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Evaluation of Eco-friendly Shielding for Medical Electromagnetic Radiation Shielding

Chang Gyu Kim*

Department of Radiological Science, Gimcheon University, Gyung Sang Buk-Do, 39528, Republic of Korea

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With the improvement in national income levels, the use of medical electromagnetic radiation has rapidly increased, resulting in a rise in medical radiation exposure. Currently, materials containing lead are mainly used as shielding agents for medical electromagnetic radiation. However, these materials are heavy, pose health risks to the human body, and cause environmental pollution, highlighting the need to develop new shielding materials. In this study, a hydrogel-based radiation shield, which is harmless to the human body, lightweight, and environmentally friendly, was fabricated and its performance was evaluated to analyze its applicability in clinical settings. When the radiation exposure dose was 2 mAs, the shielding efficiency at 40 kVp was highest for the bismuth material at 10.88%, followed by barium at 7.94%, tungsten at 7.35%, and iron at 1.47%. The pure hydrogel showed a shielding efficiency of 1.47%. At a radiation exposure dose of 16 mAs, the shielding efficiency of each material showed similar results at 60 kVp and 80 kVp as those at 40 kVp. Bismuth exhibited the best efficiency, followed by barium, tungsten, and iron. These results suggest that bismuth is expected to show the best efficiency when fabricating eco-friendly hydrogel-based shielding materials to prevent medical X-ray exposure. It is considered necessary to continue research on producing shielding materials by adding barium and tungsten.

Keywords : Electromagnetic radiation, radiation shielding, eco-friendly, hydrogel, radiation dose

1. Introduction

Medical X-rays are a type of electromagnetic wave with a short wavelength, and two types of X-rays—bremsstrahlung X-rays and characteristic X-rays—are generated through the interaction between high-speed accelerated electrons and the atomic nuclei of a target material. Medical X-rays are used to obtain medical images for early diagnosis of diseases in the human body or to treat tumors [1-3].

With the improvement in income levels and advances in medical technology, the use of medical X-rays has rapidly increased. Excessive radiation exposure can lead to diseases such as cataracts and cancer. For this reason, systematic management is required to reduce radiation exposure to patients and radiation-related workers [4, 5].

Institutions that use medical X-rays must install protective facilities and utilize shielding equipment to reduce unnecessary radiation exposure for patients, caregivers, and radiation workers [6, 7].

Lead is the most widely used material for protective facilities and shielding equipment designed to reduce radiation exposure. However, lead can emit toxic gases in the event of a fire, and if absorbed into the human body, it can cause serious issues to the nervous and cardiovascular systems. In addition, if appropriate separation procedures are not carried out during the closure or demolition of medical facilities, there is a risk of environmental contamination, including soil and groundwater. These issues underscore the need for the development of lead-free, eco-friendly shielding materials [8-10].

Hydrogels have physical properties similar to biological tissue, minimizing immune responses in the body and facilitating interaction with tissues. Hydrogels, a type of crosslinked polymer material, have evolved from being inert substances to complex stimuli-responsive materials since Wichterle's research in the 1960s. They are now widely used in various applications such as tissue engineering, wound dressings, sensors, drug delivery systems, and separation science [11-13].

*Corresponding author: Tel: +82-54-420-4073
Fax: +82-54-420-4462, e-mail: radkcg@hanmail.net

Although lead is still the most widely used material for radiation shielding, due to concerns regarding its impact on the human body and the environment, its use in shielding materials is now being avoided. Polymer compounds mixed with materials such as barium, bismuth, and tungsten are increasingly used as eco-friendly, lead-free radiation shielding materials [14-17].

Chemically composed hydrogel-based materials have excellent workability, are lightweight, harmless to the human body, and do not cause environmental pollution. Therefore, they hold potential for development as eco-friendly shielding materials that protect the human body by blocking externally irradiated radiation.

