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Research Article

STUDY OF SHIELDING PROPERTIES FOR POLYAMIDE 6/ACRYLONITRILE-BUTADIENE – STYRENE BLENDS USING NON–DESTRUCTIVE ASSAY TECHNIQUE

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Abstract

Polymer material such as 6/Acrylonitrile–Butadiene–Styrene Blends with different concentrations has been prepared and its gamma shielding properties was investigated using experimental technique and Monte Carlo Neutral Particle version 5 (MCNP5) program. The experimental setup and also the MCNP5 program were designed using ^{137}Cs as a gamma ray source. The purpose of this work was to characterize 6/Acrylonitrile–Butadiene–Styrene Blends behaviour against gamma rays, as well as to test different blend concentrations in an effort to improve gamma rays shielding efficiency. Linear and mass attenuation coefficients, mean free path and half value layer were determined experimentally and theoretically. Comparison between Monte Carlo calculations and experimental works showed that, the most concentration of this material under study could be used as shielding against gamma rays. A good agreement between the experimental data and Monte Carlo calculations proved that the MCNP5 simulation can be employed for determination of different attenuation properties when no experimental data are available.

Keywords: Monte Carlo Neutral Particle version 5; Linear attenuation coefficient; Mass attenuation coefficient; Mean free path; Half value layer.

INTRODUCTION

Nuclear radiation has applications in many fields like medicine, industry, agriculture, archaeology, geology, academics, nuclear reactors, as well as research reactors in the field of power generation and many others (Mohammad Qasim Al-Fakhar and Fawzi Abdul Karim Akram, 2006). Radiation shielding materials are required to protect the population and equipment from harmful effect of radiation. For shielding design, gamma rays are the main types of nuclear radiation. Nuclear shields are the most important for protecting peoples who work in the field of radiation and also reducing the radiation exposure. The theme of the protective shields of radiation has become an important part in our daily lives, especially after the great scientific progress, which began to concentrate on the subject of the use of radioactive materials. Polymers are the good choices for tissue equivalents in dosimetry and medical physics because of their physical and chemical properties (Singh *et al.,* 2015). Recently, an attempt has been made for determination of the mass attenuation coefficient for some polymers using Monte Carlo method (Bose *et al.,* 2009). A good agreement was observed for intermediate and high energies (Seyed Milad Vahabi *et al.,* 2017). Polymers-supported mineral have been used to replace the metal lead in the shielding of medical devices, especially those are used in nuclear medicine. They possessed low shielding properties when compared to lead as well as they are characterized by being non-toxic, easy configuration and low-cost materials. Amongst plastic materials, polyamides (PAs) have a distinguished role in this context. They are extensively used in engineering applications, which is due to their relatively high toughness under certain conditions and excellent chemical resistance (Unal, 2004). One of the major limitations of PAs applications is its significant brittleness under impact loading at low temperatures.

Toughening of polyamide has been used to improve its performance. In particular, one of the most widespread is acrylonitrile-butadiene-styrene (ABS) copolymer due to its good mechanical properties at a competitive cost (De León, 2019; Hosseinpour *et al.,* 2019). Acrylonitrile-Butadiene-Styrene (ABS) is an important engineering copolymer, which widely used in industry due to its superior mechanical properties, chemical resistance, ease of processing, and recyclability. Various applications of ABS are in building, construction, personal care products, toys, computers, business equipment, medical devices, and in automotive interior components (Al-Saleh *et al.,* 2008; Chen *et al.,* 2017). Many shielding materials have been designed against the harm of different types of radiation to the human body; lead and concrete-based materials have been especially preferred for this. Today, polymer-based lightweight composites such as polyethylene, polystyrene, and rubber have been chosen by the radiation protection industry (Huang *et al.,* 2016; Chen *et al.,* 2013). Different concentrations of the lead ore mineral were incorporated into composites of natural rubber, were studied by (Gwaily *et al.,* 2002), who has been determined to what extent these materials could be used as a gamma radiation shield. Gamma-ray's interaction parameters with six polymers [Bone-equivalent plastic, polyvinyl chloride, air-equivalent plastic, radio chromic dye film, polyethylene terephthalat and polymethyl methacrylate] and plastic materials have been computed and investigated by Mann *et al.* (2015), for their shielding behaviors in the energy range 10-1400 keV. The Monte Carlo N-particles (MCNP) code (Briesmeister, 1997) is a neutron/electron/photon Monte Carlo transport code developed at the Los Alamos National Laboratory, NM, USA. It relies on the selection of random numbers to generate probability distributions governing such statistical events as the interaction of nuclear particles within a medium. MCNP simulates individual particles and records some aspects of their average behaviour (in our case, the energy deposition in a detector). Input parameters include a geometric and material

