COMMISSIONING OF HEAVY-ION TREATMENT FACILITY I-ROCK IN KANAGAWA

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Abstract

As part of the Kanagawa "Challenge-10-years strategy to cancer" it was decided in March 2005 to establish a carbon-ion therapy system at the Kanagawa Cancer Center (KCC). From around 2009, the basic design and the foundational planning of the facility were considered and in January 2012 a contract was made with the Toshiba Corp. In December of the same year, the construction of the main building for the acceleration and treatment devices was started and completed in October 2014. Currently, the KCC is in a commissioning phase with the aim to start treatment in December of this year. Various treatments for cancer, which include the present photon LINAC for the radiation therapy, will be provided to patients in cooperation with our cancer center hospital. In addition, we will combine a compact dissemination treatment system of carbon-ion therapy to the pencil beam 3D scanning technique designed by the National Institute of Radiological Sciences (NIRS). The treatment experience with the carbon-ion scanning technique will be the second in the country following NIRS. In this paper, we report on the progress of the beam commissioning at KCC.

INTRODUCTION

The carbon-ion therapy facility of the KCC, which is called "Ion-beam Radiation Oncology Center in Kanagawa (i-ROCK)", has been introduced with concepts for cancer treatment as described below. At first, we aim to provide the most suitable treatment, which includes the existing photon LINAC for the radiation therapy, to any patient in cooperation with our hospital organization. The facility for carbon therapy has been constructed, focusing the cancer treatment on "Quality of Life (QOL)".

The general layout and schedule of the i-ROCK project was considered with its original specifications from around 2009. In January 2012, an agreement with the Toshiba Corp. was made to introduce and install the carbon-ion therapy system. The construction of the facility building was started from December 2010 by the Kajima Corp. and was completed in October 2014. The equipment of the treatment system was delivered from May 2014. At present, various commissionings have been performed to start first treatment in December 2015.

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SPECIFICATIONS

The original specifications of the facility used for the treatment follow that of the compact dissemination treatment system of carbon-ion therapy [1] designed and developed by the NIRS. This system was already used for the cancer treatment in Gunma University and SAGA HIMAT achieving good results while each facility vendor was different. One of the main features in i-ROCK is the combined installation with a 3D pencil beam scanning system [2] developed by NIRS and the compact dissemination treatment system of carbon-ion therapy. The main specifications are indicated in Table 1.

Table1: Specifications of i-ROCK

Item	Basic specifications
Ion	C^{6+}
Energy	140～400 MeV/u (variable)
max. Field	20×20 cm^2
max. Dose rate	2 Gy/min
Beam intensity	~1.2×10^9 pps (variable)
Irradiation type	Scanning Extended scanning
Treatment room	Horizontal: 2 rooms Horizontal/Vertical: 2rooms

In order to use efficiently use the pencil beam delivered from the synchrotron accelerator, the treatment room set up contains 4 (Horizontal/Vertical x 2 rooms, Horizontal x 2 rooms, 6 ports for total of 4 rooms). Generally, more than one treatment room per accelerator was set up in the present facility because during treatment time more than 80 % is spent on the positioning of the patient by the X-ray imaging system. However for our facility, it is a little bit different. We considered with the ration of the treated tumor in Kanagawa and the treatment protocol for the carbon therapy to fix the number of the treatment room. With these considerations, our facility can accept 880

