Buildup factor calculation for high density poly ethylene, and high density poly ethylene with lead

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حساب عامل التراكم للبولي أيثيلين عالي الكثافة ,والبولي أيثيلين عالي الكثافة مع الرصاص

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المستخلص

دراسة عامل التراكم لعينات اسطوانية (دروع) من البولي أيثيلين علي الكثافة ,البولي أيثيلين عالي الكثافة مع الرصاص. حيث حسب عامل التراكم باستخدام اسماك من(0-3) معدل مسار حر ومصدر سيزوم- 137. Cs^{137}($E\gamma$=0.662 MeV) حيث استخدم الكاشف ألوميضي يوديد الصوديوم المطعم بالليثيوم ,NaI(Tl) تظهر الحسابات هذه ان نتائج البولي أيثيلين عالي الكثافة مع الرصاص تعطي عامل تراكم اقل من ذلك للبولي أيثيلين كما هو متوقع بسبب إضافة الرصاص.

الكلمات ألمفتاحية: عامل التراكم, شعاع كاما, درع,اشعة.

Abstract

The buildup factor of cylindrical samples (shields) for High Density Poly Ethylene, High Density Poly Ethylene with lead (HDPE+ Pb) was studied, where the buildup factor calculated using thickness between (0-3) m.f.p. Cs^{137} sources ($E\gamma$=0.662 MeV) have been used together with scintillation detector NaI(Tℓ) (2.5 x 2.5).These calculations show that the results of (HDPE +Pb) give buildup factor lower than that of (HDPE) as expected due to the addition of lead.

Key words: Buildup factor, gamma ray, shield, radiations.

1. Introduction

Shielding is the using of materials to lower the effects of incident radiation to any expectable level by reducing the intensity of radiation. Today the design and construction of radiation shielding used to protect people, equipment, and structures from the harmful effects of radiationof the most important problems innuclear engineering. Radiation shields required some facilities to determine and calculate x-ray radiation, gamma ray, and neutron. x-ray and gamma ray facilities for the detection of defects in materials, radiation facilities in food and plastics industries, The purpose of a radiationshieldisto protect from external radiation and in this context does not include the prevention of internal biological radiation hazards due to eating, drinking or breathing radioactive material (1). The buildup factor is defined as the ratio of the total photon beam(collided and un collided) response (e.g., flux, dose or exposure) to the response of the unclouded photon beam fraction. The gamma ray radioactive source have been used is ^{137}Cs. The radioactive sources ^{137}Cs are considered to be point isotropic source because of their small dimension. As it will be evidently shown later, the effect of the solid angle in the present work is negligible, thus the source have been consider as point source. (2)

The shielding idea using a point source, narrow beam, and broad beam attenuationsare used to explain "buildup factor" concept. Different values of buildup factors are presented and their behaviors in several materials are considered.

2. Theoretical concept

2.1 Gamma ray interaction with matter

Photons are classified according to their mode of origin, not to their energy. The term ɣ-ray is normally reserved for radiation emitted by nuclei, while the x-ray terms refer to radiation originating dueto the transitions of atomic electrons andbremsstrahlung.Thereis, no fundam-ental difference between the two radia-tions.

There are number of processes which cancauseɣ-raytobe scattered or absorbed (interact) by matter. However, only three processes are usually taken into account in nuclear physics or nuclear engineering problems. These processes are:

1. Photoelectric effect,
2. Compton effect (Compton scattering),
3.Pairproductionand inhala-tion.

The photoelectric effect predomina-tes at low energies and high Z-value, pair production predominates at high energies and high Z-value. Whereas, the Compton effect is the main interaction at moderate energies (≈ 1 MeV) for all Z and significant even at low energies for small Z. (3).

2.2 Types of buildup factors

The buildup factor may be expressed in terms of different quantities. These are the “number”, the “energy” and the “dose” buildup factor and shown by the following equations (4).

