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# Flyash : A radiation shielding material

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**Abstract** : To support the use of flyash material as a radiation shielding material for gamma or X-rays, the radiation interaction parameters (attenuation coefficients and buildup factors) have been studied as a function of incident photon energy The attenuation coefficients are found to have large values in low and high energy region whereas the buildup factor values have a maxima in the medium energy region These variations in attenuation coefficient as well as in the buildup factor in different energy regions, have been interpreted in terms of Z-dependence of partial photon interaction processes and have been presented in the form of graphs

**Keywords** Flyash, radiation shielding material, interaction parameters

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## 1. Introduction

With the ever increasing applications of radiation in various fields such as medicine, radiotherapy, agriculture, mining, industry *etc.* it becomes equally important to protect or shield the living or non-living beings from the harmful effects emanating due to primary radiation as well as secondary radiation. As far as studies relating to radiation in the laboratory are concerned, the source as well as the detector are well collimated with a suitable high Z- material such as lead. But in practical or field studies neither the source nor the detector is collimated from radiation. In those cases the cheap and easily available materials like soil, concrete *etc.* can serve the purpose as a suitable radiation shield.

Recently, the use of flyash is gaining importance in a large number of fields such as in manufacturing of bricks and ceramics, for the construction of roads and bridges, as an admixture with cement, *etc.* Flyash is a waste product of thermal power stations which use powdered coal in the furnace. It is a finely divided product residue resulting from the combustion of coal [1] in the furnace of boiler.

Because of its cheap availability, the flyash material can be considered to be used as a shielding material. So it becomes a prerequisite to study the interaction of radiation with this material and to investigate the transmitted photon spectra, considering both the primary as well as secondary part of the radiation. In such studies the main radiation interaction parameters are attenuation coefficients and buildup factors which are functions of the incident photon energy and nature of the material. The attenuation coefficient is a characteristic property of the absorbing material and is related to total interaction cross section whereas the buildup factor is a multiplicative factor used to obtain corrected response to uncollided photons by including the contribution of scattered photons. Both these parameters are useful for practical calculations in gamma ray shield designs.

In the present work, an attempt has been made to generate data for attenuation coefficients and buildup factors for flyash material and to study them as functions of photon energy. A large number of data for attenuation coefficients and buildup factors is available for elements, compounds and other composite materials. But it is for the first time in literature that such a radiation related data is being presented for flyash.

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## 2. Computational work

The sample material of flyash is a product of Guru Gobind Singh Thermal Power Station (GGSTPS), Ropar (India). The elemental composition of flyash is given in Table 1.

**Table 1.** Chemical composition by weight of flyash.

| | Compound | Percentage |
|---|---|---|
| 1 | $SiO_2$ | 57 5 |
| 2 | $Al_2O_3$ | 27 2 |
| 3 | $Fe_2O_3$ | 5 4 |
| 4 | CaO | 3 1 |
| 5 | $Na_2O$ $K_2O$ | 0.9 |
| 6 | MgO | 0.4 |
| 7 | Unburnt Carbon | 4 1 |
| 8 | Others | 1.4 |

The attenuation coefficients of flyash have been calculated with the help of the state-of-the-art computer program due to Berger and Hubbel [2], named XCOM : 'Photon cross section on a personal computer'. Using the XCOM program, the attenuation coefficients were computed in units of $cm^2/g$ over a wide energy range from 1 keV to 100 GeV in a large number of steps.

For calculating the buildup factor, different workers [3-5], have provided different formulae to approximate the buildup factor. But the Geometrical Progression (GP) fitting formula given by Harima *et al* [6] is considered to be the most accurate for the generation of buildup factor [7] data.

By using this GP fitting formula, our group has already generated a large number of data in different composite materials [8-12], such as, perspex, bakelite, soils, HCO materials, biological materials, *etc*. In the present investigation, energy absorption as well as exposure buildup factors have been generated for the flyash material by interpolation method using the GP fitting formula.

The energy absorption buildup factor is defined as the photon buildup factor in which the quantity of interest is the absorbed or deposited energy in the shield medium and the detector response function is that of the absorption in the material. On the other hand, the exposure buildup factor is defined as that buildup factor in which the quantity of interest is exposure and the detector response function is that of absorption in air.

