DUNBLAD: the Delft University Neutron Backscattering LAndmine Detector

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***Abstract*—The neutron backscattering technique has successfully been used to detect landmines in relatively dry sandy soils. For this purpose a novel, ergonomic detector system was constructed. Preliminary tests show that both anti-tank (AT) and anti-personnel (AP) landmines could be detected down to at least five centimeters of depth. These measurements will be extended to more realistic environments in the near future. A neutron backscattering imager is currently under development and the use of a pulsed neutron generator will further improve the detection system.**

I. Introduction

Neutron backscattering has been used in the oil industry for several decades. The unique feature of this method is that it is mainly sensitive to the amount of hydrogen atoms in its surroundings. For example, the technique is used to determine sand, liquid and gas levels in large oil tanks. In recent years, neutron backscattering has also been considered for the detection of landmines [1]. Experiments at the Interfaculty Reactor Institute (IRI) at Delft in November 1999 with a non-optimized neutron backscattering detection system were rather successful [2]. This led to the design of an experimental set-up with which all the important parameters for a detector based on neutron backscattering were examined. These are for example, the mine depth, stand-off distance (distance between the detector and the soil), soil composition and moisture content, neutron detection medium, neutron reflector material, etc. Based on these results and Monte Carlo simulations, a prototype handheld detector was developed that was tested in several test fields at the IRI-facilities [3,4]. From tests with this prototype several new ideas emerged and this was the start of a further optimized, handheld detector unit. This latest detector has a metal detector incorporated to be able to detect both metallic and hydrogen-rich (plastic) landmines. Other optimizations include an ergonomic carrying technique, new electronics and a more robust detector head [5].

II. The neutron backscattering detection technique

The neutron backscattering method is based on the moderation of high energy neutrons produced by either a radio-isotopic source or neutron generator. The amount of low (thermal) energy neutrons that is 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 a thermal neutron detector in combination with a neutron source is scanned across the soil, the presence of a landmine will be indicated by an increase in the count rate.

Generally speaking, there are two main detection techniques for thermal neutrons. One is based on the use of a gas-counter and the other is based on a scintillator. Currently, a 10 bar helium (^{3}He) gas detector is being used. This is the most commonly used thermal neutron detector. The other technique is based on a scintillator in which the reaction product of a neutron interaction with a nucleus produces ionization. This results in a flash of light that is detected by a photo-detector.

The optimum The optimum initial energy of the neutrons depends on the depth of the landmine, but lies around 1 MeV. The most commonly used radio-isotopic source that emits neutrons is californium (^{252}Cf). The average energy is in the order of ~2 MeV, which is well suited for this application. In all the experiments with the neutron backscattering method californium was used. Other advantages of this material are that it is relatively cheap, readily available and compact. Generally, its container has the dimensions of a few centimeters.

The use of a radio-isotopic source also has some disadvantages. It cannot be switched of, which means that when it is not being used, it needs to be placed in a container with sufficient shielding. Also, in case of an accident one has to make sure that no radio-active materials are being scattered around. This implies that the requirements for packaging of the californium are extremely high.

Another way to produce neutrons is to use a neutron generator. There are several types of neutron generators available. All have the main advantage that they can be switched on and off. The typical weight of a compact neutron

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generator is in the order of 20 kilograms. This implies that it cannot be used in a portable system and therefore requires a movable platform. The main contender for use with the neutron backscattering technique is a neutron generator based on the nuclear reaction of deuterium atoms (D-D generator). The mono-energetic neutrons from the source have an energy of ~2.5 MeV. This still fits relatively well to the optimum energy for this technique and another advantage is that no radio-active materials are being used.

Another advantage of a neutron generator is that it can produce pulsed neutrons. This makes that a huge background reduction can be obtained. Although it is little, a neutron detector also has a certain detection probability of fast neutrons. The fast neutrons that are detected directly from the source can be ignored if during the first neutron pulse the detector is not being read out.

