STUDY OF THE DEPENDENCE OF GAMMA-ABSORPTION COEFFICIENT ON THE ORDER OF THE DOUBLE LAYER SHIELD

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Abstract

Gamma absorption coefficient dependence on the order of the shielding material is measured using a proper electronic system and Cs-137 source. The measurements were carried out for iron, steel, copper, brass, lead and concrete as shielding materials.

The dependence of gamma absorption coefficient on the atomic number and density of the absorber material is taken into account. The experimental and theoretical calculations are in a good agreement.

It is found that the absorption coefficient value increases with increasing the absorber thickness of high atomic number (or density) and decreases with increasing the absorber thickness of low atomic number (or density), and slightly changes with increasing the thickness of any absorber when the difference between their atomic number (or density) is small, whereas it is affected by the order of the two-layer absorber if the difference between their atomic number is high.

دراسة اعتماد معامل امتصاص أشعة كاما على ترتيب طبقتي التدريع

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الخلاصة

أستخدمت منظومة الكترونية مناسبة ومصدر سيزيوم-١٣٧ لقياس اعتماد معامل امتصاص أشعة كاما على ترتيب طبقتي مادة التدريع.

أجريت القياسات على مجموعة من مواد التدريع، الحديد، الفولاذ، النحاس، النحاس الأصفر، الرصـاص، والكونكريت آخذين بنظر الاعتبار اعتماد معامل الامتصاص على العدد الذري (أو كثافة) مادة التدريع.

لقد وجد تطابق تام بين القياسات العملية والحسابات النظرية لمعامل الامتصاص حيث وجد أن هذا المعامل يزداد بازدياد سمك المادة ذات العدد الذري (أو الكثافة) الواطئ، ويتغير تغيرا طفيفا عندما يكون الفرق بين العدد الذري (أو الكثافة) لمادتي التدريع قليلا. بينما يتأثر كثيرا بترتيب طبقتي التدريع عندما يكون الفـرق بين عدديهما الذري (أو كثافتيهما) عاليا.

Introduction

Gamma ray is an electromagnetic radiation of nuclear origin, travels with the velocity of light in vacuum. It interacts with matter by several ways, but only three processes must be taken into account. They are: the photo-electric, Compton scattering and pair production [1,2,3].

The basic property of gamma-rays passing through a matter is an exponential decrease in the intensity of radiation in a homogenous beam of gamma-rays [4].

The absorption mechanism of gamma-rays by matter is different from that of charges particles, as indicated by the very much greater

penetration power of gamma-rays [4].

When a beam of gamma-rays of intensity I is incident on a slab of thickness Δx, the change in intensity of the beam as it passes through the slab is proportional to the thickness and to the incident intensity, that is [4] :

$$\Delta I = -\mu\ I\ \Delta x \quad \text{.....(1)}$$

Where the proportionality constant μ is called the absorption coefficient, which is equal to the sum of photoelectric, Compton scattering and pair production absorption coefficients.

If all the photons of gamma-rays have the same energy, μ is independent of x, and the integration of equ. (1) yields [1,4]:

$$I = I_o \exp(-\mu x) \quad \text{.....(2)}$$

or

$$\ln\left(\frac{I_o}{I}\right) = -\mu x \quad \text{.....(3)}$$

When a graph between $\ln\left(\frac{I_o}{I}\right)$ and the thickness (x) of the absorber is plotted, the slope for the best fit represents the absorption coefficient (μ) of the absorber.

For a mixture of elements, μ is given by the following formula [2]:

$$\mu = \mu_1 + \mu_2 + \mu_3 + ... + \mu_n \quad \text{.....(4)}$$

for multi-layer absorber equation 2 becomes:

$$I = I_o \exp(-\sum_{i=1}^{n} \mu_i\ x_i) \quad \text{.....(5)}$$

where i represents the i^{th} absorber.

