



Review of Alloy Containing Bismuth Oxide Nanoparticles on X-Ray Absorption in Radiology Shields

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Abstract

Background: Managing potential risks that can threaten the health of medical staff including risks associated with treatment tools and equipment has always played an important role in the healthcare systems. This study aimed to investigate the documentation on the effect of nanoparticle shields on the absorption of hazardous radiation in radiology, and specifically alloy containing bismuth oxide (Bi₂O₃) nanoparticles.

Materials and Methods: Several databases including ScienceDirect, Web of Science, Scopus, PubMed, and Magiran were searched to collect the required documents. The articles were selected based on the year of publication and their relationship with the subject and objectives.

Results: Studies confirm the effectiveness of bismuth oxide nanoparticles in order to protect against radiation in different types of radiological shields. These findings show the relationship between different parameters of nanoparticles and their effect on radiation absorption, such as the size of nanoparticles, used kilovoltage peak (kVp), thickness of shields, density of nanoparticles, as well as different methods of using these particles in different types of radiological shields.

Conclusion: Bismuth oxide nanoparticles have a significant effect on the absorption of X-rays in radiology. Using these particles results in lighter shields with lower cost and lead content. In particular, bismuth oxide nanoparticles are very efficient at absorbing radiation and reducing the cost of production for shields.

Keywords: Nanoparticles, Bismuth oxide, X-ray, Radiological shields

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Introduction

X-rays are part of the electromagnetic spectrum having high frequencies and short wavelengths that are very powerful and dangerous(1). The effect of X-rays on human health has always been an essential issue. This issue is more important for those who deal with this radiation, especially in radiology. Increasing the protection and comfort of employees is an important issue. Moreover, since X-rays compromise the health of radiology staff, any negligence in protection can have serious consequences (2). Using lead as a shield is generally due to its higher K absorption edge (K-edge) and accessibility. As a result, lead has always been used as the main metal in protectors. Since this element has some disadvantages such as high weight, toxicity, and low flexibility, new approaches have suggested the use

of nanoparticles to fix them (3). Nanoparticles have interesting properties due to their small size, including strength, durability, conductivity, high specific surface area, etc. (4). Nanoparticles can be used in various forms such as alloys, composites, solutions, etc (1, 5). Using nanomaterials in radiation protection is a new issue, and research is being conducted on it. The application of nanoparticles in various fields has led to more attention to these particles in health sciences. Due to the serious effects of radiation, new methods are needed for radiation protection to minimize the problems that exist in the current approach. Nanoparticles have shown desirable properties in many studies. For example, the reduction in particle size has been shown to affect the absorption of radiation. This is due to the increase in the specific surface area of the particles as the size decreases, the adsorption

rate increases.(5-7). In another study, the effect of the thickness of polymers or composites containing these particles was investigated and the results showed that the increase in thickness affects the weight of the protector; furthermore, they showed better absorption performance than lead protectors (5, 7, 8). Studies have also focused on the effect of particle density, voltage, shielding weight, and the cost of production of the shield; in all cases, the advantage of these particles has been proven as a new protective approach (5, 6). Moreover, studies have paid special attention to bismuth oxide (Bi_2O_3) nanoparticles due to advantages such as more radiation absorption due to larger K-edge, lower weight, lower production cost, easier access compared to other elements, etc.

These properties caused researchers to study nanoparticles and assess their applications in the healthcare field, and particularly radiology (1). The use of these particles has resulted in the production of shields with higher absorption intensity, lower weight, and higher cost-effectiveness (5, 9). The particles used for this purpose, in addition to reducing the weight of the shield, must be able to create a greater absorption for the shield, which means that they must have an acceptable K-edge. The K-edge depends on different elements, but not all elements can be modified due to their high cost and scarcity. (10). Bismuth is the best choice compared to other elements due to its higher K-edge and availability, and research has proven the efficiency of its nanoparticles (11). Therefore, more studies are needed to investigate different aspects of these nanoparticles in radiology (9). Hence, this study aimed to investigate the documentation on the effect of nanoparticle shields on the absorption of hazardous radiation in radiology, and specifically alloy containing bismuth oxide (Bi_2O_3) nanoparticles.

