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Review Article

Radiation Shielding Materials: A Bibliometric Review

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Abstract: Radiation shielding is a fundamental strategy for protecting individuals and the environment from the harmful effects of radiation exposure. Over the past two decades, a wide array of shielding materials has been developed to address the specific requirements of medical, nuclear, and space applications. This study employs a bibliometric approach to systematically analyze the scientific literature concerning radiation shielding materials. A total of 6,515 documents published between 2000 and 2023 were retrieved from the Scopus database and examined. The findings indicate that the most frequently investigated materials include silica, tungsten, polymers, carbon nanotubes, and lead. Emerging research trends—particularly in nanotechnology and composite materials—have also received significant scholarly attention. Keyword and co-word network analyses reveal that research is primarily concentrated on the concepts of "radiation shielding" and "radiation protection," with strong thematic links to terms such as "gamma rays" and "neutrons". This study underscores the diversity of materials and innovative approaches being explored in the field. Furthermore, it provides a structured overview and a guiding framework for future research, particularly regarding the development of cost-effective and eco-friendly shielding materials.

Keywords: *Radiation shielding, Bibliometric analysis, Material development, Nanomaterials, Radiation protection*

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I. INTRODUCTION

Radiation plays a critical role in diverse fields such as health, energy, space exploration, and scientific research, making it an integral component of modern life. While it offers significant benefits through its wide range of applications, its importance is particularly evident in the health sector. Radiation is central to both the diagnosis and treatment of diseases. Imaging methods such as X-ray, computed tomography (CT), and magnetic resonance imaging (MRI), as well as therapeutic approaches including radiotherapy and nuclear medicine, are vital in managing serious illnesses such as cancer. Beyond healthcare, radiation is also widely applied in the food industry. Food irradiation technologies are used to extend shelf life, preserve nutritional value, and improve hygiene standards. These methods contribute substantially to the global food supply chain by both reducing harmful microorganisms and enhancing food security. Given these wide-ranging applications, radiation has become an essential element not only in specialized fields but also in everyday life (International Atomic Energy Agency, 2014).

Despite these benefits, uncontrolled or prolonged exposure to radiation can result in serious health risks. Ionizing radiation (alpha, beta, gamma, and X-rays) damages biological systems, creating a pressing need for reliable and cost-effective shielding solutions (Yamamoto, 2013). Developing effective radiation protection strategies and materials is therefore essential. Well-designed shielding not only allows society to benefit from the positive applications of radiation but also minimizes its harmful effects.

Radiation shielding materials are thus critical in protecting against ionizing radiation, although each material carries specific advantages and limitations. Among traditional options, lead, concrete, and iron are the most widely used. Lead provides strong attenuation due to its high density; however, its toxicity, weight, and reduced effectiveness at certain photon energy ranges restrict its use (Mortazavi et al., 2024). Concrete is valued for its cost-effectiveness and good protective capacity, but its bulk and heaviness limit its applicability in some settings. Iron also offers effective protection, yet its heavy structure and design challenges make it unsuitable for certain applications.

In recent years, new generations of materials have been developed in response to environmental and performance concerns. For example, while barium sulfate is noted for its effective radiation absorption and low environmental impact compared to lead (Aral et al., 2016; Zakaly et al., 2021), materials such as magnetite and bismuth are being investigated for their protection potential in composites (Creutz & Downes, 1949; Chen et al., 2019). With their lightweight and flexible structures, polymers and metal alloys are among the alternatives to replace traditional heavy metals, increasing comfort while reducing toxicity (Kilicoğlu et al., 2021; Huang et al., 2021).

Glass systems stand out as an important option, especially with their high-density formulations against photon

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energies (Abouhaswa et al., 2021). Lead-free glass systems offer both effective protection and environmentally friendly properties with environmental benefits such as low melting temperatures and carbon emissions (Kurtulus, 2024). In addition, nanocomposites are being developed with the aim of providing effective protection, especially in low energy ranges. Tungsten and bismuth nanocomposites aim to overcome the limitations of traditional materials such as lead and concrete (Kobayashi et al., 1997).

Although traditional materials are still widely used, the trend towards environmentally friendly and efficient alternative materials is rapidly increasing. The development of nanocomposites and glass systems is a tangible reflection of this trend, which aims at effective radiation shielding and reduction of environmental impacts. However, there are still significant challenges in the development of lightweight, non-toxic, and flexible materials for widespread adoption. This situation once again reveals the importance of research on innovative approaches in the field of radiation shielding.

The aim of this study is to provide a bibliometric analysis of scientific research on materials used for radiation shielding. Specifically, it seeks to identify the most frequently investigated materials, highlight emerging research trends, and offer guidance for future studies. While several recent works have examined radiation shielding using bibliometric or related methods (Kilicoğlu & Mehmetcik, 2021), this study distinguishes itself by presenting a broader and more detailed analysis.