Multiplying and dividing the exponential term of equ.(5) by X (the total thickness of the absorbers) then it becomes:

$$I = I_o \exp\left(-X \sum_{i=1}^{n} \mu_i \left(\frac{x_i}{X}\right)\right) \quad \text{.....(6)}$$

Let $\frac{x_i}{X}$ be equal α_i, the fractional thickness of each absorber , then equ.(6) yields to :

$$I = I_o \exp\left(-X \sum_{i=1}^{n} \mu_i \alpha_i\right) \quad \text{.....(7)}$$

for two-layer absorber:

$$\mu = \alpha_1 \mu_1 + \alpha_2 \mu_2 . \quad \text{.....(8)}$$

The main purposes of the shield are to protect operating persons from possible injury by nuclear radiation, and in some cases to-reduce radiation exposure. Since the radiation entering the shield from the reactor can produce internal heating and causes possible radiation damage to shield materials, therefore it is necessary to estimate the types and intensities of radiation through the shield [2,5].

Many authors [6-20] studied gamma-rays absorption coefficient, the attenuation of neutron from a point source, the design method of compensation shield and the reactor shielding materials.

The aim of the present study is to investigate the dependence of gamma-absorption coefficient on the order of the double layer absorber material, in order to reduce the shielding thickness and its cost.

Materials and Method

The measurement system consists of NaI(Tl) detector (7.62 cm x 7.62 cm) (BIKRON), a photomultiplier and preamplifier (ORTEC 276) , amplifier (ORTEC 485), bias supply (ORTEC 478) and multi-channel analyzer (Normal 5300). The radioactive source is Cs-137 (Amersham-England) with an activity of 8 mCi at the experimental time.

Six shielding materials are used in the present study these are: lead, brass, copper, steel, iron and concrete.

The first five shielding materials have cylindrical forms with different thickness, whereas the concrete has a block shape with dimensions of (10 cm x 10 cm x 3 cm).

Ordinary concrete was made of cement, sand, and stones, whereas other types were prepared by adding fractional weight of iron, brass, or lead to ordinary concrete as shown in Table (1).

The electronic system was arranged, using suitable operating voltage and gain. The distance between the source and the detector was adjusted to be 60 cm. The accumulation time for gamma spectra was 1 hour. Measurements were carried out for each two-layer absorber materials, and the absorption coefficient was calculated and tabulated.

Results and Discussion

Gamma absorption coefficients for two-layer absorbers were measured experimentally and calculated theoretically, using equation (8). The results are plotted as a function of fractional thickness (α_i) as in Figures (1-7).

Comparison between experimental and theoretical results gave a good agreement. The

variation of the measured and calculated absorption coefficient with respect to the variation of the fractional thickness α_1 and α_2, and the variations per unit α_2 are summarized in Table (2). Although the thickness of the first layer was fixed and to be constant, but the value of α_1 decreases as a result of increasing α_2 values. The results show that the absorption coefficient increases with increasing α_2 for the layer of the high atomic number (or density) absorber, and-decreases with increasing α_2 for the layer of the low atomic number (or density) absorber.

This is due to increase of the average linear density of the two-layer absorbers in the first case and to decrease of the average linear density in the second case and the absorption coefficient is proportional to the atomic numbers of the absorber. This increase in the absorption coefficient is noticed in the case of Brass + Pb, Concrete 5+ Steel, Concrete 3+Cu and Concrete 4+ Fe and Concrete 2 + brass for two-layer absorbers, whereas the decrease is noticed when the order of the above layers is altered and shown that the absorption coefficient slightly changed if the fractional thickness of either layer absorber is increased, their average linear density slightly changed as in case of Fe + Brass and Brass + Fe .

The results indicate that the order of the layer does not affect the absorption coefficient when the difference between their atomic number is small, such as in case of Concrete 2 and Brass. The same result is noticed in case of Fe+Pb and Pb+Fe layers, where the order of the low atomic number (Fe) does not affect the absorption coefficient when it is added to the layer of high atomic number Pb of fixed thickness.

Table 1 : The fractional weights of concrete types

Type of Concrete	Fractional Weight of Component Material						Density (gm/cm^3)
	Cement	Sand	Stones	Iron	Brass	Lead	
Concrete 1	1	2	4				2.38
Concrete 2	1	2	3	1			2.35
Concrete 3	1	2	4	1			2.39
Concrete 4	1	2	4		1		2.44
Concrete 5	1	2	4			1	2.46

Table 2 : Results of variation of μ with variation of α for the two-layer absorbers.

