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## Variation of Energy Absorption and Exposure Build-up Factor Dependence with Effective Atomic Number and Electron Density of Amino Acids

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Goal of the present work is the dose distribution of biological material by X-ray and  $\gamma$ -photon at 0.015 to 15 MeV up to penetration depth 40 MFP. The mass attenuation coefficient, effective atomic number ( $Z_{\text{eff}}$ ), effective electron density ( $N_{\text{eff}}$ ) were calculated at 1 keV to 100 GeV and energy absorption build-up factor (EABF) and energy absorption build-up factor (EBF) at 0.015 to 15 MeV upto the penetration depth 40 mfp of selected unnatural amino acids are N-acetyl-L-tryptophan, N-acetyl-tyrosine, D-tryptophan, N-acetyl glutamic acid, D-phenylalanine, D-threonine. The build-up factors obtained with the function of the incident photon energy penetration depth, effective atomic number ( $Z_{\text{eff}}$ ) and effective electron density ( $N_{\text{eff}}$ ). The value of EABF and EBF maximum their Compton scattering was the main interaction process. The EABF and EBF versus  $Z_{\text{eff}}$  and  $N_{\text{eff}}$  at 0.015, 0.02, 0.03, 0.04, 0.05, 0.06, 0.08, 0.1, 0.15 MeV shows  $Z_{\text{eff}}$  and  $N_{\text{eff}}$  enhancing the value of EABF and EBF decreases.  $Z_{\text{eff}}$  and  $N_{\text{eff}}$  parameter are dependent on incident photon energy.

**Keywords:** Energy absorption build-up factor, Energy absorption build-up factor, Geometrical progression method, Amino acids.

### INTRODUCTION

The study of  $\gamma$ -radiation interaction with matter having changes in physical and chemical properties are very important role in shielding because radiation is harmful for living organisms as reported by Manohara *et al.* [1]. The basic quantities mass attenuation coefficient, effective atomic number ( $Z_{\text{eff}}$ ), *i.e.*, effective electron density ( $N_{\text{eff}}$ ), energy absorption build-up factor (EABF) and exposure build-up factor (EBF) studied the interaction of X-ray and gamma photon with matter were used in the medical, radiation dosimetry, radiation protection, radiation biophysics and biosensor [2,3]. There are two types of build-up factors: (a) Energy absorption build-up factor (b) exposure build-up factor. The energy absorption build-up 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 as reported by Kurudirek *et al.* [4]. Exposure build factor is the ratio of density due to total flux and density due to uncoiled flux. The study of energy absorption and exposure build-up factor of soil, biological material, space materials, tissue, teeth, space sample, concrete fly ash and amino acid discussed [5-8]. Different methods were used by various research groups to compute the build-up factors geometrical progression (G-P) fitting method as suggested by Harima *et al.* [9], invariant embedding method as suggested by Sakamaoto *et al.* [10] and

Shimizu *et al.* [11], iterative method as suggested by Suteau & Chiron *et al.* [12] and Monte Carlo method as suggested by Sardari *et al.* [13]. Study of build-up factor help to detect or knowledge of scattered photon, radiation interacts with human body and dose level to radiotherapy patients [14]. The status of  $\gamma$ -ray shielding calculation for build-up factor comparison with American National Standards (ANS) and Atomic Energy Society of Japan (AESJ) standard database and G-P fitting method up to penetration depth upto 100 MFP as suggested by Sakamoto *et al.* [15].

The amino acids are a basic building block of living organism. The human body uses 20 different amino acids for building peptides and proteins. The present study involves the mass attenuation coefficient, effective atomic number; effective electron density calculated in the wide energy region 1 keV to 100 GeV and energy absorption build-up factor and exposure build-up factor at 0.015 to 15 MeV up to different penetration depth 40 mfp. This study reflects the dose distribution in the biological material by X-ray and gamma photon at 0.015 to 15 MeV up to different penetration depth 40 MFP.

### EXPERIMENTAL

The mass attenuation coefficients of selected amino acid were calculated by using NIST XCOM database for 1 keV to 100 GeV.

The effective atomic number calculated by

$$Z_{\text{eff}} = \frac{\sigma_t}{\sigma_e} \quad (1)$$

Firstly, we calculate the total attenuation cross section and electronic cross section.