All detectors were tested at either the indoor or outdoor test facility at IRI. These consist of a 50 cm deep sandpit with the dimensions 2x5 m (outdoor) and 1.2x1.2 m (indoor). The water content of the sand was monitored both with the gravimetric method and a detection system based on LCR. This is a rather complex measurement due to the fact that the water content varies with depth. In general the water content of the first 10 cm of sand lies in the order of 2-3 % (weight).

To study the many important parameters in such a system, Monte Carlo simulations were extensively used. The input of these simulations include information on the geometry, the materials used, the detection method and source characteristics. The package itself contains information about all the various interaction mechanisms and cross sections. If enough random events are generated, like in the experiments, information about certain parameters can be gathered. The software that was used was GEANT 3 and 4. The neutron cross section data that was used was extracted from the ENDF-VI libraries.

III. Detector Description

The final detector-head geometry is shown in Figure 1. It consists of two times four helium detectors with a length of 50 cm and a diameter of 2.54 cm, placed approximately 18 cm apart. The source is placed exactly between the two arrays with a glass container, filled with heavy water, above it. This container acts as a neutron reflector and increases the backscattered flux in the detectors by approximately 60% without reducing the signal-to-background ratio. Also, the two coils from the metal detector are shown. The presence of the helium tubes and source, which are made of metal, influences the sensitivity of the metal detector somewhat. However, as long as these metals do not move in relation to the coils, the metal detector works properly. The main material that is used for the construction is polychlorotrifluorethylene (PCTFE), a plastic that does not contain any hydrogen.

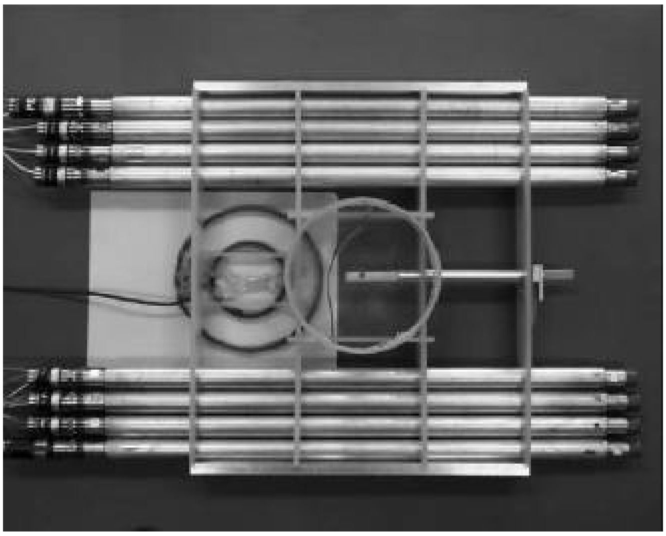

Fig. 1: Photograph of the detector-head. The source, which is on the end of a 20cm long stick, is placed at the center. A glass heavy water container (diameter 17 cm, height 5 cm) is positioned directly above it. To the left of it one can see the two coils of the metal detector. At both sides four 50 cm long helium-tubes are placed.

The detector-head is carried by the user in the way shown in Figure 2. Two carbon fiber poles hold the detector head at approximately 1.5 meter away from the person carrying the detector. The counter balance that contains the batteries makes that the center of gravity of the complete unit is rather low. This makes the whole construction very stable and sudden uncontrolled movements do not result in touching the soil with the detector head. The detector head is scanned at approximately 5 cm above the soil, like a metal detector. The scanning speed is also similar as a metal detector, about 0.3-0.5 m/s. The power consumption of the whole system is approximately 4 Watts. With the current batteries this means that the detector can run more than 8 hours before the batteries need to be recharged.

Fig. 2: Photograph of the DUNBLAD system. It is carried by the deminer using a comfortable harness. The audio signals from both detectors are clearly indistinguishable.

The total weight of the detector is about 18 kilograms. The experience from the first field trials is that this weight is acceptable to work with, but should be reduced in future versions if possible. In hilly or rocky terrain this detector is difficult to handle which limits its applicability. New ideas exist to make a much smaller detector that can be used like the well-known metal detector. This, however, has certain technological implications that need to be overcome.

