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Research Article

Evaluation of Gamma Irradiation Shielding Performance of Polymer Composites Doped with *Chamelea Gallina* Shells

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Abstract: This study investigates the ability of PLA/PEG blend composite materials doped with *Chamelea gallina* shells to protect against gamma rays. The focus of the study is to determine the effects of increasing the shells ratio on the gamma absorption coefficients. The analyses measured the absorption of gamma rays at both low and high energy levels by these composites. It shows that the gamma absorption coefficient generally increases as the white sand mussel shell content increases. Especially at high ratios (such as 15%) and high gamma energies (1332.51 keV), these materials provide more effective protection at higher energy levels. These findings suggest that shells-enriched polymers can be used as potential radiation shielding materials in areas such as nuclear medicine, radiation therapy, military and space applications. It also supports the potential use of natural materials in the development of radiation shielding materials and offers new avenues for future applications.

Keywords: *Chamelea gallina;* gamma shielding; polymers; composite materials

Chamelea gallina Kabukları Doplu Polimer Kompozitlerin Gama Işınlama Zırhlama Performansının Değerlendirilmesi

Özet: Bu çalışma, *Chamelea gallina* kabukları ile katkılanmış PLA/PEG karışımı kompozit malzemelerin gama ışınlarına karşı koruma yeteneğini incelemektedir. Çalışmanın odak noktası, beyaz kum midyesi kabuğu oranının arttırılmasının gama soğurma katsayısı üzerindeki etkilerini belirlemektir. Analizler, bu kompozitlerin hem düşük hem de yüksek enerji seviyelerindeki gama ışınlarını nasıl soğurduğunu göstermiştir. Beyaz kum midyesi kabuğu oranı arttıkça gama soğurma katsayısının genel olarak arttığı görüldü. Özellikle yüksek oranlarda (%15) ve yüksek gama enerjilerinde (1332.51 keV) bu malzemeler daha yüksek enerji seviyelerinde daha etkili bir koruma sağlamaktadır. Bu bulgular, beyaz kum midyesi kabuğu ile zenginleştirilmiş polimerlerin nükleer tıp, radyasyon terapisi, askeri ve uzay uygulamaları gibi alanlarda potansiyel radyasyon koruyucu malzemeler olarak kullanılabileceğini düşündürmektedir. Aynı zamanda radyasyon zırhlama malzemelerinin geliştirilmesinde doğal malzemelerin potansiyel kullanımını desteklemekte ve gelecekteki uygulamalar için yeni yollar sunmaktadır.

Anahtar Kelimeler: C*hamelea gallina*; gama zırhlama, polimerler, kompozit malzemeler

1. Introduction

Materials with high absorption coefficients can be used in various fields, such as nuclear medicine, space exploration, and nuclear power plants. Especially in space applications, it is critical to provide effective radiation shielding for equipment and people exposed to high energy levels. Lead equipment and thick concrete walls are commonly used as shielding materials. Due to the inelasticity, heavy weight, and toxic effects of lead materials, easy-to-use and biocompatible materials have been sought. It is of great importance that the material to be used as a shielding material be flexible, lightweight, highly absorbent, and biocompatible. For this reason, analyses such as ease of production at low, medium, and high gamma energies, cost, accessibility, usability in terms of health, and absorption ability are very important in the selection of shielding materials. Such detailed analyses are critical for planning practical applications of the material and assessing potential risks.

Evaluating the data in a broader context allows for a more informed development and utilisation of these new materials. The properties of a suitable shielding material are high atomic number (Z), high density, low half-value thickness (HVL), durable, long life, flexible, light weight, economical and easily accessible. These properties provide important information for choosing which materials to use in the design of radiation shielding materials. Materials that absorb gamma rays well can be used as effective radiation shields in areas such as nuclear medicine, radiation therapy, military applications, recycling facilities (scrap yards), nuclear power plants and space applications. In order for the selected material to be used as a shielding material, it is necessary not only to have high absorption coefficient values, but also to better understand the long-term use performance and durability of these materials in environmental conditions.

