Development of accelerator and detector systems for radiation medicine in DLNP JINR


Joint Institute for Nuclear Research, Dubna, Russia.

M.Abs, A. Blondin, Y. Jongen, S. Zaremba, D. Vandeplassche, IBA, Belgium.
The project is aimed at developing two directions in radiation medicine:

- accelerator technique for proton and carbon treatment of tumors
- and new types of detector systems for spectrometric computed tomography (CT) and combined magnetic resonance tomography (MRT)/positron emission tomography (PET).
JINR Medical-Technical Complex on proton beams of synchrocyclotron

1967 – First investigations at cancer treatment;
1968–1974 – 84 patients were irradiated by proton beams on synchrocyclotron;
1975–1986 – Upgrade of synchrocyclotron, creation of Medic-Technical Complex (MTC) of hadron therapy in JINR;
1987–1996 – 40 patients were radiated by proton beams;
1999, – Creation of radiological department in Dubna hospital;
2000–2010, – 660 patients were radiated by proton beam.

During last years around 100 patients per year were radiated by proton beam in JINR Medical-Technical Complex in frame of research program of Medical Radiological Research Center of Russian Medical Academy of Science.
JINR MTC WITH PROTON BEAMS

Cancer treatment in cabin №1

Prostate treatment equipment

3D conformal proton beam treatment were realized in Russia only in JINR.
Dubna Center of Radiation Medicine (CRM) involves: Cyclotron Center of Proton Therapy, PET center, Department of conventional radiotherapy with electron linac, Diagnostic department, Proton therapy clinic.

The Center of proton therapy has 3 treatment cabins, 1 with the gantry and 2 rooms with the fixed beams.

About 1000 patients per year will be treated there.
2.3 million of tumor patients there are in Russia 450 thousands of new patients are appeared per year.

The proton therapy is recommended 50 thousands of patients per year in Russia.

There are 25 centers of the proton therapy and 4 centers of carbon therapy at the world now. More than 60 thousand patients were treated with application of hadron therapy during last 50 years, 60% of them were treated over last 10 years and 90% of total patients now treated in the hospital based facilities.
Cyclotrons for hadron therapy in DLNP JINR

- Dubna project of the cyclotron for proton therapy C250 (Alenitsky Yu.G. poster, RUPAC-2010)

- Modification of the proton therapy cyclotron C235 (IBA, Belgium)

- Project of the superconducting cyclotron C400 for carbon ions therapy (IBA, Belgium)
<table>
<thead>
<tr>
<th>General parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton energy, MeV</td>
<td>235</td>
</tr>
<tr>
<td>Internal current, nA</td>
<td>300</td>
</tr>
<tr>
<td>Beam emittances, ( \pi \cdot \text{mm} \cdot \text{mrad} )</td>
<td>12/11</td>
</tr>
<tr>
<td>Magnetic field (min/max) T</td>
<td>0.9/2.9</td>
</tr>
<tr>
<td>Number of sectors</td>
<td>4</td>
</tr>
<tr>
<td>Magnet diameter, m</td>
<td>4.3</td>
</tr>
<tr>
<td>Radius of beam extraction, m</td>
<td>1.08</td>
</tr>
<tr>
<td>Elliptical hill gap, cm</td>
<td>9.6/0.9</td>
</tr>
<tr>
<td>Duant aperture, cm</td>
<td>2</td>
</tr>
<tr>
<td>RF frequency, MHz</td>
<td>106.1 (4 harmonic)</td>
</tr>
<tr>
<td>Dee voltage, (min/max) kV</td>
<td>60/130</td>
</tr>
<tr>
<td>Ion source</td>
<td>PIG, internal</td>
</tr>
<tr>
<td>Electrostatic deflector field, kV/cm</td>
<td>170</td>
</tr>
<tr>
<td>Extraction efficiency, %</td>
<td>50</td>
</tr>
<tr>
<td>Power, kW</td>
<td>446</td>
</tr>
<tr>
<td>Weight, t</td>
<td>220</td>
</tr>
</tbody>
</table>
Improvement of extraction efficiency from 50% to 75% with new extraction system
JINR-IBA collaboration develops a medical cyclotron for the proton therapy. This year it is planned to complete its construction, to start assembling in 2011 and to carry out the beam tests in 2012.

After that the accelerator could be installed in the Dimitrovgrad Centre of proton therapy.

The main modernization efforts are directed on optimization of the magnetic system oriented on an increase of the axial betatron frequency.

