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Full Length Research Paper

A semi-empirical approach to the geometric progression (GP) fitting approximation in estimating photon buildup factor in soft tissue, water, and dosimetric materials

D. Sardari[1] and M. Kurudirek[2]*

[1]Faculty of Engineering, Science and Research Branch, Islamic Azad University, P. O. Box 14515-775, Tehran, Iran.
[2]Department of Physics, Faculty of Science, Ataturk University, 25240, Erzurum, Turkey.

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Photon buildup factors for soft tissue, water, and dosimetric materials have been computed in the energy range of 0.2 to 2 MeV using geometric progression (GP) fitting approximation. The results for soft tissue and water have been compared with the values obtained through Monte Carlo code MCNP4C. Data obtained from GP fitting method quite well obey a semi empirical relation which is a function of penetration depth, Compton scattering and energy absorption cross section. With the help of this semi-empirical approximation, buildup factors for gamma and X-rays in soft tissue, water, and dosimetric materials consisting of elements Hydrogen (H), Carbon (C), Nitrogen (N) and Oxygen (O), can be easily estimated in the energy range of 0.2 to 2 MeV up to penetration depths of 10 mfp.

Key words: Buildup factor, geometric progression (GP) fitting method, Monte Carlo method, radiation shielding.

INTRODUCTION

Photon buildup arises from the collided part of the incident beam and brings up an undesired situation faced by radiation physicists, oncologists, and engineers while designing the shield or estimating the absorbed dose. In the medical and biological context, gamma ray buildup factor is of importance in estimating distribution of photon flux and in calculation of radiation dose received by the biological molecules, in addition to the importance of knowledge on other photon interaction parameters such as mass attenuation coefficients and effective atomic numbers in biological materials (Chilton et al., 1984; Kurudirek and Ozdemir, 2011). The knowledge about how radiation interacts with matter, especially with the human body is of importance because when photons enter the medium (body), they degrade their energy and buildup in the medium, giving rise to secondary radiation which can be estimated by the 'buildup factor' (Sidhu et al., 2000a). Up till now, studies regarding photon buildup factors in different materials have been widely made using the well-known methods that is, geometric progression (GP) fitting method, invariant embedding (IE) method, generalized feed-forward neural network (GFFNN), and Monte Carlo N-Particle (MCNP) codes (Singh et al., 2008; Manohara et al., 2010; Sidhu et al., 2000a; Sardari and Baradaran, 2010; Singh et al., 2010; Mann et al., 2012; Mann and Sidhu, 2012; Mann et al., 2012; Sakamoto and Tanaka, 1988; Shimizu, 2002; Shimizu et al., 2004; Harima et al., 1986; Kucuk, 2010). However, there is almost no study based on applying a semi-empirical approach to the data obtained through five parameter GP fitting method. This prompted us to focus on this study. Recently, Sardari and Baradaran (2010) developed a new relationship estimating buildup factor as a function of penetration depth, Compton scattering, and energy absorption cross sections (Sardari and Baradaran, 2010). This new equation estimates buildup factor with 5% dethroughtion compared with the existing data. In the present study, we applied the semi-empirical approach which is developed by one of the authors

*Corresponding author. E-mail: mkurudirek@gmail.com. Tel: +90 442 2314167. Fax: +90 442 2360948.

recently (Sardari and Baradaran, 2010) to the energy absorption buildup factor data obtained by GP fitting method for soft tissue, water, and Hydrogen (H), Carbon (C), Nitrogen (N) and Oxygen (O) based dosimetric materials namely alanine, gafchromic sensor (GS), radiochromic dye film nylon based (RDF:NB), Tissue-equivalent gas-methane based (TEG:MB), and Tissue-equivalent gas-propane based (TEG:PB) for the first time. Results are presented in tabular as well as in graphical forms. The chemical composition data of dosimetric materials were taken from ICRU Report 44 (1989). Also, the chemical composition data of soft tissue were taken from previous studies (Sardari et al., 2009; Wilson, 1946).

COMPUTATIONAL WORK

GP fitting method

To calculate the buildup factors, the GP fitting parameters were obtained by the method of interpolation from the equivalent atomic number (Z_{eq}). Computations are illustrated step by step as follows:

a) Calculation of the equivalent atomic number, Z_{eq}, ,
b) Calculation of GP fitting parameters,
c) Calculation of energy absorption buildup factors.

