International Journal of Scientific and Research Publications, Volume 2, Issue 9, September 2012
ISSN 2250-3153

Gamma Ray Photon Exposure Buildup Factors in Some Fly Ash: A Study

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Abstract- Exposure buildup factor for some flyasheslike Bituminous, Subbituminous, lignite, high calcium, high iron, low calcium, low iron has been calculated in the energy region 0.015-15.0 MeV up to a penetration depth of 40 mfp. The five G.P. fitting parameters have been used to calculate EBF. Variation of EBF with incident photon energy and penetration depth has been studied. It has been observed that chosen flyash have maximum value of EBF at 0.3 MeV. Variation in value of EBF is due to dominance of different interaction processes in different energy regions. Comparison of calculated exposure buildup factor with standard shows good agreements.

Index Terms- Exposure buildup factor (EBF), Mean free path (mfp), Shielding.

Abbreviations-mfp: mean free path, Z: Atomic number, Zeq: Equivalent atomic number, EBF: Exposure buildup factor.

I. INTRODUCTION

Intense gamma radiation can kill bacteria and other microbes. Gamma rays are ionizing radiation and are thus biologically hazardous, if there is no proper knowledge of shielding of gamma rays. In the study of radiation dose received by the materials and dosimetry calculations, gamma ray buildup factor is of great importance. When gamma radiations interact with matter through Compton scattering, the energy of incident photon reduces and its direction also changes which results in creating scattered photons which can be estimated by the buildup factor. Buildup factor is a multiplicative factor used to obtain corrected response by including contribution of scattered photons to the Lambert-Beer's equation. To calculate buildup factor there are different methods like G.P. fitting method, Harima et al. 1986 [1], invariant embedding method, Shimizu, 2002 [2]; Shimizu et al., 2004 [3], iterative method, Suteau and Chiron, 2005 [4] and Monte Carlo method, Sardari et al., 2009 [5]. American National Standards, ANSI/ANS 6.4.3., 1991 [6] calculated buildup factor for 23 elements, one compound and two mixtures viz. water, air and concrete at 25 standard energies in the energy range 0.015-15.0 MeV up to penetration depth of 40 mean free path using G.P. fitting method. Hirayama and Tanaka,1985 [7] calculated the exposure buildup factor for plane isotropic, point isotropic and plane normal source by using PALLAS-PL, SP-Br code [8] in infinite and finite water shields in the energy range of 0.06 MeV to 0.1MeV. Harima et al. 1986 [1] also computed buildup factors using G.P. fitting method. Sakamoto et al., 1988 [9] compared the results of buildup factors for compounds with PALLAS code. Fujisawa 1994 [10] studied experimentally the buildup factor for multilayer of lead and aluminium for 0.5, 1 and 10 MeV photon energies. Sidhu et al. 1998 [11] has attempted to generate buildup factor data for composite materials in the energy range of 0.015 -15.0 MeV. Shimizu et al. 2004 [3] compared the buildup factor values obtained by three different methods i.e. G.P. fitting, invariant embedding and Monte Carlo method for low-Z elements up to 100 mean free paths. D. Sardari and S. Baradaran 2010 [12] calculated buildup factor of gamma and X-ray photon the energy range of 0.2-2.0 MeV in water and soft tissue using Monte Carlo code MCNP4C. The results are compared with buildup factor data of pure water. In each case very small deviation is observed.

So, any of these methods/codes can be used to compute buildup factor data for low-Z materials. This data is of very great importance for engineers from the radiation shield designing point of view. In the present work exposure buildup factor is computed using G.P. fitting method for some flyashes. Energy region is selected from 0.015-15.0 MeV up to a penetration depth of 40 mean free path (mfp). The exposure buildup factor is defined as the photon buildup factor in which the quantity of interest is the exposure and the detector response function is that of absorption in air. The generated exposure buildup factor data has been studied as a function of incident photon energy and penetration depth.

II. MATERIALS AND METHODS

A. Selection of Materials

For the present investigations seven flyash samples are chosen. The chemical compositions of these flyashes are given in Table 1.

Flyashes can be used as good radiation shielding material because of their low cost and easy availability. As buildup factor data for these samples is not available in any form, so exposure buildup factor (EBF) of the chosen flyash samples has been calculated for incident photon energy from 0.015- 15.0 MeV and up to a penetration depth of 40 mfp.

Table 1: Percentage Chemical Composition of the chosen Flyash samples.

