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Research Article

SHIELDING DEPTH DETERMINATION OF COBALT PHOTON SHOWER THROUGH LEAD, ALUMINUM AND AIR USING MONTE CARLO SIMULATION

[1]Ngadda, Y. H., [2]Ewa, I. O. B. and [3]Chagok, N. M. D.

[1]Physics Department, Faculty of Science, University of Maiduguri, Borno State
[2]Minister, Science and Technology, Abuja, Nigeria
[3]Physics Department, Faculty of Natural Sciences, University of Jos, Plateau State

E-mail: yhngadda@yahoo.com

ABSTRACT

Here a Monte Carlo technique through the PENELOPE code has been applied to simulate photons of ^{60}Co with initial energy of 1332.502 keV through lead, aluminum and air as shields. The showers, resulting from 50 primary photons simulated, show the pictorial shielding abilities of the slabs. It also shows how secondary particles are generated by the primary photons. Graphical plots of photon transmission as a function of a material shield thickness show that photon flux decreases with increasing slab thickness in accordance with Lambert's law of absorption. All simulated primary photons are stopped within a lead thickness of 20 cm, aluminum thickness of 100cm and a distance of 1.1 km in air at sea level.

Keywords: Monte Carlo, PENELOPE, simulation, photon, ^{60}Co, lead, aluminum, slab, air

INTRODUCTION

Radiation transport in matter has been a subject of intense work since the beginning of the 20th century. High energy photons penetrating matter suffer multiple interactions by which energy is transferred to the atoms and molecules of the material and secondary particles (photons, electrons or positrons) are produced (Briesmeister, 2000). By repeated interaction with the medium, a high energy photon originates a cascade of particles which is referred to as a shower (Zheng-MingandBrahme**,** 1993).The study of radiation transport problems was initially attempted on the basis of the Boltzmann transport equation. This procedure faced considerable difficulties when applied to limited geometries, with the result that numerical methods based on the transport equation have only had a certain success in simple geometries, mainly for unlimited and semi-infinite media. At the end of the 1950's, with the availability of computers, Monte Carlo simulation methods were developed as a powerful alternative to deal with transport problems (Salvat et al., 2001). By Monte Carlo methods, one learns and understands many aspects of radiation transport without employing empirical formulas and numerical tables.

The first numerical Monte Carlo simulation of photon transport (Hayward and Hubbell, 1954), generated 67 photon histories using a desk calculator. The simulation of photon transport is straightforward since the mean number of events in each history is fairly small. The photon is effectively absorbed after a single photoelectric or pair-production interaction or after a few Compton interactions (say, of the order of 10) (Salvat et al., 2003). With modern present computers, detailed simulation of photon transport is a simpler task (Bielajew and Rogers, 1987).The development, modification and application of Monte Carlo codes, of which PENELOPE is, one, have resulted in significant technological break-through in nuclear instrumentation (Laborie et. al., 2000 and Ewa et. al., 2002). Many physical nuclear physics experiments through the application of detectors have given way to Monte Carlo experiments. PENELOPE version 2003 is a program subroutine package.It consists of sub-programs for Monte Carlo simulation of photon, electron and positron transport in arbitrary material systems consisting of a number of homogeneous regions (bodies) limited by sharp interfaces. PENELOPE stands for **PEN**etration and **E**nergy **LO**ss of **P**ositrons and **E**lectrons in matter (Salvat et al, 2001). Photons were introduced in versions 2001 and later versions. PENELOPE, being subroutines of programs, cannot operate by itself. The user must provide a steering main program for the particular problem in question to control the evolution of the tracks simulated by PENELOPE and keep score of relevant quantities.

The PENELOPE subroutine package performs “analogue” simulation of electron-photon showers which are replicas of actual showers in infinite unbounded media of various compositions. Here photon histories are generated by assuming that all the interaction events experienced by a particle are simulated in chronological succession and the production of secondary particles are disregarded so that only one kind of particle is transported at a time. Lead and aluminum are widely used for their shielding and light weight properties respectively. While lead is used in nuclear sciences for its powerful shielding property, aluminum is used as nuclear detector housing and detector end-cap due to its low shielding property. This is the essence of this investigation.

THE SIMULATION PROCEDURE

In Monte Carlo simulation of radiation transport, the history (track) of a photon is viewed as a random sequence of free flights that end with an interaction event where the particle changes its direction of movement, loses energy and occasionally produces secondary particles (Briesmeister, 1997 and Briesmeister, 2000). The Monte Carlo simulation of a given experimental arrangement, for example, an electron beam coming from an accelerator and impinging on a water phantom, consists of the numerical generation of random histories. To simulate these histories we need an “interaction model”, that is, a set of Differential Cross-Sections (DCS) for the relevant interaction mechanisms. A detailed description of the cross sections and simulation methods adopted in PENELOPE, and a discussion of their reliability and domains of validity, are described in detail by Baro et al., 1995 and Sempau et al., 1997. The DCSs determine the Probability Distribution Functions (PDF) of the random variables that characterize a track, considering the following:

(i) free path between successive interaction events,
(ii) kind of interaction taking place and
(iii) energy loss and angular deflection in a particular event (and initial state of emitted secondary particles, if any).

