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Original Article

The Radiation Attenuation Property of High-Density Polyethylene Doped with Zinc Oxide as an Alternative Gonadal Shield

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Abstract

Background: *The study investigated the radiation attenuation properties of high-density polyethylene doped with zinc oxide as an alternative to the commercially available gonadal shield in different concentrations.*

Methods: *A Geiger Muller Counter was used to record the values per exposure, which were used to compute the Half Value Layer, and were subjected to statistical analysis.*

Results: *The means of the HVL values from the three concentrations are 9.38±3.92, 7.84±2.53, and 8.62±1.77 for the HDPE and 125% of ZnO, HDPE and 100% of ZnO, and HDPE and 75% of ZnO, respectively. The mean radiation attenuation among the three concentrations is 0.21±0.03 for HDPE and 75% ZnO, 0.19±0.06 for HDPE and 100% ZnO, and 0.27±0.07 for HDPE and 125% ZnO. After the One-Way Repeated-Measures ANOVA, it was found that there was no significant difference between the means of the radiation attenuation of the HDPE doped with ZnO radiation shields and the lead shield: $F(3,12) = 2.158$, $p = 0.146$. In addition, a supplemental survey revealed that the shields were generally well-received in terms of their comfortability and wearability.*

Conclusion: *Overall, the HDPE doped with ZnO radiation shields could attenuate a significant amount of radiation, suggesting its potential to be an alternative to a lead radiation shield.*

Keywords

radiation shielding, half-value layer, high-density polyethylene, zinc oxide

INTRODUCTION

Radiation shielding is one of the cardinal principles of radiation protection alongside time and distance which are fundamental to maintaining minimum radiation exposure. Time entails keeping the exposure time as short as possible. Distance entails maintaining as much distance as possible from the radiation source as acceptable. Shielding entails using radiation-absorbing or blocking barriers to prevent unnecessary radiation exposure to patients and personnel during the procedure (Guidelines for ALARA – as Low as Reasonably Achievable, 2024). Protective shields can differ according to the organ's level of radiosensitivity. Practicing these principles assures the health and safety of individuals exposed to areas with radiation.

For a material to be considered a good radiation shield, it should effectively attenuate or reduce the penetration of ionizing radiation. The material should have a high absorption capability, reducing the intensity of the radiation passing through the shield, and be chemically stable to avoid significant changes when exposed to radiation over time. Lead material has excellent radiation-attenuating properties due to its high density and atomic number. A lead equivalent thickness of at least 0.5 mm is a requisite for a radiation shield to attenuate 90% of the x-rays that traverse it. It is also an effective radiation shield because of its long-term stability and durability.

Lead shields have become the radiology department's primary material for radiation protective equipment in the radiology department (Bushong, 2020). Patients and staff working in the hospital utilize this radiation protection equipment. Shields are given to patients who undergo a procedure to cover areas such as the reproductive organs and thyroid from harmful scatter radiation. Occupational shielding is advised during fluoroscopic procedures to protect personnel from scatter radiation. However, lead shielding among radiation health workers is associated with possible occupational health risks such as musculoskeletal disorders and exposure to lead particles that could cause various cerebrovascular and respiratory disorders (Alshareef et al., 2023).

Lead alternatives for radiation shields are emerging, with polymer composites showing promising potential. The researchers are focusing on the use of high-density polyethylene (HDPE) doped with high-atomic-number materials like zinc oxide nanoparticles. Zinc oxide is a versatile inorganic compound used in a wide range of products in the market. Reinforcing zinc oxide fillers in various polyester composites exhibits an increase in radiation shielding effectiveness (Kaçal et al., 2020). HDPE's inherent radiation attenuation properties stem from its high hydrogen content and density, effectively absorbing ionizing radiation and reducing its energy. This translates to better penetration protection. Beyond its shielding capabilities, HDPE offers versatility due to its flexibility, rigidity, and corrosion resistance, making it a suitable material for diverse applications.

Moreover, this study aims to prove that HDPE doped with Zinc Oxide can be an effective alternative to the commercially available lead gonadal shield. The radiation attenuation property of HDPE-Zinc Oxide composites makes them a promising choice for generating an effective and cheaper radiation shield.

