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Research Article

Determination of the mass attenuation coefficients, effective atomic numbers and effective electron numbers of some concrete containing barites for 511, 835 and 1275 keV gamma rays

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Abstract

The linear attenuation coefficients (µl) of concretes including barite fractions of 0%, 50% and 100% were measured at the gamma energies of 511, 835 and 1275 keV. The measurements have been performed using a low level gamma counting spectrometer including a 3"x3" NaI(TI) detector by ORTEC Inc., connected to a multichannel pulse height analyzer. Total mass attenuation coefficients, effective atomic numbers and effective electron numbers of concretes are calculated in the energy range from 1 keV to 100 GeV. The values of mass attenuation coefficients used in the calculations are taken from the XCOM. The measurement values were compared with the theoretically calculated results. The measured results of mass attenuation coefficients, effective atomic numbers and effective electron densities were found to be in good agreement with the calculations.

Keywords: Barite concrete, mass attenuation coefficients, effective atomic numbers, effective electron density

1. Introduction

With the development of technology, radiation has gained great importance in the day. Different types of shielding materials have begun to be produced against radiation by the use of radiation in fields such as medicine, biology, nuclear power plants and space sciences. The radiation absorption mechanism of these materials produced for this purpose should be known. Especially when the interaction of photons with matter is examined, it is important to know the parameters such as mass attenuation coefficient (μ_m), linear attenuation coefficient (μ_l), total atomic cross section (σ_t), electronic cross section (σ_e), effective atomic number (Z_{eff}), electron density (N_e) and the physical properties of average free path (λ) composite materials.

The scattering and absorption phenomena of γ-radiation interacting with matter are related to the density and atomic numbers of an element. It is associated with effective atomic number (Z_{eff}) and electron density (N_e) in composite materials. In composite material, a single number cannot represent the atomic number uniquely in the entire energy range, since the partial interaction fraction is dependent on a different atomic number (Z) [1]. This number is called the effective atomic number (Z_{eff}), a very useful parameter for examining the interaction of radiation with matter. The effective atomic number is a suitable parameter for representing the absorption of radiation in a composite environment. The effective atomic number in particular the attenuation of γ rays in dose calculation in radiation therapy and an initial estimate of the chemical composition of the material may provide. [2]. In general, the effective atomic number is small for the indication of organic materials, while it is great for inorganic compounds and metals. The other significant quantity is the number of effective electrons or electron density and is defined as the electron per unit mass of the absorber.

Numerous experimental and theoretical studies have been carried out to determine the mass absorption coefficients (μ_m) values of the various elements and compounds / mixtures as a result of the interaction of the photons with the substance. First, Hubbel worked on 40 elements and 45 mixtures / compound over an energy range of 1 keV to 20 MeV [3]. Later, Hubbel and Seltzer reported mass adsorption coefficients for all elements and 48 additional substances in their work [4]. Berger and Hubbel developed theoretical tables and computer program (XCOM) to calculate attenuation coefficients for elements, compounds and mixtures for photon energies from 1 keV to 100 GeV [5].

Several investigators have made extensive the effective atomic number and electron density studies in variety of complex materials such as compounds, crystals, alloys, glasses, semiconductors, organic and inorganic compounds [6-22].

In the present study, linear attenuation coefficients (μ_l) of barite-added concretes for different gamma energies (511, 835 and 1275 keV) were experimentally measured using different

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point radioactive sources (^{22}Na and ^{54}Mn). The experimentally measured results were compared with the calculation results obtained through XCOM. In addition, effective atomic number (Z_{eff}), electron density (N_e) and photon mean free path (λ) were calculated using the mass attenuation coefficient (μ_m) in the photon energies of 1 keV-100 GeV and the results were compared at 511, 835 and 1275 keV photon energies for three different concrete, namely normal concrete (N), barite concrete (NB) and barite (B).

