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A comprehensive study on energy absorption and exposure buildup factors for some Vitamins and Tissue Equivalent Materials

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Abstract- The five parameters geometrical progression fitting approximation has been used to calculate energy absorption buildup factor (EABF) and exposure buildup factor (EBF) for some Vitamins and tissue equivalent materials in the energy region 0.015-15.0 MeV up to a penetration depth of 40 mfp. Variation of EABF with incident photon energy and penetration depth has been studied. We observed that chosen Vitamins have maximum value of EABF and EBF around 0.1 MeV and that of TEM around 0.08 MeV. Variation in value of EABF was due to dominance of different interaction processes in different energy regions. Bee Wax has the maximum EABF and EBF at 0.08 MeV and all the samples except Vitamin A1 have maximum EBF at 0.1 MeV.

Index Terms- Energy absorption buildup factor (EABF), Exposure buildup factor (EBF), Mean free path (mfp), Tissue equivalent materials (TEM). Effective atomic number (Zeff).

I. INTRODUCTION

Determination of radiation dose received by the biological molecule exposed to gamma rays requires buildup factor besides other photon interaction parameters like mass attenuation coefficients, effective atomic numbers in biological materials such as Vitamins [1].Energy range of photons becomes important in different fields like radiography, radiation biology and in medical diagnostics [2, 3]. When photons enter the human body they degrade their energy and produce secondary photons. The estimation of these buildup photons is done by buildup factor which explains the interaction of radiation with matter especially with human body [4]. There are two types of buildup factors naming energy absorption buildup factor (EABF) and exposure buildup factor (EBF). The energy absorption buildup factor is that 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 the exposure buildup factor is that in which the quantity of interest is the exposure and the detector response function is that of absorption in air [5]. To calculate buildup factor there are different methods like G.P. fitting method, Harima et al. 1986 [6], invariant embedding method, Shimizu, 2002 [7]; Shimizu et al., 2004 [8], iterative method, Suteau and Chiron, 2005 [9] and Monte Carlo method, Sardari et al., 2009 [10]. American National Standards, ANSI/ANS 6.4.3., 1991 [11] calculated buildup factor 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 up to penetration depth of 40 mean free path using G.P. fitting method. Harima et al. 1986 [6] also computed buildup factors using G.P. fitting method. Shimizu et al. 2004 [8] compared the buildup factor values obtained by three different methods i.e. G.P. fitting, invariant embedding and Monte Carlo method for low-Z elements up to 100 mean free paths. D.Sardari and S. Baradaran 2010 [12] calculated buildup factor of gamma and X-ray photon the energy range of 0.2-2.0 MeV in water and soft tissue using Monte Carlo code MCNP4C. The results are compared with buildup factor data of pure water. In each case very small deviation is observed.

So, any of these methods/codes can be used to compute buildup factor data for low-Z materials. In the present work buildup factor is computed using G.P. fitting method for some Vitamins and biological materials. Energy region is selected from 0.015-15.0 MeV up to a penetration depth of 40 mean free path (mfp). The generated energy absorption buildup factor data has been studied as a function of incident photon energy and penetration depth.

II. MATERIALS AND METHODS

A. Selection of Materials:

For the present study five Vitamins and five tissue equivalent materials (TEM) are taken. Tissue equivalent materials (TEM) are the materials which simulate human tissue and organs for long time. These materials are used to study the doses received by the humans exposed to ionizing radiations. We studied five materials used as soft tissue-simulating naming bolus, modeling clay, bee wax, paraffin and pitch. The chemical composition of these samples and the symbols used are listed in table 1 and 2. As buildup factor data for these samples is not available in any form, so energy absorption and exposure buildup factor of the chosen samples has been calculated for incident photon energy from 0.015- 15.0 MeV and up to a penetration depth of 40 mfp.

