DESIGN AND OPTIMIZATION OF THE TARGET IN ELECTRON LINEAR ACCELERATOR

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Abstract

The target in electron linear accelerator plays an important role in the production of photon. Different materials and thickness of target have influence on dose rate. For 6MeV electron beam, this study gives the thickness of target for several materials in which the dose rate can be higher and drain electron can be lower. Then a X-ray target had been designed for 6MeV electron linac by FLUKA simulations. It can deliver 1000 cGy/min at 1 meter in front of the target if providing 6 MeV electron beam with 100uA current, which can achieve high-dose rate radiotherapy.

INTRODUCTION

As known to all, with the efforts of many scientists, the X-ray has been widely used in medical therapy, agriculture and industry since 1895. Especially, it plays an important role in medical imaging and tumor cutting operation. Many simulations have been done to calculate the dose rate in medical accelerators [1].

The main three kinds of source to generate X-ray are laser plasma, synchrotron radiation and X-ray tube. Although laser plasma has a huge radiation intensity and synchrotron radiation can achieve a continuous wide frequency spectrum, X-ray tube is the most common generator because of its small size and cheap prize.

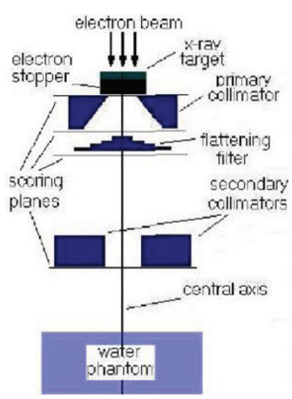

Figure 1: Schematic representation of the simulated Clinac 2300EX treatment head [2].

Figure 1 shows a typical work principle of accelerator treatment head. Incident electrons shoot a target to generate X-ray through the bremsstrahlung effect, then the X-ray passes through the primary and second collimator to become a cone beam. Flattening filter is used as a radiation filter to affect the energy spectrum. For a certain kind of energy of incident electrons, a target with different thickness and materials has different conversion efficiencies.

To find the best thickness and material of target with biggest conversion efficiency, a simulation for scanning parameters is needed. The Monte Carlo Method is the most popular tool in simulation to calculate the efficiency [3]. For 6 MeV electron beam, the conversion efficiency can be estimated by dose rate, which is an important parameter in radiation therapy. According to the report of ICRU, the accuracy of dose generated by irradiating tumor is within 5% [4], so the dose rate should be known accurately. This study shows that how the dose rate changes with materials and thickness.

MODEL

Considering that the simulation is calculated with FLUKA program, a simplification for the actual model is necessary.

Single Material Target Model

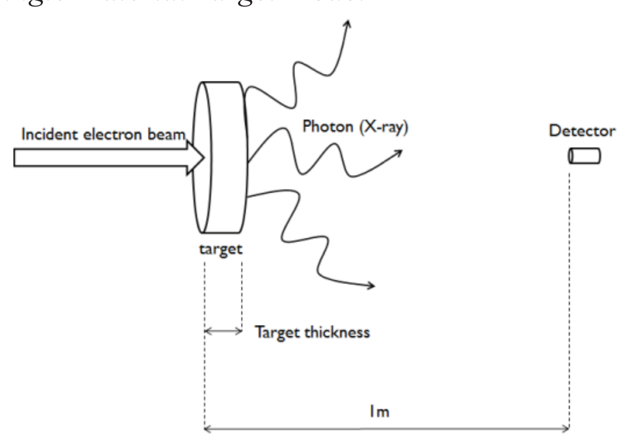

Figure 2: Single material target model.

Figure 2 shows a single material target model established in FLUKA program. A circle plane surface electron source with a radius 2mm is used as the incident electron beam to hit on the centre of target. Then the photons generated by bremsstrahlung escape mainly from the other side of the target. A water phantom dose detector is placed at the distance of 1m from the source to give the dose rate result. The energy spectrum of electron source is generated by a 6 MeV accelerating tube which is designed by Qingxiu Jin in department of engineering physics, Tsinghua [5]. The target materials are respectively carbon, aluminium, copper, silver, tungsten, gold and lead. Each material is pure simple substance.

