Experimental Investigation of gamma-ray shielding capability of clay used as building materials in Thi Qar Province

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Abstract: Clay is one of the oldest building materials known to man uses in construction. This material has many important potentials and features, and the methods of using this material in construction in the past and present varied greatly, responding to environmental determinants; Such as the climate, the quality of the soil, and the available materials on the one hand. The aim of the present study is to test the ability of this material to attenuate gamma-ray radiation. Gamma ray attenuation coefficients such as linear and mass attenuation half value layer, tenth value layer, and mean free path for different thickness slabs of clay was measured using 3”x3” NaI(Tl) gamma spectroscopy system at energy 662 KeV, 1173 KeV, and 1332 KeV. The measured values of the attenuation parameters showed good agreement with the theoretical calculations. The elemental compositions of the clay slabs analyzed by using an EDXRF spectrometer. The obtained results appear that the clay is a suitable alternative for radiation protection and achieve a safe level of radiation exposure for photons that have moderate energy.

Keyword: Clay, gamma ray attenuation, building materials, radiation shielding.

1. Introduction

Gamma rays have many applications in various fields such as medicine, agriculture, biology, industries, and astronomy. There are three different methods of protection from radiation; the first is the distance, so the greater person’s distance from the radiation source the smaller amount of exposure. The amount of exposure is inversely proportional to the square distance from the source [1]. The second method is barriers, which used to prevent radiation, absorb it and use it as appropriate to reduce the amount of radiation behind it [2]. The last method or parameter to prevent radiation is time, where the more time you are near the radioactive source, the exposure is increase. Among the most important materials used to block the radiations are lead, iron, and concrete, paraffin, and water, etc. [3].

Differently from charged particles that slowly lose up their energy to matter, when gamma rays traverse matter, some are absorbed, some pass through without interaction, and some are scattered as lower energy photons. Gamma-ray radiation vanishes because of the interaction [4]. Clay is a relatively impermeable soil. It is available naturally, cheap and environmentally friendly.
In southern Iraq, many houses built it using clay are widespread especially in the current study area. The aim of the present study is to determine the gamma-ray attenuation Coefficients of slabs of the clay in different thicknesses. The focusing on this material comes because still used widely in the region.

2. Theory

When gamma rays fall on a barrier (absorbent material or shield) before they reach the detector, they will suffer from reduced in both intensity and energy. This reduction in intensity and energy can be useful to study the changing thickness of the material and calculating the rate of gamma rays transmitted from the barrier or shield using the following relation: [5].

\[ I = I_0 / e^{\mu x} \]  \hspace{1cm} (1)

Where, \( I_0 \) & \( I \) are the incident and transmitted intensity of photons, \( x \) is the thickness (cm) of the absorber, \( \mu \) is the linear attenuation coefficient (LAC).

The mass attenuation coefficient (MAC), which is define as the linear attenuation coefficient per unit mass density (\( \rho \)) of the material given by equation bellow [6],

\[ MAC = \frac{\mu}{\rho} \]  \hspace{1cm} (2)

The thickness of the material in which reduces the photon intensity to one-half of the initial intensity called the half-value layer (HVL). This parameter can be calculates using the following equation [7].

\[ HVL = \ln 2 / \mu \]  \hspace{1cm} (3)

Ten-value layer (TVL) is the amount of thickness that decreases the gamma-ray photons intensity entering into the material by a tenth. This attenuation parameter calculates from the equation [8].

\[ TVL = \ln 10 / \mu \]  \hspace{1cm} (4)

Mean free path (MFP) is the average distance that a photon travels into the material before interaction. The following equation used for calculating this parameter [9].

\[ MFP = 1 / \mu \]  \hspace{1cm} (5)

3. Materials and methods

3.1 Experimental procedure

Six slabs 8x8 cm of clay were prepared in different thicknesses using fine wooden molds. Slabs left in the open air to dry completely by the heat of the sun. A tight geometry arrangement was designed and implemented to decrease the radiation background and improve the efficiency and energy resolution of the spectroscopy system as well as produce a narrow beam
transmission from gamma-ray photons. The arrangement made of lead and a layer of copper consists of four parts, the main part is a box opened from the top and other parts are compact cover to the box, gamma source holder and collimator as shown in Fig. (1).