2. Materials and Method

The linear attenuation coefficients (μ) of concretes including barite fractions of 0%, 50% and 100% were measured at the gamma energies of 511, 835 and 1275 keV obtained from ^{22}Na and ^{54}Mn γ-ray sources. The measurements have been performed using a low level gamma counting spectrometer including a 3”x3” NaI(TI) detector by ORTEC Inc., connected to a multichannel pulse height analyzer (Figure 1). The necessary power for the detector as well as the acquisition of gamma spectra was achieved by an integrated spectroscopic system. This system is controlled by a personal computer. The control of acquisition parameters and analysis of the collected spectra are carried out using MAESTRO-32 (version6.06) software package.

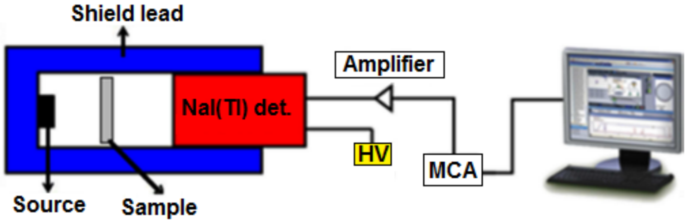

Figure 1. Schematic view of gamma Spectrometer and electronic units

The linear attenuation coefficients have been evaluated comparing I and I_0, which are the measured count rates in detector, respectively, with and without the absorber of thickness x (cm).

$$\mu_l = \frac{1}{x} Ln \frac{I_0}{I} \tag{1}$$

γ-rays spectrum obtained from ^{22}Na and ^{54}Mn sources are displayed in Figure 2, where attenuated (I) and unattenuated (I_0) γ-rays at 511, 835 and 1275 keV can be clearly seen.

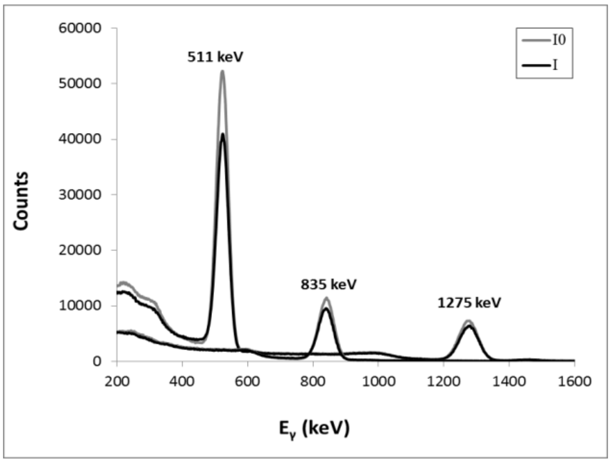

Figure 2. Attenuated and unattenuated γ-rays spectrum obtained from ^{22}Na and ^{54}Mn sources

The measured linear attenuation coefficients (μ_l) were compared with the calculated values obtained by using XCOM computer code in which the mass attenuation coefficients (μ_m) were imported. The XCOM is a data base and can run on a PC and it uses pre-existing data bases for coherent and incoherent scattering, photoelectric absorption, and pair production cross-sections to calculate mass attenuation coefficients at photon energies of 1 keV–100 GeV [5]. In the XCOM code chemical contents were input and output is the mass attenuation coefficients (μ_m).

The total atomic cross-section (σ_t) for materials can be obtained from the measured values of μ_m using the following relation [9].

$$\sigma_t = \frac{\mu_m N}{N_A}$$

Where $N = \sum_i n_i A_i$ is atomic mass of materials and N_A is the Avagadro’s number.

Total electronic cross-section (σ_e) for the element is expressed by the following equation [9].

$$\sigma_e = \frac{1}{N_A} \sum_i \frac{f_i N_i}{Z_i} (\mu_m)_i = \frac{\sigma_t}{Z_{eff}}$$

Where f_i denotes the fractional abundance of the element i with respect to the number of atoms such that $f_1+f_2+f_3+f_4+...f_i=1$, Z_i is the atomic number of i_{th} element.