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Composite Material Target

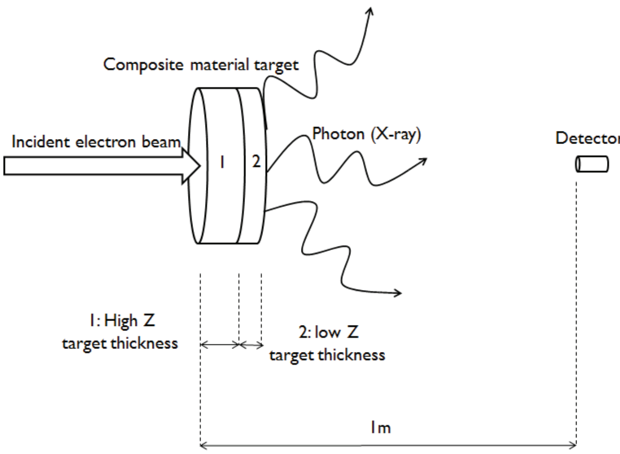

Figure 3: Composite material target model.

Figure 3 shows a composite material target model established in FLUKA program. The target is designed with two layers, the former is made of high atomic number material and another is low Z material, which means the incident electron beam irradiates on the high Z target firstly. Other parameters have the same meaning as they do in single material target.

RESULTS

When the model is established, simulation can start. The number of particles in simulation is set to be 1000000 so that the relative error is lower than 5%. For each model, the detector records dose rate and leakage rate of electron energy. The electron energy leakage rate is the percentage of electron energy escaping from target.

Results of Single Material Target Simulation

For each material, the simulation scans the thickness of target to calculate the dose rate and the electron energy leakage rate.

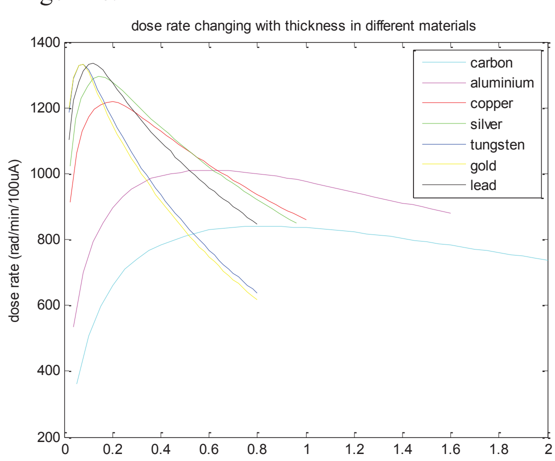

Figure 4: dose rate changing with thickness in different materials.

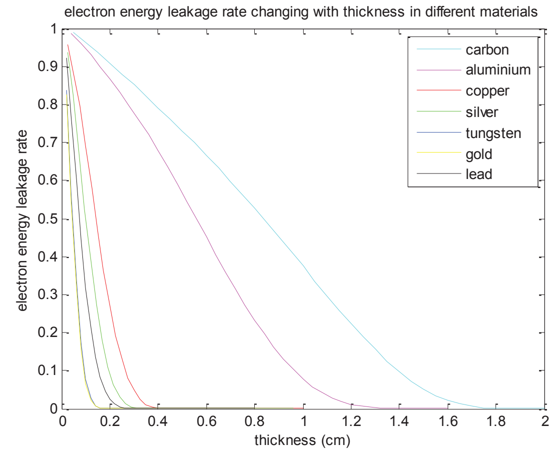

Figure 5: electron energy leakage rate changing with thickness in different materials.

Figure 4 and Figure 5 show the simulation result of single material target. It can be founded that there is a peak dose rate when the thickness is changing. Considering the condition that electron energy leakage rate should be lower than 0.05%, there is a thickness that can generate max dose rate. Combining the figure 3 and figure 4 it is easy to find the best thickness and dose rate.

Table 1: best thickness for single material target

Material	**Best thickness** (cm)	**Dose rate** (rad/min /100uA)	**Leakage rate** (%)
Carbon	1.8449	745.52	0.05
Aluminium	1.3780	914.78	0.05
Copper	0.4311	1111.90	0.05
Silver	0.3596	1167.10	0.05
Tungsten	0.2682	1078.10	0.05
Gold	0.3166	1003.10	0.05
lead	0.4828	1033.80	0.05

At the best thickness, the incident electron hitting on the target not only can generate a high dose rate but also can have a lower leakage rate.

Results of Composite Material Target Simulation

Composite material target has two parameters to be scanned. For each layer thickness of the material, FLUKA program can give the dose rate and electron energy leakage rate.

In this work, combination of W and Al, W and Cu, W and Ag, W and Au (two similar materials) are studied. The reason why these materials is chose to be studied mainly is that they are common and can be got easily. Obviously, these materials are usually used in single material target.

