# SECONDARY BEAM COURSE FOR THE MEDICAL USE AT HIMAC

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*Abstract*

To verify the depth dose distribution in the cancer treatment with carbon beam, the beam of positron emitter is a promising tool. For this purpose we have constructed a secondary beam course and have started the beam test. The obtained yield rate of the $^{11}$C beam was 0.2% with a purity of 97%. To measure the stopping point of this beam, the preliminary beam tests of positron camera and a PET are now underway. We have also started to construct the irradiation system, where the spot scanning method will be used with $^{11}$C and $^{12}$C beams.

## 1 INTRODUCTION

Radiation therapy with carbon ions was started in June 1994 at HIMAC[1][2], which has good concentration of the dose on the cancer volume. This merit comes from both the existence of the Bragg peak and no significant dose with primary beam behind this peak. From these reasons the range is a very important parameter in the heavy ion therapy, and is calculated with X-ray CT number by using an empirical formula. Though this calculation is carefully checked, there are still several sources of errors, such as;

1. error in the empirical formula,
2. hardening of the X-ray in the human body,
3. complexity of the x-ray image of human body,
4. error in the calibration of CT number itself.

If we use the beam of positron emitter, we can directly measure its stopping point by the positron camera or the PET. For this purpose we have started to construct a new course for secondary beams since 1995[3], and its construction has just finished. To use this course for medical use, the control should be easy, and also the beam-tuning time should be short. To realize these requirements, we have developed an automated tuning system. The test of this tuning system and its upgrade are now underway. To achieve high reproducibility of the course, the dipole magnetic fields are controlled with NMR. Owing to these developments, easy and quick handling of the secondary beam course has been achieved.

As a next step of this project, we have started to construct the irradiation system. There are two irradiation schemes. One is to make use of a pencil beam, whose range in the patient is detected with the positron camera. The other one is to know the dose distribution, which is measured with PET. Former method was used at LBL with $^{19}$Ne beam[4], where the resolution of positron camera is 8mm(FWHM). The accuracy to determine the range is less than 1mm by employing the center of the measured activity distribution. Although this accuracy is good enough for the treatment, the information is limited to several points in the tumor volume. By use of the PET, the volume information can be obtained from this measurement. As for the commercially available PET, its efficiency has been drastically improved with 3D data acquisition. Since the beam intensity of the positron emitter is low, a spot scanning method is used to improve utilization rate of the beam in the irradiation system.

## 2 BEAM COURSE AND ITS BASIC PARAMETERS

Secondary beam courses have been designed as branched course from PH2 course as shown in figure 1, where the first and the second quadru-pole magnets in the PH2 are used with opposite polarities. In the design, there are two achromatic courses, SB1 and SB2, and the straight course, SB3. In the first stage, SB1 and SB3 courses are constructed, in which the irradiation system will be installed at SB1. In the second stage SB2 course will be constructed for basic experiments, because SB1 will be used exclusively for medical applications. A production target was set in the existing PH2 line, and the produced projectile fragment is focused at the dispersive focal point of F1 to separate the produced secondary beam with magnetic rigidity. Passing through the achromatic degrader at F1, the projectile fragments are further separated with energy loss difference at the double achromatic focal point of F2. Separated projectile fragment is finally focused at F3 with triplet quadru-pole magnets. The calculated transfer matrix elements from the production target point to each focal point are listed in table 1.

Table 1-1:Specifications of the secondary beam course.

