Investigation of Gamma Ray Shielding by Polymer Composites

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Abstract The present work deals with the shielding properties of polymer composites using gamma ray emitted from (Cs-137), point source. Polymer composites with different Lead ratio (0, 50, and 70 wt. %) with different lead size (powder and shot ball) have been prepared. To clarify the difference in the spectrum absorption gamma rays through the process of exponential equations graphic representation of the count rate as a function of composite thickness. The incident and transmitted intensities were measured using gamma spectrometer Sodium Iodide with traces of Thallium Na (Tl) scintillator detector connected to a multi-channel analyzer using the (USC-30) program. The linear attenuation coefficient were obtain of the prepared samples through graphic representation of natural allegartm count rate as a function of the thickness of absorbent material the obtained data are presented in the form of gamma spectra behind the prepared samples. Linear attenuation coefficients (µ) gamma ray were calculate .The results show that, the density of the composites was observed to increase with increase filler loading .The result shows a directly relationship, between the thickness of the absorbent material and linear attenuation confection. The linear attenuation coefficient of the composites was found to increase with increased filler content in the composites and the highest value was 0.277 cm⁻¹ was found for 70 wt. % of lead powder. The results shows that, the composites prepared of good absorption for gamma low energy the displayed results indicated that the constructed materials showed good radiation protection properties.

Keywords: polymer, lead, gamma rays, intensity (I), linear attenuation coefficient (µ)

1. Introduction
Gamma-ray which is used widely in medical care, electricity generation, and industry, it's the most penetrating of ionizing radiation that is known to be harmful to human health. The shielding for radiation purposes are based on the type and energy of the radiation itself. Therefore, high density materials are used to protect life from Gamma hazardous radiation [1]. Lead bricks or high density concrete are often used. In addition, other metallic shields include copper, bismuth, tungsten, steel etc. [2]. However lead is an excellent choice over all these shielding materials because of its higher atomic number, density, and low cost [3]. However, lead is toxic and aprons are so heavy for personal shielding, Materials which are environment friendly, nontoxic and a polymer based can be used with both personal and material lighter shield[4 ].Recently, there was a continuous demand for improved polymers for use as shielding materials [5]. Polymers are inefficient to stop gamma rays on their own. [4] So compound material filled with radiopaque powder is now becoming more and more popular [6].
Nowadays, researchers are generally studying various polymers and high density metals for radiation protection, in (2009) Harish, et al. Had been used unsaturated polyester resin as matrix material and used lead (II) oxide as filler. They found linear attenuation coefficient of the composite with 50% filler amount as 0.206 cm⁻¹. Thus they reported that their composite’s attenuation performance was better than cement, copper and silver [7]. In (2011) Shafik,S.S . et al. had been studied the linear absorption factor for gamma rays were studied in shields from epoxy reinforced by lead powder and by aluminium powder, for NaI(Tl) scintillation detector using two radioactive sources (Co-60 and Cs-137). The experimental results showed that the linear absorption factor increased with increasing the concentration for the powders and decreased with increasing thickness of the shields [8]. In 2012 K.H.Mahdi et al. had been studied attenuation Coefficients for particulate Al, Fe, and Pb with different weight percentages (10,20,30,40,50)wt % reinforced unsaturated polyester resin . The results show the attenuation coefficients will increase as the concentration of particulate increased while it decreases when the gamma energy increase [5] in (2013). Dhameer A. Mutlak and Ahmed .H. Ali had been studied the properties of gamma shielding by using epoxy /lead powder and lead shut composite and found linear absorption caffeine[9]. In (2014) E. Eren Belgin et al. had been studied A Novel Metal Oxide Filled Polyethylene Based Composite Shielding Material for Protection from Harmful Effects of Ionizing Electromagnetic Radiation [3].In (2015) Le Chang et al had been studied the preparation and characterization of tungsten/epoxy composite for γ-rays radiation shielding [10].in (2016) AL fakhar .M, et al. had been measured experimentally and calculated for both pure silicone, and silicone supported with lead. Two sizes of lead particles have been used the gamma radiation source have been used 137Cs. The results showed that the attenuation coefficient of silicone with lead additive is greater than the attenuation coefficient of silicone alone [11]. In 2017 Najwa .J. Jubier had been studied the linear attenuation coefficient for particulate reinforced polymer- based composites. Unsaturated polyester resin (UPE) was used as matrix filled with (10wt. %) granite and then added different concentrations of (Fe) iron metal powders (5, 10,15and20) wt. % as reinforcements. The results show, as the metallic particulates (Fe) content increased, the linear attenuation coefficients will increase too [12].

2. Theoretical Concepts of Gamma Interactions.

When gamma rays traverse matter, some are absorbed, some pass through without interaction, and some are scattered as lower energy photons in directions that are quite different from those in the primary beam [13].

