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Gamma Ray Interaction Studies with Composites Inorganic Materials in the Energy Range 122 keV – 1330 keV

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***Abstract* -** The gamma ray attenuation in inorganic materials was measured using transmission experiment. Measured results of attenuation parameters were compared with theoretical results obtained from XCOM code. Attenuation parameters were measured for composite inorganic materials such as mass attenuation coefficient,total attenuation cross section ,electronic cross section, molar extinction coefficient, effective electron density, effective atomic number. Gamma ray transmission experiment was used for experimental procedure. Six radioactive sources were used to irradiade gamma rays. Gamma ray sources emit energies 122 keV to 1330 keV were used to irradiate inorganic materials. Attenuation parameters were observed to vary with the intensity of photons and decreased with increment of energy. Chromium oxide and Calcium oxide have the highest mass attenuation coefficient as compared to other materials. Thus it was concluded Chromium oxide and Calcium oxide that are good candidates in the preparation of efficient gamma ray shielding materials.

Keywords : Mass attenuation coefficient, Total attenuation cross section , Electronic cross section , Effective atomic number, Effective electron density.

INTRODUCTION

The mass attenuation coefficient of low Z- dosimetric and tissue substitute materials have been estimated . MCNP simulation results agreed with experimental results and with the Win-XCOM results (A.M.Khayyat etal,2015).The concrete samples containing tincal have been observed more effective than ordinary concrete for gamma ray shielding application(B.Otto etal,2012). Mass attenuation coefficient values of few carbohydrates have been noticed are dependent on the physical and chemical environments (Bibifatima.m.ladaf etal,2015). Mass attenuation coefficient computed using by two methods such as graphical method and transmission method for sample of unknown chemical composition at low energy (more etal,2016).Attenuation parameters mass attenuation coefficient ,mass energy absorption coefficient, kerma factoreffective atomic number investigated for soft tissue (Degrelle,2016). Gamma ray attenuation coefficient for elastin protein determined using a narrow collimated beam method ,obtained results shown excellent accuracy with the theoretical data (salehi,2015).The effective atomic number and electron density of superconductor at different energy levels has measured (Essam,2013). A new empirical formula investigated for elements those are atmic number greater than one and less than ninty two ,which is useful in radiation physics and dosimetry(H.Balta, etal,2008). Author carried out the experimental work for collagen protein which are biologically compounds to and measured attenuation coefficient (Manjunatha etal,2017). From the experimental data it is clear that mass attenuation coefficient is depends in inident photon energy, experimental mass attenuation coefficient estimated 1-4 % (Mautaz etal,2012). Mass attenuation values affected by deviation in physical and chemical environmental samples have reported by pawar bichile (Mustafa etal,2012). Attenuation property in saturated fatty acid investigated at diagnostic energy range ,attenuation coefficient of butyric acid was observed higher than other fatty acid (pawar etal ,2013). Biswas et al., reported attenuation in polyboron and shown that attenuation changes with concentration of high and low atomic number constituents elements (kore etal,2016). The effective atomic number are useful parameters for low Z- materials at all energies greater than 1 keV electron density is closely related to effective atomic numbers, (Biswas etal,2015).Few amino acids like histidine ,luicine ,lysine,methionine,phenylalanine, threonine,tryptophan and valine were studied it was observed that parameters changes with energy and composition of amino acids (Manohra etal,2008). The sugars rhamnose ,melezitos,and raffinose has a lower effective atomic number compared to other sugars (Gowda etal,2005). The effective atomic number and electron density has been calculated of TLD compounds (Shivllinge etal,2004) . Attenuation parameters such as effective atomic numbers and effective electron density has been calculated for, narcotic drugs ,which is usefulin medical diagnostic (Gounhalli etal,2012). whole the radiological components of organic nonlinear optical are important in diagnostics ,domestic material is depends on its chemical composition(Awasarmol etal 2016). The measured total attenuation cross section of elements are useful for dosimetry and radiation shielding purpose (Tupe etal 2012).

In the present study, mass attenuation coefficient, total attenuation cross section, electronic cross section, effective atomic numbers and effective electronic density of inorganic composites materials such Calcium oxide Carbonic acid Chromium oxide Magnesium carbonate Disulfure Dichloride and Aluminium nitrate have determined experimentally in the energy range 122 keV to 1330 keV.