Component	Bituminous	Sub bituminous	Lignite	Class F Low -Fe	Class F High-Fe	Class C High-Ca	Class C Low-Ca

Sample	S1	S2	S3	S4	S5	S6	S7
SiO_2	20-60	40-60	15-45	46-57	42-54	25-42	46-59
Al_2O_3	5-35	20-30	20-25	18-29	16.5-24	15-21	14-22
Fe_2O_3	10-40	4-10	4-15	6-16	16-24	5-10	5-13
CaO	1-12	5-30	15-40	1.8-5.5	1.3-3.8	17-32	8-16
MgO	-	-	-	0.7-2.1	0.3-1.2	4-12.5	3.2-4.9
K_2O	-	-	-	1.9-2.8	2.1-2.7	0.3-1.6	0.6-1.1
Na_2O	-	-	-	0.2-1.1	0.2-0.9	0.8-6.0	1.3-4.2
SO_3	-	-	-	0.4-2.9	0.5-1.8	0.4-5.0	0.4-2.5
LOI	0-15	0-3	0-5	0.6-4.8	1.2-5.0	0.1-1.0	0.1-2.3
TiO_2	-	-	-	1-2	1-1.5	<1	<1

B. Computational work

Exposure buildup factors are computed using G.P. fitting parameters and the equivalent atomic number Z_{eq} of selected flyashes following three steps given below:

Step 1.Computation of equivalent atomic number (Z_{eq})

To compute equivalent atomic number of selected flyashes, the value of Compton partial attenuation coefficient ($\mu_{compton}$) and total attenuation coefficient (μ_{total}) in cm^2/gare obtained for selected flyashes in the energy range of 0.015 to 15.0 MeV and also for elements from Z=1 to Z=40 in the same energy range by using the state of art and convenient computer program WinXCOM computer program Gerward et al. 2001 [13]; Gerward et al. 2004 [14]) initially developed as XCOM, Berger and Hubbel, 1999 [15]. Ratio R ($\mu_{compton}$/ μ_{total}) for selected flyash samples and for elements from Z=1 to 40 is calculated at energies 0.015 to 15.0 MeV using a simple computer program. For the interpolation of $Z_{eq}$for selected samples, the ratio R of particular sample at a given energy is matched with the corresponding ratio of elements at the same energy. For the case, where the ratio R lies between two successive ratios of known elements, the value of $Z_{eq}$is interpolated using following formula, Sidhu et al., 2000 [16]

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

where Z_1 and Z_2 are the atomic numbers of elements corresponding to ratio R_1 and R_2.The computed values of $Z_{eq}$for different flyashes samples are given in Table 2.

Table2:Equivalent atomic numbers of the chosen Flyash samples.

E (MeV)	S1	S2	S3	S4	S5	S6	S7
0.015	16.03	14.09	15.37	14.67	15.24	14.05	14.05
0.02	16.3	14.26	15.56	14.87	15.47	14.23	14.23
0.03	16.59	14.46	15.77	15.04	15.72	14.42	14.46
0.04	16.74	14.56	15.86	15.14	15.84	14.55	14.58
0.05	16.83	14.62	15.97	15.23	15.97	14.62	14.64
0.06	17	14.75	16.06	15.32	16.08	14.75	14.78
0.08	17.16	14.87	16.07	15.4	16.16	14.87	14.95
0.1	17.23	14.88	16.33	15.51	16.33	14.88	14.88
0.15	17.26	14.92	16.31	15.49	16.6	14.92	14.92
0.2	17.64	14.96	16.89	14.96	16.92	14.96	14.49
0.3	16.99	14.5	16.5	14.5	16.99	14.5	14.5
0.4	16.5	14.5	16.5	14.5	16.5	14.5	14.5
0.5	16.5	14.5	16.5	14.5	16.5	14.5	14.5
0.6	16.5	14.5	16.5	14.5	16.5	14.5	14.5
0.8	16.5	14.5	16.5	14.5	16.5	14.5	14.5
1	16.5	14.5	16.5	14.5	16.5	14.5	14.5
1.5	16.5	14.5	16.5	14.5	16.5	14.5	14.5
2	15.07	12.88	12.88	12.88	12.94	12.88	12.9
3	13.67	12.58	13.61	13.16	13.21	12.58	12.62
4	13.78	12.31	13.02	12.66	12.74	11.94	12.35
5	13.33	12.48	13.54	12.73	13.07	12.24	12.28
6	13.61	12.54	13.51	12.87	12.95	12.21	12.29
8	13.51	12.44	13.42	12.86	12.91	12.44	12.3
10	13.73	12.34	13.61	12.97	12.83	12.42	12.28
15	13.76	12.51	13.5	12.99	13.12	12.38	12.14

S1----- BituminousFlyash
S2 ----- Sub bituminous Flyash
S3 ------ Lignite Flyash
S4------- High Calcium Flyash
S5------ High Iron Flyash
S6------- Low Calcium Flyash
S7------- Low Iron Flyash

Step2. Computation of G.P. fitting parameters:

