COMPARISON OF SHIELDING STRENGTH FOR LEAD, COPPER AND ALUMINUM

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Abstract

Human safety and structural material that may be compromised from radiation exposure are vital concerns in nuclear technology. Gamma attenuation coefficient of shielding material is measured using a proper electronic system under condition of narrow beam geometry. The radiation shielding characteristics of three elemental materials were examined by using half thickness method. From the experimental data, it is found that while only 0.6cm thickness of lead is required to reduce the gamma photon intensity to half of its original value, about 1.2 cm of copper and 1.8 cm of aluminum. To achieve this goal, linear attenuation coefficient of these samples was calculated. It is cleared that lead has a far better absorber of gamma photon than copper and aluminum. In this research, comparing shielding strength of the three elemental materials, it is concluded that lead is the best as copper is the second and aluminum is the third.

Keywords: *attenuation coefficient, elemental materials, shielding materials, shielding strength.*

Introduction

Radiation is naturally present in our environment and exists since the birth of this planet. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction, materials used to build our homes. Today, radiation refers to the whole electromagnetic spectrum as well as to the atomic and subatomic particles that have been discovered. One of the many ways in which different types of radiation are grouped is in terms of ionizing and nonionizing radiation. The ionizing radiations are commonly classified into two principal types. Directly ionizing radiations include radiations of energetic particles carrying an electric charge, such as beta particles, alpha particles, protons, and other recoil nuclei. They cause ionization by direct action on electrons in atoms of the media through which they pass. [2]

Another type of radiation, indirectly ionizing such as neutrons and x-ray or gamma-ray photons, are not charged and cause ionization through a more complicated mechanism involving the emission of energetic secondary charged particles which cause most of the ionization. Directly ionizing radiation interacts very strongly with shielding media and is therefore easily stopped. By contrast, indirectly ionizing radiation, may be quite penetrating and the shielding required may be quite massive and expensive. [2]

Gamma Ray Shielding as Elemental Materials

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 by one half (the half value layer $t_{1/2}$). The knowledge of this thickness is an indication of the minimum thickness we have to use in order to ensure appreciable protection from that source. The shielding efficacy of the three metallic materials; Copper, Aluminum and Lead have equally been compared. [1]

There are some basic principles for radiation shielding. The type and amount of shielding required depend on the type of radiation, the activity of the radiation source and the dose rate that

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is acceptable for outside the shielding material. However, there are other factors for choice of shielding material such as their cost and weight. The good shielding material should have high absorption cross-section for radiation and at the same time irradiation effects on its mechanical and optical properties should be small. A number of experimental and theoretical works have been performed on radiation shielding, which has large different application areas with different materials (e.g. concrete, semi-conductor, lead, copper and aluminum etc.) A study of absorption of gamma and neutron radiations in shielding materials has been an important subject in the field of radiation physics. [1]

Radiation attenuation

The attenuation coefficient of gamma rays was determined by measuring the fractional radiation intensity N_x passing through the thickness x as compared to the source intensity N_0. The linear attenuation coefficient (μ) has been obtained from the solution of the exponential form: [1]

$$N_x = N_0 e^{-\mu x} \qquad (1)$$

Half-value layer (HVL) is the thickness of an absorber that will reduce the gamma-radiation to half. This is obtained by using the following equation: [1]

$$x_{1/2} = \frac{\ell n2}{\mu} \qquad (2)$$

Some properties of Elemental Materials

Lead had a particularly high density, 11.3gcm^{-3} compared with many other metals (e.g iron 7.8gm^{-3}, copper 8.9 gcm^{-3}, aluminum 2.7 gcm^{-3}, Lead owes its high density to two factors: Its high atomic number and hence high relative atomic mass of 207, the metal atoms (or, more precisely, ions) are arranged in a dense, close packed structure (face centered cubic structure).The high density of lead has important bearings on other properties, particularly attenuation of X-rays gamma rays and sound waves. Some properties of lead, copper and aluminum are shown in Table (1). [4]

Table 1 Some Physical Properties of Lead, Copper and Aluminum

Physical Properties	Pb	Cu	Al
Density (g/cm^{-3})	11.34	8.96	2.70
Atomic number	82	29	13
Atomic weight	207.19	63.54	26.98

Experimental setup

Source for Gamma Ray

In the present work, gamma source Cs-137 forms gamma disc shape from Nuclear Lab in University of Yangon is chosen ^{137}Cs has one energy. It has an activity of 5μCi, half-life is 30.17 years and energy of the source is 0.662 MeV.