EXPERIMENTAL DETAILS

The μ_m of selected samples was measured using the gamma ray transmission experiment (Fig.1). A gamma ray spectrometer (NUCLEONIX, GR611M) includes a 3x3 (inch) NaI (Tl) well type scinitllation detector connected to the multichannel analyzer (MCA) card, was used to perform the experiments. The NaI(Tl) scintillation detector has the following specifications; NaI(Tl) crystal of 0.656" diameter and 1.546" depth, coupled optically with bialkali phototube, magnetic/light shield and 8.2% energy resolution at 0.662 MeV. Gamma ray sources ^{57}Co, ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co were used to obtain 122, 356, 511, 662, 840, 1170, 1275, 1330 Kev energies. An Anuspect computer program was used to analyze the γ-ray spectrum. The glasses were the thickness in the range 0.5 to 1.5 mm, irradiated by a narrow beam of gamma rays. In order to produce the narrow beam, gamma ray source was kept in a lead collimator of cylindrical shape with 0.52 orifice and collimators were placed in front of the lead cylinder to get 0.42 cm beam of gamma rays. The source-detector distance was 40 cm. The samples were placed one by one between the source and detector to measure attenuated intensity of gamma rays for 1000 s. The measured counts for the intensities without (I_0) and with glass (attenuated, I) were used to determine μ_m for all the selected samples by the following equation;

$$\mu_m = \frac{\mu}{\rho} = \ln\left(\frac{I_0}{I}\right)\frac{1}{\rho t} \qquad (1)$$

Where and t are the density and thickness of the selected glasses, respectively. The total attenuation cross section measured using the following formula.

$$\sigma_{tot} = \mu_m \left(\frac{M}{NA}\right) \qquad (2)$$

Where M= (=∑ niAi Molecular weight of the sample and N_A is Avogadro's number.

Also n_i and A_i are number of atom and atomic mass, respectively.

The total electronic cross section calculated using the following formula

$$б_t = \frac{i}{NA} \sum \frac{fiAi}{zi} (\mu_m)_I \quad (3)$$

Where fi is the number fraction of atoms of elements. The effective atomic number (Z_{eff}) calculated using the following for

$$Z_{eff} = \frac{бtot}{бele} \quad (4)$$

The effective electron desity (Neff) calculated using the following formula.

$$N_{eff} = \frac{\mu_m}{б_{ele}} = \frac{N_A}{M} Z_{eff} \sum_i ni \quad (5)$$

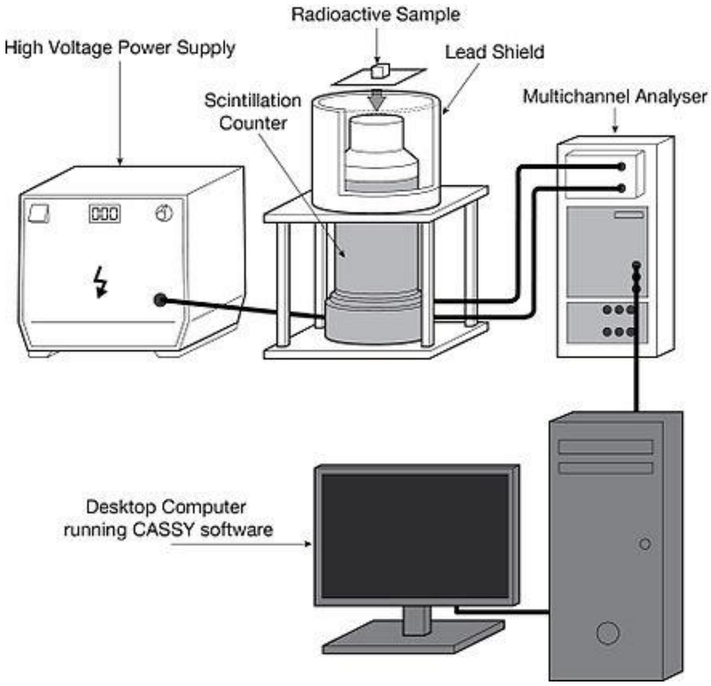

Fig. 1 The schematic view of the experimental set up.