Many studies have been carried out as an alternative shielding material to lead. There are shielding material studies, especially by doping alloy materials and polymer composites with various materials [1-5]. Nagaraja et al. (2020) investigated the absorption ability of various silicone polymers by exposing them to gamma and X-rays. B-polymethyl hydro-siloxane (CH_4SiO) polymer was found to have the best absorption ability [6]. Yılmaz and Akman (2023) carried out a study using silicone-based polymer composites, and these polymer composites were enriched with high-atomic-number additives such as tin, cerium oxide, tungsten oxide, and bismuth [7]. Shahzad et al. (2022) investigated the shielding properties of various polymer composites and nanocomposites in detail [8].

C. gallina is known as the white sand clam [9]. In this study, the gamma ray shielding capabilities of PLA/PEG blend composites doped with *C. gallina* shells were investigated. The results obtained are thought to provide important information to researchers in the field of materials sciences and radiation physics to develop more effective radiation shields using natural materials such as white sand mussel shell. At the same time, these data can be a source of inspiration for new material designs and contribute to the development of sustainable materials that will reduce environmental impact. The development of polymers with high seashell content may create new opportunities in the radiation shielding materials market.

2. Materials and Methods

2.1. Theoretical Background

The linear absorption coefficient (μ) is a parameter that describes how much electromagnetic radiation (X or gamma ray) a material absorbs per unit length. This coefficient varies depending on the type of material and the energy of the beam [10]. μ is used to describe how the intensity of radiation passing through a material decreases with the thickness of the material. The change in the intensity of radiation passing through the material is calculated from Equation (2.1) [11].

$$I = I_0 e^{-\mu x} \tag{2.1}$$

Here, I_0 represent the intensity of the gamma ray from the radioactive source, and I represent the intensity of the radiation passing through the x (cm) thick absorber material placed between the radioactive source and the detector. The half-value thickness (*HVL*), which is an important concept in radiation absorption, provides important information about the success of the absorber material and is calculated as in Equation (2.2) [13-15].

$$HVL = \frac{ln2}{\mu} \tag{2.2}$$

The lower the *HVL* values, the higher the absorptive ability of the absorbing material [12]. Another important expression for evaluating the effectiveness of shielding materials is Radiation Protection Efficiency (*RPE*), which is calculated by Equation (2.3) [13-15].

$$RPE = \left(1 - \frac{I}{I_0}\right) \times 100 \tag{2.3}$$

2.2. Preparation of *C. gallina* Shells Doped PLA/PEG Blend Composite

Initially, 0.5 grams of PLA was dissolved in chloroform and 0.5 g of PEG was added and stirring continued until completely dissolved. *C. gallina* shells were added to the resulting PLA/PEG mixture at the rates of 2.5%, 5.0%, 10.0% and 15.0%, respectively, and homogenized in a water bath for 15 minutes. The obtained *C. gallina* shells added polymer composites were poured into a petri dish and dried in an oven at 40 °C.

2.3. Experimental Procedure

In this study, gamma radiation attenuation was investigated using PLA/PEG composites with different ratios of *C. gallina* shells. In this study, a 3″×3″ sized thallium-activated sodium iodide (NaI(Tl)) scintillator detector was used to measure the attenuation of gamma radiation. The attenuation coefficients of gamma radiation and other relevant parameters were calculated by measuring I and I_0 at three specified energy levels (0.662, 1.173 and 1.332 MeV). The NaI(Tl) scintillator detector works on the principle of atomic excitation and is widely used in the study of gamma rays.

The experimental setup shown in Figure 1 is based on the interaction of gamma rays emitted from a radioactive source with a scintillator material after passing through a protective barrier. This interaction produces low-energy photons. These photons hit the photocathode of the detector and cause photoelectrons to break off. The photoelectrons are accelerated and multiplied in the photomultiplier tube. As a result, an output signal proportional to the intensity of the radiation is obtained and counted. Reliable data was collected by counting for a total of 1000 seconds for each sample. This method is critical for a detailed assessment of the extent to which various materials attenuate gamma radiation.

