DOI: 10.24996/ijs.2026.67.3.23

ISSN: 0067-2904

Study of The Properties of Radiation Shielding Using Epoxy with BeO, MgO, TeO_2, and Bi_2O_3 Compounds

Mustafa Y. Rajab[1*], Kareem K. Mohammad[2]

[1]*Department of Physics, College of Science, Al-Nahrain University, Baghdad, Iraq*

[2]*Department of Bio Mass, Al-Nahrain Renewable Energy Research Center, Al-Nahrain University, Baghdad, Iraq*

Received: 14/11/2024 Accepted: 12/ 3/2025 Published: 30/3/2026

Abstract

The technological development and the radiation use in various fields, industry, medicine, agriculture, scientific research, etc., and getting on the principle of As Low As Reasonably Achievable (ALARA) in protection radiation, shielding is one of the important protection rules, representing placing different materials between the radiation sources and the object to reducing the intensity of radiation and protected. Samples of composite materials were prepared with different reinforcing elements and epoxy as the fundamental substance. BeO, MgO, TeO_3, and Bi_2O_3 with various ratios 10, 20, 30, and 40% with diameter 2.5 cm and high 2 cm were prepared to study the effect of these materials on the Half Value Layer (HVL), Tenth Value Laye (TVL), and mean free path (MFP) as examples of attenuation coefficients, in addition to basic coefficients linear and mass attenuation. These parameters were measured using sodium iodide system NaI(Tl) gamma spectroscopy (2"×2") after irradiation with gamma ray at energy 661 keV from the radioactive source Cs-137. The results showed that these coefficients are affected by the addition of reinforcing materials with epoxy and lead to attenuation of gamma-ray intensity. The linear attenuation coefficient was increased with an increase in the atomic number and ratio of the reinforcing materials. At the same time, the (HVL) decreased, proving the availability of using some composite as gamma-ray shielding.

Keywords: Gamma ray, Attenuation, Shielding, attenuation coefficients, epoxy.

دراسة خواص الدروع الاشعاعية باستخدام الايبوكسي مع مركبات BeO, MgO, TeO_2 and Bi_2O_3

مصطفى يوسُف رجب[1*] , كريم خلف محمد[2]

[1]قسم الفيزياء, كلية العلوم, جامعة النهرين, بغداد, العراق

[2]مركز بحوث النهرين للطاقة المتجددة, جامعة النهرين, بغداد, العراق

*Email: mostafaheete@gmail.com

الخلاصة

ان تطور التكنولوجيا واستخدام الإشعاع في مختلف المجالات مثل الصناعة والطب والزراعة والبحث العلمي وما إلى ذلك، والحصول على مبدأ ALARA (كقانون يمكن تحقيقه بشكل معقول) في الحماية من الإشعاع ، يعد التدريع أحد القواعد المهمة للحماية والتي تتمثل في وضع مواد مختلفة بين مصادر الإشعاع والشيْ المراد حمايته لتقليل شدة الإشعاع. في هذه الدراسة تم تحضير عينات مكونة من مواد مركبة تحتوي على الايبوكسي كمادة اساسية مع مواد تقوية مختلفة MgO, BeO , TeO_3 و Bi_2O_3 بنسب مختلفة 10 ، 20 ، 30 و 40٪ وبسمك 2سم لدراسة تأثير هذه المواد على معاملات التوهين مثل معامل التوهين الخطي وطبقة القيمة نصف (HVL) وطبقة القيمة العاشرة (TVL) ومتوسط المسار الحر. تم القياس باستخدام نظام يوديد الصوديوم NaI (Tl) مطياف جاما ("2× "2) بعد التشعيع بأشعة گاما بطاقة 661 كيلو فولت من المصدر المشع Cs-137. وأظهرت النتائج أن هذه المعاملات تتأثر بإضافة مواد التسليح بمادة الايبوكسي وتؤدي إلى توهين شدة اشعة گاما. وجد أن معامل التوهين الخطي يزداد مع زيادة العدد الذري ونسبة مواد التسليح بينما تنخفض طبقة نصف القيمة (HVL) مما اثبتت ان بعض المواد المركبة تصلح لاستخدامها كدروع لأشعة گاما.

