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Mass Attenuation of Gamma Photons in Special Lead Glass that Can be Used in Radiation Shielding Windows

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ABSTRACT

Three samples of special lead glass are suggested for radiation protection and radiation shielding. Each one of these samles consist of seven oxides (Lead Oxide, Silicon Oxide, Barium Oxide, Sodium Oxide, Calcium Oxide, Aluminum Oxide and Cerium Oxide) with different weight ratio for each sample.

The mass attenuation coefficient for these samples was theoretically calculated according to Bragg additivity rule for two energies of gamma rays (0.66 and 1.25MeV). The sample which gave higher attenuation coefficient was experimentally manufactured and its mass attenuation coefficient was experimentally measured using (^{137}Cs and ^{60}Co) and G. M. counter. The results obtained was compared with the mass attenuation coefficient of standard lead glass.

التوهين الكتلي لفوتونات كاما في الزجاج الرصاصي الخاص الذي قد يستخدم في نوافذ التدريع الأشعاعي

الملخص

لقد تم اقتراح ثلاث نماذج من الزجاج الرصاصي الخاص لإمكانية استخدامها في نوافذ التدريع الإشعاعي وللحماية من الإشعاع وهذه النماذج الثلاثة تتكون من سبعة أكاسيد لاعتبارها من مشكلات الزجاج الرئيسية وهي (أوكسيد الرصاص، اوكسيد السليكون، اوكسيد الباريوم، اوكسيد الصوديوم، اوكسيد الكالسيوم، اوكسيد الألمنيوم واوكسيد السيريوم) بنسب وزنية مختلفة لكل نموذج.

تم حساب معامل التوهين ألكتلي نظريا باستخدام قانون براك للنماذج الثلاثة المقترحة ولطاقتين من فوتونات أشعة كاما (0.66 and 1.25 MeV), والنموذج الذي أعطى معامل توهين عالي تم تصنيعه وقياس معامل توهينه ألكتلي عمليا باستخدام مصدرين مشعين (^{137}Cs and ^{60}Co) وباستخدام عداد كايكر ميلر. تم مقارنة النتائج المستحصلة مع قيم معامل التوهين ألكتلي للزجاج الرصاصي القياسي.

INTRODUCTION

The lead glass is widely used in radiation protection and shielding against x and γ -rays used in diagnostic radiology and radiotherapy, because of its high absorption coefficient and its high transparence to light. The mass attenuation coefficient varies strongly with the energy of the incident photon (E) and the atomic number (Z) of the shield material. An approximately expression illustrating these dependence give for the photoelectric cross section (´ل Z^m E^{-n}) for γ- ray energies of few hundreda lead glass window (Galy et al, 2004).

Friedman and singh (2003), have performed detailed measurements to sort out the shielding properties of Demron Fabric in the x and γ-rays and β- particles emissions. The results showed that Demron Fabric is affective as radiation shield comparable to lead in terms of g/cm^2 and Tantalum according to the mass attenuation coefficient.

Yousif (2003), has suggested especial kind of lead glass consists of standard elements with small amount of cerium oxide.

The attenuation of x and γ-ray is exponential and many half thicknesses are required to safe shield for a strong sources (Lilly, 2001).

In this study three sample of lead glass have been listed with different weight ratio of cerium oxide.

THEORETICAL CALCULATIONS

We suggest three samples of special lead glass, taken from Yousif (2003), after modif- ying the oxide compounds appeared in each sample. Also calcium oxide has been introduced in each sample with different percent as shown in Table (1).

Table 1 : Shows three samples of special lead glass.

