

NEW SECONDARY BEAM COURSE FOR MEDICAL USE IN HIMAC

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Abstract

A new beam course, a projectile fragment separator to provide radioactive beams, is under construction at HIMAC. A primary purpose of the new beam course is to study medical applications of radioactive beams. The specifications and status of the beam course and a preliminary result using carbon beams are summarized.

1 INTRODUCTION

In heavy-ion therapy, it is critical to control the dose distribution in a patient's body as accurately as possible in order to utilize the superiority to conventional methods. We, however, have no methods to validate irradiated volumes inside a body. Furthermore, since beam ranges are calculated based on the CT values obtained by CT scanned images, in some cases large uncertainties may be unavoidable. If the dose distribution can be measured accurately enough, heavy-ion therapy will become a more advanced technique.

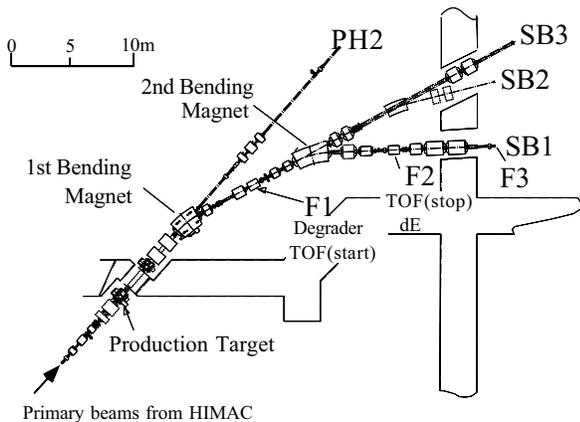


Figure: 1 Layout of the secondary beam course in HIMAC at NIRS.

Beams of positron emitters, such as ^{11}C or ^{19}Ne , may enable us to evaluate the dose distribution inside a body, because positron emitters injected into a body produce a pair of annihilation gamma rays (511 keV), mainly, near to the locations where they stop.

For a study of medical applications of radioactive beams, a secondary beam course is under construction at HIMAC (Heavy Ion Medical Accelerator in Chiba) at National Institute of Radiological Sciences[1,2]. Research on medical applications covers two categories. The first category is the measurement of the beam ranges. If we can measure the ranges of secondary beams accurately enough, we can feedback this knowledge to treatment

planning and make the planning more reliable. This would allow us to apply heavy-ion treatments to targets which are located near to radiation-sensitive organs. The development of new positron cameras to detect the annihilation gamma rays are being carried out in order to measure the range with high accuracy, in parallel with the construction of beam course. The second category is a treatment by radioactive beams, themselves. It is a large advantage that irradiated volumes can be scanned and confirmed immediately after each irradiation.

2 DESIGN OF THE BEAM COURSE

2.1 Layouts and beam optics

A layout of the secondary beam course is shown in Figure 1. New courses branch off the existing course, PH2, which is used for physics experiments, and three courses are included in the design. A course labeled SB1 is under construction. All devices up to F2 in the figure were installed by the end of March, 1997, and the remaining devices of SB1 will be placed in August, 1997. Spaces for two other courses, SB2 and SB3, are being kept open for future construction.

Beam course SB1 is a spectrometer comprising a pair of bending magnets, eleven quadrupole magnets, a production target and an energy degrader [3], satisfying a double-achromatic condition. The principle to separate ions with specific A and Z numbers is based on the work of Dufour et al.[3]. The SB1 course has three focusing points, F1, F2 and F3, as shown in Figure 1; point F1 is dispersive in momentum, while two other points, F2 and F3, are doubly achromatic. The degrader is set at F1. The specifications of the beam course are summarized in Table 1, and the calculated beam envelopes are shown in Figure 2.

The effect of the degrader was estimated by a code ORBIT2 [4], which allows us to treat the degrader as an optical element[5].

Table: 1 Specifications of the secondary beam course in HIMAC.

