Shielding Cosmic Ray Muon using Copper and Aluminium Sheets Composited with Polyethylene Sheets for a Better Protection

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ABSTRACT

Muons are usually among the most common secondary cosmic ray particles on Earth's surface. Muon research has confirmed their occurrence in a variety of locales. It has been claimed that cosmic radiation in general, and muons in particular, have disastrous consequences on biological things and electrical components on Earth and in space. According to medical sources, cosmic rays have been linked to many ailments affecting people and other creatures. Because of these issues, cosmic ray shielding has become a crucial component of this and comparative studies. Muons emitted by cosmic rays were detected using a muon telescope made of coaxial Geiger-Muller (GM) tubes. This experiment was carried out within the muon lab of Universiti Kebangsaan Malaysia (UKM) in Malaysia to examine how the cosmic ray muon count fluctuates with the shielding of metals (Copper (Cu) and Aluminium (Al)) and polyethylene. The measured muon count for each metal sample was statistically analysed. Using both metals as shielding in this experiment revealed that adding additional Cu and Al sheets reduced the muon count. Generally, the numbers drop as the thickness increases. The results suggest that Cu outperforms Al in shielding efficacy (19% vs 16%). Because Cu has a more significant density than Al, the correlation coefficient R^2 for Cu = 0.9372 is greater than R^2 for Al = 0.6593, indicating that the trend for Cu is better than the trend for Al in this experiment. To study the shielding capabilities of the two composites, Al/PE and Cu/PE, ten sheets of Polyethylene (PE) were gradually put individually between the Al and Cu

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sheets. The results showed that PE sheets slightly increased cosmic ray shielding.

Keywords: *Muon, Cosmic ray, Copper, Aluminium, Polyethylene*

Introduction

The scope of the risks associated with the health, safety, and performance of crews exposed to ionizing radiation during space flight have been identified previously [1]. A lepton is a fundamental constituent and primary particle of the matter [2]. Electron, proton, and neutron are the essential components of atom. The preferable recognized of all leptons is the electron that governs nearly all chemistry that tied to the chemical characteristics [3]. The primary generation is the electronic (e^-) leptons. The e-lepton first compromises the (e^-) and electron neutrinos (v_e). Moreover, the muonic leptons compromise muons (μ^-) and muon neutrinos (v_μ). The third lepton is the tauonic leptons which compromises taus (τ^-) and tau neutrinos (v_τ). For all leptons flavour, there is a corresponding kind of anti-particle, recognized as anti-lepton, that is different from the lepton in its characteristics; however, it has equal magnitude but opposite sign. According to certain theories, neutrinos may be their own anti-particle, but it was theorized in the mid-19th century [4]-[8] and was find out in 1897 by Thomson [9]. The second lepton to be shown was the muon, found out through Stone [10], but it was erroneously categorized as a meson at the time [10]. After investigations, it was understood that the muon did not have the expected characteristics of a meson but rather behaved like an electron, only with a higher mass. It was until 1947, leptons were considered as a part of the family of charged particles. The first neutrino, the electron neutrino, was suggested by Jung [11] to demonstrate certain properties of beta decay as shown by the Cowan-Reines neutrino experiment that was carried out by Reines et al. [12]. The muon neutrino was discovered by Danby et al. [13] in 1962 while the tau discovery was between 1974 and 1977 by Perl [14]. The tau neutrino remained elusive until July 2000, when the donut collaboration from Ericson announced its discovery [15]-[16]. Leptons are a significant part of the Standard Model. Instead of electrons, exotic atoms with muons and taus could be synthesized along with lepton–antilepton particles such as positronium. The Geiger-Muller (GM) tube was used as a radiation counter in 1908 at Manchester University by Hans Geiger and Ernest Marsden and later improved by Walther Muller [17]. This study aims at detecting cosmic ray muons event at ground level at UKM using a muon telescope of coaxial GM tubes; to observe the count rate of muons at ground level through the shielding layer of Copper (Cu) and Aluminium (Al); and to determine the attenuation coefficient when there is the exponential decay rate of muon due to the increases of shielding thickness.

The shielding process is not limited to a metal sheet such as Cu or Al; it can also be done using sheets of polymers of different thicknesses. In this report, the focus on the particular importance of polyethylene (PE) as reference material for laboratory tests of shielding materials was also carried out. PE, the most widely produced plastic in the world, is a thermoplastic polymer with a variable crystalline structure and a vast range of applications. It is one of with tens of millions of tons produced worldwide each year. PE can be found either with High-Density Polyethylene (HDPE) or Low-Density Polyethylene (LDPE), where HDPE has more applications than LDPE Laurenzi et al. [18]. The chemical structure of PE is shown in Figure 1. The two hydrogen atoms are highly effective and one carbon atom per molecule (CH_2) [19]. PE is readily available, non-toxic, and chemically stable under typical conditions, making it a convenient reference material for shielding tests at heavy-ion accelerators.

