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.

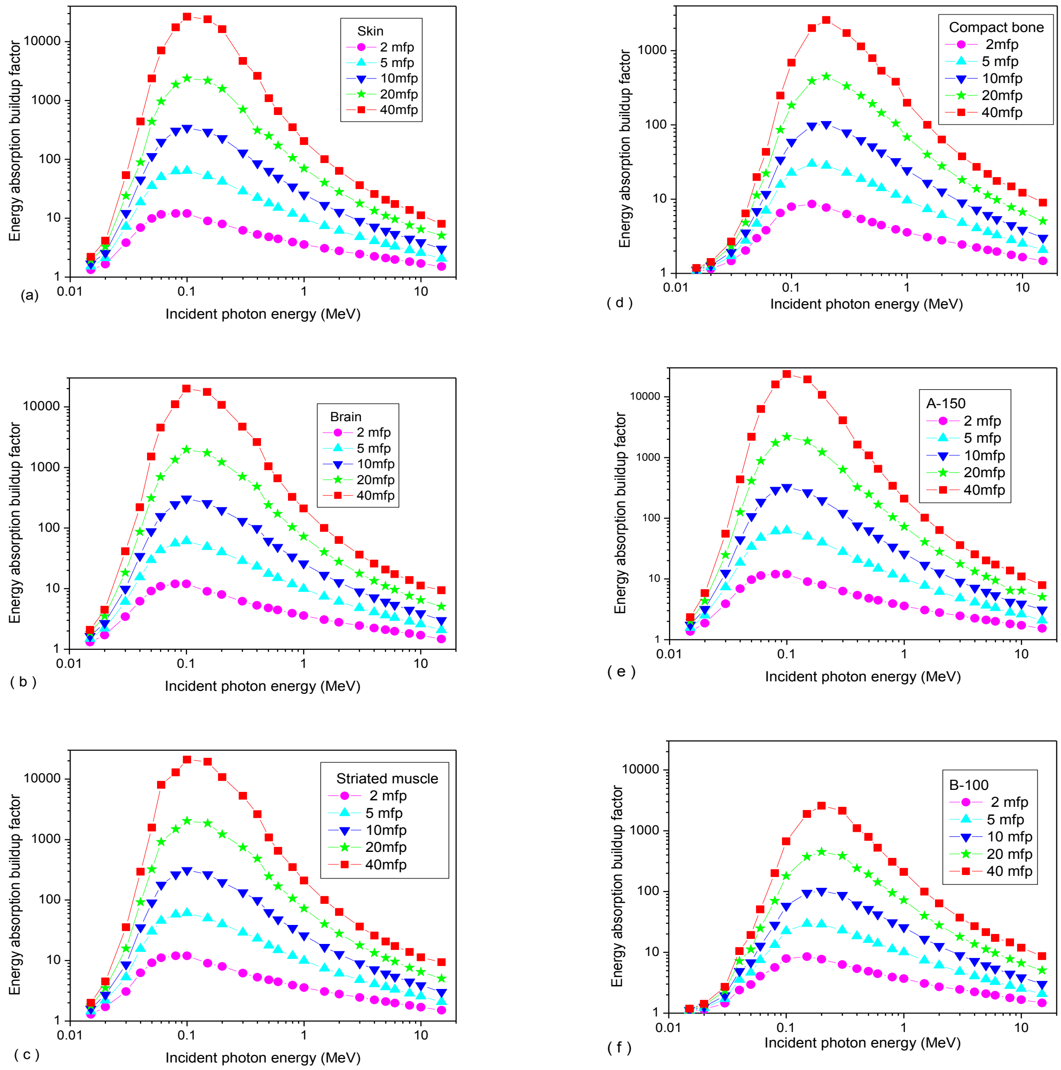

Fig. 1. Variation of the energy absorption buildup factor with incident photon energy: (a) skin tissue, (b) brain, (c) striated muscle, (d) compact bone, (e) A-150 Tissue-Equivalent Plastic and (f) B-100 Bone- Equivalent Plastic.

