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RI BEAM FOR MEDICAL USE AT HIMAC

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Abstract

Secondary-beam courses have been constructed at HIMAC in order to study medical applications of radioactive beams. We have also started construction of an irradiation system from 1998. Range measurements will be carried out using a positron camera and beams of positron emitters. Images of a target irradiated by positron emitters were measured by PET.

1 INTRODUCTION

Radiation therapy with carbon beams started at HIMAC in June, 1994 [1][2]. Its advantage is good concentration of the dose due to existence of the Bragg peak and no significant dose behind the peak. The penetrating range is, thus, an important parameter in heavy-ion therapy. While the range is elaborately calculated using X-ray CT numbers and empirical formulae, there remain several sources of calculation errors, such as;

1. errors in the empirical formulae,
2. hardening of the X-ray in a human body,
3. complexity of the X-ray image of a human body,
4. errors in the calibration of CT numbers.

If we employ beams of positron emitters, we can directly decide a stopping position of the beams by detecting annihilation gamma-rays with a positron camera or PET. In order to study medical applications of radioactive beams, we have constructed new courses for secondary beams [3]. Because of medical applications, the following requirements were stressed in the design; the control should be easy, a beam-tuning time should be as short as possible, and stability and reproducibility should be excellent. In order to achieve these requirements, an automated tuning system has been developed.

In 1998, we have begun construction of an irradiation system. There are two schemes for applications of positron emitters. The first scheme is to make use of pencil beams, whose range in a patient's body is determined with a positron camera. Since the range can be determined with an irradiation of relatively low dose, this scheme is applicable to confirmation of treatment plans. The scheme was employed at LBL using a ^{19}Ne beam [4]. We aim to decide a center of an activity distribution with an accuracy of ~1mm.

The second scheme is to measure a whole irradiated volume using PET to obtain a 3D image. Recent progress of commercially available PET makes this scheme practical. A required dose is, however, larger than the first scheme. A possible application is a measurement of an activity distribution after an irradiation in order to confirm the irradiated volume.

2 SECONDARY-BEAM COURSES

Secondary-beam courses branch from the PH2 course as shown in figure 1. There are two achromatic courses, SB1 and SB2, and a straight course, SB3. In the first stage, the SB1 and SB3 courses have been constructed. In the irradiation system will be installed at SB1. In the second stage, the SB2 course will be constructed for basic experiments, while the SB1 course will be dedicated to medical applications.

A production target is set in the PH2 course. Projectile fragments with a given q/A value are focused on a dispersive focal point, F1, to be separated from the primary beams or secondary beams with different q/A values. After passing through an achromatic degrader at F1, the specified projectile fragments are further separated due to differences of energy lost in the degrader. They are focused at a double achromatic focal point at F2. Separated projectile fragments are finally focused at F3 with triplet quadrupole magnets. Specifications of the SB1 course are listed in table 1.

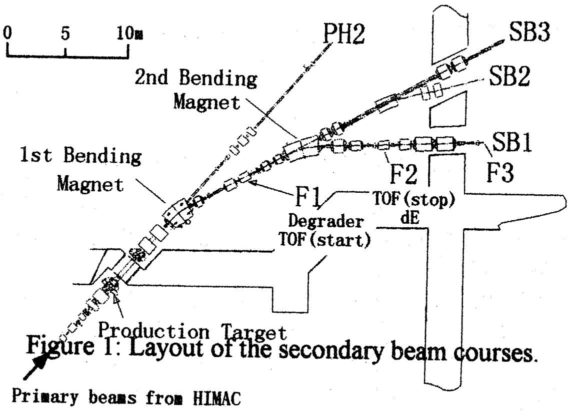

Figure 1: Layout of the secondary beam courses.

Table 1 : Specifications of the SB1 course.

