https://doi.org/10.1080/17445647.2020.1784806 BFSZU 50 (2019) 48-53

ASRT

Bulletin of Faculty of Science - Zagazig University

https://bfszu.journals.ekb.eg

FS-ZU

SHIELDING ELECTRONIC CIRCUITS FROMSPACE-NEUTRONS AND CAPTURE GAMMA-RAYS

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ARTICLE HISTORY

Received: 17 March 2019

Revised: 20 April 2019

Accepted: 1 May 2019

KEY WORDS

Shielding materials

Space Neutron

Capture Gamma- Rays

MCNP5 code

Simulation Calculation

ABSTRACT: This work study the shielding effectiveness of polyethylene, polyethylene loaded with both boron (5% & 10% Boron) and lithium (7.5% lithium), aluminum and multilayer shield composed of aluminum and polyethylene loaded lithium against space-neutrons and neutron induced gamma rays to protect electronic circuits against space-neutrons and capture gamma-rays. MCNP5 code was used to analyze the shield thickness required to attenuate 14 MeV neutrons and secondary photons that produced from the interaction of fast neutrons with these materials. Effective attenuations for all sample materials have been calculated. No significant attenuation effect of adding boron to polyethylenedue to its low absorption cross section at high neutron energy. It was found that the multilayer shield is the best material to attenuate fluxes and doses of neutrons and gamma rays.This shield can attenuate neutron flux up to 99.62%, neutron dose to 99.73%, gamma flux to 96.90% and gamma dose to 97.97%.

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1. INTRODUCTION

By the increasing demand to utilize the electronic component devices in the radiation fields (biological diagnose, space trips), there is a need to understand the effect of neutrons to electronic component devices and circuits. Electronic system in high energy physics experiments and nuclear reactors exposed to radiations, such hard environment is negative and destructive to electronic devices and provide the performance of the device and also may stop its operation. When neutron incident on a target material, it knocked out the atoms from the lattice, producing a primary knocked atom (PKA). The displaced atom with the hole made in a lattice forms a Frankel pairs. If the PKA has sufficient high energy it can produce further secondary displace atoms on its bath in the material. To assure proper electronic devices operation, optimum shielding materials must be selected for protection against the effect of these radiations[Billings and Langley (1965),Bruzzi (2001), Mark´etaSedl´aˇckov´a(2014), NASA (1970)a,b, Omid Zeynali (2011)Omid Zeynali et al. (2012), William (200), Zeynali et al.(2011)].

Weight rather than cost is generally the principal design criteria in the application to mobile shield systems. The efficiency of a neutron attenuator can be correlated to its hydrogen density, and the efficiency of a gamma-ray attenuator can be correlated to the total density of the material. Polyethylene is a pure hydrocarbon $(CH_2)_n$ which contains 18% (by volume) more hydrogen than does water[Schaeffer, 1973]. In this study, we used polyethylene, polyethylene loaded with boron and with lithium, aluminum and multilayer shield.

Space is the tougher natural environment that electronic component devices are exposed toradiations in space is being classified into three major classes; the first class is caused by solar storms, dominated by proton, the second class of space radiation consists galactic cosmic rays originate outside solar system consist of 85% proton, 14% alpha particles and 1% heavier ions covering the full range of elements, the third class is consists of trapped electron and proton in Van Allen belts. Van Allen belts are a region where radiation is trapped in earth's magnetic field. The earth atmosphere protects the low earth orbit (LEO) from radiation belts. This radiations are the most penetrating radiations because of their high energy; each types of them has its individual effect on electronic component devices and it is necessary to know which type of device to be exposed and by which type of radiation,then the optimum shielding material will be selected for the protection purpose[Jevremovicand Kallimani (2005), Pham and El-Genk (2010)].

Secondary gamma rays, resulting from capture of neutrons of all energies and inelastic scattering of fast neutrons are often the determining factor in the shield design. Essentially all the elements exhibit radiative capture to a greater or a least extent. In a few cases, e.g., hydrogen and carbon-12, all the excitation energy of the compound nucleus formed by neutron capture appears as a single photons[Glasstone and Sesonske (1981)].

