Experimental study of some shielding parameters for composite shields

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Abstract. In this study radiation protection shields have been prepared consist of composite materials have epoxy as a basis material and different reinforcing materials C Ni PbO and Bi with various reinforcing ratios 10 20 30 40 50 % and dimensions 1 ×10 ×10 cm For examination the suitability of using this shields to protect from gamma ray some shielding parameters were calculated like Linear attenuation coefficient $\mu$ Effective atomic number $Z_{eff}$ Heaviness and half value thickness $X_{1/2}$ for energy rang 1218 – 1480 KeV These parameters have been measured by using sodium iodide system NaI{Tl with deferent radiation sources $^{152}\text{Eu}$ $^{60}\text{Co}$ and $^{137}\text{Cs}$The results show that this parameters are effected by the reinforcing ratio and gamma ray energy it is found the linear attenuation coefficient and atomic effective number increases with reinforcing ratio increases and decreased with energy increasing especially with high concentrations 40 50 % and at low energies $E_{\gamma} < 0662$ MeV with certain energy while the values of $X_{1/2}$ is decrease with reinforcing ratio increases Heaviness was calculated too for all shields with respect to lead from its values we found that this shields lighter than lead which make it preferable to traditional material such as lead and concrete

Key words Attenuation coefficient Composite materials Gamma rays Shielding

1 Introduction

The continuation of development in nuclear technology led to make the radiation sources intervention in many relevant fields such as agriculture industry medicine nuclear power generation and scientific research[1] so the nuclear shields used to reduce the exposure to nuclear radiation and their secondary interactions with the material and to minimize the effects on human tissue[2] Most of these shields are made from different types of materials depending on the energy type of radiation availability of the shielding material [3] The polymerbased composites such as polyethylene polystyrene and epoxy have been selected in the field of radiation protection[4]In the recent years composite materials are employed in the gammaray shielding and showed good efficiency in this field Composite materials are multiphase materials that are obtained by artificial combination of different materials so as to attain properties that the individual components by themselves cannot attain[5] In our study we use composite material consist of epoxy as based material and C Ni PbO and Bi as reinforcing material with five reinforcing ratios 1020304050 %
2. Experimental part

2.1 Counting system for gamma ray

The gamma rays counting system which is used in the search shown in figure 1

![Diagram of counting system](image)

**Figure 1** Diagram of counting system

2.2 Geometric arrangement of the system

For studying the attenuation coefficients we used a collimator to get a good geometry arrangement. This collimator made of lead with dimensions 5x10x20 cm. The detector was placed at 20 cm from the source. Two collimators were used: the first placed near the source and the second placed near the detector. This arrangement was used to measure the total linear attenuation coefficient. This arrangement was shown in figure 2.

![Good geometric arrangement for system](image)

**Figure 2** Good geometric arrangement for system

2.3 Materials

Epoxy resin was used as a matrix in the preparation of polymeric composite material which is one of the thermosetting polymers types. The form of this resin will change from liquid to solid state by adding hardener which is transparent liquid added to the epoxy resin by 3 grams per 100 grams of resin at room temperature. The reinforced materials are in powder form to get many types of composites as in table 1.
Table 1 Reinforcement materials

| Name of composite | Matrix | Reinforcement |
|-------------------|--------|---------------|
| Comp1             | Epoxy  | C             |
| Comp2             | Epoxy  | Ni            |
| Comp3             | Epoxy  | PbO₂          |
| Comp4             | Epoxy  | Bi            |

3. Theoretical part

3.1. Linear attenuation coefficient

The linear attenuation coefficient $\mu$ is one of the most important parameters that describe the gamma rays penetrating process which depends on the energy of incident photons and atomic number or effective atomic number of the target and it is considered as the main factor for the derivation of other shielding parameters [6]. When a package of gamma rays is passing through a substance each photon packet of photons either go out without interaction or displaced entirely from the package brokered by absorption or scattering. If $I_0$ is the gamma rays original intensity which falling off on the slice thickness $x$ the intensity of outgoing $I_x$ is given by the following [7]

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

Where $\mu$ total linear attenuation coefficient

To apply the above equation there are two conditions must be provided the thickness of the absorbent material is to be small and the gamma rays beam is to be narrow and monoenergetic.

3.2. Effective atomic number

The effective atomic number is one of the important parameters for the interaction of photons with the matter it is included in many of the technological and engineering fields [8]. The atomic number of composite materials is not represented by intervalued as in the case of the elements but represents a numerical quantity called the effective atomic number which is calculated based on the percentage of the participation of each element in the composite material [9]. The effective atomic number of composite materials calculated by the following equations [10]

$$Z_{\text{matrix}} = \frac{\sigma_a}{\sigma_e}$$

$$Z_{\text{effe}} = \sum_{i=1}^{2} W_i Z_i$$

Where $\sigma_a$ atomic crosssection $\sigma_e$ Electronic cross section $Z_{\text{matrix}}$ Atomic number of the polymer $Z_{\text{effe}}$ effective atomic number of composite material $W_i$ the weight ratio of shielding materials $Z_i$ atomic number of ith material in composite.