Table I. Chemical composition of selected Vitamins

S. No.	Vitamin	Symbol	Chemical Formula	Z_{eff}
1.	Vitamin D_3	VD3	$C_{27}H_{44}O$	5.440
2.	Vitamin E	VE	$C_{29}H_{50}O_2$	5.458
3.	Vitamin K	VK	$C_{31}H_{46}O_2$	5.501
4.	Vitamin D_2	VD2	$C_{28}H_{44}O_2$	5.504
5.	Vitamin A_1	VA1	$C_{20}H_{29}OH$	5.928

Table II. Percentage chemical composition of selected tissue equivalent materials

Tissue Equivalent Material	C (%)	N (%)	S (%)	H (%)	O (%)
Bee Wax	75.25	8.42	0.19	1.87	14.27
Bolus	82.22	0.78	0.09	0.50	16.41
Paraffin	81.73	0.74	0.10	0.61	16.81
Pitch	42.18	0.42	0.46	0.19	56.76
Modeling Clay	19.76	0.86	3.55	0.00	75.83

B. Computational Work:

Buildup factors are computed using G.P. fitting parameters and the equivalent atomic number Zeq of selected Vitamins and TEM following three steps given below:

Step1. Computation of equivalent atomic number (Zeq):

To compute equivalent atomic number of selected samples, the value of Compton partial attenuation coefficient (µcompton) and total attenuation coefficient (µtotal) in cm2/g are obtained for selected samples in the energy range of 0.015 to 15.0 MeV and also for elements from Z=1 to Z=40 inthe same energy range by using the state of art and convenient computer program WinXCOM computer program Gerward et al. 2001 [13]; Gerward et al. 2004 [14]) initially developed as XCOM, Berger and Hubbel, 1999 [15]. Ratio R ($\mu_{compton}/\mu_{total}$) for selected samples and for elements from Z=1 to 40 is calculated at energies 0.015 to 15.0 MeV using a simple computer program. For the interpolation of $Z_{eq}$for selected samples, the ratio R of particular sample at a given energy is matched with the corresponding ratio of elements at the same energy. For the case, where the ratio R lies between two successive ratios of known elements, the value of $Z_{eq}$is interpolated using following formula, Sidhu et al., 2000 [16]

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

where Z_1 and Z_2 are the atomic numbers of elements corresponding to ratio R_1 and R_2.The computed values of $Z_{eq}$for different Vitamin and TEM samples are given in Table 3 and 4.

Step2.Computation of G.P. fitting Parameters:

American National Standard 1991, ANSI/ANS- 6.4.3 [11] has provided the exposure and energy absorption G.P. fitting parameters of twenty three elements (Ca, Fe, Si etc.) in the energy range of 0.015-15.0 MeV and up to 40 mfp. The computed values of $Z_{eq}$for selected samples were used to interpolate G.P. fitting parameters (b, c, a, X_k, d) for the exposure and energy absorption buildup factor in the chosen energy range of 0.015-15.0 MeV and penetration depth (1-40 mfp). The formula, Sidhu et al., 2000 [16] used for the purpose of interpolation of the G.P. fitting parameters is given below:

$$P=\frac{P_1(\log Z_2-\log Z_{eq})+P_2(\log Z_{eq}-\log Z_1)}{\log Z_2-\log Z_1}$$

where P_1 and P_2 are the values of G.P. fitting parameters corresponding to atomic number Z_1 and Z_2 respectively at a given energy and Z_{eq} is the equivalent atomic number of chosen soils at same energy. Z_1, Z_2 are the successive elemental atomic numbers such that

$$Z_1<Z_{eq}<Z_2$$

Table III. Equivalent atomic number (Zeq) of chosen Vitamin samples in energy range of 0.015-15.0 MeV.

Energy (MeV)	Equivalent atomic number (Z_{eq})				
	Vitamin A_1	Vitamin D_2	Vitamin D_3	Vitamin E	Vitamin K
0.015	5.782	5.836	5.709	5.786	5.825
0.02	5.785	5.851	5.715	5.804	5.846
0.03	5.769	5.857	5.693	5.809	5.798
0.04	5.798	5.876	5.703	5.78	5.885
0.05	5.781	5.972	5.76	5.949	5.984
0.06	5.859	5.62	5.613	5.843	5.859
0.08	6.369	5.771	5.76	5.76	5.782
0.1	6.5	5.5	5.5	5.5	5.5
0.15	6.5	5.5	5.5	5.5	5.5
0.2	6.5	5.5	5.5	5.5	5.5
0.3	6.5	5.5	5.5	5.5	5.5
0.4	6.5	5.5	5.5	5.5	5.5
0.5	6.5	5.5	5.5	5.5	5.5
0.6	6.5	5.5	5.5	5.5	5.5
0.8	6.5	5.5	5.5	5.5	5.5
1	6.5	5.5	5.5	5.5	5.5
1.5	6.5	5.5	5.5	5.5	5.5
2	6.5	5.5	5.5	5.5	5.5
3	5.489	5.475	5.446	5.431	5.504
4	4.879	5.197	5.167	4.837	4.893
5	4.897	5.213	4.864	4.848	4.913
6	5.244	5.244	5.202	5.202	5.266
8	5.137	5.137	5.106	5.074	5.362
10	4.922	5.062	4.894	4.867	4.922
15	5	5	4.867	4.96	5.188