At the first step, the equivalent atomic number, Z_{eq} for a particular material has been calculated by matching the ratio, $(\mu/\rho)_{Compton}/(\mu/\rho)_{Total}$, of that material at a specific energy with the corresponding ratio of an element at the same energy. Thus, firstly the Compton partial mass attenuation coefficient, $(\mu/\rho)_{Compton}$, and the total mass attenuation coefficients, $(\mu/\rho)_{Total}$, were obtained for the elements of $Z=4-40$ and for the chosen materials in the energy region 0.015 to 15 MeV, using the WinXCom computer program (Gerward et al., 2001a; 2004b) [initially developed as XCOM (Berger and Hubbell, 1999)]. For the interpolation of Z_{eq} for which the ratio $(\mu/\rho)_{Compton}/(\mu/\rho)_{Total}$ lies between two successive ratios of elements, the following formula has been employed (Sidhu et al., 1999b):

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

Where Z_1 and Z_2 are the atomic numbers of elements corresponding to the ratios R_1 and R_2, respectively, R is the ratio for the material at a specific energy.

At the second step, to calculate the GP fitting parameters, a similar interpolation procedure was adopted as in the case of the equivalent atomic number. The GP fitting parameters for elements were taken from the ANSI/ANS-6.4.3 (ANSI/ANS, 1991) standard reference database which provides the GP fitting parameters for elements from beryllium to iron in the energy region 0.015 to 15 MeV up to 40 mfp.

At the final step, these parameters were used to calculate the energy absorption buildup factors from the GP fitting formula (Harima et al., 1986):

$$B(E,X)=1+\frac{b-1}{K-1}(K^{x}-1) \quad \text{for } K\neq 1 \quad (2)$$

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

Where,

$$K(E,x)=cx^{a}+d\,\frac{\tanh(x/X_k-2)-\tanh(-2)}{1-\tanh(-2)} \quad \text{for } x\leq 40mfp \quad (4)$$

Where E is the incident photon energy, X is the penetration depth in mfp, a,b,c,d and X_k are the GP fitting parameters, and b is the value of buildup factor at 1 mfp. The parameter K represents the photon dose multiplication and the change in the shape of the spectrum.

Semi-empirical approach

The MCNP values of buildup factors for the soft tissue and water was taken from previous study for comparison (Sardari and Baradaran, 2010). The following semi-empirical relationship was used to describe the variations of buildup factor as a function of energy absorption cross sections and penetration depth (Sardari and Baradaran, 2010):

$$B=\left(1+a\mu r\frac{\sum s}{\sum a}\right)^{b} \quad (1)$$

Where '*a*' and '*b*' are parameters to be found so that the results of Equation 1 fit to the data obtained from GP fitting method. The following relationship was defined for ORIGIN software with a given set of *B* and *X* as input data:

$$B=(1+aX)^{b} \quad (2)$$

For each set of data at specific photon energies, ORIGIN computed the best quantity for '*a*' and '*b*' parameters. For detailed explanations on the semi-empirical relation used in the present study, we may refer to the previous study in which the use of semi empirical relation is explained in detail (Sardari and Baradaran, 2010).

RESULTS AND DISCUSSION

The ratio of macroscopic scattering to absorption cross sections for materials of interest in dosimetry are given in Table 1. These values were further used to fit buildup factor data as shown in X-axis of each graph. One should note that beyond 2 MeV the ratios are more or less the same for the given H, C, N, O based dosimetric materials. Table 2 lists the available buildup factor data obtained by different methods for water at different energies for different penetration depths. Variations of photon buildup factors as a function of energy absorption cross section and penetration depth was given for the

Table 1. Scattering to energy absorption cross section ratios for some dosimetric materials.

Energy (MeV)	∑s/∑a (Ratio of scattering to energy absorption cross section)				
	Alanine	GS	RDF:NB	TEG:MB	TEG:PB
0.2	3.086	3.227	3.272	3.448	3.452
0.3	2.718	2.718	2.718	2.717	2.717
0.4	2.232	2.234	2.234	2.232	2.233
0.5	1.931	1.930	1.930	1.930	1.930
0.6	1.722	1.723	1.723	1.723	1.723
0.8	1.455	1.457	1.457	1.455	1.456
1	1.274	1.274	1.274	1.274	1.274
2	0.873	0.874	0.874	0.873	0.874

Table 2. Available buildup factor data obtained by different methods for water at different energies.