The "number" buildup factor

$$B_n = 1 + \frac{\text{Scattered photon flux reaching the detector}}{\text{Unscattered photon flux}} \quad (1.1)$$

The "energy" buildup factor:

$$B_e = 1 + \frac{\text{Scattered energy flux reaching the detector}}{\text{Unscattered energy flux reaching the detector}} \quad (1.2)$$

The "dose" buildup factor:

$$B_D = 1 + \frac{\text{Absorbed dose from scattered photons}}{\text{Absorbed dose from Unscattered photons}} \quad (1.3)$$

The dose buildup factor is related to the number buildup factor, in the following inner:

Dose intensity = number flux × energy per number × absorption coefficient

2.3 Narrow Beam (NB) and Broad Beam (BB) geometries

If each scattered photon will be removed from the path between the source and the detector, and never reach the detector, then applying equation(1.4) in suitable manner the experimental and theoretical results will be the same. But unfortunately some of the scattered photons will be scattered back toward the detector and recorded as un collided photons.

$$I = I_\circ e^{-\mu x} \quad (1.4)$$

It is important at this point to discuss what is so called Narrow beam geometry (NBG) and Broad beam geometry (BBG).

The NBG, as shown in figure1. 1, is the geometry where only the uncollided photons may reach the detector. While the BBG, as shown in figure1. 2, is the geometry where both the unclouded and some of the scattered photons may reach the detector (5). The "buildup factor" is defined as the ratio of the actual gamma flux encountered by the detector according to the geometry shown in figure 1.1 with simple exponential attenuation that following the geometry shown in figure 1.2 It is important to mention here that the geometry represented in figure 1.5 will not follow equation 1.7. This is because, according to this equation, each scattered photon will be removed from the path between the source and the detector and never reach the detector. Thus, there will be more gamma flux encountered by the detector and the result of calculation will be larger. Therefore, equation 1.8 should be corr-ected to match the actual experim-ental results as shown in the equation (1.5).

$$I = BI_\circ e^{-\mu x} \quad (1.5)$$

where **B** is the buildup factor.

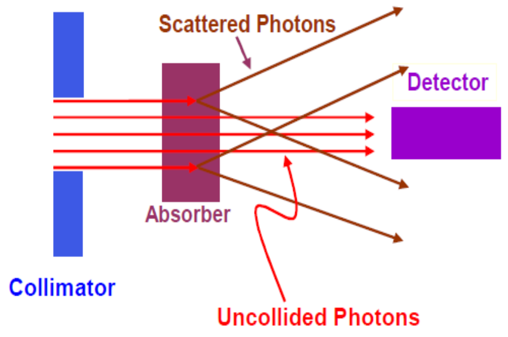

Figure (1.1): The narrow beam geometry (NBG) where only the un collided photons may reach the detector.

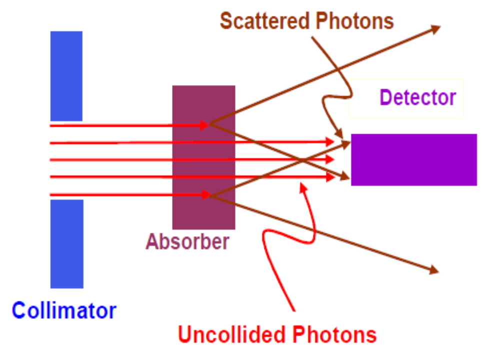

Figure (1.2): The broad beam geometry (BBG) where both the unclouded and some of the scattered photons may reach the detector.

3. Photon attenuation

The probability of a photon intera-cting in a particular way with a given material, per unit path length, is usually called 'linear attenuation coefficient' μ (cm^{-1}). This coefficient is of great impo-rtance in matters concerning radiation shielding.Consideringa point source of gamma rays separated from a detector by a dist-ance "X", with a material shield of thickness "x" and radius "r" located between them as shown in figure 1.3 . (4).

If the dimensions are such that :

X- x » 0 and **x >> r** **(1.6)**

Then every photon collision with the used material produces a scattered photon. Each one of these scattered photons will be removed from the path between the source and the detector, and never reaches the detector.