1- Introduction

Due to using radiation in various disciplines, including astronomy, agriculture, medicine, and biology, protecting the environment and the human population from radiation is necessary; it depends on three principal factors; the first is distance: more distance from the radiation source leads to less exposure. The second factor in minimizing radiation is time; exposure increases the longer spent near a radioactive source. The third factor is shielding, which reduces the radiation quantity by absorption [1-4]. The shields are materials that minimize the number of incoming photons by absorbing or attenuating as much incoming radiation as possible [5-7].

Key factors, such as weight, space, cost, attenuation, and absorption capabilities of the materials used for radiological protection must be cosidered in the synthesis and development of shielding materials to obtain a good radiation shield that can attenuate, absorb, or block most gamma radiation. The most popular materials for shielding are lead (Pb), lead-equivalent compounds, and concrete. However, these materials have some disadvantages, such as Pb's harmful effects on the environment and human health, low durability, not being transparent to visible light, heavy, expensive, opaque, and cracks in concrete when overused. Consequently, scientists have been working on environmentally acceptable, incredibly dense, and chemically homogeneous materials that could be utilized in place of concrete and safeguard human life through attenuation or absorption of harmful radiations due to radiation exposure [6-8].

It is essential to study the different coefficients related to the passage of gamma radiation through a substance which reveal the energy percentage that is scattered or absorbed, such as mass attenuation coefficients (μ/ρ), linear attenuation coefficient (μ), half-value layer (HVL), which is the attenuator thicknesses necessary to reduce the γ-ray intensity by 50% of its initial value, and tenth value layer (TVL), which is the attenuator thicknesses required to reduce the γ-ray intensity to 10% of its initial value. It is an essential measure in studying how radiation interacts with matter. The attenuation coefficients in various categories have been calculated by different workers for lead, lead-equivalent compounds, tungsten carbide cobalt materials, concrete, glasses, and polymers [8-11]. Epoxy was used as a base material , which was mixed with different composite materials consisting of beryllium oxide (BeO), magnesium oxide (MgO), tellurium oxide (TeO_2), or bismuth oxides (Bi_2O_3), as reinforcing in four different ratios, 10%, 20%, 30%, and 40% for each compound.

2- Experimental part

2.1 Epoxy resins

Resins are defined as organic, natural, or industrial polymers; the most used are polyethylene, polystyrene, and epoxy; epoxies fall under the "thermoset" family of resins. Figure (1) shows the chemical formula of the epoxy resin. Epoxy resins are solid, lightweight, foamy structures with good insulating qualities that can be created during the "potting and casting" process. Epoxy has several benefits, including the ability to attach firmly to the majority of materials, being extremely resistant to chemical solvents and ambient moisture due to their long hydrophobic chains, excellent electrical insulating properties, and minimal shrinkage during the curing process, which results in good dimensional stability [12-14].

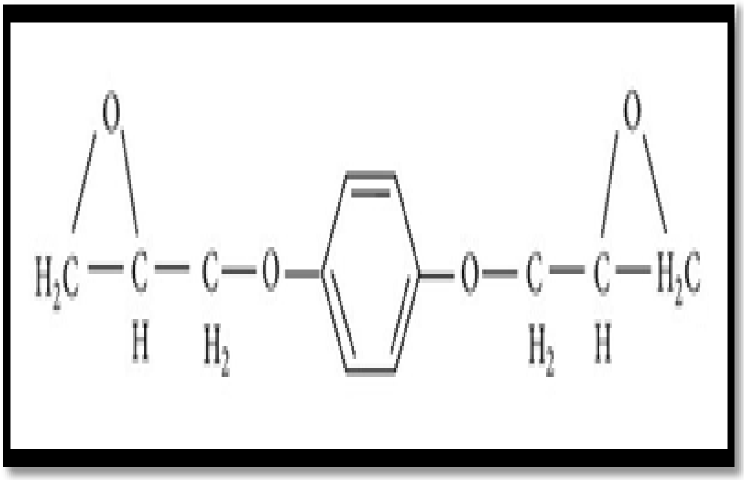


Figure 1: The chemical formula of the epoxy resin.

