Hyogo Hadron Therapy Center

Takashi AKAGI, Morimasa HASHIMOTO, Yoshio HISHIKAWA, Akio HIGASHI,
Hiroshi KARASHIMA, Kyoichi ISHIDA, Akifumi ITANO, Michhisa KATO and Yoshihisa NAKAYAMA
Public Health Department, Hyogo Prefectural Government
Kobe, Hyogo, 650 JAPAN
Masahiro ENDO, Yasuo HIRAO, Tatsuaki KANAI, Kiyomitsu KAWACHI,
Koji NODA, Masami TORIKOSHI and Satoru YAMADA
National Institute of Radiological Sciences
Inage, Chiba, 263, JAPAN

Abstract

Hyogo Prefectural Government has decided and started construction of Hyogo Hadron Therapy Center in Harima Science Garden City, where is about 75km away from Kobe City to the north-west. The center has injector, synchrotron, high energy beam transport system and treatment system. The accelerator complex can accelerate proton, helium, and carbon. The energy ranges are 70-230 MeV/u for proton and helium, and 70-320 MeV/u for the carbon. The beam intensity is required to satisfy the dose rate of 5Gy/min. for treatment volume of 15cmϕ field size and fully extended spread out Bragg peak(SOBP). The beam transport system consists of three horizontal ports, one vertical ports, and one 45° oblique port for proton, helium and carbon beam, two isocentric gantry ports only for proton beam. A hospital within 50 beds is constructed with the site. Patient treatment will be started in the year 2001.

1 Introduction

Since the proton beam has a good dose distribution due to so called Bragg peak comparing to X-ray, radiotherapy with proton has been trend in the present days. The Bragg peak can be extended three-dimensionally as to fit to tumor size by treatment system devices. Heavy ions like carbon have more excellent distribution of the dose than proton due to the small multiple scattering and the small beam straggling. They have also higher radio-biological effectiveness than X-ray and proton. Clinical trials with the carbon beam have been successfully progressing at Heavy Ion Medical Accelerator in Chiba (HIMAC) in the National Institute of Radiological Sciences (NIRS) [1] from June in 1994.

Hyogo Prefectural Government has decided construction of a Hadron Therapy Center referring to the results of HIMAC [2]. The beam particles are proton, helium and carbon. Accelerator and treatment system are designed to satisfy the clinical requirement shown in Table 1. The beam should be well controlled with an accuracy. The intensity of the beam should be enough to finish the irradiation within a few minutes. Furthermore, the center aims to have treatment of 1200 patients per year. In order to achieve the aim, the stable operation and reproducibility are required to the accelerator and the beam transport. The operation is automated as possible to reduce man power and running cost.

Table 1
Clinical requirement

Particles	Proton, Helium, Carbon
Dose Rate	5Gy/min for maximum treatment volume of 15cm$\phi\times$full SOBP
Beam Range	4-30cm for p & He 1.3-20cm for C
Field size	15cm$\times$15cm
Field homogeneity	$\pm$2%
Displacement of beam	$\pm$ 2mm (from isocenter)

2 Accelerator

The injector consists of two 10GHz ECR ion sources with 35keV/u output energy, 1 MeV/u RFQ linac, Alvarez linac and debuncher. The linaces accelerates the hydrogen molecule, helium(Q/A=1/2) and carbon(Q/A=1/3) up to 5 MeV/u. A stripper located downstream of the linaces cascade makes the particles fully stripped. The operation RF frequency of the linac is 200 MHz. The debuncher then reduces a momentum spread of the beam. The synchrotron ring is a separated function type with a strong FODO focusing structure and its super periodicity is 6. The maximum rigidity of the ring is 5.58Tm. The beam is extracted by the third-order resonance scheme and sent to the beam transport system. Fig. 1 shows a layout of the accelerator complex and the beam transport system. We summarize the beam specifications of the accelerator in Table 2, which satisfy the clinical requirements

Table 2
Beam specifications

Energy Range	70-230 MeV/u for p & He 70-320 MeV/u for C
Beam Intensity	7.2×10^{10} pps for p 1.8×10^{10} pps for He 1.2×10^{9} pps for C
Beam spill length	400ms
Beam repetition rate	1Hz for p 0.5Hz for He & C

We have four fixed beam transports for all particles and two gantry ports for proton which are identical. The fixed beam ports consist of two horizontal ports, a vertical and an 45° oblique port. Another beam port is constructed for physical and/or biological experiments. All the magnets are made from laminated steel for the beam