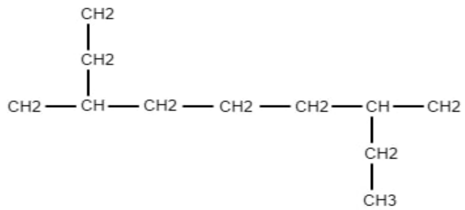


Figure 1: The structure of PE [19]

The current study discusses one of the most important topics concerning the health hazards caused by cosmic radiation. Previous studies have focused on using inorganic materials such as aluminum and copper as muon-stopping materials. The authors have separately added polyethylene with aluminum or copper as organic material in the current study. The results showed an increase in the performance of composite aluminum/polyethylene and copper/polyethylene in cosmic stopping materials. The study adds an essential piece of knowledge that plays a vital role in avoiding the consequences of cosmic radiation.

Theoretical Approach

The cosmic-ray muon’s source known as a cosmic-ray proton is resulted at the surface of the earth caused by the cosmic-ray muon’s source which is originated from deep-space supernova remnants [20]. As the protons arrive at the atmospheric earth, they produce hadronic showers caused by the highly energetic cosmic-ray proton interacting with atmospheric nuclei forming secondary particles, including hadrons and mesons. The delta resonance of this interaction is responsible for most of the pion production in the atmosphere. A high energy cosmic-ray proton interacts with a nucleon in the atmosphere producing a delta baryon, Δ, and residual nucleus, N, as shown in Equation (1) [21]:

$$p+N=\Delta+N \tag{1}$$

As a result of delta resonance, the group of $\Delta^-, \Delta^0, \Delta^+,$ and Δ^{++} is produced where $\Delta^- \rightarrow n + \pi^-$ and $\Delta^{++} \rightarrow p + \pi^+$, with $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$, $\pi^+ \rightarrow \mu^+ + \nu_\mu$, and $\pi^0 \rightarrow \gamma + \gamma$.

At altitude of nearly 15 km, the cosmic-ray muons originate and pass through the atmosphere losing about 2 GeV due to ionization [22]. The cosmic rays reach the earth's surface with the energy of ~3-4 GeV and slow down due to interaction and decaying. Upon decay of the cosmic-ray muon, an electron (or positron) and two neutrinos are emitted as described in Equation (2) [18]:

$$\begin{aligned} &\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu, \text{ and} \\ &\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \end{aligned} \tag{2}$$

Reyna model

Reyna, [23] has proposed a model ($\Phi_R(p,\theta)$) to extend the vertical sea-level model that estimated the differential flux to all zenith angles (θ) of Bugaev's original model ($\Phi_B(pcos\theta)$). Reyna verified the new model using experimental data analysis of sea-level muons. The Reyna model has shown that there was no significant difference between multiplying the flux by $\cos^3(\theta)$ or $p * \cos(\theta)$. Based on this finding, Reyna model proposed using momentum ($p * \cos(\theta)$) instead of the coefficient $\cos^3(\theta)$, where $0 \leq \theta \leq 90$ and p lies between 1 GeV and 2000/cosθ, as shown in Equation (3) [20]:

$$\Phi_R(p,\theta) = \cos^3(\theta)\, \Phi_B(p\cos\theta) \tag{3}$$

The momentum distribution of $\Phi_R(p,\theta)$ represents the muon distribution at the surface of earth.

Mechanism of Muon energy

The essential foundation of cosmic-ray muon energy loss mechanisms depends on the ionization and radiative processes where the binding energy is considered to identify the energy loss. Critical energy is the amount of energy loss between ionization and radiative processes. For cosmic-ray muons, the average energy of the cosmic-ray muon spectrum is ~3-4 GeV. For muons, energy could demonstrate total energy loss in a material. The range of achieving total energy loss of muon stopping criteria may occur within the order of meters for a cosmic-ray muon with an average energy of 4 GeV. This penetrative power of muons enabled the actual uses of cosmic-ray muons to measure pyramids and mine shafts.

The roles of materials in cosmic radiation

Muons are low-energy particles, yet they may be a source of radioactive background due to capture processes in certain materials. The employment of inorganic materials, such as copper and aluminium, and organic materials, such as polyethylene, as stopping materials is crucial for protecting those who operate close to a cosmic ray environment. The use of plastic track detectors to quantify the ratio between the vertical and horizontal components of the flux of deficient energy terrestrial muons at ground level [24].

The uncontrolled interaction of biological and nonbiological substances is one of the broad issues of space radiation. As a result, the safety of biological beings has become a significant concern and developing shields according to the ALARA principle is needed. Therefore, the availability of the data to space stations might make cosmic radiation safe for the community of aerospace engineers. From a materialistic perspective, shielding is a procedure that requires several materials with distinct properties. Such materials are mostly unavailable now; nevertheless, researchers are experimenting with polymer and inorganic material composites to attain this objective. The rationale for utilising composite materials is to minimise, to some extent, secondary neutron generation in order to reduce radiation produced by neutrons [25].

In another research, the effects of cosmic radiation were analysed in detail, exposing the difficulties engineers face when coping with this radiation during space travel [26]. In addition to this peril, humans on earth face a similar, albeit less severe, issue brought about by cosmic radiation. Microsatellites and other unscrewed spacecraft may be vulnerable to the effects of cosmic radiation on their electronics and varied materials. This conclusion opens the door to the requirement of employing spaceship-covering materials or materials used to manufacture electronic equipment such as transistors and processors. In this way, the fibre may be appropriate for reaching this objective [26].