Sample Collection and Sample preparation

Three elemental materials, aluminium, copper and lead were collected in Yangon Division. Aluminium and copper sample has a thickness of (0.1) cm and area has (5.4×5.4) cm^2. Lead sample has a thickness of (0.1) cm and area has (7.4×7.4) cm^2.

Equipment

In the present work, the equipments used in gamma ray spectrometry were described as:

- Thallium Activated Sodium Iodide detector (Model 802.5)
- High Voltage Power Supply (Model 3002)
- ST-360 Radiation Counter with Windows (Model ST-360) and Macintosh Software Electronic setup of NaI (TI) detector system for γ-ray spectrometry in the forms of narrow beam is used. Detector transforms the radiations energy into electronic pulses: the preamplifier followed up these pulses by making impedance matching and put into the main amplifier. The operation of the main amplifier is amplifying, shaping and rejecting the pulses and feeding to the analog to digital converter portion of ST-360 RC. Finally is generates number of counts.

Experimental set up and procedure

The three elemental material were used as absorbers for gamma radiation. These samples were placed midway position between the source and detector. The detector was placed horizontally and the distance between the source and detector was 20 cm. The Cs-137 source was fixed in the lead shield. First the gamma intensity I_0 (in the absence of the shield sample) was used. Then, the sample position was placed at the centre of the source and detector. The detector was located forward direction of gamma beam. The above procedures were repeated for three types of elemental shield sample.

The transmitted gamma counts collection was done for 100s. Detector working voltage is 900V(positive bias). For each thickness of elemental shield sample, the gamma intensity reaching the detector was measured and the results obtained were recorded.

Gamma Rays Transmitting Measurement

Gamma ray's transmission was measured at the direction normal to the specimen, used with 5µCi of Cs-137. The absorption type operates in such a way that the radiation source and they were usually located in the different sites of the object to be measured. The detector in the lead shield was placed 20 cm from the source. Firstly, the intensity of gamma ray which pass through (without absorber of shield sample) was collected, and then passing through with absorber. The net count was recorded and the graphs were plotted for different thickness of various elemental shield samples. From the graph, the thickness of each sample which reduces the gamma photon intensity to half of its original value was obtained. And then the linear attenuation coefficients for three types of elemental shield samples were calculated by using equation (2).

The standard error of counting rates

The determination of error associated with the measurement is a very important task. It is probably as important as the measurement. So, to reduce the error in the research work, the standard error of counting rate for different thickness of each sample are calculated by using equation (3). The calculated values are recorded in Table (2), (3) and (4). [3]

In practice, the number of counts is usually recorded in a scalar, but what is reported is the counting rate, i.e. counts recorded per unit time. The following symbols and definitions will be used for counting rates. [3]

G = number of counts recorded by the scalar in time t_G with the sample present

= gross count

B = number of counts recorded by the scalar in time t_B without the sample

= background count

$$g = \frac{G}{t_G} = \text{gross counting rate}$$

$$b = \frac{B}{t_B} = \text{background counting rate}$$

$$r = \text{net counting rate} = \frac{G}{t_G} - \frac{B}{t_B} = g-b$$

The standard error of the counting rate,

$$\sigma_r = \sqrt{\frac{G}{t_G^2} + \sqrt{\frac{B}{t_B^2}}} \qquad (3)$$

The standard error of the average counting rate is

$$\sigma_{\bar{r}} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} \sigma_{r_i}^2} = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(\frac{G_i}{t_G^2} + \frac{B_i}{t_B^2}\right)}$$

$$= \frac{1}{N}\sqrt{\frac{G_i}{t_G^2} + \frac{B_i}{t_B^2}} \qquad (4)$$

For many the background rate is negligible compared to the gross counting rate

$$\sigma_{\bar{r}} = \frac{1}{N}\frac{\sqrt{G}}{t_G} \qquad (5)$$

Results, Discussion and Conclusion

Results

The transmission data of without absorber, with absorber and net count rate of different thickness for lead absorber is described in Table (2). The transmission data of without absorber, with absorber and net count rate of different thickness for copper and aluminum are also described in Table (3) and (4). The standard error of each counting rate for three samples are calculated by using equation (3) and then recorded in Table (2), (3) and (4).