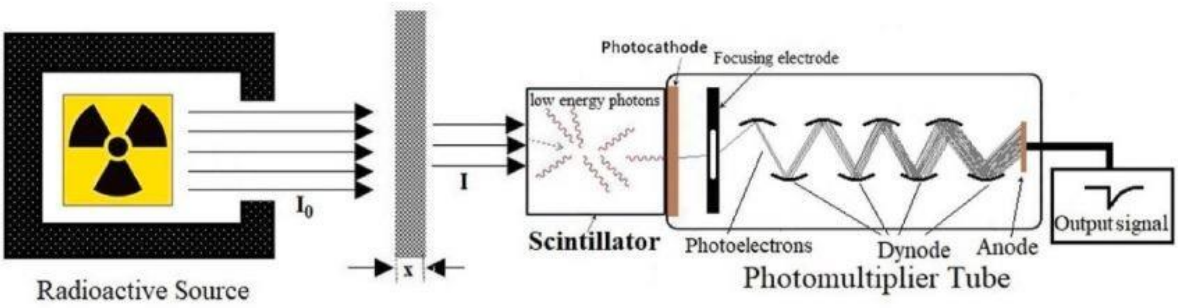

Figure 1. The experimental setup [3].

3. Conclusion and Discussion

The energy levels of each isotope provide important information for analysing nuclear decay processes and the radioactive properties of the material. When white sand mussel shell is added to the polymer material, it changes the physical and chemical properties of the material. Figure 2 shows how the ability of the material to protect against gamma rays is affected by the changes in the gamma absorption coefficients as the percentage of seashell addition to the polymer increases. *HVL* (cm) and *RPE* (%) values of PLA/PEG composites doped with *C.gallina* shells at different ratios (Pure PLA/PEG, 2.5%, 5.0%, 10%, and 15%) at gamma energies of 661.62 keV, 1173.23 keV, and 1332.51 keV are shown in Table 1.

Table 1. *Half value layer (HVL) and absorption percentages*

Energy	**661.62 (keV)**				**1173.23 (keV)**				**1332.51 (keV)**			
Sample	I/I_0	HVL (cm)	μ/ρ ($cm^2 g^{-1}$)	RPE (%)	I/I_0	HVL (cm)	μ/ρ ($cm^2 g^{-1}$)	RPE (%)	I/I_0	HVL (cm)	μ/ρ ($cm^2 g^{-1}$)	RPE (%)
Pure	0.987	1.316	0.044	1.3	0.991	1.906	0.031	0.9	0.978	0.769	0.075	2.2
%2.5	0.983	1.030	0.056	1.7	0.989	1.517	0.038	1.1	0.977	0.749	0.077	2.3
%5.0	0.980	0.850	0.067	2.0	0.987	1.305	0.044	1.3	0.975	0.698	0.081	2.5
%10	0.972	0.615	0.089	2.8	0.971	0.591	0.093	2.9	0.970	0.566	0.097	3.0
%15	0.967	0.524	0.102	3.3	0.967	0.509	0.104	3.3	0.968	0.533	0.103	3.2

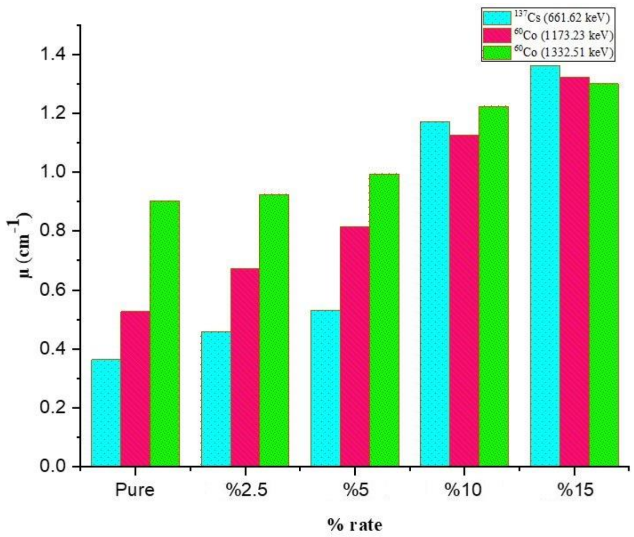

Figure 2. Linear absorption coefficients of PLA/PEG blend composites doped with *C. gallina* shells.