Step3.Computation of buildup factor:

In this last step computed G.P. fitting parameters of selected samples are used to calculate buildup factors. Following formulae,

Harima et al., 1986 [6] are used.

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

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

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

where a, b, c, d, and X_K are the G.P. fitting parameters that depend upon attenuating medium and source energy, x is the distance between source and detector in the medium. E is the incident photon energy. b is buildup factor at 1 mfp. K is the photon dose multiplication and change in the shape of spectrum with increasing penetration depth. K is represented by tangent hyperbolic function of penetration depth in mfp.

To standardize this interpolation method, exposure and energy absorption buildup factor for water are computed up to 40 mfp in energy range of 0.015–15 MeV with this method. The results so obtained are compared with the result of ANSI/ANS 6.4.3 standard. The two results are in good agreement within the limits of statistical error. Thus we can assume safely that the present method is appropriate and suitable for calculation of exposure and energy absorption buildup factor of chosen samples.

Table IV. Equivalent atomic number (Zeq) of chosen TEM in energy range of 0.015-15.0 MeV.

Energy (MeV)	Equivalent atomic number (Z_{eq})				
	Bee Wax	Bolus	Paraffin	Pitch	Modeling Clay
.015	6.467	6.461	6.473	7.396	8.364
0.02	6.48	6.46	6.472	7.412	8.39
0.03	6.442	6.417	6.44	7.408	8.43
0.04	6.442	6.405	6.463	7.404	8.43
0.05	6.415	6.553	6.433	7.421	8.482
0.06	6.466	6.502	6.244	7.431	8.53
0.08	6.487	6.507	6.507	7.348	8.792
0.1	6.892	6.917	6.917	6.917	8.443
0.15	6.5	6.5	6.5	6.5	8.5
0.2	6.5	6.5	6.5	6.5	8.5
0.3	6.5	6.5	6.5	6.5	8.5
0.4	6.5	6.5	6.5	6.5	8.5
0.5	6.5	6.5	6.5	6.5	8.5
0.6	6.5	6.5	6.5	6.5	8.5
0.8	6.5	6.5	6.5	6.5	8.5
1	6.5	6.5	6.5	6.5	8.5
1.5	6.5	6.5	6.5	6.5	8.5
2	6.5	6.5	6.5	6.5	8.737
3	6.424	6.023	6.475	6.94	7.485
4	5.938	6.039	6.039	7.343	7.951
5	6.219	6.325	6.325	6.934	7.727
6	6.142	6.227	6.465	7.231	8.019
8	6.406	6.307	6.307	7.203	8.006
10	6.202	6.293	6.293	7.281	7.863
15	6.258	6.383	6.198	7.218	7.901

III. RESULTS AND DISCUSSIONS

The chemical composition of Vitamins and TEM are listed in Table 1 and Table 2 respectively. The equivalent atomic numbers of selected Vitamins and TEM are provided in Table3 and Table 4 respectively. Results for EABF and EBF of Vitamins and TEM at fixed penetration depths (Fig.1-4) as well as at fixed energies (Fig.5-8) have been expressed in graphical form. Significant differences between EABF and EBF for selected samples of high and low Zeq have been observed. Effect of Incident Photon Energy and penetration depth on Energy Absorption Buildup Factor and exposure buildup factor are discussed below.