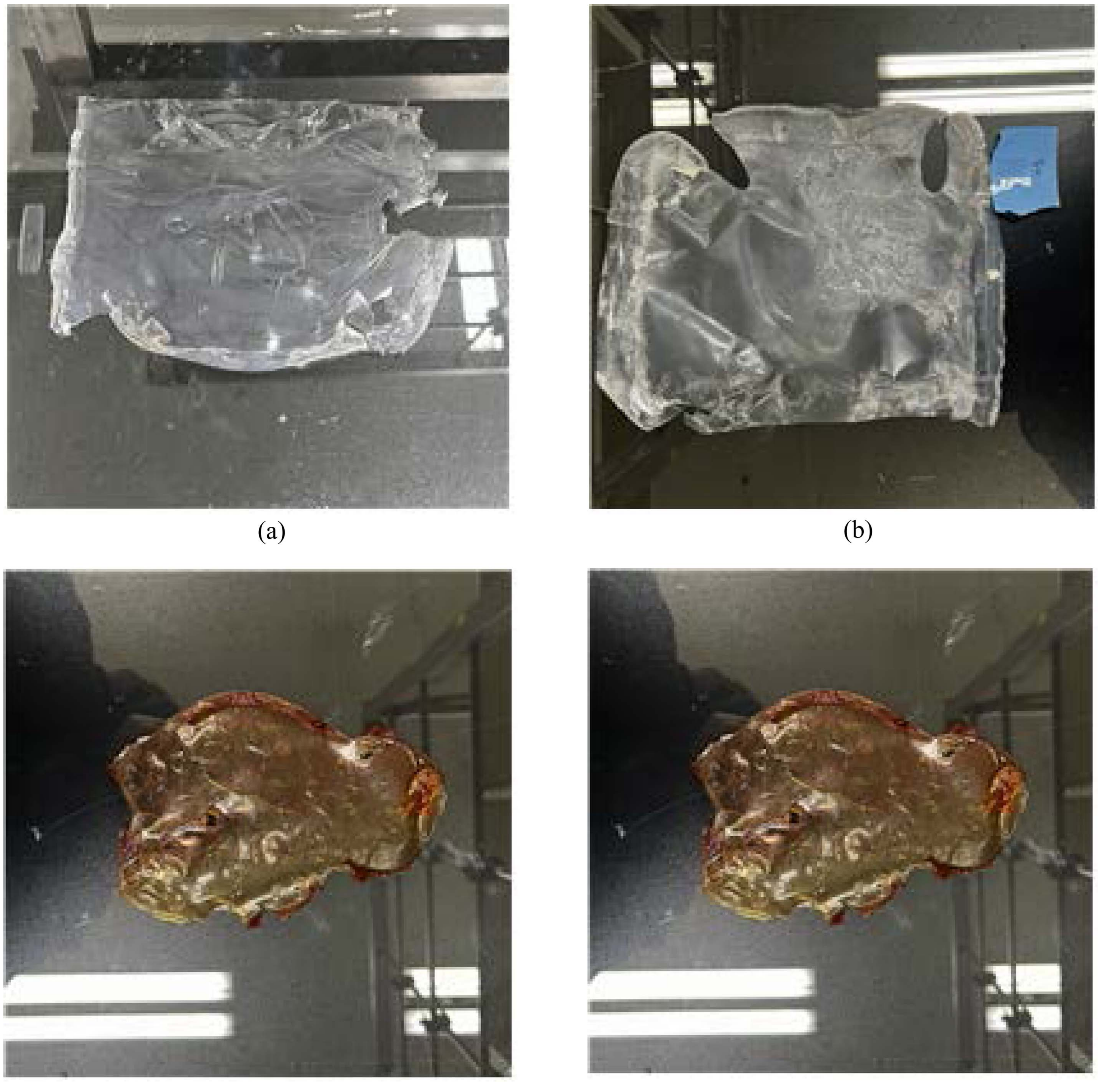
However, research on the development of hydrogel-based shielding materials capable of shielding medical X-rays is currently almost nonexistent.

In this study, a shielding material based on hydrogel capable of blocking medical electromagnetic radiation (X-rays) was manufactured, and its radiation shielding performance was evaluated. The aim was to provide foundational data for the development of a new eco-friendly shielding material that can reduce radiation exposure.

2. Materials and Methods

2.1. Fabrication of Hydrogel Shielding Material for Medical electromagnetic radiation Shielding

For Hydrogel is a crosslinked polymer in gel form that has the ability to absorb and retain water. It is primarily composed of hydrophilic polymers, with 90% of its composition being water, while the remaining components



(a) (b) (c) (d)

Fig. 1. (Color online) Photos of eco-friendly hydrogel shielding materials: (a) Bismuth, (b) Barium, (c) Iron, (d) Tungsten

serve as a structural support for the water. A representative supporting component is saccharide. The physical characteristics of hydrogel include low tensile sensitivity, flexibility, soft texture, adhesiveness, and a cooling sensation. Its chemical properties include high water content, sensitivity to heat and pH, and water solubility [11, 12].

