International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972

Volume 7 Issue 22 (September 2025) PP. 497-510
DOI 10.35631/IJIREV.722028

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.ijirev.com

GLOBAL ACADEMIC EXCELLENCE

RADIATION SHIELDING PERFORMANCE OF DOUBLE-LAYERED TIN-PDMS AGAINST 661.7 KEV GAMMA RAYS

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Article Info:

Article history:
Received date: 22.06.2025
Revised date: 17.07.2025
Accepted date: 17.08.2025
Published date: 12.09.2025

To cite this document:

Roslan, N. S., Mukhtar, N. M. A., Mahmood, A., Abdul Wahab, N. A.,

Abstract:

This study aims to investigate the ability of double-layered tin-PDMS composites to block gamma radiation at medium energy levels using Cs-137 (661.7 keV). Three composite series were fabricated, known as the PS, AS, and TM series, with different tin content and layer arrangements for observation purposes. Measurements are performed on two distinct irradiation surfaces of the series involving shielding parameters such as the linear attenuation coefficient (LAC), mass attenuation coefficient (MAC), radiation protection efficiency (RPE), half-value layer (HVL), and tenth-value layer (TVL). Analysis reveals that the irradiation surface has a substantial impact on the shielding performance of the material. The highest RPE value was recorded for

International Journal of Innovation and Industrial Revolution
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IJIREV
Volume 7 Issue 22 (September 2025) PP. 497-510
DOI 10.35631/IJIREV.722028

Abidin, H. Z., Shah, A. Z., & Zainon, R. (2025). Radiation Shielding Performance of Double-Layered Tin-PDMS Against 661.7 KeV Gamma Rays. *International Journal of Innovation and Industrial Revolution, 7* (22), 497-510.

DOI: 10.35631/IJIREV.722028

the TM6 composite with the alloy irradiation surface at 22.052%, with a LAC of 0.996 cm⁻¹, MAC of 0.187 cm²/g, HVL of 0.696 cm, and TVL of 2.311 cm. The TM6 exhibits exceptional shielding properties, which prove its capability as a potential radiation shielding material for medium-energy gamma ray protection applications. On the other hand, the RPEs for pure lead and pure PDMS were 48.863 and 5.502 percent, respectively. According to the results, various double-layer tin-PDMS material compositions have good promise for attenuation, and the TM6 arrangement may be helpful as a lighter and safer substitute for traditional lead shielding.

Keywords:

Metal-Polymer, Double-Layer Composite, Radiation Shielding, Lead-Alternative, Tin-PDMS

Introduction

Multiple operational fields require radiation shielding for their operations (N. M. A. Mukhtar et al., 2024). Radioactive materials emit powerful radiation during decay periods. Many nuclear applications utilize lead as a shielding material because it possesses a high atomic number, Z = 82, and a compact density of 11.34 g/cm³. Lead has high inherent toxicity properties. The elastic nature of lead material enables its tiny powder particles to disperse within the environment, thus creating hazardous conditions for human health (Gurumurthi & Rajasekar, 2025; Zainal Abidin, Mukhtar, Mahmood, Abdul Wahab, Zainon, & Roslan, 2025; Zainal Abidin, Mukhtar, Mahmood, Abdul Wahab, Zainon, Roslan, et al., 2025). This research investigates the effect of double-layered composites composed of tin-polydimethylsiloxane (PDMS) with pure tin and tin alloy fillers, as well as surface modifications, on enhancing radiation absorption performance. The research evaluates the attenuation efficiency of gamma radiation emitted by a Cs-137 source with energy 661.7 keV, which is observed on three different composite series consisting of pure tin, tin alloy, and PDMS. The shielding analysis focuses on LAC, MAC, RPE, HVL, and TVL to determine the superior composite setup.

Metal and Polymer Composite

As a metal element, tin has an atomic number of 50 and a density of 7.31 g/cm³. Scientific studies recognize tin as being both toxicologically safe and biologically compatible with polymers and compatible with biological tissues, which makes it suitable for use in composite materials (Chen et al., 2023). Polydimethylsiloxane (PDMS) is a methyl-group polymer that exhibits outstanding thermal properties, as well as flexible characteristics and easy processing capabilities. Research shows that PDMS serves biomedical needs because it possesses both biocompatibility and low-weight properties, being silicon-based (Zainal Abidin, Mukhtar, Mahmood, Abdul Wahab, Zainon, Roslan, et al., 2025).

