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Measurement of Shielding Effectiveness of Building Blocks against 662 KeV Photons

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Abstract: *This study uses building blocks as a shield for gamma energy source of 662 KeV from Cs-137. The attenuation from the block is compared with those obtained when conventional shields like iron, lead and concrete are used as shield for Cs-137. This was done with the aim of finding out the level of shielding and the thickness of building block needed to confer same level of shielding as the already mentioned conventional shields. The results obtained using a gamma spectrometer with a NaI(Tl) detector showed that the Half Value Thickness (HVT) of building block, concrete, iron and lead were 5.1420 cm, 3.8043 cm, 1.1908 cm, and 0.5581 cm respectively. With the results from this work, a shield of 37 cm building block (though bulky in size) will attenuate the source and can be used as a substitute for lead which would require a 4.4 cm thickness.*

Keywords: Half Value Thickness, radiation, shielding, attenuation, gamma energy

1. INTRODUCTION

As resources become more and more limited, the cost and availability of materials for radiation shielding is an issue, especially for new institutions planning to harness atomic energy for socio-economic advancement in developing countries. Hence, it is imperative and proactive to research into other effective means of shielding, which could provide certain level of protection at minimal cost.

Lead has been used as a traditional shielding material in many nuclear installations worldwide. Its high physical density and high atomic number has made it a choice material where small space is required and low energy X-rays are to be shielded. Lead has recently been recognised as a source of environmental pollution, including the lead used for radiation shielding in radiotherapy facilities.[1] Other non-lead materials have been suggested for radiation shielding and interventional radiology. The use of tungsten and hydrogenated styrene-butadiene-styrene copolymer has been suggested as shielding materials.[1,2] However, the demonstrated experimental usage is limited to radiotherapy alone.

A relatively cheaper alternative to lead is high-density concrete. Research has shown that material composition and thickness of the concrete commonly used for shielding has made the idea of concrete relatively expensive for developing countries.[3] A closely related research to this work is the work of Mann et al.,[4] where the shielding properties for gamma rays of a few low Z materials were investigated. Their work details how the values of the mass attenuation coefficient, equivalent atomic number, effective atomic number, exposure build-up factor and energy absorption build-up factor were calculated and used to estimate the shielding effectiveness of some building material samples. They verified good shielding behaviour in the investigated building material samples for photon with energy region of 0.015–0.30 MeV and of dolomite in 3–15 MeV.

Also, a similar effort was made by Sharaf et al.,[5] where they investigated the mass attenuation coefficients of some Jordanian building material interaction with 50–3000 keV gamma-ray energy range photon. However, none of these referenced works made a useful comparison between the investigated materials and conventional shielding materials nor did they detail the peculiar attenuation properties of the commonly used building materials in developing countries.

This work investigates the possibility of using conventional building blocks and the level of thickness or bulkiness which would offer same shielding properties as lead or concrete, thus providing a cheaper alternative to institutions in developing countries. This is done by obtaining the Half Value Thickness (HVT) of building blocks and comparing the values with those of standard shielding materials, in order to obtain the corresponding thickness of building blocks that will offer the same level of shielding with concrete, lead and steel.

2. EXPERIMENTAL

Commercially available sharp sand, cement and the appropriate water ratio used in making conventional building blocks were used in this work. The materials were used to prepare four samples, with a cement-sand ratio of 1:5. The composition of the samples prepared was:

1. Sharp sand: SiO_2 and minor organic debris
2. Portland Cement: Elephant Ordinary Portland Cement a commercial cement brand sold in Nigeria was used having a composition of SiO_2 (19.2 ± 1.76%), Al_2O_3 (5.2 ± 1.48%), Fe_2O_3 (3.2 ± 0.60%), CaO (62.0 ± 0.09%), MgO (1.48 ± 0.72%) and SO_3 (2.34 ± 0.04%)
3. Water: Natural water

Cylindrical samples were fabricated using a suitable mould. The sample diameter was 5 cm, 0.5 cm above the required thickness per sample (to create allowance for smoothening of the samples and removing any rough edge before placing in the sample holder bearing the detector). The wet sample was poured into four different moulds, with a steadily increasing height of 1 cm. This sample was then dried and smoothened. After removing the rough edges, the measured sample diameter was 4.5 cm and the height of the four samples was from 1 cm to 4 cm.