Figure (1) shows the relationship between exponential decrease of gamma photon net count rate versus the different thickness of elemental materials (lead, copper and aluminum absorber). In the research work, from Figure (1), the thickness of lead, copper and aluminum that requires to reduce the gamma photon intensity to half its original value are obtained 0.6cm, 1.2cm and 1.8 cm. The half thickness of lead, copper and aluminum absorber are recorded in Table (5). The linear attenuation coefficient for lead absorber is calculated by using equation (2) and is obtained 1.16 cm^{-1}. The linear attenuation coefficient of copper and aluminum are also calculated by using equation (2) and are obtained 0.58 cm^{-1} and 0.39cm^{-1}. The standard error of the average counting rate for three elemental materials is calculated by using (5).

In the present work, the linear attenuation coefficient and standard errors 1.16±0.31cm^{-1} for lead, 0.58±0.23cm^{-1} for copper and 0.39±0.22cm^{-1} for aluminum and are recorded in Table (5).

From the Figure (1), the graph of lead has very sharp exponential decrease of gamma photon; the graph of copper has second and aluminum has third. In three elemental materials, lead is better shield because it requires just a few thicknesses of it to reduce the photon intensity to half its original value, then follow by copper and aluminum being the least. In comperes of linear attenuation coefficient for three elemental materials, lead is most, copper is the second and aluminum is the third. In this research, lead is far better of gamma photon when compared to copper and aluminum. Copper is a better absorber than aluminum.

Discussion

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 γ-rays by one half (the half value layer, HVL). In the improved shielding calculations, the thickness of the materials used in the shielding, the minimum thickness that could give us the maximum shielding from the emitting source, or even 99%.

The knowledge of thickness us an indication of the minimum thickness we have to use in order to ensure appreciable protection from the source. It is clearly seen that, lead that minimum thickness and most linear attenuation coefficient is the best gamma shielding strength then follow by copper and aluminum being least.

Table 2 The gross count, net count and net count rate for increasing lead absorb thickness

Sr No.	Absorber thickness (cm)	Gross count (G)	Net count	Net count rate (r) C/s
1	0	10823	7334	73.34±1.20
2	0.1	9989	6500	65.00±1.17
3	0.2	9339	5850	58.50±1.15
4	0.3	8639	5150	51.50±1.12
5	0.4	8089	4600	46.00±1.10
6	0.5	7589	4100	41.00±1.08
7	0.6	7156	3667	36.67±1.06
8	0.7	6749	3260	32.60±1.05
9	0.8	6409	2920	29.20±1.03

Table 3 The gross count, net count and net count rate for increasing copper absorber thickness

Sr No.	Absorber thickness (cm)	Gross count (G)	Net count	Net count rate (r) C/s
1	0	9078	7334	73.34±1.04
2	0.1	8644	6900	69.00±1.02
3	0.2	8244	6500	65.00±0.99
4	0.3	7894	6150	61.50±0.98
5	0.4	7544	5800	58.00±0.96
6	0.5	7244	5500	55.00±0.95
7	0.6	6914	5170	51.70±0.93
8	0.7	6614	4870	48.70±0.91
9	0.8	6394	4650	46.50±0.90
10	0.9	6124	4380	43.80±0.89
11	1.0	5864	4120	41.20±0.87
12	1.1	5664	3920	39.20±0.86
13	1.2	4689	3667	36.67±0.80

Table 4 The gross count, net count and net count rate for increasing aluminum absorber thickness

Sr No.	Absorber thickness (cm)	Gross count (G)	Net count	Net count rate (r) (C/s)
1	0	8360	7334	73.34±0.97
2	0.2	7826	6800	68.00±0.94
3	0.4	7326	6300	63.00±0.91
4	0.6	6876	5850	58.50±0.88
5	0.8	6426	5400	54.00±0.86
6	1.0	6026	5000	50.00±0.84
7	1.2	5676	4650	46.50±0.82
8	1.4	5316	4290	42.90±0.80
9	1.6	4976	3950	39.50±0.77
10	1.8	4689	3667	36.67±0.76
11	2.0	4426	3400	34.00±0.74
12	2.2	4176	3150	31.50±0.72

Table 5 The shielding strength [Atomic Mass, Half Value Layer (HVL) and Linear Attenuation Coefficient, (μ)] of three elemental materials