The total atomic cross-section (σ_t) and total electronic crosssection (σ_e) are related to the effective atomic number (Z_{eff}) of the material through the following relation [9].

$$Z_{eff} = \frac{\sigma_t}{\sigma_e}$$

Effective electron number or electron density (N_e) (number of electrons per unit mass) can be calculated using the following relation [9].

$$N_e = \frac{N_A}{N} Z_{eff} \sum_i n_i = \frac{\mu_m}{\sigma_e}$$

The average distance between two successive interactions, called the photon mean free path (λ), is given by

$$\lambda = \frac{\int_0^\infty x \exp(-\mu x)\, dz}{\int_0^\infty \exp(-\mu x)\, dx} = \frac{1}{\mu_l}$$

Where (μ_l) is linear attenuation coefficient and x is the absorber thickness.

3. Results and Discussion

The μ_m for concretes including barite in different rates have been calculated at photon energies of 1 keV–1 GeV and the results were compared with the measurements for the photon energy of 511, 835 and 1275 keV. This is displayed in Figure 3 where it can be seen that the calculated and the measured results are in good agreement for the present steels. It can also be clearly seen from this figure that the μ_m depends on the incoming photon energies as the interaction mechanism of photons with the matter is different for different photon energy.

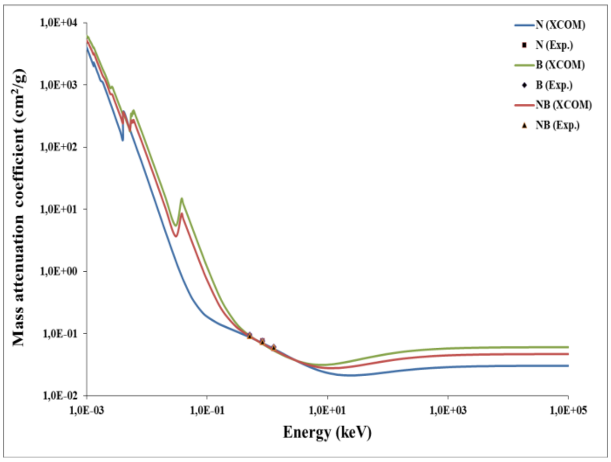

Figure 3. The calculated photon mass attenuation coefficients of steels at 1 keV–1 GeV and comparison with the measurements.

The effective atomic number (Z_{eff}) for concretes at photon energies of 1 keV–100 GeV have been calculated using formula 4 and the results were displayed in Figure 4 as a function of photon energy. In this figure the calculated results were compared with the measurement performed at the photon energies of 511, 835 and 1275 keV. It can be seen from this figure that the good agreement between measurement and the calculation has been obtained. It is also clear from this figure that the effective atomic number decreased with the increasing photon energy at low energy and it started to increase above about 500 keV. This could be the result of different interaction processes of photon with the material for different energy ranges. The dominating photon interaction process is photoelectric absorption at low energies, Compton scattering (mainly incoherent) at intermediate energies, and pair production gradually becomes the dominant interaction process above about 1 MeV. Almost a constant structure has been observed after this energy.

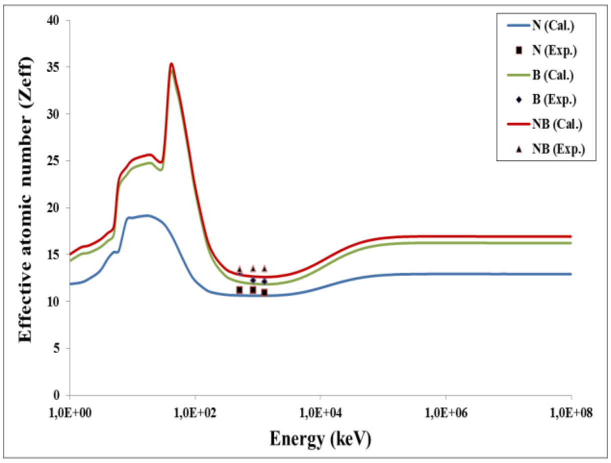

Figure 4. The effective atomic number of concretes as a function of photon energy

The effective electron numbers for concretes at photon energies of 1 keV–1 GeV have been calculated using Formula 5 and the results were displayed in Figure 5 as a function of photon energy. In this figure the calculated results were compared with the measurement performed at the photon energies of 511, 835 and 1275 keV. It can be seen from this figure that good agreement between measurement and the calculation has been obtained. Similar structure has been obtained as seen in Figure 4 for the case of effective atomic number.

