MEDICAL APPLICATION OF THE POSITRON EMITTER BEAM AT HIMAC

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Abstract

A treatment planning of heavy ion cancer therapy is performed with an aid of X-ray CT, which has uncertainties in an estimation of ion range. In order to obtain a dose distribution with high accuracy, irradiation and range measurement systems are developed at HIMAC using positron emitter beams. Exact stopping points of the ions can be measured by detecting annihilation γ-rays from positron emitters themselves. A new irradiation system has been installed, for creating an irradiation field with 3-dimensionally desired shape. A positron camera, which is similar to an Anger-type γ camera, is used to determine a range distribution of the heavy ions in a patient's body. An existing PET system can be also used to measure an image of the 3-dimensional irradiation-field.

1 INTRODUCTION

Since 1994, the heavy ion cancer therapy has been carried out with HIMAC at NIRS [1]. Heavy-ion radiotherapy has two advantages clearly over other types of radiation therapies. One is a high dose-concentration just on a tumour due to the Bragg peak. The other is large relative biological-effectiveness (RBE) due to high linear energy transfer (LET).

In the present treatment planning, a range distribution is calculated from the X-ray CT number [2] and empirical formulae. There remain several sources of the range errors as follows; (1) error in empirical formulae (2) hardening effects of X-ray in a human body (3) error in calibration of CT-number. Since an irradiation area has to keep a margin due to the errors, the irradiation to the tumour near a critical organ is difficult. In this case, important to know the 3-dimensional dose distribution inside patient's body accurately.

The distribution can be measured with an irradiation of radioactive isotope beams such as ^{11}C and ^{10}C[3]. The PET technique is available to measure the stopping area of radioactive isotope. A positron camera system has been also developed to get a precise range distribution in a human body. A secondary beam line had been completed in 1998 [4]. An irradiation system has been constructed during 2000.

2 SECONDARY BEAM IRRADIATION SYSTEM

2.1 Production of secondary beam

The projectile-fragmentation method is used for the production of radioactive isotope beam. An on-line isotope separator has two dipole magnets, and it identifies and separates the required isotope from various fragments. The first magnet analyzes the momentum of the fragment. The second analyzer magnet selects the particles of the desired charge Z with a wedge-shaped energy-degrader. The purity of the secondary beam is measured by a particle identification system that consists of a TOF counter and a ΔE counter.

2.2 Description of the irradiation system

The irradiation system is comprised of a pair of scanning magnets, a beam scatterer, a multi-leaf collimator, a ridge filter, a range shifter and several beam monitors. The layout of the irradiation system is shown in Fig.1. A pair of scanning magnets is orthogonal bending magnets and is used to sweep the beam position in a lateral direction. The maximum irradiation area is 100×100mm for ^{12}C beam with the energy of 350MeV/n.

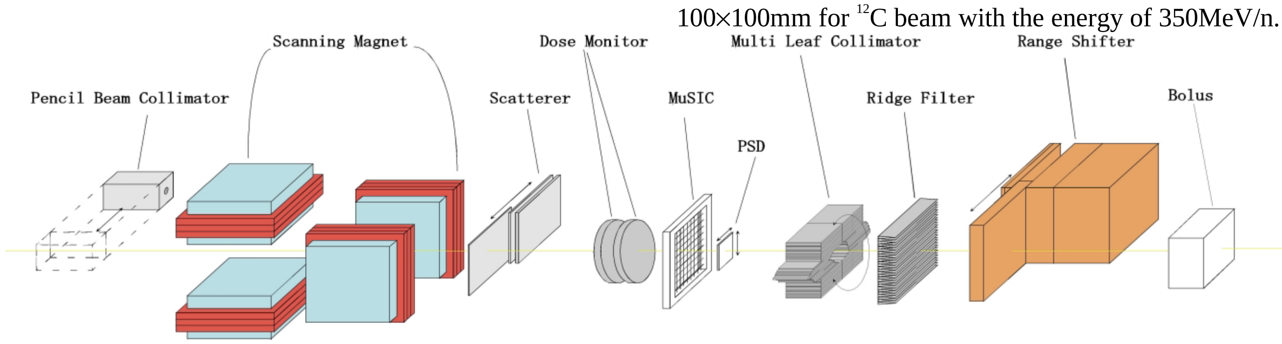

Figure 1: A layout of secondary beam irradiation system.