METHODS

The study followed an experimental research design in which the radiation attenuation properties of HDPE and ZnO were explored to determine their potential as radiation shields. The molding process of the HDPE doped with ZnO radiation shields was done at the Cebu Doctors' University-College of Medicine-Experimental Research Laboratory. Meanwhile, the radiation attenuation characteristics of the shields were measured at the Cebu Doctors' University Hospital (CDUH) - Radiology Department.

The Geiger-Muller counter was exposed to the factors selected by the researchers. A digital image receptor was used to visualize the difference in attenuation of the different concentrations of the HDPE doped with ZnO radiation shields. Additionally, three registered radiologic technologists assessed the wearability and comfortability of the shields by answering a Likert scale survey questionnaire.

The researchers preferred a Geiger Muller counter as the study instrument as it can quantify the radiation present, not just its presence. This decision was also influenced by the study conducted by Veloso (2023). Additionally, Geiger Muller is used in radiation safety monitoring in medical settings, such as X-ray departments and nuclear medicine facilities (Bushberg et al, 2020).

Before the study was conducted, the researchers prepared transmittal letters that were addressed to the heads of the departments involved. These letters requested permission and ensured the researchers adhered to all the department policies.

The molding process of the HDPE doped with ZnO radiation shields was done at the Cebu Doctors' University-College of Medicine-Experimental Research Laboratory, a controlled laboratory within the university. PPEs were used in the process, and proper waste disposal was made per RA 9003 and DENR A.O 92-29 under the heavy supervision of the university's Institutional Biosafety Committee. Meanwhile, the radiation attenuation characteristics of the shields were measured at the Cebu Doctors' University Hospital (CDUH) - Radiology

Department under the supervision of registered radiologic technologists and radiation safety protection officers.

A one-shot case study design was used to evaluate a post-test result regarding the shield's radiation attenuation properties. This pre-experimentation allowed the researchers to identify the optimal concentration of the ZnO that served as the baseline of the actual experiment. It eliminated the need for unnecessary radiation exposure and allowed the optimization of resources.

The determination of the zinc concentration during the pre-experimentation stage was based on the study conducted by Alsheeraf et al. (2023), wherein seven concentrations of ZnO were used, from 0% with a 2% increment. The highest concentration of ZnO, 12%, was found to have the highest attenuation across all the samples. In the pre-experimentation, four concentrations of ZnO were utilized, starting from 0% to 45%, with a 15% increment. However, there was no significant difference between the samples. The researchers decided to double the concentration based on the study of Alshareef et al. (2023) and rounded it to 25%, which explains the 255 increments of their concentrations. In order to obtain the initial concentration, the researchers then stacked the two highest concentrations during their pre-experimentation, 30% and 45%, which showed a significant difference. Hence, the researchers selected the 75% baseline concentration. To support this, various studies, such as the study conducted by Alshareef et al. (2023), have also shown that having a higher zinc oxide concentration increases its radiation attenuation property, which enhances its practical usage as a radiation shield.

One-Way Analysis of Variance (ANOVA) was used to determine the study's sample size. Twenty exposures will be made, five for each HDPE doped with a ZnO radiation shield with varying concentrations, and the standard lead radiation shield will be used. This sample size ensures no more than five percent of errors that may arise during the gathering and analysis of data.

Before preparing the radiation shields, HDPE and ZnO were purchased from reputable sources. The HDPE rods were melted via thermal conduction at a controlled temperature of 120-130 degrees Celsius. They were then poured into a stainless steel mold. Three different concentrations of ZnO, starting from 75%, were added to each mold in 25% increments.

The HDPE doped with ZnO radiation shields were exposed to determine its radiation attenuation properties. The technical factors used during the experimentation are as follows: 80 kVp, 200 mA, 36 msec, and 40" source-to-image receptor distance. During the exposure, the Geiger Muller counter recorded the values needed to compute the Half Value Layer of each shield. The data recorded during the experimentation was sent to the university's statistician for data analysis. Meanwhile, three radiologic technologists tested the shield's comfortability and wearability by answering a Likert scale survey questionnaire as supplemental data for the study.

