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Study of Gamma Ray Interaction with Dana's Minerals

Harpreet Singh Isher, Sandeep Gupta, Vishal Pathak, Gurdeep Singh Sidhu, Vipan Kumar

***Abstract*— The Shielding properties of gamma rays of a few minerals such as Analcime (M1), Chabazite (M2), Heulandites (M3), Pyrophyllite (M4), Scapolite (M5), Stilbite (M6) and Serpentine (M7) were investigated. Gamma-ray interaction parameters viz. Mass attenuation coefficient (μ_m), Equivalent atomic number ($Z_{eq.}$), Effective atomic number ($Z_{eff.}$) and Energy Absorption Buildup factor (EABF) were calculated and used to study the process of penetration and degradation of gamma rays in the chosen minerals. The generated interaction parameters of the chosen minerals has been studied as a function of penetration depth upto 40 mfp and incident photon energy from 15 keV to 15 MeV. The results have been shown graphically with more useful conclusions. It has been concluded that the values of energy absorption buildup factor are very large in the medium incident photon energy range i.e. 300 keV to 1000 keV where Compton scattering process is dominant and the values of EABF are less in the lower incident photon energy range where photoelectric absorption process is dominant and in the higher incident photon energy range where Pair production process is dominant.**

***Index Terms*— Equivalent atomic number, Effective atomic number, Energy Absorption Buildup factor, Mass attenuation coefficient,.**

I. INTRODUCTION

Use of gamma radiations for diagnostic such as nuclear medicine, CT (computed tomography) scanning, radiography, mammography, etc. and agriculture, industry and research is increasing rapidly, however its exposure for longer duration can be very harmful for living objects. For the safer use of these highly penetrating gamma ray photons, proper shielding materials play very important role. To check the feasibility of the use of some minerals with lower equivalent atomic number materials $Z_{eq} < 20$ as gamma ray shielding materials the following studies conducted.

Since, these materials are available in abundance and can be easily designed as required. Moreover, in case of nuclear accidents {Fukushima, japan (2011), Three Mile Island, Dauphin County, Pennsylvania, United States (1979)}, such data is very important as it tells about how safe we are in buildings made up of such minerals.

Dana's minerals are a group of rock-forming framework alumina silicates common in a wide variety of igneous and metamorphic rocks. These minerals have chemical inertness and brittle fracture behaviour and aluminosilicate members of the family of microporous solids known as "molecular sieves". Considering such properties, such chosen samples have been selected to visualize the feasibility of using these materials as gamma ray shielding material. So the effective, wide and harmless use of gamma rays in different fields , the knowledge of photon interaction parameters such as Mass attenuation coefficient (μ_m), Equivalent atomic number ($Z_{eq.}$), Effective atomic number ($Z_{eff.}$) and Energy Absorption Buildup factor (EABF) are required.

The build-up factor is a dimensionless multiplication factor which corrects the response of uncollided photon beam. The build-up factor is defined as the ratio of total value of specified radiation quantity at any point to the contribution to that value from radiation reaching the point without having undergone a collision. There are two types of buildup factors, energy absorption buildup factor in which the quantity of interest: (a) the absorbed or deposited energy in the interacting materials and detector response function is that of absorption in the interacting medium; (b) the exposure build-up factor in which quantity of interest is the exposure and detector response function is that of absorption in air (2). The build-up factors have been computed by various codes such as PALLAS (3), ADJMONI (4, 5), ASFIT (6), and EGS4 (7). These codes are using an accurate algorithmic for the Klein-Nishina cross section which eliminated other sources of errors. The compilation for build-up factors by various codes was reported in ANSI/ANS-6.4.3-1991 by American Nuclear Society (8).The data in the report covers energy range from 0.015 to 15 MeV up to penetration depth of 40 mean free path (mfp). The build-up factors in the ANS-6.4.3 are for 23 elements of atomic number, = 4 to 92.The build-up factors of ANS-6.4.3 can be calculated by invariant embedding (9,10). Harima et al. (11) developed a fitting formula, called geometric progression (GP), which gave build-up factors of the good agreement with the ANS-6.4.3. The GP fitting formula is known to be accurate within the estimated uncertainty (<5%) and Harima (2) had extensive historical review and reported the current gamma photon build-up factors and applications (12). Various researchers have investigated gamma-ray build-up factors in

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Harpreet Singh Ishar, Department of Physics, Faculty of Applied Physics, Singhania University, Rajasthan.

Sandeep Gupta, Department of Physics, Punjabi University College, Dhilwan (Barnala) Punjab.

Vishal Pathak, Department of Physics, M.B.B.G.R.G.C. Education Trust, Mansowal, Hoshiarpur.

Gurdeep Singh Sidhu, Department of Physics, Govt. Girls Sen. Sec. School, Chak Ruldu Singh Wala, Bathinda.

Vipan Kumar, Department of Physics C.J.S. Public school, Jalandhar.

different materials such as concretes (12–15), vitamin and tissue equivalent material (16), human tissues (17], Low-Z composite material(18) soils and ceramic (19) which showed that the GP fitting is a very useful method for estimation of exposure and energy absorption build-up factors. Recently the radiation shielding by fly-ash concretes (12) and building materials (20), Teeth (21) and Heavy metal oxide glass (22) has been reported (23).

Mass attenuation coefficients of the given materials have been calculated by the WinXCom program (24-25). This program which is based on the DOS based compilation XCom (26-27) provides total mass attenuation coefficient and total attenuation cross section data for about 100 elements as well as partial cross sections for incoherent and coherent scattering, photoelectric absorption and pair production at energies from 1 keV to 100 GeV. G. J. Hine (29) has pointed out that in composite materials, for photon interactions, a single number cannot represent the atomic number uniquely across the entire energy region, as in the case of pure elements.This number for composite materials is known as "effective atomic number" (Z_{eff}) and it varies with energy.