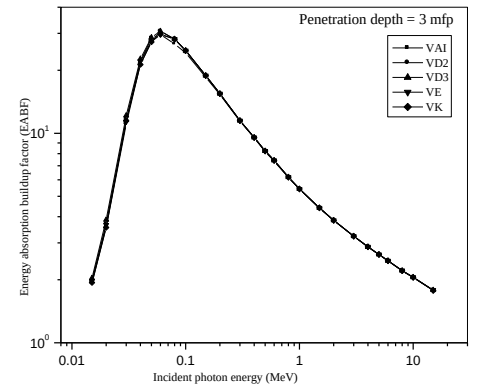
A. Effect of Incident Photon Energy on Energy Absorption Buildup Factor and Exposure Buildup Factor

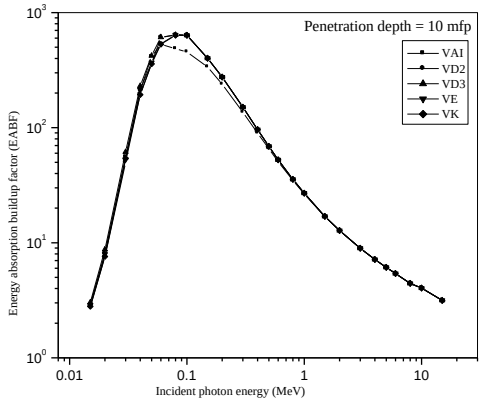
From figures 1-4(a-c)It has been observed that EABF and EBF values of Vitamins and TEMs start increasing with increase in incident photon energy up to a maximum value at intermediate energies. Further increase in photon energy decreases the value of EABF and EBF. This is due to the photoelectric absorption at lower energies and with increase in photon energy the Compton scattering process pre dominates which results in more multiple scattering and leads to increase in EABF and EBF values. Within the selected energy range TEM have the largest EABF and EBF at 0.08MeV fig.2, 4 (a-c) whereas maximum values of EABF and EBF for Vitamins have been observed at 0.1 MeV fig. 1, 3 (a-c). After the energy region > 1.5 MeV another absorption process of pair production starts which leads to lower the values of EABF and EBF. At the energy value of 2.0 MeV, the EABF are practically same for all samples. Therefore the variation of EABF with incident photon energy seems to be independent of the chemical composition of given samples at this energy region.

B. Effect of Penetration Depth on Energy Absorption Buildup Factor and Exposure Buildup Factor

The curves at different energies in figures 5-8(a-d) show that there is continuous increase in EABF and EBF with increase in penetration depth for all samples. It is due to the fact that the increase in penetration depth increases the interaction of gamma-radiation photons with matter resulting in generation of large number of low energy photons due to occurrence of Compton scattering process. It has been observed that at lower energies the values of EABF and EBF for the Vitamins under study remain constant for all penetration depths. The variation of EABF and EBF with penetration depth is almost not affected by the chemical composition of all the Vitamin samples. At low energies there is small variation between EABF of different TEM samples but at high energies there is coincidence between EABF. It is also noted from the figures 1 to 4 that for a fixed value of penetration depth, the buildup factor increases with increase in incident photon energy from 0.015 to 0.1 MeV for Vitamins and 0.015 to 0.08 for TEM. The buildup factor values are highest at 0.1 MeV and at 0.08 MeV after which the buildup factor decreases with the increase in incident photon energies up to 15.0 MeV. It is seen that for energies greater than 1.0 MeV, there is a sharp fall in the value of buildup factor which ultimately depicts the dominance of pair production process in the energy region.
Among selected TEM, Bee Wax has the maximum EABF and EBF at 0.08 MeV for all penetration depths whereas among selected Vitamins, all the samples except Vitamin A1 have

maximum EBF at 0.1 MeV at all penetration depths. Similar trend is observed for maximum EABF of Vitamins.





