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Photon Shielding Competence of Some Concrete Doped Materials for Nuclear Application

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Abstract: In this study, photon shielding properties of standard concrete (SC), concrete doped ferro boron (CFB), concrete doped boron carbide (CBC), concrete doped galena (CG) and concrete doped ilmenite (CI) were investigated. A theoretical study of the mass attenuation coefficients (MAC) of standard concrete and concrete doped materials were determined by a winXCOM computer program. The radiation shielding parameters such as mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), half value layer (HVL), tenth value layer (TVL) and mean free path (MFP) of the mixture were calculated in the photon energy range of 0.01-10.0 MeV. The MAC values showed a sharp decline as the energy increases to a certain extent and reduces smoothly after that for all the materials investigated. The maximum (minimum) MAC values were 10.88 (0.023), 34.90 (0.024), 15.80 (0.022), 39. 20 (0.027), and 34.50 (0.023) cm2/g for SC, CFB, CBC, CG and CI respectively. The maximum value of LAC was obtained at 0.010 MeV with value of 44.10, 81.22, 20.40, 16.90 and 99.20 cm-1 for SC, CFB, CBC, CG and CI respectively. The MAC and LAC value are in the order of CG > CI> CFB > SC > CBC. The HVL, TVL, and MFP show similar pattern and are in the order of CBC > CI > SC > CFB > CG. The results indicate that adding galena compound into concrete mixture can significantly enhance the photon shielding capability.

Keywords: Mass attenuation coefficient, standard concrete, WinXCOM software and photon shielding

1. Introduction

The deployment of nuclear technology requires that the biological beings protected from the adverse consequences of radiation exposure [1-3]. Therefore, proper shielding is required to guarantee that everyone in the surrounding area of radiation and nuclear facilities are safe from any negative consequences of ionizing radiation [2, 4]. By using techniques that involve time, distance, and shielding, radiation exposure can be minimised [3-6]. In comparison to the other methods, shielding is the most crucial and practicable. In many radiation and nuclear facilities radiological centers, concrete is frequently employed as the radiation shielding material [3, 7, 8]. Cement, aggregates, and water are the essential ingredients of concrete. The concrete's capacity to block radiation is significantly influenced by the characteristics of the materials used in making it [1, 9, 10].

In order to keep radiation exposure as low as possible, concrete is used as a radiation shield in radiotherapy centers, isotope and accelerator laboratories, and especially in nuclear facilities. Concrete is a cheap, versatile, and widely used construction material because of its efficiency, flexibility, and simple manufacturing process [9, 11- 13]. This study investigates the photon shielding ability of standard concrete and concretes containing ferro boron, boron carbide, ilmenite and galena respectively using the winXCOM software.

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2. Illustrations

The radiation shielding properties of standard concrete, concrete doped ferro boron, concrete doped boron carbide, concrete doped ilmenite, and concrete doped galena codes as SC, CFB, CBC, CI and CG respectively were investigated. In this study, gamma attenuation parameters of SC, CFB, CBC, CI and CG were determined, and their application as shielding material were discussed. Theoretical mass attenuation coefficients (MAC) of standard concrete and concrete doped materials were determined using winXCOM software installed in a laptop computer. The XCOM code is a database for calculating mass attenuation coefficients at different photon energies [14- 16]. Theoretical linear attenuation coefficients were calculated by multiplying the obtained theoretical MAC value by the density of the standard concrete and concrete doped materials. The linear attenuation coefficients (LAC) defined as a measure of the shielding ability of the material against radiation is investigated for many materials both theoretically and experimentally. The linear attenuation coefficient is related to the mass attenuation coefficient as [15, 17]:

$$MAC = \frac{LAC}{\rho} \qquad (1)$$

where ρ represents the density of the absorbing medium. It has the dimensions of area per unit mass (cm^2g^{-1}). The half value layer and mean free path r important related shielding parameters were calculated using [14, 15]:

$$HVL = \frac{ln2}{LAC} \qquad (2)$$

and

$$MFP = \frac{1}{LAC} \qquad (3)$$

The HVL and MFP reflect the necessary thickness that should be used to attenuate gamma rays or x-rays by half and a factor of e, respectively.

