# Radiation attenuation of MWCNT and magnetic nanoparticle reinforced PMMA comparative analysis of coefficient [*]

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## Abstract

Poly(methyl methacrylate) (PMMA) is a thermoplastic material used in various industrial applications due to its lightweight and durable structure. Multi-walled carbon nanotubes (MWCNT) and magnetic nanoparticles are widely used to improve the mechanical, electrical and radiation attenuation properties of composite materials. It is important to comparatively investigate the ionizing radiation attenuation performance of polymer composites reinforced with MWCNT and cobalt-containing magnetic nanoparticles. In the experiments, measurements were carried out by gamma transmission method using Co-60 and Cs-137 sources. By analyzing the linear attenuation coefficient (μ) and half-value thickness (HVL), the effects of magnetic reinforcement particles and nanoparticle (MWCNT) additives containing cobalt on the radiation absorption capacity of polymer samples were evaluated. By examining the radiation permeability properties of the polymer composite structure, HVL values were determined and comparatively, the gamma radiation absorption capacity was investigated. This study includes results for the development of lightweight and effective radiation shielding materials.

## Keywords

XCOM, PHY-X/PSDPMMA , MWCNT , Radiation shielding, Gamma Transmission, Neutrons

## 1. Introduction

Poly(methyl methacrylate) (PMMA) is a thermoplastic material used in various industrial applications due to its lightweight and durable structure [1-5]. Multi-walled carbon nanotubes (MWCNT) and magnetic nanoparticles are widely used to improve the mechanical, electrical and radiation attenuation properties of composite materials [6-8]. It is important to comparatively investigate the ionizing radiation attenuation performance of polymer composites reinforced with MWCNT and cobalt-containing magnetic nanoparticles [9].

## 2. Method

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In the experiments, gamma transmission method was applied using Co-60 and Cs-137 sources to determine the gamma radiation attenuation performances. Gamma transmission, which was carried out in ITU Energy Institute Radiation Detection and Measurement Laboratory, was performed using NaI Scintillation detector.

Scintillation detectors are systems that detect ionizing radiation by converting it into visible light. NaI(Tl) crystal produces light (scintillation) when interacting with gamma rays. Figure 1 demonstrates types of radiation and ways of protection. Figure 2 shows gamma spectroscopy with NaI scintillation device.

