**American International Journal of Research in Science, Technology, Engineering & Mathematics**

Available online at http://www.iasir.net

ISSN (Print): 2328-3491, ISSN (Online): 2328-3580, ISSN (CD-ROM): 2328-3629

AIJRSTEM is a refereed, indexed, peer-reviewed, multidisciplinary and open access journal published by International Association of Scientific Innovation and Research (IASIR), USA

*(An Association Unifying the Sciences, Engineering, and Applied Research)*

# Simulated Results for Neutron Radiations Shielding Using Monte Carlo

C .E. Okon[*1], I. O. Akpan[2]

[*1]School of Physics & Astronomy,
University of Manchester,
Manchester, UNITED KINGDOM.

[*2]Department of Physics,
University of Calabar, NIGERIA.

***Abstract**: This report demonstrates the results of the experiment that was carried out in the Radiation Laboratory in University of Liverpool, United Kingdom. The radiation source used for the Neutron experiment was Americium Beryllium (Am/Be) put in water tank. Materials used as moderators were 2cm by 100cm by 100cm Polythene and 1cm by 100cm by 100cm. Cadmium sheet was also used to filter out thermal neutrons with energies of 0.025eV or less. The cadmium sheet was placed by the tank so that it is backed by adequate material for attenuating the capture neutrons. The detector used for the neutron experiment was $^{3}$He-RSP41640203 Detector (100cm long x 5cm diameter).*

## I. Introduction

Nuclear radiation such as gamma and neutron radiations are hazardous to human beings due to their ionizing effect in body tissue[3]. Gamma radiation and neutrons have high penetrating power and sources of these radiations must be shielded[6]. Although it present a serious shielding problem in any situation where it is produced in large scale. It is very difficult to shield high-speed neutrons because absorption cross sections are much lower at higher energies[1]. In reactor physics, it is important when constructing a nuclear reactor to provide adequate shielding so that neutrons and gamma radiation originating in the reactor core are prevented from escaping into the reactor's surroundings where people are working[2]. The same problem arises to a smaller extent with radioactive isotopes which are used on a large scale in science and engineering. Although the size and strength of the radioactive sources in this aspect is very much less than the core of a nuclear reactor, it is nevertheless necessary to reduce the radiation escaping from such a source to an acceptably low level.

## II. Aim & Objective

The aim of this research was to establish the relationship between the source strength and shield thickness. Monte Carlo simulations using MCNP was also employed for the analysis.

## III. Methodology

The radiation source used for the Neutron experiment was Americium Beryllium (Am/Be) put in water tank because water slows down an appreciable fraction of the moderately fast neutrons. Water is the best neutron shield material, although it is a poor absorber of gamma radiation[5]. Materials used as moderators were 2cm by 100cm by 100cm Polythene and 1cm by 100cm by 100cm Borated Polythene. Cadmium sheet was also used to filter out thermal neutrons with energies of 0.025eV or less. Cadmium is more effective than boron for absorbing thermal neutrons, whereas boron is more effective for absorbing epithermal neutrons (energy range 0.1eV to 10eV)[4]. Since cadmium captures slow neutrons so readily, and it also has a fairly high mass number, it was used as a shielding material. The cadmium sheet was placed by the tank so that it is backed by adequate material for attenuating the capture neutrons. There is a drawback associated with cadmium sheet, having a high resonance peak for the capture of neutrons in a limited energy range (below about 1eV). Although most of the neutrons within this range are captured, a large proportion of those with higher energies still penetrate the shield[8]. The detector used for the neutron experiment was $^{3}$He-RSP41640203 Detector (100cm long x 5cm diameter).

## IV. Result & Discussions

### A. *Polythene before the Detector (MCNP-Simulations)*

As the polythene is added, neutrons are thermalized and, therefore more are detected. As the moderator thickness is increased further, it causes the neutrons to lose too much of their energy. Some neutrons would be captured or would scatter off its path to the detector which causes the drop in the detected number of neutrons as a function of moderator thickness. The results also show that, the incident high, the detected high and the total incident all decrease with moderator thickness; whereas the incident thermal, detected thermal and total detected all increase parabolically with a maximum value at about 8cm moderator thickness.