![Diagram of geometric arrangement](image1)

**Fig. (1):** Dimensions of the geometric arrangement used in the current study.

The gamma-ray spectroscopy system used in the present study consisting of a (3"x 3") NaI(Tl) scintillation detector attached to electronic units, and the Cassy lab2 program. Two gamma ray sources were used in measurements are $^{137}$Cs (662 KeV) and $^{60}$Co (1173 KeV, 1332 KeV). Fig. (2) Shows a diagram of the measuring system used in the current study.

![Gamma spectroscopy setup](image2)

**Fig. (2):** Gamma spectroscopy system and measurement setup used in the present study.
3.2 Measurements

The attenuation parameters (linear and mass coefficients, half-value layer, ten-value layer, and Mean free path) of clay slabs were measured with a NaI (Tl) detector at 661.6 KeV, 1,173.2 KeV, and 1,332.5 KeV. For the investigation of their shielding behavior. For each thickness of clay slabs, the gamma-ray spectrum recorded as a function of the energy of the gamma-ray photons. To calculate the intensity (I) of the transmitted photons from the clay slab at different thickness we measure the area under the peak at specific energy and the area under the peak at the same energy without any slabs, which is the initial intensity (Io). After the measurements, completed the attenuation parameters (transmitted photons (I), the linear (LAC) and mass (MAC) attenuation coefficients and the coefficients derived from them such as the half value layer (HVL), the ten value layer (TVL) and the mean free path (MFP)) were calculated. The elemental compositions of the clay slabs analyzed by using an EDXRF spectrometer and given as a relative percentage of the elements expressed as oxides in the sample as shown in Table (1).

| Chemical composition of the Sample (Weight %) |
|---------------------------------------------|
| SiO₂  | Fe₂O₃ | MgO   | CaO  | K₂O   | TiO₂  | P₂O₅  | Al₂O₃ |
| 58.511| 0.88  | 0.610 | 0.320| 1.902 | 0.520 | 0.298 | 36.950|

4. Results and Discussion

Table (2) shows the results obtained of gamma-ray attenuation measurements of clay slabs in different thicknesses at energies 662, 1173, and 1332 KeV with an increment of 1 cm for each measurement. The results showed that this material is efficient in attenuating gamma-ray photons according to energy, approaching 87% at 662 KeV and 77% at 1173 KeV, and 76% at 1332 KeV at the highest thickness (6 cm). The comparison between Experimental (present study) and Theoretical (XCOM) results of gamma-ray attenuation coefficients of clay slab at 1 cm thickness are shown in table (3). The result of the comparison showed that there is good agreement between the two results. To find out the efficiency of clay to attenuate gamma ray photons in comparison with concrete, slabs of concrete measured similarly to the dimensions of the clay slabs in the current study with a thickness of 1 cm; the results were as in table (4). The result of the comparison showed that the clay under study showed good compatibility with concrete, although the concrete showed higher efficiency in attenuating gamma-ray photons.
Table (2): Attenuation coefficients for clay slabs as a function of energy and thickness.

