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"Research Note"

DETERMINATION OF NEUTRON DETECTORS SHIELD USED FOR THE DETECTION OF LANDMINES*

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Abstract – As a result of being hydrogenous moderators, several landmine detection methods based on nuclear techniques have been suggested in recent years. Because of elastic scattering and moderating neutrons from hydrogen atoms in landmines, detection of backscattered neutron shows an anomaly in the reflected thermal neutrons count when a detector scans over a mine. On landmine detection using neutron sources, a detector and its shielding play an important role. In this paper, based on the investigations and calculations performed by MCNP code (Monte Carlo N-Particle transport code), detector shielding materials and their thicknesses have been determined. Therefore, the effects of moderators such as graphite, heavy water, beryllium, polyethylene and boric acid on backscattered neutron flux have been investigated.

Keywords – MCNP, shielding, detection, landmine, Am-Be, neutron backscattering, polyethylene, boric acid

1. INTRODUCTION

Many of the anti-personal mines (APM) used after the second-world-war are small (< 300g) and contain little metal, so they are difficult to detect by metal detector [1]. Application of nuclear techniques has somehow been reported in others works. For example, the detection system provided by the SHELL Nuclear Measuring Techniques Group has been employed for the detection of oil, water, gas, and sand levels in large tanks [2]. In another work Kiraly et al. examined the energy spectrum of backscattered neutrons from various materials using a ^{239}Pu-Be source which emits neutrons with energy from 1.2 to 10 MeV. They employed a liquid scintillator (NE213) as a fast-neutron detector [3]. Esam et al. used the ^{3}He Detector and ^{252}Cf source [4]. Bom et al. have constructed the Delft University Neutron Backscatter Landmine Detector (DUNBLAD) in the Netherlands, using 8 number of proportional ^{3}He neutron detectors in their set-up [5]. In this work we have used only one BF_3 detector to detect the sample. It must be mentioned that gamma emitted from neutron activation and the neutron source has no effect on thermal neutron counts. It was experimentally obtained and reported [6].

Three factors can contribute to make neutron scattering useful for detecting APM. First, there is the fact that the hydrogen content in plastic APM is relatively high. The atom percentages of hydrogen in typical plastics and explosives are 55–65% and 25–35% respectively. Second, for neutron energies below 3 MeV, the total cross section of neutron-proton (n-p) interaction is significantly higher than that of other nuclides commonly found in the soil or in metal debris. Third, n–p elastic scattering, which is the dominant process in the interaction of neutrons with protons at these energies, has two unique features: the

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average energy loss per scattering by the neutron is large (50%), which makes hydrogen a good neutron energy moderator; and the angle of scattering of the neutron (in the laboratory frame) cannot exceed 90° [7]. We have tried to use those factors in this work. Three points were noted on detector shielding determination:

1. It must be portable
2. It should be easily used
3. It must be cheap

Experimental results have confirmed that this method has the ability to detect landmines [8]. There are some parameters such as soil moisture, depth, distance from soil surface and landmine weight effect on the detection result. The effects of these types of parameters will be considered in future.

2. MATERIAL AND METHODS

It is assumed that a TNT (Trinitrotoluene $C_7H_5N_3O_6$) sample has been buried in the soil. The soil generally contains 10 elements (Table 2) [9]. We have experimentally determined the mass percent of the elements by NCHS (nitrogen, carbon, hydrogen, sulfur combustion analyzer) and AA (atomic absorption spectrometer) methods; the soil moisture was 0.634% by weight. The composition of the explosive material and the soil has been listed in Tables 1 and 2 respectively.

Table 1. Composition of the explosive material (TNT) used in simulations [4]

Element	Mass fraction
H	0.02170
C	0.37007
N	0.18529
O	0.42294

Table 2. Chemical composition of the soil

Element	Mass (%)
H	3.760
C	5.936
O	44.144
Si	34.560
Al	0.940
Fe	2.381
Ca	4.494
K	0.083
Na	0.075
Mg	3.627

Am-Be neutron source, which has a 0.5 cm diameter and a 1cm height, has been placed 1.5 cm under the soil surface. The BF_3 detector, which has a 2.45 cm diameter and a 20 cm length, has been placed on top of the Am-Be source.

