Small Field Dosimetry: An Overview of Reference and Relative Dosimetry in Non-Equilibrium Condition

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Lecture Organization

Overview of Reference and Relative Dosimetry

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SRS: Detector Selection

Sonja Dieterich

An Independent Audit and Quality Assurance

David Followill
Outline of Presentation

Definition of Small Field
- Electron range
- Electronic Equilibrium
- Transient Equilibrium
- Lateral Equilibrium

Source Occlusion
- Variation is shape, size
- Machine specific, age, vintage
- Source size and dose
- Size of detector

Detector Issues
- Volume averaging
- Perturbation

IAEA/AAPM Framework
- Nomenclature
- Reference Dosimetry
TG-155: Small Fields and Non-Equilibrium Condition
Photon Beam Dosimetry

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Treatment Fields

Magna-Fields

200x200 cm²

Traditional Fields

40x40 cm²  4x4 cm²

Advance Therapy Fields

SRS/SRT
Gamma Knife
Cyber-Knife
Tomotherapy
IMRT

Small Field

4x4 cm²  0.3x0.3 cm²
Meaning of Small Field?

- Lack of charged particle
  - Dependent on the range of secondary electrons
  - Photon energy
- Collimator setting that obstructs the source size
- Detector is comparable to the field size
CPE & Electron Range

- CPE, Charged Particle Equilibrium
- Electron range = $d_{\text{max}}$ in forward direction

- Electron range in lateral direction
  - Nearly energy independent
  - Nearly equal to penumbra (8-10 mm)
  - rLEE (g/cm$^2$) = $5.973[\text{TPR}(20,10)] - 2.688$

- Field size needed for CPE
  - Lateral range
  - 16-20 mm
Electronic Equilibrium, CPE, TCPE

Dose = KERMA

CPE
Dose = KERMA
Bragg-Gray Cavity: Range and Cavity Size

Dose is calculated only by crossers in the cavity & Cavity should be non-perturbing

Range

Cavity

Dose = \( \phi \cdot \frac{S}{\rho} = (\text{number/cm}^2)(\text{MeVcm}^2/\text{g}) = \text{MeV/g} = \text{J/kg (Gy)} \)

IJDas [9]
Lateral Electronic Equilibrium, LEE

Large Field

Small Field
Lateral Electron Range

Small Range Electrons

Large Range Electrons

LEE

No LEE
Definition of Small Fields

Penumbra dose profiles at CPE
Field dose profiles

a) b) c)

Actual field size setting
FWHM of resulting dose profiles

IJDas [12]
Energy Fluence Penumbra/Output

Source sizes

--- 0.01
--- 0.35
--- 0.50

Large field

0.5x0.5 cm²

Understanding Profiles

Large Field

Small Field

IJDas [14]
Distance

Dose

Large Detector

Small Detector
Source Size

90%, 70%, 50%, 30%, 10% iso-intensity line

Varian TrueBeam

Dimensions x, y (mm)

<table>
<thead>
<tr>
<th>Energy</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>Sawkey et al, Med Phys, 40, 332, 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MV</td>
<td>0.9, 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 MV FFF</td>
<td>0.8, 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 MV</td>
<td>0.9, 0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 MV FFF</td>
<td>0.9, 0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dose and Penumbra with Spot Size

Scott et al, Med Phys, 36, 3132, 2009
Dosimetry

- Absolute
  - Dose
- Relative
  - Depth Dose
    - \([D(r,d)/D(r,dm)]\)
  - TMR
  - Profiles
  - Output, \(S_{cp}\) (total scatter factor)
    - \([D(r)/D(ref)]\)
Small Field Dosimetry Problem

Institutional variability in 6 MV Radionics SRS dosimetry

Das et al, J Radiosurgery, 3, 177-186, 2000

Total scatter factor from different institutions

Cone Diameter (mm)

Cone Factor (St)

WEH
U-Arizona
Temple U
U Penn
Erlanger
Serago et al.
Fan et al.
Zhu et al.

