Status of heavy-ion therapy at Institute of Modern Physics
Chinese Academy of Sciences
Guoqing Xiao

PTCOG53
2014.6.8-14, Shanghai
Outline

- Carbon therapy researches at IMP
- Status of Heavy Ion Medical Machine (HIMM) Projects at Lanzhou and Wuwei
Part 1

Carbon therapy researches at IMP
Situation:

Cancer patients increased ~3.2M/year in China.

New technologies and new treatment methods are required.

Heavy-ion beam is considered to be one of the most advanced and effective cancer treatments in the world.

Clinical trial studies at IMP, collaborated with two hospitals in Gansu province are successful performed, with the permission and support of local government.
IMP is founded in 1957, with ~900 employees. With the quick expanding of the Lanzhou city with a population of ~3M, the site of the largest heavy-ion accelerator system in China becomes the city center.
Heavy Ion Research Facility in Lanzhou (HIRFL)

**SSC (K=450)**
- 100 AMeV (H.I.), 110 MeV (p)
- Operated in 1988

**SFC (K=69)**
- 10 AMeV (H.I.), 17-35 MeV (p)
- Operated in 1963

**CSR (Cooling Storage Ring)**
- 1000 AMeV (H.I.), ≤ 2.8 GeV (p)
- Circumference: 160 m
- Operated in 2005

**RIBLL1**
- RIBs at tens of AMeV
- Operated in 1997

**RIBLL2**
- RIBs at hundreds of AMeV

**Clinical trial for Skin-tumor therapy started in 2006**

**Clinical trial for deep-seated tumor therapy started in 2009**
<table>
<thead>
<tr>
<th>Element</th>
<th>Charge</th>
<th>Energy (GeV)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2⁺</td>
<td></td>
<td>0.8</td>
<td>30μA</td>
</tr>
<tr>
<td>¹²C⁶⁺</td>
<td></td>
<td>12</td>
<td>10mA</td>
</tr>
<tr>
<td>³⁶Ar¹⁸⁺</td>
<td></td>
<td>36</td>
<td>1.2mA</td>
</tr>
<tr>
<td>⁵⁸Ni¹⁹⁺</td>
<td></td>
<td>27</td>
<td>0.45mA</td>
</tr>
<tr>
<td>⁷⁸Kr²⁸⁺</td>
<td></td>
<td>37</td>
<td>0.8μA</td>
</tr>
<tr>
<td>¹²⁹Xe²⁷⁺</td>
<td></td>
<td>30</td>
<td>0.5mA</td>
</tr>
<tr>
<td>²⁰⁹Bi³⁶⁺</td>
<td></td>
<td>35</td>
<td>60μA</td>
</tr>
<tr>
<td>²³⁸U³²⁺</td>
<td></td>
<td>23.8</td>
<td>160μA</td>
</tr>
</tbody>
</table>
Therapy terminal @ HIRFL for superficially-placed tumor treatment

Beam line and vertical treatment room

Irradiation system
Beam Conformal System of Shallow-seated Tumor Therapy Terminal

physical or biological dose (Gy or GyE)
depth in water (cm)

Beam Shutter
Scanning Magnets
Ionization Chamber
Plastic Scintillator Detector
Mini-Ridge Filter
Range Shifter
MLC

(a)

Body Surface
Tumor
Processes of cancer treatment

Diagnostics

TPS

Monitoring of heavy-ion beam

Patient Immobilization

Dose monitoring

Treatment monitoring

60~75Gy/4~12fr.
## Tumor types and distribution of patients with superficial tumor

<table>
<thead>
<tr>
<th>Tumor type</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutaneous squamous cell carcinoma</td>
<td>16</td>
</tr>
<tr>
<td>Basal cell carcinoma</td>
<td>12</td>
</tr>
<tr>
<td>Malignant melanoma of skin</td>
<td>7</td>
</tr>
<tr>
<td>Soft-tissue sarcoma</td>
<td>11</td>
</tr>
<tr>
<td>Malignant lymphoma</td>
<td>6</td>
</tr>
<tr>
<td>Adenocarcinoma</td>
<td>4</td>
</tr>
<tr>
<td>Other skin lesions</td>
<td>38</td>
</tr>
<tr>
<td>Malignant metastatic lymph node</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total (from 2006 to 2008)</strong></td>
<td><strong>103</strong></td>
</tr>
</tbody>
</table>
- **Squamous cell cancer** treated with carbon ion beam
- Lesion disappears completely after the radiotherapy
Clinical results of Superficial tumor treated with Carbon ions

**local tumor control rate**

- Cutaneous squamous cell carcinoma
- Basal cell carcinoma
- Malignant melanoma of skin
- Soft-tissue sarcoma

**Overall survival (OS)**

- Other skin lesions
- Malignant lymphoma
- Adenocarcinoma
- Malignant metastatic lymph node

