Landmine Detection With the Neutron Backscattering Method

Cor P. Datema, Victor R. Bom, and Carel W. E. van Eijk

***Abstract*—Neutron backscattering was selected as a promising new method for the detection of landmines. With this technique, a ^{252}Cf source and a thermal neutron detector are used. Fast neutrons from the Californium source are better moderated by the landmine, especially plastic mines, than in the surrounding soil. This leads to an increase in the number of reflected thermal neutrons above the mine. Results from experimental trials with the Delft University Neutron Backscattering Landmine Detector (DUNBLAD) are presented and compared with results from Monte Carlo simulations. The limitations of this method and the radiation dose for the user are investigated. Based on these results, a new portable prototype detector is presented.**

I. Introduction

IT IS widely recognized that the contamination of the earth with landmines is a huge problem [1]. Many techniques to clear landmines have been suggested [2] and are under development to replace the slow, dangerous, and laborious prodding method that is still most frequently used. The huge variety of landmine types coupled with the range of properties of the terrain in which they are concealed make the landmine problem difficult to solve. The United Nations has compiled a set of guidelines and standing operation procedures (SOPs) for detectors and detection methods [3]. One of the main criteria for any detector used for demining is that the minimum clearance be 200 mm, which is the main challenge of this work.

Several nuclear techniques have been suggested for the detection of landmines and/or explosives, of which some are based on the use of neutrons [4]. A more recent review of nuclear techniques can be found in [5].

Techniques that can give information on the content of the mine are thermal neutron analysis (TNA) [6], [7] and pulsed fast neutron analysis (PFNA), or a combination of the two [8]. Also, information on the content of the mine can be gathered from the energy of neutrons that elastically interact in the hidden explosive, also known as elastically backscattered spectrometry (EBS) [9]. Although some of these methods have shown great potential, due to the long acquiring time per hidden object these techniques have only proven to be useful as a confirmation tool.

Nuclear techniques that are used for the localization of anomalies (landmines) in the soil include X-ray [10], [11], gamma [12] and neutron backscattering imaging. The first two techniques are based on changes of the density in the soil. The main problem with these techniques is to achieve an acceptable penetration depth due to attenuation and multiple scattering.

In contrast, the neutron backscattering method gives mainly information on the amount of hydrogen atoms present in the soil. Since the 1980s, several groups have investigated the neutron backscattering technique for the detection of landmines buried in the soil, but the idea was abolished each time for unknown reasons. More recently, Brooks *et al.* [13] have presented new results based on several detector types with a Californium source and a neutron generator (D-D type). Craig *et al.* [14] have designed a similar device and have introduced the use of timing information to enhance the signal-to-background ratio. Imaging of mine-like targets with backscattered thermal neutrons was successfully shown by Vernier *et al.*using a coded-aperture imaging technique [15]. The Radiation Technology group at Delft University started to investigate the neutron backscattering method for landmine detection when a detector made for the oil industry was used to successfully detect several landmines in a large sandpit [16]. After these initial successes, the neutron backscattering technique was further investigated with both simulations and experimental work, of which the results are presented in this paper.

II. Neutron Backscattering

The working principle of the neutron backscattering method is explained in Fig. 1. A ^{252}Cf source is placed above the soil together with a thermal neutron detector. The amount of detected thermal neutrons that are moderated in the soil and then scattered back in the direction of the detector mainly depends on the hydrogen content of the soil. In almost all cases, the hydrogen concentration in a landmine is higher than that of the surrounding soil. Therefore, if the detector is moved above the landmine, an increase in the detected thermal neutron flux can be observed. Earlier measurements [16] showed that small variations in the distance between the detector and the soil (the standoff distance) significantly influence the count rate. It was therefore decided to use two identical detectors, with a certain distance between them and a source positioned exactly in the middle. In this way, there is always a reference value available if one detector is above the mine and the other is not.