As outlined above, the wide variety of materials employed in radiation protection, their diverse application areas, and their differing effectiveness against radiation types have all contributed to the expansion of research in this field. However, a comprehensive overview of which materials are most intensively studied and how thematic trends are evolving is still lacking in the existing literature. This study aims to fill this gap by presenting a structured analysis of publication trends, key materials, and thematic networks in radiation shielding research.

Studies on radiation shielding materials are critical for both safety and cost-effectiveness. Considering that new generation nanomaterials and hybrid materials offer lighter, more effective and more economical solutions compared to traditional materials, the direction and scope of scientific production in this field is of great importance for both academic and industrial applications. Therefore, determining which materials stand out in this study will shed light on future research and development activities.

In this study, scientific articles covering the years 2000-2023 obtained from the Scopus database were analyzed by scanning at the level of title, abstract and keyword. With the bibliometric methods used, the distribution of publications by years, classification according to material types, citation performances and geographical distribution were examined. Thus, the general trends in the literature and the focal points of the research on armoring materials were determined.

This article consists of three main sections, each focusing on different aspects of the research. The first section, Materials and Methods, explains in detail the data set, analysis methods and bibliometric approach used in the study. This section supports the reliability of the findings by revealing the methodological background of the research. The second part, Findings and Discussion, comprehensively analyzes research trends for radiation shielding materials. This chapter discusses important findings such as which materials are being studied more, trends over time, and the countries and institutions that publish the most, and authors. Finally, the conclusion summarizes the findings of the study and provides recommendations for future research.

II. MATERIAL AND METHOD

In this study, the Scopus database was utilized for the scientific literature review. Although the analysis was limited to Scopus-indexed documents—meaning the results may not fully capture studies indexed exclusively in other major databases such as Web of Science, IEEE Xplore, or PubMed—Scopus was selected due to its broad disciplinary coverage and inclusion of high-quality scientific publications. It is particularly well-suited for bibliometric studies as it indexes publications across multiple fields, enables detailed citation analysis, and provides structured datasets through powerful filtering tools.

Within the scope of this research, scientific publications spanning the years 2000–2023 were retrieved. The search strategy was implemented using the following query, which targets terms related to radiation protection and shielding materials within the title, abstract, and keywords:

> *TITLE-ABS-KEY(("radiation shielding" OR "radiation protection" OR "radiation attenuation") AND ("material*" OR "composite*" OR "nanomaterial*" OR "polymer*" OR "concrete" OR "lead")) AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO(SUBJAREA, "PHYS") OR LIMIT-TO(SUBJAREA, "MATE") OR LIMIT-TO(SUBJAREA, "ENGI"))*

This query was designed to create a focused dataset by limiting the scope to disciplines such as physics, materials science, and engineering. Furthermore, document types such as reviews and technical notes were excluded to prioritize original research, including articles, books, book chapters, and conference proceedings.

As a result of the search, a total of 6,515 publications were identified. These documents contain metadata such as

author information, publication year, source journals, keywords, and citation counts. This data forms the basis for analyzing the focal points of research regarding shielding materials and how the field is evolving.

Bibliometric analysis is a method used for the systematic review and quantitative measurement of scientific literature. This approach provides a structured overview to understand the development of research areas, key contributors, and emerging areas of interest (Andrés, 2009; Erkoyuncu et al., 2025). When navigating a vast body of literature, such as that concerning radiation shielding materials, bibliometric analysis serves as an essential tool for mapping trends, identifying influential studies, and evaluating international collaborations.

In this study, data from Scopus were analyzed using the *Bibliometrix* package in the R programming language (Aria & Cuccurullo, 2017). The primary variables analyzed include:

- **Authors and Institutions:** Identification of the most prolific contributors and analysis of co-authorship and collaboration networks.
- **Keywords and Topics:** Use of keyword analysis and thematic mapping to determine the most frequently studied materials and focal topics.
- **Publication Years:** Examination of temporal trends to analyze shifting interest in shielding materials.
- **Journals and Citation Counts:** Evaluation of journals with the highest publication volumes and identify influential studies through citation analysis.
- **International Collaborations:** Examination of research activities and partnerships between different countries.

The specific analytical methods employed are as follows:

- **Publication Volume and Trend Analysis:** To evaluate the growth of literature over time.
- **Citation Analysis:** To identify the most impactful studies and authors.
- **Keyword Mapping:** To identify frequently studied shielding materials and research hotspots.
- **Network Analysis:** To visualize collaborative networks between authors, institutions, and countries.

While the analysis is based solely on the Scopus database and citation metrics may not capture every qualitative contribution, these methods provide a robust approach to understanding the broad landscape of research on shielding materials. This methodology ensures a comprehensive understanding of which materials are most studied and highlights prevailing research trends to guide future investigations.

