PRESENT STATUS OF THE RI BEAM PROJECT IN HIMAC

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Abstract

A positron emitter beam provides the possibility of the range verification in the patient's body accurately. To utilize this beam, the fragment separator was constructed in HIMAC. The irradiation and the positioning systems with treatment chair were constructed successively. In an irradiation system, the spot scanning method was applied with RF-KO slow beam extraction from synchrotron. In parallel with construction of these systems, we have performed the beam experiments, where a commercially available PET was used. In this paper, current status of the RI beam project will be presented.

1 INTRODUCTION

Since 1994, the heavy ion cancer therapy has been carried out at HIMAC (Heavy Ion Medical Accelerator in Chiba) in NIRS (National Institute of Radiological Sciences) [1]. With good clinical results, many kinds of tumors were treated and patient number was increased favorably [2]. Accumulated total number became over one thousand in early 2001. The important advantage of heavy ion therapy is its dose concentration on the tumor, and less dose on the normal tissue. To obtain ion range in the patient, we must depend on the calculation with X-ray CT data. Though this calculation is checked carefully, there will be still error in the calculation. One reason comes from the different process between the energy loss of the charged particle and the attenuation of X-ray, and the relation between these strengths depends on the material. If we use positron emitter beam, its shape of stopped activities can be measured directly with positron camera or PET (Positron Emission Tomography). Though this provide unique tool to measure the range directly, the production rate is small. With the fragment separator in HIMAC [3], its value is smaller than 1%. With this beam intensity, efficiency of beam utilization in the irradiation system must be as high as possible. For this purpose, we have developed spot scanning irradiation system, where the knockout beam extraction [4] from the synchrotron is adopted. Concerning the 3d conformal irradiation system, several groups are discussing [5,6]. In their scenario, there is no beam on/off control during spot irradiation. In our system, the extraction is stopped in the transit period from one to next spot irradiations. In the period of beam off, we can check the previous spot in its dose value and spot position, which is important for quality assurance in the irradiation. In this paper we describe the irradiation system and experimental results with this system.

2 BEAM COURSE

Secondary beam courses have been designed as branched course from PH2 course as shown in Fig. 1. There are two achromatic courses, SB1 and SB2. At first, SB1 course was constructed, and the irradiation system and patient positioning system were installed. In the second stage SB2 course was constructed for basic experiments, because SB1 will be used exclusively for medical applications. Both courses have same angular and momentum acceptance of ±13mrad (x and y directions) and ±2.5%, respectively.

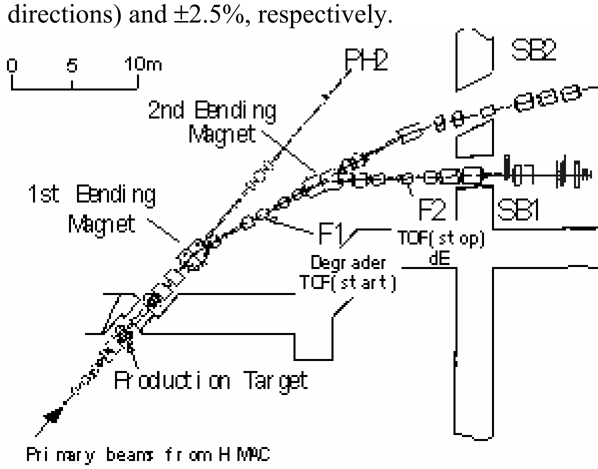

Figure 1: Layout of the secondary beam courses.

3 IRRADIATION SYSTEM

In the irradiation system (Fig. 2), there is a pair of scanning magnets with which we can move spot position from one point to next quickly. The sweep speeds are 5 mm/ms and 2.5mm/ms with horizontal and vertical magnets, respectively. These speeds are required to keep the transit time short. The spot depth can be controlled with range shifter that is placed just in front of the patient position to minimize the effect of the multiple scattering. The thickness can be adjusted by the combination of ten acrylic plates can be adjusted from 0mm to 159.79mm with minimum thickness of 0.29mm. Required time is 480ms to change the thickness with different combination of the plates. To measure the dose of each spot, we have used two parallel plate ionization chambers as main and sub dose monitors. One is for control and another one is for check. There are profile monitors of horizontal and vertical directions, and the each spot position is checked. There is multi-leaf collimator to cut the distribution tail, that is installed downstream of the beam monitors. In the positioning system, we can use a treatment chair. A brain tumor is planned with this system, because the brain will not move during spot scanning. With a turn table of 360° with treatment chair (see Fig. 3), we can have multi-port irradiations.