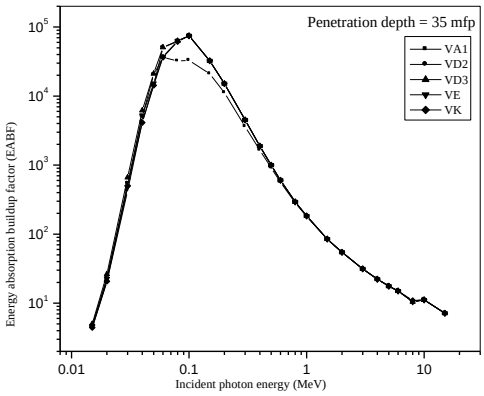
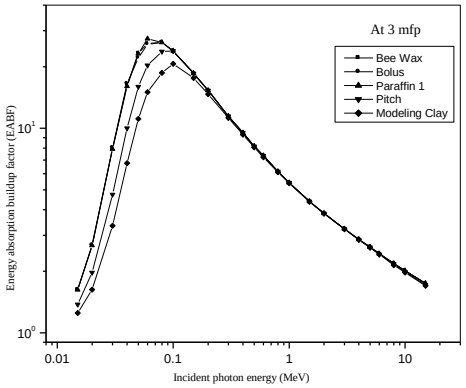
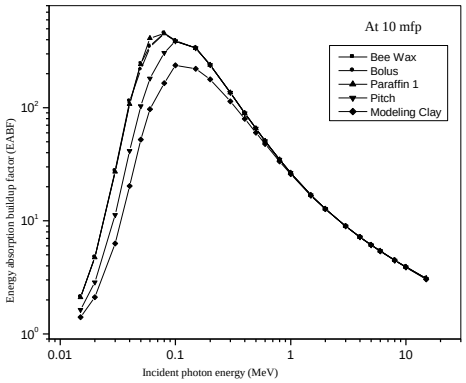


Fig. 1 (a, b, c). The energy absorption buildup factor for Vitamins in the energy range 0.015-15.0 MeV at 3, 10, 35 mfp





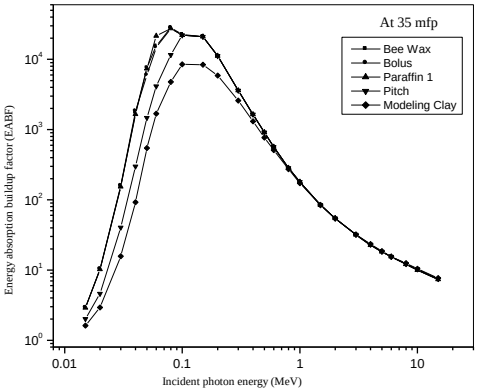
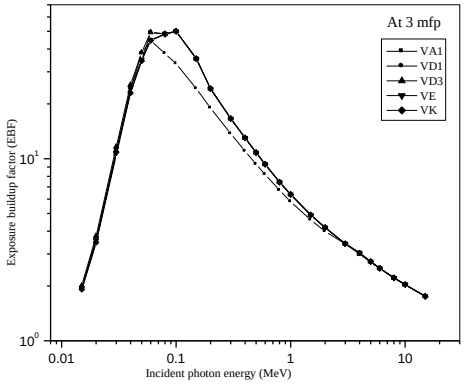
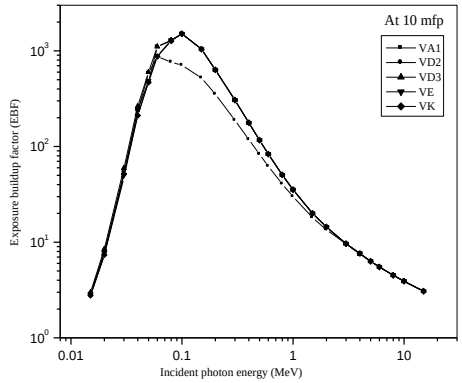


Fig. 2(a,b,c). The energy absorption buildup factor for tissue equivalent materials in the energy range 0.015-15.0 MeV at 3, 10, 35 mfp