RESULTS AND DISCUSSION

The mean atomic number and molar mass of Calcium oxide Carbonic acid Chromium oxide Magnesium carbonate Disulfure Dichloride and Aluminium nitrate were calculated from their chemical formula is presented in Table.1. The < Z > is found in the range of 5.3335 to 16.501.

Table1. Mean atomic number (Z) calculated from the chemical formula for composite inorganic materials.

Inorganic materials	Chemical formula	Molar mass	Mean atomic no (Z)
1. Calcium oxide	CaO	56.0774 g/mol	14.00
2. Carbonic Acid	CH_2CO_3	62.03g/mol	5.3335
3. Chromium Oxide	Cr_2O_3	151.99 g/mol	14.4
4. Magnesium Carbonate	$MgCO_3$	84.3139 g/mol	8.4006
5. Disulfur Dichloride	S_2Cl_2	135.04 g/mol	16.501
6. Aluminium Nitrate	$Al(NO_3)_3$	212.996 g/mol	10.6001

Measured values of along with theoretical results are given in Table.2 and plotted in ``Fig.2. It is seen from the table and figure that decreases with the increment energy of gamma ray. A fairly good harmony between the measured and calculated (XCOM) results is observed. It is also seen from Fig.2 that □$_m$ decreases rapidly with energy up to 1170 keV then decrease slowly. This may be because of Compton and pair production photon interaction processes. The Chromium oxide and Calcium oxide has □$_m$ values 0.204 and 0.186 at 122 keV which are highest results among the selected samples as shown in Table2 and Fig.2. It is also observed that Carbonic acid Magnesium carbonate Disulfure Dichloride and Aluminium nitrate have almost similar range of □$_m$ results. It is also observed that barium sulfate has high □$_m$ values for low to high energies (122 - 1330 keV). Thus it is indicated that Chromium oxide is a potential candidate for gamma ray shielding.

Table 2

Mass attenuation Coefficient (μ_m) : Theoretical and Experimental Values of composite Inorganic material																	
Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	0.186	0.186	0.102	0.101	0.087	0.086	0.078	0.079	0.069	0.068	0.026	0.025	0.026	0.026	0.026	0.024
2	Carbonic Acid	0.149	0.150	0.103	0.102	0.089	0.089	0.080	0.078	0.071	0.070	0.020	0.021	0.019	0.018	0.019	0.018
3	Chromium Oxide	0.204	0.205	0.098	0.097	0.083	0.081	0.074	0.073	0.061	0.062	0.025	0.024	0.026	0.025	0.026	0.027
4	Magnesium Carbonate	0.147	0.146	0.100	0.099	0.086	0.087	0.077	0.077	0.069	0.068	0.020	0.018	0.020	0.019	0.020	0.019
5	Disulfur Dichloride	0.171	0.171	0.099	0.098	0.085	0.086	0.075	0.076	0.067	0.067	0.057	0.058	0.055	0.054	0.054	0.055
6	Aluminium Nitrate	0.145	0.146	0.1	0.102	0.086	0.088	0.077	0.075	0.069	0.068	0.06	0.061	0.056	0.057	0.055	0.054

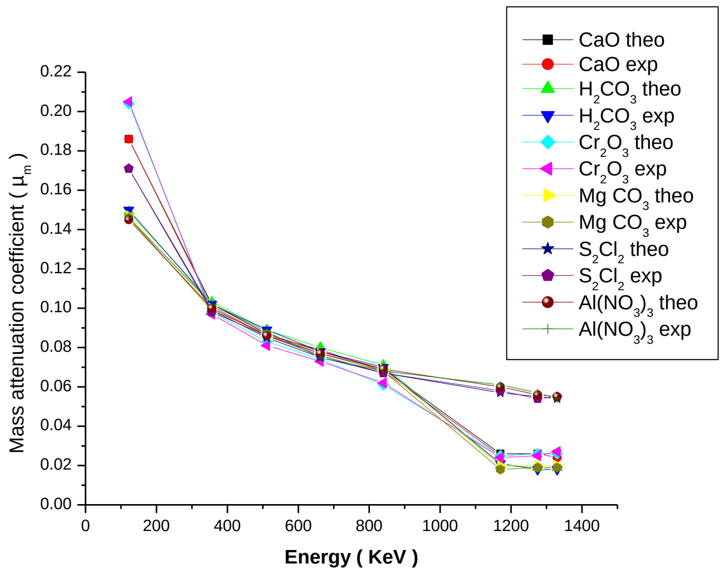

Fig.2. Typical plots of μ_m Versus Energy for Composite Inorganic materials.

