

Buildup Factor Measurement of Gamma Photons of Co-60 Radioactive Source in Polyester Composite Shields Fortified by Different Concentrations of CaFe_2O_4 Powder Prepared at Different Thermal Degrees

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ABSTRACT: The efficient and convenient substance to use as a shield against gamma photons depends on two important properties which are buildup factor and the coefficient of linear attenuation, so adoption of study of these two properties had been done in the polyester composite shield (PCS) supported by different concentrations (2%, 7%, 15%) of Spinel Ferrite (CaFe_2O_4) powder prepared at different final sintering degrees of temperature (sintering temperature) (800, 1000, 1200) °C. For the purpose of this study, system of Geiger detector and the Cobalt-60 radioactive source were used. By studying the nine different types of the (PCS) supported with different concentrations and preparation methods of a reinforcement substance powders in addition to pure polyester shield (PPS), found that the coefficient of the linear attenuation increases with increasing of the concentration and temperature degree of reinforcement substance preparation in the used polymer substance, while build factor value increase with increasing of the shield substance thickness and decreases with increasing of the sintering temperature and the reinforcement substance concentration. The study concluded that the shield with higher concentration of a reinforcement substance prepared at higher sintering temperature was more efficient than the other types to use as shields against the used gamma photons.

KEYWORDS: Buildup Factor, Gamma Photons, polyester Shield, Spinel Ferrite.

I. INTRODUCTION

The subject of the design of nuclear shields against gamma photons has great importance to withhold these photons or decreasing their severity to the allowed limits. Shields can be designed from different substances with different atomic numbers in form of composite substances due to ease of manufacture and forming them by simple ways according to the desired shape so that the subject of design them must be harmonization among the scientific, health and economic considerations [1]. Upon entering the photons of gamma to the substance, part of them interacts with the absorption and scattering interactions and the other part passes without any interaction. The first part constitutes a secondary ray or so-called interactive band (Nontransmission band) and the second part is defined as band noninteractive or transmission. The ratio between the number of photons interactive and non-interactive influential at a certain point to the number of photons noninteractive and influential at the same point is known as a photons numerical buildup factor [2]. Many researchers have studied different types of composite substances and different reinforcement substances with different concentrations to determine the possibility of using them as a nuclear shield against nuclear radiation,

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where these studies have shown that the shields have a good specification and a good possibility in the attenuation and weakening of fallen nuclear radiation depend on the thickness of the shield and the concentration of reinforcement substance, where the relationship is a direct correlation between them [1,3,4].

II. MATERIALS AND METHODS

Reinforcement substances have been prepared from the compounds of Spinel Ferrite, that is represents Calcium Ferrite which have a chemical formula of CaFe_2O_4 , using the method of ceramic (method of solid-state reaction). The final sintering temperature degrees (sintering temperatures), which used to preparing reinforcement substances, were three temperatures (800, 1000 and 1200°C) and have used in the form of powders to reinforce of pure Polyester Polymer so as to form composite shields samples. In general, the reason for the choice of Calcium Ferrite substance due to its own magnetic characteristics that makes it with high-absorbency for photons or rays, it is very important to choose the primary substances of high purity in order to avoid any effect on composite properties[9].

The required system of devices and measurement consists of the Australian origin detector of Geiger-Muller counter (GAT: PA1885-020, 030, type ABC), radioactive source of Cobalt-60-60 with activity of 0.699 μCi and half-life of 5.27 years gives Gamma photons with 1.253 MeV energy value and was placed on a distance of 12 cm from the detector window. The time of count was 1000s for detector operation voltage of 500V.

