J. Myanmar Acad. Arts Sci. 2021 **Vol. XIX. No.2**

INVESTIGATION ON SHIELDING PROPERTIES OF SOME COMPOSITE MATERIALS BY USING NAI(Tl) DETECTOR

Win Mar[1]

Abstract

The high-density composite materials have similar behavior of heavy metals when increasing the proportion of material supported in composite material. In other word measure and determination for the amount of shielding required to provide personal protection on an environment with lowest costs and appropriate selecting materials to reduce radiation doses in industrial facilities and surrounding areas. In this research, the numerical buildup factor and the linear attenuation coefficient were accounted as a function for the concentration of cement in shields with 25%, 50% and 75% of iron powder. The shield thickness of shielding composite materials that supported by these concentrations of iron in cement powders in the range of (5-40) mm was done. From the results, it is found that the better attenuation coefficient become in its each composite sample, the more iron concentration increased in cement. In this research, it is cleared that the most iron concentration in cement is the best shielding ability.

Keywords: *attenuation coefficient, buildup factor, composite materials, personal protection, shielding materials.*

Introduction

Ionizing radiation is known to be harmful to human health and heredity. In the field of radiation protection, the shielding materials protected from gamma radiation, such as concrete, lead, requires large block and then high cost. Various materials which are used for shielding include aluminum, iron, cement and organic compounds. The shields could take different like blocks, plates, rods, pellets etc. which can act as fillers for ducts, trenches and penetrations. At the present time it is an important need to improve new shielding materials and also to develop properties of the conventional shielding materials. So, the composite material helps to solve the problem of shielding, these composite materials have properties of multiple commensurate with many industrial applications. Shielding pellets are useful in areas that are irregular in shapes or inaccessible to personnel.

Relation between Buildup Factor, Gamma Attenuation and Mean Free Path

The mean free path is the distance that a molecule travels between collisions. In particle physics the concept of the mean free path is not commonly used, being replaced by the similar concept of attenuation length. In particular, for high-energy photons, which mostly interact by electron-positron pair production, the radiation length is used much like the mean free path in radiography.

When a narrow parallel of photons passes though relatively thin shield as shown in Figure (1), the relative intensity of mono-energetic photons transmitted without interaction through a shield of thickness is:

$$\frac{I}{I_0} = e^{-\mu x} \qquad (1)$$

Where I and I_0 are the shielded and initial beam intensities, respectively, μ is the linear attenuation coefficient (in cm^{-1}), and x is the shield thickness (in cm). Ideally, the beam should be well

[1] Associate Professor, Department of Physics, Meiktila University.

collimated, and the source should be as far away as possible from the detector. The absorber should be midway between the source and the detector, and it should be thin enough so that the likelihood of a second interaction between a photon already scattered by the absorber and the absorber is negligible. In addition, there should be no scattering material in the vicinity of the detector.

The linear attenuation coefficient can be considered as the fraction of photons that interact with the shielding medium per centimeter of shielding. It is also known as narrow beam conditions because the source and detector are assumed to be collimated and the measurement made at a short distance.

If the incident beam is broad as shown in Figure (2), then the measured intensity will be greater than that described by equation (1), because scattered photons will also be detected. Such conditions usually apply to the shields required for protection from gamma ray source. The increased transmission of photon intensity over the measured in good geometry can be taken into account.

$$\frac{I}{I_0} = B\,e^{-\mu x} \qquad (2)$$

where B is the buildup factor for one energy at the shield thickness x.

This formula attempts to estimate the correct number of scattered photons that reach the detector (closest estimate) by using a correction factor to add in the Compton scatter and pair production photons that are ignored by the linear attenuation coefficient formula. Therefore, the value of B can be obtained by dividing equation (2) by equation (1).

The absorbance ratio (R_A) for radiation inside the material shield by the following form

$$R_A = e^{\mu x} \qquad (3)$$

Where $R_A = (\frac{I_0}{I})$

The above equation shows that the relationship absorbance ratio (R_A) to thickness of the material shield or absorbent is exponential, so this relationship can be converted to a linear relationship as in the following form:

$$\ln R_A = \mu x \qquad (4)$$

The recent equation can be used to calculate the linear attenuation coefficient, which represents the slope of straight line of the relationship between (x) and ($\ln R_A$), i.e. μ=slope.