Table 3

Total attenuation cross section (6_t) :

Theoretical Values and Experimental Values of composite Inorganic material

Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	17.329	17.3205	9.526	9.4052	8.131	8.0083	7.234	7.3565	6.47	6.3322	2.409	2.328	2.396	2.4211	2.391	2.2349
2	Carbonic Acid	15.389	15.45	10.64	10.5065	9.19	9.1675	8.209	8.0344	7.36	7.2104	2.051	2.1631	1.998	1.8541	1.973	1.8541
3	Chromium Oxide	51.487	51.74	24.835	24.481	21.049	20.443	18.679	18.425	16.685	15.648	6.536	6.0573	6.521	6.3097	6.521	6.8185
4	Magnesium Carbonate	20.595	20.441	13.993	13.86	12.074	12.18	10.782	10.78	9.664	9.52	2.859	2.52	2.797	2.66	2.769	2.66
5	Disulfur Dichloride	38.413	38.345	22.339	21.975	19.121	19.285	17.031	17.042	15.239	15.024	12.941	13.006	12.391	12.109	12.129	12.333
6	Aluminium Nitrate	51.533	51.639	35.368	36.307	30.545	31.125	27.28	26.527	24.461	24.051	21.296	21.575	19.913	20.16	19.948	19.099

Table 4

Electronic cross section (6_e) :

Theoretical Values and Experimental Values of composite Inorganic material

Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	1.2377	1.2371	0.6804	0.6718	0.5807	0.572	0.5167	0.5254	0.4621	0.4523	0.172	0.1662	0.1711	0.1729	0.1707	0.1596
2	Carbonic Acid	2.8854	2.8968	1.995	1.9699	1.7231	1.7189	1.5391	1.5064	1.38	1.3519	0.3845	0.4055	0.3746	0.3476	0.3699	0.3476
3	Chromium Oxide	3.5754	3.593	1.7246	1.7	1.4617	1.4196	1.2971	1.2795	1.1586	1.0866	0.4538	0.4206	0.4528	0.4381	0.4528	0.4735
4	Magnesium Carbonate	2.4517	2.4334	1.6658	1.65	1.4378	1.45	1.2835	1.2833	1.1504	1.1333	0.3403	0.3	0.3329	0.3166	0.3296	0.3166
5	Disulfur Dichloride	2.328	2.3239	1.3538	1.3318	1.1588	1.1687	1.0321	1.0328	0.9235	0.9105	0.7843	0.7882	0.7509	0.7338	0.735	0.7474
6	Aluminium Nitrate	4.8616	4.8716	3.3366	3.4034	2.8816	2.9363	2.5736	2.5025	2.3076	2.2689	2.009	2.0354	1.8785	1.9019	1.8819	1.8018

Table 5

Molar Extinction Coefficient (ε) : Barn/Atom

Theoretical Values and Experimental Values of composite Inorganic material

Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	4.532	4.5299	2.4913	2.4598	2.1265	2.0944	1.1891	1.9239	1.692	1.656	0.63002	0.6088	0.62662	0.6332	0.6253	0.5845
2	Carbonic Acid	4.0246	4.0407	2.7826	2.7478	2.4034	2.3976	2.1468	2.10128	1.9248	1.8857	0.53639	0.5657	0.5225	0.4849	0.51599	0.4849
3	Chromium Oxide	13.406	13.5318	6.495	6.4026	5.5049	5.3465	4.8851	4.8188	4.3636	4.0925	1.7093	1.5814	1.7054	1.6502	1.7054	1.7832
4	Magnesium Carbonate	5.3862	5.346	3.6595	3.6248	3.1577	3.1855	2.8198	2.8193	2.5274	2.4898	0.7477	0.659	0.73149	0.6956	0.7241	0.6956
5	Disulfur Dichloride	10.0463	10.0285	5.8424	5.7472	5.0008	5.0437	4.4542	4.457	3.9855	3.9293	3.3845	3.4015	3.2406	3.1669	3.1721	3.2255
6	Aluminium Nitrate	13.4778	13.5055	9.25	9.4354	7.9886	8.1403	7.1348	6.9378	6.3975	6.2902	5.5696	5.6427	5.2079	5.2727	5.2172	4.9952

