International Journal of Research and Review
Vol. 9; Issue: 6; June 2022
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Research Paper

The Effectiveness of Bi_2O_3 Apron on Attenuation of X-Ray and Gamma Ray by MCNPX Simulation

Veronika Dyah Suryanti, Eko Hidayanto, Fajar Arianto

[1]Department of Physics, Diponegoro University, Semarang, Indonesia.

Corresponding Author: Eko Hidayanto

DOI: https://doi.org/10.52403/ijrr.20220608

ABSTRACT

Apron is one of the radiation shields, generally the apron used in radiodiagnostic installations is made of lead. However, lead aprons have disadvantages such as toxicity and relatively heavy weight. Therefore, it is necessary to innovate apron materials that are better than lead. This research was conducted by modelling an apron made of Bi_2O_3 with polyvinyl chloride as a coating and Pb as a standard apron. The used energies are 60, 90 & 120 keV for X-rays, 662 keV for Cs-137 (gamma ray), and 1173 and 1333 keV for Co-60 (gamma rays). The thickness of the radiation barrier is from 0.5 to 4 cm, and the distance of radiation source and detector is 45 cm. Bi_2O_3 apron geometry modelling was carried out using the MCNPX program. The modelling results show that at X-ray energy of 60 keV, the Bi_2O_3 apron can replace the Pb apron at a thickness of 1 cm to 4 cm. While at X-ray energy of 90 keV, the Bi_2O_3 apron can replace the Pb apron at a thickness of 2,5 cm to 4 cm, and at X-ray energy of 120 keV Bi_2O_3 apron can replace the Pb apron at a thickness of 1,5 cm to 4 cm. From these results it can be seen that the technology apron made from Bi_2O_3 with polyvinyl chloride as a coating with a certain thickness can be a non-lead radiation shielding material that is more environmentally friendly. But at the gamma energy of Cs-137 of 662 keV, Co-60 of 1173 keV and 1333 keV, Bi_2O_3 apron cannot replace Pb apron because the absorption of gamma rays is smaller than the absorption of X-rays.

Keywords: Bi_2O_3 apron, X-ray attenuation, Gamma ray attenuation, MCNPX

INTRODUCTION

Currently, radiation using gamma rays and X-rays are widely used for the diagnosis and treatment of various diseases in medical physics, so radiation workers are at risk of receiving higher amounts of radiation exposure. A dose limit for radiation workers so radiation shields are needed for radiation protection. Protecting the body from the harmful effects of ionizing radiation in particular regulating and controlling exposure to ionizing radiation is one of the goals of radiation protection. To achieve this goal, it is mandatory to apply radiation protection requirements which include justification, dose limitation, and optimization of radiation protection and safety. As know that to reduce radiation exposure, there are somethings to do, the time of exposure, the distance from the radiation source, and shielding from radiation. The most important is shielding [1].

One of the radiation protection devices is an apron. So far, the apron used in radiodiagnostic installations is made of lead. One of the disadvantages of lead-based aprons is toxicity [2]. Some of the uses of aprons in radiation protection by researchers such as those carried out by Cheon [3] in interventional pain management focused on lead aprons and thyroid shields. Hyun [4] explored the efficiency of protective lead aprons. Livingstone [5] carried out the study of Radiation-Protective Apron among Interventionists in Radiology. Taniguchi [6] reported the use of effective shielding materials in nuclear medicine.

This encourages research on the exploration of alternative materials that can be used as a comfortable apron material but without leaving their protective function. In previous studies, several researchers have conducted research on the characterization of materials using a Monte Carlo simulation of lead-free and lead-free X-ray shielding materials [7-10].

Bismuth has a high atomic number (Z 83), high density (8.90 g/cm^3), and an atomic mass of 208.98 AMU, and also has the capacity to interact with photons that can be generated during X-ray and gamma-ray emission processes. For radiation shielding, metal elements that have a high atomic number and high density can provide protection against higher radiation exposure. In Bi_2O_3, the total elemental bismuth in the bismuth oxide component reaches 89% by weight and therefore can increase the efficiency of both X-ray and gamma-ray protection compared to lead oxide. Therefore, in this study, Bi_2O_3 was chosen as the lead-free apron material.

The use of bismuth as a radiation shield has been widely used. Mehnati [11-12] assessed the effect of bismuth (Bi) shielding on dose reduction and image quality in computed tomography (CT). Verma [13] synthesized bismuth oxide (Bi_2O_3) nanoparticles for X-ray shielding and antibacterial. Tijani and Al-Hadeethi [14-15] performed the study of influence of TeO_2 and Bi_2O_3 on the shielding ability. The use of bismuth is also studied for gamma shielding application [16].