Energy (MeV)	Buildup factor (1 mfp)						
	MCNP	GP fitting method (ANSI)	Jaeger	Schaeffer	Chilton	Shultis	Kucuk
0.2	3.53	3.42			3.42	3.42	3.41
0.3	2.97	2.85					2.86
0.4	2.68	2.61					2.58
0.5	2.61	2.44	2.56	2.52	2.45	2.44	2.44
0.6	2.41	2.33					2.34
0.8	2.17	2.17					2.18
1	2.14	2.08	2.10	2.13	2.08	2.08	2.07
2	1.71	1.83	1.73	1.83	1.83	1.83	1.81
Energy (MeV)	**Buildup factor (2 mfp)**						
0.2	7.44	8.31			8.22	8.31	8.26
0.3	6.35	6.30					6.34
0.4	5.45	5.44					5.49
0.5	4.95	4.88	5.10	5.14	4.87	4.88	4.86
0.6	4.60	4.49					4.46
0.8	3.89	3.96					3.91
1	3.60	3.62	3.58	3.71	3.62	3.62	3.55
2	2.30	2.81	2.55	2.77	2.82	2.81	2.82
Energy (MeV)	**Buildup factor (4 mfp)**						
0.2	25.00	27.00			26.40	27.00	27.00
0.3	20.20	19.30					19.30
0.4	15.80	15.30					15.30
0.5	12.50	12.80	13.50	14.30	12.70	12.80	12.90
0.6	11.30	11.20					11.40
0.8	8.90	9.00					9.05
1	7.21	7.68	7.42	7.68	7.66	7.68	7.59
2	4.75	4.98	4.40	4.88	4.99	4.98	5.06
Energy (MeV)	**Buildup factor (7 mfp)**						
0.2	66.00	88.50			86.20	88.50	88.50
0.3	52.50	57.80					57.80
0.4	40.50	41.90					41.90
0.5	31.00	32.70	35.00	38.80	32.20	32.70	32.60
0.6	25.20	26.70					27.00
0.8	18.20	19.80					19.70
1	14.50	15.80	15.20	16.20	15.70	15.80	15.50
2	6.36	8.65	7.51	8.46	8.66	8.65	8.73

Table 2. Contd.

Energy (MeV)	Buildup factor (10 mfp)						
0.2	157.00	208.00			202.00	208.00	208.00
0.3	107.00	126.00					126.00
0.4	81.50	85.00					84.90
0.5	60.60	62.90	68.10	77.60	61.80	62.90	62.70
0.6	47.90	49.30					49.70
0.8	32.60	34.20					34.00
1	23.00	26.10	25.10	27.10	26.00	26.10	25.60
2	9.15	12.70	10.90	12.40	12.70	12.70	12.40

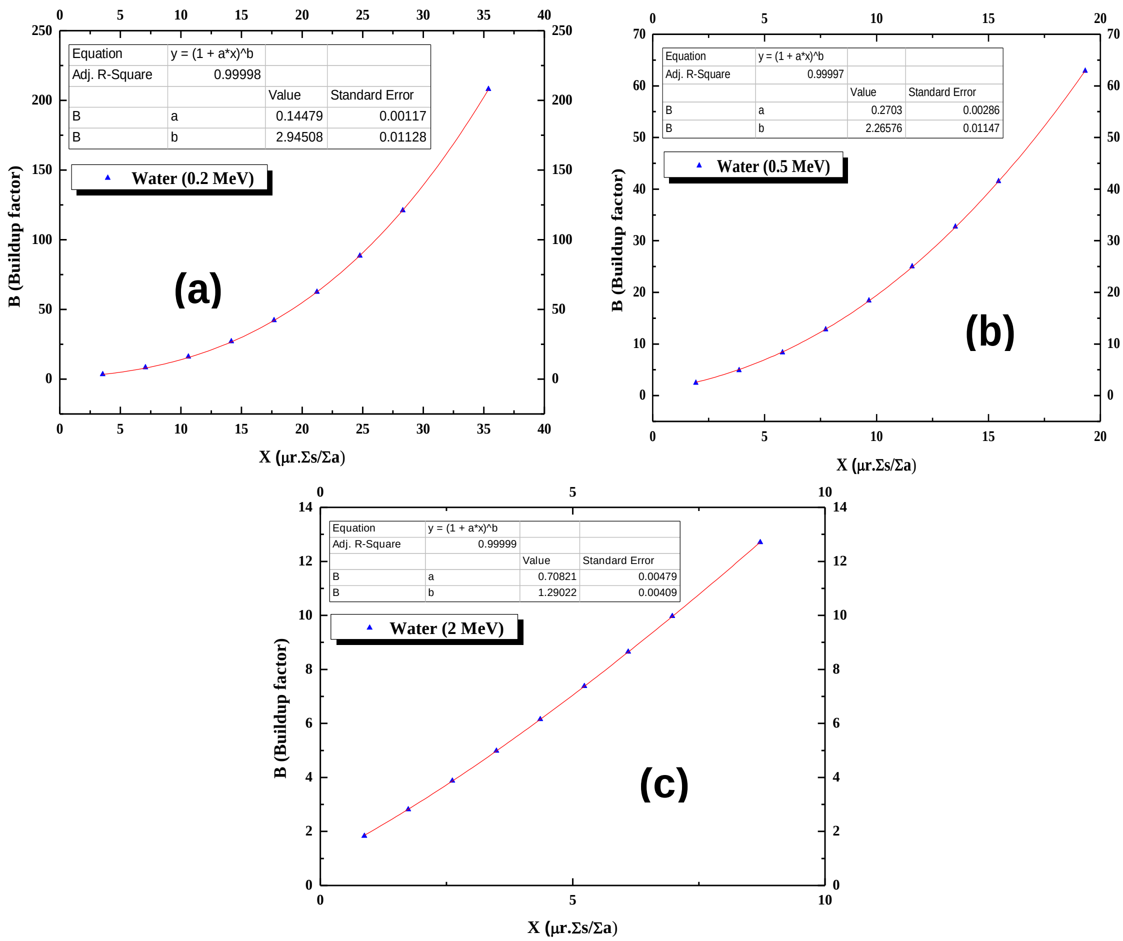

Figure 1. Photon buildup factor versus X (μr.Σs/Σa) variant for water at (a), 0.2, (b), 0.5 and (c) 2 MeV.