The buildup factors have been computed in the energy range of 0.015 to 15.0 MeV and for thickness upto the penetration depth of 40 mean free path (mfp), where the mean free path is the average distance that the photon of a given energy travels before an interaction in a given medium occurs.

The computational work was carried out in three steps *viz.* calculation of equivalent atomic number, $Z_{eq}$, GP fitting parameters and buildup factors. An interpolation method was used for the calculation of $Z_{eq}$, which was based on the total and partial attenuation coefficients obtained from XCOM computer program. The $Z_{eq}$ was calculated by matching the ratio $\mu_{comp} / \mu_{tot}$ at a given energy with the corresponding ratio of an element at the same energy. In cases where the ratio value lies between two ratios for known elements, the value of $Z_{eq}$ was interpolated using the following formula :

$$Z_{eq} = \frac{Z_1(\log R_2 - \log R) + Z_2(\log R - \log R_1)}{\log R_2 - \log R_1}, \quad (1)$$

where, $Z_1$ and $Z_2$ are elemental atomic numbers corresponding to the ratios ( $\mu_{comp} / \mu_{tot}$ ) $R_1$ and $R_2$ respectively, and $R$ is the ratio ( $\mu_{comp} / \mu_{tot}$ ) at a particular energy for flyash which is used in equation 1. The values of equivalent atomic number, $Z_{eq}$, so obtained are given in Table 2.

**Table 2.** Equivalent atomic numbers and energy absorption GP fitting parameters of flyash

| E (Me V) | $Z_{eq}$ | b | c | a | $X_k$ | d |
|---|---|---|---|---|---|---|
| 015 | 12.710 | 1 0313 | .3744 | .2318 | 13.8973 | - 1599 |
| 020 | 12.830 | 1 0745 | 3617 | 2318 | 14 2911 | - 1225 |
| .030 | 12.970 | 1 2280 | 4159 | 2056 | 14 0658 | - 1127 |
| .040 | 13.080 | 1.4955 | 4889 | 1734 | 14 8118 | - 0956 |
| .050 | 13 190 | 1 8845 | .5767 | 1423 | 15 0727 | - 0832 |
| .060 | 13.260 | 2.3671 | .6619 | 1170 | 14.4247 | - 0783 |
| 080 | 13 290 | 3 2978 | 8944 | .0422 | 14.0743 | - 0376 |
| .100 | 13.530 | 3.8406 | 1.0828 | -.0044 | 13.6594 | - 0180 |
| 150 | 13.440 | 4.0970 | 1.3992 | -.0688 | 14 1053 | 0147 |
| 200 | 14 490 | 3 6945 | 1 4581 | --.0780 | 15 2625 | .0184 |
| 300 | 14.500 | 3.1212 | 1.5545 | - 0954 | 14.3025 | 0261 |
| .400 | 14.500 | 2.7932 | 1.5486 | - 0959 | 14.9057 | 0275 |
| 500 | 14.500 | 2.5802 | 1.5222 | - 0934 | 15.0887 | .0277 |
| .600 | 14.500 | 2.4381 | 1.4858 | - 0890 | 14.9744 | .0270 |
| .800 | 14 500 | 2.2435 | 1.4169 | -.0795 | 15.1461 | 0254 |
| 1.000 | 14.500 | 2 1194 | 1.3580 | -.0710 | 14.9953 | .0242 |
| 1.500 | 14.500 | 1.9420 | 1.2374 | -.0500 | 14.6903 | .0177 |
| 2.000 | 9.7720 | 1.8428 | 1 1588 | -.0351 | 14 7017 | 0132 |
| 3.000 | 10.730 | 1.7063 | 1.0502 | -.0092 | 10.9211 | -.0010 |
| 4.000 | 10.990 | 1.6140 | .9830 | .0090 | 13.1595 | -.0120 |
| 5.000 | 11.230 | 1.5437 | .9403 | .0214 | 12.7532 | -.0179 |
| 6.000 | 11.310 | 1.4774 | .9290 | .0243 | 15.7943 | -.0275 |
| 8.000 | 11.270 | 1.3858 | .9047 | .0327 | 12.1908 | -.0232 |
| 10.000 | 11.000 | 1.3240 | .8940 | .0360 | 13.9300 | -.0286 |
| 15.000 | 11.230 | 1.2264 | .8806 | .0428 | 14.5868 | - 0372 |