Samples of shields were manufactured from pure Polyester Polymer reinforcement by Spinel Ferrite powder prepared at different temperatures of sintering (800, 1000 and 1200°C) and with addition concentrations 2%, 7% and 15% of the powder to the polymer mass in the sample shield. Manufactured samples have cylindrical shapes with circular section diameter of 4 cm and thickness of 0.9 cm. To study the linear attenuation in the shields samples, the system of work has been put in a good geometrical arrangement as shown in fig. 1(a), which represents the good geometric arrangement or the system arrangement with collimators existence in order to get a narrow band of gamma photons by using two collimators of lead substance with dimensions of (5 \times 5 \times 1.5) cm where radioactive source collimator that contains a central circular hole amount of 0.5 cm placed at a distance 0.5 cm from the source and the detector collimator which has a central circular hole amount of 1.6 cm placed on distance 1.5 cm from the detector window.

III. THEORETICAL BASES

The Lambert-Pierre equation used to study the attenuation of gamma rays (absorption and scattering) inside the substance by measuring the variation of the well collimated photon beam (narrowband) intensity, by using collimators of lead substance for the good geometrical arrangement, with variation of the substance thickness which given by the following relation [5]:

$$N = N_0 e^{-\mu x} \dots\dots\dots (1)$$

where:

N - the shielded account rate.

N_0 - the initial account rate.

μ - the coefficient of linear attenuation in units of (cm^{-1}).

x - the shield thickness in units of (cm).

This equation only valid when the photons beam have been very narrow, parallel and mono-energy and the thickness of absorbent substance have been very little (in the case of the good geometrical arrangement).

When a large portion of the photons scattered and the secondary radiations reach detector, the geometrical arrangement called a bad geometrical arrangement (broadband) by raising collimators as shown in fig. 1(b), which represents the bad geometrical arrangement or the system arrangement without collimators existence, and due to the effect of secondary radiations in detector, attenuation in the case of broadband will be greater than it in the case of narrowband and a correction factor called buildup factor (B) of gamma photons will enter in this equation, as in the following relation [6]:

$$N = BN_0 e^{-\mu x} \dots\dots\dots (2)$$

From the equation (1) for the narrowband (good) we get:

$$\ln (N/N_0)_{\text{good}} = -\mu x \dots\dots\dots (3)$$

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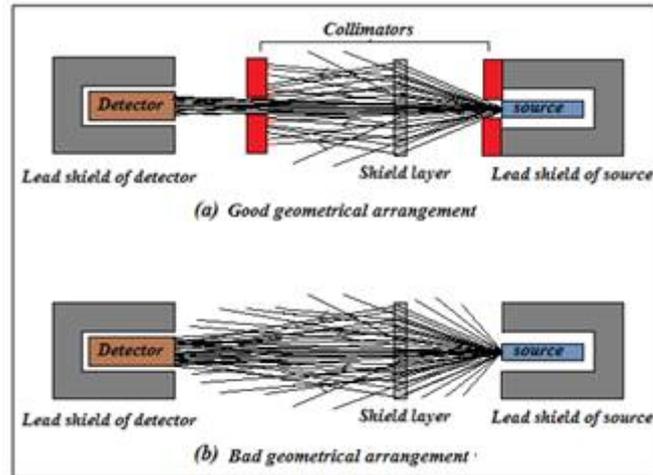


Fig.1 Measurement system arrangement for:

(a) The good geometric arrangement (with collimators existence), (b) The bad geometrical arrangement (without collimators existence).

And from the equation (2) broadband (bad) we get:

$$\ln(N/N_o)_{\text{bad}} = \ln B - \mu x \quad \dots\dots\dots (4)$$

Subtracting the equation (4) from the equation (3) produces:

$$-\ln B = \ln(N/N_o)_{\text{good}} - \ln(N/N_o)_{\text{bad}} \quad \dots\dots\dots (5)$$

By drawing the relation between $\ln(N/N_o)$ and (X) for both cases, one can find the value of buildup factor (B) as a function of thickness (X) [7].

