Original paper

Energy Absorption Buildup Factor in A Few Human Tissues and Tissues-Equivalent Plastic

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Abstract

Background: Energy absorption buildup factor inhuman tissuesare very importantfor the researchers working to help in estimating safe dose levels for radiotherapy patients and useful in radiation therapy, diagnostics, and dosimeters.

Aim: The mainemphasis has been focused on the dependence of energy absorption buildup factor on the incident photon energy, penetration depth and effectiveatomic number (Z_{eff})in the human tissues and tissues equivalent plastic.

Materials and Methods: Energy absorption buildup factor ina fewhumantissuessuch as skin, brain, striated muscle and compact bone as well as in tissue-equivalent plasticA-150 and bone- equivalent plasticB-100have been computedusing the five parameter geometric progression(G.P) fittingformula in the energy range of 0.015-15 MeV up to penetration depth 40 mfp. The half value layer (HVL) for selected tissues were also estimated.

Results & Discussion: The variation of energy absorption buildup factorfor selected tissueshas been studied as a function of incident photon energy, penetration depth and effective atomic number(Z_{eff}).The energy absorption buildup factor increases with increasing photon energy and reaches a maximum value at gamma ray energy range(0.1-0.2MeV), then start decreasing further with the increasing photon energy. There is continuous increase in energy absorption buildup factor with increase in penetration depth.

Comparison of calculated energy absorption buildup factor with standard database from ANSI/ANS6.4.3-1991 (American National Standard, 1991)shows good agreements.

Conclusion:Variation in value of energy absorption buildup factor was due to dominance of different interaction processes in different energy regions and chemical compositions of thehuman tissues. In general, the energy absorption buildup factor is lower for compact bone and boneequivalent plastic B-100 at photon energy range (0.015- 1 MeV) .

Keywords: GP fitting formula, Energy absorption buildup factor, effective atomic number, human tissues, tissue equivalence.

Introduction

Gamma and X-ray photons are widely used in radiotherapy and diagnostics. Buildup factor is an important parameter in estimating distribution of photon flux and calculation of radiation dose received by the biological materials. Buildup factor has been classified into two categories viz. energy absorption and exposure buildup factor. Theenergy absorption buildup factor 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

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in the interacting material. Whereas the exposure buildup factor is defined as that buildup factor in which the quantity of interest is the exposure and the detector response function is that of the absorption in air(1).There are different available methods to calculate the buildup factor in materials such as geometric progression (G.P) method(Harimaet al., 1986)(2), invariant embedding (IE) method (Shimizu, 2002)(3)and EGS4 code (Nelson et al.,1985)(4). American National StandardsANSI/ANS 6.4.3-1991(5) 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 standardenergies in the energy range 0.015–15 MeV with suitable interval up to the penetration depth of 40 mean free path (mfp). Several researchers contributed in computing buildup factors for different materials such as for some commonly used solvents(6),some soils (7) and some biological materials (8).In the present work, the energy absorption buildup factor have been computed for human tissues such as skin, brain, striated muscle, compact bone and for tissue equivalent such as Tissue-equivalent plastic (A-150) and Bone- equivalent plastic (B-100) in the energy range of 0.015–15 MeV up to the penetration depth 40 mfpby using the GP fitting formula. The mainemphasis has been focused on the dependence of energy absorption buildup factor on the incident photon energy, penetration depthand effective atomic number (Z_{eff})of the selected tissues. The present computed data will be of high importance to help in estimating safe dose levels for radiotherapy patients and useful in radiation therapy, diagnosticsand dosimeters.

Materials and methods

The chemical compositions of the selected tissues are given in Table 1. These data have been taken from (Mc Conn et al.,2011)(9).

Table1. Density and elemental compositions for selected tissues (9).

Samples	Density (g/cm3)	Chemical composition of samples (fraction by weight)
Skin (ICRP)	1.100	H: 0.100588 , C: 0.228250 N: 0.046420 ,O: 0.619002 Na: 0.000070, Mg:0.000060 , P: 0.000330 , Si: 0.001590, Cl:0.002670 , K:0.000850, Ca:0.000150, Fe: 0.000010 , Zn:0.000010
Brain (ICRP)	1.030	H: 0.110667 , C: 0.125420 , N: 0.013280 , O: 0.737723 , Na: 0.001840 , Mg: 0.000150 , P: 0.003540 , S: 0.001770, Cl: 0.002360 , K: 0.003100 , Ca: 0.000090, Fe: 0.000050
Striated muscle (ICRU)	1.040	H: 0.101997, C: 0.123000 , N: 0.035000, O: 0.729003, Na: 0.000800, Mg: 0.000200
Compact bone (ICRU)	1.850	H: 0.063984 , C: 0.278000 , N: 0.027000, O: 0.410016,Mg: 0.002000, P: 0.070000, S: 0.002000, Ca: 0.147000
A-150 Tissue-equivalent plastic	1.127	H: 0.101327 , C: 0.775501 , N:0.035057, O:0.052316, F:0.017422 , Ca:0.018378
B-100 Bone- equivalent plastic	1.450	H: 0.065471, C: 0.536945 , N:0.021500 , O:0.032085 ,F: 0.167411 , Ca: 0.176589

ICRP: International Commission on Radiological Protection
ICRU: International Commission on Radiation Units and Measurements

Computational work

The computations have been carried out in three steps, as follows: The first step deals with the computation of equivalent atomic number (Z_{eq}) for the selected tissues. The second step concerns with thecomputation of G.P fitting parameters and finally in the third step, energy abortion buildup factor values have been computed.