**Table 3.** Equivalent atomic numbers and exposure GP fitting parameters of flyash

| E (MeV) | $Z_{eq}$ | | | | $X_k$ | |
|---|---|---|---|---|---|---|
| 015 | 12.710 | 1.0313 | 3960 | .2074 | 14.8956 | -.1372 |
| 020 | 12.830 | 1.0700 | 3930 | .2131 | 13 8972 | -1156 |
| 030 | 12.970 | 1 2249 | 4228 | .1977 | 15 0792 | - 1041 |
| 040 | 13 080 | 1.4721 | .4993 | .1678 | 14 7427 | 0907 |
| 050 | 13.190 | 1.7405 | .6490 | 1060 | 16.1011 | 0536 |
| 060 | 13 260 | 2.1102 | 6983 | 1008 | 13 5386 | 0563 |
| 080 | 13.290 | 2 5686 | 8984 | .0418 | 13 4872 | - 0397 |
| 100 | 13 530 | 2 7284 | 1 0604 | 0023 | 13 3413 | -.0247 |
| .150 | 13.440 | 2.8123 | 1 3193 | -.0508 | 16 6366 | 0 0011 |
| 200 | 14 490 | 2 6331 | 1.3471 | 0530 | 8 3732 | 0070 |
| 300 | 14 500 | 2.4566 | 1 4507 | · 0749 | 18.0497 | .0130 |
| 400 | 14.500 | 2 3397 | 1.4562 | 0779 | 16 5066 | 0150 |
| 500 | 14.500 | 2 2378 | 1.4438 | - 0780 | 16 3051 | 0169 |
| 600 | 14 500 | 2 1617 | 1 4199 | - 0755 | 17 5358 | 0197 |
| 800 | 14 500 | 2 0438 | 1 3799 | - 0720 | 15 4631 | 0208 |
| 1 000 | 14 500 | 1 9693 | 1 3230 | 0630 | 16 4254 | 0194 |
| 1 500 | 14 500 | 1 8379 | 1 2280 | - 0475 | 15 2421 | 0158 |
| 2 000 | 9.772 | 1 8106 | 1 1577 | .0347 | 14 7906 | 0128 |
| 3 000 | 10 730 | 1 6861 | 1 0557 | - 0110 | 10 6581 | 0010 |
| 4 000 | 10 990 | 1 6061 | 9920 | 0060 | 12 8818 | - 0089 |
| 5 000 | 11 230 | 1 5365 | 9524 | 0179 | 14 0037 | - 0208 |
| 6 000 | 11 310 | 1 4908 | .9204 | 0288 | 11 5812 | · 0229 |
| 8 000 | 11.270 | 1 4057 | 9020 | 0333 | 13 6192 | -.0267 |
| 10 000 | 11 000 | 1 3470 | 8760 | 0430 | 13 1900 | 0335 |
| 15 000 | 11 230 | 1 2606 | .8287 | .0623 | 14 3238 | -.0550 |

The G-P fitting parameters for buildup factor were computed by the similar process of interpolation as in case of equivalent atomic number calculations. The reference data of GP fitting parameters for pure elements was taken from the literature generated by ANSI/ANS 6.4.3 [13]. The computed energy absorption and exposure GP fitting parameters are given in Tables 2 and 3 respectively. Further, these GP fitting parameters were used to generate buildup factor, $B(E, x)$, data for flyash using the following GP fitting formula due to Harima *et al* [6], as a function of energy $E$ and thickness $x$.

$$B(E,x) = 1 + \frac{(b-1)(K^x - 1)}{K-1} \quad \text{for } K \neq 1, \tag{2}$$

$$B(E,x) = 1 + (b-1)\,x \quad \text{for } K = 1, \tag{3}$$

where

$$K(E,x) = cx^a + d\,\frac{\tanh(x/X_k - 2) - \tanh(-2)}{1 - \tanh(-2)} \quad x \leq 40 \text{ mfp}, \tag{4}$$

where $x$ = Source detector distance of the medium in mfp,

$b$ = The value of the exposure buildup factor at one mfp,

$K(E, x)$ = Dose multiplication factor and represents change in the shape of the dose weighted spectrum with increasing penetration depth and is represented as hyperbolic tangent function of penetration depth in mfp and $c$, $a$, $X_k$ and $d$ are computed GP fitting parameters that depend on attenuating medium and source energy. These parameters are listed in Tables 2 and 3. The variation of parameter $K$ with penetration depth represents the photon dose multiplication and change in the shape of spectrum from that at one mean free path, which determines the value of $b$.

