Water & tissue equivalent phantom materials for clinical proton beam dosimetry

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Motivation and aim

- **Motivation**
  - ICRU: dose to the PTV should be delivered with an uncertainty of less than 5% at the 2σ level
  - Uncertainties for an absorbed dose measurement in a phantom should be less than 3%-5% at the 1σ level
    - Dose measurement
    - Dose calculation
    - Dose delivery

    → Uncertainty in the order of 1% for absorbed dose measurements
  - There is no water or tissue equivalent plastic phantom specifically for dosimetry in proton therapy

- **Aim:** Find ideal and realistic atomic compositions of water and tissue phantom materials for clinical proton beam dosimetry

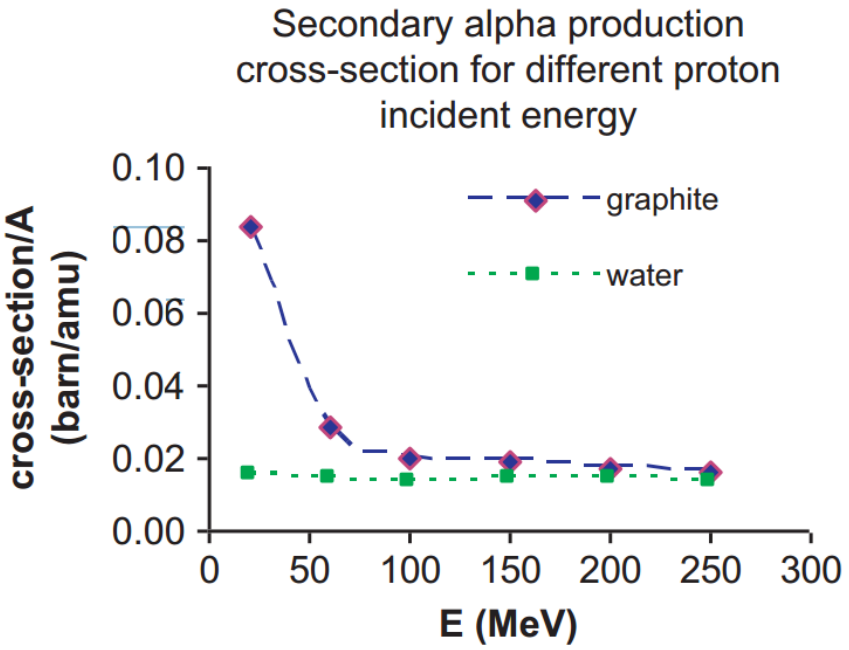
Why phantoms are not water & tissue equivalent for protons?

Nuclear interactions are different depending on the medium

Different production rates of secondary particles at equivalent depths

Difference in the **particle fluence** between water and a target material at an equivalent depth

Fluence correction factor



ICRU-63, 2000

Fluence correction factors: Analytical model

$$D_{w(z_{w-eq})} = D_{ph(z_{ph})}$$

Fluence correction factors: Analytical model

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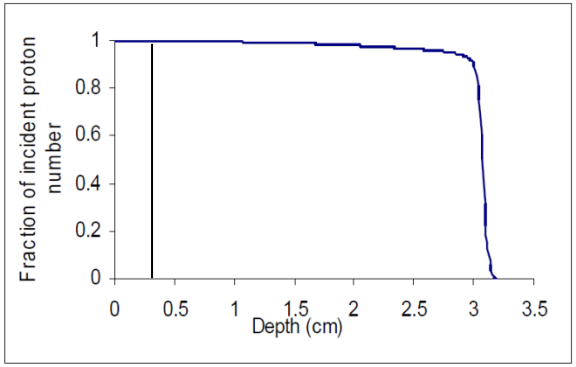
- Simplifications
  - Primary mono-energetic protons go along a straight line
  - Energy loss is according to continuous slowing down approximation
  - Secondary particles are not transported

Palmans H. et al, 2013. Fluence correction factors for graphite calorimetry in a low-energy clinical proton beam: I. Analytical and Monte Carlo simulations. Phys. Med. Biol., 58:3481-3499.