American National Standard 1991, ANSI/ANS- 6.4.3 [6] has provided the exposure G.P. fitting parameters of twenty three elements (Ca, Fe, Si etc.) in the energy range of 0.015 -15.0 MeV and up to 40 mfp. The computed values of $Z_{eq}$for selected soils were used to interpolate G.P. fitting parameters (b, c, a, X_k, d) for the exposure buildup factor in the chosen energy range of 0.015-15.0 MeV and penetration depth (1-40 mfp). The formula, Sidhu et al., 2000 [17] used for the purpose of interpolation of the G.P. fitting parameters is given below:

$$P = \frac{P_1(\log Z_2 - \log Z_{eq}) + P_2(\log Z_{eq} - \log Z_1)}{\log Z_2 - \log Z_1}$$

where P_1 and P_2 are the values of G.P. fitting parameters corresponding to atomic number Z_1 and Z_2 respectively at a given energy and Z_{eq} is the equivalent atomic number of chosen flyashes at same energy. Z_1, Z_2 are the successive elemental atomic numbers such that

$Z_1 < Z_{eq} < Z_2$

The G.P. fitting parameters of buildup factors for some selected flyashes are given in Table 3-6.

Table3: Energy Exposure G – P fitting parameters for Bituminous Flyash

E (MeV)	b	c	a	Xk	d
0.015	1.0169	0.2962	0.3221	10.7412	-0.2526
0.02	1.0371	0.3365	0.2318	26.4606	-0.3531
0.03	1.1045	0.3738	0.2264	13.7547	-0.1264
0.04	1.2271	0.40	0.2086	14.577	-0.1165
0.05	1.3855	0.4638	0.1872	14.4468	-0.1057
0.06	1.5429	0.541	0.1544	14.4859	-0.0864
0.08	1.8295	0.6988	0.096	14.601	-0.0552
0.1	2.071	0.83	0.056	13.9458	-0.042
0.15	2.3395	1.0731	-0.0024	13.1149	-0.0227
0.2	2.3732	1.1911	0.0241	11.873	-0.0181
0.3	2.352	1.3375	-0.0519	8.4364	-0.0102
0.4	2.2717	1.3974	-0.0666	17.2679	0.009
0.5	2.1864	1.4053	-0.0712	17.8397	0.0156
0.6	2.1227	1.386	-0.069	18.2821	0.0156
0.8	2.0199	1.3499	-0.0655	16.5769	0.0166
1	1.9442	1.3104	-0.0605	15.897	0.0171
1.5	1.8273	1.214	-0.0437	16.1518	0.0129
2	1.7629	1.1555	-0.0329	14.9851	0.0098
3	1.6703	1.0577	-0.01	10.5459	-0.0026
4	1.5897	1.0031	0.004	15.1213	-0.0133
5	1.5266	0.9604	0.0173	10.944	-0.0161
6	1.4767	0.9454	0.0217	13.419	-0.0209
8	1.3924	0.9238	0.0284	13.6671	-0.0255
10	1.3318	0.9064	0.0365	13.2733	-0.0322
15	1.2379	0.8828	0.0477	13.7447	-0.0442

Table4: Energy Exposure G – P fitting parameters for lignite Flyash

E (MeV)	b	c	a	Xk	d
0.015	1.0176	0.3584	0.2547	11.4172	-0.1748
0.02	1.0399	0.3798	0.2051	21.8094	-0.2943
0.03	1.1208	0.3886	0.2146	14.0067	-0.1154
0.04	1.2648	0.4209	0.2028	14.5768	-0.112
0.05	1.4427	0.488	0.1756	14.6123	-0.0985
0.06	1.6293	0.5738	0.1409	14.6211	-0.0786
0.08	1.9565	0.759	0.0754	14.8907	-0.0452
0.1	2.2195	0.8586	0.0524	13.2535	-0.0435
0.15	2.4534	1.1178	-0.0111	12.7303	-0.0204
0.2	2.4297	1.2258	-0.0307	11.471	-0.0155
0.3	2.3788	1.3504	-0.0539	8.1457	-0.0101
0.4	2.2717	1.3974	-0.0666	17.2679	0.009
0.5	2.1864	1.4053	-0.0712	17.8397	0.0156
0.8	2.0199	1.3499	-0.0655	16.5769	0.0166
1	1.9442	1.3104	-0.060	15.897	0.0171
1.5	1.8273	1.214	-0.0437	16.1518	0.0129
2	1.7817	1.1532	-0.0321	15.4115	0.0093
3	1.6705	1.0576	-0.01	10.5672	-0.0026
4	1.6065	0.9748	0.0128	12.2965	-0.0163
5	1.5252	0.9625	0.0169	10.9714	-0.0164
6	1.4774	0.9434	0.0224	13.2439	-0.0214
8	1.393	0.9226	0.0287	13.7041	-0.0256
10	1.3321	0.9057	0.0368	13.2342	-0.0324
15	1.2399	0.8782	0.0485	14.1359	-0.0454

