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# Evaluation of the Usefulness of Tungsten Nanoparticles as an Alternative to Lead Shielding Materials in Electron Beam Therapy

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**ABSTRACT**

The purpose of this paper is to evaluate whether tungsten nanoparticles have a shielding effect on scattered light generated at high doses as an alternative material to lead used to shield scattered light in electron beam therapy. A plate was manufactured to set the position of the dosimeter and the size of the radiation field to be constant. The glass dosimeter was placed at 12 points, which were 1, 2, and 4 cm apart from the center of the field of 10 × 10 $cm^2$ in the cross direction. A total of 12 types of tungsten nanoparticle shields were developed with a thickness of 0.75 mm to 4.00 mm and a size of 10 × 10 $cm^2$ using 0.4, 0.75, and 1 mm materials. Using a linear accelerator, measurements were made four times at 6 MeV and four times at 12 MeV, and the dose intensity was investigated at 100 MU. The 4 mm shielding plate showed the highest shielding effect at 1 cm from the irradiation field. The 1 mm shielding plate at 2 cm from the irradiation field had the lowest shielding effect. As the thickness of the tungsten shielding plate increased, the electron beam's shielding effect increased sharply. It was confirmed that tungsten nanoparticles can reduce the amount of scattered light generated by electron beam therapy. Therefore, this study will provide basic data when follow-up studies are conducted on the shielding ability of tungsten nanoparticles.

Keywords: electron beam therapy, scattered radiation, lead, tungsten nanoparticles, glass dosimeter

## I. INTRODUCTION

The mortality rate of malignant neoplasms in 2019 was 158.2 per 100,000 people, a 12.6% increase compared to that in the 2009, and malignant neoplasm is the number one cause of death[1]. Treatments for malignant neoplasms include surgery, chemotherapy, and radiation therapy[2]. Radiation therapy is non-invasive and can treat tumors located in areas that are difficult to treat with surgery. Radiations mainly used in radiation therapy include photon, electron, proton, and heavy particle beams[3]. In particular, high energy electron beams are widely used to treat superficial tumors of less than 5 cm, as they rapidly decrease across the depth after delivering a dose to the range[4]. However, scattering(lateral & back scattering) exists, sharply changing the dose distribution according to the composition of the tissue[5]. In addition, the scattered rays generated by scattering have a relatively low energy, so they do not penetrate the human body and are absorbed into the body, which may cause radiation damage[6,7]. Therefore, a shielding material that can protect normal tissues by reducing scattered rays generated by electron therapy is needed[8].

Lead, which is most widely used as a shielding

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material, has a high atomic number and electron density, leading to excellent shielding rate[9]. However, it is physically thick and heavy, so wearing it for a long time increases the physical fatigue of the patient and has a fatal problem of lead poisoning; therefore, various alternative materials have been investigated[10,11].

Recently, tungsten which is thinner and lighter than lead, is being used as a means of protecting surface organs in radiology such as CT scans[12]. A heavy metal with atomic number of 74, tungsten is known to have excellent physical properties due to its high specific gravity and being harmless to the human body. Tungsten shows an excellent linear attenuation coefficient compared to lead and a very similar mass attenuation coefficient with lead. To block high energy X-rays, a high-density material must be used. Tungsten has a very high density of 19.95 g/cm$^3$, which is higher than that of lead, 11.34 g/cm$^3$. Moreover, the lattice constant of tungsten is significantly lower than that of lead[13]. In this respect, tungsten has sufficient conditions to shield scattering rays. Therefore, this study selected tungsten nanoparticles, which have the same shielding effect as lead and overcome the disadvantages of lead as an alternative material in electron beam therapy. We compared the shielding effect of scattered rays according to thickness and investigated whether tungsten nanoparticles can replace lead.

## II. MATERIALS AND METHODS

### 1. Equipment and Materials

A linear accelerator (Elekta Synergy, Crawley, the UK), a glass dosimeter (GD-302M, Shizuoka, Japan,), and a dose reader (FGD-1000, Shizouka, Japan) were used. The glass dosimeter had an excellent reproducibility of less than 5% (100 μGy, 137 Cs) and less than 2% (1 mGy, 137 Cs). Therefore, it was possible to obtain accurate values without repeated experiments. The tungsten nanoparticles with a size of 215(L) × 300(W) cm$^2$ used as a shielding material were heat-resistant and had a thickness of 0.4, 0.75, and 1.0 mm[Fig.1].