soft tissue and water as well as dosimetric materials in Figures 1 to 7. It has been observed from Figures 1 to 7 that the semi-empirical relationships are consistent with the fitted data obtained from GP fitting method. In each graph, the best fit coefficients are given through the R-square values and standard errors. From the values of R^2 and standard errors, it can be concluded that the present semi-empirical approximation could yield accurate resultsof buildup factor data obtained by GP fitting for the given materials namely soft tissue, water, and H, C, N, O based dosimetric materials namely GS, RDF:NB, TEG:MB, and TEG:PB. It should be mentioned that the ANSI/ANS-6.4.3 (1991) standard has been administratively withdrawn, but work is still in progress for updating this standard (Ryman et al., 2008). The relative differences in buildup factors between the MCNP code

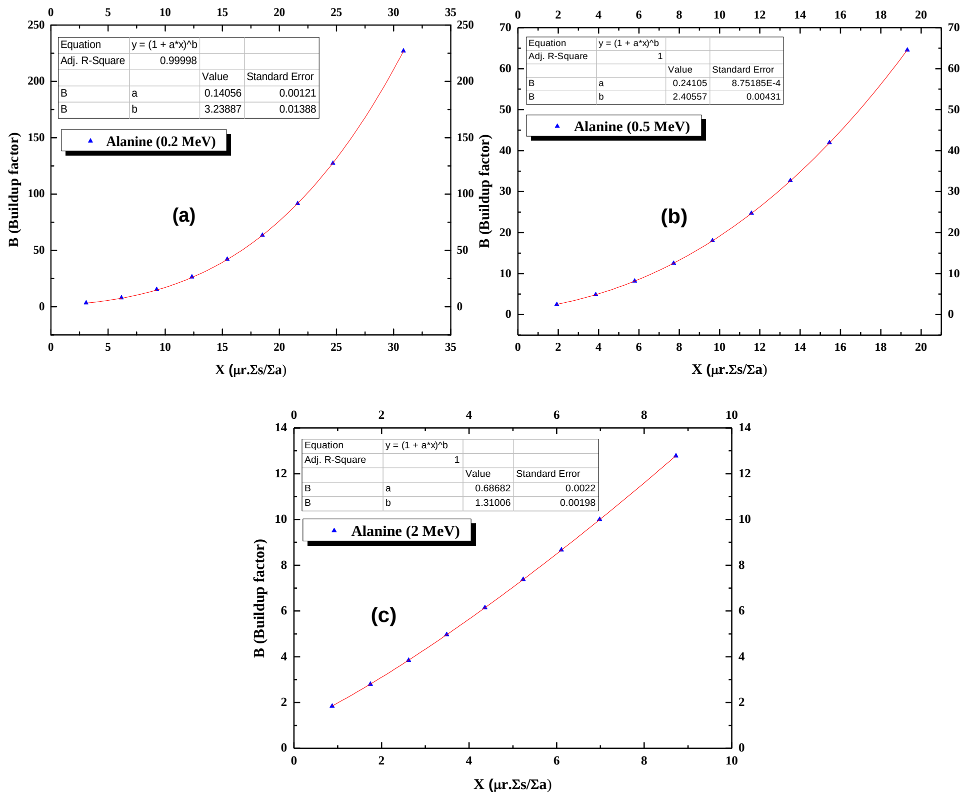

Figure 2. Photon buildup factor versus X (μr.Σs/Σa) variant for alanine at (a), 0.2, (b), 0.5 and (c), 2 MeV.