The exponential relationship in equation (1) prevent a specific range existence of the photons or rays inside the substance, so the scientists were agreed on the term of mean free path (mfp) that represents the traveled distance average inside the substance before absorption of photons that is calculated by the following relationship:

$$\lambda(\text{cm}) = \frac{\int_0^{\infty} x e^{-\mu x} dx}{\int_0^{\infty} e^{-\mu x} dx} = 1/\mu \quad \dots\dots\dots (6)$$

This term is used as a appropriate unit in the study of traveled photons inside the substance where many variables such as the buildup factor defined in (mfp) terms as a measure of distance inside the substance or what is called depth of penetration [1].

Thickness of the substance in unites of (mfp) is given by [8]:

$$X(\text{mfp}) = \frac{x(\text{cm})}{\lambda(\text{cm})} = \mu x \quad \dots\dots\dots (7)$$

where X(mfp) is the depth of penetration of gamma photon inside the substance .

IV. RESULTS AND DISCUSSION

Certain codes to samples of shields were used and laid according to the type of each of them in table, so refer to them in plotted graphs easily and as shown in table 1 that represents the codes of samples, the concentration ratios of the reinforcement powder and the sintering temperature..

The results of calculations of this research have been arranged in a table 2, which includes coefficient of linear attenuation (μ) values in units of (cm^{-1}) as a function of the type of composite shield, and by calculation of the account rate logarithm $\ln(N/N_o)$ for all samples, the coefficients of linear attenuation (μ) were calculated from the plotted relationship between $\ln(N/N_o)$ and the shield thickness (X) in units of (cm), as shown in fig. 2 which shows $\ln(N/N_o)$ values as a function of thickness (x) of PPS and figs. 3, 4 and 5 which show $\ln(N/N_o)$ values as a function of thickness

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(x) of PCS800, PCS1000 and PCS1200 with different concentrations of reinforcement substance powder for each of the good and bad geometrical arrangement respectively.

Table1: Represents the code of the type of sample, the concentration ratios and the sintering temperature.

No. of Sample	Type of Shield	Code
1	Pure Polyester Shield	PPS
2	Polyaster + 2% Spinel Ferrite Powder prepared at 800C ^o	PCS800 (2%)
3	Polyaster + 7% Spinel Ferrite Powder prepared at 800C ^o	PCS800 (7%)
4	Polyaster + 15% Spinel Ferrite Powder prepared at 800C ^o	PCS800 (15%)
5	Polyaster + 2% Spinel Ferrite Powder prepared at 1000C ^o	PCS1000 (2%)
6	Polyaster + 7% Spinel Ferrite Powder prepared at 1000C ^o	PCS1000 (7%)
7	Polyaster + 15% Spinel Ferrite Powder prepared at 1000C ^o	PCS1000 (15%)
8	Polyaster + 2% Spinel Ferrite Powder prepared at 1200C ^o	PCS1200 (2%)
9	Polyaster + 7% Spinel Ferrite Powder prepared at 1200C ^o	PCS1200 (7%)
10	Polyaster + 15% Spinel Ferrite Powder prepared at 1200C ^o	PCS1200 (15%)

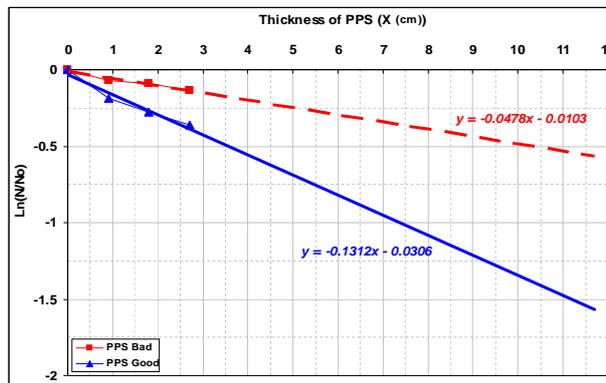


Fig. 2 Ln(N/N₀) values as a function of thickness (x) of PPS for each of the good and bad geometrical arrangement by using Co-60.

