PRESENT STATUS OF HIMAC AT NIRS

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Abstract

Since 1994 clinical trials have been performed successfully with carbon beam. To improve the clinical result further, new irradiation systems are under development such as a 3D-irradiation system and a verification system of range with positron emitter. There are also improvements on the accelerator performances. One is the wide range of ion species; the others are concerned with the machine devices and new beam monitors to get good machine operation. In this report we present current status of HIMAC.

1 INTRODUCTION

Heavy ion therapy has both the advantage of high RBE (Relative Biological Effectiveness) and low OER (Oxygen Enhancement Ratio) with good dose concentration on the tumour. To verify its effectiveness in the cancer treatment, the HIMAC (Heavy Ion Medical Accelerator in Chiba) project[1] had started in 1987. In the treatment the carbon ion was selected because of its good dose distribution with high RBE value. Since June 1994, 557 patients were treated. In the first treatment in 1994 the head and neck tumours were treated, and now we are carrying out treatments on 9 tumour sites. The systematic clinical studies are made and suitable dose value is decided in each tumour site. Reports are published on the clinical results with the cases treated until August 1998[2][3].

In parallel with the clinical treatment in daytime, developments of new irradiation systems have been made during night and weekend. First is a synchronized irradiation with respiration, where newly developed extraction method was adopted[4]. Now the treatment with this technique is routinely used for the tumour site like lung and liver, whose movement due to respiration is not negligible. Second is 3-D irradiation system[5], which will be started in this year for the routine treatment. In this method the synchronized irradiation will also be combined, and the concentration of dose on the tumour can be improved. By this irradiation method the moving tumour site is also possible to be treated. Third is an irradiation system with positron emitter beam like ^{11}C. With this beam we can verify the range of the ion beam inside the patient body. For this, the secondary beam course has been constructed and its beam tests have also been completed. Now we are constructing an irradiation system.

To supply the beam for various kinds of experiments, the injector linac system has been improved to accelerate different kinds of ions simultaneously. The accelerated beam are transported to medium experimental hall, upper and lower synchrotron rings, and the beam can be used in the different three experimental halls. Owing to this improvement the 53 groups of biological experiments and the 52 groups of physical ones were programmed during 1998 financial year by use of night and weekend machine time.

2 OPERATION AND ITS IMPROVEMENTS

In the daily operation, treatment is scheduled between 8:30 and 19:00 from Tuesday to Friday. Experiments are assigned from Monday night to Saturday night except the time for the treatment. Between treatment and experiment, it takes 90 minutes to change ion species, energies in two synchrotrons and to adjust corresponding transport lines. For the treatment in the horizontal irradiation system the beam energies of 290 and 400 MeV/u are used, and in the vertical one the beam energies of 290 and 350 MeV/u are used. Change of beam energy in each case is scheduled once a day. To switch the beam energy in the synchrotron and the transport line, 30 minutes are required. Additional 30 minutes are also necessary for range check in the irradiation system. Within this time beam centres are adjusted in all the treatment rooms, and the beam intensity is also adjusted. After that it is sufficient to only change the excitation of one switching magnet for the switch of the beam course from one treatment room to another. It is not necessary to check the beam centre again in the treatment room after switching the beam course. This reliability is highly important to treat many patients in the routine irradiation. To make this period short further, improvements on the control software’s of accelerator [6] and monitors in the irradiation system are planed. One of these improvements is an automatic tuning system of the beam transport line[7]. Another improvement is the range check in the irradiation system when the beam energy is switched.

For the experiments three different ions can be used simultaneously in the three experimental halls, which are

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accelerated in the injector linac, upper synchrotron and lower synchrotron[8]. Available ion species are increased with new ion sources of 18 GHz ECR[9] including proton and iron. Former is important for the R&D of the proton therapy whose facilities are now increasing. Latter is important to test the biological damage in the space ship.