III. Experimental Setup

The first version of the Delft University Neutron Backscattering Landmine Detector (DUNBLAD v1.0) was designed to systematically determine the influence of various system param-

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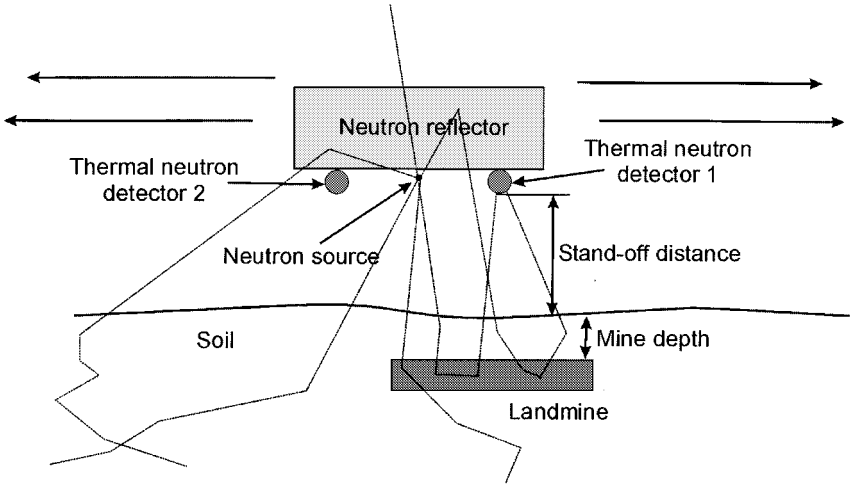


Fig. 1. The working principle of the neutron backscattering landmine detector. The dashed lines show several neutron paths.

eters on its performance. A photograph of the setup is shown in Fig. 2.

A 1.85-MBq (220.000 n/s) Californium source was used for the measurements. It is placed on the end of an aluminum rod, between the two thermal neutron detectors and below a neutron reflector material. Carbon was used as the reflector material and has dimensions of $20 \times 20 \times h$ cm, where h is the height of the reflector.

The neutron detectors are ionization chambers based on ^{3}Helium gas, which is compressed to a pressure of 1 MPa. The two detectors have a compact unit with the associated electronics and high-voltage power supply incorporated. Both devices have an effective length of 15 cm and a diameter of 2.5 cm and are operated at a voltage of 1800 V. The detector unit was moved in one direction on rails that were placed above a sandpit with the dimensions of $5 \times 2 \times 0.5$ m. Both the position of the detector unit and the measurement of the number of counts in the two detectors are remotely controlled by software programmed in Labview (PC-based).

One anti-tank (AT) mine and two antipersonnel (AP) mines were made and filled with melamine powder ($C_3N_6H_6$) with a density of 0.75 g/cm^3. Melamine is a thermosetting plastic that was chosen because it is relative similar to explosive materials like TNT ($C_7H_5N_3O_6$) and RDX ($C_3H_6N_6O_6$). The thickness of the casing was 5 mm. An overview of the dimensions and materials used is given in Table I.

The water content of the sand was determined through the gravimetric method. The sand in the sandpit becomes wetter as the depth increases. At the surface, the water content is 0.2%; at a depth of 10 cm, it is 2%; and at 20 cm, it increases to 4.2% (in percent of weight).

Using the software package GEANT 3.21, the experimental results presented in the next section are compared with the results of Monte Carlo simulations. A model was constructed to optimize the geometry of the neutron backscattering detector. To include neutron interactions down to subthermal energies, GEANT was extended with the neutron simulation package MICAP. The neutron cross-section data for these simulations was obtained from the ENDF/B-V library.

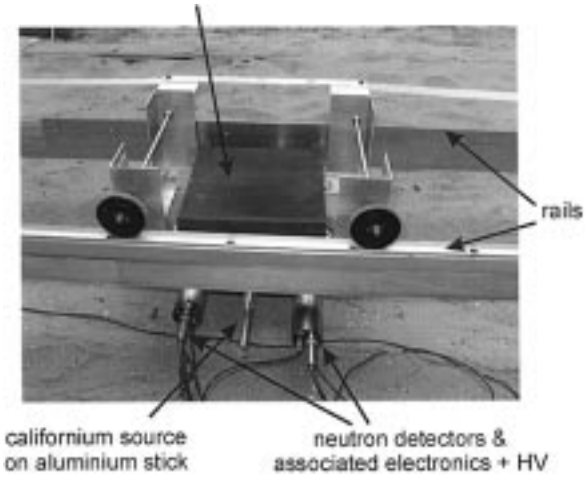


Fig. 2. Photograph of DUNBLAD v1.0.

