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Technical Note

Verification of some low-Z silicates as gamma-ray shielding materials

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ABSTRACT

G-P fitting method has been used to compute buildup factors of some low atomic number (Z) silicates for the wide energy range (0.015–15.0 MeV) up to the penetration depth of 40 mean free path. The variation of buildup factors with equivalent atomic numbers, penetration depth and incident photon energies for the selected samples has been studied. Among the observations was the inverse relationship between values of buildup factors and equivalent atomic numbers for all samples. It has been concluded that the sample with least equivalent atomic number possesses the maximum value of buildup factor. It has been verified that datolite and diopside can be used as good shielding materials. The results have been depicted graphically with some useful conclusions.

1. Introduction

The exposure to gamma radiations with human body can occur during radiological diagnosis, nuclear research establishments, nuclear reactors and nuclear fuel cycle facilities. Since the energetic gamma rays are hazardous for living cells and tissues. So, a detailed study is required for the safe and acceptable use of gamma radiation, radioactive materials and nuclear energy. Additional area of interest is gamma radiation shielding development, which has grown considerably due to all aspects related to the protection from these ionising radiations. A number of nuclear accidents have occurred (Fukushima, Chernobyl, Three Mile Island, etc.) and there is a possibility of facing such issues in the future. Also, one should consider leakage of radiations sources, transportation and storage of nuclear waste, increasing demand of radiotherapy, radiological terrorism and nuclear weapons being used in wars. Good shielding materials should be developed which could effectively protect from these hazardous radiations.

In the study of design of the gamma radiations shielding or estimating the absorption dose, there is an undesired situation faced by radiation physicists and engineers due to secondary radiations that can occur due to buildup of photons from the collided part of the incident beam. For this reason it is of importance to determine the buildup factors to make corrections for effective energy absorbed in different shielding materials. The buildup factor is a multiplicative factor used to obtain the corrected response to the uncollided photons by including the contribution of scattered photons. It can be defined as the ratio of the total detector response to that of uncollided photons. The buildup factor measures the degree of violation of the Lambert–Beer law ($I = I_o * e^{-\mu x}$) due to multiple scattering of photons. The modified equation becomes $I = B * I_o * e^{-\mu x}$ (Singh et al., 2008), where B is the buildup factor for one energy at the shield thickness x, I_o is the initial dose rate, I is the shielded dose rate, μ is linear attenuation coefficient in cm^{-1} and 'x' is the shield thickness in cm. The average distance that photons of a given energy travel before an interaction in a given medium is equal to the reciprocal of the attenuation coefficient. The distance x in ordinary units can be converted into the dimensionless quantity μx, termed as mean-free-path (mfp). This parameter 'B' is always equal to or greater than unity ($B = 1$; in case narrow beam geometry, interacting material is thin and the photon is assumed to be mono-energetic, otherwise it is greater than unity). Buildup factor has been classified into two categories named as energy absorption buildup factor and exposure buildup factor. The energy absorption buildup factor (EABF) is the buildup factor in which the quantity of interest is the absorbed or deposited energy in the interacting material and the detector response function is that of absorption in the interacting material. Whereas for the exposure buildup factor (EBF) the quantity of interest is the exposure and the detector response function is that of the absorption in air; that is, exposure is assumed to be equivalent to the absorbed dose in air as measured by the nonperturbing detector.

Different methods such as G-P fitting method (Harima et al., 1986), invariant embedding method (Shimizu, 2002; Shimizu et al., 2004), iterative method (Suteau and Chiron, 2005) and Monte Carlo method (Sardari et al., 2009) are available for

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Table 1
Elemental composition of the silicate-samples.

Sample	Symbols	Chemical formula and weight fraction in percentage
Kyanite	S1	Al_2SiO_5; O(49.37), Al(33.30), Si(17.33)
Sodium silicate	S2	Na_2SiO_4; O(39.32), Na(37.67), Si(23.01)
Datolite	S3	$CaBSiO_4(OH)$; H(0.63), B(6.76), O(50.00), Si(17.56), Ca(25.05)
Diopside	S4	$CaMgSi_2O_6$; O(44.33), Mg(11.22), Si(25.94), Ca(18.51)
Slag	S5	$Mg_3Si_4O_{12}H_2$; H(0.53), O(50.62), Mg(19.22), Si(29.62)
Anorthite	S6	$CaAl_2Si_2O_8$; O(46.01), Al(19.40), Si(20.19), Ca(14.41)

Table 2
Physical properties of the samples.

