Heavy Ion Therapy- The search for the Holy Grail of Radiation Therapy

Presented by
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Energy deposited (on film) per unit length vs. nuclear charge of particle
Cell damage by DNA strand breaks
### Effects of 1 Gy dose on typical mammalian cell nucleus

<table>
<thead>
<tr>
<th>Radiation type</th>
<th>No. of tracks</th>
<th>Ionization in nucleus</th>
<th>Ionization in DNA</th>
<th>DNA strand breaks (initial)</th>
<th>Strand breaks after repair</th>
<th>Ave. No. of lethal events</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Rays (6 MV)</td>
<td>2000</td>
<td>2 x 10^5</td>
<td>2000</td>
<td>1000</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>Helium Nuclei</td>
<td>5</td>
<td>2 x 10^5</td>
<td>2000</td>
<td>300</td>
<td>60</td>
<td>1</td>
</tr>
</tbody>
</table>

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Why use particles heavier than protons?
Advantageous physical characteristics: small lateral scattering
What are the consequences of using Carbon and other heavy nuclei?

• The RBE is not as well known as for protons and X-rays and 50 years of clinical experience in tumor control and side effects do not carry over to Carbon

• Heavy ion accelerators are much more costly. Higher $P$ or $B_\rho$ $\rightarrow$ Higher $R$ $\rightarrow$ Higher $$$

• Heavy ions do not yet have FDA clearance in the USA $\rightarrow$ no reimbursements yet

• A Carbon (430 MeV/amu) gantry will weigh 600 tons, more than 6 times the weight of the Loma Linda Gantry and is not yet offered commercially.
Heidelberg Heavy Ion Facility

- compact design (60m x 70m)
- full clinical integration
- raster scanning only
- treatments with various ions: p, He, C, O change within minutes
- world-wide first scanning ion gantry
- state of the art med-tech equipment
- > 1000 patients per year

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Technical Challenges in the Preparation of the Heidelberg Ion Therapy Center for IMPT

Thomas Haberer
Scientific-technical Director
Heidelberg Ion Therapy Centre
Construction Site

Heavy Ion Therapy Unit at the University of Heidelberg Clinics

Sections 51, 54 scale 1:100

Th. Haberer, Heidelberg Ion Therapy Center
General Requirements

- compact design (60m x 70m)
- full clinical integration
- raster scanning only
- treatments with various ions: p, He, C, O
  change within minutes
- world-wide first scanning ion gantry
- state of the art med-tech equipment
- > 1000 patients per year
Key Developments @ GSI

- Scanning-ready pencil beam library (25,000 combinations): 253 energies (1mm range steps) x 7 spot sizes x 15 intensity steps
- Rasterscan method incl. approved controls and safety
- Beammonitors follow the scanned beams (v <= 40 m/s) in real-time
- Biological interaction model based on 25 years of radiobiological research
- Physical beam transport model
- Planning system TRiP
- In-beam Positron Emission Tomography
- QA system
- ...

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Rationale / PET + RBE

• Positron Emission Tomography (PET): autoactivation allows for dose monitoring (+ functional imaging in the future)
• Biological selectivity: increased radiobiological efficiency in the target volume (Z>2)
Basis: Carbon Ion Therapy @ GSI
Beam Scanning

scanning of focussed ion beams in fast dipole magnets

active variation of the energy, focus and intensity in the accelerator and beam lines

utmost precision via active position and intensity feedback loops

intensity-controlled raster scan technique @ GSI

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Fixed Beamline Shielding

1 mSv/2000h
Linac

- compact design
- proven technology
- fast change of the ion species
- fast intensity variation (1000-times)
- constant beam parameters
Sources and LEBT

work in progress:
- design intensity for carbon reached
- 90% transmission from the source down to the RFQ
Synchrotron

- compact design
- proven technology
- multiturn-injection => high intensities
- rasterscanning optimized, extremely flexible beam extraction
- fast variation of energy (range)

Multiple extraction
0.5 bis 10 sec

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Scanning Ion Gantry

- optimum dose application
- world-wide first ion gantry
- world-wide first integration of 2d beam scanning
- 13 m diameter
  25 m length
  600 to overall weight
  420 to rotational
  0.5 mm max. deformation
- prototype segment tested at GSI

MT Aerospace

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Scanning Ion Gantry

test of scanning gantry segment at GSI

90° Dipole Magnet

Quadrupole Magnets

Diagnostic Box with Viewing Screen

Scanner Magnets

Isocenter Diagnostics

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Medtech Equipment

department-wide workflow concept (photons and particles)

fixed lines:
• robotic patient positioner
• robotic digital x-ray imagers
  o C-arm
  o 30 Hz
  o Cone-beam CT capability
• in-beam PET

gantry:
integration of
• robotic patient positioner
• digital X-ray systems
• stereotactic equipment
  (PET-upgrade available)

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HIT/ Organisation and Structure

• Project is managed by Heidelberg University Hospital existing contracts with:
  University Civil Engineering Department (building)
  GSI (accelerator, gantry, and beam line components))
  Heidelberg Ion Therapy Limited will maintain and operate facility
  Siemens contracted Danfysik for industrial partnership for commercialization of Carbon/Proton therapy systems
• GSI and HIT Limited: design and installation of “heavy” ion therapy equipment, tendering documents, supervision of industrial partners, integration, commissioning, staff training
• Cooperations:
  German Cancer Research Center in Heidelberg
  FZ-Rossendorf near Dresden (PET)
• 12 Subcontractors
HIT / Milestones

- Building ready for equipment installations 10 / 2005
- First Accelerated Carbon/Proton Beams 11 / 2006
- Gantry cave installed 06 / 2007
- Horizontal caves handing-over 01 / 2008
- Gantry cave patient-ready 09 / 2008
- Gantry cave handing-over 12 / 2008