Attenuation Properties of Fired Brick and Concrete Formed From Two Popular Brands of Cement in Nigeria

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Abstract

The linear attenuation coefficients μ, of concrete formed from two popular brands of cement in Nigeria as well as fired bricks have been determined for a narrow, collimated beam of γ-rays at incident energies of 511, 609, 1120, 1460 keV, using a gamma spectroscopy set-up. The half-value layers and the tenth-value layers of the materials were also computed. Concrete demonstrated a slightly better attenuation ability than fired brick within the energy range of interest. The difference in the attenuation abilities of the concrete formed from the two cement brands was however negligible.

Keywords: *Linear Attenuation Coefficient, Photons, Concrete, Fired Bricks, Lafarge*

1.0 Introduction

Worldwide, the number and range of x-ray facilities and x-ray equipment is increasing rapidly [1]. This is also the situation in Nigeria. The use of these facilities in hospitals contribute by far the largest man-made source of radiation exposure for the population [2]. Exposure to the population includes patients' exposure and exposure to the public in cases where the sources are not well contained. Though beneficial to the patient if well managed, radiation exposure above certain limits to the public can be harmful. This is because to every unit of exposure, there is an associated degree of detriment (risk).

In a bid to minimize the health risks consequent upon exposure to radiation sources, the 'ALARA' concept –an acronym, from the phrase, 'As Low As Reasonably Achievable' is adopted by radiation protection agencies. The concept entails keeping radiation doses and releases of radioactive materials to the environment as low as can be achieved based on technological and economic considerations. Of the three principles involved in achieving this concept, shielding is the most commonly employed. Shielding materials of high density and high atomic number such as lead are the most effective absorbers or shields for x- and gamma rays, but they cannot be used directly in building constructions due to their durability and heavy cost-implication.

In Nigeria, a number of radiation sources are installed in brick buildings or buildings made with concrete materials. It is not certain whether all of these buildings have lead linings in them to effectively contain or attenuate ionising radiation that could emanate from radioactive sources installed in such buildings. Fired bricks, which are made of clay, are standard structural element of building construction having high durability, versatility, flexibility and consequently better cost-effectiveness compared to lead [3]. Concrete on the other hand has been reported to have better structural properties than lead [4]. These materials, no doubt are cheaper, readily available and accessible compared to lead, but not much may be known or have been reported of the extent to which they can effectively shield radiation within the intermediate and high energy ranges. This is the thrust of this research.

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2.0 Methodology

2.1 Sample preparation

The fired bricks and concrete were prepared at the Clay industry, Oregun and Lafarge laboratory, Ogudu, in Lagos State, respectively following standard procedures. Two popular brands of cement (grade 42.5) in Nigeria were separately mixed with gravel, sand and water in appropriate ratios to form the concrete. The concrete was poured into prepared, greased cylindrical moulds of heights 2.5, 4.0, 6.0, 8.0 and 10.0cm, where they were allowed to harden. The fired bricks of varying thicknesses were prepared,following the extrusion of clay from the earth. The phases involved in the preparation involved winning, crushing, blending, mixing, grinding, screening and shaping of the clay materials following standard industrial procedures. Five cylindrical-shaped processed clay materials of thicknesses 3, 5.5, 8, 11 and 14 cm were formed. The materials were thereafter de-aired, properly dried, before being fired at a temperature of 850°C for about 20hours. The brick and concrete samples were transported to the Centre for Energy and Research Development, Obafemi Awolowo University for gamma analysis.

2.2 Gamma Spectrometer Measurements

The gamma spectrometer method was used to measure the attenuation coefficient of the brick samples. The set up consists basically of a sodium iodide detector and a multi-channel analyser. The detector produces an electric output pulse proportional to the incident gamma ray. The output of the detector goes to a multi-channel analyser. The multi-channel analyser (MCA) consists of an analogue-to- digital converter (ADC) coupled to a computer type memory, together with control circuits and one or more output devices. The ADC digitizes the input voltage amplitude, dividing it into N continuous intervals or channels of equal width, where N is usually a power of two from 2^8 (256 channels) to 2^{13} (8192 channels). The channels correspond to an address in memory. The MCA gives a plot of the pulse height spectrum of all the pulse input to it. The pulse height is proportional to the energy lost by a gamma ray. Separation of the pulses, based on pulse height shows the energy spectrum of the gamma ray that is emitted.

