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Moisture effect in prompt gamma measurements from soil samples

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HIGHLIGHTS

- Silicon, hydrogen and oxygen prompt gamma ray measurements from soil samples containing 0–14 wt% moisture (water) concentration.
- 14 MeV neutrons based PGNAA setup with $LaBr_3$:Ce gamma ray detector.
- With increasing moisture concentration decreasing intensity of Si and O prompt gamma rays.
- With increasing moisture concentration increasing intensity of H prompt gamma rays.
- Monte Carlo calculation of Si, H and O prompt gamma ray intensities from soil samples.
- Good agreement between the experimental and calculated results.

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Increasing intensity of hydrogen with moisture
Monte Carlo calculation for gamma ray intensity from soil samples

ABSTRACT

The variation in intensity of 1.78 MeV silicon, 6.13 MeV oxygen, and 2.22 MeV hydrogen prompt gamma rays from soil samples due to the addition of 5.1, 7.4, 9.7, 11.9 and 14.0 wt% water was studied for 14 MeV incident neutron beams utilizing a $LaBr_3$:Ce gamma ray detector. The intensities of 1.78 MeV and 6.13 MeV gamma rays from silicon and oxygen, respectively, decreased with increasing sample moisture. The intensity of 2.22 MeV hydrogen gamma rays increases with moisture. The decrease in intensity of silicon and oxygen gamma rays with moisture concentration indicates a loss of 14 MeV neutron flux, while the increase in intensity of 2.22 MeV gamma rays with moisture indicates an increase in thermal neutron flux due to increasing concentration of moisture. The experimental intensities of silicon, oxygen and hydrogen prompt gamma rays, measured as a function of moisture concentration in the soil samples, are in good agreement with the theoretical results obtained through Monte Carlo calculations.

1. Introduction

Soil contamination is a major issue in environmental studies. There are several factors which contribute to soil pollution, but some of the major factors contributing towards soil contamination are industrial toxic waste discharge into the ground (Mulligan et al., 2001) and Petroleum hydrocarbons (PHC) contamination of soil surface (Atlas, 1981; Kirka et al., 2005). Prompt Gamma Neutron Activation Analysis (PGNAA) techniques have been successfully used to analyze hydrocarbon contents of bulk samples using 14 MeV Neutron beams (Drake et al., 1969; Doron et al., 2014; Defense Nuclear Agency Report # DNA 2716, 1972; Engesser and Thompson, 1967; Simakov et al., 1998; Falahat et al., 2012; Naqvi et al., 2013; Shultis et al., 2001; Wielopolski et al., 2011). In short, 14 MeV neutrons beams can be used to analyze bulk soil samples for environmental studies.

The presence of moisture in bulk samples causes problems in prompt gamma analysis of bulk samples utilizing 14 MeV neutron beams. Hydrogen contents of moisture in bulk samples act as a moderator for fast neutrons, thereby reducing the 14 MeV neutron flux in the sample. This results in a decrease in intensity of 14 MeV neutron-induced prompt gamma rays from the sample. This

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requires a correction in the intensity of 14 MeV neutron-induced prompt gamma rays for the intensity loss due to sample moisture. This correction may be done by measuring the corresponding increase in intensity of thermal neutron-induced gamma rays from a specific element, say hydrogen contained in the same sample. These inverse trends in intensity variation of 14 MeV neutron- and thermal neutron-induced prompt gamma rays from a sample containing moisture may be used to correct for the moisture-dependent intensity loss of 14 MeV neutron induced prompt gamma rays in a sample following the standard Multiple Linear Regression (MLR) analysis techniques used in commercial on-line PGNAA gauges for correction of moisture effects in the samples.

A systematic study has been carried out to measure the intensity of 14 MeV neutron-induced 1.78 MeV silicon gamma rays, 6.13 MeV oxygen prompt gamma rays and 2.22 MeV hydrogen prompt gamma rays from a soil sample containing various moisture concentrations. The 2.22 MeV hydrogen prompt gamma rays are produced in the soil sample due to the capture of thermal neutrons in the hydrogen of the moisture added to the soil sample, while the thermal neutrons are produced in the sample due to moderation of incident 14 MeV neutrons from hydrogen in the moisture contents added to the soil sample. The study is described in the following sections.

2. Gamma ray intensity calculations from soil samples

The intensities of 1.78 MeV silicon, 6.13 MeV oxygen, and 2.22 MeV hydrogen prompt gamma rays were calculated from soil samples containing 0–15 wt% moisture using the general purpose MCNP4B2 code (Briesmeister , 1997). The calculations were carried for the 14 MeV neutron-based PGNAA setup shown in Fig. 1. The procedure used in the present study was similar to the one described earlier (Naqvi et al., 2013). For continuation's sake, it will be described briefly. The simulations were carried out for prompt gamma rays induced by 14 MeV neutrons inelastic scattering in bulk soil samples. The PGNAA setup mainly consists of a cylindrical polyethylene plastic sample container with 106 mm × 125 mm (diameter × height) dimensions. The sample container is placed at 0° angle with respect to the 14 MeV neutron beam and at a center-to-center distance of 70 mm from the 14 MeV neutron source. The neutron source was assumed to be point source. The empty polyethylene container has a mass of 96 g with a density of 0.92 g/cm^3. In the simulation study, the plastic container was modeled thereby resulting in non-zero hydrogen gamma ray counts for zero-moisture concentration. The density of dry soil was taken as 1.69 g/cm^3. A cylindrical 76 mm × 76 mm (diameter × height) $LaBr_3$:Ce detector, placed at a center-to-center distance of 125 mm from the sample, detects the gamma rays from the sample at an angle of 90° with respect to the 14 MeV neutron beam axis. The detector was shielded against 14 MeV neutrons and gamma rays through tungsten and lead shielding, respectively. For this simulation study, the sample was divided into sub-cells of 1 cm thickness. This allowed the transport of the neutrons and gamma rays of appropriate statistical weight to the next adjacent cell, without any loss.