Once these PDFs are known, random histories can be generated by using appropriate sampling methods. If the number of generated histories is large enough, quantitative information on the transport process may be obtained by averaging over the simulated histories.

Here PENELOPE version 2003 has been run on the plat form of FORTRAN G77. Photon showers have been generated as a result of 50 primary photons which were initially simulated. Monte Carlo average results are obtained for each of the four initial energy values for lead slab, aluminum slab and air medium of the same thickness, 4.237cm, see Tables 1(a), (b) and (c). Transmissions of photon as a function of slab thickness and the maximum shielding thickness of a slab or the distance in air have also been determined.

RESULTS AND DISCUSSION

(a) Photon Showers

The showers of Figs. 1(a), (b) and (c) are pictorial representations of the Monte Carlo simulated results showing the simulated pictures of the particle tracks through lead slab, aluminum slab and air medium respectively, for a

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thickness of 4.237 cm, from ^{60}Co(1332.502 keV) photon source. It is a shower resulting from 50 primary photons simulated. It shows the actual trace of each particle's path, within the slab, from initiation to the end of its history.

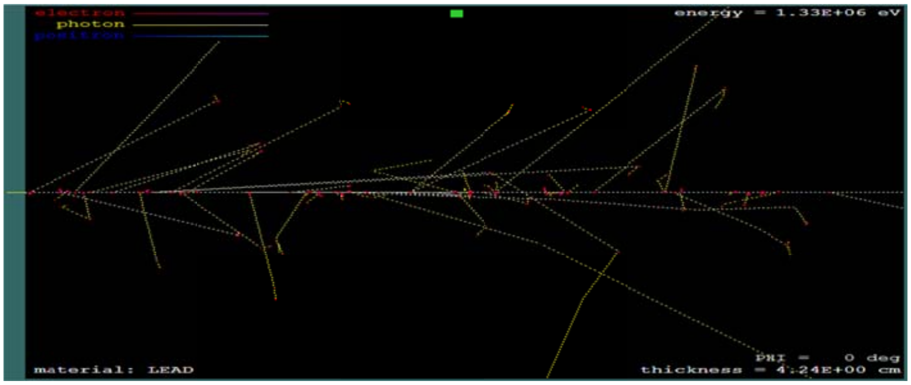

Figure 1 (a): Photon shower through lead slab of thickness = 4.237cm

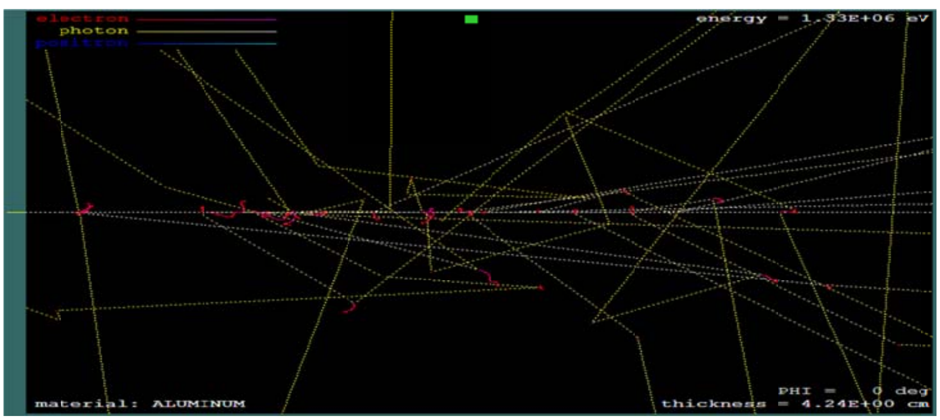

Figure 1 (b): Photon shower through aluminum slab of thickness = 4.237cm

Figure 1 (c): Photon shower through air medium of thickness = 4.237cm

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Fig. 1 Shower of particles simulated through lead, aluminum and air by of the same thicknesses from cobalt ^{60}Co (1332.502keV) photon source.

The shower shows how photons as the primary particles generate secondary particles. The computer output depicts electrons (in red), photons (in yellow) and positrons (in blue).

(b) Average Simulated Results

The average transmitted photon distribution with slab thickness for Pb slab, Al slab and air **(**Table 1), obtained through the PENELOPE's main program, penslab, which has been plotted graphically in Figs. 1, 2 and 3 depict the exponential decay of transmitted photons as a function of slab thickness for lead, aluminum and air respectively. We have used the high energy ^{60}Co (1332.502 keV) photon source for the simulation.

