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Experimental optimization of a landmine detection facility using PGNAA method

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Abstract The optimum moderator geometry increases the performance of prompt gamma neutron activation analysis (PGNAA) method considerably. In this work an ^{241}Am-Be source was used in the moderator geometry for detecting buried landmines by PGNAA method. Experiments were done to find the best moderator geometry for the moderated ^{241}Am-Be source, by replacing the mine with a neutron detector and counting the thermal neutron flux. The flux of thermal neutrons at the place of mine was used as a determining factor to introduce the best moderator geometry.

Key words Am-Be neutron source, Landmine detection, Optimization, BF_3 detector, PGNAA

CLC numbers O657.4, TJ51$^+$2

1 Introduction

A lot of people are accidentally killed by small plastic landmines yearly. The detection of these types of mines is difficult by classic mine detectors commonly used these days. Recently, some methods of landmine detection based on nuclear techniques have been suggested to solve the problem of detecting the plastic mines[1-7]. Prompt gamma neutron activation analysis (PGNAA), which has a wide range of applications, has shown great potential in detecting landmines[7-10]. The detection of buried landmine using PGNAA method is to irradiate the land with neutrons to activate the elements. The detection of prompt gamma rays produced by activated nitrogen, which is in a much larger quantity in mines than in the soil, shows the existence probability of buried landmine in that area. Since the cross section of neutron capture reactions on ^{14}N increases with decreasing neutron energy, the optimum moderator geometry that leads to the maximum thermal neutron flux, certainly improves the efficiency of this method. The primary purpose of this paper is to investigate the best and optimum structure of the moderated ^{241}Am-Be source used to detect landmines. The problem was tackled in the way that a thermal neutron detector was buried instead of mine. The dimensions of the moderator have been varied several times and the flux of thermal neutrons at the place of mine measured by the detector and considered for determination of the best moderator geometry.

2 Experimental approaches

An LND 20210 BF_3 detector (gas volume =111 cm^3, pressure =0.9×10^5 Pa) from LND Inc., USA was used as a thermal neutron detector. It replaces the mine for measuring the thermal neutrons flux at the place of mine.

By varying the upper and lower thickness of the moderator (polyethylene/graphite), the optimum moderator geometry based on the maximum BF_3 count rate, was obtained.

Since the most practical BF_3 counters are filled with pure boron trifluoride and the ^{10}B reaction with neutron obeys the $1/v$ law quite well like the general $1/v$ dependence exhibited by nitrogen nuclei, so using a BF_3 tube instead of a real mine in these experiments is reasonable.

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The benefit of this approach is that there is a good signal-to-noise ratio because the BF_3 is less sensitive to the gamma-ray background. The work in this paper is an enhancement of the PGNAA method, made possible by using a BF_3 to detect the thermal neutron produced due to the applied source-moderator configuration.

3 Source-moderator geometry definition

The design of the PGNAA setup configuration is shown in Fig.1. An ^{241}Am-Be neutron source with 1.85×10^{11} Bq activity contained in standard Amershan X.14 capsules format (code AMN24), was used in this PGNAA facility. The PGNAA facility is composed of some parts. The fixed part of the facility during the experiments includes the source, Pb shield, and the central part of the moderator.

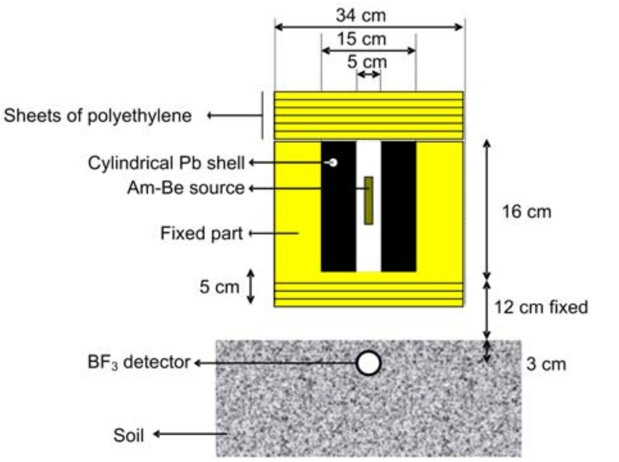

Fig.1 The land mine detection system details.

The cylinder of Pb embedded in the moderator is considered to filter gamma rays emitted by the neutron source. Such shielding material would act intrinsically as an external neutron reflector/moderator[11]. The central part of the moderator is to slow down fast neutrons emitted by the neutron source and to absorb outgoing flux of thermal neutrons to protect personnel from biological effects of neutrons. Because of the great ability of hydrogen in slowing down fast neutrons and its considerable absorption cross section for thermal neutrons, the middle part of the moderator uses high density polyethylene (HDPE). Since neutron shielding is very important for personnel safety, the best thickness of cylindrical HDPE moderator was studied. Fig.2 shows the MCNP (Monte Carlo N-Particle code) results of the total neutron dose equivalent (Sv) per neutron emitted from the neutron source when the operator is 4 m far from the system. It is clear that the neutron dose equivalent decreases rapidly as the outer radius of the cylindrical polyethylene increases.

