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ASSESSMENT OF GAMMA ABSORBED DOSE AND BUILDUP FACTOR FOR A POINT SOURCE; CASE STUDY

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ABSTRACT:

The aim of this study is to verify and audit the gamma absorbed dose and gamma buildup factor, for point and isotropic gamma source, for modified Portland cement used shielding. In this study a modified Portland cement with different thickness was used as a shield for gamma radiation. The thickness of the shield ranged from 0.5 to 10 mean free path (mfp) with gamma energy ranges from 0.5 to 10 MeV. Gamma absorbed dose and gamma buildup factor for a point and isotropic gamma source were calculated using gamma shield equation as described in the text (closer to real life in going back to the basic). The human absorbed dose rate in radiation field using modified cement shield, concerning that the density of skin tissue is equivalent to the density of water at the dose point. There are a relation between dose rate (mGy/h) and the thickness of the shield (cm). Half Value Layer (HVL) and Tenth Value Layer (TVL) were calculated. The obtained data was compatible and comply with national (Egyptian) and international (IAEA) regulations. .

Keywords: *radiation shielding; buildup factors; mean free path; gamma dose.*

1. Introduction

Radiation shielding is based on the principle of radiation attenuation, which is the ability of a shielding material to effectively reduce or minimize the radiation's intensity by blocking particles or electromagnetic energy. Some radiation sources gamma ray and others emit both neutron and gamma ray from absorption of high-energy gamma ray by atomic nuclei and ejection of protons and neutrons from the nuclei. Therefore, neutrons and gamma ray are the main types of nuclear radiation that have to be considered in radiation shielding design [1].
Gamma radiation interacts with the shielding material and become attenuated by photoelectric effect, Compton scattering, and pair production processes. The effectiveness of gamma ray shielding depends on the atomic composition (Z) of the shielding material and

the photon energy. Certain gamma ray interaction processes can also result in emission of secondary photons [2].

The transmission of gamma radiation through materials depends on the attenuation factor and the buildup factor [1]. The attenuation factor accounts for the relaxation length which is the reduction of uncollided photons. The buildup factor accounts for the increased radiation intensity from secondary or scattered radiation and also the number of relaxation lengths [1], which can be computed from the multiplication of linear attenuation coefficient and shielding thickness or μx.

The buildup factor is considerably important for multi-energy gamma-rays with poor geometry for the reason that attenuation coefficients and cross sections of various mediums are not accurate. The buildup factor is described as the ratio of total value of specified radiation quantity at any point of contribution to the value from radiation transmission at the point without undergoing a collision [3].

Linear Attenuation Shielding Formula was used in the unshielded and shielded calculations. When the intensity of gamma rays passing through matter fall exponentially. In good geometric condition, i.e. when the thickness of the absorbent is low and the beam is parallel, the following relationship describe the gamma attenuation through the shield [4]

$$\mathbf{I} = \mathbf{I_0} e^{-\mu \mathbf{T}} \qquad (1)$$

Where $\mathbf{I_0}$ is the incident beam and $\mathbf{I}$ is the transmitted radiation intensity, $\mathbf{T}$ is the thickness of the shield and $\boldsymbol{\mu}$ is the linear attenuation coefficient of absorbent. The linear attenuation coefficient is a function of the incident photon energy and atomic number of the media. The linear attenuation coefficient increases as the atomic number of the absorber increases and decreases with the energy of the gamma rays.

To determine the shield thickness to yield a specific dose rate, the following equation can be uses by educated guesses for the value of T, looking up the corresponding values of B, and through an iterative process using a computer or calculator, solve for the desired thickness; results can be plotted, and the correct value of T determined for the desired value of dose rate. There are a number of algebraic expressions that have been used to represent B.

$$\mathbf{B} = \mathbf{A_1} e^{-\alpha_1 \mu \mathbf{T}} + (1-\mathbf{A_1}) e^{-\alpha_2 \mu \mathbf{T}}$$

In this work gamma absorbed dose and gamma buildup factor, for point and isotropic gamma source, for modified Portland cement will be assessed. Additionally, Half Value Layer (HVL) and Tenth Value Layer (TVL) will be calculated.

