as a buried pipe, and uniformly distributed contamination, Wilson (1997) developed the method of shape factor analysis. The concept of shape factor analysis is that the shape of the peak in a gamma energy spectrum and the ratio between direct and scattered gamma rays is influenced by the spatial distribution of the gamma ray source.

Results

Significant advances in the understanding of the vadose zone contaminant distribution in the vicinity of SST's have resulted from the geophysical baseline characterization program.

Previous investigators had reached a general consensus that contamination extended deep into the vadose zone enveloping SST's. An independent expert panel was convened in 1996 (DOE 1997) to review baseline data and to resolve conflicting interpretations as to whether ^{137}Cs had reached substantial depths in the vadose zone. In general, the expert panel report supported the analysis and conclusions drawn from the spectral gamma data, which indicated that ^{137}Cs had migrated through the vadose zone to significant depths within tank farms. Thus, contaminant migration through the vadose zone has occurred in the past. Repeat geophysical log measurements suggest that deep migration by contaminants is continuing.

Future Activities

The baseline characterization data provide a reference point for future comparative measurements. Subsequent geophysical monitoring will help scientists track the migration of gamma-emitting radionuclides in the vadose zone. The current geophysical characterization baseline developed for the vicinity of Hanford's SST's will be extended to include the liquid effluent waste disposal sites of Hanford's 200 Area Plateau. A geophysical logging system employing a simpler and more cost-effective sodium iodide detector is under development for routine monitoring in the tank farm drywells. Neutron moisture logging was recently implemented for identifying variations in moisture content in the vadose zone. Neutron capture logging is under current development for use in detecting and quantifying highly mobile, non-radioactive constituents of tank waste, such as nitrates.

References

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