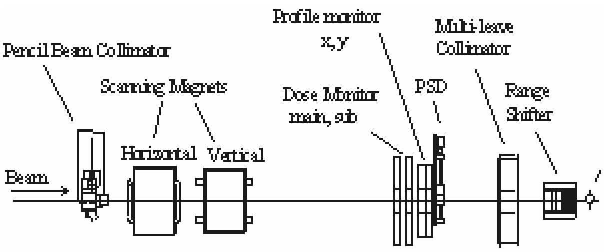

Figure 2. Irradiation system in the secondary beam course.

Figure 3. Patient positioning system, where treatment chair can be used with a 360 degree rotating table. There are x-ray tube (left), attachment of x-ray film with square shape and one detector (round shape) of a positron camera (right).

4 BEAM TESTS OF SPOT SCANNING

In the beam extraction system, we have used RF knockout method where the transverse rf field excites horizontal betatron oscillation. With this extraction device, we have quick control of beam on and off, which is required in this spot scanning irradiation. We have also merit with a fixed separatrix in the extraction process, where extracted beam axis will not move during whole period of extraction. In Figures 4-1 and 4-2 beam spills are shown with this extraction, where the spill monitor has response up to 10 kHz.

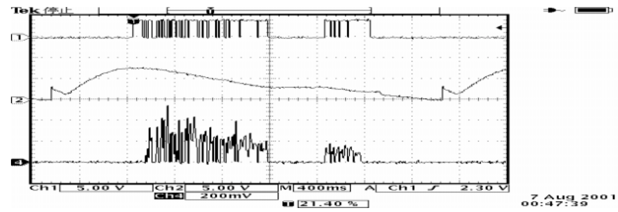

Figure 4-1. Upper is beam gate, middle is beam intensity in the ring and lower is extracted beam signal. One time division (horizontal axis) is 400ms.

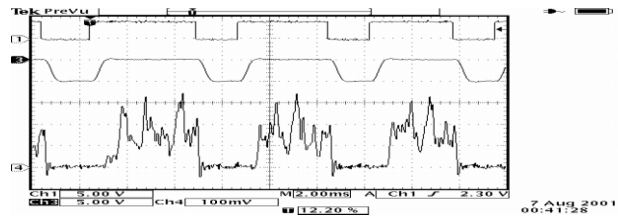

Figure 4-2. Beam spill signal in the successive small spots. One time division (horizontal axis) is 2ms. Upper signal is beam gate, and middle signal is current of QDS magnet.

.In the beam test of the spot scanning, simple case of irradiation volume was used. The irradiated volume of SOBP (Spread Out Black Peak) was 35×35×43mm^3 in the acrylic block, and the injected physical dose was 1Gy at the center of this volume. The spot sizes are about 9mm (FWHM) in vertical and horizontal direction, and spacing of each spot was 3mm to obtain smooth dose distribution. In the irradiation, 4050 spot points were used to form the required dose distribution in the above volume. The strength of each spot must be calculated from the data of lateral and depth dose distribution of the spot beam. The calculated results are shown in Figure 5 in the depth direction [7].

At first, we measured the irradiation time varying the strength of rf knockout field with same ramp shape of the amplitude. As shown in Figure 6, we obtain shorter irradiation time with higher rf field. With the higher value, the irradiation time become constant. This indicates that the accelerated beam can be extracted well, and we can't obtain the extracted beam further with higher voltage.

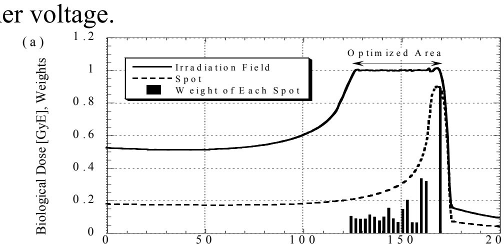

Figure 5. Depth distribution of biological dose. Dashed line show the distribution of spot beam. Solid curve is superimposed data of each spot with weight of solid bar.

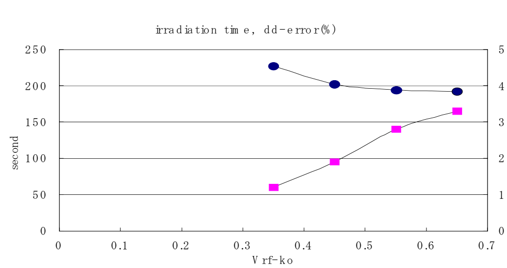

Figure 6. Irradiation time (upper data) vs. rf knockout voltage (relative). Lower data are error ratios (% in right axis) of extra dose due to cut off time of the beam extraction. Irradiated dose was 1 Gy (physical dose).