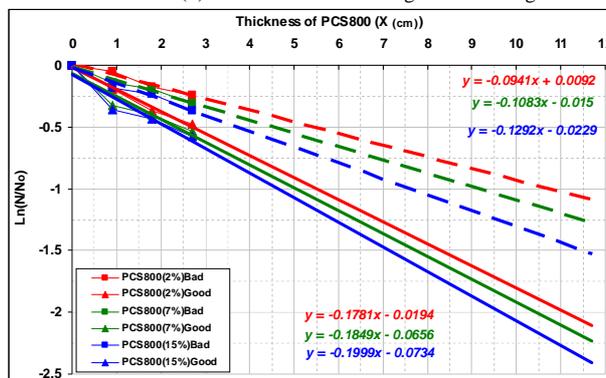


Fig. 3 Ln(N/N₀) values as a function of thickness (x) of shields PCS800 with different concentrations of reinforcement substance powder for each of the good and bad geometrical arrangement by using Co-60.

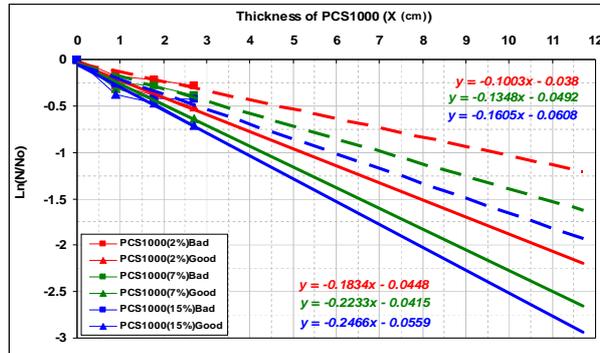


Fig. 4 $\ln(N/N_0)$ values as a function of thickness (x) of shields PCS1000 with different concentrations of reinforcement substance powder for each of the good and bad geometrical arrangement by using Co-60.

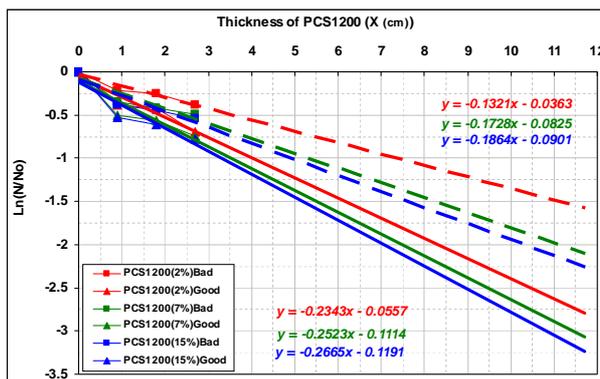


Fig. 5 $\ln(N/N_0)$ values as a function of thickness (x) of shields PCS1200 with different concentrations of reinforcement substance powder for each of the good and bad geometrical arrangement by using Co-60.

The straight line slope of this relationship in any one of shields in the case of the good geometrical arrangement represents the coefficient of linear attenuation for a shield substance against gamma photons with energy value of 1.253MeV, where the values of this coefficient stretched from 0.1312cm^{-1} for pure polyester shield (PPS) to 0.2665cm^{-1} for polyester composite shield supported Spinel Ferrite powder with concentration of 15% prepared at sintering temperature of 1200C° (PCS1200(15%)), thus it becomes clear that the latter is the best in the attenuation of gamma photons compared to other shields used in this research, as clearly shown in the table 2 and the fig. 6 which represents a sketch of the coefficients values of the linear attenuation (μ) as a function of the concentration and type of the reinforcement powder in the shield.

Table 2: linear attenuation coefficient (μ) values in units of (cm^{-1}) as a function of the type of composite shield by using Co-60.

