Nuclear Instruments and Methods in Physics Research A 652 (2011) 1–4

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Investigations of shield effect and type of soil on landmine detection

Nassreldeen Elsheikh [a,*], Farouk Habbani [b], Ibrahim ElAgib [a,c]

[a] *College of Applied & Industrial Science, Department of Physics, University of Juba, Khartoum, P.O. Box 12327/1, Sudan*
[b] *Faculty of Science, Physics Department, University of Khartoum, Khartoum, P.O. Box 321, Sudan*
[c] *College of Science, King Saud University, P.O. Box 2455, Saudi Arabia*

ARTICLE INFO

Available online 20 May 2011

Keywords:
Landmine detection
Shield effect
Soil type

ABSTRACT

This paper investigates the possibility of optimizing the performance of the neutron backscattering method in landmine detection by designing a suitable shield around a ^{252}Cf neutron source to reduce the background due to soil and the neutrons emitted from the source that hit the detector directly. A series of Monte Carlo simulations were performed to improve the source shield thickness and to study the elastically backscattered (EBS) ^{252}Cf neutrons from the buried explosive material TNT in the soil; the optimal configuration was examined against different soil types and source heights. The results obtained in terms of performance of the relative (EBS) neutrons confirmed that the proposed source shield has significantly improved the signal to background ratio. Higher signal-to-background ratio was observed using ^{252}Cf neutron source as compared to Pu–Be source.

1. Introduction

Landmines present physical and psychological threats to communities: they inhibit agricultural production, food security, economic activity and freedom of movement. Therefore it is highly significant to review the techniques available in use for landmine detection and propose the most simple and straightforward method. The most common explosives used in landmines are TNT (C7H5N3O6) and RDX (C3H6N6O6). The anti-personnel landmines are usually designed in the form of a disk or a cylinder, with diameters from 20 to 125 mm, lengths from 50 to 100 mm, mass as little as 30 g and are usually shallow-buried [1]. Several landmine detection methods, based on nuclear techniques, have been suggested in recent years, including neutron energy moderation, neutron-induced gamma emission, neutron and gamma attenuation, and slow and fast neutron backscattering [1–6]. Neutron backscattering technique has successfully been applied to the detection of non-metallic landmines buried in relatively dry sandy soil. Fast neutrons from a radio-isotopic source are moderated and backscattered more by the buried landmines than the surrounding soil [2]. The number of slow neutrons that are reflected from the soil is a direct indication of the amount of hydrogen. In most cases, the amount of hydrogen in a plastic landmine is much higher than that of the surrounding soil. Therefore, if an appropriate neutron detector in combination with a neutron source is used to scan across the soil, the presence of a landmine will be indicated by an increase in the count rate. Also, the elastic scattering cross-sections have been shown to be much higher than the inelastic, or radiative capture ones [5]. Consequently, in order to use a source of modest strength in a radiologically acceptable portable device, it is sensible to devise a detection system that relies on elastic scattering of neutrons. A landmine can be detected only if the net signal due to the hidden explosive is significantly higher with respect to the background due to the soil and the neutrons emitted from the source that hit the detector directly [7]. Therefore, in order to optimize the final performance of the EBS neutrons method and consequently improve the population of neutrons contributing to landmine detection, the background needs to be effectively minimized by the proper selection of a source–sample–detector geometry and an effective shield around a suitable neutron source. The present work investigates such a possibility. The possibility of using polyethylene (PE) and borated complexes as shielding materials was investigated [8]. The investigations confirmed that the presence of ^{10}B in borated complexes makes them suitable absorbers of thermal neutrons and the presence of ^{1}H in hydrogenous materials such as PE makes them suitable moderators. Such a system for neutron source shield will increase signal-to-background ratio and thus facilitate the landmine detection process. On the basis of such considerations, Monte Carlo simulations were carried out to investigate the feasibility of using a neutron shield consisting of two layers: high density polyethylene (PE) and 5% borated polyethylene (BPE) as the first and second layer, respectively. The results were obtained in terms of variations in the signal-to-background ratio (S/B) due to changes in soil type, source position and type of source. The signal-to-background

---

[*] Corresponding author. Tel.: +24 9906082101; fax: +249 9183222142.
E-mail address: nassreldeen.elsheikh@yahoo.com (N. Elsheikh).