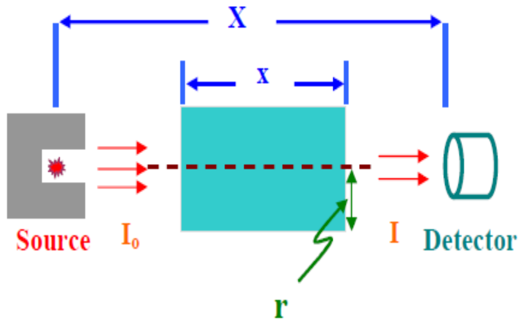

Figure (1.3): Point source of gamma rays separated from a detector by a distance "X", with a material shield of thickness "x" and radius "r".

The flux-level reduction rate is proportional to the flux-level itself. Mathematically,

$$-\frac{dI}{dx} = \mu I \qquad (1.7)$$

or

$$I = I_{\circ}\, e^{-\mu x} \qquad (1.8)$$

where:

"Io" is the collimated flux in the direction of the detector.

"μ" is a coefficient representing the macroscopic probability density for a collision between the gamma photons

and an atom of the material at a depth "dx" (linear attenuation coefficient).
The magnitude of the linear attenuation coefficient "μ" depends upon the energy of gamma and shielding material.

4. Experimental arrangement for buildup factor calculation

The top views of the experimental arrangements are shown in figures 1.4 and 1.5. Figure 1.4 shows the NB arrangement. However, figure 1.5 shows the BB arrangement (with detector shield).The radioactive source is well shielded with lead block from all sides. The NaI(Tl) detector is also well shielded with lead blocks from all sides except its front face to reduce the background radiation that may reach the crystal. The source, detector and the two collimators are arranged and aligned in a straight line on a wooden stage especially built for this experimental work. (6).

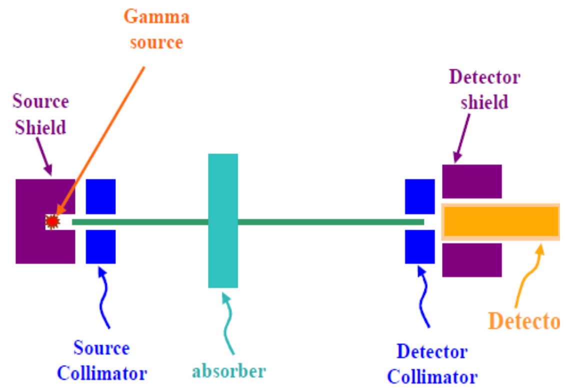

Figure (1.4): Top view of the narrow beam (NB) experimental arrangement.

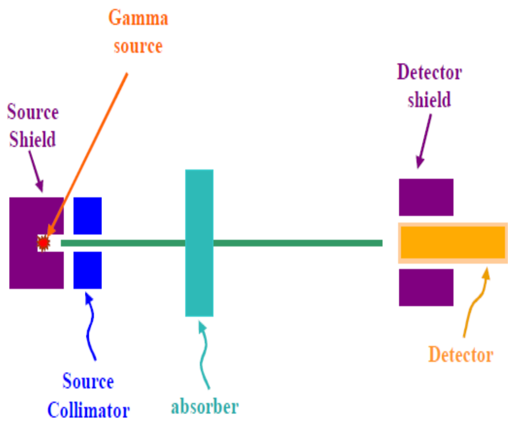

Figure (1.5): Top view of the (BB) experimental arrangement configuration (with detector shield).

5. Collimators

In the NB measurements, two collimators are used. Each collimator is a lead block of 5 cm radius and 8.4 cm width, with a central hole of 1.45 cm radius. The collimator near the radioactive source is usually used to obtain a narrow and collimated beam of gamma photons from a point source. While, the collimator near the detector is used to prevent scattered photons and allow those emitted straight forward by the radioactive source to reach the front face of the NaI(Tl) detector.