Table 6

Effective Atomic Number (Zeff) : Theoretical Values and Experimental Values of composite Inorganic material																	
Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	14	14.0008	14	14	14	14.0005	14	14.0017	14	14.6476	14	14.0072	14	14.0028	14	14.0031
2	Carbonic Acid	5.3334	5.3334	5.3333	5.3335	5.3334	5.3333	5.3336	5.3335	5.3333	5.3335	5.3342	5.3344	5.3336	5.334	5.3338	5.334
3	Chromium Oxide	14.4	14.4002	14.4	14.4005	14.4	13.6323	14.4	14.4001	14.4	14.4008	14.4	14.4015	14.4	14.4024	14.4	14.4002
4	Magnesium Carbonate	8.4002	8.4001	8.4001	8.4	8.4	8.4	8.4004	8.4002	8.4005	8.4002	8.4014	8.4	8.4019	8.4017	8.401	8.4017
5	Disulfur Dichloride	16.5004	16.5002	16.5009	16.5002	16.5006	16.5012	16.5013	16.5007	16.5013	16.5008	16.5	16.5008	16.5015	16.5017	16.502	16.5012
6	Aluminium Nitrate	10.6001	10.6001	10.6001	10.6002	10.6	10.735	10.6001	10.6002	10.6004	10.6004	10.6002	10.6	10.6005	10.6002	10.6001	10.6002

Table 7

Effective Electron Density (Neff) : Theoretical Values and Experimental Values of composite Inorganic material																	
Sr. No.	Samples	122KeV		356KeV		511KeV		662KeV		840KeV		1170KeV		1275KeV		1330KeV	
	Inorganic	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.
1	Calcium Oxide	3.0068 X10^{23}	3.0070 X10^{23}	3.0068 X10^{23}	3.0068 X10^{23}	3.0068 X10^{23}	3.0069X 10^{23}	3.0068 X10^{23}	3.0072 X10^{23}	3.0068X 10^{23}	3.1459 X10^{23}	3.0068X 10^{23}	3.0083 X10^{23}	3.0068X 10^{23}	3.0074X 10^{23}	3.0068 X10^{23}	3.0075X 10^{23}
2	Carbonic Acid	3.1061 X10^{23}	3.1066 X10^{23}	3.1061 X10^{23}	3.1067 X10^{23}	3.1061 X10^{23}	3.1066X 10^{23}	3.1062 X10^{23}	3.1067 X10^{23}	3.1061X 10^{23}	3.1067 X10^{23}	3.1166X 10^{23}	3.1075 X10^{23}	3.1062X 10^{23}	3.1070X 10^{23}	3.1064 X10^{23}	3.1070X 10^{23}
3	Chromium Oxide	2.8527 X10^{23}	2.8527 X10^{23}	2.8527 X10^{23}	2.8528 X10^{23}	2.8527 X10^{23}	2.7006X 10^{23}	2.8527 X10^{23}	2.8527 X10^{23}	2.8527X 10^{23}	2.8528 X10^{23}	2.8527X 10^{23}	2.8530 X10^{23}	2.8527X 10^{23}	2.8553X 10^{23}	2.8527 X10^{23}	2.8527X 10^{23}
4	Magnesium Carbonate	2.9997 X10^{23}	2.9998 X10^{23}	2.9996 X10^{23}	2.9998 X10^{23}	2.9996 X10^{23}	2.9998X 10^{23}	2.9997 X10^{23}	2.9998 X10^{23}	2.9998X 10^{23}	2.9998 X10^{23}	3.0001X 10^{23}	2.9998 X10^{23}	3.0003X 10^{23}	2.9070X 10^{23}	2.9999 X10^{23}	2.9070X 10^{23}
5	Disulfur Dichloride	2.9432 X10^{23}	2.9432 X10^{23}	2.9433 X10^{23}	2.9432 X10^{23}	2.9433 X10^{23}	2.9434X 10^{23}	2.9434 X10^{23}	2.9433 X10^{23}	2.9434X 10^{23}	2.9433 X10^{23}	2.9432X 10^{23}	2.9433 X10^{23}	2.9434X 10^{23}	2.9435X 10^{23}	2.9435 X10^{23}	2.9434X 10^{23}
6	Aluminium Nitrate	2.9969 X10^{23}	2.9969 X10^{23}	2.9969 X10^{23}	2.9969 X10^{23}	2.9969 X10^{23}	3.0350X 10^{23}	2.9969 X10^{23}	2.9969 X10^{23}	2.9970X 10^{23}	2.9970 X10^{23}	2.9969X 10^{23}	2.9969 X10^{23}	2.9970X 10^{23}	2.9969X 10^{23}	2.9969 X10^{23}	2.9960X 10^{23}

