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Original article

On the use of flyash-lime-gypsum (FaLG) bricks in the storage facilities for low level nuclear waste

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ABSTRACT

In the present study, radiation shielding and protection ability of prepared Flyash-lime-Gypsum (FaLG) bricks has been studied in terms of energy exposure build up factors and dose parameters. The energy exposure build up factors of Flyash-lime-Gypsum (FaLG) bricks have been calculated for the energy range of 0.015 MeV–15 MeV and for penetration depth upto 40 mfp directly using a new and simplified Piecewise Linear Spline Interpolation Method (PLSIM). In this new method, the calculations of G.P fitting parameters are not required. The verification and accuracy of this new method has been checked by comparing the results of exposure build up factor for NBS concrete calculated using present method with the results obtained by using G.P fitting method. Further, the relative dose distribution and reduced exposure dose rate for various radioactive isotopes without any shielding material and with Flyash-lime-Gypsum (FaLG) bricks have been calculated in the energy range of 59.59–1332 keV. On the basis of the obtained results, it has been reported that the prepared Flyash-lime-Gypsum (FaLG) bricks possess satisfactory radiation shielding properties and can be used as environmentally safe storage facilities for low level nuclear waste.

1. Introduction

At nuclear waste storage facilities, various nuclear radiations like multi-energy gamma radiations, neutrons flux and fission fragments are emitting spontaneously. Thus, wide walls made of an appropriate shielding material are required to shield the environment outside the storage facilities. The energy exposure build up factor is a result of secondary gamma radiations with lower energies than the incident radiations. It is an important factor which should not be ignored in the shielding and protection design. Otherwise, the calculated value of thickness of the shield design would be less than the true value, which, in turns may cause major radiation hazards to the environment. In order to protect the public and the environment from such hazardous, the design and selection of appropriate shielding material is very important.

Radioactive nuclear waste material is continuously accumulating from nuclear power reactors being used all over the world. In order to handle the large volume of nuclear waste material, the safe and environment friendly storage facilities are required. Usually, the nuclear waste material can be divided into two sub categories namely high-level nuclear waste and low-level nuclear waste. The high-level nuclear waste material is usually stored in deep (50–500 m below the earth's surface) storage facilities, on the other hand, low level and very low level nuclear waste can be stored in subsurface or surface storage facilities.

Along with the nuclear power plants, increasing use of thermal coal power plants for electricity production in developing countries like India, results in production of huge amount of fly ash, disposal of which poses serious challenges to the environment. Besides fly ash, lime and gypsum are also available in huge quantity in many regions of India. Therefore, production FaLG (flyash-lime-gypsum) bricks for construction purpose is considered to be best way of utilizing these materials. Moreover, it also provides an effective solution to the ever increasing disposal problem of fly ash as well as

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offers a viable, energy efficient and environment friendly alternative over traditional burnt clay bricks used for construction. At the same time it allows value added economical utilization of industrial waste. Since preparation of FaLG bricks does not involve sintering, thus eliminating the burning of fossil fuels required in the clay brick production process and ultimately contributes to the reduction of greenhouse gas emissions [1]. Therefore, keeping in view of use of Flyash-lime-gypsum bricks (FaLG) as construction material, an accurate evaluation of exposure build up factors of such bricks are needed for estimating appropriate amount of shielding required to achieve a desired reduction in gamma dose.