Table5: Energy Exposure G – P fitting parameters for High calcium Flyash

E (MeV)	b	c	a	Xk	d
0.015	1.0196	0.3822	0.2281	12.0003	-0.1444
0.02	1.0423	0.4312	0.1755	14.3107	-0.1684
0.03	1.1399	0.3937	0.2131	14.3885	-0.115
0.04	1.3058	0.436	0.1963	14.4545	-0.109
0.05	1.5111	0.5122	0.1653	14.6711	-0.0922
0.06	1.7131	0.6144	0.1245	14.7309	-0.0683
0.08	2.1065	0.7594	0.0799	13.7433	-0.0487
0.1	2.3521	0.9027	0.0414	13.5105	-0.0422
0.15	2.5517	1.1656	-0.0205	12.1382	-0.0166
0.2	2.5933	1.3212	-0.0484	8.9793	-0.0087
0.3	2.4566	1.4507	-0.0749	18.0497	0.013
0.4	2.3397	1.4562	-0.0779	16.5066	0.015
0.5	2.2378	1.4438	-0.078	16.3051	0.0169
0.6	2.1617	1.4199	-0.0755	17.5358	0.0197
0.8	2.0438	1.3799	-0.072	15.4631	0.0208
1	1.9693	1.323	-0.063	16.4254	0.0194
1.5	1.8379	1.228	-0.0475	15.2421	0.0158
2	1.7817	1.1532	-0.0321	15.4115	0.0093
3	1.6723	1.0572	-0.01	10.7306	-0.0025
4	1.604	0.9816	0.0104	12.4849	-0.014
5	1.5314	0.9528	0.0257	12.2898	-0.0233
8	1.3972	0.915	0.0305	13.8759	-0.0265
10	1.3342	0.9015	0.0381	13.0317	-0.0332
15	1.2441	0.8688	0.0501	14.9036	-0.0476

Table6: Energy Exposure G – P fitting parameters for low Iron Flyash

E (MeV)	b	c	a	Xk	d
0.015	1.0227	0.3515	0.2594	11.9816	-0.1765
0.02	1.0486	0.4274	0.1781	16.7401	-0.1242
0.03	1.1612	0.3945	0.2146	14.1868	-0.1157
0.04	1.3432	0.4476	0.1921	14.3888	-0.1076
0.05	1.5707	0.5408	0.1525	14.8414	-0.0836
0.06	1.7816	0.6478	0.1116	14.8892	-0.061
0.08	2.2135	0.7609	0.0827	13.0232	-0.0515
0.1	2.4565	0.9491	0.0288	14.0211	-0.039
0.15	2.6205	1.2038	-0.0282	11.58	-0.0131
0.2	2.6331	1.3471	-0.053	8.3732	-0.007
0.3	2.4566	1.4507	-0.0749	18.0497	0.013
0.4	2.3397	1.4562	-0.0779	16.5066	0.015
0.5	2.2378	1.4438	-0.078	16.3051	0.0169
0.6	2.1617	1.4199	-0.0755	17.5358	0.0197
0.8	2.0438	1.3799	-0.072	15.4631	0.0208
1	1.9693	1.323	-0.063	16.4254	0.0194
1.5	1.8379	1.228	-0.0475	15.2421	0.0158
2	1.7816	1.1532	-0.0321	15.3962	0.0093
3	1.6734	1.0596	-0.0015	12.9026	-0.0024
4	1.6012	0.9887	0.0079	12.7327	-0.0117
5	1.5354	0.9456	0.0223	10.3804	-0.0199
6	1.4831	0.9337	0.0246	12.1055	-0.0206
8	1.4022	0.9066	0.0328	13.8593	-0.0278
10	1.3397	0.8906	0.0401	13.0727	-0.0332
15	1.2517	0.8502	0.056	14.3371	-0.0506

Step3. Computation of Exposure buildup factor:

In this last step computed G.P. fitting parameters of selected flyashes are used to calculate exposure buildup factors. Following formulae, Harima et al., 1986 [1] are used.

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

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

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

where a, b, c, d, and X_K are the G.P. fitting parameters that depend upon attenuating medium and source energy, x is the distance between source and detector in the medium. E is the incident photon energy. b is buildup factor at 1 mfp. K is the photon dose multiplication and change in the shape of spectrum

ISSN 2250-3153

with increasing penetration depth. K is represented by tangent hyperbolic function of penetration depth in mfp.

To standardize this interpolation method, exposure buildup factor for water are computed up to 40 mfp in energy range of 0.015–15 MeV with this method. The results so obtained are compared with the result of ANSI/ANS 6.4.3 standard, (Table 7) Sidhu et al. 2000 [16] for a few randomly selected energies of 0.015, 5.0, 10.0, 15.0 MeV. The two results are in good agreement within the limits of statistical error. Thus we can assume safely that the present method is appropriate and suitable for calculation of exposure of buildup factor of chosen flyashes.

