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Research Article

SIMULATION OF PHOTON ATTENUATION THROUGH ALUMINIUM USING E-RADIATION SIMULATOR (EGS5 CODE)

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ABSTRACT

Radiation education is necessary for a wide variety of people, such as radiation workers and students of medical imaging. In order to understand radiation behaviour inside the material, we have developed an e-radiation simulator by using Monte Carlo simulation programme (EGS5 code). Anyone who has no programming knowledge will able to simulate photons in a material through this easy to use web-based environment radiation simulator. To validate our simulator, we calculate photon linear attenuation coefficient (μ) of an aluminium material which commonly used as a filter in diagnostic radiology. For the sake of comparison, we calculate at high energy photon of 662 keV to compare our results of μ with the XCOM database and literature. Consequently, the results from the developed simulator comparable with the database and literature for the case of photon attenuation study.

Keywords: Monte Carlo, EGS5, e-radiation simulator, XCOM database, linear attenuation coefficient

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1. INTRODUCTION

1.1. Radiation Attenuation

The high-energy radiation photons can be dangerous for people who work in radiation field such as medical radiotherapy and radiosurgery centers and particle accelerator laboratories. The radiations can cause cancer or completely diseases. Thus, the proper radiation shielding with sufficient radiation attenuation is vital to protect people and environment from the harmful radiation. There are many researches, which were studied to find the radiation attenuation capability of elements or compounds [1]. Also, there are studies that have been conducted to compare the simulated linear attenuation coefficients from Monte Carlo calculation to the values from XCOM database [2] and experiments [3] in order to get the value of descrepancies.

The radiation attenuation is an intrinsic property of materials, which can be explained by the exponential decay equation as

$$\frac{I}{I_0} = e^{-\mu x}, \tag{1}$$

where I_0 and I are the initial and the attenuated intensity of photons, respectively. The quantity x is the thickness of material and μ is the linear attenuation coefficient. Commonly, the linear attenuation coefficient has a unit of cm^{-1}. However, it is usually identified as the mass attenuation coefficient μ/ρ in a unit of cm^{2}g^{-1}. The attenuation of the radiation in the material is determined by the interaction of photons with atoms, electrons or molecules in matter including coherent scattering, Compton scattering, photoelectric effect and pair production [4, 5].

1.2 Monte Carlo Simulation of Radiation

There is a lot of work done before by the scientist to simulate radiation using Monte Carlo methods. Despite its useful benefit to perform radiation simulation, most of the available Monte Carlo methods are for experienced users and require long learning time process. For the time being, Monte Carlo is the most accurate way of calculating radiation distribution dose in a patient. A number of Monte Carlo codes has been used to simulates how radiation enters the body, and more recently in treatment planning. There are many Monte Carlo codes available such as Electron Gamma Shower (EGS), FLUKA, PENELOPPE, GEANT4, XRAYSIM and others to simulate radiation inside the materials [6]. Computer programming language skill is necessary in written the Monte Carlo simulation code before ones able to transport photon inside the materials and outputted correctly.

EGS5 code has been developed at High Energy Accelerator Research Organization, Japan [7]. EGS code is a general purpose package for the Monte Carlo simulation to transport electrons and photons in an arbitrary geometry with energies above a few keV up to several hundred GeV [7]. Simulation results obtained from this code were reported in many publications. As an example, simulations of the longitudinal and radial distributions of energy deposition of electrons of various energies made using EGS5 were compared with experimental results in the literature [8]. This example research confirms that the results from EGS5 simulation can be used for approximating the various energy depositions of electrons. Suffian et al. [9] stated that they were successfully demonstrated two-energy calibration (~200 keV and 662 keV) to be used for survey meter calibration from a monoenergetic radioactive source (Cs-137) and believed that their method would be very effective for accurate calibration of dosimeters which in turn essential for any instrument. Weber et al. [10] also agreed that simulations indicate an excellent polarimeter quality of such detector systems when used as Compton polarimeters. Moreover, good agreement is found between simulations and recently obtained experimental data.

