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INVESTIGATION OF POLY(LACTIC ACID) (PLA)/TITANIUM CARBIDE (TiC) NANOCOMPOSITE FILMS GAMMA RAY SHIELDING PROPERTIES

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Abstract

Original scientific paper

In this study, gamma rays absorption properties of Poly(lactic Acid) (PLA)/Titanium Carbide (TiC) nanocomposite films produced by containing 5% TiC were investigated. In applications where radioactive sources such as industry and medical are used, protection from the harmful effects of radiation is very important. Researches on materials to be used in shielding as an alternative to lead are becoming widespread. Comfortable, easily shaped, thin, durable, non-toxic to the environment and the user are the features sought in an ideal shield materials. For this purpose, the gamma ray absorption properties of the PLA/TiC nanocomposite material and its effect on radiation shielding were investigated. The linear attenuation coefficient value of the sample with different thicknesses was obtained with the NaI(TI) scintillation detector. A monochromatic gamma source, Cs-137 gamma radioisotope with 661.62 keV energy was used as the gamma radiation source. To determine the gamma ray shielding ability of materials Half value layer (*HVL*), tenth value layer (*TVL*) and radiation shielding efficiency (*RPE*) parameters of the material were calculated.

Keywords: *Gamma irradiation, Linear attenuation coefficient, NaI(Tl), Nanocomposite film.*

POLİLAKTİK ASİT (PLA) / TİTANYUM KARBÜR (TiC) NANOKOMPOZİT FİLMİN GAMA IŞINI ZIRHLAMA ÖZELLİKLERİNİN İNCELENMESİ

Özet

Orijinal bilimsel makale

Bu çalışmada, %5 TiC içeren Polilaktik Asit (PLA)/Titanyum Karbür (TiC) nanokompozit filmlerin gama ışınları absorpsiyon özellikleri incelenmiştir. Endüstri ve medikal gibi radyoaktif kaynakların kullanıldığı uygulamalarda radyasyonun zararlı etkilerinden korunmak çok önemlidir. Kurşuna alternatif olarak zırhlamada kullanılacak malzemeler üzerine araştırmalar yaygınlaşmaktadır. Rahat, kolay şekillendirilebilen, ince, dayanıklı, çevreye ve kullanıcıya toksik olmayan ideal bir zırh malzemelerinde aranan özelliklerdir. Bu amaçla PLA/TiC nanokompozit malzemenin gama ışını soğurma özellikleri ve radyasyon kalkanına etkisi araştırılmıştır. NaI(TI) sintilasyon dedektörü ile farklı kalınlıktaki numunenin lineer zayıflama katsayısı değeri elde edilmiştir. Gama radyasyon kaynağı olarak monokromatik bir gama kaynağı olan 661.62 keV enerjili Cs-137 gama radyoizotopu kullanılmıştır. Malzemelerin gama ışını zırhlama kabiliyetini belirlemek için, malzemenin Yarı değer katmanı (*HVL*), onuncu değer katmanı (*TVL*) ve radyasyon zırhı verimliliği (RPE) parametreleri hesaplanmıştır.

Anahtar Kelimeler: *Gama radyasyonu, lineer zayıflama katsayıları, NaI(Tl), Nanokompozit film.*

1 Introduction

Radiation is the emission or transfer of energy in the form of electromagnetic waves or particles. In our daily life, we are inevitably exposed to natural radiation sources. Cosmic radiation coming to our world from space, radiation emitted by the decay of radioactive elements in water, soil, building materials and atmosphere can be counted among natural radiation sources [1]. In addition, it is known that exposure to artificial radiation sources in many fields such as medical fields and industry for diagnostic and therapeutic purposes. Depending on the dose exposed, it causes genetic diseases caused by DNA damage, and diseases such as cancer, radiation burns, which can damage living cells and tissues [2-4]. Therefore, radiation protection methods are important. There are three basic rules among radiation protection methods: distance, time and shielding. The further our stay away from the radiation source, the less the dose is exposed. The radiation dose depends on inverse-square law. It changes inversely with the square of the distance. The less time is spent in the radiation environment, the

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less dose is exposed. A barrier to be placed between the radiation source and the person will minimize the dose received [5]. The shield chosen for different types of radiation should be different. Chemical composition of the material, the radiation absorption coefficient of the material, the radiation energy and type are important factors in the selection of the shield material and determination of thickness [6]. Lead (Pb) sheets and lead vests are used in shielding. Pb is a very suitable material that is widely used in radiation shielding due to its physical and chemical properties. However, it has disadvantages such as inflexibility, heavy material and toxic effects. For this reason, many studies are carried out on radiation shielding as an alternative to lead [6-10].