Table 7.Comparison of calculated exposure buildup factors (EBF) for water with standard database from ANSI/ANS 6.4.3.-1991. (Harima, Y. 1993)

Energy = 0.015 MeV **Energy = 5.0 MeV**

mfp	Standard Value	Calculated value	Error (%)	Standard value	Calculated value	Error (%)
1.0	1.18	1.20	1.69	1.56	1.57	0.64
2.0	1.27	1.30	2.36	2.08	2.11	1.44
3.0	1.33	1.37	3.01	2.58	2.63	1.94
4.0	1.38	1.42	2.90	3.08	3.15	2.27
5.0	1.43	1.46	2.10	3.58	3.66	2.23
6.0	1.46	1.50	2.74	4.08	4.16	1.96
7.0	1.5	1.53	2.00	4.58	4.66	1.75
8.0	1.53	1.56	1.96	5.07	5.15	1.58
10.0	1.58	1.62	2.53	6.05	6.14	1.49
15.0	1.68	1.73	2.98	8.49	8.62	1.53
20.0	1.75	1.83	4.57	10.9	11.11	1.93
25.0	1.82	1.90	4.40	13.3	13.55	1.88
30.0	1.87	1.94	3.74	15.7	15.90	1.27
35.0	1.91	1.99	4.19	18	18.20	1.11
40.0	1.94	2.03	4.64	20.4	20.59	0.93

Energy = 10.0 MeV **Energy = 15.0 MeV**

mfp	Standard value	Calculated value	Error (%)	Standard value	Calculated value	Error (%)
1.0	1.37	1.37	0.00	1.28	1.27	-0.78
2.0	1.68	1.69	0.60	1.49	1.51	1.34
3.0	1.97	1.99	1.02	1.7	1.73	1.76
4.0	2.25	2.28	1.33	1.9	1.94	2.11
5.0	2.53	2.56	1.19	2.1	2.13	1.43
6.0	2.8	2.84	1.43	2.3	2.33	1.30
7.0	3.07	3.10	0.98	2.49	2.51	0.80
8.0	3.34	3.37	0.90	2.68	2.70	0.75
10.0	3.86	3.89	0.78	3.05	3.06	0.33
15.0	5.14	5.18	0.78	3.96	3.97	0.25
20.0	6.38	6.47	1.41	4.84	4.89	1.03
25.0	7.59	7.70	1.45	5.69	5.77	1.41
30.0	8.78	8.87	1.03	6.51	6.58	1.08
35.0	9.96	10.03	0.70	7.26	7.30	0.55
40.0	11.2	11.32	1.07	7.91	8.04	1.64

III. RESULTS AND DISCUSSIONS

The generated exposure buildup factor for the chosen flyashes has been studied as a function of incident photon energy and penetration depth.

A. *Effect of incident photon energy on Exposure buildup factor*

Figures 1 to 7 show the variation of exposure buildup factor for selected flyashes with incident photon energy in the range 0.015 to 15.0 MeV at different mean free paths. All the flyash samples show almost similar behavior at different mean free paths. Exposure buildup factor (EBF) is comparatively smaller for incident photon energy less than E_{pe} for all flyash samples at different penetration depths. The reason behind this is that at lower incident photon energies, photoelectric absorption takes place and photons are completely absorbed by the material. Here E_{pe} is the incident photon energy at which the photoelectric interaction coefficient matches the Compton interaction coefficient for a given flyash sample. Table 8 gives the approximate values of $E_{pe}$for the present flyash sample. These values have been estimated by matching the two interaction coefficients calculated with the help of a computer program and data base XCOM [15].

It is observed that for incident photon energy $E_{pe} < E < E_{pp}$ Compton scattering starts dominating photoelectric absorption. The energy of incident photon is degraded and photons build up due to multiple scattering. Here E_{pp} is the incident photon energy value at which the pair production interaction coefficient matches the Compton interaction coefficient for a particular soil sample. The approximate value of E_{pp} is also given in Table 8. It is also observed that due to dominance of Compton scattering for all selected flyashes, exposure buildup factor (EBF) has larger values at 0.08 MeV to 3 MeV.

Also broad peak around the energy 0.2 to 0.3 MeV for all flyash samples shows the exclusively dominance of Compton scattering in this energy range resulting in very large value of EBF. The incident photon energy at which EBF for different flyashes has maximum value is E_{peak} and is given in Table 8. In addition to this it is also clear from curves that for a particular flyash, the incident photon energy at which exposure buildup factor (EBF) is maximum shifts to slightly higher side with increase in penetration depth. For incident photon energy greater than 2.0 MeV, the dominance of pair production phenomenon over the Compton effect increases resulting in lowering of buildup factor above this energy for all the chosen sample. It is also noted from the figures that flyashes with smaller Z_{eq}has high value of exposure buildup factor whereas with larger Z_{eq}has low value of exposure buildup factor at fixed penetration depth.