2.2 Sample preparation

To form a shield for attenuation of gamma rays, epoxy, which was used as the basic material, was mixed with the powder of the composite materials (BeO, MgO, TeO_2, and Bi_2O_3) as reinforcement whose physical properties are shown in Table (1). Shields of different concentrations (10%, 20%, 30%, and 40%) of reinforcement (BeO, MgO, TeO_2, and Bi_2O_3) with epoxy were prepared by pouring them into a sample container with a diameter of 3 cm and a thickness of mixture 2 cm. To finish the mixing, the mixture was transferred to an ultrasonic device for around 15 minutes at room temperature to get the optimum mix free of bubbles and was left to dry well.

Table 1: Physical properties of the used element

Element	Molar mass / Molecular weight (g/mol)	Appearance	Density (g/cm^3)	The atomic number of the element
BeO	25.011	White powder	2.9	4
MgO	40.305	White powder	3.55	12
TeO_2	159.60	White powder	6.25	52
Bi_2O_3	465.958	yellow powder	8.90	83

2.3 Counting system

A 2"×2" thallium-doped sodium iodide (NaI(Tl)) detector was employed, which is highly efficient for gamma-ray detection. It has a high stability compared to the accompanying electronic devices. The ORTEC software (Scintivision-Buffer) with an integrated measuring system was employed as an electronic system with detailed engineering arrangements for the best practical results, measurement, and analysis steps. Figure (2) shows the Cs-137 spectrum. The collection time was 10 min.

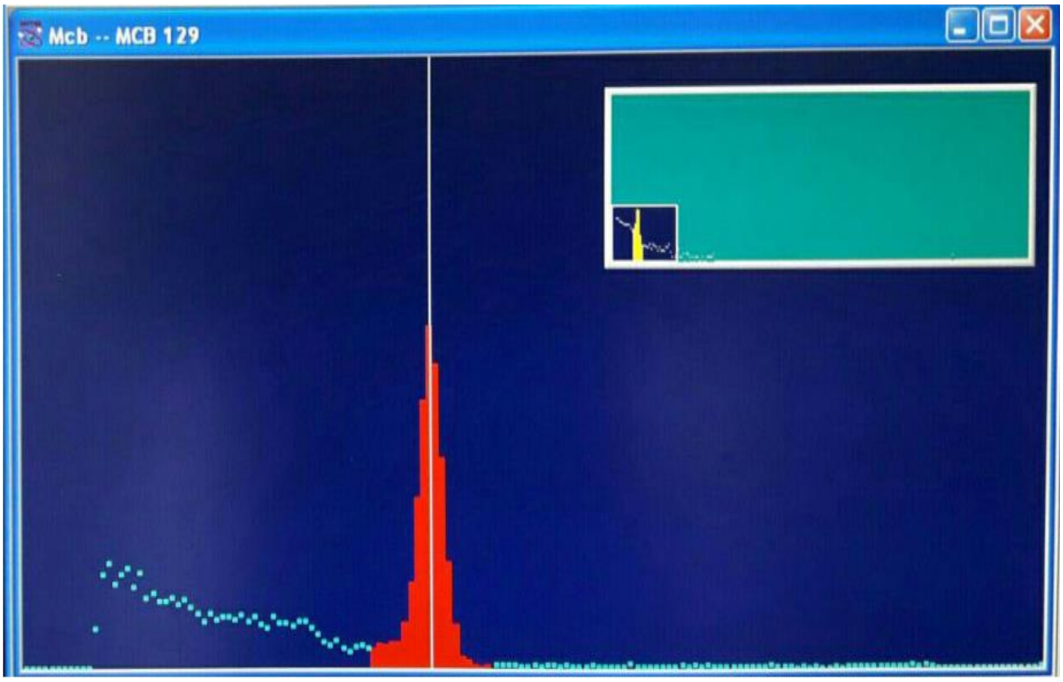


Figure 2: Spectrum of Cs-137 at energy 662 KeV

2.4 Arrangement of the system's geometry

A cylindrical lead with a diameter of 5 cm and a height of 5 cm was the collimator used to calculate the attenuation coefficients. The source-detector distance was 10 cm. Two collimators were employed, the first near the source and the other near the detector and the shield between them, as shown in Figure (3).