In the present work an attempt has been made to compute EABF values by using G-P fitting method for some low-Z minerals in the energy range 15 keV- 15 MeV up to a penetration depth 40 mfp. Such data will be of prime importance for radiation shield designing (30) and production of a new materials made up from minerals for gamma radiation shielding. The emphasis has been focused on the dependence of energy absorption buildup factor on the chemical composition or equivalent atomic number (Zeq), mass attenuation coefficient [μ_m or $(\mu/\rho) = (\mu/\rho)_c$] and effective atomic number ($Z_{eff.}$) of the selected samples . The molecular formula's of the chosen minerals samples obtained from Handbook of "Dana's minerals and how to study them" by "Cornelius S. Hurlbul and W.Edwin Sharp (31). The Molecular formula's of the selected minerals has been given in table 1.

Table 1.Molecular formula's of Dans's Minerals

Sr. No.	Name of chosen minerals	Molecular formula	Density (gm/cc)
1	Analcime (M1)	$Na_2Al_2Si_4O_{12}.2H_2O$	2.27
2	Chabazite (M2)	$CaAl_2Si_4O_{12}.6H_2O$	2.10
3	Heulandites (M3)	$CaAl_2Si_7O_{18}.6H_2O$	2.20
4	Pyrophyllite (M4)	$Al2Si_4O_{10}(OH)_2$	2.81
5	Scapolite (M5)	$(Na,Ca)_4(Al_2Si_2O8)_3(Cl, CO_3)$	2.65
6	Stilbite (M6)	$NaCa_2Al_5Si_{13}O_{36}.14H_2O$	2.15
7	Serpentine (M7)	$Mg_6Si_4O_{10}(OH)_8$	2.60

II. The Method of Computation on Theoretical Basis

A parallel beam of mono energetic X-ray or Gamma photons passing through matter is attenuated due to absorption and scattering. Attenuation due to absorption follows the "Beer –Lambert"s law,

$$I = Io\ e^{-\mu x} = Io\ e^{-(\mu/\rho)d}, \qquad (1)$$

where Io and I are the un-attenuated and attenuated photon intensities, d is the mass per unit area (g/cm^2) and μ/ρ is the photon mass attenuation coefficient (cm^2/g). The photon mass attenuation coefficient $(\mu/\rho)c$ for any chemical compound or mixture of elements is given by the "mixture rule"

$$(\mu/\rho)c = i\ wi(\mu/\rho)i, \qquad (2)$$

where *wi* and $(\mu/\rho)i$ are the weight fraction and photon mass attenuation coefficient of the *i*th constituent element, respectively. For a chemical compound the fraction by weight (wi) is given by; $w_i = \frac{n_i A_i}{\sum_j^{n_j A_j}} w$, where A*i* is the atomic weight of the *i*th element and *ni* is the number of formula units.

The total cross- section (σ) in turn can be related as the sum of partial cross sections,

$$\sigma = \sigma coh + \sigma incoh + \tau + K + \sigma ph, n, \qquad (3)$$

where σcoh , σincoh, are coherent (Rayleigh) and incoherent (Compton) scattering cross-sections, respectively. τ is the atomic photoelectric cross-section, K is the positron electron pair production cross section and σph, n is the photonuclear cross –section .

The values of mass attenuation coefficient were then used to determine the total molecular crosssection (σm) by the following relation,

$$\sigma_m = \frac{M}{N_A}\left(\frac{\mu}{\rho}\right)_c, \qquad (4)$$

where $M = \sum_i n_i A_i$, is the molecular weight of the compound, N_A is the Avogadro"s number,N_i is the total number of atoms (with respect to mass number) in the molecule, A_i is the atomic weight of *i*th element in a molecule.

The effective (average) atomic cross-section (σa) can easily be determined from the following equation,

$$\sigma_a = \frac{1}{N_I}\sum f_i A_i \left(\frac{\mu}{\rho}\right)_i \qquad (5)$$

Similarly, effective electronic cross- section (σe) for the individual element is given by the following formula

$$\sigma_e = \frac{1}{N_I}\sum \frac{f_i A_i}{z_i}\left(\frac{\mu}{\rho}\right)_i = \frac{\sigma_a}{z_{eff}} \qquad (6)$$

Where $f_i = \frac{n_i}{\sum_j n_j}$ and Z*i* are the fractional abundance and atomic number of constituent element, respectively. *ni* is the total number of atoms of the constituent element, $\sum_j n_j$ is the total number of atoms present in the molecular formula.

Now, the effective atomic number (Zeff) can be given as(32)

$$Zeff = \frac{\sigma_a}{\sigma_c} \qquad (7)$$

III. Buildup Factor

The computational work of energy absorption buildup factor has been divided into three parts. The first part concern with the computation of equivalent atomic number (Z_{eq}) for the selected minerals. The second part deals with the computation of G.P. fitting parameters and finally in the third part, energy absorption buildup factor values have been computed. The results so obtained have been shown in the tabular form (Table 3) for Z_{eq} the selected minerals.

A. Computation of equivalent atomic number

Firstly the values of Compton partial attenuation coefficient ($^{\mu}$comp) and total attenuation coefficients ($^{\mu}$tot.) in cm^2/g were obtained for elements from Z = 1 to 25 and chosen samples in the energy of 15 keV-15.0 MeV, using the state-of-the-art and convenient computer program XCOM and WinXCom (24-25).Further, by using a simple computer program, the ratio R ($^{\mu}$cmop/$^{\mu}$tot) was obtained for selected minerals. Then the value of equivalent atomic number (Z_{eq}) for these samples was calculated by matching the ratio R ($^{\mu}$cmop/$^{\mu}$tot) of particular sample at a given energy with corresponding ratios of elements at the same energy. For the case the ratio lies in between the two ratios of known elements. The value of Z_{eq} was interpolated by using the following formula of interpolation (2) given in the following equation

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

WhereZ_1 and Z_2 are the atomic numbers of elements corresponding to the ($^{\mu}$cmop/$^{\mu}$tot.) ratios, R_1 and R_2, respectively; and R ($^{\mu}$cmop/$^{\mu}$tot.) is the ratio for the selected minerals at a particular energy which lies between ratios R_1 and R_2.

