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Article

Gamma-ray exposure build-up factors of some brick materials in the state of Punjab

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ABSTRACT **The gamma-ray exposure build-up factors of raw materials of bricks (soils and fly-ashes) in the state of Punjab were investigated for the photon energy range 0.015 to 15 MeV up to 40 mfp penetration depth by the geometrical progression (GP) method. Appreciable variations in the exposure build-up factor (EBF) are noted for the raw materials. The EBFs of the raw materials of bricks change depending on the photon energy, penetration depth and chemical composition. The build-up factors are low at low and high photon energies, whereas they are very high in the medium-energy region. The peak energy of the EBF for soils is 0.3 MeV and 0.2 MeV for fly ashes. The EBFs of the raw materials of bricks are also compared with those of bricks of red mud and common brick materials. Common bricks were found to have the lowest gamma-ray EBF. This study should be useful for emergency preparedness planning and emergency dose estimation for future planned nuclear power plants in the state of Punjab.**

Keywords: exposure / build-up factor / brick / building / gamma / accident / dose / reactor

1. Introduction

The application of radiation such as in nuclear and radiation physics, industry, medicine, the environment, hydrology, power production, dosimetry, biology and agriculture is increasing rapidly and growing day by day. Nuclear and radiological accidents have created apprehension in the public regarding nuclear energy. It is vital to know how well residential and non-residential buildings are resistant to or safe against radiation. The radiation safety of buildings is estimated by the shielding properties such as mass attenuation coefficients, energy absorption coefficients and the half-value layer. The most probable radiation in the normal operation of a facility as well as accidents are polyenergetic gamma radiation which is emitted by various radionuclides (Shlein, 1984; Sich, 1995).

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Presently, various new nuclear power plant projects are being proposed in the country; Punjab state is one of them. A small population is allowed to live in the emergency planning zone (up to 30 km) around a nuclear power plant. The houses and buildings in which people live are constructed with bricks made of raw materials such as soil and environmentally-friendly fly ash. Various studies have been conducted on gamma interaction with soils and fly ash (Mudhahar and Sahota, 1988; Chaudhari and Dayanand, 2012). Soil can be used as radiation shielding, as has been reported earlier (Mudhahar and Sahota, 1988; Miller *et al.*, 2009).

The intensity of a gamma-ray beam through a medium follows the Lambert-Beer law under three conditions, which are: (i) monochromatic rays; (ii) thin absorbing material, and (iii) narrow beam geometry. In cases where any of the conditions are not met, this law is no longer applicable. The law can be applicable by using a correction factor, called a "build-up factor". The build-up is defined as the ratio of the total value of a specified radiation quantity at any point to the contribution to that value from radiation reaching the point without having undergone a collision. Build-up factors have been computed by various codes such as PALLAS (Takeuchi and Tanaka, 1984), ADJMON-I (Simmons, 1973; Chilton *et al.*, 1980), ASFIT (Gopinath and Samthanam, 1971) and EGS4 (Nelson *et al.*, 1985). These codes use an accurate algorithm for the Klein-Nishina cross-section which eliminates other sources of error.

The compilation of build-up factors by various codes was reported in ANSI/ANS-6.4.3-1991 by the American Nuclear Society (ANSI/ANS-6.4.3, 1991). The data in the report covers the energy range 0.015-15 MeV up to a penetration depth of 40 mean free path (mfp). The build-up factors in the ANS-6.4.3 are for 23 elements of the atomic numbers Z = 4 to 92. The build-up factors of ANS-6.4.3 can also be calculated by invariant embedding (Shimizu, 2002; Shimizu *et al.*, 2004). Harima *et al.* (1986) developed a fitting formula, called Geometrical Progression (GP), which gave build-up factors in good agreement with the ANS-6.4.3. The GP fitting is more accurate than three-exponential fit in the water medium. The GP fitting formula is known to be accurate within the estimated uncertainty (< 5%), and Harima carried out an extensive historical review and reported the current gamma photon build-up factors and applications (Harima, 1993). Various researchers have investigated gamma-ray build-up factors in different materials fly-ash, concretes (Brar *et al.*, 1994; Singh *et al.*, 2010; Singh and Badiger, 2012a, 2012b), solvents (Parjit *et al.*, 2008), polymers (Tejbir *et al.*, 2010; Murat and Yuksel, 2011), human tissues (Murat *et al.*, 2011), soils & ceramic (Sandeep and Gurdeep, 2012; Jasbir *et al.*, 2012; Tejbir *et al.*, 2013), and fly ash (Sukhpal *et al.*, 2010), which showed that GP fitting is a very useful method for estimation of exposure and energy absorption build-up factors.

Recently, radiation shielding by building materials has been reported for concretes and other building materials (Yilmaz *et al.*, 2011).

In view of the radiation safety of the people living inside the houses or buildings near a power plant, the exposure build-up factors (EBF) of the raw materials of the bricks in the state of Punjab were calculated. In the present work, we calculated the EBFs of the raw materials of bricks in the state of Punjab by GP fitting in the photon energy range 0.015–15 MeV up to 40 mfp. The EBFs of the raw materials of bricks are also compared with those of bricks of red mud (BOM) and common brick (COM) materials. It should be noted that this study is useful for selection of raw materials for preparation of bricks to protect against radiation, emergency preparedness and estimation of the dose during any nuclear accident.

2. Computation method

The elemental compositions of the raw materials for making bricks are taken from Kulwinder *et al.* (2013), and given in Table I. These raw materials are common in use in the construction of building materials. The soil samples were collected from various districts which cover the entire state of Punjab. Two fly ash samples were also collected from Guru Nanak thermal power plant and Guru Hargobind thermal power plant for study and comparison of the build-up factors. The elemental compositions of some materials (Nipe clay, lime, gypsum and cement) used were taken from the published literature (Singh and Mudahar, 1992; Singh *et al.*, 2004). The raw materials required for manufacturing common bricks are clay, silt and sand as per IS 2117. The common bricks investigated are made from a mixture of soil (70%), Nipe clay (20%) and Ordinary Portland Cement (10%).