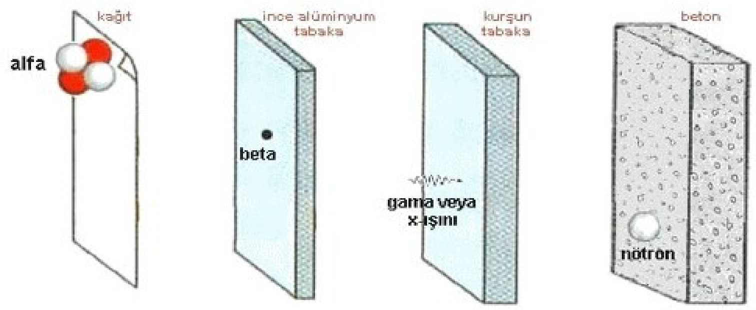


**Figure 1.** Types of radiation and ways of protection

**Figure 2.** Gamma spectroscopy with NaI scintillation device

Gamma ray interaction : Gamma rays lose energy by interacting with the NaI(Tl) crystal through the photoelectric effect, Compton scattering, or pair production mechanisms. Light production : This loss of energy results in the production of visible light photons within the NaI(Tl) crystal. Photomultiplier tube (PMT) is activated : The light emitted by the crystal is detected by a photomultiplier tube (PMT). The PMT generates a signal by converting the light photons into electrons. Electronic signal processing : The signal from the PMT is amplified, converted into digital data, and analyzed. Collimator working mechanism; Collimator selects the rays coming from a certain angle or direction and allows them to reach the detector. Collimators used in scintillation detectors are usually made of lead and are used for the following purposes: Directing the rays : Blocking the rays coming from different angles and allowing only those coming from a certain direction to pass. Reducing background noise increases the sensitivity of the measurements by blocking gamma rays coming from unwanted directions.It is based on the principle that gamma rays interact with atoms of matter as they pass through the material. As a result of these interactions, gamma rays lose some or all of their energy. The gamma radioisotope source and detector are placed on both sides of the material on the same axis and the radiation intensity coming from the source and passing through the material is measured. The count values obtained using different thickness values of the material are compared to the count value obtained without using the material, and relative count values are obtained for each thickness value of the material. Thickness-relative count graphs are drawn for each material, gamma attenuation curves of the material are created, compared with each other and evaluated in line with the purpose. The gamma radiation attenuation capacity of the materials was analyzed by measuring the linear attenuation coefficient (μ) and half-value thickness (HVL). Radiation measurements were performed using a NaI(Tl) sodium iodide scintillation detector. This detector detected gamma photons with high sensitivity, allowing accurate determination of radiation attenuation coefficients. Beta measuring device: The beta filter in front of the detector is in the closed position , Since beta particles cannot pass through the filter, only gamma rays are measured. The measurement obtained showed the background gamma radiation (gamma dose rate) . The detector's beta filter was in the open position ,beta particles can also reach the detector and are included in the measurement. In this case, the measurement obtained gives the sum of (Beta + Gamma). To find the beta number, pure beta is found by subtracting the gammas from the total count. Then, a graph is created showing the count amount depending on the thickness.Calculated three times using strontium 90 as the radiation source.

**Figure 3**. Beta spectroscopy and survey meter

**Figure 4**.Neutron measuring device; Howitzer and Neutron hand detector

Neutron measurement; The measurement is repeated 3 times using the Howitzer neutron detector , AM241 as the material and source.Since the source being worked on is active, a protective container and rope services are used inside the welding howitzer to minimize radiation exposure and similar measurements are obtained by maintaining the distance between the source materials. It is supported by protective methods such as paraffin, wooden barriers and cadmium to minimize scattering. 3 measurements were made and the material  observes by keeping the experiment time the same.

## 3. Theoretical Calculations

During the experiment, firstly the radiation of the laboratory environment was measured. Then, the measurement was made while the source was present, then the measurements were made while the source and the material were together, and the i and ı values of the samples with increased thickness were obtained. The rpe and attenuation coefficient values were found in accordance with the values obtained . As a result of the values found, the variance parts and the percentage distributions of the thickness permeabilities were calculated. According to the channel range selected in the Maestro program and the energy of the source, the highest discrimination was obtained with the material pairs, Relative percentage error (rpe ), linear attenuation coefficient (μ) percentages and $Ln(I/I_o)$ used to analyze the radiation absorption or permeability of the material. Peak heights gave a more discrimination result compared to the energy ranges of the peaks. If special results are selected and compared to increase discrimination in each method, discrimination increases. This allows us to distinguish the differences between our samples, even if they are small.