B. Computation of G.P. fitting parameters

American National Standard has provided the energy absorption G.P. fitting parameters of 23 elements (Be, B, C, N, O, Na, Mg, Al,Si, P, S, Ar, K, Ca, Fe, Cu, Mo, Sn, La, Gd, W, Pb and U), one compound(water) and two mixtures (air and concrete) in the energy range of 15 keV -15.0 MeV and upto a penetration depth of 40 mfp (ANSI/ANS-6.4.3 1991).

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_{eq}), in the chosen energy range (15 keV -15.0 MeV) up to penetration depth of 40 mfp. The formula used for the purpose of interpolation (33) is as follows:

$$C = \frac{C_1\left(\log Z_2 - \log Z_{eq}\right) + C_2\left(\log Z_{eq} - \log Z_1\right)}{\log Z_2 - \log Z_1}$$

Here C_1 and C_2 are the values of G.P. fitting parameters corresponding to the atomic numbers Z_1 and Z_2 respectively at a fixed energy, whereas Z is the equivalent atomic number of the chosen sample at the same energy. Z_1 and Z_2 are the elemental atomic numbers between which the equivalent atomic number Z of the chosen samples lies.

C. Computation of Energy Absorption Buildup Factor

The computed G.P. fitting parameters were then used to compute the energy absorption buildup factors for the selected samples at some standard incident photon energies up to a penetration depth of 40 mean free paths, with the help of G.P. fitting formula, as given by following equations (2).

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

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

Where

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

$$\text{for } x \leq 40mfp \qquad (5)$$

where a, b, c, d and Xk are the G-P fitting parameters and x is source to detector distance in the medium (mfp). The parameter K (E, x) represents photon dose multiplication.

Table 3 Equivalent atomic numbers (Z_{eq}) of different minerals in the energy range of 15 keV - 15.0 MeV

E(MeV)	M1	M2	M3	M4	M5	M6	M7
0.015	11.04	11.85	11.77	11.27	13.35	11.66	10.76
0.02	11.08	11.96	11.87	11.33	13.46	11.74	10.83
0.03	11.12	12.11	12.01	11.37	13.56	11.86	10.86
0.04	11.17	12.17	12.05	11.4	13.65	11.94	10.91
0.05	11.24	12.24	12.12	11.45	13.72	11.96	10.98
0.06	11.23	12.31	12.18	11.44	13.79	12.01	10.93
0.08	11.24	12.27	12.2	11.47	13.77	12.1	10.96
0.1	11.34	12.33	12.35	11.55	13.84	12.14	11.09
0.15	10.9	11.82	11.85	10.9	14.01	11.85	10.88
0.2	12.92	12.87	12.89	12.92	14.49	12.89	10.5
0.3	12.5	12.5	12.5	12.5	14.5	12.5	10.5
0.4	12.5	12.5	12.5	12.5	14.5	12.5	10.5
0.5	12.5	12.5	12.5	12.5	14.5	12.5	10.5
0.6	12.5	12.5	12.5	12.5	14.5	12.5	10.5
0.8	12.5	12.5	12.5	12.5	14.5	12.5	10.5
1	12.5	12.5	12.5	12.5	14.5	12.5	10.5
1.5	12.5	12.5	12.5	12.5	14.5	12.5	10.5
2	9.711	8.663	9.622	9.711	12.9	9.608	9.637
3	10.3	10.18	10.21	10.3	12.62	10.58	9.745
4	10.28	10.43	10.14	10.6	11.99	10.14	9.769
5	10.18	10.27	10.31	10.49	12.28	10.31	9.788
6	10.17	10.51	10.57	10.46	11.92	10.57	10.06
8	10.09	10.49	10.55	10.29	12.16	10.36	9.973
10	10.21	10.3	10.51	10.5	12.14	10.37	9.931
15	10.26	10.43	10.43	10.51	12.01	10.31	10.05

IV. Result And Discussion

In the present work, the variations of mass attenuation coeff. (μ_m) and Effective atomic number(Z_{eff}) with photon energy for selected minerals composed of different elements (Table 1) were studied. The results are shown graphically in Figs. 1-2 for total photon interaction processes. The Z_{eff} values are given in (Table 2) only for total photon interaction. The present results clearly confirm the comment made by Hine [29] that the effective atomic number varies with energy. Also we discussed the results of energy absorption buildup factor as a function of incident photon energy and penetration depth.

Table 2: Effective atomic numbers (z_{eff}) of selected minerals (listed in table 1) for total photon interaction (with coherent)