Total attenuation cross section

$$\sigma_t = \frac{1}{N_A} \sum f_i A_i (\mu_m)_i \quad (2)$$

where  $N_A$  is the Avogadro constant,  $\mu_m$  is the mass attenuation coefficient and  $A_i$  is the molar mass of the sample.  $\sum f_i = 1$  ( $f_i$  is the mole fraction).

**Electronic cross section:**

$$\begin{aligned} \sigma_e &= \frac{1}{N_A} \sum_i \frac{f_i A_i}{Z_i} (\mu_m)_i \\ &= \frac{\sigma_t}{\sum Z_{\text{eff}}} \end{aligned} \quad (3)$$

Electronic cross section is the ratio of total attenuation cross section and effective atomic number.

**Effective electron density:** Effective electron density shows that the number of electron per unit mass.

$$N_{\text{eff}} = \left( \frac{N_A}{A_{\text{eff}}} \right) \times Z_{\text{eff}} \quad (4)$$

where  $A_{\text{eff}}$  is effective atomic mass also known as the ratio of atomic weight and total number of atom

**Computation of energy absorption build-up and exposure build-up factor:** The computation of EABF using G-P fitting method and equivalence atomic number of selected amino acids. There are three steps:

- Calculate equivalence atomic number ( $Z_{\text{eq}}$ ).
- Computation of geometric progression (G-P) parameters.
- Calculating the energy absorption build-up factor.

**Calculate equivalence atomic number ( $Z_{\text{eq}}$ ):** The  $Z_{\text{eq}}$  depends on the chemical composition of materials. The different energy shows the different interaction processes such as photoelectric, Compton, pair production [4]. The  $Z_{\text{eq}}$  defined by for the computation of equivalent atomic number, the ratio Compton partial attenuation coefficient ( $(\mu_m)_{\text{comp}}$ ) and total attenuation coefficient ( $(\mu_m)_{\text{total}}$ ) interacting material have been interpolated within the corresponding ratios ( $(\mu_{\text{Comp}}/\mu_{\text{total}})$ ) database of the elements in the same energy (0.015-15 MeV). The total mass attenuation coefficient ( $(\mu_m)_{\text{comp}}$ ) and partial Compton attenuation coefficient ( $(\mu_m)_{\text{total}}$ ) were calculated by using NIST- XCOM database [16].

$$Z_{\text{eq}} = \frac{Z_1 (\log R_2 - \log R) + Z_2 (\log R - \log R_1)}{\log R_2 - \log R_1} \quad (5)$$

where  $R$  is the ratio of selected biological materials at given energy. The  $Z_1$  and  $Z_2$  are the elemental atomic number corresponding to the ratio  $R_1$  and  $R_2$  respectively.

**Computation of geometric progression (G-P) parameters:** The build-up factor data for 23 elements, one compound, two mixtures (air and water) and concrete at energies in the range 0.015-15 MeV up to penetration depths of 40

mfp using the G-P method provided by American National Standards (ANSI/ANS-6.4.3) [17]. Using the interpolation formula, five G.P. fitting parameters ( $b$ ,  $c$ ,  $a$ ,  $X_k$  and  $d$ ) for selected samples were computed at the different incident photon energies using equivalent atomic number ( $Z_{\text{eq}}$ ), in the chosen energy range (0.015-15.0 MeV) up to penetration depth of 40 mfp. The formula used for the purpose of interpolation is:

$$C = \frac{C_1 (\log Z_2 - \log Z_{\text{eq}}) + C_2 (\log Z_{\text{eq}} - \log Z_1)}{\log Z_2 - \log Z_1} \quad (6)$$

where  $C_1$  and  $C_2$  are the values of the coefficients of G-P fitting parameters corresponding to the atomic numbers  $Z_1$  and  $Z_2$ , respectively at a given energy and  $Z_{\text{eq}}$  is the equivalent atomic number of the given material.