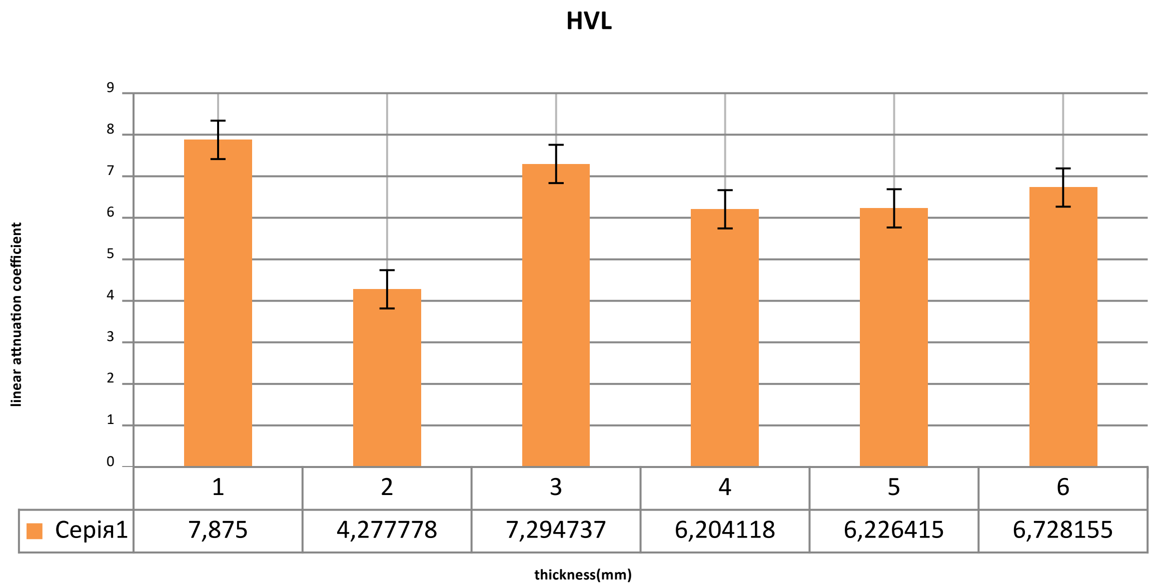


**Figure5.** Linear attenuation coefficient ratio of half-value layer numbers and nanoparticle source PMMA/MWCNT containing materials

MWCNT and magnetic nanoparticle doped PMMA composites increase the radiation attenuation performance by gamma transmission technique . It proves that MWCNT doped composites supported with magnetic nanoparticles are more effective in absorbing gamma radiation compared to samples containing only MWCNT. It has also been observed that Co-60 absorbs high energy gamma photons better, while Cs137 has a significant effect on the absorption of medium energy gamma rays.

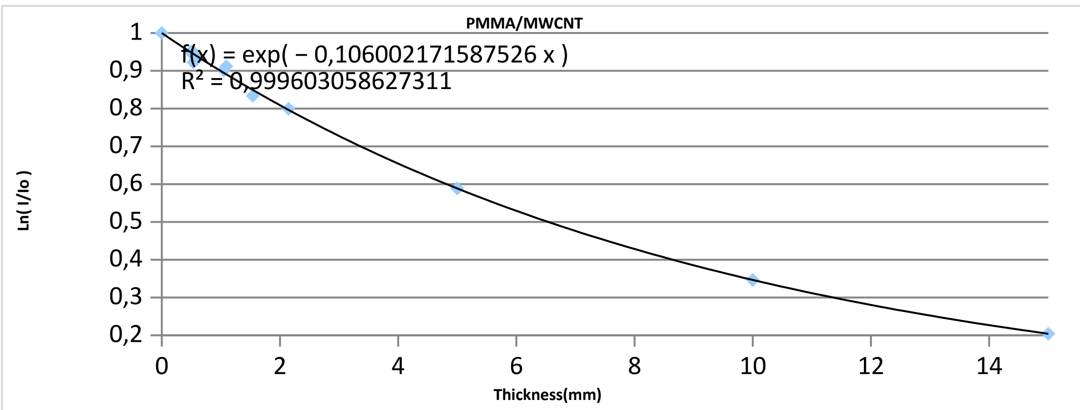


**Figure6.**Relationship between the linear attenuation coefficient and the thickness of materials containing and nanoparticle doped PMMA/Mwcnt

When the relationship between pure beta count and thickness is evaluated in the measurements made with beta spectrometer, the passage of beta particles through the material decreases as the thickness of the material increases. This decrease is explained by absorption and scattering effects .

As the Thickness Increases, the Beta Number Decreases .

- Beta particles are absorbed in matter and most of them do not reach the detector.
- Exponential decrease is seen:

$$N=No.e^{(-\mu x)}$$

N = Number of betas reaching the detector

N o = Initial beta number

x= Material thickness (cm )

μ= Attenuation coefficient of beta rays

Lower Energy Beta Particles Are Absorbed More Quickly .

- Beta particles with low energies (e.g. E<100keVE < 100 keVE<100keV ) can be completely absorbed even in thin materials.
- Higher energy beta particles (e.g. E>500keVE > 500 keVE>500keV from Sr-90) can pass through thicker materials.

Energy Shift is Seen in the Beta Spectrum .

- In thin materials: While the entire spectrum can be detected ,
- In thick materials: Low energy beta particles disappear completely, only the high energy part of the spectrum can be measured.