Analytical model: implementation

- Dose is calculated along a grid of predefined step lengths

60 MeV proton beam



The number of protons is reduced by about 4% along the track

$$D(z) = \text{Number of protons} \cdot \left(\text{Energy loss due to stopping power} + \text{Energy loss due to nuclear interactions} \right)$$

$$D(z) = \Phi^{p_{prim}}(z) \cdot \left(\frac{S_{el,p}(E_{p_{prim}})}{\rho} + \frac{N_A}{A} \cdot \sum_i \sigma_{prod,i} \cdot \langle W_{rec,i} \rangle \right)$$

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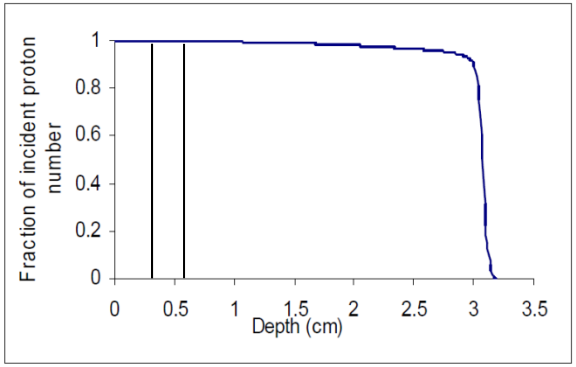

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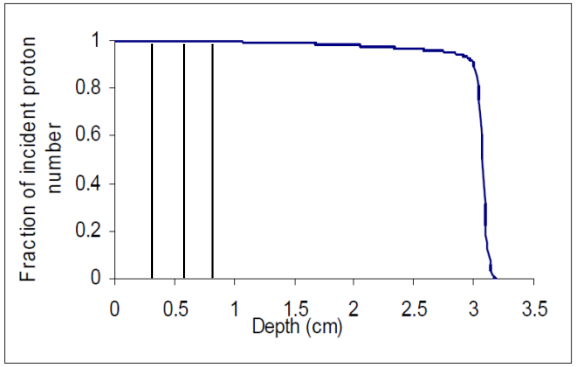

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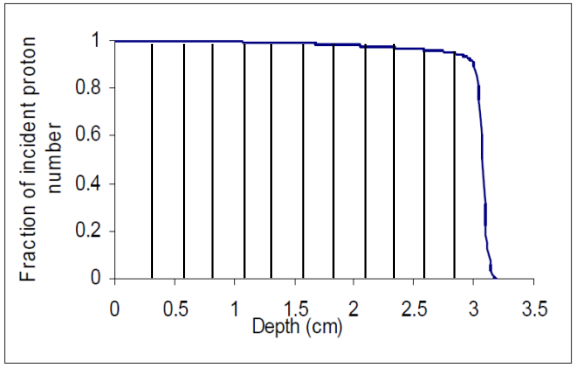

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- Attenuation of primary protons is calculated using the total nuclear interactions cross sections over each step (ICRU Report 63)

Analytical model: implementation

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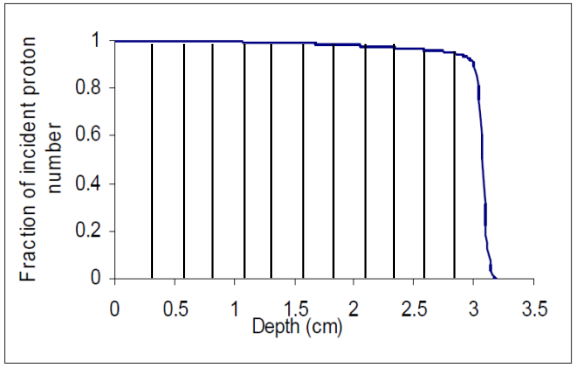
60 MeV proton beam



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- Energy loss of primary protons is derived from ICRU Report 49

