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The safety of a landmine detection system using graphite and polyethylene moderator

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Background: Several landmine detection methods, based on nuclear techniques, have been suggested up to now. Neutron-induced gamma emission, neutron and gamma attenuation, and fast neutron backscattering are the nuclear methods used for landmine detection. In this paper an optimized (safe and effective) moderating structure using an ^{241}Am-Be neutron source for detecting landmines has been investigated by experiment and MCNP simulation. ***Materials and Methods:*** The experimental set up was composed of a lead (Pb) cylindrical shell enclosing the neutron source, embedded in a fixed size high-density polyethylene (HDPe) cylinder with the variable thickness of the upper and lower moderator/reflector. Some experimental groups were used to measure several moderator configurations' responses by replacing a thermal neutron detector with the mine and counting the neutron capture events. ***Results:*** the total experimental results led to the introduction of optimum moderator geometry for landmine detection. A safe landmine detection system was obtained which enabled the operator to use it for 950 h/year, regarding the dose limit recommended by ICRP. ***Conclusion:*** The novel method for optimization applied in this work is more applicable than the usual approach that is based on measuring the prompt gamma rays emitted by the landmine. Results showed that the method can be optimized in short time, without the usual difficulties of the other methods. **Iran. J. Radiat. Res., 2007; 5 (3): 137-142**

Keywords: *Am-Be neutron source, landmine detection, optimization, BF3 detector, HDPe, graphite.*

INTRODUCTION

The detection of landmines, using classic technologies (Metal detector, prodding), is a time consuming, expensive and extremely dangerous procedure. Although metal detectors are very efficient in finding mines containing metal parts, they are much less efficient in finding almost metal-free mines (1). Several landmine detection methods based on nuclear techniques have been suggested during the recent years (2-12). The nuclear approaches in landmine detection have their own limitations (13), and some attempts have been done recently to resolve these technical limitations (14). One of the proposed techniques to detect non-metallic landmine that has shown great potential, is prompt gamma-rays neutron activation analysis (PGNAA) method (15-19). PGNAA Method is actively investigated for finding mines (20, 21). In this method the landmine is activated with neutrons. The active landmine emits several prompt gamma rays with various intensions. Ordinarily, the energy spectrum of these gamma rays is the evidence of the elements contained in the landmine. The PGNAA method is based on capturing thermal neutrons by sample nuclei (here landmine). The optimum moderator geometry that leads to the maximum thermal neutrons flux will certainly improve the efficiency of this method (15). The primary purpose of this paper has been to investigate the best and optimum structure of the moderated ^{241}Am-Be source geometry to detect landmines. One way to obtain the optimum structure could be based on measuring the production rate of prompt gamma rays. However, due to the disturbing effect of high-rate background gamma rays, this method for optimization is difficult to be experienced. Although, the authors investigated the optimum geometry using this approach, due to the difficulties in long-term stability of the detection system to maintaining the high quality of the obtained experimental data, (15, 22) they didn't get

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satisfactory results. Also, since this method has been based on the acquisition of high energy prompt gamma rays with usually low intensity, it would have been time consuming, which certainly made the long-term stability more difficult than a simple spectroscopy. Totally the gamma spectroscopy system hardly worked for a month, to get the spectrum with and without mine (background) for each configuration (more than 124 cases), but because of the mentioned problems, authors did not get satisfying and reportable data. Finally, the problem was tackled so that instead of using a real landmine and detecting the ^{14}N prompt gamma rays, 10.8 MeV, a thermal neutron detector was replaced with the mine. Therefore, the variation of the near thermal and thermal neutron flux, produced by the source-moderator geometry, have been measured in the optimization process.

MATERIALS AND METHODS

Experimental approaches

Using the concept of PGNAA method and the fact that the production rate of prompt gamma rays is related directly to the thermal neutrons flux, and if we apply the maximum thermal and near thermal neutron rate on the sample position, the best moderator geometry can be obtained. In order to measure the thermal neutrons flux, an active instrument was utilized.