2. Buildup factor

Dose buildup factors for point isotropic sources have been determined under the assumption that both the source and the dose point reside within an infinite volume of the shield material. As a consequence, shielded doses evaluated using such buildup factors tend to be conservative for most practical situations in which the dose point is outside the shield and not subject to backscattering from shield material behind the dose point.

The buildup factor is of most important parameters in designing the shields for radioactive sources. It is also used in calculations of gamma dose absorbed in the issues. Magnitudes of buildup factors vary widely, ranging from a minimum of 1.0 to very large values, depending on source and shield characteristics. The value of the buildup factor depends on the photon energy (E), the shield material and thickness (T), the source and shield geometry, and the distance from the shield surface to the dose point(r).

3. Point isotropic source

The most popular source geometry involved in many calculations is the point isotropic source. While no real source is a true point, many sources are sufficiently small in dimensions that they can be treated mathematically as point sources.

The assumption that the source is isotropic means that radiation of concern is emitted uniformly in all directions throughout a 4π geometry [5]. A source of monoenergetic gamma radiation that emits strength gamma rays (S) per second and situated at a distance r (cm) from the dose point will be defined. Further, a shield of thickness T (cm) through which the gamma radiation passes before reaching the dose point will be assumed.

Dose buildup factors for point isotropic sources have been determined under the assumption that both the source and the dose point reside within an infinite volume of the shield material.

4. Half-value layer (HVL)

Half-value layer (HVL) is the width of a material required to reduce the air kerma of an x-ray or gamma-ray to half its original value. This applies to narrow beam geometry only as broad-beam geometry will experience a large degree of scatter, which will underestimate the degree of attenuation. It is used to quantify polyenergetic beams as opposed to linear and mass attenuation coefficients which are used for monoenergetic beams.

It is an indirect measure of photon energy or the hardness of a beam. A lower HVL indicates low photon energy. HVL is measured in millimeters of aluminum. After filtration by one HVL, the subsequent HVL will be higher as the filtered photons have higher energy (thicker material is required to attenuate half of the penetrating beams)

It is related to linear attenuation coefficient (μ) with following formula:

$$HVL = 0.693 / \mu$$

2. Materials and Methods of calculations

2.1. Materials and shielding preparation

The simulated geometry consists of an isotropic point source at the center of a sphere. The material of the sphere is considered to be (Cement-Illuminate). Gamma detector surrounds the sphere shield.

(Cement-Ilmenite) as a shield:

Cement has been described as adhesive substances capable of uniting fragments of solid matter to compact solid block.

Ilmenite is one of the main titaniferousiron. It is an opaque mineral. It is strong and fairly corrosion resistant.

The shielding material in this research composed of Ordinary Portland Cement and ilumenite and fabricated into a rectangular shape with different thickness and with dimensions 10 x 5 cm.

30% Ilmenite with 500µm grain size was used as additives to improve the properties of ordinary Portland cement as a radiation shield [6]. The heavy material (Ilmenite) has significant effect in attenuation coefficient of the gamma rays (µ). The density (ρ)of cement mixed with Ilmenite was 2.43 (g/cm^3) and linear att. Coefficient (µ) was 0.87 (cm^{-1}). Gamma buildup factors with respect to thickness (mfp) were calculated at different energies.

2.2 Buildup factor (B)

For weak geometry (in which photons are diverging and the shield is relatively thick) Equation (2) will be used to calculate transmitted radiation intensity [7].

$$\mathbf{I} = \mathbf{B}(E,\mathrm{T})\, \mathbf{I_0} e^{-\mu \mathrm{T}} \qquad (2)$$

Equation 3 will be used to calculate the buildup factor and dose rate.

$$\mathbf{D} = \left(\frac{kSE\frac{\mu_{en}}{\rho}}{4\pi r^2}\right)\mathbf{B}e^{-\mu\mathrm{T}} \qquad (3)$$

Where: **D**; dose rate at a point of interest outside the shield.