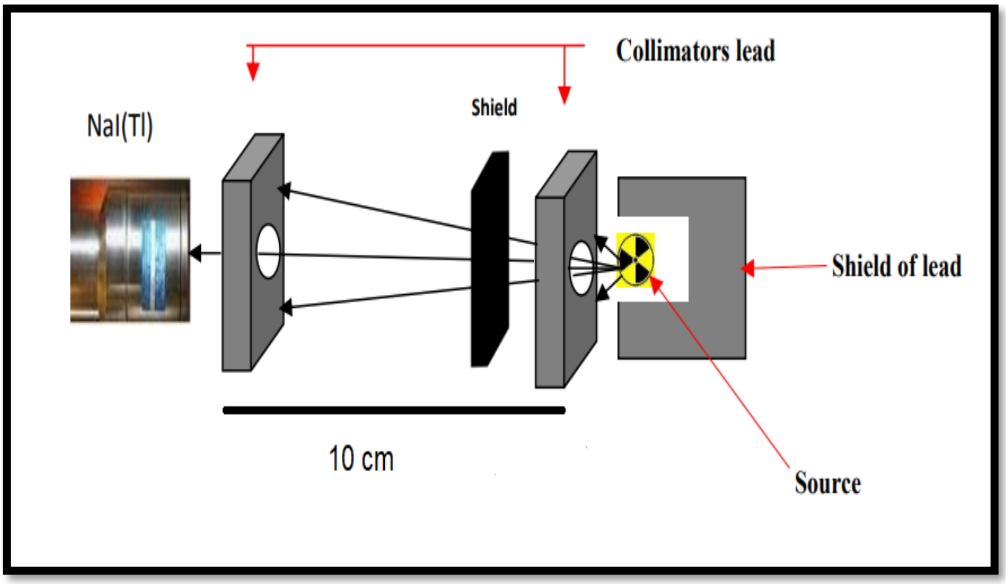


Figure 3: Good of Geometric Arrangement.

3- Theoretical part

Different parameters, including μ, μ/ρ, HVL, TVL, and Mean Free Path (MFP, λ), which represents the average distance a gamma ray passes in the absorber before interacting, can be calculated to test the shielding material's gamma-ray attenuation properties. An important factor in characterizing gamma radiation in a material is the linear attenuation coefficient, defined as the likelihood per unit route length that a photon would interact with the absorber. This characteristic changes with the incident photon energy, the material's mass density, and its atomic number. The following equation applies Beer lambert's law to get the linear attenuation coefficient [15-17]:

$$I = I_{\circ} e^{-\mu x} \tag{1}$$

where $I_{\circ}$ represents the main emission intensities from a radioactive source, I represents the emission intensities out of the shield absorber, μ is the linear attenuation coefficient, and x is the absorber thickness. Several radiation attenuation factors, such as μ/ρ, HVL, TVL, and MFP, employ the linear attenuation coefficient to be calculated. The half and tenth value layers are two essential variables to consider for an ideal radiation shielding material. These values were calculated using Equations (2) and (3) [18]:

$$HVL = \ln 2/\mu \tag{2}$$

$$TVL = \ln 10/\mu \tag{3}$$

The mean free path (MFP) (λ) was determined by Equation (4), [19,20]:

$$\lambda = 1/\mu \tag{4}$$

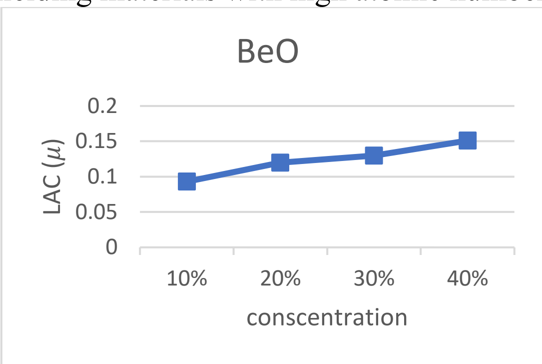
4- Results and Discussion

The radioactive source used in the experiment part was Cs-137 with an activity of 9.49 μci (its initial activity was 25 μci in 1970), which emits gamma rays at energy 661 keV. Protection against gamma rays requires shield materials with high atomic numbers and density. Lead is the appropriate shield compared to other shielding materials such as concrete, soil, and aluminum. The shield leads to an exponential decrease in intensity with thickness, as in Equation (1) in a narrow beam geometry. As shown in Table 2, the attenuation coefficients were calculated for the four different reinforcement compounds prepared in different concentrations (10%, 20%, 30%, and 40%) with epoxy. Epoxy alone cannot be used as a shield for gamma rays due to its poor radiation attenuation (approximately 15%).

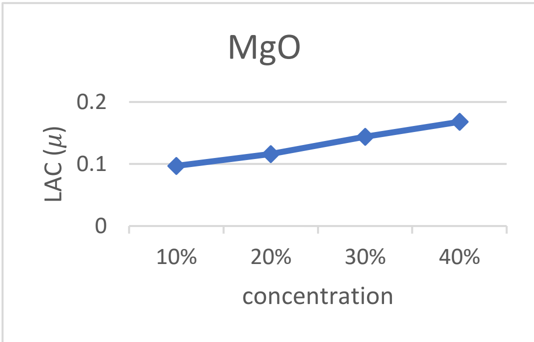
Table 2: Values of the attention coefficients μ, HVL, TVL, and λ for different reinforcing material concentrations

materials	concentration	μ	HVL	TVL	λ
BeO	10%	0.093	7.4	24.7	10.7
	20%	0.120	5.6	19.2	8.6
	30%	0.130	5.3	17.7	7.7
	40%	0.151	4.6	15.3	6.6
MgO	10%	0.097	7.1	23.6	10.6
	20%	0.116	6.0	19.9	8.6
	30%	0.144	4.8	16.0	6.9
	40%	0.168	4.1	13.8	5.9
TeO_2	10%	0.130	5.3	17.7	7.7
	20%	0.176	4.0	13.1	5.7
	30%	0.226	3.1	10.2	4.4
	40%	0.263	2.6	8.7	3.8
Bi_2O_3	10%	0.192	3.6	12.0	5.1
	20%	0.260	2.7	8.9	3.9
	30%	0.354	2.0	6.5	2.8
	40%	0.490	1.4	4.7	2.0

Figures (4) a, b, c, and d show the relationship between the linear attenuation coefficient and the different concentrationc of BeO, MgO, TeO_2, and Bi_2O_3 in the shield materials, respectively. As the concentration increased, the linear attenuation coefficient values increased due to the increase in the material's concentration and distribution within the basic material composition (epoxy), which caused the shield's density to rise, increasing the shield's ability to absorb gamma-ray radiation. Figure (1 e) describes the relation between the linear attenuation coefficient with the different concentrations for each material, which also shows the increase in the linear attenuation coefficient values with the increase in the atomic number of those materials; this theoretically corresponds to an increase in the gamma rays absorption in shielding materials with high atomic numbers.



