Progress in the Application of Hadron Therapy
(protons or ions)

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The boost in particle therapy

Particle therapy group: until 2015 > 150,000 patients treated

www.ptcog.ch
Contents

• Introduction: particle therapy

• Accelerators
  • Synchrotron
  • Cyclotron

• Treatment facilities

• What is so special?
X-ray beams (IMRT) from 7 directions

- X-rays
- Heart
- Lung
- Spinal cord

X-ray dose
Dose profile of protons

Bragg peak
X-rays vs. Protons

X-ray beams (IMRT) from 7 directions

Proton beams from 3 directions

pictures: Medaustron
**Radio Biological Effectiveness:** \( RBE_{\text{carbon}} = \frac{D_{\text{Xray}}}{D_{\text{Carbon}}} \) for same cell killing.

- **RBE > 1:** Less dose for same cell killing
- \( RBE = 1.1 \)
- \( RBE \approx 3 \)

Electron track (or energy) density at nm scale effects RBE (this means: \( RBE \neq 1 \))
Pencil beam scanning

Spot scanning: \textit{step\&shoot}

Continuous scanning

\textbf{kHz-Intensity modulation}

allows fast target \textbf{repainting}: 15-30 scans / 2 min.
Present accelerator choice

Protons
- in use, $\phi 3.5-5$ m
- e.g.: Boston, Florida, Seoul, Tsukuba

Carbon ions
- in design, $\phi 6$ m

Synchrotron
- in use, $\phi 8-10$ m
- e.g.: Loma Linda, Houston, München, Orsay, Tsukuba

Cyclotron
- in use, $\phi 3.5$ m
- PSI, München
Synchrotron

Protons only:

(\(\varnothing \sim 8 \text{ m}\))

Ions (p-C):

(\(\varnothing \sim 25 \text{ m}\))
“spill” time
- fill ring with $\sim 10^{11}$ particles
- accelerate to desired energy
- extract slowly during 1-10 sec
- decelerate and dump unused particles
“spill” time
- fill ring with \(~10^{11}\) particles
- accelerate to desired energy
- extract slowly during 1-10 sec
- decelerate and dump unused particles
Cyclotron

230 MeV (IBA, SHI, 1996)  
im. 5 m, 200 tons

250 MeV (ACCEL/Varian, 2005)  
SC coils: diam 3.5 m, 100 tons
E-adjustment with cyclotron

At PSI:
Graphite degrader
238-70 MeV

All following magnets:
1% field change in 50-80 ms

250 MeV cyclotron
Small cyclotron

very strong magnetic field:

\[ T_{circle} = \frac{2\pi m}{B q} \]

\( B \) decreases with radius

\( \Rightarrow T_{circle} \) increases with radius.

SO: decrease \( f_{RF} \) with radius and extract

Repeat 1000 x per sec
Small cyclotron

very strong magnetic field:

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Each pulse: set intensity at source within ms
(=> typ 10-30% accuracy)
=> Spot scanning requires >2 pulses per spot.

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Synchro-Cyclotron

8-10 T  250 MeV Synchro-cyclotron on a gantry

First system installed in 2013
Progress in Application of Hadron Therapy

Accelerator status (protons)

- Now
- Mañana

Time until useable

Current Useability => Quality

- cyclotron
- synchrotron
- small synchro-cyclotron
- linac
- FFAG
- laser
- Dielectr. wall linac
- Plasma wake field
Proton therapy: multi-room facility

Cyclotron or synchrotron

At cyclotron: degrader + energy selection

beam transport

gantries

IBA
Gantries

~90 t  
Loma Linda (Optivus)

10-12 m
 PSI-Gantry-2: fast 3D scanning

PSI-"Gantry-2"
Eros Pedroni
David Meer
Gantry for carbon-therapy

HIT, Heidelberg
NEW: SC gantries

NIRS, Japan

Pronova,
Knoxville, USA
PSI’s superconducting gantry design

- Degrader mounted on the gantry
- Momentum acceptance of approx. ±12.5%
  - Treatment of the small tumors without change of the SC magnet field
Operators
Technicians
Experienced workshops
More improvised actions

Radiologist operates
CE/FDA-certification: PROCEDURES
Local technicians: only small repairs
Service by equipment company
Separate interlock systems e.g.:

**Machine interlocks:**
all components technically OK

**Area access & area dose:**
Doors closed, dose rate < μSv/h

**Patient safety:**
Dose delivery as planned
Redundancy

measurement → BEAM off

Alarm level → Patient safety interlock system

Redundancy → stop

Redundancy → stop

Redundancy → stop

Redundancy → stop
Operation: non-accelerator experts

What has happened?

Strong need for 
ERGONOMIC display of: 
Status 
Instructions 

NO BEAM
What is so special?

- **Technics:** dedicated, but not on the limit of technology ….but…
  
  Reliable, Reproducible, Reliable, Reproducible

- **Operation:** by non-accelerator experts
  
  strictly according procedures

- **Control and safety:**
  
  VERY DEDICATED and SPECIAL :

  Reliable & Redundant, but not too sensitive
SUMMARY

- Dose:
  - finite range
  - maximum dose at end of track

- Apply the dose by Pencil Beam Scanning

- Accelerators for Medical Application:
  - Cyclotron
  - Synchrotron

- Medical applications: VERY Special Operation

- Facilities: Gantry aims the beam from all directions
- Recent development: SC magnets
first scanning gantry: PSI, 1996

Gantry: Eros Pedroni
Tumours in kids: Beate Timmermann, Gudrun Goitein

Thank you!!