Extending Bragg peak of heavy ion beam and melanoma cell inactivation measurement*

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Abstract A rotating range modulator was designed and manufactured, which is applied to extend Bragg peak of heavy ion beam. Bragg curves of 75 MeV/u ^{16}O and 75 MeV/u ^{12}C ion beams through this range modulator were measured respectively and two evident spread-out Bragg peaks corresponding to the modulated beams above are shown. In addition, inactivation effect of the modulated 75 MeV/u ^{16}O ion beam at nine different penetration depths on melanoma cells (B_{16}) was measured. Results indicate that lethal effects at the spread-out Bragg peak region are larger than at the plateau of the particle beam entrance.

Keywords Heavy ions, Spread-out Bragg peak, Range modulator

1 Introduction

For irradiating extended target volume in radiotherapy research with heavy ion beam, it is usually necessary to spread out Bragg peak of heavy ion beam in depth according to the size and shape of the target in order to reduce the irradiation time. Then it is very important to master the technique of widening Bragg peak for heavy ion beam and to make a spread-out Bragg peak in which cells are uniformly killed. The spread-out Bragg peak is realized by using a range modulator, which superposes shifted dose distributions of various monoenergetic beams. The superposing ratio should be determined so as to make a suitable extended peak. In this paper a rotating range modulator designed and manufactured by ourselves is introduced, Bragg curves of 75 MeV/u ^{12}C and ^{16}O ion beams supplied by Heavy Ion Research Facility at Lanzhou (HIRFL) through this range modulator were measured respectively. For probing the biological response of modulated heavy ion beam, inactivation effect of the modulated 75 MeV/u ^{16}O ion beam was measured with the same irradiation dose level at nine different penetration depths on melanoma cells (B_{16}).

2 Range modulator

Herein the rotating range modulator is made of a stack of nine thickness sheets of polymethyl methacrylate (PMMA, ρ=1.19 g/cm^3) on a common shaft, each cut to a fan shape with two opposing blades to maintain dynamic balance. It looks like a wheel propeller and is inserted in the beam course. The ratio of the opening angle of the each sector equals the superposing ratio of the shifted Bragg peaks for the spread-out Bragg peak. The thickness discrepancies of adjacent PMMA degraders of the nine are all 0.5 mm, from the edge 0.5 mm to the center 4.5 mm. A monoenergetic beam becomes a mixed energy one through the modulator, and the different depth-dose distributions in a temporal variation are superposed. So the Bragg peak of the initial irradiation beam is extended.

3 Experimental principle and arrangement

The experimental principle of Bragg curve measurement with double ionization chamber method refers to Ref.[1]. The experimental arrangement schematic is shown in Fig.1. After the 75 MeV/u ^{12}C and ^{16}O ion beams supplied by HIRFL go through 24 μm nickel window and ionization chamber IC_1, the energies decrease to about 74.55 and 74.28 MeV/u, respectively. IC_1 and IC_2 are air-free ionization

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chambers, each plate was made of 10μm Mylar foil which is covered with 100μg/cm^3 gold-plating, the distance between collecting and high-voltage plates is 3 mm, the supply voltages applied to the two ionization chambers are 300 V. The collected ionized charge is inputted to a beam integrator and changed into pulse signals, hence is counted by a counter. F in Fig.1 is the PMMA degrader (ρ=1.19g/cm^3) whose thickness can be adjusted. The penetration depth of the incident beam is simulated by changing the degrader's thickness. When measuring Bragg curve of particle beam, IC_2 was installed at downstream 50 mm from IC_1; when cell inactivation being measured, sample plate carrying B_{16} cell culture dishes was fixed at the downstream instead. Finally, the thickness of PMMA degrader was equivalent to the penetration depth of particle beam in water when the experimental data were proceeded.

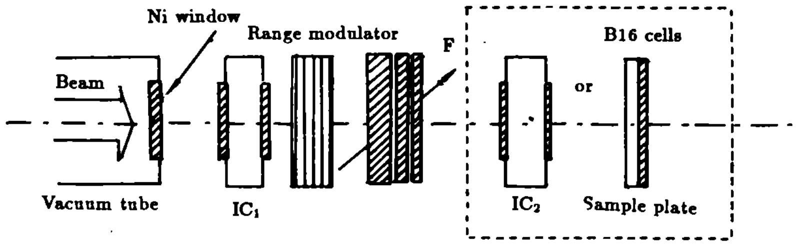

Fig.1 Schematic of experimental arrangement

4 Results and discussion

Relative doses between different penetration depths and medium surface (connecting relative doses at different penetration depths forms Bragg curve) for modulated 74.28 and 74.55 MeV/u ^{16}O and ^{12}C ion beams through the range modulator were measured. The results are shown in Fig.2 and Fig.3, respectively. It is clear that the extended Bragg peaks are displayed in the measured Bragg curves for the above two beams. For 74.28 MeV/u ^{16}O ion

