Simultaneous effect of collimator size and absorber thickness on the gamma ray build-up factor

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The build-up factor values have been measured for 662 keV gamma rays in the extended media of bakelite and perspex under different collimation conditions. A correlation effect has been obtained in the measurements due to collimator size and absorber thickness to prevent the multiple scatter photons reaching the detector.

[Keywords: Gamma ray build-up factor, Photons]

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1 Introduction

The interaction processes experienced by gamma rays in different media give rise to a number of secondary radiations. The presence of these secondary radiations greatly influence the entire process of gamma ray interaction and diffusion, because these scattered radiations may reach the detector and get counted. So, while studying the interaction of radiation with matter, the most important requirement is that of narrow beam geometry, in which the photons, which are incoherently and coherently scattered by a few degree are prevented from reaching the detector.

Compton scattering is the most dominant process for medium energy gamma rays, especially in low-Z composite materials. Scattered gamma ray photons tend to accumulate in the lower portion of the spectrum down to energy range where photoelectric effect becomes prominent. The phenomenon of accumulation of secondary gamma rays during attenuation gives rise to a correction factor known as Build-up Factor. Build-up factor can be defined as the interaction parameter, which corrects the attenuation calculations so that they include the contribution to the radiation field produced by scattered part of the beam. White\(^1\) initially introduced the concept of a gamma ray build-up factor and its importance in attenuation studies was confirmed by Fano\(^2\). Many theoretical and some experimental studies of build-up factor have been conducted by different researchers\(^3\)\(^-\)\(^6\) in different materials such as soil, HCO materials etc.

Build-up factors are geometry dependent parameter, that is, it depend on (i) the configurations of the source and the material i.e. how the radiations are approaching the sample, (ii) incident energy of the radiations via total linear attenuation coefficient.

The exponential law of gamma ray transmission is \(I = I_o e^{-\mu x}\) where \(x\) is the thickness of the medium, \(\mu\) is the attenuation coefficient, \(I\) and \(I_o\) are the transmitted and initial intensities of gamma rays respectively. The validity of above equation depends upon (i) source energy (ii) geometry and (iii) thickness of the absorber. That is, it is valid only when the beam is mono-energetic, collimated (small solid angle) and passing through a thin absorber. In good geometry experiments, it is assumed that photons, which undergo scattering and degrade their energy are unable to reach the detector. But with the increase in thickness of absorber between source and detector the multiple scattering increases the probability of low energy photons to reach the detector along with the incident photons. So in this case the exponential law of attenuation becomes invalid. To keep the validity of this equation it becomes necessary to apply a correction factor called build-up factor \((B)\). So the modified, equation becomes:

\[ I = B I_o e^{-\mu x} \]
The increase in thickness of absorber between source and detector is responsible for the generation of multiple scattered photons, which may reach the detector. But by using proper size of collimators these multiple scatter photons can be prevented from reaching the detector, which may effect the build-up factor value.

Considering the role of precision and accuracy in attenuation measurements an attempt has been made in the present paper to study the combined effect of absorber thickness and collimator size (solid angle) on build-up factor of bakelite and perspex materials.

2 Experimental Details

For the present investigations 662 keV gamma rays were obtained from the decay of about 8-mCi point source of $^{137}$Cs radioactive isotope, which was procured from Bhabha Atomic Research Center, Mumbai. To vary the thickness of the sample between source and detector square blocks of bakelite and perspex were used. Solid angle subtended by incident radiation was varied by using different collimator diameters as given in Table 1.

The assembly of NaI (Tl) detector (4.5 cm diameter and 5.1 cm thick) spectrometer and computerized MCA card was used for recording pulse height spectra. To prevent extraneous radiations from reaching the detector, it was kept in a lead housing well shielding from all sides. The lead shield was lined on the inside with brass and aluminium to stop the fluorescence X-ray ($\approx 75$ keV) of lead from reaching the detector. Whole assembly was placed in the center of room so as to avoid the contribution of scattered photons from the concrete material of the walls.