In this study, gamma irradiation attenuation properties of PLA/TiC nanocomposite films and its effect on radiation shielding were investigated. Its usability as an alternative to lead shielding, which is frequently used today, was examined.

2 Material and Method

2.1 Theoretical Background

A decrease in the intensity of the photon beam falling on a material with a thickness of dx occurs. This decrease is due to the absorption of part of the incident photon beam by the material (Figure 1).

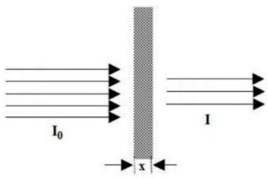

Figure 1. Attenuation of a photon beam.

The decrease in intensity of gamma rays as they pass through the *dx* thick layer can be written as in Eq.(1).

$$dI = -\mu I dx \quad (1)$$

In here, μ is the linear attenuation coefficient and is defined as the energy absorption fraction per unit thickness. The linear attenuation coefficient (μ) depends on the atomic number of the absorbing material and the energy of the photons that make up the incoming gamma ray beam [10]. *I* is the energy amount of the ray per unit time perpendicular to the direction of propagation of the gamma rays beam. Eq.(3) is obtained by integrating in Eq.(1) over a finite thickness *x*.

$$\int_{I_0}^{I} \frac{dI}{I} = -\int_{0}^{x} \mu dx \quad (2)$$

$$\ln I - \ln I_0 = -\mu x \quad (3)$$

This is the equation of a line with a slope of -μ and crossing the x-axis at lnI_0 using logarithmic operation properties, Eq.(4), known as Beer–Lambert's Law, is obtained.

$$I = I_0 e^{-\mu x} \quad (4)$$

$$\mu = \frac{\ln(I_0 / I)}{x} \quad (5)$$

I_0; the intensity of the incident photon without absorbing material between the source and the detector, and *I*; indicates the intensity after passing through the absorber of thickness *x* [11]. Inhere, negative sign indicates the reduction in incoming intensity. If the energy of the incident beam changes, the values of the absorption coefficient of the shielding materials also change. The half value layer (*HVL*) and tenth value layer (*TVL*) of the material are described to quantify the gamma ray shielding. *HVL* and *TVL* are the thicknesses of a sample that will attenuate by half and tenth the incident photon intensity [12]. These values were calculated with Eq.(6) and 7, respectively.

$$HVL = \frac{ln2}{\mu} \quad (6)$$

$$TVL = \frac{ln10}{\mu} \quad (7)$$

HVL is the shielding thickness required to stop half of the gamma rays from the radioactive source. It is dependent on the gamma energy and the atomic number (*Z*) of the shielding material [10]. *TVL*, corresponds to the thickness value that reduces the incident beam by 10 times. The Radiation Shielding Efficiency (*RPE*) is an important parameter that indicates the shielding ability of the material and is calculated as shown in Eq.(8) [13].

$$\mathrm{RPE} = \left(1 - \frac{I}{I_0}\right) \times 100 \quad (8)$$

2.2 Preparation of PLA/TiC Nanocomposite Films

PLA/TiC nanocomposite film containing 5% TiC was prepared by solvent casting method. For this, 0.025 grams TiC nanoparticles were dispersed in 5 mL chloroform for 1 hour in an ultrasonic homogenizer. Meanwhile, 0.5 grams polylactic acid was mixed in a magnetic stirrer until it was completely dissolved in 5 mL chloroform. After 1 hour, the TiC nanoparticle solution was added to the PLA solution and the PLA/TiC nanocomposite was dispersed for an additional 15 minutes. The mixture was poured into a petri dish, dried in an oven at 40 °C for 24 hours, and a polymeric film was obtained. PLA/TiC nanocomposite films produced in different thicknesses are shown in Figure 2.

