BUILDUP FACTORS FOR GAMMA ATTENUATION IN SOME SHIELDING MATERIALS

Wunna Ko[*]

Abstract

The aim of this research is to determine the buildup factors which are involved in studying gamma attenuation in some kinds of shielding material such as aluminum, iron and steel. So, samples with dimension [76mmx76mmx0.9mm] and [76mmx76mmx1mm] are made. Then the photon attenuation after passing through the investigated samples is carried out by using NaI detector. The experimental arrangements include 2"x2" NaI (Tl) scintillation detector (Model No. 2M2/2), the photomultiplier tube base (digiBASE) with USB connection and MAESTRO-32 gamma detection software installed in a computer. ^{137}Cs source is used for the incident photon beam. By analyzing the spectra the photon intensities before and after the samples are obtained. From these, the attenuation coefficients and the buildup factors for the given samples can be calculated by using the relative methods.

Key words : buildup factors, gamma attenuation, NaI (Tl) detector

Introduction

When gamma rays traverse a small thickness of matter dx at any point in a medium, the extent of interaction of the photons is proportional to the radiation intensity at that point and to the thickness traversed. Consequently, in traversing the distance dx, the intensity of the gamma-ray photons which have not undergone interaction will be decreased by

$$\mathrm{dI} = \mu \mathrm{Idx} \quad (\mathrm{or}) \ \frac{\mathrm{dI}}{\mathrm{I}} = -\mu \mathrm{dx} \qquad (1)$$

where I is the intensity, e.g., in photons per m^2 per sec, and u is the proportionality constant, usually expressed in units. If all three types of interaction of gamma-ray photons with matter are included, then

$$\mu = \mu_{pe} + \mu_{c} + \mu_{pp}$$

where and represent the contributions of photoelectric effect, the Compton effect, and pair production, respectively, and is then called the linear attenuation coefficient of the absorber for the given radiation. If a

[*] Wunna Ko, Dr, Assistant Lecturer, Department of Physics, Yadanabon University

collimated (parallel) beam of monoenergetic gamma rays of intensity I_0 passes through a thickness x of a absorber, the intensity I_x of the emerging photons which have not suffered any interaction is obtained by intergration of equation (2); the result is

$$\ln \frac{I_x}{I_0} = -\mu x \qquad (2)$$

or

$$I_x = I_0 e^{-\mu x}$$

The intensity I_x defined in this manner is called the uncollided intensity or, more commonly, the uncollided flux, which emerges from the absorber. This is not necessarily the same as the actual intensity because some of the photons which gave experienced Compton scattering may remain in the emerging beam. However, for a narrow collimated beam of gamma rays (or a thin absorber) the photons which have undergone the Compton Effect will be scattered completely out of the beam and then the uncollided emerging intensity will be the same as the actual intensity.

One of the consequences of the exponential attenuation of gamma rays, as represented by equation (1), is that, although the amount of radiation attenuated by a specified thickness of material is proportional to the initial intensity, the fraction attenuated (or emerging) is independent of this intensity. Thus, it requires the same thickness of absorber to decrease the intensity of the (uncollided) gamma rays of a given energy from 1 to 0.1 percent of its initial value as is required to reduce it from 100 to 10 percent. Another consequence is that, theoretically, an infinite thickness of material would be necessary to attenuate gamma radiation completely, i.e., to make Ix = 0. Nevertheless, in shielding, a finite thickness can reduce the intensity to an amount that is relatively insignificant.

Buildup Factors

For a relatively thin layer of attenuating material, especially for photons of high energy, the probability that a scattered radiation particle will reach the detector after a single collision is small. The total flux measured is then essentially the same as the uncollided flux given by equation. On the other hand, if the shield is relatively thick, some particles which have suffered two or more scattering collisions within the absorber may reach the detector. In this case the scattered particles are not removed, and the flux at the observation point exceeds the uncollided flux; the simple exponential expression for the uncollided flux will then give results that are too low.

In order to allow for the collided (or scattered) flux that reaches the detector from the point source, it has been found convenient to introduce a point buildup factor , which is a function of the number of mean free paths as well as of the photon energy for a given attenuating medium. The total photon flux (collided and uncollided) at a distance R from a point monoenergetic source S_p can then be written as

$$\phi(R) = S_P B(\mu R) \frac{e^{-\mu R}}{4\pi R} \quad (3)$$

The corresponding expression for the point kernel is

$$\phi(R) = S_P B(\mu R) \frac{e^{-\mu R}}{4\pi R} \quad (4)$$

The buildup factor concept can be applied, in principle, to both gamma rays and neutrons, but it is almost invariably used for gamma rays. The point-source buildup factors are of special interest for point attenuation kernels. The calculations give the buildup factors as a function of the mean free paths of the gamma rays, i.e., of µx, where x is the distance along the path of the rays in the specified material.

