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# Evaluation of Efficiency and Performances of Building Materials used in Sudan Combined with Lead as the Gamma Ray Shieldings

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**ABSTRACT**

In this study the linear attenuation coefficient (μ) and the half value layer (HVL) of some building materials like iron, concrete, cement and clay used in Sudan as a combined with the lead have been investigated, the results have been experimentally determined using Cs-137 and Co-60 source and compared with the theoretical values. The measurements were performed for radiation intensity without shielding and with specific thickness of selected samples using ion chamber placed at 2 meters from Cs-137 and Co-60. An obtained results showed that the linear attenuation coefficient (μ) has a linear relationship with the corresponding densities of the samples studied and inversely with photon energy, and the half value layer (HVL) was proportional directly with photon energy. As a results of this evaluation the lead combined with the selected materials as indicated above showed an improvement the efficiency of building materials as the gamma ray shielding.

***Keywords:*** *Gamma radiation, attenuation coefficient, half value layer, shielding, building materials*

## 1. Introduction

Shielding remains an important aspect of radiation physics, radiation shielding is very pertinent in nuclear industries as well as in radioisotopes production and usage, and in particle accelerator facilities. Materials for shielding gamma rays are typically measured by the thickness required to reduce the intensity of the gamma rays[(1)]. When a gamma radiation beam reaches some absorber material the attenuation occurs in accordance with the type of material and the photon energy, resulting in reduction of its intensity[(2)]. So that it is necessary to study different parameters related to the passage of gamma radiation through a building materials such as half value layer and linear attenuation coefficient to know the effectiveness of building materials so as to shield gamma radiation. Different workers have been calculated the attenuation coefficients in different categories such as [(3)] in Lead and pure tungsten, tungsten carbide-cobalt (WC_Co) Materials against Gamma Irradiation, [(4)]used Aluminum, Iron, Copper and Lead, [(5)]in building block, concrete, iron and lead, [(6)]design and construction of light and heavy weight concrete biological shields from ionizing radiation, [(7)]in heavy concrete, [(8)] in Cement material, [(9)]in clay, silica fume and cement samples, [(10)]used clay-flyash bricks, [(11)]in boron doped clay for 662, 1173 and 1332 keV gamma rays, [(12)]in glass, concrete, marble, fly ash, cement and lime, [(13)]used solid waste containing lead was analyzed as shielding material for gamma radiation, [(14)]in concrete mixed with different percentages of lead is used to study gamma-ray shielding properties, [(15)]used a combination of materials contains aluminum, iron, copper and lead as shielding for gamma radiation, [(16)]used Portland cement mixed with different percentages of granulated lead for gamma ray shielding.

## 2. 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 * 150 * 150 mm and 100 * 100 * 100 mm) cubes. For Cement mortar which mixed by 1 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.

**Experimental setup:**

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 inOB-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). 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 after that adding attenuator with constant operation voltage 400 volt , to calculate linear attenuation coefficient[17].

**Linear attenuation coefficient**

The linear attenuation coefficient (μ) describes the fraction of a beam of x-rays or gamma rays that is absorbed or scattered per unit thickness of the absorber, depend on the composition of the attenuating material and photon energy, and it is expressed in equation

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

Where μ is the linear attenuation coefficient in(cm$^{-1}$), $x$ is the thickness of the sample in (cm), $I_0$ is initial intensity and I is thickness intensity[18, 19]. The theoretical values of linear attenuation coefficient of combined samples calculated using the equation below,

$$\mu = \sum \frac{\mu_i x_i}{x_i} \tag{2}$$

Where $\mu_i$ is the linear attenuation coefficient, and $x_i$ is the thickness of combination samples.