See Data: Appendix "A" Table 1 & 2

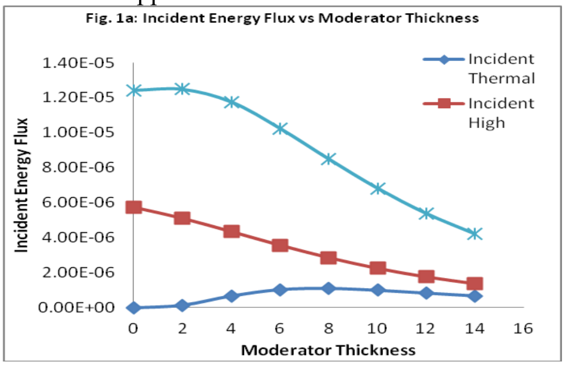


Fig. 1a: Incident Energy Flux vs Moderator Thickness

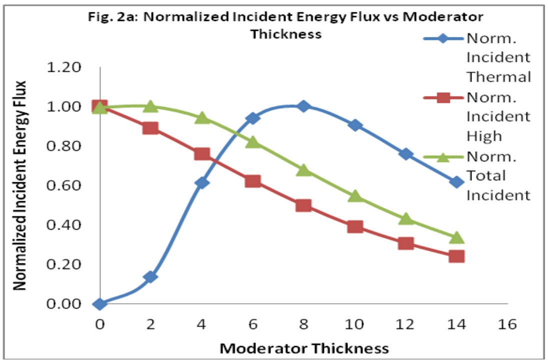


Fig. 2a: Normalized Incident Energy Flux vs Moderator Thickness

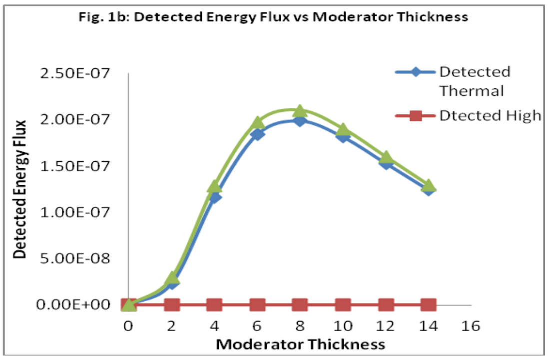


Fig. 1b: Detected Energy Flux vs Moderator Thickness

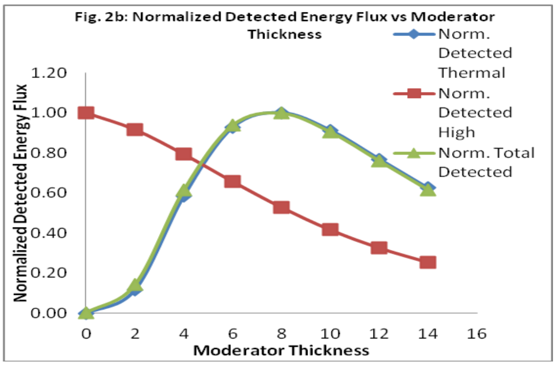


Fig. 2b: Normalized Detected Energy Flux vs Moderator Thickness

### *B. Polythene after the Detector (MCNP-Simulations)*

The moderator thickness ratio increases as polythene is added behind the detector, but not as greatly as when the polythene is between the source and the detector. This is because, when the fast neutrons which passes the detector gets to the moderator, it is thermalized and reflected back through the scattering process which leads to the thermalization of the fast neutrons, thus the polythene moderated behind the detector acts both as a moderator and a reflector. As the thickness increases, the number of neutrons detected approaches a constant value because at this point the moderator might have reached its effective moderation thickness. The graphs below also indicate that, the incident thermal, detected thermal and detected total all increase exponentially with moderator thickness; whereas the moderation effect of the polythene material is not really effective as much of the high neutrons are being detected in the detector as compared to that observed with the polythene before the detector.