Absorber layer	$\Delta\alpha_2$	$\Delta\mu m$	$\Delta\mu c$	$\Delta\mu m/\Delta\alpha_2$	$\Delta\mu c/\Delta\alpha_2$	$\Delta\alpha_1$%	$\Delta\alpha_2$%	$\Delta\mu m$ %	$\Delta\mu c$ %
Fe*+ Brass	0.557	0.044	0.030	0.079	0.054	-70.6	264	7.97	5.38
Brass* +Fe	0.563	-0.028	0.029	-0.052	0.052	-71.9	259.5	-4.8	-4.9
Pb*+Brass	0.530	-0.336	0.303	-0.634	-0.572	-63.8	313.6	-31.3	-28.2
Brass*+Pb	0.236	0.205	0.185	0.869	0.784	-41.5	54.8	26.2	23.2
Stee1*+Concrete 5	0.318	-0.120	-0.121	-0.377	-0.381	-68.2	59.6	-33.2	-33.5
Concrete 5* + Steel	0.389	0.150	0.148	0.386	0.380	-58.3	116.8	48.4	47.4
Concrete 3*+Cu	0.543	0.261	0.255	-0.435	-0.424	-71.9	221.6	94.9	90.11
Cuv--Concrete 3	0.557	-0.144	-0.152	0.481	0.470	-65.8	63.5	-36.9	-38.1
Fe*+Concrete 4	0.323	-0.107	-0.108	-0.366	-0.366	-70.24	50.9	-32.4	-32.4
Concrete 4*+ Fe	0.295	0.197	0.192	0.379	0.369	-59.3	422.8	90.8	85.7
Concrete 2*+Brass	0.520	0.235	0.234	0.431	0.429	-65.2	332.3	97.9	97.1
Brass*+Concrete 2	0.545	0.237	0.234	-0.435	-0.429	332.3	-65.2	99.6	97.1
Fe+Pb*	0.545	-0.306	-0.317	0.605	0.626	392.3	-58.1	-28.4	-29.03
Pb*+Fe	0.506	-0.310	-0.137	0.605	0.626	-58.1	392.3	-28.9	-29.03

*** : The layer thickness is constant**
Δ : Final value – initial value
m : measured
c : calculated

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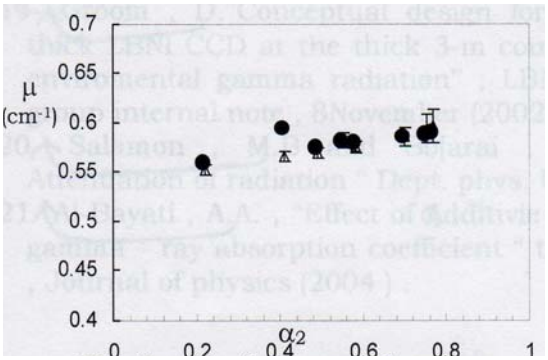

Figure ١-a: μ for Iron + brass as a function of α_2.

