PRESENT STATUS OF HIMAC

E. Takada, T. Honma, Y. Iwata, M. Kanazawa, A. Kitagawa, M. Kumada, T. Murakami,
M. Muramatsu, K. Noda, Y. Sato, M. Suda, M. Torikoshi, S. Yamada, NIRS, Chiba, Japan
C. Kobayashi, Y. Sano, and H. Ogawa, AEC, Chiba, Japan
e-mail: takada@nirs.go.jp

Abstract

HIMAC has been in operation as an ion-therapy facility since June ’94. More than 700 patients have been treated with carbon beam of 290 to 400 MeV/u by the end of ’99. The intensity of the therapeutic beam has been increased about five times, to meet clinical needs for higher dose and smaller fraction size. HIMAC provided beams for various researches ranging from atomic and nuclear physics to radiobiology to detector development for space science with beams from proton to heavier ions including Si, Ar, Fe, Kr, and Xe. Radioactive beam courses have been constructed to utilize carbon-11 beam for clinical irradiation. Electron cooling system and other improvements for higher quality beams are also under way. Recent progress on accelerator facility and operations will be reported.

1 INTRODUCTION

HIMAC accelerator complex [1] has successfully provided carbon beam for clinical study on the cancer treatment since June 1994, 745 patients, or 765 target volumes, have been already completed in the treatment until this spring.

The clinical trial has been in a phased approach as defined by the individual protocols for each organ of the body to confirm efficacy of ion therapy. Of 765 targets, Head and Neck cases amount to 128, Lung 124, Prostate 97, Liver 90, Bone and Soft tissue 66, Uterus 54, CNS 46, and several other parts of the body share the balance. In the earliest phase, toxicity is a focus of study and an adversary side effect is scored null or tolerable grade, generally, with about 4 % of cases registered grade III in acute skin reaction. (Scoring with RTOG/EORTC standard) Although there are variances, e.g., dose-escalation and reduction of fraction-number, local control rate after one-year period is 82 % for available 510 cases. It is also to be noted that the protocol requires only those patients who are not curable with other conventional modality be included. Considering these conditions, initial results are satisfying one as expected. However, further systematic investigation is necessary to establish therapeutic effect of carbon ion.

HIMAC accelerator complex has been required to supply ion beams, not only for an ion therapy, but also for wider range of biological and physics experiment. Fe ions are strongly required, in particular, because it is very important to study a radiation effect on human body in the space. Accelerator physics study has also been done for improved utilization of beam to medical purposes, in collaboration with KEK, RIKEN, and RCNP researchers.

The last couple of years have seen installation of secondary beam courses and the electron cooling system in HIMAC. We report the operational status of the accelerator complex and activity at each subsystem, i.e., the injector (ion sources & linac), the synchrotron rings, and the beam transport lines. The irradiation system for therapy is beyond the scope of this report and described elsewhere. [2] Further, its recent developments in gating with breathing (respiratory) motion [3] and in three-dimensional technique [4] are not discussed in this report.

2 OPERATIONS

Operations of HIMAC are carried out by the company with whom NIRS (National Institute of Radiological Sciences) made a contract on accelerator operation, maintenance, and assistance for paramedical and other relevant research activities. It has been Accelerator Engineering Corporation, since the commissioning period of the machine. Engineers from AEC work on both maintenance and operation of the accelerator, in order to enhance a feedback from beam acceleration viewpoint to maintenance/improvement of subsystems such as power supply, beam monitoring, vacuum, etc.

At present, HIMAC operation is based on weekly cycle, with emphasis on regular delivery of the beam to treatment use that is scheduled during 8:30 to 19:30 period from Tuesday to Friday. Preventative maintenance work is carried out every other Monday, while nights and weekends are used for various experimental researches.

Operational statistics of recent years can be summarized as follows: In the last 4 years, HIMAC has been run quite stably. The injector linac was operated 4818 hours (FY96) to 5513 hours (FY99) and supplied beams 3873 hours (FY96) to 5221 hours (FY99). Time sharing operation in FY99 amounts to 1697 hours, or more than 30 % of total operation time. The unscheduled downtimes in the corresponding period of FY96 and FY99 are 57 hours and 21 hours, respectively. The synchrotron rings were operated also well. Beam acceleration time were 3973 hours and 4602 hours for “upper” and “lower” rings, respectively. Unscheduled downtimes are 1 and 6 hours, in FY99. Accordingly, no accelerator trouble has caused a change of treatment schedule, during the period. The only trouble that affected the schedule was a water-leak problem at the flange of supply-pipe, which was then fixed in 3hour span. Nevertheless, one patient has to be postponed to the next day.