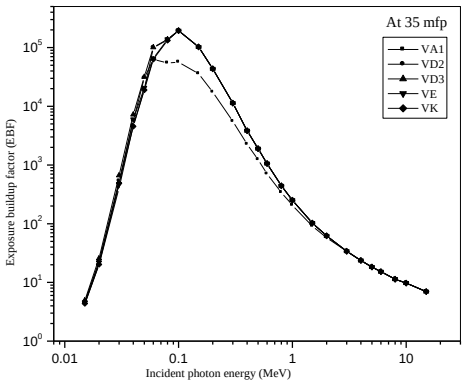
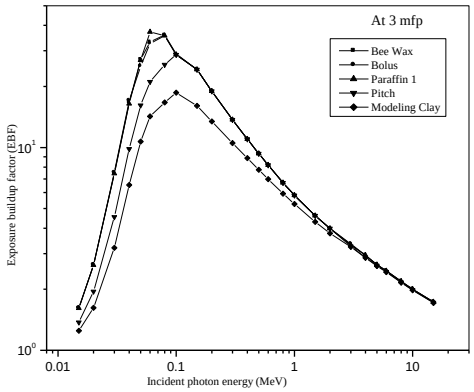
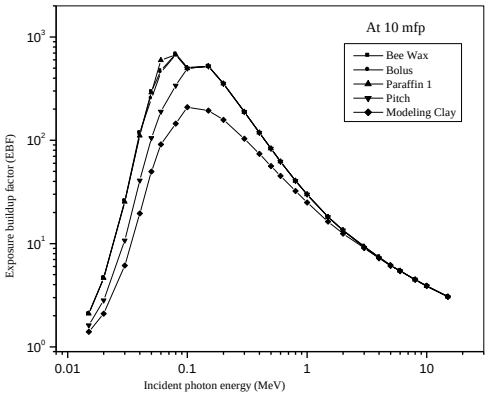


Fig. 3(a,b,c). The exposure buildup factor for Vitamins in the energy range 0.015-15.0 MeV at 3, 10, 35 mfp





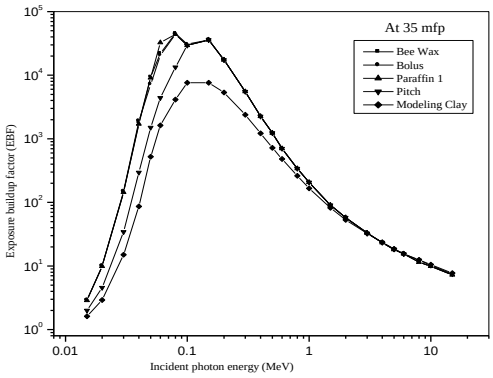
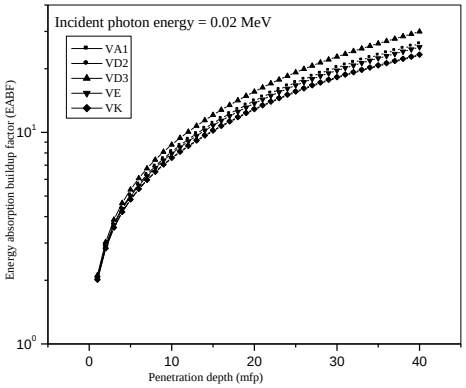
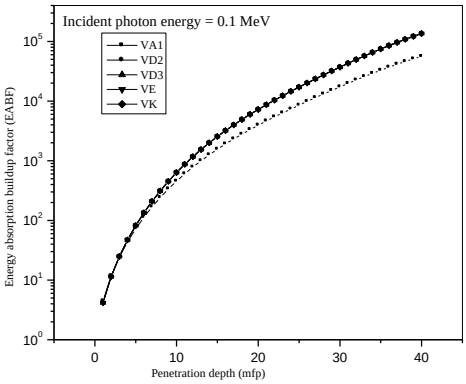
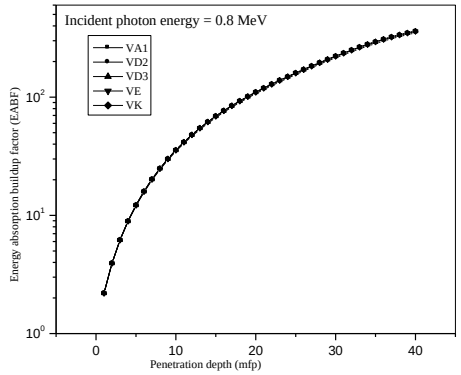


Fig. 4(a,b,c). The exposure buildup factor for tissue equivalent materials in the energy range 0.015-15.0 MeV at 3, 10, 35 mfp