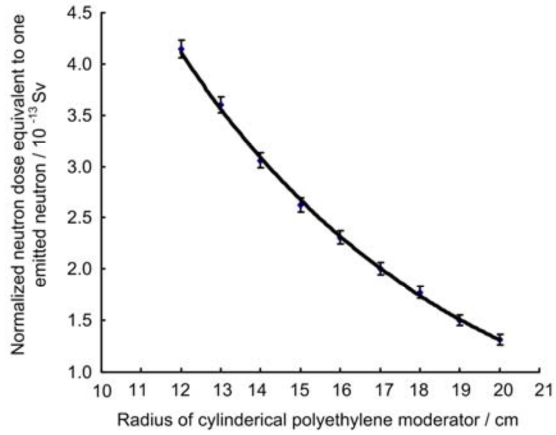

Fig.2 Total neutron dose equivalent at the 4 m far from the landmine detection system.

In order to increase safety of the system, boric acid (H_3BO_3, fine powder, ρ= 0.89 g·cm^{-3}) in the form of a cylindrical layer was used as an absorber of thermal neutrons to protect the personnel. Simulations were done by MCNP as shown in Fig.3. When the radius of the cylindrical moderator is fixed at about 17 cm, the outgoing thermal neutron flux decreases with increasing layer thickness of the boric acid, and just a 2 cm layer could decrease the thermal neutron flux up to 50%.

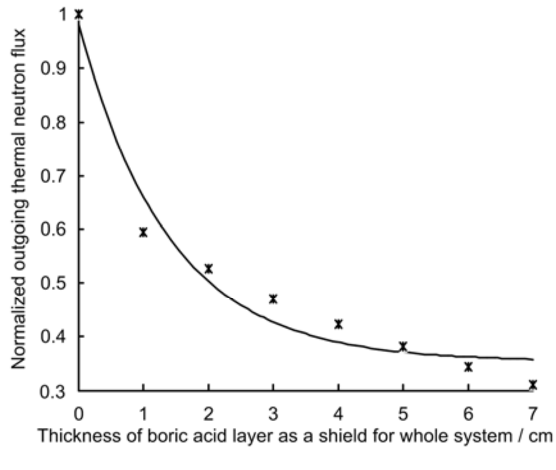

Fig.3 Outgoing thermal neutron flux *vs*. the thickness of the boric acid layer when the radius of the cylindrical polyethylene fixed 17 cm.

The other parts are the moderator sheets (1 cm thickness, polyethylene/graphite) which lie on/under the fixed part as a reflector/moderator. Graphite has a low ability to moderate neutrons but reflect them well and it is placed above the fixed parts. Note that the lower side of the fixed part is about 12 cm above ground level during the experiments. As was mentioned before, each of the three parts of the moderator assembly exerts its special effects on factors of interest, such as thermal neutron flux on the mine and personnel absorbed dose. The effects of each part are as follows:

1) The radius of the cylindrical polyethylene plays an important role in minimizing the absorbed dose for the personnel, and somewhat leads to minimize the leakage of the neutrons from the setup and scatter them to the mine position.

2) The thickness of the lower side of the moderator plays a critical role in the setup. This part, located between the source and detector, can moderate and absorb neutrons. So, its best thickness must be investigated exactly in such a way to minimize the absorption probability of thermal neutrons.

3) The role of the upper side is backscattering of those neutrons which go upward.

During the experiments, thickness of each part was increased until a negligible increase of the thermal neutron flux was detected.

4 Results

An increase in the thermal neutron count rate is interpreted as that the setup goes to the optimum structure. Totally 124 kinds of configurations were examined.

Fig.4 shows the total experimental data obtained by varying the upper and lower polyethylene thickness. The relative increase between the worst and the best configuration's count rate is about 20%. The rate increases when the lower HDPE thickness increases up to 5 cm. The number of capture events is very sensitive to the thickness of the lower HDPE part. A further increase (up to 8 cm) of the HDPE thickness causes a significant reduction of the capture events in the detector. This effect is due to absorption of the thermalized neutrons by the hydrogen of HDPE, which partially screens the detector from the thermal neutrons produced in the central part of the structure. Therefore, the critical thickness of the lower HDPE part is 5 cm. It is clear that with the lower part in 5 cm thickness, the counting rate increases with the thickness of the upper HDPE part. The maximum counting rate in Fig.4 is related to the best geometry of 7 cm thickness of HDPE above the fixed part.

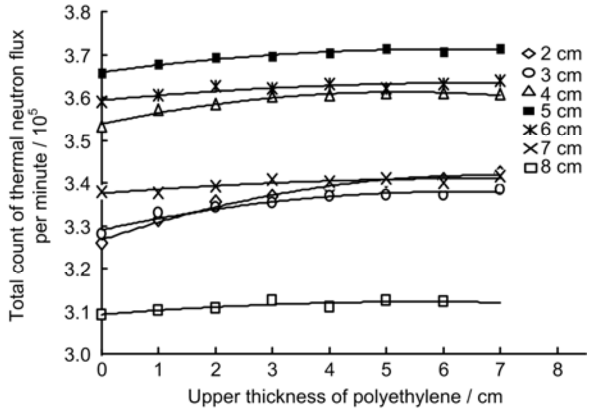

Fig.4 Total neutron flux per minute using polyethylene at both upper and lower parts.

