Study of gamma rays shielding parameters of some building materials used in Sudan

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▶ ***Original article***

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Revised: April 2020
Accepted: June 2020

Int. J. Radiat. Res., January 2021; 19(1): 191-196

DOI: 10.18869/acadpub.ijrr.19.1.191

ABSTRACT

Background: This study investigated the γ-rays shielding properties of some building materials in Sudan has been investigated. ***Materials and Methods:*** Photons attenuation coefficients and half value layer (HVL) were experimented using Cs-137 and Co-60 sources. The measurements were performed to gauge the intensity of radiation when performed unshielded, the specific thickness of selected samples was examined, using an ion chamber placed at 2 meters from Cs-137 and Co-60. ***Results:*** The results indicated that the linear attenuation coefficient (μ) possesses a linear relationship with the corresponding densities of the samples studied and inversely with photon energy. HVL was directly proportional with photon energy. ***Conclusion:*** As a result of this evaluation the study concluded that selected samples were suitable as shielding material for gamma radiation in Sudanese laboratories.

Keywords: *γ-radiation, attenuation coefficient, half value layer, shielding, building materials.*

INTRODUCTION

Due to the use of radiation in many fields such as industrial, medical and agricultural, etc. So, the γ- radiation penetration through matter depends on the photon energy and the nature of absorbing material (1). Ionizing radiation is considered a risk factor for cancer due to its potential to induce the stochastic effect, e.g., DNA damage, especially in rapidly cell-cycling tissues, such as the epithelial and endocrine tissues, in addition to immune and stem cells.

Gamma radiation can alter biologic molecules through direct or indirect mechanisms (2). With the increasing use of radioisotopes in many fields such as medical, industrial and agricultural. It becomes necessary to study the different parameters related to the passage of gamma radiation through a material. Attenuation coefficient is an important parameter for study of interaction of radiation with matter that gives us the fraction of energy scattered or absorbed (3).

So that it is necessary to study different parameters related to the passage of γ-radiation through a building materials, and experimentally obtained the gamma ray shielding parameters such as half value layer, linear and mass attenuation coefficients to know the effectiveness of building materials as the gamma ray shielding.

Different workers have been calculated the attenuation coefficients in different categories such as in Lead and tungsten carbide cobalt (WC

[DOR: 20.1001.1.23223243.2021.19.1.22.3]

[DOI: 10.29252/ijrr.19.1.191]

-Co) Materials against γ- Irradiation, used Aluminum, Iron, Copper and Lead, in building block, concrete, iron and lead, (4-7) design and construction of light and heavy weight concrete biological shields from ionizing radiation, in heavy concrete, in Cement material (8-10), in clay, silica fume and cement samples, used clay-fly ash bricks, in boron doped clay for 662, 1173 and 1332 keV γ-rays (11-13) in glass, concrete, marble, fly ash, cement and lime.

MATERIALS AND METHODS

Selected building materials (Clay, Cement mortar, Concrete Mix Design) as samples for shielding and prepared separately: the concrete mix was designed according to the British design method and the design result was as follows:

The mixture was designed to give strength of 25 n/mm^2 and the concrete was then mixed and casted into (150^3 mm^3 mm and 100^3 mm^3) cubes. For Cement mortar which mixed by cement was mixed with 4 sand and 0.5 water and cubes were casting in the same way for the concrete mix. For clay Proctor test was performed of clay sample to determine the optimum moisture content of the clay. The result was a 40% optimum moisture content, of clay weight.

The feature of lead and iron materials used was in form of slabs with different thicknesses, the density of lead, iron, concrete, cement and clay was 11.34 (g/cm^3), 7.87 (g/cm^3), 2.374 (g/cm^3), 2.139(g/cm^3) and 1.335 (g/cm^3) respectively. The measurement was performed at secondary standard dosimetry laboratory (SSDL–Sudan) in order to determine the air kerma rate as radiation intensity at a reference distance from γ source (Co-60, Cs-137) located in OB-85 Irradiator two lead attenuators are available that are placed at the exit window of the irradiator, so shielding samples was placed at this point, and connected to Electrometer UNIDOS, Thermometer and barometer were used to conduct this measurement. Concerning dosimetry systems, the laboratory has one secondary standard ionization chamber designed and manufactured at the Austrian research centre, Siebersdorf.