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

S; is the gamma rays per second;

r ; is distance (cm) from the source the dose point;

T; shield thickness (cm) through which the gamma radiation passes before reaching the dose point;

μ_{en}; mass energy attenuation coefficients.

ρ; shield material mass density(g/cm^3);

E; is the photon energy (MeV);

μ_{en}/ρ; is the mass energy absorption coefficient for the material at the dose point (cm^2 g^{-1}).

k; is a collective constant to convert energy fluence rate to dose rate with a value of **5.76 x 10^{-7}**.

This formula in equation (3) 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.

2.3. Absorbed dose (D)

Taylor's form of the buildup factor [8], given by

$$\mathbf{B = A_1 e^{-\alpha_1 \mu T} + (1-A_1) e^{-\alpha_2 \mu T}} \qquad (4)$$

Equations 3, 4 used for calculate the buildup factor and the absorbed dose rate at dose point. For materials with a thickness of 0.5-10 (mfp), gamma buildup factors are calculated using the relation (4), where A_1 , α_1, and "α_2 are constants for a given energy and shield material [8].

$$\mathbf{D = \frac{kSE\frac{\mu_{en}}{\rho}}{4\pi r^2} [(A_1 e^{-\alpha_1 \mu T} + (1-A_1) e^{-\alpha_2 \mu T})] e^{-\mu T}} \qquad (5)$$

$$\mathbf{D = \frac{kSE\frac{\mu_{en}}{\rho}}{4\pi r^2} [(A_1 e^{-(1+\alpha_1) \mu T} + (1-A_1) e^{-(1+\alpha_2) \mu T}]} \qquad \mathbf{(6)}$$

Equation (6) was derivative from equation (5). From this equation the absorbed dose rate was calculated for the (Cement-Illuminate) shield with a thickness of 0.5-10 (mfp).Where absorbed dose (Gy) = effective dose (Sv) numerically for gamma ray.

2.4. Half Value Layers (HVL)and Tenth Value Layer (TVL)

Instead of using attenuation coefficients to perform shielding calculations, half and tenth value layers can be calculated. A half Value layer is the thickness of the materials that reduce the radiation intensity by one-half.

$$\mathbf{HVL = 0.693/\mu} \qquad \mathbf{(7)}$$

And

$$\mathbf{TVL = 2.3/\mu} \qquad \mathbf{(8)}$$

3. Result and Discussions

3.1. Buildup factor

The buildup factors, B (E, x), is generally defined as the ratio of the total dose to the unscattered dose [9]. The buildup factor is of most important parameters in designing the shields for radioactive sources including power reactor cores. It is widely used in calculations of gamma dose absorbed in the issues. Buildup factors are greater than unity and approach to unity when the absorption is dominant or when the scattering cross section vanishes [10]. Buildup factor for prepared shielding material (cement - illuminate) at different thickness and different energy were calculated from equation 4 and the data obtained are represented in table 1 and figure 1.

Table 1 Gamma buildup factors for prepared cement-illuminate shield

Thickness (cm)	**Energy(MeV)**							
	0.5	**0.663**	**1**	**2**	**4**	**6**	**8**	**10**
0.5	1.41	1.45	1.5	1.24	1.36	1.21	1.27	1.32
1	2.32	2.3	2.01	1.66	1.37	1.34	1.52	1.46
2	4.27	4.01	3.35	2.61	2.25	2.14	1.88	1.08
4	9.12	7.95	6.09	4.07	3.41	2.8	2.64	2.02
6	16.2	15.13	10.2	6.19	4.68	3.61	3.27	3.19
8	25.4	20.41	15.16	9.05	6.41	4.17	3.8	2.95
10	37.1	30.15	21.19	11.28	7.39	5.7	4.63	4.63