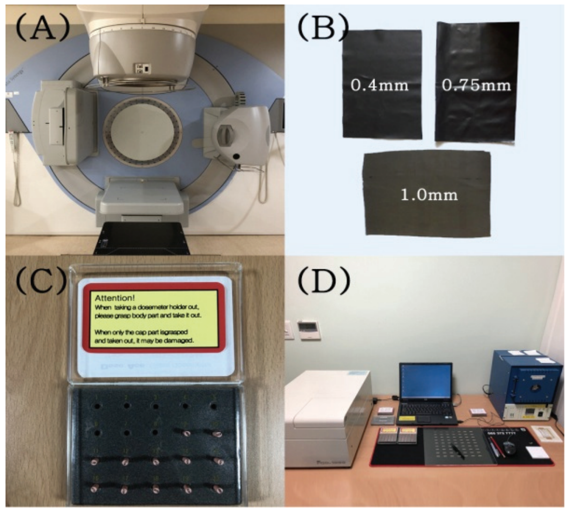


Fig. 1. (A) Linear accelerator to test (B) tungsten nanoparticle's shielding ability (C) glass dosimeter and (D) dose reader for dose measurement.

### 2. Experimental Method

A plate was manufactured to set the position of the dosimeter and the size of the radiation field to be constant before the experiment. First, the irradiation field was marked by drawing a square with a size of 10×10 cm$^2$ where the dose would be incident on the center of the paper with the standard of 21(W) × 29.7(L) cm$^2$. Then, a total of 12 points were indicated at 1, 2, and 4 cm away from the irradiation field in the cross direction, respectively, to mark the plate where the glass dosimeter would be located. Since the plate would be damaged by the high heat of the linear accelerator, it was printed and coated.

After adjusting the irradiation field so that the isocenter of the square in the center of the plate and that of the source match, the head of the equipment was adjusted so that the Source-Skin Distance (SSD) was set to 100 cm. The three sides of the 10 × 10 ㎠ square were aligned with the sides of the shield so that tungsten nanoparticles could fully cover the glass dosimeter. The glass dosimeter on the other side was not covered with tungsten nanoparticles, and the dose was irradiated to check a value of without shielding[Fig.2].

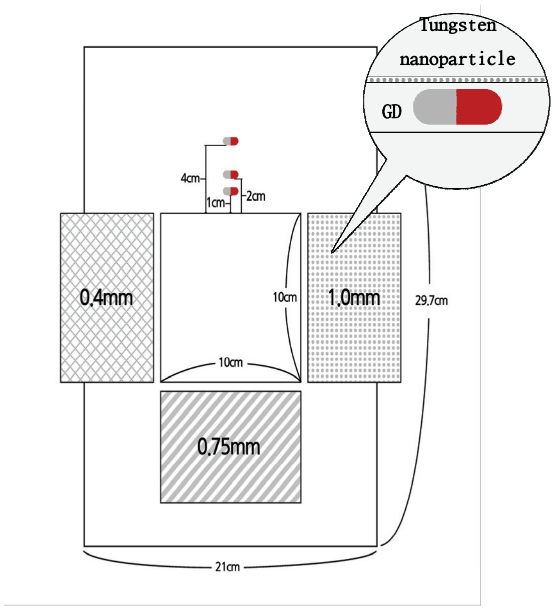


Fig. 2. glass dosimeters were installed 1, 2, 4 cm away from the center of each side of the 10×10 cm² square. And Glass dosimeters located on the other three sides, except one side, were shielded with three thicknesses of tungsten nanoparticles.

The following thicknesses of tungsten nanoparticles, which covered glass dosimeter, were applied: 0.8, 2, 3.2, and 4 mm with a 0.4 mm material; 0.75, 2.25, 3, and 3.75 mm with a 0.75 mm material; and 1, 2, 3, 4 mm with a 1 mm material. The two types of dose were used in the experiment, 6 and 12 MeV, and the intensity of the dose was irradiated with 100 MU (Monitor Unit). After irradiation, the glass dosimeter was separated from the plate, stored for 24 hours to generate fluorescence crystals, and then placed on a reading board of the dose reader to obtain the results. A total of eight incidences was applied by repeating four times at 6 MeV and four times at 12 MeV under the same condition. As a result, a total of 26 experimental results were obtained with two results without shielding and with 24 results with shielding.

