Detectors for small field and relative dosimetry

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- I am working with Sun Nuclear Corporation and Lifeline Software Inc on technology commercialization projects
- I am working with RefleXion Medical on a nonstandard field dosimetry project
- I am a founding advisor of Gray Oncology Solutions, Inc
- Some brand names of commercial products may be mentioned in this presentation. This does not represent any endorsement of one product or manufacturer over another

Content

- Reference fields and small fields
  - Nonstandard reference field calibration
  - Some post-TRS483 comments
- Small field dosimetry
  - Characteristics of suitable detectors
  - Unanswered questions
Two important reports came out in 2017

Dosimetry of nonstandard and small fields

- Characteristics that lead to dosimetric issues of two kinds:
  - Reference dose calibration
    - Reference fields are not 10 x 10 cm², SSD/SAD is not 100 cm, etc; they are "machine-specific reference fields" (mrf)
    - Flattening filter-free beams, beam quality specification
  - Output factors
  - Small fields
  - Detector correction factors
- Problem put on the backburner: calibration of composite fields

Physics of small fields

Small field conditions

Source occlusion

Detector correction factors

Repercussions on how we determine dose in a small field
Lateral charged particle loss

In small fields there is no depth at which $D = K_{col}$

Note: Estimates using this method are inaccurate for FFF beams.

Reference calibration fields

Concept of the msr field
Detector size relative to field size

- Small field conditions exist when one of the edges of the sensitive volume of a detector is less than a lateral charged particle equilibrium range \( r_{LCP} \) away from the edge of the field

\[
f_{msr} < 6 \times 6 \text{ cm}^2
\]

\[
r_{LCPE} \text{[cm]} = 8.369 \times (TPR_{20,10} - 4.382)
\]

\[
r_{LCPE} \text{[cm]} = 0.07997 \times \%dd(10) - 4.112
\]

\[
\text{FWHM} \geq 2 \times r_{LCP} + d
\]

Example:  \( \text{FWHM} \geq 2 \times r_{LCP} + d \)

- \%dd(10) = 67.2 \( \rightarrow \) \( r_{LCP} \geq 11.2 \text{ mm} \).
- An IBA CC08 ion chamber has a cavity length \( l = 4 \text{ mm} \), a cavity radius \( r = 3 \text{ mm} \) and a wall thickness \( t_{wall} = 0.07 \text{ g/cm}^2 \); with \( \rho(C-552) = 1.76 \text{ g/cm}^2 \), \( t_{wall} = 0.40 \text{ mm} \).
  \[ d = l + t_{wall} = 4.4 \text{ mm} \]
  \[ d = 2(r + t_{wall}) = 6.8 \text{ mm} \]
  \[ \text{FWHM should be at least } 2 \times 11.2 \text{ mm} + 6.8 \text{ mm} = 29.3 \text{ mm at a depth of } 10 \text{ cm in water.} \]

\[ \rightarrow \text{The "equivalent square field size" should exceed 3 cm for the field to be an msr!} \]

Equivalent square fields \( msr \)

\[
s = \frac{1}{2\pi} \int \int (\lambda e^{-\lambda r^2} - \mu e^{-\mu r^2} + \mu\lambda e^{-\lambda r^2}) F(r) dr d\theta
\]

Make the scattering component equivalent!

WFF beams:
- BJR 25 - equivalent field size is energy independent

FFF beams:
- equivalent field size is energy dependent; Tables are provided for 6 MV and 10 MV
Getting the beam quality in nonstandard reference fields
for $\text{TPR}_{20,10}(10) = \text{TPR}_{20,10}$

$$\text{TPR}_{20,10}(10) = \frac{\text{TPR}_{20,10}(10-5)}{1+e^{(10-2)}}$$

for $\%d_d(10,10) = \%d_d(10,10)_X = \%d_d(10)_X$

$$\%d_d(10,10) = \frac{\%d_d(10,5)+80\%d_d(10-5)}{1+e^{(10-2)}}$$

Note: FFF beams $\Rightarrow$ use the Pb filter and equations in TG-51 to get $\%d_d(10,10)_X$.

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$f_{\text{marr}} \geq 6 \times 6 \text{ cm}^2$

$f_{\text{marr}} < 6 \times 6 \text{ cm}^2$

$$r_{\text{LCPB/CM}} \text{ cm} = \frac{8.69 \times \text{TPR}_{20,10}(10)}{4.92}$$

$$r_{\text{LCPB/CM}} \text{ cm} = \frac{0.6797 \times \%d_d(10)_X}{4.112}$$

FWHM $\geq 2 \left( r_{\text{LCPB}} + d \right)$

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Practical implementation $msr$ dosimetry – beam quality index

Note: FFF beams $\Rightarrow$ use the Pb filter and equations in TG-51 to get $\%d_d(10,10)_X$. 