See Data: Appendix "A" Table 3 & 4

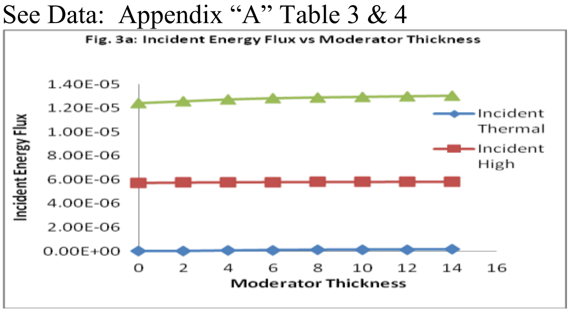


Fig. 3a: Incident Energy Flux vs Moderator Thickness

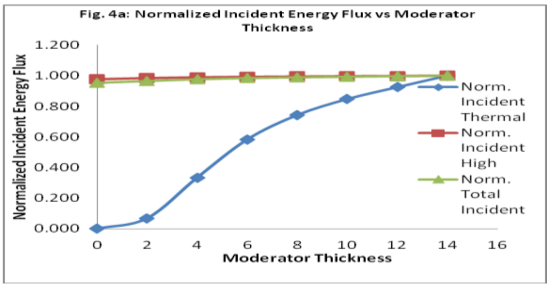


Fig. 4a: Normalized Incident Energy Flux vs Moderator Thickness

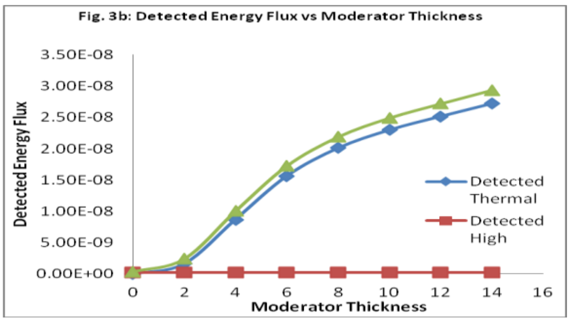


Fig. 3b: Detected Energy Flux vs Moderator Thickness

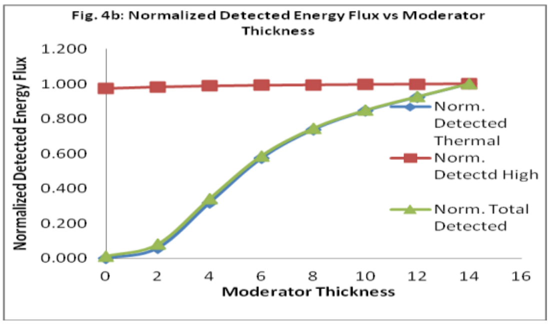


Fig. 4b: Normalized Detected Energy Flux vs Moderator Thickness

### *C. Borated Polythene before the Detector (MCNP-Simulations)*

More effective shield can sometimes be obtained by adding borated polythene. The addition of borated polythene results in a lower capture neutron does than that provided by pure polythene[7]. In the experiment setup, it shows that with borated polythene, the moderation effect of polythene is removed. The number of neutrons detected greatly decreases as the thickness of the borated polythene is increased. This is a neutron shield. Cadmium and Boron-10 both have high neutron cross-section as well as serve as good neutron absorbers. Hence, these materials greatly shield the neutrons from reaching the detector. The thermal neutrons which escaped from being captured in the cadmium is easily captured in the borated polythene and the fast neutron which cadmium is ineffective in capturing is thermalized by the hydrogen atom in the borated polythene and some are captured further thereby reducing the number of observed neutrons.

