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Lateral Scattering of Single Pencil Beam Spots in Proton Tissue Equivalent Materials

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INTRODUCTION

The developed proton-tissue-equivalent materials (Pro-TEMs) have been validated for out-of-field and in-field applications in Proton Therapy by matching several quantities such as relative proton stopping power, Hounsfield Units and physical density as well as secondary neutron dose deposition compared to its corresponding actual human tissues. Another property of these Pro-TEMs that need to be studied is scatter .

To evaluate the scattering powers of ProTEMs, measured lateral profiles of single spot for the pencil-beam-scanning (PBS) protons are compared with Monte Carlo (MC) simulations using ICRP reference human tissue compositions. To assess the scattering properties of these tissues, fluence measurements of protons passing through a block made of Pro-TEMs were performed and computed fluency of protons passing through real human tissues were simulated using the Monte Carlo code PHITS and compared with the experimental results.

To validate our Monte Carlo source model, water is used as reference standard and a comparison between spot sizes obtained from measurements and simulations of protons traversing a 5 cm water tank was completed.

MATERIAL AND METHODS

Measurements

- 3 ProTEMs were studied: soft tissue, pediatric bone (10y/o) and lung tissue
- 5.0 cm thick block with 10cmx10cm cross-section was manufactured for each ProTEM
- Fluence measurement conducted at 5 energies (138, 156, 172, 198, 220 MeV)
- 2D proton fluence distribution were acquired by a scintillating device Lynx (IBA)
- 1D profiles were extracted and fitted to single Gaussian functions.

Monte Carlo Simulations

- PHITS MC Code 3.08 Parallel Version | 16 parallel executable tasks | 5min/task
- Simulating a total of 10^8 primary protons at nozzle exit | Tally: Cross Sectional Proton Fluence
- Source Model parameters for PHITS input was obtained from in-air spot size commissioning data.
- Simulated Spot Size in water was used a gold standard to validate against measured spot size in water
- ICRU report 46 and Publication 89 of the ICRP were used to define the composition of reference tissues

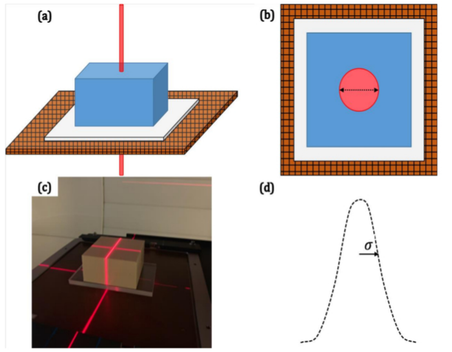

Figure 1. Experimental setup for spot-size measurements. A side-view diagram of the Pro-TEMs (blue) irradiated by a pencil beam (red) sitting on a slab of PMMA and the Lynx detector (a), and a top view (b) is displayed. The actual experiment is also shown (c) along with the estimate of the spot-size σ (d).

CONCLUSIONS

- Protons fluence profiles obtained after protons traverse each of our Pro-TEM are in excellent agreement with those computed profiles obtained from MC after protons traverse each reference human tissue studied.
- The spot sizes for each Pro-TEM in general decreases equally when proton energy increases
- The trend of spot-size of measured profiles for each ProTEMs is within 2% to calculated spot-size of corresponded human tissue that indicates the each ProTEM has similar scattering power that its corresponded human tissue.
- Although the elemental compositions of each Pro-TEM and its corresponding real tissue differ, this fact does not cause a noticeable change in the scattering properties.
- Further study on the trend of spot-size as a function of air-gap will be conducted.

RESULTS AND DISCUSSION

- Both measured and computed spot-sizes decrease as a function of energy for three ProTEMs.
- Measured spot-sizes of irradiated ProTEMs are within 0.1mm with respect to the MC ones for all energies.
- Large spot sizes are generated by both ProTEM and reference bone in comparison with water, while small size was seen for ProTEM and reference lung tissues.

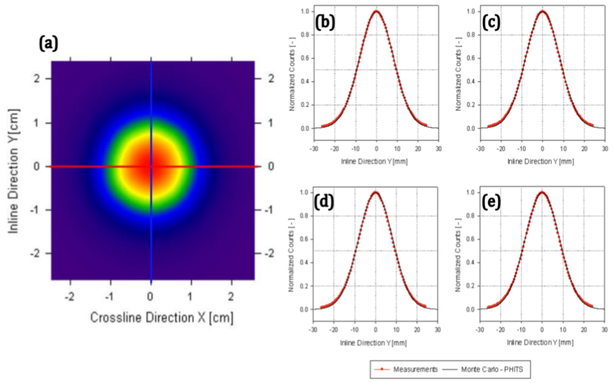

Figure 2. 2D Profile measured by Lynx using water block phantom through the location with the maximum counts (a). Measured and computed lateral-scattering 1D-profiles for 138 MeV protons traversing 5 cm water (b), soft-tissue (c), inhaled lung (d) and pediatric bone (e)

Table V. Summary of the theoretical tissue and measured Pro-TEM spot-sizes across a range of beam energies

Energy [MeV]	Pencil Beam Spot-Size [mm]											
	Water			Soft Tissue			Pediatric Bone			Inhaled Lung		
	Theoretical Target	Measured	% Diff.	Theoretical Target	Measured Pro-TEM	% Diff.	Theoretical Target	Measured Pro-TEM	% Diff.	Theoretical Target	Measured Pro-TEM	% Diff.
138	8.23	8.21	-0.24	8.24	8.23	-0.12	8.29	8.27	0.18	8.20	8.18	-0.24
156	7.29	7.31	0.27	7.29	7.31	0.27	7.33	7.35	-0.29	7.26	7.27	0.14
172	6.58	6.60	0.30	6.58	6.62	0.61	6.62	6.66	-0.59	6.55	6.59	0.61
198	5.89	5.96	1.19	5.89	5.96	1.19	5.92	5.99	-1.15	5.87	5.93	1.02
220	5.19	5.10	-1.73	5.19	5.11	-1.54	5.22	5.15	1.32	5.18	5.09	-1.74

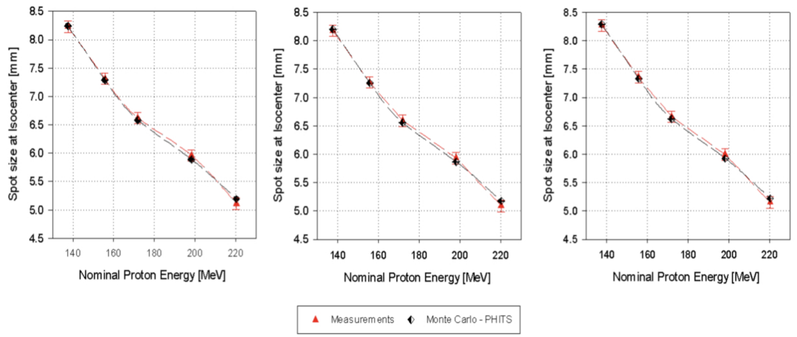

Figure 3. Measured Spot sizes in three proton tissue equivalent materials at Isocenter as a function of the proton energy (red triangles). Computed spot sizes by using ICRP-ICRU reference tissues as a function of proton energy (black squares). Soft Tissue (Left), Inhaled Lung (Middle) and Pediatric Bone (Right)

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