III. RESULTS AND DISCUSSIONS

The dataset analyzed in this study spans the period from 2000 to 2023, comprising a total of 6,515 documents across 1,639 unique sources, including journals, books, and conference proceedings. The analysis revealed an annual growth rate of 9.59%, indicating that radiation protection has garnered progressively increasing attention within the scientific community over the past two decades.

The average age of the documents was calculated to be 8.75 years, reflecting a field that balance established foundational knowledge with a significant volume of recent contributions. Regarding citation impact, the average number of citations per document is 17.68, with an average annual citation rate of 2.601. Furthermore, these studies utilized a substantial total of 155,363 references, underscoring the depth of the scholarly dialogue and the cumulative nature of research in this domain. Collectively, these metrics highlight the rapid expansion of the field and its growing significance within the broader academic literature.

Table 1. Basic Information.

Statistics	Value
Timeframe	2000-2023
Total Documents	6515
Annual Growth Rate (%)	9.59
Average Document Age (years)	8.75
Citations Per Document (Average)	17.68
Total Number of References	155,363
International Collaborations (%)	22.75

The documents within this dataset exhibit significant structural diversity across different publication formats. Specifically, the collection includes 4,225 original research articles, 33 books, 112 book chapters, and 2,145 conference papers. Journal articles constitute approximately 65% of the total dataset, serving as the primary medium for establishing the theoretical foundations and rigorous experimental validations within the field. However, the substantial representation of conference proceedings (approximately 33%) is noteworthy; it underscores the dynamic nature of the discipline and its strong emphasis on the rapid dissemination of applied research and emerging technological developments.

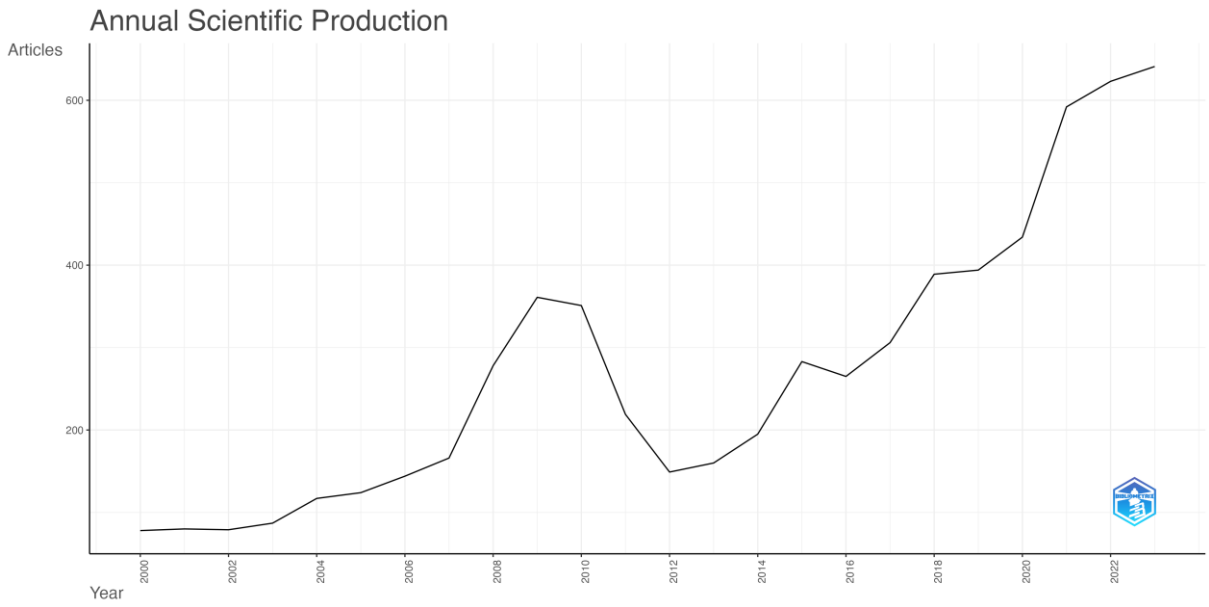


Figure 1. Number of Publications by Year (2000-2023).

According to the data covering the years 2000-2023, the number of publications on radiation protection and shielding materials has increased steadily with an annual growth rate of 9.59%, while it was quite low at the beginning. Between 2000 and 2010, there was a gradual increase in the number of publications, while the annual number of publications generally remained below 100. However, since 2010, there has been a significant increase in the number of publications, and this increase accelerated in the post-2020 period, reaching a total of 641 articles by 2023. On the graph, the black dots represent the total number of publications for each year. This trend makes it clear that the number of publications has been steadily increasing over the years.