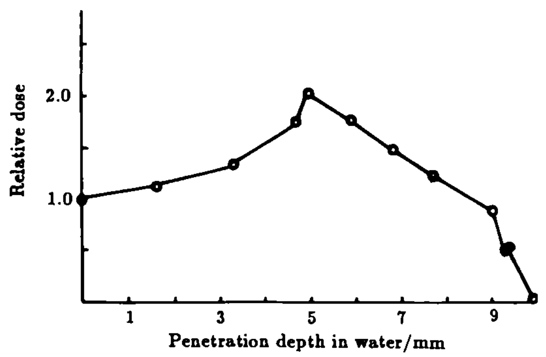

Fig.2 The modulated Bragg curve for 74.28 MeV/u ^{16}O ion beam

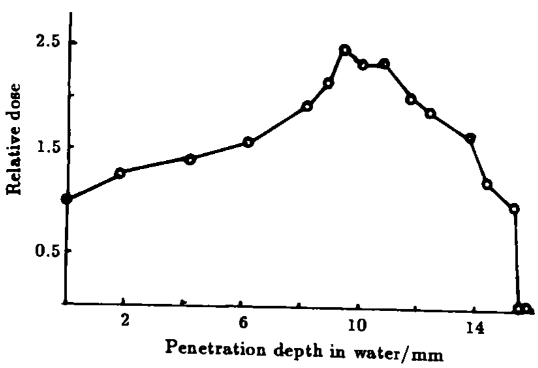

Fig.3 The modulated Bragg curve for 74.55 MeV/u ^{12}C ion beam

The symbols represent measured relative doses beam, the extended Bragg peak lies in penetration depths between about 5 mm and 9 mm; for 74.55 MeV/u ^{12}C ion beam, the widened peak does between about 9 mm and 15 mm. From the experimental results it can be said that the present rotating range modulator spreads out Bragg peak quite well, we have mastered the technique of widening Bragg peak for heavy ion beam, next, inactivation effect measurements of modulated beam at different penetration depths on B_{16} cells were done.

B_{16} cells were exposed at room temperature attached in culture flasks. After 24 h of further incubation post-irradiation, the cells were stained with Trypan blue reagent and observed under an optical microscope. The dead cells which do not reproduce become blue, then the numbers of the dead and survivors of B_{16} cells were counted. So the surviving fraction was evaluated (inactivation fraction=1.0–surviving fraction). During the course of this experiment the B_{16} cell surviving fractions were measured at nine penetration depths for modulated 74.28MeV/u ^{16}O ion beam, the irradiation doses were all 30 Gy at every depth, the results are exhibited in Fig.4. The B_{16} cell surviving fractions decrease remarkably at the spread-out Bragg peak region, on the contrary, elevated surviving fractions at the plateau of the charged particle entrance are displayed. So it is indicated that this characteristic is of great use in therapy with heavy ion beam. In principle, a tumor could be exposed with spread-out Bragg peak, this results in killing cancer cells efficiently at malignancy position and sparing the normal tissue on which the charged particles enter.

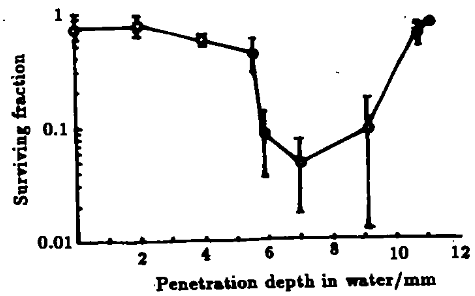

Fig.4 B_{16} cell surviving fractions at different penetration depths for modulated 74.28 MeV/u ^{16}O ion beam, the symbols are measured results

5 Summary

It is verified that Bragg peaks of heavy ion beams could be widened by the range modulator designed by ourselves through the experimental measurements. This contributes to the further physical research work in therapy with heavy ions. Inactivation measurements of melanoma cells devote to accumulating fundamental data for shallow-seated tumor therapy.

Reference

1 Wei Zeng-Quan, Xie Hong-Mei, Li Wen-Jian *et al.* Nucl Techn (in Chinese), 1996, 19(1):18