**Computation of energy absorption build-up factor:**

Firstly, computed G-P fitting parameters were then used to compute the energy absorption and exposure build-up factors for the selected samples at some standard incident photon energies up to the penetration depth of 40 mean free paths of shielding thickness as given by following equations, with the help of G-P fitting formula:

$$B(E, X) = 1 + \frac{b-1}{K-1} (Kx - 1) \quad \text{at } K \neq 1 \quad (7)$$

$$B(E, X) = 1 + (b-1) \quad \text{at } K = 1 \quad (8)$$

$$K(E, x) = cx^a + d \frac{\tan h \left( \frac{x}{X_k} - 2 \right) - \tan h (-2)}{1 - \tan h (-2)} \quad (9)$$

where parameters  $b$  and  $K$  are corresponding to a build-up factor at 1 MFP and a multiplication factor of dose through 1 MFP photon penetration respectively. Parameter  $K$  is obtained by for  $X$  using parameters  $b$ ,  $c$ ,  $a$ ,  $d$  and  $X_k$ .

## RESULTS AND DISCUSSION

Calculated photon interaction parameter total mass attenuation coefficients ( $\mu_m$ ), of selected amino acid in the wide energy range 1 keV to 100 GeV using NIST XCOM database are graphically represented in Fig. 1. It reflects the behaviour of photon energy increases mass attenuation coefficients decreases. The  $\mu_m$  depending on chemical composition and physical parameter of the composite material discussed by El-Khayatt *et al.* [18]. In energy region 0.01 MeV <  $E$  < 0.05 MeV shows the maximum variation with increasing photon energy of mass attenuation coefficients decreasing value of amino acids. From eqns. 1 and 4 calculate the effective atomic number and effective electron density of the amino acids (Figs. 2 and 3). At same energy, the effective atomic number ( $Z_{\text{eff}}$ ) is dependence with energy, energy is increased  $Z_{\text{eff}}$  decreases spontaneously (Fig. 2). Compton scattering interaction process of the composite material depends on the effective atomic number. N-Acetyl glutamic acid has maximum and D-threonine has minimum value of the effective atomic number. Effective electron density ( $N_{\text{eff}}$ ) was measured the probability distribution of electron, effective electron density with incident energy graphically. Fig. 3 shows that the N-acetyl glutamic acid has

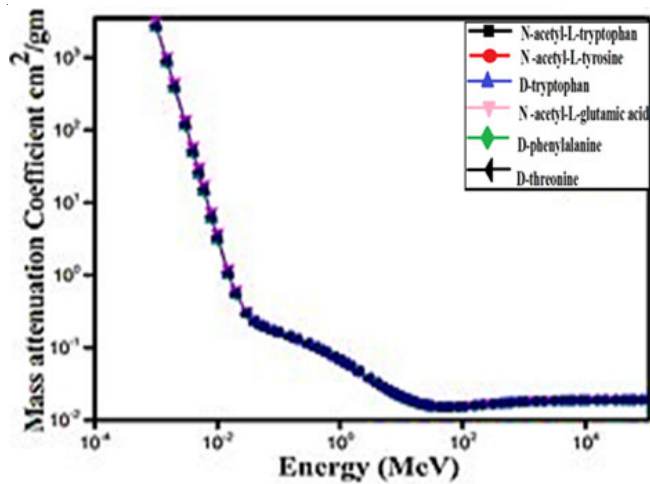


Fig. 1. Variation of mass attenuation coefficient with incident photon energy 1 keV to 100 GeV

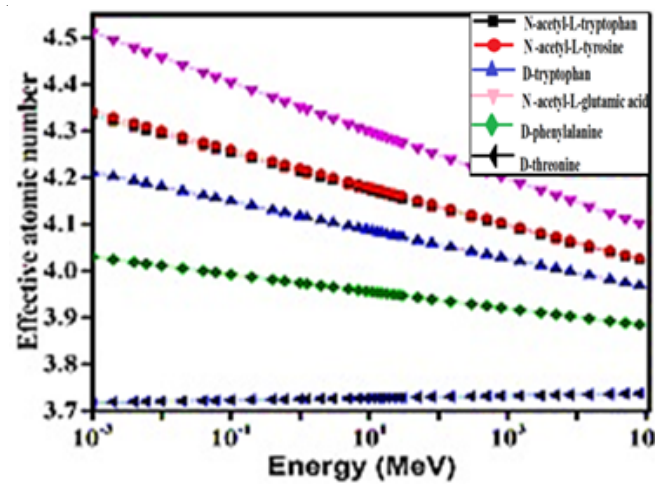


Fig. 2. Variation of  $Z_{\text{eff}}$  with incident photon energy 1 keV to 100 GeV