As a result, it is understood that studies on radiation protection and shielding materials are receiving more and more attention. In particular, the increase in environmental and health-oriented concerns and technological developments have contributed to the rapid growth of research in this field. The jump observed in the post-2020 period indicates that the field is open to more research and innovation in the future. This increase reflects the magnitude of the demand for radiation safety and new shielding materials.

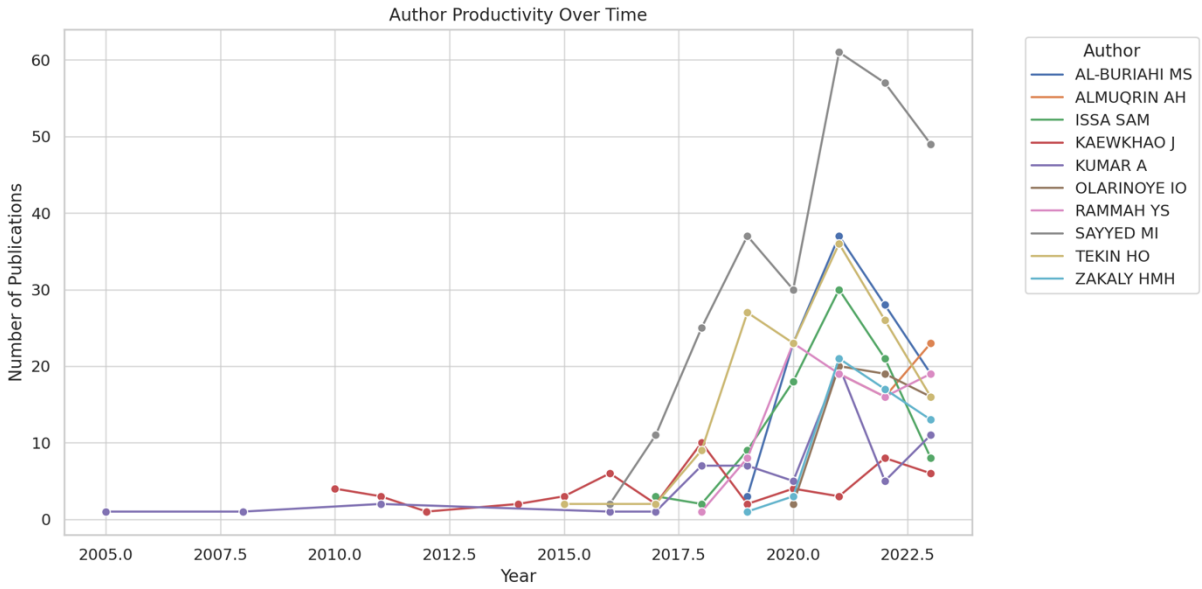


Figure 2. Authors' Publication Performance.

The analysis of author productivity shows that a small group of researchers accounts for a substantial share of publications in the field of radiation shielding materials. The top contributors demonstrate both high publication counts and significant collaborative outputs, indicating that their work has strongly influenced the development of the literature. These findings highlight the concentration of expertise among a limited number of prolific authors, whose contributions have shaped research directions and supported the field's steady growth.

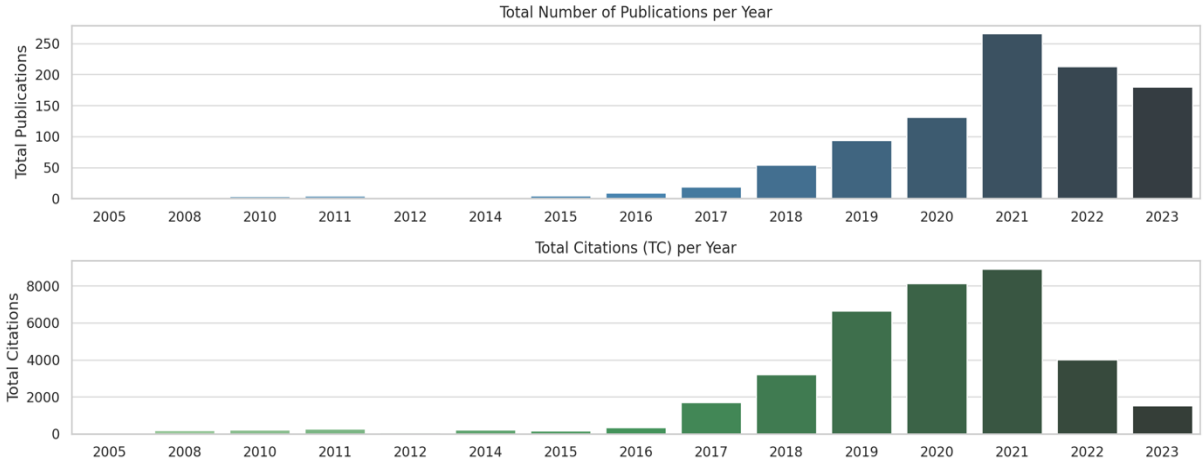


Figure 3. Average Number of Publications/Citations Per Article by Years.