Most significant gamma ray spectroscopic parameters used to determine shielding effectiveness of materials against these radiations are mass attenuation coefficient, mass absorption coefficient, half value layer (HVL), mean free path (mfp). Accurate evaluation of these gamma ray parameters for a given material require validity of Beer Lambert Law ($I(x) = I_o e^{-\mu.x}$) subjected to three condition namely (a) ray should be monochromatic (b) absorbing material should be thin (c) narrow beam geometrical setup. In case, any of the aforesaid conditions is not met, this law will no longer be applicable. Thus, the law needs to be corrected using correction factor called Build up factor (B). The build up factor, in general is defined as ratio of total value of a specified radiation quantity at any point to the contribution to that value from uncollided radiation reaching that point, whereas exposure build up factor refers to the physical parameter in which quantity of interest is the exposure and detector response function is that of absorption in air [2]. Since radiation protection is preliminary assessed on the basis of exposure field before and after use of radiation shield, so exposure build up factor is of most general use for estimation of photon flux distribution in medium and amount of radiation exposure dose. White [3] introduced the concept of build up factor with first ever experimental measurement of this parameter in water. Since then, a significant developments have been made in accurate computation of build up factor in various materials of medical, dosimetric and shielding interest using number of codes such as such as ADJMON-I [4], PALLAS [5] and EGS4 [6]. Standard report ANSI/ANS-6.4.3 [7] covers complied data of build up factors calculated using various codes for 23 elements of atomic number, $Z = 4$ to 92 as well as for mixtures air, concrete and compound water for the energy range 0.015–15 MeV up to penetration depth of 40 mean free path (mfp). The build-up factors of standard report ANSI/ANS-6.4.3 [7] can also be reproduced within estimate (<5%) by new fitting method called Geometrical Progression (GP) [8]. Similarly, Shimizu et al. [9], purposed invariant embedding technique for evaluating build-up factors. Harima [10] has reported a detail historical review and current status of gamma-ray build up factor and its usefulness in designing appropriate shielding material. Calculations of gamma-ray build-up factors using GP fitting method have been reported by various researchers for different materials such as concretes [11,12], human tissues [13,14], radioprotective agents and chemotherapy drugs [15,16], ternary composites [17], glasses [18], thermo luminescent dosimetric compounds [19], silicate [20], steels [21], construction and building material [22,23] and Flyash bricks [24]. Whereas only a single study on direct approximation of EFBs without using G.P. fitting parameters has been reported so far [25]. Besides this, the application of EFBs in the calculation of relative dose distribution had been discussed by Singh et al. [26]. Manjunatha and Rudraswamy [27,28] calculated relative dose distribution in teeths and Hydroxyapatite (HA) at various distances from the radioactive source. Similarly, reports on the reduction in exposure dose rate in diaspore-flyash concretes shielding material [29], Al-based glassy alloys [30], Mg–Gd–Y–Zn–Zr alloys [31] were also available in literature.

In present study, an attempt has been made to calculate the energy exposure build up factors of flyash-lime-gypsum (FaLG) bricks with varying composition of flyash and gypsum by using new Piecewise linear spline interpolation method (PLSIM). This present method involves direct computation of EBFs using single mathematical relation as compared to standard G.P fitting method [8] involving multistep calculations for computing EBFs. Accuracy and verification of this method has been checked by comparing exposure build up factor of NBS concrete [32] obtained using present technique with well established G.P fitting method [8]. In addition to it, the relative dose distribution and exposure dose rate for various radioactive isotopes without shielding material and with Flyash-lime-Gypsum (FaLG) bricks have been calculated in the energy range of 59.59–1332 keV to assess shielding efficiency of Flyash-lime-Gypsum (FaLG) bricks.

2. Materials and methods

Unfired FaLG bricks are compressed mixture contains Fly ash (Fa), lime (L) and gypsum (G) that forms water impermeable composite having similar hydrated mineralogical phases to those in hydrated Portland cement. Pozzolanic materials consist of silica and alumina in reactive form is responsible for the growth of cementitious compounds in the presence of lime and water. The fly ash-lime pozzolanic reaction does not need external heat while manufacturing FaLG bricks. Moreover, the strength and rheology of fly ash-lime blend can be significantly improved by adding gypsum [33]. The roll of gypsum is to acts as an accelerator in FaLG reaction mechanism thereby increasing the formation of calcium silicate hydrates. In fly ash the aluminate phase is present as aluminosilicate and requires an appropriate activator. The affinity between alumina and sulphate ion results in the destruction of the glass and activate alumina [34]. Lime has been used as a stabilizing agent and found to develop long-term strength gain [35,36]. Nagaraj et al. [37] prepared compressed stabilized Earth Blocks by replacing popular stabilizer cement with lime and reported the efficiency of lime in convalescing the lasting build-up of strength enhanced than using cement alone. In addition to this, investigations on the influence of different curing techniques and additives on compression strength, flexural strength, water absorption, durability, stress-strain characteristics and dimensional stability of cementitious binder composed of flyash, lime and Phosphogypsum has been reported in detail in various research reports [38–43].All these studies clearly indicate that Flyash-lime-gypsum binder possesses adequate mechanical and physical properties over ordinary burnt bricks for potential use in the manufacturing of building construction material like bricks and blocks etc.. However, radiation shielding properties of such FLaG bricks still require to be investigated in order to assess the possibility of using them in making low level nuclear waste disposal tanks and pits etc. For this purpose, samples of flyash-lime-gypsum (FaLG) with different weight percentages i.e. (Flyash (80-x)-lime (20)-Gypsum (x) where x = 10,15,20,25,30) have been prepared in laboratory of Physics Department of Sant Longowal Institute of Engineering and Technology (Deemed University), Longowal, Punjab, India. Flyash used in samples has been procured from Guru Hargobind Thermal Plant Lehra Mohabat, Bathinda, Punjab, India. While lime and gypsum has been procured from Loba Chemie Pvt, Ltd. and Merck chemical Pvt. Ltd. Procedure used for sample preparation was same as given elsewhere in literature [44]. Elemental composition of prepared FaLG samples is given in Table 1.