This chamber was calibrated at IAEA laboratory with its calibration traceable to the German National Laboratory (PTB)TM. Ionization chamber was placed at 2 meters from Cs-137 source as usual in reference standard measurements.

Measurements of linear attenuation coefficients; γ-ray beam used here was characterized in terms of air kerma as radiation intensity without attenuator further adding attenuator with constant operation voltage 400 volt, to calculate linear attenuation coefficient (14).

Linear attenuation coefficient

The Photon attenuation coefficient is an important parameter characterizing the penetration and diffusion of gamma rays in composite materials such as soil (15). Attenuation coefficient is one of the fundamental parameters that is important for characterization of the diffusion and penetration of gamma rays in a given medium (16).

The attenuation coefficient equation [1] measures the probability of all possible interactions between γ- rays and atomic nuclei, it is important for solving various problems in radiation physics and in radiation dosimetry. The probability of a photon interacting in a way with a given material, per unit path length is usually called the linear attenuation coefficient μ, is great importance in radiation shielding. Linear attenuation coefficients depend on the density ρ of the shielding material, the incident photon energy and the nature of the absorbing material.

$$\mu = \frac{1}{x}\ln\left(\frac{I_0}{I}\right) \quad (1)$$

Where μ is the linear attenuation coefficient in (cm^{-1}) and x is the thickness of the sample in (cm) (17-19).

Mass attenuation coefficient

Mass attenuation coefficient μ_m is an important parameter for study of interaction of radiation with matter that gives us the fraction of energy scattered or absorbed, it is a measure of probability of interaction that occurs between incident photons and matter in a given mass per unit area thickness of the material encountered. It is a basic quantity used in the calculation of photon penetration and energy deposition in biological, shielding and other dosimetric materials. The magnitude of μ_m equation (2) [20,21] depends on the incident photon energy, the chemical structure and bonding in the absorbing material and parameters such as thickness and density ρ.

$$\mu_m = \mu/\rho \, cm^2 g^{-1} \quad (2)$$

Half Value Layer (HVL)

The thickness of any given material where 50% of the incident energy has been attenuated is known as the half value layer HVL, useful parameters for understanding the interaction of γ-ray and depends on linear attenuation coefficient, is expressed in units of distance (cm). A half value of layer equation (3) [21,22, 23] of shielding material, $X_{1/2}$ defined at $I = \frac{I_0}{2}$, is given as:

$$X_{1/2} = \frac{0.693}{\mu} \quad (3)$$

RESULTS

Results illustrating the decrease of 662, 1173 and 1332 keV γ-rays with the increasing of the thickness of selected materials have been tested, for each energy the measurements were carried out ten times for all samples and the average values summarized in tables 1 to 4 which showed the value of doses through different lead and iron slabs thickness by using Cs-137and Co-60 sources. The measuring time, temperature and pressure were 60s, 24.6 C and 968.9 hpa, respectively.

Also the attenuation coefficients and HVL for the all studied building materials have been obtained for 662, 1173 and 1332 keV γ-rays and the results have been listed in tables 5 and 6. Figures 1, 2, 3 and 4 show graphical patterns linear attenuation coefficients (μ) values for the selected materials through two γ- rays sources, Cs-137 and Co-60, and the variation of linear attenuation coefficients with energy is shown as well. The linear attenuation coefficient of each one of the tested materials decreases with an increase in energy region (inverse relationship). This indicates photon attenuation in materials with increasing thickness analyzed at different energies of γ-rays. Figure 5 shows the comparison of HVL for the selected materials analyzed using two γ-rays sources, Cs-137 and Co-60. The results show a direct relationship between the HVL values and the energies. Figure 6 shows the comparison of density-dependence for the analyzed materials.

Table 1. The value of Doses through different lead and iron slabs thickness by using Cs-137 source. The measuring time, temperature and pressure were 60s, 24.6 and 968.9hpa, respectively.

Lead thickness (cm)	Dose (μGY)	Iron thickness (cm)	Dose (μGY)	Frequency
0.000	474.76	0.000	474.74	10
0.154	400.46	0.202	434.58	10
0.472	274.69	0.522	373.03	10
0.812	190.42	1.036	289.54	10
0.966	164.63	1.350	249.21	10

Table 3. The value of Doses through different building materials cubic's thickness by using Cs-137 source. The measuring time, temperature and pressure were 30s, 30 and 964.7hpa, respectively.