1. Computations of equivalent atomic number (Z_{eq})

The equivalent atomic number, Z_{eq}, is a parameter assigned to a compound or mixture by giving a proper weight toCompton scattering. Values of the Compton partial mass attenuation coefficient $(\mu/\rho)_{Comp}$ and the total mass attenuation coefficient $(\mu/\rho)_{total}$ have been obtained for the elements and selected tissues by using the XCOMcomputer program[10]. The Z_{eq}, for a given tissue is then calculated by matching the ratio, $(\mu/\rho)_{Comp}/(\mu/\rho)_{total}$, of that human tissue at a given energy with the corresponding ratio of a pure element at the same energy. If this ratio lies between the two ratios for known elements, then the value of $Z_{eq}$is interpolated using the following formula[11]:

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

Where Z_1 and Z_2 are the elemental atomic numbers corresponding to the ratios (μ_{comp} / μ_{total}) R_1 and R_2 respectively and R is ratio for given material at a particular energy. The computed Z_{eq} for selected building samples is given in Table 2.

2. Computations of G.P. fitting parameters

The computed values of Z_{eq} for the selected tissues were used to interpolate G.P fitting parameters (b, c, a, X_k and d) for the energy absorption buildup factor, in the energy range (0.015–15 MeV) and penetration depth (1–40 mfp), using the following interpolation formula [2]:

$$P = \frac{P_1(\log Z_2 - \log Z_{eq}) + P_2(\log Z_{eq} - \log Z_1)}{\log Z_1 - \log Z_2} \qquad (2)$$

Where, Z_1 and Z_2 are the atomic numbers of elements between which the equivalent atomic number, Z_{eq}, of a given tissue lies. P_1 and P_2 are the values of G.P fitting parameters corresponding to the atomic numbers Z_1 and Z_2 respectively, at a given energy. The G.P fitting parameters for the pure elements were taken from the standard reference ANSI/ANS-6.4.3-1991[5]. The resulting GP fitting parameters for selected tissues are given in Tables 3–8.

Table 2.Equivalent atomic number (Z_{eq}) of selected tissues.

Energy (MeV)	Equivalent atomic number (Z_{eq})					
	Skin	Brain	Compact bone	Striated muscle	A-150	B-100
0.015	7.1823	7.3254	11.4697	7.4974	7.0035	11.3949
0.02	7.6762	7.5459	11.6584	7.5380	7.1081	11.6368
0.03	7.2784	7.5893	11.8808	7.5768	7.2341	11.8635
0.04	7.2943	7.615	12.0285	7.5975	7.3055	12.0313
0.05	7.3000	7.6255	12.1227	7.6060	7.3645	12.1436
0.06	7.2957	7.6423	12.4565	7.6201	7.3987	12.2306
0.08	7.3481	7.8017	12.2026	7.6606	7.4480	12.3311
0.1	7.2782	7.6152	12.3718	7.5571	7.4175	12.4222
0.15	7.0999	7.7446	12.4647	7.5663	7.5663	12.6104
0.2	6.7777	7.7499	12.4883	7.7499	7.7499	12.4883
0.3	6.9052	6.9033	13.1850	6.9574	6.8599	12.8332
0.4	5.0000	5.0000	13.2499	5.0000	9.3769	13.5998
0.5	7.1250	7.8182	12.5999	7.6060	7.3333	12.5999
0.6	7.9230	7.9231	12.6666	8.5262	8.5999	13.0435
0.8	7.0000	8.1539	13.2333	7.0000	7.8667	13.0769
1	10.8500	8.0000	13.0147	8.0000	8.0000	12.7674
1.5	7.1304	6.7857	9.3330	7.8024	4.9250	8.6664
2	6.4442	6.6665	8.7931	6.5553	5.7142	8.4493
3	6.3251	6.5111	8.8322	6.5576	5.4867	8.3179
4	6.3108	6.4795	8.7534	6.5315	5.4665	8.3089
5	6.3023	6.4400	8.7642	6.5210	5.5027	8.2572
6	6.4325	6.4628	8.7689	6.5403	5.4646	8.2677
8	6.3144	6.4555	8.7574	6.5237	5.5016	8.2362
10	6.3231	6.4557	8.7519	6.5363	5.4978	8.2332
15	6.2285	6.4529	8.7341	6.5288	5.4809	8.2183

3.Computation of buildup factor

The computed G.P fitting parameters were then used to compute the energy absorption buildup factors for the chosen tissues at incident photon energy, with the help of G.P fitting formula, as given by equations [2]:

$$B(E,x) = 1 + \frac{(b-1)(K^x - 1)}{K-1} \qquad for\ K \neq 1 \qquad (3)$$

$$B(E,x) = 1 + (b-1)x \qquad for\ K = 1 \qquad (4)$$

$$K(E,x) = cx^a + d\,\frac{\tanh\left(x/X_k - 2\right) - \tanh\left(-2\right)}{1 - \tanh(-2)} \qquad x \le 40\ mfp \qquad (5)$$

Where E is the incident photon energy, x is the penetration depth in unit of mean free path.a, b, c, d and X_k are the G.P fitting parameters.*K* is the photon dose multiplication and change in the shape of the spectrum with increasing penetration depth. Tostandardize this interpolation method, absorption buildup factor for water are computed up to 40 mfp in energy range 0.015-15 MeV using G.P method.The results so obtained are compared with the results of ANSI / ANS6.4.3standard,(Table 9)for a few randomly selected energies 0.015, 2 and 15 MeV. 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 energy absorptionbuildup factor in chosen tissues.

