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Research Article

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Evaluation of X and Gamma-rays Attenuation Parameters for Polyacrylamide and ZnO Composites as Light Shielding Materials Using MCNP and X-COM Simulation

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Abstract

Introduction: In this study, ZnO/Acrylamide composites were considered as gamma and x-ray shielding. The mass attenuation coefficient and half value layer for the bulk of ZnO and various percentages of the ZnO composites were calculated for different range of energy.

Materials and methods: In this paper, the Monte Carlo N-Particle eXtended (MCNP-X) version 2.4.0T was used as a tool for determining the mass attenuation coefficient and half value layer of the shielding samples.

Results: The obtaining data were in good agreement with the data that were come from the X-COM program. Also, the data show that the composite's ability in attenuation of the gamma rays is similar to the bulk of ZnO.

Conclusion: The results show the preferences of using composites as a radiation shielding in comparison with the bulk of the ZnO.

Keywords: MCNP Code; X-COM; Mass attenuation coefficient; Half value layer

Introduction

Radioactive sources are used in wide variety of purpose such as educational, medical, research, industrial, governmental, and commercial facilities [1]. But it is impossible to ignore the negative effects of the radiation on the human and materials. So, the researchers started to set some official rules and shielding materials to limit the exposure and protect individuals from radiation's hazard, especially who handling ionizing radiation. They have done a lot of effort to design a useful and practical shielding that can absorb most part of the radiation and do not let them to receive to the people [2]. The famous materials that have been used for several years are lead, Tungsten, and the others. Although, these materials have a high absorption rate, they have a high weight which sometimes makes them unpractical such as space. In this situation, the researchers have carried out many kind of research to produce new materials that have lack the problems of the high weight and can use as a light shielding [3].

There are various candidates such as glasses and composites that can be the best replacement of the lead and concrete, and the other conventional material. In all of the researches [4-28], the linear and mass attenuation of the materials have been either tested or simulated with MCNP code. The results from these researches prove this claim that some of the new materials are better in comparison with conventional materials in attenuation of gamma and x-ray from the economic and environmental point of view. The main goal of this article is simulating a new form of shielding materials by MCNP code and evaluating its correctness by comprising with the X-COM program.

Material and Methods

Materials

The composites are combination of ZnO particles in polyacrylamide matrix. The percentage of each sample on the basis of relative mass of nanoparticle is calculated, and the area densities of the samples are calculated by this formula

As seen in the Table 1, the Z_{20} C has the high density which has the high percent of the ZnO particles. The thickness of the all composite samples, bulk of ZnO and Lead, are 1.5 cm, and the areal of all them are 4.9 cm^2, and all of them are in the form of pill. To introduce the samples in the MCNP, the atomic number, mass number, elemental mass fraction (for compounds or mixtures) and density were specified. So, material definitions of samples of composites, ZnO and lead were defined in input file.

Sample	Thickness (cm)	Surface density (g/cm^2)	Volume density (g/cm^3)
Air	1.50	0.0018075	0.001205

Z_5C Composite 5%	1.50	2.0017500	1.334500
$Z_{10}C$ Composite 10%	1.50	2.3385000	1.559000
$Z_{15}C$ Composite 15%	1.50	2.6752500	1.783500
$Z_{20}C$ Composite 20%	1.50	3.0120000	2.008000
Bulk ZnO	1.50	8.4000000	5.600000

Table 1: The physical properties of composites, bulk of ZnO.

MCNPX Simulation

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for photon, electron transport [26]. It is a practical tool for measuring the stimulation environment of test in various fields such as radiation dosimetry and shielding, radiography, medical physics, and designing detectors and analyzing them. This simulation code (MCNP 2.6) was used as a main tool for the implementation of this work. We just ran MCNP code in photon transport mode only for omitting the problem of interaction of photon with the desired samples. The strength of the source was assigned to show the normalized source, and it was considered as a monoenergetic isotropic point source. The photon weight factor is 1 in all cells and zero in the cutoff region (outside the boundary surface of the problem). F4 Tally (flux over detector cell) is concerning with total cross-section. The geometry of the simulation set-up system for is shown in Figure 1. It is built of source, collimator, and detector collimator separated by 11.8 cm. The length of the detector and the shield that sounded it is 12 cm, and the first and second collimator is 5.3, 6.5, respectively. There is a cylinder shield behind the source by the 8.2 cm length, and the samples are of 1.5 cm diameter. For the various samples, the transmitted beam of photons is calculated. The atomic components of samples were introduced to MCNPX 2.6 code, and their areal densities were inserted in the code. The calculations were performed for gamma photons of energies 0.2547, 0.393, 0.662, 1.253 MeV. MCNPX 2.6 uses mcplib22 cross-section data file for performing these calculations. The results which are obtained from stimulation have relative error less than 0.1%.