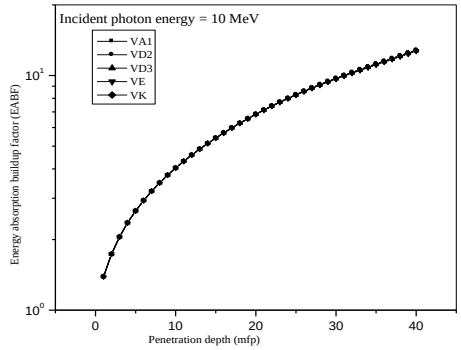
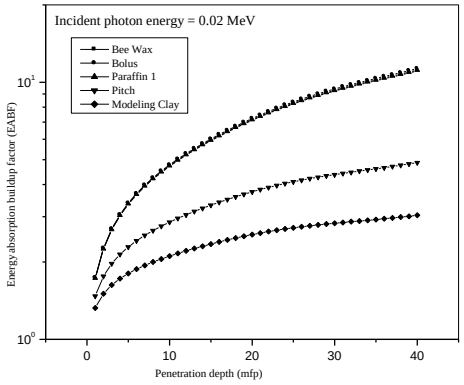
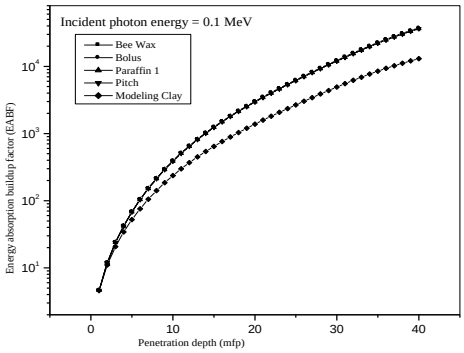
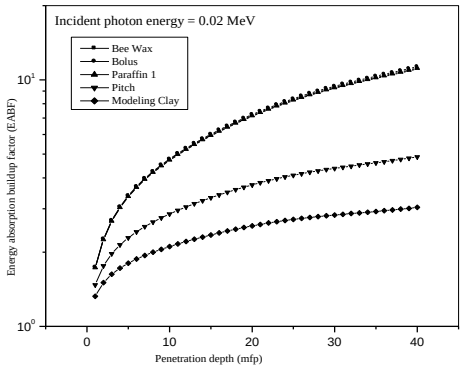


Fig. 5(a,b,c,d). The energy absorption buildup factor for Vitamins up to 40 mfp at 0.02, 0.1, 0.8, 10.0 MeV







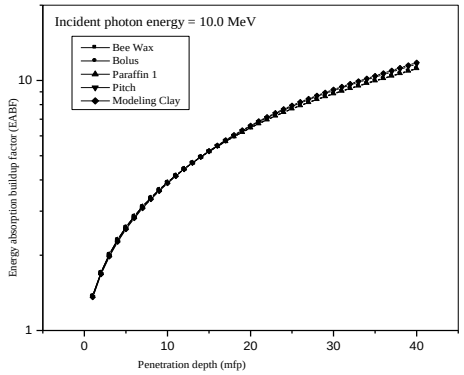
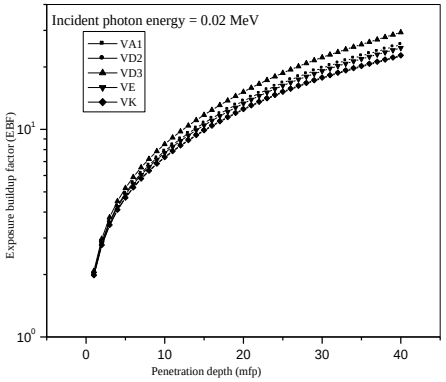
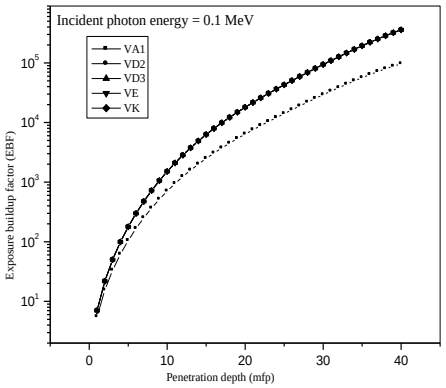
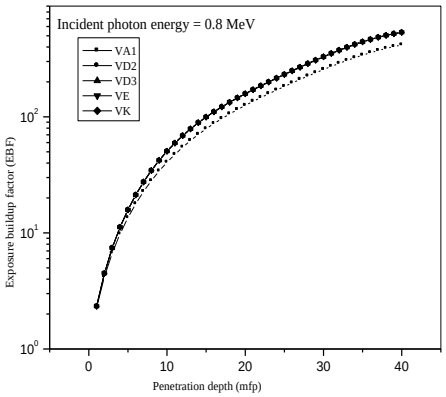