Type of Shield	PPS	PCS800			PCS1000			PCS1200		
Powder Concentration	0%	2%	7%	15%	2%	7%	15%	2%	7%	15%
$\mu(\text{cm}^{-1})$	0.1312	0.1781	0.1849	0.1999	0.1834	0.2233	0.2466	0.2343	0.2523	0.2665

Fig. 6 shows the increasing in linear attenuation coefficients with increasing of each of the reinforcement powder concentration and sintering temperature. This act is a natural behaviour of attenuation coefficient [4, 10]. From figs. 2,3,4 and 5 we can get $\ln(N/N_0)$ values corresponding a wide range of thickness values for all linear relationships in these figures by using the special equation of each line of those lines graphically described, and using equation (5) we can find a wide range of buildup factor values.

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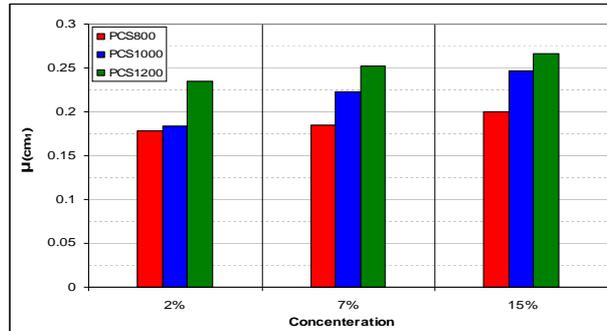


Fig. 6 The sketch represents the values of the linear attenuation coefficient (μ) in units (cm^{-1}) of gamma photons emitted from Co-60 as a function of the concentration and type of the reinforcement powder in the shield.

Coefficient values of the linear attenuation were used to calculate of the substance thickness in units of mean free path (mfp) as shown in table.3 that contains the corresponding values of buildup factor (B) for all used shield types.

Table 3: Values of Buildup Factor (B) as a function of the depth of penetration in units of (mfp) for all used shield using Co-60.

X (mfp)	Buildup Factor									
	PPS	PCS800 (2%)	PCS800 (7%)	PCS800 (15%)	PCS1000 (2%)	PCS1000 (7%)	PCS1000 (15%)	PCS1200 (2%)	PCS1200 (7%)	PCS1200 (15%)
0.25	1.1958	1.1576	1.1656	1.1479	1.1269	1.0952	1.0857	1.1364	1.1142	1.1097
0.5	1.4019	1.3022	1.2927	1.2539	1.2624	1.2092	1.1847	1.2672	1.2088	1.1967
0.75	1.6435	1.4650	1.4337	1.3696	1.4141	1.3350	1.2927	1.4131	1.3115	1.2906
1	1.9267	1.6480	1.5900	1.4959	1.5840	1.4739	1.4106	1.5759	1.4228	1.3918
1.25	2.259	1.8540	1.7634	1.6339	1.7744	1.6274	1.5392	1.7574	1.5436	1.5009
1.5	2.6480	2.0857	1.9557	1.7847	1.9877	1.7967	1.6795	1.9598	1.6747	1.6186
1.75	3.1043	2.3463	2.1689	1.9493	2.2266	1.9837	1.8326	2.1855	1.8169	1.7456
2	3.6393	2.6395	2.4055	2.1292	2.4942	2.1901	1.9997	2.4371	1.9712	1.8825
2.25	4.2665	2.9693	2.6678	2.3256	2.7940	2.4181	2.1819	2.7178	2.139	2.0301
2.5	5.0018	3.3404	2.9587	2.5402	3.1298	2.6697	2.3809	3.0308	2.3202	2.1893
2.75	5.8638	3.7578	3.2813	2.775	3.5060	2.9475	2.5979	3.3798	2.5172	2.3610
3	6.8744	4.2274	3.6391	3.0305	3.9274	3.2543	2.8348	3.7690	2.7309	2.5462
3.25	8.0591	4.7557	4.0360	3.3101	4.3995	3.5929	3.0933	4.2031	2.9628	2.7458
3.5	9.4480	5.3499	4.4761	3.6155	4.9282	3.9668	3.3753	4.6871	3.2144	2.9612
3.75	11.076	6.0185	4.9642	3.9491	5.5206	4.3796	3.6830	5.2269	3.4873	3.1934
4	12.9851	6.7706	5.5055	4.3135	6.1841	4.8354	4.0188	5.8289	3.7835	3.4438
4.25	15.2229	7.6167	6.1058	4.7114	6.9274	5.3386	4.3852	6.5001	4.1048	3.7139
4.5	17.8464	8.5685	6.7716	5.1461	7.7599	5.8942	4.7850	7.2487	4.4533	4.0052
4.75	20.9220	9.6392	7.5100	5.6209	8.6927	6.5076	5.2213	8.0835	4.8314	4.3193
5	24.5277	10.8437	8.3289	6.1395	9.7375	7.1848	5.6973	9.0144	5.2417	4.6580