The range shifter is a device for the tuning the range of the irradiated RI-beam. The range can be tuned between 0 and 160mm water equivalent. The minimum step is 0.29mm.

In order to measure the irradiated dose, two ionization chambers are placed separately. These are used to protect against overdose irradiation in a case of either counter disabled. The multi-strip ionization chamber (MuSIC) is used to monitor the beam position [5].

2.3 Irradiation system by wobbler method

Two irradiation methods are planned in the system. One is a wobbler method [6] and the other is a spot scanning method. In the wobbler method, the beam scatterer is used with the scanning magnets to form a large uniform dose distribution in the lateral distribution.

A multi-leaf collimator is a field-shaping device which cuts the beam to the cross section of the tumour. The ridge filter is a device for expanding the range distribution to form a spread out Bragg peak (SOBP). The beam compensator (so called ‘bolus ‘) is used to adjust the beam range to the longitudinal shape of the tumour. The wobbler method has been adopted in the heavy ion therapy at HIMAC with an excellent reliability and it is easy to apply the treatment gated by a patient-respiration motion. An efficiency of beam usage, however, is rather low and the wobbler method requires higher beam intensities than a spot scanning method.

2.4 Spot scanning method

The spot-scanning method realizes a required 3D-irradiation field by changing a lateral position of a spot beam step by step with a pair of scanning magnets. An axial position of the spot beam is adjusted step by step with a variable range shifter. Since the scanning irradiation method shapes the irradiation field close to the form of the tumour, its beam efficiency is good for a complicated irradiation field. The irradiation to organs which move with patient-respiration motion has some difficulties.

2.5 Positron camera for range measurements

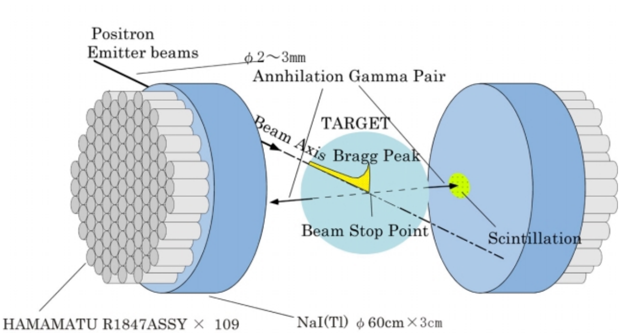

Figure 2: Range measurement with positron camera.

Positron camera is similar to an Anger-type γ-camera [7]. The design of the camera was optimized not to observe the image, but to determine the precise range of the positron. Just before the treatment, a trial spot beam is planned to be irradiated on a patient to check a residual range of the positron emitters, such as ^{11}C. Stopped positions of the positron emitters are measured by detecting a pair of annihilation γ-rays by the positron camera as shown in Fig.2. The difference between the planning and measured position can be certified.

2.6 Treatment chair

Medical treatment with the secondary beam is planned to use a treatment chair. The patient sits on the motor-driven treatment chair. The chair is movable in three orthogonal directions and can be rotated horizontally around an isocenter. A head of the patient is fixed on the headrest with a mask-type immobilization device. The headrest is adjustable to directions of rolling and pitching.

Chair with horizontal beam port realizes the similar flexibility as with the gantry beam port for heavy-ion radiotherapy. In addition, the mechanical system is compact as compared with the gantry port, so it may be easy to achieve the high-accuracy positioning system.

3 BEAM TEST

3.1 Production rate of ^{11}C at HIMAC secondary beam line

A production rate of ^{11}C was measured as a function of the target and the degrader thicknesses. The maximum angular acceptance and momentum acceptance are ±13mrad and ±2.6%, respectively.

With a primary beam intensity of a 2×10^{9}pps ^{12}C, a production rate of 0.3% of ^{11}C is required to realize reasonable length of a treatment time. The result satisfies this requirement.