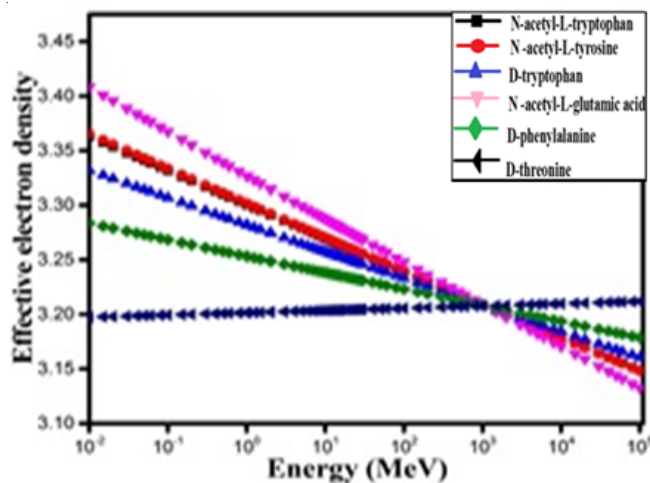


Fig. 3. Variation of  $N_{\text{eff}}$  with incident photon energy 1 keV to 100 GeV

maximum value  $3.41 \times 10^{23}$  electron/cm<sup>3</sup> at 1 keV and minimum  $3.13 \times 10^{23}$  electron/cm<sup>3</sup> at 100 GeV. In energy region,  $100 \text{ keV} < E < 1500 \text{ keV}$  does not show the variation of  $Z_{\text{eff}}$  and  $N_{\text{eff}}$  [19]. The wide energy range 1 keV to 100 GeV of amino acids, borate glass materials, narcotic drugs as earlier discussed by Manohara *et al.* [14], Sayyed *et al.* [20] and Gounhalli *et al.*

[21]. By comparing the present results with them have nearly the same behaviour.

**Variation of EABF and EBF with incident photon energy:** The variation of EABF and EBF of selected amino acids was shown in Fig. 4(a-d) and Fig. 5(a-d) with incident photon energy 0.015-15 MeV up to penetration depth 1 MFP, 10 MFP, 20 MFP, 40 MFP using G-P fitting method. The photoelectric process ( $E_{\text{pe}}$ ) shows the lowest energy region in this region EABF and EBF increases slightly with increasing photon energy by definition  $E_{\text{pe}}$  directly to  $Z^2$  and inversely to  $E^3$ . This shows the photoelectric process is dominant in lower energy region. The value of incident photon energy increases EABF and EBF is enhancing in an intermediate region. The Compton scattering is main interaction process because of multiple scattering photon living longer time in materials. Energy was increasing EABF and EBF simultaneously decreasing their pair production is a main interaction process. Present study shows the observed behaviour of interaction process with EABF and EBF showed graphically as  $E_{\text{pe}} < E_{\text{comp}} > E_{\text{pp}}$ . D-Phenylalanine has the highest value of EABF and EBF, which nearly equal to  $10^4$  at penetration depth 40 MFP and N-acetyl glutamic acid has the lowest value of EABF and EBF in 0.015-15 MeV energy range. The value of  $Z_{\text{eq}}$  is high EABF and EBF is maximum conversely the value of  $Z_{\text{eq}}$  is low EABF and EBF is minimum. This result reflects the EABF and EBF are depend on the chemical composition of amino acids.

**Variation of EABF and EBF dependence with penetration depth:** The EABF and EBF as a function of penetration depth up to 40 MFP at 0.1 MeV incident photon energy graphically shown in Fig. 6 this shows the value of EABF and EBF was increased with increasing penetration depth. The D-phenylalanine EABF and EBF were maximum and N-acetyl glutamic acid EABF and EBF were minimum at 0.1 MeV at penetration depth upto 40 MFP. Graphically N-acetyl-tyrosine and D-tryptophan has shown the same nature.