2. MATERIALS SPECIFICATIONS AND COMPOSITIONS

Five low density materials are tested as shielding materials for space shielding against high energy 14 MeV neutrons. These materials are polyethylene (Density =0.92 g/cm^3), polyethylene loaded with 5% boron (Density =0.95 g/cm^3) and 10% boron (Density=1.12 g/cm^3),polyethylene loaded with 7.5% lithium (Density = 1.06 g/cm^3), aluminum (Density =2.7 g/cm^3) and multilayer shield (Density = 1.71 g/cm^3).The natural abundance for boron isotopes is: 19.9% ^{10}B and 80.1% 11B.The natural abundance for lithium isotopes is: 7.42% 6Li and 92.58% ^{7}Li. The multilayer shield layout consists of pure aluminum (4 cm), lithium-polyethylene (12 cm) and pure aluminum (4 cm) as shown in Figure 1. These materials are selected with low density to reduce the mass of the shield and increasing the attenuation by adding boron or polyethylene [Schaeffer, 1973].

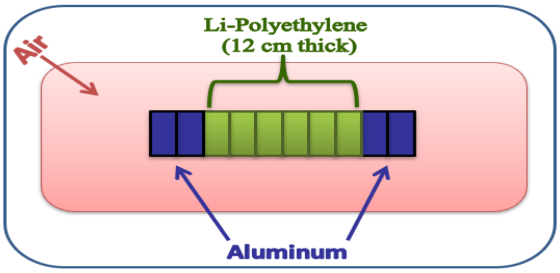

Fig. 1: Multilayer shield (3 Zones).

3. COMPUTATIONAL AND MATHEMATICAL MODEL

The MCNP5 Computer code [Briesmeister, 1993] which is based on Monte Carlo Method is used to model a shielding thickness of 20 cm with 100 cm x 100 cm for length and wide, respectively. A 14 MeV neutrons source that emits neutrons isotopically is impingement on the surface of the shield. The total neutron flux and dose rate (μSv/h) are calculated through the shield thick. Also the neutron induced gamma rays are also calculated. ANSIbuilt in MCNP5 module is used to convert neutron and gamma fluxes to dose rate. The entire thickness is divided into 10 intervals each with 2 cm thick [Jevremovic and Kallimani (2005)].

The purposes of these calculations are to develop computational models to examine the effectiveness of shielding materials and develop the best combination of materials to give the lowest weight and the highest shielding protection. Both neutron and neutron induced gamma rays analysis are performed for all six types of shielding materials included in Table 1.

4. RESULTS AND DISCUSSIONS

A point isotropic 14 MeV neutron source is located at one side of the shield and the tallies are calculated at the other side of the shield. The calculated tallies represent neutron flux (n/cm^2.s), neutron dose rate (μSv/h) and also neutron induced gamma flux and dose. Neutrons emitted from the source interact with shield materials, thermal neutrons interact with H_2 and produce gamma rays also fast neutrons interact with carbon atom with the emission of gamma rays, which all are calculated with F4 Tally for γ rays.

4.1. Neutron Flux

The neutron fluxesare calculated for the six types of shielding materials as shown in Table 1. Figure 2 shows the relation between shield density and the neutron flux for all materials at 10 cm and 20 cm thicknesses. Figure 3 represents the relation between shield thickness (cm) and the neutron flux (n/cm^2.s) for all material. No significant attenuation effect of boron due to its low absorption cross section at high neutron energy.

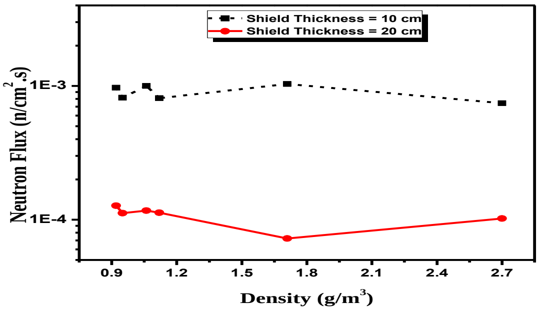

Fig 2: Relation between shield density and neutron flux at 10 cm and 20 cm shield thicknesses.

