GATE/GEANT4 AS A MONTE CARLO SIMULATION TOOLKIT FOR LIGHT ION BEAM DOSIMETRY

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Motivation

End-to-end testing

- Logistic chain of RT treatment using a phantom containing dosimeters (IC and alanine)

- Alanine dosimetry performed in collaboration with the National Physics Laboratory (NPL) as a dosimetry auditing tool

Carlino et al Novel dosimetry audit based on end-to-end testing with alanine detectors in proton beam therapy (Abstract ID 45). Session Title: Dosimetry Audits for New Technologies
Thursday 20, 14:45 at Board Room A
Motivation

End-to-end testing

- Logistic chain of RT treatment using a phantom containing dosimeters (IC and alanine)
- Alanine dosimetry performed in collaboration with the National Physics Laboratory (NPL) as a dosimetry auditing tool
- Several parameters for dose calculation need to be determined

Purpose of this work:

To use GATE/Geant4 as a toolkit for ion beam dosimetry (protons and carbon ions)

Main focus on the calculation of:
- Water-to-medium stopping power ratio (SPR)
- Relative effectiveness (RE) of solid-state detectors
Materials and methods
SPR and relative effectiveness determination

❖ “GateRTion 1.0” based on GATE 8.1 and GEANT4 10.03.p03

\[
\begin{align*}
S_{\text{med, det}} &= \frac{(E_{\text{dep}})_{\text{med}} / m_{\text{med}}}{(E_{\text{dep}})_{\text{med}} / m_{\text{med}} \left( \frac{(S/\rho)_{\text{det}}(T_j)}{(S/\rho)_{\text{med}}(T_j)} \right)} \\
&= \frac{1}{m_{\text{med}}} \left[ \sum_{j=0}^{N} e_j \right]_{T_j > E_{\text{cut}}} + \frac{1}{m_{\text{med}}} \left[ \sum_{j=0}^{N} T_j \right]_{T_j \leq E_{\text{cut}}} \\
&= \frac{1}{m_{\text{med}}} \left[ \sum_{j=0}^{N} \frac{(S/\rho)_{\text{det}}(T_j)}{(S/\rho)_{\text{med}}(T_j)} \right]_{T_j > E_{\text{cut}}} + \frac{1}{m_{\text{med}}} \left[ \sum_{j=0}^{N} T_j \frac{(S/\rho)_{\text{det}}(E_{\text{cut}})}{(S/\rho)_{\text{med}}(E_{\text{cut}})} \right]_{T_j \leq E_{\text{cut}}}
\end{align*}
\]

Continuous energy loss \( e_j = S_w \cdot \Delta s_j \)

\( S_w = \text{stopping power} \)
\( \Delta s_j = \text{track length} \)

Small stopping power variation along the step!
Materials and methods

SPR and relative effectiveness determination

\[ \eta_{aln}(E_j, Z_i) \] as published by R. Herrmann [PhD thesis]
based on “Hansen and Olsen model”

❖ “GateRTion 1.0” based on GATE 8.1 and GEANT4 10.03.p03

\[
\tilde{\eta}_{al} = \frac{1}{m_w} \left[ \sum_{j=0}^{N} e_j \eta_{aln}(E_j, Z_i) \frac{(S/\rho)_{al}(T_j)}{(S/\rho)_{w}(T_j)} \right]_{T_j > E_{cut}} + \frac{1}{m_w} \left[ \sum_{j=0}^{N} T_j \eta \frac{(S/\rho)_{al}(E_{cut})}{(S/\rho)_{w}(E_{cut})} \right]_{T_j \leq E_{cut}}
\]

For comparison, RE calculations were also done using:

❖ Proton Monte Carlo dose engine of the RaySearch (RS) Treatment Planning System (TPS) (v5.99.50 research version)
Results
Water-to-air SPR (protons)

$\rightarrow I_w = 78\text{eV}$

- **Treatment plan verification at MA:**
  - Patient plan is delivered to a water phantom
  - The dose deposited is measured at different positions with a 3D block of 24 PinPoint IC.

- 1.3% variation in water-to-air SPR
Results.
Water-to-detector SPR (protons)

- Comparison of literature data with GATE calculations

→ 150 MeV proton beam
→ 0.5-2.5% difference
Results
Alanine detectors (protons)

- Water phantom
- Polystyrene phantom

Experimental data from proton beam commissioning at MedAustron 2016/2017

NPL Report IR 48
Results
Alanine detectors (protons)

- Water phantom

<table>
<thead>
<tr>
<th></th>
<th>SPR</th>
<th>RE</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GATE RS GATE Deviation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square field E=179.2 MeV (entrance)</td>
<td>1.019</td>
<td>1</td>
<td>1.00092 -0.10%</td>
</tr>
<tr>
<td>Box $R_{res} = 4\text{cm}$</td>
<td>1.015</td>
<td>0.9908</td>
<td>0.9891 0.18%</td>
</tr>
<tr>
<td>Box $R_{res} = 2\text{cm}$</td>
<td>1.014</td>
<td>0.9824</td>
<td>0.9810 0.14%</td>
</tr>
</tbody>
</table>

- Statistical uncertainty in GATE less than 1%
- RE uncertainty ~2.5%
Results
Alanine detectors (protons)

- Water phantom

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- Comparison of alanine and IC dosimetry using RE calculated with RS or GATE

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<th>Deviation (RS)</th>
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<tbody>
<tr>
<td>Square field E=179.2 MeV (entrance)</td>
<td>0.61%</td>
</tr>
<tr>
<td>Box $R_{res} = 4\text{cm}$</td>
<td>-0.30%</td>
</tr>
<tr>
<td>Box $R_{res} = 2\text{cm}$</td>
<td>-1.24%</td>
</tr>
</tbody>
</table>
Results
Alanine detectors (protons)

- Polystyrene phantom
- Comparison of alanine and IC dosimetry using RE calculated with GATE

![Graph showing deviation (%): A1 to D5, Oct 2016 and Nov 2016, Mean deviation, Stdev]
Conclusions and perspectives

- Relative effectiveness and stopping power ratio tools were successfully implemented.

- Water-to-medium SPR results for protons has been compared with literature data.

- Validation of the RE implementation based on commissioning measurements at MedAustron and comparison with RS was done in water and polystyrene phantoms.
  - It will be extended to anthropomorphic phantoms.

- Application of these tools to carbon ion end-to-end testing is ongoing.

- The use of ICRU 90 for GATE calculations is foreseen.
Thanks to…

MedAustron Medical Physics team and Monte Carlo group

Medical University of Vienna

S. Greilich and L. N. Burigo (DKFZ)

V. Ivantchenko (CERN)
Geant4 Collaboration

GATE Collaboration

Thanks for your attention