Calculation of buildup factor for gamma-ray exposure in two layered shields made of water and lead.

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Abstract

The buildup factor for gamma ray exposure is most useful in calculations for biological protective shields. The buildup factors for gamma ray exposure were calculated in two layered shields consist of water - lead and lead - water up to optical thickness 20 mean free path (mfp) at gamma ray energies 1, 2 and 6 MeV by using kalos's formula. The program has been designed to work at any atomic number of the attenuating medium, photon energy, slab thickness and the arrangement of materials. The results obtained in this search leading to the buildup factor for gamma ray exposure at energies (1 and 2 MeV) in lead-water were higher than the reverse case, while at energy 6 MeV the effect was opposite. The calculated data were parameterized by an empirical formula as a function of optical thickness of two materials. The results obtained were in reasonable agreement with a previous work.

حساب عامل تراكم تعرض أشعة كاما في دروع ذات طبقتين مصنوعة من الماء والرصاص .

عباس جواد السعدي

قسم الفيزياء – كلية العلوم – جامعة كربلاء

الخلاصة

عامل تراكم تعرض أشعة كاما مفيـــد في حسابات الوقاية من الإشعاع . تم حساب عامل تراكم تعرض أشعة كاما في كل من الدروع ثنائية الطبقات ماء - رصاص و رصاص – ماء لسمك بصري يصل إلى 20 متوسط مسار حر عند الطاقات (1 و 2 و 6) مليون إلكترون فولت باستخدام علاقة كالوس. صمم برنامج لحساب عامل التراكم ليعمل عند أي عدد ذري لمادة الدرع وطاقة الفوتون الساقط وسمك الطبقة وكذلك ترتيب طبقات الدرع.

تشير النتائج الحاصلة في هذا البحث أن عامل تراكم تعرض أشعة كاما عند الطاقات (1و2) مليون إلكترون فولت في رصاص - ماء أكبر من قيمته في الحالة العكسية (ماء - رصاص). بينما عامل تراكم تعرض أشعة كاما عند الطاقة 6 مليون إلكترون فولت في رصاص - ماء أقل من قيمته في الحالة العكسية (ماء - رصاص) . كذلك وجدت علاقة استنتاجيه لعامل التراكم تعتمد السمك البصري للمادتين . البيانات الحاصلة في هذا البحث كانت متفقة مع البيانات المنشورة في الأدبيات ذات العلاقة.

Introduction

Buildup factor for gamma ray provides a convenient method for calculating exposure response after various shielding configurations, as well as gives information about behavior of radiation in these configurations.

The buildup factor for gamma ray photon (B) can be defined as the ratio of the correct value of a flux (or exposure dose) to the uncollided photon flux (or exposure dose) after transmission through a slab of a given optical thickness.

The buildup factor for gamma ray depends on the atomic number of the attenuating medium, energy of gamma ray, number of mean free path penetrated by gamma ray and geometrical form of the radiation source.

The first comprehensive sets of photon buildup factors were reported by Goldstein and Wilkin, 1954[1].

The importance of this factor is emphasized by the number of papers published in this subject [2 -7]. A detailed of historical review on buildup calculation and use are given by Tanaka et al.[8] and Harima et al.[9]. The buildup factor data have been computed by various code, some of the codes are ASFIT (Gopinath and Samthanam,1971)[10], PALLS(Takeuchi and Tanaka, 1984)[11] and Monte Carlo Code EGS4 (Nelson et al. 1985) [12].

Calculation of the buildup factor

There are a number of algebraic expressions that have been used to represent buildup factor for gamma ray exposure, Berger's formula have been used to parameterize buildup factor data for single layer, it is given by [13, 14]:

… (1) $B(\mu T) = 1 + a\mu T\, e^{b\mu T}$

Where a and b are constants for a given photon energy and shielding material.

is the linear attenuation coefficient μ for photons of the source energy in the shield material.

T is the shield thickness.

Usually expressed as the product μT is called the optical thickness (X) in mean free path (mfp).