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Table 1 — Different collimator diameters

<table>
<thead>
<tr>
<th>Collimator size (Diameter) (mm)</th>
<th>Solid angle (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2°</td>
</tr>
<tr>
<td>16</td>
<td>3°</td>
</tr>
<tr>
<td>20</td>
<td>5°</td>
</tr>
<tr>
<td>25</td>
<td>9°</td>
</tr>
<tr>
<td>33</td>
<td>14°</td>
</tr>
<tr>
<td>50</td>
<td>24°</td>
</tr>
</tbody>
</table>

Fig. 1 shows the experimental set-up used for the present measurements. Radioactive isotope of $^{137}$Cs was kept in a lead container with a small opening for incident radiation. The transmission experiments were conducted by increasing the thickness of the absorber in various steps between source and detector and were repeated for different collimator sizes (solid angles) for both the materials of bakelite and perspex. The spectra were recorded for 1000 seconds. In some measurements if there were some change in recording time that was normalized to 1000 seconds. During this measuring time a large number of counts were recorded to make the statistical error $\ll 1\%$. The background counts recorded for the same time were subtracted from each spectrum. All the experiments were conducted at low temperature to avoid any shift in the peak due to environmental changes.

3 Calculations

For defining build-up factor, let us consider that a beam of gamma rays of intensity $I_0$, falls upon a slab

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![Experimental arrangement](image)
Mass attenuation coefficient of chosen materials of bakelite and perspex were obtained from the state-of-the-art computer program by Berger and Hubbell. Then multiplying by actual density of the material, the values of the linear attenuation coefficients were obtained. Now, knowing the value of attenuation coefficient $\mu$, thickness $x$ and intensity of the incident gamma rays $I_0$, we can calculate $I_{\text{calculated}}$ using the exponential law i.e.

$$I_{\text{calculated}} = I_0 e^{-\mu x}.$$ 

then ratio $= \frac{I_{\text{measured}}}{I_{\text{calculated}}}$ is called the build-up factor ($B$).

It is found that the $I_{\text{measured}}$ is always greater than $I_{\text{calculated}}$. So this implies that the values of build-up factors are always greater than one.

In the present paper, the intensities of incident radiation ($I_0$) and transmitted radiation ($I_{\text{measured}}$) have been measured. Using $I_{\text{measured}}$ and $I_{\text{calculated}}$, the values of build-up factor ($B$) were obtained for different thicknesses of chosen materials of bakelite and perspex under various collimation conditions.

4 Results and Discussion

The build-up factor values for bakelite and perspex are plotted against the absorber thickness for different solid angles, respectively, in Figs 2 and 3. From Figs. 2 and 3, it is clear that build-up factor value is constant (unity) for all the solid angles upto a particular absorber thickness after which the build-up factor value increases. This is because of the reason that with increase in absorber thickness more number of multiple scattered photons are generated which do reach the detector thereby increasing the build-up factor. It is also seen that for maximum absorber thickness, the build-up factor value increases with increase in solid angle. Which is due to the fact that for greater solid angle the exposed area of the detector to the radiations increases, so large number of photons are detected thereby increasing the value $I_{\text{measured}}$ which results in the increase in build-up factor value.

From Fig. 2, it is seen that in case of bakelite for a solid angle of 2' (collimator size 9 mm), the build-up factor is unity upto the absorber thickness of 4 mfp. Similarly it is observed that for solid angles of 3', 5', 9', 14' and 24' the thickness values are 3.2, 2.4, 2.0, 1.6 and 1.3 mfp's, respectively, where the build-up factor remains unity. From these results it is clear that by making an arrangement of very narrow beam
geometry the build-up factor values can be obtained equal to unity even up to a large absorber thickness. This is because when the solid angle subtended by radiation at the detector is small, multiple scattered photons that mainly contribute to buildup factor are prevented from reaching the detector. So the value of $I_{\text{measured}}$ remains almost equal to $I_{\text{calculated}}$ due to which build-up factor remains equal to unity.

For perspex (Fig. 3) a similar trend is also observed in build-up factor value as in case of bakelite. Here for solid angles of 3', 5', 9', 14' and 24' the absorber thickness values are 3.8, 3.05, 2.28, 1.92, 1.48 and 1.22 mfp, respectively, where build-up factor remains unity.

Hence, it is concluded that for a fixed solid angle (collimator size), there is a minimum thickness of the absorber up to which the value of build-up factor remains unity. With the increase in solid angle, absorber thickness up to which build-up factor is unity, decreases. So there is a correlation between the absorber thickness and collimator size for the determination of build-up factor. It is also concluded that the increase in solid angle (collimator size) does not affect the measured build-up factor value at the absorber thickness up to about one mfp where the build-up factor remains unity for all the solid angles.

The similar findings have also been reported in our previous work for the interaction parameters of attenuation coefficient\(^7\) and build-up factor\(^8\) for different composite materials.

References