To have better performance of synchrotron, we have made several improvements after commissioning. To obtain better spill structure of the slow extraction beam, power supplies of dipole and quadrupole magnets are improved in its control circuit to have low ripple currents. Strong ripples, which were existed in the beginning of the machine operation, are now suppressed satisfactory[10]. As a next step the spill control with feedback and feedforward systems[11] will be tested. To obtain higher beam intensity, sextupole magnets are installed to correct the vertical cromaticity. COD monitors and steering magnets are also installed to increase the beam intensity[12]. To obtain maximum beam intensity of 2×10^9pps (particles per second) from the synchrotron in the case of carbon beam, the vertical COD correction is important. Further increase of the beam intensity will be required for the basic experiments. This is also strongly required in the secondary beam course. For this purpose the further machine study is important, and new following beam monitors are installed for the machine study.

a) A beam profile monitor with MCP in the synchrotron ring[13].
b) Tune monitor system with white noise generator and a real time spectrum analyzer. With this system we can measure the tune value in the acceleration period.
c) Quadrupole kicker and pick-up monitor to measure the incoherent tune shift.

3 NEW IRRADIATION SYSTEM IN THE SECONDARY BEAM COURSE

The secondary beam line for medical use has been constructed, and its beam test has showed the expected performances[14]. To use this course for medical use, the control should be easy, and the beam-tuning time should also be short. To realize these requirements, we have developed an automatic tuning system. 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. The tuning of the secondary beam course becomes easy and requires only about 20 minutes for ^{11}C. The production rate of ^{11}C was 0.2% with 97% purity, which suggests a possibility to directly irradiate a small tumour volume. As a next stage, we have started to construct the irradiation system with a spot scanning method and the verification systems. 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 adopted. This irradiation system is also interesting from the viewpoint of better dose concentration on the cancer volume. In this beam scanning, the horizontal and vertical scanning magnets are used. The energy will be changed by the range-shifter placed just in front of the patient as shown in Figure 1. 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 with the given beam energy to obtain high secondary beam intensity with good purity. Table 1 summarizes the irradiation system.

As a verification system, we are now considering a positron camera and also PET. As for the positron camera, a prototype is being tested with RI source and ^{11}C beam. A pair of large NaI block attached with 109 phototubes in each is used to achieve higher efficiency. 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 time and to inject the beam at the several 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 possibility requires an increase in the efficiency, which is possible with modern 3D data acquisition PET such as Siemens HR+. With this PET 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.

Table 1: 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) 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

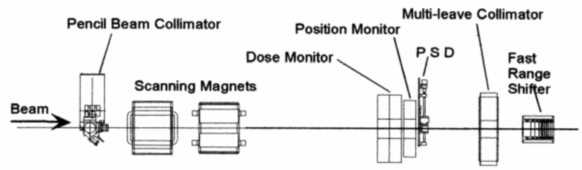

Figure 1: Irradiation system for the secondary beam course.

4 DEVELOPMENTS OF MACHINE COMPONENTS

Encouraged with nice results of heavy ion therapy, there are developments that have possibility to be used in the dedicated machine for therapy with carbon beam.

One is design study of an injector linac with IH type for carbon beam of C^{4+}. Characteristic point of this type is its high shunt impedance, and it is possible to make short injector linac. It has structure of APF (Alternative Phase Focusing) with input and output energies are 65 keV/u and 6 MeV/u in the tentative design. This low input energy can be obtained directly from ion source, and this make the injector linac system simple.

Others are compact acceleration cavities in the synchrotron that hasn't tuning system. In one type all pass network (APN) is used to obtain wide frequency range, where the acceleration cavity is one element in the APN circuit. In another type of the acceleration cavity, low Q material (Magnetic Alloy) is used in the cavity to obtain wide frequency range. Because of no tuning system in the wide frequency range, higher harmonics can be added in the acceleration voltage. This possibility is important to suppress the space charge effect, and is important for the small and low injection energy ring, that should be necessary for dedicated synchrotron. The beam test with one of these cavities is presented in this conference[15].

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