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Investigations on landmine detection by BF_3 detector

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Abstract Experiments were carried out to investigate the possible use of neutron backscattering for the detection of polyethylene (PE) sample buried in the soil. In detection of landmine by neutrons, the neutron detector and its shield play an important role. In this paper, the effects of graphite, heavy water, polyethylene and boric acid moderators on the flux of back scattered neutrons were investigated. We have also experimentally verified the effect of BF_3 detector shield and obtained good agreement with theory.

Key words Landmine, Am-Be neutron source, Neutron backscattering, Moderator, Heavy water, BF_3 detector

CLC numbers TL816$^+$.3, TJ51$^+$2

1 Introduction

Numerous anti-personal mines (APM) developed after World War II are less than 300g and contain very little metal. Consequently, it is difficult to detect them with metal detectors[1]. As estimated, over 60 million landmines have been buried in many countries[2]. 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[3]. Many hundred thousands of landmines left buried in the western part of Iran by the end of the eight-year war (1980–1988) with Iraq, resulted in many people, children in particular, to lose their lives or become disable[4].

The International Atomic Energy Agency (IAEA) has encouraged research groups to develop nuclear methods for detecting landmines. These methods have been supported by participants from universities and research institutions in 18 countries. 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[3,5,6]. In this work, we have investigated neutron energy moderation method for landmine detection.

Three factors contribute to making neutron scattering useful for detecting APM: a) Hydrogen content in plastic APM is relatively high. The fraction of hydrogen atoms in typical plastics and explosives are between 55%–65% and 25%–35%, respectively. b) For E_n<3 MeV, the total neutron cross section for the 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 neutron- proton interactions 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 neutrons (in the laboratory frame) cannot exceed 90° [7].

Obviously, a landmine detector has to be nondestructive and portable. And it should be simple to operate, and inexpensive.

Other researchers have used 2 or 8 neutron detectors which make the detection set-up very bulky[8]. In this work, we have used an Am-Be neutron source and only one BF_3 detector.

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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 cm×10 cm ×10 cm) is buried in a volume of dry soil of 60 cm(l)×40 cm(h)×100 cm(w) with 1.610 g•cm^{-3} density. The soil generally contains 10 elements[9] (Table 1). We have experimentally determined mass percent of elements by NCHS (Nitrogen, Carbon, Hydrogen, Sulphur combustion analyzer) and AA (Atomic Absorption spectrometer) methods and the soil moisture was 6.34 mg•g^{-1}.

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

The Am-Be neutron source of ϕ4.5 cm×20 cm was placed 1.5 cm from the soil surface. Only fast neutrons emitted in Z direction interact with soil and landmine. As seen in Fig.1, BF_3 detector, ϕ2.54 cm ×28 cm, placed next to the Am-Be source possesses the same Y-axis direction, normal to paper, to show neutron flux. Backscattered neutron flux as a function of energy was obtained by using Monte Carlo N-Particle transport code (MCNP) [10]. As seen in Fig. 2, most neutrons backscattered lie between thermal and epithermal region.

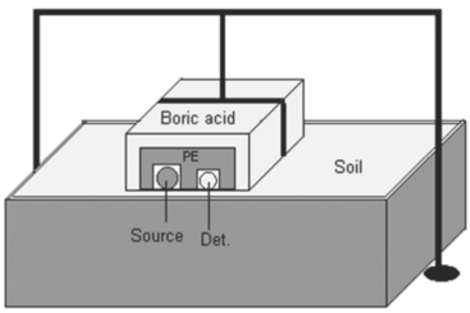

Fig.1 Schematic diagram of Monte Carlo simulation.

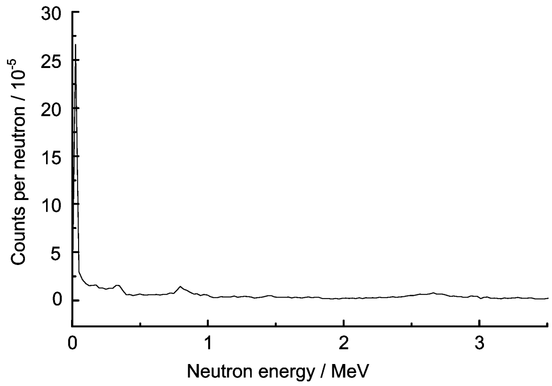

Fig.2 Backscattered neutron flux as a function of the neutron energy. The TNT is buried 3 cm under the soil.

We use the relative counts as the parameter of signal-to-noise. Signal-to-noise ratio=$[(N-N_0)/N_0]\times100$, where N and N_0 are the neutron counts with and without TNT sample in ground respectively. As shown in Fig.3-b, when the detector has no shield, the signal-to-noise ratio increase a little above the TNT sample.