Calculation of half value layer

The thickness of the material that reduces the photon beam intensity to half of its original value (I_0), i.e. (½) I_0, is called the half-value layer (HVL) and is given by:

$$HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \qquad (6)$$

Where μ is the linear attenuation coefficient of material at given photon energy. Since, the linear attenuation coefficient varies with photon energy, HVL is also energy dependent.

Table 3. GP Energy absorption buildup factor coefficients for skin in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.2202	0.4734	0.1697	14.2966	-0.0833
0.02	1.4223	0.5255	0.1547	14.6030	-0.0788
0.03	2.5546	0.7887	0.0707	14.7297	-0.0400
0.04	3.7480	1.1850	-0.0314	13.6242	0.0077
0.05	4.6659	1.5304	-0.0943	13.7872	0.0388
0.06	5.0185	1.8130	-0.1361	13.7390	0.0611
0.08	4.9239	2.1112	-0.1729	13.5318	0.0769
0.1	4.6514	2.1996	-0.1792	14.2553	0.0770
0.15	3.7672	2.2798	-0.1870	14.4089	0.0756
0.2	3.3200	2.2306	-0.1826	14.7937	0.0760
0.3	2.8371	2.0625	-0.1686	14.2763	0.0670
0.4	2.5330	2.0270	-0.1670	14.3400	0.0653
0.5	2.4643	1.7798	-0.1372	14.1412	0.0551
0.6	2.3667	1.6577	-0.1203	14.3049	0.0478
0.8	2.2020	1.5440	-0.1050	14.2000	0.0434
1	2.1117	1.3887	-0.0774	14.8220	0.0258
1.5	1.9327	1.2748	-0.0594	14.3703	0.0256
2	1.8393	1.1712	-0.0384	14.2613	0.0156
3	1.7126	1.0524	-0.0117	13.8286	0.0032
4	1.6270	0.9867	0.0034	13.3115	-0.0036
5	1.5650	0.9419	0.0162	14.5589	-0.0094
6	1.5082	0.9158	0.0246	14.5128	-0.0172
8	1.4300	0.8790	0.0353	12.0868	-0.0184
10	1.3732	0.8627	0.0393	14.3234	-0.0222
15	1.2803	0.8382	0.0475	15.6894	-0.0332

Table 5. GP Energy absorption buildup factor coefficients for striated muscle in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.1938	0.4542	0.1810	13.8400	-0.0914
0.02	1.4490	0.5359	0.1506	14.6616	-0.0763
0.03	2.1726	0.7327	0.0899	13.3757	-0.0429
0.04	3.5147	1.0990	-0.0124	13.4504	-0.0016
0.05	4.4466	1.4329	-0.0780	13.6180	0.0306
0.06	4.8866	1.7308	-0.1205	13.7064	0.0528
0.08	4.9333	2.0136	-0.1617	13.6191	0.0723
0.1	4.6421	2.1528	-0.1755	14.0385	0.0770
0.15	3.8492	2.1936	-0.1779	14.4042	0.0721
0.2	3.3650	2.1424	-0.1752	14.1750	0.0656
0.3	2.8393	2.0675	-0.1683	14.2397	0.0669
0.4	2.5330	2.0270	-0.1670	14.3400	0.0653
0.5	2.4679	1.7714	-0.1359	14.1757	0.0545
0.6	2.3740	1.6386	-0.1168	14.3600	0.0454
0.8	2.2020	1.5440	-0.1050	14.2000	0.0434
1	2.1040	1.4270	-0.0860	14.2000	0.0347
1.5	1.9408	1.2040	-0.0567	14.3231	0.0230
2	1.8384	1.1722	-0.0387	14.1969	0.0160
3	1.7110	1.0540	-0.0122	13.3555	0.0036
4	1.6277	0.9845	0.0052	13.6458	-0.0048
5	1.5656	0.9384	0.0178	14.2181	-0.0111
6	1.5056	0.9196	0.0233	15.0291	-0.0169
8	1.4300	0.8759	0.0368	12.0720	-0.0201
10	1.3702	0.8651	0.0389	14.3256	-0.0222
15	1.2770	0.8385	0.0481	15.4114	-0.0341

Table 4. GP Energy absorption buildup factor coefficients for brain tissue in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.2081	0.4626	0.1749	14.0868	-0.0870
0.02	1.4477	0.5353	0.1509	14.6582	-0.0763
0.03	2.3857	0.7304	0.0907	13.3229	-0.0430
0.04	3.5015	1.0941	-0.0113	13.4405	-0.0021
0.05	4.4286	1.4268	-0.0770	13.6075	0.0301
0.06	4.8766	1.6931	-0.1193	13.7039	0.0522
0.08	4.9374	1.9708	-0.1568	13.6574	0.0702
0.1	4.6402	2.1433	-0.1748	13.9942	0.0770
0.15	3.8792	2.1620	-0.1746	14.4024	0.0709
0.2	3.3650	2.1424	-0.1752	14.1750	0.0725
0.3	2.8370	2.0626	-0.1686	14.2777	0.0670
0.4	2.5330	2.0270	-0.1670	14.3400	0.0653
0.5	2.4761	1.7527	-0.1330	14.2525	0.0531
0.6	2.3667	1.6577	-0.1203	14.3049	0.0478
0.8	2.2157	1.5154	-0.0993	14.4057	0.0373
1	2.1040	1.4270	-0.0860	14.2000	0.0347
1.5	1.9330	1.2766	-0.0600	14.3618	0.0262
2	1.8375	1.1731	-0.0390	14.1337	0.0163
3	1.7113	1.0537	-0.0121	13.4488	0.0035
4	1.6275	0.9850	0.0050	14.5706	-0.0045
5	1.5654	0.9397	1.0172	14.3431	-0.0105
6	1.5074	0.9169	0.0242	14.6589	-0.0242
8	1.4300	0.8769	0.0363	12.0768	-0.0195
10	1.3714	0.8642	0.0391	14.3247	-0.0222
15	1.3306	0.8385	0.0479	15.4804	-0.0339