2.3 Methods of Attenuation Coefficient Determination.

Initial energy calibration of the multichannel analyser was done using standard gamma sources of known energies. The calibration was done to include all the energies of the gamma sources used. Mixed radioactive sources were placed in turn on an adjustable sample shelf directly above the detector. The background intensity, with no absorber placed in between the source and detector was measured for a pre-set time. The energy spectrum for the four sources was displayed on a personal computer connected to the multi-channel analyser and background intensities for selected 'regions of interest 'were recorded. Afterwards, the intensities for the different thicknesses of the samples, placed in turn in between the radioactive source and the detector were measured.

The attenuation of gamma radiation was measured in a narrow beam good geometry by using collimators placed between the source and absorber and as well between the absorber and detector.

The intensity of the attenuated beam according to Beer –Lambert's law [5] is

$$I = I_o e^{-\mu x} \quad (1)$$

where I_o and I are the un-attenuated and attenuated photon intensity, respectively, x is the thickness of the material and $\mu (cm^{-1})$ is the linear attenuation coefficient of the material.

Re-arranging equation 1, the linear attenuation coefficient μ, is obtained as

$$\mu = \frac{1}{x} ln\left(\frac{I_o}{I}\right) \quad (2)$$

3.0 Results and Discussion

Tables 1- 3 show the background and transmitted photon intensities for the sampled materials at photon energies of 511, 609, 1120 and 1460 keV. The intensity of the transmitted photons increased with increasing energy for a constant thickness of the clay material. On the other hand, transmitted photon intensities for a specific photon energy decreased with increasing thickness of clay slabs. This is consistent with literature [6] [7]. A similar trend is observed in the concrete samples also except at photon energy of 1120 keV where transmitted photon intensity is slightly lower compared to photon intensity at energy 609 keV for sample thickness of 2.5cm using Asaka cement and those of 2.5 and 4.0 cm thicknesses using Dangote cement.

Table 1 Background and Transmitted Photon Intensities for Concrete Using Asaka Cement

Height (cm)	*511kev*	*609kev*	*1120kev*	*1460kev*
0.0	9164	14349	14491	15699
2.5	5712	10555	10451	13532
4.0	4586	8497	8890	10567
6.0	4513	7966	8087	8273
8.5	3901	6136	7042	7104
10.0	3810	5504	5968	6399

Table 2: Background and Transmitted Photon Intensities for Concrete Using Dangote Cement

Height (cm)	*511kev*	*609kev*	*1120kev*	*1460kev*
0.0	9164	14349	14491	15699
2.5	5687	10764	10686	13148
4.0	4590	8826	8801	10874
6.0	4513	7966	8087	8273
8.0	3947	6366	7053	7291
10.0	3795	5490	6120	6450

Table 3: Background and Transmitted Photon Intensities for Fired Brick

Height (cm)	*511kev*	*609kev*	*1120kev*	*1460kev*
0.0	9164	14349	14491	15699
3.0	7687	12023	12802	12904
5.5	6974	10920	11890	11976
8.0	5392	7398	8793	8873
11.0	4438	5818	5954	6954
14.0	4284	5725	5761	5808

The linear attenuation coefficients μ, of the sampled materials are the slope values from the linear plots of ln (I_o/I) against x , in figures 1-3, where I_o is the background intensity, I is the transmitted intensity and x is the thickness of the absorber. The results are shown in table 4

The linear attenuation coefficients decrease with increasing energy for the sampled materials. This behaviour agrees with theoretically established relationship between linear attenuation coefficient and energy [8]. At lower incident photon energies (511 - 609 keV), the linear attenuation coefficients of both concretes formed from Asaka and Dangote cement are slightly higher than the values obtained at higher incident energies (1120 -1460 keV). It implies that there is a greater interaction of radiation with the absorbers at the lower energy levels compared to what occurs at higher energy levels. The attenuation values obtained from both types of concrete compare favourably well with each other. It is also noticeable that within the range of photon energy under consideration, the attenuating ability of the concrete is fairly the same. It follows therefore that the amount of radiation exposure to ionising radiation within the energy range under consideration is approximately the same, should concrete formed from either of these brands of cement be used as a shielding material. Fired brick, on the other hand had approximately the same linear attenuation coefficient for energy range of 609 -1460 keV.