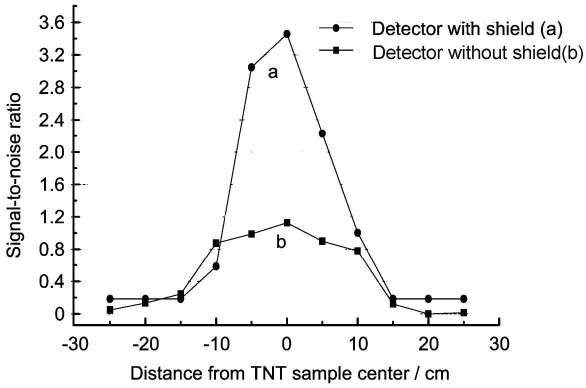

Fig.3 Signal-to-noise ratio as a function of distance from center of buried TNT sample. a)Detector with two layers shields, boric acid thickness=4cm (outer layer) and PE thickness=10cm (internal layer). b)Detector without shield (MCNP code results).

3 Shield description

3.1 Moderator selection

According to accomplished investigations, ^{10}B in borated complexes is suitable absorber and ^{1}H in hydrogenous material is suitable moderators[11,12]. We investigated four moderators by using MCNP code. For this purpose, as shown in Fig.1, moderators covered the detector each turn and the calculation was performed by MCNP code.

Fig.4 shows the results of MCNP calculation on moderators of polyethylene (PE), heavy water and graphite. About 10 cm PE in a density of 0.92 g•cm^{-3} (Fig.4-a) is sufficient as the shield of BF_3 detector. On the other hand, heavy water (Fig.4-b), with its maximum value of neutron flux at 25cm thickness, can hardly be used as landmine detector shield, while graphite with a density of 1.6 g•cm^{-3} (Fig.4-c), with its maximum neutron count at 30 cm, is not suitable for detector shield because of its great mass and volume.

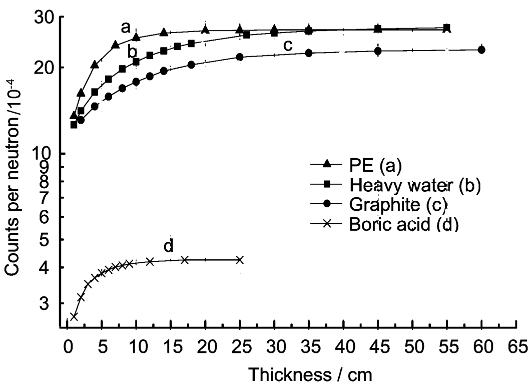

Fig.4 Neutron population as a function of the moderator thicknesses.
a) PE, b) Heavy water, c) Graphite, d) Boric acid.

Because of $^9Be(n,2n)2\alpha$ reaction[13] it was understood that 10cm of beryllium is enough to increase neutron flux, but due to some problems such as being strategic, poisonous, and expensive, we cannot apply it in the landmine detector.

By using 10 cm thickness of graphite, heavy water, beryllium, and PE, we have obtained fluxes of 0.00178, 0.00209, 0.00283, 0.00253 counts per neutron respectively. By considering these numbers and previous notations, PE is the suitable moderator. Therefore, we chose 10 cm PE as the first layer shield around the detector.

3.2 Neutron absorption layer

In order to prevent backscattered neutron entrance, a neutron absorber must be used around the detector except its bottom. As we know, ^{10}B is a suitable neutron absorber, so we must use a material with boron in its structure. Acid boric has hydrogen and natural boron, which contents 19.8% of ^{10}B and 80.02% of ^{11}B. Due to presence of hydrogen and ^{10}B, boric acid can play an important role on the detector shield. Therefore, it can be applied as neutron absorber in the second layer of detector shield. Like previous examples, neutron flux in the detector has been calculated by MCNP code. The calculation results are given in Fig.4-d. About 9cm thickness of boric acid is sufficient as a detector shield. If an incident neutron strikes the hydrogen, it will be scattered and more probably detected by the detector. But if it hits ^{10}B, it will be absorbed.

4 Effect of polyethylene and boric acid layers

PE as a moderator and boric acid as an absorber must be used in the first and second layers around the detector respectively. In order to determine the layer's effects on neutron flux, we assumed the thickness of PE (first layer) as 1, 2, 3 …10 cm, respectively, and investigated effects of boric acid thickness (second layer) by MCNP code. The results are shown in Fig.5. The neutron flux is saturated when PE and boric acid thicknesses are about 10 cm and 4 cm respectively. As seen in Fig.1, a landmine detector with two layers of shields has scanned the soil surface where the landmine is buried. Calculation results are shown in Fig.3-a.

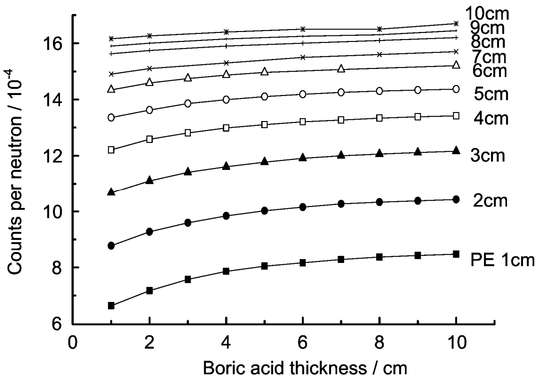

Fig.5 Neutron flux as a function of boric acid thickness (second layer) for different thicknesses of PE (first layer).