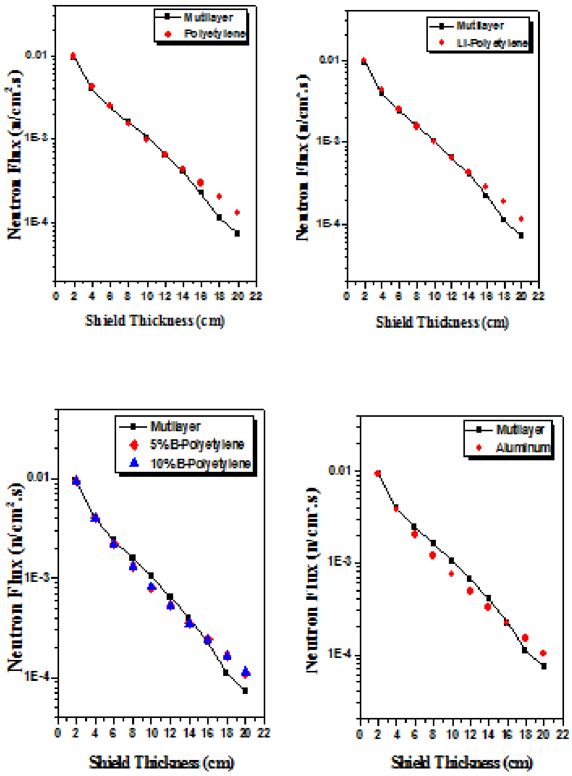

Fig 3: Neutron flux for multilayer shield compared with flux for other materials.

Table 1: Neutron flux (n/cm^2.s) calculated for shielding materials at different shield thickness x (cm).

x (cm)	Multilayer	Polyeth-ylene	5%B – Polyethylene	10%B – Polyethylene	7.5 Li – Polyethylene	Aluminum
2	9.43E-03	9.62E-3	9.49E-3	9.48E-3	9.72E-3	9.38E-3
4	3.91E-03	4.23E-3	4.00E-3	3.98E-3	4.36E-3	3.81E-3
6	2.39E-03	2.43E-3	2.19E-3	2.18E-3	2.53E-3	2.04E-3
8	1.61E-03	1.50E-3	1.30E-3	1.29E-3	1.56E-3	1.19E-3
10	1.04E-03	9.70E-4	8.15E-4	8.10E-4	1.00E-3	7.43E-4
12	6.52E-04	6.42E-4	5.30E-4	5.27E-4	6.52E-4	4.82E-4
14	4.02E-04	4.32E-4	3.54E-4	3.53E-4	4.32E-4	3.22E-4
16	2.24E-04	2.49E-4	2.41E-4	2.41E-4	2.88E-4	2.20E-4
18	1.12E-04	1.99E-4	1.66E-4	1.66E-4	1.11E-4	1.51E-4
20	7.23E-05	1.27E-4	1.12E-4	1.13E-4	1.17E-4	1.02E-4

The Attenuation ratio [Emergent flux/ Initial flux (ϕ/ϕ0)] were calculated for polyethylene, Boron polyethylene (5% B), Boron polyethylene (10% B), Boron polyethylene (10% B), Lithium polyethylene (7.5% Li), Aluminum and Multilayer shield (Al+Li-Poy.+Al) shield samples using the initial flux of 0.01893 neutrons/ cm2.s; their values are 0.00672, 0.00591, 0.00596, 0.00618, 0.539 and 0.00382, respectively. It was found that the best condition for calculations to attenuate 14 MeV neutrons with the multilayer shield.

4.2. Neutron Dose

The neutron doses are calculated for all six types of shielding materials as shown in Table 2.Figure 4 represents the relation between shield thickness (cm) and the neutron dose (μ Sv/h) for all material.