See Data: Appendix "A" Table 5 & 6

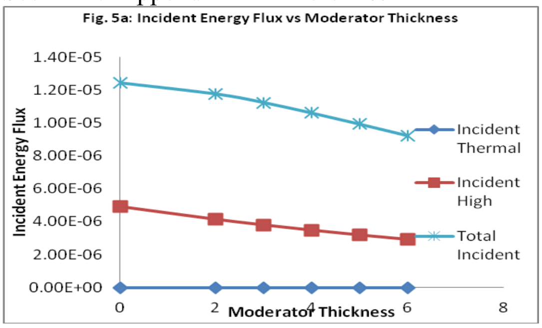


Fig. 5a: Incident Energy Flux vs Moderator Thickness

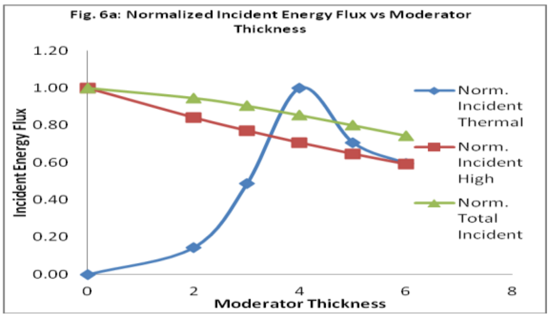


Fig. 6a: Normalized Incident Energy Flux vs Moderator Thickness

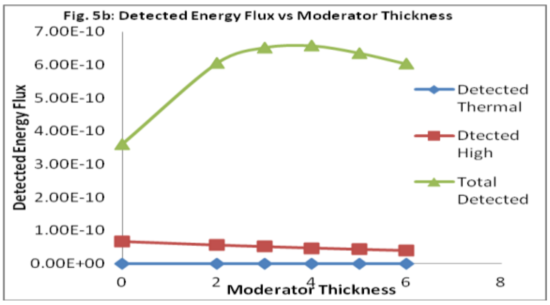


Fig. 5b: Detected Energy Flux vs Moderator Thickness

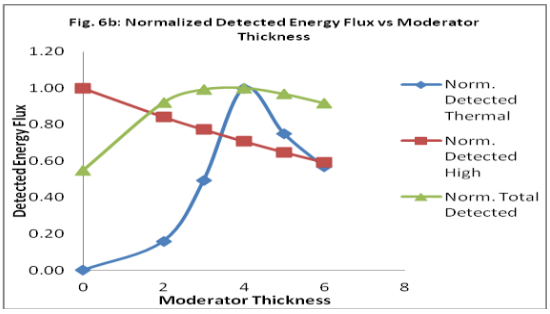


Fig. 6b: Normalized Detected Energy Flux vs Moderator Thickness

### *D. Borated Polythene after the Detector (MCNP-Simulations)*

The case shown in Fig.8 shows the reverse case of when the Borated Polythene is before the detector. In this instance, more neutrons are being detected as a result of backscattering effect and fewer neutrons are being absorbed compared to the case where the material was before the detector.