- **3-year local tumor control rate >70%**
- **3-year OS ≥ 70%**
Treatment room, CT scanner room, control and planning room, etc.
(therapy terminal @ HIRFL-CSR)
Beam Conformal System of Deep-seated Tumor Therapy Terminal

Beam

- Scanning magnets
- Mini ridge filter
- Range shifter
- Multi-leaf collimator
- Compensator
- Body surface
- Tumor
## Tumor types and distribution of patients with deep-seat tumor

<table>
<thead>
<tr>
<th>Tumor type</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung cancer (primary + metastases )</td>
<td>22</td>
</tr>
<tr>
<td>Liver cancer (primary + metastases )</td>
<td>16</td>
</tr>
<tr>
<td>brain cancer (brain glioma, malignant meningioma and metastatic encephaloma)</td>
<td>25</td>
</tr>
<tr>
<td>Head and neck neoplasms</td>
<td>16</td>
</tr>
<tr>
<td>Bone and soft tissue sarcoma</td>
<td>13</td>
</tr>
<tr>
<td>Pancreatic cancer</td>
<td>3</td>
</tr>
<tr>
<td>Pelvic malignant tumor (rectal cancer and prostate cancer )</td>
<td>9</td>
</tr>
<tr>
<td>others</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total (from 2009 to 2013)</strong></td>
<td><strong>110</strong></td>
</tr>
</tbody>
</table>
Before treated | After treated
--- | ---
**metastatic carcinoma of lung** | disappears

**primary carcinoma of liver** | reduces 30%

**cell carcinoma of salivary gland** | disappears

**Brain glioma** | reduces 10%

**prostatic carcinoma** | reduces 30%
Local tumor control rate & overall survival
pencil beam

broad beam @ isocenter

continuous raster scanning

Uniformity irradiation field

(5cm×5cm @ HIRFL; 10cm ×10cm @ CSR)
Beam Active Scanning System

- **transverse**: pencil beam spot scanning
- **Longitudinal**: variable beam energy

3 × 3 points scanning  5 × 5 points scanning

![3x3 points scanning](image)
![5x5 points scanning](image)

![China Map](image)
Heavy-ion Microbeam Setup

1GeV $^{12}$C

300 μm

Single-ion Irradiation system
Part 2

Status of HIMM Project
Charged Particle Therapy Facilities in the World

- Med-AUSTRON (Austria)
- Wuer (China)
- IMP (China)
- KIRAMS (Korea)
- GSI (Germany)
- Heidelberg University (Germany)
- Etoile Project (France)
- CNAO (Italy)
- KACST (Saudi Arabia)
- Shanghai PTH (China)
- Berkeley (USA)
- Mayo Clinic (USA)
- Taipei (Taiwan)

Legend:
- C: Carbon Ion Radiotherapy Facility
- C: Carbon Ion Radiotherapy Facility (in planning stage or under construction)
- Purple: Proton Radiotherapy Facility
- ※: Terminated

See Below
Two heavy-ion treatment facilities are under construction at Lanzhou city and Wuwei city in Gansu province.
A: horizontal beam line
B: horizontal+vertical
C: vertical beam line
D: 45° oblique

Injector: cyclotron
Main accelerator: synchrotron
56.17m in circumference

compact heavy ion therapy facility designed at IMP
<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion</td>
<td>$^{12}\text{C}^{6+}$</td>
</tr>
<tr>
<td>$E_{\text{max.}}$</td>
<td>~400 MeV/u</td>
</tr>
<tr>
<td>Intensity</td>
<td>$4 \times 10^8$ pps</td>
</tr>
<tr>
<td>Beam Diameter</td>
<td>2~10mm</td>
</tr>
<tr>
<td>Cut-off time</td>
<td>&lt;300 $\mu$s</td>
</tr>
<tr>
<td>Range</td>
<td>27 cm</td>
</tr>
<tr>
<td>Step size</td>
<td>2mm</td>
</tr>
<tr>
<td>Dose rate</td>
<td>2 Gray/min</td>
</tr>
<tr>
<td>Dose uniformity</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Irradiation field</td>
<td>$20 \times 20\text{cm}^2$</td>
</tr>
<tr>
<td>Positioning accuracy</td>
<td>$\pm 0.5\text{mm}$</td>
</tr>
<tr>
<td>Source-skin distance</td>
<td>&gt;6m</td>
</tr>
<tr>
<td>Therapy terminals</td>
<td>1H, 1 H+V, 1V, 1V, 1 45°</td>
</tr>
</tbody>
</table>
ECRIS

