

Design of a Rotating Range Modulator for 45MeV Proton Beam

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1. Introduction

We have interests in producing new various mutants and developing new profitable flowers and vegetables by using energetic proton beam. In general, Fast proton slows down as it passes through a material, and finally stops after it delivers the remaining kinetic energy to the material when the proton extremely slows down. In the process, high linear energy transfer (LET) happens in a local region near the proton's stop.

However, the local high energy transfer is not effective to induce a mutation in very small seeds or much larger biological targets. We designed a rotating range modulator to offer uniform depth-dose distribution as well as to transfer high LET over the whole volume of a target corresponding to the range of the proton. The designed range modulator can produce 16.8mm spread-out Bragg peak (SOBP), deliver high LET of 9.8keV/um in water, and accept large beam of 170mm.

2. Methods and Results

If 45MeV proton is incident on pure water, Bragg peak is formed about 18.1mm in depth of water. As the incident proton energy decreases, Bragg peaks are formed at more shallow depths. Therefore, if the incident energy is varied periodically, high LET near Bragg peak is distributed to broader region of target in depth. The range of target affected by proton is determined by the range of energy modulation, which can be achieved by varying thickness of a range modulator that the proton passes through. If we decrease the proton beam energy to zero, high LET is transferred from the penetration depth of unmodulated beam to the surface of target as shown in Figure 1. Due to this property, proton beam irradiation for mutation does not depend on the biological target size. In addition,

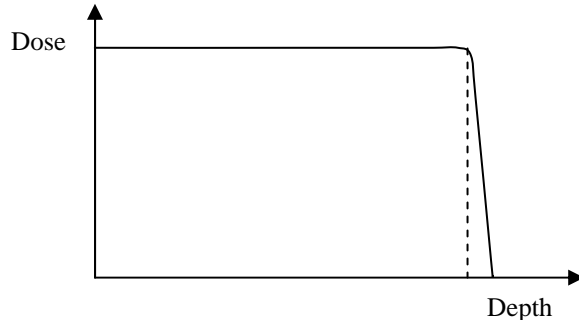


Figure 1. Uniform depth-dose distribution over the full range of proton beam.

depth-dose distribution is achieved by adjusting the opening angle of specific thickness in range modulator. The relative opening angle corresponds to the ratio of traversing protons.

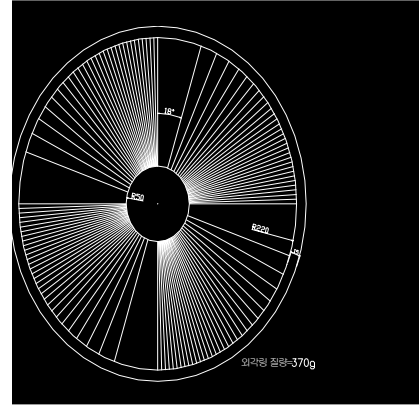


Figure 2. Designed rotating range modulator with different thicknesses and opening angles for 45 MeV proton beam; it is made of polymethylmetacrylate (PMMA) and its maximum thickness is 14.5mm which corresponds to the range of proton beam.

We used SRIM code to design the rotating range modulator shown in Figure 2.[1,2] With the aid of SRIM, we can calculate the stopping powers and ranges for various proton energies, and simulate the effect of range modulator. To obtain the uniform depth-dose distribution, a series of beam weight should be determined from which the relative opening angles are given.[3,4] Figure 3 shows the determined beam weights and Figure 4 shows the obtained SOBP for 45MeV proton beam. The fluctuation of depth-dose distribution is less than 1%.

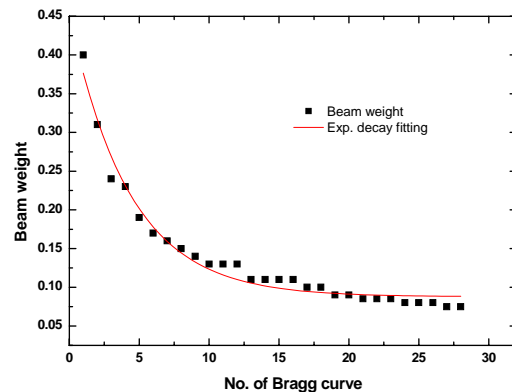


Figure 3. Beam weights and their fitting; an exponential decay function is adopted to fit the beam weights.

[4] A. M. Koehler, R. J. Schneider, and J. M. Sisterson, Range Modulators for Protons and Heavy Ions, Nuclear Instruments and Methods, Vol.131, p.437, 1975.

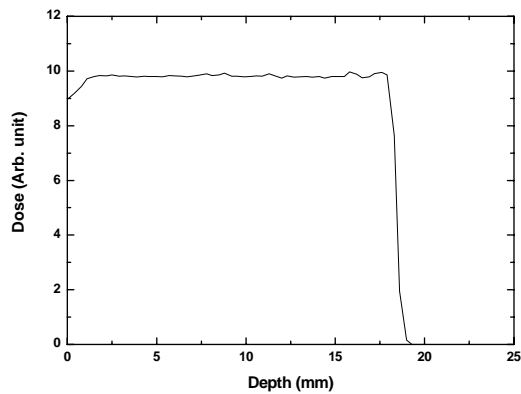


Figure 4. Obtained SOBP for 45MeV proton beam by the determined beam weights; the width of SOBP is 16.8mm, its non-uniformity is about $\pm 0.2\%$ on the flat top, and LET of unmodulated beam is 9.8keV/um.

If we apply the same beam weights to lower energy of proton, absorbed dose fluctuates and then the uniformity is degraded. But the average dose still maintained. This is caused by the narrower Bragg curve as the proton energy decreases.

Finally, the effects of energy spread and beam divergence due to scattering in the range modulator and target were considered qualitatively. The energy spread will cause the spread of Bragg curve, while the divergence of beam will decrease the fluence in the deep region of target. We expect that the effects of energy spread due to scattering in the range modulator and target will be compensated each other. Therefore, the depth-dose distribution will be affected by fluence reduction.

3. Conclusion

A rotating range modulator was designed for applications to BT, such as, producing new various mutants and developing new profitable flowers and vegetables. For the design of the range modulator, we used SRIM code to calculate the stopping powers and ranges of a target after transmitting the range modulator. The range modulator can produce 16.8mm of SOBP, with less than 1% of non-uniformity. Also, for 45MeV proton beam, it transfers 9.8keV/um of LET over the full range in water, and its acceptable beam size is 170mm.

REFERENCES

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- [3] W. T. Chu, B. A. Ludewigt, and T. R. Renner, Instrumentation for Treatment of Cancer Using Proton and Light-ion Beams, Rev. Sci. Instrum., Vol.64, p.2055, 1993.