0168-9002/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.09.183

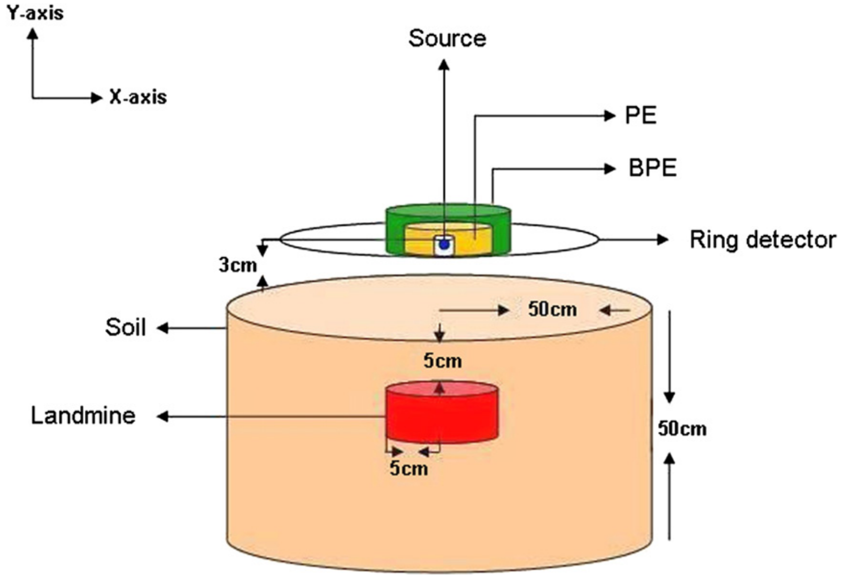

Fig. 1. Geometry as modeled in the MCNP simulations.

Table 1
Composition of each soil type, TNT explosive, PE and BPE as modeled in MCNP simulation, rounded off.

Material/density (g/cm^3)	Weight fractions											
	H	B	C	N	O	Si	Al	Fe	Ca	K	Na	Mg
Dry porous 1.1810	**0.015**				**0.529**	**0.243**	**0.071**	**0.044**	**0.032**	**0.023**	**0.025**	**0.018**
Dry dense 1.7714	**0.015**				**0.529**	**0.243**	**0.071**	**0.044**	**0.032**	**0.023**	**0.025**	**0.018**
Wet porous 1.3957	**0.030**				**0.585**	**0.205**	**0.060**	**0.037**	**0.027**	**0.019**	**0.021**	**0.015**
Wet dense 2.0935	**0.030**				**0.585**	**0.205**	**0.060**	**0.037**	**0.027**	**0.019**	**0.021**	**0.015**
TNT 1.8	**0.022**		**0.370**	**0.185**	**0.423**							
Polyethylene 0.955	**0.143**		**0.857**									
Borated polyethylene 0.95	**0.116**	**0.05**	**0.612**		**0.222**							

ratio was determined as: $S/B=[(I-I_o)/I_o]\times 100$ where I and I_o are the neutron counts with and without TNT sample in soil, respectively.