In addition to, we can be calculation standard of statistical deviation and fractional statistical deviation from follow:

$$S.D = B\left[\left(\frac{1}{l_g}\right) + \left(\frac{1}{l_{ob}}\right)\right]^{1/2} \qquad (5)$$

$$F.S.D = \left[\left(\frac{1}{l_g}\right) + \left(\frac{1}{l_{ob}}\right)\right]^{1/2} \times 100\% \qquad (6)$$

Where:

S.D = Standard of statistical deviation

F.S.D = Fractional statistical deviation

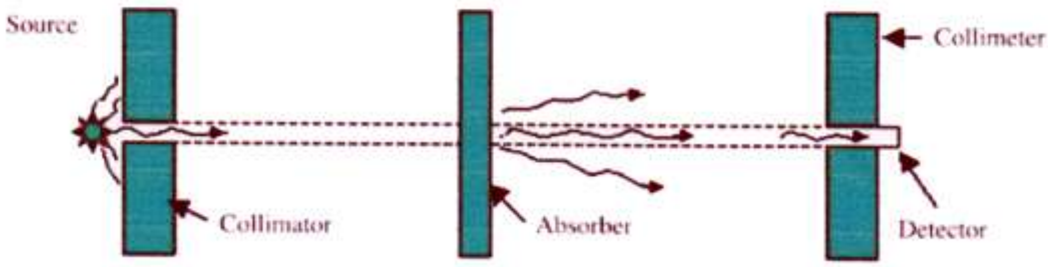

Figure 1 Measurement of the attenuation of gamma radiation under conditions of good (collimated) geometry.

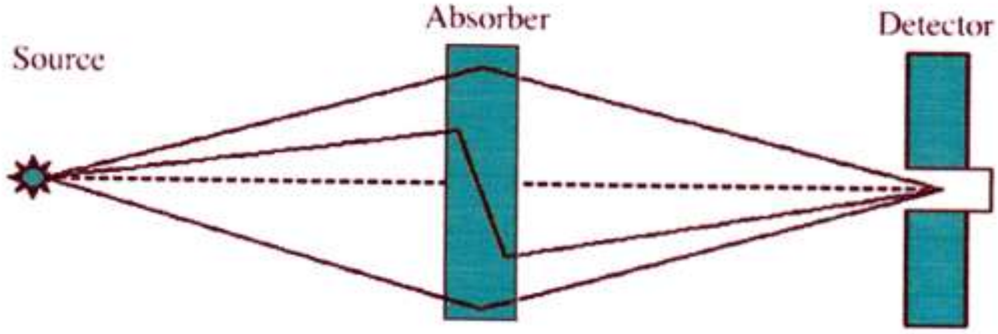

Figure 2 Gamma radiation attenuation under conditions of bad (broad beam) geometry showing the effect of photons scattered into the detector

Source for Gamma Rays

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

Equipment

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

(1) Thallium Activated Sodium Iodide detector (Model 802-5)

(2) High Voltage Power Supply (Model 3002)

(3) ST-360 Radiation Counter with Windows (Model ST- 360)

Sample Collection, Sample Preparation and Elemental Analysis

Iron powder was collected from Myanmar Supply Co., Ltd in Yangon Division. The brand of cement that used in this research was Double Rhinos cement.

Cement powder was poured into the mold and pressed with hydraulic press, weighting 5 tons into pellets. Each pellet has a thickness of 0.5 cm and 2.5 cm diameter. The above procedure was repeated for the mixture of iron (25-75%) in cement powder. These four types of sample preparation were performed at University Research Centre (URC) in University of Yangon.

The elemental analysis was done on cement powder and iron powder by using EDXRF method. The chemical compositions for iron powder and cement were shown in Table (1) and Table (2). The elemental analysis of these samples by EDXRF method was performed at Department of Chemistry in Monywa University.