The research utilizes two layers for the tin-PDMS composite structure. This flexible part serves to improve system stability while adding mechanical resistance. The double-layered structure solves crucial safety issues of heavy and toxic conventional radiation shielding materials by offering safer and lighter PPE alternatives (J. A. Kamarolzeman & N. M. A, 2020; N. M. A. Mukhtar et al., 2024; Nakamura et al., 2024). Layered composites offer flexibility and conformability that enable their use in protective garments, as well as adaptable materials for radiation exposure needs (J. A. Kamarolzeman & N. M. A, 2020). This shielding material demonstrates controlled properties because engineers modify the composition and thickness of its separate layers to adapt it for specific uses.

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The fabrication layering technique enables the fabrication of metal-polymer composites, significantly enhancing the shielding effectiveness of the material and its structural strength. This fabrication method creates alternating layers of metal with a polymer, which results in better radiation attenuation by implementing multiple scattering and absorption processes (Nakamura et al., 2024). Through layering manufacturing techniques, the producer achieves exact control of composite thickness and properties, enabling applications across various uses (Gilys, Griškonis, Griškevičius, & Adlienė, 2022; Gouda, Abbas, Hammoury, Zard, & M.El-Khatib, 2023; Nakamura et al., 2024)

Materials and Methods

This research utilized corresponding metal powders: tin (Sn) with a density of approximately 7.31 g/cm³ obtained from Bendosen in Kuala Lumpur, Malaysia, and tin alloy with a density of about 8.8 g/cm³ from Sigma Aldrich in Taufkirchen, Germany (Figure 1). This work used the Sylgard 184 Kit Set of Silicone Elastomer Base PDMS, along with Sylgard elastomer curing agent at a 10:1 ratio.

(a) Sylgard 184 Kit Set of Silicone Elastomer Base PDMS (b) Pure tin metal powder (c) Tin alloy metal powder

Figure 1: Raw Materials

The composite samples were prepared layer by layer using the proportions as presented in Table 1 by mixing the tin powder with the PDMS polymer. About 19 samples were prepared, consisting of the control PDMS and six samples of each of the three composite series, which are PS series (with a pure tin filler), AS series (with the filler containing a tin alloy), and TM series (a combination of pure tin filler and tin alloy filler). For details, Layer 2 for the PS series and AS series is a PDMS layer containing 100 % of PDMS polymer, while Layer 1 of the composite is prepared by mixing the tin and PDMS through extensive stirring for 7-10 minutes, before being poured into a mold. A mold containing the 0.25 cm-thick mixture was then cured in a desiccator for 24 hours until the solidification process was complete, before repeating another layer. The samples were then subjected to characterization using FESEM, FTIR, and Gamma-Spectroscopy to observe their morphology and structural integrity, as well as radiation absorption capabilities. Figure 2 shows an overview of the PS series, the AS series, and the TM series samples accordingly. The thickness of each layer is equal, which is about 0.25cm.

(a) Control PDMS (b) PS-series (c) AS-series (d) TM-series

Figure 2: Overview Double-Layered Tin-PDMS Composites

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Table 1: The Composition Percentage of Fillers in the Composites

Filler / Matrix	Composite label	Filler composition of each layer	
		Layer 1	Layer 2
PDMS	Control PDMS	0	
Lead	Control Lead	0	
Pure Tin	Control tin	100	
Pure tin (PS-Series)	PS1	0	10% pure tin
	PS2	0	20% pure tin
	PS3	0	30% pure tin
	PS4	0	40% pure tin
	PS5	0	50% pure tin
	PS6	0	60% pure tin
Tin Alloy (AS-Series)	AS1	0	10% tin alloy
	AS2	0	20% tin alloy
	AS3	0	30% tin alloy
	AS4	0	40% tin alloy
	AS5	0	50% tin alloy
	AS6	0	60% tin alloy
Pure Tin-Tin Alloy (TM-Series)	TM1	10% pure tin	10% tin alloy
	TM2	20% pure tin	20% tin alloy
	TM3	30% pure tin	30% tin alloy
	TM4	40% pure tin	40% tin alloy
	TM5	50% pure tin	50% tin alloy
	TM6	60% pure tin	60% tin alloy

Sample Analysis

Effective Density of The Composites

Table 2 and Figure 3 show the relationship between density and mass for the PS, AS, and TM series composites. From the table, each PS series member has a relatively lower density and weight, with an effective density of 1.36 g/cm³ (PS1) to 3.15 g/cm³ (PS6). While the AS series shows intermediate density and structural load-carrying capacity, with the density tabulated across 1.24 g/cm³ in AS1 up to 3.42 g/cm³ (AS6). The TM series, which contains two metal-mix layers, has considerably higher packing density with a lower amount of porosity, where the effective density was tabulated from 1.77 g/cm³ (TM1) to 5.32 g/cm³ (TM6), compared with the other series.