**Half value layer**

The thickness of the attenuator that reduces the photon beam intensity to half of its original value $I_0$ is called the half-value layer, HVL, and is given by

$$\mathrm{HVL} = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \; {}^{(20,5)} \tag{3}$$

## 3. Results and Discussion

**Table1**. 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$c^0$ 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 |

**Table2.** The value of Doses through different lead and iron slabs thickness by using Co-60 source. The measuring time, temperature and pressure were 30s, 24.6$c^0$ and 968.9hpa, respectively.

| Lead thickness(cm) | Dose(μGY) | Iron thickness(cm) | Dose(μGY) | Frequency |
|---|---|---|---|---|
| 0.000 | 1.906 | 0.000 | 1.906 | 10 |
| 0.154 | 1.744 | 0.202 | 1.797 | 10 |
| 0.472 | 1.428 | 0.522 | 1.602 | 10 |
| 0.812 | 1.169 | 1.036 | 1.346 | 10 |
| 0.966 | 1.079 | 1.350 | 1.202 | 10 |

**Table3.** 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$c^0$ 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 |

**Table4.** The value of Doses through different building materials cubic's thickness by using Co-60 source. The measuring time, temperature and pressure were 30s, 34.5$c^0$ 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 |

**Table5.** Linear attenuation coefficient and half value layer for selected shielding materials using Cs-137 gamma rays.

| Materials | Linear attenuation coefficient μ($cm^{-1}$) | Standard error ($cm^{-1}$) | Half value layer(cm) | Standard error (cm) |
|---|---|---|---|---|
| Lead | 1.121 | 0.028 | 0.617 | 0.008 |
| Iron | 0.463 | 0.009 | 1.496 | 0.031 |
| Concrete | 0.151 | 0.007 | 4.593 | 0.236 |
| Cement | 0.139 | 0.006 | 4.965 | 0.206 |
| Clay | 0.101 | 0.003 | 6.779 | 0.175 |

**Table6:** The value of Doses through different (lead + Iron) slabs thickness by using Cs-137 source. The measuring time, temperature and pressure were 30s, 24.5$c^0$ and 970.7hpa, respectively.

| (Lead + Iron) Thickness (cm) | Dose(μGY) | Frequency |
|---|---|---|
| 0.000 | 237.74 | 10 |
| 0.154+0.202 | 182.72 | 10 |
| 0.154+0.522 | 157.52 | 10 |
| 0.154+1.036 | 122.43 | 10 |
| 0.154+1.35 | 105.61 | 10 |
| 0.472+0.202 | 127.20 | 10 |
| 0.472+0.522 | 110.09 | 10 |
| 0.472+1.036 | 86.36 | 10 |
| 0.472+1.35 | 74.86 | 10 |
| 0.812+0.202 | 87.74 | 10 |
| 0.812+0.522 | 76.17 | 10 |
| 0.812+1.036 | 59.86 | 10 |
| 0.812+1.350 | 51.84 | 10 |

**Table7:** The value of Doses through different (lead slabs +Building materials Cubic's) thickness by using Cs-137 source. The measuring time, temperature and pressure were 30s, 32$c^0$ and 986.7hpa, respectively.