## III. RESULT

### 1. 6 MeV Electron beam energy

The values of 1 cm, 2 cm, and 4 cm without shielding were 36,810 μGy, 18,350 μGy, and 12,020 μGy, respectively. When the 0.4 mm shield was measured at 1 cm from the irradiation field, the highest dose, 35,327 μGy, was obtained at a thickness of 0.8 mm, and at a thickness of 4 mm, the lowest value, 32,740 μGy, was shown.

When measured at 2 cm, the maximum value, 15,355 μGy, was displayed at 0.8 mm, and the minimum value, 12,030 μGy was observed at 4 mm. When measured at 4 cm, the maximum value was 6,725 μGy at 0.8 mm, and the minimum value was 4,318 μGy at 4 mm. When the 0.75 mm shield was measured at 1 cm from the irradiation field, the highest dose, 35,260 μGy, was obtained at a thickness of 0.75 mm, and at a thickness of 3.75 mm, the lowest value, 25,800 μGy, was shown.

When measured at 2 cm, the maximum value, 18,260 μGy, was displayed at 0.75 mm, and the minimum value, 10,280 μGy was observed at 3.75 mm. When measured at 4 cm, the maximum value was 10,360 μGy at 0.75 mm, and the minimum value was 4,689 μGy at 3.75 mm.

When the 1 mm shield was measured at 1 cm from the irradiation field, the highest dose, 32,560 μGy, was obtained at a thickness of 1 mm, and at a thickness of 4 mm, the lowest value, 10,660 μGy, was shown.

When measured at 2 cm, the maximum value, 18,270 μGy, was displayed at 1 mm, and the minimum value, 6,355 μGy was observed at 4 mm. When measured at 4 cm, the maximum value was 8,873 μGy at 1 mm, and the minimum value was 3,392 μGy at 4 mm[Fig.3].

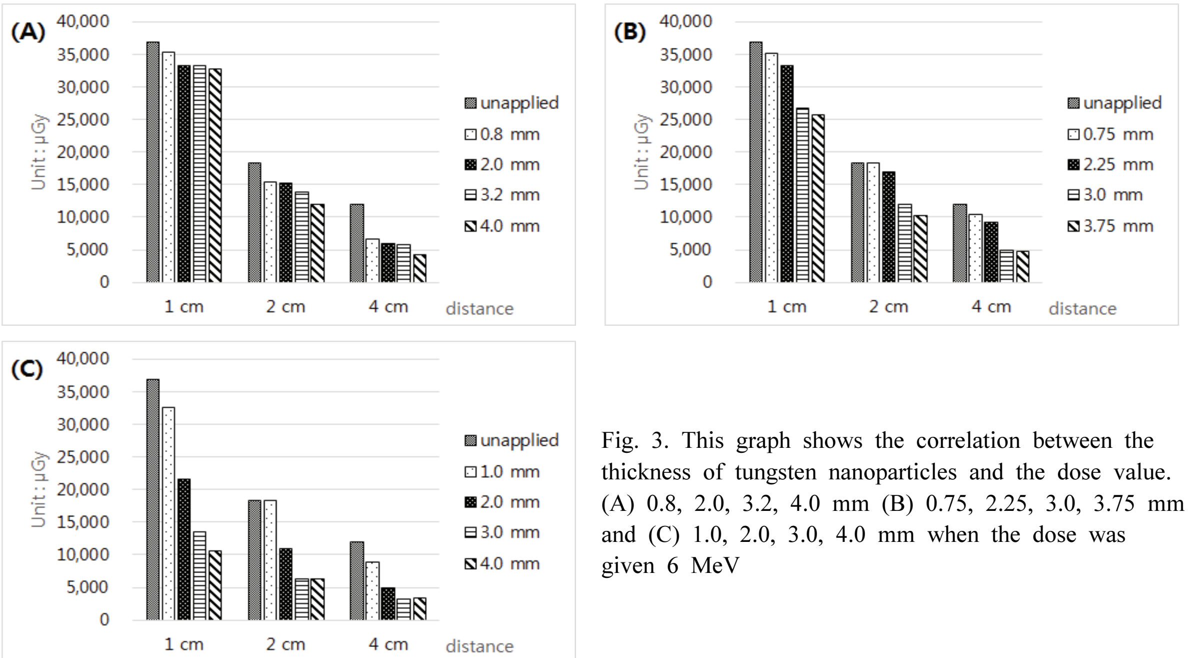


Fig. 3. This graph shows the correlation between the thickness of tungsten nanoparticles and the dose value. (A) 0.8, 2.0, 3.2, 4.0 mm (B) 0.75, 2.25, 3.0, 3.75 mm and (C) 1.0, 2.0, 3.0, 4.0 mm when the dose was given 6 MeV