| Thickness (cm) | Energy (KeV) | T (%) | LAC (cm⁻¹) | MAC cm²/g | HVL (cm) | TVL (cm) | MFP (cm) |
|---------------|--------------|-------|-------------|-----------|----------|---------|---------|
| 1             | 662 1173 1332 | 0.634821 | 0.454413 | 0.284008 | 1.52505  | 5.06698 | 2.2006  |
|               |              | 0.743478 | 0.29642  | 0.18526  | 2.33793  | 7.76781 | 3.3736  |
|               |              | 0.764384 | 0.26869  | 0.16793  | 2.57922  | 8.5695  | 3.7313  |
| 2             | 662 1173 1332 | 0.456328 | 0.392272 | 0.24517  | 1.76663  | 5.8997  | 2.5492  |
|               |              | 0.513043 | 0.3337   | 0.20856  | 2.07673  | 6.8997  | 2.9967  |
|               |              | 0.528767 | 0.31860  | 0.19913  | 2.17512  | 7.22685 | 3.1387  |
| 3             | 662 1173 1332 | 0.326847 | 0.372754 | 0.232971 | 1.85913  | 6.17699 | 2.6827  |
|               |              | 0.402174 | 0.30362  | 0.18976  | 2.28243  | 7.5834  | 3.2935  |
|               |              | 0.413699 | 0.29421  | 0.17200  | 2.51819  | 8.36673 | 3.6337  |
| 4             | 662 1173 1332 | 0.229554 | 0.367904 | 0.22994  | 1.88364  | 6.25842 | 2.7180  |
|               |              | 0.332609 | 0.2752   | 0.17200  | 2.51819  | 8.36673 | 3.6337  |
|               |              | 0.353425 | 0.26002  | 0.16251  | 2.66517  | 8.85505 | 3.8462  |
| 5             | 662 1173 1332 | 0.158742 | 0.368095 | 0.23006  | 1.88266  | 6.25517 | 2.7166  |
|               |              | 0.313043 | 0.23228  | 0.14518  | 2.98343  | 9.91249 | 4.3051  |
|               |              | 0.328767 | 0.22248  | 0.13905  | 3.11487  | 10.3492 | 4.4964  |
| 6             | 662 1173 1332 | 0.131236 | 0.338459 | 0.211537 | 2.04751  | 6.80289 | 2.9545  |
|               |              | 0.236957 | 0.23998  | 0.14999  | 2.88774  | 9.59456 | 4.1670  |
|               |              | 0.241096 | 0.23709  | 0.14818  | 2.9229   | 9.71136 | 4.2194  |

Table 3. A comparison between Experimental (present study) and Theoretical (XCOM) results of Gamma-ray attenuation coefficients of clay slab at 1cm thickness.

| Thickness (cm) | Energy (KeV) | LAC (cm⁻¹) | MAC cm²/g | HVL (cm) | TVL (cm) | MFP (cm) |
|---------------|--------------|-------------|-----------|----------|---------|---------|
| Expr.         | 1            | 662 1173 1332 | 0.454 | 0.284 | 1.525 | 5.066 | 2.200 |
|               |              | 0.296 | 0.185 | 2.337 | 7.767 | 3.373 |
|               |              | 0.268 | 0.167 | 2.572 | 8.569 | 3.731 |
| Theo. (Xcom)  | 1            | 662 1173 1332 | 0.483 | 0.310 | 2.030 | 6.115 | 2.070 |
|               |              | 0.330 | 0.193 | 2.418 | 7.983 | 3.030 |
|               |              | 0.321 | 0.184 | 2.469 | 8.668 | 3.115 |
Table 4. A comparison between Experimental (present study) results of Gamma-ray attenuation coefficients of clay and concrete slabs at 1cm thickness.

| Material | Thickness (cm) | Energy (KeV) | LAC (cm⁻¹) | MAC (cm²/g) | HVL (cm) | TVL (cm) | MFP (cm) |
|----------|----------------|--------------|------------|-------------|----------|----------|----------|
| Clay     | 1              | 662          | 0.454      | 0.284       | 1.525    | 5.066    | 2.200    |
|          |                | 1173         | 0.296      | 0.185       | 2.337    | 7.767    | 3.373    |
|          |                | 1332         | 0.268      | 0.167       | 2.572    | 8.569    | 3.731    |
| Concrete | 1              | 662          | 0.532      | 0.231       | 1.301    | 4.325    | 1.878    |
|          |                | 1173         | 0.279      | 0.121       | 2.483    | 8.251    | 3.583    |
|          |                | 1332         | 0.156      | 0.068       | 4.416    | 14.675   | 6.373    |

Figures (3) to (6) show the range of variation in the attenuation coefficients of gamma-ray photons in clay as a function of thickness and energy. We notice that the photons that carry less energy are more attenuated than others.

**Fig. (3):** Linear Attenuation Coefficient (LAC) (cm⁻¹) as a function of the energy of Gamma-ray photons and thickness of clay slabs.
5. Conclusions

The slight increase in the theoretical calculations from the experimental measurements is because the XCOM program takes the ideal data of the compound or mixture according to the data entered. In general, experimental and theoretical results show good agreement over the range of the energies used in this study also showed that the clay material used showed reasonable efficiency when compared to concrete for the same energies used at 1 cm thickness. Finally, we conclude that clay in the study area is safe as a building material and as a barrier from gamma-ray radiation.

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