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EVALUATING MULTI-LAYERED SHIELDS FOR LOW ENERGY PHOTONS USING MCNP5 CODE AND XCOM PROGRAM

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Abstract
MCNP5 was used to evaluate the shielding properties of different composite shields made of combinations of four elements; Tungsten (W), Bismuth (Bi), Tin (Sn), and Zinc (Zn), at different weight ratios. Attenuation coefficients calculated by MCNP5 were compared with XCOM theoretical data for 11 different photon energies ranging from (15 -150 keV). Mass attenuation coefficient (μ/ρ), half-value layer (HVL), and mean free path (MFP) were also calculated. MCNP5 calculations were in good agreement with the XCOM data. Attenuation coefficients were sensitive to changes in photon energy. Two of the studied composite shields were found better alternatives to lead shields over the medical diagnostic photon energies up to 150 keV.

Keywords:
MCNP5 code, XCOM, Mass attenuation coefficient, Half-value layer, Mean free path

INTRODUCTION

Lead has long been used as shield against X- and gamma rays. However, the now known toxicity of lead (Hulbert & Carlson, 2009) forced searching for lead-free radiation shields (Katoh et al., 2007). Many researchers introduced suitable alternative materials (Künzel & Okuno, 2011, Azman et al., 2013, Azman et al., 2013, Mehdi et al., 2015). Kyung et al. (Kyung et al., 2010) illustrated the potential dose reduction using bismuth shielding in computed tomography. Several combinations of lead free materials including (W-Si), (W-Sn-Ba-EPVC), (W-Sn-Cd-EPVC) have been investigated within the energy range of diagnostic radiology and the results compared with those of some lead-containing materials e.g. (Pb-Si), (Pb-EPVC). The results showed that lead shields provided better protection at low energies (< 40 kVp). However, a composite of (W-Sn-Cd-EPVC) showed better radiation attenuation properties between 60-90 keV, and a composite of (W-Sn-Ba-EPVC) provided the best attenuation at 120 keV, surmounting the lead- containing composites (Kazempour et al., 2015). Other researchers investigated other shielding combinations (Chen & Wei, 2008, Aghamiri et al., 2011, Korkut et al., 2012).

In the present work, composites of four elements viz. Tungsten (W), Bismuth (Bi), Tin (Sn) and Zinc (Zn) at different weight fractions were tried as shields against X- and gamma rays in the medical energy range between 15 -150 keV. Modeling, calculations, and verification were carried out using MCNP5 Code and XCOM program. Attenuation coefficients were calculated using XCOM program. These in addition to other photon shielding parameters including μ/ρ, HVL and MFP, were calculated using MCNP5.

OBJECTIVES

The main objective of the study is to investigate the efficacy of different lead-free composite materials as shields against X- and gamma - rays at medical energy range.

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METHODOLOGY

Multi-layer shield composed of W, Bi, Sn, and Zn at different weight ratio (**Table 1)** were exposed to 11 different photon energies most commonly used in diagnostic radiology. A mono-energetic isotropic radiation source was assumed. Lead collimators were used to define the radiation going out the source.

Table 1. N1-N4 Weight ratios of the different composites.

Materials	N1	N2	N3	N4
W	73.27	52.23	7.51	12.17
Bi	22.89	43.28	6.37	3.72
Sn	1.46	2.82	33.18	52.52
Zn	2.38	1.66	52.93	31.59

MCNP geometry (see Figure 1) replicated the experimental parameters to validate the input file. The statistical uncertainty of the tallies did not exceed 3% for any composite in all energy bins.

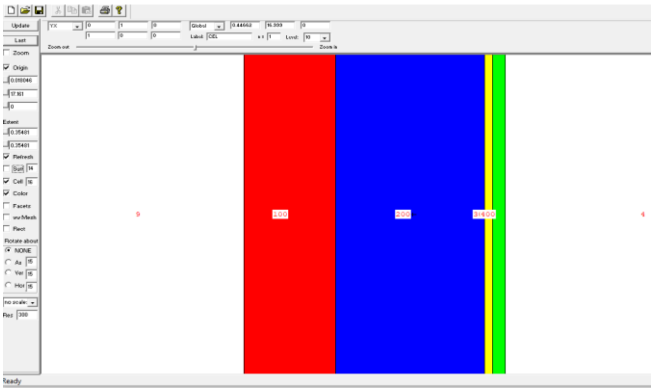

Fig. 1. Multi-layered radiation shielding plotted by Visual Edit.

To verify the input file, mass attenuation coefficients of N1-N4 were compared to XCOM (Berger et al., 2010) results. Mass attenuation coefficient (μ/ρ), half-value layer (HVL), and mean free path (MFP) were calculated to evaluate the interactions of photons within the shielding materials. Results were compared to those for lead.