**2. 12 MeV Electron beam energy**

The values of 1 cm, 2 cm, and 4 cm without shielding were 30,520 μGy, 19,380 μGy, and 15,120 μGy, respectively. When the 0.4 mm shield was measured at 1 cm from the irradiation field, the highest dose, 28,188 μGy, was obtained at a thickness of 0.8 mm, and at a thickness of 4 mm, the lowest value, 27,514 μGy, was shown. When measured at 2 cm, the maximum value, 19,539 μGy, was displayed at 0.8 mm, and the minimum value, 18,041 μGy was observed at 4 mm. When measured at 4 cm, the maximum value was 16,151 μGy at 0.8 mm, and the minimum value was 12,860 μGy at 4 mm. When the 0.75 mm shield was measured at 1 cm from the irradiation field, the highest dose, 9,760 μGy, was obtained at a thickness of 0.75 mm, and at a thickness of 3.75 mm, the lowest value, 22,503 μGy, was shown. When measured at 2 cm, the maximum value, 19,640 μGy, was displayed at 0.75 mm, and the minimum value, 16,235 μGy was observed at 3.75 mm. When measured at 4 cm, the maximum value was 15,110 μGy at 0.75 mm, and the minimum value was 11,760 μGy at 3.75 mm. When the 1 mm shield was measured at 1 cm from the irradiation field, the highest dose, 29,590 μGy, was obtained at a thickness of 1 mm, and at a thickness of 4 mm, the lowest value, 18,740 μGy, was shown. When measured at 2 cm, the maximum value, 20,470 μGy, was displayed at 1 mm, and the minimum value, 14,010 μGy was observed at 4 mm. When measured at 4 cm, the maximum value was 14,800 μGy at 1 mm, and the minimum value was 8,525 μGy at 4 mm[Fig.4].

**3. Reference Value − Measured Value**

To find out the shielded dose for each thickness at 6 MeV and 12 MeV, the above-measured value after shielding was subtracted from the unshielded value, which was the reference value. At 1, 2, and 4 cm from the 6 MeV electron beam, the 0.4 mm shield had the least shielding at 0.8 mm thickness, 1,483 μGy, 2,995 μGy, and 5,295 μGy, respectively. At 4 mm thickness, it was most fielded with 4,070 μGy, 6,320 μGy, and 7,702 μGy. At 1, 2, and 4 cm from the irradiation field, the 0.75 mm shield had the least

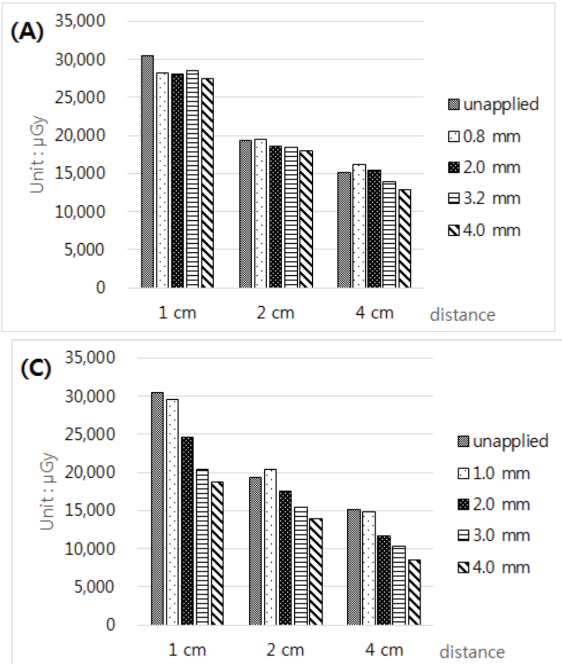


Fig. 4. This graph shows the correlation between the thickness of tungsten nanoparticles and the dose value. (A) 0.8, 2.0, 3.2, 4.0 mm (B) 0.75, 2.25, 3.0, 3.75 mm and (C) 1.0, 2.0, 3.0, 4.0 mm when the dose was given 12 MeV

