Present Status of NIRS - HIMAC

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Abstract

NIRS-HIMAC has been used for clinical trial of cancer particle therapy since it was commissioned 3 years ago. More than 300 patients were treated and preliminary evaluation is good enough to extend more treatment in advanced phase. Beam was also provided for physics and biology experiments from He to Ar.

Recent developments include RFKO extraction system for gating beam with patient's breathing, preparation of secondary beam lines for positron emitter such as ^{11}C, modification of linac system for Time Sharing Acceleration, and installation of 18 GHz ECR for providing heavier ion such as Fe.

1. Introduction

In the last symposium of the series (Symp. Acc. Sci. & Tech. in October 95), we reported the HIMAC commissioning and initial results of therapeutic irradiation of carbon ion for cancer treatment, which was carried out for about 50 patients at the time. [1] Since then, we have advanced the ion-therapy programme both in quality and quantity. The number of patients who were treated at HIMAC now totals more than 300. Table I shows the breakdown of tumor targets (patients) that were irradiated at HIMAC. It is readily seen that both number of patients and tumor site are increasing. Since medical result (of tumor control) needs to follow the cases at least in 5 years range, present evaluation is preliminary. Nevertheless, 1)Damage to normal tissue and skin is usually minimal except for intestine with prostate treatment. 2)Local control of tumor depends on site, but as for Head & Neck cases, in more than 90 % of tumors responded to irradiation and reduced its volume to less than half in 18 months period. For more clinical details, see Ref.[2].

We report here progress in the last two years, which would characterizes HIMAC as an excellent medical accelerator.

2. Machine Operation

Presently, HIMAC provides beams for treatments and experiments for 39 weeks per year, from Monday evening to Saturday (or Sunday morning once a month). It amounts to about 2200 hours operation in case of lower ring and its following courses from April to August 2 (including the first week of operation, 18 weeks). Of 2200 hours, more than 580 hours were allocated to clinical use. Physics experiments usage are nearly 700 hours. The rest was shared by beam tuning and waiting for user. Daily operation of HIMAC is carried out by operators from AEC, a company contracted for operation, maintenance, and relevant support of HIMAC with more than 30 operators. Clinical treatment practice has extended to use beam of different energy, and daily operation now includes energy change and reconfirmation process of the beam. Details of the operations are described in another contribution to this symposium.[3]

3. Recent Developments

3.1 Respiration-Gated Beam Control

A motion of body by breathing, or respiration, causes unwanted change in position (and in shape) of the target volume. Since the motion deteriorates the localization of beam, we had developed a system of beam control and irradiation to avoid superfluous dose to normal organ.[4] The system was installed to HIMAC in March '96, and began operation in June '96, including a beam deceleration operation in the ring for non-extracted beam.[5] Since then most of lung and liver cancer treatments, which amounts to more than 50 patients, have been carried out using the system. In actual operation, efforts are paid to elongate flat top period to the maximum possible duration, and in some cases, more than 90 % of spill was used for a treatment due to the improvement.

3.2 Construction of Secondary Beam Course

The verification of the distribution of beam within the target volume is one of the key issue to establish advanced method of particle therapy. So far, the range calculation was limited by several factors. A beam of positron emitter nucleus can be used as a verification tool of the range with PET or positron camera technique. Fundamental physics research will also be an important area of the secondary beam facility. We began to construct a secondary beam course that should be used for diagnostic and clinical purpose with ^{11}C beam in mind.[6] Preliminary tuning for upstream section has been under way since April '97, and the tuning system is performing well.[7]

3.3 Studies on Synchrotron Beam

Synchrotron studies to understand beam condition better have been performed. Tune shift at the injection was measured and the space charge effect was found to play non-negligible role.[8] The COD measurement and correction was also investigated for horizontal direction and it was confirmed that correction scheme works fine to reduce the COD from about 10 mm (max.) to about 2 mm.[9] Further, study was done on effect of digitizing step size on acceleration efficiency in RF system that utilizes Direct Digital Synthesizer, and HIMAC's 0.2 Gauss step clock is estimated adequate in terms of acceleration efficiency.[10] Both of the ordinary and RFKO slow extraction were investigated for improvement on spill structure, emittance, and efficiency.[11]

3.4 Ion Sources

Improvement and development works on ion sources were actively pursued. New 18 GHz ECR source was installed and has been tested for Fe and other heavier ions.[12] Study on compact ion source has been carried out to find suitable design of simple ion source for medical application.[13] In working sources of ECR and PIG, efforts for higher output and stability beam were extended. Also seeked was for variety of beam species, e.g., ^{13}C beam, H_2^+ molecular ion from CH_4 operated ECR, and copious beam of C^{+2} from PIG source.