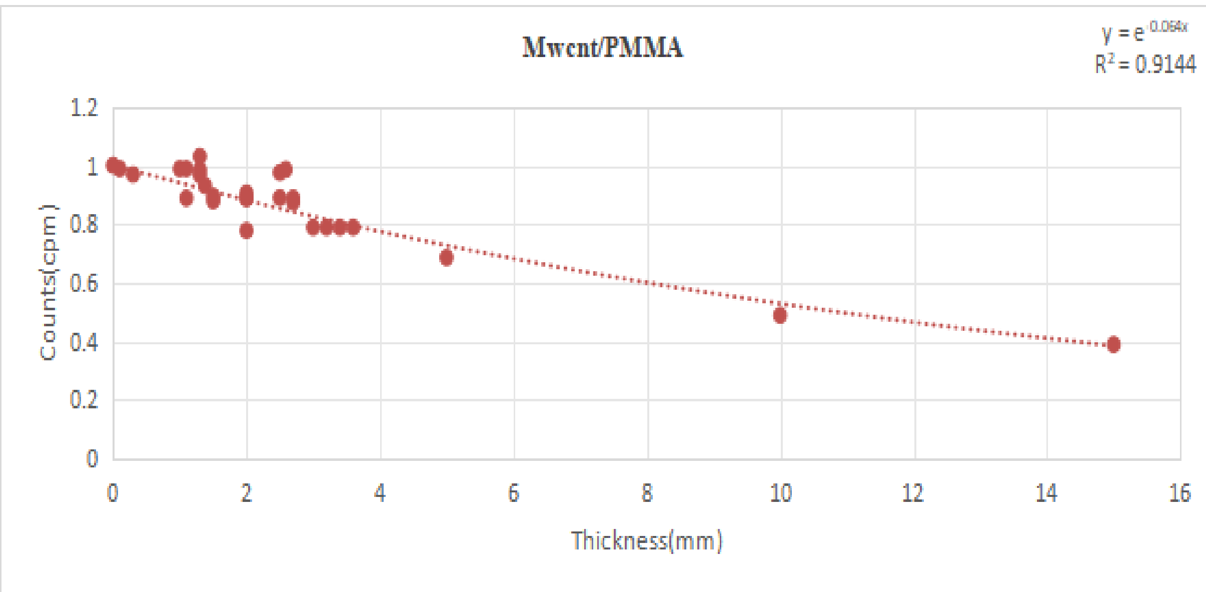


**Figure7.**Beta counting graph of nanoparticle doped PMMA/Mwcnt

**Table1.**

Thickness dependent beta comparison percentile values

| Thickness (mm) | Normal PMMA Beta Count | MWCNT/Magnetic Nanoparticle PMMA Beta Count |
|---|---|---|
| 1mm | 1 | 90% - 95% |
| 3mm | 0,75 | 60% - 70% |
| 5mm | 0,5 | 30% - 40% |
| 10mm | 10% - 20% | 5% - 15% |