6. Method Buildup factor Calculation

This method can be summarized as follows:

For a narrow beam (with collimation):

$$I = I_{\circ}\, e^{-\mu x}$$

$$\therefore \frac{I}{I_{\circ}} = e^{-\mu x} \quad \text{or} \quad \ln\left(\frac{I}{I_{\circ}}\right) = -\mu x$$

(1.9)

Because **(I < Io)** always, then, **ln(I / Io)** is a negative value and hence

- (ve) value = - μ**x** or **+ (ve) value = µx (1.10)**

Forabroad beam (without collimation)-

$$I = BI_{\circ}\, e^{-\mu x} \qquad \ln(I / I_{\circ}) = \ln B - \mu x \quad (1.11)$$

Then, in the same manner:

$$+\ (\text{ve})\ \text{value} = \ x - \ln B \quad (1.12)$$

Atypical plotting **ln (I/Io)** as a function of **x** for the two cases (**NB** and **BB**) is shown in **figure 1.7**, from which, the buildup factor **B** at each thickness can be calculated (7,8) .

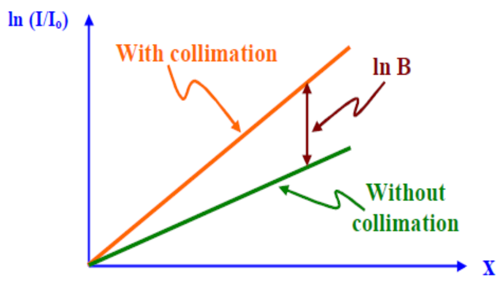

Figure (1.7): ln(I/Io) as a function of absorber thickness x (mfp)

7. Experimental results and discussion:

7.1 Effects of lead addition to standard polymer

In order to determine the effects of lead additive to polymer, its attenuation coefficient and buildup factor are examined. of course, it is desired to increase the attenuation coefficient and decrease its buildup factor in order for it to be a suitable shielding material or at least make good optimization between them. For this reason the two different kinds of polymer [(High Density Poly Ethylene), and High Density Poly Ethylene with lead)],have been examined and compared witheachother. Figure 1.6 shows a comparison of attenuation coefficients for these different kinds of polymer. It is clear from this figure that the attenuation coefficients increase with using Pb additive

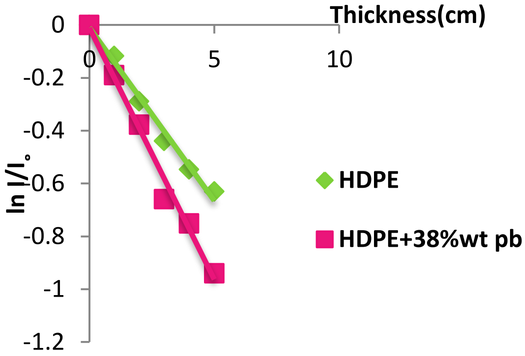

Figure (1.6): ln(I/I_O) as a function of absorber thickness used to compare the attenuation coefficients for [(High Density Poly Ethylene)and(High Density Poly Ethylene with lead)] . for ^{137}Cs gamma source, (Eγ=0.662 MeV).

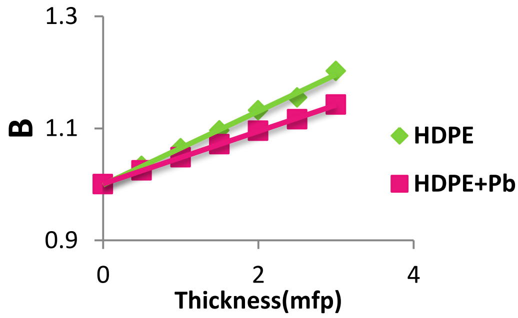

Figure (1.8): The experimental buildup factor curves for [(High Density Poly Ethylene)and(High Density Poly Eth-ylene with lead)]. for ^{137}Cs gamma source, (Eγ=0.662 Mev).

Tables and graphs of the experimental results to determine the buildup factor for each material.

Table (1.1): The experimental buildup factors for (High Density Polyethylene + lead) a using ^{137}Cs gamma source, Eγ=0.662MeV.

