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Using of Boron Waste as a Shielding Material on Landmine Detection with NBS Imaging Technique

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Boron wastes are produced as a result of production route of boron products and these wastes still contain a small amount of boron. In order to understand the possible use of boron waste in non-metallic landmine detection as a shielding, Monte Carlo simulations were applied by neutron backscattering imaging technique using two different neutron sources of ^{252}Cf and deuterium–deuterium (D–D) reaction. NBS imaging detector system consists of a group of thermal neutron ^{3}He detectors. To investigate the performance of the landmine detection system, a suitable shield around the neutron source was designed and this system was tested for localisation of buried landmine.

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1. Introduction

Several landmine detection methods have been proposed to detection of non-metallic anti-personnel landmines and the application of a neutron backscattering (NBS) method is one of the fastest ways of them [1–5]. This method is based on the measurement of high energy neutrons moderated due to the hydrogen content of explosive and plastic case of the landmine. In this way, a landmine of buried in the irradiated soil can be determined by counting of low energy backscattered neutrons depending on the hydrogen content of the soil [6, 7]. NBS based systems can be used to scan an area where the landmine was buried, because of the advantage of high-speed of NBS method when a sufficiently strong neutron source is used [8].

Use of the shield around the neutron sources is reduced to background noises via absorption of backscattered neutrons from soil and increased the number of thermal neutrons which contributes to landmine detection [9]. Therefore, landmine detection systems must be properly shielded and optimized. In neutron shielding materials, boron is an important chemical element because of the high cross-section for capturing thermal neutrons. Turkey is the second largest producer of boron after the United States in the world. Large amounts of boron oxide (B_2O_3) containing wastes are come into being during its extraction process [10]. Because of its chemical composition, boron waste can be considered as a suitable shield material.

In this study, the possible use of boron waste material known as clay pulp, due to the presence of clay minerals in addition to boron oxide, was investigated as a shielding material in NBS imaging system and the detection system was tested by the Monte Carlo method.

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2. Monte Carlo simulations

2.1. Geometry of the simulation model

The sample–source–detector geometry used in the simulations is shown in Fig. 1. A cylindrical landmine (TNT, 1.68 g/cm^3), 3.5 cm in radius and 2 cm in height, was buried 3 cm deep in soil in a container ($200 \times 300 \times 50$ cm^3).

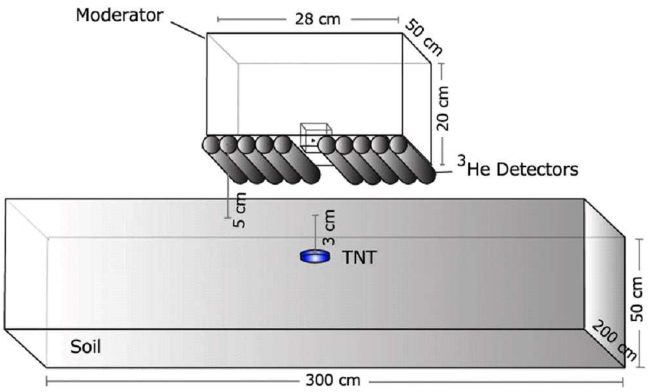

Fig. 1. Schematic diagram of simulation geometry.

Simulations have been performed using Monte Carlo particle transport code (MCNP) version 4C2 [11]. For the cross-sections interested ENDF/B-VI and ENDF/B-VII libraries were utilized. In the simulations, two different neutron sources were used: 10 μg ^{252}Cf (2.306×10^7 n/s) neutron source and D–D mini neutron generator. The neutron energy spectrum for the ^{252}Cf was simulated as a Watt fission spectrum using coefficients provided by the MCNP code. The other source is mono-energetic 2.45 MeV mini neutron generator (10^7 n/s which is radiating isotropically only in the lower half of the solid angle) in a capsule configuration that is 0.4 cm in radius and only 2 cm long [12]. These sources were positioned at

7.5 cm above soil surface. The detector system consists of ten He-3 gas based neutron detectors. All detectors have an effective length of 50 cm, a diameter of 2.54 cm and a gas pressure of 250 Torr. Neutron detectors were arranged in two groups and placed side by side horizontally under moderator block and neutron source (D–D or ^{252}Cf) was replaced in a hole above the center of them.

In this study, 10^6 neutrons were tracked in simulations. This means that landmine detection time was reduced to 0.1 s for D–D neutron generator and 0.04 s for ^{252}Cf neutron source. The density and mass rates related to the elements used in calculations have been listed in Table I. Soil and clay pulp data were taken from Refs. [5] and [13], respectively.