Three registered radiologic technologists were present during the experiment to ensure radiation safety. The three cardinal principles of radiation safety, time, distance, and shielding were also observed. Furthermore, ALARA, or "As Low As Reasonably Achievable," was applied during the exposure. The materials used in the study were disposed of in accordance with the RA 9003, the "Ecological Solid Waste Management Act of 2000". The excess chemicals were disposed of in accordance with DENR Administrative Order 92-29, the "Hazardous Waste Management."

The steps mentioned in the experimental process ensure that the study adheres to a controlled and structured process to stand a chance of being further developed. This will allow a research environment wherein students can further cultivate their research and innovations because research culture is evidence-based. Its existence cannot be assumed; it has to be proven. (Olvido, 2020). Therefore, a structured process can give us definite answers that can prove the efficiency of the shield.

RESULTS

Table 1. *Half-Value Layer Values among the Experimental Group*

Treatment Groups	N	Mean	SD
100 g of HDPE and 75% of ZnO	5	8.62	1.77
100 g of HDPE and 100% of ZnO	5	7.84	2.53
100 g of HDPE and 125% of ZnO	5	9.38	3.92

Table 2. *Radiation Attenuation among the Experimental Groups and Lead Shields*

Treatment Groups (mR/hr)	N	Mean	SD
100 g of HDPE and 75% of ZnO	5	0.21	.03
100 g of HDPE and 100% of ZnO	5	0.19	.06
100 g of HDPE and 125% of ZnO	5	0.27	.07
Lead Shields	5	0.25	.04

Table 2.1 *One-way Repeated-measures ANOVA among the Treatment Groups*

Source	Type III Sum of Squares	*df*	Mean Square	f-value	p-value	Conclusion
Treatment	0.021	8.62	.007	2.158	.146	Not Significant
Error	0.039	7.84	.003			

Table 3. *Results of Supplemental Survey on the Alternative Gonadal Shield's Comfortability and Wearability*

	Frequency Value	Frequency Rate	Average Value per Criterion	Frequency Rate
COMFORTABILITY				
1. The shield serves its purpose in terms of comfortability	4.33	SA	4.07	SA
2. I do not mind wearing this shield	4.33	SA		
3. The shield would not cause any discomfort	3.67	A		
4. The shield doesn't hinder movements	3.67	A		
5. The shield could be an addition to the shields in a radiology department	4.33	SA		
WEARABILITY				
1. The shield serves its purpose in terms of wearability	5	SA	4.53	SA
2. The material of this shield feels sturdy and nice	4.67	SA		
3. The shield is light in comparison to the commercially available shields	4	A		
4. The shield is light in comparison to the commercially available shields	4.67	SA		
5. I would recommend this shield to our institution	4.33	SA		

Table 4. *Supplemental Data: Cost Comparison between the Experimental Groups and Lead Shields*

	Cost	No. of Shields	Cost per Shield
Lead Shield	₱ 2,800	1	₱ 2,800
HDPE/ZnO Shield	₱ 5,500	>5	< ₱ 1,500

DISCUSSION

The average half value layer (HVL) across the (3) different experimental groups are as follows: 9.38 ± 3.92 for the 100g of HDPE and 125% of ZnO, 7.84 ± 2.53 for 100g of HDPE and 100% of ZnO, and 8.62 ± 1.77 for 100g of HDPE and 75% of ZnO as shown in Table 1.

It is observable that the average HVL rises as the ZnO concentration used increases. However, there were some discrepancies between the 100g of HDPE and 75% ZnO and 100g of HDPE and 100% ZnO, possibly due to the mixing errors during the experimentation process. This finding, however, still shows that the highest concentration of ZnO still has the highest radiation attenuation among the three. In a study by Alshareef et al. (2023), it was found that the ZnO/HDPE compound (12%) containing the highest concentration of ZnO had superior shielding efficacy compared to the rest of the manufactured samples.