RESULTS AND DISCUSSION

For the 4 suggested composites (N1-N4) shields, mass attenuation coefficient (μ/ρ) was inversely proportional to photon energy over the considered energy range of; 15, 20, 30, 40, 50, 60, 70, 80, 90.53, 100, and 150 keV, (see Figure 2). These results were compared with the values acquired using XCOM data base. Figure 3 shows a good agreement between the results. At 15 keV; mass attenuation coefficients of N1 and N2 were 130.9 and 125.4 cm^2/g respectively, higher than that of lead (111.6 cm^2/g), while N3 and N4 had mass attenuation coefficient lower than that of lead (76.26 and 71.35 cm^2/g, respectively).

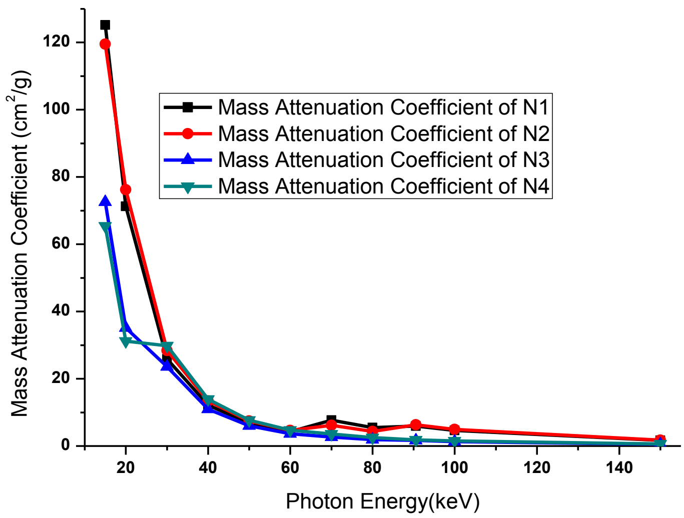

Fig. 2. Mass attenuation coefficient vs. photon energy using MCNP5.

The half value layer (HVL) was calculated for the four investigated composites and compared with HVL of lead,(see Figure 4) . The HVL curves of N2 and Pb coincided over all energies >15 keV except between 60 - 90 keV where N2 had lower HVLs than Pb. HVL of N1 was lower than those for Pb and N2 at all energies. At 70 and 80 keV; HVLs of N1 was much lower than those of lead, (see Figure 5).Essntially, N1 and N2 showed better gamma ray shielding properties than Pb. N3 and N4 composites exhibited the greatest HVL over the whole energy range, (see Figure 4).

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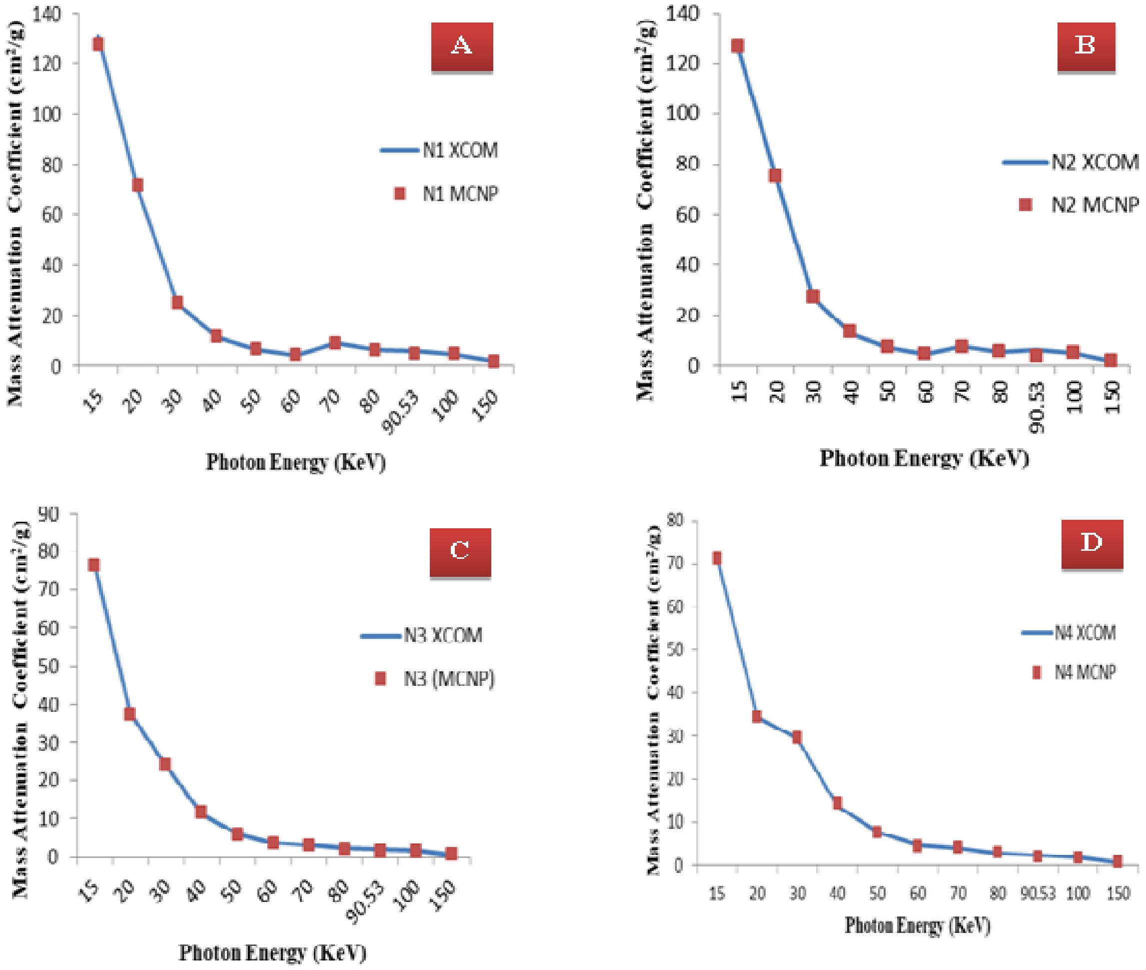