The average number of citations per article has fluctuated considerably over the years. After a variable start in 2000–2003, a noticeable decline occurred between 2006 and 2012, during which the average citation count generally remained in the range of 10–15. The 2014–2017 period stands out as a peak phase, with the average number of citations exceeding 25, suggesting that the publications of this period were disseminated in high-impact journals and reached a broad scholarly audience.

Following 2020, a sharp decline in citation averages is observed. This trend can partly be attributed to the natural citation cycle, as recently published articles have had limited time to accumulate references. However, other factors may also contribute, including the saturation of certain research topics, shifts in scholarly focus toward new materials and methodologies, and potential disruptions in research productivity and dissemination during the COVID-19 pandemic. Overall, the graph highlights a highly productive and impactful period around 2014–2017 and 2020–2021, followed by a downturn that reflects both recency effects and evolving research dynamics.

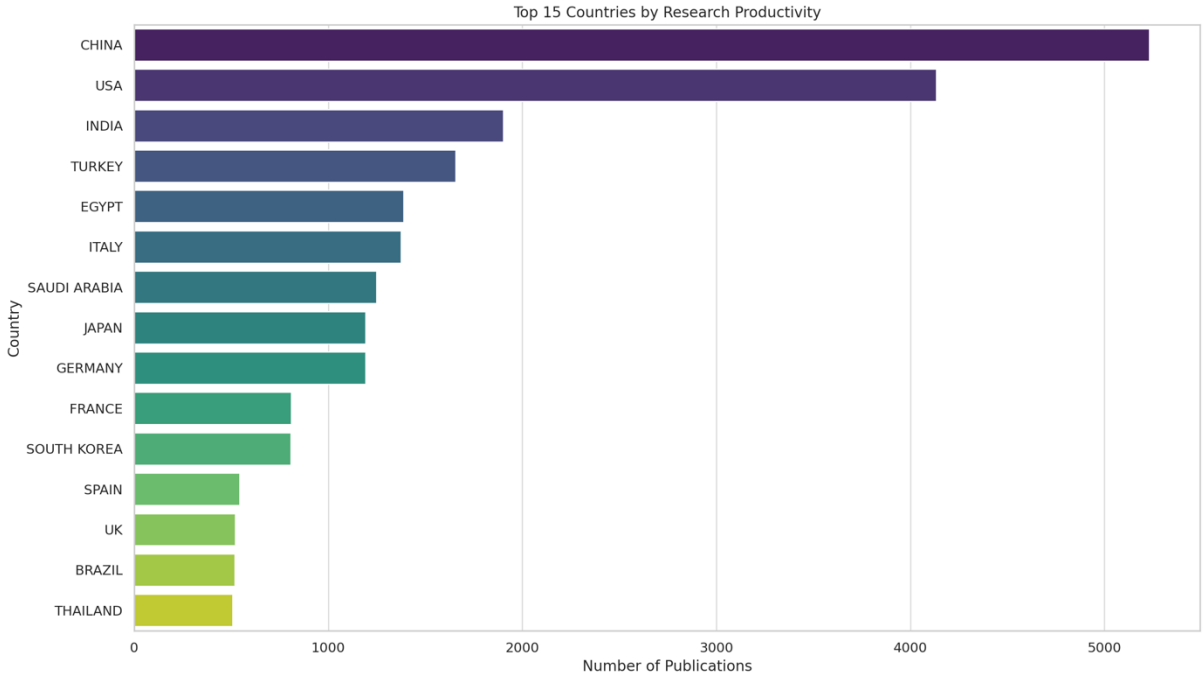


Figure 4. Country Based Publication Amounts.

In studies on radiation protection and shielding materials, a remarkable cooperation and citation effect has been observed between countries. **China** stands out as the country with the highest number of publications with 755 articles, followed **by the USA** (486 articles) and **India** (368 articles). These countries are among the important producers of the field with the number of publications and make significant contributions to the literature. The distribution reveals a steep drop-off after the USA and China, indicating these two countries' dominant research roles. This pattern underscores the concentration of research output in major global powers, particularly highlighting the influence of China and the USA.

In terms of citation impact, the countries with the highest average citations **are Canada** (56.98 citations/article), **Saudi Arabia** (34.40 citations/article), and **Turkey** (33.41 citations/article). These countries both focus on high-quality research and have a high impact at the international level. Turkey also has an important position in this field with 1656 articles. In the bar chart, the differences in the amount of production between countries can be clearly seen and it is understood that China has a very high production compared to other countries. Similarly, the high average citation shows that these countries produce effective and referenced studies in the literature. These data highlight the critical role played by collaborations between countries and contributions from different geographies in the development of the field.

