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Rapid communication

Determination of mass attenuation coefficient for some polymers using Monte Carlo simulation

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ABSTRACT

Mass attenuation coefficient, μ/ρ for some polymers with potential applications in dosimetry, and medical physics has been calculated using Monte Carlo simulation code, MCNP-4C at different gamma ray energies, 59.5, 279.1, 511, 661.6, 662, 1115.5, 1173, 1173.2, 1274.5 and 1332.5 keV. Appreciable variations were noted for mass attenuation coefficients for the polymers by changing the photon energy. The simulated μ/ρ values were compared with possible available experimental data and theoretical XCOM results, and good agreement was observed. Present study indicates that simulation geometry method is suitable to be used as an alternative method for the experiments. The present geometry can be used as standard geometry for MCNP simulation for low-Z materials. The calculated μ/ρ values using MCNP-4C code signify that the simulation geometry method can be followed to determine the gamma ray attenuation coefficients for the polymers for which there are no experimental values available.

Radiation is used in agriculture, medical, consumer product, archeology, industries, nuclear engineering science and technologies, etc. Radiological protection is being implemented by the measurement of X- and γ-rays using different types of radiation monitors, detectors and personnel dosimeters. The personnel dosimeters are being calibrated with standard phantom and tissue equivalent materials. The tissue equivalent materials are being used to understand the radiation interaction properties in the original human organs. Polymers are found to be the most suitable tissue equivalents for human organs and phantom in dosimetry. Water exhibits adequate suitability for tissue equivalence in medical applications. The characterization of the materials is based on the gamma ray interaction parameters such as effective atomic number, mass attenuation coefficients, effective electron densities and mass-energy absorption coefficients. The mass attenuation coefficient is a fundamental factor to derive other dosimetric and shielding parameters such as molecular, atomic and electronic cross sections, effective atomic number, electron density, energy deposition and shielding effectiveness [1–5]. Monte Carlo simulation for mass attenuation coefficients for concretes and heavy metal oxide glasses [6–9] are reported in literature. Recently an attempt has been made for estimation of the mass attenuation coefficients around the *k*-edges for low-Z dosimetric materials using the MCNP code which agree very well with theoretical values [10].

Monte Carlo simulation code, MCNP is found to be an effective tool to calculate radiation interaction parameters for different types of compounds or mixtures for attenuation, energy deposition in human organs, tissues and shielding materials. MCNP is a general purpose Monte Carlo code for transport of neutrons, photons and electrons. The user can apply up to second order surfaces (boxes, ellipsoids, cones, etc.) and fourth order torii to build a 3D geometry which can be filled with materials of arbitrary composition and density. Point, surface or volume sources of radiation can be defined, from which the mentioned particles are emitted with user specified probability distributions for energy and direction. The code then simulates the particle tracks and interactions with the materials, according to probability density distributions [11]. In the present study, Monte Carlo N Particle transport (MCNP-4C) code developed by the Los Alamos National Laboratory was used for simulation of mass attenuation coefficients of the polymers and water.

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The gamma ray beam intensity (no. of photon per unit volume) for particular energy is incident on a material is being transmitted, absorbed and/or back scattered towards source. The photon attenuation coefficient, the probability of interaction is the combination of partial gamma ray interaction processes namely photoelectric absorption, Compton scattering and pair production. These partial interaction processes dependent upon gamma ray energy and atomic number (Z) of the elements of a compound or mixture. The XCOM program is usually employed for calculating X- and γ-ray attenuation coefficients and interaction cross sections for compounds or mixtures in energy 1 keV to 100 GeV [12]. The new version of XCOM program is called as WinXcom [13] is user friendly which is Windows base operating system.

Polymers are low-Z, non-flammable, light weight, high durability, and tough, ease processing, less expensive, low maintenance and stable over a wide temperature range. These qualities make it very useful for manufacturing containers, piping, electrical insulation, valves and pumps for corrosive fluids in nuclear technology, protective coating and base materials for gamma and neutron shielding. The polymers are being used for phantom like PMMA for dosimetry services, calibration of radiation detector and tissue equivalence. Polymers play a vital role in radiological protection for primary and scattered secondary gamma rays. Polymers are being used as a host matrix for shielding material and provide flexibility, ease shaping, cost effectiveness and stability against chemicals. In order to interpret the behavior and performance of polymers in medical, dosimetry and radiation shielding application, it is important to determine the mass attenuation coefficients for the polymers and identify new geometry for simulation.