This research was conducted to determine the effectiveness of an apron made of Bi_2O_3 with polyvinyl chloride (PVC) as a coating. PVC coating is a method often used to structure flexible fabrics used in clothing. The fabric provides strength and the PVC coating creates a leather-like material.

METHODS AND MATERIAL

In this radiation barrier modeling system, apron was formed into a slab. The used material of apron as radiation shielding in this study is apron made of Bi_2O_3 with polyvinyl chloride as a coating and Pb as a standard apron. The used energies are 60, 90 & 120 keV for X-rays, 662 keV for Cs-137 (gamma ray), and 1173 and 1333 keV for Co-60 (gamma rays). The thickness of the radiation barrier is from 0.5 to 4 cm, and the distance of radiation source and detector is 45 cm as shown in Figure 1. The study was conducted with variations in the rate of radiation dose without a radiation barrier to determine the initial dose that comes out of the radiation source. Then proceed with measuring the dose rate using a radiation shield. The radiation dose rate was measured using a radiation detector placed 22.5 cm from the radiation barrier location.

The steps in apron modeling in this study was carried out using the Monte Carlo N-Particle eXtended (MCNPX) by designing geometry, then determine the surface boundaries, and enter the required material data along with the parameters to be searched, then run, and calculate the attenuation value using the material absorption dose value.

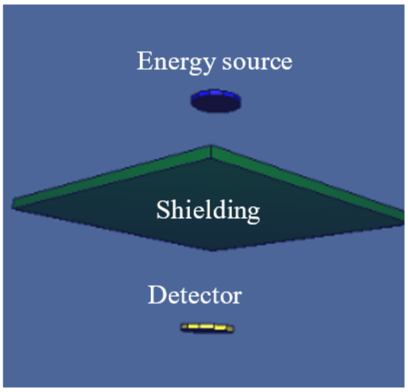


Figure 1: Experiment set up modelling

RESULTS AND DISCUSSION

X-Ray Energy of 60 keV

The attenuation transmission value can be calculated by comparing the intensity that passes through the barrier with the previous intensity (I/I_o). At the X-ray energy of 60 keV, the transmission value is shown in figure 2.

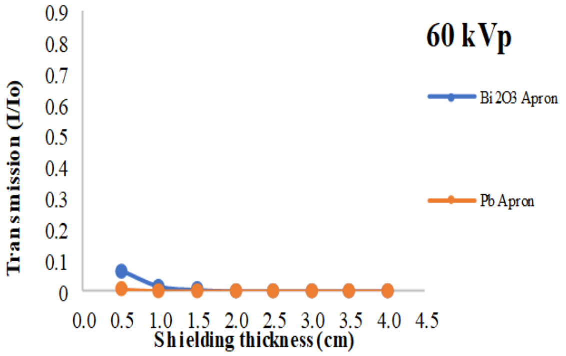


Figure 2: Transmission value (I/I_o) of X-ray energy of 60 keV in shielding thickness variation

It seen that the transmission value of the Bi_2O_3 apron is slightly higher than the transmission value of Pb apron due to the absorption power of Pb is greater compared to the absorption power of Bi_2O_3. The thicker the Bi_2O_3 apron has a very small difference in transmission value with Pb apron. The calculation of the absorption capacity of radiation shielding materials at an X-ray energy of 60 keV is shown in table 1.

Table 1: Calculation of absorption at X-ray energy of 60 keV

Thickness (cm)	Absorption of Bi_2O_3 (%)	Absorption of Pb (%)
0.50	93.31	99.40
1.00	98.36	99.96
1.50	99.49	99.99
2.00	99.93	100.00
2.50	99.97	100.00
3.00	99.99	100.00
3.50	99.99	100.00
4.00	99.99	100.00

It seen that the absorption power of Bi_2O_3 apron material is almost equivalent to the absorption power of Pb apron, at a thickness of 1 cm has a difference of 1.59%. The thicker the apron, the higher the absorption. So that at X-ray energy of 60 keV, Bi_2O_3 apron can replace Pb apron at a thickness of 1 cm to 4 cm.

X-Ray Energy of 90 keV and 120 keV

At X-ray energy of 90 and 120 keV, the transmission value is shown in figure 3 and figure 4 respectively.