The EBF and the GP fitting parameters are calculated by the method of interpolation from the equivalent atomic number (Z_{eq}). The computational work of these parameters is done in three steps:

1. calculation of the equivalent atomic number, Z_{eq};
2. calculation of GP fitting parameters;
3. calculation of build-up factors.

Z_{eq} is a parameter which describes the material properties in terms of equivalent elements similar to the atomic number for a single element. Since interaction processes of gamma photons with matter, photo-electric absorption, Compton scattering and pair production are energy-dependent, therefore the Z_{eq} for each interaction varies according to the photon energy. However, the build-up of photons in the medium is mainly due to multiple scattering events by Compton scattering, so that Z_{eq} is derived from the Compton scattering interaction process.

TABLE I
Elemental composition (% by weight) of raw materials of bricks, brick of red mud and common brick (Kulwinder *et al.*, 2013).

Location	Abohar	Ferozpur	Bathinda	Amritsar	Jalandhar	Bathinda	Lehra Mohabbat		
Elements	Soil-AR	Soil-FR	Soil-BA	Soil-AM	Soil-JR	[a]FAGNTP-B	[b]FAGHTP-LM	BOM	COB
H	–	–	–	–	–	–	–	–	0.24
C	–	–	–	–	–	02.85	–	–	0.06
N	–	–	–	–	–	–	–	–	0.01
O	53.14	51.14	50.53	49.66	48.05	48.16	49.95	54.6	45.35
Na	–	–	–	–	–	–	0.14	0.11	0.01
Mg	–	–	01.83	–	–	0.44	–	0.11	0.04
Al	08.53	07.47	06.51	08.79	08.54	14.91	13.49	4.95	7.88
Si	23.64	23.67	26.52	27.03	27.13	28.41	31.07	5.96	20.78
P	–	0	–	–	–	v	0.10	–	–
S	–	0	–	–	–	0.04	–	–	0.02
K	03.48	03.08	04.04	02.45	03.80	–	0.04	–	2.66
Ca	–	03.7	01.95	–	–	01.59	2.15	34.01	4.75
Ti	01.42	–	–	–	–	–	0.81	–	0.09
Mn	–	–	–	–	–	–	–	–	0.17
Fe	09.82	10.98	08.65	12.10	12.51	03.64	2.29	0.30	17.96

a: fly ash of Guru Nanak Thermal Plant, Bathinda.
b: fly ash of Guru Hargobind Thermal Plant, Lehra Mohabbat.

The Z_{eq} for brick materials is estimated by the ratio of $(\mu/\rho)_{Compton}$ / $(\mu/\rho)_{Total}$, at a specific energy with the corresponding of an element at the same energy. Thus, first the Compton partial mass attenuation coefficient, $(\mu/\rho)_{Compton}$, and the total mass attenuation coefficients, $(\mu/\rho)_{Total}$, are obtained for the elements Z = 4 to 40 for the brick materials in the energy region 0.0015 to 15 MeV using WinXCom (Gelward *et al.*, 2001; Gelward *et al.*, 2004).

The interpolation of Z_{eq} is employed by the formula (Harima, 1983; Maron, 2007):

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

where Z_1 and Z_2 are the atomic numbers of the elements corresponding to the ratios R_1 and R_2, respectively. R is the ratio $(\mu/\rho)_{Compton}$ / $(\mu/\rho)_{Total}$ at specific energy and the ratio $(\mu/\rho)_{Compton}$ / $(\mu/\rho)_{Total}$ for Z_{eq} lies between two successive ratios of the elements.

The GP fitting parameters are calculated in a similar fashion to the interpolation procedure for the equivalent atomic number. The GP fitting parameters for the elements were taken from the ANS-6.4.3 standard reference database which provides the GP fitting parameters for twenty-three elements (Z = 4 to 92) in the energy region 0.015 to 15 MeV up to 40 mfp penetration depth. The GP fitting parameters for the soils and fly ash were interpolated using a similar formula:

$$C = \frac{C_1(\log Z_2 - \log Z_{eq}) + C_2(\log Z_{eq} - \log Z_1)}{\log Z_2 - \log Z_1} \quad (2)$$

where C_1 and C_2 are the values of the GP fitting parameters corresponding to the atomic numbers of Z_1 and Z_2, respectively, at a given energy. The GP fitting parameters of the selected materials are given in Tables II to VII.

TABLE II
Equivalent atomic number of raw materials of bricks.

Energy (MeV)	Equivalent atomic number								
	Soil-AR	Soil-FR	Soil-BA	Soil-AM	Soil-JR	FAGNTP-B	FAGHTP-LM	BOB	COB
0.015	14.16	14.57	14.05	14.50	14.71	12.59	12.52	14.61	15.97
0.02	14.37	14.79	14.26	14.72	14.92	12.71	12.63	14.78	16.22
0.03	14.61	15.02	14.47	14.96	15.16	12.86	12.75	14.95	16.50
0.04	14.76	15.17	14.61	15.12	15.32	12.96	12.84	15.06	16.67
0.05	14.87	15.29	14.71	15.23	15.44	13.04	12.90	15.14	16.79
0.06	14.96	15.38	14.79	15.32	15.53	13.09	12.95	15.20	16.88
0.08	15.09	15.49	14.90	15.44	15.65	13.16	13.02	15.28	17.02
0.1	15.18	15.57	14.99	15.53	15.73	13.22	13.06	15.33	17.12
0.15	15.33	15.70	15.12	15.66	15.86	13.29	13.13	15.41	17.24
0.2	15.42	15.78	15.20	15.74	15.95	13.34	13.17	15.46	17.31
0.3	15.39	15.87	15.24	15.83	16.04	13.40	13.21	15.51	17.40
0.4	15.48	15.92	15.29	15.88	16.08	13.44	13.24	15.54	17.45
0.5	15.51	15.95	15.31	15.92	16.11	13.45	13.25	15.55	17.48
0.6	15.53	15.97	15.33	15.94	16.13	13.46	13.26	15.56	17.50
0.8	15.54	15.98	15.34	15.95	16.14	13.47	13.27	15.57	17.52
1	15.54	15.99	15.34	15.95	16.14	13.47	13.27	15.57	17.52
1.5	13.15	13.69	13.26	13.52	13.76	11.76	11.77	13.66	15.15
2	12.36	12.75	12.39	12.69	12.92	11.35	11.42	13.00	14.01
3	12.17	12.54	12.21	12.48	12.70	11.26	11.34	12.82	13.70
4	12.10	12.47	12.15	12.42	12.63	11.22	11.31	12.76	13.63
5	12.09	12.45	12.14	12.40	12.61	11.21	11.30	12.75	13.59
6	12.07	12.44	12.12	12.38	12.60	11.21	11.29	12.73	13.57
8	12.05	12.42	12.11	12.36	12.58	11.20	11.29	12.72	13.54
10	12.04	12.41	12.10	12.35	12.57	11.19	11.28	12.71	13.53
15	12.03	12.40	12.09	12.34	12.56	11.19	11.28	12.70	13.51