The experimental results indicate that the tin filler directly affects the matrix density, hence resulting in increased attenuation capabilities (shown in Table 2). Based on the result, effective density is a vital factor in determining gamma-ray shielding effectiveness. Among all series, TM6 displayed the greatest RPE efficiency of 22.05%, with an LAC value of 0.5536 cm^{-1} and a small HVL value of 1.25 cm among all studied samples. The highly effective density value of 5.32 g/cm³ in TM6 enabled effective photon absorption through material atomic interactions in the composite. The TM series exhibited the greatest effect in gamma ray attenuation because it contains two layers of metal composition with a higher distribution and higher packing density throughout the composite.

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The attenuation performance of composites was directly linked to their effective density measurement. The radiation shielding properties, such as LAC, MAC, and RPE, increased when effective density values increased, whilst HVL and TVL decreased. Distinct attenuation parameters were detected in the TM series, enabling effective radiation shielding because of their dense composition. These findings emphasize the huge impact that controlled fabrication methods and homogeneous filler distribution have in achieving the outlined material properties. By reducing flavor imperfections such as porosity and uneven dispersion, it is possible to significantly increase the performance and quality of the composites in all series (Chen et al., 2023).

Table 2: Effective Density For Multilayered Tin-PDMS Composite

Composite Label	Effective Density (g/cm^3)
Control PDMS	0.962
Control Lead	11.34
Control Tin	7.29
PS1	1.36
PS2	1.37
PS3	1.83
PS4	1.95
PS5	2.34
PS6	3.15
AS1	1.24
AS2	1.45
AS3	2.32
AS4	2.79
AS5	3.11
AS6	3.42
TM1	1.77
TM2	2.47
TM3	3.24
TM4	3.96
TM5	4.69
TM6	5.32

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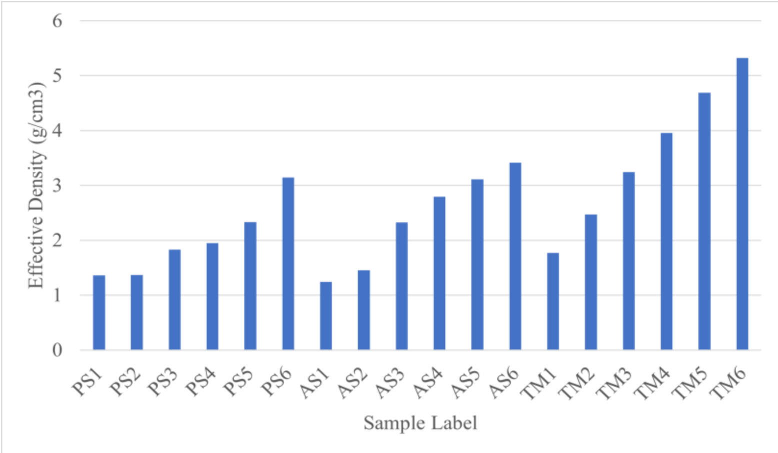
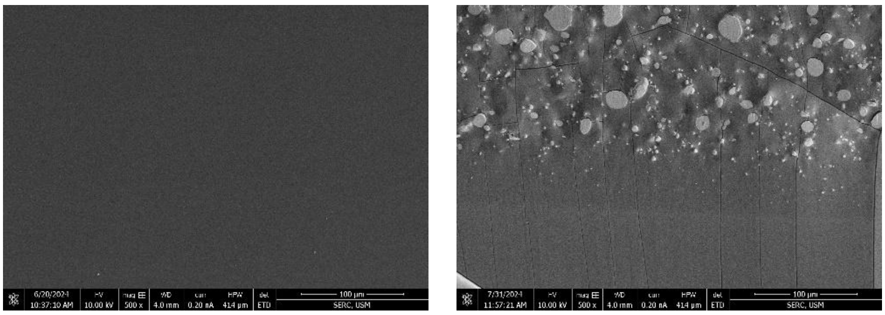


Figure 3: Distribution Pattern of Effective Density for Multilayered Tin-PDMS Composite.