Table 1 Chemical Composition for Iron

Mineral	Fe_2O_3	CaO
Percent	99.872	0.128

Table 2 Chemical Composition for Cement

Mineral	CaO	SiO_2	Fe_2O_3	SO_3	K_2O	TiO_2	MnO	SrO	CuO	ZrO_2	V_2O_5	ZrO	NiO
Percent	78.277	12.188	5.133	2.758	1.183	0.313	0.076	0.067	0.024	0.018	0.018	0.014	0.002

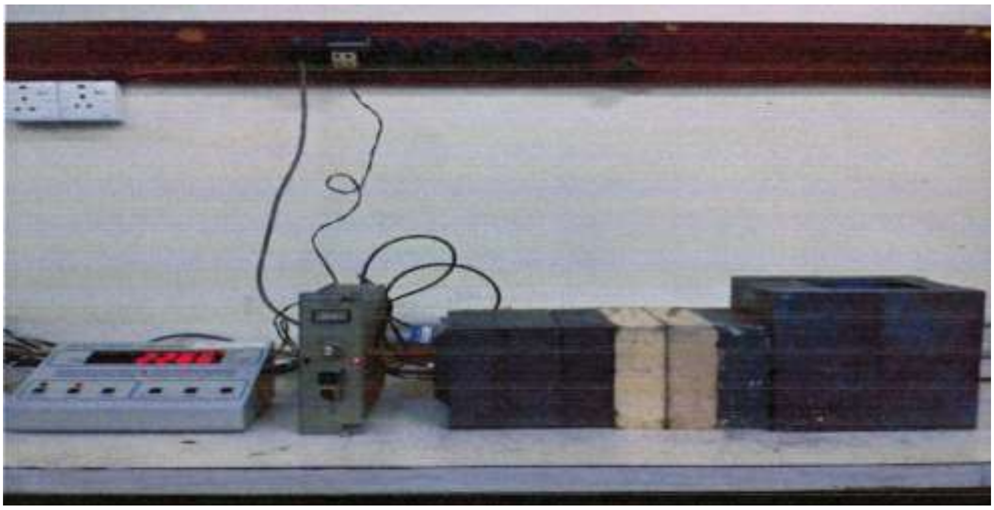

Figure 3 The operating system of NaI (TI) detector and ST-360 radiation counter with high voltage power supply in the form of narrow beam (good geometry)

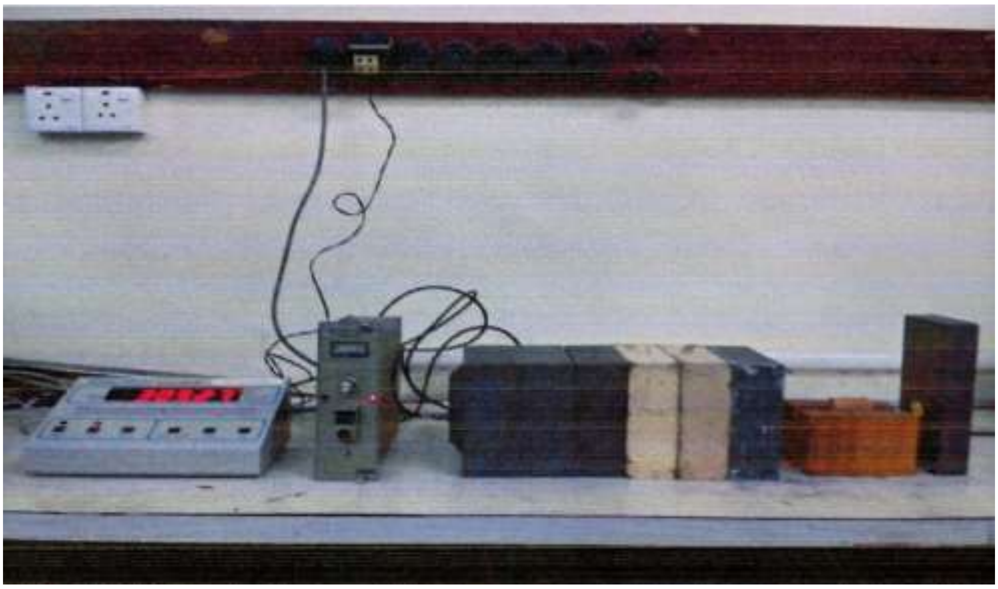

Figure 4 The operating system of NaI (TI) detector and ST-360 radiation counter with high voltage power supply in the form of broad beam (bad geometry)

Experimental Setup and Procedure

The materials which used as absorbers are cement and composite slabs. These pellets of cement as composite materials were placed midway position between the source and detector. The detector was placed horizontally and the distance between the source and detector was 20cm. The Cs-137 source was fixed in the lead shield.

