The effect of using Nano iron oxide in radiological shielding

Muhammed Abdul Kadar Abdul sttar, Ahmed Fadhil Mkhaiber, Aseel Mustafa Abdul Majeed
1 Physics Department – College of Education (Ibn Al-Haitham) – University of Baghdad, Iraq
2 Physics Department, College of Science, Al-Mustansiryah University, Baghdad, Iraq
Ahmad27@gemail.com, e-mail: aseelalaziz@uomustansiriyah.edu.iq

Abstract. In this study, some attenuation parameters of gamma shields were studied. This shields consisting of composite materials of Unsaturated polyester as a base material and Nano iron oxide (Fe₂O₃) and micro iron (Fe) as reinforcement materials at different percentages (1, 3, 5, 7 and 9) wt%, and with different thickness (1, 1.5, 2, 2.5, 3, 3.5 and 4) cm. The results showed that the use of nanoparticles is better than the microparticles in the field of radiation shielding. It has been shown that the values of attenuation parameters of gamma it better in the case of nanoparticles than case of the use of micro material.

Keywords: Nano material, Linear Attenuation coefficient, buildup factor.

INTRODUCTION.

Shielding is one of the most effective radiation protection methods, and there are anthers methods include decrease the time, dose rate and increases the distance to the source [1]. In addition, different types of radiation can be protected by different types of materials [2]. For shielding designs, gamma rays are one of the main types of nuclear radiation that must be observed; any shielding that reduces gamma rays will reduce other radiation more effectively [3]. Therefore, composite materials are used for this purpose. Since the polymer material contains its own hydrocarbon material [4]. Therefore, in this study some shielding properties like linear Attenuation coefficient (μ), mean free path and buildup factor were studied. We attempted to prepare and characterize polymer-based composite shields using unsaturated polyester resins as matrix, and (Fe₂O₃) or (Fe) as reinforcement, which were filled with different concentrations (1%, 3%, 5%, 7%, and 9%) with different thickness (1, 1.5, 2, 2.5, 3, 3.5, 4) cm [5].

THEORY

Linear Attenuation coefficient (μ)

The probability of removing photons from the beam per distance where it has the unit of cm⁻¹ [6]. Linear attenuation coefficient (μ) the parameter depends on many variables such as photons Energy and shielding density. The Linear attenuation coefficient is related to mass attenuation coefficient by the following relationship [7].

\[ \mu_a = \mu / \rho \text{ (cm}^2/\text{g)} \] ...............(1)

Where \( \mu_a \) is mass attenuation coefficient (cm³), \( \rho \) the density of material (g/cm³). This parameter is one of the most important factors for describing the Penetration of gamma rays through materials [8].
Mean Free path (\(\lambda\))

The mean free path (MFP), which is defined as the average distance between two successive interactions of photons is one of the most important parameters and it by the equation [ ].

\[
\lambda = \frac{1}{\mu} \ldots \ldots \ldots \ldots (2)
\]

Build up Factor

The buildup factor and symbol (B) and knows that is the ratio between the total beam intensity recorded by the detector to the unscattering intensity beam of the beam reaching the detector without precipitation. In general, it is clear that the accumulation factor depends on photon energy, the free path rate that the photon travels through the material, detector), as well as the shield material (thickness and atomic number) the buildup factor was calculated as in the following relationship [42-44].

\[
B = \frac{\text{The total beam intensity}}{\text{The unscattering beam intensity}} \ldots \ldots \ldots \ldots (3)
\]

Preparation the sample

In this work, the composite material was prepared from a base material (Unsaturated polyester) with different ratio of reinforcement material (1%,3%,5%,7%,9%) from (Fe2O3) in nano-scale with grain size(13.2 nm) and (Fe) in micro. Samples prepared with different thickness (1,1.5,2,2.5,3,3.5,4)cm at 3% of Fe2O3.