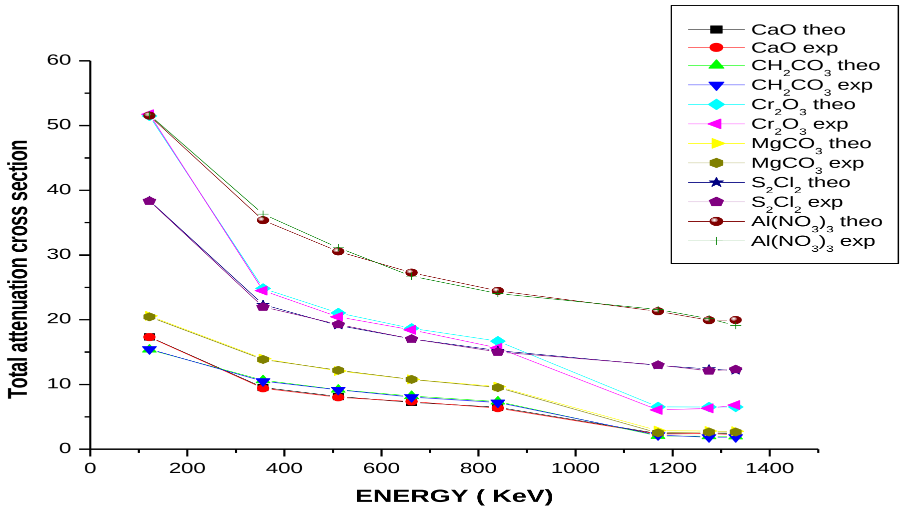

Fig.3 The typical plots of Z_{eff} versus energy for composite Inorganic materials.

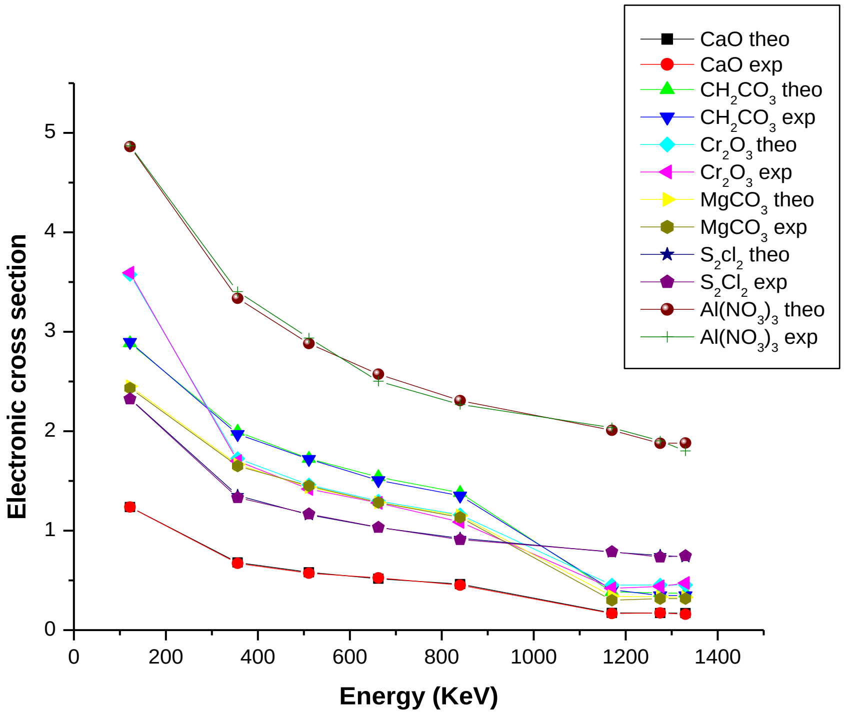

Fig.4 . The typical plots of б $_{tot}$ versus energy for composite Inorganic materials.