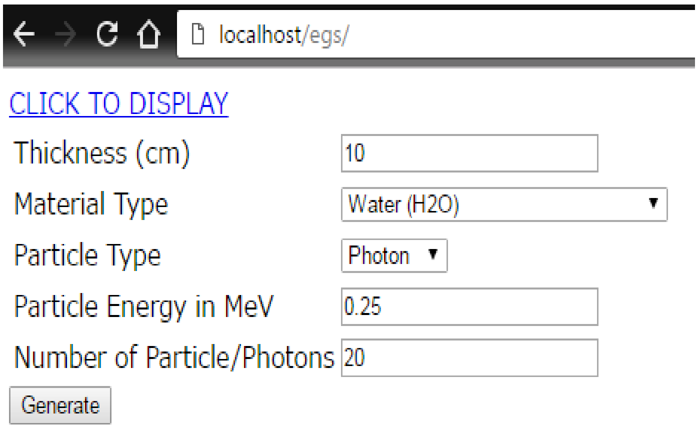
2.0 E-RADIATION SIMULATOR

It seems now that in the near future, the Monte Carlo methodology will be widely used for study of radiation properties, despite of experimental. In this study, we present an e-radiation simulator based on the EGS5 code for education purposes. E-radiation simulator has been developed using PHP and Java applet to integrate and visualize the EGS5 Monte Carlo simulations engine into an easy to use web-based environment [11]. By integrating EGS5 code into our system, this system can be used for wide areas like radiation physics and shielding. This system has also been successfully registered under the intellectual property numbered LY2017003000.

At this moment, the simulator is only accessible within our institution (UniSZA) through the e-radiation simulator web link given by the author, where one could perform the simulations anywhere as long as the personal computer connected to the internet. For example, students could assess the given web link at their hostel room or library without need to install any Monte Carlo components such as text editor and computer language compiler. A computer desktop, where only the author has the authority to write and modify the EGS5 code programme, had been dedicated as a server of the e-radiation simulator to run the simulations requested.

One could easily change the properties of radiation such as the types of radiation, its energy (MeV) and the numbers of incident photon to simulate from the selectable option in simulator interface (Fig. 1). At this moment, five type of materials were prepared in the simulator such as water (H_2O), aluminium (Al), polymethyl methacrylate (PMMA), lead (Pb), and concrete. Despite its easier usage, we recommend to limit the number of incident photons for simplicity of manually eye evaluation at the outputted photon trajectories (Fig .2).

In this study, the photons energy was set at 0.662 MeV and were propagated in a parallel beam towards the Al. We then determined the number of unscattered photons that pass through the aluminum manually by examined the photon trajectories as Figure 2. Therefore we limit the number of incident photons up to 60 photons for easier eye evaluation and short simulation running time. The same procedure repeated for several thickness of aluminium to create a graph of photon attenuation as a function of material thickness. For better statistic, we also included the results of 10,000 incident photons where the result of penetrated unscattered photons were outputted directly in the form of figure instead of manually perform eye evaluation at the photon trajectories. The reason is to compare how significant is e-radiation simulator in term of statistics for radiation properties study as we limit up to 60 incident photons. In many cases of simulation, we normally use very high number of incident photons for better results in the statistic point of view even though it will cost us a lot of simulation running time.



localhost/egs/

CLICK TO DISPLAY

Thickness (cm): 10
Material Type: Water (H2O)
Particle Type: Photon
Particle Energy in MeV: 0.25
Number of Particle/Photons: 20

Fig.1. User friendly interface to perform radiation simulation with simple one "Generate" click to get the photon trajectories output [11]