Table 1
Elemental composition of FaLG samples in terms of Weight fraction.

Element	FaLG-1	FaLG-2	FaLG-3	FaLG-4	FaLG-5	NBS Concrete*
Si	0.1878	0.1744	0.1609	0.1475	0.1341	0.3158
Al	0.0827	0.0768	0.0709	0.0649	0.0590	0.0456
Fe	0.0305	0.0283	0.0262	0.0240	0.0218	0.0122
Ca	0.1528	0.1629	0.1730	0.1831	0.1933	0.0826
Mg	0.0108	0.0100	0.0093	0.0085	0.0077	0.0024
S	0.0201	0.0293	0.0385	0.0477	0.0569	0.0012
K	0.0157	0.0146	0.0135	0.0124	0.0112	0.0192
Na	0.0027	0.0025	0.0023	0.0021	0.0019	0.0171
O	0.4648	0.4696	0.4745	0.4793	0.4841	0.4983
H	0.0083	0.0095	0.0107	0.0119	0.0130	0.0056

*Grodstein, G.W., (1957).

3. Theory

3.1. Calculation of energy exposure build-up factor by using piecewise linear spline interpolation method (PLSIM)

Energy exposure build up factors of FaLG samples were calculated directly using piecewise linear spline interpolation method **(PLSIM)** by making use of equivalent atomic number Z_{eq} of samples. Computational procedure involves following two steps:

a) Calculation of equivalent atomic number Z_{eq} of samples
b) Evaluation of exposure build-up factors.

Z_{eq} is a parameter which characterise materials properties of compound/mixture in terms of equivalent elements similar to the atomic number of a single element. Gamma rays interact with matter mainly through Photoelectric, Compton and Pair production processes. Since all these interaction processes are energy dependent, therefore, Z_{eq} for each process varies with photon energy accordingly. However, Build up of photon in material medium occurs mainly as a result of multiple scattering events caused by Compton scattering. So, Z_{eq} of samples under study were derived using Compton partial mass attenuation coefficients. Value of Z_{eq} for a particular sample is estimated by matching the ratio (R_{eq}), $\mu/\rho_{\text{Compton}}/\mu/\rho_{\text{Total}}$ of that sample at a specific energy with the corresponding ratio of an element at the same energy. For this, first values Compton partial mass attenuation coefficients, $\mu/\ \rho_{Compton}$ and total mass attenuation coefficients, μ/ρ_{Total} of elements with Z = 7 to 20 as well as FaLG samples were obtained from WinXCom [45]. Then interpolation of Z_{eq} for a given sample was employed using piecewise linear spline interpolation formula as

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

where, Z_1 and Z_2 are atomic number of elements with corresponding ratios R_1 and R_2 which lies on immediate lower and upper side of ratio (R_{eq}) of sample under study. Computed values of Z_{eq} of FaLG samples at various energies of interest in the range 0.015 MeV–15 MeV are given in Table 2.

Values of Z_{eq} of different FaLG samples so obtained were then used for direct approximation of exposure Build up factors of samples for each energy values (0.015 MeV–15 MeV) at penetration depths (0.5 mfp to 40 mfp) using relation (1) but with modified form as

$$B_{ex} = \frac{B_2(Z_{eq} - Z_1) - B_1(Z_{eq} - Z_2)}{(Z_2 - Z_1)} \tag{2}$$

where B_{ex} exposure is Build up factor of FaLG sample under study,

Table 2
Equivalent atomic number of FaLG samples and NBS concrete*.