Materials and Methods

To obtain the required information, a list of keywords was searched in five databases including ScienceDirect, Web of Science, Scopus, PubMed, and Magiran. The results of search in both Persian and English languages were reviewed. The search keywords were 'Nanoparticles AND Radiology Shielding', 'Alloys AND Nanoparticles', 'Bismuth nanoparticles', 'Shielding OR Nanoparticles', and 'Radiology shielding AND bismuth nanoparticles'.

All related articles were collected and included in the study according to the following inclusion criteria: conformity of the title with the subject under study; conformity between research methodology and study objectives; and conformity of the abstract and text with study objective.

The selection process was based on searching for appropriate keywords and using filters for limitations in the desired years and considering the use of nanoparticles in radiology. The selected articles were used from studies between 2002 and 2021, with an emphasis on studies conducted during the past 10 years. Finally, 25

articles were included in the study due to their relevance to the objectives of the study. The relevance of the included studies was assessed according to the following criteria: relationship of nanoparticles in radiology; their application in radiation absorption; and the use of bismuth oxide nanoparticles in radiology shields. Finally, the full-texts of all the included articles were studied and their relationship with each other was examined.

Results

Out of a total of 1316 studies retrieved, 853 articles were selected after rescreening of title. Then, 559 duplicate studies were removed. Of these, 26 studies were selected for full-text review, and finally 25 studies were included in the final review. Figure 1 summarizes the data collection process included in the study.

The results of the research indicated a variety of nanoparticles used in radiation protection, and new approaches for using these materials show their wider use in the future. Lead is the most common material used to create protections against radiation due to its cheapness (12). However, disadvantages such as the toxicity and high weight of lead protectors have prompted researchers to look for other solutions (3). El-Sawy considered weight and cost as the most important factors to choose the protective material (13, 14). Using nanoparticles has been considered a new approach because of the many benefits in protecting against radiation (5). These particles have gained a lot of attention and different production methods (3, 14, 15). Ayyıldız et al used four elements, Ti, Zr, Ag, and Co, which were selected because of their low weight in nanopowder (16). Regarding production methods, Fontainha et al used the sol-gel method, which is a common method for the production of nanoparticles, which was eventually used in nanocomposite polymers (1). Li et al showed that when bismuth nanoparticles are used in a polymer matrix, they can have higher adsorption than macroparticles with the same mass ratio (17). Also, due to the special feature of nanoscale materials, different elements can be used to produce these particles (6, 18). However, elements with acceptable K-edge, such as bismuth and tungsten, are preferred.

The size of nanoparticles can significantly affect the amount of radiation they absorb. In their study, Aghaz et al showed that the use of 20 to 100 nm nanoparticles has a better absorption value than microparticles with an average size of 20 μ at different voltages (6). Shirkhanloo et al used bismuth oxide with a size of 70 to 100 nm and recorded 56.79% absorption for these particles, which is equal to 0.5 mm of lead (3). Salimi et al used cerium oxide nanoparticles with a size of 10 to 30 nm with single-walled carbon nanotubes (SWCNT); this combination showed a 3% increase in the amount of total absorption (7). Also, the study by Noor Azman et al regarding particle size showed that nanoparticles with starch show more adsorption than nanoparticles without starch