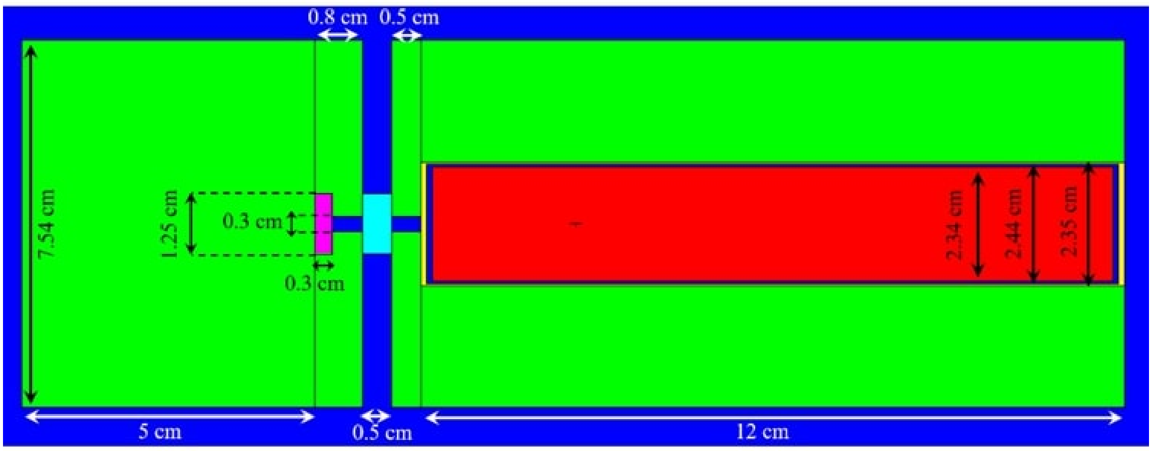

Figure 1: Experimental setup scheme for measuring gamma ray attenuation coefficient.

The X-COM program

The program is applied as a tool for obtaining data of the total cross sections and attenuation coefficients for the incoherent and coherent scattering, photoelectric absorption, and pair production in the field of the atomic nucleus and in the field of the atomic electrons. The total attenuation coefficient is the sum of the individual processes attenuation coefficient. In this work, the version (3.1) of XCOM is used, the ZnO/Acrylamide composites are considered as a mixture and ZnO as a compound. For the ZnO, the Formula of the compound just need to write down, but for the mixture samples, the fractions by weight of the various components have to entere [27]. The quantity of the mass attenuation coefficient describes the probability of interaction of the photon with the material [28]. The attenuation of the intensity is according to the exponential attenuation law that is shown in the following equation.

$$I(x)= I0(x)\ e\ (\mu/\rho)$$

In this equation the I0(x) is the intensity of the source in the absence of shielding, I(x) is the attenuated intensity, x the thickness of the matter, and μ/ρ is the mass attenuation coefficient. The half-value layer of the shielding materials demonstrates the thickness in which the intensity of the photon reduces to one-half of its original value [5]. It is obtained by this function:

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Results

The mass attenuation coefficient and half value layer in the energy range the 0.122061, 0.136474, 0.276398, 0.302853, 0.356017, 0.383851, 0.661657, 0.898042, 1.173237, 1.27453, 1.332501, 1.836063 were obtained by the MCNP and XCOM. The data were shown in Tables 2 and 3. In the Figure 2, the diagrams of a mass attenuation coefficient were drawn as a function of the incident photon energy.