Gamma radiation can only be reduced in intensity by increasingly thicker absorbers; it cannot be completely absorbed. If gamma-ray attenuation measurements are made under good geometry, narrow beam of radiation The attenuation of gamma-ray when they pass through an absorber of thickness (x) sketched in Figure 1 is expressed by the exponential law equation (1) [14].

\[ I = I_0 e^{-\mu x} \]
where $I_0$ is incident gamma ray, $I$ is attenuated gamma ray, $X$: thickness, $\mu$: is the linear attenuation coefficient.

The interaction is expressed through the linear attenuation coefficient ($\mu$) which is depend on the energy of the incident gamma ray on the material being traversed [15]. Gamma ray interaction with matter, in three major types play an important role in radiation measurements: photoelectric absorption, Compton scattering, and pair production [16].

2.1 Photoelectric Effect
The photoelectric effect is an interaction between a photon and a bound atomic electron. As a result of the interaction, the photon disappears and one of the atomic electrons is ejected as a free electron, called the photoelectron [17].

2.2 Compton Scattering
In the Compton process, the photon interacts with an atomic electron as though it were a "free" electron, that is, the binding energy of the electron is much less than the energy of the bombarding photon. In this interaction, the electron receives some energy from the photon and is emitted at an angle $\theta$ the photon, with reduced energy, is scattered at an angle $\Phi$ [18].

2.3 Pair Production
The photon interacts strongly with the electromagnetic field of an atomic nucleus and gives up all its energy in the process of creating a pair consisting of a negative electron ($e^-$) and a positive electron ($e^+$). Because the rest mass energy of the electron is equivalent to 0.511 MeV, a minimum energy of 1.022 MeV is required to create the pair of electrons. [18]

The relative contributions of these three effects to total absorption, depends primarily on the energy of the gamma ray and the atomic number of the absorber. The sum of the probability of interaction by photoelectric $\mu_c$, Compton scattering $\mu_t$ and pair produce $\mu_k$ is attenuation coefficient $\mu$ equation [19].

$$\mu = \mu_c + \mu_t + \mu_k \quad \cdots \quad (2)$$

Where the subscripts C, $\tau$, and $\kappa$ denote Compton scattering, photoelectric effect and pair production, respectively. In Eq. 2 the parameter $\mu$ is linear attenuation coefficient of the material for gamma rays with appropriate energy and $x$ is thickness of the material. According to Eq. 2, $\mu$ can be determined by using linear graph of $\ln (I/I_0)$ versus $x$ of the material.

3. Material and Methods

The materials used to prepare the composite samples as a shield with different thicknesses of this work are; Epoxy Resin (EP) EUXIT 50 (Swiss Chem.), polyurethane (PU) EUXIT TG10 (Swiss Chem.) Polyurethane (PU) EUXIT101 and Lead (powder and shot/ball).

3.1 Preparation of EP/PU Blends
1. An exact amount of special hardener is added to the resin with weight ratio of hardener to resin (1:3) using a sensitive electronic balance of sensitivity (0.01gm). The content is mixed thoroughly by a fan type stirrer until the mixture becomes homogeneous.

2. A sufficient amount of isocyanate hardener is also added to resin (polyol) with weight ratio of hardener to resin (1:9). The content is also mixed thoroughly by a fan type stirrer before adding epoxy to the mixture.

3. The epoxy/polyurethaneTG10 blends are prepared with weight ratio of both polymers as (%EP+%PU) multiple blends with different ratio and different thickness were done.
4. Also made another blends but used the polyurethane TG10 polyol (without hardener) with epoxy (puTG10 polyol+%EP) by the same manner of the previous Preparation were prepared the blend

5. The (resin)/polyurethane PU101 blends are prepare with Weight ratio of both polymers as (EP%+ PU101%) made multiple blend with different ration this blends appear flexible mixture becomes ready after they are stored at room temperature for 72 hours

6. The best compatibility blends after made the bending tests according to ASTM (American Society For Testing and Materials) standard D-790,[20] and tensile test D638[ 21] was , (80%EP+ 20%PUTG10 polyol) and (30resin+70%PU101)

The mixture was placed in a circular templates its Diameter proportional to the Diameter Detector For the most accurate results as shown in figure (2). The samples chose and cod as in table (1)

![Figure 2. Different types of samples](image)

**Table 1: Blends' sample codes**

| Samples choice                                                                 | Blend code |
|--------------------------------------------------------------------------------|-------------|
| 20% polyurethane ( PU)TG10 without hardener +80% epoxy (EP)                     | B           |
| 70% polyurethane(PU)101 +30% resin                                             | Y           |

**3.2 Preparation of Lead /Ep/PU Composite**

By the same manner of the previous preparation of blend, using the best ratio of blends, the lead/EP/PU composites will be prepared different weight ratios of lead(0%,50% & 70%), and different lead sizes shot boll (1mm) and powder size of (500µm & 200µm), as in table (2).