TABLE III
GP fitting parameters of soil-AR and soil-FR.

Energy (MeV)	Soil-AR					Soil-FR				
	b	c	a	X_k	d	b	c	a	X_k	d
0.015	1.022	0.357	0.254	11.985	–0.171	1.020	0.377	0.233	11.997	–0.149
0.02	1.047	0.428	0.177	16.185	–0.096	1.043	0.431	0.176	14.627	–0.084
0.03	1.155	0.394	0.214	14.250	–0.115	1.140	0.394	0.213	14.419	–0.115
0.04	1.331	0.444	0.193	14.407	–0.108	1.304	0.435	0.197	14.461	–0.109
0.05	1.547	0.528	0.159	14.745	–0.088	1.505	0.510	0.166	14.666	–0.093
0.06	1.757	0.636	0.116	14.802	–0.063	1.707	0.611	0.126	14.723	–0.069
0.08	2.183	0.758	0.083	13.114	–0.051	2.084	0.760	0.079	13.926	–0.048
0.1	2.405	0.927	0.035	13.872	–0.041	2.342	0.898	0.043	13.442	–0.042
0.15	2.571	1.176	–0.023	11.986	–0.016	2.527	1.152	–0.018	12.330	–0.018
0.2	2.552	1.298	–0.044	9.852	–0.010	2.519	1.280	–0.041	10.551	–0.012
0.3	2.422	1.406	–0.066	14.706	0.004	2.410	1.373	–0.058	9.274	–0.007
0.4	2.305	1.429	–0.073	18.784	0.015	2.288	1.419	–0.071	20.198	0.015
0.5	2.212	1.424	–0.074	16.294	0.015	2.202	1.416	–0.073	16.281	0.015
0.6	2.141	1.403	–0.072	17.313	0.017	2.135	1.393	–0.070	18.015	0.016
0.8	2.032	1.363	–0.068	16.163	0.018	2.029	1.353	–0.066	16.576	0.017
1	1.955	1.317	–0.062	16.373	0.019	1.951	1.313	–0.061	15.866	0.017
1.5	1.853	1.230	–0.048	15.877	0.017	1.846	1.230	–0.048	15.392	0.016
2	1.785	1.154	–0.033	15.816	0.010	1.782	1.153	–0.032	15.512	0.010
3	1.674	1.063	–0.012	15.509	–0.002	1.673	1.060	–0.011	13.380	–0.002
4	1.599	0.995	0.006	12.934	–0.010	1.602	0.986	0.009	12.636	–0.013
5	1.537	0.942	0.023	10.236	–0.021	1.534	0.948	0.021	10.509	–0.019
6	1.484	0.934	0.024	12.033	–0.020	1.483	0.934	0.025	12.152	–0.021
8	1.404	0.903	0.034	13.823	–0.028	1.401	0.908	0.032	13.846	–0.028
10	1.342	0.887	0.041	13.087	–0.033	1.339	0.893	0.040	13.065	–0.033
15	1.253	0.848	0.057	14.263	–0.051	1.249	0.856	0.054	14.512	–0.050

The third and final step is build-up factor estimation by the GP fitting parameters (b, c, a, X_k and d) in the photon energy range of 0.015–15 MeV up to 40 mfp by equations (Harima *et al.*, 1986) as:

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

$$B(E, X) = 1 + (b-1)X \quad \text{for} \quad K = 1 \tag{4}$$

$$K(E, X) = cX^a + d\frac{\tanh\left(\frac{X}{X_K} - 2\right) - \tanh(-2)}{1 - \tanh(-2)} \tag{5}$$

TABLE IV
GP fitting parameters of soil-BA and soil-AM.

Energy (MeV)	Soil-BA					Soil-AM				
	b	c	a	X_k	d	b	c	a	X_k	d
0.015	1.023	0.352	0.259	11.982	–0.176	1.020	0.374	0.236	11.995	–0.153
0.02	1.048	0.428	0.178	16.642	–0.100	1.044	0.430	0.176	14.863	–0.085
0.03	1.161	0.395	0.215	14.193	–0.116	1.142	0.394	0.213	14.395	–0.115
0.04	1.341	0.447	0.192	14.392	–0.108	1.307	0.436	0.196	14.451	–0.109
0.05	1.563	0.537	0.154	14.811	–0.085	1.511	0.512	0.165	14.671	–0.092
0.06	1.780	0.647	0.112	14.884	–0.061	1.713	0.614	0.125	14.730	–0.068
0.08	2.222	0.764	0.082	13.099	–0.041	2.096	0.760	0.079	13.830	–0.048
0.1	2.437	0.941	0.031	14.064	–0.014	2.349	0.901	0.042	13.492	–0.042
0.15	2.597	1.190	–0.025	11.789	–0.014	2.532	1.155	–0.018	12.291	–0.018
0.2	2.572	1.309	–0.046	9.420	–0.010	2.523	1.282	–0.041	10.473	–0.011
0.3	2.425	1.416	–0.068	16.358	0.007	2.411	1.375	–0.059	9.693	–0.006
0.4	2.313	1.433	–0.074	18.127	0.014	2.289	1.420	–0.071	20.082	0.015
0.5	2.217	1.427	–0.075	16.300	0.015	2.203	1.416	–0.073	16.282	0.015
0.6	2.143	1.408	–0.073	16.982	0.017	2.136	1.393	–0.070	17.961	0.016
0.8	2.033	1.367	–0.069	15.968	0.019	2.029	1.354	–0.066	16.545	0.017
1	1.956	1.320	–0.062	16.615	0.019	1.951	1.313	–0.061	15.904	0.017
1.5	1.851	1.230	–0.048	15.769	0.017	1.848	1.230	–0.048	15.536	0.017
2	1.785	1.154	–0.033	15.794	0.010	1.783	1.154	–0.032	15.555	0.010
3	1.674	1.062	–0.012	15.241	–0.002	1.674	1.061	–0.012	13.686	–0.002
4	1.599	0.993	0.006	12.893	–0.010	1.602	0.987	0.008	12.679	–0.012
5	1.537	0.943	0.023	10.276	–0.021	1.534	0.948	0.022	10.469	–0.019
6	1.484	0.934	0.024	12.051	–0.020	1.483	0.934	0.025	12.135	–0.021
8	1.404	0.904	0.034	13.827	–0.028	1.402	0.908	0.033	13.842	–0.028
10	1.341	0.888	0.041	13.084	–0.033	1.339	0.892	0.040	13.068	–0.033
15	1.252	0.849	0.056	14.303	–0.051	1.250	0.855	0.055	14.476	–0.050