E (MeV)	M1	M2	M3	M4	M5	M6	M7
.1000E-02	.4061E+01	.4193E+01	.4173E+01	.4102E+01	.4127E+01	.4165E+01	.4061E+01
.1500E-02	.4412E+01	.4305E+01	.4281E+01	.4199E+01	.4445E+01	.4314E+01	.4952E+01
.2000E-02	.5674E+01	.5484E+01	.5579E+01	.5748E+01	.5505E+01	.5547E+01	.5600E+01
.3000E-02	.5896E+01	.5674E+01	.5789E+01	.5997E+01	.5854E+01	.5751E+01	.5806E+01
.4000E-02	.6024E+01	.5794E+01	.5925E+01	.6093E+01	.6004E+01	.5884E+01	.5933E+01
.5000E-02	.6083E+01	.6340E+01	.6311E+01	.6159E+01	.6835E+01	.6273E+01	.6016E+01
.6000E-02	.6126E+01	.6407E+01	.6378E+01	.6205E+01	.6946E+01	.6337E+01	.6057E+01
.8000E-02	.6170E+01	.6496E+01	.6461E+01	.6256E+01	.7055E+01	.6414E+01	.6095E+01
.1000E-01	.6179E+01	.6537E+01	.6490E+01	.6273E+01	.7105E+01	.6444E+01	.6102E+01
.1500E-01	.6055E+01	.6451E+01	.6402E+01	.6147E+01	.7078E+01	.6349E+01	.5955E+01
.2000E-01	.5584E+01	.6146E+01	.6092E+01	.5730E+01	.6809E+01	.6044E+01	.5457E+01
.3000E-01	.3878E+01	.4592E+01	.4497E+01	.4052E+01	.5496E+01	.4415E+01	.3722E+01
.4000E-01	.2398E+01	.2887E+01	.2817E+01	.2495E+01	.3586E+01	.2763E+01	.2317E+01
.5000E-01	.1759E+01	.2040E+01	.2000E+01	.1812E+01	.2424E+01	.1971E+01	.1718E+01
.6000E-01	.1458E+01	.1633E+01	.1603E+01	.1489E+01	.1856E+01	.1585E+01	.1434E+01
.8000E-01	.1216E+01	.1305E+01	.1286E+01	.1229E+01	.1388E+01	.1280E+01	.1210E+01
.1000E+00	.1122E+01	.1176E+01	.1169E+01	.1129E+01	.1209E+01	.1162E+01	.1122E+01
.1500E+00	.1044E+01	.1081E+01	.1074E+01	.1051E+01	.1074E+01	.1074E+01	.1059E+01
.2000E+00	.1024E+01	.1048E+01	.1048E+01	.1024E+01	.1032E+01	.1048E+01	.1032E+01
.3000E+00	.1008E+01	.1036E+01	.1026E+01	.1017E+01	.1008E+01	.1026E+01	.1026E+01
.4000E+00	.1008E+01	.1029E+01	.1023E+01	.1008E+01	.1001E+01	.1024E+01	.1019E+01
.5000E+00	.1008E+01	.1029E+01	.1023E+01	.1008E+01	.0000E+00	.1024E+01	.1020E+01
.6000E+00	.1005E+01	.1025E+01	.1020E+01	.1005E+01	.0000E+00	.1020E+01	.1016E+01
.8000E+00	.1006E+01	.1026E+01	.1020E+01	.1006E+01	.0000E+00	.1021E+01	.1017E+01
.1000E+01	.1006E+01	.1027E+01	.1020E+01	.1006E+01	.0000E+00	.1022E+01	.1017E+01
.1022E+01	.1005E+01	.1026E+01	.1019E+01	.1005E+01	.0000E+00	.1021E+01	.1016E+01
.1250E+01	.1005E+01	.1025E+01	.1019E+01	.1005E+01	.0000E+00	.1019E+01	.1016E+01
.1500E+01	.1006E+01	.1025E+01	.1019E+01	.1006E+01	.0000E+00	.1021E+01	.1016E+01
.2000E+01	.1014E+01	.1034E+01	.1027E+01	.1014E+01	.1005E+01	.1029E+01	.1025E+01
.2044E+01	.1016E+01	.1037E+01	.1030E+01	.1016E+01	.1007E+01	.1032E+01	.1028E+01
.3000E+01	.1043E+01	.1063E+01	.1057E+01	.1043E+01	.1040E+01	.1060E+01	.1054E+01
.4000E+01	.1079E+01	.1103E+01	.1099E+01	.1082E+01	.1082E+01	.1099E+01	.1089E+01
.5000E+01	.1121E+01	.1145E+01	.1141E+01	.1125E+01	.1133E+01	.1141E+01	.1129E+01
.6000E+01	.1163E+01	.1189E+01	.1185E+01	.1168E+01	.1185E+01	.1185E+01	.1172E+01
.7000E+01	.1205E+01	.1233E+01	.1228E+01	.1210E+01	.1233E+01	.1228E+01	.1214E+01
.8000E+01	.1251E+01	.1281E+01	.1276E+01	.1256E+01	.1286E+01	.1271E+01	.1261E+01
.9000E+01	.1299E+01	.1326E+01	.1320E+01	.1304E+01	.1342E+01	.1320E+01	.1304E+01
.1000E+02	.1339E+01	.1368E+01	.1368E+01	.1350E+01	.1390E+01	.1362E+01	.1345E+01
.1100E+02	.1384E+01	.1414E+01	.1414E+01	.1390E+01	.1437E+01	.1408E+01	.1390E+01
.1200E+02	.1426E+01	.1457E+01	.1451E+01	.1432E+01	.1488E+01	.1451E+01	.1426E+01
.1300E+02	.1460E+01	.1493E+01	.1493E+01	.1473E+01	.1531E+01	.1486E+01	.1467E+01
.1400E+02	.1505E+01	.1532E+01	.1532E+01	.1511E+01	.1579E+01	.1525E+01	.1505E+01
.1500E+02	.1537E+01	.1572E+01	.1572E+01	.1551E+01	.1620E+01	.1565E+01	.1537E+01
.1600E+02	.1572E+01	.1608E+01	.1608E+01	.1586E+01	.1665E+01	.1600E+01	.1572E+01
.1800E+02	.1647E+01	.1685E+01	.1677E+01	.1662E+01	.1745E+01	.1670E+01	.1640E+01
.2000E+02	.1710E+01	.1749E+01	.1749E+01	.1726E+01	.1820E+01	.1742E+01	.1703E+01
.2200E+02	.1774E+01	.1814E+01	.1814E+01	.1790E+01	.1895E+01	.1806E+01	.1766E+01
.2400E+02	.1826E+01	.1868E+01	.1868E+01	.1843E+01	.1960E+01	.1860E+01	.1818E+01
.2600E+02	.1883E+01	.1926E+01	.1926E+01	.1900E+01	.2017E+01	.1918E+01	.1875E+01
.2800E+02	.1933E+01	.1977E+01	.1977E+01	.1951E+01	.2068E+01	.1960E+01	.1925E+01
.3000E+02	.1978E+01	.2018E+01	.2018E+01	.1996E+01	.2106E+01	.2011E+01	.1969E+01
.4000E+02	.2132E+01	.2171E+01	.2171E+01	.2147E+01	.2286E+01	.2163E+01	.2124E+01
.5000E+02	.2237E+01	.2276E+01	.2283E+01	.2260E+01	.2400E+01	.2268E+01	.2221E+01
.6000E+02	.2310E+01	.2357E+01	.2357E+01	.2333E+01	.2489E+01	.2341E+01	.2302E+01
.8000E+02	.2411E+01	.2457E+01	.2465E+01	.2442E+01	.2606E+01	.2450E+01	.2403E+01
.1000E+03	.2480E+01	.2519E+01	.2526E+01	.2503E+01	.2674E+01	.2511E+01	.2464E+01
.1500E+03	.2560E+01	.2613E+01	.2613E+01	.2591E+01	.2773E+01	.2598E+01	.2545E+01
.2000E+03	.2605E+01	.2649E+01	.2657E+01	.2635E+01	.2821E+01	.2642E+01	.2590E+01
.3000E+03	.2646E+01	.2689E+01	.2697E+01	.2675E+01	.2864E+01	.2682E+01	.2624E+01
.4000E+03	.2660E+01	.2710E+01	.2710E+01	.2689E+01	.2882E+01	.2696E+01	.2639E+01
.5000E+03	.2665E+01	.2714E+01	.2722E+01	.2700E+01	.2890E+01	.2707E+01	.2651E+01
.6000E+03	.2673E+01	.2722E+01	.2729E+01	.2701E+01	.2896E+01	.2715E+01	.2652E+01
.8000E+03	.2684E+01	.2732E+01	.2739E+01	.2711E+01	.2904E+01	.2718E+01	.2663E+01
.1000E+04	.2682E+01	.2729E+01	.2736E+01	.2715E+01	.2905E+01	.2722E+01	.2661E+01
.1500E+04	.2678E+01	.2724E+01	.2730E+01	.2704E+01	.2895E+01	.2717E+01	.2658E+01
.2000E+04	.2689E+01	.2735E+01	.2742E+01	.2716E+01	.2907E+01	.2729E+01	.2669E+01
.3000E+04	.2674E+01	.2718E+01	.2725E+01	.2706E+01	.2891E+01	.2712E+01	.2655E+01
.4000E+04	.2678E+01	.2730E+01	.2736E+01	.2710E+01	.2897E+01	.2717E+01	.2659E+01
.5000E+04	.2684E+01	.2729E+01	.2736E+01	.2716E+01	.2903E+01	.2723E+01	.2665E+01
.6000E+04	.2670E+01	.2721E+01	.2728E+01	.2702E+01	.2892E+01	.2708E+01	.2658E+01
.8000E+04	.2676E+01	.2727E+01	.2733E+01	.2708E+01	.2892E+01	.2714E+01	.2657E+01
.1000E+05	.2682E+01	.2726E+01	.2733E+01	.2707E+01	.2898E+01	.2720E+01	.2663E+01
.1500E+05	.2669E+01	.2719E+01	.2725E+01	.2700E+01	.2887E+01	.2706E+01	.2650E+01
.2000E+05	.2674E+01	.2718E+01	.2724E+01	.2699E+01	.2887E+01	.2712E+01	.2655E+01
.3000E+05	.2674E+01	.2724E+01	.2731E+01	.2706E+01	.2887E+01	.2712E+01	.2655E+01
.4000E+05	.2674E+01	.2724E+01	.2730E+01	.2705E+01	.2893E+01	.2711E+01	.2655E+01
.5000E+05	.2674E+01	.2724E+01	.2730E+01	.2705E+01	.2893E+01	.2711E+01	.2655E+01
.6000E+05	.2674E+01	.2724E+01	.2730E+01	.2705E+01	.2893E+01	.2711E+01	.2661E+01
.8000E+05	.2674E+01	.2724E+01	.2730E+01	.2705E+01	.2893E+01	.2718E+01	.2661E+01
.1000E+06	.2679E+01	.2723E+01	.2730E+01	.2704E+01	.2893E+01	.2717E+01	.2660E+01