In the graph, the pink bars represent the gamma counts measured from the detector for the ^{60}Co radioactive source at the 1173.23 keV energy level, and the green bars represent the ^{60}Co radioactive source at the 1332.51 keV energy level. The blue bars represent the counts at the 661.62 keV energy level of ^{137}Cs. Both energy levels of ^{60}Co show similar trends, as different energy levels of the same isotope generally have similar decay rates. ^{137}Cs generally appear to have lower counts. Therefore, it can be concluded that the absorption ability is lower at medium and low energies. It shows that the gamma absorption coefficient increases at all energy levels as the proportion of white sand mussel shell increases. This suggests that higher shell concentrations form more effective shield against gamma rays. Figure 3 shows the linear absorption coefficients of pure polymer material and different ratios (2.5%, 5%, 10%, and 15%) of shell-doped polymers against different gamma energy levels. The x-axis represents the different gamma energy levels, while the y-axis represents the gamma absorption coefficient.

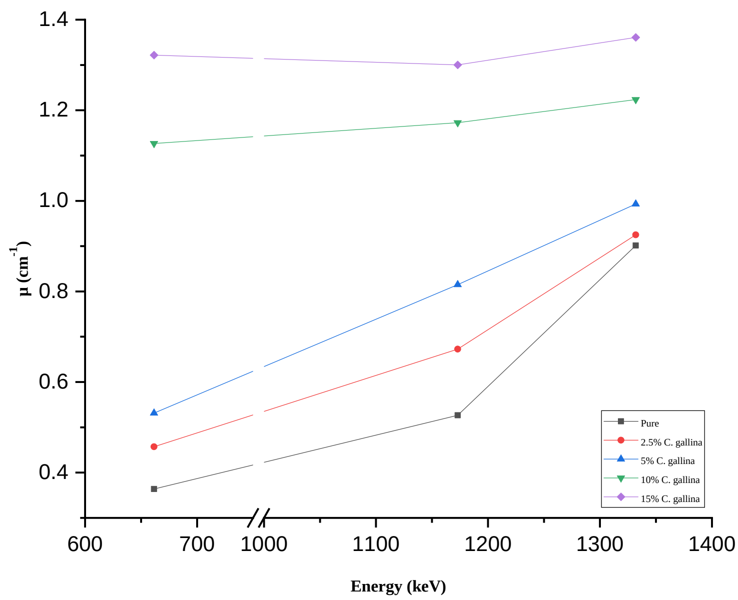

Figure 3. Photon energy versus absorption coefficient results of PLA/PEG blend composites doped with *C. gallina* shells.

The pure polymer has the lowest absorption coefficient, while the absorption coefficient increases as the seashell content increases. This indicates that the seashell increases its shielding ability against gamma rays. In particular, the polymer containing 15% seashell has the highest absorption coefficient, which makes it the most effective shielding doping ratio. In addition to the shell content, absorption coefficients differ at different gamma energy levels. At low energy levels, the absorption ability of the polymers doped with white sand mussel shell increases more significantly, while this difference decreases as the energy increases. This shows that the polymer material may exhibit different behaviors depending on the energy of gamma rays. As seen in the graph, the absorption coefficient generally increases as energy levels increase. This indicates that higher-energy gamma rays should absorb more energy from the material. However, this trend becomes more complex as the percentage increases. Especially at high doping ratios (such as 15%), the absorption coefficient appears to increase faster as the energy increases, indicating that the material is better adapted to higher energy levels. This is an important factor to consider when selecting materials for high-energy environments. It is important to understand whether materials with higher absorption coefficients are more resistant to the degradation and ageing effects caused by radiation. In long-term use, ageing tests and continuous radiation exposure tests may be required to assess how the performance of the material is affected.