Field Emission Scanning Electron Microscopy (FESEM)

Field Emission Scanning Electron Microscopy (FESEM) at various magnifications. Figure 4 shows FESEM images at 500× magnification of PS4 and AS4, analyzing the internal structure and dispersion uniformity of the manufactured composites. The cross-sectional examination of the composite showed no observable inhomogeneities, voids, or phase separation through the entire sample area. Tin particles dispersed throughout the PDMS matrix showed a uniform distribution as the layers maintained an uninterrupted interface. Just as anticipated, the control sample of 100% polydimethylsiloxane shows a flat and evenly textured surface, as shown in Figure 4 (a). The PS4 sample in Figure 4 (b) has two different layers. The first layer is made up of tiny tin particles that are evenly spread out in the PDMS material. The uniform distribution shows that the reinforcement and the matrix are well blended and spread out evenly in the composite. The second layer is made only of PDMS and exhibits a clear surface from FESEM. The well distribution between the particle-filled and clear surface of the PDMS layer shows that stacking went well and helps keep the two layers separate, as shown in Figure 4 (b). In the AS series composite (AS4), shown in Figure 4 (c), the tin alloy particles in the tin-PDMS mixture have sunk to the bottom of the first layer. The disparity in density and viscosity between the PDMS matrix and alloy filler led to gravitational settling of the alloy particles during the curing stage. It is quite noticeable that the middle region excess PDMS becomes thinner and is reduced as more tin is added to the alloy. Lower tin alloy in the sample results in a higher PDMS thickness, which suggests that increasing the number of fillers can cause a lack of space in the matrix.



(a) Control PDMS (b) PS4

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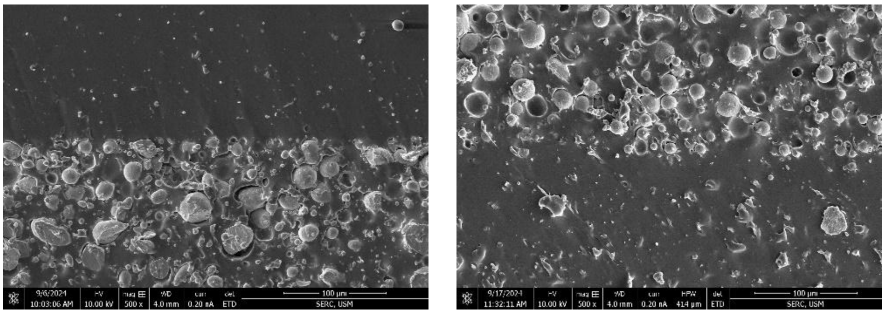

(c) AS4 (d) TM4

Figure 4: FESEM Images At 500x Magnification

Figure 4 (d) shows the TM series composite (TM4), which is composed of both pure tin and tin alloy particles with PDMS in both layers, which makes it quite different from PS4 and AS4. As observed in the FESEM images, both layers have highly dense particle regions. This shows that the structure is symmetrical and has a high cross-sectional area of the particle for more radiation to interact with. The tabulation of particles in both layers increases the potential for the TM series to absorb and attenuate the radiation significantly, compared with the AS and PS series, which consist of a PDMS layer (layer 2). Not only that, but the composite layer also contains high atomic number material, thus highly contributes to better attenuating radiation (Dejangah, Ghojavand, Poursalehi, & Gholipour, 2019; Hubbell & Seltzer, 1995).

No agglomeration and particle clusters demonstrate that filler elements were mixed properly during the preparation process (Punera, 2021). The FESEM images validate the intentional design of each composite series and provide insight into the microstructural behavior influenced by filler type, filler concentration, and layer configuration. The PS4 demonstrates effective filler dispersion and clear stratification, while AS4 highlights the effects of filler density and phase separation. TM4 shows a more homogenous double layer with high filler loading, likely contributing to its superior shielding performance in RPE and MAC studies.

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy (*brand PerkinElmer*), with model Spectrum 100 series and wavenumber range of 4000 to 500 cm^{-1}, is used to assess the chemical bonds and molecular vibration in the sample structure (Abualroos, Idris, Ibrahim, Kamaruzaman, & Zainon, 2024). The FTIR spectra of the tin-PDMS composites (Figure 5) show strong signals for the PDMS polymer, showing up as the stretching vibration of Si–O–Si and the bending vibration of $Si–CH_3$, which means that the PDMS is mixed in. The introduction of tin filler made the peaks in the FTIR pattern a bit different and less intense, showing that the tin particles interacted a lot with the polymer and might have stuck together with it. No new peaks or significant chemical changes were seen, which means that adding tin did not change the main make-up of PDMS, but it did seem to help PDMS stick better to the metal surface. These chemical reactions help the composite become stronger, more consistent, and evenly spread out the tin throughout the layers.

The double-layer configuration provides improved shielding capabilities to these structures. FTIR analysis allows researchers to verify the distinctiveness of PDMS functional groups, Si–O–Si, $Si–CH_3$, and CH_3, following tin integration, while simultaneously detecting possible changes in chemical composition (Zainal Abidin, Mukhtar, Mahmood, Abdul Wahab, Zainon,

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& Roslan, 2025). The filler and matrix demonstrate excellent chemical compatibility because peak positions and intensities remain unchanged in the analysis.