TABLE I

Densities ρ in g/cm^3 and mass rates of the some materials used in the simulations.

material (ρ)	H	B^{10}	B^{11}	C	N	O	Na	Mg	Al	Si	Ar	K	Ca	Fe
clay pulp [13] (2.24)		0.007	0.032			0.388	0.093	0.075	0.066	0.058		0.103	0.089	0.088
TNT (1.68)	0.020			0.370	0.190	0.420								
soil [5] (1.12)	0.015					0.552			0.073	0.364				
air (0.0012)					0.755	0.232					0.013			

2.2. Monte Carlo simulations for shielding design

In the first place, to determine of the optimum moderator/shield thickness a number of Monte Carlo simulations were performed. Neutron fluxes were obtained using the F4 tally in MCNP as a function of moderator thickness (Fig. 2). It was seen that 20 cm of moderator height was sufficient for both neutron sources. Additionally, when the moderator was used in the detection system, the number of neutrons which contributes to landmine detection increased as we expected. Net thermal neutron flux and net neutron flux (0–1 keV) values for without moderator and with moderator (with a height of 20 cm) has been given in Table II. Monte Carlo calculations showed that when the moderator block was installed, the net thermal neutron fluxes for both of source increased as a factor of 4.8 and 1.5, respectively, ^{252}Cf neutron source and D–D neutron generator. According to these results, use of clay pulp as a moderator material seems to be correct.

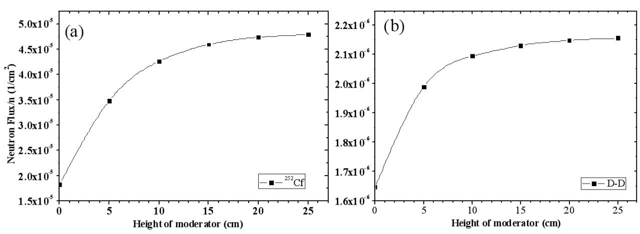

Fig. 2. Backscattered neutron flux on ^{3}He detectors as a function of moderator height (a) ^{252}Cf neutron energy distribution (b) mono-energetic neutrons of 2.45 MeV (D-D neutron generator).

TABLE II

Comparison of neutron fluxes for detection system with (+) and without (–) moderator (sizes are $28\times50\times20$ cm).

source	Net neutron flux [1/cm^2]			
	(+) thermal (–)		(+) total (–)	
^{252}Cf	1.62×10^{-7}	3.39×10^{-8}	2.73×10^{-6}	1.53×10^{-7}
D-D	2.60×10^{-9}	1.76×10^{-9}	1.70×10^{-7}	1.34×10^{-8}

3. Results and discussion

3.1. Performance of the NBS imaging system

Landmine detection with NBS imaging technique is based on the recognition of the contrast between the target and its surroundings. In testing performance of the system, detection system was moved over horizontally above the ground. During this movement, Monte Carlo simulations were made to build an image of thermal neutron flux. The simulation results for two different neutron sources are shown in Fig. 3.

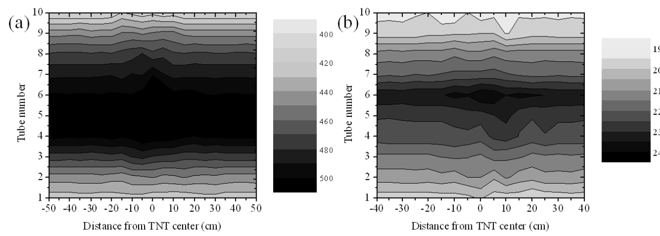

Fig. 3. Backscattered neutron flux image. Simulation results for TNT at a depth of 3 cm. (a) ^{252}Cf source, (b) 2.45 MeV neutron generator.

Furthermore, background which is caused from neutrons by scattering from the soil and hitting the detector without entering the soil was subtracted (Fig. 4). It is clearly seen that anti-personnel landmine can be easily detected if the landmine signal can be distinguished from the background noises.

When the distance from landmine center was increased, landmines were less detected by using D–D neutron generator than ^{252}Cf neutron source. As it can be

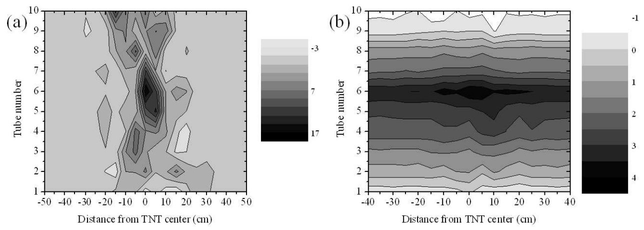

Fig. 4. Backscattered neutron flux image. All backgrounds removed. Simulation results for TNT at a depth of 3 cm. (a) ^{252}Cf source, (b) D-D neutron generator.

seen, signal-noise ratio was higher at the landmine location and this increased the probability of the landmine detection. Although, net neutron fluxes seem to be very small, considering the whole surface area of the detector assembly ($\approx 28 \times 50$ cm^2), this amounts to a total number of $\approx 10^4$ and $\approx 10^5$ net neutrons, respectively, for D–D and ^{252}Cf neutron sources which are very good for a measurement.

4. Conclusion

Use of the neutron boron waste (clay pulp) shielding block of the dimensions of $28\times50\times20$ cm^3 behind the detectors increased the backscattered thermal neutron flux for both neutron source. NBS imaging system which is integrated with this shield can detect landmines when background noise is removed. Landmine detection scan speeds of this system are 1.5 m^2/s for D–D mini neutron generator and 3.8 m^2/s for ^{252}Cf neutron source. These scanning speeds are sufficient to detect non-metallic landmines.

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