Marco Schippers, Paul Scherrer Institut, Villigen

Developments in Particle Therapy using Nuclear Science and Technology

Helsinki, NUSPRASEN workshop, November 26, 2019
• Proton Therapy

• Recent developments in dose delivery and p.th.-accelerators

• Current major topics of research:
  – Treatment when organs are moving
  – High intensity
  – Proton range determination
Why Particle therapy?

X-ray beams
- from 7 directions

Proton beams
- from 3 directions

pictures: Medaustron
Proton therapy facility

accelerator

Gantries 10-12 m Ø

IBA
Accelerators for Proton therapy

Cyclotron

Synchrotron
Recent Developments in dose delivery and accelerators
Dose delivery techniques

Scatter technique:

From nucl physics lab:
Pencil Beam Scanning
compact “Gantry-1” at PSI (1996)

scanning proton pencil beam
Typical Gantry ~1996...

Roberts Proton Therapy Center
Philadelphia

Schär Engineering - Munich

10-12 m
NEW: gantries with SC magnets
NEW: optics in SC gantry design

Proton SC Gantry (PSI)

Energy acceptance = ± 30%

→ NO Magnetic Field change for tumors 15-30 cm
E− changes with Cyclotron

Degrader unit

All following magnets:
1% field change (5mm) in 50-80 ms (PSI)

Steerer Q Q Q

Kicker

250 MeV Cyclotron

graphite multi-wedge degrader → 238-70 MeV

recent development:

Gaphite → Boron Carbide

Less scattering → less losses at low E
E−changes with Synchrotron

Energy is set per spill

1 spill:

- Slow Extraction
- 0.5 sec
- 0.5 – 5 sec
- Acceleration
- Deceleration

Beam energy

Time

Energy adjustable during extraction

recent development:

several spills

NIRS: Y. Iwata et al., MOPEA008, Proc. IPAC’10
cyclotrons in proton therapy

IBA (1996), SHI
Isochronous Cyclotron

Varian (2005)
Isochronous Cyclotron

IBA (2018)
Synchrocyclotron

MEVION (2013)
Synchrocyclotron

Pulsed beam:
Limits speed in dose delivery

Superconducting Coils
In Production: Linac 230 MeV

Spin-off from TERA and CERN:

Coupled Cavity Linac → 230 MeV

E-change by:
switching on/off power of cavity units

Laser driven proton accelerator

Thin foil, doped with hydrogen

Laser light creates plasma and pushes electrons out

Electric field from electrons pulls protons out of foil

Now used:
6x10^{17} W/mm^2
Pulsed at low rate

But: more research needed for:
- 100x more power (for Ep)
- MUCH higher pulse rate
- better energy spectrum
Current major topics of research

Treatment with moving organs
High intensity + verification
Range determination
Possible solutions:

- Gating
- Adaptive scanning (tumor tracking)
- Fast (+ rescanning)
Cont. scanning “TV” mode

kHz-Intensity modulation

7 s for a 1 liter volume.
High intensity:

- Reduces motion problems
- FLASH irradiation: 0.03 Gy/s → 40 Gy/s

To be modified:

- Source / accelerator / beam transport
- How to verify?
beam delivery system

proton pencil beams

CCD camera

light

Light emitting Screen or …gas scintillation with a GEM

Advantages of gas scintillation:
No quenching at low E
Very fast (μs)

Particle range in tissue

Particle beams are sensitive to

- CT Hounsfield number → Stopping Power accuracy
- Organ motion
- Change of patient’s anatomy

→ Uncertainty in range in patients ~3%

….. but impossible to measure range directly

→ Various methods are in development
Proton range in tissue

Effect of: 3 cm bone

Effect of: CT

CT images: based on X-ray interaction.

- Calibration to stopping power is needed
- Range error from CT calibr ~1%

X-rays:
- Dose drops 11%

Protons:
- Range 2 cm less

CT - Hounsfield nr
CURRENT STATUS:
- Need to know tissue constituents and predict PET signal
- Compare measured signal with prediction
- → accuracy ~3mm
- but new developments are coming......
Range measurements

CURRENT STATUS:

- Dependent on $E_\gamma$ selection
- Know tissue constituents
- Accuracy of range change: ~1mm

\textit{e.g.: Verburg et al., PMB 60(2015)1019}
Proton radiography

CURRENT STATUS:

- Range accuracy: ~1%
- Proton CT: 3D stopping power

Mumot et al, PMB (2010).
Conclusions

What developments are needed and where can Nuclear Technology contribute?

- Lower price (50%) \(\leftarrow\) (SC) Magnets + Acc.
- Faster \((x \ldots 100)\) \(\leftarrow\) Acc. + **Nucl techn**.
- Motion detect., imaging \(\leftarrow\) **Nucl. Techn**.
- Range detection \(\leftarrow\) **Nucl. Techn**.

**But take care when implementing new developments:**

- Do not propose a solution looking for a problem
- Proven idea \(\rightarrow\) clinic takes 10-20 years
- Long term \((>20 \text{ yr})\) commitment: service / upgrades...
Thank you for your attention