A variety of organisations have conducted research into long-term effects on astronauts. Proton exposure alters the function of neurons and microglia, resulting in cognitive impairment [27]. Other studies have suggested that the central nervous system may be damaged [28] and that muscular movement may be disturbed [28]. In response to galactic cosmic irradiation, Almeida-Porada et al. [29] found DNA damage and alterations in human hematopoietic stem cells [29]. Since it is more challenging to repair complex DNA damage caused by HZE irradiation, it is likely to cause substantial issues [30]. Other health concerns include carcinogenesis, which has been studied extensively in animal studies, with results revealing that HZE particles cause more aggressive cancers. In contrast, long-term exposure to gamma or X rays has shown much lower risks of carcinogenesis than acute exposure [31].

Data analysis

The cosmic ray muon data analysis is performed using Excel or MATLAB. Data analysis can be divided into two stages: separation thickness analysis and angle observation analysis. Excel was used to analyse the preliminary data for the different separation counts of cosmic ray muon and the different thicknesses of Cu sheets, Al sheets, and PE. Descriptive statistics were used to analyse muon data. The descriptive statistical parameters are used to consolidate a large amount of information which contains minimum, maximum, median, mode, average, range, standard deviation, coefficient of variation, skewness, and kurtosis.

Descriptive statistics

In this research the descriptive statistical parameters of average, minimum, maximum, median, standard deviation, mode, range, coefficient of variation, skewness and kurtosis were used to analyse the data according to a set of numbers $x_1, x_2, x_3, \dots, x_{20}, x_n$, where n is the total number of the samples. The estimation of the values of the descriptive statistical parameters are performed by measuring the maximum value (x_{max}), then, the minimum value (x_{min}), followed by the range value (R_x) using $R_x = x_{max} - x_{min}$, then, the median value (x_{mid}), followed by the mode value, and the average value ($\bar{x}$) according to the following equation $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, and the standard deviation (S_x), and the coefficient of variation (C_v), and finally the standard error (S_e).

Other measurements of the descriptive statistics include the skewness value, which measures the symmetry of the data distribution (positive, negative, or zero) and the kurtosis value, which measures whether the data are peaked or flat relative to a normal distribution. Data sets with high kurtosis tend to have a distinct peak near the mean. The kurtosis for a standard normal distribution is three.

The linear regression equation

When muon passes through a sheet as a charged particle, the number of the particles is reduced by the sheet layers due to absorption of these particles. The change of muon counts with the shielding thickness results in calculating the correlation coefficient and the absorption (attenuation) coefficient (μ) of the Cu, Al, or PE sheets. Linear regression used to determine the relationship between two variables such as x and y using linear equation: $y = mx + c$, where c is the intercept on the y-axis, and m is the slope. To explain the trend line using the basic linear regression equation and the value of R^2 as explained by [32]. The two error types (small and large) of prediction for a point are a value minus the predicted value (the value on the line). Then we can calculate m, c, and their standard error of Δm, and Δc. The value of R^2 (between 0 and 1.0) is the correlation coefficient (or coefficient of determination) measures the strength of the relationship between the variables or statistically shows closeness between the data are to the fitted regression line.

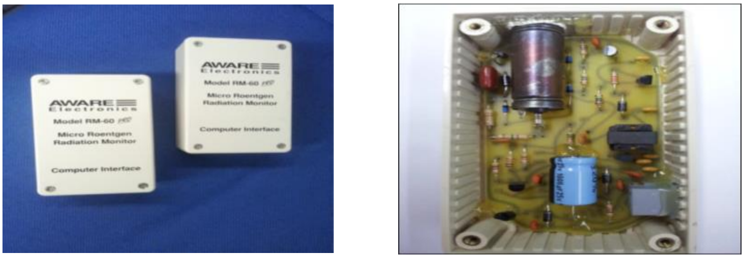
Materials and Method

Materials

The equipment used in this research consists of the RM60 radiation monitor, coincidence box (C-box), LCD-60 display module, and muon telescope. Concerning the addition complimentary materials, three sheet materials of Cu and Al of impurity 99.9% for each, and sheets of polyethylene. All sheets were available locally in the lab.

Radiation monitor (RM-60)

The radiation monitor used in this experiment is RM-60 manufacture by Aware Electronics (www.aw-el.com). It is a highly sensitive and easy to use Geiger counter that can continuously record natural background radiation, and low levels radiation from building materials. The RM-60 can detect all types of radiation emitted by radioactive elements such as alpha, gamma, or X-ray radiation. It is also used to detect the cosmic ray muons. Figure 2 shows the radiation monitor RM-60.



(a) (b)

Figure 2: the appearance of RM-60 radiation monitoring system; (a) outside, and (b) inside where a LND712 Geiger-Muller (GM) tube

The window of the GM tube Figure 3 has an areal density that varies from 1.5 to 2.0 mg/cm^2, effective diameter D of 9.14 mm and effective area of 65.61 mm^2. The wall of the radiation monitor has a thickness of 0.381 mm, and effective length L of 38.1 mm. The distances of the GM tubes from the radiation monitor box upper and lower edges are 0.9 cm and 0.5 cm. The power supply of the RM60 radiation monitor is a 9 V battery. Figure 3 shows the LND712 GM tube produced by LND Inc (www.lndinc.com).