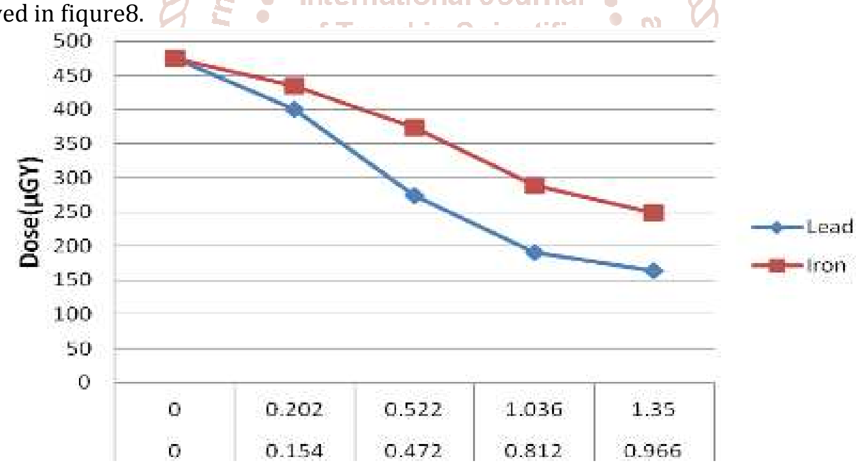
| Thickness (cm) | Dose(μGY) through (lead+ Concrete) shield | Dose(μGY) through (lead+ Cement) shield | Dose(μGY) through (lead+ Clay) shield | Frequency |
|---|---|---|---|---|
| 0.000 | 233.23 | 233.23 | 233.23 | 10 |
| 0.154+10 | 43.79 | 47.03 | 94.50 | 10 |
| 0.154+20 | 15.94 | 16.29 | 58.95 | 10 |
| 0.154+25 | 4.30 | 6.04 | 20.31 | 10 |
| 0.154+35 | 2.46 | 3.32 | 13.87 | 10 |
| 0.472+10 | 31.09 | 33.73 | 67.62 | 10 |
| 0.472+20 | 11.95 | 12.08 | 42.38 | 10 |
| 0.472+25 | 3.10 | 4.31 | 14.39 | 10 |
| 0.472+35 | 1.81 | 2.41 | 9.76 | 10 |
| 0.812+10 | 22.81 | 24.27 | 47.40 | 10 |
| 0.812+20 | 9.10 | 9.47 | 28.85 | 10 |
| 0.812+25 | 2.25 | 3.25 | 9.93 | 10 |
| 0.812+35 | 1.30 | 1.78 | 6.77 | 10 |

**Table8:** Linear attenuation coefficient and half value layer for selected shielding materials using Cs-137 gamma rays

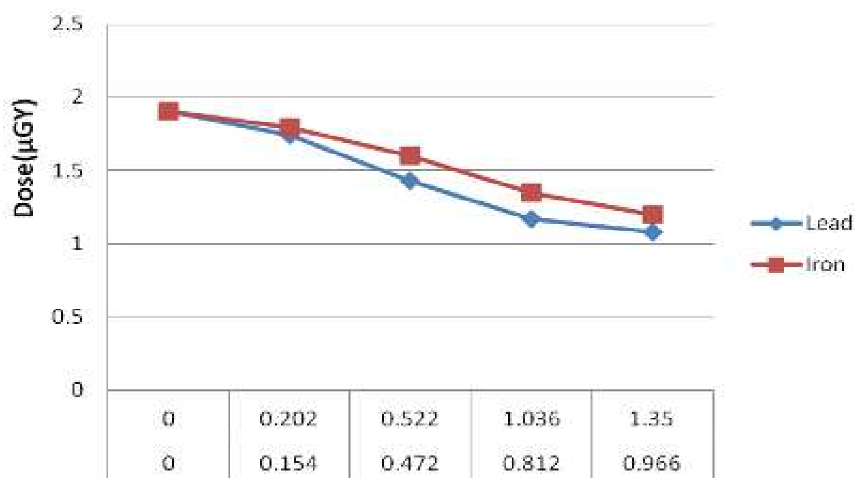
| Materials | Experimental | | | | Theoretical | | | |
|---|---|---|---|---|---|---|---|---|
| | Linear attenuation coefficient μ($cm^{-1}$) | Standard error ($cm^{-1}$) | Half value layer (cm) | Standard error ($cm^{-1}$) | Linear attenuation coefficient μ($cm^{-1}$) | Standard error ($cm^{-1}$) | Half value layer(cm) | Standard error ($cm^{-1}$) |
| Lead +Iron | 0.727 | 0.040 | 0.982 | 0.053 | 0.737 | 0.040 | 0.971 | 0.053 |
| Lead +Concrete | 0.160 | 0.007 | 4.412 | 0.189 | 0.175 | 0.008 | 4.031 | 0.178 |
| Lead +Cement | 0.150 | 0.007 | 4.630 | 0.198 | 0.164 | 0.007 | 4.305 | 0.182 |
| Lead +clay | 0.115 | 0.013 | 6.066 | 0.628 | 0.127 | 0.023 | 5.580 | 0.910 |