When evaluating the performance of polymers with different doping ratios, factors such as material cost and processing difficulty should also be considered. Seashell is an economical and environmentally friendly material for absorbing gamma rays because it is abundant and economical. Furthermore, the potential effects of these materials on human health, especially in areas of intensive use, should be studied in detail.

HVL is used as a measure to determine how effectively a material attenuates radiation. It expresses the distance required for the radiation in the material to drop to half its intensity. The *HVL* plot of seashell-doped polymers against different gamma energy levels is shown in Figure 4. In this graph, the x-axis represents the different gamma energy levels, and the y-axis represents the mean free path (*HVL*) values. Different seashell doping ratios (2.5%, 5%, 10%, and 15%) were added to the pure form, and their gamma absorption abilities were compared.

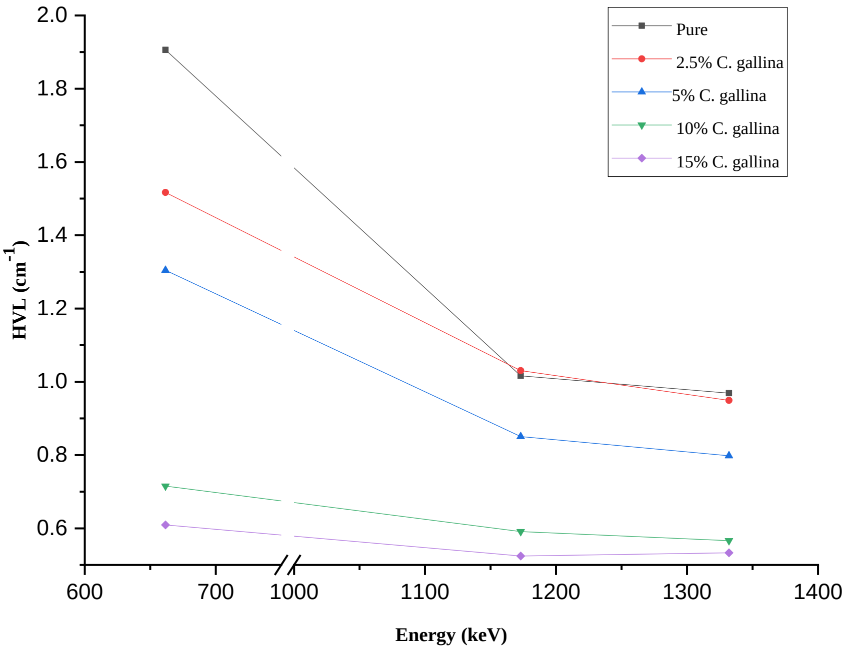

Figure 4. Half value layer (*HVL*) versus photon energy of prepared samples

Looking at the shielding performance of the material produced depending on the *HVL* values, the pure polymer has the highest *HVL* values in the graph. This shows that it attenuates the radiation the least. In other words, depending on the molecular structure of the pure polymer, it blocks and absorbs gamma rays less. Gamma rays can travel longer distances in pure polymers. As the shell ratio increases, *HVL* values decrease. In other words, radiation is reduced to half its intensity at shorter distances. This suggests that higher shell ratios attenuate radiation more effectively and provide better protection. When the graph is interpreted in terms of the variation of gamma energies, the effect of energy levels also affects the absorption ability. As the gamma energy levels increase, the *HVL* values of all materials decrease. At higher energy levels, since the radiation performs better, the distance required for the radiation in the material to drop to half its intensity decreases. Therefore, it shows that the studied material can provide more effective protection against high-energy radiation. This is in agreement with Figures 2 and 3. High radiation resistance is critical, especially in space applications and extremely radiated environments such as nuclear reactors.