More precise methods are available in certain cases, Kalos's empirical formula have been found to be rather accurate for slabs containing two layers as diverse as water and lead, which can be written in the following form [14, 15]:

1) For $Z_1 \rangle Z_2$ and $0.5 \le E_0 \le 10 MeV$

$$B(X_1, X_2) = B_2(X_2) + K(X_1)[B_2(X_1 + X_2) - B_2(X_2)] \quad ..(2)$$

Where $B(X_1, X_2)$ is buildup factor for gamma ray exposure in two layered shields with optical thickness X_1 of the first material and X_2 of the second material.

is exposure buildup factor for $B_i(X)$ material *ith* layer with an optical thickness X .

$$K(X_1) = \frac{B_1(X_1) - 1}{B_2(X_1) - 1} \qquad \ldots (3)$$

2) For $Z_1 \langle Z_2$ and $0.5 \le E_0 \le 10 MeV$

$$B(X_1, X_2) = B_2(X_2) + [B_2(X_1 + X_2) - B_2(X_2)] K(X_1) C(X_2) \qquad .(4)$$

$$\cdots C(X_2) = e^{-1.7 X_2} + \frac{\alpha}{K(X_1)} [1 - e^{-X_2}] \qquad (5)$$

$$\alpha = \frac{(\mu_c / \mu_t)_1}{(\mu_c / \mu_t)_2} \qquad \ldots (6)$$

is the ratio of Compton scattering α cross section (μ_c) to total cross section (μ_t) in the first and second material respectively.

Through many situations call for photon attenuation, few data bases for buildup factor in multi layer shields exist.

In this work, a computer program was designed to calculate the buildup factor for gamma ray exposure in two layered shields with any atomic number of the attenuating medium, photon energy, slab thickness and the arrangement of the slab layers. Berger's formula have been used to calculate buildup factor for gamma ray exposure in single layer. After that, Kalos's formula has been used to calculate buildup factor for gamma ray exposure in two layers.

The mass attenuation coefficients have been performed by using XCOM code (version 3.1). It is a computer code developed by Berger and Hubbell [16].

Materials and energies

The order of materials with varying atomic number (Z) affects on the photon buildup factor in a two layer shields.

In this research we used two layer configurations of materials with varying atomic number low -high (water - lead) and high - low (lead - water) for representative energies are shown in table 1.

Table1. Photon energies used in this search, the rationale for their use and some possible sources [17, 18].

Photon energy (MeV)	Reason for energy selection	Possible sources
1	Slightly below pair production threshold	Am-237, Pu-233 , Pu-245
2	Above pair production threshold	Te-131m , Ir-183
6	pair production dominates	Be-11, B-14, N-16

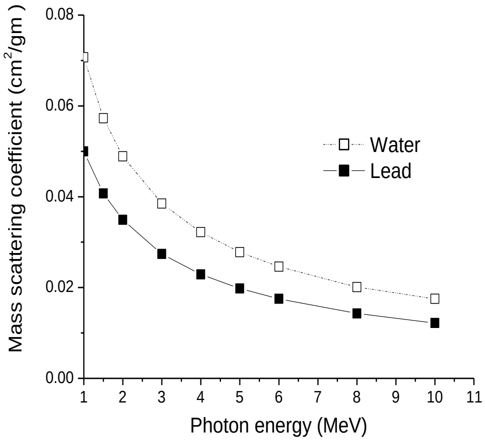

Fig.1. Mass scattering coefficient for water and lead.

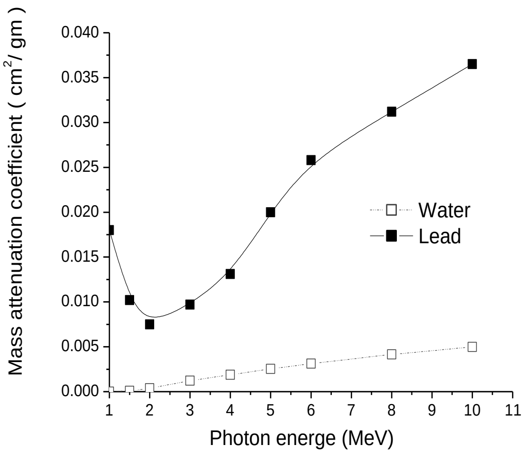

Fig.2. Mass attenuation coefficient (photoelectric + pair production) for water and lead.

Results and discussion

Figs. (1 and 2) show mass attenuation coefficients for water and lead will prove an invaluable tool in the analysis of the results.

Incident photons of energy 1 MeV

The calculated values of buildup factor for gamma ray exposure (B) in the shields of lead - water and water - lead at energy 1 MeV for different optical thickness (X) were shown in Fig. 3.