Table 2 shows the average radiation attenuation across the (3) different experimental groups and the commercially available lead shields. As expected, the mean attenuation level increases with increasing ZnO concentration. However, the 100g of HDPE and 75% ZnO combination with an average of 0.21 ± 0.03 is slightly higher than the 100g of HDPE and 100% ZnO with an average of 0.19 ± 0.06. This discrepancy can be due to the inhomogeneous mixing during experimentation, where ZnO particles might not have been uniformly dispersed throughout the melted HDPE. A uniform ZnO distribution maximizes its interaction with incoming radiation, as each particle is more likely to encounter radiation particles, leading to more absorption and scattering events (Alsayed et al., 2019). Importantly, the 100g of HDPE and 125% ZnO combination with an average of 0.27 ± 0.07 exhibits significantly higher attenuation, surpassing that of the lead shield with an average of 0.25 ± 0.04. According to a study by Alshipli et al. (2023), higher ZnO concentration within an HDPE mold leads to greater radiation attenuation due to ZnO's properties. Zinc's high atomic number compared to Carbon in HDPE makes it more likely to absorb x-rays and gamma rays through the photoelectric effect, where Zn atoms completely absorb incoming radiation.

Table 2.1 presents the significant difference in the radiation attenuation between the HDPE doped with ZnO radiation shields and the lead shield. After the One-Way Repeated-Measures ANOVA, it was found that there was no significant difference between the means of the radiation attenuation of the HDPE doped with ZnO radiation shields and the lead shield: $F(3,12) = 2.158$, $p = 0.146$. This implies that the HDPE doped with a ZnO radiation shield, regardless of the differences in concentration, attenuated a significant amount of radiation comparable to that of a lead shield.

Table 3 shows the results of the supplemental survey regarding the alternative shield's comfortability and wearability. The data showed strong agreement on most statements for both comfortability and wearability. Respondents generally agreed on the comfortability in terms of their purpose without causing discomfort or hindering movement. For wearability, respondents generally showed strong agreement in terms of their purpose, sturdiness, and lightness compared to commercially available shields, suggesting a positive overall feedback on the comfortability and wearability of the shields.

Gonadal lead shields sold in the market would at least cost ₱ 2,800. This is attributed to the high cost of lead (Ahmed et al., 2024) as its raw material. The total cost of the raw materials alone was ₱ 2,500. Considering the cost of the other materials involved in the production, such as the PPEs, it would sum up to ₱ 5,500. From that amount, at least five shields were made and there were still excess raw materials that were not utilized and could be used to produce more shields. This proves the cost-effectiveness of the HDPE-doped gonadal shield.

CONCLUSION

HDPE combined with zinc oxide presents a promising alternative to traditional lead-based radiation shields. This innovative composite material demonstrates exceptional radiation attenuation capabilities, effectively matching the performance of conventional lead shields. Notably, the significantly reduced weight of the HDPE-ZnO shields offers substantial wearability and user comfort advantages. Including a higher concentration of ZnO in the gonadal shield resulted in comparable radiation protection to lead, further highlighting the material's potential. Lead gonadal shield was chosen as the end product of this investigation. As students, the researchers have limited time and capacity to complete this study. The researchers took advantage of its small surface area compared to the lead apron, which enabled them to maximize their resources. These findings strongly support the feasibility of replacing lead shields with HDPE-ZnO composites across various applications, marking a significant advancement in radiation safety technology.

Author Contributions

Pumar: Conceptualization, Project Administration, Investigation, Methodology, Resources, Funding Acquisition, Investigation, and Writing- original draft; **Espinosa:** Data Curation, Formal Analysis, Investigation, Methodology, Resources, Funding Acquisition, Software, and Writing-original draft; **Bitoon:** Visualization, Formal Analysis, Investigation, Methodology, Resources, Funding Acquisition, and Writing-original draft; **Pros:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Funding Acquisition, and Writing-original draft; **Tagalog:** Supervision and Validation

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Ethical Approval

The study protocol was reviewed and exempted by the Cebu Doctors' University – Institutional Ethics Review Committee (CDU-I) under IERC Code: EX2024-053-Bitoon-ZincOxide-Radiation on February 14, 2024. It was subsequently referred to the Institutional Biosafety Committee (IBC), which granted approval for implementation under Protocol No. BSRT_2024_01 on April 6, 2024. The ethical clearance remains valid until April 6, 2027.

Competing interest

The authors declare no conflicts of interest.

Data Availability

The corresponding author will make the data accessible upon request, and it can be obtained by reaching out to them directly.

Declaration of Artificial Intelligence Use

In this work, the authors did not utilize artificial intelligence (AI) tools and methodologies.

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