Energy	FaLG 1	FaLG 2	FaLG	FaLG 4	FaLG 5	NBS concrete
1.50E-02	13.97	14.00	14.04	14.06	14.09	12.90
2.00E-02	14.16	14.19	14.23	14.25	14.28	13.00
3.00E-02	14.35	14.38	14.41	14.44	14.47	13.15
4.00E-02	14.46	14.49	14.52	14.55	14.58	13.25
5.00E-02	14.54	14.57	14.60	14.62	14.65	13.30
6.00E-02	14.59	14.62	14.65	14.68	14.70	13.35
8.00E-02	14.67	14.70	14.73	14.75	14.78	13.40
1.00E-01	14.72	14.75	14.78	14.81	14.84	13.44
1.50E-01	14.81	14.84	14.87	14.89	14.92	13.50
2.00E-01	14.86	14.89	14.92	14.95	14.98	13.54
3.00E-01	14.92	14.96	14.99	15.01	15.03	13.59
4.00E-01	14.96	14.99	15.02	15.04	15.06	13.61
5.00E-01	14.98	15.01	15.04	15.05	15.08	13.62
6.00E-01	15.00	15.02	15.06	15.08	15.09	13.64
8.00E-01	15.00	15.03	15.07	15.07	15.10	13.67
1.00 E+00	15.00	15.00	15.05	15.05	15.10	13.64
1.50 E+00	13.03	13.06	13.06	13.08	13.08	12.03
2.00 E+00	12.45	12.46	12.47	12.47	12.48	11.65
3.00 E+00	12.29	12.30	12.31	12.31	12.31	11.55
4.00 E+00	12.24	12.25	12.25	12.25	12.26	11.51
5.00 E+00	12.23	12.23	12.24	12.24	12.25	11.50
6.00 E+00	12.22	12.22	12.23	12.23	12.23	11.50
8.00 E+00	12.20	12.21	12.21	12.21	12.22	11.49
1.00 E+01	12.20	12.20	12.21	12.21	12.21	11.48
1.50 E+01	12.19	12.19	12.19	12.19	12.20	11.48

*Grodstein, G.W., (1957).

B_1 and B_2 are the exposure build up factors of elements of atomic number Z_1 and Z_2 respectively which lies immediately below and above Z_{eq} . Values of B_1 and B_2 at each energy and penetration depth needed for calculation of exposure build up factor of FaLG samples were obtained from standard report ANSI/ANS-6.4.3 [7].

4. Verification of the "piecewise linear spline interpolation method (PLSIM)"

To verify the applicability of piecewise linear spline interpolation method for computing build up factors, EBFs of NBS concrete [32] in the energy range of 0.15 MeV–15 MeV were calculated and compared with the values evaluated using standard G.P. fitting method [8]. Fig. 1 give the ratio of EBFs obtained employing G.P method to that by present (PLSIM) method for each penetration depth and for all energies falling within above given energy range.

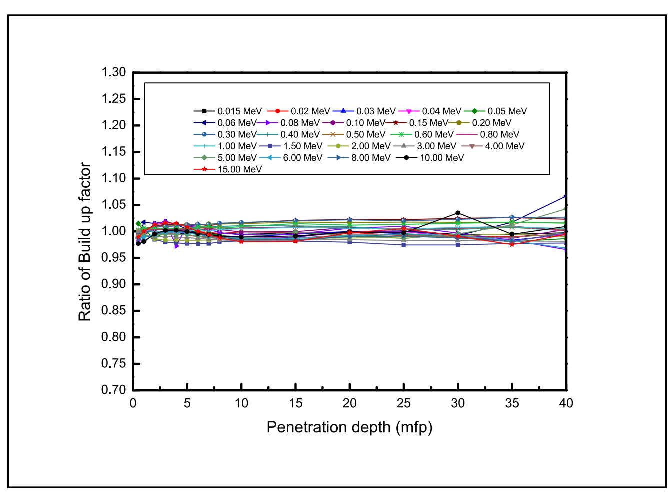


Fig. 1. Ratio of exposure build up factor calculated by G.P fitting method [8] to that calculated by PLSIM method.

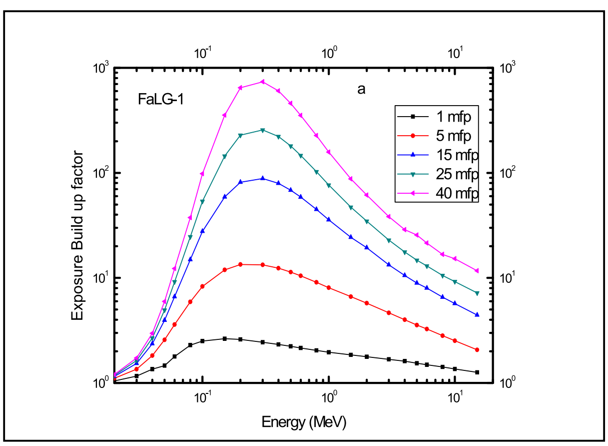
It is shown that ratio of EBFs lies in between 0.97 and 1.03 (within discrepancy of 4%) except in case ratio is 1.06 (with discrepancy of 6%). Thus an overall excellent agreement between the values of EBFs calculated by both method indicates that piecewise linear spline interpolation method can be used with confidence for computing exposure build up factors of FaLG samples.