	Mass Attenuation Coefficient (cm^2/g)				
Energy	**5%**	**10%**	**15%**	**20%**	**ZnO**
0.122061					
X-COM	0.1606	0.1677	0.1748	0.1819	0.2952
MCNP	0.1597	0.1659	0.1733	0.1807	0.2944
0.136474					
X-COM	0.1534	0.1583	0.1632	0.1681	0.2463
MCNP	0.1525	0.1576	0.1624	0.1671	0.2455
0.276398					
X-COM	0.1177	0.1178	0.1179	0.1179	0.119
MCNP	0.1168	0.117	0.1171	0.1172	0.1186
0.302853					
X-COM	0.1137	0.1136	0.1135	0.1134	0.1121
MCNP	0.1129	0.1127	0.1126	0.1123	0.1116
0.356017					
X-COM	0.1067	0.1065	0.1062	0.1059	0.1018
MCNP	0.1058	0.1055	0.1052	0.105	0.1011
0.383851					
X-COM	0.1036	0.1032	0.1029	0.1026	0.0976
MCNP	0.103	0.1026	0.1022	0.1019	0.0968
0.661657					
X-COM	0.08217	0.0817	0.0813	0.0809	0.7403
MCNP	0.08206	0.0816	0.0812	0.0808	0.7397
0.898042					
X-COM	0.07129	0.0709	0.0705	0.0701	0.06364
MCNP	0.0625	0.0708	0.0704	0.07	0.06351
1.173237					
X-COM	0.06254	0.0622	0.0618	0.0614	0.5551
MCNP	0.07118	0.062	0.0617	0.0614	0.05464
1.27453					
X-COM	0.05993	0.0596	0.0592	0.0589	0.05322
MCNP	0.05986	0.0595	0.0591	0.0588	0.05311
1.332501					

X-COM	0.05858	0.0582	0.0579	0.0575	0.5203
MCNP	0.05821	0.0581	0.0578	0.0572	0.05117
1.836063					
X-COM	0.04953	0.0493	0.049	0.0487	0.04451
MCNP	0.04949	0.0492	0.0482	0.0487	0.04439

Table 2: The mass attenuation of composites, bulk of ZnO.

	Half value layer (cm)				
Energy	**5%**	**10%**	**15%**	**20%**	**ZnO**
0.12206					
X-COM	3.23416	2.65122	2.22337	1.89771	0.41885
MCNP	3.25239	2.67999	2.24261	1.91031	0.41999
0.13647					
X-COM	3.38596	2.80866	2.3814	2.0535	0.50201
MCNP	3.40594	2.82113	2.39313	2.06579	0.50364
0.2764					
X-COM	4.41296	3.77428	3.29639	2.92784	1.03902
MCNP	4.44697	3.80009	3.31891	2.94533	1.04253
0.30285					
X-COM	4.56821	3.91382	3.42418	3.04403	1.10298
MCNP	4.60058	3.94508	3.45155	3.07385	1.10792
0.35602					
X-COM	4.86791	4.17474	3.65955	3.25961	1.21458
MCNP	4.90932	4.21431	3.69434	3.28755	1.22299
0.38385					
X-COM	5.01357	4.30824	3.77691	3.36445	1.26684
MCNP	5.04278	4.33343	3.80278	3.38756	1.27731
0.66166					
X-COM	6.32111	5.43932	4.77979	4.26796	0.16702
MCNP	6.32959	5.44665	4.78508	4.27483	0.16715
0.89804					
X-COM	7.28582	6.27272	5.51425	4.9257	1.94286
MCNP	7.29708	6.28335	5.52209	4.93133	1.94684
1.17324					
X-COM	8.30518	7.15152	6.28874	5.61929	0.22274
MCNP	8.31049	7.17229	6.29588	5.62662	2.2628

1.27453					
X-COM	8.66688	7.46241	6.56161	5.86365	2.32326
MCNP	8.67701	7.47872	6.57271	5.87262	2.32807
1.3325					
X-COM	8.86661	7.63541	6.7135	5.99918	0.23764
MCNP	8.92297	7.65513	6.72744	6.04012	2.41656
1.83606					
X-COM	10.4867	9.02395	7.93152	7.08233	2.77789
MCNP	10.4952	9.04047	8.06316	7.09543	2.7854

Table 3: The half value layer of composites, bulk of ZnO.

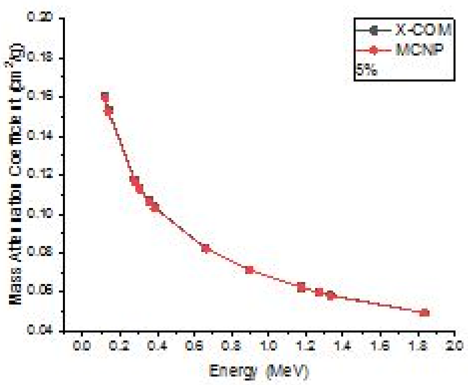

Figure 2A: The mass attenuation coefficient of the composites and bulk of ZnO and Pb sample versus of the incident energy of the photons (5%).