Figure 3: The LND 712 GM tube used in the RM-60 radiation monitor

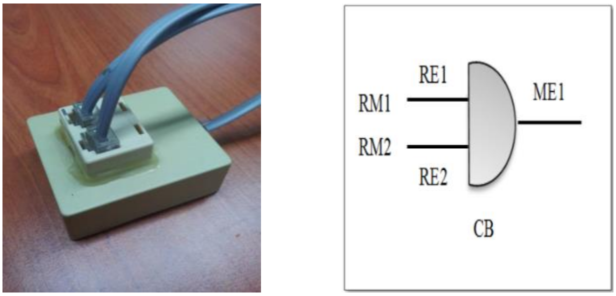
Coincidence Box (CB)

CB is used to detect simultaneous events in GM tubes. The box's output sends an impulse to an external counter, when two (or optionally three) of the inputs receive an impulse simultaneously (i.e. within 1 microsecond). CB detects the radiation cascade whether it is caused by Co-60 or the cosmic ray. CB connects to two or three single GM tubes. The output impulses are registered by a GM counter 513600, counter 200250 or via a Pasco digital adapter PS-2159.

The coincidence box (CB-box) manufactured by Aware Electronic (www.aw-el.com) is used to give out a signal when the two radiation monitors register simultaneous radiation events as shown in Figure 4. It is connected to the two RM-60 radiation monitors by RJ-45 telephone cables (Figure 4a). The schematic diagram of the coincidence box where RM1 and RM2 are the two RM-60s radiation monitors producing the two radiation events of RE1 and RE2, the RE1 and RE2 is the radiation output connected to coincidence box CB and the coincident event produced a muon event ME connected to LCD-60 display module as shown in Figure 4b.

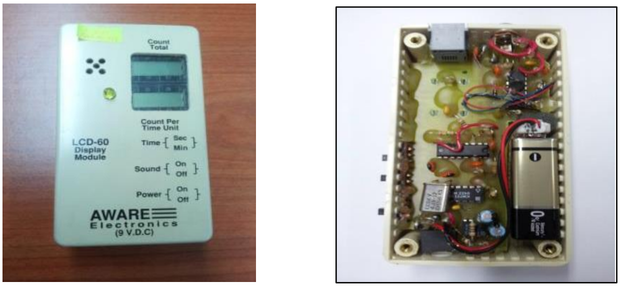
LCD-60 display module

The LCD-60 (powered by a 9-V battery) display module produced by Aware Electronics (www.aw-el.com) is used to display the output signal of the coincidence box to indicate a cosmic ray muon event. The LCD-60 used to display the count of cosmic ray muon events within a time period. It has two-digit readouts, one show counts per minute or counts per second and the other displays total counts. It is often useful to have the ability to separate the readout from the sensor unit with the snap in telephone wire. Figures 5a and 5b show the LCD-60 display module.



(a) (b)

Figure 4: (a) Coincidence box, and (b) schematic diagram of the coincidence box



(a) (b)

Figure 5: The LCD-60 display module from; (a) outside, and (b) inside

Housing box

A housing box was fabricated to hold the MT telescope and metal sheets, as shown in Figure 6. The housing box is made of Perspex plastic with dimension 30 x 60 x 30 cm. The MT telescope is placed inside the housing box and the metal sheets are placed at the top of the housing box. The housing box is strong enough to carry the weight of the metal sheets.

Copper, aluminium, and polyethylene sheets

Sheets of the metals of Cu, Al and PE sheets are used as the absorber or shielding material in this study as shown in Figures 7a, 7b, and 7c. There are 14 copper sheets of dimension 20 x 20 x 0.12 cm and 6 sheets of dimension 20 x 20 x 0.2 cm. For Al, 20 sheets of dimension 20 x 20 x 0.12 cm. In addition, there are 20 PE sheets with dimensions of 20 x 20 x 0.1 cm. Table 1 summarizes the physical properties of the three used sheets.

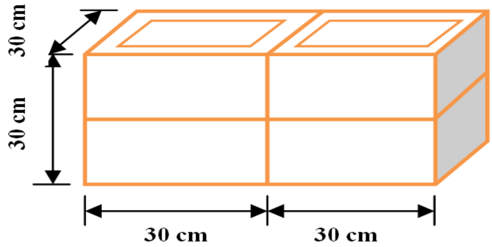
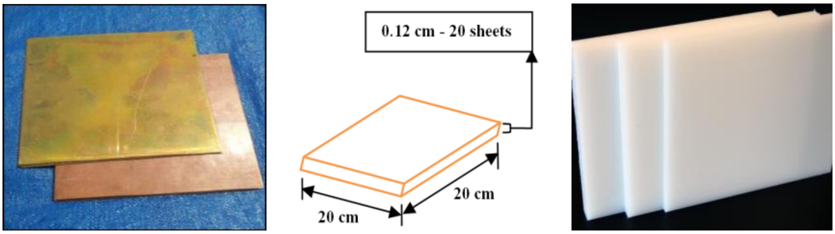