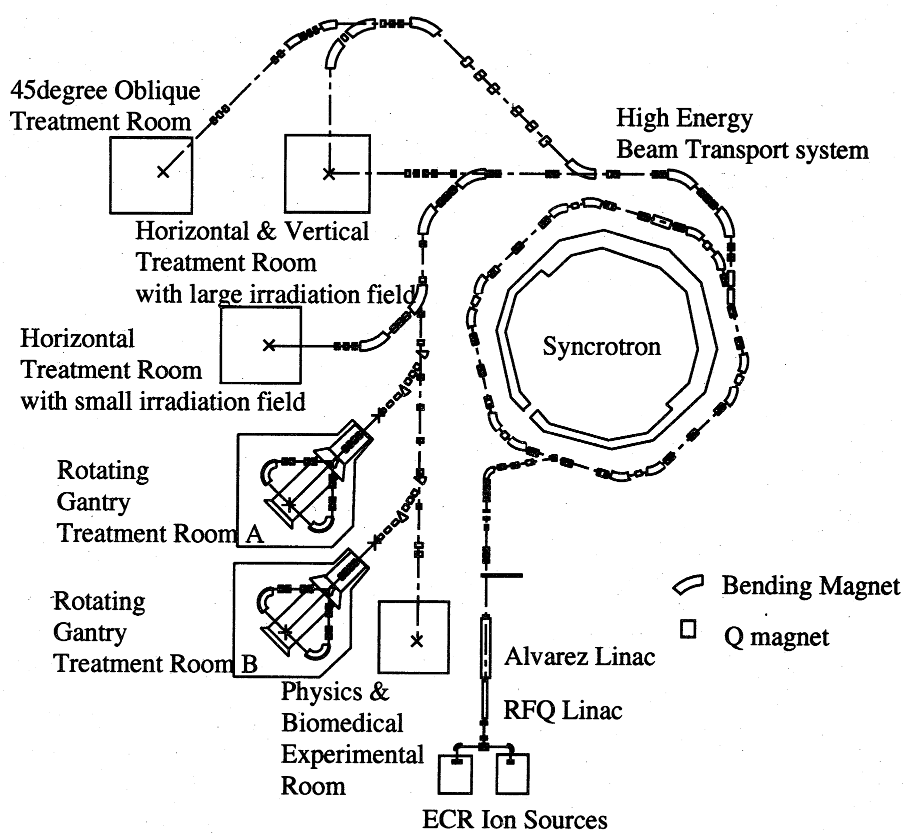

Fig. 1 Layout of the accelerator complex and treatment rooms

to have good reproducibility and energy variability. The magnet rigidity is 1.231 to 2.332 Tm for the gantry port corresponding to the proton beam energy range, 70 to 230 MeV/u, and 1.231 to 5.578 Tm for the fixed port corresponding to the carbon beam energy range, 70 to 320 MeV/u. The stability and reproducibility of the beam spot position is within ±2mm at the isocenter. The time to switch beam condition to another one should be taken short to treat many patients. The switching is done by initializing the corresponding magnets on the accelerator complex and changing the excitation pattern (and the ion source for switching particles). The sufficient machine study and automation of the switching operation make the switching time short. The expected times to switch beam condition are summarized in Table3.

Table 3
Expected time to switch beam to another condition.

Treatment room	1 min.
Energy	15 min.
Particles	30 min.

3 Treatment System

Treatment system devices are arranged at the end of each port to make an irradiation field. One horizontal port has a large irradiation field (15cm×15cm) and another horizontal port has a small irradiation field (5cm ϕ) aimed for radiosurgery. The horizontal fixed port with the large field is shown in Fig.2, and the gantry port is shown in Fig.3. The distance between the last bending magnet and the isocenter is 9m for the fixed ports (8m for the fixed port with the small irradiation field) and 3.4m for the gantry port. The gantry port is shorter than the fixed port to make its size compact. In order to reduce the multiple scattering on the fixed port, the beam line is evacuated until the end of the neutron shatter. The vacuum is 5×10^{-7} Torr in the average.

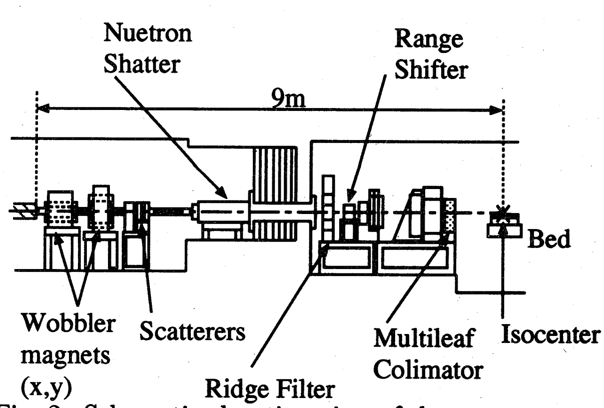

Fig. 2 Schematic elevation view of the treatment system on the horizontal fixed port.