Analytical model: implementation

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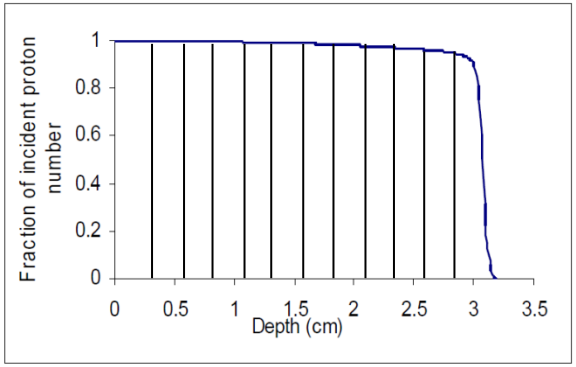
60 MeV proton beam



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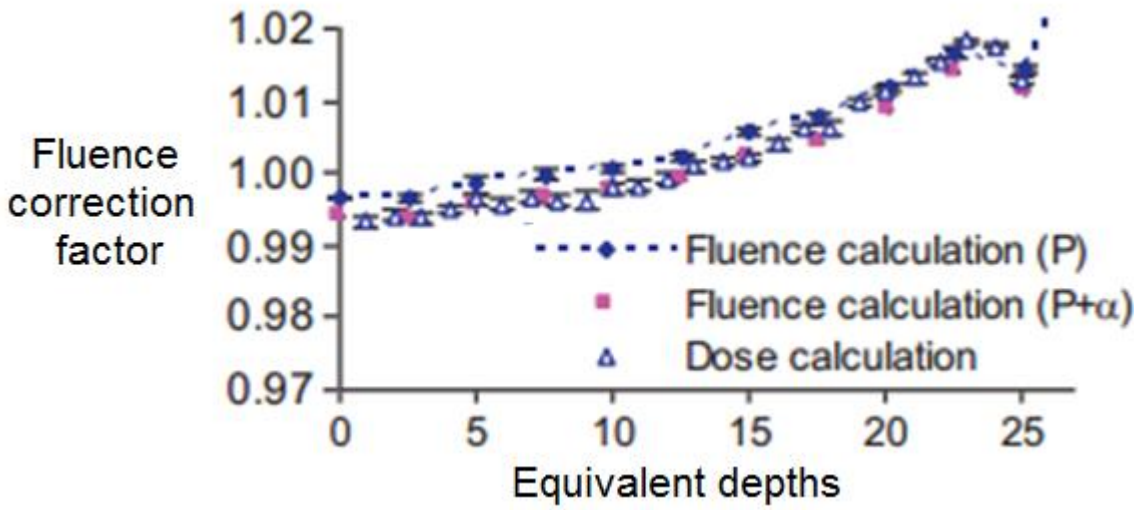
- Attenuation of primary protons is calculated using the total nuclear interactions cross sections over each step (ICRU Report 63)
- Energy loss of primary protons is derived from ICRU Report 49
- Energy loss due to nuclear interactions is according to average cross sections and average production energies

Example

- Liquid water vs solid water phantom (WT1) for 200 MeV

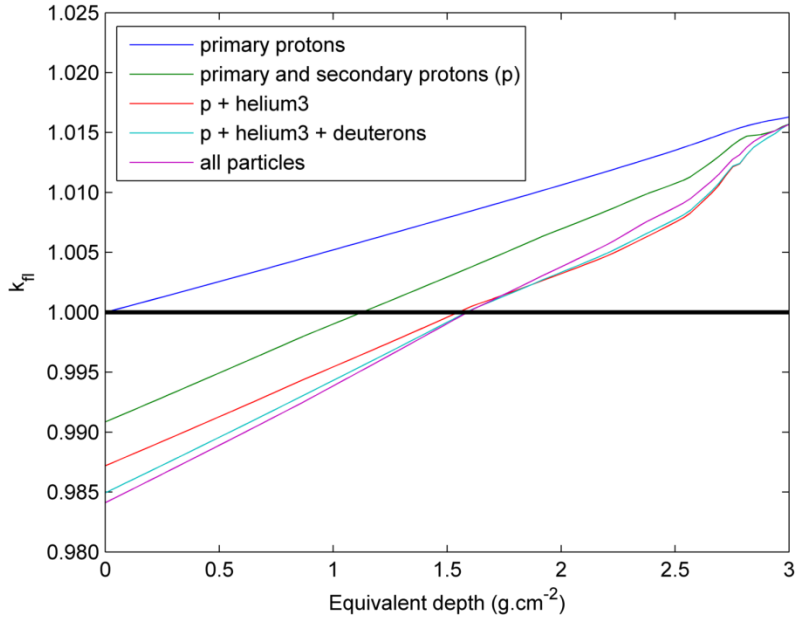


Al-Sulaiti L. et al, 2012. Water equivalence of some plastic-water phantom materials for clinical proton beam dosimetry. Appl. Radiat. Isot. 70, 1052–5