Accelerated ion species range from Hydrogen to Xenon. A total of 7175 hours is recorded for beam acceleration in FY99, including time-sharing-acceleration hours. Breakdown is following: Carbon was accelerated in 4665 hours, and in descending order of time, Ar 733 hours, He 457 hours, Fe 448 hours, Ne 298 hours, Si 252 hours, H 173 hours, Xe 76 hours, Kr 32 hours, N 30 hours, and O 11 hours.

3 ION SOURCES AND INJECTOR LINAC

Recent developments of ion sources at HIMAC are reported by Kitagawa et al. [5] in this conference.

Injector linac has been working stably, as shown above Under the time-sharing-acceleration scheme, RFQ an Alvarez linac operates with a wide range of ε, Q/A, from 1/6.6 to ½, varying pulse-by-pulse. Since initial year experienced a series of problems with power tubes, several efforts have been made. One is to introduce solid state amplifier for driver stage of the RF system, which excludes tuning work due to characteristic variance o final stage power tube. Another is an independent (off line) conditioning system for the tube (SIEMENS RS2074SK). It allows conditioning of reserve tubes prior to the installation to the main system and, thus, enables a proper exchange of power tube and reducing downtim due to the tube problem.

It has also been tested to accelerate ions only with first tank of Alvarez, giving 2.6 MeV/u beam, and with the first two tanks, resulting in 4.3 MeV/u beam, successfully. This result provides us another margin of safety that we can run carbon beam for treatment at the latter energy injection. Other relevant R&D activities in this region are also reported [6,7] in this conference.

4 SYNCHROTRON RINGS

Synchrotron rings deliver carbon beams for cancer therapy, at present, of 290, 350, and 400 MeV/u. Clinical practices are known as taking time in patient immobilization to irradiate as planned. While the time for immobilizing a patient is reduced by about a quarter of the amount, call for shorter irradiation time also becomes strong, especially for breath-gating cases. Since the synchrotron had already been delivered $2x10^9$ pps (particles per second) carbon beam for biology and physics experiment, we decided to make efforts to establish the set of parameters for treatment use. The safety regulation was also reviewed and the previous limit of the intensity, $3.6x10^8$ pps has been re-formulated as a norm for weekly-integrated value.

The greatest care was exercised to control the beam extraction process, for the gating function by breathing motion must be kept as before the intensity-up. By suppressing a ´ringing´ at the end of ramping for main power supply, and adjusting beam position and tune at flat-top, and further by utilizing a tune shifter quadrupole (QDS), we were able to provide the beam for treatment, where the leakage from the off-gate timing is within the sensitivity limit for the intensity monitor at the treatment room, or less than 10^{-5} level.

It is also desired by the experimenters to deliver beams for experiment in ever-shorter switching time and less adjustment from the medical shift, while the intensity should be controllable in a large span of 5 to 6 orders of magnitude as they wish. Augmenting RFKO electrode and waveform generators would provide a suitable tool to such intensity handling, by applying RFKO before the acceleration. Improvement of the power supply control is under way so that tuning for new beam should be done more easily.

Electron cooling device had been constructed and installed in the ring by March 2000 when initial study was carried out rather successfully. [8]

R&D works for improvement of operation and instrumentation are being undertaken by AEC engineers.[9] Studies on accelerator/beam physics are also undertaken at HIMAC synchrotron ring, to develop an advanced medical accelerator. [10]

5 HIGH ENERGY BEAM TRANSPORT SYSTEM AND RI BEAM COURSES

As mentioned above, the safety regulation requires integral beam intensity of treatment room be monitored and a weekly limit of that quantity be observed. To meet this requirement, we have developed a system with so-called "quasi-non-destructive" beam profile monitor. This BPM is of same make as ordinary multi-wire type BPM we are in use at HIMAC [11], but operated with atmospheric air at the end of beam transport line. (Thus without windows that have destructive effects but applicable for medical treatment lines and biology experiment line only.) The dynamic range of the system is somewhat less than ideal at HIMAC, but satisfactory for treatment beam, whose intensity is within a small variance.

Major effort is directed to construct secondary beam courses, to realize a diagnostic and a treatment using a positron emitter, such as ^{11}C. [12,13,14]

Researches of biological and physical interests have been carried out using the beams from HIMAC during nights and weekends. In Table 1, representative results in various fields of physical sciences are listed.