Long-term stability test

Emittance measurement
Cyclotron

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion species</td>
<td>$^{12}\text{C}^{5+}$</td>
</tr>
<tr>
<td>Harmonic mode</td>
<td>4</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>2.8 m</td>
</tr>
<tr>
<td>Height</td>
<td>1.6 m</td>
</tr>
<tr>
<td>Pole radius</td>
<td>0.77 m</td>
</tr>
<tr>
<td>Hill gap</td>
<td>50 mm</td>
</tr>
<tr>
<td>Valley gap</td>
<td>360 mm</td>
</tr>
<tr>
<td>Pole tip field</td>
<td>1.67 T</td>
</tr>
<tr>
<td>Hill angular width</td>
<td>56°</td>
</tr>
<tr>
<td>Spiral</td>
<td>0°</td>
</tr>
<tr>
<td>Extraction radius</td>
<td>75 cm</td>
</tr>
<tr>
<td>Frequency</td>
<td>31.02 MHz</td>
</tr>
</tbody>
</table>

Cyclotron is being tested right now
### RF System Specifications

<table>
<thead>
<tr>
<th></th>
<th>Specifications</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency (MHz)</strong></td>
<td>0.6~3.9</td>
<td>0.563~4.0</td>
</tr>
<tr>
<td><strong>Voltage (kV)</strong></td>
<td>5.0</td>
<td>≥5.2</td>
</tr>
<tr>
<td><strong>Repeat frequency rate (s)</strong></td>
<td>3.2-13.2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Duty ratio</strong></td>
<td>1.6/3-1.6/12</td>
<td>1/2,1/3</td>
</tr>
<tr>
<td><strong>Vacuum (mbar)</strong></td>
<td>≤5×10⁻⁹ mbar</td>
<td>≤6×10⁻¹⁰ mbar</td>
</tr>
<tr>
<td><strong>Increased accuracy (Hz)</strong></td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td><strong>Voltage stability</strong></td>
<td>≤1×10⁻²</td>
<td>≤2.68769×10⁻³</td>
</tr>
<tr>
<td><strong>Long-term Stability test (72 h)</strong></td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

RF system has passed the test
nozzel design suitable for both passive and active beam deliveries
Heavy Ion Radiotherapy Treatment Planning System (HIRTPS)

- Patient information management
- Organ and target delineation
- 3D reconstruction
- Field setup
- Dose calculation (pencil beam algorithm)
- Plan evaluation
- Plan verification
- Virtual simulation
- Patient positioning
- …
plan evaluation (iso-dose curve, DVH histogram, et al.)

patient positioning verification
dosimetry verification software system

input

planned dose distribution from TPS

verification system

comparison between measured and planned doses

output
dosimetry verification system (hardware + software)
TPS

Treatment planning, simulation and verification software

Secondary collimator/multi-leave collimators /Compensator support all-in-one machine
Treatment Terminal

C-arm DR

Core Server

DAQ Test
Vacuum System

Vacuum leak test
Ceramic vacuum chamber
Trail assembly
Vacuum chamber package

Everything is ready for shipment
Beam Diagnostical System

Radial probe test
Fluorescent target
Slit
Bam position monitor
Ionization chamber
New arrival

All diagnostic device has been manufactured and are being tested
Magnet System

Field mapping of magnets is in progress
Power Supply System

Test results of pulse power supply (Quadrupole magnet of ring)
- Risetime: 1.6s
- Rated current: 373A
- tracking error: ±7.8E-5

Test results of pulse power supply (Quadrupole magnet of HEBL)
- Risetime: 1.56s
- Rated current: 340A
- tracking error: ±4.4E-5

Performance test of power supply with resistant load is in progress
Control System

Central control tier (1)

Front-End Computer tier (2~3)

Device Control tier (3)

全局控制：32节点，InfinitBand x8 (40Gb)
Oracle RAC，Platform
150KW模块化UPS电源、25KW水冷机柜

实时工业以太网

局域网
Radiation Protection System

- Neutron detector
- Beam shutter
- Dose monitor
- Personnel Security Interlock
Qualification Standards

- Registered product standard of HIMM
- Quality documents
- Risk analysis report

- Quality management system training
- The first internal audit
Heavy-ion therapy center in Wuwei

Installation started from April, 2014
Heavy ion therapy center in *Lanzhou*

Installation of Facility will start in July, 2014
R&D and Test Center of HIMM in Lanzhou

Trail Assembly Hall

Test center for magnet and power supply
Test center for vacuum system and RF system
Test center for electronics and control system
Summary

- Clinical trials for 213 cancer patients have been performed with carbon-ion therapy at the existing research accelerator facility of IMP. Different beam deliveries for 2D, 2D plus layer-stacking, 3D and spot-scanning conformal irradiations have been developed;

- Two dedicated carbon therapy facilities are under construction in Gansu province in China (one in Lanzhou city, another one in Wuwei city). Commissioning is planned between the end of 2014 and 2015;

- Requirements for more carbon and proton therapy facilities are expected.
Thank you!
Welcome to IMP!