A. Dependence of shielding effectiveness on mass attenuation coefficient

Fig. 1 shows the results of total mass attenuation coefficient of chosen minerals against photon energy. From figure it can be easily seen that (i) there are three energy ranges where photoelectric absorption, Compton scattering and pair production, respectively, are the dominating attenuation processes. It is seen that variation in (μ_m) with chemical composition is large below 100 keV and significant between 0.3- 1 MeV and further there is negligible variation in (μ_m) above 1 MeV incident photon energy. These variations are interpreted as being due to (i) photoelectric effect which varies as Z^{4-5} and (ii) less but significantly due to coherent scattering which varies as Z^{2-3}. This fact has been verified experimentally by Singh [34] by measuring total mass attenuation coefficient of some soils.

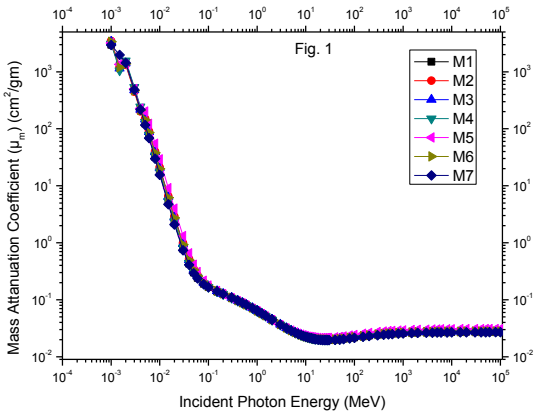


Fig. 1 Variation of photon mass attenuation coefficient (μ_m) of selected samples with incident photon energy

. The present theoretical results are similar to the observations of Zavel"ski [35] who proposed a direct relation of μ_m with low energy of heavy metals in the rock salt. In the intermediate energy region, where incoherent scattering is the most dominant process, the mass attenuation coefficient is found to be constant and is due to the linear Z-dependence of incoherent scattering and insignificant role played by pair production. In the high energy region, the variation in mass attenuation coefficient is due to the Z^2-dependence of pair production (35).