Maximum magnetic rigidity	8.13 Tm
Momentum acceptance	2.6% (full width)
Angular acceptance	Horizontal 26mrad (full width) Vertical 26mrad (full width)
Momentum dispersion at F1	1.78m
Bending Magnet	Radius 5m
Bending angle	1st bending magnet 20 degrees 2nd bending magnet 26.5 degrees

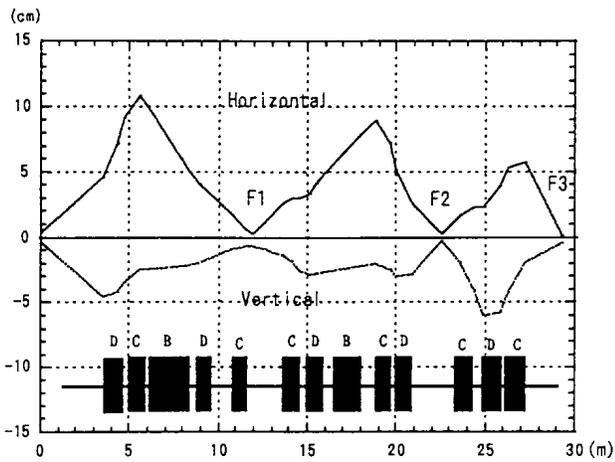


Figure: 2 Beam envelopes of the secondary beam course SB1. Emittance of the vertical and horizontal are assumed to be 40π mm mrad at the production target.

2.2 Beam monitoring detectors

Secondary particles are identified by using time of flight (TOF) and delta E data. A start and a stop counter for TOF, plastic scintillators with a thickness of 0.5 mm, are placed at F1 and F2, respectively. A delta E counter, a silicon detector with a thickness of 0.5 mm, is set at F2.

Profile monitors of multiwire proportional chambers are installed at F1, F2, and F3 in order to measure the positions and sizes of primary beams.

2.3 Control system

Beam courses for medical use are required to have characteristic features: a good reproducibility of beam qualities and easy operation. A good reproducibility includes energies, intensities, sizes, and purity of the secondary beams. Easy operation is indispensable so that operators with no special knowledge about reaction products can operate the beam course as routine work.

A new control system, to satisfy those requirements, is designed and constructed. The control system comprises three computers connected by a network, as shown in Figure 3. The system processes many functions, including: (1) control of devices, such as magnets and targets; (2) analyses of data from monitoring detectors; and (3) beam-optics calculations. Each function proceeds according to the programmed sequences. Since these functions are dealt within one framework, measured or calculated data can be referred swiftly and automatically. Thus, a sizable reduction of the tuning time is expected for such processes as the optimization of parameters, which requires reiteration of device-settings and measurements.

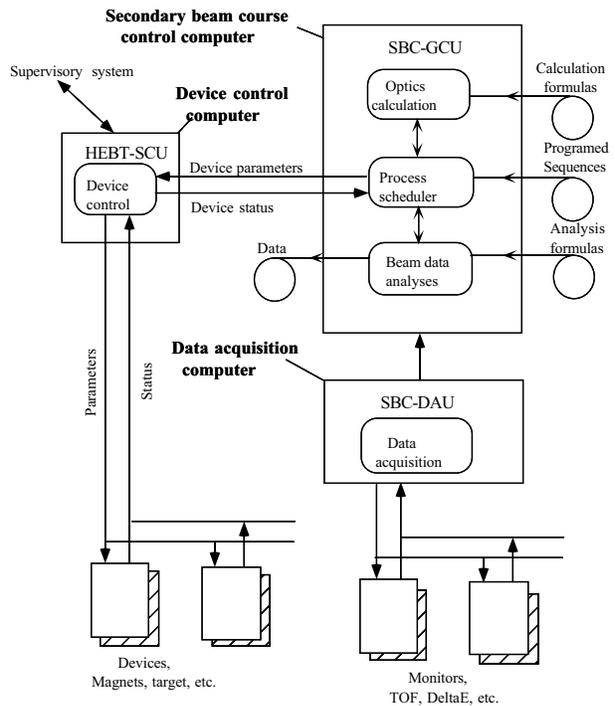


Figure: 3 Block diagram of the control system of the secondary beam course.

3 RESULTS OF THE BEAM TESTS

A first beam test of the new course was carried out using ^{12}C beams with energies of 290 MeV/u and 400 MeV/u. The results verified the calculated beam optics and alignments of the devices.

Projectile fragments produced in aluminium targets were also measured. The thickness of the targets was 3.6 cm and 5.5 cm for 290 MeV/u and 400 MeV/u ^{12}C beams, respectively, corresponding to the thickness with which the maximum yields of ^{11}C were expected by a computer code, INTENSITY2[6]. A scatter plot of TOF vs. delta E is shown in Figure 5. It can be seen that the events are clearly separated from each other depending on A and Z numbers.