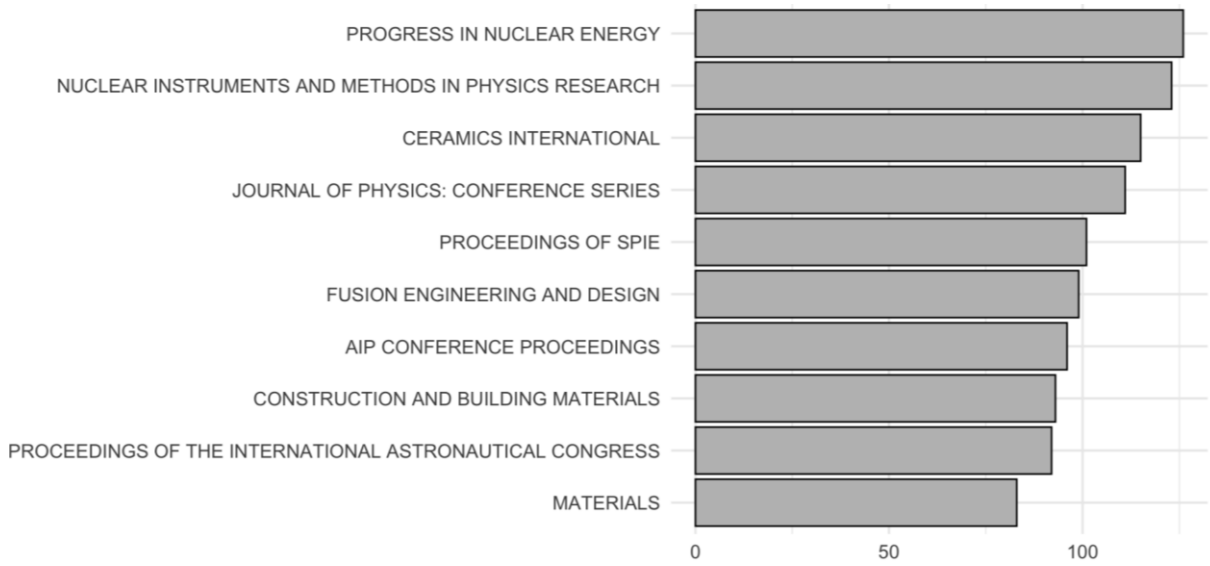


Figure 5. Source-Based Publication Amount.

Among the sources that published the most articles**, "Progress in Nuclear Energy"** (126 articles) and **"Nuclear Instruments and Methods in Physics Research"** (123 articles) rank first. These two sources stand out as a critical publishing platform in the field of radiation protection and shielding materials. In addition, sources such as **"Ceramics International"** (115 articles) and **"Journal of Physics: Conference Series"** (111 articles) have made significant contributions to the literature.

These data show that there is a multidisciplinary interest in shielding materials and radiation protection, and both applied and theoretical studies have been published in various journals. In addition, the image above clearly reveals the importance and contribution of these resources in the field. The distribution of articles suggests a balanced productivity among top journals, signifying a healthy competition and collaboration within these key sources.

The presence of specialized journals indicates focused research themes, particularly in nuclear energy, physics instrumentation, ceramics, and materials science.

According to the results of another analysis, both the keywords determined by the researchers (Author Keywords)[1] and the added keywords (Keywords Plus)[2] reveal the scope and trends of radiation protection studies. Among the most commonly used terms, "Radiation Shielding", "Radiation Protection" and "Shielding" stand out, while specific materials such as "Concrete" and "Glass" are critical for armoring work. In particular, terms such as "Mass Attenuation Coefficient" and "Mechanical Properties" have often been studied to understand the physical properties of materials and their radiation absorption performance. In the Keywords Plus analysis, more general terms such as "Gamma Rays", "Ionizing Radiation" and "Electromagnetic Shielding" reflect the wide range of applications and multidisciplinary nature of the field.

These findings clearly reveal the main trends of the literature and their focus on armoring materials. "Radiation Shielding" is at the heart of radiation protection studies as a dominant term in both Author Keywords and Keywords Plus analysis. This analysis provides a powerful guide to understanding what topics and materials research in the field of shielding materials and radiation protection focuses on. In the future, it is expected that more material diversity and innovative applications will be studied.

[1] These keywords are determined by the researchers conducting the study and usually include a specific focus. For example, terms such as "Radiation Shielding" and "Concrete" are directly related to the materials or topics that researchers are studying. Author Keywords reflect the main themes of the research and the methods used.

[2] Keywords Plus is derived from terms that are often used in article references, allowing the work to be understood in a broader context. These keywords offer more general and comprehensive terminology, such as "Gamma Rays" and "Electromagnetic Shielding". Keywords Plus is useful for understanding connections in the literature and bridging research.