Table 1. Recent works from experiments at HIMAC

Accelerator
M. Muramatsu *et al.*, Rev. Sci. Instr. 71, 984-986 (2000)
E. Urakabe *et al.*, Jpn. J. Appl. Phys. 38, 6145-6149 (99)
Nuclear Physics
Kazunori Sato *et al.*, Nucl. Phys. A654, 735c-738c (99)
Atomic Physics
T. Azuma *et al.*, Phys. Rev. Lett. 88, 528 (1999)
T. Matsuo *et al.*, Phys. Rev. A 60, 3000-3007 (1999)
Chemistry
N. Chitose *et al.*, J. Phys. Chem. A 103, 4769-4774 (99)
A. Yokoyama *et al.*, J. Radioanal. Nucl. Chem. 239, 143 (99)
Medical Physics
N. Matsufuji *et al.*, Phys. Med. Biol. 43, 3261-3275 (98)
T. Tomitani *et al.*, Jpn. J. Med. Phys. 19, 192 (1999)
H. Bichsel *et al.*, Radiat. Res. 153, 208 (2000)
Detectors
H. Takahashi *et al.*, Nucl. Instr. Meth. A 422, 751 (99)
K. Amemiya *et al.*, Nucl. Instr. Meth. B 159, 75-80 (99)
S.-L. Guo *et al.*, Radiat. Meas. 31, 167-172 (99)

6 SUMMARY

HIMAC accelerator complex has been successfully providing beams for cancer therapy and for a wide scope of multi-disciplinary studies.

ACKNOWLEGEMENTS

The authors would like to express their thanks to the colleagues of Accelerator Physics & Engineering Division of NIRS, and to the crew members of Accelerator Engineering Corporation.

REFERENCES

[1] S. Yamada *et al*., "HIMAC and Medical Accelerator Projects in Japan", APAC'98, Tsukuba, March 1998.

[2] T. Kanai *et al*., "Biophysical characteristics of HIMAC clinical irradiation system for heavy-ion radiation", Int. J. Radiat. Oncol. Biol. Phys. 44, 201-210 (1999).

[3] S. Minohara *et al*., "Respiratory gated irradiation system for heavy-ion radiotherapy", Int. J. Radiat. Oncol. Biol. Phys., 47, 1097-1103 (2000).

[4] Y. Futami *et al*., "Broad-beam three-dimensional irradiation system for heavy-ion radiotherapy at HIMAC", Nucl. Instr. & Meth. A430, 143-153 (1999).

[5] A. Kitagawa *et al*., "Recent Developments on ECR Ion Sources at the medical accelerator HIMAC", EPAC2000, THP5A01, in these proceedings.

[6] K. Ohtomo *et al*., "Short Bunching Beam Simulation under un-tuned Cavity", EPAC2000, MOP5A13, in these proceedings.

[7] Y. Hashimoto *et al*., "Development of a Beam Profile Monitor using an Oxygen Gas Sheet", EPAC2000, WEP1A12, in these proceedings.

[8] K. Noda *et al*., "Commissioning of Electron Cooler for Medical and Other Application at HIMAC", EPAC2000, TUP4A01, in these proceedings,
also, K. Noda *et al*., "Electron cooler for medical and other application at HIMAC", Nucl. Instr. & Meth. A441, 159-166 (2000).

[9] H. Izumiya *et al*., "Beam tuning with a real-time spectrum analyser at HIMA synchrotron", Proc. of 12th Symp. Acc. Sci. Tech., 567-569, Wako, Japan, Oct. 1999.
H. Ogawa *et al*., "Test of Non-destructive Beam Profile Monitor at HIMAC", ibid, 513-515.

[10] a)Kenji Sato (RCNP, Osaka U.) *et al*., EPAC2000, MOP3B19,
b)M. Inabe *et al*., EPAC2000, TUP4B11,
c)T. Uesugi *et al*., EPAC2000, THP5A10, and
d)Y. Shirakabe *et al*., EPAC2000, THP5A08,
in these proceedings.

[11] M. Torikoshi *et al*., "Beam monitor system for high-energy beam transportation at HIMAC", Nucl. Instr. & Meth. A435, 326-338 (1999).

[12] M. Suda *et al*., "Medical Application of the Positron Emitter Beam at HIMAC", EPAC2000, WEP5A01, in these proceedings.

[13] Kohsuke Sato (Toshiba) *et al*., "Spot Scanning System with RI Beam of HIMAC", EPAC2000, WEP1A17, in these proceedings.

[14] Y. Iseki *et al*., "Positron Camera System for Heavy Ion Radiotherapy at HIMAC", EPAC2000, WEP1A16, in these proceedings.