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description of the source matrix and of the radiation detector (Shultis and Faw, 2011). Elmahroug *et al.* (2014) studied the neutron and gamma shielding properties of four types of resin (K-resin, resin 250WD, epoxy resin and resin with high density). They showed that resin with high density is an effective for shielding gamma rays and resin 250WD is effective for shielding fast neutrons. The total mass attenuation coefficients μ_m, for wrought aluminum alloy 5070 have been measured at 59.5, 661.16, 1173, and 1332 keV photon energies by Narender *et al.* (2013) who found a good agreement between the experimental results and theoretical values estimated from mixture rule (Win XCOM program (Berge and Hubbell, 1999). The mass attenuation coefficients of boron ores such as tincal, ulexite and colemanite at 59.54 keV gamma-rays of ^{241}Am point source were determined experimentally and theoretically by Demir (2010), who concluded that boron ores could be used as shielding against neutrons and gammas simultaneously. Styrene-butadiene rubber/lead oxide composites have been prepared and used as gamma-radiation shields by Abdel-Aziz *et al.* (1997). Dasharatham (2007) studied the properties of shielding against gamma rays and neutrons for composite materials as glass supported by lead in different proportions, lead, boron, lithium or some of their compounds. He concluded that shielding gamma rays and neutrons techniques using multiple compounds composite materials better than one compound. Korkut *et al.,* (2013) investigated the radiation shielding effects of ferrochromium slag loading hardened epoxy resin samples. They found that radiation shielding performance increases with increasing ferrochromium slag additive in epoxy. Several authorizers (Akkurt *et al.,* 2010a, 2010b; Damla *et al.,* 2010; Gallego *et al.,* 2009; Kurudirek *et al.,* 2009; Mann *et al.,* 2012; Mann and Sidhu, 2012; Mann and Korkut, 2013; Turkmen *et al.,* 2008) have studied the shielding properties of polymers, concretes, silicates and building materials. In the present work, Polyamide 6/Acrylonitrile–Butadiene–Styrene Blends samples with different concentrations have been prepared and tested to study the shielding propertied of these material against gamma radiation. Linear and mass attenuation coefficients, mean free path and half value layer were determined experimentally and theoretically using MNCP5 code. Comparison between the experimental and simulation results have been investigation for materials attenuation properties.