A LND 20210 BF_3 detector (gas volume=111 cm^3, pressure=0.9 atm) LND, INC. USA was used as thermal neutron detector and has been replaced with the mine to measure the thermal neutrons flux at the mine location. By changing the upper and lower moderator thickness, (polyethylene/graphite) the optimum moderator geometry based was obtained, on the maximum BF_3 count rate.

It might seen in justifiable to claim any of similarity between a real situation and a simulated one at the first glance; because there was not any mine in the experimental procedure, but only a BF_3 detector was buried 3 cm lower than the ground level. Considering to the procedure precisely it would be seen that the ^{10}B reaction has had a rather featureless cross section, and obeyed the l/v law quite well even up to 0.5 MeV approximate similar to the general l/v dependence exhibited by nitrogen nuclei (17-38% by weight in a usual mine). Also, since the most practical BF_3 counters were filled with pure boron trifluoride enriched to about 96% in ^{10}B, so the concern about was vanished the similarity of using a BF_3 tube instead of real explosive material. The benefit of this approach was the poor signal-to-noise ration, since the BF_3 was less sensitive to the gamma-ray background. The present work has been an improvement of PGNAA method, made possible by using a BF_3 to detect the thermal neutron produced due to the applied source-moderator configuration.

Source-moderator geometry definition

The designed PGNAA setup configuration is shown in figure 1. A ^{241}Am-Be neutron source with 5Ci activity in a standard Amersham X.14 capsule format (code AMN24), was used. One part of the facility included the source and a cylindrical Pb shield enclosed in a cylindrical high density polyethylene (HDPe) with fixed size and positions during the experiments.

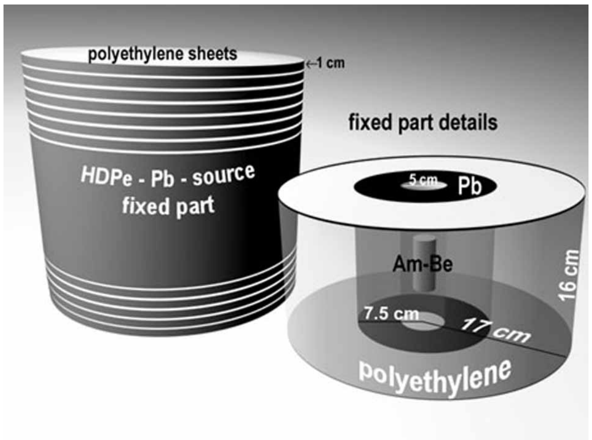

Figure 1. The details of land mine detection system.

The cylindrical Pb shield was considered as a filter material for gamma rays to protect the operators from the hazardous 4.438 MeV Am-Be gamma-rays. Because of the great potential of hydrogen in slowing down the fast neutrons, as well as its considerable absorption cross section for thermal neutrons, the cylindrical HDPe was used as neutron shield to protect the personnel from biological effects of neutrons and to reduce background counts in an executive system using NaI detector. Since neutron shielding is very important for the personnel safety, the best thickness of cylindrical HDPe shield has been studied in this investigation.

The other part of the facility has been changed during the several experiments to achieve the best geometry. The part included the moderator sheets (each sheet thickness is 1cm, polyethylene/graphite) which were laid on/under the fixed part as a reflector/moderator. Graphite was fixed above the fixed parts due to its lower ability (in comparison with polyethylene) to moderate neutrons but able to reflect them. It should be noted that the lower side of the fixed part was fixed about 12 cm above the ground level during the experiments.

RESULTS AND DISCUSSION

Because of the importance of neutron shielding, the best thickness of cylindrical HDPe was studied using Monte Carlo simulation MCNP4-C code [23]. Several setups as shown in figure 1 with different outer radius of HDPe were simulated. Figure 2 shows the results of the total neutron dose equivalent (Sv) per neutron emitted from the neutron source when the operator was 4m far from the system. It was shown that with increasing the outer radius of the cylindrical polyethylene, the neutron dose equivalent decreased.