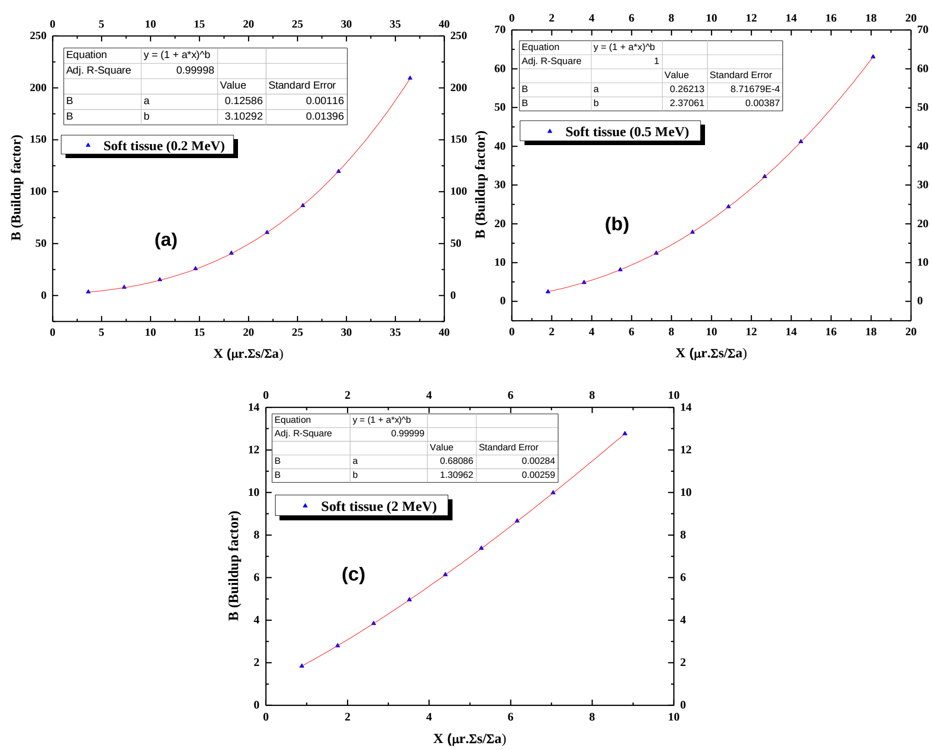

Figure 3. Photon buildup factor versus X (μr.Σs/Σa) variant for soft tissue at (a), 0.2, (b), 0.5 and (c), 2 MeV.

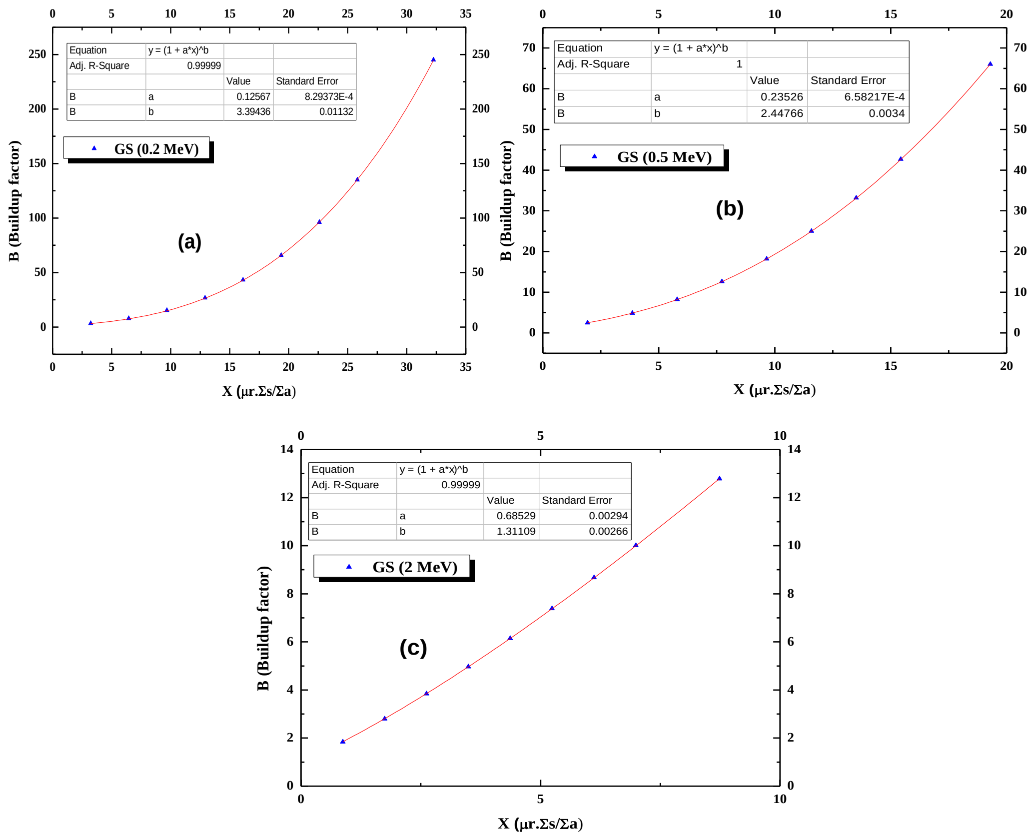

Figure 4. Photon buildup factor versus X (μr.Σs/Σa) variant for GS at (a), 0.2, (b), 0.5 and (c), 2 MeV.

