Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/090308

Exploring Advances in Radiation Shielding Materials: A Brief Overview

Atef El-Taher[*]

Physics Department, Faculty of Science, Al-Azhar University, Assiut, 71542, Egypt.

Received: 2 Jun. 2024, Revised: 22 Jul. 2024, Accepted: 1 Aug. 2024.

Published online: 1 Sep 2024

Abstract: Electromagnetic interference shielding is crucial for users of electronic devices to minimize electromagnetic noise. Current research is exploring the use of polymeric composites with various compositions as materials for EM interference shielding. Additionally, ionizing radiation, such as X-rays and gamma rays, plays a significant role in areas like medical diagnostics, cancer therapy, food preservation, and nuclear energy. However, exposure to ionizing radiation can adversely affect health, depending on the dose absorbed. Therefore, effective shielding is essential to protect users in these environments. Traditionally, metallic lead (Pb) has been used for this purpose, but its toxicity poses serious long-term health and environmental risks. Polymer composites containing high atomic number (Z) fillers present a viable alternative to lead in shielding applications due to their lightweight nature, cost-effectiveness, mechanical flexibility, and reduced toxicity. This paper reviews recent advancements and methods in the preparation of polymer composites for radiation shielding applications.

Keywords: Radiation Shielding materials; Ionizing radiation; Polymer composites; Lead shield; Gamma radiation.

1 Introduction

The application of nuclear physics methods in material science is experiencing rapid growth. Techniques such as positron annihilation spectroscopy, neutron scattering, external bremsstrahlung studies, and energy-dispersive X-ray fluorescence (utilizing radioisotopes as radiation sources) enable researchers to gain deeper insights into materials at elementary, microscopic, and sub-microscopic levels. A significant number of researchers are exploring condensed matter using these nuclear methods, leading to the emergence of a new field known as Nuclear Condensed Matter (NCM) Physics. Consequently, the use of radioisotopes and other radiation sources, such as X-ray tubes, in advanced materials research has increased significantly in recent decades [1-4].

Electromagnetic radiation that causes ionization, including gamma rays and X-rays, poses health risks to humans. Exposure to these radiations can occur from various sources found in industries, medical diagnostic centers, nuclear research facilities, nuclear reactors, and applications involving radioisotopes or nuclear weapons development. To protect personnel and sensitive electronic equipment from ionizing radiation, effective shielding is essential. Radiation shielding involves safeguarding individuals and the environment from the harmful effects of such radiation. This concern is particularly critical in the context of nuclear power plants, the use of high-activity radioisotopes in applications like food preservation and cancer treatment, particle accelerator facilities, and medical X-ray systems, all aimed at preventing significant health issues among users [5-8].

Historically, metallic lead (Pb) has been the preferred material for radiation shielding due to its high atomic number, density, low cost, and ease of processing, which provide effective protection against penetrating gamma radiation. However, Pb is known for its toxicity, environmental impact, and low neutron absorption. This has prompted a search for alternative materials that can effectively replace lead in radiation shielding applications. Polymer composites infused with high atomic number constituents (other than Pb) are emerging as viable options. While these alternative materials may have lower effective density, they often provide sufficient, and sometimes enhanced, protection against harmful radiation. They are also useful in dosimetry and

[*]Corresponding author e-mail: atef.eltaher@gmail.com

can effectively absorb neutrons, such as those from nuclear reactors [9-11]

One of the most promising areas in material science is the development of polymeric materials. Over the past two decades, these materials have become integral to daily life due to their wide-ranging applications in industrial, biological, consumer, and medical fields. Scientists are increasingly drawn to polymeric materials for their unique properties, including affordability, lightweight composition, flexibility, good mechanical strength, and notable optical and electrical characteristics. Electrically conducting polymers have garnered significant interest from both scientific and industrial research communities, not only for their intriguing properties but also for their potential to create innovative devices. Conducting polymers like polypyrrole (PPy), polythiophene, polyacetylene (PAc), and polyaniline (PANI) are utilized in solid corrosion-resistant materials, electrical appliances, battery electrolytes, and electromagnetic shielding applications. Among these, conducting polymers play a crucial role in electromagnetic shielding and dosimetry [12-13].

2 Research on (ionizing) radiation shielding materials.

High atomic number (Z) materials can serve as effective replacements for toxic lead (Pb), and these alternative elements, salts, or compounds can be integrated into a polymer matrix. Some common high Z constituents used in radiation shielding applications include tungsten, dysprosium, gadolinium, and tin. These materials are recognized for their non-toxicity and environmentally friendly characteristics compared to lead. They offer significant advantages over lead compounds, such as lead nitrate, and are considered the least toxic among heavy metals. Additionally, a binder can be incorporated alongside the high Z constituents and the polymer matrix to enhance the physical, radiological, and electrical properties of the resulting composite. Some of these materials have been successfully applied in radiology and dosimetry.