Figure 6: Dimensions of the housing box

Table 1: The physical properties of the Cu, Al, and PE sheets

Property	Cu	Al	PE
Density (g/cm^3)	8.9	2.71	0.91
Melting Temperature (°C)	1083	660	110
Thermal Conductivity (W/mK)	390	226	0.4
Thermal Expansion (1/°C)*10^{-6}	17	24	100-126
Specific Heat Capacity (kg.°C)	385	946	1550
Dimensions (cm)	20 x 20 x 0.12	20 x 20 x 0.20	20 x 20 x 0.10

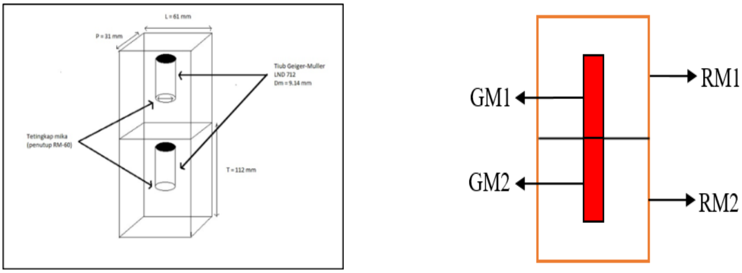


(a) (b) (c)

Figure 7: The sheets used (a) Cu sheet, (b) Al sheet, and (c) PE sheet

Muon telescope

Cosmic ray muon telescope (MT) is used to detect muon events or coincidence. The coincidence means that the radiation events occur simultaneously in both RM60s determined by a coincidence box (CB-box). Two of the RM60 radiation monitor units are stacked on top of each other making a cosmic ray MT, which can be connected to an LCD-60 display module. The measurements are performed with a smaller solid angle $\Delta\Omega$. The smallest angle is better defined, suggesting that the smaller $\Omega(\theta)$ is better for the arrival direction of the cosmic ray muon. Figure 8 shows a schematic diagram of the cosmic ray muon telescope comprising of two RM-60 that were stacked together (coaxially) with no separation between the two GM tubes.



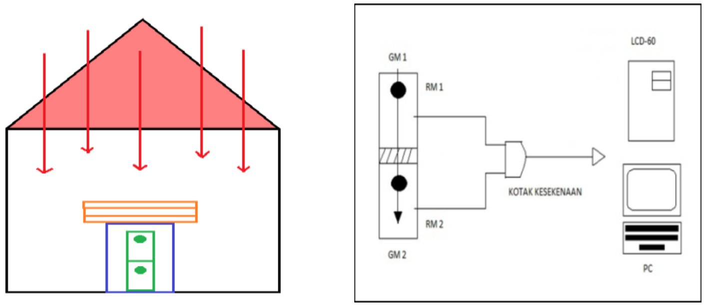
(a) (b)

Figure 8: The schematic diagram of a cosmic ray muon telescope; (a) front view, and (b) side view

Measurement Method

The experiment set up

This study was designed to detect the effect of Cu sheet, Al sheet, and PE sheets on shielding cosmic ray muon event rate at ground level using an MT which consists of two RM-60 radiation monitors. The monitor contains two coaxially GM tubes with no separation. The muon telescopes were pointed coaxially, i.e., at the zenith angle of θ = 0º. The two RM-60 radiation monitors connected to a coincidence box (CB) to determine the radiation events that occur simultaneously in both RM-60s. CB is connected to the LCD-60 display module where the counts recorded appear on it. The MT is placed inside a housing box and the metal sheets are placed at the top of the housing box. Figure 9a shows the diagram of the experimental set up while Figure 9b shows the schematic diagram of the experiment set up. The setup consists of RM1, RM2, RM60, two GM tubes (GM1 and GM2). The experimental setting produces two radiation events of RE1 and RE2, where both are connecting to the radiation output to coincidence box CB where the coincidence event produced a muon event.



(a) (b)

Figure 9: (a) Geometric diagram of the experiment set up, and (b) schematic diagram of the experiment set up

The experiment procedure

The experiment is divided into two similar parts in terms of methodology and location. However, the two parts are different in the material used. Previous studies on ground level muon at UKM were performed either inside the physics building which contains walls, ceilings, and roof shielding [33] or in the open area on the third floor of the physics building [34]. This experiment was performed to measure the cosmic ray muon inside and the third floor of the physics building. The first part is called the external experiment that was designed to detect the effect of various sheets of aluminium on cosmic ray muon at ground level (inside). The second part is the internal experiment that was designed to detect the effect of sheets of Cu and PE on cosmic ray muon at ground level inside the muon lab (room no. 3113). Figure 10 shows the muon telescope MT experiment set up inside the building.

Figure 10: Two sets of MT experiment set up (2 metals simultaneous Cu and Al) inside the building)

Measurement of density of Cu and Al sheets

There are 11 sheets of Al of dimension 20 x 20 x 0.12 cm and 11 sheets of Cu of dimension 20 x 20 x 0.2 cm and 10 sheets of PE of dimension 20 x 20 x 0.10 cm. The measurement of density of Cu and Al sheets is to verify the impurity of the Cu and Al sheets to compare it with the standard values of the pure Cu and Al sheets. Table 2 shows the mathematical values of the density ρ (mass/volume) (kg/m^3) of Cu and Al sheets. Figure 11 shows the density (ρ) (mass/volume) (kg/m^3) of Cu and Al sheets as a function of the number of layers.