Sr No	Elemental Material	Atomic Mass	Half Value Layer (HVL) (cm)	Linear Attenuation Coefficient (μ) (cm^{-1})
1	Lead (Pb)	82	0.6cm	1.16 ± 0.31
2	Copper (Cu)	29	1.2cm	0.58 ± 0.23
3	Aluminum (Al)	13	1.8cm	0.39 ± 0.22

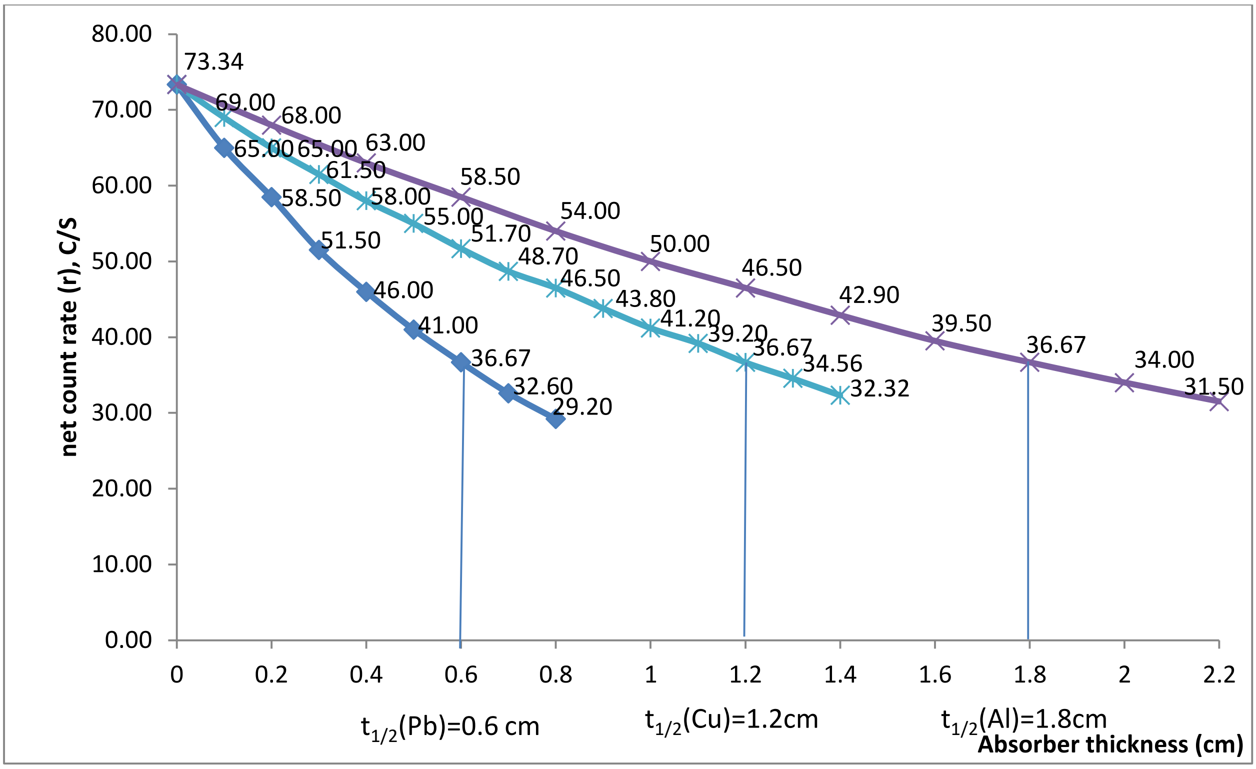

Figure 1 Exponential decrease of gamma photon net count rate versus different thickness of elemental metals

Conclusion

Radiation shielding against high energy photons is based on materials with high atomic number and high density that are known to absorb and attenuate ionizing radiation emitted from natural, human-made sources and radiation producing devices.

Effective of shield depends upon energy of radiation, thickness and type of the shielding materials. The higher atomic number and density of shielding materials, the more effective it is in reducing intensity of gamma radiation.

Lead was a very common shielding materials used to shield gamma radiation as it can reduce gamma particle. High gamma absorption cross section and high atomic number properties of lead enable it to be very effective in shielding γ and X radiations.

In this research, the half value layer and linear attenuation coefficient for three elemental materials were experimentally investigated.

It is clearly seen that the highest atomic number of leads is the best then followed by copper and aluminum being the least are remarkably effective for shielding gamma rays. It is concluded that, the shielding strength are most for lead, more for copper and less for aluminum in gamma radiation.

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