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STUDY ON THE INFLUENCE OF THE RANGE SHIFTER MATERIAL IN A SCANNING NOZZLE FOR PROTON THERAPY BASED ON MONTE CARLO METHOD *

Y.C. Yu, P. Tan†, Y.J. Lin, Y.Y. Hu, X.D. Tu, H.D. Guo, L.G. Zhang, X.Y. Li
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,
School of Electrical and Electronic Engineering, Huazhong University of Science and Technology,
Wuhan 430074, China

Abstract

Range shifter plays a key role in decreasing the energy of the proton beam to realize shallow tumours treatment with the scanning nozzle in Huazhong University of Science and Technology Proton Therapy Facility (HUST-PTF). To control the transverse scattering and decrease the damage to healthy tissue caused by secondary particle, influence of the range shifter material was studied. In this paper, the Monte Carlo software Geant4 and FLUKA are applied to analyse the transport process of proton beam in the range shifters made of six different materials: PMMA, Lexan, Lucite, Polyethylene, Polystyrene, and Wax. The beam spot sizes at the iso-center with or without range shifter was calculated for the HUST-PTF scanning nozzle. The relationship between the thickness of the range shifters of the six materials and the proton energy was obtained. The secondary neutron yield at the end of the nozzle was also analysed.

INTRODUCTION

Proton therapy is now developing rapidly around the world. The Huazhong University of Science and Technology Proton Therapy Facility (HUST-PTF) adopt an active scanning nozzle to provide 70-230 MeV proton beam for treatment. The range for the proton beam in water is determined by the initial energy [1], as shown in Fig. 1. However, for the shallow tumours, effective treatment cannot be obtained due to the limitation of minimum energy of 70 MeV. So the range shifter is applied to decrease the energy of the proton beam, enabling shallow tumours to be treated.

The scanning nozzle is mainly composed of a pixel ionization chamber, a helium pipe, a dual integral plane ionization chamber, two scanning magnets and a range shifter as well as a series of mechanical support structures, as shown in Fig. 2. Due to the Coulomb's scattering in the air and the collision with the materials, the energy loss and transverse scattering of proton beam in the nozzle will be brought.

After applying the range shifter, due to its blocking effect on the proton beam, it will increase the transverse scattering of the beam, also, the lateral penumbra will be greater and the requirement for treatment cannot be meet. At the same time, secondary particles, including neutrons will be brought during the elastic and inelastic collision of with the target nucleus. Neutrons have a strong ability for penetration, and the biological effect of inducing tumours is high, and is much more serious than the same dose of X-ray and gamma rays [2]. In this paper, the beam parameters, the structure and materials of the components of the nozzle system are designed and calculated according to the actual parameters of HUST-PTF, and Fig. 3 shows the nozzle model in Geant4. Six materials commonly used as range shifters were used for analysis.

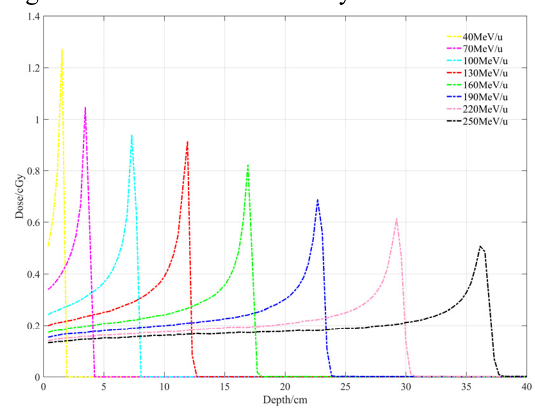

Figure 1: The proton beam dose distribution in water.

INFLUENCE ON BEAM SPOT SIZE

The spot size at the iso-center plane with 100/200MeV proton beam passing through the range shifter is analysed in Geant4, when the range shifters are made of six different materials: PMMA, Lexan, Lucite, Polyethylene, Polystyrene and Wax respectively. And the distance between the range shifter and the iso-center plane is set as 5, 10, 20, 30, 40, 50cm respectively. The results of the spot size at the iso-center after the proton beam passed through the nozzle are presented in Fig. 4. The energy loss in each material range shifter maintains the same.