Recently photon interaction with polymers, wax and plastics is reported by Singh et al. [14]. Experimental results of mass attenuation coefficients for some polymers are available for limited energies. In the present work, we have calculated mass attenuation coefficients for some polymers (see in Table 1) using simulation geometry method with MCNP-4C code with the objective to test the simulation geometry method to provide the radiation safety. Firstly, mass attenuation coefficients were calculated for the polymers, and results were compared with XCOM program and experimental data from literature [15–22]. The mass attenuation coefficients for water were also determined, and compared with experimental data, theoretical XCOM [12] and FLUKA simulation reported by Demir et al. [23]. At present the experimental values of mass attenuation coefficient for very few polymers are available for limited photon energies. Therefore, this investigation would be very useful for potential applications in dosimetry, medical and radiation protection. The MCNP-4C code can be utilized for gamma ray energies where experimental mass attenuation coefficients are not available.

Table 1
Elemental compositions.

Description	Density (g/cm^3)	Element weight (%)				
		H	C	N	O	F
Water	1.00	11.19	–	–	88.81	–
Poly-propylene	0.95	14.37	85.63	–	–	–
Perspex	1.18	8.05	59.98	–	31.96	–
Bakelite	1.36	5.74	77.46	–	16.80	–
Teflon	2.20	–	24.02	–	–	75.98
Polyethylene	0.92	14.4	85.6	–	–	–
Poly-carbonate	1.22	5.55	75.58	18.88	–	–
Nylon 6-6	1.13	9.80	63.70	12.40	14.10	–
PMMA	1.18	8.05	59.98	–	31.96	–

The linear attenuation coefficient is the probability of gamma ray interaction with a material per unit path length. The linear attenuation coefficient, μ is defined as the fraction of a beam of X-rays or gamma-rays that is absorbed or scattered per unit thickness of absorber in narrow beam geometry. The linear attenuation coefficient accounts for the number of atoms in a cubic cm volume of material and the probability of a photon being scattered or absorbed from the nucleus or an electron of one of these atoms. The linear attenuation coefficient is given by Eq. (1):

$$\lim_{\Delta t \to 0} \Delta I / I \Delta t = -\mu \quad (1)$$

where $\Delta I/I$ is the fraction of the gamma ray beam attenuated in the medium of thickness Δt [24].

MCNP-4C code is a radiation transport code used for modeling the radiation transport and the interaction of X- and γ-ray, neutron and electrons radiation with the matter. It is based on the Monte Carlo method to solve the transport equation; furthermore, it can work on different modes of delivery that are capable to consider neutrons, electrons and photons, alone, or in pairs all three together. It utilizes the nuclear cross section libraries and physics models for particle interactions and gives the required quantity with certain error [7,25,26]. The simulated phantom consists of a cubic model of 10 × 10 × 1 cm^3 with a polymer or water. The environment except the mentioned phantom was filled with the air. Finally, the cubic model was centered in an air sphere for variance reduction. The simulation setup is shown in Fig. 1. Anything outside the air cube was considered void into which MCNP-4C did not perform particle transport. Tally F2 was used to obtain MCNP-4C simulation data. This tally calculates flux in the cube sides for every source. The MCNP-4C source was modeled as a directional plane source in a vacuum. This source located at 1 cm away from the entry plane of the mentioned cube. The initial direction of gamma source was parallel to the beam axis. For each tally, MCNP-4C not only calculates the sample mean $\bar{x}$, but several other statistics. One of the most important is the relative error R defined as $R \equiv S\bar{x}/\bar{x}$. R generally must be less than 10% for meaningful results.

The μ/ρ values for the polymers were calculated by using mixture rule $((\mu/\rho)_{polymer} = \sum_i^n w_i(\mu/\rho)_i)$ where w_i is the

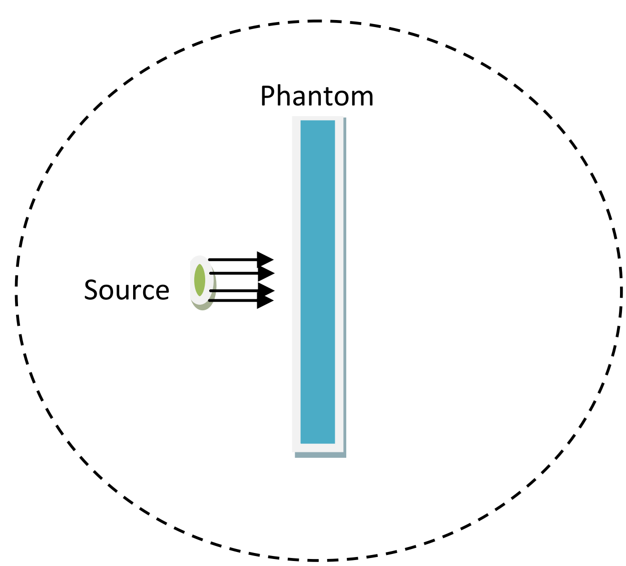

Fig. 1. The simulation setup for MCNP-4C code.