**Variation of EABF and EBF dependence with  $Z_{\text{eff}}$  and  $N_{\text{eff}}$ :** The  $Z_{\text{eff}}$  is basic parameter used in medical diagnosis. We studied  $Z_{\text{eff}}$  of amino acids with EABF and EBF at 40 MFP at different incident photon energy shown in Fig. 7. The highest value of  $Z_{\text{eff}}$  as comparing EABF and EBF is at 0.1 MeV and lowest at 0.015 MeV. At 0.15 MeV shows the behaviour of an effective atomic number of D-phenylalanine (comparing with N-acetyl glutamic acid) is low shows the value of EABF and EBF is maximum conversely effective atomic number of N-acetyl glutamic acid is high shows the value of EABF and EBF was minimized. This result reflects that the effective atomic number increases EABF and EBF were decreasing. This result reflects that the effective atomic number increases EABF and EBF were decreasing. The electron density had been studied earlier using scattered photon energy; the Compton scattering is a main interaction process for normal and diseased breast tissue types [22]. Here we have explained the properties of energy absorption and exposure with electron density ( $N_{\text{eff}}$ ) of amino acid at 0.015 to 15 MeV up to penetration depth 40 MFP result shows the highest EABF and EBF value their Compton scattering was dominant in Fig. 7, which shows the behaviour of electron density with EABF and EBF. The importance of these radiobiological parameter data before the radiological