EXPERIMENTAL SETUP

The experimental arrangement is schematically shown in figure (1) [11]. The assembly was placed in lead castle. The energy calibration was performed using a set of standard gamma sources
Geometrical arrangement

In this work, the lead was used as a protective shield from the radioactive source. The detector was placed horizontally, and placed at 10 cm away from the radioactive source. A pair of lead was used as collimators; the first collimator was placed near the radioactive source the second collimator depositor is placed near the detector. This arrangement was used to measure the linear attenuation coefficient by applying the Per-Lambert equation, this arrangement good geometrical. And to get the buildup factor there are two types of arrangements good geometrical, and the bad geometrical arrangement, it obtain when remove a collimators lead from the source and the detector and use equation (3) was to calculate the buildup factor.

Source

The radioactive sources used in this study were Cs-137 with activity of 5μci and Co-60 with activity of 1μci.

RESULT AND DISCUSSION

Gamma-ray attenuation coefficients.

Linear attenuation coefficients were measured of all shields at different concentrations and energies. Figures (2, 3, and 4) show the relation between linear attenuation coefficient and concentration of reinforced material and the table (1, 2, 3) show the information.

It is obvious from these figures that the value of the attenuation coefficient changes with the concentration., this can be returned to increase the absorption processes which due to the distribution of the additive material (Fe₂O₃, Fe) inside the matrix material and this is leading to increased density of the shields this means that the (Unsaturated polyester) 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 show the add reinforcement from (Fe₂O₃) give higher attenuation than the shield reinforcement with (Fe) .Figure (5) show the relation between the (μ) and shield thickness for (Fe₂O₃) at concentration 3% ,we can find that the (μ) increase gradually with the increase the thickness. From figure (6, 7) we can observe 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 show that the highest values of the attenuation coefficient are being within the low energy region for all types and concentrations of reinforcement materials(Fe₂O₃)and(Fe) 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.

![Figure 2](image1.png)  
Figure (2 ) linear attenuation coefficients as a function of Concentration for (Fe₂O₃),(Fe) at energy 0.662 Mev  

![Figure 3](image2.png)  
Figure (3 ) linear attenuation coefficients as a function of Concentration for (Fe₂O₃),(Fe) at energy 1.172 Mev
Table 1: Linear attenuation coefficient values at different energy and at different concentration.

| Concentration | %   | Fe₂O₃ μ(cm⁻¹) | Fe μ(cm⁻¹) |
|---------------|-----|---------------|------------|
|               | 0.662 Mev | 1.172 Mev | 1.332 Mev | 0.662 Mev | 1.172 Mev | 1.332 Mev |
| 0.662 Mev     | 0.095266 | 0.071957 | 0.061656 | 0.094645 | 0.070862 | 0.061629 |
| 1%            | 0.097983 | 0.073574 | 0.06245 | 0.096314 | 0.071595 | 0.062016 |
| 3%            | 0.099784 | 0.075035 | 0.070003 | 0.097086 | 0.072085 | 0.064136 |
| 5%            | 0.10157 | 0.078133 | 0.072247 | 0.099115 | 0.074126 | 0.068286 |
| 7%            | 0.103557 | 0.079892 | 0.073922 | 0.101966 | 0.077364 | 0.070389 |
| 9%            | 0.105557 | 0.081656 | 0.075678 | 0.104715 | 0.080786 | 0.072489 |

Table 2: Linear attenuation coefficient values at different thickness and at different energies at concentration of 3% of (Fe₂O₃) .

| Thickness cm | 0.662Mev | 1.172Mev | 1.332Mev |
|--------------|----------|----------|----------|
| 1            | 0.097982835 | 0.073574 | 0.06245 |
| 1.5          | 0.14788561 | 0.11048 | 0.093087 |
| 2            | 0.1966431 | 0.147356 | 0.1268 |
| 2.5          | 0.2454081 | 0.184578 | 0.158225 |
| 3            | 0.2948762 | 0.220787 | 0.18935 |
| 3.5          | 0.34198 | 0.25959 | 0.219656 |
| 4            | 0.3919143 | 0.296239 | 0.2499 |

Mean free path (\(\lambda\))