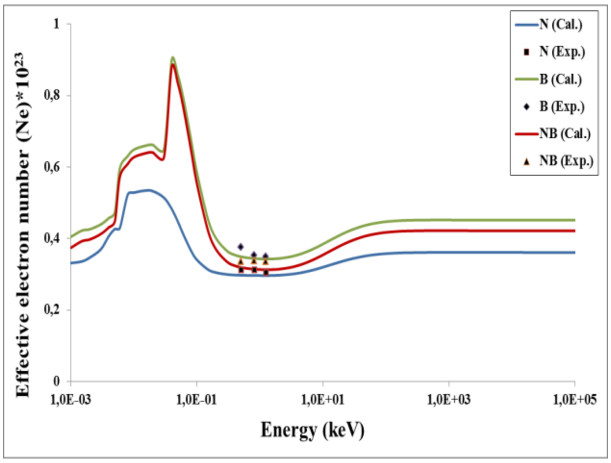

Figure 5. The effective electron number of concretes as a function of photon energy.

The photon mean free paths (λ) for concretes at the photon energies of 511, 835 and 1275 keV have been calculated by using linear attenuation coefficients obtained from the measurements and the results were displayed in Figure 6 as a function of photon energy. It can be seen from this figure that the mean free path increased with the photon energy.

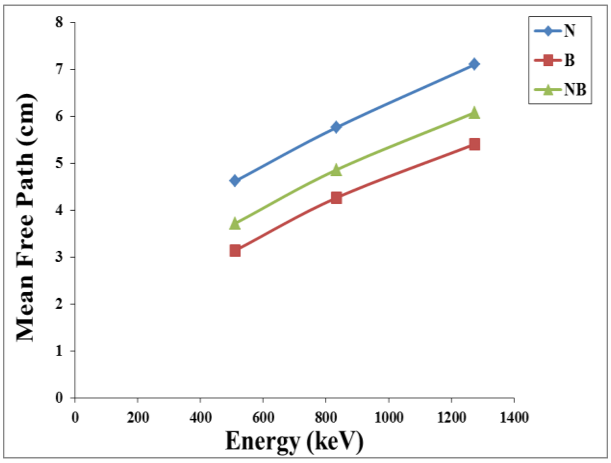

Figure 6. The mean free path of concretes as a function of photon energy.

4. Conclusion

This study presents the experimental and theoretical determination of radiation attenuation coefficients, effective atomic numbers and effective electron densities for concrete containing barite at different ratios. In the interaction of photon with matter, the values of these parameters are dependent on the physical and chemical environments of the sample. The obtained mass attenuation coefficient values decrease with increasing photon energy. It was found that the experimental results of this work are in good agreement with the computed values. It could be concluded that the experimental results were consistent with the theoretical data. The results of this study will be helpful to understand better how mass attenuation coefficient values change with the variation in effective atomic numbers and effective electron densities of concretes.

References

[1] Hine G.J., The effective atomic numbers of materials for various gamma interactions, Physics Review, 85, 725–737 (1952)

[2] Jackson D.F. and Hawkes D.J., X-ray attenuation coefficients of elements and mixtures, Physics Report 70, 169–233 (1981)

[3] Hubbell J.H., Photon mass attenuation and energy absorption, International Journal of Applied Radiation and Isotopes, 33, 1269–1290 (1982)

[4] Hubbell J.H. and Seltzer S.M., Tables of X-ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients 1 keV to 20 MeV for Elements Z= 1 to 92 and 48 Additional Substances of Dosimetric Interest, National Institute of Standards and Physics Laboratory, NISTIR, 5632 (1995)

[5] Berger M.J. and Hubbell J.H., (XCOM) Photon Cross Section on a Personal Computer NBSIR, 87, NIST, 3597 (1987)

[6] Akkurt, _I., Basyigit, C., Kilincarslan, S., Mavi, B., 2006. Radiation shielding of concretes containing different aggregates. Cem. Concr. Compos. 28 (2), 153– 157.