As a rough evaluation, a production ratio of ^{11}C with a primary beam of ^{12}C was found to be on the order of 10^{-3} . The ratio is consistent with an estimation by INTENSITY2.

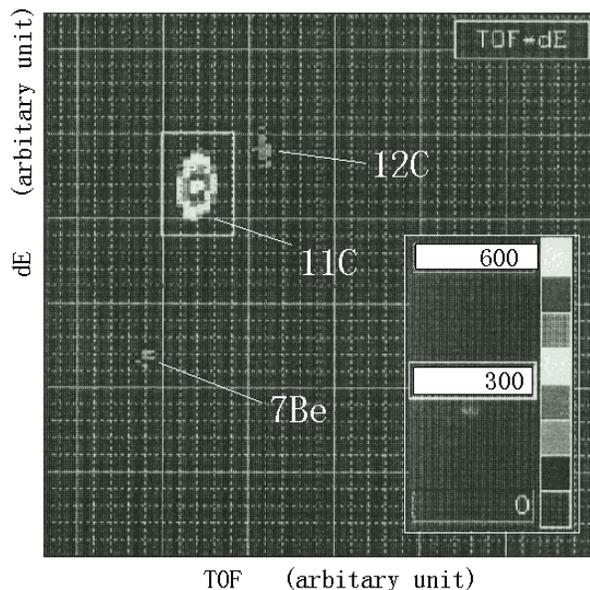


Figure: 4 Scatter plot of TOF vs. delta E obtained in the beam test. Events of ^{11}C , ^{12}C and ^7Be are clearly separated. The intensity ratio of ^{11}C , ^{12}C and ^7Be are about 90%, 5% and 5%, respectively.

4 ACCURATE RANGE MEASUREMENTS USING SECONDARY BEAMS

The development of new positron cameras for accurate range measurements is in progress. The conditions required to the positron cameras are twofold: large detection efficiency and high spatial resolution (about 1mm). The first condition comes from a fact that a dose level allowed for diagnosis is very low (typically less than 0.1 Gy). Efficiency and spatial resolution of existing PET cameras are not good as being expected. A method to determine the beam ranges using the positron camera is shown in Figure 6. A pencil beam of positron emitters is injected to a body from the left, and a pair of annihilation gamma rays are emitted at a near place where the beam stops. A pair of detectors detect those gamma rays and define a line along which gamma rays produced. The point where annihilation gamma rays produced is chosen as a crossing point of the beam axis and the line.

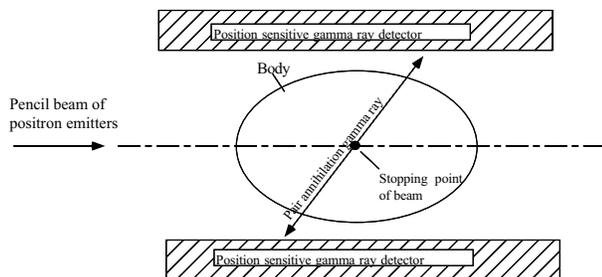


Figure: 5 Method of range evaluation by the positron camera.

A test detector was assembled for the development of positron cameras. The detector resembles an Anger-type camera, except for the collimators. An NaI(Tl) crystal with a size of 10 cm x 10 cm x 3 cm is viewed by an array of 6x6 photo-multiplier tubes (HAMAMATU H3166). Outputs from the photo-multiplier tubes are independently measured by charge-sensitive ADCs (LeCroy 2249). The positions where a gamma ray hits are decided by the distribution of the light outputs from the nearby photomultiplier tubes. NaI(Tl) scintillators were employed due to their properties of large light outputs, relatively high efficiency for 511 keV gamma rays and availability of a large crystal. The position resolution and efficiency of the test detector are being evaluated.

5 SUMMARY

For the advancement of heavy-ion therapy, we are constructing a secondary beam course, with a computer-assisted control system. The first beam test was carried out with satisfying results. The amount of the ^{11}C produced was consistent with the estimation. We are also developing positron cameras for accurate range measurements.

6 ACKNOWLEDGEMENTS

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