Out-of-field Dose Reconstruction for Proton Therapy and Measurement of Secondary Neutron Dose

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2019 CIRMS Meeting – Session I: Medical Applications
8th April 2019
Late-Effects of Pediatric Proton Therapy?

Number of Proton Centers Worldwide

*projected based on construction plans

*Zhang et al, Physics in Medicine and Biology (2013)*
A Clarion Call for Large-Scale Collaborative Studies of Pediatric Proton Therapy

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Monte Carlo (MC) Pencil Beam Scanning (PBS) Model
MC Modeling for PBS System

Nozzle

Proton beam

(QUAD, ICs, SMX, SMY, …)

Mean energy ($E_0$)
Energy spread ($\sigma_E$)
Spot size ($\sigma_x, \sigma_y$)
Divergence ($\sigma_\theta, \sigma_\phi$)

By matching beam commissioning data of a proton center

MC PBS model

Patient

Tumor
Beam Commissioning Data of Maryland Proton Treatment Center (MPTC)

Spot profiles

Nozzle

40 cm
-20 cm -10 cm 0 cm 10 cm 20 cm

Integrated depth dose (IDD) profiles

Nozzle

45 cm

Water phantom

PTW Bragg Peak chamber

Beam optical properties

Spot size \((\sigma_x, \sigma_y)\)
Divergence \((\sigma_\theta, \sigma_\phi)\)

Beam energy properties

Mean energy \((E_0)\)
Energy spread \((\sigma_E)\)
Automatic MC Beam Modeling Program

1. Start
2. Initial value of the target beam property (spot size, spot divergence, mean energy, or energy spread)
3. Generation of a TOPAS parameter file and execution of TOPAS for MC simulation
4. Comparison of the MC simulation result with the beam commissioning data
5. Dose the comparison result meet a desirable criterion?
   - No
   - Change the value of the target beam property
5.1. Generation of a TOPAS parameter file and execution of TOPAS for MC simulation
5.2. Comparison of the MC simulation result with the beam commissioning data
   - Yes
   - Final value of the target beam property
6. STOP
MC Simulation vs Commissioning Data – Spot Sizes

\[ \text{Difference} = \text{simulation} - \text{measurement} \]
MC Simulation vs Commissioning Data – IDDs

<table>
<thead>
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<th>Energy (MeV)</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
<th>170</th>
<th>180</th>
<th>190</th>
<th>200</th>
<th>210</th>
<th>220</th>
<th>230</th>
<th>240</th>
<th>245</th>
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<tbody>
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<td>$\epsilon_{\text{mean}}$ (%)</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
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</table>
Proton Irradiations

NCI computational phantoms

Created by Treatment Planning System of MPTC
Dose Distributions (TPS vs MC)

5 year – intracranial irradiation

Gamma index passing rate (3 mm, 3%): 99%
Dose Distributions (TPS vs MC)

1 year - craniospinal irradiation

Gamma index passing rate (3 mm, 3%): 98%
Organ Doses – 1 year
Organ Doses – 1 year

Dose equivalent per prescribed dose (mSv / Gy)

- Brain
- Active marrow
- Muscle
- Skin
- Oral cavity layer
- Salivary glands
- Lens
- Thyroid
- Esophagus
- Thymus
- Lungs
- Heart
- Breast
- Adrenals
- Spleen
- Liver
- Stomach
- Gall bladder
- Kidney
- Pancreas
- Ureters
- Small intestine
- Large intestine
- Urinary bladder
- Prostate
- Testes
Secondary Neutron Measurement to Validate MC Model
Neutron Spectrum Measurement at NIST

Neutron Source: Cf-252  
(Mean energy: 2.1 MeV)

Polyethylene phantom
Measurement vs MC Simulations
Neutron Dose Measurement at MPTC (Future Plan)

1) 100 MeV
2) 150 MeV
3) 200 MeV

Proton pencil beam

(1) Water (30 x 30 x 30 cm³)
(2) Water (30 x 30 x 30 cm³)
(3) Water (30 x 30 x 30 cm³)

WENDI-2 neutron detector
Summary

- The MC PBS model was developed for dose reconstruction of proton patients for epidemiological studies of late effects.
  - Dose reconstruction for Pediatric Proton/Photon Consortium Registry (PPCR)
- Experimental measurement of out-of-field dose (i.e., secondary neutron dose) is critical to validate the MC model
  - Collaboration work with experts in neutron measurement field and supports by proton centers (e.g., beam times)
Thank you!