Table 2: Neutron dose (μ Sv/h) calculated for different shield thickness x (cm).

x (cm)	Multilayer	Polyeth-ylene	5%B – Polyethylene	10%B – Polyethylene	7.5 Li – Polyethylene	Aluminum
2	1.75E-02	1.84E-2	1.84E-2	1.84E-2	1.83E-2	1.86E-2
4	7.19E-03	7.10E-3	7.09E-3	7.11E-3	7.04E-3	7.21E-3
6	3.62E-03	3.67E-3	3.66E-3	3.68E-3	3.62E-3	3.74E-3
8	1.93E-03	2.10E-3	2.09E-3	2.10E-3	2.05E-3	2.14E-3
10	1.10E-03	1.28E-3	1.27E-3	1.28E-3	1.23E-3	1.31E-3
12	6.45E-04	8.21E-4	8.13E-4	8.22E-4	7.77E-4	8.34E-4
14	3.92E-04	5.44E-4	5.37E-4	5.44E-4	5.05E-4	5.56E-4
16	2.41E-04	3.69E-4	3.64E-4	3.70E-4	3.37E-4	3.77E-4
18	1.55E-04	2.55E-4	2.51E-4	2.56E-4	2.28E-4	2.59E-4
20	1.04E-04	1.76E-4	1.73E-4	1.77E-4	1.53E-4	1.77E-4

Figure 5 shows the relation between shield density and the neutron dose for all materials at 10 and 20 cm thickness. It was found that the best condition for calculations to attenuate 14 MeV neutrons with the multilayer shield type.

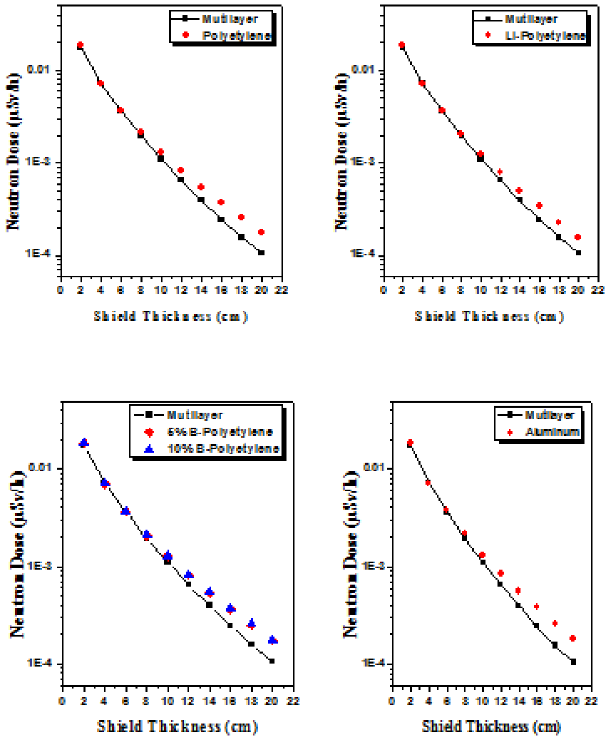

Fig 4: Neutron dose for multilayer shield compared with flux for other materials.

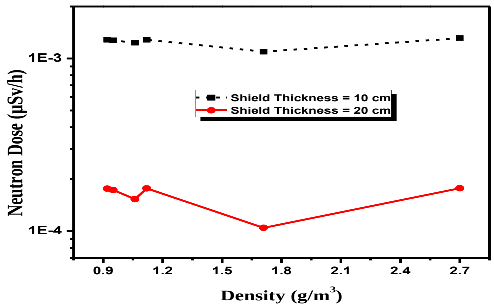

Fig 5: Relation between shield density and neutron dose at 10 cm and 20 cm shield thicknesses.

4.3. Gamma Flux

Secondary gamma rays, resulting from capture of neutrons of all energies are often the determining factor in the shield design. The Gama fluxesare calculated for all six types of shielding materials as shown in Table 3.Figure 6 represents the relation between shield thickness (cm) and the gamma flux (γ/cm2.s) for all material.