Table 8: Values of E_{pe}, E_{pp} and E_{peak} for selected flyash samples.

Flyash sample	$\mathbf{E_{pe}}$	$\mathbf{E_{pp}}$	$\mathbf{E_{peak}}$
Low-Calcium	0.2 MeV	3.0 MeV	0.25 MeV
High-Calcium	0.2 MeV	3.0 MeV	0.25 MeV
Low-Iron	0.2 MeV	3.0 MeV	0.25 MeV
Sub bituminous	0.2 MeV	3.0 MeV	0.25 MeV
Lignite	0.3 MeV	3.0 MeV	0.25 MeV
High-Iron	0.3	3.0	0.25 MeV

	MeV	MeV	
Bituminous	0.3 MeV	3.0 MeV	0.25 MeV

B. Variation of Exposure buildup factor with penetration depth

In figures 7 to 21, variation of exposure buildup factors is studied with penetration depth up to 40 mfp at chosen incident photon energy range 0.015-15.0 MeV for all flyash samples. The curves at different energies show that there is continuous increase in EBF with increase in penetration depth for all samples. It is due to the fact that the increase in penetration depth increases the interaction of gamma-radiation photons with matter resulting in generation of large number of low energy photons due to occurrence of Compton scattering process.

It is also noted from the figures 8, 10, 12, 14,16,18,20 that for a fixed value of penetration depth, the buildup factor increases with increase in incident photon energy from 0.015 to 0.3 MeV. The buildup factor values are highest at 0.3 MeV after which the buildup factor decreases with the increase in incident photon energies from 0.6 to 15.0 MeV as is clear from figures 9,11,13,15,17,19,21. It is seen that for energies greater than 1.0 MeV, there is a sharp fall in the value of buildup factor which ultimately depicts the dominance of pair production process in the energy region

IV. CONCLUSION

This study of buildup factor of Flyash will be helpful in estimating the transport and degradation of gamma radiations in these flyashes. Mostly Lead and Mercury are used as shielding materials. But these are difficult to use at large scale due to their higher cost and availability. Flyash can be used as a gamma-ray shielding material in field experiments which is suitable from the point of view of cost and availability. Above studies projects Flyash as a potential radiation shielding material.

Figure:1-Variation of Exposure buildup factor with incident photon energy (MeV)for Bituminous Flyash at different penetration depths

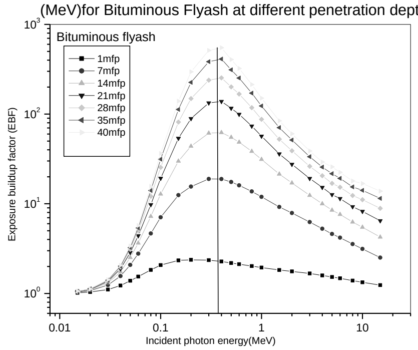


Figure:2-Variation of Exposure buildup factor with incident photon energy (MeV)for Subbituminous Flyash at different penetration depths

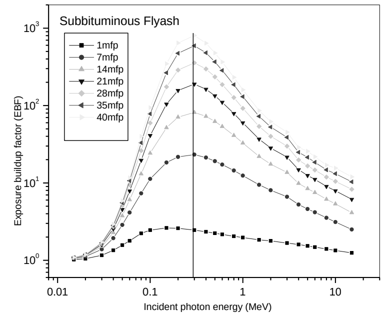


Figure:3-Variation of Exposure buildup factor with incident photon energy (MeV)for Lignite Flyash at different penetration depths

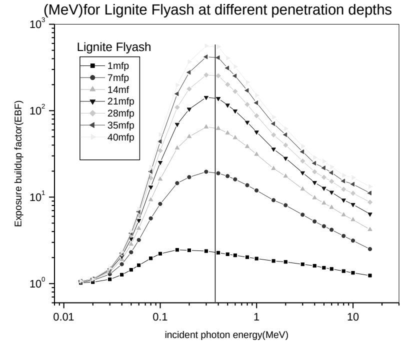


Figure:4-Variation of Exposure buildup factor with incident photon energy (MeV)for High calcium Flyash at different penetration depths

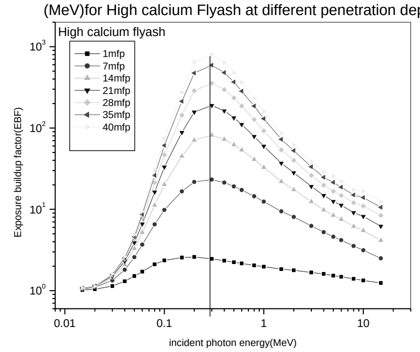


Figure:6-Variation of Exposure buildup factor with incident photon energy (MeV)for low calcium flyash at different penetration depths