Table 2: The experimental values of mass, volume and density of Cu and Al sheets

No. layers	Mass (m) (kg)		Volume (V) (m^3)	
	Cu	Al	Cu	Al
2	1.00	0.42	0.000104	0.00016
4	1.93	0.83	0.000208	0.00032
6	2.92	1.29	0.000312	0.00048
8	3.90	1.70	0.000416	0.00064
10	4.82	2.10	0.00052	0.0008

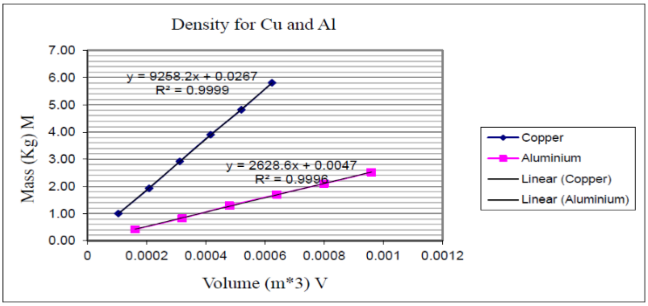


Figure 11: The mass of metal versus the volume of metal

From the graph, the density of Cu and Al sheets are 9258 ± 26 kg m^{-3} and of 2628 ± 4 kg m^{-3}, respectively. The results are very close to the reported results of Cu ≈ 9.3 g/m^3 and Al ≈ 2.6 g/m^3. The standard values for the density of pure Cu and Al sheets are ρ for (Cu = 8.96 g/m^3) and ρ for (Al = 2.70 g/m^3).

Measurement of Muon events

The muon counts through metal sheets were studied with different sheets of Al and Cu sheets separately. A single sheet was tested first (0 layers), and then the number was increased by another sheet to form the first layer. The process continued until reaching 11 sheets which represent ten layers. The exact process was repeated to the Al sheets. The second part of the experiment was performed by adding 10 PE sheets gradually until using all PE sheets. Two experiments were performed: one for Al and another for Cu sheets.

An internal experiment to observe the muon event rate on metal layers has been conducted and measured from August to November 2021 on all sheets of Cu and Al of dimension 20 × 20 cm with 11 samplings set for each metal with a sampling period overnight (≥ 24 hours) per count inside the building at muon lab. This experiment was done inside the muon lab overnight to determine the muon event at ground level for a longer time and with more shielding (the more shielding is the concrete of the muon lab ceiling and walls). All experiments were done in the exact location and within the same period of two months. The muon telescope was pointed at the vertical direction, where $\theta = 0°$ under defining the size of the detector (RM-60s) as the solid angle of the telescope.

Result and Discussion

Muon telescope performance test unit

Ten observations of muon were performed using two muon telescopes simultaneously by placing a coaxially 2-radiation monitor with no spacer. Performance testing was conducted to test the observed ability of both muon telescopes. This test is essential because both units are used simultaneously on different material thicknesses. Table 3 explains the two-set observations of the muon telescope.

Table 3: The performance of the two sets of observations of the test muon telescope

Observations	Set A	Set B	Observations	Set A	Set B
1	35	35	6	52	56
2	152	145	7	56	58
3	35	64	8	43	57
4	53	45	9	53	47
5	50	44	10	57	59

Set A and B to consist of radiation monitoring equipment, the coincident, and the display module. Table 4 shows the observed data with a sampling period of 24 hours without shielding material placed above the muon telescope. Paired t-test was performed to test both the muon telescopes. Based on Table 3, the value obtained was 0.60, which is greater than the alpha value set to 0.10. In conclusion, there is no difference in the mediator between the two muon telescopes used. Therefore, the two muon telescopes have the same performance.

Table 4: Two-sample t-test of paired for min

	Set A	Set B
The mean	2.066	2.152
Variance	0.082	0.098
Observation	10	10
Pearson correlation	-0.414	-0.405
Hypothesis distinction the mean	0	0
Degree of Freedom	9	9
t Stat	-0.537	-0.502
p $(t \leq 1)$ one end of	0.302	0.297
t critical one end of	1.833	1.785
p $(t \leq 1)$ two-end	0.604	0.589
Critical two-tailed t	2.262	2.198

Al and Al/PE sheets

The observations of muon events with 11 Al sheets of dimension 20 x 20 x 0.12 cm from August to November 2019 are reported in Table 5 where I is the number of samplings, NL is the number of layers, N is the muon count and the time is the sampling time. The same experiments were repeated with sandwiching 10 PE sheets to make with Al sheet 10 layers. The sampling time is the time of exposing the layers to cosmic rays and N is the number of GM tube ionization events.

