Advocacy for a dedicated 70 MeV Proton Therapy Facility

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Hahn-Meitner-Institut
(reactor, cyclotron, solar energy)  +  BESSY (synchrotron) = HZB
Helmholtz Zentrum Berlin

largest non-university research centre in Berlin
Introduction: Statistics

- eye tumour therapy with protons since 1998
- cooperation between the Charité and HZB (formerly HMI)
- 12 therapy weeks per year, 1 treatment room
- work flow allows the treatment of 200 - 300 patients per year
- tumour control rate after 3-years' follow-up $\geq 97\%$
  - 85 % Melanoma 97 % control
  - 6 % Iris Melanoma 100% control
  - 5 % Hemangioma 100% control
Introduction: Beam Conditions

- k = 132 isochronous cyclotron with 5 MV Van-de-Graaff injector, 5 GHz ECR source on HV terminal
- 68 ± 0.3 MeV proton beam with simple single scattering technique
- depth dose profile: distal fall-off 90 - 10% = 0.94 mm
  penumbra 80 - 20% = 2.1 mm
- all required therapeutic beam intensities delivered from cyclotron with dose rate of at least 15 Gy / min
Special Patients: Children

- proton therapy = powerful tool against ocular tumours (control rates higher than 95%)
- cooperation of the patient is indispensable during treatment
- small children are unable to cooperate
  ⇒ treatment under general anaesthesia
  ➲ installation of mobile anaesthesia workstation with UPS
  ➲ modification of two conventional car seats for positioning
Special Patients: Children

- 2x retinoblastoma (7 and 10 months: 6x 5.27 CGE)
- 1x choroidal osteoma (5 years: 4x 5.0 CGE)
- Daily treatment duration: ~ 2 h
  - Anaesthesia and positioning: ~ 1 h
  - Irradiation: ~ 1 min
  - Dismounting: ~ 1 to 2 min
    (emergency dismounting: ~ 1 min)
  - Recovering from anaesthesia: ~ 45 min
- Frontal approach: possibility to spare bone structures nearly completely
- High precision in patient positioning (up to 0.2 mm)
Summary of our Experiences

- proton therapy - excellent tool for the treatment of eye tumors giving very high local control rates
- 70 MeV ± 0.5% proton beam - distal dose fall-off ≤ 1.0 mm:
  - often critical for preventing irradiation of sensitive structures
  - essential for sight (optic nerve, papilla, macula)
- dose rate over 15 Gy/min - permits the use of lid retractors
- patients require elaborate positioning
- CT/MRI based planning + digital image guided planning
  - essential for maximum plan conformity with tumour
Centres under Construction

- 11 centres with cyclotrons listed – all $E_p > 200$ MeV

<table>
<thead>
<tr>
<th>Institution</th>
<th>Country</th>
<th>Energy</th>
<th>Start Treatment Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI Villingen</td>
<td>Switzerland</td>
<td>250 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>WPE Essen</td>
<td>Germany</td>
<td>230 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>CPO Orsay</td>
<td>France</td>
<td>230 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>PTC Tohoku</td>
<td>Japan</td>
<td>230 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>HUPBTC Hampton VA</td>
<td>USA</td>
<td>230 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>CMHPTC Ruzomberok</td>
<td>Slovak. Rep.</td>
<td>250 MeV</td>
<td>2010</td>
</tr>
<tr>
<td>Chang Gung Mem. Taipei</td>
<td>Taiwan</td>
<td>235 MeV</td>
<td>2011</td>
</tr>
<tr>
<td>ProCure Chigaco</td>
<td>USA</td>
<td>230 MeV</td>
<td>2011</td>
</tr>
<tr>
<td>Northern Illinois...</td>
<td>USA</td>
<td>250 MeV</td>
<td>2012</td>
</tr>
<tr>
<td>Trento</td>
<td>Italy</td>
<td>230 MeV</td>
<td>2013</td>
</tr>
<tr>
<td>Skandion Uppsala</td>
<td>Sweden</td>
<td>250 MeV</td>
<td>2013</td>
</tr>
</tbody>
</table>
**Status Quo**

- degraded beam, 230(250) MeV → 70 MeV:
  - huge losses in beam intensity of more than 95%
  - large energy spread to allow reasonable treatment times

W. Newhauser et al  

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**Graphical Data**

- Bragg Peak  
  - 68 MeV protons from cyclotron:
    - CN injector
    - tandemron injector

