Practical Basic Physics for Hadrontherapy

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1 QUESTION:

In a clinical proton beam, the LATERAL PENUMBRA increases with depth. This is mainly related to:

1) No sunshine in depth?

2) Beam divergence /source?

3) Interactions with the nuclei?

4) None of them

5) I don’t know
Beam production

Acceleration of a Charged Particle

‘Dee’ Electrodes in Magnet

Particle Motion in Magnetic Field
d) Synchrotron

(Mitsubishi, Hitachi, Octopus, Siemens,..)

Diam 12m
250 MeV

C) Cyclotron (IBA, Accel,..)

Diam 4m
235 MeV
BEAM-TARGET INTERACTIONS:
- Elastic & inelastic collisions
- Coulomb Forces: (+) & (-) charges

Incident Proton or Ion (+)

Which are the Main Interactions of Interest in our field?
Many interactions of particles with matter … but keep 3:

- **Inelastic collision w/nuclei**: neutrons…
- **Inelastic collision with electrons**: Dose
- **Elastic collision w/nuclei**: «multiple Coulomb scattering»: all the effects you do not know why
BEAM-TARGET INTERACTIONS  = f (E)

- Very high Energy (> 300 MeV protons)
- Mid & High Energy (10-250 MeV protons)
- Intermediate Energy (0.1-250 MeV)
- Low Energy (keV protons)
BEAM-TARGET INTERACTIONS:

# Mid & High Energy: (10-250 MeV protons)

Inelastic collision w/nucleus & nuclear reactions

Incident Proton or Ion (+)

- Neutrons: shielding patient dose
- Fragments
- Protons (large angles)
- Activation $\rightarrow$ gamma, …

Accelerator, Beam line Patient $\rightarrow$ PET

$\rightarrow$ Disappearance of incidental protons
Nuclear interactions

NUMBER OF PROTONS

Faraday Cup (Q)

Incident Proton or Ion (+)
Number of particles

Nuclear interactions

NUMBER OF PROTONS

~ 1% per cm

Nuclear interactions

threshold = f(E)

Range = f(E)

water equivalent depth (cm)

relative fluence p+ 200 MeV
So, why do we have a « Bragg peak »?

Number of particles

Dose (ionisation)

Pure Bragg peak depth of 60.4 MeV protons
BEAM-TARGET INTERACTIONS:

# Intermediate Energy (0.1-250 MeV)

**Inelastic Collision with electrons**

- **Protons:** E loss & very small angle
- **Electrons:** Ionization, excitation

**Incident Proton or Ion (+)**

*Addition of Small Amounts of Converted Energy per Unit Mass* «CEMA»
Collisions with electrons:

1\textsuperscript{st} concept:

Large number of events loosing small energy

Statistical $\Rightarrow$ “range straggling”
Collisions with electrons

2nd concept) Statistics ➔
W : mean energy to form an ion pair

Ex in air : ~ 34.8 J/C ➔ Protocols for ion chamber dosimetry
Collisions with electrons

3rd concept) **Stopping Power** « S » = dE / dx

Mean Energy dE lost in electronic collisions while traversing a distance dx [MeV/mm]

\[
(dE/dx) = 4 \pi z_{\text{eff}}^2 e^4 (N_A Z) \left\{ \ln \left( \frac{2mv^2}{I(1-\beta^2)} \right) - \beta^2 - \sum \frac{C_i}{Z} \right\}
\]

Small Energy → High Stopping Power
A bit of fun: the « S power »
Or the power of Skate Board

Stopping power increases with depth like a skate ramp
Scattering power increases with depth like a skate ramp
Stopping Power and Range $= f(E)$

- Mass Total Stopping Power $S/\rho_o$ [MeV.cm$^2$.g$^{-1}$]
- Range [mm Water]
- Energy [MeV]
Stopping Power

- Mass Total Stopping Power: S/ro
- Unit: [MeV.cm².g⁻¹]

Residual Range [mm Water] ~ Distance to peak ~ depth

1st S Power: Stopping
Dose distribution in nanometer scale

M. Kraemer, M. Scholz
Number of protons
Number of protons

Effect of each proton
(Ionisation = Dose)

water equivalent depth (cm)
Number of protons $\times$ Effect of each proton

Ionisation of all protons: Bragg Peak
Spread-out Bragg Peak (SOBP)

Concept of Residual range Still valid

(Niek Schreuder & Orsay)
Stopping power effect on detectors: saturation...

→ Test any detector in the peak area to know its response to S/ro!
BEAM-TARGET INTERACTIONS:

Elastic collision w/nucleus

Incident Proton or Ion (+)

\[ \theta_0 = 14.1 \, z \left\{ \sqrt{\frac{L}{L_R}} \left( 1 + \frac{\log(L/L_R)}{9} \right) \right\} \]

\( p \, v \)

\( \rightarrow \) after traversing a thin foil \( \rightarrow \) ~ gaussian

Coulomb multiple small angle scattering
Clinical passive lines:

Occluding Rings and second Scatterer

First Scatterer

Final Collimator

(from Niek Schreuder, Indiana)
spreading “ears”

(van Luijk et al)
Lateral penumbra in depth: (multiple) Scattering Power

- Cobalt
- p(66)/Be Neutrons
- X rays
- 20 MV
- 8 MV
- 4 MV

Depth in water (mm)

80 - 20% Penumbra (mm)

Protons
Neon
proximal peak
distal peak
tall
Spot Scanning Principle

Pictures With compliments from PSI

Single Spot

Few Spots

Total Picture
Do you remember… ?

Stopping power effect

![Graph showing stopping power effect with different materials: Diode, PP ion ch., Diamond, film Xomat-V. The graph plots relative dose (%) against depth in water (cm).]
Stopping power effect again?
Stopping power effect again?
No, this time is the scattering power!😊

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Diagram with dose vs depth plot, showing curves for different depths (5 mm, 10 mm, 20 mm, 80 mm).
Conclusions:

Neutrons...

Ionisation
(= Dose)

Multiple Scattering
« This is not an apple »

« This is not a patient »

→ Listen to next speakers!
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