3.3. Heaviness

The advantage of polymeric-based composite materials is that its performance is best relative to its low density and the parameter which reflects this characteristic is called gravity where it calculated relative to the lead by the following equation [12]

$$\text{Heaviness} \% = \frac{\text{density of material}}{\text{lead density}} \times 100\%$$
3.4. **Halfvalue thickness** $X_{1/2}$

The halfvalue thickness of an absorber is the thickness of the absorber material which makes the intensity of output gamma ray reduced to one half of its original intensity and can be calculated as [13]

$$X_{1/2} = \frac{0.693}{\mu}$$

4 **Results and discussion**

Linear attenuation coefficients were measured of all shields at different concentrations and energies. Figures 3-6 show the relation between linear attenuation coefficient and concentration. It is clear from these figures that the values of the attenuation coefficient vary with concentration. This can be returned to increase the absorption processes which due to the distribution of the additive material inside the matrix material and this is leading to increased density of the shields. This means that the epoxy alone is not useful for use as a shield against gamma rays but when we add some reinforcement materials it is become possible to use as a shield against gamma rays and this result agrees with [14].

![Figure 3](image1.png)  **Figure 3.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of concentration (%) for Comp1.

![Figure 4](image2.png)  **Figure 4.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of concentration (%) for Comp2.

![Figure 5](image3.png)  **Figure 5.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of concentration (%) for Comp3.

![Figure 6](image4.png)  **Figure 6.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of concentration (%) for Comp4.
Attenuation coefficient as a function of gamma rays energy shown in figures 7-10 and it is clear from these figures that the attenuation coefficient decrease with energy increase and this is due to the interaction mechanism of gamma rays with a matter which depends on the energy values. These figures show that the highest values of the attenuation coefficient are being within the low energy region for all types and concentrations of reinforcement materials and this can be interpreted to the dominance of the photoelectric effect which its cross-section is high in this region. Then the attenuation coefficient decrease slowly down to the extent of high energy which has the effect of the pair production is in control where there is no noticeable change in the values of the attenuation Coefficient within this area and this is consistent with [15].

**Figure 7.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of energy (keV) for Comp1.

**Figure 8.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of energy (keV) for Comp2.

**Figure 9.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of energy (keV) for Comp3.

**Figure 10.** Attenuation Coefficient $\mu$ (cm$^{-1}$) as a function of energy (keV) for Comp4.
The effective atomic number was calculated for all shields at different concentrations and the result was plotted in figures 11-14. From these figures, we can note that the effective atomic number increases with increasing concentration of reinforcement material, especially for Comp3 and Comp4, which have the highest value of \( Z_{\text{eff}} \) and can be interpreted as an increase of the concentration of reinforcement material. The attenuation coefficient will increase, and thus increasing atomic number of shields. This means that there is an improvement in the properties of the matrix material epoxy towards the properties of reinforcement material.

![Figure 11. Effective atomic number \( Z_{\text{eff}} \) as a function of concentration (%) for Comp1.](image1)

![Figure 12. Effective atomic number \( Z_{\text{eff}} \) as a function of concentration (%) for Comp2.](image2)

![Figure 13. Effective atomic number \( Z_{\text{eff}} \) as a function of concentration (%) for Comp3.](image3)

![Figure 14. Effective atomic number \( Z_{\text{eff}} \) as a function of concentration (%) for Comp4.](image4)

The values of half-value thickness \( X_{1/2} \) for all shields were calculated at different concentrations. The relationship between \( X_{1/2} \) and concentration of reinforcement materials was plotted in the figures 15-18.
and it is noticeable from these figures that the half values thickness decreases with increasing concentration and that arise from the fact that the increase in the concentration of the additive material lead to improving the properties of the matrix material towards the attenuation of gamma radiation so this contribute in determining the appropriate thickness for this shields.

![Figure 15](image1.png)  
Figure 15. Half value thickness $X_{1/2}$ (cm) as a function of concentration (%) for Comp1.

![Figure 16](image2.png)  
Figure 16. Half value thickness $X_{1/2}$ (cm) as a function of concentration (%) for Comp2.

![Figure 17](image3.png)  
Figure 17. Half value thickness $X_{1/2}$ (cm) as a function of concentration (%) for Comp3.

![Figure 18](image4.png)  
Figure 18. Half value thickness $X_{1/2}$ (cm) as a function of concentration (%) for Comp4.

The heaviness values were calculated and plotted as a function of the type of shield at a certain concentration 50%. It is clear from figure 19 that manufactured shields from Polymeric Composite Material be light when it is compared with materials of conventional shielding such as lead and concrete as well as their performance as a radiation protection shields more receptive when adding high concentrations to it and when it is used with low energy and this agrees with the study [12].
5 Conclusion

In this study we find that there is an improvement in the properties of the matrix material epoxy toward gamma rays shielding by adding some reinforcement materials where it is possible to use this shields in some nuclear applications such as radiation therapy rooms shielding as well as radioactive sources containers. The results show that the shielding properties of these shields such as attenuation coefficient effective atomic number and others affected by increased reinforcement ratios. It was found that the effectiveness of the shields was best in the case of increasing concentration of reinforcement materials ratio specially when using PbO as reinforcing materials due to its high atomic number for lead.

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