To fabricate the hydrogel film, 1 g of HEC (Hydroxyethyl Cellulose) was dissolved in 350 mL of distilled water and stirred at 50°C for 30 minutes. Then, 3 g of CMC (Carboxymethyl Cellulose) powder was added to the HEC solution and stirred magnetically for 1 hour. Next, 0.2 g of CA (Citric Acid) was added, and the mixture was stirred using a mechanical stirrer for 15 minutes, followed by an additional 15 minutes of magnetic stirring. Afterward, 1.75 g of sodium benzoate was added, and the mixture was stirred using a mechanical stirrer for 30 minutes, then magnetically stirred for another 30 minutes. To remove bubbles, the solution was left undisturbed overnight. The resulting transparent solution was poured into Petri dishes of specific diameters and dried in air for 48 hours. The dried CMC-HEC film was then cured at 80°C for 8 hours to promote reactions between the polymer chains.

To adsorb metallic substances into the dried hydrogel film, 0.5 mol metal solutions of lead-free shielding materials bismuth, tungsten, iron, and barium were prepared. The hydrogel films were soaked in these solutions for 30 minutes to allow for adsorption, producing shielding materials with a thickness of 0.6 mm (Fig. 1).

2.2. Medical electromagnetic radiation Shielding Performance and Dose Evaluation of Eco-Friendly Hydrogel Shielding Materials

Medical electromagnetic radiation, such as X-rays, is used to acquire diagnostic images by differentiating the absorption characteristics of materials as the X-rays pass through them. These images are then reconstructed and utilized for disease diagnosis.

To evaluate the shielding performance of the custom-fabricated eco-friendly hydrogel radiation shielding materials, a general-purpose X-ray generator manufactured by JW Medical was used. This X-ray device is capable only of standard radiographic imaging. The maximum rated output of the device was 500 mA for tube current and 150 kVp for tube voltage.

Radiation dose measurements were conducted using the Unfors Xi semiconductor dosimeter. The distance between the X-ray tube and the dosimeter detector was set to 100 cm, which is the standard in diagnostic radiology. The irradiation field size was set to 8 × 10 cm for the experiments (Fig. 2).

Fig. 2. (Color online) Photo of the custom-fabricated hydrogel shielding performance evaluation device for medical X-ray shielding.

Shielding performance was evaluated by varying the tube voltage to 40, 60, and 80 kVp and changing the exposure dose to 2, 4, 8, and 16 mAs.

The X-ray shielding efficiency was calculated by measuring the shielded dose and dividing it by the incident dose, then converting the result into a percentage for evaluation.

3. Results and Discussion

3.1. SEM and Elemental Analysis of the Custom-Fabricated Hydrogel-Based Radiation Shielding Material

In To develop an eco-friendly shielding material for medical electromagnetic radiation, the surface and chemical composition of the fabricated shielding material were analyzed using SEM-EDAX (Scanning Electron Microscope - Energy Dispersive Analysis X-ray).

Figure 3 shows the SEM-EDAX analysis of the surface of the bismuth-infused hydrogel film. Through the image, it was confirmed that bismuth and various other elements were present on the surface, verifying that the selected metal material was successfully adsorbed onto the hydrogel film. The elemental composition was analyzed as follows: carbon 43.62%, oxygen 37.40%, bismuth 10%, chlorine 5.54%, sodium 0.60%, and aluminum 0.61%.

Figure 4 shows the SEM-EDAX analysis of the surface of the barium-infused hydrogel film. From the image, it was confirmed that barium and various other elements were present on the surface, indicating that the selected metal material was successfully adsorbed onto the hydrogel film. The elemental composition was analyzed