for the penetration depth (X) $\leq$ 40 mfp, where X is the source-detector distance for the medium in terms of mfp, b is the value of the exposure build-up factor at 1 mfp, K (E, X) is the dose multiplicative factor, and b, c, a, X_K and d are computed GP fitting parameters which depend on the attenuating medium and source energy.

The calculation technique adopted here is valid for a homogeneous medium. Therefore, we considered a homogeneous brick free from cavities to simplify the study. A building or house wall is a heterogeneous medium as it is made of bricks and mortar to seal the bricks. The percentage of mortar content is significantly

TABLE V
GP fitting parameters of soil-JR.

Energy (MeV)	Soil-JR				
	b	c	a	X_k	d
0.015	1.019	0.384	0.226	12.002	–0.142
0.02	1.042	0.432	0.175	14.109	–0.079
0.03	1.137	0.393	0.213	14.322	–0.115
0.04	1.295	0.432	0.198	14.486	–0.110
0.05	1.491	0.505	0.168	14.654	–0.094
0.06	1.689	0.603	0.129	14.700	–0.071
0.08	2.048	0.761	0.077	14.229	–0.047
0.1	2.317	0.887	0.046	13.273	–0.043
0.15	2.508	1.142	–0.016	12.479	–0.019
0.2	2.505	1.272	–0.039	10.870	–0.012
0.3	2.405	1.363	–0.056	7.863	–0.010
0.4	2.283	1.414	–0.070	19.917	0.014
0.5	2.198	1.413	–0.073	16.629	0.015
0.6	2.132	1.390	–0.070	18.117	0.016
0.8	2.026	1.352	–0.066	16.586	0.017
1	1.949	1.303	–0.061	15.863	0.017
1.5	1.845	1.230	–0.048	15.325	0.016
2	1.781	1.153	–0.032	15.384	0.009
3	1.673	1.059	–0.011	12.470	–0.002
4	1.604	0.982	0.010	12.508	–0.014
5	1.532	0.951	0.020	10.625	–0.018
6	1.482	0.933	0.025	12.204	–0.022
8	1.400	0.911	0.032	13.855	–0.027
10	1.337	0.895	0.039	13.055	–0.033
15	1.248	0.859	0.053	14.619	–0.049

smaller compared with bricks in the construction of a wall. A typical wall of brick contains 15–20% mortar. The density and equivalent atomic number of the mortar used for construction of a wall is of the same order as or higher than the bricks, as mortar is generally prepared with cement, lime, sand and clay. This heterogeneity of the wall may not much affect the transmitted gamma radiation from the wall. Therefore, for simplicity, we considered a homogeneous wall made of bricks, with the mortar excluded in the present study.

TABLE VI
GP fitting parameters of FAGNTP-B and FAGHTP-LM.

Energy (MeV)	FAGNTP-B					FAGHTP-LM				
	b	c	a	X_k	d	b	c	a	X_k	d
0.015	1.032	0.397	0.208	14.632	–0.137	0.397	0.208	14.480	–0.134	1.033
0.02	1.072	0.399	0.208	13.957	–0.034	0.404	0.205	14.002	–0.110	1.074
0.03	1.232	0.426	0.197	15.004	–0.104	0.428	0.196	14.929	–0.104	1.238
0.04	1.485	0.505	0.165	14.794	–0.089	0.511	0.162	14.841	–0.087	1.502
0.05	1.760	0.663	0.100	16.295	–0.050	0.663	0.102	16.127	–0.051	1.797
0.06	2.161	0.697	0.103	12.843	–0.057	0.702	0.102	13.000	–0.058	2.203
0.08	2.599	0.909	0.039	13.274	–0.038	0.922	0.035	13.021	–0.035	2.636
0.1	2.798	1.090	–0.004	13.129	–0.021	1.104	–0.008	13.022	–0.019	2.833
0.15	2.833	1.332	–0.053	18.304	0.003	1.346	–0.056	20.255	0.005	2.858
0.2	2.732	1.427	–0.068	13.742	0.006	1.441	–0.071	15.426	0.009	2.747
0.3	2.500	1.493	–0.082	16.496	0.016	1.501	–0.083	16.368	0.016	2.532
0.4	2.382	1.487	–0.083	16.170	0.018	1.492	–0.084	16.294	0.018	2.391
0.5	2.271	1.465	–0.082	16.359	0.019	1.469	–0.082	16.381	0.019	2.278
0.6	2.188	1.437	–0.079	17.807	0.022	1.441	–0.080	17.474	0.022	2.192
0.8	2.067	1.385	–0.072	15.777	0.021	1.384	–0.072	15.974	0.020	2.073
1	1.987	1.330	–0.065	15.831	0.020	1.332	–0.065	15.839	0.021	1.990
1.5	1.870	1.233	–0.049	14.679	0.017	1.233	–0.049	14.672	0.013	1.870
2	1.792	1.154	–0.034	15.043	0.012	1.154	–0.034	15.156	0.012	1.792
3	1.681	1.058	–0.012	12.090	0.000	1.059	–0.012	12.579	0.000	1.680
4	1.604	0.993	0.006	12.897	–0.009	0.994	0.006	12.911	–0.009	1.603
5	1.536	0.953	0.018	14.089	–0.021	0.951	0.018	13.649	–0.021	1.537
6	1.492	0.918	0.029	11.516	–0.024	0.920	0.029	11.572	–0.023	1.491
8	1.406	0.902	0.033	13.595	–0.027	0.902	0.033	13.624	–0.027	1.406
10	1.346	0.878	0.043	13.170	–0.033	0.879	0.042	13.161	–0.033	1.346
15	1.261	0.828	0.063	14.329	–0.055	0.830	0.062	14.319	–0.055	1.260