5. Result and discussion

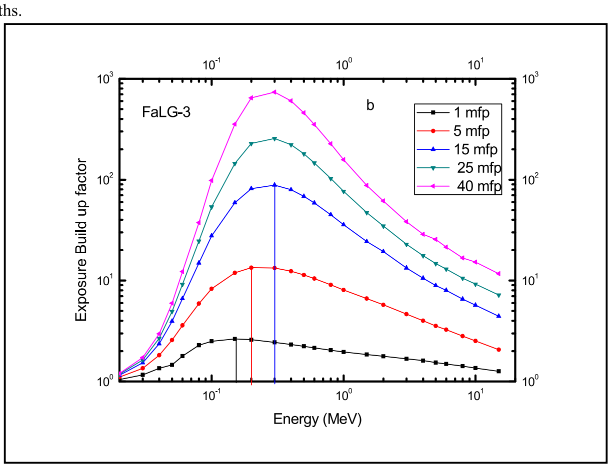
This section has been divided into two parts. In the first part, the variation in EBFs with photon energy and penetration depth has been discussed in detail and in the second part, the results of relative dose distribution and exposure dose rate for various radioactive isotopes without shielding material and using Flyash-lime-Gypsum (FaLG) bricks have been discussed in details to assess their shielding effectiveness.

5.1. Energy dependence of exposure build up factors (EBFs)

Photon energy dependence of EBFs for the sample FaLG-1 and FaLG-3 at some selected penetration depths is shown in Fig. 2 (a, b). It can be clearly observed that for a given sample, build up factor exhibits small value both in low energy (<0.06 MeV) and high energy (>1.5 MeV) region whereas possesses large value in intermediate energy range at a particular penetration depth. Similar trend is shown by other samples at selected penetration depths.



(a). Variation of EBFs of FaLG-1 samples with photon energy at selected penetration depths.



(b).Variation of EBFs of FaLG-3 samples with photon energy at selected penetration depths

Fig. 2. (a,b). Variation of EBFs of FaLG-1 samples with photon energy at selected penetration depths.

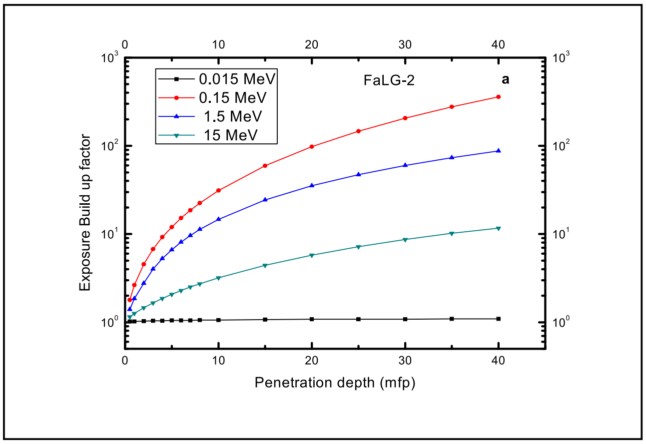
Small value of EBFs in low energy region is due to complete absorption of gamma photon due to photoelectric absorption. Hence removal of photon from material volume as a result of photoelectric effect leads to the reduction of EBFs. Further, the photoelectric interaction cross-section varies directly with atomic number as $Z^{4\text{-}5}$ and inversely with energy of the incident gamma photon as $E^{-7/2}$, therefore, this interaction process is more significant at low energy photons particularly for high Z-materials only. As energy of the incident gamma photons increases, Compton scattering process starts competing with photoelectric absorption process due to which values of build up factor starts enhancing and thereby attaining maximum value in intermediate energy region (0.08 MeV–0.6 MeV). The energy at which EBFs exhibit maximum value gradually shifts towards higher energy as we increase penetration depth upto 15 mfp thereafter remain constant for almost all samples. For example, in case of FaLG-3, maximum EBF value of 1.79 occurs at 0.1 MeV at 0.5 mfp, 13.41 at 0.2 MeV at 5 mfp and 88.44 at 0.3 MeV at 15 mfp. Reason for larger value of build up factor in this energy region is due to non absorbance of scattered photon by material medium completely. Thus maximum multiple scattering of photon occurs which results in accumulation of large number of photons of degraded energy. These degraded energy photons exists in material medium for a long time period, which led to enhancement of EBFs. Again in high energy region (>1.5 MeV), pair production process took over Compton scattering process resulting in absorption of photons, therefore, life time of their existence in medium become short. Consequently, from 3 MeV onwards the values of EBFs start decreasing gradually with increases in energy and exhibits very small value at 10 MeV and 15 MeV.

