Plastic Scintillation Detectors: Principle and Application to Radiosurgery

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Disclosure

- Université Laval, together with MD Anderson, has licensed a plastic scintillation technology to Standard Imaging

- Luc Beaulieu is the holder of a research contract with Standard Imaging
Learning Objectives

1. Understanding the basic principal of scintillation dosimetry.

2. Knowledge of the various components of PSDs.

3. Application of PSDs to radiosurgery dose measurements.
PSD work

Researchers and Collaborators

• Luc Beaulieu
• Sam A Beddar (MD Anderson)
• Louis Archambault
• Luc Gingras
• M McEwen and C Cojocaru from NRC, Ottawa
• M Lepage, Sherbrooke

Grad. Students

• François Lessard (2010 - )
• Jonathan Morin (2010 - )
• Mathieu Goulet (2009 - )
• François Thériault-Proulx (2008 - )
• Mathieu Guillot (2007- )
• J-C Gagnon (2008-2010)
• Nicolas Tremblay (2007-2009)
• Maxime Villeneuve (2006-2008)
• Frédéric Lacroix (2005-2007)
• Louis Archambault (2002-2006)
Scintillators?
Two types of scintillators:

A. Inorganic materials

B. Organic materials (e.g. plastics)

- Lower density … and (!!!) nearly equivalent to water
  - Density on the order of 1.03-1.06 g/cm$^3$
  - (Generally) No high Z materials content.

- Excitation and emission spectra are similar in solid, liquid or vapor states
Physics of plastic scintillation detectors

• Scintillation detectors:

  • Impinging particles will excite atoms or molecules of the scintillating medium.

  • The decay of these excited states will produce photons in the visible part of the spectrum.

  • These photons will be guided to a photodetector and converted in an electric signal.
Light Production and Collection

- Ionizing radiation
- Scintillating material
- Scintillation light
- Coupling agent
- Optic guide
- Photo-detector
Stem Effect Removal: Cherenkov

\[ \mu kD_{sci}N(\ ) + \frac{C}{2} \]
Stem Effect Removal: Cherenkov

\[ m_i = \int_0^\infty \left( kD_{sci}N(l) + \frac{C}{2} \right) e^{-x/l(l)} S_i(l)
dl \]

\[ D_{sci} = Am_1 + Bm_2 \]

PROPERTIES OF PLASTIC SCINTILLATORS

• Linear response to dose

• Dose rate independence

• Energy independence
  • Particle type independence (clinical electrons and photons beam energy range)

• Pressure independence

• Spatial resolution

**WATER EQUVALENCE**

- **W-E is achieved by:**
  - Media-matching (walls and sensitive volume)

- **W-E depends on:**
  - Mass energy-absorption coefficients
  - Mass collision stopping powers
  - Size of the sensitive volume (according to Burlin cavity theory)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scintillator</th>
<th>Polystyrene</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.032</td>
<td>1.060</td>
<td>1.000</td>
</tr>
<tr>
<td>Electron density</td>
<td>3.272</td>
<td>3.238</td>
<td>3.343</td>
</tr>
<tr>
<td>(10²³ e⁻/g)</td>
<td>H: 8.47</td>
<td>H: 7.74</td>
<td>H: 11.19</td>
</tr>
<tr>
<td>Composition (by weight %)</td>
<td>C: 91.53</td>
<td>C: 92.26</td>
<td>O: 88.81</td>
</tr>
</tbody>
</table>
According to Burlin cavity theory, above 125 keV:

\[
\frac{D_{sci}}{D_{med}} = 0.980 \pm 0.005
\]

*Beddar A S et al, PMB 2002*
Water Equivalence: 80kVP x-ray in water

PTW 30013

SUN Egde

SI W1 Scint.

NE 2571

IBA SFD

SI W1 Scint.

30 kVP
Plastic Scintillation Dosimeters or PSDs

- PSDs are the most water-equivalent of the potential real-time dosimeters.
  - Can be stacked – no perturbation!
    - Guillot et al, Med Phys 38 (2011) 6763-74
  - Mixed-beam dosimetry (photons and electrons)
Radiosurgery
Why PSDs?

- For small field dosimetry (≤20 mm)
  - High spatial resolution
  - Water equivalence
  - Energy independence
  - Dose rate independence
  - Real-time measurements
Lab PSD system used

- Scintillating fiber
- Optical fiber
- Optical lens
- Polychromatic CCD (U2000C)
- Aluminum box
- Mobile supports
Total scatter factors

- Total scatter factors
  - Collimator diameters used: 5, 7.5, 10, 12.5, 15, 20, 30, 40, 50, 60 mm
  - Stem parallel to the beam axis with all detectors
Total scatter factors

- Comparison with two independent Monte Carlo studies
  - Araki (3.2 mm and 6.7 MeV)$^1$
  - Francescon (2.2±0.1 mm and 6.6±0.1 MeV)$^2$

Total scatter factors


Total scatter factors

\[ \frac{S_{c,p_{\text{measured}}} - S_{c,p_{\text{MC}}}}{S_{c,p_{\text{MC}}}} \times 100 \]

Collimator size [mm]


Total scatter factors


Total scatter factors
Corrected for composition and volume averaging effect

\[ F_{\text{average}} = \frac{\int_0^{2\pi} \int_0^{\theta} D(r, \theta) r \, dr \, d\theta}{\pi r^2} \]


## Correction factors extracted using PSD!

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Collimator diameter [mm]</th>
<th>Correction factors</th>
<th>Literature</th>
<th>Difference [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTW 60008 diode</td>
<td>5</td>
<td>0.950</td>
<td>0.944</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.942</td>
<td>0.951</td>
<td>0.9</td>
</tr>
<tr>
<td>PTW 60012 diode</td>
<td>5</td>
<td>0.963</td>
<td>0.957</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.971</td>
<td>0.967</td>
<td>-0.4</td>
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<tr>
<td>SFD diode</td>
<td>5</td>
<td>0.957</td>
<td>0.952</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.980</td>
<td>0.976</td>
<td>-0.4</td>
</tr>
<tr>
<td>MicroLion chamber</td>
<td>5</td>
<td>1.020</td>
<td>1.023</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.984</td>
<td>0.997</td>
<td>1.3</td>
</tr>
</tbody>
</table>

What we have learned

• Current commercial dosimeters provide accurate results once corrected

• PSDs need no corrections
  • Worst case scenario for 1 mm diameter PSD is a 1% underestimation for the 5 mm cone

• PSDs perfect for small field / radiosurgery
Cross-Hair Matrix for SRS/SRT

Closely pack array of 49 PSDs
4 mm cone

0.3 mm, 2%
Merci!

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