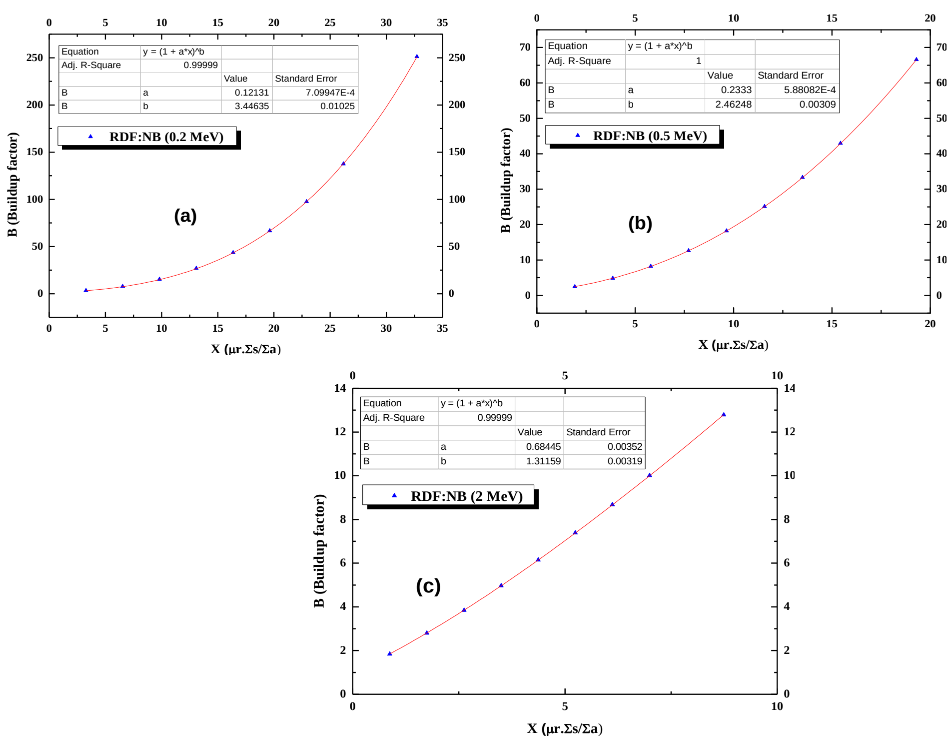

Figure 5. Photon buildup factor versus X (μr.Σs/Σa) variant for RDF:NB at (a), 0.2, (b), 0.5.

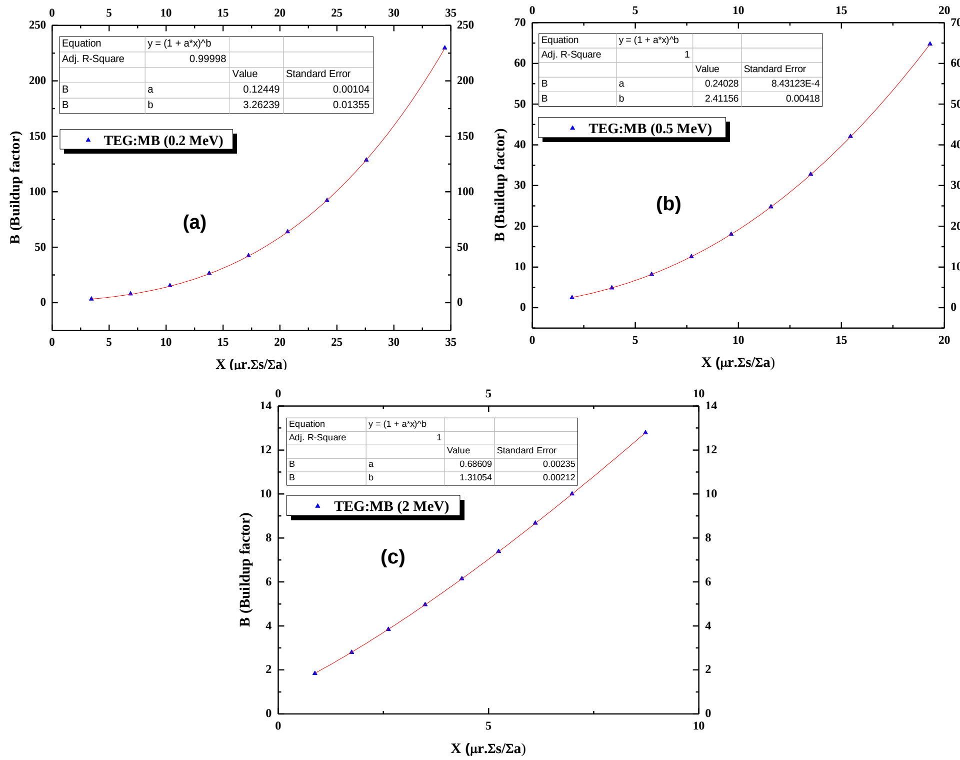

Figure 6. Photon buildup factor versus X (μr.Σs/Σa) variant for TEG:MB at (a), 0.2, (b), 0.5 and (c), 2 MeV.

