International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-019-02240-7

ORIGINAL PAPER

Radiation shielding properties of some ceramic wasted samples

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Received: 12 September 2018 / Revised: 14 January 2019 / Accepted: 22 January 2019

Abstract

The radiation has great importance in human life; it enters into various fields of agricultural, industrial, medical and food sterilization, for example, in the medical field, X-ray is used to diagnose many cases of a disease. The exposure to radiation has great risks to human life and must be protected against it. There are several ways to protect the human body from radiation; one of these ways is shielding; in the present work, eight types of ceramic materials have been used as a shielding material and tested against gamma ray, each type of ceramic modified as glazed and unglazed. The radiation sources ^{137}Cs and ^{60}Co were used to calculate attenuation coefficients and half-value layers by gamma-ray spectrometer system with scintillation detector NaI(Tl). The obtained results show that the photon attenuation coefficient for all samples decreases with increasing energy, while half-value layers increase with increasing energy. The results of the study showed that glazed ceramics are better than unglazed in the attenuation of gamma radiation which makes their use of shielding better.

Keywords Attenuation coefficients · Ceramic · Gamma-ray spectrometry · Scintillation detector NaI(Tl)

Introduction

Radiation is the process of the propagation of energy in space in the form of various waves and particles; these include infrared, ultraviolet, visible light, as well as ionizing radiation. In our life, human exposed to different sources of ionizing radiation, like natural radiation sources, medical utilization, industrial application, liquid waste from nuclear installations, the fallout from nuclear weapon testing and the effect of nuclear accidents. A human who exposed to ionizing radiation of increased levels can be harmful to him. It must be protected against the radiation; the fundamental principle of radiation protection is to minimize exposure to radiation; it is possible to employ three main principles by reducing time, increase the distance and shielding between the source and personnel.

The shielding is very important in radiation protection. Lead usually uses to protect from gamma ray because it has a high density (high atomic number). Many researchers have studied different types of shielding materials such as ceramic, concrete, barite, marble and limra instead of lead. Akkurt et al. (2005) studied the effect of adding barite to concrete attenuation of gamma ray; El-Khayatt (2010; El-Khayatt and Akkurt 2013; Akkurt and Elkhayat 2013) studied concretes containing different materials as a radiation shielding; Akkurt et al. (2004) used barite, marble and limra to calculate photon attenuation coefficients; Najam et al. (2016) measured the attenuation coefficient of the gamma rays for ceramic, granite, bricks, concrete and marble. They concluded from their experiments that these materials are good shields.

Ceramic entered within building materials and used in different applications such as mechanical applications, electrical and magnetic applications, nuclear power, etc. Ceramics are composite materials that have mechanical properties such as strength, toughness, wear resistance, high melting point and hardness (Ceramics 2017). Ceramic is defined as a solid, complex and difficult material; this material is characterized by many properties including durability, toughness and hardness, chemical reaction, lack of porosity, limited risk and contamination and the flexibility of formation.

Editorial responsibility: İskender Akkurt.

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Published online: 29 January 2019

In the present study, the linear attenuation coefficient for some ceramic samples has been measured by using a gamma-ray spectrometer and two sources ^{60}Co and ^{137}Cs. Measurements are carried out in Suleyman Demirel University, Physics Department, Isparta, Turkey. The samples are produced in Kocaeli University Degirmendere Ali Ozbay Vocational School Ceramic Technology Laboratory.

The aim of this research is to develop a shield of local and inexpensive materials (ceramic) to replace the common materials that are used to attenuate gamma radiation.

Materials and methods

Ceramics are the materials that are formed of non-organic compounds and obtained in this study by hand shaping, then, dried and fired till it reaches a sufficient hardness; two kinds of ceramic were prepared for four types: biscuit (unglazed) ceramic and glazed ceramic. The materials used in this study consisting of several types of ceramics are presented in Table 1.

Ceramic samples were arranged and placed between radioactive sources and detector; they are placed on the same axis; the sources ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV) were used as a radioactive source.

The measurements were performed using gamma-ray spectrometer system containing 3×3 inch sodium iodide with thallium NaI(Tl) detector, multichannel analyzer, high voltage–power for detector from which an integrated spectrum is obtained by analyzing these pulse. Gamma-ray spectrometer may also be used in some other application (Günay et al. 2018; Gunay 2018). The data are analyzed by a computerized program MAESTRO-32 (Akkurt et al. 2006, 2009, 2010; Al-Sarray et al. 2017). The system is shown in Fig. 1.