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What is included in $k^{\text{ref}}_{Q_0}$?

- FFF beams $\rightarrow s_{w,\text{air}}$
- Volume averaging in generic FFF fields ($P_r$ is included)

\[
\begin{align*}
D^{\text{ref}}_{w} &= M^{\text{ref}}_{w} \times N^{\text{ref}}_{w} \times S^{\text{ref}}_{w} \\
\left( k^{\text{ref}}_{Q_0} Q^{\text{ref}}_{w} \right) &= k^{\text{ref}}_{Q_0} Q^{\text{ref}}_{w} \\
&= M^{\text{ref}}_{w} \times N^{\text{ref}}_{w} \times S^{\text{ref}}_{w} \\
&= M^{\text{ref}}_{w} \times N^{\text{ref}}_{w} \times S^{\text{ref}}_{w}
\end{align*}
\]

Data consistent with TG51 Addendum data
In summary

For the beam of interest:

- Get equivalent square $S$
- Measure the $%dd(10,5)$ (if FFF: use lead filter!)
- Use conversion formula for SSD, Pb, $S$ to get $%dd(10,10)$
- Look up $k_{f_{ext}}^{f_{ext}}$ or $k_{Q_{max}}^{f_{ext}}$

\[ D_{w,Q_{max}}^{f_{ext}} = M_{w,Q_{max}}^{f_{ext}} N_{w,Q_{max}}^{f_{ext}} k_{f_{ext}}^{f_{ext}} k_{Q_{max}}^{f_{ext}} \]

What to do when largest field size is not $msr$?

- Reference dosimetry field size (10 x 2 cm$^2$)
- SSD = 85 cm
- $2r_{LCPE} + d > $ FWHM
- Two approaches
  - Direct MC calculation
  - $k_{Q_{max}}^{f_{ext}}$

Small fields and detectors
Source occlusion

FWHM > geometric field size

Small field dosimetry-related parameters must be specified as a function of FWHM

Field size specification $S_{\text{clin}}$

$S_{\text{clin}} = \sqrt{A \cdot B}$

$0.7 < A/B < 1.4$

$S_{\text{clin}} = r \cdot \sqrt{\pi}$

Spectral changes

- The photon fluence spectrum is modified as a function of field size
Concept of field output correction factors

• Field output factor relative to reference field (ref stands here for a conventional reference or msr field)

\[
\frac{O_{\text{ref}}}{O_{\text{clin}}} = \frac{M_{\text{ref}}^2}{M_{\text{clin}}^2} \cdot \frac{K_{\text{ref}}}{K_{\text{clin}}}
\]

• Field output factor relative to reference field using intermediate field or 'daisy chaining' method

\[
\frac{O_{\text{ref}}}{O_{\text{clin}}} = \frac{M_{\text{ref}}^2(\text{det})}{M_{\text{clin}}^2(\text{det})} \cdot \frac{M_{\text{ref}}^2(\text{IC})}{M_{\text{clin}}^2(\text{IC})} \cdot K_{\text{ref}} \cdot K_{\text{IC}}
\]

where

Output factors are DOSE RATIOS not reading ratios!!

Small field output correction factors

• There are large corrections to reading of virtually any type of detector
• For air-filled chambers: large upwards correction factors in small fields
• For solid state detectors: correction factors depend on the construction, density, Z and size of the sensitive volume

ICRU 91 Report (2017)
Detector suitability criteria for small fields

- There is no ideal detector
- Suitability in general is tied to
  - the sensitive region of the detector is close to water equivalent in terms of radiation absorption characteristics;
  - the density of the sensitive region is close to the density of water;
  - the size of the sensitive region can be made small compared to the field size while keeping noise levels under control.

Diodes for small field dosimetry

Shielded and unshielded diodes
Microdiamond detector

Small field correction factor issues

- The correction factors are likely energy dependent
- Detailed geometry is critical for MC simulations
- SN EDGE detector below 2 cm in 10 MV FFF beam significantly different from IAEA-AAPM 483
- See left panel for similar differences with PTW microdiamond

Scintillators W1 and W2
Conclusion

- IAEA-AAPM TRS-483 has significantly improved consistency in small field dosimetry
- The use of more than a single detector to quantify small field output factors is recommended
- Accelerators are getting increasingly reproducible. It makes therefore sense to compare output factors of a given machine with those of a similar machine
- Post IAEA-AAPM TRS483
  - New machines will come to the market that invalidate nonstandard field conditions
  - The last word about so-called promising detectors has not yet been said
- Small field dosimetry for field sizes below 1 x 1 cm² remains challenging