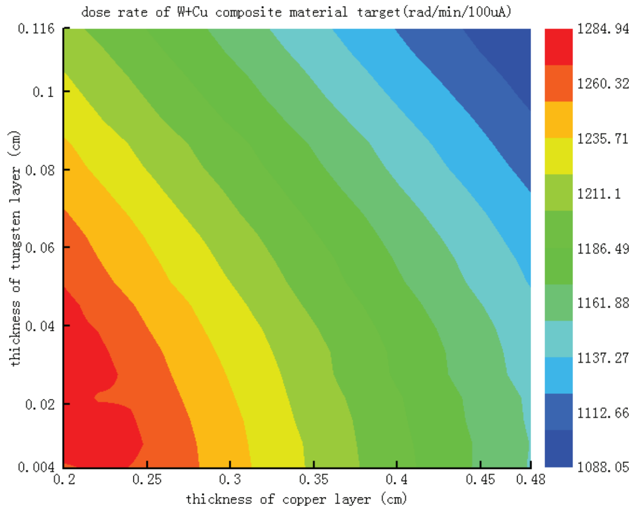

Figure 6: dose rate of W+Cu composite material target.

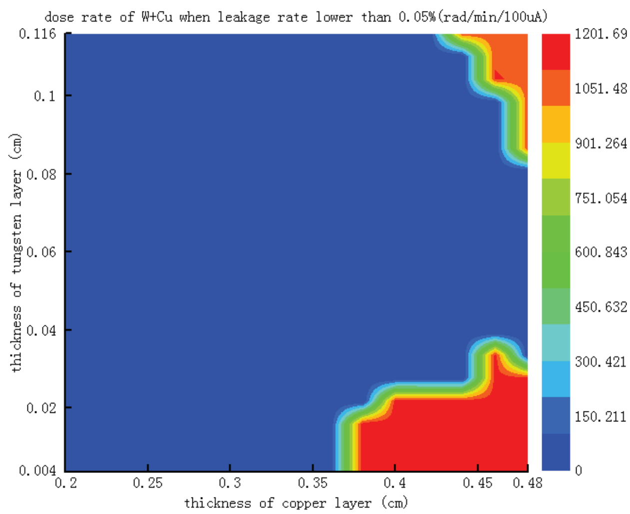

Figure 7: dose rate of W+Cu composite material target when electron energy leakage rate is lower than 0.05%.

Figure 6 shows the dose rate of W and Cu composite target with different layer thickness. However, if the layer thickness is too low, the electron energy leakage rate will be high. To meet the requirement that leakage rate is lower than 0.05%, the layer thickness should be higher than some value. Figure 7 indicates the dose rate of W +Cu if leakage is lower than 0.05%, otherwise the dose rate will be shown as 0 manually. It will be easy to find the best thickness at which the dose rate has a high value of this composite material target.

Using the same method, it can be calculated that the best thickness and relevant dose rate of all the composite material targets mentioned above.

Table 2: best thickness for composite material target

Material	**Best thickness of 1st layer** (cm)	**Best thickness of 2nd layer** (cm)	**Dose rate** (rad/min/100uA)	**Leakage rate** (%)
W+Al	0.060	1.080	1196.9	0.049
W+Cu	0.084	0.172	1086.3	0.049
W+Ag	0.110	0.190	1191.3	0.049
W+Au	0.040	0.380	1201.7	0.048

Table 2 indicates that the composited material target can generated a higher dose rate than single target, so it may become a new target with higher dose rate and lower leakage rate and it may be popular in radiation therapy.

CONCLUSION

Optimization of Single Material Target

In this work, a simulation model is established and several common materials have been optimized to find the best thickness at which the dose rate can be highest and the leakage rate of electron can stay in a low level.

Design of Composite Material Target

Four kinds of composite material target have been calculated and the result indicates that it can deliver 1000 rad/min/100uA at 1 meter in front of the target.

REFERENCES

[1] Yinghua Shi et al., The Monte Carlo Simulation of 6 MV medical electron linear accelerator [J]. Chinese Journal of Radiological Medicine and Protection. 2011, 31(2):220-224.

[2] F. A. A. Ajaj and N. M. H. Ghassala.An MCNP-based model of a medical linear acceleratorx-ray photon beam[J]. Australasian Physical & Engineering Sciences in Medicine .2003，26(3):140~144.

[3] Shuyan Xu. The application of Monte Carlo method in experimental nuclear physics [M]. Beijing:

[4] Meilian liu et al., Comparison of Monte Carlo n particle transportation method between calculation and measurement in ^{60}Co treatment head[J]. Chinese Journal of Radiological Medicine and Protection. 2011,31(2):236~238.

[5] Qingxiu Jin. The beam work characteristics of 6MeV standing wave accelerating tube in IMRT treatment[J]. the 8th Chinese medical accelerator proceedings of academic exchange, 2009.

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