The system devices consist of two wobbler magnets, scatterer, ridge filters, fast range shifter, and multi-leaf collimator from the upstream as shown in Fig.'s 2 and 3. The beam is extended in the lateral by combination of the wobbler magnets and the scatterer. The range of the beam is modulated by the ridge filters to make spread

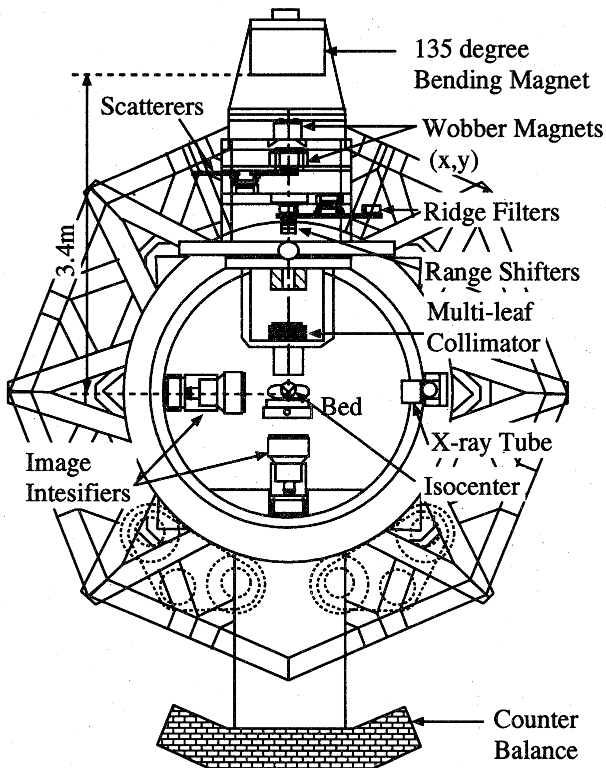

Fig. 3 Schematic front view of the treatment system on the gantry port.

Budget year	Accelerators beam delivery & instrumentation	Accelerator Building & conventional plan	Hospital
1995	Basic design		
1996	Detrailed design	Basic design Design	Basic design
1997	Construction	Construction	
1998			Design
1999	Installation	Commssioning	Construction
2000	Commssioning		Commssioning
2001	Routine beam operation		Patient treatment

Fig. 4 Construction time schedule

out Bragg peak(SOBP). The multi-leaf collimator consists of many narrow leaves of which width is expected to be less than 6mm. It can make any shape by moving the leaves one by one to fit to target tumor. The fast range shifters change the range to adjust the depth of the penetration in a very short time of 30cm/sec expected. The beam range can be also changed by changing the beam energy extracted from the synchrotron pulse by pulse. It makes a three-dimensional broad beam irradiation [3] possible. These energy modulation is also prepared for treatment with voxel/raster scanning method in the future. The irradiation during treatment is synchronized with patient's breathing. A breathing signal of patient is taken, and the beam is gated by RF knock-out extraction method [4] during the signal below a threshold.

4 Conclusion

The accelerators and treatment system has been designed as to satisfy the clinical requirement. The detail design is still in progress. The construction of the building will be started on October in 1997, this year, and be completed in two years. The detail construction schedule is summarized in Fig. 4. Patient treatment is expected to be started in the year 2001.

Acknowledgment

We would like to thank members of committee of the treatment system and committee of the accelerator for their effort to design the center.

References

[1] H. Tujii, "Commencing heavy-ion clinical trial at HIMAC.", Proceedings of NIRS International Seminar on the Application of Heavy Ion Accelerator to Radiation Therapy of Cancer in connection with XXI PTCOG Meeting, Editor T. Kanai and E. Takada, NIRS, Chiba, Japan, November 1994, NIRS-M-103 and HIMAC-008.

[2] A. Itano *et al.*, "Hyogo Hadrontherapy Center Project.", Contribution paper for II Internal Symposium on Hadrontherapy, September 1996.

[3] Y. Futami *et al.*, "Broad Beam There-dimensional Irradiation System for Heavy-Ion Radiotherapy at HIMAC", to be published.

[4] K. Noda *et al.*,"Slow beam extraction by a transverse RF field with AM and FM.", Nucl. Instru. and Meth.,A374 (1996) 267-277.