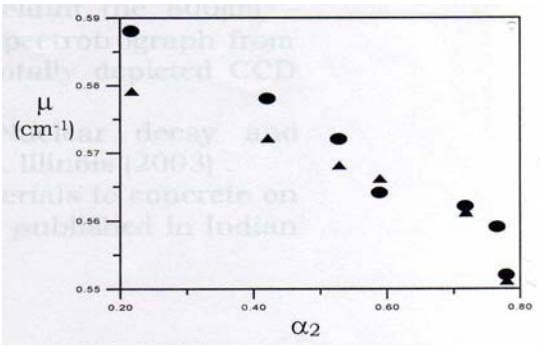

Figure ١-b: μ for brass + Iron as a function of α_2

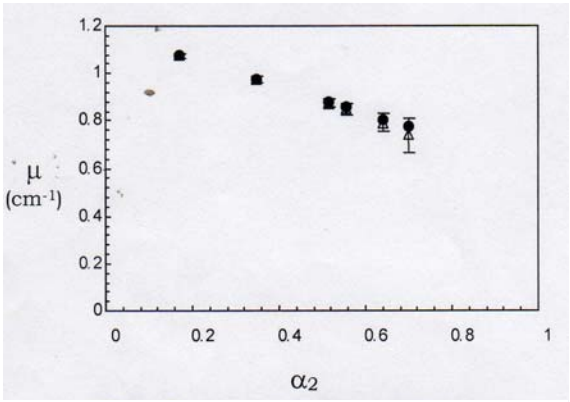

Figure ٢-a: μ for Pb + brass as a function of α_2

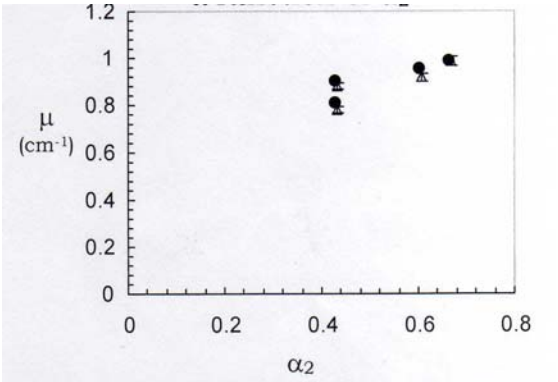

Figure ٢-b: μ for brass + Pb as a function of α_2

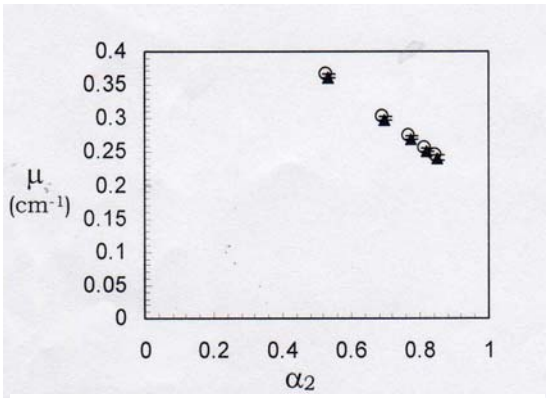

Figure ٣-a: μ for steel + concrete 5 as a function of α_2

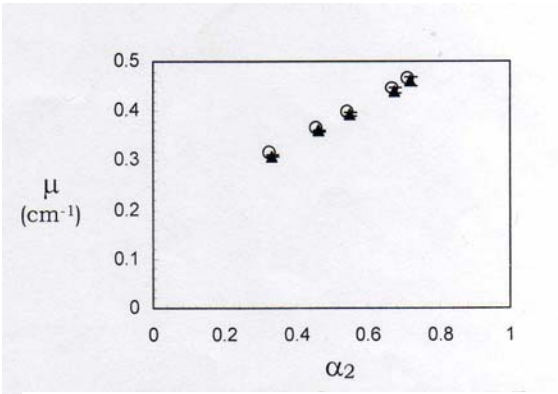

Figure ٣-a: μ for concrete 5+ steel as a function of α_2

Δ : represents μ mesurments.
O : reperesents μ calculated.

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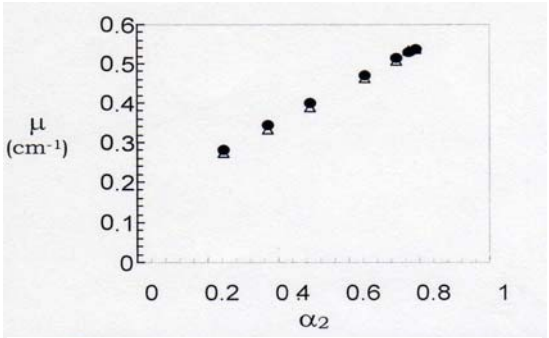

