Tumour therapy with heavy ions

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Tumor therapy with heavy ions

Content

- Cancer situation
- Physics of the ion beams
- Process of the tumour radiotherapy
- Outlook: Radiotherapy at Heidelberg: HICAT
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Cancer Situation

- Germany (2005):
The therapies fail at one third of the patients with local disease (~70,000 people each year)
Physical Dose Distribution I

- inverted dose distribution for heavy ions
- maximum energy loss at the end of the particle track
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Physical Dose Distribution II

Ion velocity in tissue
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**Bethe-Bloch-Formula**

\[
\frac{dE}{dx} = \frac{4\pi e^4 Z_{\text{eff}}^2 N}{m_e v^2} \ln \left( \frac{2m v^2}{I (1 - \beta^2)} \right) + \text{relativistic}
\]

- \( m_e \) ... electron mass
- \( v \) ... projectile velocity
- \( N \) ... density of the electrons of the target material
- \( e \) ... elementary charge
- \( I \) ... mean ionisation potential
- \( Z_{\text{eff}} \) ... effective charge
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Physical Dose Distribution III

Penetration depth can be varied by changing the ion energy

Maximum penetration depth: 30 cm $\triangleq$ 430 MeV/u
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Relative Biological Effectiveness

RBE illustrated for cell survival curves

\[ RBE = \frac{D_x}{D_{ion}} \]
Protons:
Locally correlated DNA damage can only be produced by increasing the macroscopic dose

Carbon ions:
Many electron tracks are produced that cause locally multiply damaged sites within the DNA
Survival Rate of Cells

Only the tumour cells are killed, the normal tissue is predominantly undamaged

⇒ relevant for the treatment of children and young people
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X-Rays vs. Ion Beams

Dose distribution of X-rays in the tissue

Dose distribution of ion beams in the tissue
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Dose Distribution

Radiotherapy with X-rays

Radiotherapy with ions
Advantages of Carbon Ion Beams

- Increased energy deposition at the end of the particle trajectory
- Increased relative biological effectiveness
- Small broadening of the beam
  ⇒ The beam can be localized to the tumour and the surrounding tissue remains undamaged
- Treatment of X-ray resistant, slow growing tumours (especially at sensitive regions like eyes, optical nerve and brainstem)
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Course of a disease

Tumor at the skull base

After the radiotherapy with ions
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**Raster Scanning Process I**

Schematic drawing of the intensity-controlled rasterscan
A cut through the irradiated tumour volume:

Every layer is split into many lines and picture points (pixels or voxels)
Positron-Emission-Tomography I

The carbon isotopes $^{10}$C and $^{11}$C are positron emitters
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Positron-Emission-Tomography II

⇒ Online-control of the carbon ion beam position
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Patient Positioning

Individually manufactured head mask and rigid immobilization device

⇒ Ensures a repositioning accuracy of 1 - 2 mm
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Heavy Ion Cancer Therapy (HICAT)

The therapy center at Heidelberg:

the second floor where the accelerators and therapy places are installed
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The Gantry (HICAT)

The gantry is a device to align the ion beam towards the tumour from different directions.
## Technical Data of HICAT

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Floor space</td>
<td>~ 60 m x 70 m</td>
</tr>
<tr>
<td>Ions</td>
<td>p, He, C, O</td>
</tr>
<tr>
<td>Water equivalent penetration depth</td>
<td>20 – 300 mm</td>
</tr>
</tbody>
</table>
| Energy                         | 50 – 220 MeV/u (p, He)  
                              | 85 – 430 MeV/u (C, O) |
| Beam width                     | 4 – 10 mm FWHM |
| Minimal intensity              | 1 x 10^6 particles/extraction |
| Maximum intensity              | 4 x 10^6 (p), 1 x 10^{10} (He),  
                              | 1 x 10^9 (C), 5 x 10^8 (O) |
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Summary

• Heavy ion beams have several advantages, e.g. an inverted dose profile, a high relative biological effectiveness, a small beam width. They can be focused on the tumor volume very well.

• The raster scanning process enables a very precise three-dimensional scanning of the target volume and therefore an effective treatment.

• The PET ensures the online-control of the beam position. This control system and individually manufactured masks increase the safety of the patients.

• HICAT is the first ion beam therapy center in Germany. 1000 people shall be treated each year.