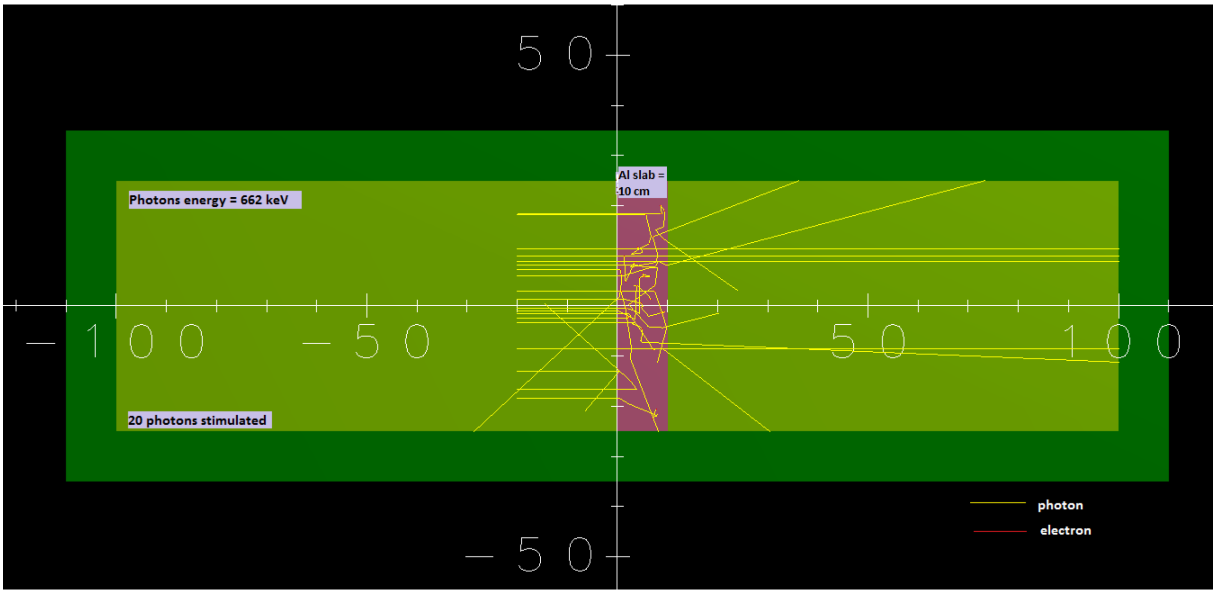


Fig.2. The system for EGS5 simulation and visualized geometry shows the photon trajectories of 0.662 MeV inside the aluminum material

3. RESULTS AND DISCUSSION

An e-radiation simulator used to calculate photon attenuation for 20, 40 and 60 incident photons of 0.662 MeV through the aluminum material. The outputted photon trajectories were examined manually by eye to calculate the numbers of unscattered photons pass through the selected material. The simulation results of 20, 40 and 60 incident photons energy of 662 keV and 10,000 incident photons energy of 662 keV from mathematical calculation of EGS5 code are shown in figure 3, figure 4, figure 5, and figure 6 accordingly. The uncertainty of the numbers of transmitted photons was evaluated as a statistical uncertainty due to counting statistics of the simulated number of incident photons ($\sqrt{n}$). All the graphs have exponential decay curves as describes in equation (1).

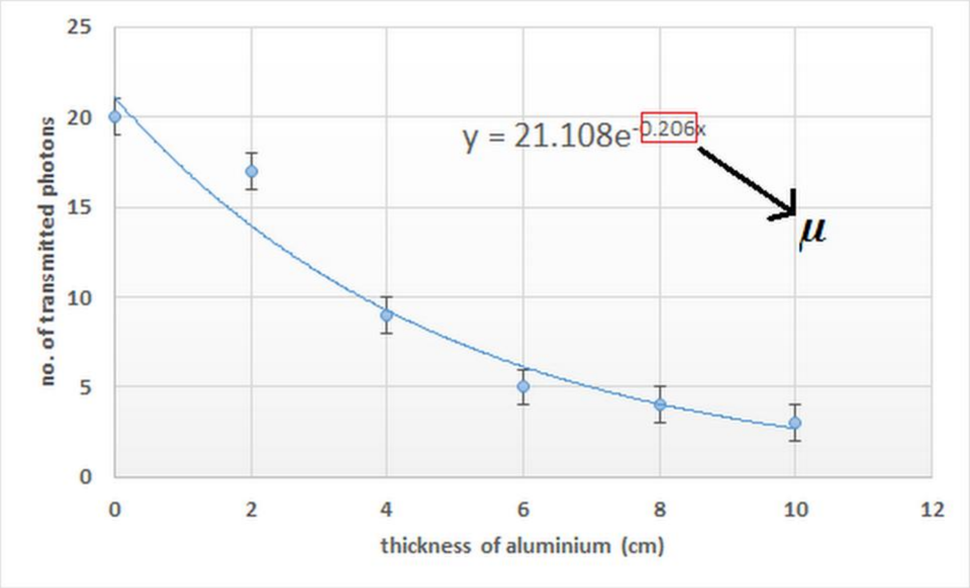


Fig.3. Simulation result from e-radiation simulator of 662 keV photons for 20 numbers of incident photons strike the aluminium (μ = 0.206 cm^{-1})