2.1 Experimental Setup

A 661.66 KeV-energy Cs-137 with half-life of 30.20 years and activity of 12.49 mCi was used as the radiation source for this work. The elemental analysis was done using gamma ray spectrometry. Thallium drifted Sodium Iodide detector (NaI(Tl)) of dimension 7.62 cm × 7.62 cm was used to detect the radiation emitted from the source. Adequate lead shielding which reduced background radiation by a factor of about 95% was also in place.

Figure 1 shows the schematic of the gamma ray attenuation experimental setup. The set up was arranged such that the Cs-137 source was placed on a source holder, made of lead having a perforation of about 2 mm. This source holder also serves as a collimator. Underneath the source are the samples, serving as absorbers, each with various thicknesses, placed in lead sample holder. The lead sample holder underneath the absorbers also has a 2 mm perforation and opens directly to the detector. Hence a source, absorber and detector are on the same straight line with each other and well collimated to ensure a good geometry. The entire set up was placed within lead blocks serving as shield to prevent stray gamma rays from escaping, thus protecting the operator and surrounding equipment. The lead shield was then supported on a steel stand which also holds the detector (in perfect alignment with the source above and the absorber in between them) under the lead shield.

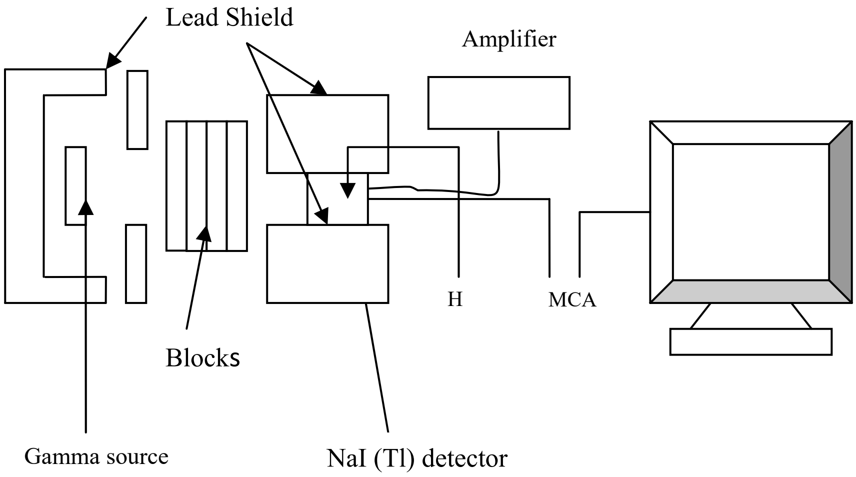

Figure 1: Schematics used for the gamma attenuation experiment.

The two radionuclides used for calibrating the NaI(Tl) detector are Na-22 and Co-60 each has two energy peaks and corresponding channel numbers. In order to properly identify various peaks in a spectrum, the NaI(TI) detector was calibrated in terms of absolute gamma ray energy because spectrometers often show nonlinearity of a channel or two over a full range of several thousand channels, it is therefore useful to have multiple calibration peaks at various points along the measured energy range to account for these nonlinearities.

Standard sources with known gamma-ray energies and activities that are widely different from those to be measured in the unknown spectrum but within the suspected range of the unknown sample are used, these sources are prepared by the Isotope Product Laboratories, Burbank California, USA were used for the energy calibration of the NaI(Tl) detector system used in this work.

The system was calibrated with standard calibration sources of Cs-137, Na-22 and Co-60 with a total of five energies. The calibration sources were counted long enough to obtain a well-defined photopeak while the gain of the system was adjusted so that the photopeak of Cs-137 was about one-third the full scale. This ensured that the range of all the radionuclides of interest was covered. The channel number that corresponds to the centroid of each full energy peak (FEP) on the MCA was recorded and the slope and intercept calculations were obtained.

It is also useful to express the exponential attenuation of photons in terms of a half-value thickness. The half-value thickness (HVT) is the thickness of the absorber required to decrease the intensity of a beam of photons to half its original value. HVT is expressed mathematically as:[6]

$$\frac{I(x)}{1_0} = \frac{I}{2} = e^{-\mu x(3/2)}$$

$$x_{(1/2)} = HVT = \frac{In2}{\mu}$$

where

I(x) = the photon intensity after passing through the material of thickness "x"
I_0 = the initial intensity of the photon
x = the thickness of the material
μ = is the attenuation coefficient

3. RESULTS AND DISCUSSION

3.1 Obtaining Attenuation Coefficient of Building Blocks

Figure 2 shows the plot of $\ln(I_0/I)$ against block thickness (x) to obtain attenuation Coefficient for building blocks. "I_0" represents the intensity or counts per second when there is no absorber between the source and detector, whereas "I" corresponds to the intensities or count after successively increasing thickness of absorber has been added.