Table 6. GP Energy absorption buildup factor coefficients for compact bone in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.0443	0.4052	0.2037	12.3482	-0.1114
0.02	1.0983	0.4207	0.1906	14.5166	-0.0999
0.03	1.3063	0.4481	0.1897	14.3094	-0.1001
0.04	1.6399	0.5551	0.1429	15.2958	-0.0751
0.05	2.1803	0.6163	0.1323	13.7322	-0.0717
0.06	2.6185	0.7347	0.0919	13.8864	-0.0644
0.08	3.6987	1.0304	0.0061	14.2998	-0.0187
0.1	4.1574	1.2328	-0.0379	12.9669	0.0018
0.15	4.1189	1.5198	-0.0902	13.7357	0.0279
0.2	3.6694	1.6343	-0.1080	13.9242	0.0364
0.3	3.1027	1.6257	-0.1073	14.2962	0.0338
0.4	2.7884	1.5873	-0.1022	14.7112	0.0304
0.5	2.5867	1.5549	-0.0985	15.0678	0.0294
0.6	2.4241	1.5285	-0.0973	14.7218	0.0329
0.8	2.2382	1.4466	-0.0833	14.7760	0.0280
1	2.1191	1.3679	-0.0730	15.0690	0.0257
1.5	1.9396	1.2571	-0.0550	14.2955	0.0219
2	1.8408	1.1631	-0.0361	14.6586	0.0138
3	1.7088	1.0514	-0.0104	13.2008	0.0009
4	1.6190	0.9852	0.0068	13.0237	-0.0084
5	1.5520	0.9431	0.0183	13.1052	-0.0134
6	1.4982	0.9126	0.0272	15.3365	-0.0262
8	1.4045	0.8980	0.0316	12.3158	-0.0185
10	1.3470	0.8764	0.0396	13.9085	-0.0277
15	1.2496	0.8601	0.0452	14.7417	-0.0355

Table 7. GP Energy absorption buildup factor coefficients for A-150 Tissue-Equivalent Plastic in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.2357	0.4848	0.1631	14.5647	-0.0749
0.02	1.5363	0.5693	0.1374	14.8506	-0.0682
0.03	2.5792	0.7972	0.0678	14.9391	-0.0396
0.04	3.7393	1.1818	-0.0308	13.6176	0.0073
0.05	4.6180	1.5095	-0.0909	13.7509	0.0371
0.06	4.9760	1.7771	-0.1311	13.7285	0.0584
0.08	4.9269	2.0796	-0.1693	13.5601	0.0754
0.1	4.6467	2.1760	-0.1774	14.1459	0.0770
0.15	3.8492	2.1936	-0.1779	14.4042	0.0721
0.2	3.3650	2.1424	-0.1752	14.1750	0.0725
0.3	2.8874	1.9943	-0.1602	14.2128	0.0632
0.4	2.6855	1.7741	-0.1330	14.1200	0.0505
0.5	2.4679	1.7714	-0.1359	14.1757	0.0545
0.6	2.3749	1.6362	-0.1164	14.3668	0.0451
0.8	2.2125	1.5221	-0.1006	14.3573	0.0401
1	2.1040	1.4270	-0.0860	14.2000	0.0347
1.5	1.9349	1.2857	-0.0622	14.2985	0.0280
2	1.8453	1.1713	-0.0383	14.4229	0.0156
3	1.7150	1.0520	-0.0120	13.7302	0.0040
4	1.6280	0.9880	0.0035	13.9129	-0.0028
5	1.5673	0.9427	0.0154	14.4710	-0.0083
6	1.5221	0.9015	0.0285	12.7704	-0.0164
8	1.4400	0.8707	0.0378	11.6534	-0.0192
10	1.3833	0.8576	0.0400	14.4111	-0.0215
15	1.2890	0.8360	0.0470	14.9869	-0.0295

Table 8. GP Energy absorption buildup factor coefficients for B-100 Bone- Equivalent Plastic in energy range 0.015–15 MeV.

Energy (MeV)	b	c	a	X_k	d
0.015	1.0453	0.4058	0.2057	12.2061	-0.1083
0.02	1.0990	0.4203	0.1910	14.5177	-0.1003
0.03	1.3081	0.4486	0.1896	14.3165	-0.1000
0.04	1.8378	0.6245	0.1159	16.1363	-0.0607
0.05	2.1742	0.6151	0.1327	13.7546	-0.0721
0.06	2.6967	0.7569	0.0846	13.5204	-0.0584
0.08	3.3091	1.0131	0.0106	14.2684	-0.0211
0.1	4.1438	1.2258	-0.0365	13.0131	0.0009
0.15	4.1250	1.4980	-0.0863	13.8751	0.0253
0.2	3.6694	1.6347	-0.1080	13.9242	0.0364
0.3	3.0508	1.7145	-0.1216	14.1216	0.0432
0.4	2.7849	1.5796	-0.1012	14.6444	0.0302
0.5	2.5867	1.5549	-0.0985	15.0678	0.0294
0.6	2.4282	1.5199	-0.0958	14.7999	0.0325
0.8	2.2374	1.4389	-0.0838	14.7118	0.0283
1	2.1798	1.3703	-0.0735	15.0928	0.0260
1.5	1.9412	1.2590	-0.0555	14.3025	0.0218
2	1.8400	1.1648	-0.0365	14.5565	0.0141
3	1.7095	1.0518	-0.0108	13.9036	0.0014
4	1.6202	0.9856	0.0064	12.9926	-0.0076
5	1.5546	0.9424	0.0181	13.2194	-0.0130
6	1.5032	0.9084	0.0285	15.1720	-0.0260
8	1.4089	0.8966	0.0312	12.3254	-0.0172
10	1.3531	0.8694	0.0405	13.9027	-0.0274
15	1.2561	0.8517	0.0472	14.7475	-0.0362

