Experimental Investigation of Exposure Buildup Factor at Different Thicknesses of Perspex

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Abstract

To investigate the extent of multiple scattering in a material, exposure buildup factors have been measured for different thicknesses (1.5 – 10.5 cm) of Perspex ($C_5H_8O_2$) at lower photon energies of 22.16 and 24.94 keV (from X-ray tube with Ag target) using Si-PIN semi-conductor detector. The transmitted photon spectra were recorded and analyzed with the help of ADMCA software provided with the detector. It has been observed that exposure buildup factor increases with the increase in thickness of the Perspex sheets.

1. Introduction

For measuring the fundamental parameters like linear attenuation coefficient, mass attenuation coefficients, molecular cross-sections etc., transmitted photon spectra were recorded and analyzed for different materials. In case, the interacting material is in the liquid/gases state, then it requires some sample container. Moreover, if the interacting material is in solid state but in powder form, then also there are two possibilities of either of fabricating pellets with the help of suitable adhesives or to use the interacting material in its original state with the help of some container. Mostly borosilicate glass test tubes were used as sample container/holder. However, the physical properties such as effective atomic number and density of the test tubes depend upon the nature/chemical composition of the glass material with which the test tube is manufactured. For borosilicate glasses, the effective atomic number (< 14 due to presence of $_{14}$Si) and density (2.25 g/cm^3). These properties suggest that there is a finite probability of interaction of nuclear radiations (α, β, γ, n, p etc.) with glass material.

Moreover, the fragile nature of thin glass material provides another drawback of its use in nuclear research laboratories. Considering the above limitations of glass material in nuclear laboratories, another material has been suggested to replace glass material. Perspex, an organic polymer $(C_5H_8O_2)_n$ can be used as a geometrical material (sample holder/container) in nuclear and radiation physics experiments due to its lower effective atomic number (< 8), lower density (1.2 g/cm^3), flexible (ease to fabricate any structure) and transparent characteristics (proper visibility). K. Parthasaradhi et al. [1] reported the mass attenuation coefficient, effective atomic numbers for Perspex and suggested that it can be used as tissue equivalent for experimental purposes. In our previous works [2-3], photon absorption parameters and exposure buildup factors have been computed for some polymers including Perspex.

Hence, for visualizing the feasibility of using Perspex material as sample container/holder at nuclear laboratories or tissue equivalent, present work has been carried out for measuring the extent of multiple scattering for different thicknesses of Perspex sheets at different photon energies in terms of exposure buildup factor.

2. Theory

Exposure buildup factor is a correction factor in a well known Lambert Beer law, which is applicable when either multi-energetic source is used or thick target is used and/or broad beam geometry is used for the measurement of mass attenuation coefficient. Mathematically, it is given be the relation:

$$B(E, x, \mu) = \frac{I_x}{I_0 e^{-\mu x}} \quad \ldots (1)$$

Where B is exposure buildup factor, which depends upon photon energy, thickness (x) and mass attenuation coefficient (μ) of the material. I_x and I_0 are photon intensities measured by the detector with and without interacting material.

The mass attenuation coefficient (μ) of the material has been computed theoretically using WinXCom software [4], the mass attenuation coefficient database.

3. Experimental Details

The experimental setup used in the present work has been shown in Fig. 1. It consists of Mini-X (X-ray tube with Ag target), a Si-PIN semi-conductor detector, collimators and Perspex sheets. Mini-X was procured from Amptek Inc. (USA). It plays an important role in generation of x-ray photons (22.16 keV K_α and 24.94 keV K_β of Ag target). It is self contained Miniature X-Ray tube system which includes the x-ray tube, high voltage power supply & USB controller. It has been operated at the high potential of 35 KV with fixed current of 50 μA. Si-PIN semi-conductor detector has been used due to its better resolution (170 eV at 5.9 keV) and good efficiency at lower photon energy. The detection efficiency is a function of the thickness of the silicon wafer. For a wafer thickness of 300 microns (ignoring attenuation in the diode window and/or package), the detection efficiency is nearly 100% at 10 KeV and it falls to approx. 1% at 150 KeV. Two collimators of 2 mm diameter and 1 cm thickness were used to make a narrow beam of photons and filter out background radiations. Si-PIN detector system includes PX4, which is a digital interface system which also includes multi-channel analyzer (MCA) internally. The PX4 requires a 5V DC power supply. The distance between Mini-X and Si-PIN has been kept fixed at 25 cm and Perspex sheets were introduced at the centre of X-ray tube and detector. All the Perspex sheets were of same dimensions (1.5 cm thick). The transmitted photon spectra were recorded for the time span of 600 second, so as to have the minimum statistical error (below 1 %).