5.2. Dependence of EBFs on penetration depth

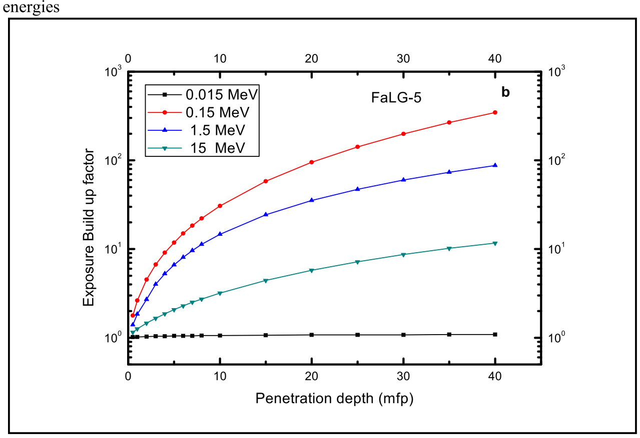
Fig. 3(a, b) shows variation of EBFs of sample FaLG-2 and FaLG-5 as a function of penetration depth at some selected energies i.e. 0.015 MeV, 0.15 MeV, 1.5 MeV and 15 MeV. It can be noted that at lowest gamma photon energy 0.015 MeV, EBF of each FaLG sample is approximately constant (near to unity) for all penetration depths. At higher energies value of EBF increases gradually with increase in penetration depth and attain maximum value at 40 mfp. This trend can be attributed to the fact that at greater penetration depth probability of multiple scattering of photon increases due to increase in volume of interacting medium thereby leading to enhancement of build up factor. Among selected energies, value of EBF is higher for 0.15 MeV followed by 1.5 MeV, 15 MeV and then 0.015 MeV. Reason for larger value of EBF at 0.15 MeV may be due to dominance of Compton scattering process, whereas at 0.015 MeV and15 MeV, photoelectric absorption and pair production process respectively plays a significant role while interaction of photon with matter. Furthermore, at 15 MeV energy, the values of EBFs increase as penetration depth increases. The reason behind this trend may be that beyond 3 MeV, pair production interaction process dominates over Compton scattering and results in generation of electron-positron pair. At shallow depth, these particles may escape from interacting medium, however, scatters at higher penetration depths besides producing secondary gamma photons (of 511 MeV energy) by annihilation to increase gamma ray photon energy. Similar variation is observed for remaining FaLG samples.

5.3. Relative dose distribution and exposure dose rate

The radial dependence of dose can be expressed by exp (-μx) B/x^2. Here μ represents the linear attenuation coefficient for the appropriate photon energy and B is an exposure build-up factor.



(a). Variation of EBFs of FaLG-2 samples with penetration depth at selected photon energies



(b). Variation of EBFs of FaLG-5 samples with penetration depth at selected photon energies

Fig. 3. (a,b). Variation of EBFs of FaLG-2 samples with penetration depth at selected photon energies

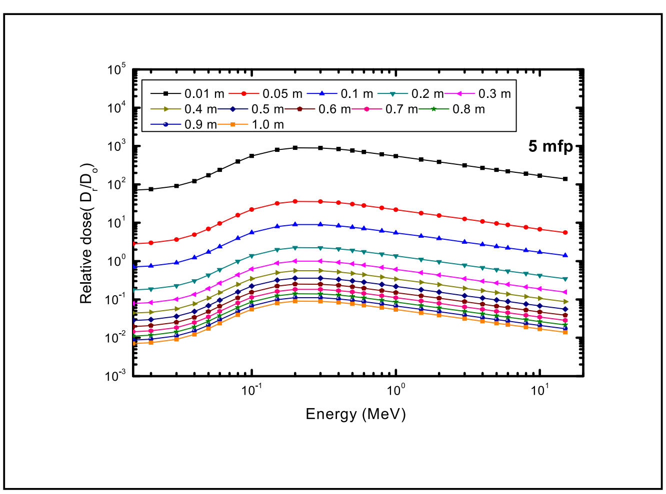


Fig. 4. Variation of relative dose (D_r/D_o) with photon energy in FaLG-5 sample at penetration depth of 5 mfp at various distances.