Table 1: Transmitted photon distribution with slab thickness for lead, aluminum and air at photon energy of 1332.502 keV.

Lead slab		**Aluminum slab**		**Air**	
Thickness (cm)	Transmitted photons	Thickness (cm)	Transmitted photons	Thickness (cm)	Transmitted photons
1	7630	1	270649	2	28144561
5	412	5	43067	5	15655696
8	88	10	16622	10	6384214
10	27	20	4502	50	315768
12	11	30	1409	100	82359
15	2	50	138	200	24197
20	0	70	13	500	5101
		80	1	1000	2488
		100	0	5000	469
				100000	3
				110000	0

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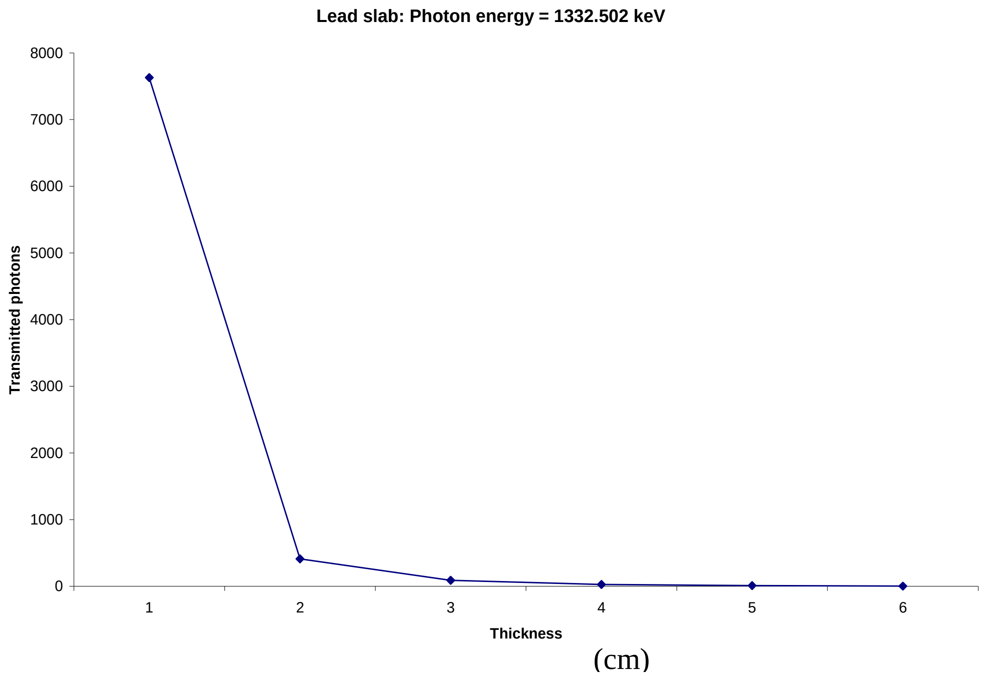