2. MCNP modeling

2.1. Geometry

Monte Carlo radiation transport code MCNP, version 5C [9], and Evaluated Nuclear Data File B-VI (ENDF/B-VI) continuous energy neutron cross-section data library were employed to perform the present computations. In order to demonstrate the validity of the proposed concepts, Monte Carlo simulations were performed to optimize the shield thickness and examine the perturbation of the signal-to-background ratio in the presence and the absence of the shield. In addition, the dependence of the EBS neutrons on soil type, source position and type of source were simulated. The sample–source–detector geometry used in the present study is shown in Fig. 1. The model consists of a cylinder of dimensions $5\times 5\ \text{cm}^2$, representing an explosive material in the form of TNT buried 5 cm deep in a soil bed in the form of a cylinder of dimensions $50\times 50\ \text{cm}^2$. The shield consists of three cylinders centered on the y-axis. The first is a cylinder of 2.5 cm height and radius varying from 2 to 5 cm, representing the first layer of the shield in the form of a high density polyethylene (PE) with density 0.955 g/cm^3, taken from Ref. [10]. The second layer is represented by a cylinder of 5 cm height and a fixed radius of 2.5 cm in the form of 5% borated polyethylene (BPE) with density 0.95 g/cm^3. The third layer is a cylinder of dimensions $1\times 1\ \text{cm}^2$, representing the source cavity. A point isotopic neutron source is assumed to be inside the source cavity and located at 3, 5 and 10 cm centrally above the soil surface. The measured and normalized neutron spectra of ^{252}Cf and Pu–Be neutron sources used in the study were taken from Ref. [11]. The compositions of soil type, TNT explosive, PE and BPE as modeled in the MCNP simulations are given in Table 1, with the data taken from Refs. [5,12,13]. A ring detector was assumed to be located around the source shield, at different radii: 8, 10, 15, 20, 25 and 30 cm along the x-axis away from the source shield.

2.2. Calculation procedure

The shield thickness was optimized by calculating the neutron counts due to background from soil (without sample) while increasing the shield radius until the optimum condition (shield thickness corresponding to minimum background) was achieved. The optimal configuration was chosen to record the EBS fast and thermal ^{252}Cf neutrons from the constituent elements of the explosive material. The EBS neutrons can be detected by a suitable detector capable of differentiating the EBS neutrons according to their energy and their flux.

3. Results and discussion

As shown in Fig. 2, the neutron counts due to background from source neutrons decrease as the shield radii increase. Minimum background is achieved when the shield thickness is 7.5 cm, i.e. 5 cm PE+2.5 cm BPE.

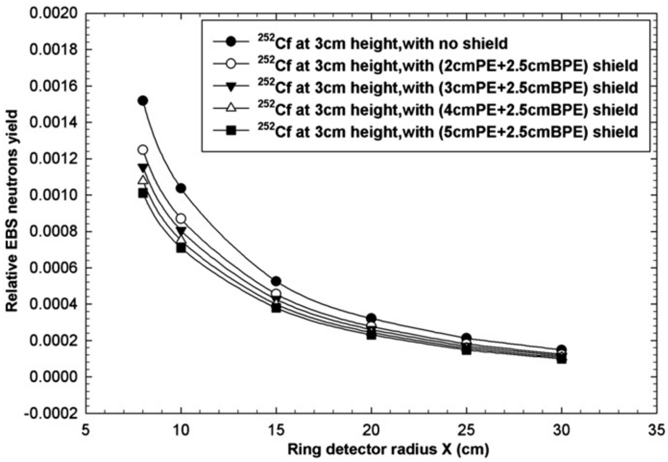

Fig. 2. Relative (EBS) neutrons yield of ^{252}Cf from dry porous soil (without landmine) with and without shield.

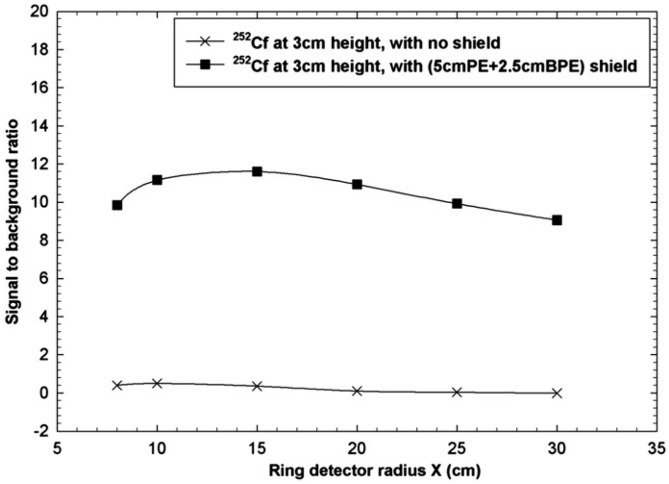

Fig. 3. Signal-to-background ratio for ^{252}Cf when landmine is buried in dry porous soil, with and without shield.

