Gamma Ray Attenuation Studies of Cement Pastes Modified With Naturally Available Additives

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Introduction

The proper shield design is an important aspect of the reduction of radiation to an acceptable level. The purpose of shielding is to protect people, animals, equipment and building structures from the harmful effects of radiation. Attempts to improve the shielding capacity by adding new multi-efficient materials to the conventional materials, are going on at various levels. Its importance is increasing as more and more radiation is made use in nuclear physics research, electronic industry, material modification, material science, agricultural service etc.

It has been discovered that clay and mineral materials possess good refractory properties: such as high melting point, thermo-chemical stability, good mechanical strength at high temperature, high thermal shock resistance, low thermal shrinkage and high resistance to corrosion. Interestingly, clay is a composite material which is abundantly available and is eco-friendly, cost-effective and nonpoisonous. These properties make clay-mineral materials suitable for shielding purpose. In the present work, we have made an attempt to study the shielding effects of cement to gamma rays by adding clay, Kaolinite, Pink salt, Vermiculite, and Perlite. These materials are normally mixtures of silicates and oxides like Portland cement. Fabrication of these composites with and without concrete find large application in the area of nuclear shielding [1]

From the theory of interaction of radiation with matter, it is well known that the intensity of incident radiation decreases according to [2]

$$I=I_0 e^{-(\mu/\rho)x\rho} \qquad (1)$$

where I_0 is the intensity of intensity of incident radiation, I ,its intensity after traversing through a thickness x, μ/ρ mass attenuation coefficient, with ρ being the density of the material.

$$\frac{\mu}{\rho} = \frac{\ln(\frac{I_0}{I})}{x\rho} \qquad (2)$$

The mass attenuation coefficient of a compound consisting of several elements with weight fraction w_i is given by the 'mixture rule'[3].

$$\left(\frac{\mu}{\rho}\right)_C = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i \qquad (3)$$

Here $\left(\frac{\mu}{\rho}\right)_i$ is the photon mass attenuation coefficient for the individual elements in the compound.

The mass attenuation coefficient is proportional to the total molecular interaction cross section σ_a through the relation [4]

$$\sigma_a = \frac{1}{N_A} \sum_i f_i M_i \left(\frac{\mu}{\rho}\right)_i \qquad (4)$$

where $M = \Sigma\, n_i A_i$ is the molecular weight of the compound (in kg), N_A is the Avogadro's number, n_i is the number of atoms of the constituent element and A_i is its atomic weight. Also f_i denote the fractional abundance ($\Sigma\, f_i = 1$).For any compound, a quantity called the effective electronic cross section σ_e is expressed by the following equation

$$\sigma_e = \frac{1}{N_A} \sum_i \frac{f_i M_i \left(\frac{\mu}{\rho}\right)_i}{Z_i} \qquad (5)$$

where Z_i denote the atomic number of the ith element.

The atomic cross-section (σ_a) and electronic cross-section (σ_e) are related to the effective atomic number (Z_{eff}) of the material through the following relation

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \qquad (6)$$

Effective electron number or electron density (N_{eff}), defined as the number of electrons per unit mass can be calculated using the following relation [5]

$$N_{eff} = \frac{(\mu/\rho)}{\sigma_e} \qquad (7)$$

Materials and Methods

Among the many shielding materials, cementitious matrices are of particular importance because of their high strength, low cost, and convenience of production.

In order to prepare the shielding material, the selected samples were mixed with cement in 2:1 proportion (the water-to-cement ratio was kept at 0.4) and the cement pastes were allowed to dry in the air for 24 hours. chemical composition as weight fraction for all samples was determined by XRF and SEM-EDAX. The samples have been molded and cured into 50 mm thickness cube.

The prepared materials have been subjected to gamma ray attenuation studies in order to determine the radiation shielding properties. The gamma ray spectrometer contains 3"× 3″ NaI(Tl) detector connected to a multichannel analyzer. The mass attenuation coefficients of six different samples have been estimated at gamma-ray energies of 662 keV, obtained from a ^{137}Cs source and repeated for ^{60}Co,^{22}Na and ^{133}Ba sources.

Table 1: Details of developed composite (Clay-Cement :(CL-C), Kaolinite-Cement :(KAL-C), Pink salt-Cement: (PIN-C), Vermiculite-Cement :(VC-C), Perlite-Cement :(PE-C), and Ordinary cement :(O-C).

Composite	Density (g/cm^3)	Dry weight (in gram)	Sample thickness (cm)
O-C	2.483	405.25	5
PE-C	2.523	432.31	5
VC-C	2.782	443.12	5
CL-C	2.745	456.38	5
PIN-C	2.281	438.16	5
KAL-C	2.041	430.54	5

Results and Discussion

The μ/ρ values for the selected materials were determined using NaI (Tl) detector and also calculated using Xcom [6] program for the photon energies of 356 keV, 512 keV, 662 keV, 1172 keV,1275 keV and 1330 keV and the results are plotted in Fig.1.

It is seen from the figure that, (μ/ρ) depends on the photon energy and the chemical content. It is also found that the experimental values are consistent with theoretical (Xcom) values, within the experimental errors. This error may be due to the effects of chemical, molecular and thermal environments on (μ/ρ). It can be seen that among the samples with the additives, the perlite-cement sample is having the largest and the pink salt-cement composite having the smallest μ/ρ values. Also bare cement without additives is having the minimum μ/ρ values.