A. *Most Frequently Used/Studied Materials*

The table below shows the most frequently studied materials/components in research and the categories of these materials together with their frequency.

Table 2. The most frequently studied materials.

#	Material	Frequency	Category
1	**Aluminium**	**97**	**Metals and Metallic Compounds**
2	**Tungsten**	**82**	**Metals and Metallic Compounds**
3	**Copper**	**70**	**Metals and Metallic Compounds**
4	**Iron**	**67**	**Metals and Metallic Compounds**
5	**Zinc**	**44**	**Metals and Metallic Compounds**
6	**Nickel**	**43**	**Metals and Metallic Compounds**
7	**Silica**	**180**	**Ceramic and Glass Materials**
8	**Optical Glass**	**12**	**Ceramic and Glass Materials**
9	**Polymers**	**153**	**Polymers & Composites**
10	**Epoxy Resins**	**92**	**Polymers & Composites**
11	**Composites**	**36**	**Polymers & Composites**
12	**Carbon Nanotubes**	**115**	**Carbon-Based Materials**
13	**Carbon Fibers**	**76**	**Carbon-Based Materials**
14	**Graphene**	**68**	**Carbon-Based Materials**
15	**Lead**	**86**	**Radiation Shielding and Heavy Materials**
16	**Tungsten**	**82**	**Radiation Shielding and Heavy Materials**
17	**Bismuth**	**45**	**Radiation Shielding and Heavy Materials**
18	**Heavy Concretes**	**37**	**Construction & Building Materials**
19	**Concrete**	**13**	**Construction & Building Materials**
20	**Tellurium Compounds**	**146**	**Chemical Compounds**
21	**Barium Compounds**	**145**	**Chemical Compounds**
22	**Hydrogen**	**48**	**Chemical Compounds**

Focusing on the question of "which materials are being studied?", which is our research problem, it is seen that the following findings come to the fore:

1. **Ceramic and Glass Materials: Materials** such as silica (180) and optical glass attract attention due to their high radiation resistance. This category is especially preferred due to their optical properties and durability.
2. **Polymers and Composites:** Polymers (153) and epoxy resins (92) are an important area of research due to their light weight and versatile uses. Composites have been widely studied for both their mechanical and radiation shielding properties.
3. **Carbon-Based Materials: Carbon** nanotubes (115) and graphene (68) are noted for their superior mechanical and thermal properties. These materials are critical for both innovative and high-performance armoring solutions.
4. **Radiation Shielding and Heavy Materials: Heavy** materials such as lead (86), tungsten (82) and bismuth (45) constitute an important area for effective attenuation of radiation.
5. **Chemical Compounds:** Tellurium compounds (146) and barium compounds (145) are priority materials in research due to their radiation interaction properties.
6. **Metals and Metallic Compounds: Aluminum** (97), copper (70) and other metals have an important place with their advantages of lightness and durability.
7. **Construction and Building Materials:** Concrete (13) and heavyweight concretes (37) have been frequently studied due to both cost-effectiveness and wide range of applications.

In summary, the table above reveals the most frequently studied materials in the field of radiation protection and the different properties of these materials. Research focuses on a combination of innovative (e.g., carbon nanotubes) and conventional (e.g., concrete) materials.

B. Common Word Network Analysis

Finally, we can look at the common word network analysis, which is produced to show the common usage relationships between frequently used keywords.

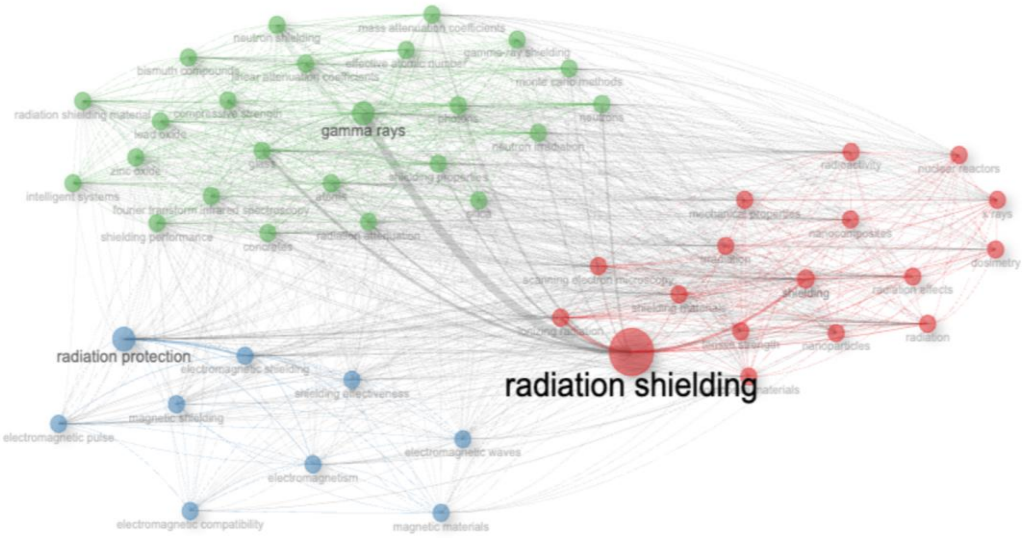


Figure 6. Network Analysis.