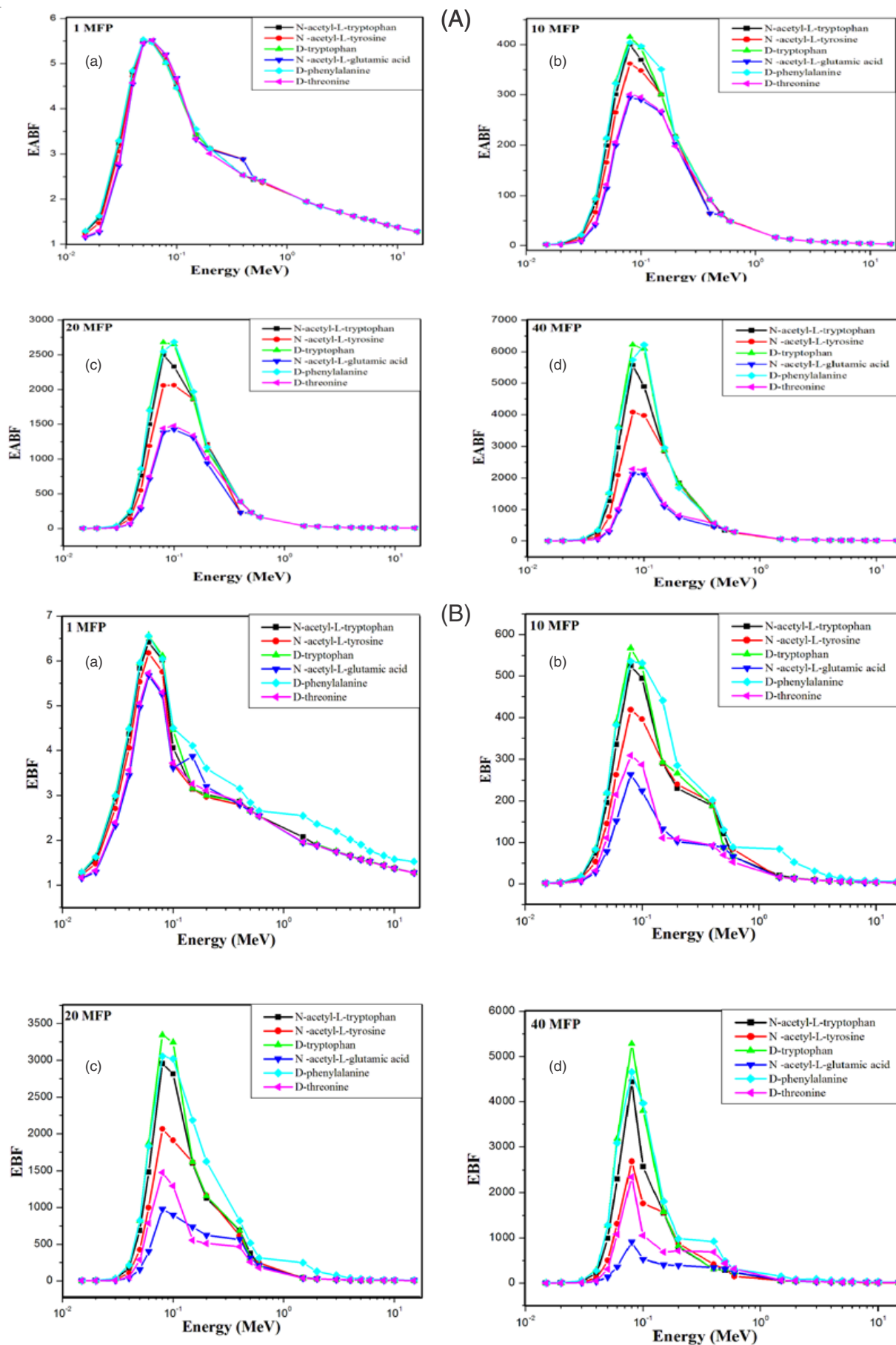


Fig. 4. (A) Variation of EABF and (B) Variation of EBF with incident photon energy 0.015 to 15 MeV at penetration depth (a) 1 mfp, (b) 10 mfp, (c) 20 mfp, (d) 40 mfp of selected amino acids