shielding at 0.75 mm thickness, 1,550 μGy, 90 μGy, and 1,660 μGy, respectively. At 3.75 mm thickness, it was most fielded with 11,010 μGy, 8,070 μGy, and 7,331 μGy. At 1, 2, and 4 cm from the irradiation field, the 1 mm shield had the least shielding at 1 mm thickness, 4,250 μGy, 80 μGy, and 3,147 μGy, respectively. At 4 mm thickness, it was most fielded with 36,150 μGy, 11,995 μGy, and 8,628 μGy[Table.1]. At 1, 2, and 4 cm from the 12 MeV electron beam, the 0.4 mm shield had the least shielding at 0.8 mm thickness, 2,332 μGy, -159 μGy, and -1,031 μGy, respectively. At 4 mm thickness, it was most fielded with 3,006 μGy, 1,339 μGy, and 2,260 μGy. At 1, 2, and 4 cm from the irradiation field, the 0.75 mm shield had the least shielding at 0.75 mm thickness, 760 μGy, -260 μGy, and 10 μGy, respectively. At 3.75 mm thickness, it was most fielded with 8,017 μGy, 3,145 μGy, and 3,360 μGy. At 1, 2, and 4 cm from the irradiation field, the 1 mm shield had the least shielding at 1 mm thickness, 930 μGy, -1,090 μGy, and 320 μGy, respectively. At 4 mm thickness, it was most fielded with 11,780 μGy, 5,370 μGy, and 6,595 μGy[Table.2].

Table 1. Shielded dose for each thickness at 6 MeV

| Thickness | 1 cm | 2 cm | 4 cm |
|---|---|---|---|
| 0.8 mm | 1,483 | 2,995 | 5,295 |
| 2 mm | 3,520 | 3,099 | 5,997 |
| 3.2 mm | 35,92 | 4460 | 6156 |
| 4 mm | 4,070 | 6,320 | 7,702 |
| 0.75 mm | 1,550 | 90 | 1,660 |
| 2.25 mm | 3,609 | 1,349 | 2,827 |
| 3 mm | 10,120 | 63,00 | 7,116 |
| 3.75 mm | 11,010 | 8,070 | 7,331 |
| 1 mm | 4,250 | 80 | 3,147 |
| 2 mm | 15,250 | 7,440 | 7,053 |
| 3 mm | 23,210 | 12,043 | 8,802 |
| 4 mm | 26,150 | 11,995 | 8,628 |

(Unapplied value − Applied value) (Unit: μGy)

Table 2. Shielded dose for each thickness at 12 MeV

| Thickness | 1 cm | 2 cm | 4 cm |
|---|---|---|---|
| 0.8 mm | 2,332 | -159 | -1,031 |
| 2 mm | 2,419 | 818 | -270 |
| 3.2 mm | 1,997 | 1,000 | 1,227 |
| 4 mm | 3,006 | 1,339 | 2,260 |
| 0.75 mm | 760 | -260 | 10 |
| 2.25 mm | 4,812 | 1,630 | 1,960 |
| 3 mm | 6,797 | 1,928 | 2,780 |
| 3.75 mm | 8,017 | 3,145 | 3,360 |
| 1 mm | 930 | -1,090 | 320 |
| 2 mm | 5,870 | 1,880 | 3,460 |
| 3 mm | 10,088 | 4,000 | 4,859 |
| 4 mm | 11,780 | 5,370 | 6,595 |

(Unapplied value − Applied value) (Unit: μGy)

## IV. DISCUSSION

This study investigated the effect of shielding scattering rays when tungsten nanoparticles were used as an alternative to lead in electron beam therapy. Doses of 6 and 12 MeV were irradiated with a linear accelerator at 100 MU, and the glass dosimeters when placed at 1, 2, and 4 cm from each side of the 10 × 10 $cm^2$ irradiation field. On three sides, 0.4, 0.75, and 1.0 mm tungsten nanoparticle shields were stacked, and the other side was left as it was to obtain the value when no shield was applied.