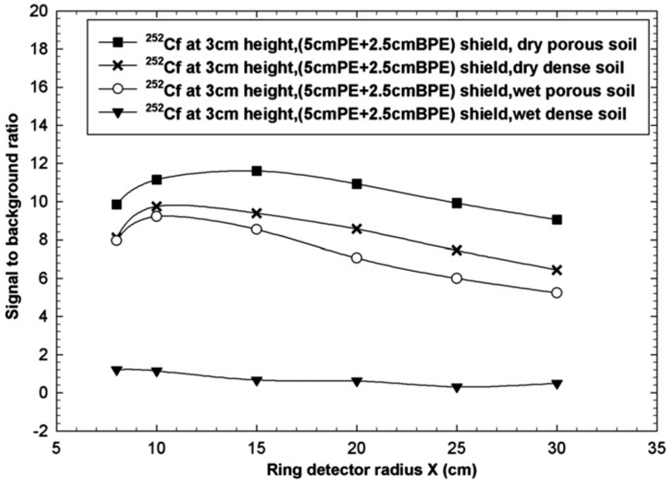

Fig. 4. Signal-to-background ratio for ^{252}Cf when landmine is buried in different soil types.

Fig. 3 shows the signal-to-background ratio of the EBS ^{252}Cf neutrons from landmine, with and without shield. The maximum signal-to-background ratio is 11.6 with shield and 0.4 without shield. The detection of landmine will significantly improve if the proposed source shield is used.

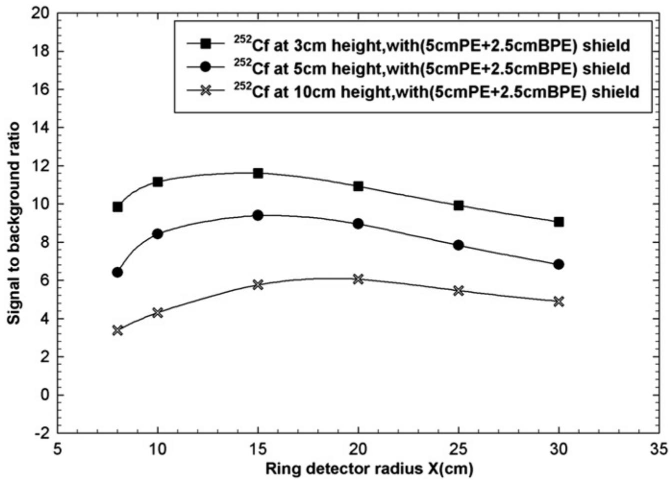

Fig. 5. Signal-to-background ratio for ^{252}Cf at different heights when landmine is buried in dry porous soil.

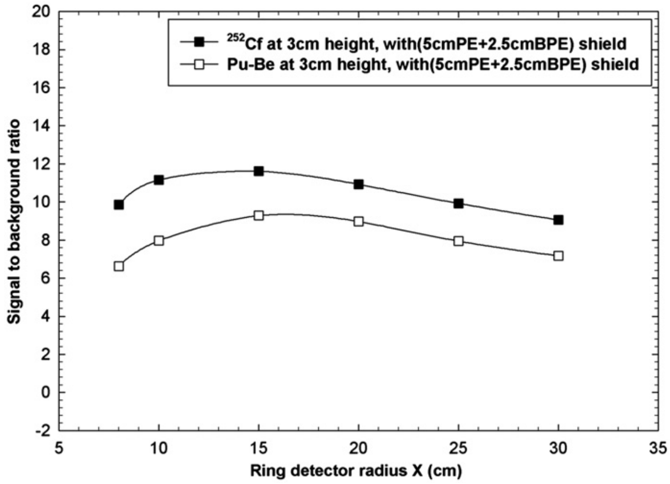

Fig. 6. Signal-to-background ratio for ^{252}Cf as compared to that of Pu–Be when landmine is buried in dry porous soil.