The highlights of the keyword co-occurrence network shown in Figure 6 can be interpreted as follows:

1. **Central Nodes:** "Radiation Shielding" appears as the central and largest node in the network. This indicates that it is the most frequently used term and the one most strongly associated with other keywords, reflecting the broad scope of research in this field.
2. **Subgroups (Clusters):**

- **Green Cluster:** Centered around terms such as "Gamma Rays," "Neutrons," and "Mass Attenuation Coefficients." This cluster represents studies focusing primarily on the physical interactions of radiation and the quantitative evaluation of shielding materials' effectiveness.
- **Blue Cluster:** Includes terms such as "Radiation Protection," "Electromagnetic Shielding," and "Magnetic Shielding." It reflects research directed at protective strategies against electromagnetic radiation and related technical applications.
- **Red Cluster:** Built around terms such as "Nanoparticles," "Radiation Effects," and "Mechanical Properties." This cluster highlights research in nanotechnology and material sciences, with emphasis on the development of advanced materials.

3. **Relationships Among Key Terms:** The term "Radiation Shielding" maintains strong connections with both the green and blue clusters, showing that studies on both the physical mechanisms of radiation attenuation and broader protective strategies are central to the field. The interconnection of terms such as "Gamma Rays" and "Neutrons" underscores the continuing importance of research focused on specific radiation types.

The dense network of connections further reflects the diversity of research directions, ranging from traditional material choices (e.g., glass, lead) to innovative approaches involving nanomaterials and composites. Notably, the prominence of nanoparticles and composite materials indicates a rising research trend.

Overall, the network analysis clearly demonstrates how research on radiation shielding is organized around a set of core concepts, while simultaneously branching into specialized and emerging areas. These findings highlight both the breadth and the evolving nature of this research domain.

In addition to conceptual clusters, the network also emphasizes the diversity of materials investigated for radiation shielding. Traditional materials such as lead, concrete, and glass remain visible, reflecting their established role in the field. At the same time, the prominence of terms like "nanoparticles," "polymers," and "composites" illustrates the growing interest in developing innovative, lightweight, and eco-friendly alternatives. This aligns with the primary aim of the study, which is to explore not only the thematic structure of radiation shielding research but also to provide insight into the evolution of materials that have been most extensively studied.

IV. CONCLUSION

This study presented a bibliometric analysis of 6,515 Scopus-indexed publications (2000–2023) on radiation shielding materials. By employing keyword networks, annual publication trends, and co-word analyses, we mapped the structure of the field, identified dominant themes, and traced emerging directions in research. The results show a steady growth of studies since 2000, with a pronounced increase after 2020, confirming the rising global importance of radiation protection.

Our analysis highlights both continuity and change in the materials investigated. Traditional shielding options such as lead and concrete continue to play a central role due to their cost-effectiveness and accessibility, while newer alternatives—silica, tungsten, polymers, carbon nanotubes, and composite systems—reflect technological advances and performance-oriented research priorities. The prominence of nanomaterials and composites in particular indicates a clear shift toward lightweight, durable, and multifunctional solutions.

Beyond materials, the field exhibits strong interdisciplinary contributions from physics, materials science, chemistry, and construction engineering. For instance, research on heavy concretes underscores the role of building sciences in shielding applications, while advances in nanotechnology demonstrate the potential for novel solutions to electromagnetic and particle radiation. Internationally, countries such as China, the USA, India, and Turkey lead in publication volume, while Canada achieves the highest citation impact, showing the global and collaborative nature of the field.

Taken together, these findings provide a structured overview of radiation shielding research, offering insights not only into which materials dominate the literature but also how the field has evolved thematically and institutionally. Looking forward, the literature suggests that the next phase of research will prioritize the development of low-cost, environmentally friendly, and sustainable materials, complementing advances in nanotechnology and composites. Such efforts will both enrich academic inquiry and translate into practical applications in medicine, energy, industry, and space exploration.

DECLARATIONS

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Conflict of Interest: The author declare no conflict of interest.

Supporting Institutions: This research received no external funding.

Ethical Approval: This study does not involve human or animal participants. All procedures followed scientific and ethical principles, and all referenced studies are appropriately cited.

Plagiarism Statement: This article has been evaluated for plagiarism and no instances of plagiarism were detected.

Use of AI Tools: The author declare that no Artificial Intelligence (AI) tools were used in the creation of this article.

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