Radiation Parameters for Some TLD Materials in the Energy Range 0.015-15 MeV

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Abstract—The mass energy absorption coefficients (μ_{en}/ρ) and kerma relative to air have been calculated for some TLD materials ($MgSO_4$, Mg_2SiO_4, $NaSO_4$ and $Na_4P_2O_7$) in the energy region 0.015-15 MeV. Also, the energy absorption buildup factors (EABF) have been determined for penetration depth of 40 mean free paths (mfp). The five parameter geometric progression (G-P) fitting approximation has been used for buildup factors. It is observed that the mass energy absorption coefficients and kerma relative to air depend on the photon energy and chemical content. The materials with least equivalent atomic number possess the maximum value of EABF. Also, the energy absorption build up factors are found the highest in intermediate energy whereas the lowest in low- as well as high energies.

Keywords —Energy Absorption Buildup Factors, Kerma, Mass Energy Absorption Coefficients, Penetration Depth.

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1 INTRODUCTION

The mass attenuation coefficients, the mass energy absorption coefficients, kerma, total atomic and electronic cross-sections and effective atomic and electron numbers materi-als are important in several applications of medical physics, nuclear science, radiation physics, radiotherapy, irradiation technology and radiation biology. The absorbed dose in a medium is measured by mass energy absorption coefficient (μ_{en}/ρ). Kerma approximation is applied to photons and neutrons. It is defined as the initial kinetic energy of all secondary charged particles released per unit mass at a point of interest by uncharged radiation.

Various researchers have calculated μ_{en}/ρ theoretically for elements and compounds from 1 keV to 20 MeV [1]. Shakhreet et al. [2] measured μ_{en}/ρ of paraffin, wax and gypsum at 662 keV photon energy. The mass energy absorption coefficients of in Ge doped optical fiber and TLD-100 thermoluminescent dosimeter in photon energy 0.2-20 MeV using Monte Carlo n-particle code version 5 was determined by Hossain and Wargian [3].

The Lambert-Beer law is valid for three conditions name-ly monochromatic rays, thin absorbing material and narrow beam geometry. The correction factor is called as "buildup factor". The modified Lambert-Beer law becomes $I = BI_0 e^{-\mu t}$, where B is the buildup factor [4]. Buildup factors were calculated theoretically for 23 elements, water, air and con-crete at the energy range 0.015-15 MeV up to the penetration depth of 40 mfp by the American Nuclear Socie-ty Standard Committee working group with the G-P fitting method (AN-SI/ANS-6.4.3-1991) [5]. Thermoluminescent dosimeter (TLD) are wide-ly used in many areas such as cancer treatment using radiotherapy, clinical diagnostic radiology, radiotherapy mailed dosime-try, environmental radiation monitoring, industrial applica-tions such as food irradiation and sterilization of health care products, the fields of environmental, industrial and per-sonnel applications [6]. The mass energy absorption coeffi-cients, kerma and buildup factors of the TLD materials can-not be found in standard reference database, but they are necessary for many applications in radiation dosimetry and therapy.

In the present work, the mass energy absorption coefficients were calculated in the energy region 0.015-15 MeV for $MgSO_4$, Mg_2SiO_4, $NaSO_4$ and $Na_4P_2O_7$ thermoluminescent dosimetric materials. The values of μ_{en}/ρ have been taken from the compilation of Hubbell and Seltzer [7]. The kerma relative to air has been computed and reported in the present work. Also, G-P fitting method has been adopted to compute buildup factors in this energy region for penetration depth of 40 mfp for TLD materials.

2 THEORETICAL BACKGROUND AND COMPUTATIONAL METHOD

The mass energy absorption coefficients of materials we-re calculated using the following equation (1):

$$\frac{\mu_{en}}{\rho} = \sum_i w_i \left(\frac{\mu_{en}}{\rho}\right)_i \tag{1}$$

where w_i and $\left(\mu_{en}/\rho\right)_i$ are the weight fraction and the mass energy absorption coefficient of the ith constituent element present in a material.