The values of (m.f.p) for all shields were measured at different concentrations the relationship between (\(\lambda\) and concentration of reinforcement materials(Fe₂O₃,Fe) was plotted in the figures (8,9,10) , that taken from table (3), and it is apparent from these figures that the (m.f.p) 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[13]. Figure (11) show that the decrease of (m.f.p) with increasing the thickness for different energy. The (m.f.p) value at low energy is higher for (Fe₂O₃) than (Fe) and the same state happen in the higher energy show in figure (12, 13) from table (4).
Figure (8) m.f.p as a function of Concentration for \((\text{Fe}_2\text{O}_3),(\text{Fe})\) at energy 0.662 Mev

Figure (9) m.f.p as a function of Concentration for \((\text{Fe}_2\text{O}_3),(\text{Fe})\) at energy 1.172 Mev

Figure (10) m.f.p as a function of Concentration for \((\text{Fe}_2\text{O}_3),(\text{Fe})\) at energy 1.332 Mev

Figure (11) m.f.p as a function of Thickness with Concentration 3% from \((\text{Fe}_2\text{O}_3)\) with different energies

Figure (12) m.f.p as a function of Energy for \((\text{Fe}_2\text{O}_3)\)

Figure (13) m.f.p as a function of Energy for \((\text{Fe})\)
Table 3: M.F.P values at different energy and at different concentration.

| Concentration % | Fe$_2$O$_3$ | Fe |
|------------------|-------------|----|
|                  | $\lambda$ cm | $\lambda$ cm |
|                  | 0.662 Mev    | 1.172 Mev    | 1.332 Mev    | 0.662 Mev    | 1.172 Mev    | 1.332 Mev    |
| 1%               | 10.49688     | 13.89717     | 16.21902     | 10.5658      | 14.1119      | 16.22614     |
| 3%               | 10.20587     | 13.59176     | 16.01281     | 10.38275     | 13.96754     | 16.12492     |
| 5%               | 10.02168     | 13.32711     | 14.28518     | 10.30205     | 13.87251     | 15.59197     |
| 7%               | 9.845396     | 12.79862     | 13.84148     | 10.08927     | 13.49054     | 14.6499      |
| 9%               | 9.65655      | 12.51685     | 13.6199      | 9.807174     | 12.92585     | 14.20684     |

Table 4: Mean Free path for 3% from Fe$_2$O$_3$ values at different thickness at different energy.

| Thickness cm | 0.662 Mev | 1.172 Mev | 1.332 Mev |
|--------------|-----------|-----------|-----------|
| 1            | 10.20586922 | 13.59175796 | 16.01281025 |
| 1.5          | 6.76198313  | 8.71801394  | 10.74263861 |
| 2            | 5.085355143 | 6.786286273 | 7.866435331 |
| 2.5          | 4.074845125 | 5.417763764 | 6.320113762 |
| 3            | 3.391253685 | 4.44701249  | 5.281225244 |
| 3.5          | 2.924147611 | 3.85228514  | 4.552573114 |
| 4            | 2.55157824  | 3.37562767  | 4.00160064  |

Build up factor (B)

The values of (buildup factor ) for all gamma shields were measured at different concentrations. And plotted the rotation ship between the buildup factor and the concentration of reinforcement materials (Fe$_2$O$_3$,Fe) was show in figures(14,15,16) that taken for table (5), From these three figures, the buildup factor decrease with increasing the concentrations. The use of Fe$_2$O$_3$ material gives lower buildup factor than Fe material. Figure (17) from table (6), show the relation between buildup factor and shield thickness. The buildup factor increase with increasing the thickness and has a high value at low energy.
Table 5: Buildup factor at different concentration at different energy.

| Concentration % | Fe$_2$O$_3$ Build up factor | Fe Build up factor |
|-----------------|-----------------------------|-------------------|
|                 | 0.662 Mev | 1.172 Mev | 1.332 Mev | 0.662 Mev | 1.172 Mev | 1.332 Mev |
| 1%              | 1.347378 | 1.42505  | 1.43839  | 1.36500  | 1.46705  | 1.51079  |
| 3%              | 1.33775  | 1.41385  | 1.42843  | 1.34999  | 1.45705  | 1.50079  |
| 5%              | 1.32511  | 1.41288  | 1.42208  | 1.33000  | 1.44683  | 1.49682  |
| 7%              | 1.31415  | 1.41168  | 1.42080  | 1.32000  | 1.43758  | 1.48746  |
| 9%              | 1.31146  | 1.41099  | 1.41769  | 1.31999  | 1.42730  | 1.47987  |