Figure 4 reveals a lesser energy dependence of the linear attenuation coefficient μ, above 609 keV for both concrete and fired bricks. This is expected for both intermediate and high energy regions of the incident photons [7]. The other determinant is the compositional characteristics of the material, which in the case of the concrete are same since both were prepared under the same conditions and with the same materials except for the cement types. It could thus be inferred that both cement types are of about the same quality with respect to radiation attenuation. Compared to the fired brick used in this work, concrete has better attenuation of radiation. This is consistent with the linear attenuation coefficient results for both oven dried natural clay and concrete obtained by [6].

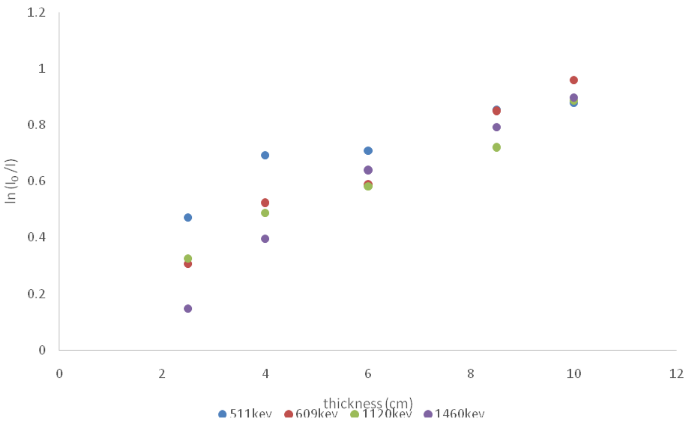

Figure 1. Determination of linear attenuation coefficient of concrete from Asaka cement

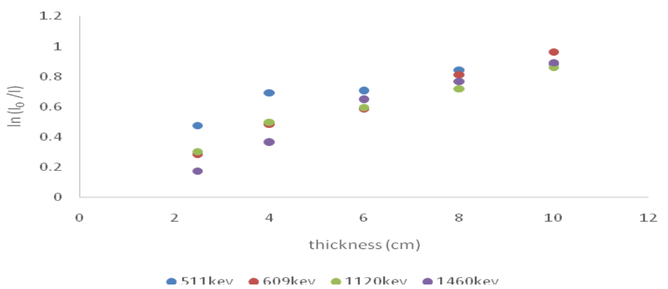

Figure 2: Determination of Linear Attenuation Coefficient of Concrete from Dangote Cement

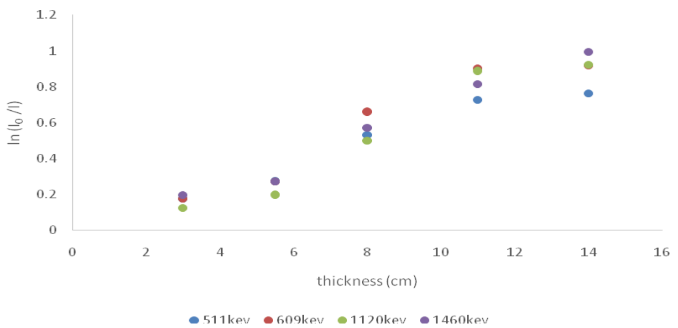

Figure 3: Determination of Linear Attenuation Coefficient of Fired Brick

Table 4: Linear Attenuation Coefficient Values (cm^{-1}) for Sampled Materials

	511kev	*609kev*	*1120kev*	*1460kev*
Asaka	**0.1051**	**0.1006**	**0.0923**	**0.0933**
Dangote	0.1069	0.1003	0.0932	0.0938
Fired brick	0.0592	0.0717	0.0670	0.0702