Numerous researchers have made substantial contributions to the field of radiation shielding materials. Kulwinder focused on gamma-ray shielding materials, double-layered shielding enclosures, and radiation computational physics. His work includes investigating the gamma radiation shielding properties of various polymeric materials, compounded plastics, boron compounds, and low-Z alkali minerals. He has also calculated the attenuation properties of certain low-Z silicates and derived energy buildup factors, which are valuable for dosimetric applications.

Kumar et al. [14] have explored the shielding effectiveness of certain alkali minerals, comparing their radiation-shielding properties to those of concrete. Concrete is a widely used, effective, and economical material for radiation shielding, serving as a protective cover in nuclear power plants, research reactors, particle accelerators, and high-level radioactive laboratories due to its compressive strength, workability, and durability. Akkurt et al. [15] tested barite-loaded concrete composites, comparing them to lead as a control material. Gencel et al. [16] prepared composites by adding colemanite to concrete, noting that increasing the volume ratio of colemanite improved both the engineering properties of the concrete and its shielding effectiveness.

3 Polymer composites as radiation shielding materials.

Polymer composites consist of a polymer matrix reinforced with metal compounds. The selection of these metal compounds primarily depends on their intended use, as their incorporation can significantly alter the properties of the polymer material. Generally, desirable characteristics include high density, enhanced radiation shielding capabilities, heat resistance, and increased toughness and durability. This article highlights a selection of research on polymer composite-based shielding materials, focusing on the development of composites with high atomic number (Z) constituents. While extensive work has been conducted in this area, the chosen studies reflect the authors' subjective preferences.

Before these materials can be released for end-user applications, they must be characterized using a variety of techniques, including nuclear methods. Nambiar et al. [17] synthesized lead-free radiation-protection nanomaterials by developing polydimethylsiloxane (PDMS) nanocomposites with varying weight percentages of bismuth oxide (BO) nanopowder, demonstrating effective shielding against X-rays. Ambika et al. [18] fabricated unsaturated polyester resin reinforced with bismuth oxide composites, finding that the gamma-ray shielding properties improved with higher concentrations of bismuth oxide. Ersoz et al. [19] introduced a new shielding material by mixing micro-sized tungsten powder with ethylene-vinyl acetate (EVA).

Organic polymeric materials, typically containing hydrogen, can also absorb neutrons. When doped with boron compounds, these polymers become effective neutron-shielding materials. Composites made from polyethylene and boron are particularly effective for slow neutron absorption and applications in space radiation. Gwailt et al. [20]

demonstrated that natural rubber (40 HAF/NR) loaded with varying concentrations of boron carbide (B4C) can be used for thermal neutron radiation shielding. Epoxy resin, known for its excellent dimensional stability and adhesion to various reinforcements, has also been utilized. Adeli et al. [21] fabricated boron carbide/epoxy composites for neutron absorption applications. Additionally, Chang et al. [22] prepared tungsten/epoxy resin composites with different levels of tungsten powder. It is essential to monitor the effects of neutron and X-ray/gamma irradiation on the mechanical properties and thermal stability of these composites at various radiation doses.

4 Materials for EMI Shielding.

Electromagnetic interference (EMI) shielding is a crucial concern for users of electronic devices, as it helps reduce ambient electromagnetic (EM) noise. The application of these materials is essential for users in commercial sectors (such as TV signal transmission, telephone microwave relay systems, and weather radar), as well as in defense and scientific electronic equipment. The use of polymeric composites with various compositions for EMI shielding is a significant area of contemporary research. A key consideration is that the shielding material should absorb EM radiation rather than reflect it. Epoxy-based polymeric composites are particularly important for protecting against electromagnetic radiation. Additionally, the exploration of organic-inorganic hybrid materials for EMI shielding applications is ongoing. Hybrid polymeric electrolytes, which possess high ionic conductivity and favorable dielectric properties, are also being investigated. The suitability of a material for EMI shielding, indicated by its shielding effectiveness, depends on factors such as magnetic properties (permeability), dielectric constant, material thickness, and the frequency of the EM radiation.