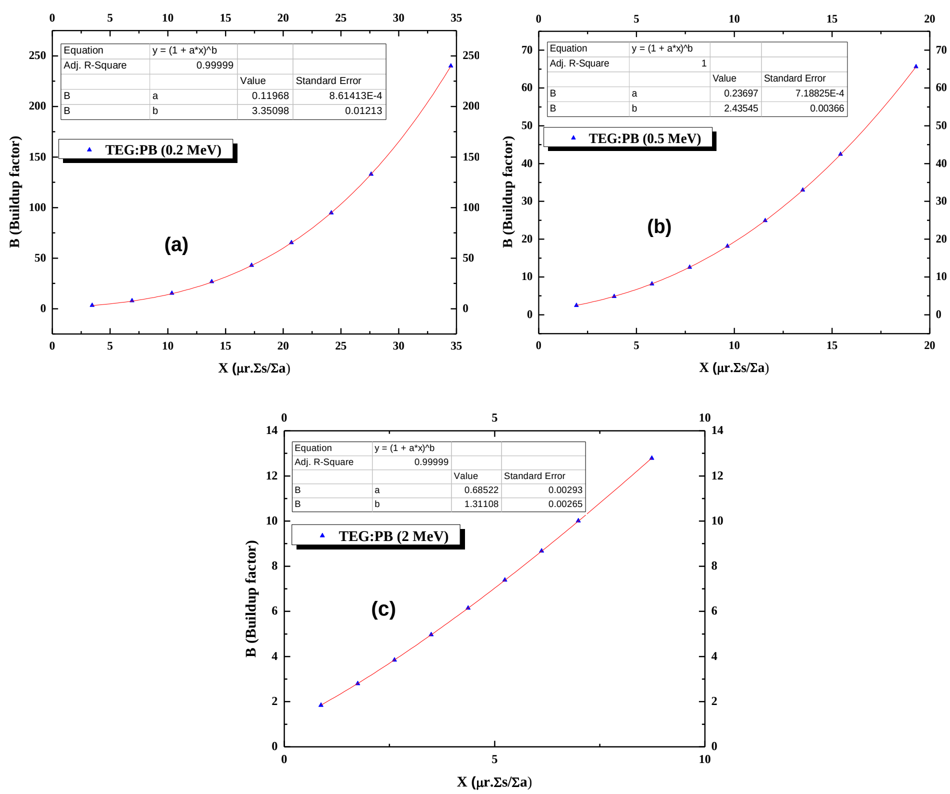

Figure 7. Photon buildup factor versus X (μr.Σs/Σa) variant for TEG:PB at (a), 0.2, (b), 0.5 and (c), 2 MeV.and (c), 2 MeV.

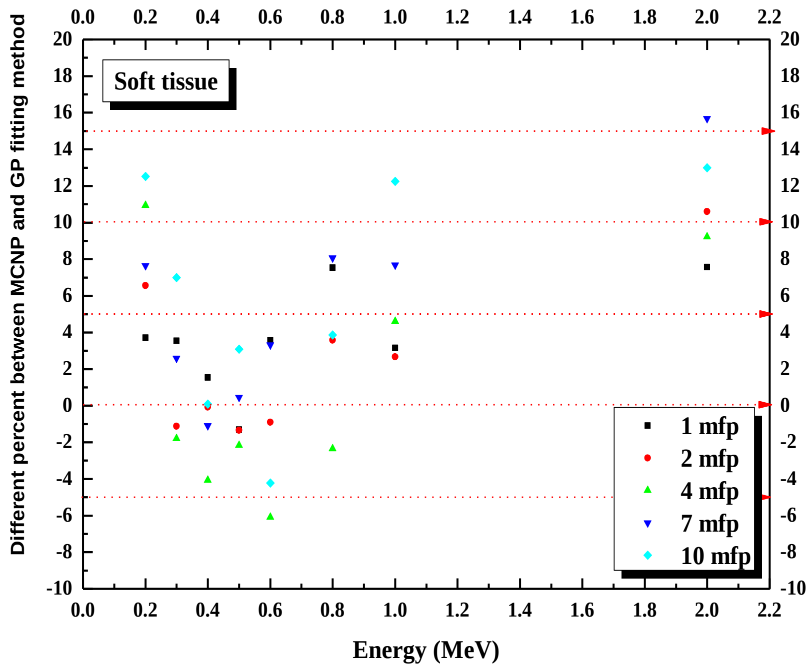

Figure 8. Relative difference (%) between the buildup factor values for soft tissue obtained through MCNP and GP fitting approximation.

and GP fitting method are shown in Figure 8 for soft tissue. It has been observed that except for the penetration depths of more than 7 mfp and photon energy values more than 1 MeV, there is a good agreement between MCNP and GP fitting methods.