Fig. 1 shows a decreasing trend for the attenuation in the studied composites, with the increase of photon energies from 356 keV to 1330 keV. The interaction via photoelectric absorption is dominant at 356 keV. The photoelectric effect energies depends strongly on the effective atomic number. A higher effective atomic number means more electrons to interact and hence more photons are likely to be absorbed.

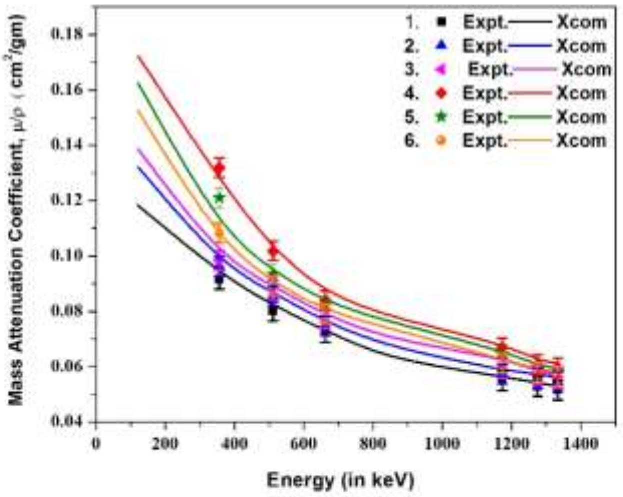

Fig.1: Mass attenuation coefficient versus energy for composites (1) Ordinary Cement (2) Pink Salt-Cement (3) Kaolinite-Cement (4) Perlite-Cement (5) Vermiculite-Cement (6) Clay-Cement.

Fig.2 represents the variation of the total electronic cross-section against the energies. The cross section for Compton scattering has a very weak dependence on atomic number and this is the reason to get the similar values for the attenuation coefficient at the higher energies mentioned here, while in this energy range, attenuation decreases slowly with increasing photon energy[7]. The photoelectric and Compton interaction processes at low and intermediate photon energy respectively as indicated above may attribute this behavior. From the Fig.3 the variation as a function of Z_{eff} as a function of energy indicates that Z_{eff} almost constant.

This is due to the linear Z-dependence of incoherent (Compton) scattering, which is the most dominant process at energies of our selection [8].

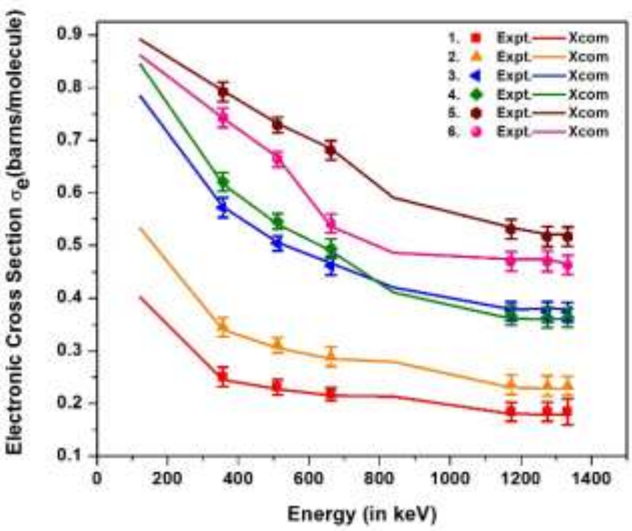

Fig.2: Electronic cross section versus energy for composites

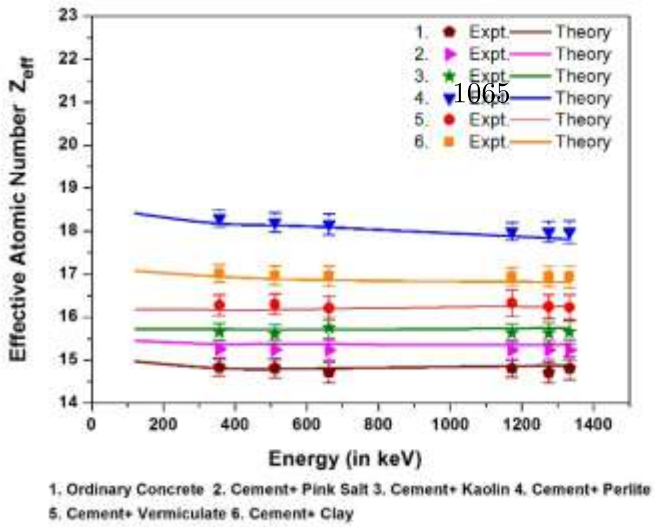

Fig.3: Effective atomic number, Z_{eff} versus energy for composites. (1) Ordinary Cement (3) Pink Salt-Cement (3) Kaolinite-Cement (4) Perlite-Cement (5) Vermiculite-Cement (6) Clay-Cement.

Values of Z_{eff} observed almost equal to the mean atomic number of the cement composites. It should be remembered that the concept of the effective atomic number is based on an underlying theory of γ-ray interactions with matter. N_{eff} value of the selected samples are in the range of 3.32–3.18 $\times 10^{23}$ electron/g).

In conclusion the above study reveals that the selected samples are suitable for gamma radiation shielding when they are prepared as composites with ordinary cement.

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