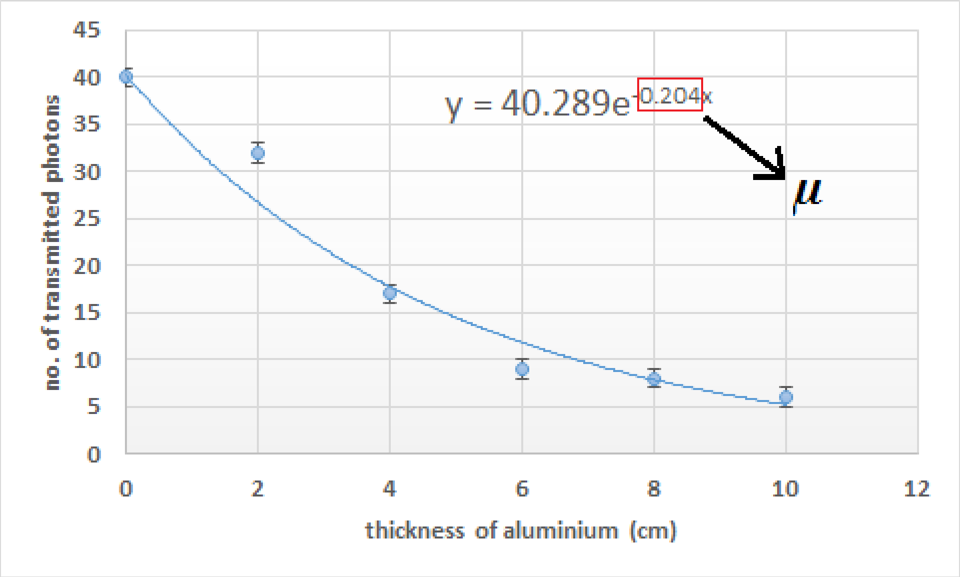


Fig.4. Simulation result from e-radiation simulator of 662 keV photons for 40 numbers of incident photons strike the aluminium (μ = 0.204 cm^{-1})

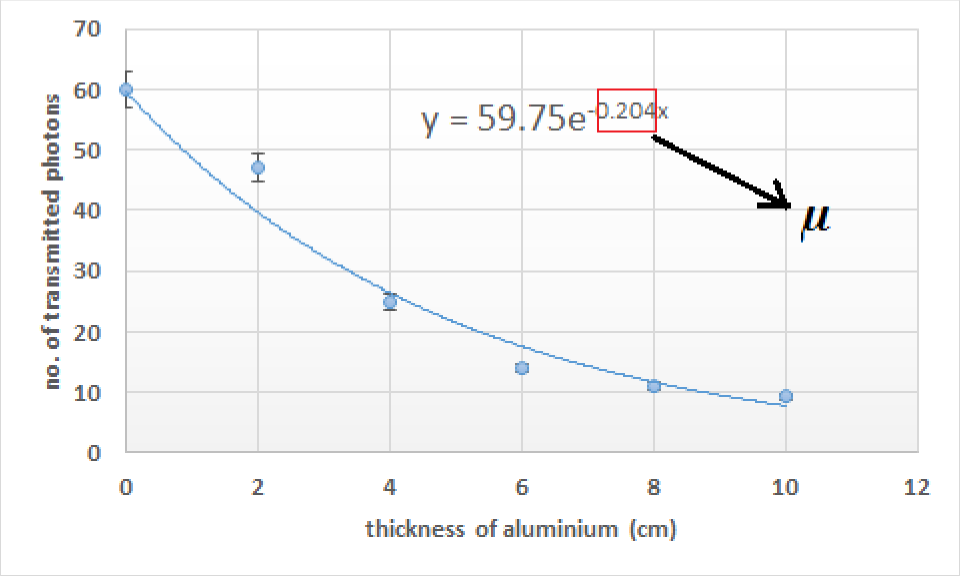


Fig.5. Simulation result from e-radiation simulator of 662 keV photons for 60 numbers of incident photons strike the aluminium (μ = 0.204 cm^{-1})