When the doses of 6 and 12 MeV electron beams were compared depending on the presence or absence of a shield, the shielded dose was the largest when the shielding body of 1 mm material laminated at 1 cm from the irradiation field was applied with a thickness of 4 mm and unapplied. The shielded dose was the largest when the shielding body of 1 mm material at 2 cm from the irradiation field was applied and unapplied. Overall, as the thickness of tungsten nanoparticles increased, the electron beam shielding effect sharply increased.

Due to the importance of shielding scattered rays in electron beam therapy, many studies have used lead as a shielding material. When lead is used as a shielding body, the thicker the lead, the greater the shielding effect. However, a thick lead shielding body may cause inconvenience to patients, so it is ideal to use a lead plate of an appropriate thickness[14]. Furthermore, the lead mask shielding material has been reported to be not effective in electron beam therapy because the difference in dose between when the lead mask is used and when it is not used is not large[15]. In addition, lead is very dangerous because it is not excreted well when accumulated in the body even in a small amount, but accumulates in the protein in our body and shows side effects over a long period of time. Moreover, hematopoietic organ dysfunction causes anemia, renal and reproductive dysfunction, quadriplegia, blindness, and serious brain diseases such as mental disorders and memory impairment[16]. However, the tungsten nanoparticles used in this study are light and flexible, so even if they are thickly stacked, patient discomfort can be minimized. In addition, since it is heat-treated and manufactured like a sheet, the manufacturing process is simple, and it can be customized for patients. When the tungsten nanoparticles were used as a shielding material, the measured dose decreased, indicating that the tungsten nanoparticles had a shielding effect during electron beam therapy[17].

This study has a limitation in that it was not possible to experiment with various electron beam energies, as it only tested with 6 MeV and 12 MeV. However, this study shows that it is possible to fabricate a shield with a light and flexible material rather than a heavy material such as lead. Moreover, it has found that the tungsten nanoparticle can be cut according to the patient, confirming the possibility of replacing the lead mask in the future.

## V. CONCLUSION

This study exhibited that tungsten nanoparticles have a scattering ray shielding effect in electron beam therapy. In addition, tungsten nanoparticles are lighter, more flexible, and not harmful to the human body than lead, confirming the possibility of tungsten as an alternative to lead. If shielding by thickness according to various energy sources is analyzed, it will be possible to find a point where the maximum shielding effect can be observed with the minimum thickness. Therefore, this study will provide basic data when follow-up studies are conducted to control the thickness of the tungsten nanoparticle shield.

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# 전자선 치료시 납 차폐체 대체물질로서의 텅스텐 나노입자의 유용성 평가

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## 요 약

본 연구의 목적은 전자빔 치료에서 산란선을 차폐하는 데 사용되는 납의 단점을 극복하기 위한 대체 재료로 텅스텐 나노입자를 선택하여 고선량에서 발생하는 산란선에 차폐 효과가 있는지 여부를 평가하는 것이다. 선량계의 위치와 조사야의 크기를 일정하게 설정하기 위해 판을 자체 제작하였다. 유리 선량계는 10 × 10 $cm^2$ 크기의 조사야의 중앙에서 십자로 1, 2, 4 cm 떨어진 지점에 위치하여 12곳의 지점에 위치시켰다. 10 × 10 $cm^2$ 크기의 텅스텐 나노입자 차폐체를 0.4, 0.75, 1 mm의 소재로 두께 0.75 mm에서 최대 두께 4.0 mm의 총 12가지 유형의 차폐가 적용되었다. 선형가속기를 사용해서 6 MeV에서 4회, 12 MeV에서 4회 측정하였고 선량의 세기는 100 MU로 조사하였다. 실험 결과 조사야로부터 1 cm 거리에서 4 mm 차폐판이 가장 높은 차폐 효과를 보였다. 조사야로부터 2 cm 거리에 적용된 1 mm 차폐판이 차폐 효과가 가장 낮았다. 텅스텐 차폐판의 두께가 두꺼워짐에 따라 전자선 차폐 효과는 급격히 증가하였다. 결론적으로 텅스텐 나노입자는 전자빔 치료에서 납의 대체 재료로 사용이 가능함을 확인하였다.

중심단어: 전자선 치료, 산란선, 납, 텅스텐 나노입자, 유리선량계

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