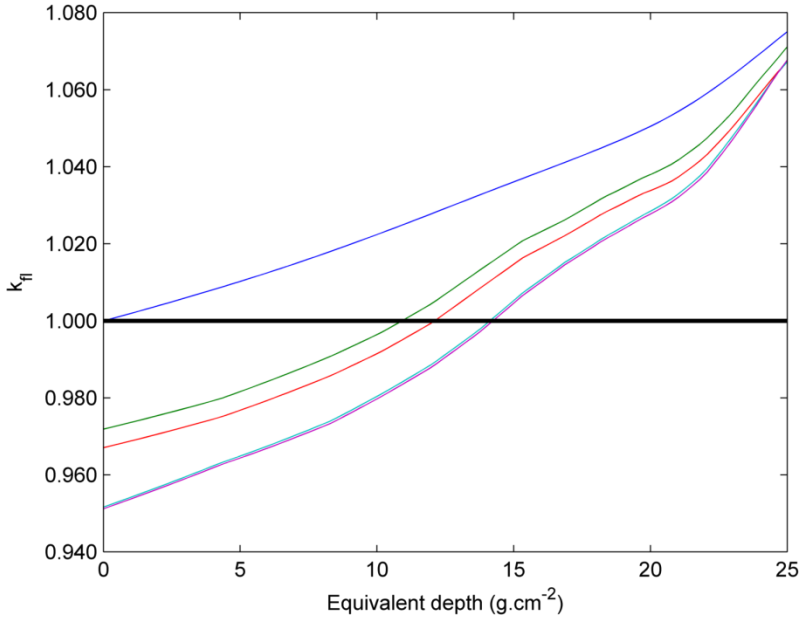
Analytical model: example

Fluence correction factor between water vs graphite

60 MeV mono-energetic proton beam



200 MeV mono-energetic proton beam



- Phantom material vs water: The aim is to find k_{fl} value of one
- Most water or tissue equivalent plastics will be predominantly composed of H, C and O
- A full Monte Carlo simulation is the only way of doing a more physically realistic simulation

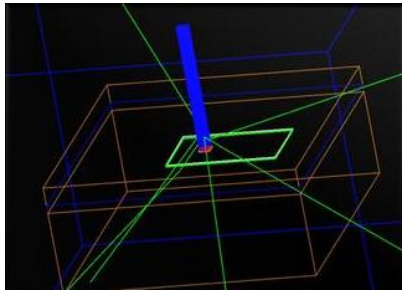
Work plan

Design

Analytical model

$$k_{fl} = \frac{D_{w(z_{w-eq})}}{D_{ph(z_{ph})} \cdot S_{el,w,ph}(\Phi_{ph})}$$

Monte Carlo



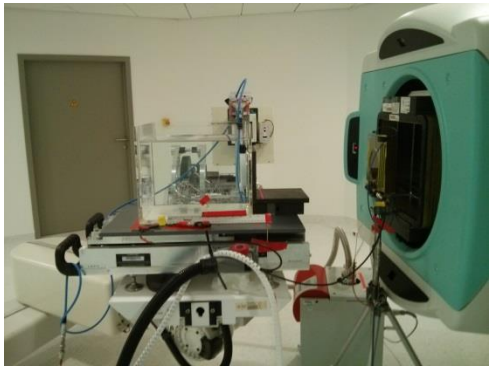
http://www.ucl.ac.uk

Production

Barts Health NHS
NHS Trust

Validation

Experimental work



Anthropomorphic phantom

www.kyotokagaku.com

Thank you! ☺

am.lourenco@ucl.ac.uk