Thermal neutron is backscattering due to the presence of hydrogen in the landmine. This is the important proof to apply this method to detect landmines. (Elastic) neutron backscattering from a landmine is different from soil, both in neutron intensity and in quality (energy) [10]. Because of the large volume of soil, the buried landmine is difficult to recognize. In order to count backscattered neutrons, the detector has scanned the soil surface 1 cm above it. As seen in Fig. 1, the MCNP code output shows little anomaly on the neutron flux above the landmine position. This is not enough to recognize landmine existence, so it must, in any case, be amplified [11, 12].

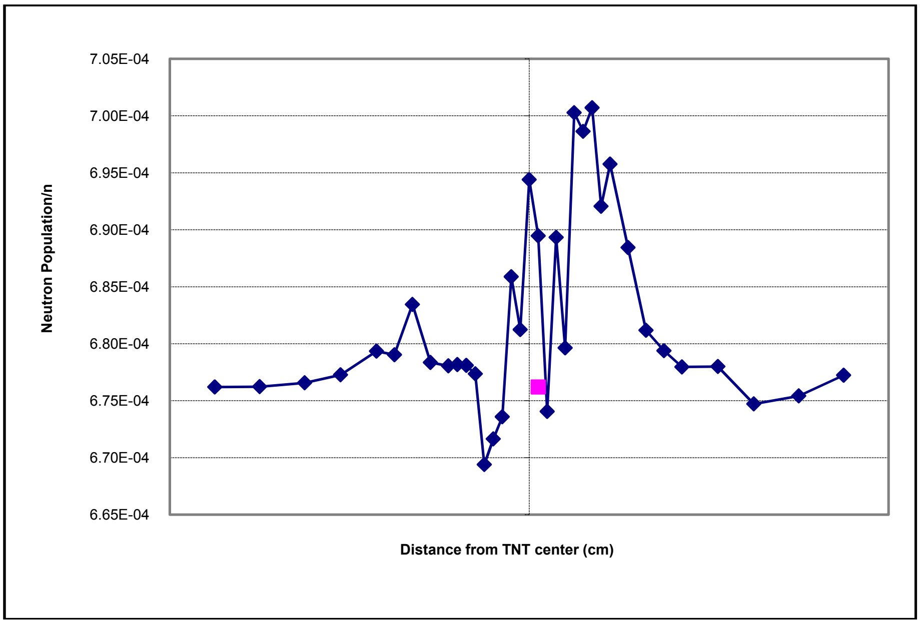


Fig. 1. Backscattered neutron flux for each neutron incident on the detector over the TNT sample position

Boron (10), at low energy range, has a high absorption cross section and is a good absorber for thermal neutrons [13]. Boric acid has natural boron that contains 19.8% ^{10}B and 80.02% ^{11}B. Therefore, it can be applied as a neutron absorber in detector shielding.

Using the MCNP code, four moderators have been investigated. Fig. 2 shows calculation results that have been obtained from MCNP calculations. As seen in Fig. 2, the neutron population is increased versus the moderator thickness increases for different moderators.