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Fig. 7 shows values of buildup factor as a function of the depth of penetration of the gamma photon in substance in units of (mfp) using Cobalt-60 radioactive source (Co-60). This figure shows that the buildup factor value increases with increasing of the shield thickness and this result corresponds with previous studies [11, 12].

From figs. 6 and 7, one can conclude Spinel Ferrite powder by concentration of 15% prepared at sintering temperature of 1200C° (PCS1200(15%)) is the better to use as a reinforcement substance with Polyester Polymer in shielding. In other words, we can say that the buildup factor decreases with increasing of sintering temperature of Spinel Ferrite powder preparing and with increasing of powder concentration in composite shield samples.

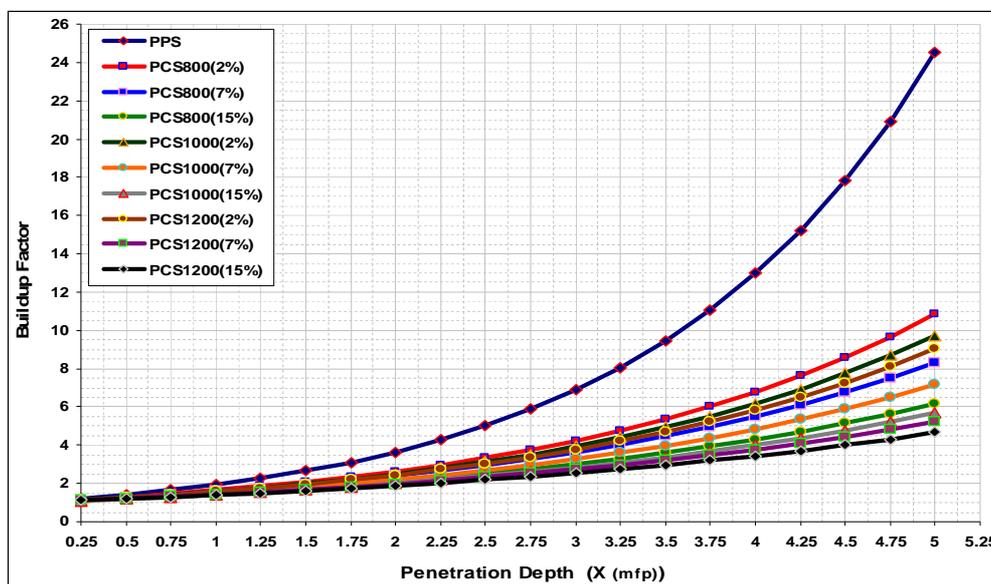


Fig. 7 Buildup factor values as a function of depth of penetration in (mfp) units for all composite shield type by using Co-60.

Fig. 8 shows that the buildup factor as a function of the type and concentration of reinforcement powder in shield for penetration depth value of 1 mfp, where demonstrated by this figure that the buildup factor in any type of shields is lowest value at the highest concentration value (15%) and its value is the lowest at the shield of PCS1200.