(a)



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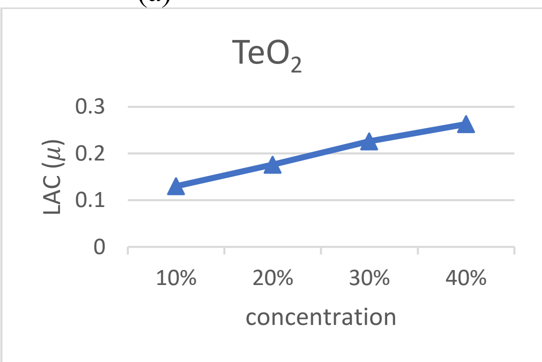

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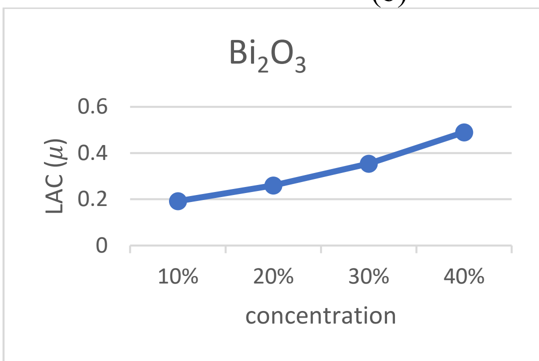

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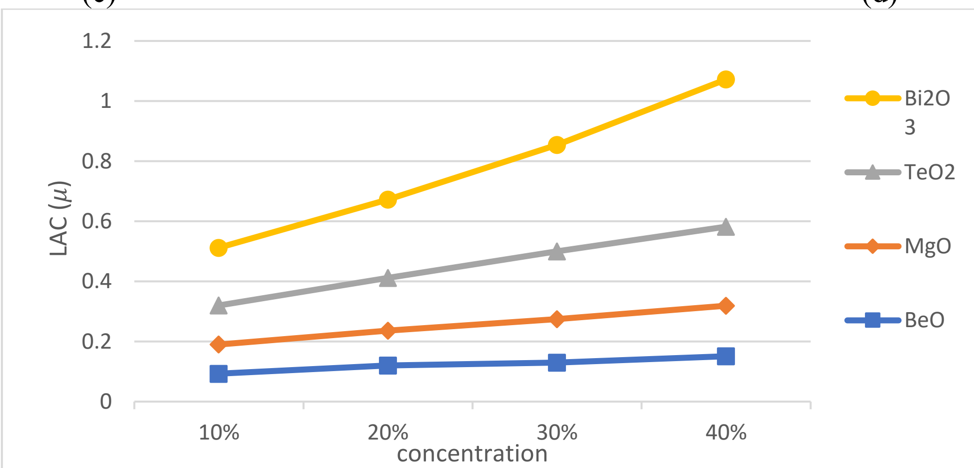
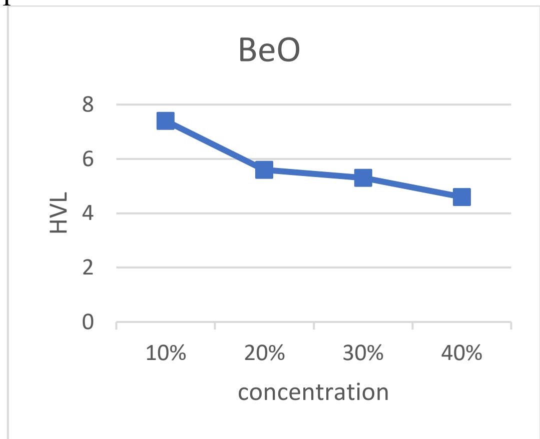


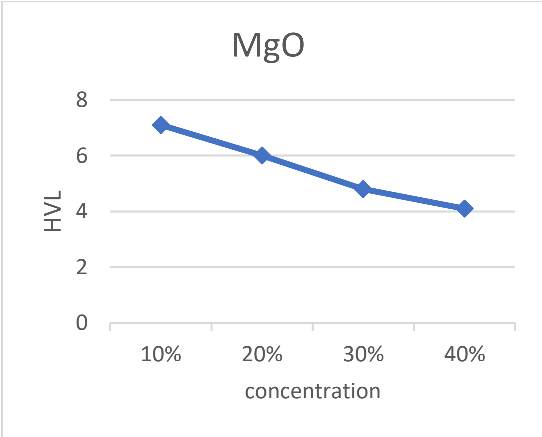
(e)

Figure 4: (a, b, c, d, and e) correlation for the linear attenuation coefficient and various composite material concentrations for the reinforcing material.