The rate of counts () in the table above are shown graphically in Figures 12a and 12b for Al sheets and Al/PE sheets, respectively. From Equation (4) and Equation (5), the shield caused was 17% and 19% for the Al sheets and Al/PE sheets, and the coefficient of determination (R^2) at 0.6593 and 0.8717, respectively. The values of the coefficients are accepted. The effect of Al ($\rho = 2.71$ g/cm^3 on the muon shielding is described by Equation (4) which states that the muon radiation decreases at rate of about 22% due to inserting 11 sheets whose total thickness is 1.32 cm. The shielding result is lower than the recent study which was found at about 33% [35]. The variance can be attributed to the method used in detecting the cosmic ray and to timing, location, and the instrument used.

$$R = -0.1685 * x + 2.422 \text{ and } R^2 = 0.6593 \quad (4)$$

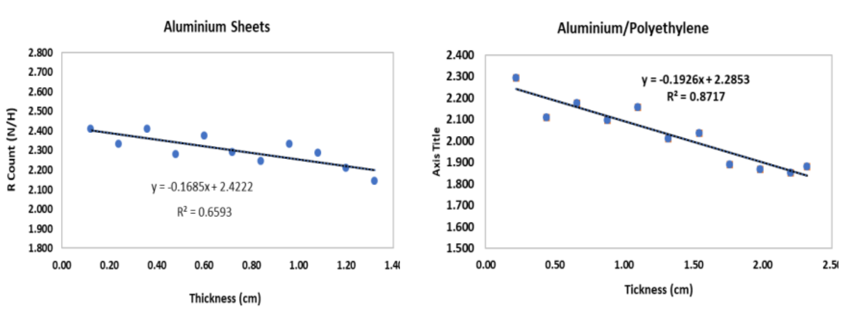
and;

$$R = -0.1926 * x + 2.2853 \text{ and } R^2 = 0.8717 \quad (5)$$

The calculated by N/h are shown in (a).

Table 5: Muon sampling for 10 layers of Al and Al/PE sheets

		Al			
I	NL	x(cm)	Sampling Time (s)	N	N/h
1	0	0.12	79200	54	2.45
2	1	0.24	86400	56	2.33
3	2	0.36	79200	53	2.41
4	3	0.48	90000	55	2.20
5	4	0.60	86400	57	2.38
6	5	0.72	86400	55	2.29
7	6	0.84	88200	55	2.24
8	7	0.96	72000	44	2.20
9	8	1.08	81900	53	2.33
10	9	1.20	86400	53	2.21
11	10	1.32	86400	49	2.04
		Al/PE			
I	NL	X (cm)	Sampling Time (s)	N	N/h
1	0	0.22	81600	54	2.29
2	1	0.44	83700	56	2.11
3	2	0.66	79500	53	2.17
4	3	0.88	82500	55	2.09
5	4	1.10	88500	57	2.16
6	5	1.32	91300	55	2.01
7	6	1.54	88400	55	2.04
8	7	1.76	87600	45	1.89
9	8	1.98	92600	52	1.87
10	9	2.20	93400	53	1.85
11	10	2.32	95700	49	1.77



(a) (b)

Figure 12: The effect of; (a) Al sheet, and (b) Al/PE on shield of muon

Cu and Cu/PE Sheets

The observations of muon events with 11 Cu sheets of dimension 20 x 20 x 0.20 cm from August to November 2021 are reported in Table 6 where I is the number of samplings, NL is the number of layers, N is the muon count and the time is the sampling time. The same experiments were repeated with sandwiching ten PE sheets to make with Al sheet ten layers. The sampling time is the time of exposing the layers to cosmic rays and *N* is the number of GM tube ionization events.

The rate of counts (R) in the table above are shown graphically in Figure 13a and 13b for Cu sheets and for Cu/PE sheets, respectively. From Equation (6) and Equation (7), the shield caused was 20% and 21% for the Cu sheets and Cu/PE sheets, respectively. In addition, Equation (6) and Equation (7) show that the coefficient of determination (R^2) is 0.9372 and 0.9382, respectively. The values of the coefficients are very high. The effect of Cu ($\rho = 8.96$ g/cm^3 on the muon shielding is described by Equation (6) which states that the muon radiation decreases at rate of about 20% due to inserting 11 sheets whose total thickness is 2.20 cm. The shielding behaviour of Cu is similar to the conclusion of the work of DeWitt and Benton [25]; however, there was no figure is available.

$$R = -0.2003 * x + 2.6827 \quad \text{and } R^2 = 0.9372 \tag{6}$$

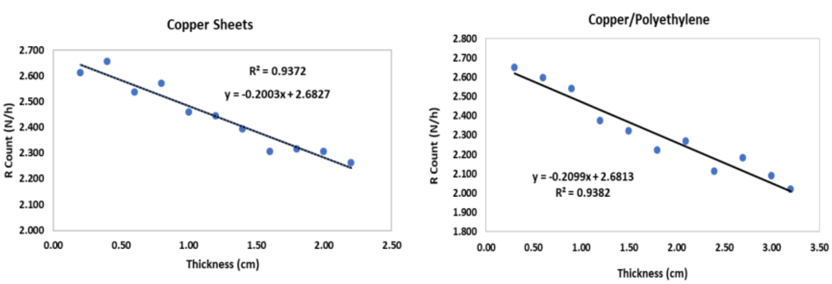
and;

$$R = -0.2099 * x + 2.6813 \quad and\, R^2 = 0.9382 \tag{7}$$

It can be noticed from Table 1 that the value of the correlation coefficient for copper is greater than that for Al ($R^2 = 0.9372 > R^2 = 0.6693$) due the fact that Cu is much denser than Al. This result agrees with the statistical approach performed by Altameemi and Gopir [36]. However, the most controversial result was that the shielding trends in the experiment performed by Altameemi and Gopir [36] has shown that the shielding increased for both Cu and Al which violates the logical trend of the shielding. For this reason, the conclusion that was adopted by Altameemi and Gopir [36] which states that “the Cu and Al are not suitable as shielding materials for cosmic ray muons” was seemingly based on the wrong assumption and wrong calculation.