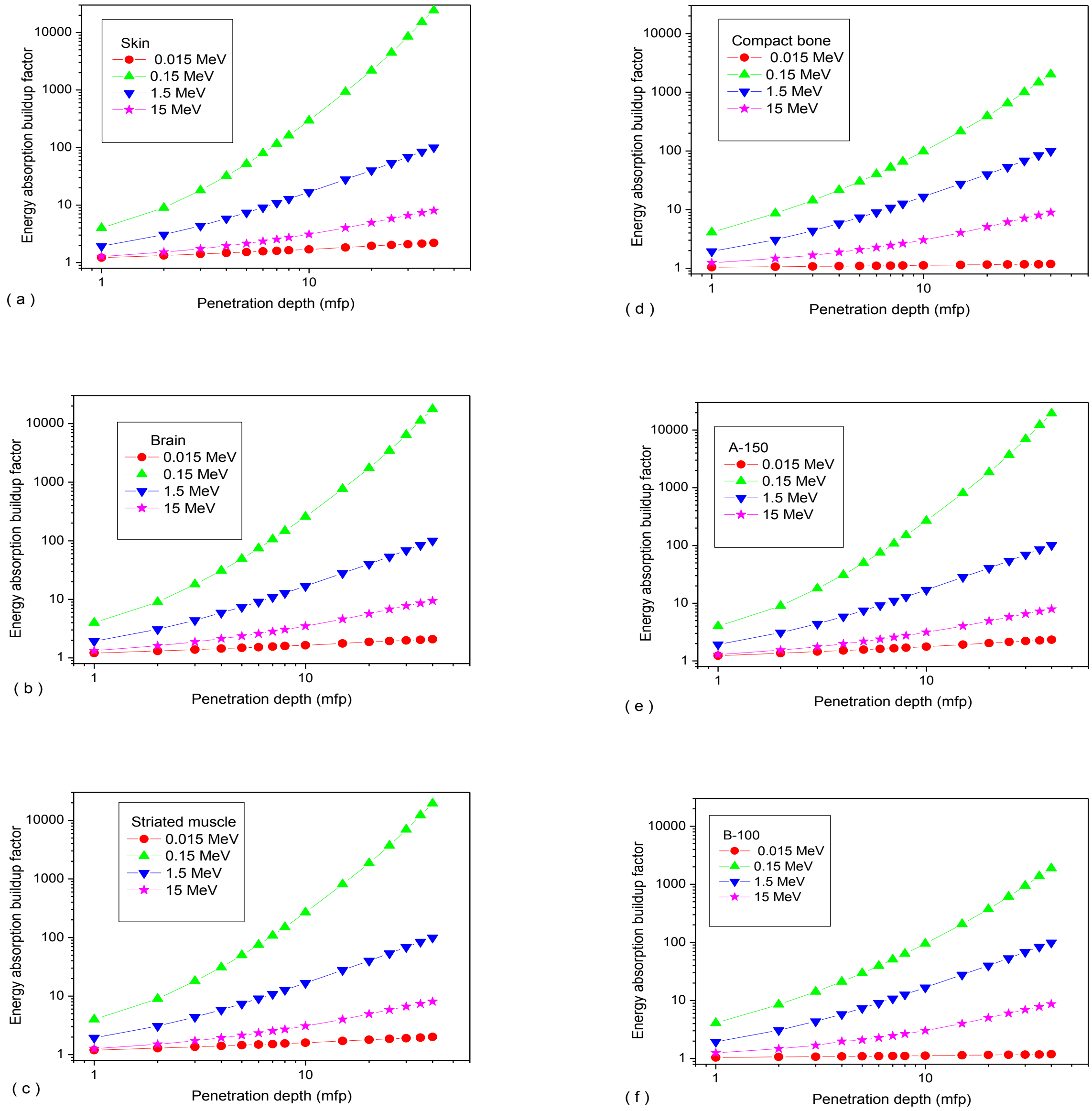

Fig. 2. Variation of the energy absorption buildup factor with penetration: (a) skin, (b) brain, (c) striated muscle, (d) compact bone, (e) A-150 Tissue-Equivalent Plastic and (f) B-100 Bone-Equivalent Plastic.