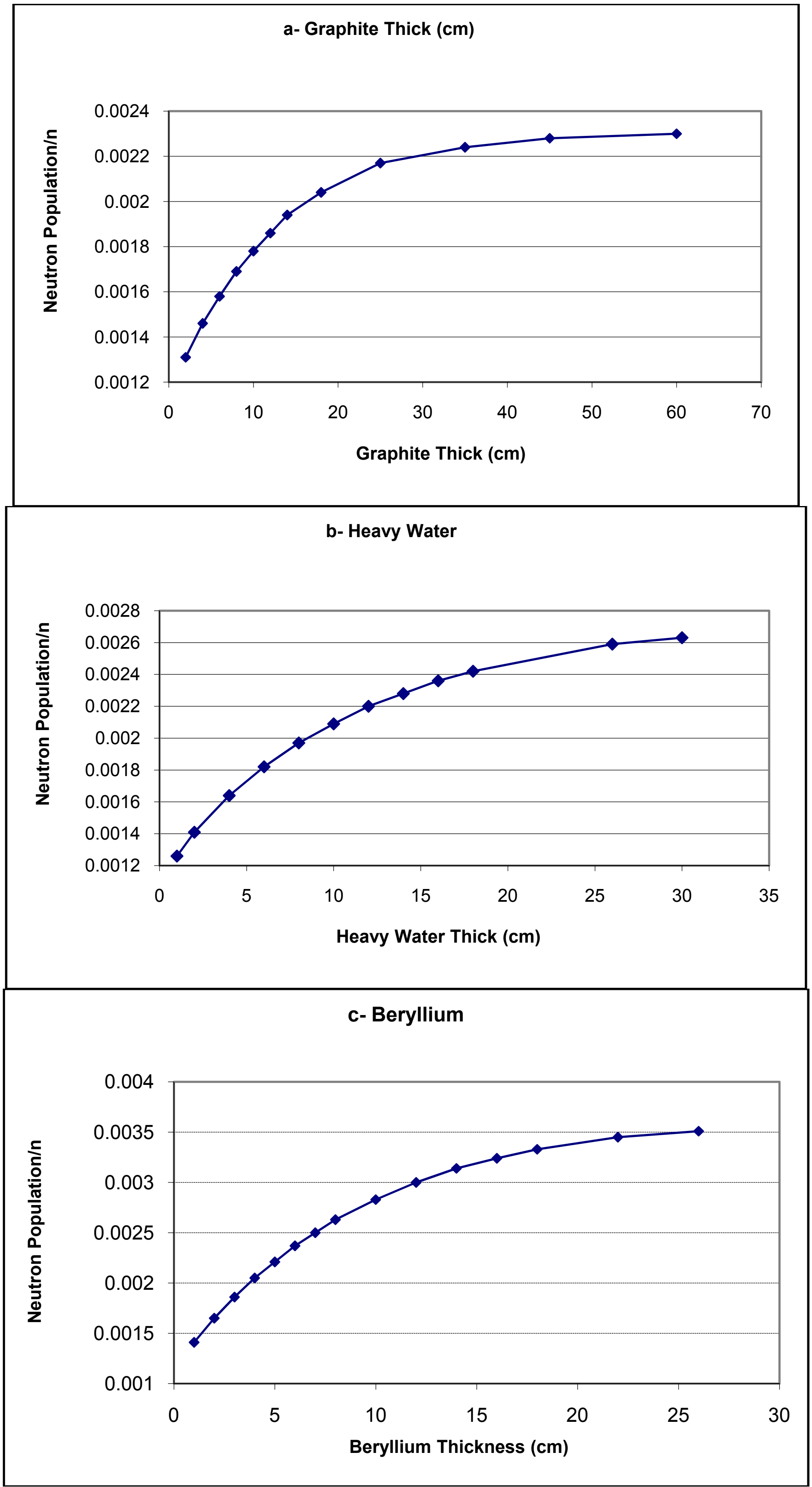
According to Fig. 2-a, neutron incident in the detector space has maximum value when the graphite thickness is about 40 cm. This shows that graphite has both reflection and moderation properties, but due to its high mass and volume it is not a good detector shield on landmine detection. According to Fig. 2-b neutron flux is at maximum value on 30 cm thickness of heavy water. Because of its unavailability and the high cost of heavy water, it is not applied as a landmine detector shield.

Fig. 2-c shows that 30 cm of beryllium is enough to increase neutron flux, but due to some problems such as being strategic, poisonous and expensive, we cannot apply it on landmine detector.

Fig. 2-d shows neutron flux variation by polyethylene thickness. It has been assumed polyethylene has CH_2 structure and 0.92 g/cm^3 density. According to Fig. 2-d, about 10 cm of polyethylene is sufficient to obtain thermal neutron flux on the detector.

Incident neutron fluxes in the detector for different moderators having 10 cm thicknesses are displayed in Table 3.