Using Equation (2), for the materials with various concentrations, the half-value layer values were determined, as shown in Table (2), and the relationship between the half-value layer and the concentrations of the added materials was drawn separately in Figure (5). The values of the half-value layer decreased with the concentration increase of the added reinforcing material because increasing the concentrations improves the base material properties towards attenuating the gamma rays. Hence, the linear attenuation coefficient is inversely proportional to the half-value layer. Figure (2) shows that the best values for the half-value layer required to mitigate the gamma rays to half their value were for the Bi_2O_3 compound.



(a)



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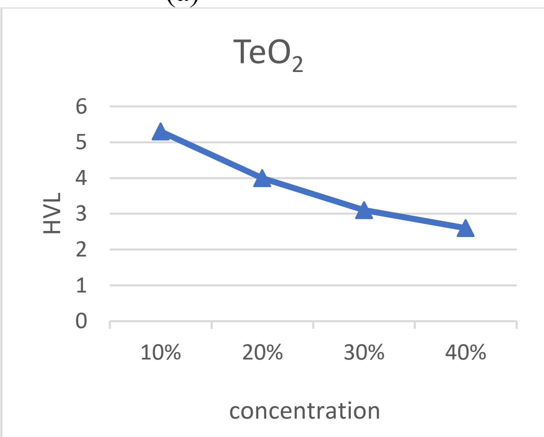

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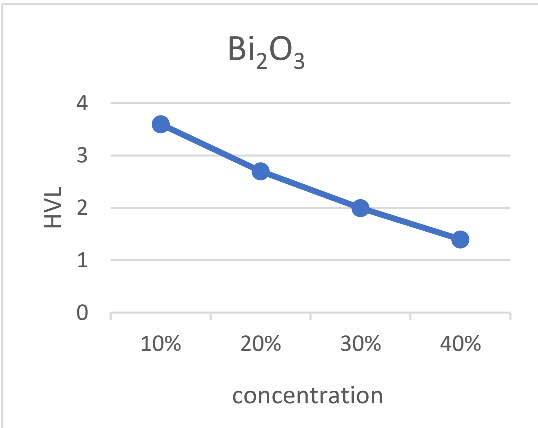

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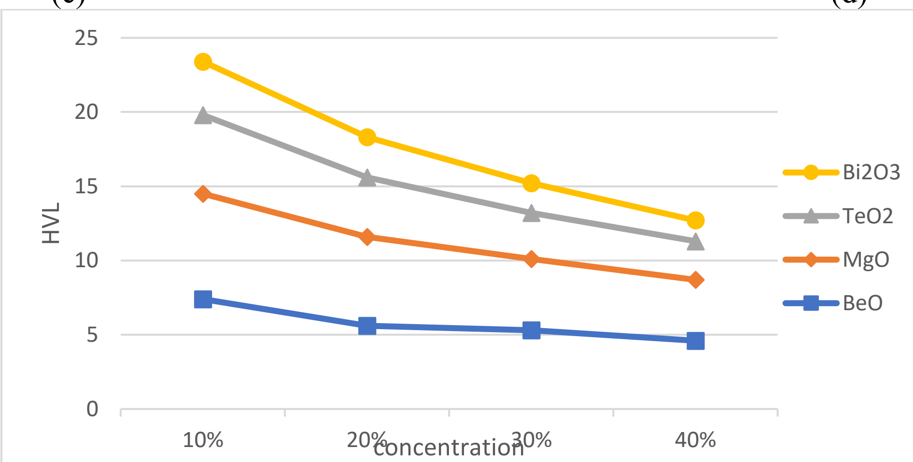

(e)

Figure 5: (a, b, c, d, and e) Correlation between the half value layer and various composite material concentrations.

The tenth value layer is an essential parameter for choosing the best types of shielding to reduce the radiation level to one-tenth of its initial value. The results of the tenth value layer in Table (2) were calculated by Equation (3), where Figure (6) shows the correlation between the tenth value layer and the concentrations of additional components. Noticing that the tenth value layer decreased as the concentrations increased. This coefficient helps choose appropriate shielding materials for gamma sources.