EXPERIMENTAL

Materials and preparation

Polyamide 6 (PA-6), kindly supplied by Domamid 27, Domo (Germany), with molecular weight of about. 17,000 g/mol, density of 1.14 g/cm^3, and an intrinsic viscosity of 1.98 dl/g (at 25 ^{o}C in 85% formic acid). It contained amine and carboxyl end groups of 34 and 35mille equivalent/Kilogram (meq/kg), respectively. Acrylonitrile-Butadiene-Styrene (ABS) was purchased from Tairilac AG12A0 Formosa, Taiwan, with number average molecular weight of about 49,000 g/mol and weight average molecular weight of 134,000 g/mol. It contained 2.7 wt% additives, 22.4 wt% acrylonitrile, 13.5 wt% butadiene, and 61.4 wt% styrene. Prior to processing; PA-6 and ABS pellets were dried in vacuum oven for 4 h at 80 ^{o}C. Five blend samples with different concentrations were prepared by feeding the polymer into the polymer melt using a twin screw extruder (Plasti-corder, PL 2100; Brabender OHG, Duisburg, Germany). Table (1) listed the characteristics (PA6 concentration, ABS concentration, thickness, density, length and width) of the five samples under study with defined code in the first column. The six heating zones were set to 230, 225, 220, 210, 205 and 200 ^{o}C; then the extruded strands were chopped into granules and dried. All of the specimens were compression-molded. Afterwards, plies with 1 mm thick were prepared by compression molding of the compound at 230 ^{o}C and then cooled under controlled conditions in a Collin P200E press and pressure of 150 bars (Hassan *et al.,* 2008). The assayed samples have a rectangular shape and its dimensions are (6.98 cm as length, 4.7 cm width and 0.5 cm thickness).

Table 1. Detailed of the prepared PA-6/ABS blend at different ratios

Sample Code	PA-6 (Wt%)	ABS (Wt%)	Density (g/cm^3)
1	100	0	1.2004
2	70	30	1.17239
3	50	50	1.2439
4	30	70	1.28452
5	0	100	1.31025

Experimental Setup and MCNP5 Setup

Specific gamma ray energy, which is signature for ^{137}Cs, is used for study the attenuation property of samples, which was produced in 2007 with activity 1 μCi at Nuclear and Radiological Regulatory Authority (ENRRA). Its energy 661.7 keV and half-life time 30.719 y. The verified samples were five samples in rectangular shape and similarly in the dimensions and thickness. For the experimental measurement, the system is composed of a portable scintillation assembly based on Miniature Multi Channel Analyzer model (MCA-166), NaI (Tl) detector model (12S12-3.VD.PA.003) with dimensions (76.2 x76.2 mm^2) and an Aluminum housing of 1 mm thickness. The energy resolution of the system is 6.5% at gamma ray energy of 662 keV. The data acquisition was carried out via gamma spectroscopy software based on ORTEC WinSPEC. Each sample was measured in such a way that its axis of symmetry is perpendicular to the extended axis of symmetry of the detector in front of the source. The sample was placed between the source and the detector where the distance between them is 10 cm. The energy spectrum for the source was recorded for the source only without sample, so the incident spectrum (without attenuation) I_0 intensity was obtained. The transmitted spectrum recorded for source and sample (after attenuation), so I intensity was obtained. In both the spectra the photo-peak had Gaussian distribution. Each spectrum was recorded for sufficient time (10 min) to accumulate an adequate number of counts under the photo peak to achieve good statistics (statistical errors are always kept below 1%). All measurements were carried out by adjusting the experimental setup in such a way that errors due to electronic losses were minimized (dead time did not exceed 2 %). MCNP5 is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate 8 values for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori. For photons, the code accounts for incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, and absorption in electron positron pair production. Electron/positron transport processes account for angular deflection through multiple Coulomb scattering, collision energy loss with optional straggling, and the production of secondary particles including K x-rays, knock-on and Auger electrons, bremsstrahlung, and annihilation gamma rays from positron annihilation at rest. Electron transport does not include the effects of external or self-induced electromagnetic fields. MCNP5 input files have to contain detailed characteristics about the detector's as well as the experimental setup configuration. The characteristics of the verified samples can be obtained from the visual measurements and the data provided by the detector's manufacturer were used. For most calculations, the number of histories was selected to keep the relative standard deviation due to MCNP5 calculations less than 2%. The number of histories used in the code is 10 x 10^6 photon.