By considering Table 3 and previous notations, polyethylene is shown to be a suitable moderator for landmine detectors. Therefore, in this work polyethylene has been assumed as the first layer shield around the detector.


a- Graphite Thick (cm)
Neutron Population/n
0.0024
0.0022
0.002
0.0018
0.0016
0.0014
0.0012
0
10
20
30
40
50
60
70
Graphite Thick (cm)
b- Heavy Water
Neutron Population/n
0.0028
0.0026
0.0024
0.0022
0.002
0.0018
0.0016
0.0014
0.0012
0
5
10
15
20
25
30
35
Heavy Water Thick (cm)
c- Beryllium
Neutron Population/n
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0
5
10
15
20
25
30
Beryllium Thickness (cm)

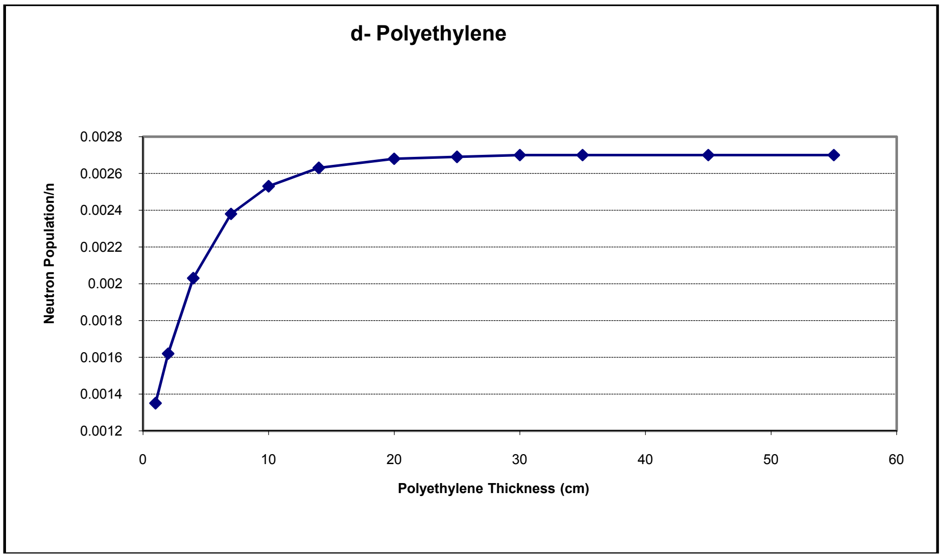


Fig. 2. Dependence of neutron flux on moderator thickness for neutrons emitted from mine: a) Graphite b) Heavy water c) Beryllium d) Polyethylene

Table 3. Incident neutron flux for different moderators (thicknesses are 10cm)

Moderator	Graphite	Heavy water	Beryllium	Polyethylene
Neutron flux(n/cm^2)	0.00178	0.00209	0.00283	0.00253

3. EFFECT OF POLYETHYLENE AND BORIC ACID LAYERS

It has been demonstrated that polyethylene and boric acid must be used as first and second layers around the detector respectively. Now their effects should be determined on neuron fluxes. For this purpose, it has been assumed that polyethylene thickness (first layer) is 1cm and the boric acid thickness effect (second layer) has been investigated. The incident neutron flux in the detector was calculated by MCNP code. The same Monte Carlo calculations have been repeated when polyethylene thickness is 2, 3 …10 cm. The result of the output has been illustrated in Fig. 3.

As seen in Fig. 3, incident neutron flux in the detector is saturated when polyethylene and boric acid thicknesses are 10 cm and 4 cm respectively. Therefore, the input file of MCNP code with a two layer shield has been established (Fig. 4). It is assumed the detector with the designed shield has been moved to the soil surface in which the landmine buried it. The result of the output has been illustrated in Fig. 5. Comparing Fig. 1 (detector without shield) and Fig. 5 (detector with shield) it appears that the detector shield can have an important role on landmine detection.