The sample was positioned on the wood stand for broad beam (bad geometry) as shown in Figure (4). The sample was positioned between two collimators beside source collimator and detector collimator for narrow beam (good geometry). Two lead blocks with 5mm diameter holes were used as collimators as shown in Figure (3).

The two collimators were aligned by passing through a steel rod. Then the alignment is checked by laser beam. The alignment shown the above Figure (3) was estimated to be accurate to within ±0.5 mm.

First the gamma intensity I_{bad} (in the absence of the shield sample, without collimator) and I_{good} (in the absence of the shield sample, with collimator) were measured by the detector. Then, the sample position was placed at the centre of the source and detector for both bad (uncollimated) and good (collimated) geometry. The detector was located forward direction of the gamma beam. Measurements were made with different thickness for both bad (uncollimated) and good (collimated) geometry. Then, the sample was fixed 10cm from the detector and measured using above procedures were repeated, shown in Figures (3) and (4).

The transmitted gamma counts collections were done for 60s. Detector working voltage is 900 V (positive bias). For each thickness, the gamma intensity reaching the detector was measured and the results obtained were recorded.

Results

From the experiment, the intensity without absorber and with absorbers in broad beam and narrow beam geometry of different thickness for 25% concentration of iron powder in cement composite samples are recorded in Table (3). And then, the above procedure also done for 50% concentration of iron powder in cement composite samples, 75% concentration of iron powder in cement composite samples and 0% concentration of iron in cement samples, and are also recorded in Table (4), (5) and (6).

The buildup factor and the logarithm of the absorbance ratio (ln R_A) for 25% concentration of iron in cement composite samples are calculated by using equation (1), (2) and (3). After that, the results are recorded in Table (3). The buildup factor and the logarithm of the absorbance ratio for 50% concentration of iron in cement composite samples, 75% concentration of iron in cement composite samples and 0% concentration of iron in cement samples are also calculated by using equation (1), (2) and (3) and also recorded in Table (4), (5) and (6).

It is found that, as the composite sample thickness increases the buildup factor will be increase accordingly with increasing the iron concentration in cement. Figure (5), (6), (7) and (8) show the logarithm of absorbance ratio versus the different thickness of 25% concentration of iron, 50% concentration of iron, 75% concentration of iron in cement composite samples and 0% concentration of iron in cement samples.

From the linear graph in each figure, the linear attenuation coefficients are obtained 0.15 cm^{-1} for 25% concentration of iron, 0.19 cm^{-1} for 50% concentration of iron, 0.24 cm^{-1} for 75% concentration of iron in cement composite samples and 0.11 cm^{-1} for 0% concentration of iron in cement samples. The relation between linear attenuation coefficient (μ) and the different iron concentration in cement as shown in Figure (9).

It is cleared that, the highest concentration of iron in cement composite sample has the greatest attenuation coefficient for gamma ray while the lowest concentration of iron in cement sample having the smallest. From Table (1) and Table (2), iron powder consist mainly ironer and cement consist second more silica. The ionic silica bonds absorbed gamma ray energy more than other bonds.

Therefore, a composite sample of highest iron concentration would have highest attenuation coefficient, this implies a best absorber of gamma radiation in this research work. 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 of

statistical deviation (S.D) and fractional statistical deviation (F.S.D) for different thickness of each samples are calculated by using equation (5) and (6). The calculated values are recorded in Table (3), (4), (5) and (6).

Discussion

Gamma ray which is used widely in medical care, electricity generation and industry, it's the most penetrating of ionizing radiation that is known to be harmful to human health. Although, high density materials like lead are used to protect life from gamma hazardous radiation, it is toxic and heavy. Therefore, materials which are nontoxic and lighter shield should be used with personal. From the results, it is cleared that the minimum attenuation of gamma ray is with the cement sample which has 0% concentration of iron, while the attenuation amount of the composite sample is higher because it contains increasing concentration of iron. The composite sample which contains 50% concentration of iron powder increase more of gamma-ray attenuation where it was found by compared with other 25% concentration of iron powder in cement composite samples. Finally, a greater attenuation was noticed as the composite sample was loaded with 75% concentration in cement. From the research, it is found that the linear attenuation of the composites was found to increase with increased concentration content in the composite and the highest value was for most concentration of elemental in cement.

