Study of 1D and 2D scaling methods for proton and carbon beams

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**GEANT4 Simulations**

→ Electromagnetic and nuclear processes
→ 20 000 events

**Beam**

→ Proton 135 MeV / Carbon 290 MeV/A
→ Gaussian profile (0.5 mm wide)
→ Gaussian energy distribution (0.1 MeV)

**Materials**

→ 76 human tissues (Woodard & White)
→ calculated CT numbers (Schneider)

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Woodard & White Br. J. Radiol (59), 1209-1219 (1986)
Woodard & White Br. J. Radiol (60), 907-913 (1987)
**Geant4 Simulation**

1D scaling method

2D scaling method

Conclusion

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**LET curve**

**Lateral Broadening**
$$z_m = z_w S^w_m$$

$$S^w_m = \text{ratio of Bragg Peak locations}$$

$$S^w_m \text{ independent of}\:
\begin{align*}
&\cdot\text{beam energy} \\
&\cdot\text{beam width} \\
&\cdot\text{particle nature}
\end{align*}$$
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1D scaling method

Geant4 Simulation

2D scaling method

Conclusion

proton 135 MeV

carbon 290 MeV

LET (MeV/mm)

- water
- water rescaled
- material

\( \gamma < 2\% / 2\text{mm} \)

cranium
Geant4 Simulation

1D scaling method

2D scaling method

Conclusion

1D scaling not sufficient for an accurate 2D energy deposit determination
\[
\left(F_w^m\right)^2 \approx \frac{\sigma_m^2(z, E_0)}{\sigma_w^2\left(\frac{Z}{S^m_w}, E_0\right)}
\]

\[
\sigma_m^2(z) = \sigma_s^2(z) - \sigma_0^2
\]

from simulations

initial beam width

projection

Gaussian fit

$F_w^m$ independent of
- beam energy
- beam width
Geant4 Simulation  

1D scaling method

2D scaling method

Conclusion

Material: 

Water: 

Water rescaled: 

$S_m^w$ 

$F_m^w$ 

1D scaling only 

2D scaling
1D scaling \( S^w_m \)
- Same factor for proton and carbon beams
- Independent of beam width and beam energy
- Good results on LET curve, insufficient if one wants to take into account lateral broadening

2D scaling \( F^m_w \)
- Improved results in 2D for proton beams
- Determination and variation of the factor still under study (for the carbon beam)

→ Consequences of the variation of this two factors with the CT number