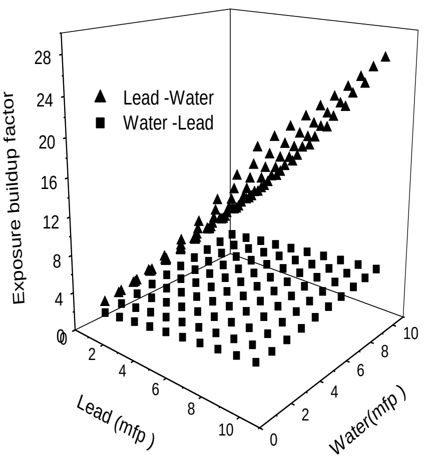

Fig3. Buildup factor values for gamma ray exposure at energy 1 MeV in lead-water and water - lead for difference thickness.

For lead-water, source energy photons and Compton scattered photons exiting from lead experience a low photoelectric effect in water, relative to Compton scattering in water (see Fig.2). Thus the Compton scattered photons contribute significantly to the responses at the exit surface of the water, leading to high buildup factors.

For reverse case (water-lead) the photons were scattered by the water so when they impinge on second layer (lead) they experienced a much higher attenuation cross section (mostly photoelectric),thus accounting for the lower buildup factors in this case.

Incident photons of energy 2 MeV

The calculated values of buildup factor for gamma ray exposure for the shields of lead-water and water-lead at energy 2MeV for different optical thickness were shown in Fig. 4.

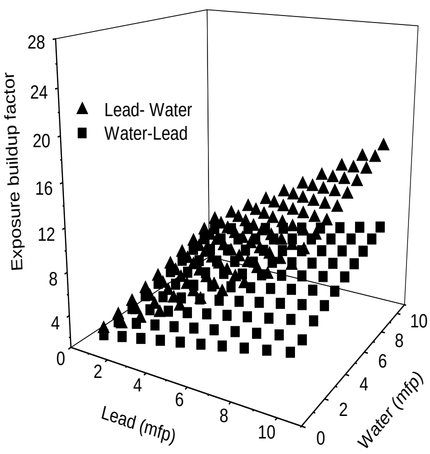

Fig. 4. Buildup factor values for gamma ray exposure at energy 2 MeV in lead-water and water-lead for difference thickness.

It can be seen that, buildup factor in shields of water-lead was increasing, this was due partly to the beginning of pair production at 1.022 MeV, an interaction much more prominent in lead than water (according to Fig.2).

At photon energy 2 MeV, shields beginning with water scattered many incident photons below 1.022 MeV). Thus, when they impinge upon the lead, they were able to avoid the effects of pair production.

In the reverse case, the 2 MeV incident photons on the lead were immediately subject to absorption by pair production. Pair production was not prominent at this energy, so the shields of lead-water still have higher buildup factors.

Incident photons of energy 6 MeV

The calculated values of buildup factor for gamma ray exposure in shields of lead - water and water - lead at energy 6 MeV for different optical thickness were shown in Fig. 5.

The shields of water-lead had higher buildup factors, unlike previous cases for lower energies, when the shields beginning in lead had higher buildup factor.

When 6 MeV photons incident on shield of water-lead, many photons were Compton scattered by water where they experienced a lower absorption cross section (mainly pair production) in the lead layer. This causes the scattered flux to increase relative to the unscattered flux and hence, buildup factor was increasing so there was higher buildup factor. The shields of lead - water now had significantly lower buildup factors. This effect was hence referred to as "buildup reversal ".

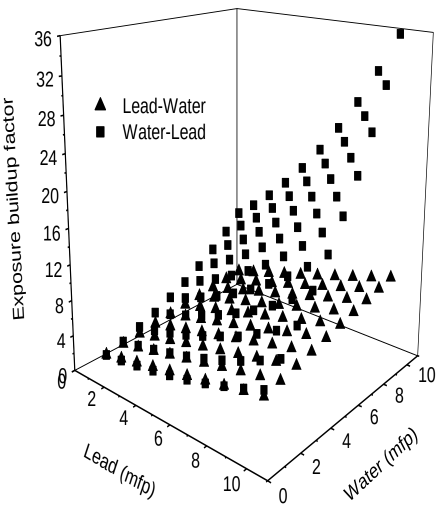

Fig.5. Buildup factor values for gamma ray exposure at energy 6 MeV in lead-water and water - lead for difference thickness.