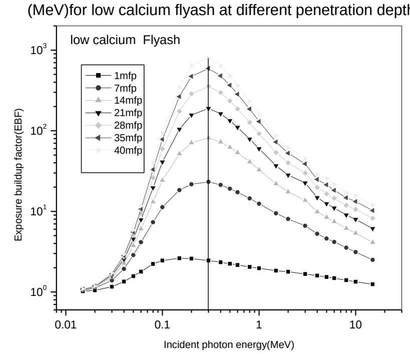


Figure:7-Variation of Exposure buildup factor with incident photon energy (MeV)for low Ironflyash at different penetration depths

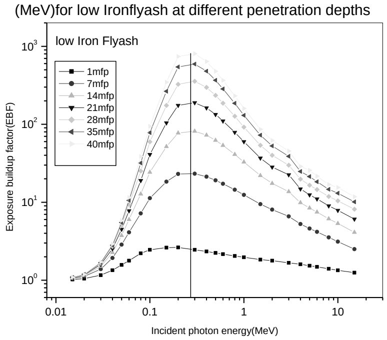


Figure:8-Variation of Exposure buildup factor with penetration depth for Bituminous Flyash at chosen energies

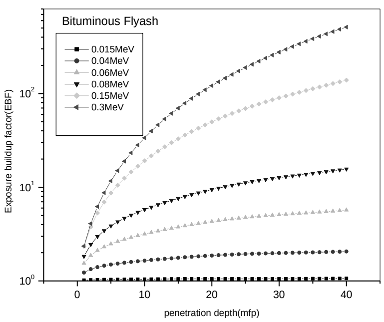


Figure9:-Variation of Exposure buildup factor with penetration depth for Bituminous Flyash at chosen energies

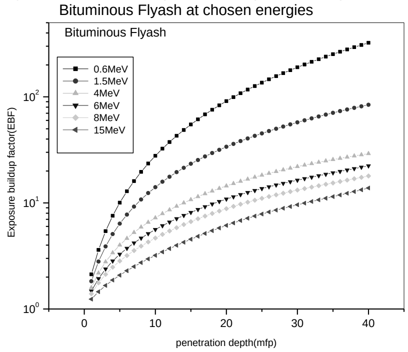


Figure:10-Variation of Exposure buildup factor with penetration depth for Subbituminous Flyash at chosen energies

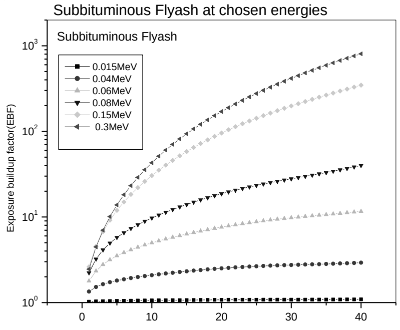


Figure:11-Variation of Exposure buildup factor with penetration depth for Subbituminous Flyash at chosen energies

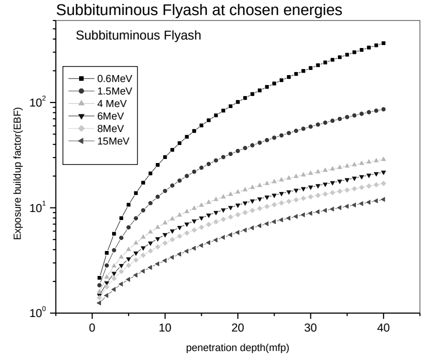


Figure:12-Variation of Exposure buildup factor with penetration depth for Lignite Flyash at chosen energies

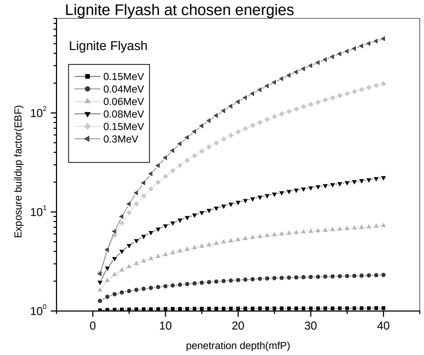


Figure:13-Variation of Exposure buildup factor with penetration depth for Lignite Flyash at chosen energies

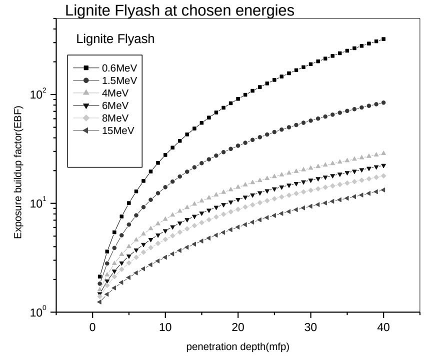


Figure:14-Variation of Exposure buildup factor with penetration depth for High calcium Flyash at chosen energies