Linear Attenuation Shielding Formula with Buildup Factors

$$I_x = I_0 B(\mu x) e^{-\mu x} \quad (5)$$

where B(µx) is a buildup factor which is a function of the number of mean free paths as well as of the photon energy for a given attenuating medium. 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.

Material and Method

Samples Preparation

In this research work, three kinds of samples are prepared, they are

(1) aluminum slabs(76mm×76mm×0.9mm),

(2) iron slabs(76mm×76mm×1mm) and

(3) steel slabs(76mm×76mm×1mm).

Experimental Set up and Procedure

The experimental arrangements include 2"x2" NaI (Tl) scintillation detector (Model No. 2M2/2), the photomultiplier tube base (digiBASE) with USB connection and MAESTRO-32 gamma detection software installed in a computer. As a gamma source, ^{137}Cs (30.07 years half-life and activity 1 μCi) is used. The detection system of the present work is set up as shown in Fig. (1).

All measurements for this research were done in Nuclear Physics Laboratory, Department of Nuclear Physics in Yadanabon University. In this research work, the voltage is adjusted to 800 V at the preset time of 300 sec by the MAESTRO-32 software. The background counts were measured for three times and average counting rate is taken. After measuring the gamma counts in the absence of sample, the different samples were placed between source and detector. The measured spectra are analyzed by the MAESTRO-32 software.

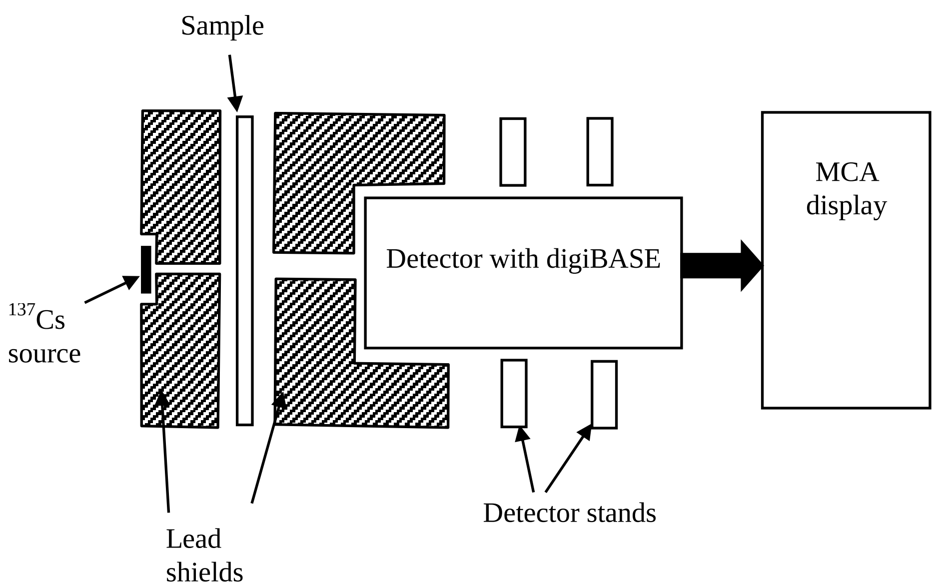

Fig. (1) Schematic diagram for experimental set up of present work

Results of the Measurements

The incident gamma intensities falling the samples and after passing through the samples of various thickness are shown in table. 1. The variations of gamma counts versus sample thickness are shown in figure 2, 3 and 4. The relative values of attenuation coefficients of the given samples can be obtained from the equation $I_x = I_0 e^{-\mu x}$. From these, the corresponding buildup factors can also be calculated by using the equation $I_x = I_0Be^{-\mu x}$ and they are shown in table 2 for different values of μx.

Table 1 The measured photon counts at the various thicknesses of aluminum, iron and steel

Samples	Sample Thickness(cm)					
	0	0.1	0.2	0.3	0.4	0.5
Aluminum	87022	78854	77272	75574	67484	64445
Iron	87022	77459	72521	68029	64165	59670
Steel	87022	80251	73888	70192	66981	64001

Table 2 The calculated buildup factors B (μx) for aluminum, iron and steel

Samples	μx					
	0.1	0.2	0.3	0.4	0.5	0.6
Aluminum	1.002	1.086	1.176	1.162	1.227	-
Iron	1.00	1.00	1.012	1.040	1.053	-
Steel	1.043	1.087	-	1.168	1.260	1.363

Discussions

In the present work, the buildup factors determined by this simple relative method are obtained by the use of mono-energetic gamma source ^{137}Cs. They may be varied with photon energies.