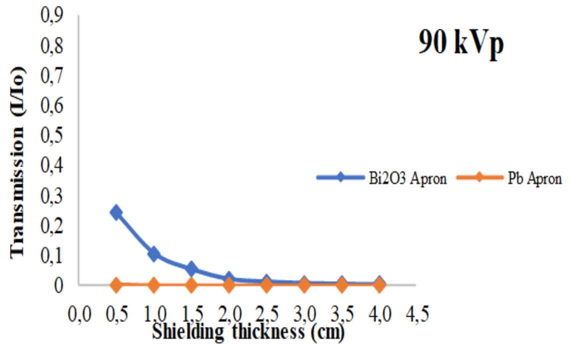


Figure 3: Transmission value (I/I_o) of X-ray energy of 90 keV in shielding thickness variation.

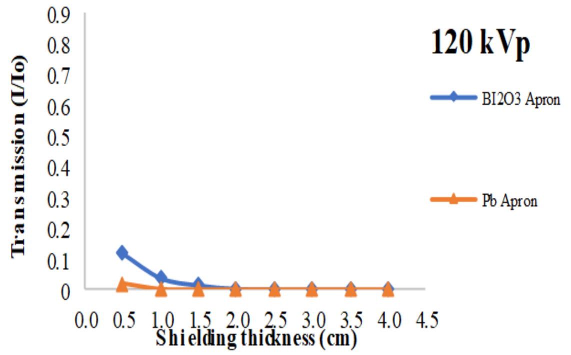


Figure 4: Transmission value (I/I_o) of X-ray energy of 120 keV in shielding thickness variation.

Trend of the transmission value of the Bi_2O_3 apron is slightly higher than the transmission value of Pb apron, not much different at the X-ray energy of 60 keV. The similar trend is also seen for its the absorption power (can be shown in table 2 and 3 respectively).

Table 2: The results of the calculation of absorption at X-ray energy of 90 keV

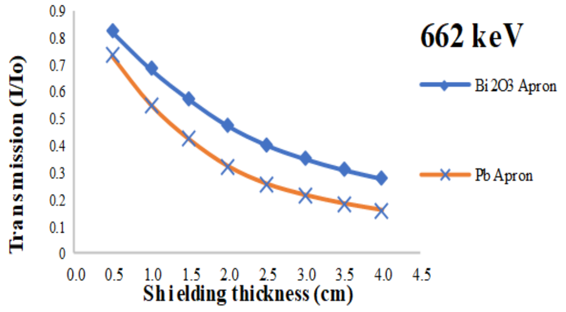
Thickness (cm)	Absorption ofBi_2O_3 (%)	Absorption of Pb (%)
0.50	75.88	99.81
1.00	89.28	99.99
1.50	94.57	99.99
2.00	97.79	100.00
2.50	98.73	100.00
3.00	99.19	100.00
3.50	99.46	100.00
4.00	99.64	100.00

Table 3: The results of the calculation of absorption at X-ray energy of 120 keV

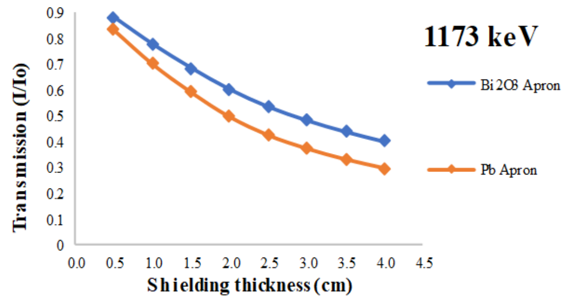
Thickness (cm)	Absorption ofBi_2O_3 (%)	Absorption of Pb (%)
0.50	88.25	98.35
1.00	96.15	99.82
1.50	98.51	99.97
2.00	99.64	99.99
2.50	99.85	99.99
3.00	99.92	100.00
3.50	99.96	100.00
4.00	99.98	100.00

Gamma Ray Energy

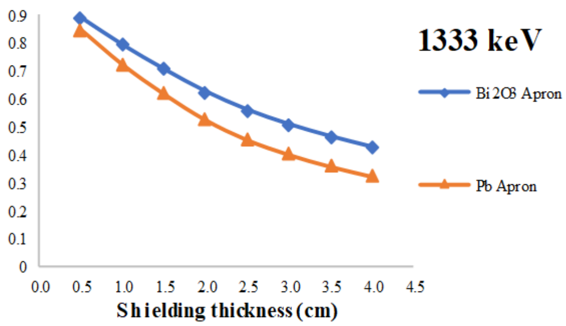
The transmission of gamma ray energy of Cs-137 of 662 keV, Co-60 of 1173 keV and Co-60 of 1333 keV are shown in figure 5(a), 5(b) and 5(c) respectively.