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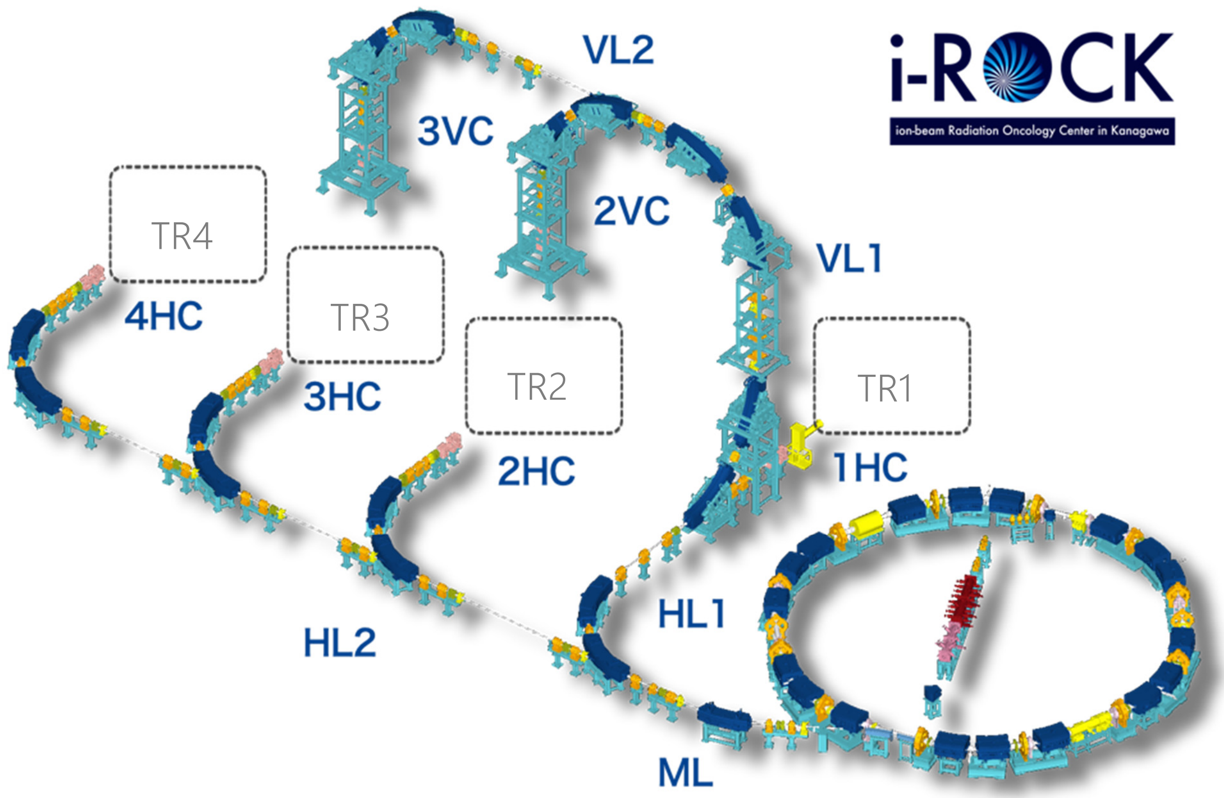

Figure 1: Configuration of the accelerator system.

patients per year when our center will be operated at full capacity.

ACCELERATOR SYSTEM

The accelerator system consists of the injector, the synchrotron accelerator, and the high energy beam transport line. Figure 1 shows the configuration of the accelerator system. The most important role of the accelerator system for the treatment is to deliver the beam with tolerable stability and certainty. To achieve the required stability of the pencil beam during the scanning irradiation, several functions were added to the conventional treatment system.

The operation mode of the synchrotron accelerator was improved to achieve efficient respiration gated irradiation for the treatment of moving organ, such as lung and liver. The synchrotron control system is capable of flexible flattop extension, called the "extended FT operation," which can decrease the dead time, as schematically shown in Fig. 2. Since a few synchrotron acceleration cycles can deliver a sufficient number of carbon ions for one fractional irradiation, the dead time of the synchrotron will be almost negligible owing to this extended FT operation.

In addition, more flexible operation of the synchrotron, as an alternative to the energy degrader, i.e. range shifter, is also be realized. This operation mode is called "multiple-energy operation", which is developed and already routinely used in NIRS [3,4]. This operation uses synchrotron operation patterns having a stepwise flattops. Cooperating with extended flattop operation, carbon ions with various energies can be provided in a single synchrotron cycle. Since the extraction energy can be quickly changed by the accelerator, no energy degrader is required to control the Bragg-peak position in the patient's body.

Accelerator system can deliver the beam automatically as required from the irradiation system without manual operation. So small number of the operators can control every system.

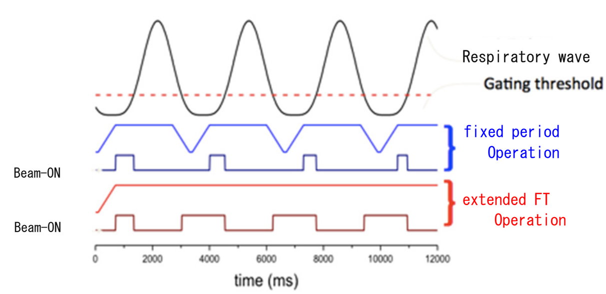

Figure 2: Schematic picture of an extended flat-top operation.

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COMISSIONING

Performance Test of Non-Scanned Beam

Since the beam stability is directly affects the delivered dose to the patient, i.e. treatment quality, the beam from the synchrotron should be highly stabilized in terms of intensity, position and size. Figure 3 shows the typical result of intensity check. In this test, 11 energies (430, 400, 380, 350, 320, 290, 260, 230, 200, 170 and 140 MeV/u) are delivered within single synchrotron cycle. As a result, it was verified that the constancy of the intensity and the ripples are suppressed within 20%.