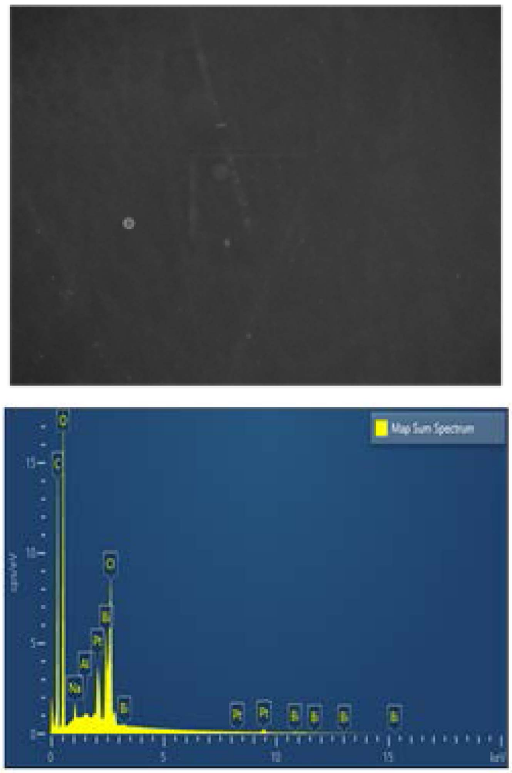


Fig. 3. (Color online) SEM and EDAX analysis of the prepared bismuth hydrogel film as radiation shielding materials.

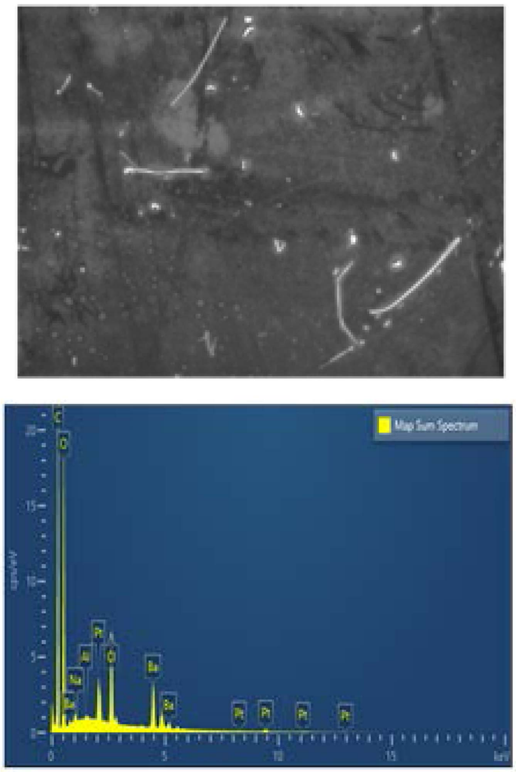


Fig. 4. (Color online) SEM and EDAX analysis of the prepared barium hydrogel film as radiation shielding materials.

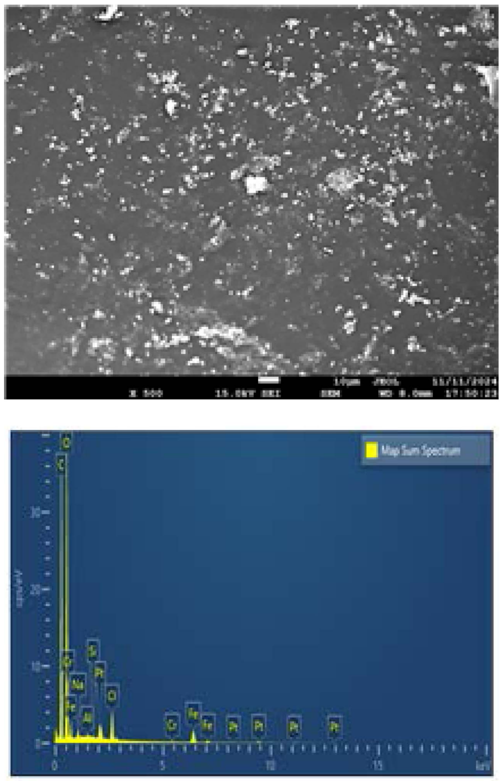


Fig. 5. (Color online) SEM and EDAX analysis of the prepared iron hydrogel film as radiation shielding materials.

as follows: carbon 49.96%, oxygen 32.87%, barium 12.65%, chlorine 3.86%, sodium 0.56%, and aluminum 0.11%

Figure 5 shows the SEM-EDAX analysis of the surface of the iron-infused hydrogel film. From the image, it was confirmed that iron and various other elements were present on the surface, indicating that the selected metal material was successfully adsorbed onto the hydrogel film. The elemental composition was analyzed as follows: carbon 49.36%, oxygen 44.71%, iron 3.79%, chlorine 1.47%, sodium 0.42%, and aluminum 0.11%.