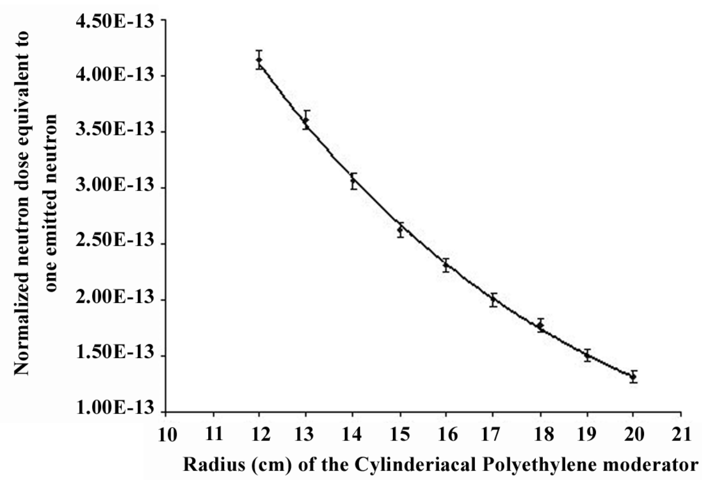

Figure 2. Total neutron dose equivalent (Sv/n) at a distance of 4m far from the landmine detection system.

Also in order to check the system's safety and the radiation protection, the neutron and gamma dose equivalent rate were measured at some different distances from the landmine detection system. Table 1 shows that the approximate safe distance from the landmine detection system (about 4 m). In an exposure of 950 h/year for an operator using this source-moderator geometry, the total dose equivalent rate was equal to the dose limit recommended by ICRP [24] (20 mSv/year).

Table 1. Total neutron and gamma dose equivalent rate (Sv h-1) due to the Landmine Detection system.

Distance	Gamma	Neutron
1m	0.32	35.5
2m	0.08	8.6
3m	0.03	3.8
4m	--	2.1

According to what mentioned before, an increase in the thermal neutron count rate was interpreted as the setup for the optimum structure. Totally, 124 kinds of configurations were examined, and the total experimental data were tabulated in 3 tables. In each table the "bold" number shows the maximum count, the specific category with the optimum structure. Table 2 lists the total experimental data obtained by changing the upper and lower polyethylene thickness. The increase between the worst and the best configuration's count rate was about 20%. Results also showed that the rate increased when the lower HDPe thickness got up to 5 cm. The number of capture events is very sensitive to the thickness of the lower HDPe part. A further increase of the HDPe thickness caused a significant reduction of the capture events in the detector. The effect was understood to be due to the absorption of the thermalized neutrons in the hydrogen contained in the HDPe, which partially screened the detector from the thermal neutrons produced in the inner part of the structure. So, the critical thickness of the lower HDPe part was about 5 cm. It was clear that with the 5 cm thickness of the lower part, the count rate would increase, while the thickness of the upper HDPe part would also increase. The maximum count rate in table 2 is related to the best geometry with 7cm thickness of HDPe above the fixed part. In order to assess the soil moderation effects on the obtained results, in slowing down neutrons, some experiments were done with BF_3 located under the moderator system without the soil existence. It should be noted that the soil could scatter those neutrons which passed the detector volume without any interaction with it. Table 3 compares the counting rate between the two configurations, bare and buried detector. The critical thickness (5 cm) of polyethylene for the lower part, shown in table 2 was used for the comparison. Therefore, the soil caused an increase in the capture events up to 170%. Results showed that in the land mine detection, the soil itself plays a highly important role for moderator, producing a flux of thermal neutrons to attain an effective capture cross section.

Lower part of the system uses the HDPe as the moderator, (table 4). The results show that 5 cm critical thickness of polyethylene at the lower part; also, it proved that the optimum geometry had 6 cm thickness of graphite above the fixed part. The increase in the count rate between the worst and best geometry was about 21%, so 6cm thickness of graphite would act the role of 7cm of polyethylene (20%). By increasing the upper thickness of the reflector/moderator, of

Table 2. Total thermal neutron flux in the 60 s of detector live time

Thickness (cm) Of upper Polyethylene Part								
	7	342434	338564	360652	371332	363846	341464	--
	6	340879	337104	361161	370769	363214	340094	312234
	5	340585	337199	360925	371405	362180	341069	312386
	4	338772	336763	360440	370410	362993	340369	310912
	3	336836	335435	360217	369556	361996	340705	312469
	2	335601	334209	358347	369411	362481	339232	310732
	1	331365	332938	357049	367719	360418	337777	310216
	0	325894	328023	353303	365606	358939	337916	309136
		2	3	4	5	6	7	8
Thickness of the polyethylene sheets (cm) lied under the fixed part								