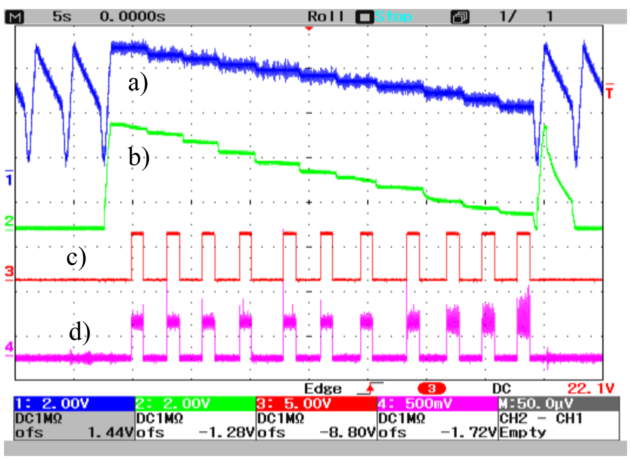

Figure 3: Spill in one cycle with the flat-top extension operation (all 11 energy). a) BM current, b) DCCT, c) Enable signal of extraction and d) Dose monitor.

The position and the size of the beam were measured using the ISO-SCN [5] (fluorescence film + CCD camera). The results of the beam position and size in the respective energy are shown in Figure 4. The measurement time was set to about 10 seconds for each energy. As a result, it was verified that the beam position and size are highly stabilized within ±0.5 mm during 10 seconds extraction. The beam size for each energy was adjusted to a symmetric profile because for the clinical requirement. Furthermore, it was adjusted so that the beam size becomes fixed to keep the compatibility for all irradiation ports (1HC, 2HC, 2VC, 3HC, 3VC and 4HC). The results are indicated in Figure 5.

Performance Test of Scanned Beam

The evaluation points for the performance test of the scanned beam are as following:

1) Verification of the scanned beam position,
2) Reliability confirmation of the dose monitor,
3) Reliability confirmation of the position monitor, and
4) Overall verification for the irradiation system.

We confirmed these points based on the protocol developed by NIRS [6].

For point 1), using the measurement of the spot irradiation, the precision of the scanned beam position was verified within ± 0.5 mm. For point 2), we verified the linearity and the position dependence of the dose monitor to accurately check the dose control. For point 3), the performance of the position monitor, which was used to

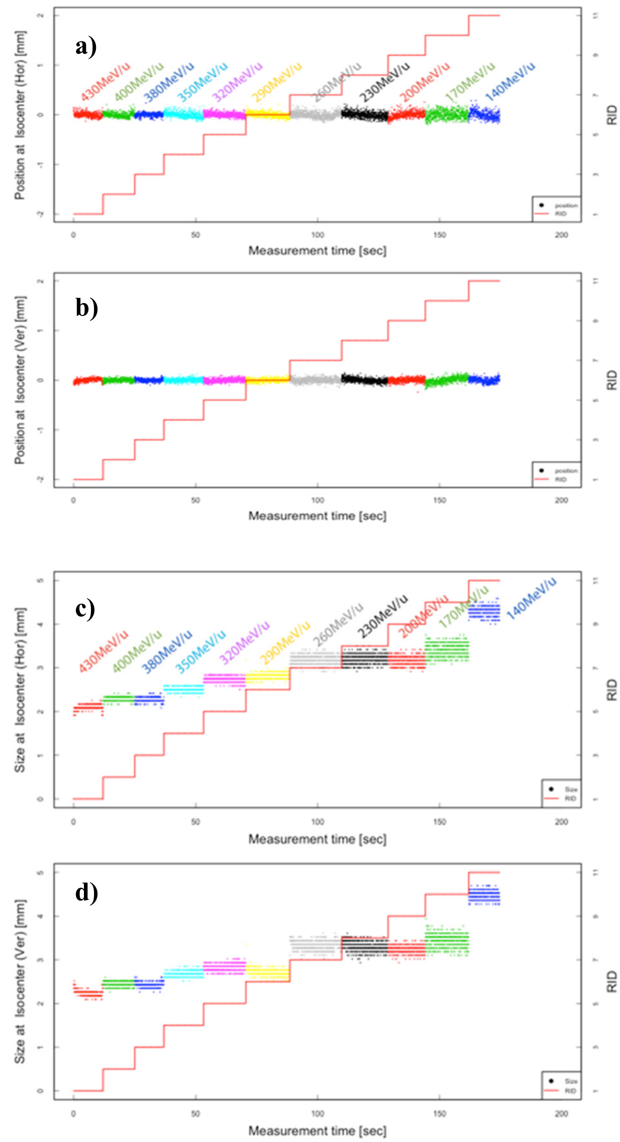

Figure 4: Beam position and size stability at 2VC. a) Beam position X, b) Beam position Y, c) Beam size X, d) Beam size Y and color differences represent the data for each energy.