TABLE I
MAIN PARAMETERS OF THE THREE "DUMMY" LANDMINES USED

Type	Casing material	Total weight	Explosive weight
AT-mine (diameter 20cm)	Nylon (1.14 g/cm^3)	1120 gram	640 gram
AP-mine (1) (diameter: 6cm)	POM/Delrin (1.41 g/cm^3)	125 gram	44 gram
AP-mine (2) (diameter; 6cm)	Aluminium (2.70 g/cm^3)	185 gram	44 gram

IV. EXPERIMENTAL RESULTS

The parameters that were investigated were mine depth, standoff distance, reflector thickness, and the distance between the two detectors. Unless otherwise stated, the values for the setup were mine depth—3 cm, standoff distance—5 cm, reflector thickness—8 cm, distance between the two detectors—16 cm, and mine diameter—20 cm. A scan was made over a distance of 1 m with a step size of 2 cm and a measuring time of 20 s per step. An example of a scan of the 20-cm diameter mine is shown in Fig. 3.

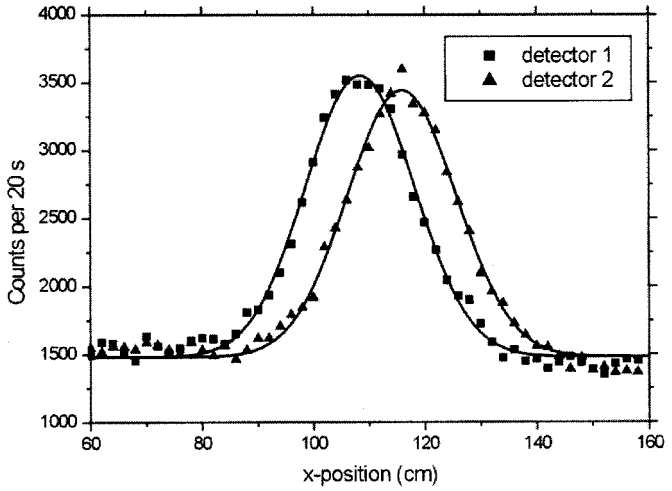


Fig. 3. Scan across the center of the 20-cm diameter landmine buried at a depth of 3 cm and a standoff distance of 2 cm.

Clearly, at a depth of 3 cm, the 20-cm diameter landmine can easily be detected with this setup. All curves that were measured are fitted with a Gaussian profile and the values of position, height, and full-width half-maximum (FWHM) were determined. An important feature of the scans is that the distance between the two peaks is approximately half the distance between the detectors. This is due to the fact that the highest flux is measured when the mine is positioned approximately halfway between the source and the detector. This agrees with the result in the Monte Carlo simulations [17].

A. Standoff Distance

The count rate of the detectors varies significantly as a function of the standoff distance. This is shown in Fig. 4, where the number of counts as a function of standoff distance can be seen. Compared with the results of the simulations, also shown in Fig. 4, the detected number of counts is approximately 30% less when no mine is present and about 50% less with a 20-cm mine 3 cm below the surface of the sand.

An extra measurement at a height of 50 cm was made to compare the experimental response of the detector with the Monte Carlo simulations. At this height, the influence of the sand and mine is negligible and the detected count rate is only due to the geometry of the detector and the detection efficiency of the two ^{3}He-tubes. The experimental count rate at this height (22 c/s) is almost identical to the one observed in the simulations. This means that the sand used in the simulations contains more hydrogen (2%, uniformly distributed) and possibly has a higher density than is the case in the experimental setup. Similarly, the mine that is defined in the simulations probably contains more hydrogen and has a higher density than the mine used in the experiments. The signal-to-background ratio, defined as the number of counts measured above the mine divided by the number of counts from the background, for the experimental data is about 10%–20% worse than the simulated results predict. This difference is mainly due to the effects described above.

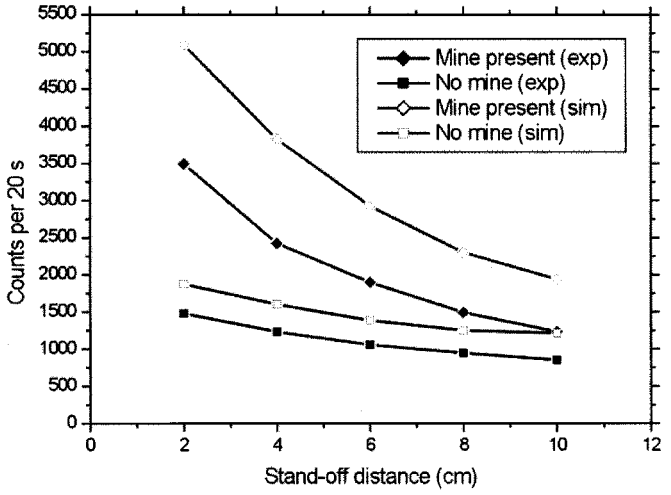


Fig. 4. The experimental and simulated count rate as a function of the standoff distance for the 20-cm-diameter mine (diamonds) and no mine present (squares).