3. Results and discussion

The photon energy dependency of the EBF of the selected brick materials is shown in Figure 1 at various penetration depths (0.5, 5, 10, 20, 30 and 40 mfp). Variation in the EBF with penetration depth is shown in Figure 2 for soil-AR, FAGHTP-LM, BOM and COB; a similar dependency is observed for the others. The chemical compositions of the raw materials were investigated and are shown for penetration depths of 5 and 40 mfp. The variation in the EBF with photon energy, penetration depth and chemical composition is explained in detail in the next sections.

TABLE VII
GP fitting parameters for BOM and COB.

Energy (MeV)	BOM					COB				
	b	c	a	X_k	d	b	c	a	X_k	d
0.015	1.020	0.379	0.231	11.998	–0.148	1.017	0.296	0.321	10.490	–0.248
0.02	1.043	0.431	0.176	14.650	–0.084	1.038	0.337	0.231	26.819	–0.340
0.03	1.143	0.394	0.213	14.390	–0.115	1.106	0.376	0.225	13.775	–0.048
0.04	1.310	0.438	0.196	14.441	–0.109	1.230	0.409	0.208	14.579	–0.116
0.05	1.519	0.515	0.164	14.678	–0.091	1.388	0.465	0.187	14.455	–0.105
0.06	1.727	0.621	0.122	14.749	–0.067	1.553	0.545	0.153	14.502	–0.085
0.08	2.135	0.759	0.081	13.507	–0.050	1.846	0.706	0.093	14.638	–0.054
0.1	2.380	0.916	0.038	13.703	–0.042	2.089	0.837	0.056	13.860	–0.042
0.15	2.561	1.171	–0.022	12.064	–0.016	2.342	1.074	–0.003	13.216	–0.023
0.2	2.548	1.296	–0.044	9.929	–0.010	2.398	1.206	–0.027	11.700	–0.017
0.3	2.419	1.397	–0.064	13.335	0.001	2.330	1.327	–0.050	8.675	–0.010
0.4	2.303	1.427	–0.073	18.953	0.015	2.247	1.361	–0.058	11.468	–0.003
0.5	2.211	1.423	–0.074	16.293	0.015	2.159	1.387	–0.068	20.771	0.017
0.6	2.140	1.402	–0.072	17.362	0.016	2.099	1.374	–0.067	18.708	0.015
0.8	2.032	1.362	–0.068	16.187	0.018	2.002	1.344	–0.064	16.552	0.017
1	1.954	1.317	–0.062	16.346	0.019	1.931	1.305	–0.059	15.991	0.014
1.5	1.846	1.230	–0.048	15.414	0.016	1.834	1.224	–0.047	15.476	0.015
2	1.781	1.153	–0.032	15.316	0.009	1.771	1.155	–0.033	14.576	0.010
3	1.673	1.058	–0.011	11.803	–0.002	1.670	1.058	–0.010	10.534	–0.003
4	1.605	0.979	0.011	12.405	–0.015	1.593	0.997	0.006	14.562	–0.014
5	1.531	0.953	0.019	10.723	–0.017	1.525	0.963	0.017	10.978	–0.016
6	1.482	0.933	0.025	12.246	–0.023	1.475	0.945	0.022	13.346	–0.021
8	1.398	0.913	0.031	13.872	–0.027	1.392	0.924	0.028	13.653	–0.025
10	1.336	0.897	0.039	13.047	–0.033	1.332	0.905	0.037	13.208	–0.032
15	1.247	0.863	0.052	14.713	–0.049	1.240	0.878	0.048	14.114	–0.045

3.1. Photon energy dependency of the EBF

The variation in the EBF values of the soils, fly ashes, BOM and COB with photon energy is shown in Figure 1. It is to be noted that the EBF values of the soils, fly ashes, BOM and COB are minimum in low-energy photon and high-energy photon sources, whereas they are higher in the intermediate-energy region. The build-up factor in low-energy photon sources is low because the photons are completely absorbed by photo-electric absorption; it gradually increases with the photon energy due to multiple scattering by Compton scattering in the intermediate-energy region and finally reduces again in the high-energy region due to pair production. The energy, E_{max}, is 0.3 MeV at which the EBF values are maximum