## 3. Results and discussion

The computed values of mass attenuation coefficient, $\mu_m$, and buildup factor of the chosen flyash material are graphically shown in Figures 1-3 as a function of photon energy. The results are interpreted in the following paragraphs.

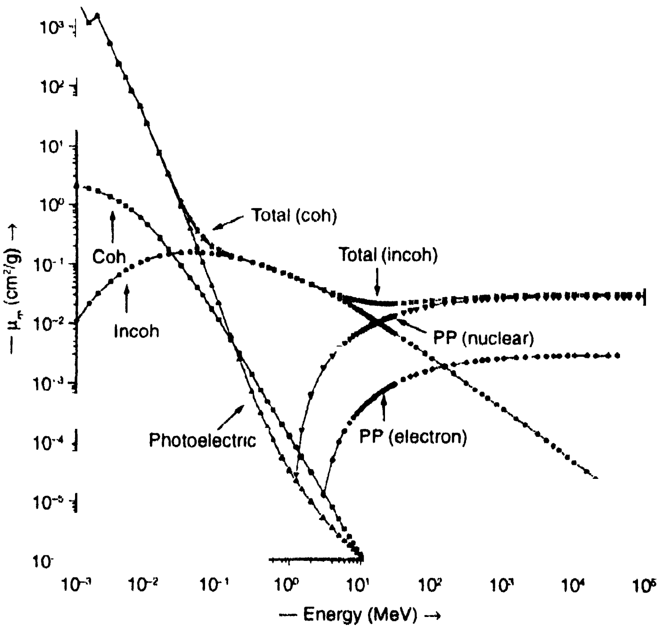


**Figure 1.** Total and partial mass attenuation coefficients of flyash material as a function of photon energy

### 3.1 *Attenuation coefficient :*

The variations of mass attenuation coefficient $\mu_m$ (cm$^2$/g) of flyash as a function of incident photon energy for the total and partial photon interaction processes are shown in Figure 1. It is seen that for total interaction process, $\mu_m$ is very high in low energy region and decreases sharply, which then after some constancy at about 2-3 MeV, shows a slight rise.

The variation in mass attenuation coefficient value is interpreted as being due to the dominance and $Z$ dependence of partial interaction processes in different energy regions. This view point is also supported by different plots of $\mu_m$ for partial interaction processes in different energy regions as shown in Figure 1. In low energy region, the variation of $\mu_m$ (total) is mainly due to photoelectric process and also less, but significantly, due to coherent scattering, because the Z dependence of photoelectric cross section is $Z^{4.5}$ and for coherent scattering it is $Z^{2-3}$. Similarly, the sharp decrease in $\mu_m$ (total) value in low energy region is due to its inverse behavior with the energy because the photoelectric cross section is inversely proportional to $E^{7/2}$.