In this study the decrease of 662, 1173 and 1332 keV gamma rays with the increase the thickness of selected materials have been obtained, for each energy the measurements for all types of samples were carried out ten times and the average values listed in Tables 1, 2, 3, 4, 6, and 7. Also the linear attenuation coefficients and half value layer for the all studied building materials have been obtained for 662 keV gamma rays and the results have been listed in Tables 5 and 8, so the comparison of experimental and theoretical of linear attenuation coefficient and half value layer have been listed also in table8.
Figures 1, 2, 3 and 4 show graphical patterns that describe how the photon was attenuated in the selected materials with increased the thickness, through different energies of gamma ray Cs-137 and Co-60.

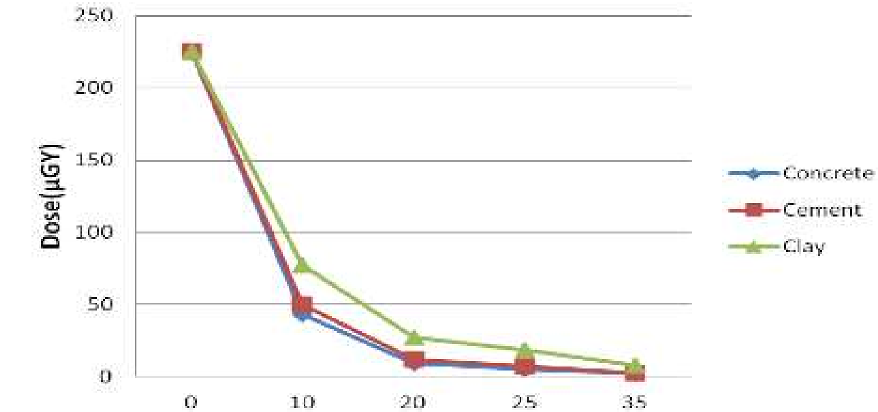
Figure5 shows the comparison of experimental and theoretical linear attenuation coefficient (μ) values for the selected materials through gamma ray energy, Cs-137. The results showed agreement between experimental and theoretical readings. In Fiqure6, shows the comparison of experimental and theoretical half value layer (HVL) values for the studied materials through gamma ray energy, Cs-137.Also the results showed agreement between experimental and theoretical readings.
In Figure7, shows the comparison of linear attenuation coefficients (μ) values for the selected materials using gamma ray source, Cs-137, and the variation of linear attenuation coefficients can be explained due to density-dependence of these materials. It is observed that the lead enhance the performance of iron, concrete, cement and clay to use as the shielding materials for gamma ray. And the comparison of half value layer (HVL) values for the selected materials using gamma ray source, Cs-137 showed in fiqure8.