Table 3 Absorbance ratio (R_A), buildup factor (B), standard of statistical deviation (S.D) and fractional statistical deviation (F.S.D) values for 25% concentration of iron powder in cement

Sr. No.	Thickness of the shield (cm)	I_b	I_g	ln R_A	buildup factor (B)	S. D ±	FSD %
1	0	65257	6441	0	1	0.0131	1.3061
2	0.5	46713	6050	0.0626	1.0121	0.0134	1.3439
3	1.0	43457	5700	0.1222	1.0136	0.0139	1.3812
4	1.5	40158	5400	0.1763	1.0198	0.0144	1.4160
5	2.0	37567	5050	0.2433	1.0245	0.0149	1.4606
6	2.5	34894	5000	0.2532	1.0280	0.0151	1.4674
7	3.0	33659	4500	0.3586	1.0319	0.0159	1.5413
8	3.5	31248	4250	0.4158	1.0386	0.0164	1.5831
9	4.0	30670	4000	0.4764	1.0415	0.0169	1.6289

Table 4 Absorbance ratio (R_A), buildup factor (B), standard of statistical deviation (S.D) and fractional statistical deviation (F.S.D) values for 50% concentration of iron powder in cement

Sr No.	thickness of the shield (cm)	I_b	I_g	ln R_A	buildup factor (B)	S. D ±	FSD %
1	0	65257	6441	0	1	0.0131	1.3061
2	0.5	46213	6000	0.0709	1.0219	0.0138	1.3490
3	1.0	42957	5650	0.1310	1.0286	0.0143	1.3868
4	1.5	39658	5240	0.2064	1.0314	0.0148	1.4358
5	2.0	37067	4950	0.2633	1.0349	0.0153	1.4743
6	2.5	34394	4650	0.3258	1.0391	0.0158	1.5178
7	3.0	33159	4300	0.4041	1.0419	0.0164	1.5744
8	3.5	30748	4050	0.4639	1.0461	0.0169	1.6194
9	4.0	30170	3800	0.5277	1.0498	0.0175	1.6688

Table 5 Absorbance ratio (R_A), buildup factor (B), standard of statistical deviation (S.D) and fractional statistical deviation (F.S.D) values for 75% concentration of iron powder in cement

Sr. No.	thickness of the shield (cm)	I_b	I_g	ln R_A	buildup factor (B)	S. D ±	FSD %
1	0	65257	6441	0	1	0.0131	1.3061
2	0.5	45713	5950	0.0793	1.0311	0.0139	1.3542
3	1.0	42457	5550	0.1489	1.0347	0.0145	1.3982
4	1.5	39158	5100	0.2334	1.0386	0.0151	1.4539
5	2.0	36567	4600	0.3366	1.0398	0.0159	1.5255
6	2.5	33894	4450	0.3698	1.0410	0.0161	1.5493
7	3.0	32659	4100	0.4517	1.0438	0.0168	1.6101
8	3.5	30248	2830	0.5198	1.0468	0.0174	16626
9	4.0	29670	3500	0.6099	1.0511	0.0182	1.7350

Table 6 Absorbance ratio (R_A), buildup factor (B), standard of statistical deviation (S.D) and fractional statistical deviation (F.S.D) values for 0% concentration of iron in cement samples

Sr. No.	thickness of the shield (cm)	I_b	I_g	ln R_A	buildup factor (B)	S. D ±	FSD %
1	0	65257	6441	0	1	0.0131	1.3061
2	0.5	47889	6020	0.0676	1.2078	0.0172	1.3469
3	1.0	44881	5600	0.1399	1.2191	0.0176	1.3925
4	1.5	42165	5200	0.2140	1.2293	0.0180	1.4409
5	2.0	39542	4850	0.2837	1.2371	0.0185	1.4883
6	2.5	36710	4550	0.3476	1.2454	0.0193	1.5333
7	3.0	34576	4250	0.4158	1.2558	0.0197	1.5831
8	3.5	32564	3950	0.4889	1.2631	0.0201	1.6386
9	4.0	30617	3650	0.5679	1.2661	0.0205	1.7009

