Radiation Physics and Chemistry 130 (2017) 112–117

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

The investigation of vermiculite as an alternating shielding material for gamma rays

Hasan Gülbiçim [a,*], M. Çağatay Tufan [a], M. Nureddin Türkan [b]

[a] Ondokuzmayıs University, Faculty of Arts and Sciences, Samsun 55319, Turkey

[b] Istanbul Medeniyet University, Faculty of Engineering and Natural Sciences, Department of Engineering Physics, 34720 Uskudar/Istanbul, Turkey

HIGHLIGHTS

- Vemiculite was investigated as an alternating shielding material for the first time.
- Radiation shielding parameters were measured for different gamma ray sources.
- Attenuation results of vermiculite were compared with ordinary shielding materials.

ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form
21 July 2016
Accepted 23 July 2016
Available online 25 July 2016

Keywords:
Vermiculite
Shielding
Gamma radiation
Attenuation coefficients

ABSTRACT

In this study, gamma ray shielding properties of vermiculite has been investigated for the first time as a shielding material. The photon total mass attenuation coefficients μ_m, the half value layer (HVL), the tenth value layer (TVL) and the mean free path (MFP) values have been experimentally determined for the photon energies at 0.244, 0.262, 0.342, 0.600, 0.778, 1.173, 1.332, 1.408 and 1.728 MeV. The theoretical data are calculated by using WinXCom computer code. At the end, we obtained good agreement between experimental and theoretical values. As well as the total mass attenuation coefficients, we have also calculated the effective atomic number, Z_{eff}, the effective electron number, N_{eff}, the total atomic cross-section, $\sigma_{t,a}$, the total electronic cross-section, $\sigma_{t,e}$, values for vermiculite and some building materials. Consequently, the obtained results showed that vermiculite could be used as a shielding material for gamma radiation.

1. Introduction

Improvements for substitution of conventional gamma ray shielding materials by new multi-efficient ones has become highly encouraged subject (Jaeger, 1975; Knoll, 1979; Meriç, 2005; Içelli et al., 2011; Akkurt et al., 2014) for serving the radiation protection needs in the daily life of scientific, industrial and health purposes. So, the searches of materials as protective shields for nuclear radiation has recently been interested increasingly.

Attenuation of X- and gamma rays is directly related to the density and atomic number of materials. To determine the gamma ray shielding capability and physical properties of materials, the mass attenuation coefficients (μ_m), the atomic and electronic cross sections ($\sigma_{t,a}$ and $\sigma_{t,e}$), the effective atomic and electron numbers (Z_{eff} and N_{eff}), the half value layer (HVL), the tenth value layer (TVL) and the mean free path values (MFP) should be known (Han et al., 2009).

Many theoretical and experimental studies (Han et al., 2009; Jackson and Hawkes, 1981; Saeed et al., 2014; Kaur and Singh, 2014; Elmahroug et al., 2014; Chen et al., 2014; Buyuk et al., 2013; İçelli et al., 2013; Mann et al., 2013; Oto et al., 2013; Akkurt et al., 2013a, 2013b, 2013c) have been used these parameters to study protective shielding. But the most of those studies are rarely innovative (Saeed et al., 2014; Kaur and Singh, 2014; Elmahroug et al., 2014; Chen et al., 2014; İçelli et al., 2013; Mann et al., 2013) and some of them are related to building materials (such as soil, fly, ash, brick, concrete, cement, clay, coleminate) of construction (Buyuk et al., 2013; Oto et al., 2013; Akkurt et al., 2013a, 2013b, 2013c; Binici et al., 2014). Lets summarize some of works related to radiation shielding materials; Ref. Han et al. (2009) is one of the rare interesting paper related to determine the mass attenuation coefficients of some natural minerals. Saeed et al. (2014) studied gamma ray attenuation in a developed borate glassy system and Kaur and Singh (2014) investigated the lead borate glasses doped with aluminium oxide, as shielding materials. Elmahroug et al. (2014) determined the shielding parameters for different types of resins. Chen et al. (2014) studied novel light-weight materials for

* Corresponding author.
E-mail address: 15210106@stu.omu.edu.tr (H. Gülbiçim).

http://dx.doi.org/10.1016/j.radphyschem.2016.07.025

shielding gamma ray and Buyuk et al. (2013) investigated the effect of boron carbide particle size on radiation shielding properties of boron carbide-titanium diboride composites. O.Icelli et al. İçelli et al., (2013) investigated the shielding properties of some boron compounds. Mann et al. (2013), Oto et al. (2013), Akkurt et al. (2013a, 2013b, 2013c) and Binici et al. (2014) investigated the shielding effectiveness, attenuation properties and shielding performances of construction materials, respectively.

In this study, the authors are surprised that the vermiculite is one of the natural minerals having high absorption capacity for the penetration of gamma radiation. So, the mass attenuation coefficients (μ_m), atomic and electronic cross sections ($\sigma_{t,a}$ and $\sigma_{t,e}$), the effective atomic and electron numbers (Z_{eff} and N_{eff}), HVL, TVL and MFP values of the vermiculite was experimentally calculated and then compared with WinXCom values (Gerward et al., 2004). It was seen that the experimental results are successfully consistent with theoretical ones.