Table 3: Gamma flux (γ /cm2.s) calculated for shielding materials at different shield thickness x (cm).

x (cm)	Multilayer	Polyeth-ylene	5%B – Polyethylene	10%B – Polyethylene	7.5 Li – Polyethylene	Aluminum
2	2.33E-03	2.52E-4	3.25E-4	3.35E-4	2.91E-4	2.41E-3
4	1.68E-03	1.95E-4	2.82E-4	2.89E-4	2.31E-4	1.89E-3
6	8.99E-04	1.41E-4	2.22E-4	2.26E-4	1.71E-4	1.31E-3
8	5.59E-04	1.04E-4	1.69E-4	1.71E-4	1.27E-4	8.93E-4
10	3.75E-04	7.73E-5	1.27E-4	1.28E-4	9.38E-5	6.12E-4
12	2.58E-04	5.76E-5	9.47E-5	9.53E-5	6.97E-5	4.23E-4
14	1.80E-04	4.32E-5	7.03E-5	7.09E-5	5.17E-5	2.94E-4
16	1.29E-04	3.23E-5	5.18E-5	5.22E-5	3.82E-5	2.06E-4
18	9.76E-05	2.37E-5	3.73E-5	3.78E-5	2.77E-5	1.42E-4
20	6.57E-05	1.67E-5	2.52E-5	2.56E-5	1.91E-5	9.06E-5

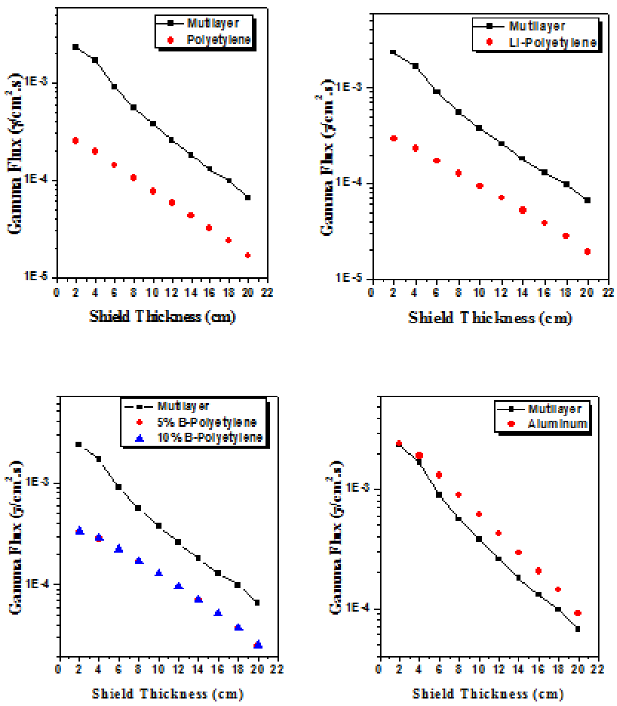

Fig 6: Gamma flux for multilayer shield compared with flux for other materials.

Figure 7 shows the relation between shield density and the gamma flux for all materials at 10 and 20 cm thickness.

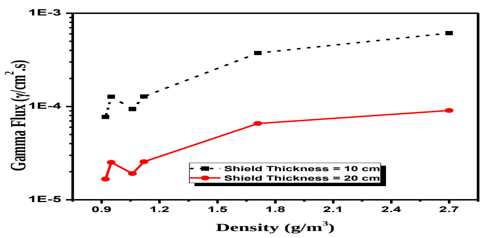

Fig 7: Relation between shield density and gamma flux at 10cm and 20 cm shield thicknesses.

4.4. Gamma Dose

The gamma doses are calculated for all six types of shielding materials as shown in Table 4. Figure 8 represents the relation between shield thickness (cm) and the gamma dose (μ Sv/h) for all material. Figure 9 shows the relation between shield density and the gamma dose for all materials.