5 Conclusions

The preparation and characterization of polymer composites reinforced with various high Z constituents is an important area of contemporary research. Numerous non-lead materials offer enhanced radiation protection compared to lead-containing shielding materials. The selection of radiation shielding material depends on the specific type of radiation it is intended to address. There is a need to develop new polymeric materials with effective radiation shielding capabilities, particularly for attenuating electromagnetic radiation. Additionally, the potential of composite polymeric materials for shielding against both electromagnetic and ionizing radiation should be further explored. Thorough experimental investigation and testing of these composite materials are essential before their commercial application in radiation shielding [23-27].

References

[1] El-Taher, Atef., Zakaly, Hesham MH., Pyshkina, Mariia., Allam, EA., El-Sharkawy, R M Mahmoud, ME., Abdel-Rahman, Mohamed AE., 2021 A comparative Study Between Fluka and Microshield Modelling Calculations to study the Radiation-Shielding of Nanoparticles and Plastic Waste composites. Zeitschrift für anorganische und allgemeine Chemie., **647 (10)**, 1083-1090, 2021.

[2] Allam, EA., El-Sharkawy, RM., Shaaban, Kh. S., El-Taher, A., Mahmoud, ME., El Sayed, Y., 2022 Structural and thermal properties of nickel oxide nanoparticles doped cadmium zinc borate glasses: preparation and characterization Digest Journal of Nanomaterials & Biostructures (DJNB)., **17 (1)**, 2022.

[3] Allam, EA., El-Sharkawy, RM., El-Taher, Atef., Shaaban, ER., Massoud, EE., Mahmoud, ME., 2022 Enhancement and optimization of gamma radiation shielding by doped nano HgO into nanoscale bentonite. Nuclear Engineering and Technology., **54(6)**, 2253-2261, 2022.

[4] El-Sharkawy, RM., Allam, EA., El-Taher, Atef., Elsaman, Reda., Massoud, EE., Mahmoud, ME., 2022 Synergistic effects on gamma-ray shielding by novel light-weight nanocomposite materials of bentonite containing nano Bi2O3 additive. Ceramics International., **48 (5)**, 7291-7303, 2022.

[5] El-Sharkawy, RM., Allam, EA., El-Taher, Atef., Shaaban, E.R. and Mahmoud, ME., 2021 Synergistic Effect of Nano-bentonite and Nano cadmium Oxide Doping Concentrations on Assembly, Characterization and Enhanced Gamma-Rays Shielding Properties of Polypropylene Ternary Nanocomposites. International Journal of Energy Research., **45 (6)**, 8942-8959, 2021.

[6] El-Sharkawy, RM., Shaaban, KS., Elsaman, R., Allam, EA., El-Taher, Atef., Mahmoud, ME., 2020 Investigation of mechanical and radiation shielding characteristics of novel glass systems with the composition xNiO-20ZnO-60B2O3-(20-x) CdO based on nanometal oxides. Journal of Non-Crystalline Solids., **528**, 119754, 2020.

[7] El-Taher, Atef., Ali, AM., Saddeek, YB., Elsaman, R., Algarni, H., Shaaban, KS., Amer, T.Z., 2019 Gamma ray shielding and structural properties of iron alkali alumino-phosphate glasses modified by PbO. Radiation Physics and Chemistry., **165**, 108403, 2019.

[8] Mahmoud, ME., El-Sharkawy, RM., Allam, EA., Elsaman, R., El-Taher, Atef., 2019 Fabrication and characterization of phosphotungstic acid-Copper oxide nanoparticles-Plastic waste nanocomposites for enhanced radiation-shielding. Journal of Alloys and Compounds., **803**, 768-777, 2019.

[9] Saddeek, Y.B., Shaaban, KH.S., Elsaman, Reda., El-Taher, Atef., Amer, T.Z., 2018 Attenuation-density anomalous relationship of lead alkali borosilicate Glasses. Radiation Physics and Chemistry., **150**, 182–188, 2018.

[10] El-Taher, A., Mahmoud, H.M. H.M and Abbady, Adel G.E., 2007 Comparative Study of Attenuation and Scattering of Gamma –Ray through Two Intermediate Rocks. Indian Journal of Pure & Applied Physics., **45**, 2007.

[11] Hesham MH Zakaly, Ahmed Ashry, Atef El-Taher, Adel GE Abbady, Elhassan A Allam, Rehab M El-Sharkawy, Mohamed E Mahmoud., 2021 Role of novel ternary nanocomposites polypropylene in nuclear radiation attenuation properties: In-depth simulation study. Radiation Physics and Chemistry., **188**, 109667, 2021.

[12] Hani Negm, Hend Abd-Allah, Atta Y Abdel-Latief, MA Abdel-Rahim, Atef El-Taher, Nagih M Shaalan., 2024 Fabrication and characterization of structured Zn1-xCdxWO4

(0≤ x≤ 1) with tunable photoluminescent and promising applicable heterometallic nanocomposites in shielding properties. Radiation Physics and Chemistry., **215**, 111335, 2024.