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

Table 1-2:The ion optical matrix elements

| Matrix element | F1 | F2 | F3 |
|---|---|---|---|
| (x,x) | -1.03 | 0.73 | -0.31 |
| (x,p) (cm/%) | 2.0 | 0. | 0. |
| (y,y) | -1.22 | 1.84 | -4.3 |

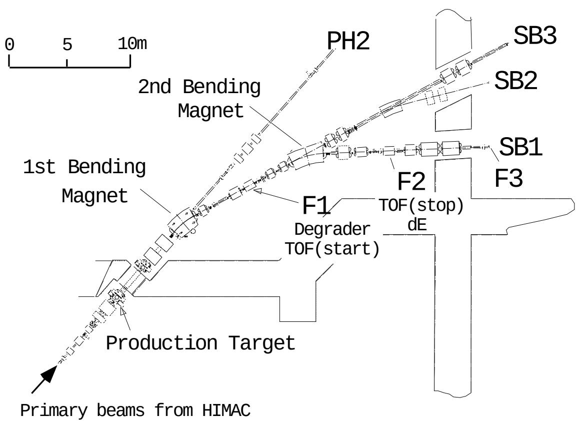


Figure 1: Layout of the secondary beam course.

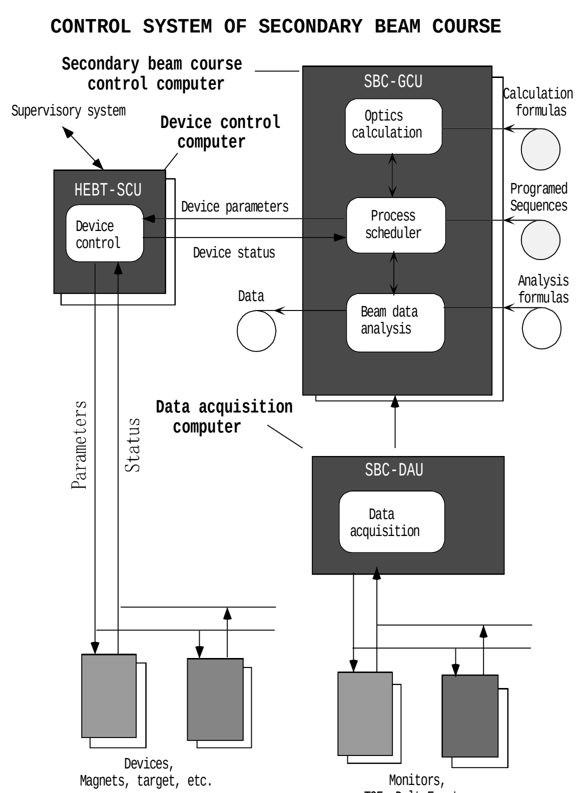


Figure 2: The control system of the secondary beam course.

# 3 CONTROL SYSTEM OF THE COURSE

To use the secondary-beam course for medical use, the beam tuning must be easy, and the tuning time must be short. To fulfil these requirements, we have developed an automated beam-tuning system. The block diagram is shown in figure 2, which consists of three control units. The first one is the existing control system (HEBT-SCU) of the beam transport line. The system controls the currents of the quadrupole magnets, magnetic fields of the dipole magnets, and slit width and position. The second one is VME board computer (SBC-DAU) for the acquisition of TOF, ΔE, and scaler data. The third one is workstation, that performs particle identification, optimization of the beam course. The data are transferred to this workstation from the existing HEBT-SCU and the SBC-DAU in synchronization with synchrotron operation. This synchronization makes the system operation simple, and is effective for the stable operation with large data transfer of TOF and ΔE. To optimize the beam course for the specified particle, a tuning loop scans each course setting until an optimum condition will be found.

# 4 BEAM TEST OF THE COURSE

In the beam test, the focus conditions are confirmed with the data on beam profile of primary beam. In the production target, we have used the ratio of magnetic rigidity between $^{11}C$ and $^{12}C$ beams. In figure 3 the data of profile monitor at F2 are shown, where the sharp $^{11}C$ beam can be seen. In this profile, there are small contaminations of $^{12}C$ and $^{7}Be$ beams. These ratios of contamination can be measured by use of particle identification with TOF and ΔE. After adjustment of the slits at F1 and F2, we have obtained a high production-rate with low impurity, as listed in table 2. The automated tuning loop made the adjustment time short (about 20 minutes for $^{11}C$). The left problem is the intensity monitor of the primary beam, with which the tuning time can be improved.