Fig. 4 shows signal-to-background ratio for the optimum shield in the cases of dry porous soil (11.6), dry dense soil (9.4), wet porous soil (8.5) and wet dense soil (0.7). The signal-to-background ratio decreases as soil density or soil moisture increases. The reduction of signal-to-noise ratio in damp soils could be attributed to the increase of hydrogen in the soil due to water saturation. This result confirms that neutron backscattering is suitable for detection of explosives buried in desert areas.

Fig. 5 shows the signal-to-background ratio for ^{252}Cf source when located at different heights. The signal-to-background ratio clearly decreases as the source height above the soil is increased, with optimum height of 3 cm.

In Fig. 6 the signal-to-background ratio is higher in the case of ^{252}Cf source as compared to Pu–Be source, this being probably due to the fact that the average energy of ^{252}Cf of about 2 MeV is much lower than the average energy of Pu–Be of about 5 MeV, leading to lower background of EBS neutrons from the soil in case of ^{252}Cf.

4. Conclusion

A suitable source–sample–detector geometry with an effective shield was investigated. The optimal shield thickness was found to be 7.5 cm, consisting of 5 cm PE+2.5 cm BPE. The results obtained demonstrate that the proposed optimal shield has significantly reduced the background and increased the signal-to-background ratio. The results showed that the neutron backscattering method is sensitive to shield configuration, soil type, source type and source height. The best results were observed with ^{252}Cf source at 3 cm above the soil when the landmine is buried in dry porous soils. The study confirmed the superiority of ^{252}Cf as compared to Pu–Be source when utilized for landmine detection.

Acknowledgments

The authors are grateful to King Saud University for partial financial support of this work under project Phys (no. 2005/35) and the University of Juba for hosting this work.

References

[1] E.M.A. Hussein, E.J. Waller, Appl. Radiat. Isot. 53 (2000) 557.
[2] Cor P. Datema, et al., IEEE Trans. Nucl. Sci. NS-48 (4) (2001).
[3] J. Csikai, R. Doczi, B. Kiraly, Appl. Radiat. Isot. 61 (2004) 11.
[4] F.D. Brooks, A. Buffer, M.S. Allie, Radiat. Phys. Chem. 71 (2004) 749.
[5] E.M.A. Hussein., M. Desrosiers, E.J. Waller, Radiat. Phys. Chem. 73 (2005) 7.
[6] M. Lunardon, G. Nebbia, S. Pesente, G. Viesti, M. Barbui, M. Cinausero, G. D'Erasmo, M. Palomba, A. Pantaleo, V. Filippini, Appl. Radiat. Isot. 61 (2004) 43.
[7] G. Viesti, M. Lunardon, G. Nebbia, M. Barbui, M. Cinausero, G. D'Erasmo, M. Palomba, A. Pantaleo, J. Obhođaš, V. Valkovic, Appl. Radiat. Isot. 64 (2006) 706.
[8] D. Rezaei Ochbelagh, H. Miri Hakimabad, R.Izadi Najafabadi, Nucl. Instr. and Meth. A 577 (2007) 756.
[9] X-5 Monte Carlo Team. MCNP—a general Monte Carlo N-particle transport code, version 5, vol. I: Overview and theory, LA-UR-03-1987, Los Alamos National Laboratory, Los Alamos, NM, 2003.
[10] R.M. Tennent, Science Data Book, Oliver & Boyd, 1971.
[11] R.V. Griffith, J. Palfalvi, U. Madhvanath, IAEA Technical Report Ser. No. 318, IAEA, Vienna, 1990.
[12] S.L. Shue, R.E. Faw, J.k. Shulis, Chem. Geol. 144 (1998) 47.
[13] C.R. Wuest. Lawrence Livermore National Laboratory, 1992.