Thickness (cm)	Dose (μGY) through concrete shield	Dose (μGY) through cement shield	Dose (μGY) through clay shield	Frequency
0	225.65	225.65	225.65	10
10	43.37	49.99	77.05	10
20	9.45	12.10	27.26	10
25	4.93	7.04	18.24	10
35	2.27	2.81	7.86	10

Table 4. The value of Doses through different building materials cubic's thickness by using Co-60 source. The measuringtime, temperature and pressure were 30s, 34.5 and 964.8hpa, respectively.

Thickness (cm)	Dose (μGY) through concrete shield	Dose (μGY) through cement shield	Dose (μGY) through clay shield	Frequency
0	1.906	1.906	1.906	10
10	0.561	0.636	0.856	10
20	0.178	0.218	0.396	10
25	0.109	0.141	0.301	10
35	0.053	0.072	0.177	10

Table 5. Attenuation coefficient and half value layer for selected shielding materials using Cs-137 gamma rays.

Materials	Linear attenuation coefficient μ(cm^{-1})	Standard error (cm^{-1})	Mass attenuation coefficient μ_m (cm^2/g)	Standard error (cm^2/g)	Half value layer(cm)	Standard error (cm)
Lead	1.121	0.028	0.098	0.001	0.617	0.008
Iron	0.463	0.009	0.058	0.001	1.496	0.031
Concrete	0.151	0.007	0.063	0.003	4.593	0.236
Cement	0.139	0.006	0.065	0.003	4.965	0.206
Clay	0.101	0.003	0.076	0.002	6.779	0.175

Table 6. Attenuation coefficient and half value layer for selected shielding materials using Co-60 gamma rays.

Materials	Linear attenuation coefficient μ(cm^{-1})	Standard error (cm^{-1})	Mass attenuation coefficient μ_m (cm^2/g)	Standard error (cm^2/g)	Half value layer(cm)	Standard error (cm)
Lead	0.594	0.015	0.051	0.001	1.167	0.034
Iron	0.325	0.023	0.041	0.002	2.137	0.161
Concrete	0.114	0.009	0.046	0.004	6.084	0.484
Cement	0.104	0.007	0.048	0.004	6.691	0.497
Clay	0.075	0.006	0.056	0.005	9.267	0.699

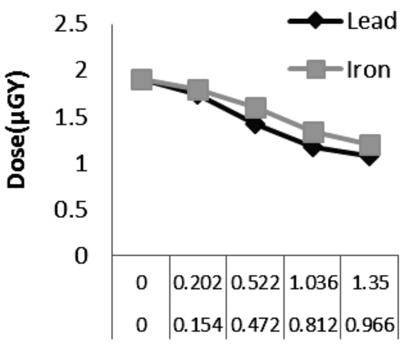

Figure 1. Attenuation of Co-60 gamma rays as a function of thickness through different shield materials.

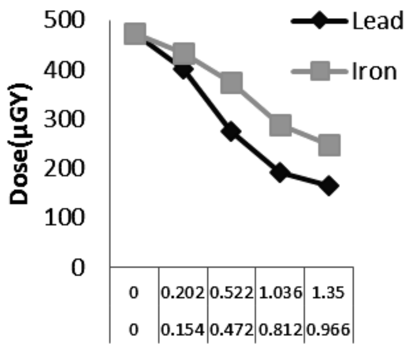

Figure 2. Attenuation of Cs-137 gamma rays as a function of thickness through different shield materials.

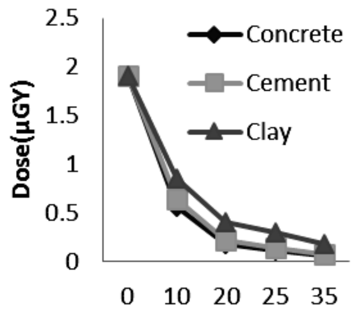

Figure 3. Attenuation of Co-60 gamma rays as a function of thickness through different shield materials.