RESULTS AND DISCUSSION

Gamma ray mass attenuation coefficient of material is measure of the relative dominance of different interaction process like photoelectric effect, Compton scattering and pair production. The Compton scattering is dominating at 1 Mev, photoelectric effect is dominating below and pair production dominates above 1 Mev. When gamma radiation of intensity I_O is incident on an absorber of thickness transmitted by the absorber is given by the exponential

$$I = I_0 e^{-\mu x}. \quad (1)$$

Where I_0 and I are the incident and transmitted intensities, respectively. x is the thickness of the absorbing medium and μ is the linear attenuation coefficient (cm^{-1}). The half value layer (HVL) which is the thickness of material required to reduce the intensity of the emergent radiation to half. It is used to describe the effectiveness of Gamma ray shielding (Saudi *et al.,* 2011; Sayyed *et al.,* 2018) as;

$$HVL = \ln 2 / \mu = 0.693 / \mu. \quad (2)$$

Therefore, once one knows the linear attenuation coefficient for a material, the half-thickness is readily calculated. The reciprocal of the attenuation coefficient has units of length and is often called the mean free path (Elbashir *et al.,* 2018). The mean free path is the average distance a gamma ray travels in the absorber before interacting as;

$$\text{Mean free path (MFP)} = 1/\mu. \quad (3)$$

The linear attenuation coefficient usefulness is limited by the physical form of the particular material. The mass attenuation coefficient (μ_m) is often used in its place and is defined as;

$$\text{Mass attenuation coefficient } (\mu_m) = \mu/\rho, \quad (4)$$

where ρ is the density of the samples. Table (2) listed the ratio between transmitted and incident intensities (I/I_0) form the experimental results for the samples under study. Also, the data from MCNP5 calculations were listed in Table (2).

Table 2. The obtained results from the experimental and MCNP simulation at energy 661.7 keV

Sample ID	Experimental work		MCNP simulation	
	I/I_0	$-\ln I/I_0$	I/I_0	$-\ln I/I_0$
1	0.97788	0.02237	0.97586	0.02444
2	0.95133	0.0499	0.95231	0.04886
3	0.96018	0.04064	0.95967	0.04116
4	0.95133	0.0499	0.95057	0.05069
5	0.95575	0.04526	0.95394	0.04716

Figures (1-4) present the comparison between experimental and MCNP results of μ, MFP, $X_{1/2}$ and μ_m for assayed samples at energy 661.7 keV. According to Tables (2) and Figures (1-4), it was found that the sample ID=1 gives lower linear and mass attenuation coefficients, large half-thickness and high mean free path. With increasing the concentration of the material, the sample density increases and the behavior is opposite compared to those of sample ID=1. The shorter (MFP) indicates more interactions of photons to materials and possesses the better shielding properties. The simulated MCNP results of μ, μ_m, MFP and $X_{1/2}$ agree with the experiment results. MCNP may be employed to make additional calculations on the photon attenuation where no experimental data exist.

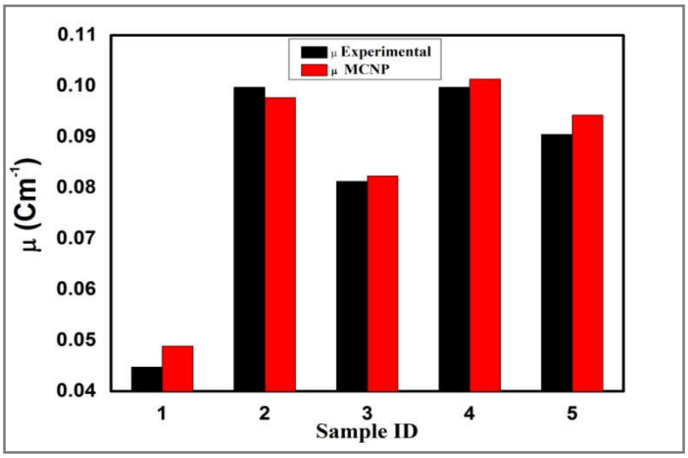

Fig. 1. Experimental and theoretical (MCNP) values of linear attenuation coefficient (μ) for different samples