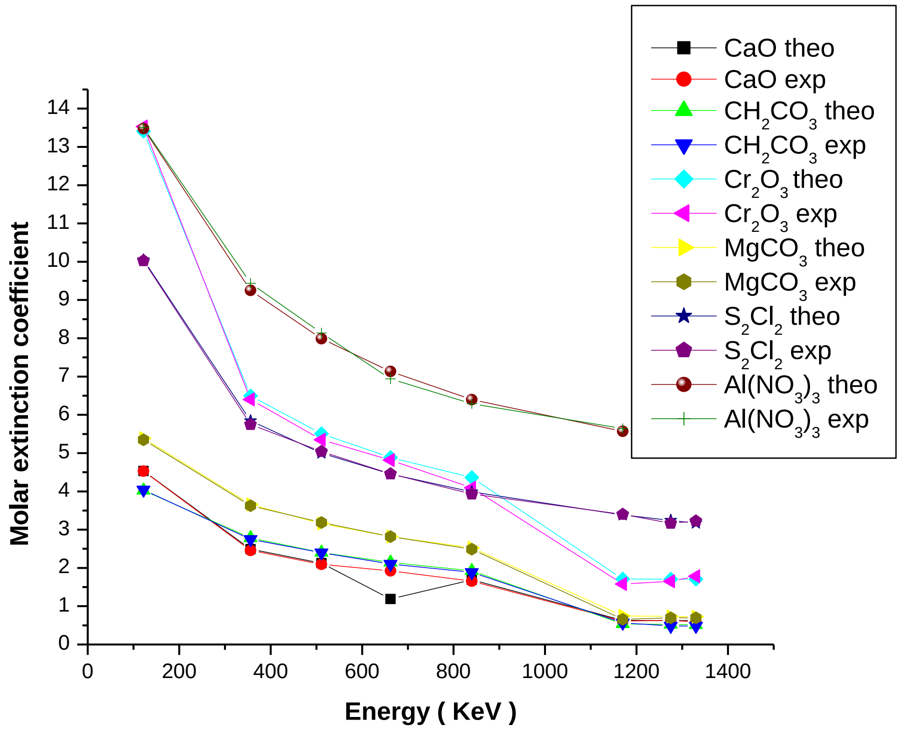

Fig.5. The typical plots of б $_{e}$ versus energy for composite Inorganic materials.

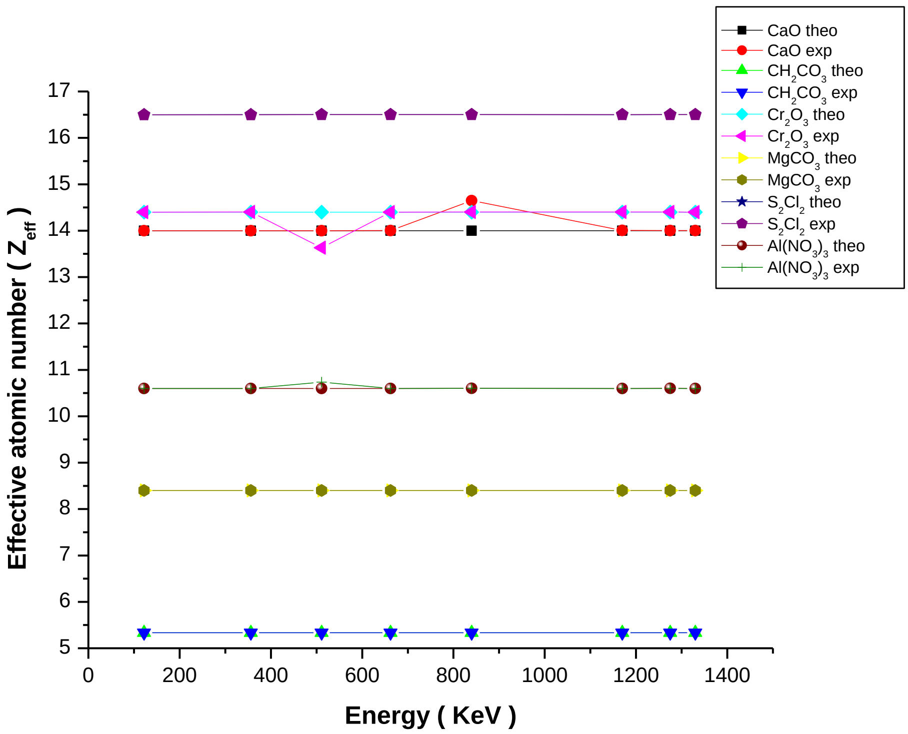

Fig.6. The typical plots of ϵ versus energy for composite Inorganic materials.