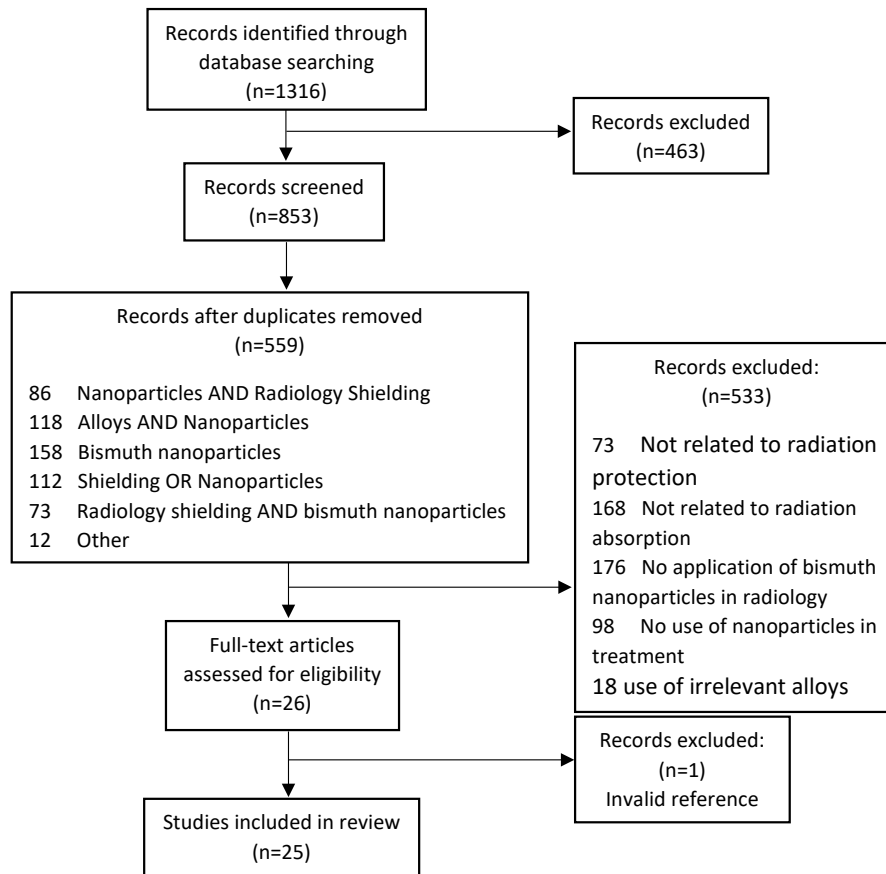


Figure 1. Flowchart of Article Selection Process.

19). Ayyıldız et al. used particles ranging in size from 5 to 70 nm, and the composite containing these particles with different thicknesses showed different amounts of adsorption; in this study, unlike other studies, a wider distribution of particle size was used, which can reduce the protective efficiency at different voltages (16). In addition to size, the morphology of nanoparticles can also have a significant impact on their efficiency. The study by Yu et al showed that nanopowder has the best absorption at different voltages (20). Also, the study by Malekzadeh et al showed that nanoparticles were more capable of absorbing gamma rays than microparticles (21). The size of the nanoparticles, depending on the type of particle, has an important effect on the amount of radiation absorption, and the use of smaller nanoparticles due to the greater surface-to-volume ratio results in greater adsorption; furthermore, the use of particles with an even size distribution provides better absorption for the shields.

In addition, the thickness of shields, which is determined by the thickness of polymers and composites containing nanoparticles, has an important effect on the amount of radiation absorption at different voltages. This increase in thickness is usually directly related to the amount of adsorption (22). The thickness of shields

affects their weight, as studies are based on the use of protective equipment with maximum attenuation and minimum weight (7). Ayyıldız et al examined the effect of composite thickness containing Co nanoparticles on radiation transmission, which showed the transmittance values ($I \cdot 106$) of 9.389, 524.0, 3.521, and 3.462 for thicknesses of 2, 5, 57, and 6.6 cm, respectively; the lowest transmittance values occurred at the maximum thickness (16). Mehnati et al. used the shields containing bismuth oxide nanoparticles with a thickness of 1 mm, and the results showed that the absorbed dose of skin and glandular layers reduced by 10% and 15%, respectively (23). Dejangah et al focused on the effect of increasing thickness and increasing the percentage of bismuth oxide, and showed that increasing the thickness (due to more interaction of photons with the shield) and the percentage of filler material (due to increasing density and atomic number) result in increasing the attenuation percentage (Table 1) (24). The effect of filler percentage has also been confirmed by Abdel Wahab et al (25). Mehnati et al investigated the effect of shielding thickness at different voltages, the results of which are shown in Table 2 (5). Moreover, the results of the study by Cho et al confirmed these results (Table 3) (8). In general, various studies confirm that increasing the thickness of