The success of the present type of detector is mainly determined by the count rate and signal-to-background ratio. There are various parameters of which the most important one is the source strength, that influence these two values. The count rate should be high enough to get good statistics, but as low as possible to limit the dose rate for the user. The current source strength is 1.1 MBq, which means that about 125.000 n/s are produced. With the current set-up this results in a count rate of about 400 c/s. The rather large distance between the user and detector head was chosen because of the radiation dose rate. With the current system the dose rate for the user is less than 0.5 μSv/h, which is well below the international standard of 15 mSv per year.

IV. Experimental Results

A typical scan with the system described in the previous section across both an AT and AP-mine is shown in Figure 3. At a depth of 3 cm, the AT-mine is easily detected. Also, the small AP-mine at a depth of 3 cm can be detected in the sand box. This is still true in the case that the AP-mine is buried at a depth of 5cm, but is approximately the maximum depth in this case. The maximum depth to which an AT-mine can be detected in the sand box at IRI is about 15 cm when a threshold to the signal-to-background ratio of 10 % is applied. The depth in this case is defined from the top of the mine to the surface of the soil. Both limits may still be improved considerably when a stronger source and/or a pulsed source is used.

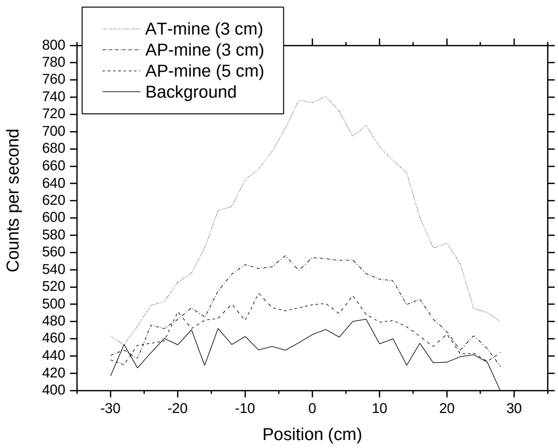

Fig. 3. Scans of both the AT-mine (20 cm diameter, height 4cm) and AP-mine (6 cm diameter, height 4 cm). A stand-off distance (or clearance height) of 5 cm was used. The solid line shows the background. The background is not flat is due to the limited size of the sand pit used for these scans. The width of the large AT-mine is only marginally larger than for the AP-mine.

The real test case for such a detector will be when it is applied in a realistic situation. However, until now we have not obtained the licenses to use this device outside the premises of IRI. At the test facilities at IRI the detector has behaved very well and we are confident that in similar test environments this detector could be a valuable addition to deminers toolbox.

V. Future Developments

Monte Carlo simulations have shown that an imaging detector provides more information about the hydrogen-rich anomaly in the soil. This has led to the design of a 2D position-sensitive neutron detection system based on position-sensitive ^{3}He-tubes. There are currently two concepts for the application of the Delft University Neutron Backscattering Imaging Detector (DUNBID). First a system that can be carried very much so as the DUNBLAD system and uses the californium neutron source. The images may be shown real-time on a small screen on the detector frame or a wearable display. The other concept is based on the use of a neutron generator and is therefore placed on a movable platform, for example in the form of a vehicle. The main advantages of this system are the large increase in the signal-to-background due to timing information and the higher flux that can be achieved by a neutron generator. This higher flux in this case is not a problem as the distance to the operator can be increased as far as needed. One of the outcomes of the simulations is the fact that although the presence of a hydrogen-rich anomaly in many cases is quite clear, it is unlikely that the shape and size of this feature can be determined. One big advantage of this system might be the fact that when a metal detector array indicates the presence of a small piece of metal, the neutron imager can add information on the possible occurrence of other hydrogen-rich materials (explosives) at the same spot. If these are not found, it is more than likely that no landmine is present, which would reduce the amount of false positives by metal detectors considerable.

VI. Conclusions

Neutron backscattering has successfully been used for the detection of landmines. Although it has its limitations, it potentially is a useful asset to the demining toolbox, especially in areas that have relatively dry soils. Still significant improvements of systems based on this technique are possible. For example, neutron backscattering imaging can provide valuable additional information and may be combined with other imaging techniques of landmines like GPR, IR, EMI, etc.

VII. References

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