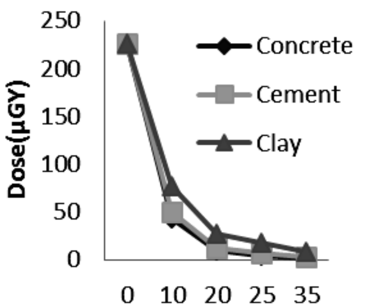

Figure 4. Attenuation of Cs-137 gamma rays as a function of thickness through different shield materials.

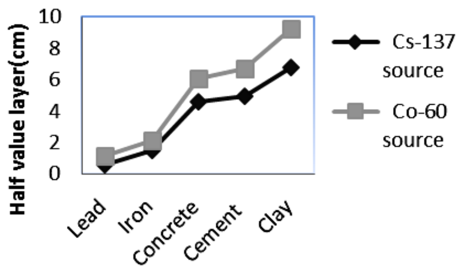

Figure 5. Comparison of half value layer of different Materials using different γ-rays sources.

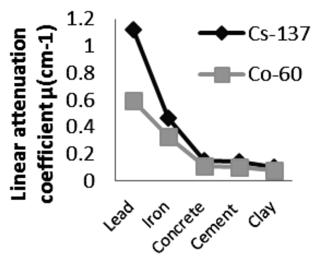

Figure 6. Comparison of linear attenuation coefficients of materials shield as a function of photon energy.

DISCUSSION

In the present study, radiological parameters such as the C0-60 and Cs-137 equivalent activity, the gamma index was determined to assess the radiation hazards associated with the samples [26]. The representative level index, the indoor absorbed dose rate and the annual effective dose all the cement samples considered do not pose any significant source of radiation hazard and the use of the cement samples in construction of dwellings is considered to be safe for inhabitants [27]. Building materials have been evaluated and discussed in terms of attenuation coefficients and HVL for different γ- rays energies. Energy absorption, in particular have been well used. Thus, many investigations subsequent to Goldstein and Wilkins have produced these kinds of buildup factors [24, 25]. The variations in activity concentration among the building materials may be attributed to their radioactive mineral content and the geological, geochemical and geographical origins of the raw materials, among other factors [28]. The investigated materials are commonly used as building materials in Sudan, results displaying the linear attenuation coefficients decrease with the increasing of photon energy as well as HVL increase with photon energy increasing for the tested materials. From the present study, it was the increasing of photon energy as well as HVL increase with photon energy increasing for the tested materials. From the present study, it was found that among the investigated building materials they can be used as a gamma ray shielding materials in educational university. These important observations clearly demonstrate the identification of γ-rays by measuring the pulse height distribution in different and mixed materials radiation field. Due to lower intensities of radiation sources, the material samples are all too thin to test shielding effects perfectly in deep penetration situations in our experiments, however the annual effective dose due to direct exposure of operating personnel is ranged from 0.003 to 0.14 mSv. The annual effective dose of operating personnel due to dust inhalation ranged from 0.003 to 0.16 mSv, it is suggested here that it is advisable to monitor the radioactivity levels of materials from a new source before using it as a building material [29, 30]. Such a large disparities in the concentrations of the radionuclides in building block samples within be explained with the variation in the radionuclide concentrations of the sand component of the blocks [31]. This fact is important from the point of view of selecting suitable materials for use in building and construction especially concerning those which have large variations in their activities, [32]. That shows some high-density materials can stop radiation; however, pure materials cannot form a stable substance such as cement or clay except in extreme situations. Therefore, the combination of different materials is required [33]. Building materials should be exempted from all restrictions concerning their radioactivity, if the excessive gamma radiation due to those materials causes the increase of the annual effective dose received by an individual by a maximum value of 0.3 mSv [34].

CONCLUSION

Therefore, it may be possible to carry out the design of a shield in a purely analytical manner with the condition that the cross section of the absorption and attenuation coefficients are available for all interactions at all energies. The results of this study are challenges for the government and encourage it to disseminate radioprotection culture among the people who is concerned with radiation. The heat and radiation resistance of materials should be studied quantitatively in experiments among all radiation areas and these results will help as a data base for future. With this information on hand, future investigations will allow us to enhance controlling the radiation.

ACKNOWLEDGMENT

The authors would like to thank Sudan University of Science & Technology, Sudan Atomic Energy commission, Radiation Safety Institute, University of Khartoum, Construction and Roads Research Institute, for their help and support all through the work.

Conflicts of interest: *Declared none.*

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