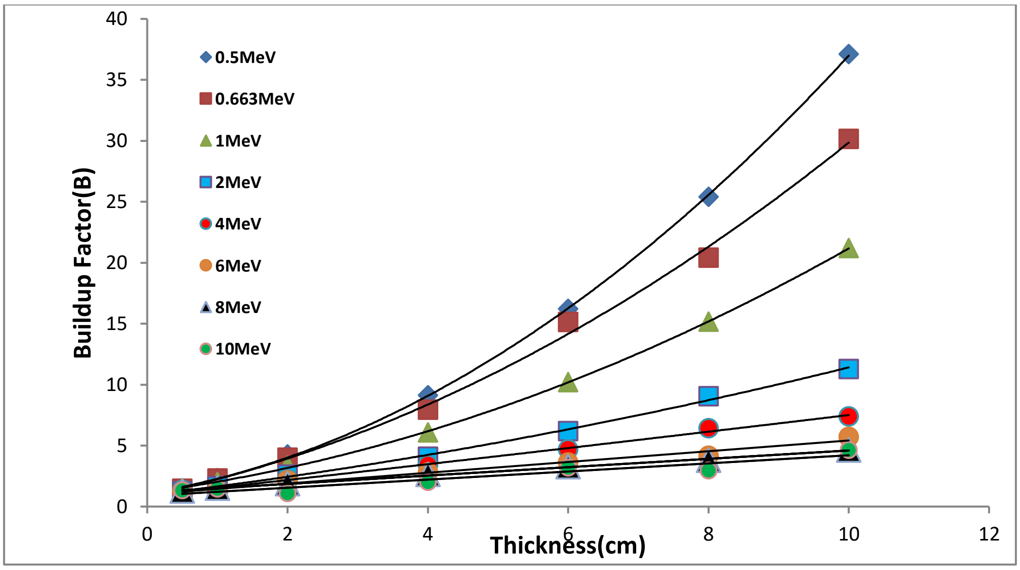

Fig. 1 Gamma buildup factors for (Cement-Illuminate) Shield at different thickness and different gamma energy

Figure 1 represents the relation between Gamma buildup factors and thickness (mfp) for (Cement-Illuminate) shield at different energies. From figure 1 it is clear that at different energies, the buildup factor (B) increases with increasing the thickness (mfp) for the Cement-Illuminate prepared shield and decreases with photon energies increases. Additionally, For 0.5 and 0.663 sharp decrease in the buildup factor compared with 8 and 10 Mev.