Table 3. Total thermal neutron flux in the 60 s of detector live time

	Upper part thickness of polyethylene (cm)							
	0	1	2	3	4	5	6	7
Buried								
BF3	365606	367719	369411	369556	370410	371405	370769	371332
Bar								
BF3	137274	137756	138078	139903	139023	138851	139616	138639
Lower part is HDPe with the critical thickness, 5 cm.								

Table 4. Total thermal neutron flux in the 60 s of detector live time

Thickness (cm) of upper Graphite Part	Thickness of the polyethylene sheets (cm) lied under the fixed part: 2	3	4	5	6	7	8
6	342209	330359	363884	376475	368044	345730	315465
5	340707	330248	363501	374598	366194	344940	314631
4	338666	339129	364293	373496	365644	343522	313767
3	338013	336300	362225	372111	364963	343465	312214
2	333937	335311	360276	371569	362637	342316	310641
1	332355	331711	357954	368801	361992	341742	309349
0	326209	329242	352604	366267	359333	338153	310126

increasing rate was very slow, so the best thickness of the upper part was considered to be up to 6 cm thickness of graphite, and the experiments didn't precede more (taking into account the total weight of the assembly).

This method of optimization is completely novel and can be utilized for other facilities using PGNAA method, without the usual difficulties of other methods regarding time, accuracy, data processing and background radiations.

The comparison between the results of the present paper with what was reported by Zuin, *et al.* (25) shows that using ^{252}Cf as a neutron source in facility (figure 1), the total assembly differs with the type that uses ^{241}Am-Be neutron source. If two neutron sources (Am-Be and ^{252}Cf), with the same activity are considered, when using Am-Be source, the amount of applied polyethylene considerably would increase. This effect is due to the fact that Am-Be source produces fast neutrons in comparison with the ^{252}Cf source (26, 27) and the setup needs more thickness of polyethylene to moderate fast neutrons.

In conclusion the best geometry for a landmine detection system using PGNAA method should use the graphite on, and polyethylene under the fixed part, simultaneously. The critical thickness of the lower part was 5 cm of HDPe while the upper side used 6-7 cm of graphite.

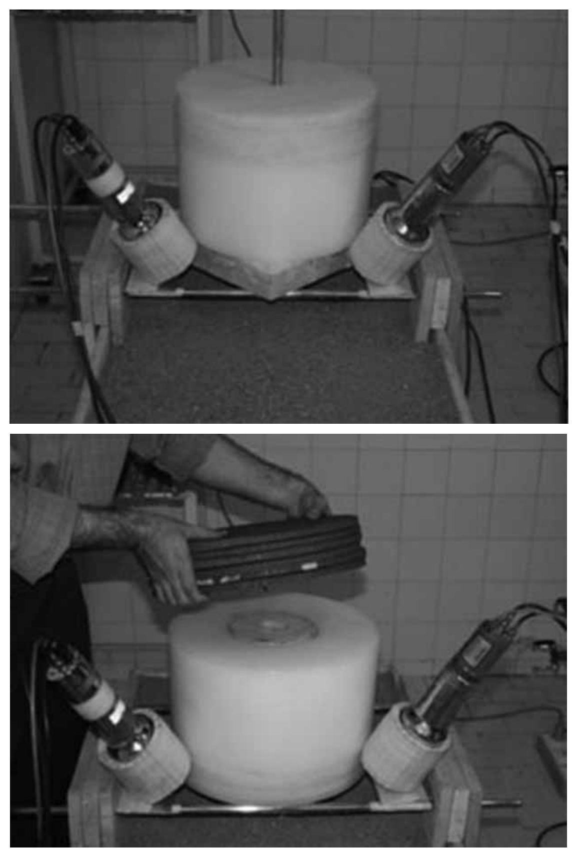

Figure 3. Two optimum geometries of the Landmine Detection system using PGNAA method.

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