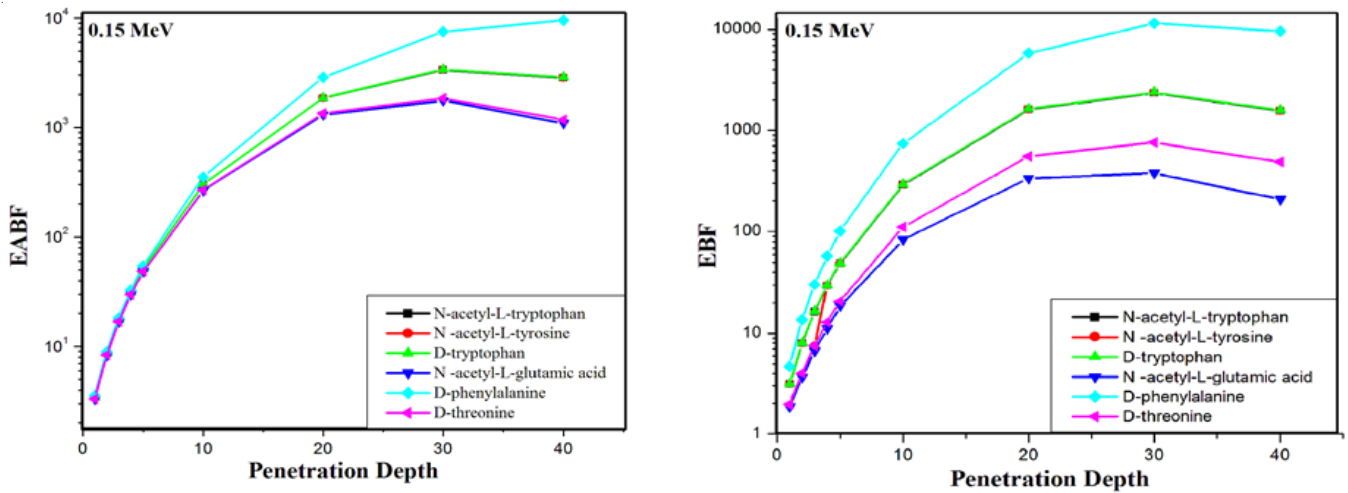


Fig. 5. Variation of EABF and EBF with penetration depth upto 40 mfp at 0.1 MeV

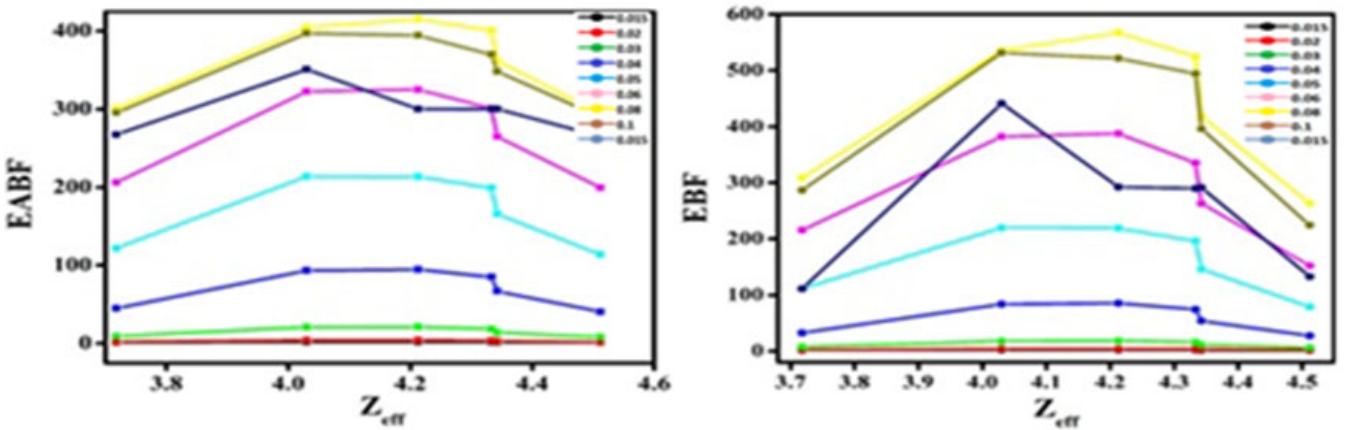


Fig. 6. Variations of EABF and EBF with  $Z_{eff}$  at selected energy region

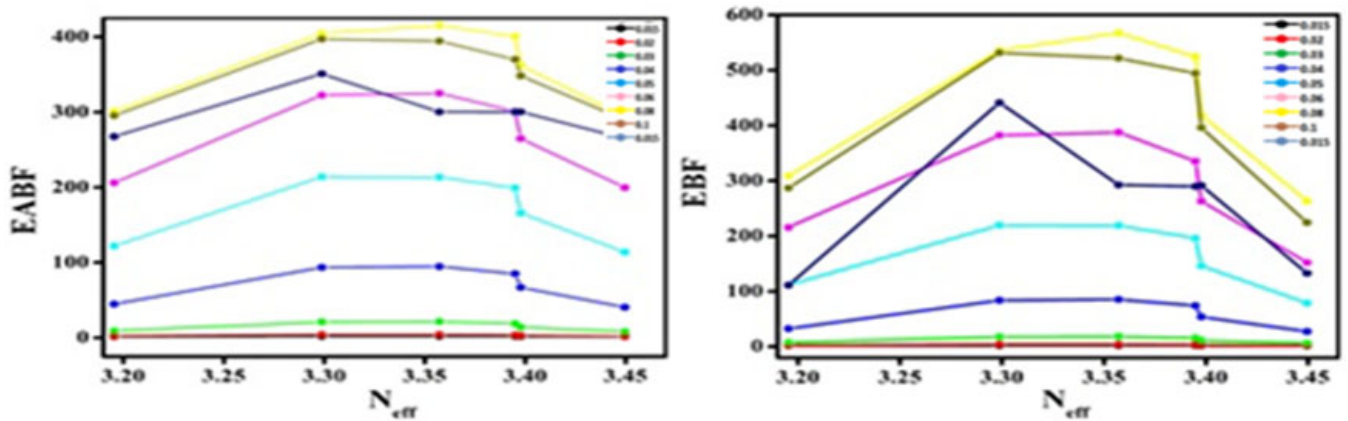


Fig. 7. Variations of EABF and EBF with  $Z_{eff}$  at selected energy region

treatment it gives the accurate information about dose distribution without harm to normal tissue *viz.* high radiation dose to tumours.

**Conclusion**

In the present study mass attenuation coefficients, effective atomic number ( $Z_{eff}$ ) and effective electron density ( $N_{eff}$ ) at wide energy range 1 keV to 100 GeV and EABF and EBF were calculated by using G-P fitting method at 0.015 to 15 MeV upto penetration depth 40 MFP using ANS/ANSI database of unnatural amino acids. The  $Z_{eff}$  and  $N_{eff}$  vary with photon

energy, energy increases  $Z_{eff}$  and  $N_{eff}$  decreases. The study gives idea of interaction process with EABF and EBF. EABF and EBF values were the highest and their Compton scattering is the main interaction process. EABF and EBF with function of  $Z_{eff}$  and  $N_{eff}$  shows that as the value of EABF and EBF increases,  $Z_{eff}$  and  $N_{eff}$  spontaneously decreases. This theoretical study investigate a new approach to biological materials on different penetration depth at different energy range and gives the information about their physical, chemical and biological properties.

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