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Review

The soil moisture and its effect on the detection of buried hydrogenous material by neutron backscattering technique

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ABSTRACT

Among the available nuclear techniques, the neutron backscattering technique, based on the detection of the produced thermal neutrons, is thought to be the most promising for landmine detections.

The results obtained from Monte Carlo simulation were used for selection of BF_3 detector and Am–Be neutron source shielding. In addition, soil moisture was discussed as a limitation of the neutron backscattering technique. It was experimentally found that this technique is useful for soil whose water content is lower than 14%.

Contents

1. Introduction

Today, an estimated over 60 million landmines have been buried in many countries (Király et al., 2004). The number of persons accidentally killed by landmines each year is estimated to exceed 25,000 and an even larger number are maimed with many of the victims being women and children (Brooks et al., 2004a, 2004b).

The search for hidden explosives is one of the most interesting and worthwhile applications of nuclear techniques.

Several landmine detection methods based on nuclear techniques have been suggested in recent years including neutron energy moderation, neutron-induced γ-ray emission, neutron and γ-ray attenuation, and fast neutron backscattering, which are nuclear-based methods (Brooks et al., 2004a, 2004b; Datema et al., 2002).

Thermal neutrons backscattering have been used in detecting the buried landmines. These neutrons can be produced by slowing down fast neutrons emitted from a radioactive source (typically an Am–Be neutron source) in soil and buried landmine. They act both as reflectors and as neutron moderators.

Three factors contribute to making neutron scattering useful for detecting APM. (a) The hydrogen content in plastic APM is relatively high. The fraction of hydrogen atoms in typical plastics and explosives is between 55–65% and 25–35%, respectively. (b) For $E_n < 3$ MeV, the total neutron cross-section for interaction with proton is significantly higher than that of other nuclides commonly found in the soil or in metal debris. (c) n–p elastic scattering is the dominant process in the interaction of neutrons with protons at these energies ($E_n < 3$ MeV). The n–p elastic scattering has two unique features: the average energy loss per scattering by the neutron is large (50%), which makes hydrogen a good neutron energy moderator; and the angle of scattering of the neutron (in the laboratory frame) cannot exceed 90° (Brooks et al., 2004a, 2004b).

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It must be mentioned, by detecting the prompt photons, that thermal neutron capture reactions can be used for the detection of landmines. Neutron systems using the detection of gamma-rays and systems using the detection of slowing down neutrons have been described in Pesente et al. (2001) and Brooks et al. (2004a, 2004b). The effects of soil moisture on 14N(n, γ) reaction have been verified by Hsoa-Hua et al. (1999) and Pazirandeh (2006).

In the radiative neutron capture method, the neutron source must emit more than 10^7 neutrons/s. On the other hand, it a longer time might be needed (few minutes) to measure gamma-ray, and good sensitivity has been obtained only for explosive quantities in the kilogram range, which corresponds to Anti Tank mines. Furthermore, the devices constructed using these methods are bulky.

On the contrary, there are some advantages in using the neutron backscattering technique, i.e. detecting slowdown neutrons. This method is based on the fact that the number of low-energy backscattered neutron depends mainly on hydrogen in all common explosive materials. The probability of emission of backscattered neutrons is several orders of magnitude larger compared to that of the emission of specific gamma-rays. This leads to the possibility of having a large counting rate also using low-activity neuron sources (i.e. 10^6–10^5 neutrons/s). The resulting counting rate is high enough to allow the usage of neutron backscattering technique sensors directly as scanning devices (McFee and Anthony, 2003).

Other researchers have used eight neutron detectors that make the detection setup very bulky (Bom et al., 2004), whereas we have used an Am–Be neutron source and only one BF_3 detector. In previous work, we have reported the experimental results (Rezaei Ochbelagh et al., 2007). In this work, we have shown Monte Carlo simulation and calculation results for selection of BF_3 detector and Am–Be neutron source shielding. In addition, we have experimentally investigated the effect of soil moisture on landmine detection.