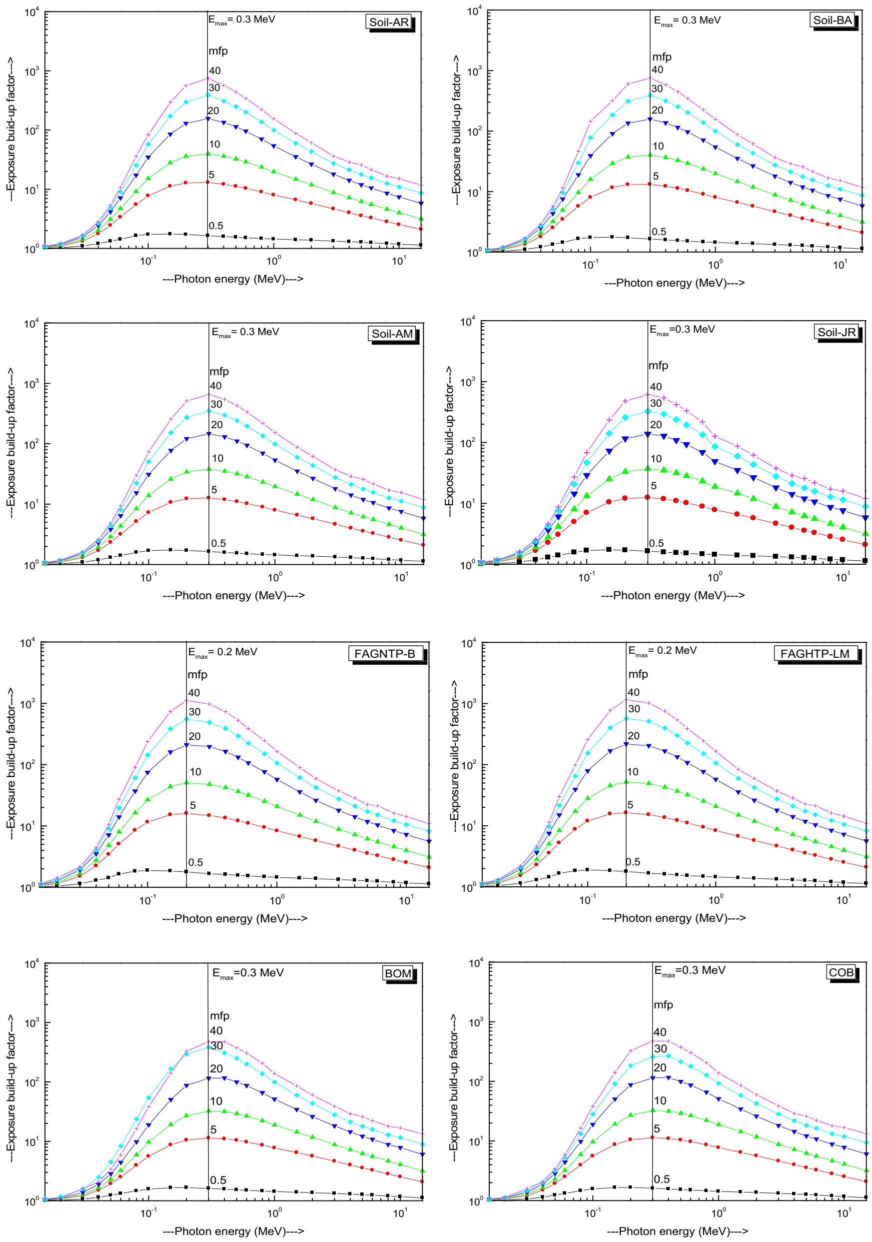

Figure 1 – ***Variation in gamma-ray exposure build-up factors of raw materials (soils and fly ash) of bricks, bricks of red mud and common bricks with photon energy.***

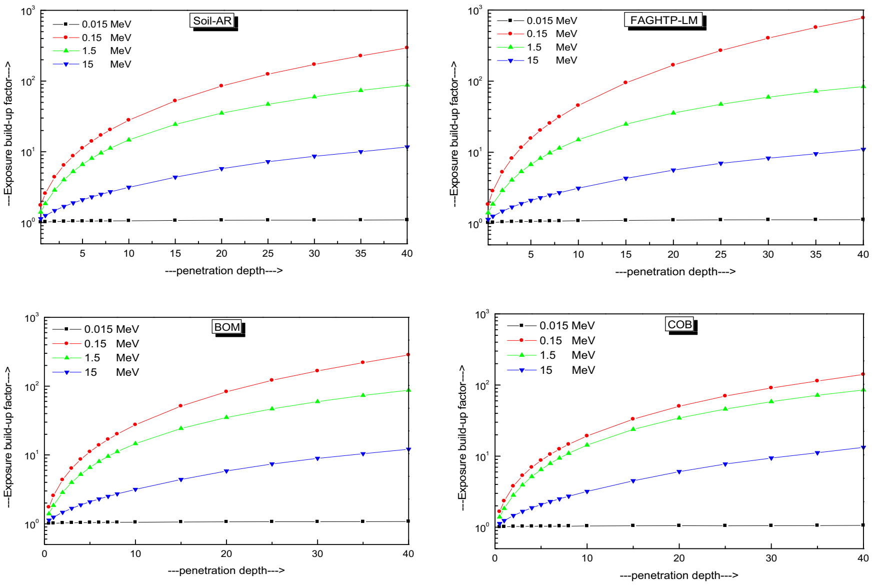

Figure 2 – ***Variation in gamma-ray exposure build-up factors for Soil-AR, FAGHTP-LM, bricks of red mud and common bricks with penetration depth.***

for all soils, BOM and COB, whereas it is 0.2 MeV for fly ashes. The analysis shows that the lowest EBF of brick materials should be considered for radiation shielding. The gamma-ray build-up factors are lowest for 0.5 mfp and highest for 40 mfp, which is due to multiple scattering events for 40 mfp. The EBFs of the soil and fly ash were found to be higher than ordinary concretes (Singh and Badiger, 2012a). It was found that the gamma-ray EBF of COB is the lowest among the selected materials, whereas BOM is comparable with soil of different locations in Punjab.

3.2. Penetration depth dependency of the EBF

The variation in the EBFs of the selected soil, fly ash, BOM and COB with penetration depth at the photon energies 0.015, 1.5, 5 and 15 MeV are shown in Figure 2. It is observed that the EBF values increase with the penetration depth initially and afterward saturate. The EBFs for soils are found to be lower than those of fly ashes at the photon energy 0.15 MeV. It can be seen that the EBF values of the raw materials of brick at 0.15 MeV and 1.5 MeV are higher than the others, whereas they decrease with an increase in the penetration depth as the Z_{eq} increases. It can be seen that the EBF values increase with an increase in Z_{eq} at