Maximum magnetic rigidity	8.13 Tm
Momentum acceptance	± 2.5 %
Angular acceptance (H/V)	± 13 mrad.
Momentum dispersion at F1	2.0 m

For medical application, excellent reproducibility of beam quality is a critical condition. In general, a so-called initialization process, in which excitation is varied in a pre-determined manner, is employed in order to erase a hysteresis of bending magnets. Unfortunately this process requires an extra time for the beam tuning. In order to save the tuning time we have employed a control system in which magnetic fields are measured by NMRs. Power supplies are controlled based on the values measured by NMRs.

A new control system has been installed for the secondary-beam courses. The control system stores monitored data (TOF and ΔE for particle identification) and set parameters of devices in the secondary-beam courses. Algorithm of automated beam tuning was developed. Device parameters corresponding to a specified ion are automatically optimized. A required time was 40 minutes for obtaining ^{11}C using primary beams of ^{12}C. It will be reduced furthermore after a new intensity monitor of the primary beam is installed.

Production rates of ^{11}C beams were measured to be 0.3 and 0.9 % for 290 MeV/u and 430 MeV/u ^{12}C beams with a Be target of 51mm thick [7]. Contamination of ^{12}C and ^{7}Be was found to be a few percent or less. In figure 2, a measured depth-dose distribution is shown as an example.

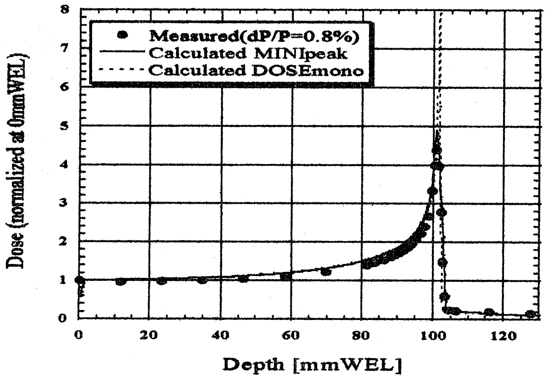

Figure 2: Measured depth-dose distribution of ^{11}C beams.

3 IRRADIATION SYSTEM

Present irradiation systems at HIMAC use wobbler magnets [5] and scatterers to form large irradiation fields. A large part of the beams are, as a result, abandoned during the beam-shaping processes. Since an intensity of secondary beams such as ^{11}C is low, the irradiation system of the secondary beams must utilize beams much more efficiently in treatments. Therefore a spot-scanning method was adopted.

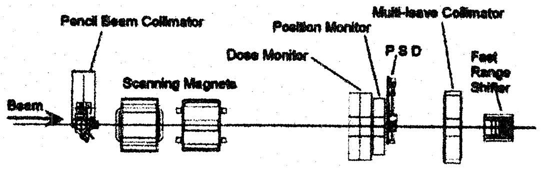

Figure 3: Irradiation system of RI beam in HIMAC.

The irradiation system is illustrated in figure 2, and is summarised in table 2. Beam directions are varied by two scanning magnets. When the spot-scanning method is used, beam energies are changed by a range shifter placed in front of a patient. This method simplifies operation of the accelerator, because it is not necessary to change the beam energies extracted from the accelerator as well as parameters of a beam transport line. This is practically a sole solution for the irradiation of secondary beams, because all parameters of the beam course including a thickness of the production target and an achromatic degrader are optimized to beams.

Table 2 : Parameters of the irradiation system.

Ion species	^{12}C, ^{11}C, ^{10}C
Distance between the last quadrupole and a patient	6 m
Target volume	10^3 cm^3
Scan field with magnets (x and y)	10 cm
Range shifter (max.)	30g/cm^2
Maximum beam energy	350MeV/u (^{12}C)
Beam intensity	$< 6\times10^6$pps
Beam monitors	two intensity monitors (main and sub) one profile monitor(x,y)
Collimator	Multi-leaves Aperture (x,y) ±75 mm step width 2.5 mm thickness (Fe) 140 mm
Patient setting	chair, bed