See Data: Appendix "A" Table 7 & 8

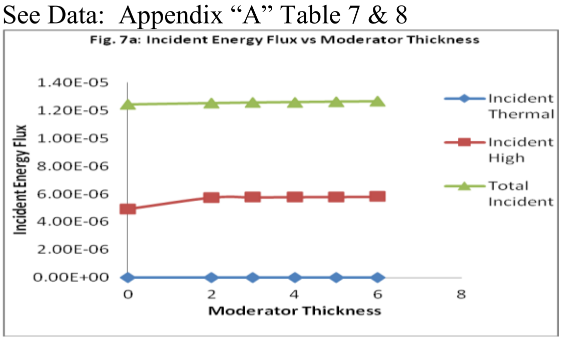


Fig. 7a: Incident Energy Flux vs Moderator Thickness

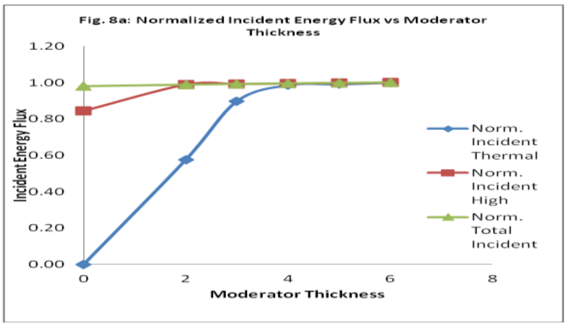


Fig. 8a: Normalized Incident Energy Flux vs Moderator Thickness

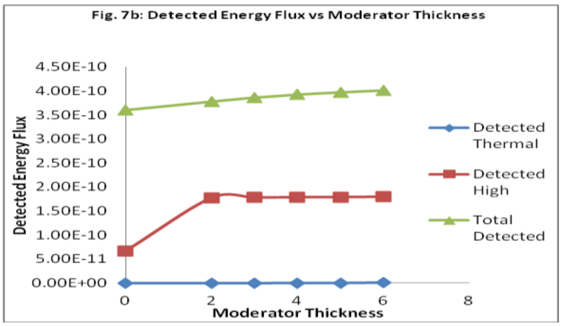


Fig. 7b: Detected Energy Flux vs Moderator Thickness

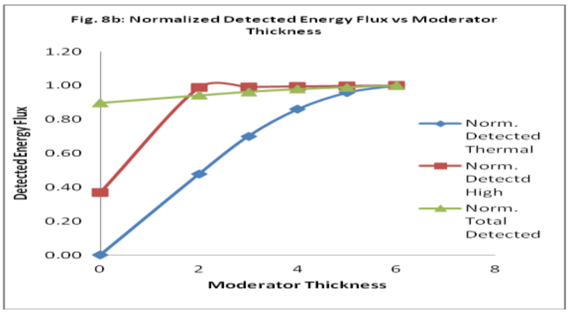


Fig. 8b: Normalized Detected Energy Flux vs Moderator Thickness

### *E. Normalized Efficiencies for Polythene and Boratedpolythene*

From the graphs below it is observed that the efficiency before the detector is higher than that after the detector. See Data: Appendix "A" Table 9 & 10

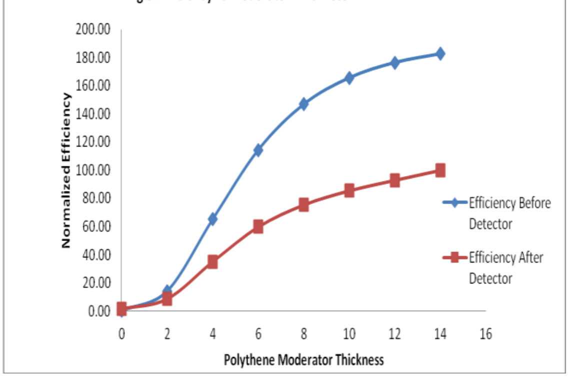

Fig.9: Efficiency vs Moderator Thickness

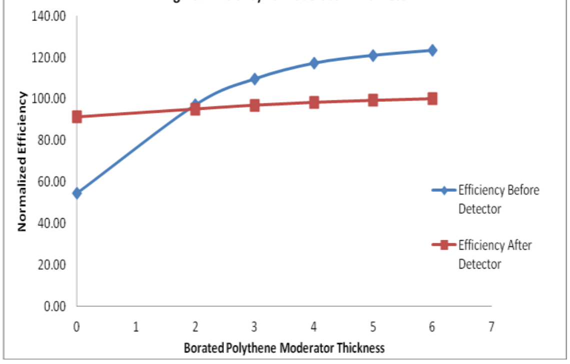

Fig.10: Efficiency vs Moderator Thickness

## References

[1] Nuclear Engineering International, 1999 World Nuclear Industry Handbook, Nick Fielder, 1999.
[2] Y. A. Cengel and M. A. Boles, Thermodynamics an Engineering Approach, McGraw Hill, 1994.
[3] M. El-Wakil, Nuclear Power Engineering, McGraw-Hill, 1962.
[4] Glassione and Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Company, 1981.
[5] J. Lamarsh and A. Baratta, Introduction to Nuclear Engineering, Prentice Hall Inc., 2001.
[6] J. Lilley, Nuclear Physics Principles and Applications, John Wiley and Sons, Ltd, 2001.
[7] N. Todreas and M. Kazimi, Nuclear Systems 1 Thermal Hydraulic Fundamentals, Thermisphere Publishing Corporation, 1990.
[8] R. H. S. Winterton, Thermal Design of Nuclear Reactors, Wheaton & Co. Ltd., Exeter, 1981.