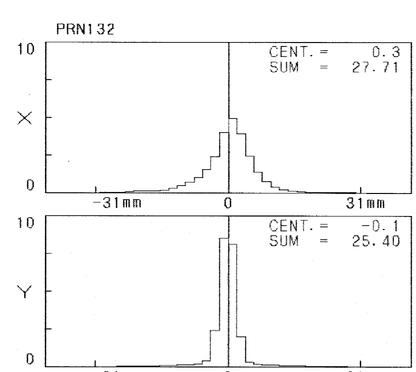


Figure 3. The beam profiles of $^{11}C$ at F2. (x; horizontal, y; vertical)

Table 2: Production rate of $^{11}C$ beam with primary beam energy of 400 MeV/u and Be target thickness of 51mm

| | | | | |
|---|---|---|---|---|
| Al degrader thickness (mm) | 3.5 | 7.0 | 11. | 17. |
| Secondary beam energy (MeV/u) | 314 | 305 | 297 | 279 |
| Production rate(%) | 0.2 | 0.19 | 0.18 | 0.13 |
| Purity(%) | 97 | 98 | 98 | 98 |

## 5 IRRADIATION SYSTEM

Irradiation system is now under the design stage, whose construction is intended to finish in three years. To use secondary beam of low intensity, such as $^{11}C$, the efficiency of the irradiation system should be much higher than that of the existing system in HIMAC, where wobbler magnets are used with a scatterer. From this reason the spot scanning method is now under consideration. This irradiation system is also interesting from the viewpoint of dose concentration on the cancer volume. In this beam scanning, the horizontal and vertical scanning magnets will be used. The energy will be scanned by the range-shifter placed just in front of the patient. This method simplifies the operation of the accelerator, because it is not necessary to change the beam energy in the accelerator including the beam transport line. This is particularly suitable for the irradiation with secondary beam, because all parameters of the beam course including the thickness of the production target and achromatic degrader are optimized to the given beam energy. We summarize the irradiation system in table 3.

Table 3: Parameters of irradiation system.

| | |
|---|---|
| Expected ion species | $^{12}C$,$^{11}C$,$^{10}C$ |
| Distance between the last quadrupole and the patient | 6 m |
| Target volume | $10^3$ $cm^3$ |
| Scan field with magnets (x and y) | 10 cm |
| Range shifter (max.) | 30g/$cm^2$ |
| Range modulation | 5mm with ridge filter |
| Beam intensity | $< 6\times10^6$pps |
| Beam monitors | two intensity monitors (main and sub)<br>one profile monitor(x,y) |
| Collimator | Multi-leaves<br>aperture (x,y) ±75 mm<br>step width 2 mm<br>thickness (Fe) 140 mm |
| Patient setting | chair, bed |

## 6 VERIFICATION SYSTEM

As a verification system, we are now considering a positron camera and PET. As for the positron camera, a prototype is being tested with RI source and $^{11}C$ beam. This prototype consists of a pair of the NaI block attached with 6×6 phototubes, which is expected to achieve higher efficiency than the camera with BGO block array. With this camera the pencil beam, whose diameter is as small as 1mm, will be used to measure the correct range in the complex human body. To shorten the measurement and to inject the beam at the multitude of points successively, $^{10}C$ beam is also under consideration.

If we irradiate cancer volume with $^{11}C$, the PET can be used to measure the irradiated volume. This requires an increase in the efficiency of the 3D data acquisition PET. With the PET of Siemens HR+, we have tested the image quality of the positron emitter in the patient, which was produced in the irradiation devices and patient with $^{12}C$ beam. Using the $^{11}C$ beam we can improve the image quality with higher statistics by about one order.

## 7 SUMMARY

The secondary beam line for medical use has been constructed, and its beam test has showed the satisfactory performances. The production rate of $^{11}C$ was 0.2% with 97% purity, which allows us to irradiate a small tumor volume. The tuning of the secondary beam course becomes easy and requires only a short time (about 20 minutes for $^{11}C$) to obtain the specified secondary beam. As a next stage, we have started to construct the irradiation system with a spot scanning method and the verification systems.


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