Parameterization of buildup factor

The calculated buildup factor for gamma ray exposure data for two layered shields of lead-water and water-lead were also computer fitted as a function of optical thickness. The better fit was obtained by fit formula in the following general form:

$$B(X_1, X_2) = a + b\,X_1 + c\,X_2 + d\,X_1^{\,2} + e\,X_1\,X_2 + f\,X_2^{\,2} \quad (7)$$

Where X_1 and X_2 were optical thickness of the first and second layers respectively.

a, b, c, d, e and f were parameters to be determined by the least squares method.

The parameter values obtained were listed in table 2.

Table 2. Empirical parameters in expression for buildup factors.

Shield configuration	Parameter	Photon energy (MeV)		
		1	2	6
Lead - Water	a	1.143	1.023	1.008
	b	1.408	0.961	0.421
	c	0.275	0.372	0.179
	d	0.073	0.014	0.002
	e	0.005	0.007	0.021
	f	0.006	0.006	0.001
Water - Lead	a	1.208	1.027	3.938
	b	0.249	0.378	-0.821
	c	0.225	0.367	-0.583
	d	-0.003	0.001	0.088
	e	-0.007	0.004	0.244
	f	0.001	0.002	0.110

The fractional difference between data obtained by Eq.7 (fit) and present data calculated by using kalos's formula were given by:

$$Fractional \quad difference\ (\%) = \frac{|\, B(fit) - B(present\ data)|}{B(present\ data)} \times 100.\%....(8)$$

The fractional differences as a function of optical thickness for lead - water shield at gamma energy 2MeV were shown in Fig. 6.

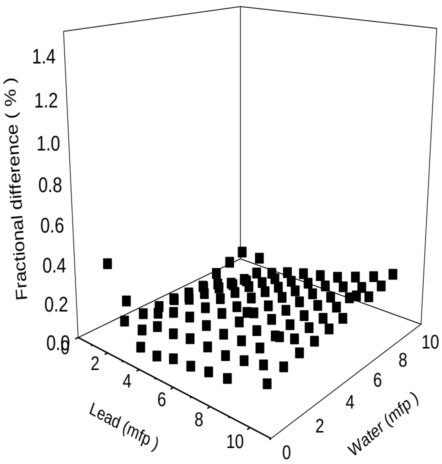

Fig. 6. Fractional difference between calculate buildup factors for gamma ray exposure in lead-water using empirical formula and present data obtained by using Kalos's formula.

In general, the fits were good. For most cases it was possible to use this formula to obtain exposure buildup factors with less than 3% fractional difference from those calculated in this work.

Comparison

Fig.7 shows the comparison of results with those of EGS4 (Electron Gamma Shower) calculations [12] for 1 MeV.

It can be seen that, the buildup factor for gamma ray exposure in water - lead and lead - water calculated by present work agree well with those of EGS4 calculations in most cases, except for some cases where a small disagreements was seen, this difference came from the data which have been used and the method of calculations.

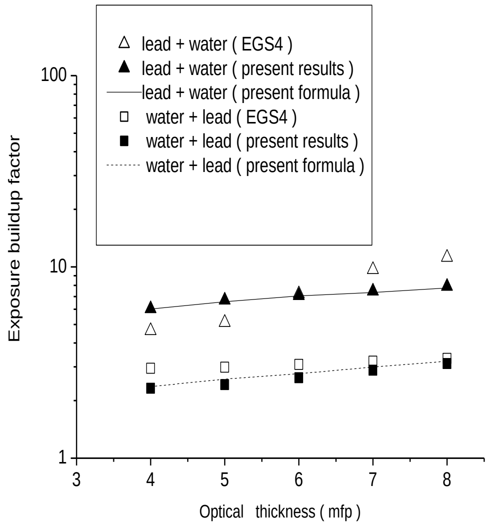

Fig.7. Comparison of buildup factor values for gamma ray exposure in two layers consisting of 3mfp of first material followed by (1-5) mfp second material for 1MeV point isotropic source.

Conclusions

In the present study, a simple method has been used for the calculation of buildup factor for gamma ray exposure in two layer shields made of water and lead of several representative energies interested in nuclear engineering.

The buildup factor for gamma ray exposure depends on material arrangement and photon energy.

For incident photons with an energies (1 and 2) MeV, buildup factor for gamma ray exposure in shields composed of lead - water was higher than the reverse case, while the buildup factor for gamma ray exposure at energy 6 MeV in lead - water was lower than the reverse case.

The fit formula obtained in this research generates the reference data of buildup factor for gamma ray exposure in very well for most cases.

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