(a)



(b)



(c)

Figure 5: Transmission value (I/I_o) in shielding thickness variation for gamma ray energy (a) Cs-137 of 662 keV ; (b) Co-60 of 1173 keV ; (c) Co-60 of 1333 keV

If the transmission value in X-ray energy tends to be slightly higher, in this gamma ray energy, the transmission value of the Bi_2O_3 apron is much higher than the transmission value of Pb apron in all of energy. Likewise with the absorption power, at this gamma ray energy Pb absorption is also much greater compared to Bi_2O_3 due to the different attenuation coefficients. The difference of absorption for Bi_2O_3 and Pb apron at 0.5 cm thickness is about 9.2%. So that the Bi_2O_3 apron cannot replace Pb apron. The linear attenuation coefficient of a material depends on the type of material.

The calculation of the absorption power of radiation shielding materials at gamma ray energy Cs-137 of 662 keV, Co-60 of 1173 keV, and Co-60 of 1333 keV are shown in table 4, 5 and 6 respectively.

Table 4: Calculation of the absorption power of gamma energy for Cs-137 of 662 keV

Thickness (cm)	Absorption of Bi_2O_3 (%)	Absorption of Pb (%)
0.50	17.70	26.93
1.00	31.60	44.92
1.50	42.95	57.80
2.00	52.65	67.75
2.50	59.81	74.26
3.00	64.95	78.45
3.50	69.00	81.57
4.00	72.31	84.04

Table 5: Calculation of the absorption power of gamma energy for Co-60 of 1173 keV

Thickness (cm)	Absorption of Bi_2O_3 (%)	Absorption of Pb (%)
0.50	12.02	16.59
1.00	22.35	29.84
1.50	31.53	40.83
2.00	39.80	50.36
2.50	46.51	57.53
3.00	51.75	62.71
3.50	56.12	66.87
4.00	59.87	70.28

Table 6: Calculation of the absorption power of gamma energy for Co-60 of 1333 keV.

Thickness (cm)	Absorption of Bi_2O_3 (%)	Absorption of Pb (%)
0.50	11.17	15.26
1.00	20.90	27.73
1.50	29.61	38.26
2.00	37.59	47.49
2.50	44.13	54.59
3.00	49.31	59.82
3.50	53.66	64.08
4.00	57.43	67.62

CONCLUSION

The simulated apron modeling using MCNPX shows that the Bi_2O_3 apron can replace the Pb apron as simulated at X-ray energies of 60, 90 and 120 keV. The apron technology made from Bi_2O_3 with polyvinyl chloride as a coating with a certain thickness can be a non-lead radiation shielding material that is more environmentally friendly. However, in these simulations with gamma radiation sources of Cs-137 of 662 keV, Co-60 of 1173 keV and 1333 keV, Bi_2O_3 apron cannot replace

Pb apron and is less effective at protecting gamma radiation.