3.5 Time Sharing Acceleration

In order to exploit the two rings and the experiment beam courses as well as treatment, Scheme for accelerating beams of different Q/A in linacs have been developed [14] and necessary hardware modification has been completed except for transport into the synchrotron. This feature will enable to accelerate, e.g., C for upper ring , Ar for lower ring, and He for 6 MeV/u experiment course. In this scheme, beam monitoring must be non-destructive when tuning one beam while the others are used. Development to meet this need of non-destructive monitor has been done and is reported in the present symposium.[15]

3.6 Improvements in High Energy Beam Transport

Lessening the manual adjustment work in routine operation of irradiation port and/or energy switching for treatment is an important element of medical accelerator development. Automatic tuning procedure has been proposed and tested for daily operation.[16] Further analysis and improvement for quicker beam delivering is under way. It was also tried successfully to deliver joined beams from both rings for apparent duty of about 80 %.

3.7 Investigations of relevant technology

The Power supply technology for synchrotron accelerator is another focus of activity. Reducing ripple components in power supply has been pursued and results are reported elsewhere.[17] In connection with this effort, measurement of ripple at the magnets are tried with novel scheme.[18] Eddy current effect in solid magnet has been studied for phenomena of minutes to hours time scale.[19]

A beam spill ripple monitor has been developed to replace the present scintillation monitor.[20] Control system development has been carried out in order to realize spill control in feed forward scheme.[21] New VME board was designed and is being tested for faster multi-pattern synchrotron operation than now.[22] Safety control system[23] has been reinforced to stabilize its operation in peak-demand.

3.8 Overview of development in irradiation system

Several works are reported to advance precision and power of patient irradiation system in the last symposium. 3D irradiation system has been tested and corresponding treatment planning software is now under development. For more efficient use of the beam, dynamic wobbling scheme has been prepared and experimented. In the area of dosimetry, efforts to accurate measurement of dose distribution in individual patient field, have been made especially in transverse directions. It is also planned to compare chamber and other measuring device output with each other world-wide. In doing this, we are going to provide proton beam from H_2^+ acceleration at synchrotron. Measurement of beam fragmentation and refinement of dose calculation to take the fragmentation into account is under way. Also the respiration gate system is to be sophisticated in order to treat the gate signal discriminator level more systematically. A comprehensive simulation system is now under design for extensive use of existing treatment room and for development of precise patient positioning system and advanced treatment planning.

4. Future Extension

Electron cooling device is to be installed in a synchrotron ring. This addition will enable emittance reduction of injected beam and thus lead not only to increase the intensity of accelerated/extracted beam, but also to shorten the pulse length to fit fast handling of the beam. It will also improve control of beam in size and stability for more precise irradiation and measurement. A new activity is being organized for a hospital based synchrotron light source.[24] In this line, R&D work has started for a 7 T superconducting wiggler magnet.

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Table I. Number of tumors treated at HIMAC (based on the press release in March 97 and on preliminary counting.)

Semester	1	2	3	4	5	6	7	Total	
Site	'94.6-8	10-95.2	95.4-8	9-96.2	96.4-8	9-97.2	97.4-8	94.6-97.8	Protocol #
Head & Neck	3	6	5	5	8	11	20	58	9301/4,9504,9601/2
Brain		6	4	4	1	9	4	28	9302
Lung		6	7	4	12	16	4	49	9303
Liver		—	5	7	6	8	7	33	9401,9603
Prostate		—	2	7	8	10	5	32	9402
Uterine Cervix		—	3	6	3	10	5	27	9403
Bone & Soft			—	—	2	7	6	15	9501
Esophagus			—	—	—	1	5	6	9502/3
Miscellaneous		—	8	16	7	10	15	56	9404
Total	3	18	34	49	47	82	71	304	

Number of patient is 2~3 less than total number of tumor.