12% diff
Dosimetric Variation with Detectors

Total scatter factor with various detectors

Das et al, J Radiosurgery, 3, 177-186, 2000
Dose to Water For Small Fields: Volume Averaging

Capote et al, Med Phys, 31, 2416-2422, 2004
Moignier et al, Med Phys 41(7), 071702, 2014
Ratio of Readings?

\[ D = \int_0^{\hmax} \frac{d\phi(hv)}{d(hv)} \left( \frac{\mu(hv)}{\rho} \right) E_{ab}(hv)d(hv) \]

\[ D_m = \left( \frac{Q}{m} \right) \left( \frac{W}{e} \right) \left( \frac{S}{\rho} \right)^m_a \]

\[ \frac{D(r)}{D_{\text{ref}}} = \left( \frac{Q(r)}{Q_{\text{ref}}} \right) \left( \frac{W}{e} \right)_{\text{ref}}^r \left( \frac{S}{\rho} \right)_{\text{ref}}^m \]

\[ Q(E,r) = Q_r P_{\text{ion}} P_{\text{repl}} P_{\text{wall}} P_{\text{ce}} P_{\text{cf}} \]

\[ \frac{D(r)}{D_{\text{ref}}} = \left( \frac{Q(r)}{Q_{\text{ref}}} \right) \left( \frac{W}{e} \right)_{\text{ref}}^r \left( \frac{S}{\rho} \right)_{\text{ref}}^m \]

\[ = \left( \frac{Q(r)}{Q_{\text{ref}}} \right) \bullet CF_1 \bullet CF_2 \]
Radiation Measurements

- Charged particle equilibrium
  - Range of secondary electrons
  - Medium (tissue, lung, bone)

- Photon energy and spectrum
  - Change in spectrum
    - Field size
    - Off axis points like beamlets in IMRT
  - Changes in \( \frac{\mu_{en}}{\rho} \) from reference field, \( f_{\text{ref}} \)
  - Change in \( \frac{L}{\rho} \) from reference field, \( f_{\text{ref}} \)

- Detector
  - Volume
  - Density
  - Signal to noise ratio

IJDas [25]
IAEA/AAPM proposed pathway

**REFERENCE DOSIMETRY**

\[
D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} N_{D,w,Q_0} k_{Q_{msr},Q_0} k^{f_{msr},f_{ref}}_{Q_{msr},Q}
\]

- Broad beam reference field \( f_{ref} \)
- Machine specific reference field \( f_{msr} \)
- Radiosurgical collimators \( \varnothing \) as low as 1.8 cm
- BrainLAB micro MLC 10cm x 10cm
- Hypothetical reference field \( f_{ref} \)
- CyberKnife \( \varnothing \) 6.0 cm
- GammaKnife \( \varnothing \) 1.6/1.8 cm
- TomoTherapy 5cm x 20cm

**RELATIVE DOSIMETRY**

\[
D^{f_{clin}}_{w,Q_{clin}} = D^{f_{msr}}_{w,Q_{msr}} \Omega^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}
\]

- Clinical \( f_{clin} \)
- e.g. a GammaKnife clinical plan

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Relative Dosimetry

\[
D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{DW,Q_{o}}^{f_{msr}} k_{Q,Q_{o}}^{f_{msr},f_{ref}} \\
\Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} = M_{Q_{msr}}^{f_{msr}} \left[ \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{clin}}^{f_{msr}}} \right] \left[ \left( \frac{D_{w,Q_{clin}}^{f_{clin}}}{M_{w,Q_{msr}}^{f_{msr}}} \right) / \left( M_{w,Q_{msr}}^{f_{msr}} \right) \right] = M_{Q_{msr}}^{f_{msr}} \left( \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} \right) k_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} \\
k_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} = \frac{\left( D_{w,Q_{clin}}^{f_{msr}} \right) / \left( M_{w,Q_{msr}}^{f_{msr}} \right)}{\left( D_{w,Q_{clin}}^{f_{msr}} \right) / \left( M_{w,Q_{msr}}^{f_{msr}} \right)} = \frac{(Output)_{rel}}{(Reading)_{rel}} \\
k_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} = \frac{\left( S_{w,air} \right)_{f_{clin}} \cdot P_{f_{clin}}}{\left( S_{w,air} \right)_{f_{msr}} \cdot P_{f_{msr}}} 
\]