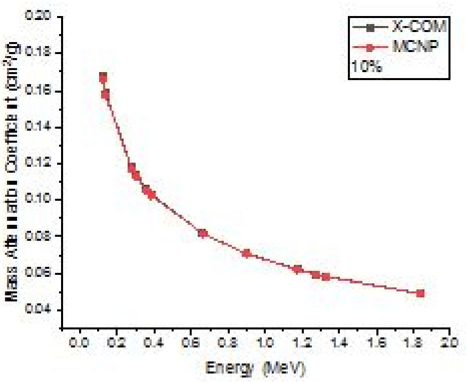

Figure 2B: The mass attenuation coefficient of the composites and bulk of ZnO and Pb sample versus of the incident energy of the photons (10%).

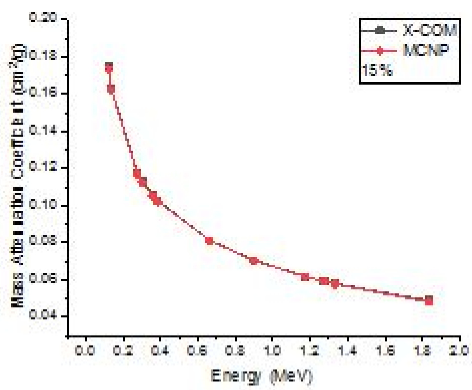

Figure 2C: The mass attenuation coefficient of the composites and bulk of ZnO and Pb sample versus of the incident energy of the photons (15%).

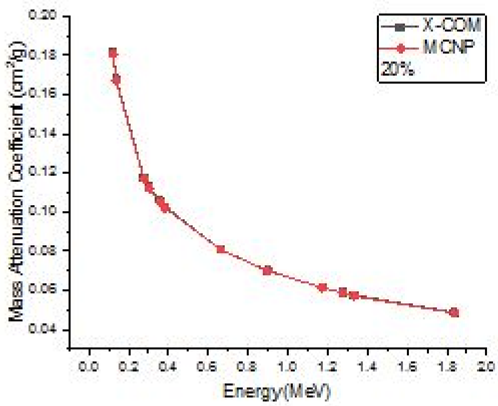

Figure 2D: The mass attenuation coefficient of the composites and bulk of ZnO and Pb sample versus of the incident energy of the photons (20%).

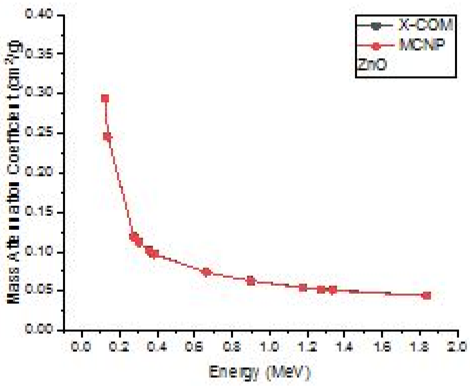

Figure 2E: The mass attenuation coefficient of the composites and bulk of ZnO and Pb sample versus of the incident energy of the photons.

Discussion

As seen in the Figure 2, the mass attenuation coefficient decreases rapidly with increasing energy of the incident photons. In the energy range of the 0.122061 MeV to 0.8 MeV, the dominant interaction between matter and incident photon is the photoelectric effect. Because of that the mass attenuation coefficient decrease rapidly, but in the photon energy of the 1 MeV to 1.836 because of the Compton scattering process, the decreasing rate of the mass attenuation coefficient is constant. The most amount of the mass attenuation coefficient belongs to the composites with the 5% of nanoparticles. By increasing the energy and percent of the ZnO, the mass attenuation is decreased. In the Table 3, the values of the half value layer of the composites and bulk of the ZnO against the energy are shown. As it seen, the half value layer is increased by the density of the particles in the polymer and energy. The half value layer of the ZnO in the high energy is 0.2 times of the composites, meanwhile the volume density of the ZnO is 4 times of the composites. In addition, there is good agreement between MCNP and X-COM date. The composite with 20 percent of ZnO particles has a less half value layer.

Conclusion

In this work, the mass attenuation and half value layer of the four different percent of the ZnO composites in the 0.122061, 0.136474, 0.276398, 0.302853, 0.356017, 0.383851, 0.661657, 0.898042, 1.173237, 1.27453, 1.332501, 1.836063 are simulated and calculated by the MCNP 2.6, and X-COM. The results from these two programs are in good agreement and shows composite better performance as a gamma-ray shielding compared to the bulk of ZnO.

Conflicts of Interest

There is none to be declared.

Authors Contributions

All authors contributed equally to the study.

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