Kerma can be given by equation (2)

$$K = \frac{\Psi A \mu_{en} dx}{\rho A dx} = \Psi\left(\frac{\mu_{en}}{\rho}\right) \tag{2}$$

where ψ is the energy fluence of mono-energetic photons passing normally through an area A in an absorber. Kerma of a material relative to air can be expressed in the equation (3)

$$K_a = \frac{\left(\mu_{en}/\rho\right)_{TLD}}{\left(\mu_{en}/\rho\right)_{Air}} = \frac{K_{TLD}}{K_{Air}} \tag{3}$$

The equivalent atomic number, Z_{eq} , for a particular material has been calculated by equation (4)

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$$Z_{eq} = \frac{Z_1\left(\log R_2 - \log R\right) + Z_2\left(\log R - \log R_1\right)}{\log R_2 - \log R_1} \qquad (4)$$

where Z_1 and Z_2 are the atomic numbers of elements corresponding to the ratios R_1 and R_2 respectively, $\boldsymbol{R}$ is the ratio for the chosen dosimetric materials at a specific energy.

The buildup factors are estimated by using G-P fitting parameters ($b,\ c,\ a,\ X_k$ *and* d) in the photon energy range 0.015-15 MeV up to 40 mfp given by equation (5) and (6).

$$B\left(E,\ X\right) = 1 + \frac{b-1}{K-1}\left(K^{x} - 1\right) \quad for\ K \neq 1 \qquad (5)$$

$$B\left(E,\ X\right) = 1 + \left(b-1\right)x \quad for\ K = 1 \qquad (6)$$

K is given by equation (7) for $x \leq 40$ mfp.

$$K\left(E,\ X\right) = cx^{a} + d\,\frac{\tanh\left(x/X_k - 2\right) - \tanh\left(-2\right)}{1 - \tanh\left(-2\right)} \qquad (7)$$

where x is the penetration depth in mfp, $b,\ c,\ a,\ X_k$ *and* d are the G-P fitting parameters and b is the value of buildup factor at 1 mfp. The variation of $K\left(E,\ X\right)$ with penetration represents the change in the shape of the spectrum from that at 1 mfp which determined the value of b.

3 RESULTS AND DISCUSSIONS

The theoretical values of μ_{en}/ρ are listed in Table 1. It is clear from Table 1 that the mass energy absorption coefficients depend on the photon energy and chemical content and decrease with increasing photon energy. The energy dependence of kerma relative to air is shown from Table 2. It is clearly seen that kerma depends on the chemical content and is highest at about 0.05-0.1 MeV. The equivalent atomic numbers and the energy absorption buildup factors of TLD materials are given in Table 3 and in Figs. 1-4. As seen from Figs. 1-4, EABF in the energy region of 0.015-15 MeV is always greater than one. The energy absorption buildup factors are the highest in intermediate energy whereas the lowest in low- as well as high energies. As can be seen Figs. 1-4, the energy absorption buildup factors of TLD materials increases with the increasing photon energy, but, then starts decrease with increase in photon energy. EABF depend on chemical composition of TLD materials and shifts to higher photon energy with the increase in penetration depth.

4 CONCLUSION

We have calculated the mass energy absorption coefficients and kerma relative to air of the TLD materials for photon energies 0.015-15 MeV. Also, the energy absorption buildup factor of the TLD materials up to 40 mfp penetration depth was determined by G-P method. The energy absorption buildup factor is less when the penetration depth is least and higher equivalent atomic number of the interacting material. The results of this study can be used for various applications such as radiation dosimetry and medical shielding used of TLD materials.