**Table 2. The different type of composites**

| Blend code | Lead size Pb | Lead ratio |
|------------|--------------|------------|
| M-B        | Shot/ball (1mm) | 70%        |
| L-B        | Shot/boll (1mm) | 50%        |
| N-B normal | Without pb     | 0          |
4. Experimental setup
The experimental arrangement with the electronic configuration is schematically shown in Figure 3. The assembly was placed in lead castle. The energy calibration was performed using a set of standard gamma sources.

![Schematic of experimental setup](image)

5. Gamma Irradiation Tests of Composites
All the samples (composites) of lead powders and lead shots were exposed to the gamma source ($^{137}\text{Cs}$) with energy 0.662MeV point sources, using narrow beam geometry. Strength of 4.686µCi half-life (30 y) [22] supplied by Baghdad university physics department nuclear laboratory. Accumulative gamma ray spectra is 1800sec Number of the counts per second (cps) recorded by the detector after placing composite materials between the source and the detector were calculated by using net areas of the photo peak. Thus (cps) values after leaving of gamma rays from the composite materials were determined. The blank measurements, helded for the source without placing any other material between source and detector, were also analysed by the same way to calculate cps values of the gamma rays before entering to the composite materials. After determination of all (cps) values attenuation coefficient were calculate.

6. Results and Discussion
The variations of count rate that was measured for each specimen that was differ in their thickness and lead weight ratio (zero, 50, 70 %) are shown in figures 4 and 5.

It was found from figure 3 that the minimum attenuation of gamma ray was with the (N-Y) sample which had a zero percent of lead, while the attenuation amount of the (L-Y) samples was higher because it contains 50% of lead shot. As the lead particles size decrease to a (200-300) micrometres as given by the (K-Y) sample which contains 50% of lead powder increase more of gamma ray attenuation where it was found by compared with other previous samples. Then, a greater attenuation was noticed as the sample (M-Y) was loaded with 70% lead shot. The maximum attenuation was clear that, by (P-Y) sample which was loaded with 70% lead powder.
The results of Figure 5 showed that the composite sample (N-B) was the maximum recorded count rate of gamma ray the cause behind this maximum because it was free of lead, while the curve of the count rate of the (L-B) sample decreased to a value lower than that of the previous sample because the latter contained 50% lead shot. A more noticeable decline of the count rate curve was found with the (K-B) sample which contained a 50% lead powder. The curve that represents the (M-B) sample which contained 70% lead shot which shows deeper decrease of count rate, compared with the results of the previous samples. The maximum attenuation of the gamma ray was clearly noticed that (P-B) composite sample which was loaded with 70% of lead powder.

The results of figures (5 and 6) described the intensity of gamma ray decrease almost exponentially with increasing the shield thickness this behaviour perfectly applicable with the theoretical concept of the equation (1). In general, the results agree largely with the results of previous studies, Dhameer A. Mutlak and Ahmed A. 2013 and Najwa, J. Jubier.2017, who state that for different kinds of shields and that the interpretation of this is that the increase in the number and intensity of reinforcement material due to increasing the total cross-section of the interaction of Gamma rays with matter. Thus shield dissipated the biggest part of incident rays away from the path of the falling beam.
6.1. Linear Attenuation Coefficient (μ) of γ-Ray

Logarithms of the transmission ratio (I/I₀) were plotted as a function of the thickness for each sample and from the regression lines of the measured values in figures (6 and 7) the value of μ was obtained for each sample as (μ₁, μ₂, ..., μ₅) where the exponent depends on the energy of the gamma energy and the atomic number of the absorber. The graphical representations of the linear attenuation coefficients were compared for each of the prepared samples as shown in figure 6. It was found that the samples (N-Y) had lowest linear attenuation coefficient of gamma ray, while the samples (L-Y) had a larger attenuation than the previous one. The attenuation value that was obtained from the (K-Y) sample showed a more increase as compared with the other two previous ones. In the same manner, the (M-Y) sample caused more attenuation of gamma ray compared with attenuation values of the previously examined samples. The maximum amount of attenuation was achieved by using the (P-Y) sample where the regression line showed the maximum decrease by compared with all of the tested samples.