## APPENDIX A

**Table 1:**

| | MCNP SIMULATION POLYTHENE BEFORE DETECTOR | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Incident Energy Flux** | | **Detected Energy Flux** | | **Total Energy Flux** | | |
| **Thickness (cm)** | **Thermal** | **High** | **Thermal** | **High** | **Incident** | **Detected** | **Efficiency** |
| **0** | 0.00E+00 | 5.72E-06 | 0.00E+00 | 1.76E-10 | 1.24E-05 | 3.60E-10 | 0.00 |
| **2** | 1.50E-07 | 5.10E-06 | 2.34E-08 | 1.61E-10 | 1.25E-05 | 2.97E-08 | 0.24 |
| **4** | 6.78E-07 | 4.34E-06 | 1.16E-07 | 1.40E-10 | 1.18E-05 | 1.29E-07 | 1.10 |
| **6** | 1.04E-06 | 3.57E-06 | 1.85E-07 | 1.16E-10 | 1.02E-05 | 1.98E-07 | 1.93 |
| **8** | 1.10E-06 | 2.86E-06 | 1.99E-07 | 9.30E-11 | 8.50E-06 | 2.10E-07 | 2.47 |
| **10** | 1.00E-06 | 2.25E-06 | 1.82E-07 | 7.33E-11 | 6.83E-06 | 1.91E-07 | 2.79 |
| **12** | 8.38E-07 | 1.76E-06 | 1.53E-07 | 5.74E-11 | 5.39E-06 | 1.60E-07 | 2.97 |
| **14** | 6.81E-07 | 1.37E-06 | 1.24E-07 | 4.48E-11 | 4.22E-06 | 1.30E-07 | 3.08 |

**Table 2:**

| | MCNP SIMULATION POLYTHENE BEFORE DETECTOR NORMALIZED VALUES | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Normalized Incident Energy Flux** | | **Normalized Detected Energy Flux** | | **Normalized Total Energy Flux** | | |
| **Thickness (cm)** | **Thermal** | **High** | **Thermal** | **High** | **Incident** | **Detected** | **Efficiency** |
| **0** | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 | 0.17 |
| **2** | 0.14 | 0.89 | 0.12 | 0.92 | 1.00 | 0.14 | 14.14 |
| **4** | 0.61 | 0.76 | 0.59 | 0.79 | 0.94 | 0.61 | 65.19 |
| **6** | 0.94 | 0.62 | 0.93 | 0.66 | 0.82 | 0.94 | 114.42 |
| **8** | 1.00 | 0.50 | 1.00 | 0.53 | 0.68 | 1.00 | 146.88 |
| **10** | 0.91 | 0.39 | 0.91 | 0.42 | 0.55 | 0.91 | 165.68 |
| **12** | 0.76 | 0.31 | 0.77 | 0.33 | 0.43 | 0.76 | 176.51 |
| **14** | 0.62 | 0.24 | 0.62 | 0.25 | 0.34 | 0.62 | 182.71 |