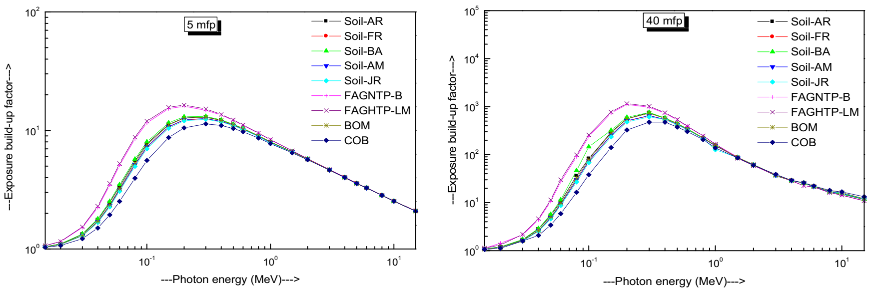

Figure 3 – ***Variation in gamma-ray exposure build-up factors of soils, fly ashes, bricks of red mud and common bricks at 5 and 40 mfp penetration depths.***

15 MeV as the penetration depth increases. The reason may be that beyond 3 MeV, the pair production is dominant on the Compton scattering and produces electron-positron pairs. These pair particles may escape from the medium of lower penetration depths and scatter at higher penetration depths as well as originating the secondary gamma photons (each of 511 keV) by annihilation to increase the gamma photon intensities.

3.3. Chemical composition dependency of the EBF

The EBFs are dependent on the atomic number of elements, hence the EBF values of the brick materials may be dependent on the chemical composition (Singh and Badiger, 2012a). The chemical element composition dependency of the EBF is analyzed for the photon energy at constant penetration depths, as shown in Figure 3. It is observed that the EBF values are low at low as well as high photon energies, whereas they are maximum in the intermediate-energy region. The reason for the peaked EBF values is that photo-electric absorption and pair production are the dominant interaction processes in low- and high-energy photons, respectively, which completely remove the photons. The intermediate-energy photons take over Compton scattering, where the photons undergo multiple scattering events to build up the exposure.

The raw materials of bricks, having a large weight fraction of low-Z elements, show high EBF values due to less removal of the photons. The fly ash (low Z_{eq}) has a higher EBF compared with soil (higher Z_{eq}) for the entire energy region 0.015 to 15 MeV at low penetration depths. The EBF of fly ash shows reverse behavior at 3 MeV at high penetration depths. It may be due to the dominance of pair production above 1.22 MeV which increases with an increase in photon energy, resulting in production of an electron and positron. The positron annihilates at zero kinetic energy and produces two new photons of energy 0.511 MeV which build up in the medium. The pair production is dependent on Z^2, signifying that the soils should have high photon intensities of energy 0.511 MeV. The EBF for soils is found to be high at the higher penetration depths due to the fact that multiple scattering is possible, whereas the positron may escape if the penetration depth is low (thickness of the medium).

4. Uncertainties

Uncertainties in the EBF estimation by GP fitting are one of the important aspects for suitability of the data. The build-up factors by ANS/ANSI-6.4.3 (1991) and GP fitting formulae for the EBF of water have been compared for ANS/ANSI-6.4.3 (1991), GP fitting and the MCNP5 photon energy range 0.015–15 MeV up to 40 mfp (Singh and Badiger, 2012a). The absolute values of maximum deviation in the EBF for water in GP fitting are within 0.5–3%, which is a lot lower compared with Berger and Taylor (Harima *et al.*, 1986). It is found that the calculation of the build-up factor database by the present work and ANSI/ANS-6.4.3 (1991) agrees for air and water within a few percent of uncertainty. This microscopic uncertainty gives confidence in our results for estimation of the EBF for raw materials of bricks (soils and fly-ashes).

5. Conclusions

The gamma-ray build-up factors of raw materials (soils and fly ashes) were calculated by using geometrical progression formulae in the energy range of 0.015–15 MeV up to a penetration depth of 40 mean free paths. The analysis was done for a homogeneous brick free from cavities, and mortar was excluded for the consideration of a wall due to its insignificant contribution. The results show that build-up factors are highest in the medium-energy range, while they are minimum at low and high photon energies. The maximum build-up factors exist for soils at 0.3 MeV and at 0.2 MeV for fly ashes. The results show that for a fixed penetration depth the values of the exposure build-up factor are very high in the medium-energy range and are low in the low- and high-energy regions. This study should be applicable for emergency preparedness planning and emergency dose estimation for future planned nuclear power plants in the state of Punjab.

REFERENCES

ANSI/ANS-6.4.3, 1991 Gamma ray attenuation coefficient and buildup factors for engineering materials.

Brar G.S., Karamjit S., Makhan S., Gurmel S.M. (1994) Energy absorption buildup factor studies in water, air and concrets up to 100 mfp using G-P fitting formula, *Radiat. Phys. Chem.* **43** (6), 623-627.

Chaudhari L., Dayanand R. (2012) Study of photon attenuation coefficient of soil samples from Maharashtra and Karnataka states (India) at gamma ray energies from 122 keV to 1330 keV, *Research Journal of Chemical Sciences* **2** (2), 49-53.

Chilton A.B., Eisenhauer C.M., Simmons G.L. (1980) Photon point source buildup factors for air, water and iron, *Nucl. Sci. Eng.* **73**, 97-107.

Gelward L., Guilbert N., Jensen K.B., Levring H. (2001) X-ray absorption in matter. Reengineering XCOM, *Radiat. Phys. Chem.* **60**, 23-24.

Gelward L., Guilbert N., Jensen K.B., Levring H. (2004) WinXcom-a program for calculating X-ray attenuation coefficients, *Radiat. Phys. Chem.* **71**, 653-654.

Gopinath D.V., Samthanam K. (1971) Radiation transport in one dimensional finite System-Part I. Development in Anisotropic Source Flux Technique, *Nucl. Sci. Eng.* **43**, 186-196.

Harima Y. (1983) An approximation of gamma buildup factors by modified geometrical progression, *Nucl. Sci. Eng.* **83**, 299-309.

Harima Y. (1993) An Historical review and current status of buildup factor calculations and application, *Radiat. Phys. Chem.* **41** (4/5), 631-672.

Harima Y., Sakamoto Y., Tanka S., Kawai M. (1986) Validity of geometric progression formula in approximating gamma ray buildup factor, *Nucl. Sci. Eng.* **94**, 24-25.