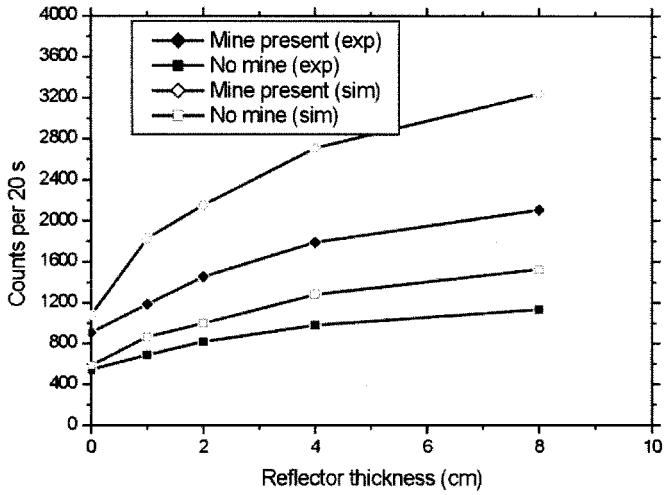


Fig. 5. The experimental and simulated count rate as a function of the reflector thickness for the 20-cm mine (diamonds) and no mine present (squares).

B. Reflector Thickness

The reflector thickness h of the carbon was varied between 0 and 8 cm. The result of this measurement is shown in Fig. 5. The experimental data correspond well to the simulated data, except for the fact that again the count rates in the simulations are 30% and 50% higher for no mine and the mine present, respectively. The restrictions on the weight of the "handheld" detector will probably limit the reflector thickness to 4–5 cm. Again, the signal-to-background is about 10%–20% worse than the simulations indicate.

C. Mine Depth

The mine depth is a critical parameter for the possible application of this method. Scans of both the 20- and 6-cm diameter plastic mine were made at various depths. The results are shown in Figs. 6 and 7.

The 20-cm-diameter mine can easily be detected down to a depth of $\sim$20 cm. The 6-cm-diameter mine produces a signal that is significantly higher than the background for depths down

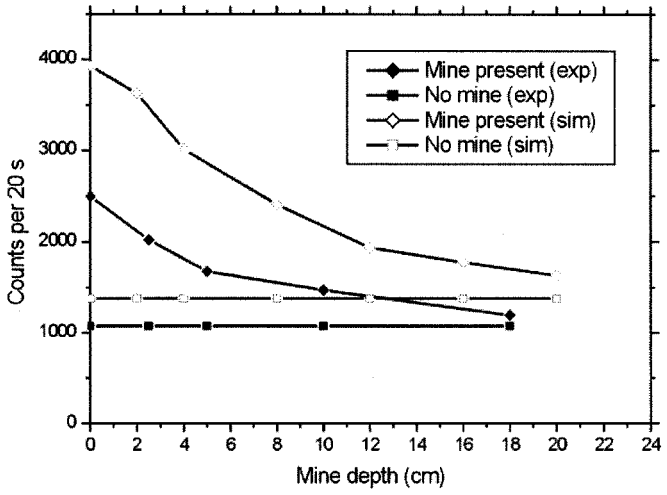


Fig. 6. The experimental and simulated count rate as a function of mine depth for the 20-cm-diameter mine. The background is shown with squares.