The spot size after the proton beam passed through the range shifter made of Polyethylene and Wax are only 1.7% larger than the situation without range shifter when they are placed 5cm away from the iso-center, which is significantly small. While the air gap increased to 50cm, the spot size with PMMA, Lucite and Lexan are larger than 130% the situation without range shifter, followed by the range shifter made of Polystyrene of 128% larger than the below situation. And when using the range shifter made of Polyethylene and Wax, spot size at the iso-center plane are about 108% larger than the below circumstance. The

* Work supported by National Key R&D Program of China (No.2016YFC0105308)
† tanping@mail.hust.edu.cn

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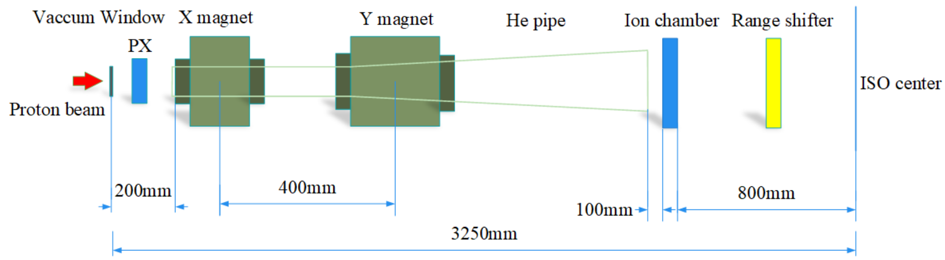


Figure 2: Schematic layout of the nozzle in HUST-PTF (PX stands for the pixel ionization chamber, and the ionization chamber is an integrated type, which can acquire position signal and dose signal simultaneously).

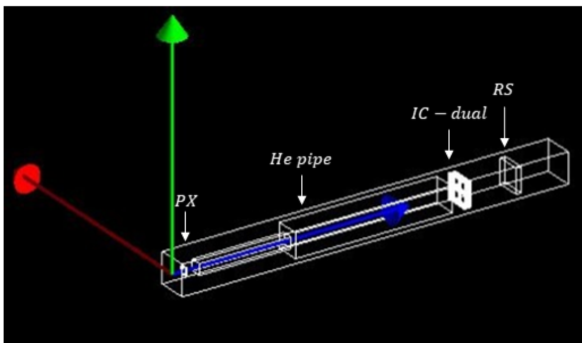
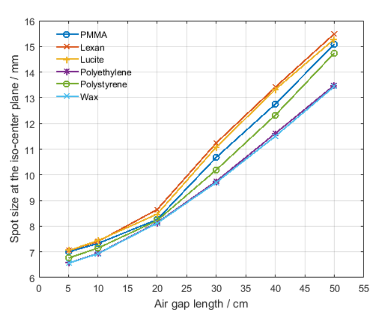
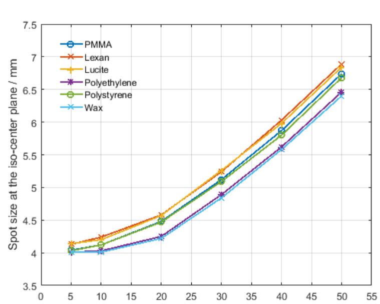


Figure 3: Model of the nozzle system in Geant4.

trend of the beam spot size at the iso-center at 200 MeV is consistent with that at 100 MeV. As the length of the air segment increases, the spot size will increase significantly. In order to minimize the beam spot size at the iso-center after the range shifter is added, Polyethylene and Wax are more recommended to be selected as the material for range shifter, and the distance between the range shifter and the iso-center plane should be decreased.



(a)



(b)

Figure 4: The spot size at the iso-center after the proton beam of 100MeV(a)/200MeV(b) passed through the nozzle.

RELATIONSHIP BETWEEN PROTON ENERGY AND THICKNESS OF RANGE SHIFTER

The energy loss in the nozzle occurs primarily in the range shifter, and there are two methods to obtain an energy modulated proton beam: changing the range shifter thickness or changing the initial proton beam energy.

The thickness of the range shifter required to reduce the 100 MeV single-energy proton to the specified average energy (40MeV) has been calculated, as shown in Fig. 5, and the simulation is calculated at intervals of 1 mm thickness. In this mode of energy reduction, to obtain the same energy, the PMMA range shifter requires the largest thickness, followed by Lucite, Lexan, Polystyrene, Polyethylene and Wax. This is positively related to the density of the material, the greater the density, the smaller the thickness of the desired range shifter.

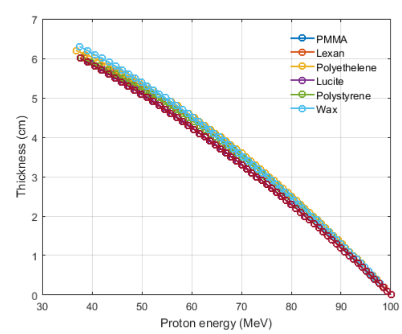


Figure 5: Relationship between thickness of different material range shifters and proton energy.

