P－10

Precise Measurement of Range of Heavy Charged Particles

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INTRODUCTION

It is important to know accurate ranges of heavy charged particles in a human body for heavy-ion radiotherapy. Although the range-energy relations have been reported in many articles, the results show difference among them in the range of 1 to 2% by using a few calculation codes, which corresponds to 6 mm for the particle having a range of 30 cm in water. The ranges have been measured for protons and electrons but not for heavy ions so far. The aim of this work is to measure precisely the range of heavy charged particles and to take data for the accurate calculation.

METHOD

(a) Energy Measurement

The energy of incident particles must be given precisely for the range measurement. In this work, the energy of carbon and helium ions was derived from two methods. In the first method, we derived the energy from the magnetic rigidity of a bending magnet by determining the particle path with three slits as shown in Fig.1. The momentum of particles is determined from the following equation by using the bending angle and the magnetic field:

$$p = \frac{ze\int Bds}{\theta}, \qquad (1)$$

where ze is the charge of the particle, $\int$ Bds is the integration of the magnetic field along the path, θ is the bending angle. In the second method, we derived the energy from the RF frequency of the synchrotron. The energy of particles is expressed by

$$\beta c = 2\pi Rf/h, \qquad (2)$$

where f is an RF frequency, R is a synchrotron radius, h is a harmonic number, which is 4 for HIMAC. The accuracy of the particle energy derived from these methods was about 0.4%.

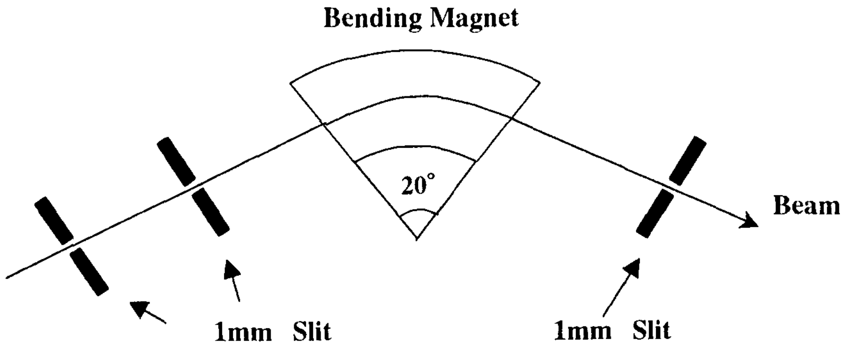

Fig.1. Arrangement of energy measurement by using a bending magnet and three slits

(b) Range Measurement and Dosimetry

The experimental set up is shown in Fig.2. Particles enter a monitor system which consists of an ionization chamber and a plastic scintillator of 50 μm thick. After passing through the monitor system, the particles enter an absorber made of aluminum or water. The particles which penetrated the absorber are detected by an ionization chamber or a ΔE-E counter. The ΔE counter is a scintillator of 100 μm thick and the E counter is a scintillator of 5 mm thick. The number of particles penetrating the absorber was measured as a function of the absorber thickness. We used the carbon beam of 290MeV/u and 400MeV/u, and the helium beam of 150MeV/u and 230MeV/u.

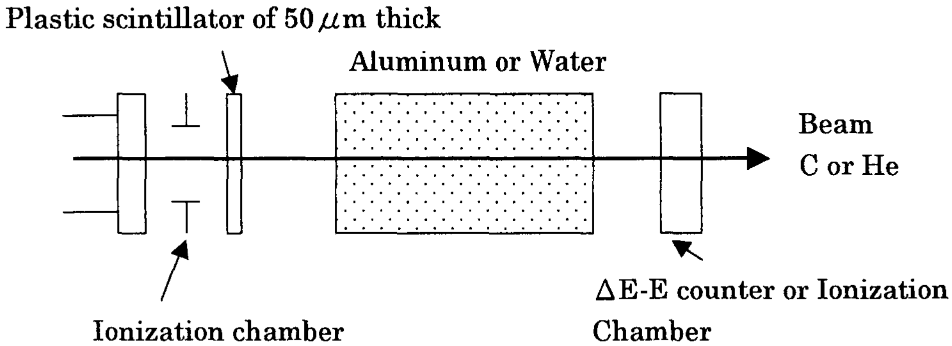

Fig.2. Arrangement of range measurement and dosimetry

RESULTS

The Bragg curve was taken by using the ionization chamber for the measurement of specific ionization. The results are shown in Fig.3. The range is determined as the thickness of the absorber at which half of the particles are penetrated. The results are compared with the values calculated by the LBL code[1] and the ICRU code[2]. Table 1 shows the results of the energy measurement, the range measurement and the calculation by the codes.

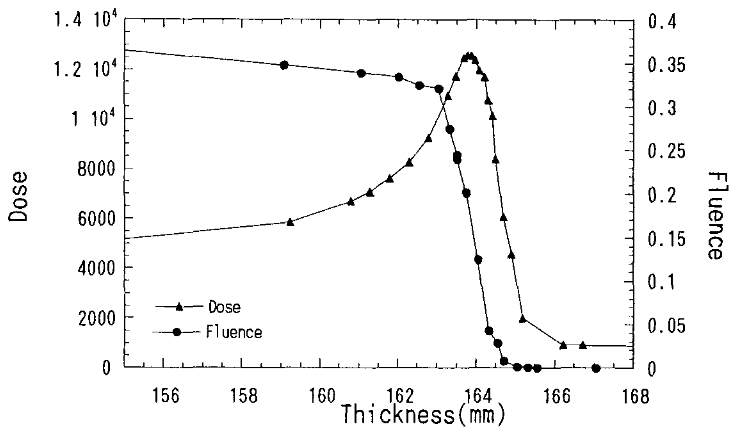

Fig.3. Results of the dose and the range measured in water for the carbon of 290MeV/u.

TABLE 1. Results of the energy measurement, the range measurement, and the calculation by the codes.

For water

Particle	Energy(MeV/u) Bending magnet	Energy(MeV/u) RF frequency	Experimental Range(mm)	LBL code (mm)	ICRU code (mm)
He	149.3	150.2	159.3	157.5	157.7
He	229.3	230.7	327.4	329.8	329.6
C	292.1	291.1	163.9	164.9	164.4
C	401.3	400.5	276.2	276.8	276.4

For aluminum

Particle	Energy(MeV/u) Bending magnet	Energy(MeV/u) RF frequency	Experimental Range(mm)	LBL code (mm)	ICRU code (mm)
He	149.3	150.2	76.0	75.1	75.2
He	229.3	230.7	158.3	156.1	156.3
C	292.1	291.1	77.2	77.9	77.7
C	400.8	—	129.9	130.1	130.1
C	401.3	400.5	130.1	130.4	130.3

REFERENCES

[1] M.H. Salamon, LBL report 10446(1980)
[2] ICRU, ICRU report 49(1993)