B. *Dependence of effective atomic number (Z_{eff}) on incident photon energy*

The variation of Z_{eff} with photon energy for total photon interaction (Fig. 2) shows the dominance of different interaction process in different energy regions. The behaviour of all selected minerals listed is almost identical. But M7 have low value of Zeff and M5 show higher value, so we conclude that M5 can be used as good shielding effectiveness than others minerals.In low energy region photoelectric interaction is dominant; Z_{eff} varies as in case of photo interaction process. From 8-10 keV onwards there is a sharp decrease in Z_{eff} with energy up to 90-100 keV, showing that contribution of scattering processes increases which decreases Z_{eff}. This fact is also confirmed by Sastry and Jayanand [36]. According to them Z_{eff} of composite material for photoelectric interaction is greater than other processes.

From 150 keV to 2 MeV, Z_{eff} is almost independent of energy. This may be due to the dominance of incoherent scattering in this region. From 3 to 200 MeV, there is regular increase in Z_{eff} with photon energy. This behaviour is due to mixed contribution of incoherent scattering and pair production. Above 200 MeV, Z_{eff} remains almost constant. This may be due to the dominance of pair production in the high energy region. It is observed that the variation in Z_{eff} also depends upon relative proportion and the range of atomic numbers of the elements of which the selected minerals are composed.

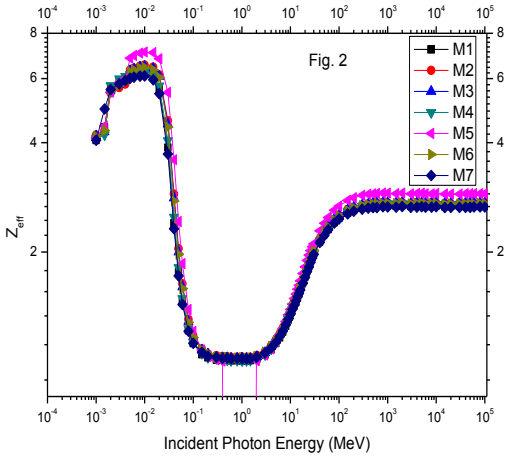


Fig. 2 Variation of effective atomic number (Z_{eff}) of selected samples with incident photon energy

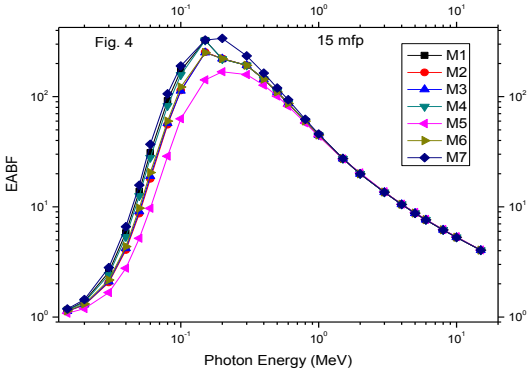
C. Dependence of Energy absorption buildup factor (EABF) on incident photon energy

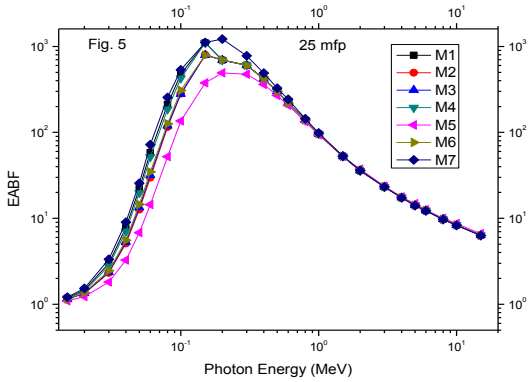
Fig. 3-6 shows the variation in EABF with incident photon energy in the energy range 15 keV- 15 MeV at different penetration depths up to 40 mfp. It is worthnoting that all the minerals show almost similar variations of EABF in the continuous energy region based on domination of different photon interaction processes in different energy regions. From all these figures it is observed that the values of EABF for all minerals in the selected incident energy region up to penetration depth of 40 mfp is always greater than one.This is because of buildup of photons is due to larger penetration depth or due to the beam divergence. At lower energy range photo electric interaction process is dominant and atomic cross-section for photoelectric absorption is proportional to Z^{4-5}. However as the incident photon energy increase the Compton scattering process dominates. Here maximum value of EABF were observed at intermediate energy range (0.09-0.3 MeV). In this energy region Compton scattering process fails to remove a photon completely but only degradation of photon energy takes place. It is due to multiple scattering of photons they exist for longer time in material which leads to a higher value of buildup factor. It is indicate that the value of EABF is minimum for sample M5 in this energy region. This implies that the contribution of secondary gamma ray photons to energy spectra would be maximum in this energy range for all the sample under consideration. This

results in a broad peak around a particular value of incident photon energy called peak value of energy (E_{peak}). At higher energies the pair production starts dominating, but there is no significant variation in the EABF with Z_{eq}. Since the cross-section of **(e^{-} - e^{+})** Pair production is approximately proportional to Z^2. The cross section increasing slowly with incident photon energy between the 1022 keV to about 4 MeV. For further higher energies it is proportional to log E. EABF have low value at lower and higher energy regions of the selected range. It is due to the dominance of photoelectric absorbtion and pair/triplet production over Compton scattering, which result in the complete removal of photon at fixed penetration depth, so in this energy range the EABF values can reach in the order of 1.

