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GAMMA RAY BUILDUP FACTOR OF BISMUTH-FILLED HIGH-DENSITY POLYETHYLENE COMPOSITES FOR NARROW SOURCE GEOMETRY

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Abstract: In this study, the gamma-ray buildup factor was calculated for bismuth-filled high-density polyethylene composites at 662 keV and 1332 keV gamma radiations. The shielding material HDPE/Bi composites were fabricated using a hydraulic press for the different weight percentages (0%, 10%, 20%, and 40%) of bismuth filler in the HDPE matrix. The study of the buildup factor was carried out using a 3″× 3″ NaI(Tl) detector and 2k MCA for 662 keV and 1332 keV. The results show that the buildup factor increases with the increase in the thickness of the sample, has lesser values at higher energies, and also decreases as the concentration of bismuth filler increases in the shielding material.

Key words: Buildup factor, gamma-ray energy, thickness, density, geometry.

1. Introduction:

Gamma rays are widely used in medicine, agriculture, industry, military applications, etc. Hence in nuclear technology, the measurement of gamma rays is an important issue. Meanwhile, these gamma radiations are hazardous to human life, they can cause cancer, cell mutations, teratogenesis, heart diseases, infertility, etc.[1]. To control the effects of ionizing radiations, the three methods can be followed by (i) the reduction in the time of exposure (ii) increase the distance from the radiation source (iii) protection from the radiation source by keeping the physical barrier between the source and the public [2]. The shielding material is generally used to reduce the intensity of radiation. If an absorber is placed between the source and the detector, some of the gamma photons travel directly from the source to the detector, and some of the gamma rays undergo Compton scattering in the absorber, and then these radiations can reach the detector. Thus, the signal at the detector increases, and this phenomenon is called buildup. Buildup factor is an important parameter, and is defined as the ratio of the total number of particles at the given point to the number of unscattered particles at the same point. The buildup factor is an important factor in the design of γ-ray shielding because in practice the gamma-rays are mostly wide beams, not narrow beams. There are a number of formulas and methods used to calculate the buildup factor. The commonly used formulas are the linear formula, Berger's formula, Capo's formula, and Taylor's formula. At high gamma-ray energy and for the larger thickness of the shielding material the difference in the value of buildup factor changes depends on the formula used for the calculation [3].
The γ-ray buildup factor depends on the γ-ray energy, type of shielding material, geometry of the instrument, the distance between the shielding material and the source, etc [4]. H. Akyildirim evaluates the gamma-ray buildup factor for Copper (Cu-29) for 0.511, 0.662, 1.275 MeV gamma-rays. The results show that the gamma-ray buildup factor increases with an increase in the thickness of the sample and decreases with an increase in the energy of gamma rays. It reveals that the good geometry of the instrument decreases the value of the buildup factor.

Abouzar Kiyani et al., calculate gamma-ray buildup factors for pointed and isotropic gamma sources in depleted uranium, uranium dioxide, natural uranium, tin, water, and concrete using MCNP4C code. It results that the buildup factor values increase with an increase in the energy of photons for uranium, uranium dioxide, natural uranium, and tin, and decrease for concrete and water. When the absorption is dominant or scattering vanishes, the buildup factors are greater than unity or approaches to unity.

Yinghong Zuo et al, done a comparative study of empirical formulas for gamma-ray dose buildup factor in iron and lead materials using Berger's formula and Taylor's formula. It found, the higher the gamma-ray energy and the thicker the shield material, the greater the difference between the gamma-ray dose buildup factors calculated according to the two empirical formulas.

Amjed Mohammed Shareef studied the impact of bismuth oxide nanoparticles in unsaturated polyester on gamma ray buildup factor measurements. It results that the buildup factor decreases with the increase in the filler concentration, and increases with the increase in the mean free path of the prepared samples. Kareem K. Mohammad et al, studied the gamma ray buildup factor of tungsten oxide nanoparticle with epoxy polymer. It showed that the buildup factor increases with the increase in the thickness of the thickness and decreases with the increase in the concentration of nano tungsten oxide.