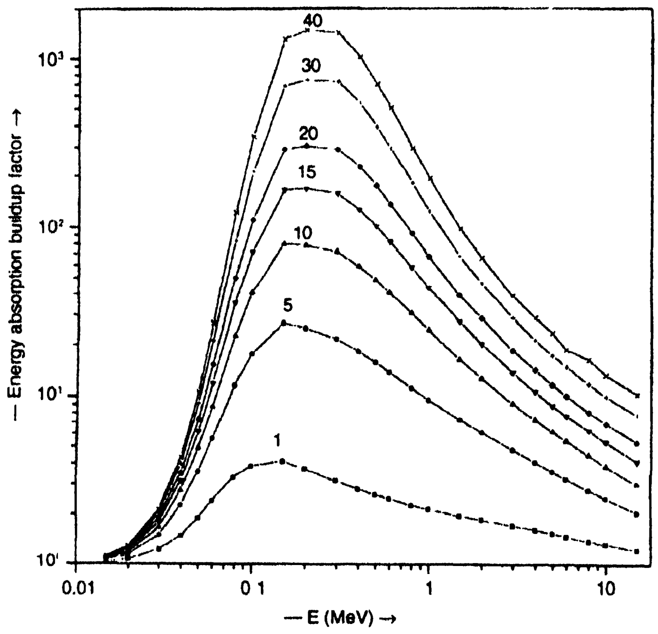


**Figure 2.** Variation of energy absorption buildup factor with incident photon energy for flyash material

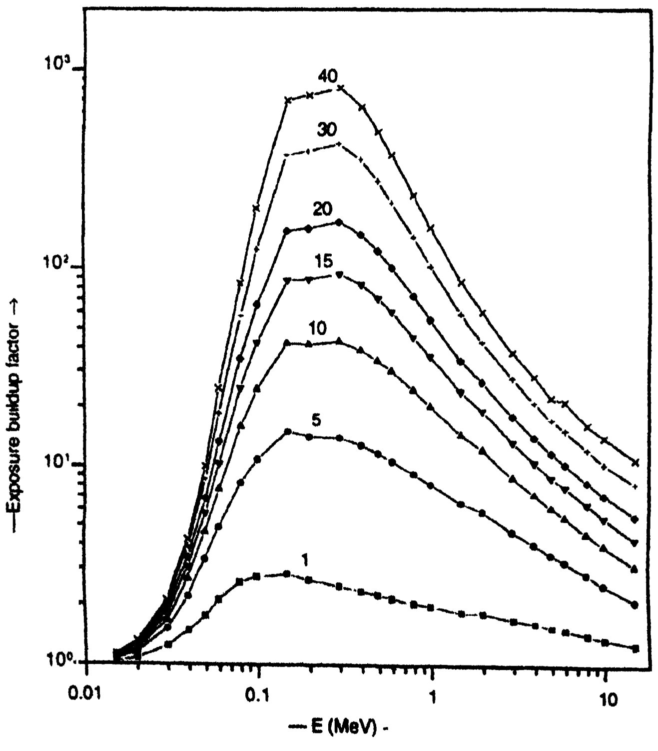


**Figure 3.** Variation of exposure buildup factor with incident photon energy for flyash material.

In the intermediate energy region the constancy of $\mu_m$ at about 2-3 MeV is due to the dominance of Compton scattering which is linearly Z-dependent. Here, pair production is relatively still insignificant. But, further at high energies due to $Z^2$ dependence of pair production, there is again a rise in $\mu_m$ (total) values of flyash material.

### *3.2 Buildup factor :*

The computed energy absorption and exposure GP fitting parameters for the present flyash material are given in Tables 2 and 3 respectively. These parameters have been used to generate the buildup factor data.

The generated data of energy absorption and exposure buildup factors for flyash material have been studied as a function of incident photon energy. The results are shown in Figures 2 and 3 for some randomly selected penetration depths. In both the cases, it is observed that buildup factor values are relatively lower for energies less than $E_{pe}$, where $E_{pe}$ is the energy value at which photoelectric attenuation coefficient matches the Compton attenuation coefficient. Similarly, there is also an energy value $E_{pp}$ where Compton attenuation coefficient matches pair production attenuation coefficient. After this value, again there are lower values of buildup factors. In the medium energy range $E_{pe} < E < E_{pp}$, the values of buildup factors are high. For the present flyash material, the values of $E_{pe}$ and $E_{pp}$ are 53.1 keV and 17.3 MeV respectively.

The reason for this behavior of changing trend in buildup factor with energy is because of the Z- dependence of different photon interaction processes. In comparison of the linear Z-dependence of Compton scattering, the Z-dependence of photoelectric and pair production processes respectively are $Z^{4.5}$ and $Z^2$. As a result of photoelectric and pair production processes, there is the probability of removal of photons in low and high energy regions. In the medium energy region the probability of buildup of photons is large which results in a broad peak around a particular energy value $E_{peak}$. In flyash material this energy value is 53.1 keV. This indicates that maximum multiple scattering occurs around this energy value which results in the accumulation of photons because large number of Compton processes are required to degrade the energy of photons. Therefore degraded energy photons exist for a longer time which results in their buildup in the material. This is why there is a high value of buildup factor in the medium energy region.

Finally, it is concluded that like Concrete, flyash can also be used as a shielding material if compacted to a very high degree, which is possible in its case.

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