survey the beam position during the irradiation, was evaluated to provide the stability of the irradiation field. The distributions of the uniform irradiation filed were measured by a screen monitor for QA (QA-SCN) [7] to estimate the position dependence of the dose monitor as shown in Fig. 6. A flatness of the field within 3 % was deduced. Finally, the overall irradiation system was checked using the QA pattern [8] in point 4), as shown in Fig. 7.

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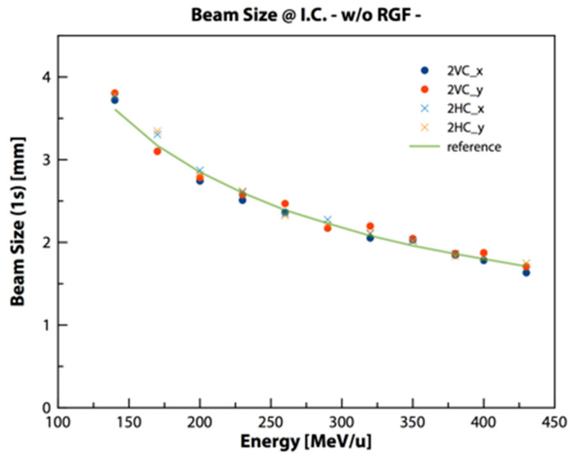

Figure 5: Beam size for each energy of 2HC and 2VC in the isocenter. Each point shows the measured data and the lines indicate the reference value for the adjustment.

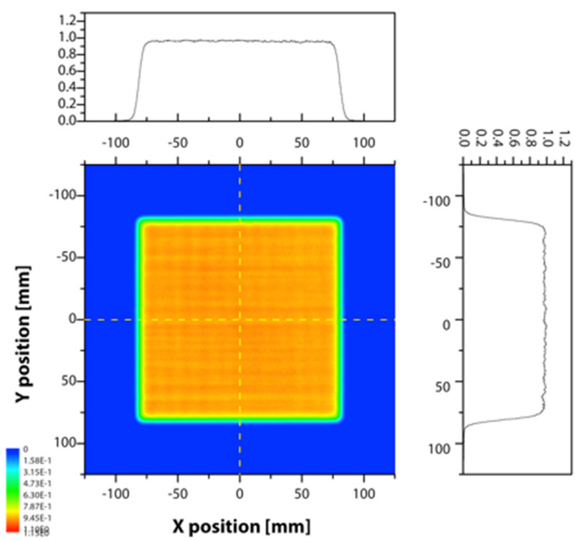

Figure 6: Measured distribution of the uniform field (150 x150 mm^2, 2 mm pitch, 290 MeV/u).

FUTURE PLAN

In June 2015, the pharmaceutical affairs in Japan was applied to prepare for the first treatment in December 2015. During summer 2015, the combination tests between each system were finished assuming several work-flows of specific protocols for the treatment. We are planning to start the preparation of the treatment with all personal (doctor, therapist, engineer, nurse and medical physicist) around this September 2015, with training of the treatment planning system, the patient positioning system and the irradiation system. We plan to provide the first treatment in December 2015.

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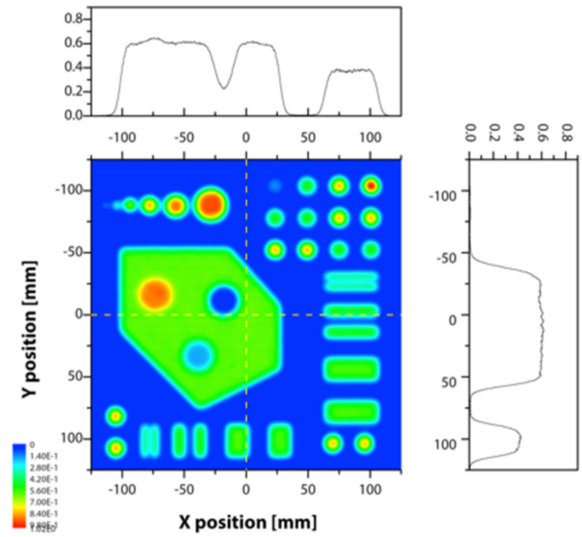

Figure 7: Measurement result with the comprehensive pattern (2 mm pitch, 290 MeV/u).

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