2. Theory:

2.1 Buildup factor:

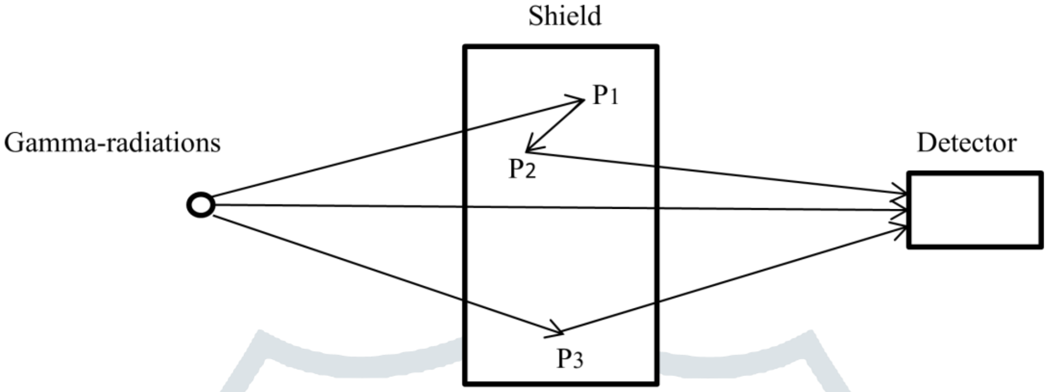

Fig. 1: Interaction of gamma-radiations with matter

Fig.1 shows, in addition to the direct gamma-radiations, the photons which undergo scattering also reach the detector. Let I_0 be the initial intensity of the gamma radiations without placing an absorbing material in between the source and the receptor and I be the intensity of gamma rays after passing through the absorber of thickness x. Then, from Beer-Lambert's law

$$I = I_0 \, e^{-\mu x} \tag{1}$$

This law is applicable only when the following conditions are satisfied: (i) The gamma-ray source must be mono-energetic. (2) The absorbing material must be very thin (3) Narrow beam geometry must be used. If, one of the above conditions is not satisfied, this law is no longer effective. However, it can be applicable after the introduction of the correction factor called the Buildup factor. Hence the above equation is altered as

$$I = BI_0 e^{-\mu x} \tag{2}$$

Where B is the buildup factor. It is equal to unity when all the above conditions are satisfied, and otherwise, it is greater than unity [5].

$$\text{i.e.,} \quad B = \frac{I}{I_0} e^{\mu x} \tag{3}$$

2.2 Density of the composites:

The density of the composites can be determined using the relation

$$\text{Density of composites} = \frac{100}{\left(\frac{M}{\rho_m} + \frac{F}{\rho_f}\right)} \ \text{gcm}^{-3} \tag{4}$$

Where, M= wt.% of the matrix, F= wt.% of the filler, ρ_m= density of the matrix &ρ_f = density of the filler [6].

3. EXPERIMENTAL METHODS:

3.1 Method of preparation of the samples

In this study, the required HDPE+Bi composites were prepared by the addition of bismuth powder in different weight percentages (0%, 10%, 20%, and 40%) as a filler with the pure HDPE matrix using a Hydraulic press. The method of preparation could be found elsewhere [7].