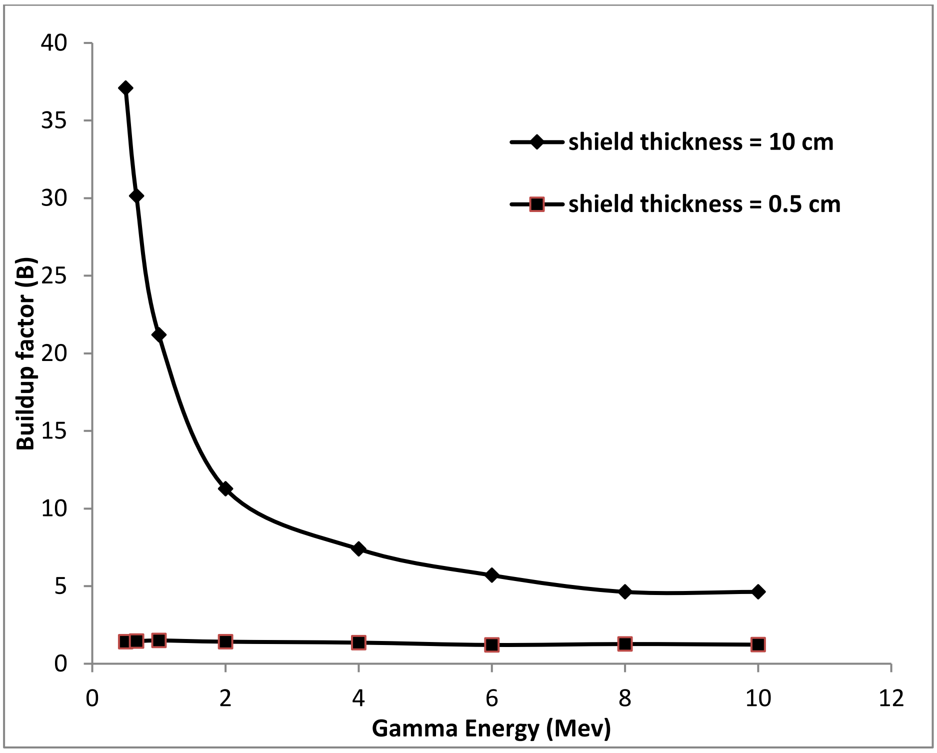

Fig.2 buildup factor (B) and gamma energy (Mev) at different (Cement-Illuminate) shield thicknesses

Figure 2 shows relation between the buildup factor (B) and gamma energy (Mev) at two different thicknesses (0.5 and 10 cm). From this figure we can see that at 10 cm shield thickness the buildup factor decreases sharply from 37.1 to 11.28 when the gamma energy increases from 0.5 to 2 Mev and then decrease slowly after 2 Mev. While at 0.5 cm shield thickness there is very slight changes on the buildup factor if gamma energy was changed from 0.5 to 10 Mev.

3.2. Gamma absorbed dose

Cesium source (Cs^{137}) with activity (3mCi) at energy line 0.663MeV has been used to calculate gamma absorbed dose rate. From equation 5 and 6 the absorbed dose rate was calculated for the (Cement-Illuminate) shield with a thickness of 0.5-10 (mfp).Where absorbed dose (Gy) = effective dose (Sv) numerically for gamma ray. The obtained data are represented in table 2 and figure 3.

Table 2 Absorbed dose rate at different thickness

Thickness (cm)	Dose (mG/h) or (mSv/h)
0.5	0.000477
1	0.000347
2	0.000178
4	4.34E-05
6	9.96E-06
8	2.2E-06
10	4.76E-07

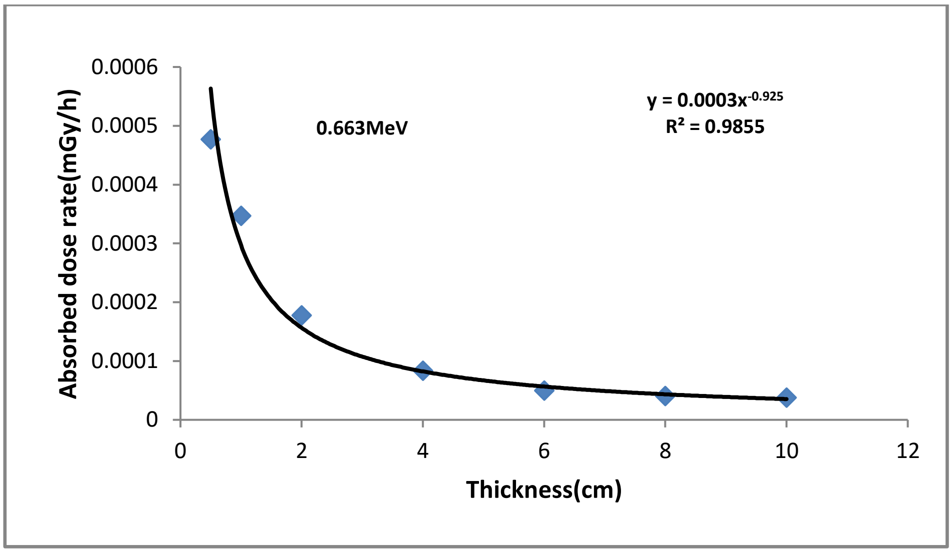

Fig. 3 Gamma absorbed dose rate with thickness (cm)

3. 3. HVL and TVL were calculated.