Simulation of magnetic field. Azimuthal angle variation
# MODIFIED CYCLOTRON C235-V3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>C235</th>
<th>C235-V3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization of magnetic field at modification of sector</td>
<td></td>
<td>Modification of azimuthal angle of sectors on 1,5°-2° at R&gt;80</td>
</tr>
<tr>
<td>Vertical betatron frequency is increased at R&gt;90</td>
<td>Q&lt;sub&gt;z&lt;/sub&gt;=0.25</td>
<td>Q&lt;sub&gt;z&lt;/sub&gt;=0.45</td>
</tr>
<tr>
<td>Vertical coherent beam displacement related to effects of median plate should be reduced</td>
<td>6-7mm</td>
<td>1.5-2mm</td>
</tr>
<tr>
<td>Beam losses should be reduced at proton acceleration</td>
<td>30-50%</td>
<td>0%</td>
</tr>
<tr>
<td>New design of the deflector Beam losses at extraction were reduced</td>
<td>50%</td>
<td>25%</td>
</tr>
</tbody>
</table>
Dependence of betatron tunes on radius in cyclotron C235 and C235-V3
CARBON CANCER TREATMENT

- The carbon $^{12}$C$^{6+}$ ion beams at intensity of $10^9$ pps are efficiently used for cancer treatment especially for patients with radioresistant tumor targets.
## Superconducting cyclotron C400

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>accelerated particles</td>
<td>$\text{H}_2^+,$ $^4\text{He}^{2+},$ $^6\text{Li}^{3+},$ $^{10}\text{B}^{5+},$ $^{12}\text{C}^{6+}$</td>
</tr>
<tr>
<td>final energy of ions, protons</td>
<td>$400$ MeV/amu, $265$ MeV</td>
</tr>
<tr>
<td>extraction efficiency</td>
<td>$\sim 70%$ (by deflector)</td>
</tr>
<tr>
<td>number of turns</td>
<td>$\sim 2000$</td>
</tr>
<tr>
<td>total weight</td>
<td>$700$ tons</td>
</tr>
<tr>
<td>outer diameter</td>
<td>$6.6$ m</td>
</tr>
<tr>
<td>height</td>
<td>$3.4$ m</td>
</tr>
<tr>
<td>pole radius</td>
<td>$1.87$ m</td>
</tr>
<tr>
<td>hill field</td>
<td>$4.5$ T</td>
</tr>
<tr>
<td>valley field</td>
<td>$2.45$ T</td>
</tr>
<tr>
<td>RF frequency</td>
<td>$75$ MHz</td>
</tr>
</tbody>
</table>
View of the median plane in the 400MeV/u Carbon/Proton superconducting cyclotron

- Cavities in the valleys
- Cryostat with SC coils
- Extraction lines
- Helium $^2$+ (alphas) source
- Carbon $^6$+ source
- $H_2^+$ source
Working diagram of the cyclotron.
The cavity model

Voltage distribution along radius.
Central region with the spiral inflector model

Mean magnetic field in the center region.
Two-turn extraction of protons with energy 265 MeV
Layout of the C400 cyclotron with two extraction lines.
The design review of the C400 cyclotron was in 2009. The group of international experts emphasized high quality of the research work done by the JINR.

The construction of C400 is planned to start in end of 2010 in the framework of Archade project (France, Caen)
Present status of X-ray technique

World market 13 bln. $/y.,
Technological cycle of manufacturing GaAs compensated with Cr

As a result, the experimental values of resistivity are \((0.5-1) \cdot 10^9 \Omega \cdot \text{cm}\), which are more than an order higher as compared to the resistivity of structures on the basis of traditional LEC SI-GaAs.
Thank you for your attention
X-ray detectors

Indirect Conversion
(scintillator - photodetector)

Direct Conversion
(semi-conductor)

1000 charges at 60 keV

10 000 charges at 60 keV
Development and production of pixel semiconductor detectors

GaAs pixel detector with pixel size of 50 μm and 65536 channels of electronics
X-ray computer tomograph

K-edge and attenuation

Detection of iodine, calcium, and air transitions from standard gray X-ray picture to color picture of separate structures.
Dual Energy Radiographs

Iodine: Pulmonary circulation
Barium: Lung
Bone: normal structure
Novel Micropixel Avalanche Photodiodes (MAPD) with super high pixel density
MAIN FUTURE OF MAPD

- High Dynamic Range (pixel densities of up to 40000 mm\(^2\))
- Photon Detection Efficiency up to 30 \%
- Gain up to \(10^5\)
- Better radiation hardness
- Insensitivity to magnetic field.
- Compact and rigid
- Low voltage supply (<100 V)

Drawbacks:
- Temperature dependence (a few \%%/°C)
- High dark rate (> 0.5 MHz/mm\(^2\))
- Large Recovery time.
MAPD APLICATION FOR POSITRON EMISSION TOMOGRAPHY
MAPD APPLICATION FOR COMBINED PET/MRT

\[ E_0 = 662 \text{ keV} \]

\[ \text{FWMH} = 11.5\% \]

\[ U_{\text{bias}} = 89.8 \text{ V} \]

\[ G_{\text{px}} = 3.7 \cdot 10^4 \]