3.2 Experimental set up

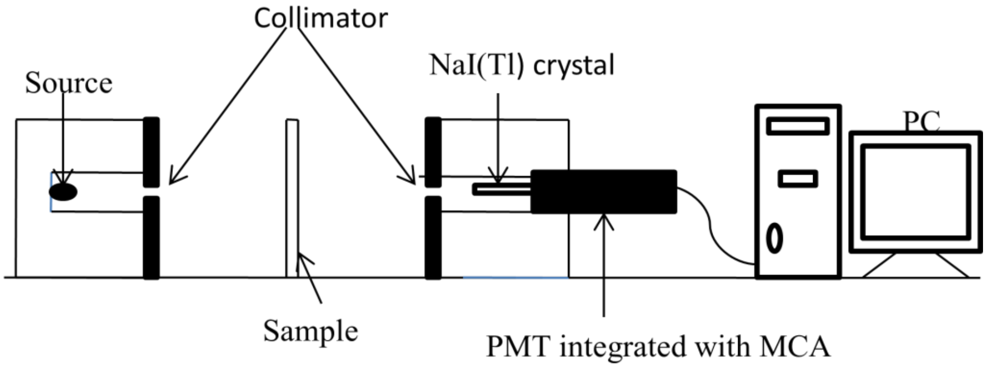

Fig. 2: Schematic diagram of the experimental setup

Fig. 3: Experimental setup at CARRT, Mangalore University, Mangalore.

Fig.2 shows the schematic diagram of the experimental arrangement using well-calibrated 3”x3” NaI (Tl) scintillation detector (Thermoscientific, Germany) for the transmission method to measure the attenuation coefficient and hence the buildup factor for gamma-rays. The NaI(Tl) detector is coupled with a photomultiplier tube, preamplifier, amplifier, and PC-based MCA (Multichannel Analyzer). In this study gamma-ray source of Cs-137 of energy 662 keV and Co-57 of energy 1332 keV are used in the form of a capsule sealed in an aluminium tube of length 115mm and diameter 20 mm.

In this experimental setup (Fig. 3) seven lead blocks in the shape of cylindrical rings of thickness 5 cm and of diameter 12 cm are used. Four of them are used to cover the back surface of the source to avoid the biological effects of gamma radiation, one of them with a hole of diameter 8 mm as a collimator to get well collimated beam of gamma radiations, one is of thickness 5 cm and of diameter 16 cm to shield the active portion of the source, and the other one is used to close the source head, when the source is not in use. A Red eye survey meter (Thermo Scientific, Germany) is used to test the goodness of the collimation. The NaI (Tl) detector is also embedded with five cylindrical lead blocks of thickness 5cm and of diameter 12cm as shown in Fig. 3, which shows the experimental arrangement made in the laboratory at CARRT (Centre for Application of Radioisotopes and Radiation Technology, Mangalore University, Mangalore). One of them is used as a collimator of diameter 16 mm to avoid the entry of scattering radiations. The distance between the source collimator and the detector collimator is 44cm. The absorber is placed at the distance of 22 cm from the source collimator. The data acquisition and analysis were performed by Win (ICx Technologies GmbH, Thermo Scientific, Germany) TMCA 32 software package. The entire arrangement is setup on the wooden table.

In the present study, HDPE+Bi composites of dimension 10 cm x 10 cm x2.5 cm is used as the absorbing material to determine the attenuation coefficient and hence the buildup factor. The sample is placed on the sample holder with the polyester support which is not a good absorber of radiation. Each measurement was taken for 2000 seconds with four trials to reduce the experimental error by 0.5.