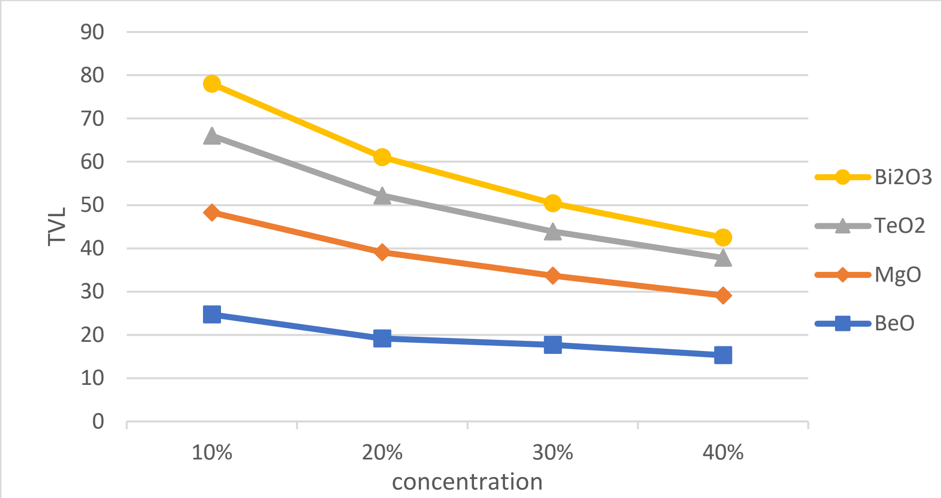

Figure 6: Correlation between the Tenth value layer and various composite material concentrations.

Figure (7) shows the relationship between the mean free path and the concentrations of the various reinforcing materials, which shows the decrease in the mean free path with the increase in concentrations due to the increase in the shield density with the increase in reinforcing materials concentration, where the distance that photon travels inside the shield decreases.

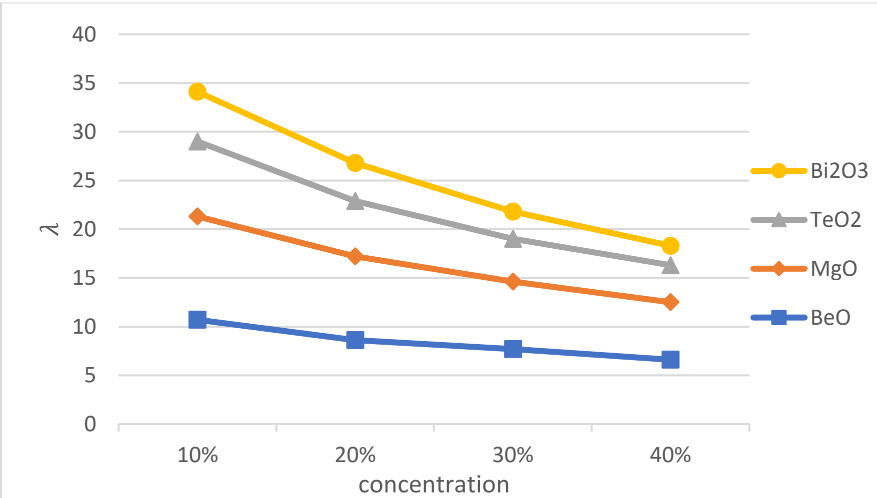

Figure 7: Relationship between the Mean free path and various composite material concentrations.

5- Conclusion

The results showed that as the concentration of the reinforcing material increases, the values of the attenuation coefficient rise due to the improvement of epoxy base material characteristics in gamma radiation protection. With the gradual addition of reinforcing materials according to the atomic number, there could be an increase in the values of the linear attenuation coefficient and a decrease in the values of the HVL, TVL, and MFP (λ), especially when using Bi_2O_3 as a reinforcing material because of the atomic number and its high density that is necessary for gamma-ray attenuation.

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