The linear attenuation coefficients of three samples are calculated by using the measurement results at sample thickness of 0 and 0.1 cm from table 1. This is because finding the attenuation coefficient is reasonable only when the experiment is carried out by using the relatively thin slabs of absorbers. So thicknesses of absorbers must be made thin as far as possible.

The buildup factor is a function of number of mean free paths and the variation of buildup factors with various μx is shown in table 2. Finding buildup factors from the linear attenuation coefficients is recommended only for the comparison of the attenuation properties of given samples. This is just the relative method and it can not give the absolute vales of the samples. To get the more exact values, the mass attenuation coefficients should be use and to do so it is necessary to know which elements contain in samples and by how much they occupied.

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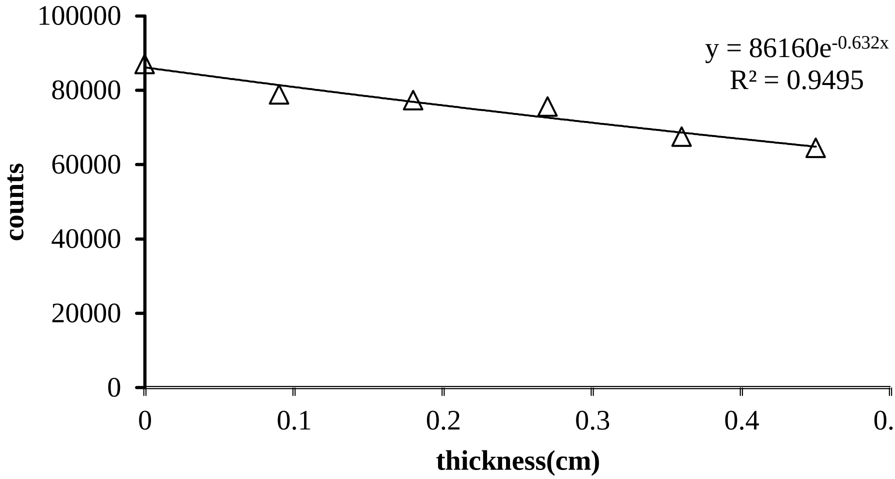