4. Results and discussion:

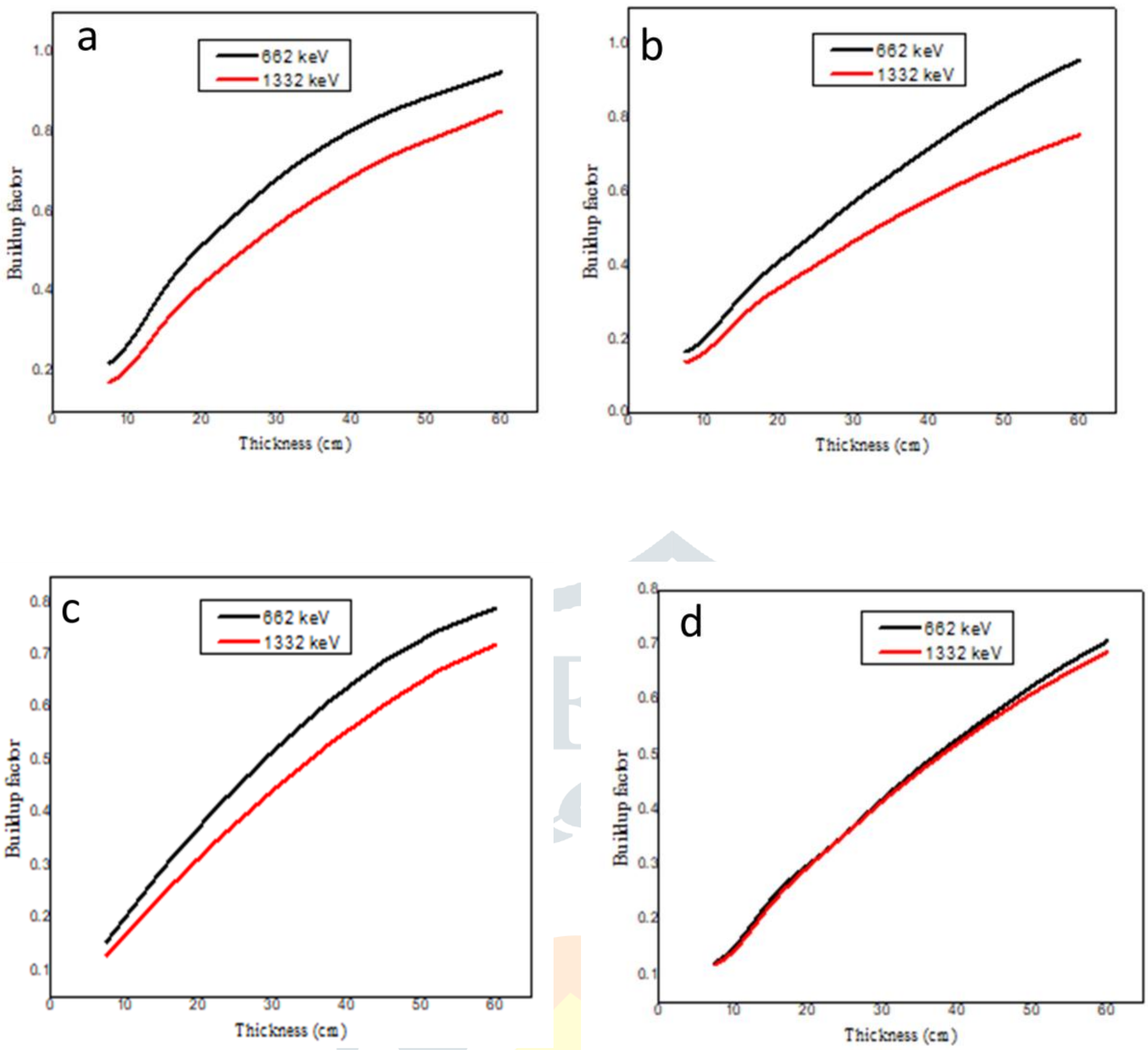

Fig. 4: Variation of buildup factor with the thickness of the composites at 662 keV and 1332 keV (a) HDPE+0 wt% Bi (b) HDPE+10 wt% Bi (c) HDPE+20 wt% Bi (d) HDPE+40 wt% Bi

