Detector Characteristics: Fluence Perturbation Effects and Volume Averaging

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Effect of the magnetic field

- The B-field influences the electron motion via the Lorentz force:
  \[ \vec{F}_L = -e \cdot \vec{v} \times \vec{B} \]

- The electron trajectory depends on:
  - Medium properties.
  - Strength and direction of the B-field.
  - Modification of radiation field.
  - Modification of detector signal.
Electron fluence perturbation in MRgRT beams

The presence of any radiation detector perturbs the particle fluence at the point of measurement. Depending on:

- Detector geometry and composition.
- Irradiation conditions such as beam energy, field size and magnetic field.
• To provide physical insights on the effects of magnetic fields on detector response.

• To calculate detector perturbation factors in MRgRT beams of multiple field sizes.

• To evaluate the magnetic field effect on the electron fluence spectra in several types of detectors.
Determination of perturbation factors

Bouchard et al (2015) formalism to determine the perturbation factors: 

\[ P_i = \frac{D_{i+1} \left( \frac{Z}{\Lambda} \right)_i}{D_i \left( \frac{Z}{\Lambda} \right)_{i+1}} \]

\[ P_{MC} = P_{\text{ext}} P_{\text{med}} P_{\rho} = \frac{D_{w,cav}}{D_{det}} \]

- \( P_{MC} \): Overall perturbation factor
- \( P_{\rho} \): Density perturbation factor
- \( P_{\text{vol}} \): Volume averaging factor
Monte Carlo simulations

<table>
<thead>
<tr>
<th>Detector</th>
<th>Solid State Detectors (SSD)</th>
<th>Ionization Chambers (IC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTW60012</td>
<td>PTW60019</td>
</tr>
<tr>
<td>Density  ([\text{g cm}^{-3}])</td>
<td>2.33</td>
<td>3.53</td>
</tr>
<tr>
<td>Sen. vol. diameter ([\text{mm}])</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Sen. vol. length ([\text{mm}])</td>
<td>0.030</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Field widths: 10, 5, 3, 2, 1, 0.75, 0.5 and 0.25 cm.

Not to scale

30 x 30 x 30 cm³
Detector orientation

1. **Perpendicular to B-field Anti-parallel to the beam**
   - γ beam
   - e-
   - FL

2. **Perpendicular to B-field Perpendicular to beam**
   - γ beam
   - e-
   - FL

3. **Perpendicular to B-field Perpendicular to beam**
   - γ beam
   - e-
   - FL

4. **Parallel to B-field Perpendicular to beam**
   - γ beam
   - e-
   - FL

7 MV FFF photon beam

143.5 cm

10 cm

Square field
Results
Density perturbation factor: $P_\rho$

- For the chambers, $P_\rho$ is one of the **dominating perturbation factors** in small fields with and without B-fields.

- For the SSD, the B-field effect on $P_\rho$ is 1% or less.
Overall perturbation factor: $P_{MC} = P_{ext} P_{med} P_{\rho}$

Effect of the magnetic field

- SSD are affected by the B-field at large field sizes.
- IC are affected by the B-field at small field sizes.
- MicroDiamond is affected by the B-field at large field sizes.
- IC are affected by the B-field at small field sizes.
- SSD: Constant B-field effect over all field sizes.
- IC are affected by the B-field at small field sizes.
- B-field effect is mostly constant and slightly decreases for the smaller fields.
Volume averaging factor: $P_{\text{vol}}$

For SSD and chamber (PTW31010), the B-field effect on $P_{\text{vol}}$ is of 1% or less from unity in all orientations an independent of field size.

For spherical IC, the B-field effect decreases with decreasing field size.

For spherical IC, the B-field effect increases with decreasing field size.
Photon beam \( \vec{F}_L \)

Parallel orientation \( \vec{F}_L \) towards stem

Perpendicular orientation \( \vec{F}_L \) towards stem

**Electron fluence spectra in IC**

Magnetic field effect: \( \Delta_B = \frac{F_e(1.5 \, T) - F_e(0 \, T)}{F_e^{\text{tot}}(0 \, T)} \)

*Vertical line: energy at which the gyration radius equals the cavity diameter*
Electron fluence spectra in SSD

Magnetic field effect: \[ \Delta_B = \frac{F_e(1.5 \, T) - F_e(0 \, T)}{F_{e_{tot}}(0 \, T)} \]

*Vertical line: energy at which the gyration radius equals the cavity diameter
Conclusions

• This study quantifies the B-field effect on detector dose response in small fields by isolating different perturbation factors.

• Solid-state detectors dose response is strongly affected by the magnetic field in all orientations, especially in orientation 1. The perturbation is mainly attributed to the extracameral components.

• For ionization chambers, the magnetic field predominantly affects the density perturbation factor.

• The B-field influence on Pvol is notable on spherical ionization chambers solely in orientations 2 and 3.
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