As it is known, some of the traditional shielding materials such as lead, concrete etc. have at least one or more disadvantages of i) heaviness for transportation and storage, ii) high production cost and iii) harmful effects on human body. However the vermiculite, as a new shielding material, has many reasonable advantages including great abundance, low production costs and light weight for transportation and storage.

Obtained experimental and computational results have also been compared with lead, concrete, granite and boron carbide which have concluded that vermiculite is a good candidate for gamma shielding applications. There are few previous papers which are only covering the neutron shielding capacities (Demir et al., 2011; Korkut et al., 2012; Demir, 2010) of vermiculite and concrete aggregate cement mixture, while our study is the pioneer for the examination of gamma absorption capacities of vermiculite (Türkan et al., 2013).

2. Theoretical and experimental studies

2.1. Theoretical background

Mass attenuation coefficient is one of the most important parameter to explain absorption properties of radiation shielding materials. For a compound or a mixture, this coefficient is calculated by the equation given by (Singh et al., 2015);

$$\frac{\mu}{\rho} = \sum_i w_i(\mu/\rho)_i \tag{1}$$

where w_i and $(\mu/\rho)_i$ is the weight fraction and mass attenuation coefficient of element i in the material, respectively; ρ is the density of the investigated sample. The linear attenuation coefficient μ is obtained by the following equation (Buyuk et al., 2013);

$$I = I_0 \exp(-\mu x) \tag{2}$$

where I and I_0 shows the attenuated and incident gamma ray intensity respectively, and x is the thickness of the sample.

Since the linear attenuation coefficient varies with the density of the absorber, even though the absorber material is the same; the mass attenuation coefficient is widely used parameter instead μ. The mass attenuation coefficients can be used to determine the total atomic cross-section ($\sigma_{t,a}$) by the following relation (Han et al., 2009):

$$\sigma_{t,a} = \frac{\mu_m N}{N_A} \tag{3}$$

where N is the atomic mass of materials and N_A is the Avogadro's number. Moreover, the total electronic cross-section ($\sigma_{t,e}$) is expressed by the following formula (Singh et al., 2015):

$$\sigma_{t,e} = \frac{1}{N_A} \sum \frac{f_i N_i}{Z_i}(\mu_m)_i = \frac{\sigma_{t,a}}{Z_{eff}} \tag{4}$$

where f_i denotes the fractional abundance of the element i with respect to the number of atoms such that $f_1+f_2+f_3+\ldots+f_i=1$, Z_i is the atomic number of ith element. The $\sigma_{t,a}$ and $\sigma_{t,e}$ are related to the effective atomic number (Z_{eff}) of the material through the following relation:

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,e}} \tag{5}$$

The effective electron number (N_{eff}) can be written as follows (Han et al., 2009):

$$N_{eff} = \frac{N_A}{N} Z_{eff} \sum n_i = \frac{\mu_m}{\sigma_{t,e}} \tag{6}$$

The theoretical μ_m values for present materials were obtained by the WinXcom. This program depends on applying the mixture rule to calculate the partial and total mass attenuation coefficients for all elements, compounds and mixtures at standard as well as selected energies.

The half value layer (HVL) is another coefficient that is known as the required thickness of shielding material where one half of the incident photons have been attenuated and it is given by;

$$HVL = \frac{0.693}{\mu} \tag{7}$$

The term called the tenth value layer (TVL) is the thickness of shielding material where one tenth of its incident photons have been attenuated and it is given by;

$$TVL = \frac{2.3026}{\mu} \tag{8}$$

One of the other value that is calculated in this study for vermiculite is the mean free path which is described in Singh et al. (2015).

2.2. Experimental details

In order to prepare shielding material, Macroscopic Granular Vermiculite was obtained from Yıldızeli, Gönenbaba mining, Sivas, Turkey. The obtained vermiculite samples were analysed with X Ray Powder Difraction (XRD) to determine chemical compounds of it experimentally. This experiment were done at X ray difractometer system situated in Karadeniz Advanced Technology and Research Center (KITAM). It was seen that chemical composition of the vermiculite contains $Na_{0.930}$ $Mg_{2.810}$ $Fe_{0.065}$ $Al_{1.185}$ $Si_{2.895}$ O_{10} $(OH)_2$ $3(H_2O)$ as major elements. As it is understood from the composition formula vermiculite has been composed of silicate layers. XRD analyse results have been indicated in Fig. 1.

Vermiculite powder samples was converted to pellets for radiation penetration measurements by using hydrolic press. The cylindrical pellets were obtained at 30 mm diameter and 20 mm height. The samples were then used to study their radiation permeability. The density of vermiculite samles are determined as 2.39 gr/cm^3. The mass attenuation coefficients (μ_m) were determined by measuring the transmission of gamma rays through targets of those five different thicknesses one by one.

In this experiment, parallel hole collimator and the scintillation detector system including a 10 cm diameter NaI(TI) detector by ORTEC Inc., connected to a multi channel pulse height analyzer are used. The schematic view of experimental setup is displayed in Fig. 2.