Figure ٤-a: μ for steel concrete 3+ Cu as a function of α_2

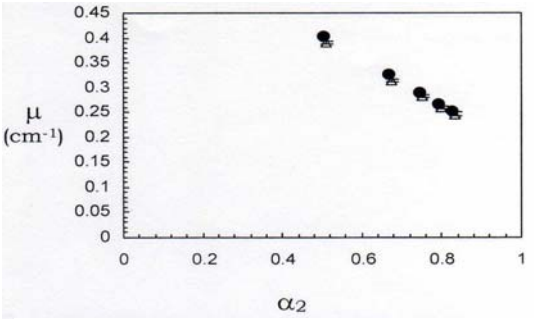

Figure ٤-b: μ for Cu + concrete 3 Cu as a function of α_2

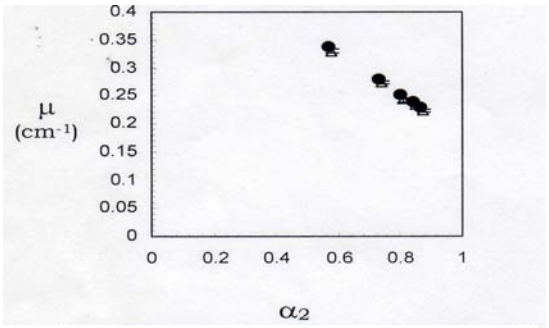

Figure ٥-a: μ for Fe+ concrete 4 as a function of α_2

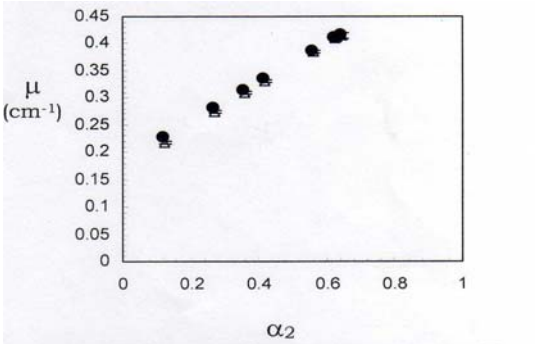

Figure ٥-b: μ for concrete 4+ Feas a function of α_2

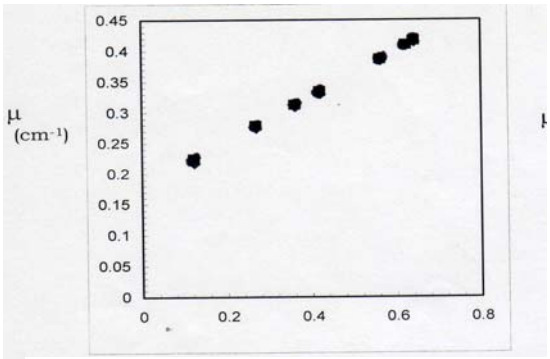

Figure ٦-a: μ for concrete 2+ brass as a function of α_2

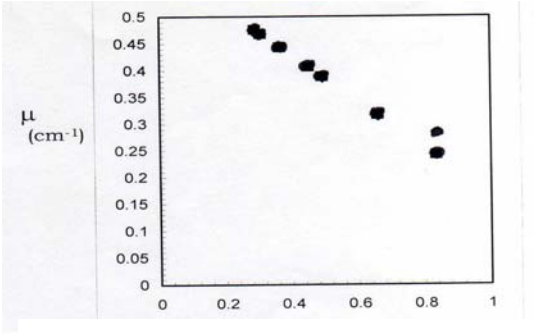

Figure ٦-b: μ for brass+ concrete 2 as a function of α_2

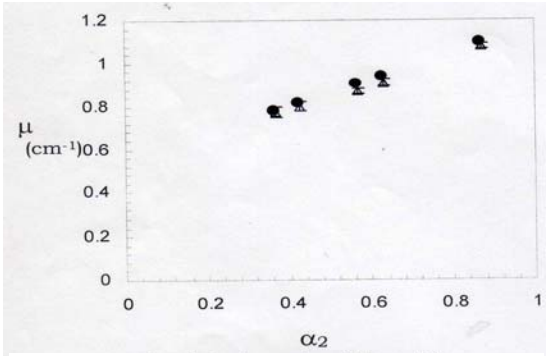

Figure ٧-a: μ for Fe+ Pb as a function of α_2

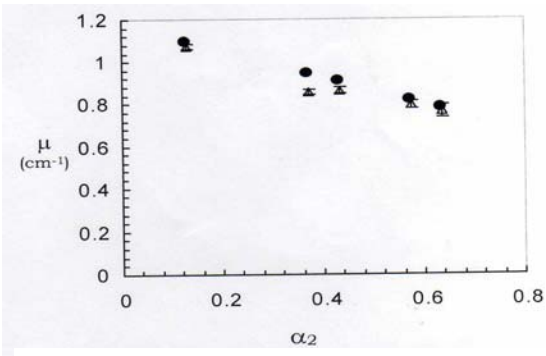

Figure ٧-b: μ for Pb + Fe as a function of α_2

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