4. CONCLUSION

Detector shield has an important role on landmine detection based on nuclear methods. It is a point that has not been observed in other works. This shield is better to be designed on two layers; the first for slowing down and scattering the neutrons, and the second for absorbing backscattered neutrons. According to investigations and MCNP calculations, 10 cm thickness of polyethylene and 4cm thickness of boric acid have been determined as first and second layers respectively. Figs. 1 and 5 show backscattered neutron flux incident in detector without and with the designed shield respectively. Comparing these figures shows that due to the existence of the two layer shield, incident neutron flux in a detector has been amplified.

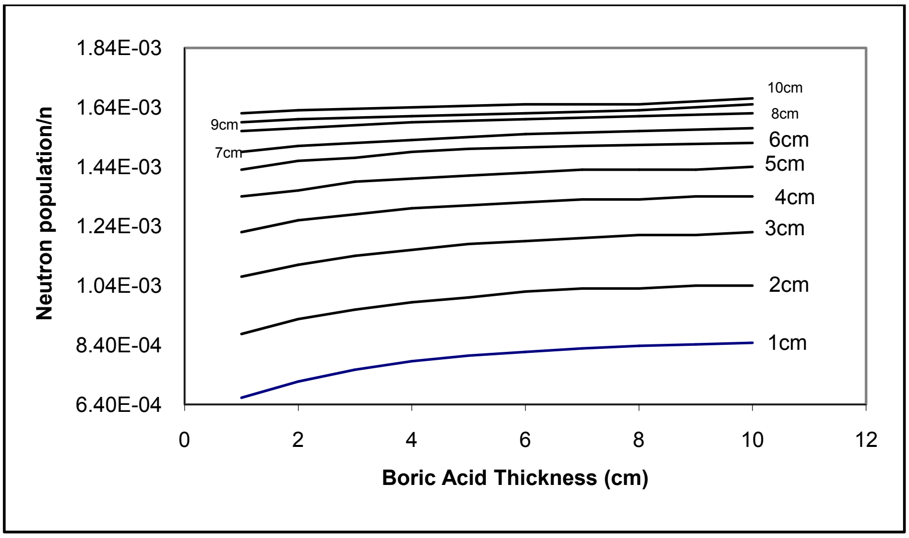


Fig. 3. Variation of neutron flux by boric acid thickness (second layer) for different thicknesses of polyethylene (first layer)