**Table 3:**

| Thickness (cm) | MCNP SIMULATION POLYTENE AFTER DETECTOR | | | | | | |
|---|---|---|---|---|---|---|---|
| | Incident Energy Flux | | Detected Energy Flux | | Total Energy Flux | | |
| | Thermal | High | Thermal | High | Incident | Detected | Efficiency |
| 0 | 0.00E+00 | 5.72E-06 | 0.00E+00 | 1.76E-10 | 1.24E-05 | 3.60E-10 | 0.00 |
| 2 | 1.03E-08 | 5.76E-06 | 1.62E-09 | 1.77E-10 | 1.26E-05 | 2.38E-09 | 0.02 |
| 4 | 5.08E-08 | 5.79E-06 | 8.69E-09 | 1.78E-10 | 1.27E-05 | 1.00E-08 | 0.08 |
| 6 | 8.88E-08 | 5.81E-06 | 1.56E-08 | 1.79E-10 | 1.28E-05 | 1.73E-08 | 0.13 |
| 8 | 1.13E-07 | 5.82E-06 | 2.01E-08 | 1.79E-10 | 1.29E-05 | 2.19E-08 | 0.17 |
| 10 | 1.29E-07 | 5.83E-06 | 2.30E-08 | 1.80E-10 | 1.29E-05 | 2.49E-08 | 0.19 |
| 12 | 1.41E-07 | 5.84E-06 | 2.52E-08 | 1.80E-10 | 1.30E-05 | 2.72E-08 | 0.21 |
| 14 | 1.52E-07 | 5.85E-06 | 2.72E-08 | 1.80E-10 | 1.30E-05 | 2.94E-08 | 0.23 |

**Table 4:**

| Thickness (cm) | MCNP SIMULATION POLYTHENE AFTER DETECTOR NORMALIZED VALUES | | | | | | |
|---|---|---|---|---|---|---|---|
| | Normalized Incident Energy Flux | | Normalized Detected Energy Flux | | Normalized Total Energy Flux | | |
| | Thermal | High | Thermal | High | Incident | Detected | Efficiency |
| 0 | 0.000 | 0.979 | 0.000 | 0.975 | 0.954 | 0.012 | 1.29 |
| 2 | 0.067 | 0.986 | 0.059 | 0.983 | 0.965 | 0.081 | 8.40 |
| 4 | 0.334 | 0.991 | 0.319 | 0.989 | 0.977 | 0.341 | 34.92 |
| 6 | 0.583 | 0.993 | 0.574 | 0.992 | 0.984 | 0.587 | 59.66 |
| 8 | 0.743 | 0.995 | 0.739 | 0.994 | 0.989 | 0.745 | 75.33 |
| 10 | 0.847 | 0.997 | 0.845 | 0.996 | 0.993 | 0.848 | 85.43 |
| 12 | 0.925 | 0.999 | 0.925 | 0.998 | 0.997 | 0.926 | 92.92 |
| 14 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 100.00 |

**Table 5:**

| Thickness (cm) | MCNP SIMULATION BORATEDPOLYTHENE BEFORE DETECTOR | | | | | | |
|---|---|---|---|---|---|---|---|
| | Incident Energy Flux | | Detected Energy Flux | | Total Energy Flux | | |
| | Thermal | High | Thermal | High | Incident | Detected | Efficiency |
| 0 | 0.00E+00 | 4.93E-06 | 0.00E+00 | 6.62E-11 | 1.24E-05 | 3.60E-10 | 0.003 |
| 2 | 1.31E-12 | 4.15E-06 | 9.84E-14 | 5.57E-11 | 1.18E-05 | 6.05E-10 | 0.005 |
| 3 | 4.37E-12 | 3.80E-06 | 3.03E-13 | 5.11E-11 | 1.12E-05 | 6.53E-10 | 0.006 |
| 4 | 9.00E-12 | 3.48E-06 | 6.15E-13 | 4.68E-11 | 1.06E-05 | 6.58E-10 | 0.006 |
| 5 | 6.37E-12 | 3.19E-06 | 4.61E-13 | 4.28E-11 | 9.93E-06 | 6.36E-10 | 0.006 |
| 6 | 5.37E-12 | 2.91E-06 | 3.49E-13 | 3.92E-11 | 9.23E-06 | 6.03E-10 | 0.007 |

**Table 6:**

| Thickness (cm) | MCNP SIMULATION BORATEDPOLYTHENE BEFORE DETECTOR NORMALIZED VALUES | | | | | | |
|---|---|---|---|---|---|---|---|
| | Normalized Incident Energy Flux | | Normalized Detected Energy Flux | | Normalized Total Energy Flux | | |
| | Thermal | High | Thermal | High | Incident | Detected | Efficiency |
| 0 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.55 | 54.74 |
| 2 | 0.15 | 0.84 | 0.16 | 0.84 | 0.95 | 0.92 | 97.22 |
| 3 | 0.49 | 0.77 | 0.49 | 0.77 | 0.90 | 0.99 | 109.67 |
| 4 | 1.00 | 0.71 | 1.00 | 0.71 | 0.85 | 1.00 | 117.20 |
| 5 | 0.71 | 0.65 | 0.75 | 0.65 | 0.80 | 0.97 | 120.96 |
| 6 | 0.60 | 0.59 | 0.57 | 0.59 | 0.74 | 0.92 | 123.36 |