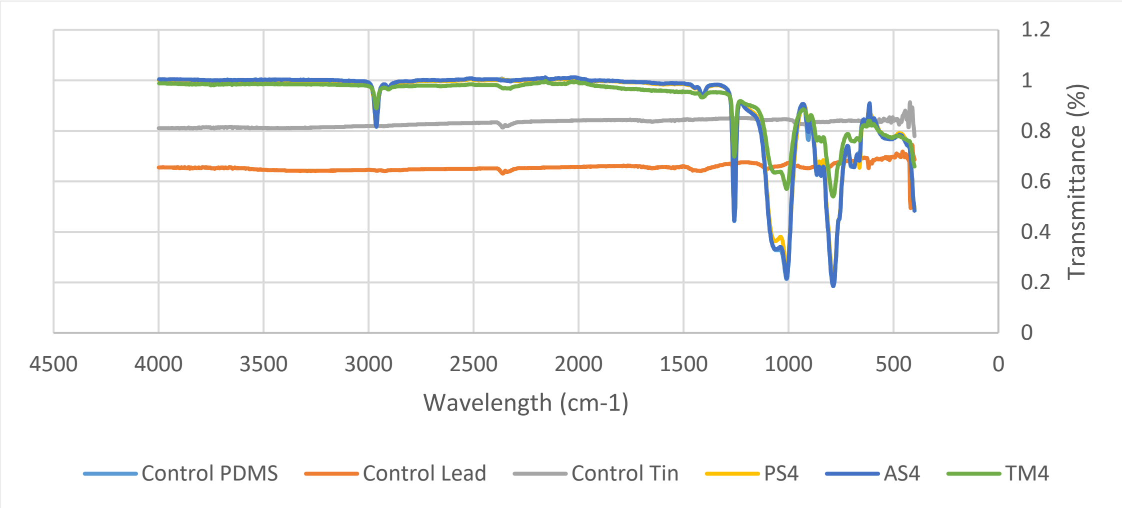

Figure 5: FTIR Spectra for Control PDMS, Control Lead, Control Tin, PS4, AS4, And TM4.

Radiation Characterization

Radiation characterization is performed using a gamma-ray spectrometer shown in Figure 6 with a Cs-137 point source of 661.7 keV and a high-purity germanium (HPGe) detector with a lead collimator. The composite is placed between the source and detector, with the surface of each composite sample receiving direct exposure to the gamma ray, as shown in the schematic diagram in Figure 7. In the procedure, the transmitted intensity is recorded as radionuclide decay activities before being used to calculate shielding parameters, such as linear attenuation coefficient (LAC), MAC, HVL, and RPE (Abualroos, Yaacob, & Zainon, 2023; Alanazi et al., 2024; Aldhuhaibat, Amana, Jubier, & Salim, 2021).

Figure 6: A Gamma-Ray Spectrometer Used for Radiation Characterization

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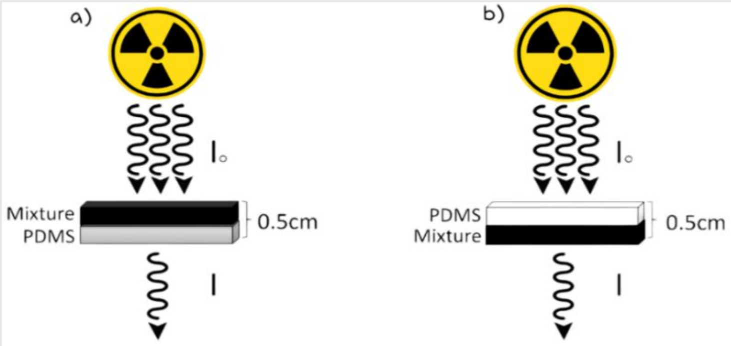

Figure 7: Illustration of Gamma Irradiation: a) Mixture Layer Irradiation Surface and b) PDMS Layer Irradiation Surface

Table 3 contains radiation shielding characteristics of the composite under study. The shielding characteristics are determined by the structure composite and the nature of the irradiation surface. As an example, in PS series samples, the samples that were irradiated through the tin surface resulted in substantially better attenuation outcomes.