Properties	Kyanite	Sodium silicate	Datolite	Diopside	Slag	Anorthite
Chemical formula	Al_2SiO_5	Na_2SiO_4	$CaBSiO_4(OH)$	$CaMgSi_2O_6$	$Mg_3Si_4O_{12}H_2$	$CaAl_2Si_2O_8$
Density (in g/cm^3)	3.56–3.67	2.30–2.50	2.96–3.00	3.25–3.55	3.20–3.60	2.74–2.76
Molecular-weight (in g)	162.05	138.06	159.98	216.55	379.27	278.21
Hardness (in mohs)	4.0–7.0	6.0–6.5	5.0–5.5	6.0–6.5	6.0–7.0	6.0–6.5
Si content (% by wt.)	17.33	23.01	17.56	25.94	29.62	20.19
Colour	Blue, white, grey, green, black	Colourless, white	Colourless, white	Blue, brown, colourless, green, grey	Grey, brown	Colourless, reddish grey, white

Table 3
Equivalent atomic numbers of silicate samples for incident photon energy range 0.015–15.0 MeV.

Sr. no.	E^a (MeV)	Equivalent atomic number (Z_{eq})					
		Kyanite	Sodium silicate	Datolite	Diopside	Slag	Anorthite
1	1.5E−02	11.31	10.98	13.71	13.59	11.15	13.17
2	2.0E−02	11.34	11.04	13.89	13.70	11.19	13.27
3	3.0E−02	11.39	11.04	14.08	13.83	11.24	13.38
4	4.0E−02	11.40	11.10	14.16	13.88	11.28	13.46
5	5.0E−02	11.43	11.16	14.26	13.98	11.34	13.52
6	6.0E−02	11.43	11.13	14.34	14.08	11.34	13.57
7	8.0E−02	11.39	11.17	14.42	14.05	11.35	13.52
8	1.0E−01	11.58	11.15	14.38	14.12	11.55	13.69
9	1.5E−01	11.98	10.94	14.41	14.43	10.90	13.44
10	2.0E−01	11.50	12.95	14.94	14.48	10.50	14.49
11	3.0E−01	11.50	12.50	14.50	14.50	10.50	14.50
12	4.0E−01	11.50	12.50	14.50	14.50	10.50	14.50
13	5.0E−01	11.50	12.50	14.50	14.50	10.50	14.50
14	6.0E−01	11.50	12.50	14.50	14.50	10.50	14.50
15	8.0E−01	11.50	12.50	14.50	14.50	10.50	14.50
16	1.0E+00	11.50	12.50	14.50	14.50	10.50	14.50
17	1.5E+00	11.50	12.50	14.50	14.50	10.50	14.50
18	2.0E+00	9.79	8.80	12.81	12.83	9.70	9.76
19	3.0E+00	10.37	10.40	12.48	12.51	10.28	12.58
20	4.0E+00	10.69	10.40	11.32	12.23	10.57	11.94
21	5.0E+00	10.62	10.35	11.87	12.44	10.14	11.99
22	6.0E+00	10.92	10.69	11.83	12.06	10.40	11.92
23	8.0E+00	10.42	10.48	11.85	12.39	10.49	12.16
24	1.0E+01	10.63	10.56	11.81	12.13	10.50	11.91
25	1.5E+01	10.61	10.59	11.77	12.27	10.51	12.01

[a] Incident photon energy.

computing buildup factors. It was shown by Shimizu et al. (2004) that by three different approaches (invariant embedding, G-P fitting and Monte Carlo methods) agree well for 18 low-Z materials within small discrepancies. Sakamoto et al. (1988) interpolated buildup factors for compounds/mixtures and reported good agreement with PALLAS code for low-Z materials (discrepancies were within 10%), whereas for high-Z materials discrepancies were found to be as large as 30%. When compared with other available approximations such as Berger, Taylor and three exponential, the geometric progression (G-P) fitting seems to reproduce the buildup factors with better accuracy. American National Standards ANSI/ANS 6.4.3 (American National Standard, 1991) used G-P fitting method and provided buildup factor data 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 with suitable interval up to the penetration depth of 40 mean free path. Harima et al. (1986) have showed that the absolute value of the maximum deviation of exposure buildup factors for water in the