D. Dependence of Energy absorption buildup factor (EABF) on penetration depth

Figures 7-10 show the variation of energy absorption buildup factor with penetration depth for different shielding materials at fixed incident photon energies 0.015, 0.15, 1.5 and 15.0 MeV. Figure 7 show the variation of energy absorption buildup factor with penetration depths for all the selected shielding materials at fixed incident photon energy of 0.015 MeV. At low incident photon energies there are significant variations of energy absorption buildup factor for all the selected materials. It has also been observed that for the materials with low values of (Zeq) i.e. M7 and M1 shield have larger values of energy absorption buildup factor while the materials with higher values of (Zeq) i.e M5 and M2 shield the values of energy absorption buildup factors are comparatively lower. The energy absorption buildup factor depends on the nature of the materials at incident photon energy of 0.015 MeV. From Figure 8 it is noted that the dependence of buildup factor on the nature of materials reduces at the incident photon energy 0.15 MeV. From Figure 9.it is also observed that the energy absorption buildup factor values are practically the same for different selected materials at the energy value of 1.5 MeV. Thus, the buildup factor values become almost independent of the chemical composition of the given materials at this energy region, where Compton scattering process dominate.These results are in accordance with the finding of our previous results (37-38). From Figure 10, it is further noted that at penetration depth greater than 15 mfp, the trend of dependence of energy absorption buildup factor on Zeq has also been reversed at the incident photon energy of 15.0 MeV.





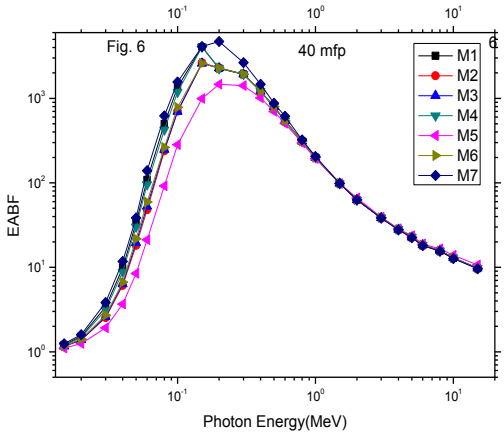
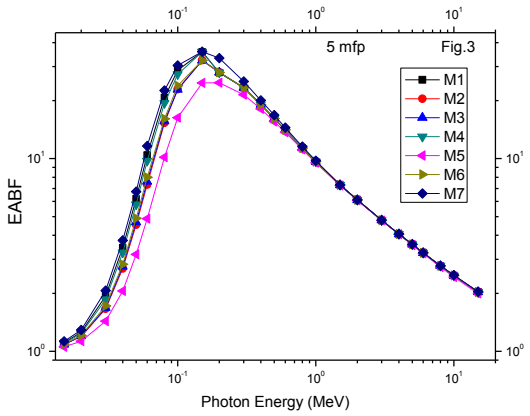
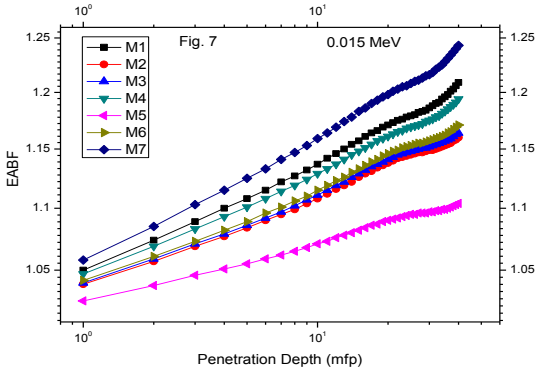


Fig. 3-6 Variation of Energy absorption buildup fator of selected samples with incident photon energy(0.015-15MeV) at 5mfp, 15 mfp, 25 mfp and 40 mfp





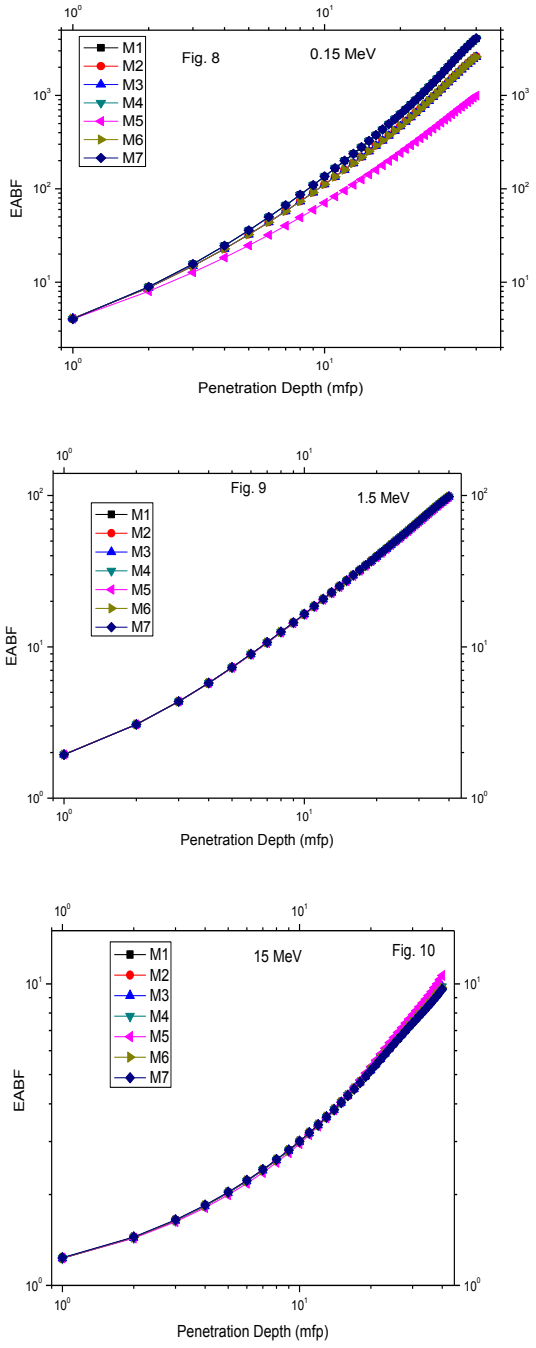


Fig. 7-10 Variation of Energy absorption buildup fator of selected samples with penetration depth up to 40 mfp at 0.015MeV, 0.15 MeV, 1.5 MeV and 15MeV