Hence, photon dose at a distance x is given by $D_r = D_0 \exp(-\mu x)\, B/x^2$, where D_0 is dose due to point gamma ray source without any absorber [27,28]. The relative dose distribution at a distance x can be expressed as $D_r/D_0 = \exp(-\mu x)\, B/x^2$. In the present work, the relative dose of gamma photons in Flyash-lime-Gypsum (FaLG) bricks has been computed by using the calculated values of exposure build-up factor. Fig. 4 shows the variation of relative dose (D_r/D_0) with photon energy in FaLG-5 brick sample having thickness equivalent to 5mfp for various chosen distances from 0.01 to 1 m. From this figure, it is observed that relative dose (D_r/D_0) has maximum value in the Compton scattering region. As discussed earlier in sections 5.2 and 5.3, the gamma photons get absorbed in low and high energy regions due to photoelectric effect and pair production, respectively, but in the intermediate energy rage the multiple scattering of gamma photons yields a high value of relative dose (D_r/D_0). Moreover, the present findings are in line with the previously reported results [28,30].

The radiation exposure rate ($\dot{X}_o$) at any distance from a radionuclide emitting photons without target material in the path was calculated from the following expression $\dot{X}_o$ (R/h) $= \frac{A\,\Gamma}{d^2}$, where Γ is specific exposure rate constant (R cm^2/mCi h), A is the activity (mCi) of isotope, and d is the distance (in cm) from a point radioactive source [29,46]. The reduced exposure rate by using shielding material can be calculated from the following expression $\dot{X} = \dot{X}_o\, e^{-\mu.x}$, where μ is the linear attenuation coefficient of the shielding material at a particular gamma photon energy and x represent the thickness of the shielding material used [29]. The activity of the radioactive isotopes used in the present calculations has been taken as 100 mCi and the distance d has been taken as 150 cm. The values of specific exposure rate constant (Γ, R cm^2/mCi h) for various isotopes has been taken from literature [46]. Exposure dose rate for 0.0595 MeV, 0.356 MeV, 0.662 MeV, 1.173 MeV, 1.274 MeV and 1.332 MeV photon energies emitted by point radioactive sources ^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co, ^{22}Na and ^{60}Co respectively, without any shielding material and using FaLG-5 sample of thickness equivalent to 5mfp, as a shielding material has been presented in Fig. 5. It is evident from this figure that FaLG brick samples as gamma ray shielding materials are significant in lowering the exposure dose rate. Further, it is also found that the gamma exposure dose rate decreases with the increasing thickness of the FaLG brick samples. These results are in agreements with the previously reported work [29–31].

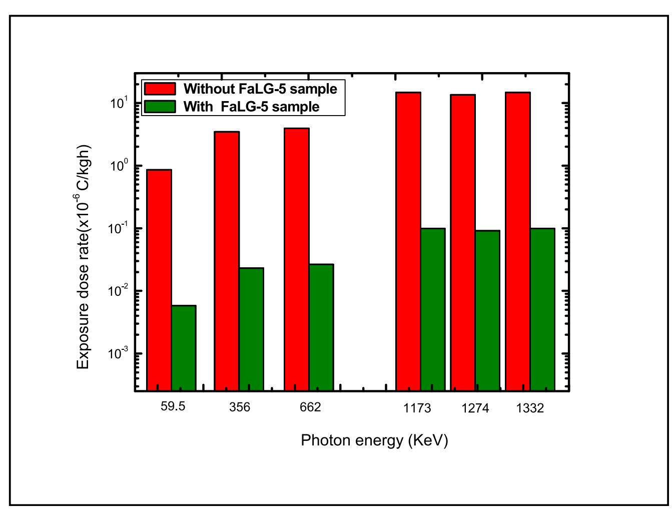


Fig. 5. Variation of exposure rate with and without FaLG-5 sample at penetration depth of 5 mfp.

Table 3
EBFs of FaLG samples and NBS concrete at some selected energies and penetration depths.