The upper HDPE thickness does not play a significant role in increasing the thermal neutron flux on the landmine position, e.g. the relative difference between 6 cm and 7 cm thickness of the upper part is about 0.15%. This indicates that increasing an upper part thicker than 7 cm does not increase the thermal neutron flux considerably.

In order to assess the soil moderation effects on slowing down neutrons, experiments were done with the BF_3 being under the moderator system without the soil. Note that the soil can scatter neutrons which pass the detector volume without any interaction with the detector. Counting rates of the bare and buried detectors were compared (Fig.5). The critical thickness (5 cm) of HDPE for the lower part was used in this comparison. The soil causes an increase of the capture events up to 170%. The result shows that in the land- mine detection, the soil plays an important role and produces a flux of thermal neutrons to attain an effective capture cross section.

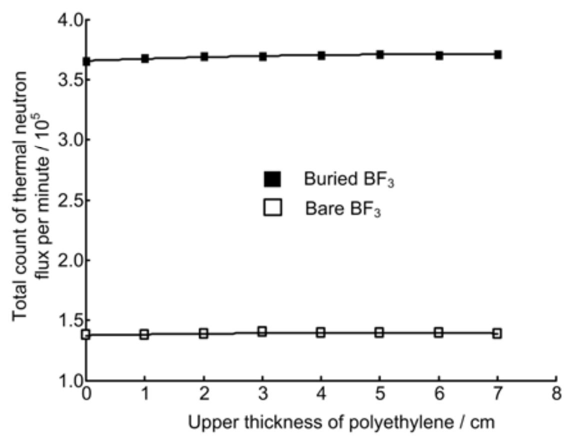

Fig.5 Comparison between the two configurations, with buried and bare BF_3 detectors.

It is worthwhile to check the role of graphite above the fixed part. The reflectivity feature of graphite for neutrons is the base of this decision, while the lower part of the system uses the HDPE as the moderator. As shown in Fig.6, with the 5 cm critical thickness of HDPE at the lower part, the optimum geometry is 6 cm thickness of graphite above the fixed part. The relative difference of counting rates between the worst and best geometry is about 21%. Thus, 6 cm thick graphite has about the same role of 7 cm HDPE (20%).

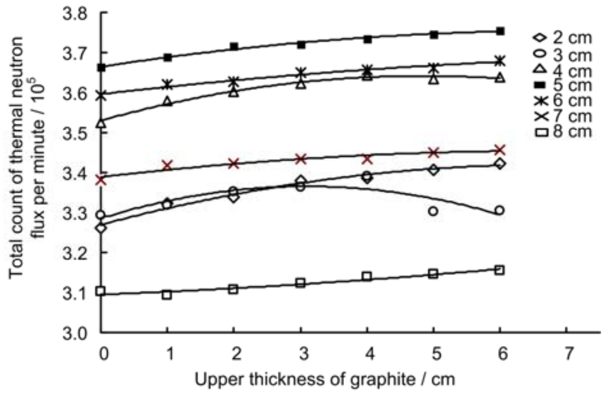

Fig.6 Total neutron flux per minute using polyethylene for lower and graphite for upper part of assembly.

By increasing thickness of the reflector/ moderator, the rate increases very slowly. With the best thickness of the upper part, 6 cm thick graphite, no significant variation in the total thermal flux occurred. The counting rate difference between 5 cm and 6 cm thickness of the graphite at the upper part is less than 0.5%.

Safety and radiation protection of the system were checked, too. The neutron and gamma dose equivalent rates were measured at different distances from the landmine detection system. As shown in Table 1, the safe distance from the landmine detection system is ≥ 4 m. In an exposure of 950 hours per year for an operator using this source-moderator geometry, the total dose equivalent rate is less than the dose limit (20 mSv per year) recommended by ICRP[12].

Table 1 Total neutron and gamma dose equivalent rate ($\mu Sv \cdot h^{-1}$) due to the landmine detection system

Distance/m	Gamma ray	Neutrons
1	0.32	35.5
2	0.08	8.6
3	0.03	3.8
4	—	2.1

5 Conclusion

Comparing the results of this paper with Ref.[13], where a landmine detection system of ^{252}Cf was used as the neutron source, the best moderator geometry for a landmine detection system is extremely dependent on the kind of the neutron source. Optimum moderator geometry for a landmine detection system using PGNAA method was obtained. The best structure should use the graphite on and HDPE under the fixed part. The critical thickness of the lower part is 5 cm of HDPE while the upper side uses 6~7 cm of graphite. The capability of the suggested method for optimization can be utilized for other facilities using PGNAA method.

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