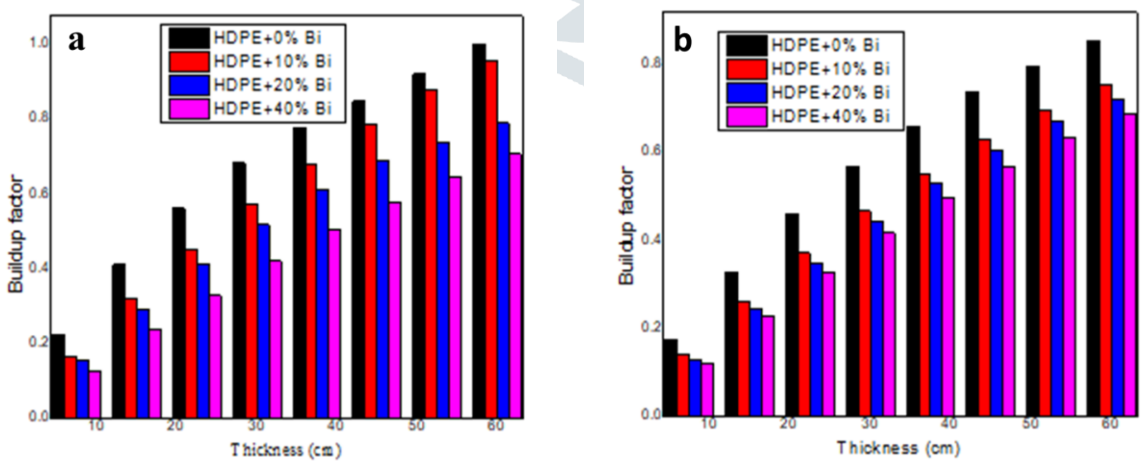

Fig.5: Variation of buildup factor with the thickness of different concentrations of bismuth in composites at (a) 662 keV and (b) 1332 keV of gamma radiations.

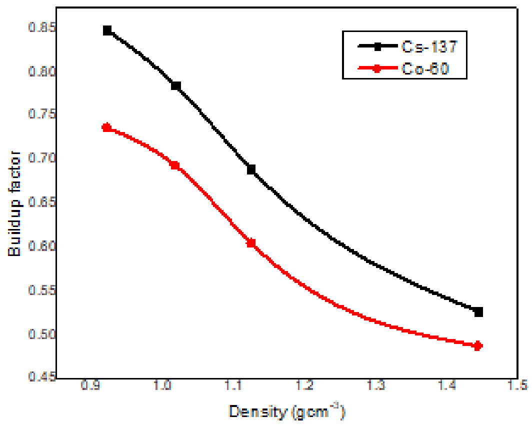

Fig. 6: Effect of density of the composites on the buildup factor at 662 keV and 1332 keV

In the present study, the effects of the concentration of bismuth in HDPE polymer matrix, the energy of incident gamma radiations, and the thickness of the prepared samples on the buildup factor were investigated. The buildup factors of the prepared composites were determined by using equation (3). Fig. 4 show the variation of a buildup factor with the thickness of the prepared composites for pure HDPE, HDPE+10 wt% of Bi, HDPE+20 wt% of Bi, and HDPE+40 wt% of Bi at 662 keV and 1332 keV respectively. The results showed that the buildup factor increases with the increase in the thickness of the sample due to the arrival of additional scattered photons to the detector, and also these figures indicate that the value of the buildup factor is higher at 662 keV than at 1332 keV. This is due to the interaction of gamma radiations with the absorbing material being more at low energy [8]. Fig. 5 shows the buildup factor increases as the thickness of the prepared sample increases and also shows that as the concentration of bismuth increases the value of the buildup factor decreases.

Fig. 6 shows the variation of the buildup factor with the density of the prepared samples for a particular thickness of about 4.5 cm of the sample. The density of the composites can be determined theoretically using the relation (4). This results that the buildup factor is high in pure HDPE, because of the transparency of the polymer towards gamma rays, indicating that the pure polymer is unsuitable for shielding. As the density of the composites increases the buildup factor decreases, implies that as the concentration of the filler increases, the characteristics of the composite material tend to be comparable with the qualities of the reinforced material, so that composite materials are good choice for the attenuation of gamma radiations [9].

5. Conclusions:

The value of the buildup factor decreases with the increase in the concentration of bismuth filler in HDPE matrix, and also it decreases with the increase in the energy of gamma radiations. This reveals that the interaction probability of the gamma radiations is high at low energy and high concentration of the metal bismuth filler. The value of the buildup factor increases with the increase in the thickness of the sample indicating the arrival of additional scattered photons to the detector. These results conclude that the characteristics of the polymer composite material tend to be comparable with the qualities of the reinforced material, so the composite materials are a good choice for the attenuation of gamma radiations. Also, this study reveals that the value of the buildup factor is nearly equal to unity indicating the good geometry of the experimental setup.

6. Acknowledgement:

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