In order to study prompt gamma ray production over the sample volume, 14 MeV neutrons as well as thermal neutron intensities were calculated over the sample diameter for 0–20% moisture concentration using the F5 tally of a point detector. Fig. 2 shows the 14 MeV and thermal neutrons intensity profiles over the sample diameter. The 14 MeV point source was located at x = −5.3 cm. The fast neutron data is shown with different symbols. The symbols are superimposed upon each other because the change in intensity of 14 MeV neutrons for various moisture concentrations is insignificant. The decrease in 14 MeV flux is mainly due to 1/distance^2 dependence of flux from the source. This is confirmed by the 1/distance^2 fit made to the 14 MeV neutron intensity data shown by the solid line. The calculated thermal neutron intensity is plotted with symbols connected with solid lines. The thermal neutron intensity shows a dependence upon radial distance as well moisture concentration. The thermal neutron intensity first increases with increasing radial distance from the source then reaches a maximum around the sample center and finally starts decreasing afterwards. The initial increase in thermal neutron intensity is due to increasing moderation of fast neutrons due to increasing moisture concentration. The decrease in thermal neutron intensity beyond the sample center is due to the loss of 14 MeV neutrons. Fig. 3 shows the thermal neutron intensity radial profile on an enlarged scale. The location of thermal neutron

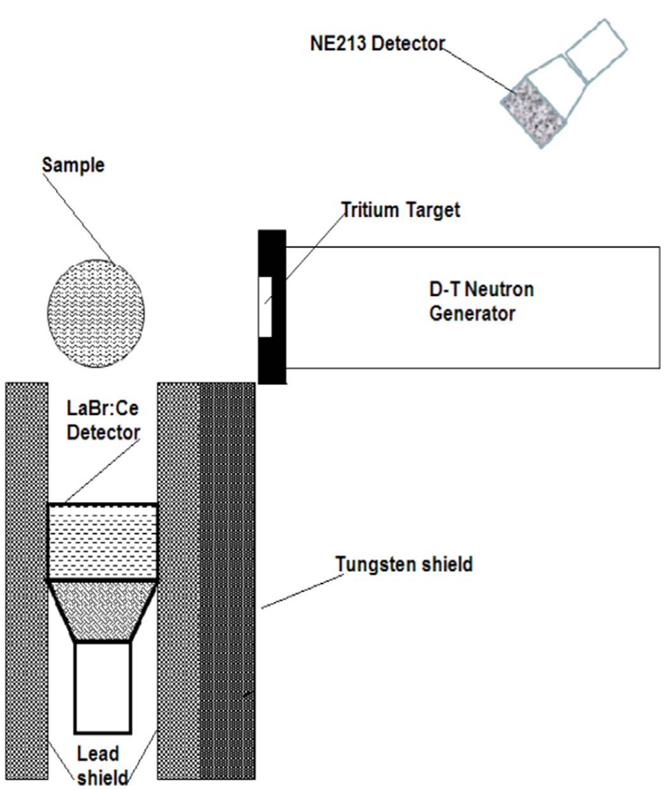

Fig. 1. Schematic of 14 MeV neutron-based setup used for analysis of soil bulk samples.

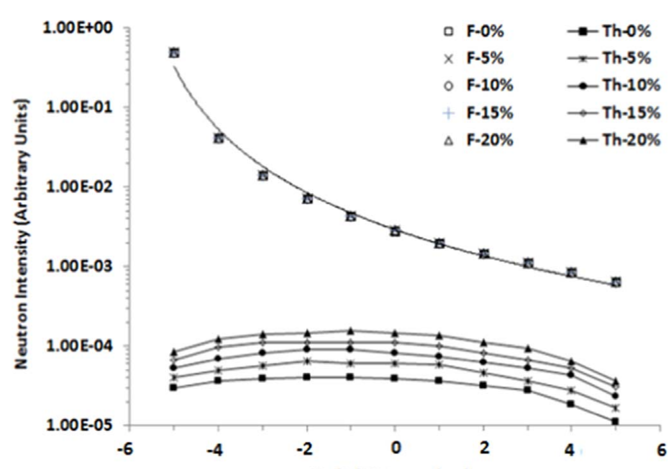

Fig. 2. Calculated intensity profile of 14 MeV and thermal neutrons plotted over the sample diameter for 0–20% moisture concentration (wt%).