Table 6: Buildup factor e values at different thickness at different energies and concentration of reinforcement materials concentrations is 3% to (Fe$_2$O$_3$)

| Concentration % | Fe$_2$O$_3$ Build up factor | Fe Build up factor |
|-----------------|-----------------------------|-------------------|
|                 | 0.662 Mev | 1.172 Mev | 1.332 Mev | 0.662 Mev | 1.172 Mev | 1.332 Mev |
| 1%              | 1.347378 | 1.42505  | 1.43839  | 1.36500  | 1.46705  | 1.51079  |
| 3%              | 1.33775  | 1.41385  | 1.42843  | 1.34999  | 1.45705  | 1.50079  |
| 5%              | 1.32511  | 1.41288  | 1.42208  | 1.33000  | 1.44683  | 1.49682  |
| 7%              | 1.31415  | 1.41168  | 1.42080  | 1.32000  | 1.43758  | 1.48746  |
| 9%              | 1.31146  | 1.41099  | 1.41769  | 1.31999  | 1.42730  | 1.47987  |

CONCLUSION

The results obtained in this study show that there is preference for use nano-material on the micro material which can be used in the field of the radiation shielding. And therefore we find that nano-material give high attenuation compared to the micro-material. The buildup factor with the increased concentration of the nano-Iron oxide. As well as the increases in the buildup factor by increasing the thickness of the shield, and shields with lighter and less expensive materials.

REFERENCES

1. Tait, W. H. "Radiation detection", London / Butterworth, P.406, (1980). Chilton, A.B., Shultis, J.K. and Faw, R.E. (1984) "Principles of radiation shielding", Prentice-Hall Inc, New Jersey.
2. N. Tsoulfanidis "Measurement and Detection of Radiation" 2 ed edition ,Braun-Brumfield ,Inc.,U.S.,1995.
3. Milewski, J.V. (1987), Handbook of Fillers for Plastics, Van Nostrand Reinhold.
4. Brian, S. M. (2004), An Introduction To Materials Engineering And Science For Chemical And Materials Engineers", John Wiley & Sons, New Jersey.
5. Ziad T. Khodair, Mushtaq A. Al-Jubbori, Ahmed M. Shano, Fadhil I. Sharrad, Chemical Data Collections, 28(2020) 100414
6. Y. Elmahroug, B. Tellili & C. Souga. (2013).” Calculation of gamma and neutron shielding parameters for some materials polyethylene-based”, Int.JPR, 3(1):33-40.
7. N. Chanthima, J. Kaewkhao. (2013). Investigation on radiation shielding parameters of bismuth borosilicate glass from 1 keV to 100 GeV, Annals of Nuclear Energy 55 (2013) 23–28.
8. M.E. Medhat and et al. (2014). Calculation of gamma-ray mass attenuation coefficients of some Egyptian soil samples using Monte Carlo methods”, Radiation Effects & Defects in Solids, Vol. 169, No. 8, 706–714.
9. H.A.H. Al-Abdli. (2002). Development of High Polymer Matrix Composition, Ph.D. Thesis, Department of Chemical Engineering- University of Technology.
10. Nicholas Tsoulfanidis. (1995). measurement and detection of radiation. Second Edition , University of Missouri-Rolla
11. K.H. Mahdi, Z.S. Ahmed, A.F. Mkhaiber, “Calculation and Study of Gamma ray Attenuation Coefficients for Different Composites” Ibn Al-Haitham Journal for Pure and Applied Science No. 3 Vol. 25 Year 2012.
12. Ahmed F Mkhaiber1, Abdulraheem Dheyaa Experimental study of some shielding parameters for Composite shields: IOP Conf. Series Journal of Physics: Conf. Series 1003 (2018) 012109