In particular, PS6 (tin surface) provided a LAC of 0.2539 cm^{-1}, MAC of 0.0937 cm^2/g, RPE of 27,22%, HVL of 2.73 cm, and TVL of 9.08 cm, which indicates that it has a better attenuation capability. However, the AS series performed better in the case of exposure to the PDMS surface. AS6 (PDMS surface) achieved a MAC of 0.0764 cm^2/g, RPE of 17.94 percent, HVL of 3.66 cm, and TVL of 12.17 cm, which was higher compared to the alloy surface variant. This could be a result of the interface effects or the attenuation features of the PDMS-facing structure. In the meantime, the samples of the TM series were proven to exhibit a significant enhancement of attenuation properties. The use of the alloy surface to irradiate TM6 yielded the highest RPE of 49.08%, which compared better to all other samples in this study with a MAC of 0.2648 cm^2/g, HVL of 1.557 cm, and TVL of 5.174 cm. This outstanding performance has been able to be credited to multi-wavelength photon attenuation due to the combination of 60% pure tin and 60% tin alloy layers, which allows an increase in the scattering and absorption mechanisms. Another factor that enhances attenuation is an increased interaction cross-section that is caused by the alloy surface.

Table 3: Radiation Properties for Different Irradiation Surfaces

Sample	Irradiation Surface	LAC (cm^{-1})	MAC (cm^2/g)	HVL (cm)	TVL (cm)	RPE (%)
Control PDMS	-	0.109	0.113	6.369	21.158	5.502
Control Lead	-	1.341	0.118	0.517	1.717	48.863
Control Tin	-	0.662	0.091	1.047	3.479	28.177
Tin Irradiation Surface	PS1	0.329	0.242	2.105	6.991	7.904
	PS2	0.387	0.282	1.791	5.951	8.515
	PS3	0.384	0.210	1.806	5.998	8.802
	PS4	0.427	0.219	1.625	5.397	8.570
	PS5	0.399	0.171	1.737	5.770	10.573
	PS6	0.439	0.140	1.578	5.240	9.214
PDMS Irradiation Surface Samples	PS1	0.257	0.189	2.694	8.948	6.472
	PS2	0.320	0.234	2.163	7.185	7.699
	PS3	0.321	0.176	2.158	7.169	7.716

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	PS4	0.339	0.174	2.047	6.801	8.115
	PS5	0.448	0.192	1.547	5.140	10.596
	PS6	0.471	0.150	1.471	4.888	8.561
Alloy Irradiation Surface	AS1	0.078	0.063	8.892	29.539	6.668
	AS2	0.213	0.147	3.257	10.819	6.782
	AS3	0.215	0.093	3.222	10.702	7.408
	AS4	0.630	0.226	1.100	3.653	9.594
	AS5	0.670	0.216	1.034	3.435	11.367
	AS6	0.553	0.162	1.253	4.161	11.462
PDMS Irradiation Surface Samples	AS1	0.492	0.397	1.408	4.677	6.199
	AS2	0.506	0.349	1.369	4.549	6.368
	AS3	0.248	0.107	2.791	9.272	9.005
	AS4	0.306	0.110	2.267	7.531	9.873
	AS5	0.326	0.105	2.124	7.056	10.209
	AS6	0.322	0.094	2.150	7.141	10.959
Tin Irradiation Surface	TM1	0.237	0.134	2.925	9.718	7.082
	TM2	0.340	0.138	2.039	6.775	10.000
	TM3	0.618	0.191	1.121	3.723	11.635
	TM4	1.479	0.374	0.469	1.557	16.262
	TM5	0.953	0.203	0.727	2.416	15.764
	TM6	1.012	0.190	0.685	2.276	18.320
Alloy Irradiation Surface	TM1	0.577	0.326	1.202	3.994	7.754
	TM2	0.465	0.188	1.491	4.954	10.139
	TM3	0.425	0.131	1.632	5.423	12.704
	TM4	0.845	0.213	0.820	2.724	15.553
	TM5	0.517	0.110	1.341	4.454	15.683
	TM6	0.996	0.188	0.696	2.311	22.052

The MAC of pure lead was the highest, followed by that of pure tin, and the lowest was that of PDMS among the control materials. This sequencing follows those predictions made based on atomic numbers (Z) and density, and adds supporting evidence to the argument of designing composites to optimize the functional performance of attenuation, and also maintain reasonable levels of weight/toxicity. The average MAC of the tin surface at the PS series was 0.0937 cm^2/g, and then the PDMS surface with an average MAC of 0.0360 cm^2/g. Their result is theoretically justified because the atomic number of tin is larger, so the probabilities of interaction with photons are also larger. Shockingly, the PS series not only performed better than pure PDMS but even pure tin, indicating a synergetic shielding feature of the double-layer arrangement.