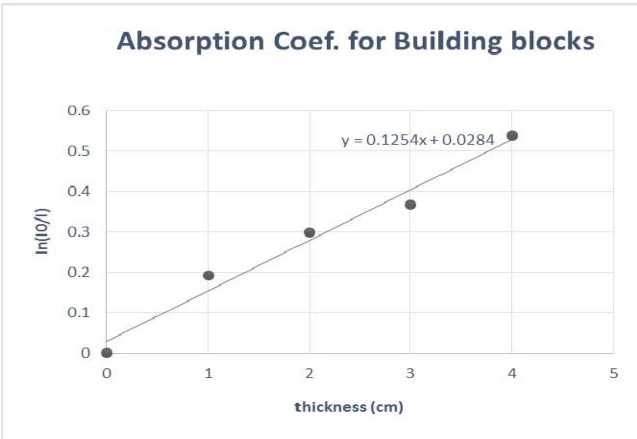

Figure 2: Plot of ln (I_0/I) against block thickness to obtain attenuation coefficient for building blocks.

From Figure 2, Absorption Coefficient = 0.1254 cm^{-1}.

The slope of $\ln(\frac{I_0}{I})$ against x gives the attenuation or absorption coefficient for a material.

Hence, the HVT is given by:

$$x_{(1/2)} = HVL = \frac{\ln 2}{\mu}$$

Table 1 shows that the attenuation coefficient for building blocks was found to be lower than those for concrete, iron or lead, due to lower density and structural strength of the blocks. The table also shows that the HVT of the absorbers studied decreased with increase in density of absorber. That is, lead being the most dense of the absorbers studied, had the lowest HVT. Also for a Cs-137 source with 662 keV photon energy, a lead block of 0.55 cm (about half of a cm) would be able to reduce the intensity of the gamma ray by half while for the same energy and source, building block would have to be about 5.5 cm thick to reduce the transmitted gamma ray by half of its original intensity.

Table 1: Attenuation coefficients of the materials and calculated HVT.

Materials studied	Attenuation coef. (μ)	HVT (ln2/μ) cm
Building blocks	0.1254	5.5275
Concrete	0.1822	3.8043
Iron	0.5821	1.1908
Lead	1.2419	0.5581

3.2 Photon Attenuation Pattern of Materials Studied with Increasing Thickness

Figure 3, 4, 5 and 6 show graphical patterns (using a log-lin scale) that describe how the photon was attenuated in the materials studied.

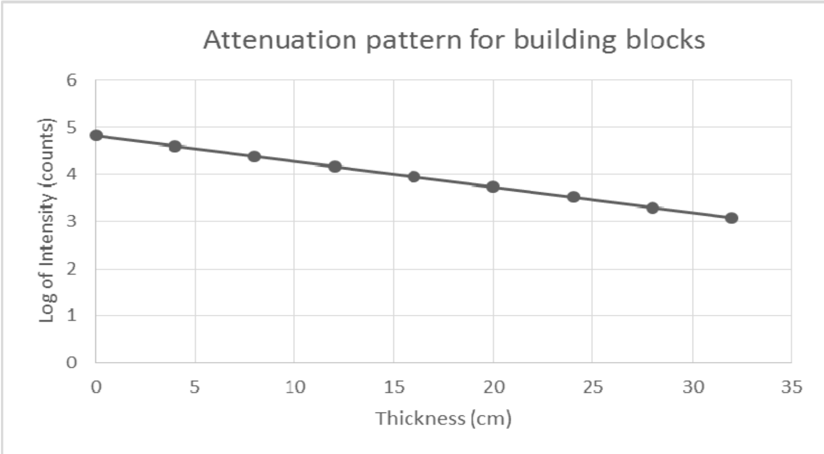

Figure 3: Attenuation of Cs-137 gamma rays as they pass through building blocks.

Figure 3 above shows the pattern of attenuation for building block and a relatively gradual decrease of the photon as the thickness increases to 32 cm. Also the curve closely approaches zero on the X-axis as the thickness approaches 37 cm.