- **Δz(90%-10%)** = 0.94 mm

- **Δz(90%-10%)** = 5.3 mm
Consequences of Degraded Beam

- 1. goal = tumour control
- 2. goal = spare healthy tissue from dose → quality of life, e.g. capacity to read

- ocular tumour therapy has to accept compromises regarding side effects or requires a sophisticated beam shaping technique as at OPTIS2 / PSI

- suggestion for a dedicated facility, optimized for the needs of ocular melanomas
Wish List: Accelerator

- quasi-DC beam with the following properties:
  - energy of extracted beam: 72 MeV
  - intensity of extracted beam ~ 100 nA
  - $dE/E \leq 0.4\%$
  - half beam extent, $\sigma_{x,y}$: 2 mm • 4 mm
  - half beam divergence $x' \cdot y'$: 4 mrad • 3 mrad

- small cyclotron
Wish List: Beam Lines

• two horizontal treatment rooms
• one vertical room: treatment of anesthetized children, physics
• broad and sharp beam in all rooms
• intensity broad beam in room: 4nA (short irradiation times)
• energy selection system: $\Delta E/E = 0.2\%$
  – close to physical limit
  – interest for the treatment of tumours lying close to sensitive structures, e.g. macula, papilla, and optic nerve
Layout of Facility: Beam Lines
Horizontal Beam: Broad Beam

Transverse Phase Space Ellipses

Beam Cross Section

Step: 1 / 2488

Horizontal
- alpha (x) = 0.1640
- beta (x) = 1.5097 m/rad
Vertical
- alpha (y) = 0.0490
- beta (y) = 1.5097 m/rad
Plot Scales
- horz ± 21.6497 mm
- vert ± 12.8071 mrad

LEGEND
- Horizontal Projection
- Vertical Projection
- Horizontal Envelope
- Vertical Envelope

SCALES
- Length 24.7562 m
- Height ± 52.0000 mm
turtle histogram of the horizontal broad beam behind the exit window: beam intensity sufficiently homogenous over more than 40 mm diameter
- turtle histogram of the horizontal sharp beam in treatment room: well-defined beam spot
Vertical Beam: Broad Beam

Transverse Phase Space Ellipses

Beam Cross Section

Step: 1 / 2493

Horizontal
- $\alpha (x) = 0.1640$
- $\beta (x) = 1.5097 \text{ mrad}$

Vertical
- $\alpha (y) = 0.0490$
- $\beta (y) = 1.5097 \text{ mrad}$

Plot Scales
- horz $\pm 13.7736 \text{ mm}$
- vert $\pm 20.9888 \text{ mrad}$

Legend
- Horizontal Projection
- Vertical Projection
- Horizontal Envelope
- Vertical Envelope

Scales
- Length 24.7409 m
- Height $\pm 52.0000 \text{ mm}$
Transmissions

- evaluated using Graphics TURTLE
- assumption: 80% extraction efficiency

<table>
<thead>
<tr>
<th>Place</th>
<th>Broad Beam</th>
<th>Sharp</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyclotron exit</td>
<td>100 nA</td>
<td>100 nA</td>
</tr>
<tr>
<td>collimator 1 m behind exit</td>
<td>60 nA</td>
<td>60 nA</td>
</tr>
<tr>
<td>energy slits</td>
<td>30 nA</td>
<td>30 nA</td>
</tr>
<tr>
<td>collimator behind scattering foil</td>
<td>6.5 nA</td>
<td></td>
</tr>
<tr>
<td>beam in treatment room</td>
<td>2.5 nA</td>
<td>30 nA</td>
</tr>
</tbody>
</table>

- these calculations are now the base for detailed FLUKA and MCNPX calculations for the radiation safety
• dedicated facility:
• 72 MeV: all ocular tumours, even in the case of optic nerve infiltration
• best therapeutic options:
  – distal falloff close to physical limit, due to energy selection system
  – sharp penumbra
• vertical beam line for anesthetized patients
• ability to deal with the time consuming positioning process
- exhaustive calculations of the neutron doses are in progress
- detailed design for treatment nozzles is planned
- next step: design of the accelerator
• step 1: anaesthesia on separate table
Children: Preparation

- step 2: transfer into car seat
Children: Preparation

- step 3: treatment position
Children: Positioning

axial position X-ray

lateral position X-ray