Conversely, the AS series performed better under the irradiation of the PDMS surface with an average MAC of 0.0764 cm^2/g, and the average MAC at the alloy surface was 0.0660 cm^2/g. The relatively less attenuation on the alloy surface could have been due to the mixed elemental content that makes the surface have a less effective atomic number of pure tin. Such measurements indicate that the composites containing alloys can be less shielded compared to those with pure tin layers.

In the case of the TM series, irradiation surfaces have almost comparable MAC values, and the alloy surface (0.0951 cm^2/g) was slightly better compared to that of the tin surface (0.0902

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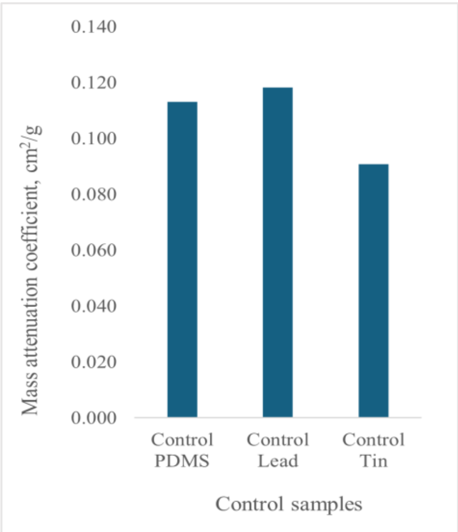
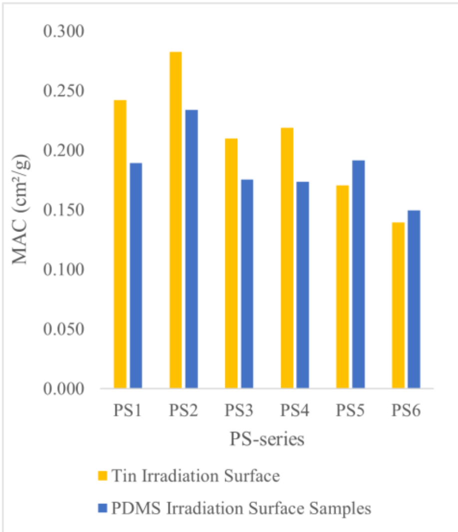
cm^2/g). It implies that, within the layered setting, the composition of the tin/alloy series has a mild effect on total attenuation, which may be affected in the building interface with constructive interference.

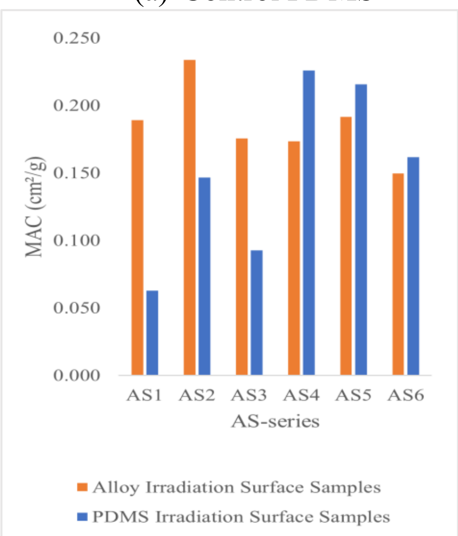
On the other hand, the MAC value of the TM Series is higher than for the AS series but lower than that of the PS composite. The PS series, with a tin facing exposed to the source, shows the highest attenuation efficiency of any of the composite designs and beats even the control lead in some cases. This verifies that the orientation of the strategic layer, particularly those that are made of pure high-Z materials such as tin, is crucial in optimizing gamma-ray shielding. Figure 8 shows the gamma attenuation performance of the PS, AS, and TM series in terms of MAC as a result of the varying irradiation surface configurations. Because the MAC is a very important parameter measuring the efficiency of gamma-ray shielding, the larger the values of MAC are, the greater the levels of absorption of photon energy will be.



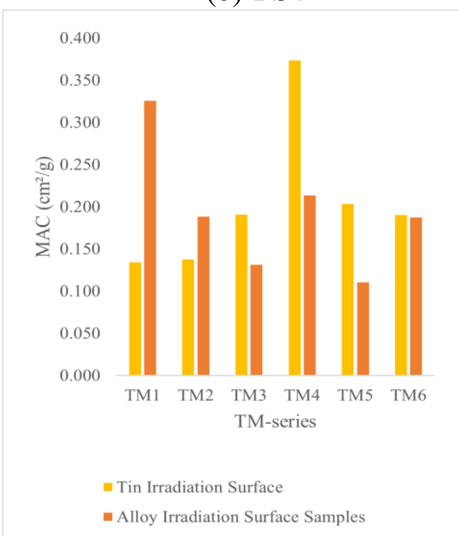
(a) Control PDMS



(b) PS4



(c) AS4



(d) TM4

Figure 3: MAC Distribution Pattern with Different Irradiation Surfaces

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 22 (September 2025) PP. 497-510
DOI 10.35631/IJIREV.722028

