Development of New Carbon Therapy Facility and Future Plan of HIMAC

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Contents

1. Introduction

2. New Carbon-Therapy Facility (Compact Facility)

3. Future Plan of HIMAC

4. Summary
Since 1994, Cancer treatment with HIMAC has been successfully progressed. Owing to accumulation of treatment number and good result of the clinical trials, the Japanese government approved the HIMAC treatment as the highly advanced medical therapy in Nov. ‘03.
Design Consideration for Compact Facility

- How high Energy?
- How large Irradiation-Field Size?
- How much Intensity delivered?
- How large Facility?

Based on experience at HIMAC, the specification is determined!!
Residual range of 250 mm covers almost all treatments at HIMAC.

Required energy: 400 MeV/n, under range loss of 25 mm due to scatterer etc.
The field diameter more than 200 mm is large enough to cover almost all treatments in HIMAC.

The SOBP more than 150 mm covers treatments more than 95%.
How much intensity?

\[ \eta = 0.9 \]

\[ \eta_{\text{cap}} \times \eta_{\text{acc}} = 0.8 \times 0.8 = 0.64 \]

\[ \frac{2 \times 10^{10} \text{ pps}}{2.1 \times 10^9 \text{ ppp}} \]

\[ \eta_{\text{inj}} = 0.4 \]

\[ \eta_{\text{ext}} = 0.9 \]

\[ \frac{1.3 \times 10^9 \text{ pps}}{1.2 \times 10^8 \text{ pps}} \]

\[ \eta = 0.95 \]

\[ \eta = 0.9 \]

\[ \eta = 0.7 \]

\[ 181 \mu A \]

\[ 163 \mu A \]

\[ 220 \mu A \]

\[ 200 \mu A \]

\[ 258 \mu A @ C^4^+ \]

\[ 5 \text{ GyE/min/l} \]
1. Ion species: high LET (100keV/μm) charged particle - Carbon
2. Range: Max. 25cm in water
3. Maximum irradiation area: 15cm square
4. Dose rate: 5GyE/min/l $\rightarrow$ $1.2\times10^9$pps (C ions)
5. Irradiation direction: horizontal, vertical
6. Treatment rooms: 3 (H&V, H, V)
7. Irradiation technique: gating & layer stacking irradiation
Design and R&D for Compact Facility

- Beam Study
- Compact RF-cavity
- Compact Injector RFQ + APF-IH
- Development Irrad. Tech.
- High-Precision MLC
The injector linac cascade consists of RFQ and APH-IH linac. The RFQ accelerates $C^{4+}$ ions from 10 to 600 keV/n. The APF-IH accelerates them to 4 MeV/n. Both the operation frequencies are 200 MHz.
Beam Test of Compact Injector

Y. Iwata et al., WEPCH169

ECR
RFQ
APF-IH
Analyzer

Transmission (%)

Pick-up voltage for IH-DTL (V)

FCN2 (μA)

Transmission (%)

Kinetic energy distribution for $^{12}\text{C}^{4+}$
Main parameters of the synchrotron.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lattice Type</td>
<td>FODO</td>
</tr>
<tr>
<td>Maximum intensity of C⁶⁺</td>
<td>2×10⁹ pps</td>
</tr>
<tr>
<td>Cell number</td>
<td>6</td>
</tr>
<tr>
<td>Long straight section</td>
<td>3.0m×6</td>
</tr>
<tr>
<td>Circumference</td>
<td>61.5m</td>
</tr>
<tr>
<td>Injection energy</td>
<td>4 MeV/u</td>
</tr>
<tr>
<td>Extraction energy</td>
<td>140-400 MeV/u</td>
</tr>
<tr>
<td>Revolution frequency</td>
<td>0.450-0.550 MeV/u</td>
</tr>
<tr>
<td>Emittance and Δp/p of injection beam</td>
<td>±0.2 %</td>
</tr>
<tr>
<td>Acceptance (after COD correction)</td>
<td>240/30 π mm mrad</td>
</tr>
<tr>
<td>Momentum acceptance</td>
<td>±0.4%</td>
</tr>
<tr>
<td>Qₓ/Qᵧ</td>
<td>1.68-1.72/1.13</td>
</tr>
<tr>
<td>Maximum β function</td>
<td>11.5/13.4</td>
</tr>
<tr>
<td>Transition gamma</td>
<td>1.72</td>
</tr>
<tr>
<td>ξₓ/ξᵧ</td>
<td>-0.5/-1.5</td>
</tr>
</tbody>
</table>

BM filling factor of 43% is much larger than that of 31% in HIMAC, which brings a compact synchrotron.
## Compact RF Cavity