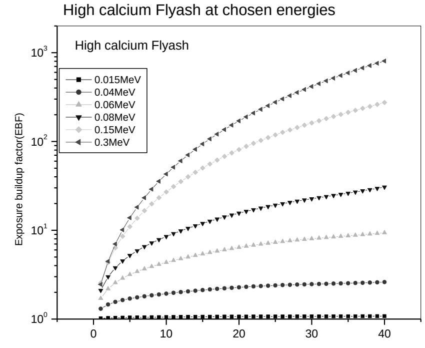


Figure:15-Variation of Exposure buildup factor with penetration depth for High calcium Flyash at chosen energies

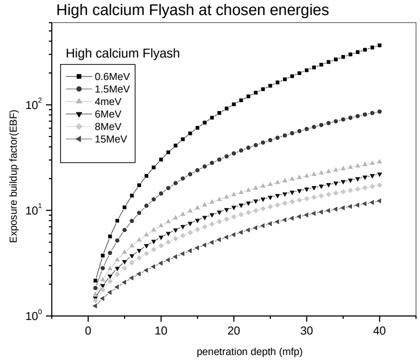


Figure:16-Variation of Exposure buildup factor with penetration depth for High Iron Flyash at chosen energies

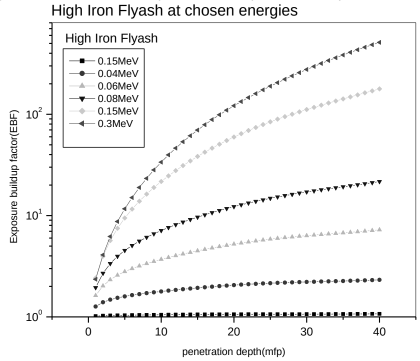


Figure:17-Variation of Exposure buildup factor with penetration depth for High Iron Flyash at chosen energies

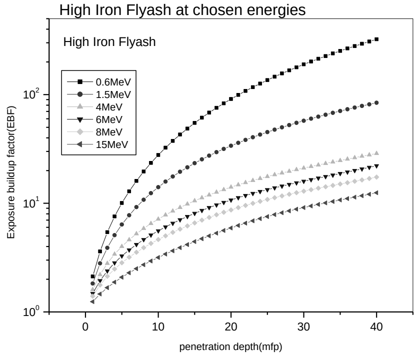


Figure:18-Variation of Exposure buildup factor with penetration depth for Low calcium Flyash at chosen energies

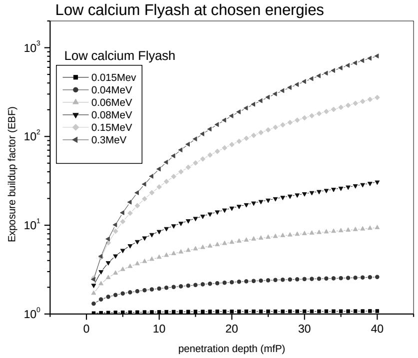


Figure:19-Variation of Exposure buildup factor with penetration depth for Low calcium Flyash at chosen energies

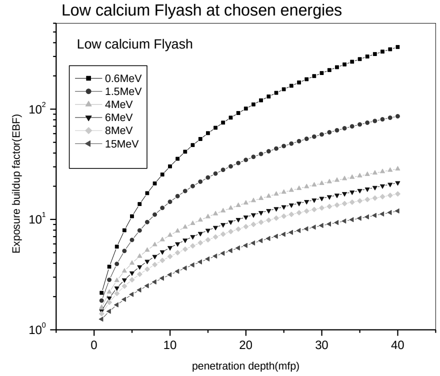


Figure:20-Variation of Exposure buildup factor with penetration depth for Low Iron Flyash at chosen energies

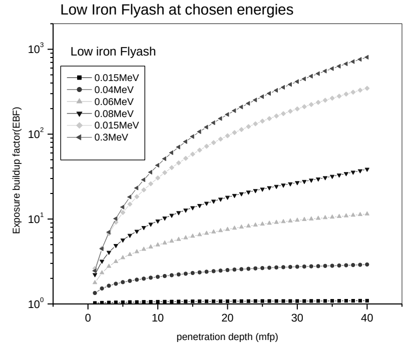
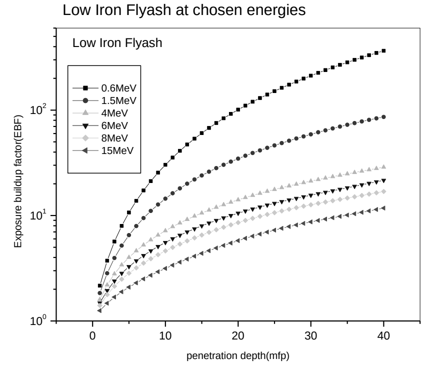


Figure:21-Variation of Exposure buildup factor with penetration depth for Low Iron Flyash at chosen energies



ACKNOWLEDGMENT

We are grateful to Berger and Hubbell for providing the convenient computer program XCOM with the help of National Institute of Standards and Technology, Gaithersburg.

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