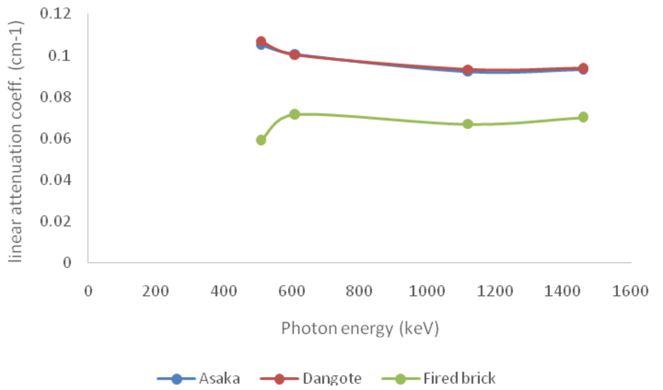

Figure 4: Dependence of Linear Attenuation Coefficient on Photon Energy

3.1 Half -Value Layers (HVL) and Tenth - Value Layers (TVL)

The thickness of any given material where 50% of the incident energy has been attenuated is known as the half-value layer (HVL). Similarly, the amount of shielding required to reduce the incident radiation levels by 1/10 is called the tenth-value layer. Both HVL and TVL are expressed in units of distance (mm or cm). Like the attenuation coefficient, it is photon energy dependent. Increasing the penetrating energy of a stream of photons will result in an increase in a material's HVL and TVL. Mathematically,

$$HVL = \frac{0.693}{\mu} \quad (3) \quad [9]$$

$$TVL = 3.323 * HVL \quad (4) \quad [10]$$

The HVL and TVL for the sampled materials in this work for photon energy range 511 keV – 1460 keV is compared to that obtained through an experimental design for lead as seen in table 5.

The computed results show an approximate average half value layers (HVL) in the ratio 7:10:1 for concrete, fired bricks and lead in that order. This means that for every 1 cm thickness of lead used as a shielding material for the energy range under review, concrete produced from the two brands of cement in this work and fired bricks would require a thickness of approximately 7 cm and 10 cm respectively to reduce the intensity of the incident photon energy by 50%.

Table 5: HVL and TVL (cm) for Sampled Materials and Lead for Energy Range 511 keV—1460 keV

Energy (keV)	Concrete (Asaka cement)		Concrete (Dangote cement)		Fired brick		Lead [11]	
	HVL	TVL	HVL	TVL	HVL	TVL	HVL	TVL
511	6.59	21.90	6.48	21.53	11.71	38.91	0.40	1.32
609	6.89	22.90	6.91	22.96	9.66	32.10	0.50	1.66
1120	7.51	24.96	7.44	24.72	10.34	34.36	1.00	3.32
1460	7.43	24.69	7.39	24.56	9.87	32.79	1.25	4.15
Mean value	7.11	23.61	7.06	23.44	10.40	34.54	0.79	2.61

The corresponding tenth- value layers for the sampled materials in comparison to lead also show that concrete and fired bricks of about 24 cm and 35 cm thickness respectively will reduce the intensity of incident photon within the range of energies considered to 1% of its initial intensity as much as a lead material of thickness 2.6 cm would do.

4.0 Conclusion

The linear attenuation coefficients of concrete formed from two popular brands of cement in Nigeria and fired brick have been determined. Within the energy range being considered, concrete demonstrated a slightly better attenuation ability than fired brick. The difference in the attenuation abilities of the concrete formed from Dangote cement and Asaka cement within the energy range of 511 -1460 keV is negligible. Both concrete and fired bricks could serve as alternative shielding materials for attenuation of high energy radioactive sources within the energy range of 511 – 1460 keV. In order to reduce the incident photon to one -tenth of its initial intensity within these energy range, the thickness of concrete and fired bricks would be about 24 cm and 35 cm respectively.

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