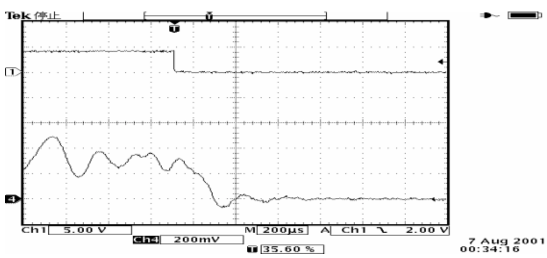

Figure 7. Beam gate (upper signal) and the extracted beam signal (lower one). One time division (horizontal axis) is 200μs.

Accurate control of each spot is required to obtain desired dose distribution in its shape and absolute value. For this requirement, cut off speed at the end of each spot should be fast. In the extraction system, turn-off of the rf knock-out power and the tune shift from resonance condition with small quadrupole magnet (QDS) in the ring are used to stop the beam extraction. With this system, beam extraction can be stopped within 200μs as shown in Figure 7. If we don't use the QDS, cut-off time become longer. (Without the rf power in the acceleration cavity, we have quick beam stop within 50μs [8]. Though this fast beam cut is desired to control the irradiation dose accurately, there is problem of strong beam spill modulation, which must be solved.)

To estimate the effect of the above control speed for the dose distribution, calculated dose distribution (D(x,y,z)) and the surplus from that value (ΔD(x,y,z)) was estimated at the point (x,y,z). In the calculation, dose contributions from all spot beam are sum-up at the point (x,y,z) as follows:

$$D(x,y,z) = \Sigma_{ijk}\, W_{ijk}\, d(x-x_i, y-y_j, z-z_k)$$
$$\Delta D(x,y,z) = \Sigma_{ijk}\, \Delta W_{ijk}\, d(x-x_i, y-y_j, z-z_k)$$

Where d(x,y,z) is physical dose distribution of the spot beam, W_{ijk} is calculated weight of each spot, ΔW_{ijk} is measured difference from preset value, and (x_i,y_j,z_k) is coordinate of the each spot. This surplus will be large at the point where the dose consists from many small spots. So the excessive ratio (ΔD(x,y,z)/D(x,y,z)) will be large at the front end of the SOBP. In the beam test, the irradiated dose was 1 Gy (physical dose) and the beam intensity was about 7×10^6pps. The obtained results are shown in Figure 6 as a function of rf knockout voltage. We can obtain acceptable condition with small error (2%) and short irradiation time.

5 PET MEASUREMENT

To see an activity shape after irradiation with ^{11}C beam, we have used offline PET. After irradiation on an acrylic block with physical dose of 1Gy, the block was moved to the PET. Measured PET data is shown in Fig. 8 with depth and lateral distributions. We can see the expected activity distribution with the planned irradiation volume as in Fig. 5. Especially there are high activities at the end of SOBP, we can recognize small difference of 2mm at the end.

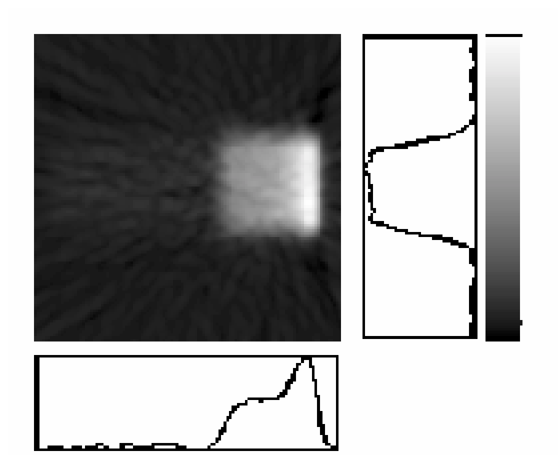

Figure 8. PET image is shown in square frame with lateral and depth distributions.

6 SUMMARY

We have secondary beam courses of SB1 and SB2. The irradiation system with spot scanning and the patient positioning system are installed in SB1, and beam tests with RI beam are doing with these systems to use for medical application.

REFERENCES

[1] Y.Hirao et al., Nucl. Phys.A538(1992) 541.
[2] H.Tsujii. Proceedings of 6th Int. Meet. on Prog. In Radio-Oncology, Salzburg, 1998, pp709-721.
[3] M.Kanazawa et al., Nucl. Phys.A701(2002)244.
[4] K.Noda et al., NIM A374(1996) 269.
K. Noda, et al., Proceeding of the XVI RCNP Osaka Int. Sym., (1997)171
[5] L. Badano et al., PIMMS, Part I, CERN, April 1998.
[6] P.Forck et al., Vienna, EPAC (2000) 2237
[7] E. Urakabe et al., JJMP Vol.19(1999)188.
[8] T. Furukawa et al., to be presented in this EPAC.