Penetration depth (mfp)	Energy (MeV)	FaLG-1	FaLG-2	FaLG-3	FaLG-4	FaLG-5	Concrete
1	0.0595	1.78	1.77	1.77	1.77	1.77	2.07
	0.356	2.38	2.38	2.38	2.38	2.38	2.43
	0.662	2.12	2.12	2.11	2.11	2.11	2.14
	1.173	1.92	1.92	1.92	1.92	1.92	1.94
	1.274	1.90	1.90	1.90	1.90	1.90	1.92
	1.332	1.89	1.89	1.89	1.89	1.89	1.90
10	0.0595	5.19	5.15	5.11	5.07	5.03	7.41
	0.356	38.28	38.15	38.03	37.98	37.93	44.21
	0.662	27.93	27.91	27.87	27.86	27.83	29.49
	1.173	18.26	18.26	18.25	18.24	18.23	18.78
	1.274	17.20	17.19	17.18	17.18	17.17	17.64
	1.332	16.59	16.58	16.57	16.57	16.56	16.96
20	0.0595	7.92	7.84	7.76	7.69	7.62	12.54
	0.356	149.34	148.81	148.31	147.97	147.62	175.01
	0.662	89.82	89.72	89.58	89.52	89.43	96.34
	1.173	48.53	48.52	48.49	48.48	48.45	49.98
	1.274	44.61	44.59	44.57	44.56	44.53	45.80
	1.332	42.32	42.30	42.29	42.27	42.26	43.34
30	0.0595	10.31	10.19	10.07	9.97	9.85	17.69
	0.356	354.27	352.78	351.39	350.40	349.36	426.16
	0.662	185.54	185.33	184.99	184.87	184.66	199.56
	1.173	87.92	87.90	87.82	87.80	87.73	90.56
	1.274	79.70	79.67	79.63	79.61	79.57	81.83
	1.332	74.82	74.79	74.77	74.75	74.72	76.68
40	0.0595	12.25	12.10	11.94	11.82	11.67	23.69
	0.356	668.48	665.31	662.36	660.33	658.21	821.04
	0.662	313.94	313.56	312.94	312.73	312.35	338.95
	1.173	134.71	134.68	134.61	134.58	134.50	139.22
	1.274	120.65	120.60	120.53	120.48	120.42	124.41
	1.332	112.59	112.54	112.50	112.45	112.41	115.66

5.4. FaLG samples as radiation shielding materials

Effectiveness of FaLG samples as a gamma radiation shielding material in comparison to ordinary concrete has also been investigated. For this purpose, the values of EBFs of FaLG samples and ordinary concrete samples have been calculated at penetration depth of 1,10,20, 30 and 40 mfp for specific energies 0.0595 MeV, 0.356 MeV,0.662 MeV, 1.173 MeV, 1.274 MeV and 1.332 MeV emitted by point radioactive sources ^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co, ^{22}Na and ^{60}Co respectively. The obtained results are presented in Table 3. The purpose of selecting these energies is their frequent use in experimental investigation of shielding properties of different materials. From tabulated values, it should be noted that magnitude of EBFs of all FaLG samples are in general smaller than that of concrete at all selected energies and penetration depths. Since, equivalent atomic number $Z_{eq,}$ of FaLG samples and ordinary concrete decreases as FaLG5> FaLG4> FaLG3> FaLG2> FaLG1> ordinary concrete, this indicates that EBFs vary inversely with respect to Z_{eq} in the energy region of interest. This can be explained on the basis that a composite material having lower value of Z_{eq} contains large weight fraction of low Z elements. Therefore exhibits higher value of EBFs due to less removal of photon from material medium. Hence, we conclude that all FaLG samples show better shielding characteristics than concrete. Whereas, lower values of EBF of sample FaLG5 among FaLG samples enhance its utility as better construction material from radiation shielding aspect. Further, smaller values of EBFs of FaLG samples relative to ordinary concrete reveals that these are cost effective, environmental friendly radiation shielding materials has potential application in the field of protection against gamma ray exposure.

6. Conclusions

EBFs of FaLG samples have been calculated for energy range 0.015 MeV to 15 MeV at different penetration depths upto 40 mfp. Relative dose distribution and exposure dose rate$\dot{X}_o$, reduced exposure rate $\dot{X}$ using prepared FaLG bricks as absorber have also been calculated to assess the efficiency of FaLG bricks as effective radiation shielding material. Following conclusions can be drawn from analysis of results:

1) EBFs of FaLG samples exhibits small values both in low and high energy range whereas possess large value in the intermediate energy region.
2) EBFs were also found to increase with increase in penetration depth and attain maximum value at 40 mfp, which is the uppermost penetration limit of present calculations.
3) Archaeological FaLG samples were found to exhibit better shielding properties as compared to concrete. Therefore, these eco friendly and economical bricks can be used for the storage of very low and low level activity nuclear waste materials for photon dose estimation and protection against radiation exposure.
4) A fairly good agreement between the values of EBFs for NBS concrete obtained with present method and values calculated using well established G.P Fitting method showed that piecewise linear spline interpolation approach can be utilized with confidence for estimation of EBFs of composite materials.
5) The exposure dose rate result indicates that FaLG bricks exhibits adequate radiation shielding ability.

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Declaration of competing interest

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The authors hereby declare that there is no Conflict of interest.

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