Thickness	ln B	Buildup factor (B)	Previous Study (B)(9)
0.5	0.024	1.0249	1.02634
1	0.047	1.04812	1.05337
1.5	0.69	1.07143	1.08220
2	0.091	1.09526	1.11182
2.5	0.10	1.1162	1.1411
3	0.133	1.1422	1.1735

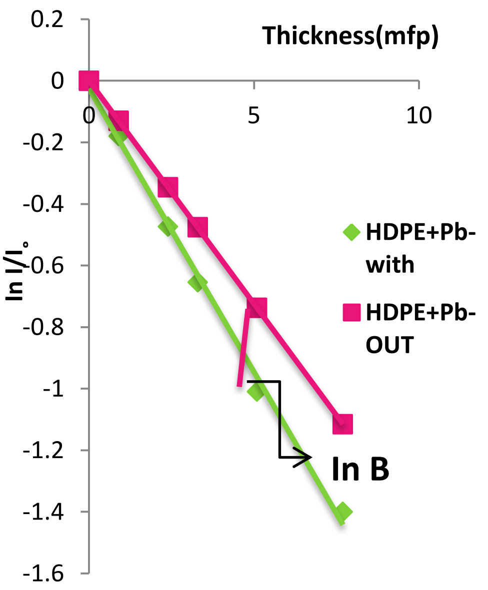

Figure (1.9): In(I/I$_0$) as function of absorber thickness(mfp) used determine the Buildup factor HDPE +Pb using ^{137}Cs gamma source ($E_γ$=0.662MeV).

Table (1.2): The experimental buildup factors for (High Density Poly Ethylene) a using ^{137}Cs gamma source, Eγ=0.662MeV.

Thickness	ln B	Buildup factor (B)	Previous Study (B)(9)
0.5	0.032	1.0328	1.0376
1	0.062	1.0639	1.0757
1.5	0.092	1.0963	1.1151
2	0.124	1.1320	1.1583
2.5	0.144	1.1548	1.2008
3	0.189	1.2020	1.2460

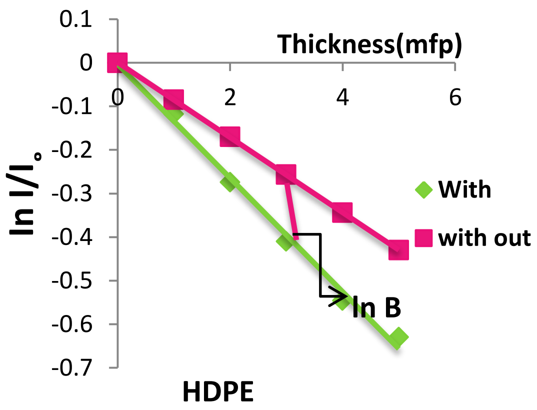

Figure (1.10): ln(I/Io) as a function of absorber thickness x(mfp) used determine the Buildup factor HDPE using ^{137}Cs gamma source ($E_γ$=0.662MeV).

References

1-Kaplan,M. F. (1989). Concrete radiation shielding,. Longman Group UK Limited.

2-Lamarsh,J. R. (1975). Introduction to nuclear engineering. Ddison-Wesley Co., N. Y.

3-ProfioA. (1979). Dadiation shielding and dosimerty,. John Wiley and Sons.

4-Glower,.D. D. (1965). Experimental reactor analysis and radiation measurements. McGraw-Hill Book company.

5-Dresner , L. (1965) . Principles of radiation protection engineering. McGraw-Hill Book company.

6-Hubbell ,**J. H. (1982).** Values of the absorption coefficients for different materials using Co-60 and Sc-137 gamma radioactive source. Appl. Radiat. Isot., 33(269) .

7-Chilton , A. B. (1968). Broad beam attenuation sec.4.3 in Engineering compendium on radiation shielding. (Springer-Verlag,).

8-Chilton ,A. B. shultis, J. K. , and Faw, R. E. (1984). Principles of radiation shielding. Prentice-Hall, INC.

9-Ali ,A. I. (2009) . Fabricating and using some polymers as single and multi-layers (with other materials) nuclear gamma ray shield, Master Thesis, Omar Al- Mukhtar University.