Table 4: Gamma dose (μ Sv/h) calculated for different shield thickness x (cm).

x (cm)	Multilayer	Polyeth-ylene	5%B – Polyethylene	10%B – Polyethylene	7.5 Li – Polyethylene	Aluminum
2	7.15E-05	1.233E-5	1.325E-5	1.363E-5	1.336E-5	7.308E-5
4	4.83E-05	9.082E-6	9.804E-6	1.009E-5	9.949E-6	5.262E-5
6	2.46E-05	6.295E-6	6.758E-6	6.953E-6	6.977E-6	3.431E-5
8	1.49E-05	4.464E-6	4.715E-6	4.841E-6	4.966E-6	2.246E-5
10	9.93E-06	3.221E-6	3.350E-6	3.435E-6	3.576E-6	1.498E-5
12	6.78E-06	2.356E-6	2.418E-6	2.482E-6	2.602E-6	1.018E-5
14	4.71E-06	1.740E-6	1.769E-6	1.818E-6	1.905E-6	7.035E-6
16	3.33E-06	1.291E-6	1.307E-6	1.342E-6	1.397E-6	4.911E-6
18	2.56E-06	9.478E-7	9.594E-7	9.881E-7	1.015E-6	3.424E-6
20	1.79E-06	6.746E-7	6.842E-7	7.054E-7	7.121E-7	2.288E-6

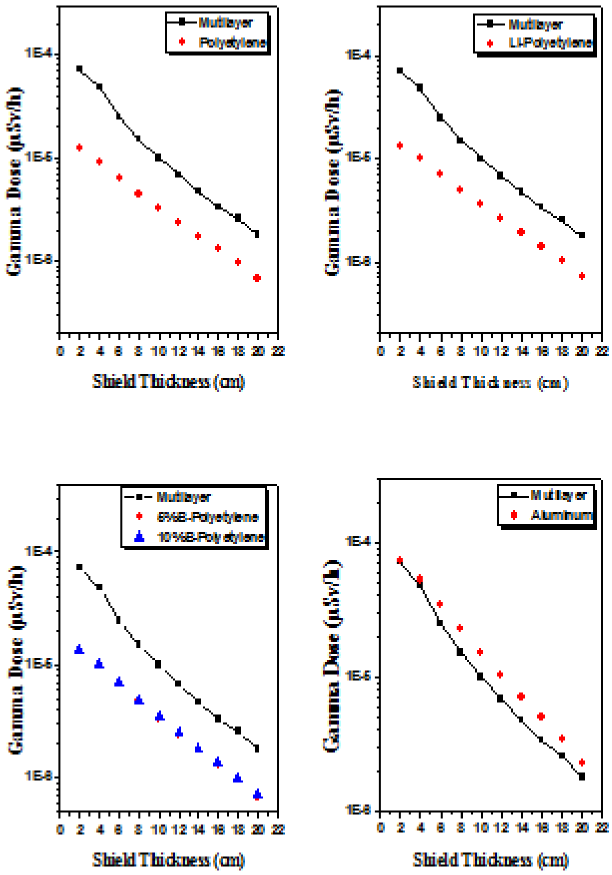

Fig 8: Gamma dose for multilayer shield compared with other materials.

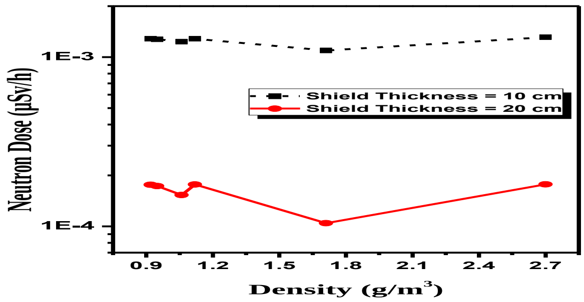

Fig. 9: Relation between shield density and gamma dose at 10cm and 20 cm shield thicknesses.

5. CONCLUSION

Five low weight materials; pure polyethylene, polyethylene- boron (5% boron) , polyethylene- boron (10% boron), polyethylene-lithium (7.5% Lithium), aluminum and a multilayer shield composed of aluminum and lithium-polyethylene are tested for protection against high energy 14 MeV neutrons which can be used in the space radiation shielding equipment's design. It was found that the multilayer shield composed of aluminum and polyethylene- lithium with 20 cm thick is the best material used to attenuate fluxes and doses of neutrons and secondary gamma rays. The multilayer shield can attenuate neutron flux up to 99.62%, neutron dose to 99.73%, gamma flux to 96.90% and gamma dose to 97.97%.

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