![Figure 6. Shows (ln I/I₀) as a function of thickness of the Composites shields](image)

The same procedure was repeated with B blend samples. The regression lines of the B blend samples showed a difference among the linear attenuation coefficients of each of B blend samples as a function a sample thickness as shown in figure 8. The (N-B) sample showed the lowest (μ) of gamma ray, while the (L-B) sample had a largest attenuation coefficient as compared with previous one. A larger attenuation value was obtained by using the (K-B) composite sample when it was compared with two previous ones, the linear attenuation coefficient of the (M-B) sample was highest than the others previous samples, but the maximum attenuation was found with the (P-B) sample.
**Figure 7.** Shows \((\ln I/I_o)\) as a function of thickness of the Composites shields

The first point noted from figures (6 and 7) is the linear attenuation coefficient of composite increases with increasing thickness of shields (composite) as explain previously. These findings are conformal by the observed results of Mutlak DA, Ali AH [9]

The second point the linear attenuation coefficient increased with increasing filler loading values.( lead ratio) because increasing the lead ratio led to increase the atomic effect and density effect of the composite due to present Pb which is (high atomic number and high density ) that increase with lead particles loading values. Increasing filler content in composites with a fine dispersion of high density filler should offer more interaction probability for photons and hence better shielding properties (Harish, et al 2009)[7].

If concentration of metal powders increased, the absorption process will also increase and this means an increase in the \((\mu)\) values. (Mahdi et al, 2012)[5]

A strong positive correlation (0.99 to 0.97) was found between the \((\ln I/I_o)\) of the two types of the examined blends' samples (Y and B) and the thickness of these samples as shown in figures (6 and 7).

Linear attenuation coefficient as function of lead powder and lead shots were tested in composites as tabulated in table (3) and plotted in figures 8and 9 ,the column (3) in table( 3) apparent the result of density of each sample increased with the increment of filler content, a phenomenon which was also observed by Harish et al 2009[7].

**Table 3.** Composite code linear attenuation coefficient

| No | Composites code | \(\rho_{eff} \ g/cm^3\) | Leaner attenuate Coefficient \(\mu cm^{-1}\) |
|----|----------------|----------------|----------------------------------|
| 1  | N-Y            | 1.0144         | 0.1251                           |
| 2  | L-Y            | 1.862          | 0.137                            |
| 3  | K-Y            | 1.862          | 0.177765                         |
| 4  | M-Y            | 2.797          | 0.1878                           |
| 5  | P-Y            | 2.797          | 0.2775                           |
| 7  | N-B            | 1.0988         | 0.096838                         |
| 8  | L-B            | 2.0034         | 0.17786                         |
| 9  | K-B            | 2.0034         | 0.17796                         |
Figures (8) and (9). Experimental results for linear attenuation coefficient ($\mu$). The improved shielding capability of (PU/EP lead) composites could be clarified by the way that, polymer (polyurethane/epoxy) alone matrix is a bad shielding material, however, when some filling add to it, it was modified and become a good shielding material for example the $\mu$ value (0.1251 cm$^{-1}$) for pure polymer (N-Y) sample while noticeable increase in (P-Y) composite to (0.2723 cm$^{-1}$). These confirm the results observed by AL fakhar M et al., 2016 [11].

|   |   |   |   |
|---|---|---|---|
| 10 | M-B | 2.987 | 0.25656 |
| 11 | P-B | 2.987 | 0.2723 |

From figures 8 and 9 one can observed that with decrease lead particles size the liner attenuation coefficient values increase. The linear attenuation coefficient of shield that is prepared from polymer with lead powder (micro size) was greater than the linear attenuation coefficient of the lead particle big size (lead shot ball) for example the $\mu$ for P-Y compsite was 0.2775 cm$^{-1}$ while for M-Y compsite was 0.1878 cm$^{-1}$ and the liner attenuation coefficient was 0.2723 cm$^{-1}$ for the composite (P-B) while 0.2565 cm$^{-1}$ for (M-B) composite this can explain how the incident radiation beam enters each attenuator the particles of small size present larger targets for the radiation to strike and hence the chance for interaction is relatively high but in the case of the big particle size absorber however the blanks between particles are large and hence the chances of interactions are reduced as in figure (9) the result confirm the results observed by Jaffer HI et al., 2011 and AL fakhar M et al., 2016[23], [11].
7. Conclusion
1. The samples manufactured in the present work are good absorbent of gamma radiation agents other pure material. The characterized samples also manufacturer properties such as light weight and easy of manufacturing, transportation and smooth installation and moulding to the desired shape can make good attenuation materials for radiation with a large range of applications (medical and environmental).

The composite sample (P-B) with lead powder ratio (70%) can be used as portable Perrier due to stiffness with high linear attenuation coefficient. While the composite (P-Y) with lead powder ratio of 70% can be used as CT Breast Shields, CT eye shield.

2. Using of the lead micro size with polymer blend in composite is better than the shot ball lead, for high attenuation of gamma radiation.

3. Attenuation of gamma ray is increased by increasing the lead particles ratio.

4. As the composite sample thickness increases, the attenuation coefficient will be increase accordingly.

5. The density of a composite sample increases with increasing the lead ratio.

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