Figure 1(a): lead slab

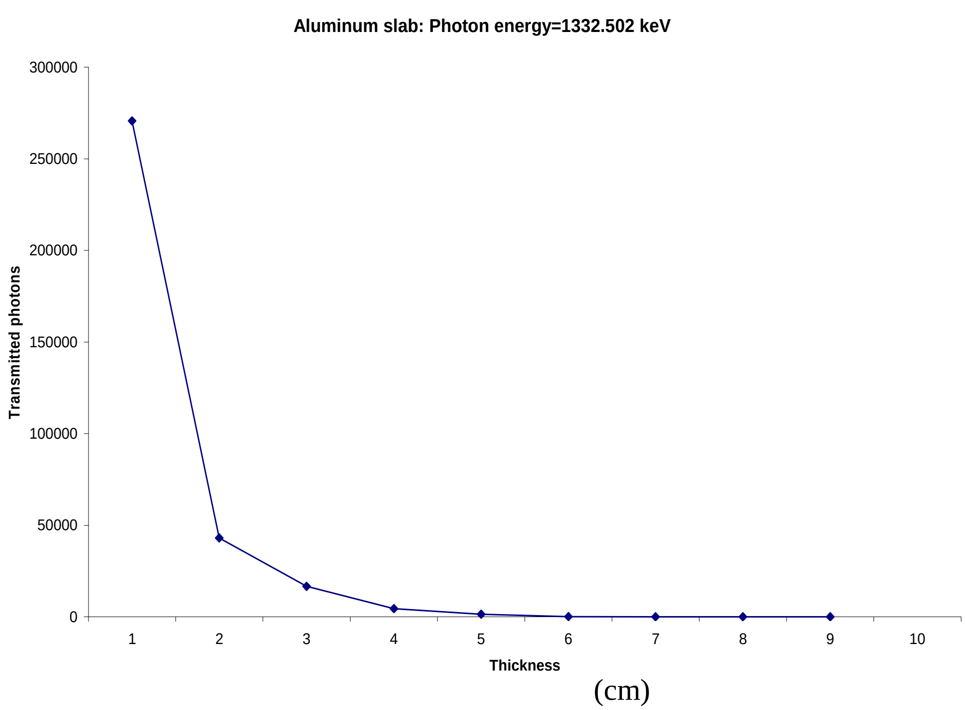

Figure 1(b):aluminum slab

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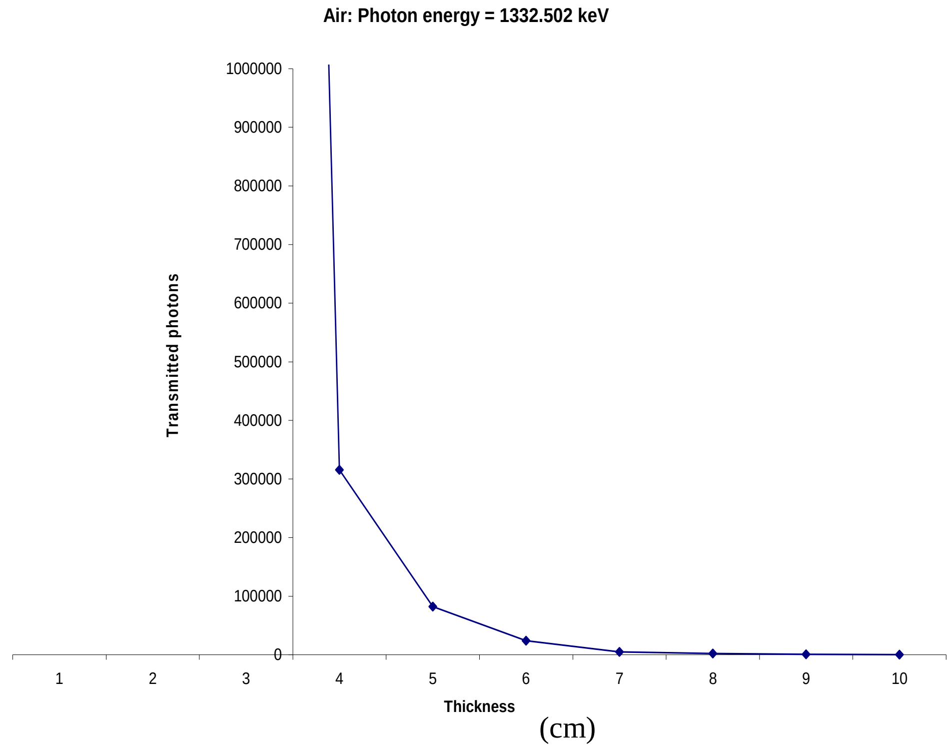

Figure 1(c): air

Figure 1: Transmitted photons as a function of shield thickness at a photon energy of 1332.502 keV for (a) lead slab, (b) aluminum slab and (c) air.

The Figures show that for low thicknesses the number of transmitted photons is asymptotically high and goes to zero at large distances. From Table 1 it can be seen that photons are completely shielded by thicknesses of 20 cm of lead slab; 100 cm of aluminum slab; and 1.1km of air medium. The scattering cross section for lead is so high that all the simulated photons of ^{60}Co (1332.502 keV) are absorbed within the thickness of 20 cm, if not backscattered. Aluminum has a lower cross section for photons and thus a larger thickness of about one metre is required to stop all the photons of ^{60}Co(1332.502 keV) while air has a much lower scattering cross section for photons and thus requires 1.10km medium of dry air, at sea level, to stop all the photons of ^{60}Co(1332.502 keV). Generally, the plots show that photon flux decreases with increasing slab thickness in accordance with Lambert's law of absorption,

$$I = I_o e^{-\mu x} \qquad (1)$$

where x is the thickness and μ is the linear absorption coefficient which depends on the physical parameters and scattering cross section of the material slab.

CONCLUSION

Graphical plots of photon transmission as a function of a material shield (lead, aluminum and air) thickness show that photon flux decreases with increasing slab thickness in accordance with Lambert's law of absorption. This exponential decay of transmitted photons is also in agreement with other earlier works (Cheney and Kincaid, 1985). The number of transmitted photons is asymptotically high at low thicknesses and approaches zero at large distances. It is also revealed that photons are transmitted to far distances in air medium, while the scattering cross section of lead is so high that all the simulated photons of ^{60}Co (1332.502) are stopped within a thickness of 20 cm.

FURTHER WORK

In this work, we have used the ^{60}Co (1332.502 keV) and the known thicknesses of lead and aluminum slabs which are available in the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. We wish to validate these simulated results in the next article.

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