**Table 7:**

| Thickness (cm) | MCNP SIMULATION BORATEDPOLYTENE AFTER DETECTOR | | | | | | |
|---|---|---|---|---|---|---|---|
| | Incident Energy Flux | | Detected Energy Flux | | Total Energy Flux | | |
| | Thermal | High | Thermal | High | Incident | Detected | Efficiency |
| 0 | 0.00E+00 | 4.93E-06 | 0.00E+00 | 6.62E-11 | 1.24E-05 | 3.60E-10 | 0.0029 |
| 2 | 4.50E-12 | 5.76E-06 | 2.73E-13 | 1.77E-10 | 1.25E-05 | 3.78E-10 | 0.0030 |
| 3 | 7.01E-12 | 5.78E-06 | 4.00E-13 | 1.78E-10 | 1.26E-05 | 3.86E-10 | 0.0031 |
| 4 | 7.69E-12 | 5.80E-06 | 4.91E-13 | 1.79E-10 | 1.26E-05 | 3.93E-10 | 0.0031 |
| 5 | 7.73E-12 | 5.81E-06 | 5.47E-13 | 1.79E-10 | 1.26E-05 | 3.98E-10 | 0.0031 |
| 6 | 7.80E-12 | 5.82E-06 | 5.71E-13 | 1.80E-10 | 1.27E-05 | 4.01E-10 | 0.0032 |

**Table 8:**

| | MCNP SIMULATION BORATEDPOLYTHENE AFTER DETECTOR NORMALIZED VALUES | | | | | | |
|---|---|---|---|---|---|---|---|
| | Normalized Incident Energy Flux | | Normalized Detected Energy Flux | | Normalized Total Energy Flux | | |
| **Thickness (cm)** | **Thermal** | **High** | **Thermal** | **High** | **Incident** | **Detected** | **Efficiency** |
| **0** | 0.00 | 0.85 | 0.00 | 0.37 | 0.98 | 0.90 | 91.44 |
| **2** | 0.58 | 0.99 | 0.48 | 0.99 | 0.99 | 0.94 | 95.18 |
| **3** | 0.90 | 0.99 | 0.70 | 0.99 | 0.99 | 0.96 | 96.96 |
| **4** | 0.99 | 1.00 | 0.86 | 0.99 | 1.00 | 0.98 | 98.30 |
| **5** | 0.99 | 1.00 | 0.96 | 1.00 | 1.00 | 0.99 | 99.22 |
| **6** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 100.00 |

**Table 9:**

| NORMALIZED EFFICIENCY VALUES USING POLYTHENE | | |
|---|---|---|
| **Thickness (cm)** | **Before Detector** | **After Detector** |
| **0** | 0.17 | 1.29 |
| **2** | 14.14 | 8.40 |
| **4** | 65.19 | 34.92 |
| **6** | 114.42 | 59.66 |
| **8** | 146.88 | 75.33 |
| **10** | 165.68 | 85.43 |
| **12** | 176.51 | 92.92 |
| **14** | 182.71 | 100.00 |

**Table 10:**

| NORMALIZED EFFICIENCY VALUES USING BORATEDPOLYTHENE | | |
|---|---|---|
| **Thickness (cm)** | **Before Detector** | **After Detector** |
| **0** | 54.74 | 91.44 |
| **2** | 97.22 | 95.18 |
| **3** | 109.67 | 96.96 |
| **4** | 117.20 | 98.30 |
| **5** | 120.96 | 99.22 |
| **6** | 123.36 | 100.00 |