Figure 2. Images of PLA/TiC Nanocomposite Films.

2.3 Measurements of Gamma Irridation

Gamma irradiation measurements were made with a NaI(Tl) scintillation detector. Based on atomic excitation, this detector is widely used for the detection of gamma-rays. The detector was operated in the plateau region (650 V), which is the most ideal voltage range. Gamma radiation attenuation of PLA/TiC nanocomposite films was measured with the experimental setup shown in Figure 3. The detector window was adjusted according to the 661.62 keV energy of the Cs-137 radioactive source. Thus, the detector will only be sensitive to gamma radiation. First of all, background radiation counts were made without a radioactive source in the environment. Then, gamma counts were taken by placing the Cs-137 radioactive source NaI(Tl) in the detector window. Counts were repeated by placing the produced absorbent material between the source and the detector. Measurements were repeated 10 times, measuring t=100 for each sample. The linear absorption coefficient of the produced nanocomposite films was calculated with Eq.(5) using the slope of the graph depending on the thickness. Consequently; performance of the absorber material in gamma shielding was investigated by calculating the *HVL*, *TVL* and *RPE* values.

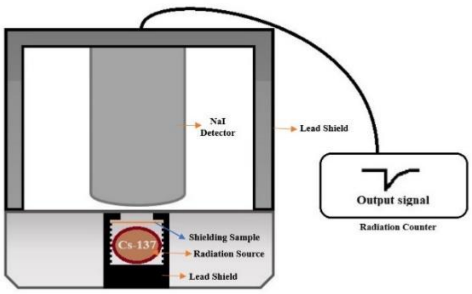

Figure 3. The experimental setup.

3 Results and Discussions

The thickness of the absorber is an important factor in attenuating gamma radiation. Samples have prepared in 3 different thicknesses, from 4.7 to 6.2×10^{-2} cm, to investigate absorption rate of the material produced. The graph of change of In(I_0/I) depending on the thickness (x) is shown in Figure 4. The slope of the graph, the parameter of μ absorption coefficient.

This value was calculated as 4.670 cm^{-1} (Eq.5). As the thickness increases, the absorptive ability of the shielding material also increases. Depending on the μ value, *HVL*, *TVL* and *RPE* parameters are calculated and shown in Table 1.

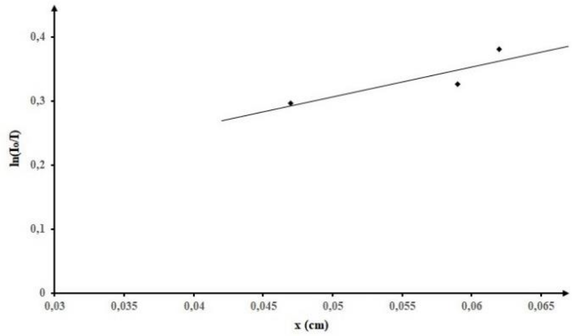

Figure 4. In(I_0/I)=f(x) graph of change.

HVL value changes according to the intensity of the incident beam (I_0). When a radioactive source with relatively higher gamma energy than Cs-137 (661.62 keV), such as Co-60 (1173.23 and 1332.50 keV), is used, the absorbent material thickness increases. As the atomic number (Z) of the absorber material increases, the thickness required for the incident gamma-ray intensity to decrease to half its value will decrease.) The low *HVL* value is important in the successful acceptance of radiation shielding [14-17]. The small *HVL* value of the produced material can be considered to be successful in shielding.

As the thickness of the material increases, the percentage of gamma intensity reduction increases. This shows that the thickness is quite effective in shielding.

PLA/TiC nanocomposite film could be a potential candidate as an alternative to lead in gamma ray shielding applications. Among the advantages of the material are light, flexible and non-toxic. Shielding capacity can be improved by doping trace amounts of higher atomic number elements such as lead, bismuth, tungsten into the produced material. At the same time, it is possible to increase the absorption property by increasing the percentage of RPE by increasing the thickness due to the lightness of the material. Considering its performance at Cs-137 (661.62 keV), it can be said that it can operate more efficiently at relatively low energies.