Figure 6 shows the SEM-EDAX analysis of the surface of the tungsten-infused hydrogel film. From the image, it was confirmed that tungsten and various other elements were present on the surface, indicating that the selected metal material was successfully adsorbed onto the hydrogel film. The elemental composition was analyzed as follows: carbon 29.79%, oxygen 24.13%, tungsten 34.04%, sodium 8.31%, strontium 3.35%, and aluminum 0.37%.

Based on the above results, bismuth, barium, iron, and tungsten were adsorbed onto dried hydrogel films by immersing them in 0.5 mol metal solutions for 30 minutes, resulting in the fabrication of shielding materials

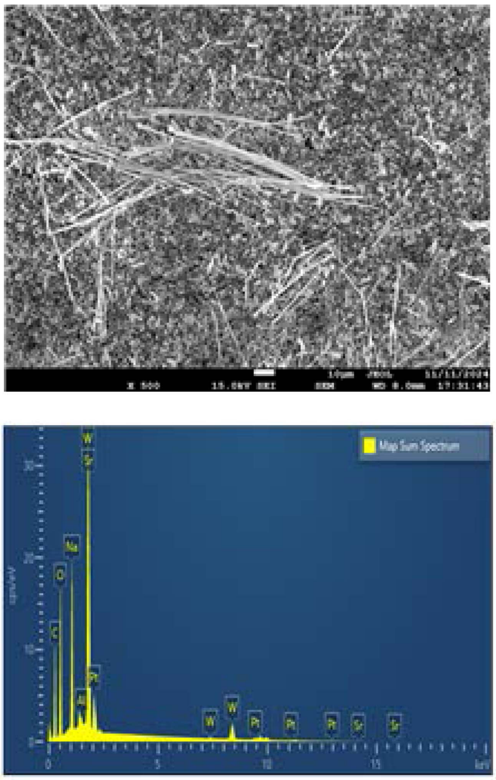


Fig. 6. (Color online) SEM and EDAX analysis of the prepared tungsten hydrogel film as radiation shielding materials.

with a thickness of 0.6 mm. The resulting compositions were: bismuth 10%, barium 12.65%, iron 3.79%, and tungsten 34.04%.

3.2. Evaluation of the Shielding Performance of the Custom-Fabricated Hydrogel-Based Medical Electromagnetic Radiation Shielding Material

To adsorb metal substances into the custom-fabricated dried hydrogel films, 0.5 mol metal solutions of lead-free shielding materials—bismuth, tungsten, iron, and barium—were prepared. The hydrogel films were immersed in the solutions for 30 minutes, resulting in shielding materials with a thickness of 0.6 mm, which were then used to evaluate electromagnetic radiation shielding performance.

At a radiation dose of 2 mAs and a tube voltage of 40 kVp, the shielding efficiency was highest with bismuth at 10.88%, followed by barium at 7.94%, tungsten at 7.35%, and iron at 1.47%. The pure hydrogel showed a shielding efficiency of 1.47% (Table 1).

As shown in Table 1, when the radiation exposure dose was 2 mAs, it was observed that the shielding efficiency tended to decrease as the tube voltage—which represents the energy of the electromagnetic radiation—increased, even when using the same shielding material.

Table 1. Evaluation of Shielding Efficiency According to Tube Voltage at 2 mAs for Custom-Fabricated Hydrogel-Based Radiation Shielding Materials.

Division	40 kVp	60 kVp	80 kVp
non	3.40±0.25 mR	9.46±0.02 mR	16.47±0.03 mR
	0%	0%	0%
Hydrogel	3.35±0.01 mR	9.43±0.02 mR	16.41±0.03 mR
	1.47%	0.4%	0.36%
Bismuth	3.03±0.01 mR	8.67±0.02 mR	15.73±0.03 mR
	10.88%	8.35%	5.04%
Barium	3.13±0.02 mR	8.76±0.02 mR	15.64±0.01 mR
	7.94%	7.40%	5.03%
Iron	3.35±0.02 mR	9.28±0.02	16.37±0.02 mR
	1.47%	1.90%	0.60%
Tungsten	3.15±0.01 mR	8.93±0.02	15.91±0.03 mR
	7.35%	5.60%	3.40%

Table 2. Evaluation of Shielding Efficiency According to Tube Voltage at 16 mAs for Custom-Fabricated Hydrogel-Based Radiation Shielding Materials.