Conclusion

Based on the analysis of gamma-ray shielding capabilities at 661.7 keV, the TM series demonstrated superior attenuation performance compared to the PS and AS series. Both tin and alloy irradiation surfaces of TM samples showed high RPE values and low HVL/TVL, indicating enhanced gamma attenuation ability. Of all the composites, TM6 with the alloy irradiation surface achieved the highest RPE (22.05%), the lowest HVL (0.696 cm), and the lowest TVL (2.311 cm), confirming it as the most effective design for medium-energy gamma-ray protection.

By comparing irradiation surfaces within the TM series, the alloy-facing side generally yielded higher RPE and lower HVL/TVL than the tin surface, suggesting better initial photon interaction and attenuation. The same trend was observed in TM4 and TM5. In contrast, the PS and AS series show moderate efficiency, with PS6 (tin surface) and AS6 (alloy surface) being the best in their respective groups but still falling short of TM6's performance, as shown in Table 4.

Table 4: Summary of Best-Performing Composites Per Series At 661.7 Kev

Best Sample & Surface	LAC (cm^{-1})	MAC (cm^2/g)	HVL (cm)	TVL (cm)	RPE (%)	Remarks
TM6 – Alloy	0.996	0.188	0.696	2.311	22.052	Best overall performance; optimal for gamma shielding
PS6 – Tin	0.439	0.140	1.578	5.240	9.214	Best in PS series; significantly better than PDMS
AS6 – Alloy	0.553	0.162	1.253	4.161	11.462	Best in AS series; moderate performance

This comparison confirms that multi-layered tin–tin alloy composites (TM series) provide a clear advantage due to their higher density, improved filler packing, and dual-metal interfaces, which enhance both photon scattering and absorption. While PS and AS series composites offer lighter alternatives with reasonable shielding efficiency, they do not match the attenuation performance of TM6. Therefore, the TM6 alloy-surface configuration is identified as the optimal composite for reducing gamma-ray intensity at 661.7 keV.

Based on the analysis done on data obtained on the shielding capabilities at 661.7 keV gamma energy, the TM series proved to be a better shield than the PS and the AS series. It was observed, both TM samples' irradiation surfaces of the tin and the alloy had high RPE values, along with low HVL and TVL, which demonstrated an increment in gamma attenuation ability. Of all the samples, TM6 with the alloy surface irradiation turned out to be the superior-performing sample that had the greatest RPE of 22.05%, the minimum HVL of the sample of 1.25 cm, and the TVL of 4.16 cm. These findings substantiate the fact that the alloy-facing structure of TM6 best provides maximum gamma radiation protection of all composites.

When contrasting performance on irradiation surfaces between the TM series, the alloy usually showed greater RPE and lower HVL and TVL values when compared with the tin surface. This could be explained by improved interaction and photon attenuation capability of the alloy layer when gamma-rays initially interact with the alloy. The same trends were also observed in the

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other TM samples, like TM4 and TM5, where alloy surfaces performed significantly well as compared to their tin counterparts.

By contrast, the PS and AS series showed moderate to poor radiation shielding efficiency. The PS5 and PS6 samples exhibited a relatively high RPE compared to previously obtained PS samples, but their RPE values were kept below the best-performing TM samples. The AS series, despite being made of alloy surfaces, exhibited generally lower LAC and RPE readings, which could be explained by lower tin alloy content or other differences in microstructural attributes that lessen effective attenuation.

Finally, the best radiation shielding was attained by the TM6 composite with the alloy irradiation surface. It offered a maximum RPE and minimum reduction efficacy of gamma ray intensity, which was reflected by low values of HVL and TVL. Therefore, the most efficient design of the TM6 alloy surface configuration is the best design for blocking gamma radiation of 661.7 keV.

Acknowledgement
The authors would like to acknowledge the Ministry of Higher Education (MOHE) for the financial support provided through the Fundamental Research Grant Scheme (FRGS/1/2023/STG05/UITM/03/3). The authors would also like to thank Universiti Teknologi MARA Cawangan Pulau Pinang, Universiti Sains Malaysia, Universiti Putra Malaysia, and Universiti Kebangsaan Malaysia for their contributions, support, and the provision of access to workstation facilities.

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