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Research Article

Determination of Photon Mass Attenuation Coefficient for Some Phantom Materials using GATE Code and Comparison with Experimental and XCOM Data#

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Abstract: The main purpose of this study is focused on testing the applicability of a Monte Carlo simulation code GATE V6.2 for studying mass attenuation coefficients for different types of phantom materials (water, RW3, silicon, acrylic and paraffin) at 662, 1173 and 1332 keV photon energies. Gamma ray transmission measurements have been used to evaluate the phantom materials. The simulated results of mass attenuation coefficients were compared with the experimental and theoretical XCOM data for the same samples. The results indicate that GATE V6.2 code show a moderately good agreement with the experimental and theoretical result.

1 Introduction

Phantoms are frequently used to simulate the patient's body in radiotherapy, radiological imaging, nuclear medicine, radiation protection and radiobiology [1, 2]. The development of phantoms that present densities similar to those observed in patients is very important because it avoids unnecessary radiation exposure. There are some requirements for tissue substitutes. It is important for these materials to be capable of being accurately measurable, available, reproducible, and ready to be used in any instance. The materials are characterized based on the photon interaction parameters such as mass attenuation coefficients, effective atomic numbers and effective electron densities. The mass attenuation coefficient is the fundamental photon interaction parameter to derive various other parameters such as molecular, atomic and electronic cross sections, effective atomic number and electron density, energy deposition, dosimetric interest and shielding effectiveness [3]. The photon attenuation coefficient is combination of the partial photon interaction processes, photoelectric effect, Compton scattering and pair production which are dependent on photon energy and atomic number, Z. The photoelectric absorption and pair production are the processes to remove initial photon whereas Compton interaction scatters the photon, lowering its energy [3]. In this study, gamma ray transmission measurements have been used to evaluate the attenuation coefficient of five different phantom materials. Co-60 and Cs-137 radioisotopes were used in narrow beam geometry and the transmission of photons measured, using a Na-I scintillation detector, through varying thicknesses of the phantom materials. The mass attenuation coefficients at the gamma ray energies of 661.2, 1173.2 and 1332.5 keV were determined from the GATE V6.2 code and compared with the measured and predicted values derived from XCOM program.

2 Materials and Methods

The phantom materials considered in the study are water, RW3 (PTW), silicone, acrylic and paraffin which are close to soft tissue density. For each sample, gamma rays were detected by Canberra Model (802-2X2) NaI scintillation detector and digiBASE model PMT with integrated bias supply, preamplifier and digital multichannel analyzer, which was supplied with MAESTRO-32 MCA Emulation software combined system. The distance between source and detector was 10 cm. The measuring time was 15 min and was carried out three times for each measurement. At first, the initial intensity (I_o) was measured without any material between source and detector. After that the gamma intensities (I) were measured at 2 to 10 cm thicknesses for all phantom materials. Then graphs plot the relative intensity (I/I_0) versus material thickness were drawn. The linear attenuation coefficients were calculated from the graphs by using Origin 8 computer program.

GATE (Geant4 Application for Emission Tomography) is an open source of Monte Carlo simulation program developed by the OpenGATE collaboration since 2001, released in 2004 [4]. Standard energy physics modules are used in GATE to set physics process. The physics processes available in GATE cover a complete set of particles and materials over a wide range of energy. Users of this software prepare an "input file" providing all necessary information for program execution.

In this study, narrow beam geometry and a spherical source emitting monoenergetic photons with 0.125 mm radius is placed into the simulation (Fig. 1).

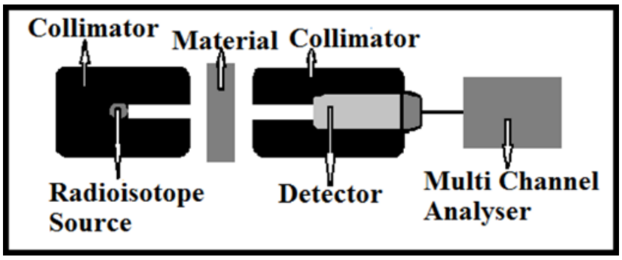
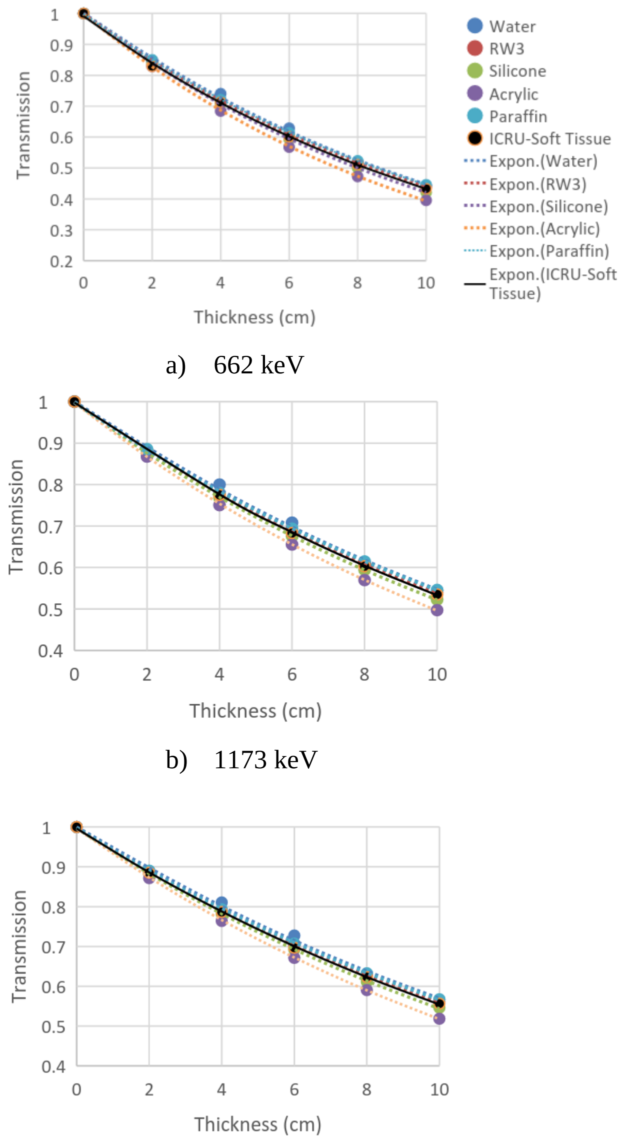