2. Monte Carlo simulation

The simulation was based on the following assumption: A sample of trinitrotoluene (TNT, $C_7H_5N_3O_6$) with a density of 1.8 g/cm^3 and a dimension of 10^3 cm^3 ($10 \times 10 \times 10$) is buried in a box of dry soil that has a surface of 60×100 cm^2 and a height of 40 cm with 1.610 g/cm^3 density (Fig. 1). The soil generally contains 10 elements (Shue et al., 1998) (Table 1). We have experimentally determined the mass percent of elements by nitrogen, carbon, hydrogen, sulfur combustion analyzer (NCHS) and atomic absorption (AA) spectrometer methods.

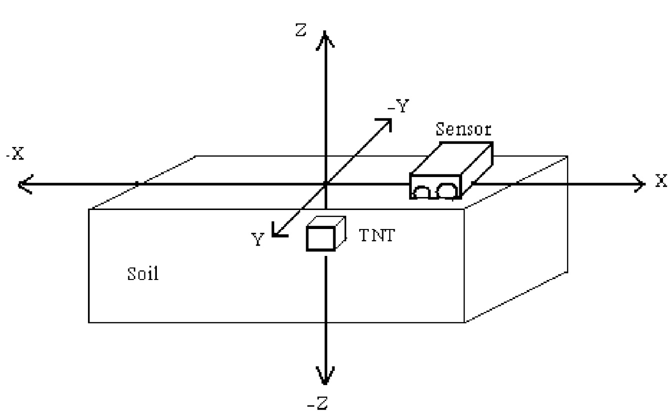

Fig. 1. Schematic diagram of Monte Carlo simulation.

Table 1
Chemical composition of the soil.

Element	Mass (%)
H	3.760
C	5.936
O	44.144
Si	34.560
Al	0.940
Fe	2.381
Ca	4.494
K	0.083
Na	0.075
Mg	3.627

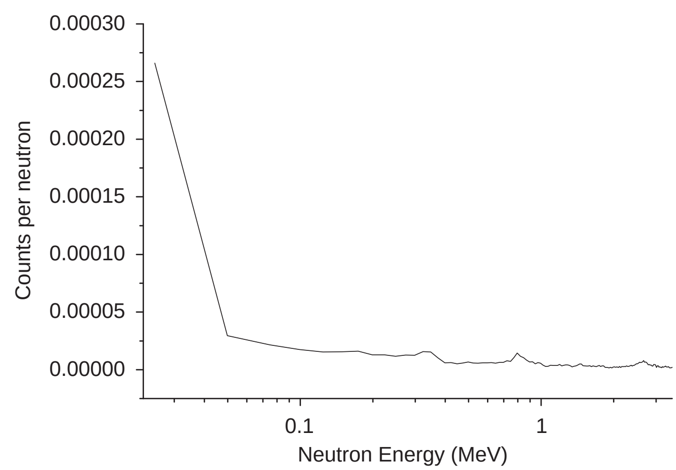

Fig. 2. Backscattered neutron flux as a function of the neutron energy. The TNT is buried 3 cm under the soil and the detector was without a shield.

The Am–Be neutron source (4.5 cm diameter and 20 cm height) was placed 3 cm from the soil surface. The Monte Carlo N-Particle (MCNP) input file has been adjusted so that an Am–Be neutron source emits neutrons only in the minus *Z* direction. These neutrons are backscattered after interaction with soil and landmine. As seen in Fig. 1, the BF_3 detector, which has a diameter of 2.54 cm and a height of 28 cm , placed next to the Am–Be source possesses the same *y*-axis direction, normal to the paper, to show neutron flux. Backscattered neutron flux, as a function of energy, has been obtained by using the Monte Carlo N-Particle transport code (Briesmeister, 2000) and is indicated in Fig. 2. These results have been acquired without a detector shield. As seen in Fig. 2, most of the backscattered neutrons are situated between the thermal and the epithermal region.

A parameter named signal-to-noise ratio is the relative excess counts, signal-to-noise ratio $= (N - N_0)/N_0 \times 100$, measured with and without TNT sample. N and N_0 are the neutron counts with and without the TNT sample in soil, respectively. Neutron inactions have been traced by the MCNP code and iterated for five million particles. As shown in Fig. 3b, when the detector has no shield, there is a little increase in signal-to-noise ratio above the TNT sample.

3. Shield description

According to accomplished investigations, the presence of ^{10}B in borated complexes is a suitable absorber and ^{1}H in hydrogenous material is a suitable moderator (Coeck et al., 2002; Hong et al., 2000). We investigated four moderators by using the MCNP