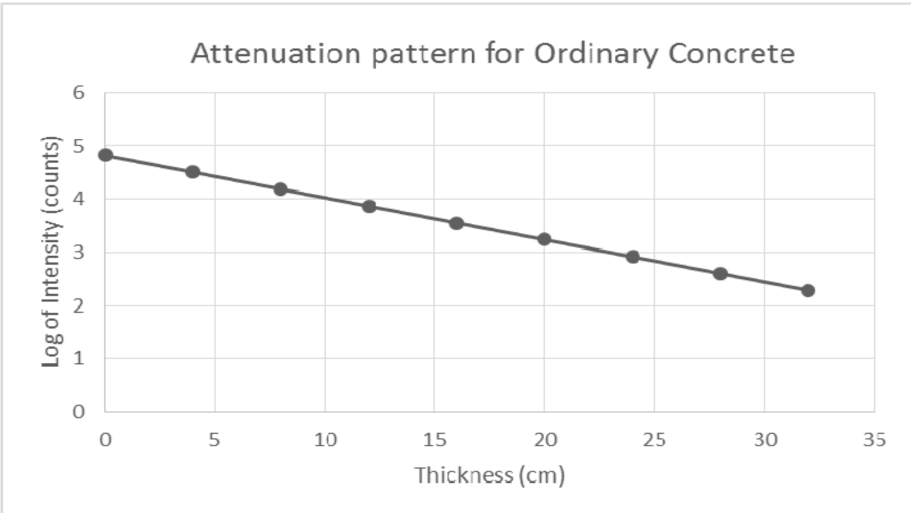

Figure 4: Attenuation of Cs-137 gamma rays as they pass through ordinary concrete.

Figure 4 gives the attenuation pattern through ordinary concrete, it is relatively similar to the attenuation pattern of building blocks as shown in Figure 3 but it is slightly steeper due to its higher attenuation coefficient. Also the curve approaches zero as the thickness gets towards 28 cm.

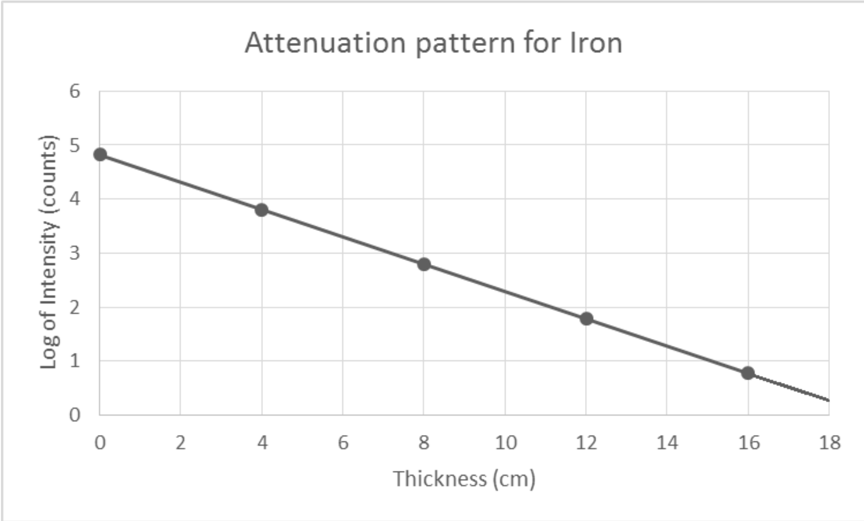

Figure 5: Attenuation of Cs-137 gamma rays as they pass through iron.

Iron with a density of 7.87 g cm^{-3} is about three times as dense as either building blocks or concrete. This accounts for the steeper nature of the curve in Figure 5. Here, the curve approaches zero as the thickness of iron approaches 10 cm. Iron in form of steel is obviously a better shield than concrete or building blocks though it is expensive to maintain.

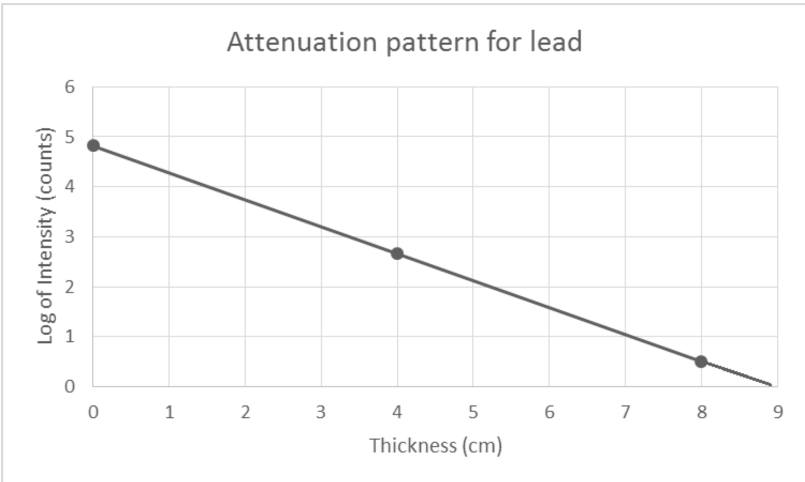

Figure 6: Attenuation of Cs-137 gamma rays as they pass through lead.