3. Results and Discursions

The elemental compositions and densities of the standard concrete and concrete doped materials studied are shown in table 1. The mass attenuation coefficient values obtained in the energy range of 0.01–10 MeV using the WinXCOM program is shown in Fig. 1. The mass attenuation values of the sampled material show a sharp decline up to 0.09 MeV as the energy increases for all the materials investigated. An abrupt increase in the mass attenuation value was observed for concrete doped galena and could be attributed to the presence of Pb in the material. The decrease in mass attenuation coefficient continued in a reduced manner after 0.09 MeV for all the materials studied. Similar pattern was observed for linear attenuation coefficient however with clearer distinction between the graphs. The MAC and LAC value are in the order of concrete doped galena > concrete doped ilmenite > concrete doped ferroboron > standard concrete > concrete doped boron carbide. The different photon interaction processes in these energy range (0.01-10 MeV) is the reason for these changes of MAC values. For low energies (< 0.2 MeV), the photoelectric cross section is direct and inversely proportional with Z 4−5 and E3.5 respectively [4, 17]. Therefore, the MAC maximum values are observed at low energies for the materials and quickly drops as the energy of photons is increases. The MAC values are almost constant and close to zero in the middle and high energy regions where Compton scattering and pair production which possess cross-section proportional to Z and Z2 respectively are effective. This study indicates that doping standard concrete with material such as galena, ilmenite, and ferroboron can enhance the mass attenuation coefficient of the materials. However, material such as boron carbide decreases the MAC value of the concrete material.

Table1: The elemental composition of some concrete shielding materials.

Sample Code	**Density (gcm^{-3})**	**Elemental Composition (%)**									
		H	**C**	**O**	**Mg**	**Si**	**Ca**	**B**	**Fe**	**Ti**	**Pb**
SC	2.34	0.10	0.23	0.40	0.02	0.12	0.12	-	-	-	-
CFB	2.33	0.08	0.18	0.32	0.02	0.10	0.10	0.03	0.17	-	-
CBC	1.29	0.08	0.23	0.32	0.02	0.10	0.10	-	-	-	-
CI	2.25	0.08	0.18	0.39	0.02	0.10	0.10	-	0.07	0.06	-
CG	2.82	0.08	0.18	0.32	0.02	0.10	0.10	-	-	-	0.17

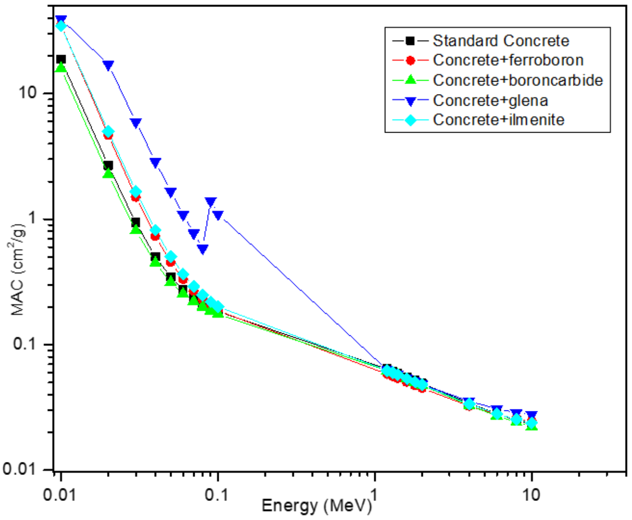

Fig. 1: Mass attenuation coefficient spectra of the standard concrete and concrete doped materials.

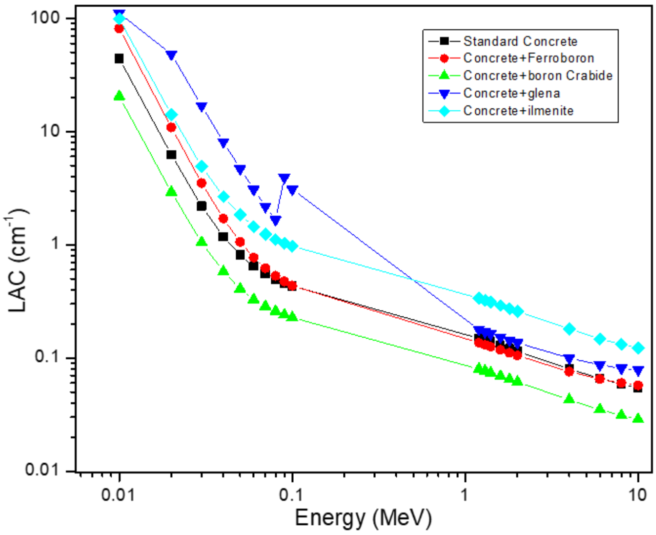

Fig. 2: Linear attenuation coefficient spectra of the standard concrete and concrete doped materials.

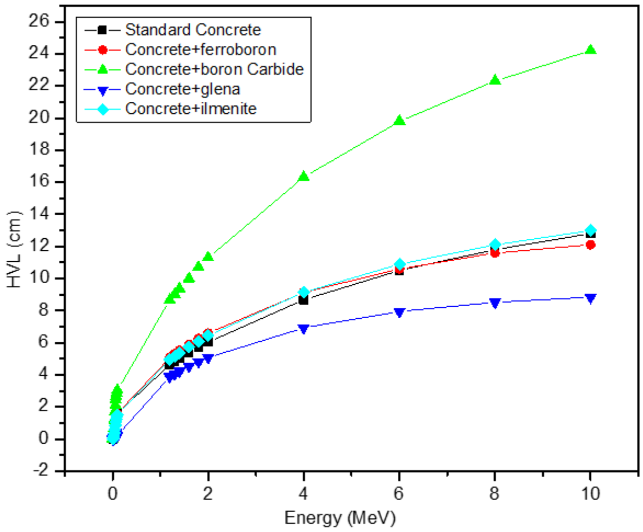

Fig. 3: Half value layer spectra of the standard concrete and concrete doped materials.