Fig. 3. Mass attenuation coefficient calculated byMCNP5 and XCOM for (N1, N2, N3, N4)

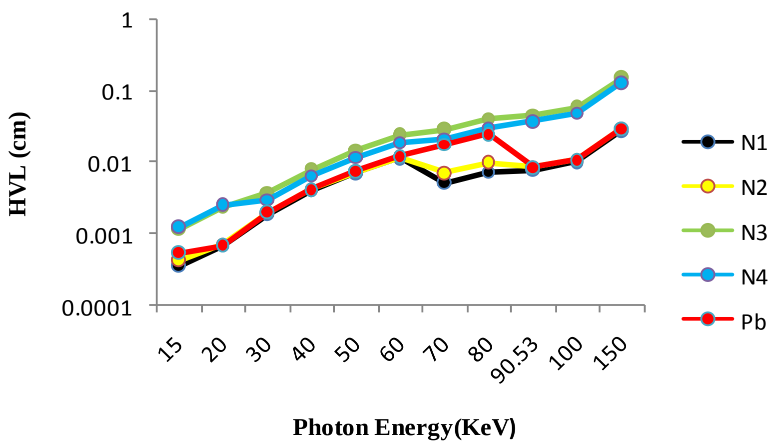

Fig. 4. Half value layer at different photon energies for N1-N4 and Pb shields.

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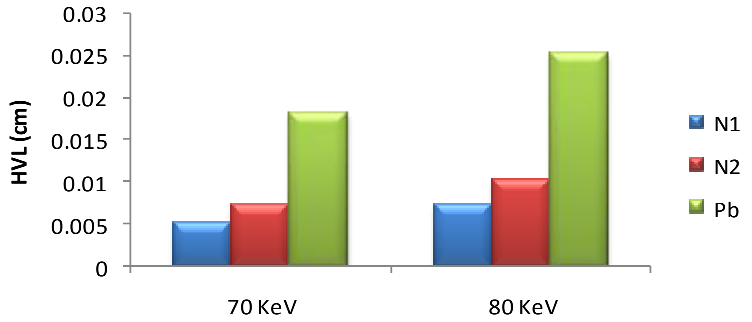

Fig. 5. HVL values for N1, N2, and Pb for 70 and 80 keV photon energies.

Figure 6 shows that the photons' MFP values of N1 and N2 were lower than those of Pb between 15 – 150 keV indicating that photons are more attenuated in N1 and N2 shields than in Pb. Thus, N1 and N2 are suitable photon shielding materials over that energy range. N3 and N4 shields had higher values of the MFP than lead.

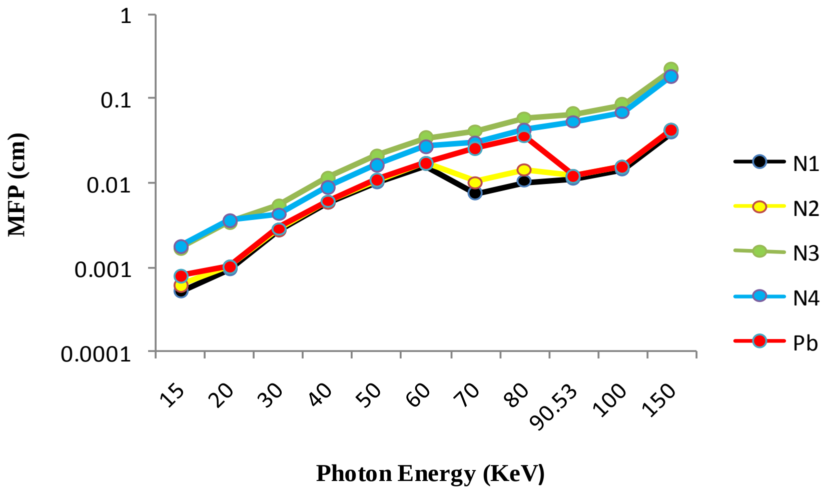

Fig. 6. MFP values for N1-N4 shields, and Pb for photon energy range (15-150) keV.

CONCLUSION

MCNP proved to be accurate tool to evaluate the shielding properties of differ materials, showing very good agreement with XCOM results. Also, N1 and N2 composite shields were good alternatives to Pb as regard shielding against low energy photons (15 – 150 keV). They were even superior to Pb between 60 – 90 keV photon energies.

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