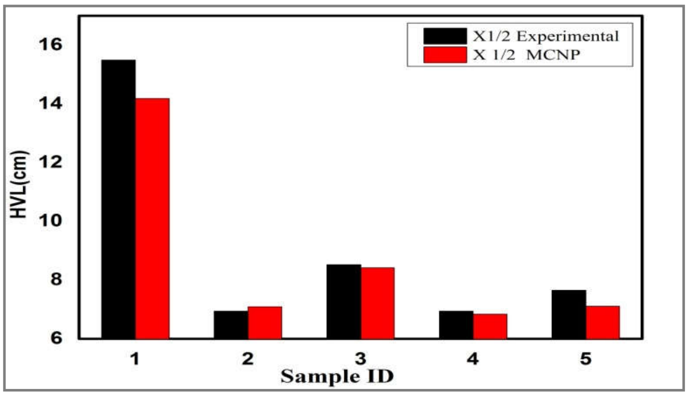

Fig. 2. Experimental and theoretical (MCNP) values of the half value layer at Different samples

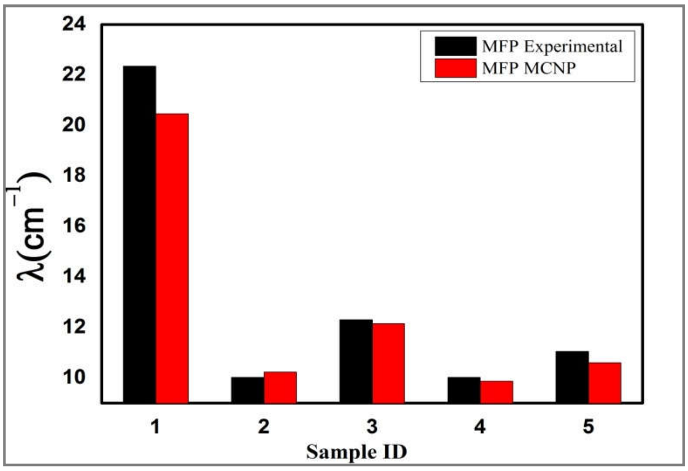

Fig. 3. Experimental and theoretical (MCNP) values of mean free path (MFP) at different samples

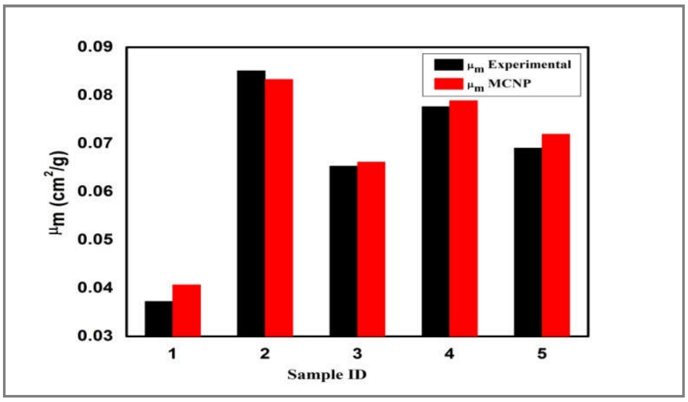

Fig. 4. Experimental and theoretical (MCNP) values of mass attenuation coefficient (μ_m) at different samples

Conclusion

The shielding properties of polymer materials with different concentration have been studied. The photon linear attenuation coefficients (μ), the mass attenuation coefficients (μ/ρ), mean free path (MFP), and half thickness ($X_{1/2}$) of assayed samples are compared by experimental work and MCNP simulation for energy 661.7 keV. It was found that the simulated MCNP results of μ, μ_m, MFP and $X_{1/2}$ are in very good agreement with the experiment data. This work may be extended to study and calculated attenuation coefficients for different types of materials that may be used as gamma shielding against different energies. MCNP may be employed to calculate attenuation coefficients for various materials for various energies.

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