Table 1: production rate of ^{11}C.

Target (Be mm)	15	27	51	51	51	51	88	105
Degrader (Al mm)	None	None	None	3.5	7	10.5	None	None
Production Rate (%)	0.50	0.71	0.83	0.80	0.74	0.76	0.81	0.63
Purity (%)	94.5	93.6	93.9	93.6	97.8	98.5	90.9	87.5

3.2 Beam profile at isocenter

Since the spot scanning method superposes a spot beam and forms an irradiation area, it is important to measure the lateral and depth profile of spot beam at an isocenter.

The beam profile at the focus position, i.e. the isocenter, is an important parameter for the spot-scanning irradiation. A beam size at the isocenter depends strongly on an angular acceptance of the secondary beam line. Fig.3 shows a typical beam profile with the angular acceptance of ±13mrad. The reproducibility of the beam profile satisfies the medical requirement.

The depth dose distribution of the spot beam is also important. It depends on the momentum distribution of ^{11}C. A typical momentum distribution with a 51mm thick

Be target and the angular acceptance of ±13mrad is shown in Fig.3.

For the spot beam, a momentum range between 97.5% and 99.5% is chosen as indicated as a hutched area in Fig.4.

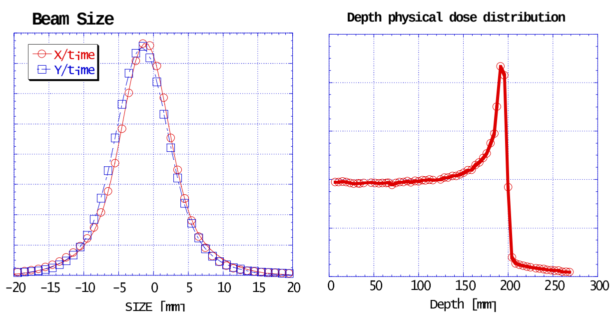

Figure 3: The lateral beam profile (left) and the depth physical dose distribution (right) of the typical spot beam.

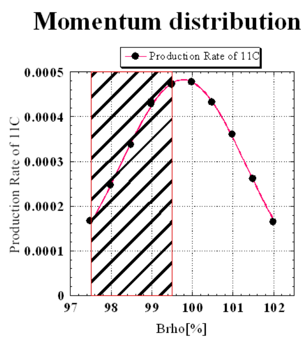

Fig. 4: typical momentum distribution of ^{11}C.beam.

A momentum spread from 97.5% to 99.5% is chosen to obtain a sharp depth dose distribution.

3.3 Dose distribution of spot scanning method

The 3D irradiation field of a 35 × 35 × 50mm^3 rectangular parallelpiped shape was created with the X and Y scanning magnets and a range shifter. The profile of the spot beam was confined same as Fig. 3. Both of lateral and depth distance between two successive spots are chosen at 5mm. The 3D dose distribution measured by the multilayer ionisation chamber is shown in Fig.5.

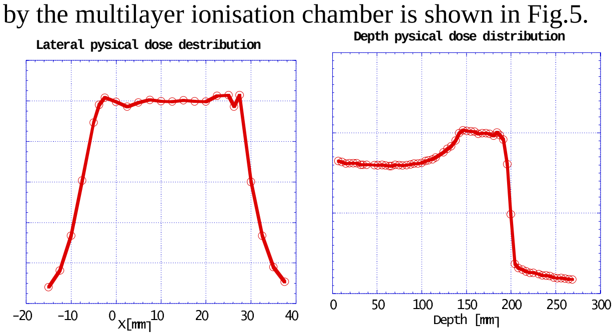

Figure 5: lateral (left) & depth (right) physical dose distribution of the 3D irradiation field.

The irradiation area of uniform dose was formed using this spot scanning method.

4 SUMMARY

The secondary beam irradiation system including a positron camera for measuring the precise range distribution are under commissioning. Verification of the performance of the hardware, and the research of the analysis technique by the PET and the positron camera have been performed. The preliminary results satisfied the medical requirements.

A treatment chair and patient-positioning device will be installed by March 2001. A treatment bed will be also installed by March 2003.

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