Figure 6 gives credence to the reason lead is a favourite choice for shielding, with the curve approaching zero at a thickness less than 5 cm. It was observed that the transmission intensity of the gamma ray from the Cs-137 decreased as it passed through increasing thickness of lead absorber as seen in Figure 6. The slope was very steep and closer to the Y-axis than any of the other attenuation patter, suggesting that very minimal increase in thickness (less than 5 cm) is required to absorb the intensity of the transmitted gamma. Building blocks attenuation pattern (Figure 3) also showed that to obtain the same level of attenuation seen in lead, more thickness of absorber would be required (about 35 cm). But as earlier stated if cost of installation and maintenance pose a challenge and were space is not a constraint an entrepreneur or scientist would rather get a substitute that can offer same level of shielding.

For clarity, Figure 7 is the graphical representations of the comparison between the attenuation coefficient obtained for building blocks with those of concrete, iron and lead.

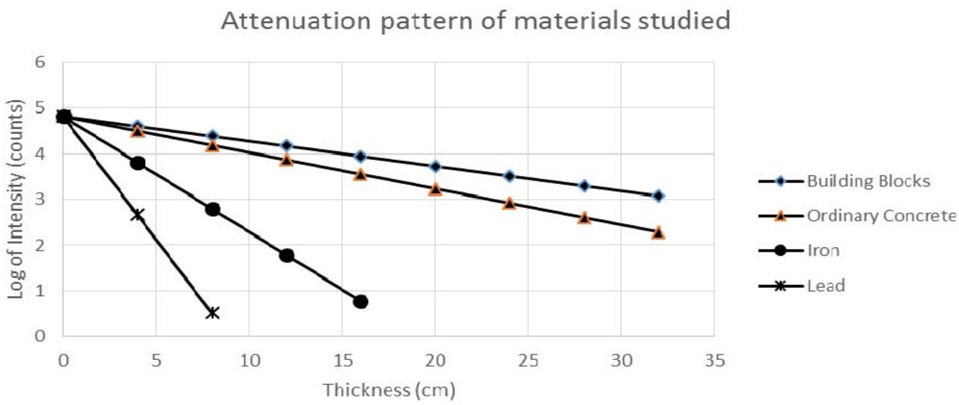

Figure 7: Attenuation of Cs-137 gamma rays as they pass through the various absorbers studied.

Another practical comparison was made by studying the thickness of the shielding walls of the 1.4 MV Tandem Accelerator at the Center for Energy Research and Development (CERD), Ile-Ife, Nigeria. Here, due to radiations involved when the accelerator is in operation, a wall of one meter concrete was constructed to protect people and environment from fast-moving radiations like gamma ray and proton particles. Using the HVT of building blocks and concrete as found in this study (5.5275 cm and 3.8043 cm for building blocks and concrete respectively) and following simple proportion, it can be seen that if the concrete wall at the CERD Accelerator facility was replaced with building block material, we would need a wall of about 1.5 m as against 1 m of concrete. This may be slightly bulky but it offers a cheaper solution compared to concrete.

4. CONCLUSION

This work shows that among the materials studied, lead is the best absorber material for the attenuation of the gamma source, thus confirming already accepted convention on its use as a shield. However, the use of lead comes with its many disadvantages which cannot be ignored. Paramount among its disadvantages is its cost of installation, maintenance and recently discovered health implications. Moreover, from the socio-economic perspective, one would rather consider cheaper alternative in using building blocks especially if space is not a constraint. This is because the use of building blocks with density of 1.56 g cm^{-3} would require a larger thickness than what would have been if lead having density of 11.35 g cm^{-3} were used. The results of this experiment shows that, by extrapolation, a building block shield of 37 cm will attenuate the radiation coming from Cs-137 source to a safe level and can conveniently be used to replace lead which would require a 4.4 cm thickness and costs a fortune. This could save research institutes in developing countries a lot of money that would have been needed to construct or import lead shield, especially for institutions where space constraints is not an issue.

5. ACKNOWLEDGEMENT

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