To illustrate buildup factor values variation with difference of the concentration of reinforcement substance for each type of prepared shield (at 800, 1000 and 1200C°), we have been drawing their relationship at the values of the shield thickness ranging from 1-5 mfp and for each sintering temperature as in figs. 9, 10 and 11 respectively.

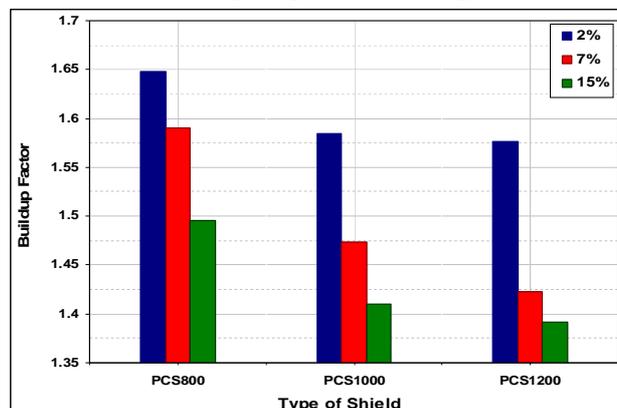


Fig. 8 The scheme represents the values of the buildup factor as a function of

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the type and concentration of reinforcement powder in shield for (1 mfp) depth of penetration.

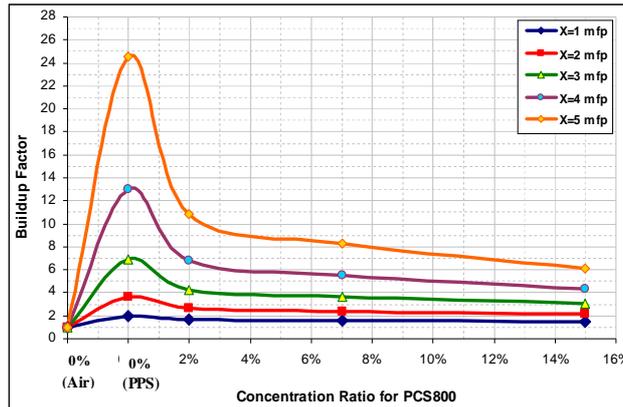


Fig. 9 Variation buildup factor values with difference of the concentration of reinforcement substance powder for PCS800.

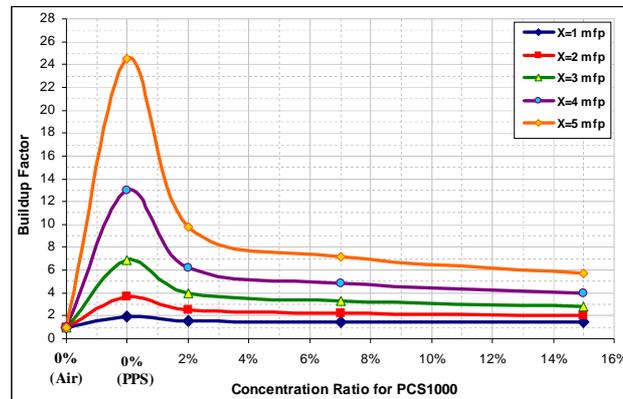


Fig. 10 Variation buildup factor values with difference of the concentration of reinforcement substance powder for PCS1000.

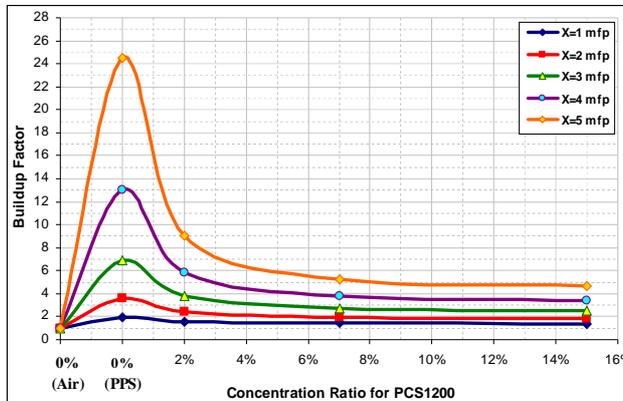


Fig. 11 Variation buildup factor values with difference of the concentration of reinforcement substance powder for PCS 1200.