Comparing Fig.3-a (detector with shield) and Fig.3-b (detector without shield), one knows that the detector shield is good for landmine detection. The shield causes a maximum rate of backscattered neutron flux above the landmine 2.5 times more than the non-shielded case.

5 Experimental procedure

The set-up contains a control panel, an electrical wagon, an Am-Be neutron source and one shielded BF_3 detector of ϕ2.54 cm × 28 cm. The neutron source, which emits 10^7 neutrons per second, is placed in an aluminum cylinder of ϕ4.5 cm × 20 cm. It has also two layers of shields: the first layer of PE with a density of 0.92 g•cm^{-3} and 3 cm thickness and the second layer of boric acid with a density of 1.52 g•cm^{-3} and 4 cm thickness. Due to the increase of detector's dead time, we could not afford to apply thicknesses more than these.

The electrical wagon is moved by order of the control panel to transfer the detector and neutron source assembly along the soil box. The control panel is located 8 m from the set-up in order to reduce the dose received by the user. Neutrons are counted at 2 cm apart from soil surface by BF_3 detector for 100 s at each point.

We tested the set-up with and without shield around the source and detector. The shielded system showed more neutron counts than the non-shielded one. Therefore, it causes anomaly on backscattered neutron flux. We have calculated signal-to-noise ratio by using experimental neutron counts in each step, which is shown in Fig.6. The signal-to-noise ratio is 170% with shield but 40% without shield.

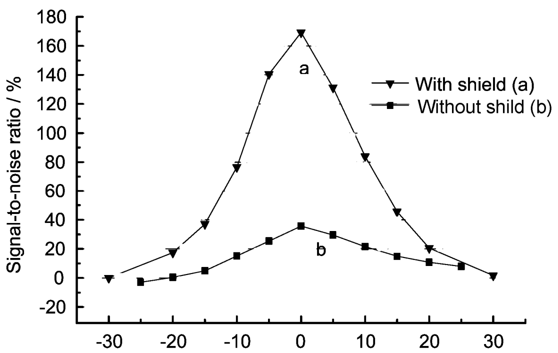

Fig.6 Variation of signal-to- noise ratio with detector's distance from landmine center.

Effects of other parameters such as soil moisture, depth, distance from soil surface and landmine weight on the detection result will be reported in next paper.

6 Discussion and conclusions

There are three reasons for using Am-Be neutron source in this work:

1) Am-Be neutron source is cheaper than ^{252}Cf and other neutron sources. In addition, it has not been experimentally used to detect landmine by other authors.

2) If we want to apply neutron and γ ray to detect landmine at the same time, the Am-Be source is a suitable selection for this purpose.

3) In view of our laboratory's possibilities, use of Am-Be neutron source in this work to detect buried landmines is considered to be reasonable.

Detector shield plays an important role on landmine detection based on nuclear analysis. It is a point that is not seen in others' works. It is better for this shield to be designed including two layers, the first layer for slowing down and scattering neutrons and the second one for absorbing the backscattered neutrons. According to the investigations and MCNP calculations, 10 cm thick polyethylene and 4 cm thick boric acid have been adopted as the first and second layer respectively. With the two shielding layers, incident neutron flux on detector (area under the curve of Fig.3) has been amplified about 2.5 times. Experimental results are given in Fig. 6. The theoretical and experimental results are in good agreement. Therefore, we can use Am-Be source and only one BF_3 detector to detect landmine.

References

1 Fioretto E, Barbui M, Giangrandi S, *et al*. Nucl Instr Meth Phys Res, 2004, **B213**: 457-459.
2 Király B T, Sanami R D, Csikai J. Nucl Instr Meth Phys Res, 2004, **B213**: 452-456.
3 Brooks F D. Drosg M, Buffler A, *et al*. Applied Radiation and Isotopes, 2004, **61**: 27-34.
4 Pazirandeh A, Maryam A, Masoudi S F. Applied Radiation and Isotopes, 2006, **64**: 1-6.
5 Hussein E M A, Desrosiers M, Waller E J. Radiation Physics and Chemistry, 2005, **73**: 7-19.
6 Datema C P, Bom V R, van Eijk C W E. Nucl Instr Meth Phys Res, 2002, **A 488**: 441-450.
7 Brooks F D A, Buffler A, Allie M S. Radiation Physics and Chemistry, 2004, **71**: 749-757.
8 Bom V R, Datema C P, van Eijk C W E. Applied Radiation

and Isotopes, 2004, **61**: 21-25.

9 Shue S L, Faw R E, Shulis J K. Chemical Geology, 1998, **144**: 47-61.

10 Briesmeister J F. MCNP: A general Monte Carlo N-particle transport code, Version 4C, Los Alamos National Laboratory, LA-13709-M, 2000.

11 Coeck M, Vermeersch F, Vanhavere F. Nucl Instr Meth Phys Res, 2002, **A476**: 273-276.

12 Hong J, Craig W W, Hailey C J. Nucl Instr Meth Phys Res, 2000, **A452**: 192-204.

13 JEF-PC Software, Version 2.0, OECD Nuclear Energy Agency, 1998.