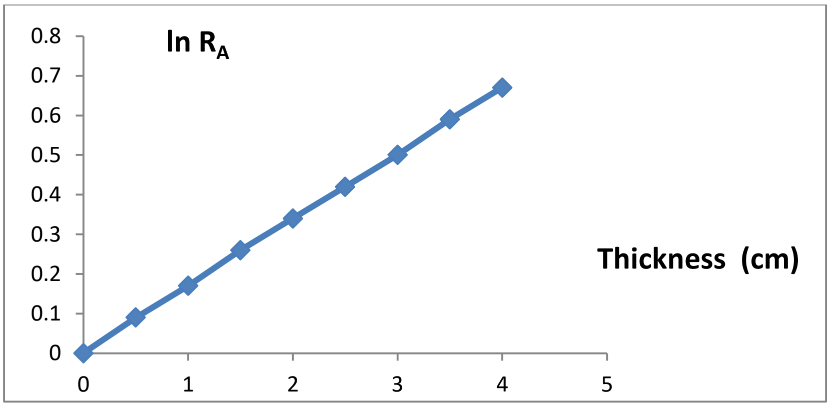

Figure 5 Logarithm of the absorbance ratio (intensity) versus different thickness of 25% concentration of iron in cement composite samples for good (collimated) geometry

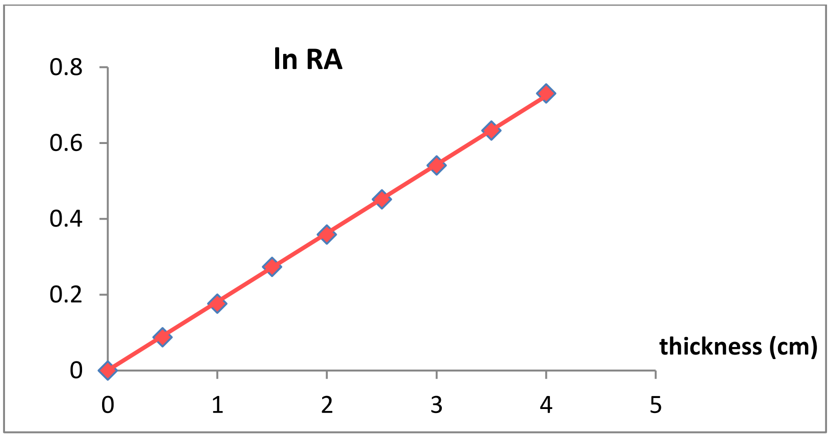

Figure 6 Logarithm of the absorbance ratio (intensity) versus different thickness of 50% concentration of iron in cement composite samples for good (collimated) geometry

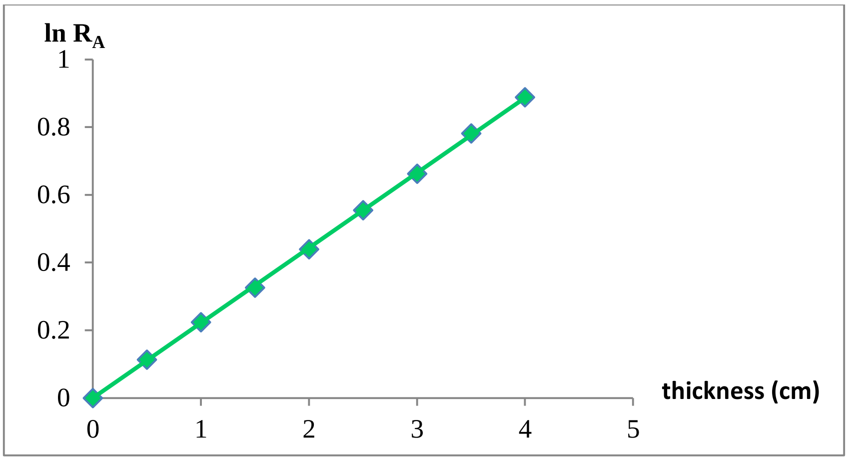

Figure 7 Logarithm of the absorbance ratio (intensity) versus different thickness of 75% concentration of iron in cement composite samples for good (collimated) geometry