Table 1. The Effect of Bismuth Oxide Content and Thickness on X-Ray Attenuation (24)

Amount of Bismuth Oxide (%)	Thickness (cm)	Experimental Attenuation (%)	Simulated Attenuation (%)	Density (g/cm ³)
10	0.2	14.4	14.9	1.23
20	0.22	27.8	27.63	1.36
30	0.26	40.19	39.99	1.52
40	0.253	54.41	57.19	1.73
50	0.23	62.19	65.96	1.99
60	0.188	68.18	70.48	2.36
70	0.215	82.15	84.26	2.84

Table 2. The Effect of Shielding Thickness at Different Voltages (5)

Doses in different thicknesses (μGy)	Voltage (kVp)		
	60	80	100
No BO ₃ nanoparticles	421	733	1110
By 0.5 mm BO ₃	240.3 ±7	475.66 ±6	763 ±13
By 1.5 mm BO ₃	192.6 ±4	402 ±8.54	676.66 ±4.58

Table 3. The Protective Effect of Shielding at Different Thicknesses and Voltages (8)

Protective Effect in Different Thicknesses (%)	Voltage (kVp)		
	50	80	100
0.2 mm	96.52	94.86	94.10
0.4 mm	97.47	96.57	95.63

the shield containing nanoparticles increases the amount of adsorption in them, which is also true for lead shield.

Since radiology devices use different voltages to image different parts of the body, the absorption of shields at different voltages should be measured and their performance at high voltages should be evaluated. Due to the fact that penetration power of the rays increases at high voltages, the shield must have an acceptable performance at these voltages. In the study by Aghaz et al, voltages of 40 to 100 kVp were used to evaluate the adsorption power of micro- and nano-particles, and the increase in kV reduced the absorption of radiation. In this study, the largest difference in radiation absorption between micro- and nano-particles occurred at 70 kV, and the absorption value was almost the same with increasing voltage to 80 and 100 kVp (6). Findings of Mehnati et al showed that the range of absorption for different shielding thicknesses at three voltages of 60, 80, and 100 was different, so that as the kV increased the protective ability of nanoparticles shields decreased (5). These findings highlight the importance of the kV used in imaging, which should be taken into account. Adding other materials as fillers or mixing them with nanoparticles also changes the amount of adsorption. Studies have shown that adding SWCNT to a sample containing cerium oxide nanoparticles increases the adsorption by 3% (7). In addition, when Fontainha et al applied the nanoparticles purely, the ZrO₂ adsorption band showed a large reduction for the dose of 100 to

1000 kGy, while the nanocomposites enriched with ZrO₂ nanoparticles showed better adsorption (1). However, the fabrication and application of nanoparticles with high purity and their alloying in radiological shields is one of the most important production and industrial limitations on a large scale. Future studies can explore cheaper and easier ways to produce nanoparticles as well as altering their alloys to make them more practical in shields. Methods such as sol-gel, which are relatively inexpensive, fast, and capable of industrial scale production, can be promising for the production of nanoparticles.

Conclusion

In this study, usage of nanoparticles in radiological shields were reviewed. Evaluation of different studies shows effective absorption of radiation by these particles. To confirm this, the particle size, thickness of shields, voltage and density of alloys in different studies were collected and compared. The results showed reducing the particle size leads to increase in radiation absorption. At different thicknesses and voltages, the density of the alloy and the percentage of nanoparticles in the alloy determine the amount of radiation absorption (higher percentages of nanoparticles in the alloy results in higher absorption). These help to produce lower weight, lower toxicity and greater absorption, thus minimizing the risks of exposure to X-rays during treatment.

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Conflict of Interest Disclosures

The authors declare no conflict of interests.

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