Jasbir S.D., Barjinderpal S., Gurdeep S.S. (2012) Gamma Ray Photon Energy Absorption Buildup Factor Study In Some Soils, *J. Appl. Phys.* **1** (6), 14-21.

Kulwinder S.M., Jyoti S., Vipan K.G., Sidhu G.S. (2012) Verification of some building materials as gamma-ray shields, *Radiat. Prot. Dosim.* **151** (1), 183-95.

Kulwinder S.M., Baljit K., Gurdeep S.S., Ajay K. (2013) Investigations of some is building materials for γ-rays shielding effectiveness, *Radiat. Phys. Chem.*, http://dx.doi.org/10.1016/j.radphyschem.2013.02.012.

Maron M.J. (2007) *Numerical analysis: A Practical approach*, Macmillan, New York.

Miller J., Taylor L., Zeitlin C., Heilbronn L., Guetersloh S., DiGiuseppe M., Iwata Y., Murakami T. (2009) Lunar soil as shielding against space radiation, *Radiat. Meas.* **44**, 163-167.

Mudhahar G.S., Sahota H.S. (1988) Soil: A Radiation Shielding Material, *Appl. Radiat. Isotopes* **39** (I), 21-24.

Mudhahar G.S., Sahota H.S. (1988) Effective Atomic Number Studies in Different Soils for Total Photon Interaction in the Energy Region 10000 keV, *Appl. Radiat. Isotopes* **39** (12), 1251-1254.

Murat K., Yuksel O. (2011) Energy absorption and exposure buildup factors for some polymers and tissue substitute materials: photon energy, penetration depth and chemical composition dependence, *J. Radiol. Prot.* **31**, 117-128.

Murat K., Bekir D., Metin I., Neslihan E., Yuksel O. (2011) Gamma-ray energy absorption and exposure buildup factor studies in some human tissues with endometriosis, *Appl. Radiat. Isotopes* **69**, 381-388.

Nelson W.R., Hirayama H., Rogers D.W.O. (1985) EGS4 code system, SLAC-265, Stanford Linear Accelerator Centre, Stanford, California.

Parjit S.S., Singh T., Kaur P. (2008) Variation of energy absorption buildup factors with incident photon energy and penetration depth for some commonly used solvent, *Ann. Nucl. Energy* **35**, 1093-1097.

Sandeep G., Gurdeep S.S. (2012) A Comprehensive Study on Energy Absorption and Exposure Buildup Factors for some Soils and Ceramic Materials, *J. Appl. Phys.* **2** (3), 24-30.

Shawkat I.J. (2011) Calculation of buildup factor for ceramics, *Iraqi journal of applied physics*, 23-26.

Shimizu A. (2002) Calculation of Gamma-Ray Buildup Factors up to depths of 100 mfp by the method of Invariant Embedding, (I) Analysis of accuracy and comparison with other data, *J. Nucl. Sci. Technol.* **39** (5), 477-486.

Shimizu A., Onda T., Sakamoto Y. (2004) Calculation of gamma-ray buildup factor upto depth of 100 mfp by the method of invariant embedding, (III) generation of improved data set, *J. Nucl. Sci. Technol.* **41**, 413-424.

Shlein B. (Ed.) (1984) *Health Physics and Radiological Health Handbook*.

Sich A.R. (1995) The Chernobyl accident revisited, part III: Chernobyl source term release dynamics reconstruction of events during the active phase, *Nuclear Safety* **36** (2), 195-217.

Simmons G.L. (1973) An adjoint gamma-ray moments computer code, ADJMOM-I. NBS Technical Note 748. National Bureau of Standards.

Singh C., Singh T., Kumar A., Mudahar G.S. (2004) Energy and chemical composition dependence of mass attenuation coefficients of building materials, *Ann. Nucl. Energy* **31**, 1199-1205.

Singh M., Mudahar G.S. (1992) Energy dependence of total photon attenuation coefficients of composite materials, *Appl. Radiat. Isotopes* **43** (7), 907-911.

Singh S., Ghumnam S.S., Singh C., Thind K.S., Mudhar S.G. (2010) Buildup of gamma ray photons fly-ash concretes: a study, *Ann. Nucl. Energy* **37**, 681-684.

Singh V.P., Badiger N.M. (2012a) Comprehensive study of energy absorption and exposure buildup factor for concrete shielding in photon energy range 0.015-15 MeV upto 40 mfp penetration depth: dependency of density, chemical element, photon energy, *Int. J. Nuclear Energy Science and Technology* **7** (1), 75-99.

Singh V.P., Badiger N.M. (2012b) Photon Energy Absorption Buildup Factors of Gaseous Mixtures used in Radiation Detectors, *Int. J. Radioprotection* **48** (1), 63-78.

Stankovica S.J., Ilica R.D., Jankovicb K., Bojovicb D., Loncarc B. (2010) Gamma Radiation Absorption Characteristics of Concrete with Components of Different Type Materials, *Acta Physica Polonica A* **117** (7), 812-816.

Sukhpal S., Ghumnam S.S., Singh C., Thind K.S., Mudhar S.G. (2010) Buildup of gamma ray photons fly-ash concretes: a study, *Ann. Nucl. Energy* **37**, 681-684.

Takeuchi K., Tanaka S. (1984) PALLAS-ID (VII). A code for direct integration of transport equation in one-dimensional plane and spherical geometries, *JAERI-M* **84**, 214.

Tejbir S., Rajni Updesh K., Parjit S.S. (2010) Photon energy absorption parameters for some polymers, *Annals of Nuclear Energy* **37**, 422-427.

Tejbir S., Gurpreet K., Parjit S.S. (2013) Study of Gamma Ray Exposure Buildup Factor for Some Ceramics with Photon Energy, Penetration Depth and Chemical Composition, *Journal of Ceramics* **2013**, 1-6, http://dx.doi.org/10.1155/2013/721606.

Yilmaz E., Baltas H., Kiris E., Ustabas I., Cevik U., El-Khayatt A.M. (2011) Gamma ray and neutron shielding properties of some concrete materials, *Ann. Nucl. Energy* **38**, 2204-2212.