Table 9. Comparison of calculated energy absorption buildup factors for water obtained by the present work with standard database from ANSI/ANS6.4.3-1991 (American National Standard, 1991).

X (mfp)	Photon energy: 0.015MeV			2MeV			15MeV		
	Calculated	ANSI Standard	error (%)	Calculated	ANSI Standard	error (%)	Calculated	ANSI Standard	error (%)
1	1.20	1.19	0.84	1.84	1.83	0.55	1.28	1.29	0.77
2	1.30	1.28	1.56	2.79	2.82	1.06	1.52	1.51	0.66
3	1.37	1.34	2.24	3.84	3.87	1.03	1.74	1.72	1.63
4	1.43	1.40	2.14	4.95	4.99	0.50	1.95	1.93	1.04
5	1.47	1.44	2.08	6.13	6.16	0.49	2.14	2.14	0.00
6	1.50	1.48	1.35	7.37	7.38	0.14	2.34	2.34	0.00
7	154	1.51	1.99	8.65	8.66	0.12	2.53	2.53	0.00
8	1.57	1.54	1.30	9.98	9.97	0.10	2.72	2.73	0.37
10	1.62	1.59	1.89	12.72	12.7	0.16	3.09	3.11	0.64
15	1.74	1.69	2.96	20.11	20.1	0.05	4.01	4.04	0.74
20	1.83	1.77	3.39	27.93	28.0	0.25	4.94	4.93	0.20
25	1.90	1.83	3.83	36.24	36.4	0.44	5.85	5.81	0.69
30	1.95	1.88	3.72	45.17	45.2	0.07	6.66	6.64	0.30
35	1.99	1.93	3.63	54.46	54.3	0.29	7.39	7.42	0.40
40	2.04	1.96	4.59	63.37	63.6	0.36	8.11	8.09	0.25

Results and discussion

The generated energy absorption buildup factor for the chosen tissues been shown in graphical form at fixed penetration depth (Figs. 1) as well as at fixed energy values (Figs. 2).

A. Effect of incident photon energy on energy absorption buildup factor

Figs.1(a-f) show the energy dependence of the energy absorption buildup for selected tissues for penetration depths 2, 5, 10, 20 and 40 mfp.2,5, 10,20 and 40mfp. Initially, the energy absorption buildup factor increases with the increasing photon energy and reaches a maximum value at intermediate energies, thenstart decreasing further with the increasing energy.Energy absorption buildup factor is comparative smaller for incident photon energy less than photon energy for which the interaction cross sections for photoelectric absorption and Compton scattering are equal (E_{pc}).The reason behind this is that at lower incident photonenergies, photoelectric absorption is the dominating in this energy range, resulting in a fastremoval of the incident low-energy gamma photons and thusnot allowing any appreciable buildup of photons. The buildup factor reaches large values at intermediate energies($E_{pc}<E <E_{pp}$),here$E_{pp}$is the energy for which the interaction cross sections for Compton scattering and pair production are equal. The values of E_{pp} and E_{pc} for chosen tissues are given in Table 10, which are obtained from XCOM computer program. The precise energy corresponding to maximumbuildup factor (E_{peak}) for each chosen tissue is given in Table10, which are obtained from figs. 1.

Table 10. Values of E_{pc} ,E_{pp} and E_{peak} for selected tissues.

Samples	E_{pc}(MeV)	E_{pp}(MeV)	E_{peak}(MeV)
Skin	0.03	26	0.1
Brain	0.03	26	0.1
Striated muscle	0.03	26	0.1
Compact bone	0.05	22	0.2
A-150	0.03	26	0.1
B-100	0.05	22	0.2

B. Effect of penetration depth on energy absorption buildup factor

The calculated of energy absorption buildup factor values have been plotted as a function of penetration depth for all selected tissues. These are shown in figs.2 (a-f) for selected photon energies 0.015, 0.15, 1.5 and 15 MeV. It is can be seen that, in general, there is continuous increase in energy absorption buildup factor with increase in penetration depth, except at photon energy 0.015 MeV, the buildup factor is almost constant (≈ unity) because of dominance of photoelectric effect, but at photon energy 0.15 MeV, the energy absorption factor values are much higher due to dominance of Compton effect. It can also be seen; at photon energy 15 MeV, the energy absorption factor values are low due to predominance of pair- production.

C. Comparison of energy absorption buildup factor for selected tissues

Figs.3 (a-d) show the variation of energy absorption buildup factor for selected tissues compared at the penetration depths 5, 10,20 and 40 mfp. Fig. 3(a) for penetration depth5 mfp, showthat the energy absorption buildup factor is generally lower for compact bone and B-100. This is due to the fact that, at low energies the photoelectric absorption is dominant for high Z_{eq}value (compact bone and B-100)leading to low value of buildup factor than other tissues.Similar results are observed for penetration depths 10, 20 and 40 mfp.Figs. 3(a-d) also show the energy absorption buildup factor has about same value for allstudied tissuesat photon energylarger than 1 MeV. In other words, the buildup factor is independent of the chemical composition at photon energy larger than 1MeV.