Table 1 Ceramic materials used in the study with sintering temperatures and thickness

Samples	Sample code	°C	Sample thickness (cm)
Kutahya tile mud (dry pressed-biscuit)	KDB	950	1.6
Kutahya tile mud (dry pressed-glazed)	KDG	950	1.6
Red mud (biscuit)	RB1	950	2.2
Red mud (glazed)	RG	1040	2.1
White mud (biscuit)	WB1	950	2.0
White mud (glazed)	WG	1040	2.0
White casting mud(biscuit)	SB	1000	2.0
White casting mud (glazed)	SG	1040	2.1

The measurement of linear attenuation coefficients

The attenuation is the process of removing the photon from the beam of gamma rays or X-ray based on the photoelectric effect, Compton scattering or pair production. This process can be described by the linear attenuation coefficient (μ) which can be expressed by the probability that a photon will interact with matter per unit length.

The linear attenuation coefficients (μ) are measured by the following equation:

$$N = N_o e^{-\mu x} \quad (1)$$

where μ is linear attenuation coefficient (cm^{-1}); N is the number of photons detected by the detector during a specified period of time when a material with a determined thickness (x) is placed between the source and the detector; N_o is the number of photon source without thickness.

Half-value layer

A half-value layer or thickness (HVL) is a geometric system placed to determine the thickness of the material required to reduce the amount of gamma rays or X-Ray to half of its original value as it travels through the air. The unit of HVL is given by (cm) or (mm).

The half-value layer (HVL) is measured by the following equation:

$$\mathrm{HVL} = \frac{Ln\ 2}{\mu} \quad (2)$$

Results and discussion

Figure 2 shows the results of (μ cm^{-1}) for all ceramic sample (eight samples glazed and unglazed ceramic) with three gamma energies 662, 1173 and 1332 keV which obtained from ^{137}Cs and ^{60}Co, respectively. The measurements show that the linear attenuation coefficient in energy 662 keV is increased, while it decreases in high energies 1173 keV and 1332 keV.

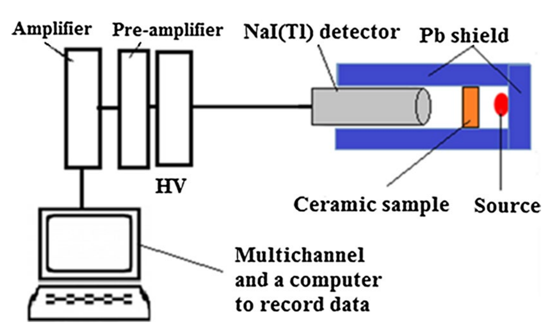

Fig. 1 Schematic view of the gamma-ray spectrometer

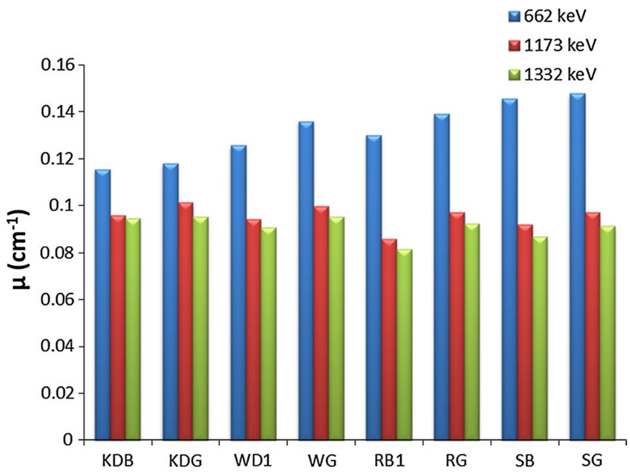

Fig. 2 Linear attenuation coefficient (μ) with energies for all ceramic samples

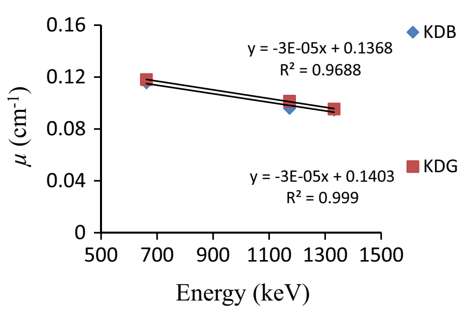

Fig. 3 Linear attenuation coefficient (μ) as a function of gamma energies for Kutahya Tile Mud Dry Pressed

It can be observed in Fig. 2 that the linear attenuation coefficient (μ cm^{-1}) of glazed ceramic for each material is higher than the unglazed (biscuit) ceramic for the same material and can be seen the samples (SG, SB, RG, WG) have a good attenuation than other samples.

The results of the linear attenuation coefficients for each material as a function of gamma-ray energies are shown in Figs. 3, 4, 5 and 6.

Figs. 3, 4, 5 and 6 appear clearly that the attenuation coefficients decrease with the increasing energies. For those relations, R^2 was found about over 96% for attenuation rate, as well as it can be noted from the figures that the attenuation coefficient of samples for glazing materials such as [white mud (glazed), red mud (glazed) and white casting mud (glazed)] was higher than the (unglazed) biscuit materials.