In the present study, a semi-empirical relationship was applied to the buildup factor data obtained from GP fitting method for the first time. The results are quite satisfactory for the soft tissue, water, and dosimetric materials such as GS, RDF:NB, TEG:MB, and TEG:PB. It was concluded that for lower penetration depths (< 10 mfp) and photon energies lower than 2 MeV, the presented semi-empirical approximation can be used as a safe tool to estimate buildup factors for gamma and X-rays in soft tissue, water, and dosimetric materials consisting of H, O, N and C.

REFERENCES

ANSI/ANS-6.4.3. (1991). Gamma ray attenuation coefficient and buildup factors for engineering materials American Nuclear Society, La Grange Park, Illinois.

Berger MJ, Hubbell JH (1999). XCOM: Photon Cross Sections Database. Web Version 1.2, available at http://physics.nist.gov/xcom, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA, August 1999. Originally published as NBSIR 87-3597, XCOM: Photon Cross Sections on a Personal Computer (July 1987) 1987-1999.

Chilton AB, Shultis JK, Faw R (1984). Principle of Radiation Shielding. Prentice Hall, Englewood Cliffs, New Jersey.

Gerward L, Guilbert N, Jensen KB, Levring H (2001a). X-ray absorption in matter. Reengineering XCOM Radiat. Phys. Chem. 60:23-24.

Gerward L, Guilbert N, Jensen KB, Levring H (2004b). WinXCom- a program for calculating X-ray attenuation coefficients Radiat. Phys. Chem. 71:653-654.

Harima Y, Sakamoto Y, Tanaka S, Kawai M (1986). Validity of the geometric-progression formula in approximating gamma ray build up factors. Nucl. Sci. Eng. 94:24-35.

ICRU (1989). Tissue Substitutes in Radiation Dosimetry and Measurement, Report 44 of the International Commission on Radiation Units and Measurements (Bethesda, MD).

Kucuk N (2010). Computation of gamma-ray exposure buildup factors up to 10 mfp using generalized feed-forward neural network. Expert Syst. Appl. 37:3762-3767.

Kurudirek M, Ozdemir Y (2011). A comprehensive study on energy absorption and exposure buildup factors for some essential amino acids, fatty acids and carbohydrates in the energy range 0.015–15 MeV up to 40 mean free path. Nucl. Instr. Meth. B 269:7-19.

Mann KS, Singla J, Kumar V, Sidhu GS (2012). Investigations of mass attenuation coefficients and exposure buildup factors of some low-Z building materials. Ann. Nucl. Energy 43:157-166.

Mann KS, Sidhu GS (2012). Verification of some low-Z silicates as gamma-ray shielding materials. Ann. Nucl. Energy 40:241-252.

Mann KS, Kurudirek M, Sidhu GS (2012). Verification of dosimetric materials to be used as tissue-substitutes in radiological diagnosis. Appl. Radiat. Isot. 70:681-691.

Manohara SR, Hanagodimath SM, Gerward L (2010). Energy absorption buildup factors for thermoluminescent dosimetric materials and their tissue equivalence. Rad. Phys. Chem. 79:575-582.

Ryman JC, Alpan FA, Durani LA, Eckerman KF, Faw RE, Ruggieri L, Sanders CE, Xu XG (2008). Revision of ANSI/ANS-6.4.3. Trans. Am. Nucl. Soc. 99:613-614.

Sakamoto Y, Tanaka S (1988). Interpolation of gamma ray buildup factors for point isotropic source with respect to atomic number. Nucl. Sci. Eng. 100:33-42.

Sardari D, Baradaran S (2010). Semi-empirical relationship for photon buildup factor in soft tissue and water Rad. Prot. Dosim. 142:209-212.

Sardari D, Abbaspour A, Baradaran S, Babapour F (2009). Estimation of gamma- and X-ray photons buildup factor in soft tissue with Monte Carlo method. Appl. Rad. Isot. 67:1438-1440.

Shimizu A (2002). Calculations 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. 39:477-486.

Shimizu A, Onda T, Sakamoto Y (2004). Calculations of gamma-ray buildup factors up to depths of 100 mfp by the method of invariant embedding, (III) generation of an improved data set. J. Nucl. Sci. Technol. 41:413-424.

Sidhu GS, Singh SP, Mudahar SG (2000a). A study of energy and effective atomic number dependence of the exposure buildup factors in biological materials. J. Radiol. Prot. 20:53-68.

Sidhu GS, Singh PS, Mudahar GS (1999b). Energy absorption buildup factor studies in biological samples. Rad. Prot. Dosim. 86:207-216.

Singh S, Ghumman SS, Singh C, Singh TK, Mudahar SG (2010). Buildup of gamma ray photons in flyash concretes: A study. Ann. Nucl. Energy 37:681-684.

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

Wilson R (1946). Radiological use of fast protons. Radiology 52:487-491.