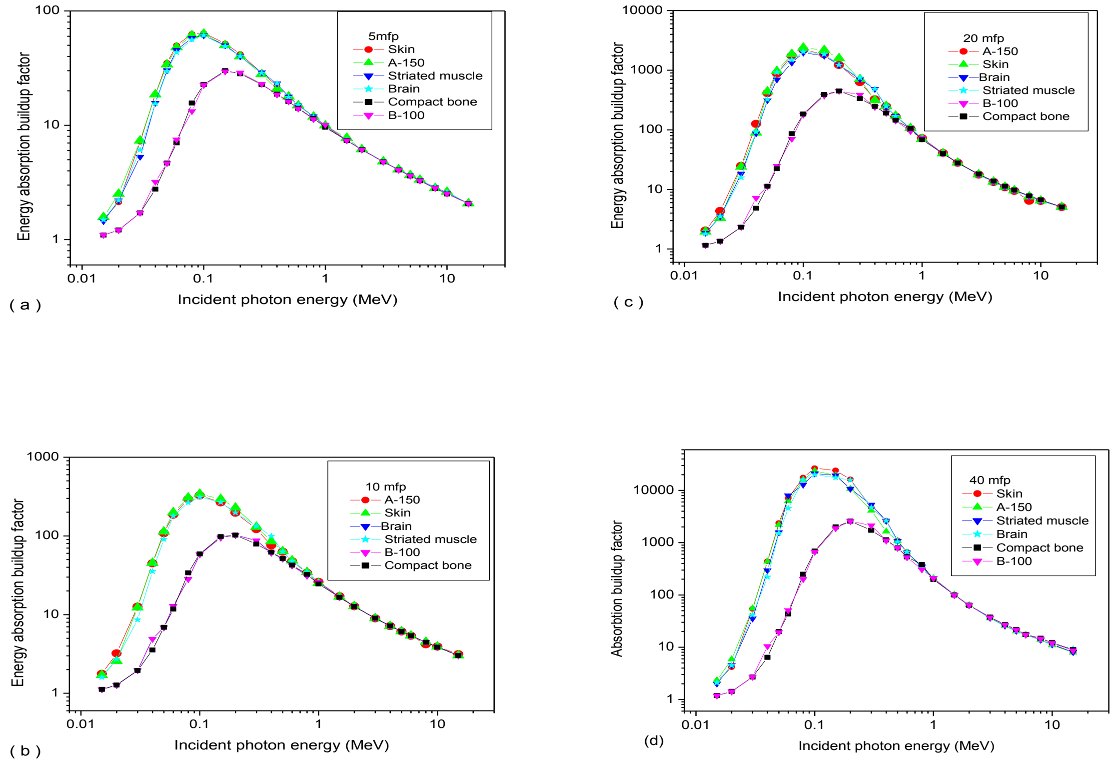

Fig. 3. Comparison of energy absorption buildup factors for human tissues and tissue equivalent plastic at: (a) 5 mfp, (b) 10mfp, (c) 20 mfp and (d) 40 mfp.