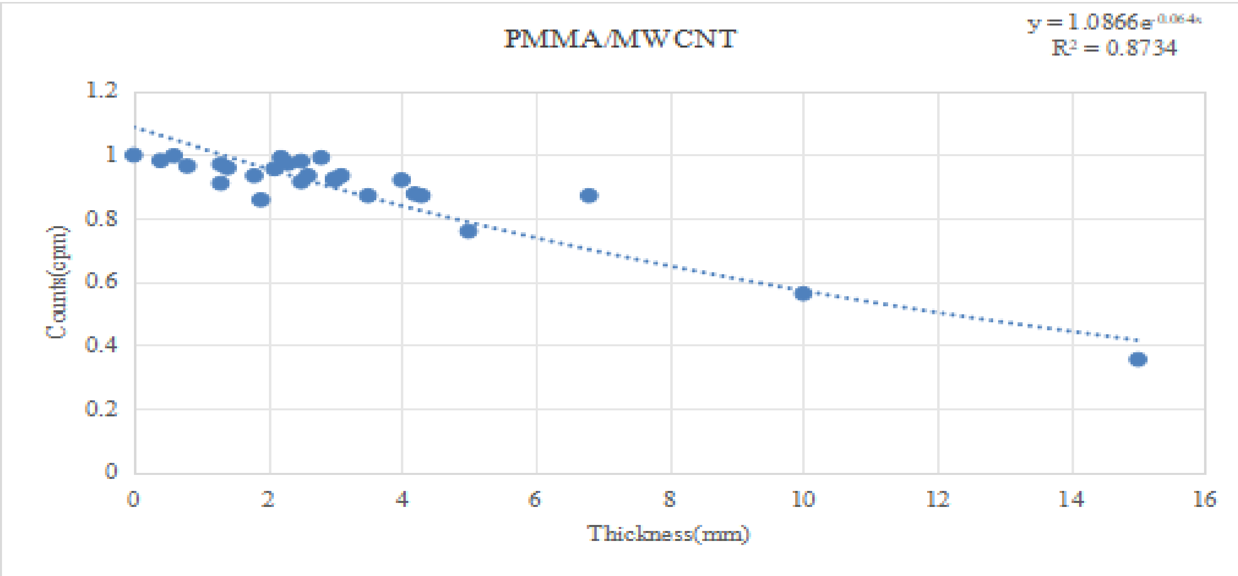


**Figure8**. Neutron counting graph of nanoparticle doped PMMA/Mwcnt

They are reflected in the setting of a multi-stage transportation problem, the objective function of which is to minimize all total costs for the production and transportation of raw materials and finished products [10].

## 4. Results

### 4.1. Electromagnetic Shielding and Integration with Data Analytics

Such composite materials provide effective protection against electromagnetic interference (EMI) and radio frequency interference (RFI) thanks to their high conductivity and magnetic properties. Sensitive electronic devices such as aircraft avionics systems, satellite communication systems and radar equipment can reduce system failures and increase reliability by taking advantage of these protective properties. In addition, with machine learning-supported data analytics, the protective levels of these materials can be optimized and instant monitoring can be provided with sensor-based systems.

**Magnetic Properties and Industrial Automation**

Cobalt, nickel or iron oxide components found in magnetic nanoparticles offer significant advantages for industrial robotic systems and smart production lines. These materials can be used in applications such as precise positioning, automatic control and magnetic sensor integration by interacting with magnetic fields. Magnetic nanoparticle-doped composites help robotic arms provide more precise motion control, while magnetic sensing properties can support data-driven decision-making mechanisms in smart manufacturing processes. Robotic arms can be used in artificial intelligence-integrated robots.

**High Temperature and Radiation Resistance in Aviation and Space.**

In environments exposed to extreme environmental conditions such as space, solar radiation and cosmic rays pose a major threat. MWCNT and magnetic nanoparticles help overcome these challenges by providing exceptional thermal and radiation protection. High temperature resistance allows these materials to perform in the long term under harsh conditions and makes them suitable for thermal management systems of spacecraft. Especially when integrated with IoT-based data analytics systems, these materials can play a significant role in instant performance monitoring and predictive maintenance applications in aviation.

**Use in Robotics Systems**

Magnetic nanoparticle-based materials can be used in various fields to increase the efficiency of robotic systems. Industrial robots can achieve high-precision positioning and error detection thanks to the compatibility of these materials with magnetic sensors. In addition, their electromagnetic shielding properties allow robots to operate reliably in environments where they are exposed to high-frequency electromagnetic fields.

**Future Directions.** The combination of MWCNTs and magnetic nanoparticles offers an innovative approach for both electromagnetic and radiation shielding applications. Future research focuses on optimizing material compositions by examining different concentrations and types of nanoparticles. Furthermore, integration into smart manufacturing systems supported by AI and data analytics will enable these composites to provide smarter, more durable, and more efficient solutions in various aerospace, industrial automation, and robotic systems.

## 5. Conclusion

MWCNT and magnetic nanoparticle doped PMMA composites can be evaluated as lightweight and effective radiation shielding materials. These materials offer significant advantages in many sectors such as nuclear power plants, medical imaging devices, aviation applications, space technologies, defense industry and industrial radiation shielding. Thanks to their unique properties, they have great potential especially in the aviation and space industry due to their electromagnetic shielding capacity, high temperature resistance and mechanical strength. In addition, their integration with smart technologies such as machine learning, artificial intelligence, internet of things (IoT) and data analytics offers new opportunities in industrial automation and robotic systems. Using it, cadets and students of fire safety will be able to get all the information they need regarding the material support of firefighters [11].

## Declaration on Generative AI

During the preparation of this study, the authors used Grammarly software to identify and correct grammatical and spelling inaccuracies. Following this process, they undertook a meticulous review of the text, made the requisite revisions, and accepted whole responsibility for the final content of this publication.

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