TABLE 1
The mass energy absorption coefficients (μ_{en}/ρ , cm^2/g) for some TLD materials

Energy (MeV)	$MgSO_4$	Mg_2SiO_4	$NaSO_4$	$Na_4P_2O_7$
0.015	5.953	4.705	5.642	4.889
0.02	2.481	1.935	2.351	2.019
0.03	0.712	0.548	0.675	0.575
0.04	0.296	0.227	0.281	0.238
0.05	0.153	0.119	0.146	0.124
0.06	0.093	0.074	0.089	0.077
0.08	0.049	0.041	0.047	0.042
0.1	0.036	0.032	0.035	0.032
0.15	0.028	0.027	0.028	0.027
0.2	0.028	0.028	0.028	0.027
0.3	0.029	0.029	0.029	0.028
0.4	0.030	0.029	0.029	0.029
0.5	0.030	0.030	0.030	0.029
0.6	0.030	0.029	0.029	0.029
0.8	0.029	0.029	0.029	0.028
1	0.028	0.028	0.028	0.027
1.5	0.025	0.025	0.025	0.025
2	0.023	0.023	0.023	0.023
3	0.021	0.021	0.021	0.020
4	0.019	0.019	0.019	0.019
5	0.018	0.018	0.018	0.018
6	0.017	0.017	0.017	0.017
8	0.017	0.016	0.016	0.016
10	0.016	0.016	0.016	0.016
15	0.016	0.015	0.015	0.015

TABLE 2
Kerma relative to air for some TLD materials

Energy (MeV)	$MgSO_4$	Mg_2SiO_4	$NaSO_4$	$Na_4P_2O_7$
0.015	4.463	3.527	4.229	3.665
0.02	4.604	3.591	4.363	3.747
0.03	4.632	3.565	4.392	3.741
0.04	4.332	3.322	4.112	3.483
0.05	3.734	2.904	3.563	3.026
0.06	3.058	2.433	2.927	2.532
0.08	2.036	1.703	1.953	1.745
0.1	1.548	1.376	1.505	1.376
0.15	1.122	1.082	1.122	1.082
0.2	1.048	1.048	1.048	1.010
0.3	1.010	1.010	1.010	0.975
0.4	1.017	0.983	0.983	0.983
0.5	1.011	1.011	1.011	0.978
0.6	1.016	0.982	0.982	0.982
0.8	1.006	1.006	1.006	0.972
1	1.004	1.004	1.004	0.968
1.5	0.982	0.982	0.982	0.982
2	0.981	0.981	0.981	0.981
3	1.021	1.021	1.021	0.972
4	1.016	1.016	1.016	1.016
5	1.034	1.034	1.034	1.034
6	1.032	1.032	1.032	1.032
8	1.115	1.049	1.049	1.049
10	1.103	1.103	1.103	1.103
15	1.183	1.109	1.109	1.109

TABLE 3
Equivalent atomic numbers of for some TLD materials

Energy (MeV)	$MgSO_4$	Mg_2SiO_4	$NaSO_4$	$Na_4P_2O_7$
0.015	21.78	19.45	21.59	21.28
0.02	21.65	19.35	21.40	21.12
0.03	20.83	18.83	20.57	20.53
0.04	19.80	18.25	19.53	19.79
0.05	18.96	17.79	18.62	19.16
0.06	18.25	17.46	17.92	18.68
0.08	17.53	17.02	17.22	18.18
0.1	17.11	16.81	16.80	17.97
0.15	16.86	16.73	16.45	17.32
0.2	16.75	16.68	16.44	17.69
0.3	16.59	16.65	16.40	17.60
0.4	16.63	16.62	16.35	17.62
0.5	16.63	16.61	16.34	17.63
0.6	16.62	16.61	16.34	17.60
0.8	16.60	16.61	16.33	17.61
1	16.63	16.60	16.34	17.60
1.5	16.62	16.62	16.35	17.61
2	16.62	16.61	16.37	17.60
3	16.67	16.65	16.40	17.65
4	16.72	16.69	16.45	17.72
5	16.81	16.73	16.48	17.72
6	16.84	16.74	16.57	17.78
8	16.96	16.84	16.70	17.87
10	17.07	16.88	16.74	17.96
15	17.21	16.99	16.89	18.08

