Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Reduced Effects of Back-scattering by Composite Layer

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1. Introduction

Currently the primary shielding of X-ray room in local hospital is constructed by lead plate or concrete to protect the radiation. Most of text books show the calculation of leakage radiation or radiation outside of X-ray room [1] [2]. Hence, the back scattered X-ray radiations from primary shielding are mostly governed by Compton scattering and they have a possibility to hurt the patients. In case of primary shielding with lead plate, intensity of Compton scattering is increased due to higher atomic number of target. The scattered intensities at certain X-ray energy are calculated by the well-known Klein-Nishina experimental formula [3] [4]. Therefore, when primary shielding with lead plate of X-ray room is covered by thin target having the lower atomic number of element, the back scattered X-ray radiation can be reduced

We are going to manufacture the composite layer which can reduce the back-scattering effects from primary shielding. The goal of this paper shows the calculation of reduced effects of back scattering, when primary shielding with lead is covered by various targets such as aluminum, silicon, or copper. We chose the X-ray energies of 50keV, 100keV, 200keV, 300keV, 500keV, and 1000keV which are normally used in the local hospitals. We calculated the reduced effects for covered target with single materials and composite layers.

2. Methods

2.1 Theoretical Aspect

When the electromagnetic waves including X-ray meet the shielding material, they interact three kinds of reaction called the photoelectric effect, the Compton scattering, and the pair production. In case of 50-250 keV energy range of X-ray, it is mostly governed by the Compton scattering.

Intensity of X-ray after passing shielding material is calculated by a well-known equation (1)

$$I = I_0 \exp(-\mu d) \qquad (1)$$

where I and I_0 are the intensities of X-ray after target and before target, μ is a linear attenuation coefficient (cm^{-1}), and d is thickness of target (cm)

The energy of X-ray after Compton scattering is calculated by equation (2)

$$E_{X'} = \frac{E_X}{1 + \frac{E_X}{m_0 c^2}(1-\cos\theta)} \qquad (2)$$

where $E_{X'}$ and E_X are X-ray energies after scattering and before scattering. $m_0 c^2$:is rest mass energy of electron, and θ is the scattered angle.

Angular distribution of the scattered X_ray is determined by the Klein-Nishina experimental formula.

$$\frac{d\sigma}{d\Omega} = Zr_0^2 \left(\frac{1}{1+\alpha(1-\cos\theta)}\right)^2 \left(\frac{1+\cos^2\theta}{2}\right) \times \left(1 + \frac{\alpha^2(1-\cos\theta)^2}{(1+\cos^2\theta)[1+\alpha(1-\cos\theta)]}\right) \qquad (3)$$

where $\alpha \equiv \frac{E_X}{m_0 c^2}$ is the X-ray energy in units of the electron rest mass energy, r_0 is a parameter called clasasical electron radius = $e^2 / 4\pi\varepsilon_0 m_0 c^2 = 2.818$ fm, and Z is the atomic number of target.

For total intensity of scattering, we must integrate equation (3) over all angles. The result is

$$\sigma_C = Z\left\{\frac{\pi r_0^2}{\alpha}\left\{\left[1 - \frac{2(\alpha+1)}{\alpha^2}\right]\ln(2\alpha+1) + \frac{1}{2} + \frac{4}{\alpha} - \frac{1}{2(2\alpha+1)^2}\right\}\right\} \qquad (4)$$

Normally, back-scattering radiation is defined by scattering angle , θ, of $\frac{1}{2}\pi < \theta < \pi$.

2.2 Calculation Results

The results of equation (3) by Klein-Nishina formula shows figure 1.

As shown in figure 1, ratio of back-scattering radiation becomes greater to lower X-ray energy. To apply in X-ray room, as we assume that patient is mostly hurt by scattered X-ray radiation with $\theta = \pi$ from primary shielding, our calculation is considered by only $\theta = \pi$. When X-ray energies are over 2MeV $(\alpha = 3.91)$, back-scattering radiation will be close to zero.

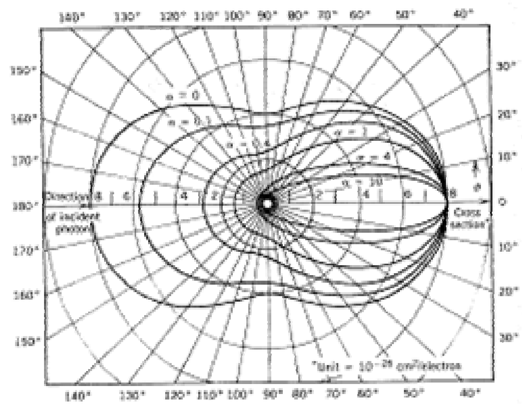

Figure 1. The Compton scattering cross section for various incident X-ray energies. The polar plot shows the intensity of the scattered radiation as a function of the scattering angle, θ . [5]

2.3 Composite layer to Reduce the Back-scattering

We assumed a composite layer which is made by three thin plates consisted by aluminum, silicon, and copper. Thickness of each plate is considered as 0.3mm, 0.5mm, 1mm, and 2 mm thickness. This total thickness of composite layer will be 0.9mm, 1.5mm, 3mm, or 6 mm. Table 1 shows the results of back-scattered cross sections for various X-ray energies and for various target material.

Shielding layer / X-ray energy	Al	Si	Cu	Pb
50 keV	0.621	0.791	1.636	4.628
100 keV	0.476	0.606	1.256	3.549
200 keV	0.322	0.409	0.849	2.401
300 keV	0.243	0.310	0.641	1.814
500 keV	0.165	0.209	0.434	1.227
1000 keV	0.093	0.118	0.244	0.690

Table 1. Back-scattering cross section (unit = 10^{-28} cm^2/electron) to scattering angle for various targets and for various X-ray energies.

For our application of the composite layer of 6 mm thickness, using by equation (1), initial intensities of X-ray are attenuated and are scattered through a composite layer of Al, Si, and Cu. The residual intensities of X-ray after a composite layer will be scattered by primary lead plate and they will be attenuated through a composite layer again by reverse direction. Table 2 shows the relative back-scattering intensities through a composite layer for various X-ray energies.

composite thickness / X-ray energy	0.9mm	1.5 mm	3 mm	6 mm
50 keV	0.217	0.078	0.006	0.000
100 keV	0.741	0.606	0.367	0.134
200 keV	0.885	0.816	0.666	0.443
300 keV	0.911	0.867	0.734	0.540
500 keV	0.931	0.887	0.788	0.621
1000 keV	0.951	0.921	0.847	0.710

Table 2. Relative back-scattering intensities for a composite layer with various thickness (back-scattering intensity without composite layer equals 1.000)

3. Conclusion

The results of this paper shows that back-scattering intensity from primary shielding with lead of X-ray room will be reduced when primary shielding is covered by the materials which atomic numbers are lower than lead. In case of our composite layer of Al, Si, and Cu, it is good example. Thus, if this idea is applied to X-ray room in local hospital, there is an advantage for patient.

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