At different gamma-ray energy levels (for ^{137}Cs and ^{60}Co), the results of the percentage ratio of shell-doped polymers attenuating radiation are shown in Figure 5. The x-axis represents the percentage of shell-doped polymers, and the y-axis represents the percentage of these materials attenuating gamma rays.

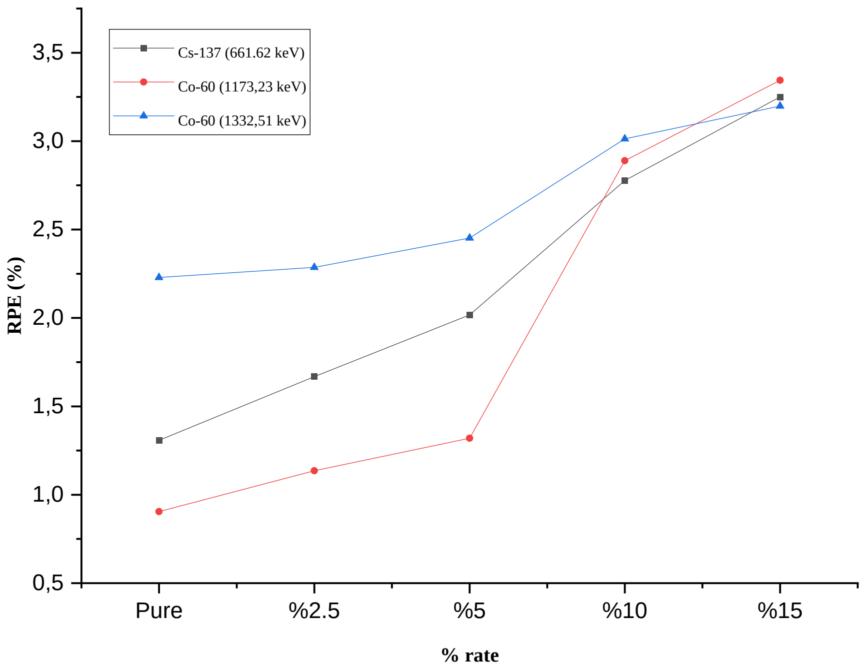

Figure 5. Radiation protection efficiency (*RPE*) results of *C. gallina* shells-PLA/PEG blend composites

Higher-energy gamma rays (^{60}Co) were found to provide better attenuation at higher shell ratios than lower-energy ^{137}Cs rays. ^{137}Cs (661.62 keV) is indicated by the grey line. It shows that at this energy level, the attenuation rate increases as the percentage of white sand mussel shell increases and then remains almost constant. It can be concluded that no significant increase in the extra attenuation rate can be obtained after a certain percentage of white sand mussel shell. For ^{60}Co, two different energy levels (1173.23 and 1332.51 keV) showed similar trends. However, the blue line at the ^{60}Co (1332.51 keV) energy level presents a higher attenuation ratio than ^{137}Cs, even at a high shell percentage.

4. Conclusion

The use of seashell-doped polymers can be suggested as a potential material for radiation shielding applications. If the material is to be more effective at absorbing gamma rays, increasing the seashell content can be considered. Since seashell is usually an abundant and economical material, it can offer an economical and environmentally friendly solution to absorb gamma rays. Seashell-doped polymers can be used as radiation shielding materials in medical applications such as radiation therapy, medical imaging, the military, space studies, and industry. It can open new doors in nuclear physics, materials science, and environmental sciences research and allow these new composite materials to be investigated on a larger scale. Higher shell ratios may be more effective in protecting against high-energy gamma radiation, in particular. Although higher shell ratios provide better radiation protection, the impact of this ratio on the cost, process ability, and overall sustainability of the material should also be considered. An optimal shell concentration should provide a favorable balance between cost and performance. As seashell is a natural material, the use of such materials is generally considered more environmentally sustainable. However, the environmental impacts during the collection, processing, and disposal of white sand mussel shell need to be carefully assessed.

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Conflict of Interest

The author declares that they have no conflict of interest regarding this article.

Research and Publication Ethics Statement

The author declares that this study complies with research and publication ethics.

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