CONF-950601--4

LA-UR- 95-107

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Submitted to:
American Nuclear Society
Philadelphia, PA
June 25-29, 1995



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# DETECTION OF CONTAMINANTS ALONG BOREHOLES WITH PROMPT GAMMA SPECTROSCOPY

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## Introduction

Geophysical borehole logging techniques are used for estimating subsurface physical, chemical, geological, and hydrological parameters. Nuclear borehole logging techniques have advantages and disadvantages that tend to be complementary to those of physical sampling and these *in situ* measurements can help address the drawbacks of physical sampling, including high costs, lengthy delays in obtaining results of analyses from laboratories, under sampling, sample handling problems, and ambiguity in long-term monitoring. As part of an effort to reduce environmental restoration costs, we are evaluating *in-situ* neutron-induced gamma-ray spectroscopy (multispectral) measurements in boreholes to map environmental contaminants. It has been known for some time that this technology is capable of identifying many elements, but earlier borehole equipment was not very sensitive.

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**Description of work**

For this project, we constructed a variable-contaminant test model at the DOE Grand Junction Projects Office. This full-scale physical model of the borehole environment allows insertion of various contaminants under controlled conditions. To investigate several contaminants, meet environmental regulations, and remain within budget, a design using 15-cm-thick disks of contaminant-containing concrete sandwiched between thicker layers of uncontaminated concrete was chosen. Two contaminated disks were manufactured containing two different concentrations of chlorine along with one disk each containing small quantities of mercury, cadmium, samarium and gadolinium. The latter two elements were included to help us understand the instrument response, not because they are considered major contaminants.

In designing the variable-contaminant model, we knew that the 15-cm-thick contaminated zones would not give the same maximum response as a homogeneous contaminated zone thick enough to be perceived by the instrument as effectively infinitely thick (say, 1 m). The relatively thin contaminant zones require that the logging instrument response be measured at enough depth positions relative to the contaminant zone to provide an accurate *thin bed* profile for the gamma-ray energy lines of interest. The thin-bed response function is the shape of the count rate curve as a function of depth in the vicinity of a thin zone of contaminated material. This response function plays an important role in determining true concentrations when the contaminants are distributed in layers less than about 1 m thick. The equivalent thick bed response is then constructed by the principle of superposition from the thin bed response[1,2].

A commercial logging company, participating in the experiments under contract, supplied the self-contained neutron generator package for the experimental prototype instrument. An N-type germanium detector with an efficiency of 22.5 percent was cooled by liquid nitrogen in a dewar with an outside diameter of about 7.6 cm. Pulses from the detector were fed to a commercially available laboratory pulse-height analyzer. The detector and its associated instrumentation and software were tested extensively before the borehole experiments began. The detector performed remarkably well, successfully handling count rates of 2,000,000 counts per second while maintaining good spectral performance.

We acquired a 16,000-channel spectrum at each of 13 depth positions in the variable-contaminant model for each of the six removable contaminant disks. Repeat measurements were made in some cases to verify reproducibility of results. In addition, spectra were acquired in other Grand Junction calibration models to determine the effects of hole size and formation nuclear properties on the instrument response. Each spectrum was acquired for 1000 s of live time, corresponding to about 1200 s or 20 min of real time. Most spectra were acquired using a timing gate selected to include largely prompt thermal-neutron activation. In addition to the capture spectra, inelastic and activation spectra were acquired for some positions in the variable-contaminant test model. While these other spectra are of little use in identifying most contaminants, they may provide important information related to lithology and water content of the material around the borehole, and other useful information as well.

**Results**

Experiments performed in the variable-contaminant model with the experimental prototype allowed us to estimate detection thresholds for the elements listed above. Since our experimental prototype was more expedient than elegant, we extrapolated from the experimental thresholds to what we believe could be achieved using existing state-of-the-art hardware and data processing technology. For a state-of-the-art system, we estimate the following approximate detection thresholds can be achieved: 4 mg/Kg for mercury, 0.2 mg/Kg for cadmium, 10 mg/Kg for chlorine, and 0.1 mg/Kg for samarium and gadolinium (these are concentrations at which the net spectral peak area is 2.33 times the standard deviation of the spectral background, where one can say with 50% confidence that the target element is present[3]) We are also extending the estimates to a number of other potential contaminants using a combination of computer simulations and analytical calculations based on the experimental spectra and nuclear cross-section tables.

Our results indicate that the multispectral borehole logging technique is sufficiently sensitive to be useful in screening for a number of contaminants. Its value is greatly enhanced by the fact that the technique analyzes some three orders of magnitude more material than physical sampling at each depth where a measurement is made. In monitoring applications, this *in-situ* technique can reanalyze the same borehole at any desired time interval for as many years as required. Based on these results, we have proposed constructing a field-ruggedized borehole instrument package, demonstrating and evaluating the technology at a contaminated DOE site, and moving the technology into the commercial sector.

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