IJDas [27]
Meaning of $k$ Defined in IAEA/AAPM

\[
k_{Q_{\text{clin}}Q_{\text{msr}}} = \frac{f_{\text{clin}}f_{\text{msr}}}{f_{\text{clin}}} = \frac{\left(\frac{L}{\rho}\right)^w_{\text{air}} \cdot P_{\text{fl}} \cdot P_{\text{grad}} \cdot P_{\text{stem}} \cdot P_{\text{cell}} \cdot P_{\text{wall}}}{\left(\frac{L}{\rho}\right)^w_{\text{air}} \cdot P_{\text{fl}} \cdot P_{\text{grad}} \cdot P_{\text{stem}} \cdot P_{\text{cell}} \cdot P_{\text{wall}}} \frac{f_{\text{msr}}}{f_{\text{clin}}}
\]

IAJdas [28]
$k_Q$ is not Constant in Small Field

Why So Much of Fuss?

- Reference (ref) conditions cannot be achieved for most SRS devices (cyberknife, gamma knife, tomotherapy etc)
- Machine Specific reference (msr) needs to be linked to ref
- Ratio of reading (PDD, TMR, Output etc) is not the same as ratio of dose

\[
\frac{D_1}{D_2} \neq \frac{M_1}{M_2}
\]

\[
\frac{D_1}{D_2} = \frac{M_1}{M_2} \cdot \left[ k \cdot f_{\text{clin}} \cdot f_{\text{msr}} \right]
\]
Das et al, TG-106, Med Phys, 35, 4186, 2008
Validity of Proposed Method

![Graph showing the relationship between Field Size (cm) and Relative Dose for different dose measurement systems including Scanditronix-SFD, Scanditronix-PFD, Extradin-A16, PTW-Pinpoint, PTW-0.125cc, PTW-0.3cc, PTW-0.6cc, PTW-Markus, and Wellhofer-IC4. The graph illustrates the varying levels of dose relative to field size.]
The influence of linac spot size on scatter factors

D Czarnecki¹, J Wulff¹ and K Zink¹,²

![Graph showing the influence of electron spot size on scatter factors with data points for different detectors (PTW60016, PTW60017, PTW31016, PTW31010).]
Summary

- Small field is a condition where dosimetry is usually difficult due to electronic disequilibrium.
- Use of IAEA/AAPM protocol for reference and relative dosimetry based on Alfonso et al (2008) is recommended.
- Focal spot of a machine is a critical parameter in small field dosimetry.
- Absolute dosimetry protocol for small field is forthcoming.
Small field is defined as a condition of?

1. Lateral electronic disequilibrium 4%
2. Range of electron beams in lateral direction 0%
3. Collimator size that obstructs the primary radiation source 2%
4. All of above 85%
5. None of above, it is field $\leq 3\times 3 \text{ cm}^2$ 9%
Answer: 4 - All of above

IAEA/AAPM have provided a framework for small field dosimetry in terms of the correction factor, $k_{\text{clin}}/k_{\text{msr}}$, which is dependent on?

- Beam energy: 2%
- Type of detector (microChambers, Diode, Mosfet etc): 8%
- Type of machine (IMRT, CyberKnife, GammaKnife etc): 1%
- Focal spot size: 2%
- All of above: 88%
Answer: 5 – all of above

Thanks