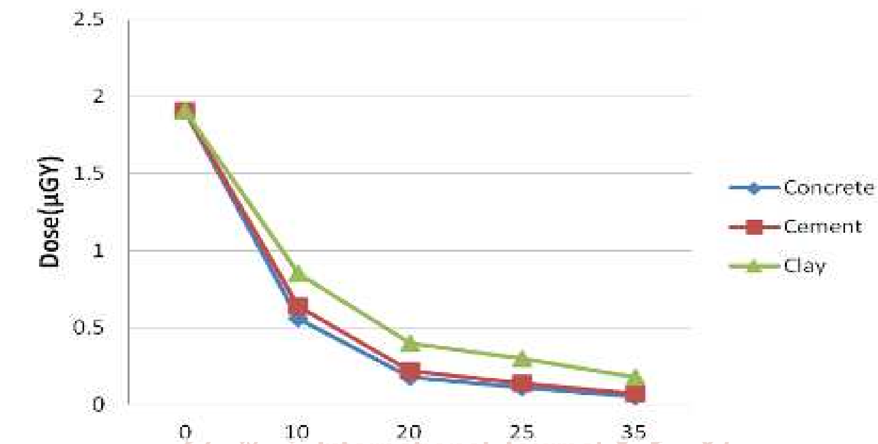

**Fiqure1.** Attenuation of Cs-137 gamma rays as a function of thickness through different shield materials




**Fiqure2.** Attenuation of Co-60 gamma rays as a function of thickness through different shield materials

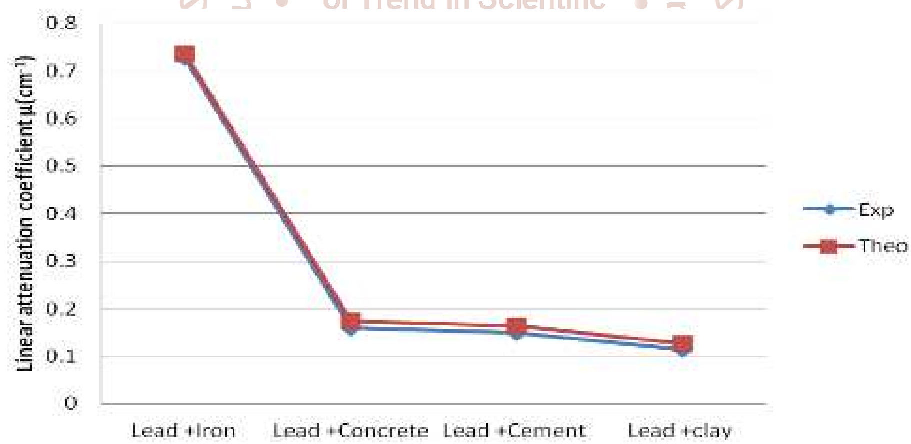



**Fiqure3.** Attenuation of Cs-137 gamma rays as a function of thickness through different shield materials

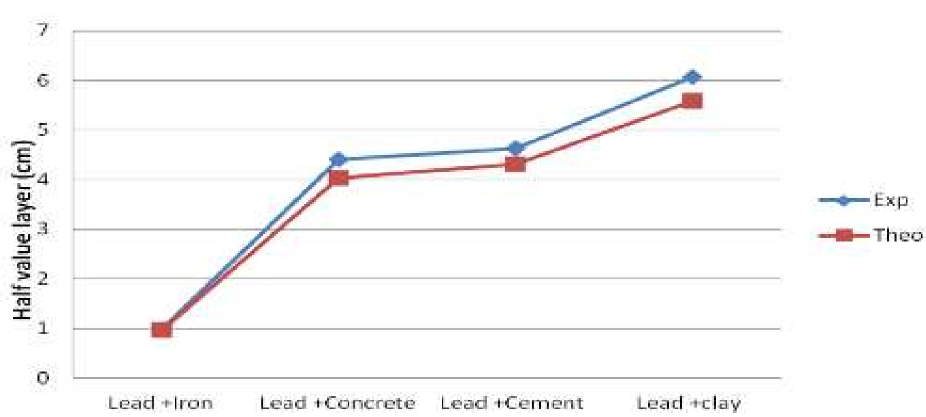



**Fiqure4.** Attenuation of Co-60 gamma rays as a function of thickness through different shield materials

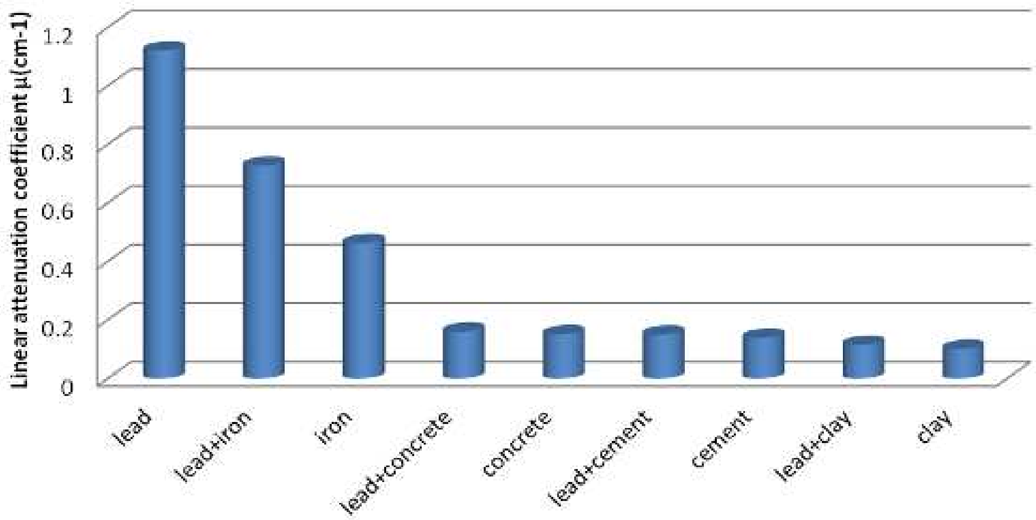




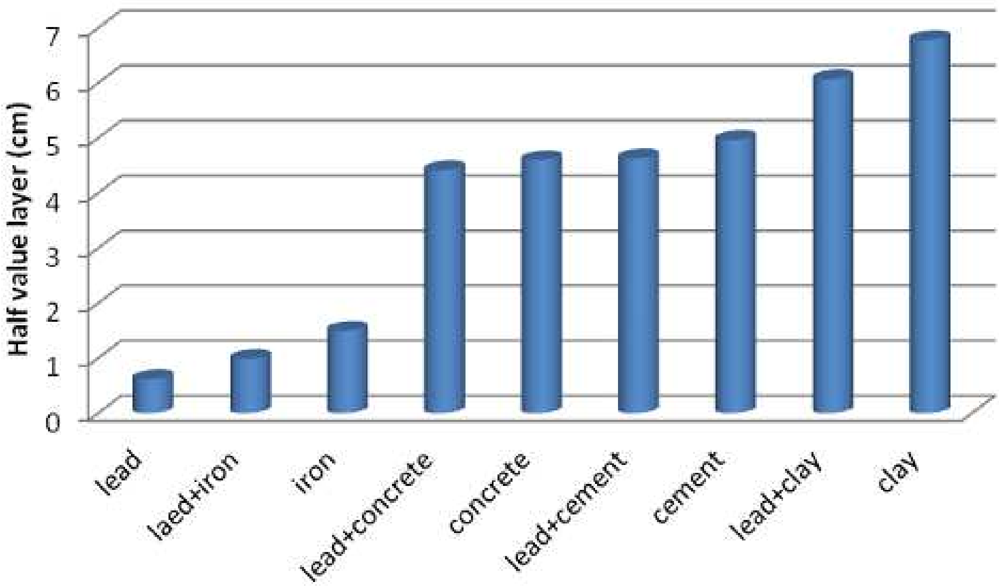

**Fiqure5.** Comparison of experimental and theoretical linear attenuation coefficient of different shield materials using Cs-137 gamma ray




**Fiqure6**. Comparison of experimental and theoretical half value layer of different shield materials using Cs-137 gamma ray




**Fiqure7.** Comparison of linear attenuation coefficient of selected shielding materials using Cs-137 gamma ray.




**Fiqure8.** Comparison of half value layer of selected shielding materials using Cs-137 gamma ray.

## 4. Conclusion

A combination of lead with the some building materials used in Sudan showed an improvement in the efficiency of these selected materials as the gamma ray shielding. Because an investigated materials showed the linear attenuation coefficients decrease with the increasing photon energy, and half value layer increase with increasing photon energy for these materials.

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