Table 3 illustrates the Half Value Layers (in cm) for different materials at gamma ray energies of 100, 200 and 500 keV [11].

Table 3 Half Value Layer for different materials

Absorber	HVL (cm)		
	100 keV	200 keV	500 keV
Air	3555 cm	4359 cm	6189 cm
Water	4.15 cm	5.1 cm	7.15 cm
Carbon	2.07 cm	2.53 cm	3.54 cm
Aluminum	1.59 cm	2.14 cm	3.05 cm
Iron	0.26 cm	0.64 cm	1.06 cm
Copper	0.18 cm	0.53 cm	0.95 cm
Lead	0.012 cm	0.068 cm	0.42 cm

The linear attenuation coefficient (μ) for prepared cement-ilumenite shield was 0.87 (cm^{-1}). Half Value Layer (HVL) for prepared cement-ilumenite shielding has been calculated at gamma ray energy 500 keV by substituting value μ = 0.87 cm^{-1} in equation 7. From the calculation process HVL was 0.80 cm. By comparing this result with results in table 3 for different materials we found that HVL for prepared cement-ilumenite lies between copper and lead, this means that at the same gamma ray energy (500 keV) the prepared cement-ilumenite better than copper and not better than lead.

Equation 8 has been used to calculate Tenth Value Layer (TVL) for cement-ilumenite shield at gamma ray energy 500 keV, When (I) was assumed to be equal (1/10 I_0).

$$T_{1/10} = 2.3/0.87 = 2.6 \text{ cm}$$

3.4. Comparison study

Figure 4 shows a comparison study between the data obtained with published research paper [7] at the same condition. From this figure it is clear that the obtained data was compatible and comply with other researchers.

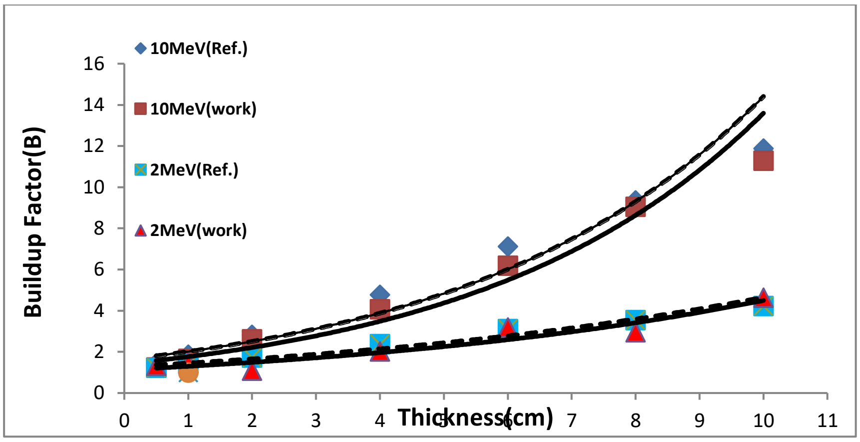

Fig. 4 Comparison of buildup factors obtained in this work with other researchers at the same condition.

The Egyptian Nuclear and Radiological Regulatory Authority (ENRRA) adopted IAEA GSR part 3 (Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards) as Egyptian regulation in the area of radiation protection. The result data (buildup factor and gamma absorbed dose rate) are in compatible and comply with Egyptian safety requirement when Cesium source (Cs^{137}), with activity (3mCi) at energy line 0.663 MeV and Cement-Illuminate shield, is used.

Conclusion

Gamma buildup factors for a point isotropic source of (Cement-Ilumenite) Shield were calculated for energies ranging from 0.5 to 10 MeV and shield thicknesses from 0.5 to 10 mfp. The buildup factors are obtained very accurately using various interactions between gamma and matter and latest cross-section available. There are inversely proportional between the energy of photons and the buildup factors. Also gamma absorbed dose decreases with increases the shield thickness. HVL and TVL were calculated. The obtained data was compatible and comply with national (Egyptian) and international (IAEA) regulations.

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