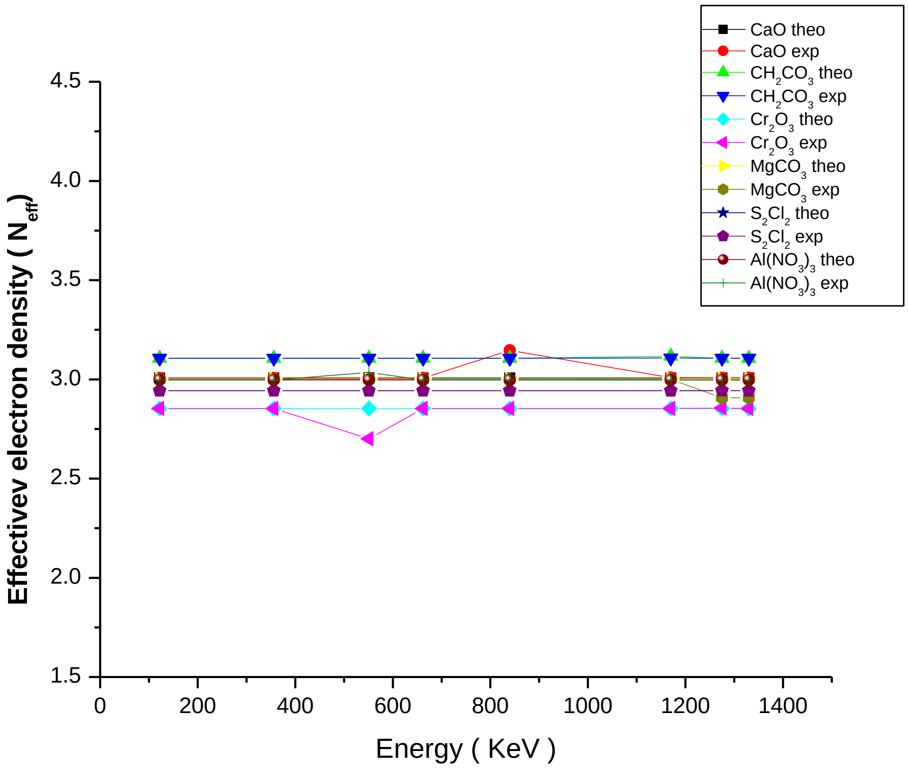

Fig.7. Energy versus effective electron density(N_{eff}) of composite inorganic materials.

Total atomic cross-section (б$_t$) and electronic cross section(б$_e$) were calculated using m_m are given in Table 3 and 4, respectively. It seen that б$_t$ and б$_e$ decrease with increase in energy and show almost similar behavior to m_m as shown in Figs 3 and 4. The values of effective atomic number (Z_{eff}) of selected samples were calculated using Eq.(5). The results of Z_{eff} are plotted in Fig.5 and displayed in Table 5. It is seen that Z_{eff} vary slowly with increase in gamma ray energy and tends to almost constant with the increment of energy. The energy independent behavior of Z_{eff} is seen in all selected samples. Results of Z_{eff} are observed close to their calculated results of mean atomic number. Effective electron density (N_{eff}) calculated using Z_{eff} is given in Table 6. The results of N_{eff} are also plotted in Fig. 6. It is observed that N_{eff} vary very little with energy of gamma ray. The Z_{eff} and Neff are closely related through Eq.(5). Thus it is obvious that Z_{eff} and N_{eff} show similar nature with energy.

CONCLUSIONS

Experimental and theoretical results gamma ray attenuation coefficients investigated for all selected samples in the energy range 122-1330 keV. It was observed, gamma ray attenuation parameters changes with the increase in energy. It is found that Chromium oxide and Calcium oxide have better gamma ray attenuation capability among selected samples. Finally it is concluded that Chromium oxide is potential at 122 keVcandidate for preparation of efficient gamma ray shielding material.

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