Figure 1. *Schematic diagram of detection system.*

The mass attenuation coefficients of phantom material samples were also calculated by using XCOM program. It uses the chemical composition of the materials to provide cross sections for various interaction processes. XCOM is database running on a PC and was prepared by combining pre-existing databases for interaction processes such as photoelectric absorption, coherent and incoherent scattering and pair production at photon energies from 1 keV to 100 GeV [5, 6].

3 Results and Discussion

Transmission values of studied materials and soft tissue of ICRU (1989) as a function of phantom thickness obtained from GATE V6.2 code simulation results are presented in Fig. 2. The results indicate that the transmission through water, RW3, silicone, acrylic, paraffin and soft tissue are in close agreement. The mass attenuation coefficients of the studied phantom materials and soft tissue are given in Table 1 for comparison. Discrepancy in the mass attenuation coefficients calculated and experimental could be due to deviations from narrow beam geometry in the experimental set up.



a) 662 keV

b) 1173 keV

c) 1332 keV

Figure 2. *Transmission values of materials as a function of phantom thickness by GATE V6.2 code at (a) 662 keV, (b) 1173 keV and (c) 1332 keV.*

***Table1** Experimental and computational results for mass attenuation coefficients*

Phantom Materials	Photon Energy (MeV)	$\mu_{exp.}$ (cm^{-1})	$\mu_{exp./\rho}$ (cm^2/g)	μ_{XCOM} (cm^2/g)	μ_{GATE} (cm^2/g)
Water (ρ=1 g/cm^3)	0.662	0.0853±0.0008	0.0853	0.0857	0.0798
	1.170	0.0646±0.0022	0.0646	0.0654	0.0598
	1.330	0.0643±0.0043	0.0643	0.0613	0.0558
RW3 (ρ=1.045 g/cm^3)	0.662	0.0861±0.0020	0.0823	0.0828	0.0790
	1.170	0.0625±0.0039	0.0598	0.0632	0.0594
	1.330	0.0577±0.0024	0.0552	0.0592	0.0558
Silicon (ρ=1.14 g/cm^3)	0.662	0.0896±0.0022	0.0785	0.0799	0.0761
	1.170	0.0729±0.0045	0.0639	0.0683	0.0572
	1.330	0.0715±0.0034	0.0627	0.0569	0.0537
Acrylic (ρ=1.18 g/cm^3)	0.662	0.1010±0.0046	0.0855	0.0833	0.0794
	1.170	0.0799±0.0032	0.0677	0.0635	0.0596
	1.330	0.0755±0.0022	0.0641	0.0595	0.0561
Paraffin (ρ=0.96 g/cm^3)	0.662	0.0929±0.0026	0.0968	0.0885	0.0845
	1.170	0.0672±0.0020	0.0699	0.0654	0.0634
	1.330	0.0657±0.0013	0.0684	0.0632	0.0596
Soft Tissue (ρ=1.04 g/cm^3) (ICRU, 1989)	0.662	-	0.0854	0.0849	0.0813
	1.170	-	0.0643	0.0647	0.0589
	1.330	-	0.0603	0.0607	0.0570

4 Conclusion

The mass attenuation coefficients for different phantom materials were investigated at three energies of 662, 1173 and 1332 keV by using GATE V6.2 code. The results were compared with experimental data and XCOM program. Mass attenuation coefficient values derived from XCOM were greater (3%-19%) than those derived from the GATE calculated transmission data. The differences between GATE and experimental results were between 1%-16% and that can be expected from probabilistic processes or due to errors in the experimental setup. Maximum difference was obtained with silicon material due to production conditions of the silicon blocks. The results were compared with reference data from International Commission on Radiation Units and Measurements report no 44 for soft tissue (Table 1). GATE V6.2 code results indicate that there is satisfactory agreement between the transmission values of soft tissue and phantom materials for the photon energies of 662, 1173 and 1332 keV (Fig. 2).

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