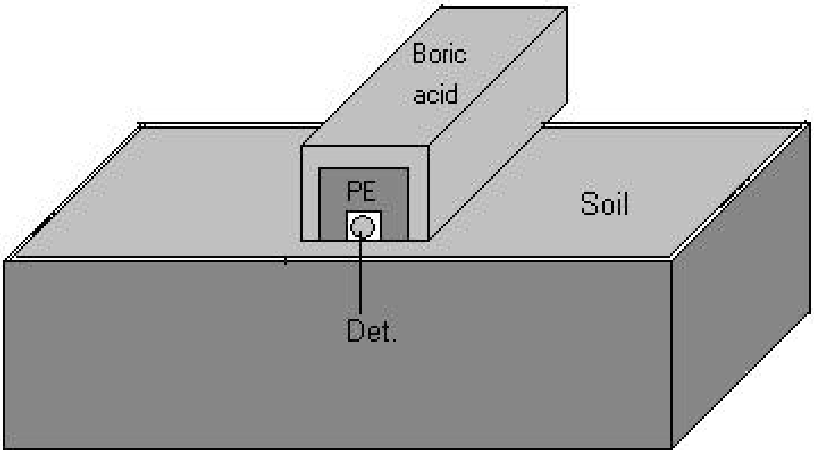


Fig. 4. Schematic diagram of Mont Carlo simulation

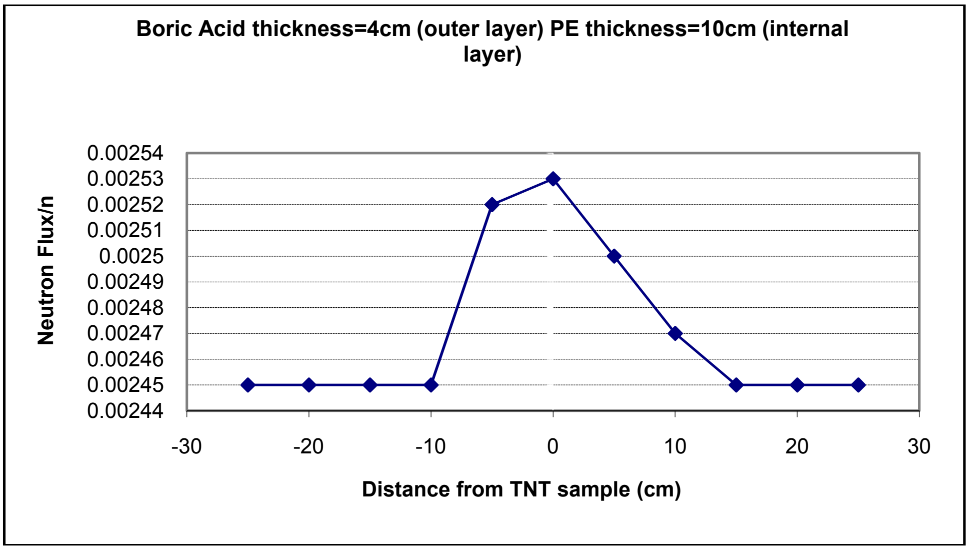


Fig. 5. Backscattered neutron flux with distance from center of TNT sample buried

REFERENCES

1. Fioretto, E., Barbui M., Giangrandi, S. M., Cinausero Nebbia, G. & Viesti, G. (2004). Neutron back-scattering sensor for the detection of landmines. *Nuclear Instruments and Methods in physics research B, 21,* 3457-459.
2. Nuclear Measuring Techniques Group & Shell Research and Technology Center, Amsterdam, P.O. Box 38000, Badhuisweg, 3, 1030, BN Amsterdam, The Netherlands.
3. Kiraly, B., Olgah, L. & Csikai, J. (2001). Neutron-based techniques for detection of explosives and drugs. *Radiation Physics and Chemistry, 61,* 781-784.
4. Esam, M., Hussein, A., Desrosiers1, M. & Edward, J. W. (2005*)*. On the use of radiation scattering for the detection of landmines. *Radiation Physics and Chemistry, 73,* 7-19.
5. Bom,V. R., Datema, C. P., Eijk, C. & Van, W. E. (2004). The status of the Delft University Neutron Backscatter Landmine Detector (DUNBLAD). *Applied Radiation and Isotopes, 61,* 21-25
6. Rezaei Ochbelagh, D., Miri Hakimabad, H. & Izadi Najafabadi, R. (2006). Determination of Am-Be neutron source used on landmine detection. *Asian Journal of Experimental sciences, 20*(2)*,* 243-252.
7. Brooks, F. D., Drosg, M., Buffler, A. & Allie, M. S. (2004). Detection of anti-personnel landmines by neutron scattering and attenuation. *Applied Radiation and Isotopes, 61,* 27-34.
8. Rezaei Ochbelagh, D., Miri Hakimabad, H. & Izadi Najafabadi, R. (2007).The investigation of Am–Be neutron source shield effect used on landmine detection. *Nuclear Instruments and Methods in Physics Research A, 577,* 756-761.
9. Shue, S. L., Faw, R. E. & Shulis, J. K. (1998). Thermal-neutron intensities in soils irradiated by fast neutrons from point sources. *Chemical Geology 144,* 47-61.
10. Drosga, M. & Brooks, F. D. (2005). Increasing the capability of MNBRP for the detection of anti-personnel landmines. *Applied Radiation and Isotopes Nov-Dec, 63*(5-6), 599-605.
11. Briesmeister, J. F. (2000). MCNP: A general Monte Carlo N-particle transport code. *Version 4C, Los Alamos National laboratory,* LA-13709-M.
12. Hadizadeh Yazdia, M. H., Mowlavi, A. A., Thompson, M. N. & Miri Hakimabad, H. (2004). Proper shielding for NaI(Tl) detectors in combined neutron-g fields using MCNP. *Nuclear Instruments and Methods in Physics Research A, 522,* 447-454.
13. Online Plotter for MCNP and ENDF cross section data, http://atom.kaeri.re.kr/endfplot.shtml.