Table 6: Muon sampling for 10 layers of Cu and Cu/PE sheets

			Cu		
I	NL	X(cm)	Sampling time (s)	N	N/h
1	0	0.20	75800	55	2.61
2	1	0.40	81300	60	2.66
3	2	0.60	82300	58	2.54
4	3	0.80	85400	61	2.57
5	4	1.00	86400	59	2.46
6	5	1.20	85400	58	2.44
7	6	1.40	82700	55	2.39
8	7	1.60	76500	49	2.31
9	8	1.80	82400	53	2.32
10	9	2.00	87400	56	2.31
11	10	2.20	87500	55	2.26
			Cu/PE		
I	NL	X(cm)	Sampling Time (s)	N	N/h
1	0	0.30	73400	54	2.65
2	1	0.60	73500	53	2.60
3	2	0.90	75200	53	2.54
4	3	1.20	77400	51	2.37
5	4	1.50	83800	54	2.32
6	5	1.80	87600	54	2.22
7	6	2.10	84200	53	2.27
8	7	2.40	83500	49	2.11
9	8	2.70	84200	51	2.18
10	9	3.00	82700	48	2.09
11	10	3.20	85600	48	2.02



(a) (b)

Figure 13: The effect of; (a) Cu sheet, and (b) Cu/PE on shield of muon

The influence of PE

PE is a good shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation. PE is widely used for radiation shielding in space and therefore it is an excellent benchmark material to be used in comparative investigations [37]. In this work, 10 sheets of PE (thickness of 1 mm and density 0.9 g/cm^3) were inserted between either Al or Cu sheets and the original experiments were repeated. The results can be traced in Table 4 (Al/PE) and in Table 5 (Cu/PE). Figure 12b and Figure 13b show the effect of inserting up to 10 PE sheets between the Al and Cu sheet, respectively. The results depicted in Equation (4) (Al/PE) and Equation (6) (Cu/PE) have shown that the PE has increased the shielding effect in the Al case from 16% to 19% with $R^2 = 0.8717$ and from 20% to 21% with $R^2 = 0.9382$ in case of Cu. Despite the fact that PE has hydrogen, the results have not shown the expected increase in shielding effect. However, Naito et al. [35] have noticed that the energy of cosmic rays was not enough to make the ionization need to be detected by GM tube [35].

Conclusion

Due to the relativistic effect, muons are one of the most abundant secondary cosmic ray particles detected at ground level. Numerous investigations on muons have been conducted in various locations using diverse equipment. It has been stated that cosmic radiation, in general, and muons, in particular, have devastating effects on living organisms. Those who work closely on cosmic radiation and fly to investigate space are influential. In addition, it has been observed that cosmic rays directly harm electronic components. According to reports in the medical field, cosmic rays have been implicated in several diseases affecting humans and other organisms. Due to these factors, protection against cosmic rays has become an essential component of this and similar research. This study is one of the studies that detected muon occurrences at ground level in tropical regions. Muons from cosmic rays were captured using a muon telescope comprised of coaxial GM tubes. This experiment was conducted to observe how the cosmic ray muon count varies with metals (Cu and Al) shielding and PE. Cu and Al sheets constituted the metal's shielding. The sample was conducted from August to November 2021; the muon count was measured throughout the night, with variations in thickness causing changes in the muon count. Statistical analysis was conducted on the measured muon count for each metal sample. Using both metals as shielding in this experiment, it was discovered that the muon count changed due to adding more Cu and Al sheets. Generally, the counts decrease with the increase of thickness of either metal. The results have shown that Cu is better than Al in shielding effectiveness (19% compared to 16%). The correlation coefficient R^2 for Cu = 0.9372 is bigger than R^2 for Al = 0.6593, meaning the trend for Cu is better than the trend for Al for this experiment because Cu is higher density than Al. In addition to investigating the Al and Cu sheets, ten sheets of PE sheets were gradually inserted separately between the Al and Cu sheets to investigate the shielding ability of the two composites Al/PE and Cu/PE. The results have shown a slight increase in the shielding of cosmic rays caused by PE sheets.

Contributions of Authors

Tayser Sumer Gaaz conducted all of the experiments and wrote the manuscript as part of his project. Malik N. Hawas was the principal investigator. The published version of the manuscript has been read and approved by all authors.

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Conflict of Interests

The authors declare no conflict of interest.

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List of abbreviations

e^-	Electron
e^+	Positron
ν_e	Electron neutrino
$\overline{\nu_e}$	Antielectron neutrino
μ^-	Negative Muon
μ^+	Positive Muon
ν_μ	Muon neutrino
$\overline{\nu_u}$	Antimuon neutrino

π^{O}	Neutral pion
$\pi\pm$	Charged pion
γ	Gamma ray
x	Thickness of the floor
X	Effective thickness
N(X)	Muon counts at effective thickness X
N_o	Muon counts when the effective thickness X=0 at vertical direction (θ=0°)
α	Linear absorption coefficient of the shielding material

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