Oxide type (ox.)	**Weight ratio of sample (1)**	**Weight ratio of sample (2)**	**Weight ratio of sample (3)**
Silicon Oxide	58 %	60%	60%
Lead Oxide	28%	22%	20%
Calcium Oxide	9%	11%	13%
Barium Oxide	1%	4%	3.5%
Sodium Oxide	2.5%	1.2%	1.8%
Aluminum Oxide	0.5%	0.3%	0.2%
Cerium Oxide	1%	1.5%	1.5%

The mass attenuation coefficient (μ/ρ) of each particular element in the oxide at 0.66 and 1.25 MeV, were extracted mostly from (μ/ρ) curves published by Hubbell (1982) and for some elements Attix (1984), was used, and listed in Table (2). For each element in the samples, the (μ/ρ) for 0.4, 0.6, 0.8, 1.0, 1.5 and 2 MeV were drawn against energy, then (μ/ρ) for 0.66 and 1.25 MeV were read from the curve.

The (μ/ρ) of each oxide in the sample has been calculated using Bragg additivity rule as shown in equation (1).

$$(\mu/\rho)_{oxi} = \Sigma\, (\mu/\rho)_i W_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

Where W_i = (no. of atoms type i × atomic weight) / Mol. Weight

The $(\mu/\rho)$of each sample was calculated by using equation (2)(Braqq additivity rule).

$$(\mu/\rho)_{samp.} = (\mu/\rho)_{ox1}.\, f_{ox1}. + (\mu/\rho)_{ox1}.f_{ox2.} + \text{---------}(\mu/\rho)_{oxn} .\, f_{oxn} \text{ ----------------- } (2).$$

Where $f_{ox1.}$ and $f_{oxn.}$ The weight ratio of oxide (1) to oxide (n) and $(\mu/\rho)_{ox1}$, $(\mu/\rho)_{ox2}$, are the mass attenuation coefficient of each oxide. For the purpose of calculation we used the average value of 1.25 MeV for the energy of γ-ray emitted from ^{60}Co source (Friedman and Singh, 2003, Johns et al, 1978).

EXPERIMENTAL METHODS AND CALCULATIONS

Sample (1) in table (1), was manufactured and the (μ/ρ) was measured experimentally because this sample gave higher attenuation coefficient as shown in table (3).

The seven oxides were mixed according to their weight ratios and sited in the thermal oven for melting at temperature (1250 - 1300 ^{o}C) and then exposed to oxygen flame for further melting , and gradually cooled to get special lead glass. The (μ/ρ) was measured for 0.66 and 1.25 MeV using the sources ^{137}Cs and ^{60}Co respectively and by using the G.M. Counter as shown in Figure (1).

Figure 1 : Experimental set-up (Mahesh and Mustafa, 1976).

The initial intensity (I_o) was measured, than the transmitted intensity (I) of γ-ray was also measured for the thicknesses (0.875, 1.805, 2.626, 3.994, 5.581 and 6.675 g/cm^2). The background count was subtracted from both I_o and I. The result are shown in Fig. (2) and Fig. (3), for two energies used. The following equation was used in the calculation.

$$\ln I - \ln I_o = -(\mu/\rho)\,(\rho x) \text{...} (3)$$

Where (ρx) represents the areal density in (g/cm^2).

The mass attenuation coefficient of standard lead glass at two used energies was calculated, as explained before, from (μ/ρ) curve published by Hubbell (1982).

The density of special lead glass is 2.73 g/cm^3 and was calculated by weighing the sample and measuring the volume and for the standard lead glass was 6.22 g/cm^3

(Hubbell, 1982). The difference between the two densities are due to the difference in the percentage of lead in the two shields.

Eventually the half thickness which reduce the intensity of the initial beam of γ -ray to one half of special lead glass and standard lead glass were calculated.

RESULTS AND DISCUSSIONS

The values of mass attenuation coefficient of each oxide in the samples are tabulated in Table (2).

Table 2 : The calculated values of (μ/ρ) for all oxides.