A positron camera will be used to determine the stopping position of the pencil beam such as ^{11}C. The positron camera consists of a pair of Anger-type scintillation detectors, and detects a pair of gamma rays. Each detector is made of an NaI crystal with a diameter of 600mm and a thickness of 30mm, and 109 photo-tubes. Because of a high detection efficiency with the thick NaI crystal, a position resolution with an accuracy of ~ 1mm is expected with an irradiation of a few percent of one fractional dose [6] used in treatments. Although a most promising candidate of the positron emitter is ^{11}C, a half-life of ^{11}C is too long for carrying out more than one measurement consecutively. Thus an isotope of a shorter half-life, such as ^{10}C, might be an alternative candidate,

Construction of the irradiation system will finish in FY1999, and a beam test is scheduled in March, 2000.

4 IMAGES MEASURED BY PET

If a target is irradiated by ^{11}C beams, the irradiated volume can be specified by using PET. A number of gamma rays produced by the ^{11}C beams is about one order larger than that produced by the auto-activation method when the same dose is injected. Furthermore, efficiency has increased in recent 3D data acquisition PET. With the PET of Siemens HR+, we have verified quality of an image measured by PET. Figure 4-1 shows an image produced with ^{11}C beams of 1.0Gy at a peak. The left figure is an image reconstructed from emitted gamma rays. The right one is a transmission-type image to show a cross section of a target. The target was a cylinder made of polyethylene with a diameter of 150mm. The end point can be determined with an accuracy of about 1mm. Another image is shown in figure 4-2, where SOBP (Spread-Out Bragg-Peak) beams with a thickness of 4cm was used. A dose was 0.1 Gy at a center of the SOPB. The SOBP region can be clearly identified.

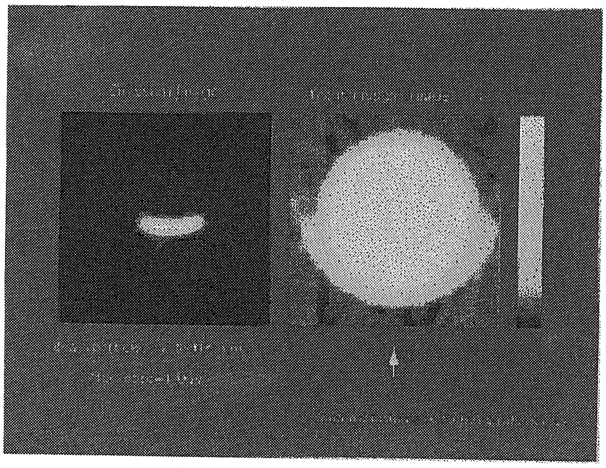

Figure 4-1: PET image of ^{11}C injected in polyethylene target.

5 SUMMARY

The secondary beam course for medical use has been constructed. It has showed satisfactory performance. The irradiation system for a spot-scanning method will be installed. Quality of images produced by 11C beams and measured by PET was tested.

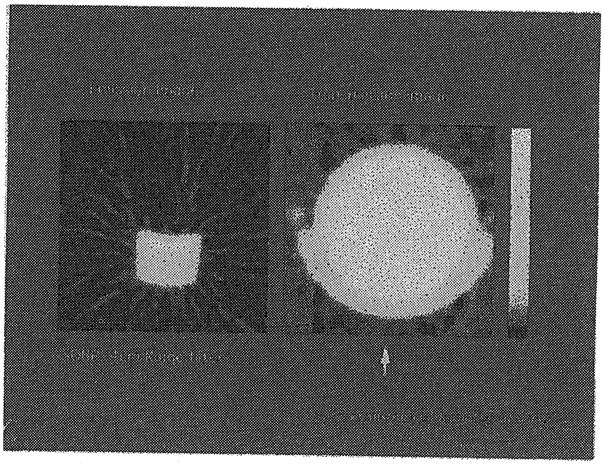

Figure 4-2: PET image with the SOBP beams with a thickness of 4cm.

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