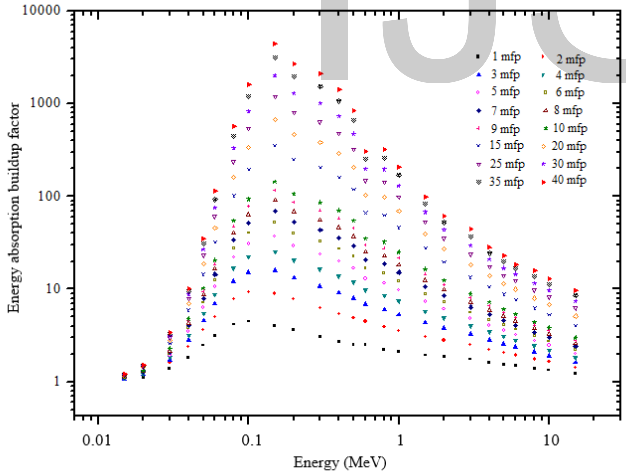

Fig. 1. EABF for MgSO4 in the energy range 0.015-15 MeV up to 40 mfp

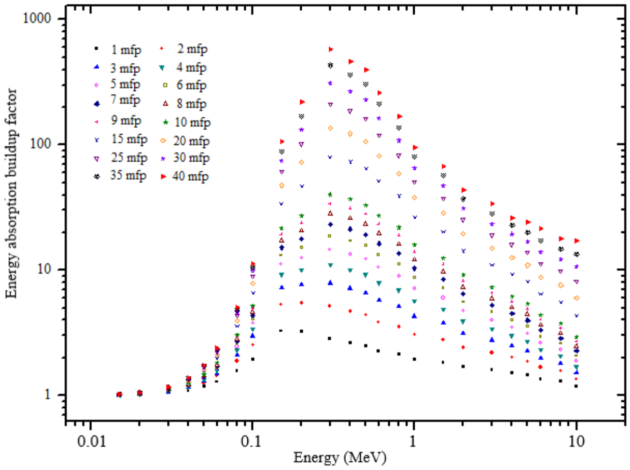

Fig. 2. EABF for Mg2SiO4 in the energy range 0.015-15 MeV up to 40 mfp

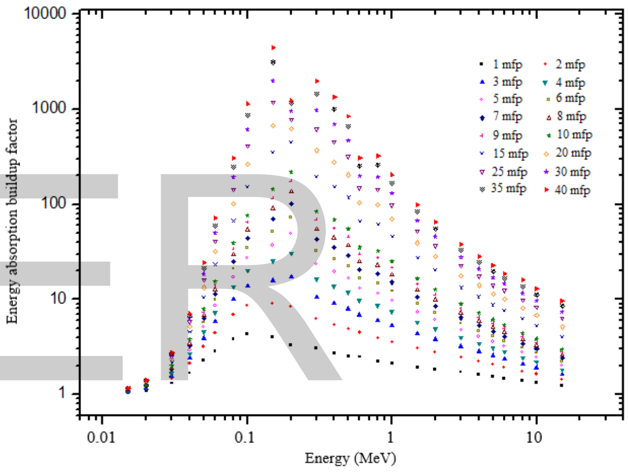

Fig. 3. EABF for NaSO4 in the energy range 0.015-15 MeV up to 40 mfp

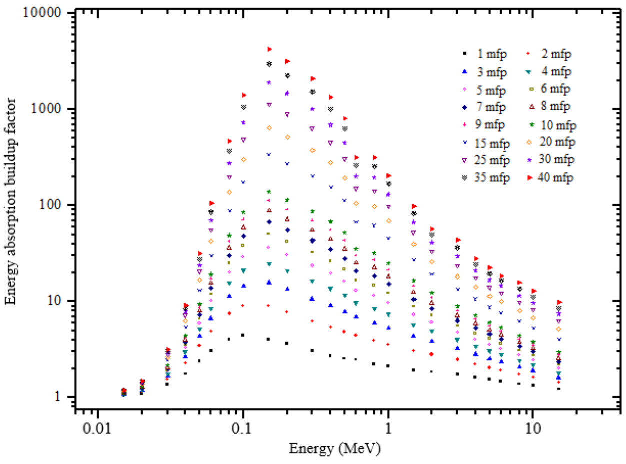

Fig. 4. EABF for Na4P2O7 in the energy range 0.015-15 MeV up to 40 mfp

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