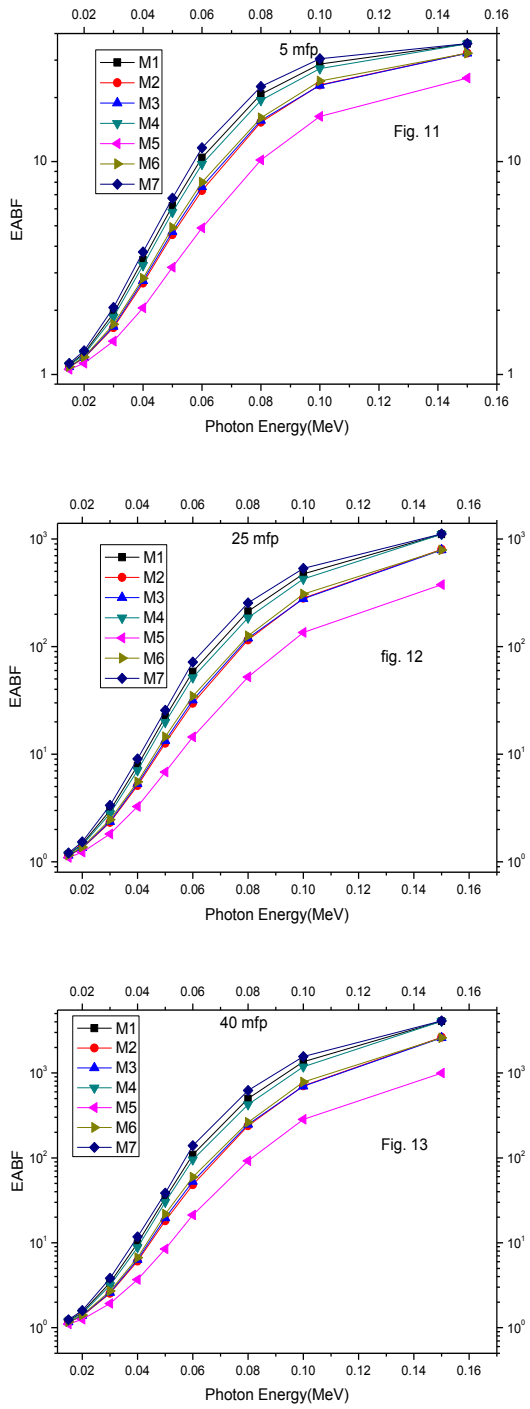


Fig. 11-13 Variation of Energy absorption of buildup factor of selected samples with incident photon energy(0.015-0.15 MeV) at 5 mfp, 25 mfp and 40 mfp

E. Variation of Energy absorption buildup factor (EABF) with chemical composition

For fixed penetration depth there are significant variations with respect to the variation in incident photon energy due to the chemical composition in Fig.11-13. At energy below 0.15 MeV EABF values increases with decrease in Z_{eq} of the selected minerals. It is due to photo electric absorption process in this energy region. Also we seen that with values of EABF at 40 mfp are comparatively very high than the values of EABF at 5 and 25 mfp .

F. Comparison of Shielding material

Concrete has been used as an effective shielding material for gamma rays. Fig. 14 compared the calculated EABF of selected minerals with standard EABF for concrete provided by ANSI/ANS6.4.3-1991 in selected energy range and at penetration depth of 20 mfp. The values of EABF of concrete are approximately shows the same pattern as in case of all selected minerals in the energy range 15 keV to 15 MeV . So we concluded that our selected materials are as useful as concrete for shielding effectiveness by gamma radiations.

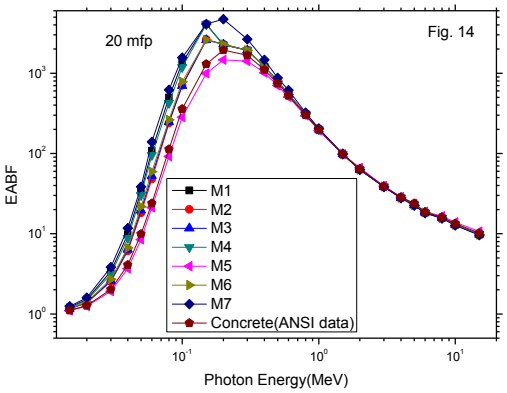


Fig. 14 Comparison of values of calculated EABF of choosen minerals with standards of EABF of concrete(ANSI/ANS 6.4.3-1991) at 20 mfp

V. Conclusion

From the present investigations, we have found that among the selected samples, M2 and M5 acts as best gamma ray shielding material, due to its higher values for mass attenuation coefficient and least values for energy absorption buildup factor in the selected energy range.

- Lambert -Beer laws violation is less in the selected energy region.
- Where photon absorption process is dominating over the scattering process.
- The computed data G.P. fitting parameters and energy absorption buildup factors for selected seven low-Z shielding materials (25 energies and 40 penetration depths) may be useful in the future study of variety of shielding configurations.

VI. Acknowledgment

We are grateful to Berger and Hubbell for providing the convenient computer program XCOM with the help of National Institute of Standards and Technology (NIST), Gaithersburg. [26]. Porting XCOM to the window ® platform was the initiative of Lief Gerward of the Department of physics at The Technical University of Denmark.

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Dr. Sandeep Gupta, M,Sc, NET-JRF, M.Phil and Ph.D Physics, 5 international journal paper, membership of ISC

Dr. Gurdeep Singh Sidhu, M.Sc, Ph. D Physics, 40 international journals paper and 10 national journal paper and Total Number of Supervision: Ph.D: 6 and M. Phil:10