D.Dependence of energy absorption buildup factor on effective atomic number

As in Table 2 every tissue have different Z_{eq} at various energy levels, so to assign a particular atomic number to each material, mean of Z_{eq} of each sample at various photon energies is calculated and mean so calculated is treated as the effective atomic number i.e. Z_{eff} of that tissue. Values of Z_{eff} for A-150 , skin, brain, striated muscle, B-100 and compact bone are 6.8270, 7.0059, 7.1506, 7.1663, 10.9610 and 11.1432 respectively. Figs.4 show the energy absorption buildup factor values have been plotted as a function of Z_{eff} for penetration depth 20 mfp, it is found that for low energy region0.015- 0.1 MeV the value of buildup factor decreasing trend with increase in the valueof Z_{eff} .It is evident that at energy range 1-15MeV, there is practically no change in values of energy absorption buildup factor(Fig. 4(b)). Thus at higher energies the buildup factor is seen to be independent of Z_{eff}.

E. Variation of half value layer (HVL)with incident photon energy

Fig.5shows the variation of HVL with incident photon energy for all selected tissues. TheHVL for skin, brain, striated muscle and A-150 tissues reaches high values, on the order of 10 cm at incident photon energy1MeV, while HVL for compact bone and B-100 have values on the order of 5cm at incident photon energy1MeV.The high value of HVL in skin, brain, striated muscle and A-150 is due to the fact that these tissues have Z_{eff} comparatively lower than for compact bone and B-100.

Conclusions

The dependence of energy absorption buildup factor has been briefly discussed and following conclusions were drawn from the investigations:

- Compton scattering process increases the value of energy absorption buildup factor and the absorption processes such as photoelectric absorption and pair production lower the values of energy absorption buildup factor.
- The energy absorption buildup factor for all tissues increases with the increasing photon energy and reaches a maximum value at energy range (0.1- 0.2 MeV).
- There is continuous increase in energy absorption buildup factor with increase in penetration depth for all tissues.
- Energy absorption buildup factor is generally lower for compact bone and B-100but it is independent of the chemical composition of the selected tissues at photon energy larger than 1MeV.
- Using HVL, thecompact bone and B-100 have more gamma ray absorption thanskin, brain, striated muscle and A-150 tissues.

The present computed data and conclusions of the present investigations will be of high importance for the researchers working to help in estimating safe dose levels for radiotherapy patients and useful in radiation therapy, diagnostics, and dosimeters.