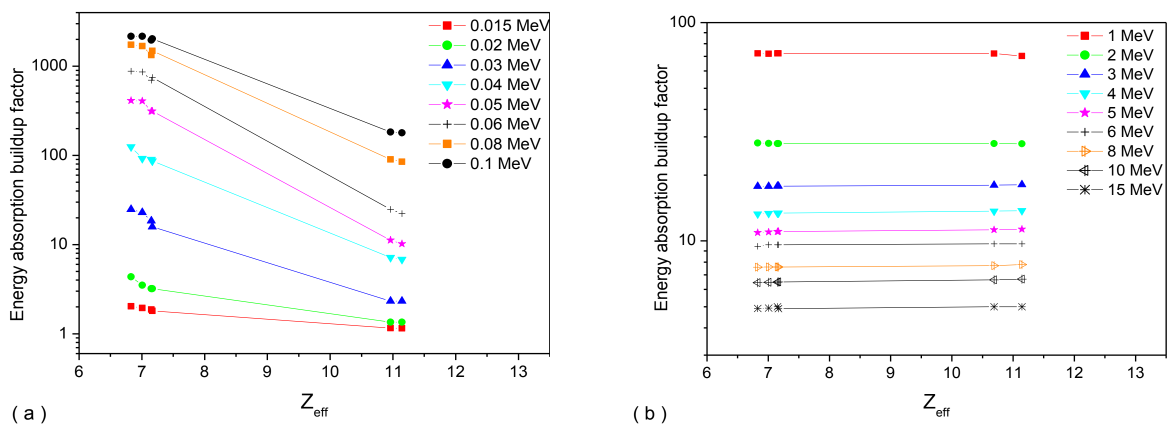

Fig. 4. The energy absorption buildup factor as a function of the effective atomic number, Z_{eff}, at 20 mfp for energy range: (a) 0.015–0.1 MeV and (b) 1–15 MeV.

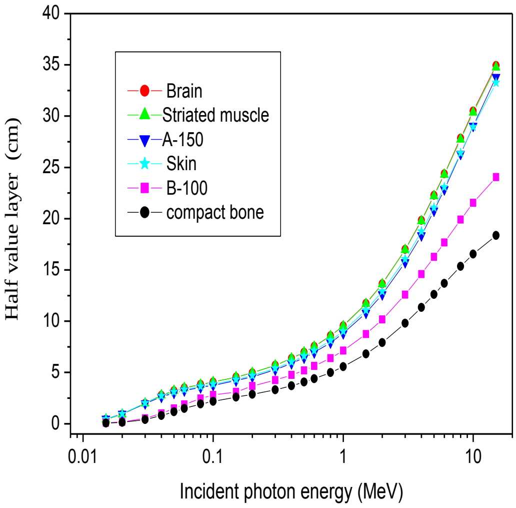

Fig. 5. Variation of the half value layer with incident photon energy range 0.015- 15MeV for all chosen tissues.

References

1. Chilton A.B., Shultis J.K. and Faw R.E. (1984) "Principle of Radiation Shielding" Prentice- Hall, Englewood cliffs, New Jersey.
2. Harima Y, Sakamoto Y, Tanaka S, Kawai M.(1986) "Validity of geometric-progression formula in approximating gamma - ray buildup factors"NuclSci Eng.;94 p.24–35.
3. 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, p.477-486.
4. Nelson, W.R., Hirayama, H.,Rogers, D.W., (1985) "EGS4 Code System" SLAC-265 Stanford Linear Accelerator Center, Stanford, California.
5. American National Standard Institute (1991) "Gamma-ray attenuation coefficients and buildup factors for engineering materials"Report ANSI/ANS-6.4.3-1991. La Grange Park, Illinois: American Nuclear Society.
6. 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,p.1093–1097.
7. SandeepGupt and GurdeepSidhu (2012) "A Comprehensive study on energy absorption and exposure buildup factor in some soils and ceramic materials" Journal of Applied Physics (IOSR-JAP) Volume 2,Issue 3, p.24-30.
8. Sardari, D. and Kurudirek,(2012) "A semi-empirical approach to the geometric progression (GP) fitting approximation in estimating photon buildup factor in soft tissue, water and dosimetric materials" International Journal of Physical Sciences Vol. 7, p.5852-5860.
9. McConn Jr., Gesh, CJ. , Pagh, RT , Rucker, RA.and Williams III ,RG, (2011) "Radiation Portal Monitor Project Compendium of Material Composition Data for Radiation Transport Modeling"Revision 1.
10. Berger M.J., Hubbell J.H. (1999) XCOM "Photon Cross Sections Database" Web Version 1.2, available. http://physics.nist.gov/xcom,National Institute of Standards and Technology, Gaithersburg, MD 20899, USA.
11. Harima,Y.(1983) "An approximation of gamma ray buildup factors by modified geometrical progression"Nucl. Sci. Eng. 83, p.299.309.