Table 1. Half Value Layer (HVL) and absorption percentages.

Thickness (cm)	I_0 (count/s)	I (count/s)	ln (I_0/I)	RPE (%)	µ (cm^{-1})	HVL (cm)	TVL (cm)
0.047	71.580	53.180	0.297	25.706			
0.059	72.536	52.342	0.326	27.840	4.670	0.015	0.493
0.062	72.706	49.690	0.381	31.656			

Declaration

Ethics committee approval is not required.

References

[1] De Santis, M., Cesari, E., Nobili, E., Straface, G., Cavaliere, A.F., & Caruso, A. (2007). Radiation effects on development. Birth Defects Research Part C: *Embryo Today*, 81, 177-182.

[2] Silindir, M., & Özer, A. Y. (2009). Sterilization methods and the comparison of E-beam sterilization with gamma radiation sterilization. *Fabad Journal of Pharmaceutical Sciences*, 34 (1), 43.

[3] Kevin M. P., Giuseppe, S., Melvyn F., & Kathryn D. H. (2005). New insights on cell death from radiation exposure, *The Lancet Oncology*, 6 (7), 520-528.

[4] Rosen, E. M., Day, R., & Singh V. K. (2015). New approaches to radiation protection, *Frontiers in Oncology*,4, 2234-943X.

[5] Martin, J.E., (2013). Physics for radiation protection. *3. upd.*
[6] Yıldız, N. Y., (2019). Gamma-ray shielding properties of lithium borate glass doped with colemanit mineral, *BEU Journal of Science*, 8 (3), 762-771.
[7] McCaffrey, J. P., Shen, H., Downton, B., & Mainegra-Hing, E. (2007). Radiation attenuation by lead and nonlead materials used in radiation shielding garments. *Medical physics*, 34(2), 530-537.
[8] Mansy, M. S., Lasheen, Y. F., Breky, M.M.E., & Selim, Y. (2021). Experimental and theoretical investigation of Pb–Sb alloys as a gamma-radiation shielding material. *Radiation Physics and Chemistry,* 183, 109416.
[9] Trubey, D. K., Eisenhauer, C. M., Foderaro, A., Gopinath, D. V., Harima, Y., Hubbell, J. H., & Shure, K. (1991). Gamma-ray attenuation coefficients and buildup factors for engineering materials. *Report ANSI/ANS* 6.4.3.
[10] McAlister, D.R., (2012). Gamma ray attenuation properties of common shielding materials. *University Lane Lisle*, USA.
[11] Canel E. (2020). A Study on the gamma-ray attenuation parameters of some commercial salt samples. *Sakarya University Journal of Science,* 24(2), 412-423.
[12] Tsoulfanidis, N. (1995). Measurement and detection of radiation. *Taylor & Francis Publisher,* London.
[13] Singh, T., Kaur, A., Sharma, J., Singh, P. S. (2018). Gamma rays' shielding parameters for some Pb-Cu binary alloys, *Engineering Science and Technology, 21(5)*, 1078-1085.
[14] Aktas, B., Yalcin, S., Dogru, K., Uzunoglu, Z., & Yilmaz, D. (2019). Structural and radiation shielding properties of chromium oxide doped borosilicate glass. *Radiation Physics and Chemistry,* 156, 144-149.
[15] Sayyed, M.I., Tekin, H.O., M. M., Taki, Mhareb, M.H.A., Agar, O., Şakar, E., & Kaky, K. M. (2020). Bi2O3-B2O3-ZnO-BaO-Li2O glass system for gamma ray shielding applications. *Optik*, 201, 0030-4026.
[16] Agar, O. (2018). Study on gamma ray shielding performance of concretes doped with natural sepiolite mineral. *Radiochimica Acta,* 106(12), 1009-1016.
[17] Soylu, H.M., Yurt Lambrecht, F. & Ersöz, O.A. (2015). Gamma radiation shielding efficiency of a new lead-free composite material. *Journal of Radioanalytical and Nuclear Chemistry,* 305, 529–534.