Division	40 kVp	60 kVp	80 kVp
non	27.70±0.01 mR	76.11±0.01 mR	132.10±0.00 mR
	0%	0%	0%
Hydrogel	27.55±0.02 mR	75.95±0.02 mR	131.80±0.00 mR
	0.54%	0.21%	0.23%
Bismuth	25.28±0.00 mR	71.06±0.02 mR	122.80±0.00 mR
	8.74%	6.64%	7.04%
Barium	25.29±0.01 mR	75.72±0.02 mR	125.70±0.01 mR
	8.70%	1.17%	4.84%
Iron	27.20±0.01 mR	75.33±0.01 mR	130.80±0.00 mR
	1.80%	1.02%	0.98%
Tungsten	26.08±0.01 mR	72.68±0.02 mR	127.00±0.02 mR
	5.85%	4.51%	3.86%

At a radiation dose of 2 mAs, the shielding efficiencies of each material showed similar patterns across 60 kVp and 80 kVp as those observed at 40 kVp. Bismuth showed the highest shielding efficiency, followed by barium, tungsten, and iron in that order.

At a radiation exposure dose of 16 mAs and a tube voltage of 40 kVp, the shielding efficiency was highest for bismuth at 8.74%, followed by barium at 8.70%, tungsten at 5.85%, and iron at 1.80%. The pure hydrogel showed a shielding efficiency of 0.54% (Table 2).

As shown in Table 2, when the radiation exposure dose was 16 mAs, it was observed that the shielding efficiency decreased as the tube voltage, which indicates the energy of electromagnetic radiation, increased even when using the same shielding material.

At a radiation dose of 16 mAs, the shielding efficiencies of each material showed similar results at 60 kVp and 80 kVp, as observed at 40 kVp. Bismuth showed the highest efficiency, followed by barium, tungsten, and iron in that order.

From the above results, it can be seen that lower exposure doses and lower tube voltages tended to result in higher shielding efficiency. Bismuth consistently demonstrated the highest shielding efficiency, followed by barium, tungsten, and iron.

These findings suggest that when fabricating eco-friendly hydrogel-based shielding materials for preventing medical X-ray exposure, bismuth is expected to provide the best efficiency. Further research into the fabrication of shielding materials incorporating barium and tungsten is also deemed necessary.

In addition, this study has the limitation of simply evaluating the shielding performance to evaluate the possibility of using the hydrogel film to produce an eco-friendly shield. In the future, in-depth research will need to be conducted based on this study.

These research results may serve as useful reference data for the fabrication of eco-friendly shielding materials that are non-toxic to the human body, lightweight, and non-polluting, and for radiation safety management in medical settings. Ongoing research and development of hydrogel-based shielding materials are anticipated in the future.

4. Conclusions

Lead-containing medical electromagnetic radiation shielding materials are heavy, can cause health issues in the human body, and contribute to environmental pollution. In this study, a hydrogel-based radiation shielding material was fabricated, and its shielding performance was evaluated.

To fabricate the shielding material, bismuth, barium, iron, and tungsten were adsorbed onto dried hydrogel films by immersing them in 0.5 mol metal solutions for 30 minutes, producing shielding materials with a thickness of 0.6 mm. The resulting compositions were: bismuth 10%, barium 12.65%, iron 3.79%, and tungsten 34.04%.

At a radiation dose of 2 mAs and 40 kVp, the shielding efficiency was highest for bismuth at 10.88%, followed by barium at 7.94%, tungsten at 7.35%, and iron at 1.47%. The pure hydrogel showed a shielding efficiency of 1.47%.

At a radiation dose of 16 mAs and 40 kVp, the shielding efficiency was again highest for bismuth at 8.74%, followed by barium at 8.70%, tungsten at 5.85%, and iron at 1.80%. The pure hydrogel showed a shielding efficiency of 0.54%.

Based on these results, it is considered that hydrogel-based radiation shielding materials can be effectively used to shield medical X-rays. Continued research into the fabrication of shielding materials using bismuth, barium, and tungsten is expected in the future.

Acknowledgment

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