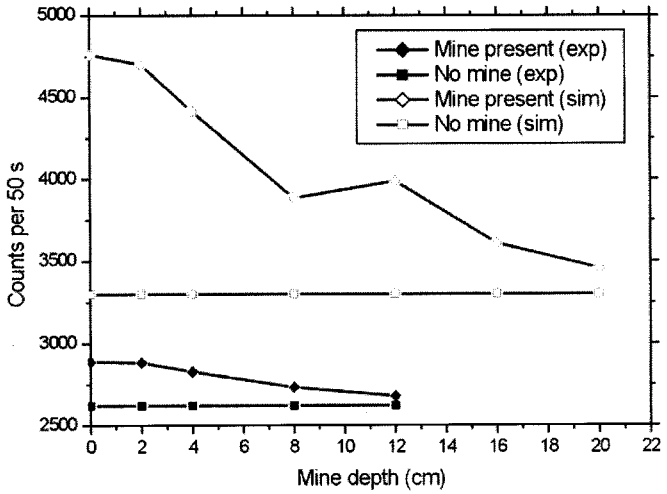


Fig. 7. The experimental and simulated count rate as a function of mine depth for the 6-cm-diameter mine. The background is shown with squares.

to ∼10 cm. Due to the low source strength, the count rate is rather low. This will be dealt with in more detail in Section VI.

D. Distance Between the Detectors

For all the scans that were made with the 20-cm-diameter mine, the FWHM of the scan profile lies between 23 and 30 cm, depending on the mine depth. As was mentioned in the beginning of this section, it was found that the distance between the peaks is approximately half the distance between the detectors. This indicates that a distance between the detectors of at least 30 cm is preferred. On the other hand, the further the detectors are from the californium source, the lower the count rate. It was found that the count rate decreases by about 10%–15% every 4 cm that the detectors are further apart. The count rate drops even faster as soon as the detectors are not covered by the reflector anymore. The signal-to-background ratio of the experimental data is also reduced when the detectors are placed further apart than ∼20 cm.

E. Metal Mines and Water Content of the Soil

It would be beneficial if metal mines would also produce a signal above the background. This was investigated by comparing the signals from the plastic and aluminum 6-cm-diameter AP-landmine. At a depth of 3 cm, the metal mine does not produce a signal above the background. Therefore, under these circumstances, it is vital that a metal detector is combined with the neutron detector.

An important influence on the performance of DUNBLAD is the water content of the soil. Simulations [17] have shown that the signal-to-background ratio decreases rapidly if the water content increases from 5% up to 10%–15%. Measurements are scheduled to determine these limitations. A useful feature of the detector is that the background count rate is a direct measure for the humidity of the soil and a simple limit can be set on the maximum count rate that is permitted to achieve the 99.6% demining standard.

V. Portable Prototype Design

Based on the results presented in Section IV, a portable prototype detector was designed. This detector, DUNBLAD v2.0, can be carried by the deminer in a similar way as a brushcutter. The detector head is scanned across the soil, and both the difference and the sum of both detectors are made visible by two analog displays. The full detector weighs approximately 18 kg, runs on two 6-V batteries, and can be used for up to 40 h before the batteries need to be recharged. A photograph of the detector and the way it is carried is shown in Fig. 8.

VI. Radiation Dose Considerations

An important feature of this type of detector is the radiation dose for the user. Data on this subject were gathered from calculations, simulations, source manufacturers, and experimental measurements. An optimal source strength needs to be selected following the "as low as reasonable achievable" (ALARA) principle, but needs to be strong enough to get good counting statistics. Dutch regulations state that the maximum yearly dose for a radiological worker is 20 mSv. With the current source strength (1.85 MBq), the dose rate at 1 m is about 1 μSv/h in air. With extra shielding and better reflector materials, it is possible to reduce the dose rate by a factor of three to four.

It is estimated that a count rate of ∼1000 c/s is needed, and therefore, the source strength needs to be increased by a factor of ten. This would result in a dose rate for the deminer of about 2–4 μSv/h. This means that the deminer is allowed to use the detector for at least 1000 h per year. Of course, this important feature of the neutron backscattering landmine detector needs to be investigated in further detail with the new prototype.

VII. Conclusion and Discussion

The modeling of the neutron backscattering method has been shown to agree with the experimental data and shows great potential to be used for landmine detection. A dedicated prototype, described in Section V, is currently being evaluated. This device will be thoroughly tested so that it can be determined to what



Fig. 8. Photograph of DUNBLAD v2.0.

extent the 99.6% clearance standard may be achieved. In the case that the radiation dose for the user is unallowably high, the detection principle needs to be expanded to an imaging device that is placed on a remotely controlled platform. However, this would mean a significant increase in the cost and also result in a far less flexible device.

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