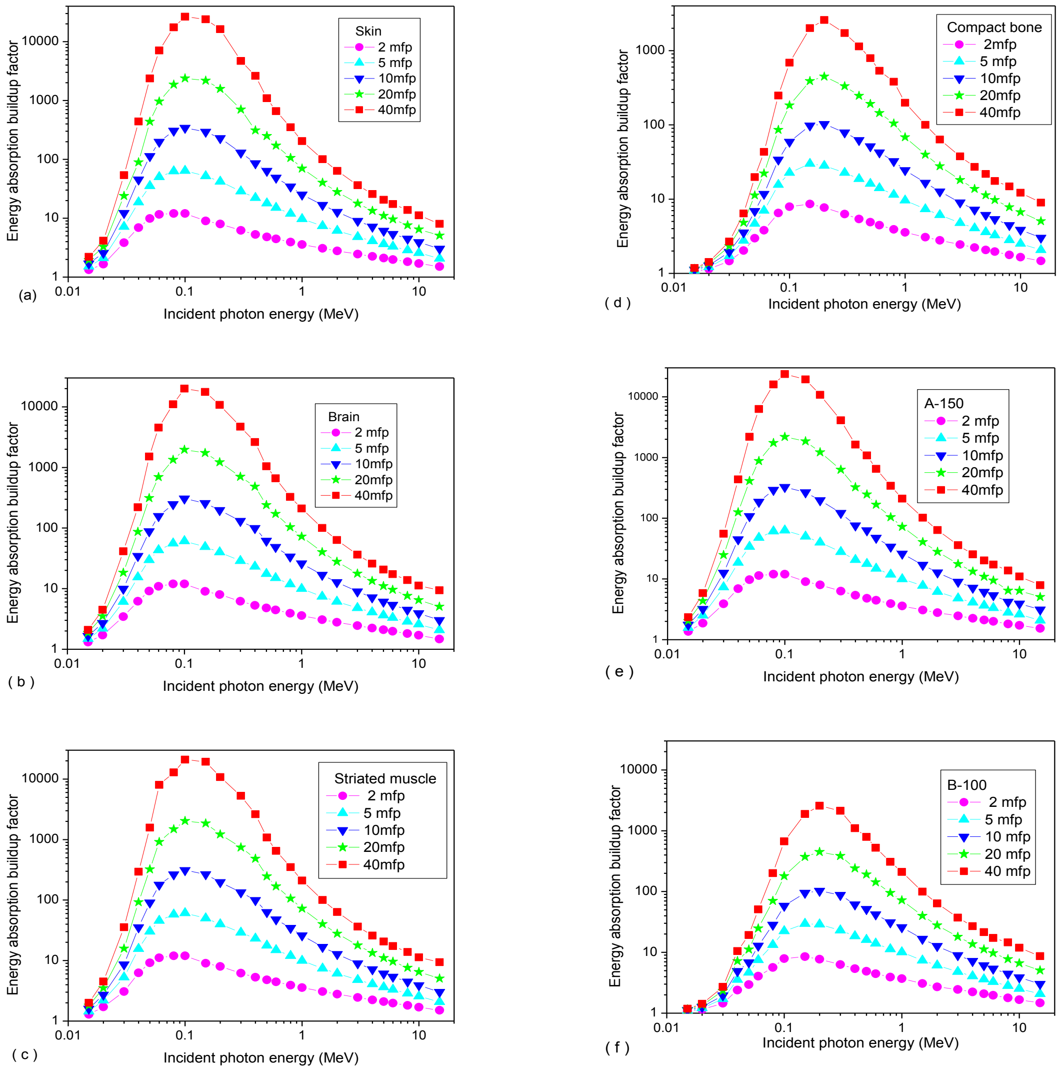

Fig. 1. Variation of the energy absorption buildup factor with incident photon energy: (a) skin tissue, (b) brain, (c) striated muscle, (d) compact bone, (e) A-150 Tissue-Equivalent Plastic and (f) B-100 Bone- Equivalent Plastic.

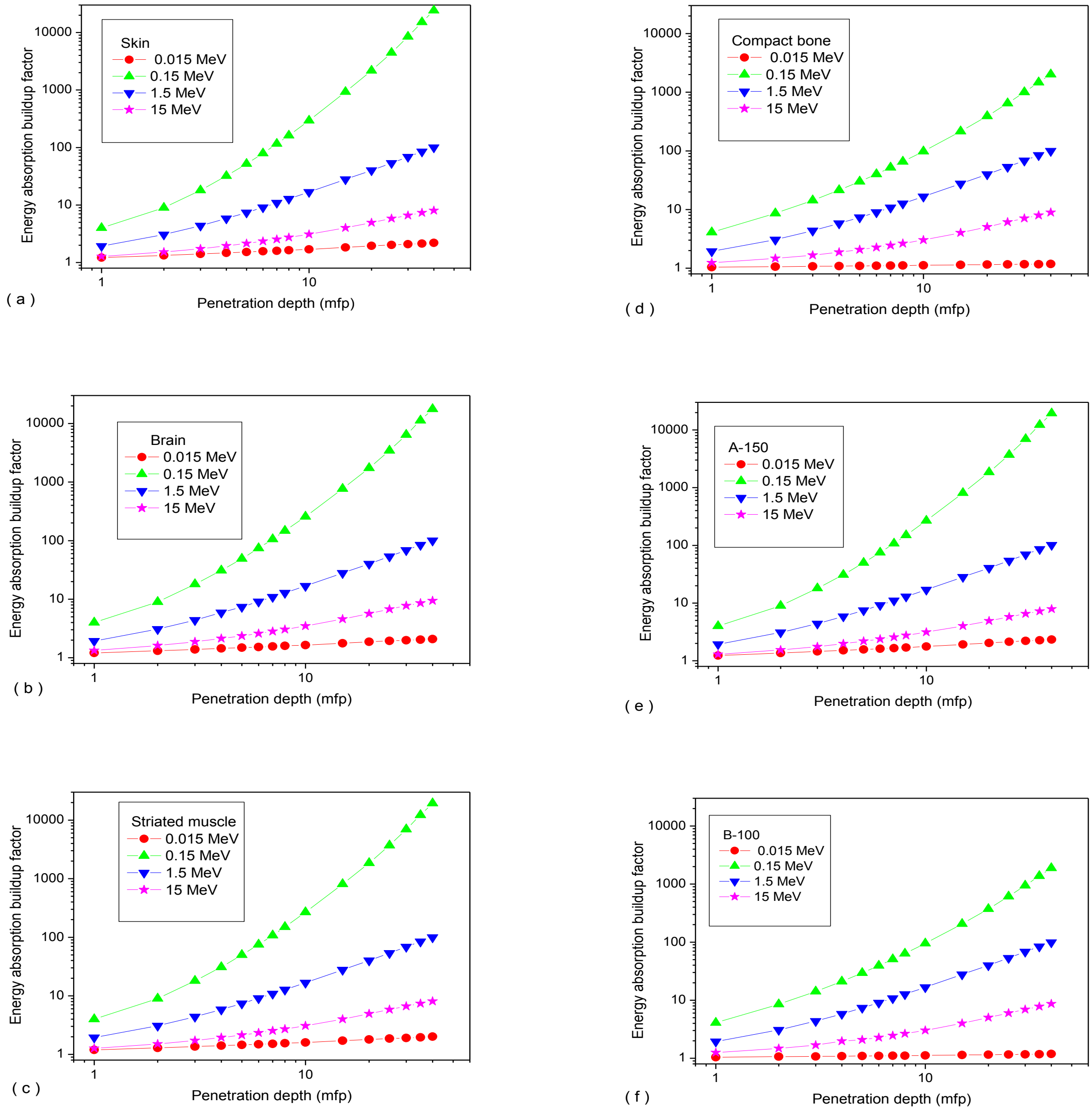

Fig. 2. Variation of the energy absorption buildup factor with penetration: (a) skin, (b) brain, (c) striated muscle, (d) compact bone, (e) A-150 Tissue-Equivalent Plastic and (f) B-100 Bone-Equivalent Plastic.