**Un-tuned RF cavity with Co-based MA**

Comparison between HIMAC cavity

<table>
<thead>
<tr>
<th></th>
<th>HIMAC</th>
<th>New cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency [MHz]</td>
<td>0.4 ~ 7</td>
<td>4.5, 6, 15</td>
</tr>
<tr>
<td>Voltage [kV]</td>
<td>6</td>
<td>4.5</td>
</tr>
<tr>
<td>Power [kW]</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Cavity size [cm]</td>
<td>277×89</td>
<td>150×140</td>
</tr>
<tr>
<td>Size of PS etc</td>
<td>Amp. with Tetrode 70×40×60 250×150×250 70×70×90 Bias PS 100×100×200</td>
<td>Transister Amp. 60×85×220</td>
</tr>
</tbody>
</table>

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*M. Kanazawa et al., TUOCF103 A. Sugiura et al., TUPCH124*
The spot scanning and layer stacking methods require an intensity modulation. Therefore, we have studied the dynamically intensity control. This figure shows three intensity steps during 50 ms. This figure shows sinusoidal intensity wave.
Beam Delivery System

The spiral wobbler and raster scanning method can form the irradiation field by thin scatterer compared with the conventional one. This brings the longer residual range in patient.

The spiral wobbler and raster scanning can be available a larger field even under thin scatterer.

Longer residual range
### Method

<table>
<thead>
<tr>
<th></th>
<th>Wobbler</th>
<th>Spiral</th>
<th>Raster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Range</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Port Length</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Forming Time</td>
<td>○</td>
<td>×</td>
<td>△</td>
</tr>
<tr>
<td>Beam Efficiency</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Field Shape</td>
<td>×</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Power supply</td>
<td>○</td>
<td>×</td>
<td>△</td>
</tr>
</tbody>
</table>
Future Plan of HIMAC (1)

♥ For High Accurate Treatment

3D scanning on a moving target
for reducing the margin of 5 - 10 mm
♣ Repainting with Raster Scan & Layer Stacking Method

3D scanning on a fixed target
for fitting irregular shape
♣ Spot Scanning or Raster Scanning Method

♥ For Flexible Treatment and One-day Treatment

Rotating Gantry
♣ Repainting with Raster Scan & Layer Stacking Method
Future Plan of HIMAC (2)

- 2 treatment rooms (H&V) with both broad beam & 3D scanning system
- 1 gantry room

T. Furukawa et al., WEPCH167

- Broad-beam Raster & Layer Stacking
- Spot Scanning
Summary

♣ Compact carbon-therapy facility was initiated at Gunma University from April 2006: 3 years project

♣ New treatment facility with HIMAC was also initiated at NIRS from April 2006: 7 years project

Thank you for your attention!!
**Future Plan of HIMAC (3)**

- **400 MeV/n Rotating Gantry**
  - Field size: 15cm x 15cm
  - SOBP : 15cm
  - Range : 25cm
  - Repainting raster scan with layer stacking

- Compensation of asymmetry distribution

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**T. Furukawa et al., WEPCH167**
Future Plan of HIMAC (2)

Experiment of spot scan for irregular shape target
One fraction irradiation on lung cancer

The treatment period and the number of fractions have been successively reduced from 18 fractions over 6 weeks to 9 fractions over 3 weeks and further 4 fractions over one week. The end-point is single fraction. It has been carried out since April 2003.

59.4 – 95.4GyE (18 fraction)
94/10 ~ 97/8

52.8 - 60GyE (4 fraction)
00/12 ~ 03/11

54 – 79.2GyE (9 fraction)
97/9 ~ 00/12

28 - 32GyE (1 fraction)
03/4 ~ 06/3
Gated irradiation with respiration

- Irradiation system of coincident with a patient’s respiratory motion -

**Accelerator**
- Interlock system
- Gated beam extraction system (RF knockout method)

**Irradiation room**
- X-ray TV
- PSD

**Treatment control**
- Gate signal generator
- Watch & record system
- Beam monitor

**Positioning area**
- Planning simulation
- Reference Image
- Compare
- Positioning Image
- Positioning system using x-ray TV images

**Ion beam**
- Irradiation system of coincident with a patient’s respiratory motion
Layer stacking irradiation

Improvement of the irradiation accuracy

Procedure

1. Mini SOBP is produced by ridge filter.

2. The target volume is longitudinally divided into slices.

3. The mini SOBP is longitudinally scanned over the target volume in stepwise manner by using range shifter.

4. At same time, the lateral field is shaped by MLC in each slice.