Half-value layer is an important parameter to determine the effectiveness of the shielding material; it has been measured by applying Eq. (2). HVL (cm) has been obtained as a function of photon energy for ceramic samples. The results have been shown in Figs. 7, 8, 9 and 10 where it can

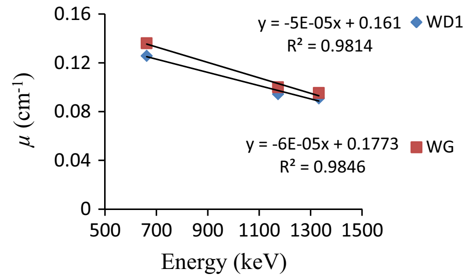

Fig. 4 Linear attenuation coefficient (μ) as a function of gamma-ray energies for White mud

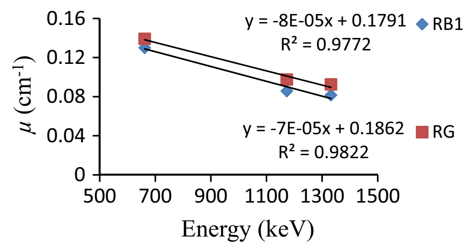

Fig. 5 Linear attenuation coefficient (μ) as a function of gamma-ray energies for Red Mud

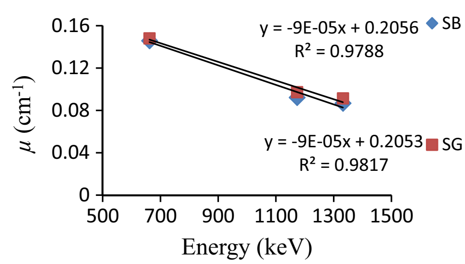

Fig. 6 Linear attenuation coefficient (μ) as a function of gamma-ray energies for White Casting Mud

be seen that the half-value layer HVL (cm) increases with increase in the photon energy for all the samples.

Conclusion

As the shielding is an important way for radiation protection to develop suitable materials, it becomes a very important subject for the researcher. Thus eight different ceramic samples were produced and their shielding properties were investigated in this work; the analysis of results was carried out by the gamma-ray spectrometer.

The linear attenuation coefficients (μ cm^{-1}) for all samples are seen to decrease with increasing energy, as will that the linear attenuation coefficients for glazing materials are

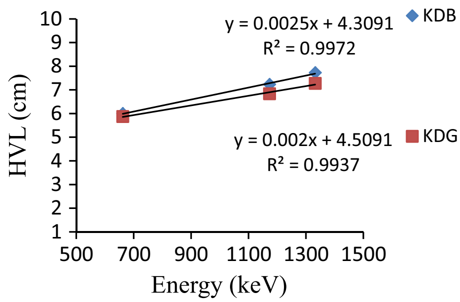

Fig. 7 Half-value layer (HVL) as a function of gamma energies for Kutahya Tile Mud Dry Pressed

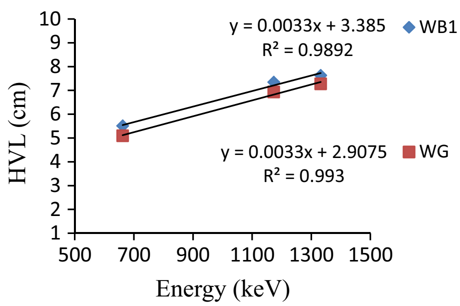

Fig. 8 Half-value layer (HVL) as a function of gamma-ray energies for White mud

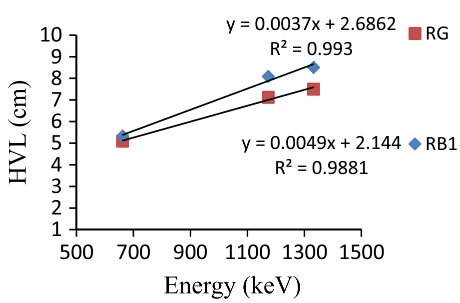

Fig. 9 Half-value layer (HVL) as a function of gamma-ray energies for Red Mud

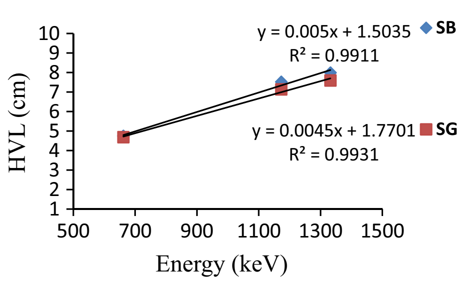

Fig. 10 Half-value layer (HVL) as a function of gamma-ray energies for White Casting Mud

larger than the biscuit materials, and those relations R^2 are found about over 96% for attenuation rate as well as half-value layer is increased with increasing photon energy.

The results of the study showed that glazed ceramics are better than unglazed in the attenuation of gamma radiation which makes their use of shielding better. The materials (SG, RG, WG) have good results than other samples as attenuation against gamma ray which can be dependents as a shield.

Acknowledgements Author thanks all the participants in this research and all the institutions that supported it.

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