E (MeV)	(μ/ρ) x10^{-2} cm^2 /g						
	Silicon Oxide	**Lead Oxide**	**Calcium Oxide**	**Barium Oxide**	**Sodium Oxide**	**Alum. Oxide**	**Cerium Oxide**
0.66	7.71	10.63	7.76	7.76	7.49	7.58	8.00
1.25	5.68	5.93	5.70	5.12	5.85	5.88	5.33

The theoretical value of mass attenuation coefficient of each sample has been calculated calculated by using Bragg additivity rule and shown in Table (3).

Table 3 : The calculated values of (ى/ٌ) for each sample.

E(MeV)	(ى/ٌ) x 10^{-2} cm^2/g		
	Sample (1)	**Sample(2)**	**Sample(3)**
0.66	8.53	8.34	8.22
1.25	5.74	5.70	5.65

The experimental results plotted in Fig.(2) and Fig.(3), for the energies (0.66 and 1.25 MeV) respectively.

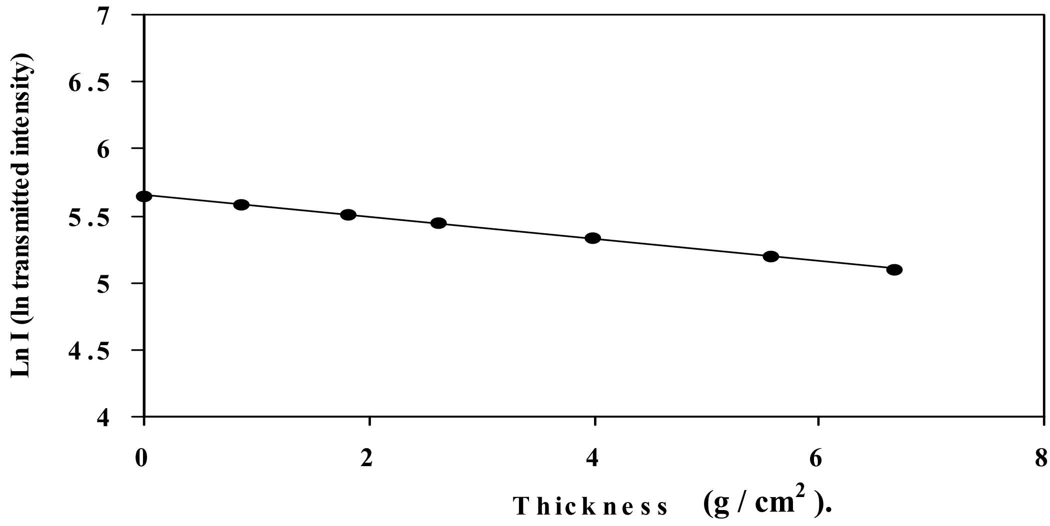

Fig. 2 : transmission of ^{137}Cs gamma dose through the special lead glass.