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The last three figures illustrate that the decreasing in buildup factor values starting from the shields of pure polymer and even greater value of the powder concentration, this applies to all types of composite shields classified by the sintering temperature which used to preparing of the reinforcement substance powder. In other words, we can say that this behaviour is a symmetrical in all types of three reinforcement powders but with different values for each buildup factor values and for each thickness value, where the values of the latter (PCS1200) with concentration 15% gives smaller value for buildup factor noting that this type of shield better and more appropriate than the other used for in this research to be used as a shield against gamma photons emitted from Co-60 isotope.

Comparison for the coefficient values of the linear attenuation and buildup factor of shields composite with the highest concentration of the reinforcement substance that is added to the shield of pure polyester polymer which calculated in current research with the some of them values of the traditional shields in previous studies was developed to prove the efficiency of manufactured shields used in this study, as shown in table.4.

Seen from this table that the composite shields possesses a coefficient of linear attenuation greater than the aluminium shield, and the values of its buildup factor values at penetration depth value of 1, 2 mfp be less than the lead shield which is considered one of the best shielding substances, but at the penetration depth value of 3 mfp, the PCS1200(15%) shield has a buildup factor value less than its value in the other traditional shields including lead shield.

In general, the buildup factor values for the three composite shields with a concentration of 15% are less than its values in the shields of Al, Fe and Cu at the penetration depth values of 1, 2, 3 and 4 mfp.

Table 4: Comparison of coefficient of linear attenuation (μ) and buildup factor (B) values of pure and composite polyester shields for concentration of 15% and depth of penetration ($X=1,2,3$ and 4 mfp) with some traditional substance shields.

Type of Shield	μ (cm ⁻¹)	B			
		X (mfp)			
		1	2	3	4
PPS	0.1312	1.9267	3.6393	6.8744	12.9851
PCS 800(15%)	0.1999	1.4959	2.1292	3.0305	4.3135
PCS 1000(15%)	0.2466	1.4106	1.9997	2.8348	4.0188
PCS 1200(15%)	0.2665	1.3918	1.8825	2.5462	3.4438
Al	0.1490 ^a	2.015 ^c	3.3400 ^c	4.8600 ^c	6.5750 ^c
Fe	0.4210 ^a	2.0454 ^c	3.2650 ^c	4.6350 ^c	6.1650 ^c
Cu	0.4720 ^{a,b}	2.1292 ^b	4.8523 ^b
Pb	0.67158 ^b	1.7550 ^c	2.2600 ^c	2.7300 ^c	3.1500 ^c

* a, b and c refer to the references of 13, 2, 14 respectively.

V. CONCLUSIONS

The important conclusions that have been obtained from this research, as follows:

1. The ceramic method used to prepare Spinel Ferrite in this work gives substance has a good attenuation of Gamma photons.
2. Final sintering temperature degree (sintering temperature) values have an important influence in forming of Spinel Ferrite material because they affect the granular size and portability of Gamma photons attenuation when used as a reinforcement powder in the polyester shield.
3. Coefficient value of the linear attenuation increases with increasing of the substance shield thickness and decreases with increasing of sintering temperature and concentration of the reinforcement powder in polyester shield.
4. Buildup factor value increases with increasing of the substance shield thickness and decrease with increasing of sintering temperature and concentration of the reinforcement powder in polyester shield.
5. The shield of PCS1200 (15%) is the best to use as a reinforcement substance with polyester polymer in shielding.

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