Based on the method of changing the initial energy of the beam, the proton energy is decreases to 5~75MeV when the thickness of the range shifter is 3.5cm and 6.5cm respectively. The corresponding initial energy has been calculated at intervals of 2MeV, as shown in Fig. 6. To decrease the 100 MeV single-energy proton to the specified average energy, PMMA range shifter requires the largest initial energy, followed by Lucite, Lexan, Polystyrene, Polyethylene, and Wax. Consistent with the conclusion when changing the thickness. The comparison shows that the use of polyethylene and wax can reduce the required range shifter thickness and save space in the nozzle.

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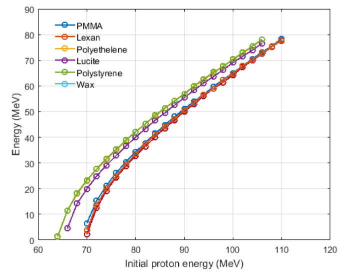
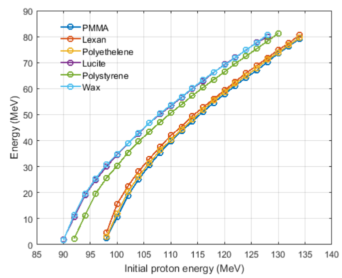


(a)



(b)

Figure 6: Relationship between the initial energy and the modulated energy(3.5cm(a)/6.5cm(b)).

INFLUENCE ON NEUTRON FLUX

During the transmission in the nozzle, especially in the range shifter, elastic and non-elastic collision with the nuclei of different materials will happen, producing a large number of secondary particles that will adversely affect the patients, as shown in Fig. 7. And the spatial distribution of the energy for the secondary neutrons in the nozzle has been calculated, as shown in Fig. 8. Figure 9 presents the secondary neutron yield interacting with six different range shifters which reduced the 100 MeV proton to 40 MeV. The results of total neutron yield for a single proton are shown in Table 1.

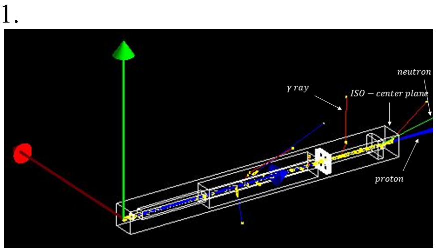


Figure 7: The simulation results of 100MeV proton beam passing through the nozzle by Geant4.

According to ICRP60, as the energy increases, the neutron radiation weight factor first increases and then decreases, and the parameter is greater than 10 when the neutron energy is between 0.1 and 10 MeV. It shows the energy range for secondary neutron is very wide, up to 90 MeV, and is mainly concentrated in the lower energy section. As energy increases, neutron yields gradually decrease. Comparing the six materials, the energy spectrums of the secondary neutrons are very close. The highest neutron yield is Polystyrene, followed by Lucite, Lexan, PMMA, Polyethylene, and Wax. The probability of generating secondary neutrons is consistent with the cross-sectional size of the proton-nuclear interaction. Since the range shifter is placed close to the patient, the material with smaller neutron yield should be considered.

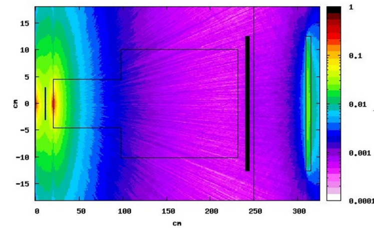


Figure 8: The spatial distribution of the energy for the secondary neutrons in the nozzle.

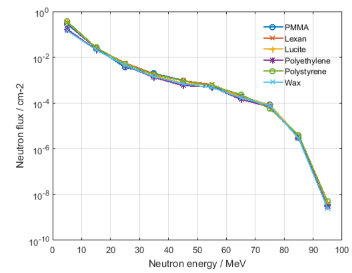


Figure 9: Neutron yield corresponding to different material range shifters.

Table 1: The Secondary Neutron Yield Interacting with Six Different Material Range Shifters

Material	Neutron flux($/cm^{-2}$)
PMMA	0.316
Lexan	0.374
Lucite	0.390
Polyethylene	0.197
Polystyrene	0.405
Wax	0.174

CONCLUSION

Six different materials for range shifter were analysed in terms of the influence on beam spot size, the relationship between the proton energy and the thickness, and the influence on secondary neutron yield. These problems were analysed using Monte Carlo method and were carried out in the scanning nozzle in HUST-PTF. The result shows that Polyethylene and Wax are preferred to as the material for range shifter when concerning about the beam spot size at the iso-center plane. Also, space can be saved by using proper material. Neutrons are mainly generated in the low energy zones, and the effects on secondary neutron yields are similar, and enough attention should be paid for the radiation protection.

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