Acknowledgement: None
Conflict of Interest: None
Source of Funding: None

REFERENCES

1. T.H. Kim, S.W. Hong, N.S. Woo, H.K. Kim, J.H. Kim, 2017, The radiation safety education and the pain physicians' efforts to reduce radiation exposure, The Korean Journal of Pain, Vol 30, pp 104–115. DOI: 10.3344/kjp.2017.30.2.104
2. H. Cetin, A. Yurt, and S.H. Yüksel, 2017. The absorption properties of lead-free garments for use in radiation protection, Radiation Protection Dosimetry, Vol. 173. No. 4, pp.345-350. DOI: 10.1093/rpd/ncw004
3. B.K. Cheon, C.L. Kim, K.R. Kim, M.H. Kang, J.A. Lim, N.S. Woo, K.Y.Rhee, H.K. Kim, and J.H. Kim, 2018, Radiation safety: a focus on lead aprons and thyroid shields in interventional pain management, The Korean Journal of Pain, Vol. 31, No. 4, pp. 244–252 DOI: 10.3344/kjp.2018.31.4.244
4. S.J. Hyun, K.J. Kim, T.A. Jahng, H.J. Kim, 2016, Efficiency of lead aprons in blocking radiation how protective are they?, Heliyon, Vol. 2, Issue 5, DOI: 10.1016/j.heliyon.2016.e00117
5. R.S. Livingstone, A. Varghese, and S.N. Keshava, 2018, A Study on the Use of Radiation-Protective Apron among Interventionists in Radiology, Journal of Clinical Imaging Science, Vo. 8 No. 34. DOI: 10.4103/jcis.JCIS-34-18
6. Y. Taniguchi, H. Wakabayashi, H. Yoneyama, Z. Chen, K. Morino, A. Otosaki, M. Yamada, A. Inaki, D. Kayano & S. Kinuya, 2022, Application of a tungsten apron for occupational radiation exposure in nursing care of children with neuroblastoma during 131I-meta-iodo-benzyl-guanidine therapy, Scientific Reports, Vol. 12, No. 47, https://doi.org/10.1038/s41598-021-03843-2
7. S. Nambiar, E.K. Osei, and J.T. Yeow, 2013. Polymer nanocomposite-based shielding against diagnostic X-rays, Journal of Applied Polymer Science, Vol. 127, No. 6, pp. 4939-4946 https://doi.org/10.1002/app.37980
8. S. Nambiar, E.K. Osei, and J.T. Yeow, 2014. Polymer nanocomposite-based shielding against diagnostic X-rays, Journal of Applied Polymer Science, Vol. 131, No. 18, pp. 4939-4946 https://doi.org/10.1002/app.40982
9. H.O. Tekin, and T. Manici, 2019, Simulations of mass attenuation coefficients for shielding materials using the MCNP-X code. Nuclear Science and Techniques, Vol. 28, No. 7, pp. 1-4 DOI: 10.1007/s41365-017-0253-4
10. N. Aral, M.SA. Duch, and M. Ardanuy, 2020. Material characterization and Monte Carlo simulation of lead and non-lead X-Ray shielding materials, Radiation Physics and Chemistry, Vol. 174, pp. 108892 https://doi.org/10.1016/j.radphyschem.2020.108892
11. P. Mehnati, R. Malekzadeh and M.Y. Sooteh, 2018, Use of bismuth shield for protection of superficial radiosensitive organs in patients undergoing computed tomography: a literature review and meta-analysis, Radiological Physics and Technology, Vol. 12, pp. 6–25 https://doi.org/10.1007/s12194-019-00500-2
12. P. Mehnati, R. Malekzadeh & M.Y. Sooteh, 2019, New Bismuth Composite Shield for Radiation Protection of Breast During Coronary CT Angiography, Iranian Journal of Radiology, Vol. 16, No. 3 https://www.sid.ir/en/journal/ViewPaper.aspx?id=690585
13. S. Verma, M. Mili, C. Sharma, H. Bajpai, K. Pal, D. Qureshi, S.A.R. Hashmi and A.K. Srivastava, 2021, Advanced X-ray shielding and antibacterial smart multipurpose fabric impregnated with polygonal shaped bismuth oxide nanoparticles in carbon nanotubes via green synthesis, Green Chemistry Letters and Reviews, Vol. 14, Issue 2 https://doi.org/10.1080/17518253.2021.1912192
14. S.A. Tijani and Y. Al-Hadeethi, 2019, The influence of TeO_2 and Bi_2O_3 on the shielding ability of lead-free transparent bismuth tellurite glass at low gamma energy range, Ceramics International, Vol. 45, Issue 17, pp 23572-23577 https://doi.org/10.1016/j.ceramint.2019.08.066
15. Y. Al-Hadeethi, S.A. Tijani, 2019, The use of lead-free transparent 50BaO-(50-x) borosilicate-x Bi2O3 glass system as

radiation shields in nuclear medicine, Journal of Alloys and Compounds, Vol. 803, pp. 625-630 https://doi.org/10.1016/j.jallcom.2019.06.259

16. M.I. Sayyed, 2016, Bismuth modified shielding properties of zinc boro-tellurite glasses, Journal of Alloys and Compounds, Vol. 688, Part B, pp. 111-117 https://doi.org/10.1016/j.jallcom.2016.07.153

How to cite this article: Veronika Dyah Suryanti, Eko Hidayanto, Fajar Arianto. The effectiveness of Bi_2O_3 apron on attenuation of X-Ray and Gamma Ray by MCNPX Simulation. *International Journal of Research and Review*. 2022; 9(6): 53-58. DOI: *https://doi.org/10.52403/ijrr.20220608*

******