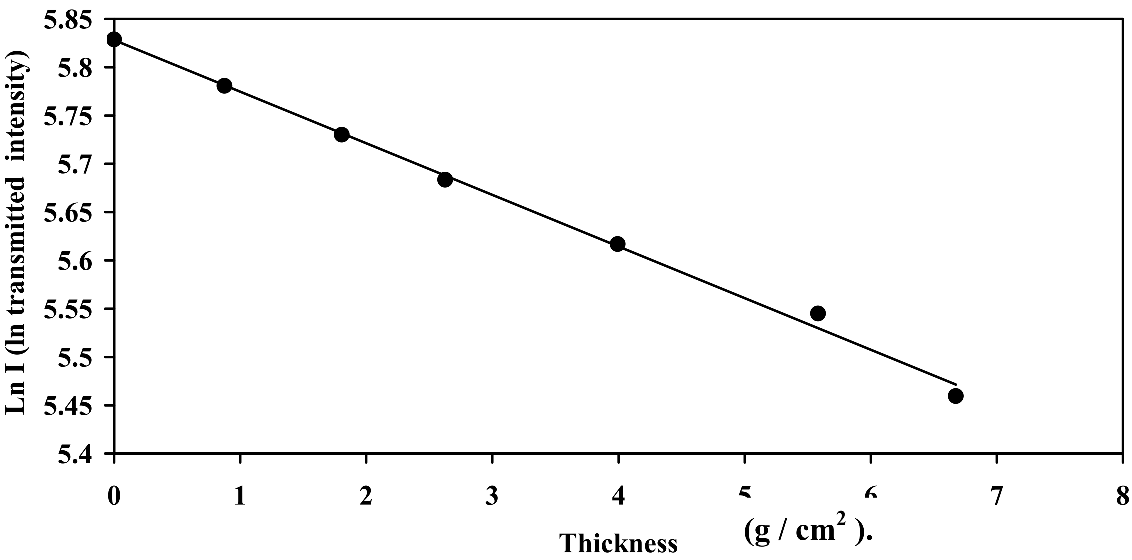

Fig.3: Transmission of ^{60}Co of gamma dose through the special lead glass.

The radionuclide of ^{60}Co has two dominate lines at (1.17 MeV) and (1.332 MeV) and the transmission curve is shown in Fig. (3), has a single slope, because the two energies are very close to each other (Friedman and Singh, 2003).

(μ/ρ) was calculated from the fitting equations of Fig. (2) and (3), which are equal to

Y=-0.0821 X +5.625…………for ^{137} Cs .
Y=-0.0534 X +5.8281………..for ^{60}Co.

Where Y represent ln (I) and X represent the thickness in (g/ cm^2).

(μ/ρ) of special lead glass (present work) is compared with the (μ/ρ) for the standard lead glass and shown in Table (4).

Table 4 : The values of (μ/ρ) for the special and standard lead glass.

E (MeV)	**(μ/ρ)x10^{-2} cm^2/g**		
	Special lead glass (present work)		**Standard lead glass (Calcu.)**
	Calcu. value	**Exper.. value**	
0.66	8.56	8.21	9.97
1.25	5.74	5.34	5.84

The values of the half thickness ($X_{1/2}$) in (g/cm^2) of the lead glass (present work) are compared with the standard in Table (5).

Table 5: The values of ($X_{1/2}$) in unit (g/cm^2) for the (present work) and the standard lead glass.

E(MeV)	**($X_{1/2}$) g / cm^2**		
	Special lead glass (present work)		**Standard lead glass (Calcu.)**
	Calcu. value	**Exper. Value**	
0.66	8.11	8.440	6.94
1.25	12.07	12.977	11.86

Table (4) showed a good agreement between the values of (μ/ρ) for both glasses, especially at the high energy, because the photoelectric effect decrease with increasing energy. The difference in (μ/ρ) at the low energy is due to the high content of lead about (80%) in the standard glass (Yousif, 2003), therefore it gives high attenuation.

The values of the half thickness of two lead glass showed a good concordance in units of (g/cm^2) Table (5).

Due to the small amount of lead (as compared with standard lead glass), the special lead glass manufactured in this work is more solid and easy to cut in any thickness or size than the standard lead glass (Yousif, 2003) and is also less toxic or less inhalation risk to the users and small biological dangers (Friedman and Singh, 2003).

CONCLUSIONS

- Sample (1) (Table 3) gave higher mass attenuation coefficient than the other two samples because of its high contain of lead.
- Sample(1) shows a good agreement for the values of (μ/ρ) of our result with standard lead glass where only 1.71% is noticed at 1.25 MeV. However, a difference of 14.4 % is noticed between our result and that of standard lead glass at 0.66 MeV.

- There is a good agreement between the experimental and calculated values of (μ/ρ) of sample (1) Table (4) with percentage error 3.827 % and 6.970 % for 0.662 and 1.25MeV respectively.
- We suggest to use the special lead glass as a radiation shielding windows and as radiation protection but with thicker thickness than the thickness of standard lead glass to compensate for the density difference. The density of the shield can be regarded as an important indicator of the attenuating power of the shield material.

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