Fig. 6(a,b,c,d). The energy absorption buildup factor for tissue equivalent materials up to 40 mfp at 0.02, 0.1, 0.8, 10.0 MeV







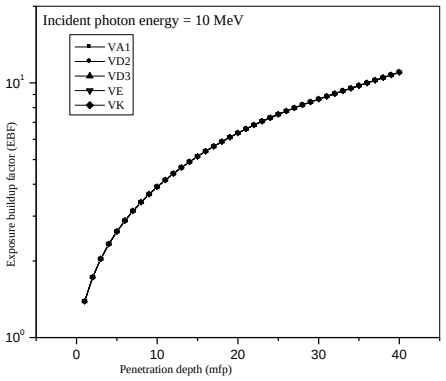
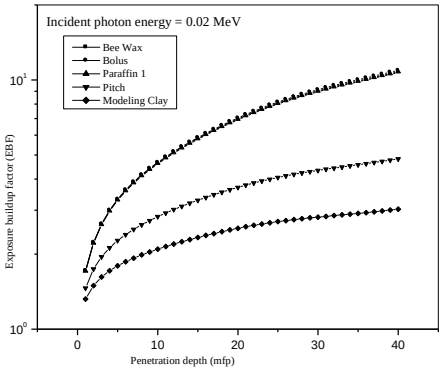
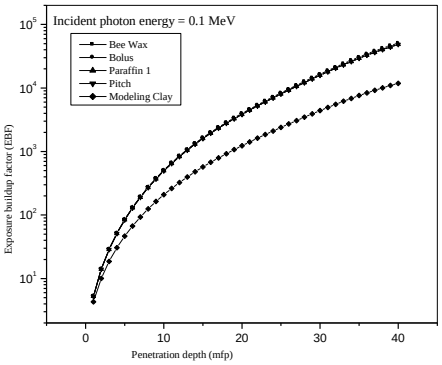
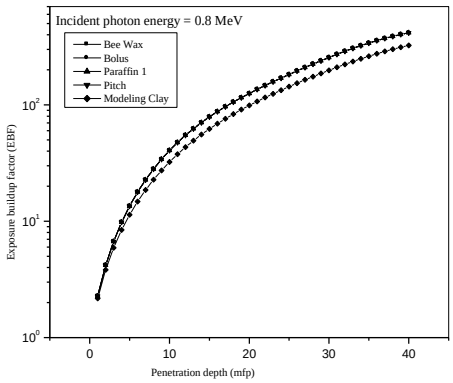


Fig. 7(a,b,c,d). The exposure buildup factor for Vitamins up to 40 mfp at 0.02, 0.1, 0.8, 10.0 MeV







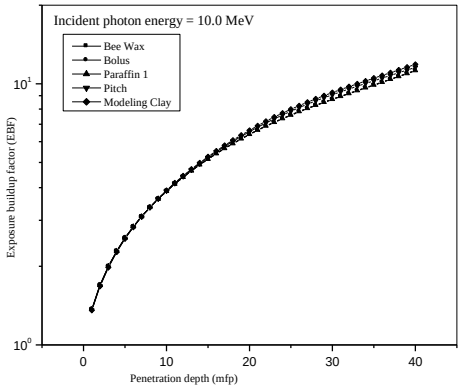


Fig. 8(a,b,c,d) The exposure buildup factor for tissue equivalent materials up to 40 mfp at 0.02, 0.1, 0.8, 10.0MeV.

IV. CONCLUSION

Present study makes Vitamins and TEMs very useful in clinical applications such as radiography and therapeutic treatments. In the field where the determination of dose of radiations to critical organ is difficult to access, tissue equivalence is also very important. When energy deposition in a tissue substitute exposed to gamma rays is calculated, the maximum radiation dose may not be at the surface but somewhere inside. Better calculation of effective absorbed dose in different materials could be obtained by modifying the intensity of radiations using buildup factor data. This generated data of buildup factors may also be very helpful to researchers working in radiological laboratories, nuclear power plants etc. to take proper precautions to avoid radiation hazards.

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