[13] HH Negm, EA Allam, E Abdeltwab, M Mostafa, ME Mahmoud, A. El-Taher., 2024 A new nanocomposite of copper oxide and magnetite intercalated into Attapulgite clay to enhance the radiation shielding. Radiation Physics and Chemistry., **216**, 111398, 2024.

[14] Kumar, V., Mann, K. S., Manohara, S. R., Sidhu, G. S., 2012. Investigation on some low-Z alkali minerals as gamma-ray shields. International Journal of Latest Research in Science and Technology [ISSN (Online):2278-5299]., **1**, 324-333, 2012.

[15] Akkurt, I., Akyıldırım., Mavi.B., Kilincarslan , B., Basyigi, C., 2010. Photon attenuation coefficients of concrete include barite at different rates. Annals of Nuclear Energy., **37(7)**, 910-914, 2010.

[16] Gencel, O., Brostow, W., Ozel, C., Filiz, M., 2010. An investigation on the concrete properties containing colemanite. International Journal of Physical Sciences., **5(3)**, 216-225, 2010.

[17] Nambiar, S., Osei., E. K., Yeow, J. T. W., 2013. Polymer nanocomposite-based shielding against diagnostic X-rays. Journal of Applied Polymer Science, 127(6), 4939-4946

[18] Ambika, M.R., Nagaiah, N., Suman, S. K., 2016. Role of bismuth oxide as a reinforcer on gamma shielding ability of unsaturated polyester based polymer composites. Journal of Applied Polymer Science., **134 (13)**, 44657, 2016.

[19] Ersoz, O. A., Lambrecht, F. Y., Soylu, H. M., 2016. Tungsten-ethylene vinyl acetate (EVA) composite as a gamma rays shielding material. Indian Journal of Pure & Applied Physics., **54(12)**, 793-796, 2016.

[20] Gwaily, S. E., Badawy, M. M., Hassan, H. H., Madani, M., 2002. Natural rubber composites as thermal neutron radiation shields: I. B4C/NR composites. Polymer Testing, 21 (2), 129-133.

[21] Adeli, R., Shirmardi, S. P., Ahmadi, S. J., 2016. Neutron irradiation tests on B4C/epoxy composite for neutron shielding application and the parameters assay. Radiation Physics and Chemistry., **127**, 140–146, 2016.

[22] Chang, L., Zhang, Y., Liu, Y., Fang, J., Luan, W., Yang, X., Zhang, W., 2015. Preparation and characterization of tungsten/epoxy composites for γ-rays radiation shielding. Nuclear Instruments and Methods in Physics Research B., 356-357, 88-93.

[23] U Rilwan, SA Edeh, MM Idris, II Fatima, SF Olukotun, GZ Arinseh,PZ Bonat, A El-Taher, KA Mahmoud, Taha A Hanafy, MI Sayyed., 2025 Influence of waste glass on the gamma-ray shielding performance of concrete. Annals of Nuclear Energy., **210**, 110876, 2025.

[24] HH Negm, EA Allam, IM Nabil, E Abdeltwab, M Mostafa, A El-Taher., 2024 Exploring the potential of attapulgite clay composites containing intercalated nano-cadmium oxide and nano-nickel oxide for efficient radiation shielding applications. Radiation Physics and Chemistry., **225**, 112149, 2024.

[25] Meshari Almeshari, Fawzy Hammad Sallam, Mohamed Tharwat, Yasser Alzamil, Mohammed Salih, Bader Alshoumr, Amjad Alyahyawi, Atef El-Taher., 2024 Preparation and structure investigation of polyethylene terephthalate polyester reinforced Ni0. 5Zn0. 5Fe2O4 nanoparticles for gamma ray shielding performance. Physica Scripta., **99 (5)**, 055311, 2024.

[26] Feras Alafer, FH Sallam, Meshari Al Meshari, Yasser Alzamil, Ahmad Abanomy, Sultan Alhujaili, Atef El-Taher., 2024 The influence of thermal treatment on the structural properties and gamma rays shielding of bentonite cla ceramic. Radiation Physics and Chemistry., **217**, 111531, 2024.

[27] U Rilwan, GM Aliyu, SF Olukotun, MM Idris, AA Mundi, S Bello, I Umar, A. El-Taher, KA Mahmoud., 2024 Recycling and characterization of bone incorporated with concrete for gamma-radiation shielding applications. Nuclear Engineering and Technology., **56(7)** 2828-2834, 2024.