Figure (2) The variation of photons with different thickness of aluminum

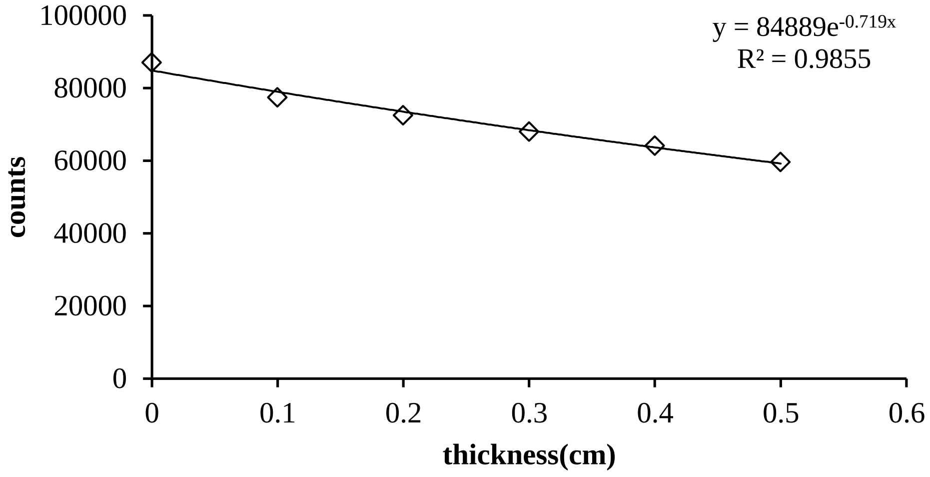

Figure (3) The variation of photons with different thickness of iron

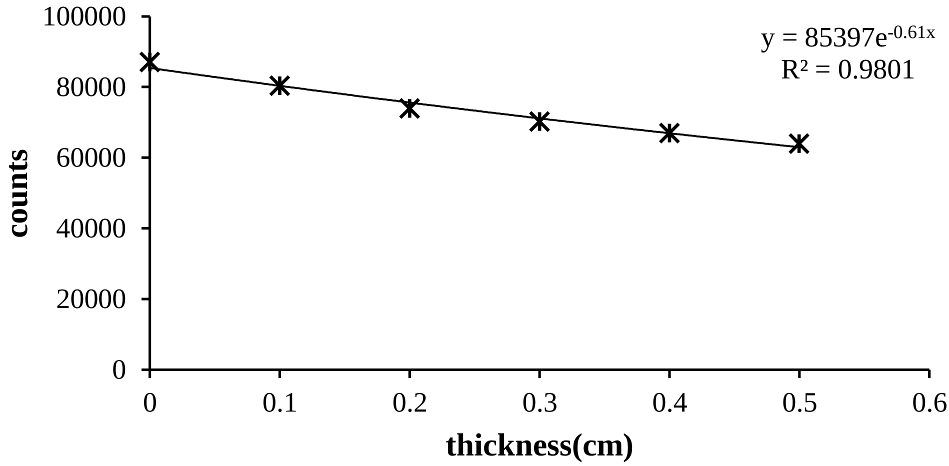

Figure (4) The variation of photons with different thickness of steel

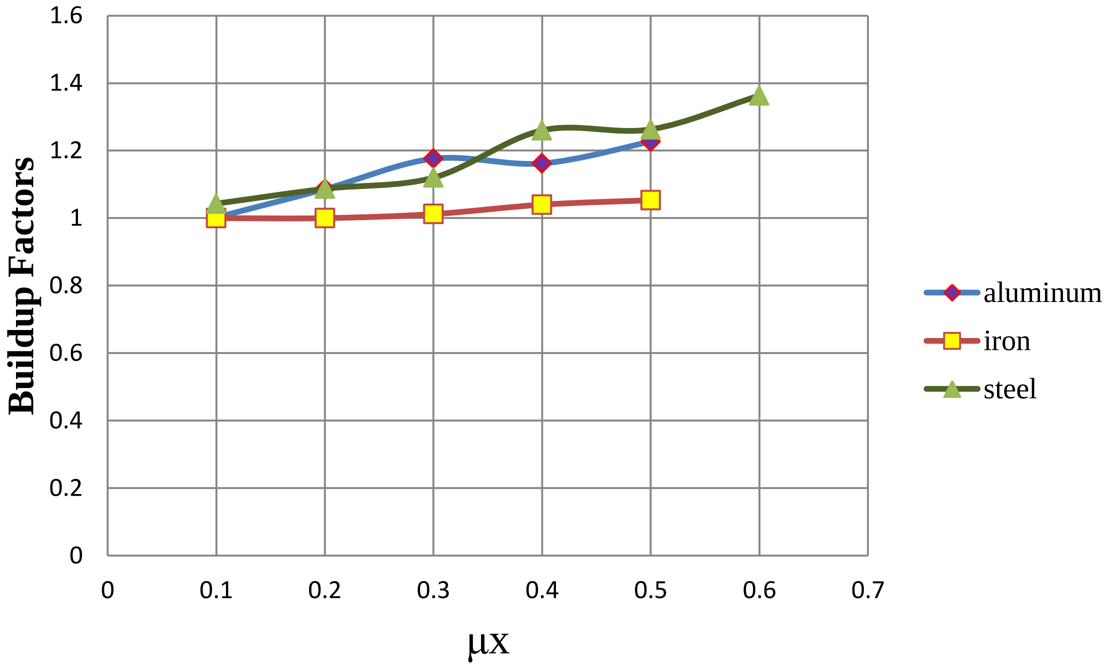

Figure (5) The variation of calculated buildup factors with µx

CONCLUSIONS

Consider a point isotropic monoenergetic gamma source at a distance r from a detector, with a shield of thickness t between source and detector. The total gamma beam hitting the detector consists of two components.

1. The unscattered beam ϕ_u consists of those photons that go through the shield without any interaction. If the source strength is S(λ/s) the intensity of the unscattered beam or the unscattered photon flux is given by the simple and exact expression

$$\phi_u(\frac{\gamma}{m^2 s}) = \frac{S}{4\pi r^2} e^{-\mu r} \quad (6)$$

2. The scattered beam ϕ_s consists of scattered incident photons and other generated through interactions in the shield (e.g., X-rays and annihilation gammas).

   The total flux hitting the detector is

$$\phi_{total} = \phi_u + \phi_s \quad (7)$$

Obviously, for the calculation of the correct energy deposition by gammas either for the determination of heating rate in a certain material or the dose rate to individuals, the total flux should be used. Experience has shown that rather than calculating the total flux using Eq. (7), there are advantages to writing the total flux in the form

$$\phi_{total} = B\phi_u \quad (8)$$

where B is a buildup factor, defined and computed in such a way that Eq. (7) gives the correct total flux. Combining Eqs. (7) and (8), one obtains

$$B = \frac{\phi_{total}}{\phi_u} = 1 + \frac{\phi_s}{\phi_u} \geq 1 \quad (9)$$

According to Eq. (7), the correct photon flux can be obtained by using the buildup factors of corresponding materials.

1. According to Eq. (9) and table 2, the calculated values determined by this research are reliable for linear attenuation of photons.
2. To get the more exact values, the mass attenuation coefficients should be use and to do so it is necessary to know which elements contain in samples and by how much they occupied.

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