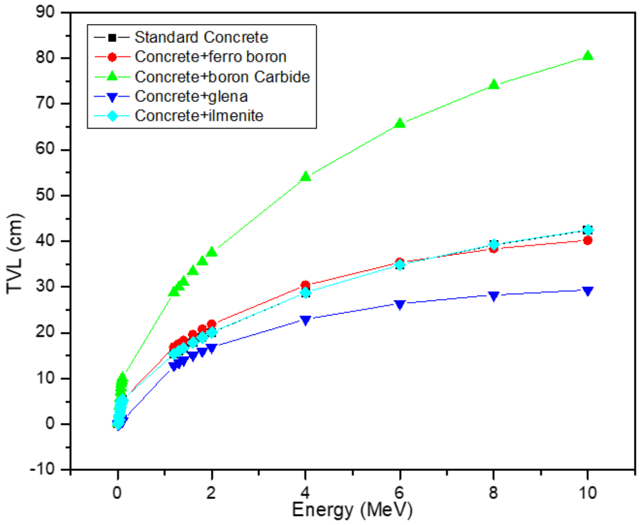

Fig. 4: Tenth value layer spectra of the standard concrete and concrete doped materials.

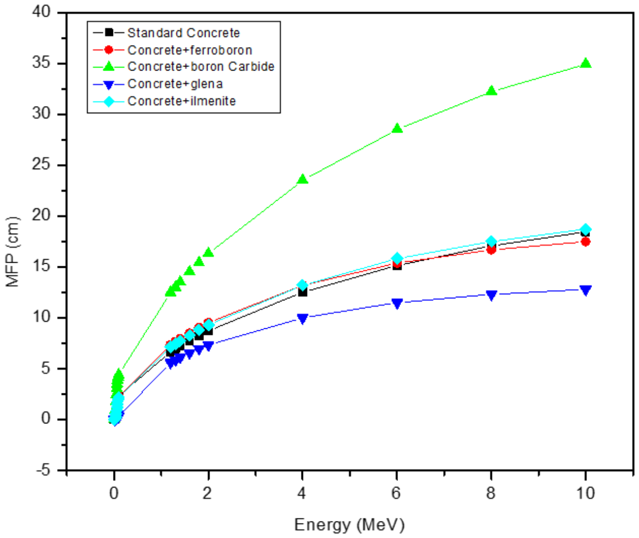

Fig. 5: Mean free path spectra of the standard concrete and concrete doped materials.

The LAC values was calculated from MAC value and the density of the concrete doped material as a function of energy is shown in Fig. 2. The LAC values vary similarly with energy as MAC values. The variation in density of the standard concrete and concrete doped material greatly affect the attenuation competence.

The calculated half value layer (HVL) and tenth value layer (TVL) of the investigated standard concrete and concrete doped materials as a function of photon energy are presented in Fig. 3 and 4 respectively. The HVL generally increase with photon energy for all the concretes, an indication that higher energy photons are more penetrating hence; more thickness of absorbing materials is required to absorb them. The result shows that concrete doped boron carbide has the highest HVL values. This implies that concrete doped boron carbide allow more photons to transmit through them than the other concrete doped materials and hence less attenuating.

The calculated mean free paths (MFP) variation with energy for standard concrete, concrete dopedg mixtures are presented in Fig. 4. It is obvious that the MFP is similar to HVL as expected and they both increases with increase in photon energy. This affirms the fact that higher energy photons travel further in the concrete due to reduced interaction cross sections of the process leading to photon absorption.

4. Conclusions

The radiation shielding properties of standard concrete and concretes containing four compounds (ferro boron, boron carbide, ilmenite, and galena) were investigated. A theoretical study of the mass attenuation coefficients (MAC) of standard concrete and concrete doped materials were determined by a winXCOM computer program. The MAC values showed a sharp decline as the energy increases to a certain extent and reduces smoothly after that for all the materials investigated. An abrupt increase in MAC value of concrete doped galena was observed and was attributed to the Pb content in the material making it a better photon shielding material among the materials investigated. The calculated half value layer, tenth vaule layer and mean free path result are in favour of concrete doped galena. The MAC and LAC values of standard concrete and concrete doped materials are in the order: concrete doped galena > concrete doped ilmenite > concrete doped ferroboron > standard concrete > concrete doped boron carbide. Therefore, galena is the better dopant of concrete among the compounds investigated for photon shielding purposes.

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