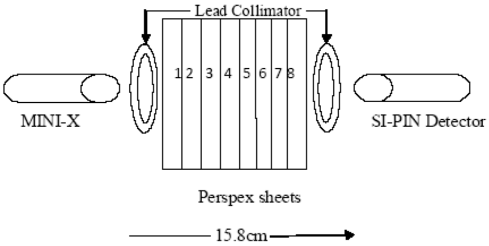

Fig. 1 Experimental Setup (not to scale)

4. Results and Discussion

The transmitted photon spectra of Ag-X-rays for different thicknesses of Perspex sheets have been shown in Fig. 2. From the figure, it has been observed that Ag K_α X-rays peak (22.16 keV) is more dominant than Ag K_β X-rays peak (24.94 keV) and the intensity of both photo peaks decreases with the increase in thickness of Perspex sheets between the X-ray tube and Si-PIN detector. The exposure buildup factors measured from the transmitted photon spectra of Ag-X-rays has been shown in Fig. 3.

Almost similar results were observed for exposure buildup factor at both the photon energies up to the thickness of 6 cm. With the further increase of thickness of Perspex sheets, the exposure buildup factor at lower incident photon energy (22.16 keV) keeps on increasing linearly, whereas the increasing rate of exposure buildup factor with thickness of Perspex seems to be saturated at slightly higher incident photon energy (24.94 keV).

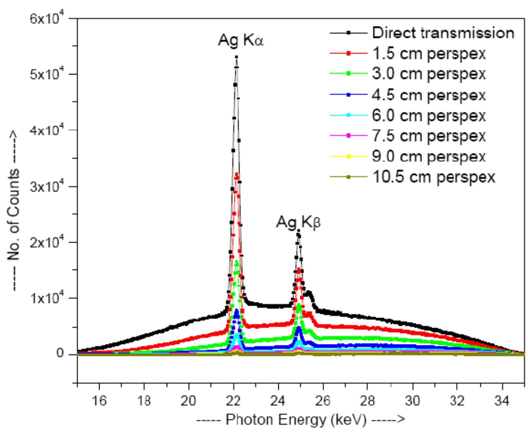

Fig. 2 Transmitted photon spectra of Ag-X-rays for different thicknesses of Perspex sheets

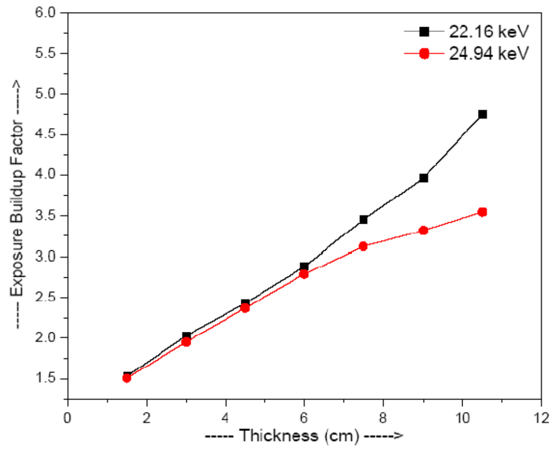

Fig. 3 Variation of exposure buildup factor with the thickness of Perspex sheets at 22.16 and 24.94 keV

This can be explained on the basis that at lower incident photon energy, the dominant photon interaction process is photoelectric absorption whereas with the increase in energy, Compton scattering also starts contributing in attenuation of photons. Moreover, the efficiency of Si-PIN detector can be another reason, which decreases with the increase in energy.

Further, the exposure buildup factor indicates the extent of violation of Lambert Beer law. For the validity of this law, exposure buildup factor value must be unity. Smaller value of exposure buildup factor above unity means smaller violation in the law.

5. Conclusion

Following conclusions can be drwan from the present investigations:

Exposure buildup factor increases with the increase in thickness of the Perspex sheets.

At lower energy, only photoelectric effect results in attenuation of X-ray photons whereas, with the increase in energy, Compton scattering also shows its contribution in attenuation of X-rays photons.

References

[1] K. Parthasaradhi, A. Esposito, M. Pelliccioni, (1992) Photon attenuation coefficients in tissue equivalent compounds, Appl. Radiat. Isot., 43: 1481.

[2] T. Singh, Rajni, U. Kaur and P.S. Singh (2010) Photon energy absorption parameters for some polymers. Ann. Nucl. Energy, 37: 422.

[3] N. Kmar, T. Singh and P. Kaur (2009) Chemical composition dependence of exposure buildup factors for some polymers. Ann. Nucl. Energy, 36: 114.

[4] L. Gerward, N. Guilbert, K. Bjorn Jensen and H. Levring (2001) X-ray absorption in matter. Reengineering XCom. Radiat. Phys. Chem.60: 23.