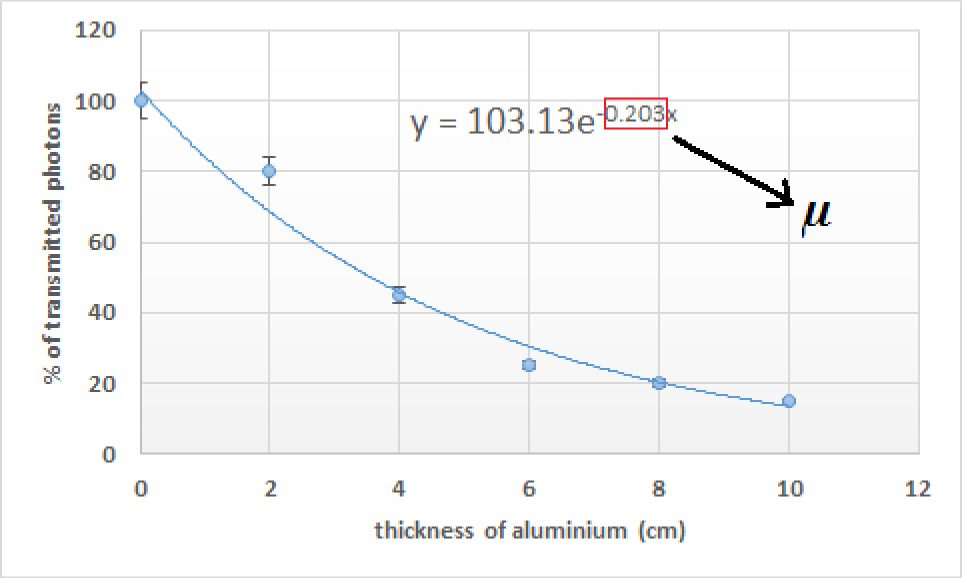


Fig.6. Simulation result of EGS5 calculation with 10,000 number of incident photons (μ = 0.203 cm^{-1})

The comparison of the measurements is done by calculating the percentage deviation as:

$$\%deviation = \frac{\left(\frac{\mu}{\rho}\right)theory - \left(\frac{\mu}{\rho}\right)\exp}{\left(\frac{\mu}{\rho}\right)theory} \times 100 \qquad (2)$$

The results presented in Table 1.

Table 1. Comparison of linear attenuation coefficients (μ) of aluminium using 662 keV obtained from e-radiation simulator, XCOM database [2] and recent experimental research [3].

Energy (keV)	No. of incident photons	μ from e-radiation simulator (cm^{-1})	μ from XCOM (cm^{-1})	μ from literature (cm^{-1})	Percentage deviation compare to XCOM (%)	Percentage deviation compare to literature (%)
662	20	0.206	0.202	0.197	2.0	4.6
	40	0.204			1.0	3.6
	60	0.204			1.0	3.6
	10000	0.203			0.5	3.0

From the simulation result in figure 3, figure 4, figure 5, and and figure 6, the graphs show they met the exponential decay equation and the linear attenuation coefficient (μ) of aluminium at that particular energy can be calculated from the slope of this graph by using microsoft excel software. Besides, the value of energy used less affecting the linear attenuation coefficient value, however photons are tend to pass through and scattered. The result presented in Table 1 shows that the deviation mostly below 5% indicating thereby the linear attenuation coefficients obtained from EGS5 simulation are agree well to the calculated values obtained from the XCOM database. However, the percentage deviation quite high when comparison is made between simulation and literature, where the values are 4.6%, 3.6% and 3.6%, respectively. This may be due to distance factor, where simulation is done in vacuum and experimental literature is influenced by distance. In vacum, air does not exist while in experiment, air affects in determinaton of linear attenuation coefficient calculation due to the interaction between air and particles. The linear attenuation coeficient is obtained by multiplying the mass attenuation coefficient of the element by its density. However, the values of percentage devation are still acceptable because they do not exceed than 10%. In order to reduce the percentage deviation, the number of incident photons needs to be increased.

4. CONCLUSION

E-Radiation simulator was succesfully developed to fulfill the growing demand of use technology in the students learning process, as well as to educate radiation technician and physicists. The online simulator particularly can become computer aided learning tool as radiation education is necessary for a wide variety of people, such as radiation workers, students of radiography and medical imaging and others who working with radiation.

The simulated linear attenuation coefficients from the simulator are comparable to the values from XCOM database and literature, where the deviations are below than 10%. Therefore, the developed web based e-radiation simulator is a good educational tool where one could understand the type of photon interactions inside the materials and also for research purposes particularly for radiation shielding calculation.

5. ACKNOWLEDGEMENTS

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