[7] Baltas H, Celik S, Cevik U, Yanmaz E (2007). Measurement of mass attenuation coefficients and effective atomic numbers for MgB2 superconductor using Xray energies. Radiat. Meas. 42:55-60.

[8] Manjunathaguru V, Umesh TK (2007). Total interaction cross sections and effective atomic numbers of some biologically important compounds containing H, C, N and O in the energy range 6.4–136 keV. J. Phys. B: Atomic Mol. Opt. Phys. 40:3707-3718.

[9] Singh, M.P., Sandhu, B.S., Singh, B., 2007. Measurement of effective atomic number of composite materials using scattering of c-rays. Nucl. Instrum. Meth. A 580, 50–53.

[10] Celik A, Cevik U, Bacaksiz E, Celik N (2008). Effective atomic numbers and electron densities of CuGaSe2 semiconductor in the energy range 6–511 keV. X-Ray Spectrometry. 37:490-494.

[11] Han I, Demir L (2009c). Studies on effective atomic numbers, electron densities from mass attenuation coefficients in TixCo1_x and CoxCu1_x alloys. Nuclear Instruments and Methods in Physics Research Section B. 267:3505–3510.

[12] Akkurt, I , 2009. Effective atomic and electron numbers of some steels at different energies. Annals of Nuclear Energy 36, 1702–1705.

[13] Manohara SR, Hanagodimath SM, Thind KS, Gerward L (2010). The effective atomic number revisited in the light of modern photoninteraction cross-section databases. Applied Radiation and Isotopes. 68:784-787.

[14] Kurudirek, M., Aygun, M., Erzeneoglu, S.Z., 2010. Chemical composition, effective atomic number and electron density study of trommel sieve waste (TSW), Portland cement, lime, pointing and their admixtures with TSW in different proportions. Int. J. Appl. Radiat. Isot. 68, 106–1011.

[15] Damla, N., Cevik, U., Kobya, A.I., Celik, A., Celik, N., Van Grieken, R., 2010. Radiation dose estimation and mass attenuation coefficients of cement samples used in Turkey. J. Hazard. Mater. 176, 644–649.

[16] Akkurt, I., Akyıldırım, H., Mavi, B., Kilincarslan, S., Basyigit, C., 2010a. Photon attenuation coefficients of concrete includes barite in different rate. Ann. Nucl. Energy 37–7, 910–914.

[17] Akkurt, I, Akyıldırım, H., Mavi, B., Kılıcarslan, S., Basyigit, C., 2010b. Gamma-ray shielding properties of concrete including barite at different energies. Prog. Nucl. Energy 52, 20–623.

[18] Yılmaz, E., Baltas, H., Kırısa, E., Ustabas, _I., Cevik, U., El-Khayatt, A.M., 2011. Gamma ray and neutron shielding properties of some concrete materials. Ann. Nucl. Energy 38 (10), 2204–2212.

[19] Sidhu BS, Dhaliwal AS, Mann KS, Kahlon KS (2012). Study of mass attenuation coefficients, effective atomic numbers and electron densities for some low Z compounds of dosimetry interest at 59.54 keV incident photon energy. Ann. Nucl. Energy 42:153-157.

[20] Medhat ME, Wang YF (2015). Investigation on radiation shielding parameters of oxide dispersion strengthened steels used in high temperature nuclear reactor applications. Ann. Nucl. Energy 80:365- 370.

[21] Un A, Caner T (2014). The Direct-Zeff software for direct calculation of mass attenuation coefficient, effective atomic number and effective electron number. Ann. Nucl. Energy 65:158-165.

[22] Elmahroug Y, Tellili B, Souga C (2015). Determination of total mass attenuation coefficients, effective atomic numbers and electron densities for different shielding materials. Ann. Nucl. Energy 75:268- 274.