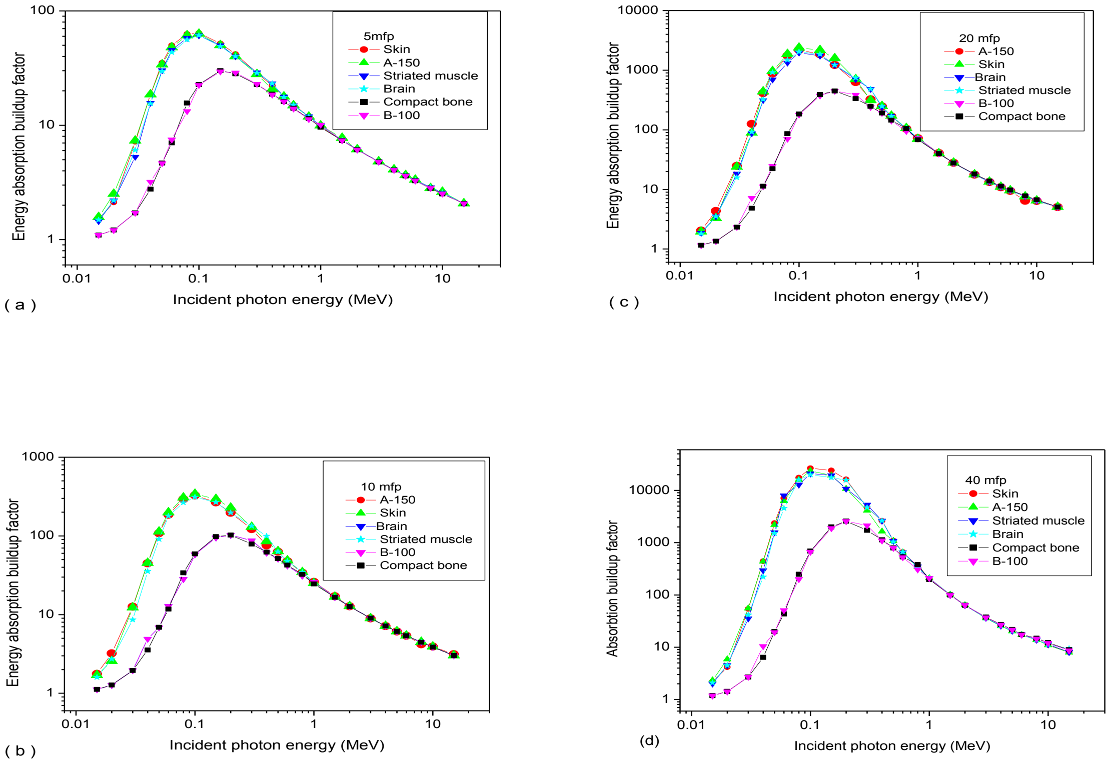

Fig. 3. Comparison of energy absorption buildup factors for human tissues and tissue equivalent plastic at: (a) 5 mfp, (b) 10mfp, (c) 20 mfp and (d) 40 mfp.

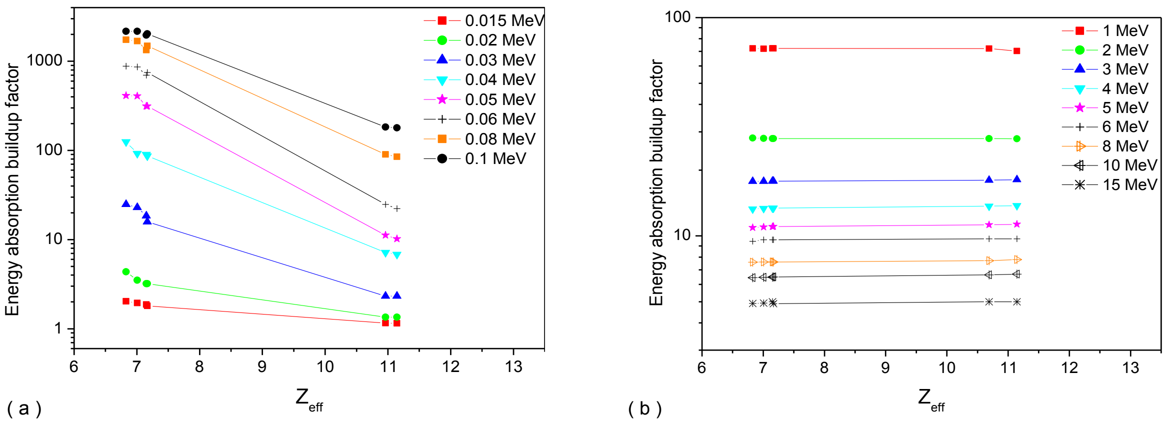

Fig. 4. The energy absorption buildup factor as a function of the effective atomic number, Z_{eff}, at 20 mfp for energy range: (a) 0.015–0.1 MeV and (b) 1–15 MeV.

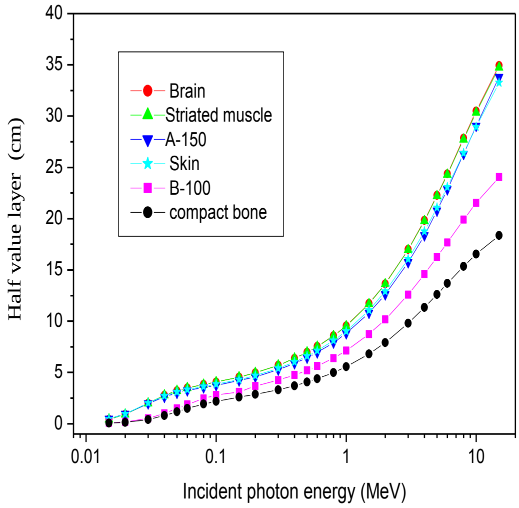

Fig. 5. Variation of the half value layer with incident photon energy range 0.015- 15MeV for all chosen tissues.

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