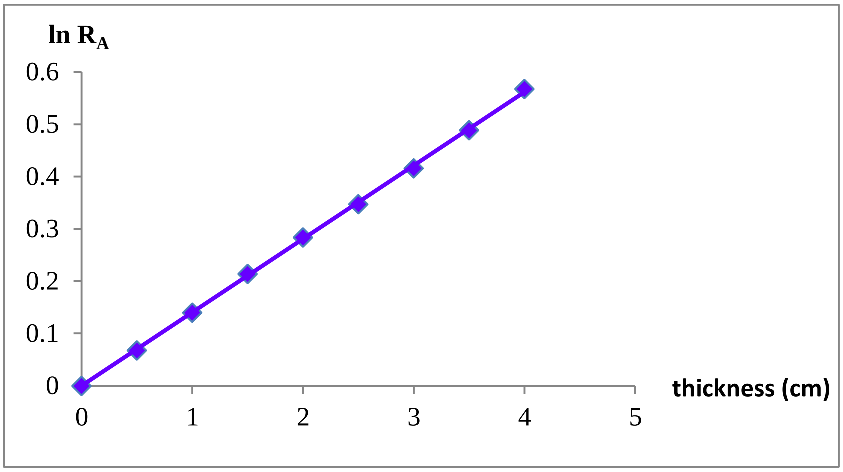

Figure 8 Logarithm of the absorbance ratio (intensity) versus different thickness of 0% concentration of iron in cement composite samples for good (collimated) geometry

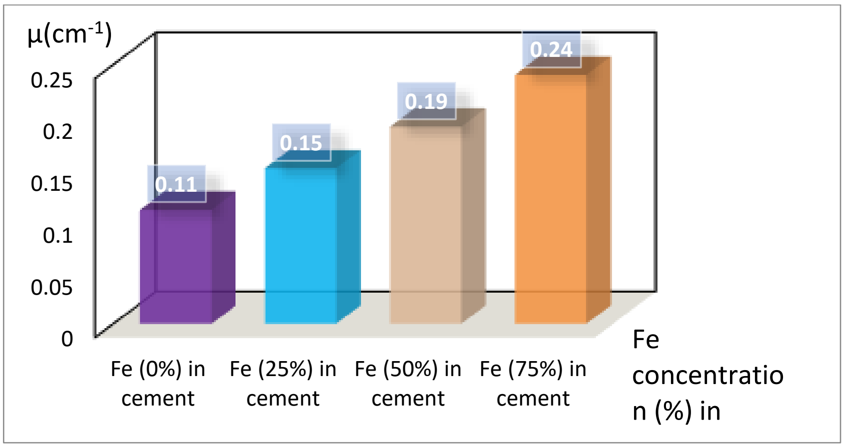

Figure 9 Relation between linear attenuation coefficient (μ) and iron powder concentration in cement

Conclusion

Materials which are environment friendly and nontoxic can be used with both personal and material lighter shield. So, composite material filled with elemental powder is now becoming more and more popular. The linear attenuation coefficient has been measured and calculated for composite samples for its use in radiation shielding, protection, and cancer treatment. The gamma rays photon beam (Cs-137 source) was used in the experimental work. It is found that the linear attenuation coefficient increases with increasing concentration of composite sample. So, composite material filled with highest concentration of iron elemental powder should be used as gamma shield.

Acknowledgement

The author would like to express my gratitude to Ministry of Education, the department of Higher education in Myanmar, University of Yangon, and Universities' Research Centre (URC) for all necessary facilities.

References

Chilton AB, JK Shultis and RE Faw: Principles of Radiation Shielding, Prentice-Hall Inc N Jersey, 1984.

Cember H., (1990) Introduction to Health Physics. New York: Pergamon Press.

Knoll G. F, Radiation Detection and Measurement.3rd Edition. New York: John Wiley & Sons, 2000. P-48-55.

Turner J.E., (2007) "Atoms, Radiation and Radiation Protection", Wiley-VCH Verlag GmbH & Co.KGaA.