Monitor Unit Calculations for Photon and Electrons

AAMD Meeting
Raleigh, NC
October 3, 2014

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Outline

I. TG71 Formation and Charge
II. Photon Calculations
III. Electron Calculations
IV. Conclusions
TG-71
Task Group Charge

• Emphasize the importance of a unified methodology
• Recommend consistent terminology for MU calcs
• Recommend measurement and/or calculation methods
• Recommend QA tests
• Provide example calculations for common clinical setups
TG71 Report Outline

1. Introduction
2. Nomenclature
3. Calculation Formalism
   1. MU Equations
   2. Input Parameters (Depth, Field Size)
4. Measurements
5. Interface to TPS
6. Quality Assurance
7. Examples
Monitor Unit Calculations
Overview

• Accuracy within ±5%
• Absolute versus Relative Dosimetry
• Consistency with Treatment Plan
• QA program
Reference and Normalization Depths

• Reference depth \( (d_{\text{ref}}) \): Defined within calibration protocols as the depth for measurement of absolute beam output.
  – TG51: \( d_{\text{ref}} = 10\text{cm} \)

• Normalization depth \( (d_0) \): The depth at which all relative dosimetry functions (e.g., Scp, TPR) are set to unity.
  – Most clinics \( d_0 = d_m \)
Normalization vs. Reference Conditions

d₀

\[ \text{d}_{\text{ref}} \]

\[ \text{d}_{\text{max}} \]
Outline

I. Introduction
II. Photon Calculations
III. Electron Calculations
Nomenclature Principals
(3 Laws of Nomenclature)

• Law 1: Use commonly understood symbols
• Law 2: Maintain consistency with other TG reports, unless it conflicts with Law 1
• Law 3: Avoid multiple-letter subscripts and/or variables, unless it conflicts with Laws 1 or 2
Nomenclature
Photon Calculations

Constants

- $D_0'$: Dose rate at normalization point
- $d_0$: Reference depth
- $r_0$: Normalization field size
- SAD: Source to Isocenter (Axis) Distance
- $SSD_0$: Source to Surface Distance under normalization conditions
Nomenclature
Photon Calculations

*Independent Variables*

- $d$: Depth to point of calculation
- $d_{\text{eff}}$: Effective or radiological depth
- $d_m$: Depth of maximum dose
- $r$: Field size at the surface
- $r_d$: Field size at the depth of the calc pt.
- $r_c$: Field size defined by the collimator jaws
Nomenclature
Photon Calculations

*Independent Variables*

- **SPD**  Source to (calculation) Point Distance
- **SSD**  Source to Surface Distance
- **x**    Off Axis Distance
Nomenclature
Photon Calculations

Dependent Variables

- $D$: Dose to the calculation point
- $OAR$: Off-Axis Ratio
- $PDD$: Percentage Depth Dose
- $PDD_N$: Normalized Percentage Depth Dose
- $S_{c,p}$: Output Factor
- $S_p$: Phantom Scatter Factor
- $S_c$: In-air Output Ratio
Nomenclature
Photon Calculations

*Dependent Variables*

- **TPR**  Tissue Phantom Ratio
- **TF**   Tray Factor
- **WF**   Wedge Factor
Depth of Normalization

• All quantities should be determined at this depth
• Recommended beyond the range of electron contamination
• Extrapolated $d_m$ for largest SSD, smallest $r$
• ESTRO Report recommends depth of 10cm.
Reference Depth

- TG71 Recommends $d_0=10\text{cm}$

- Why $d_0=10\text{cm}$?
  1. Consistency with TG-51
  2. $\text{PDD}(d_{\text{max}})$ is inaccurate.
  3. Electron Contamination at $d_m$ creates problems

- TG71 Formalism Valid for $d_0=\text{maximum } d_m$
Isocentric Calculations

Calculation to the Isocenter

\[
MU = \frac{D}{D_0 \cdot S_c(r) \cdot S_p(r_d) \cdot TPR(d,r_d) \cdot WF(d,r_d) \cdot TF \cdot \left( \frac{SSD_0 + d_0}{SAD} \right)^2}
\]
Isocentric Calculations

Calculations to Arbitrary Points

\[ MU = \frac{D}{D_0 \cdot S_c(r_c) \cdot S_p(r_d) \cdot TPR(d, r_d) \cdot WF(d, r_d) \cdot TF \cdot OAR(d, x) \cdot \left( \frac{SSD_0 + d_0}{SPD} \right)^2} \]
Non-Isocentric (SSD) Calculations

\[
MU = \frac{D \cdot 100\%}{D_0 \cdot S_c(r) \cdot S_p(r_{d_0}) \cdot PDD_N(d,r,SSD) \cdot WF(d,r) \cdot TF \cdot OAR(d,x) \cdot \left(\frac{SSD_0 + d_0}{SSD + d_0}\right)^2}
\]
Determination of Field Size
Method of Equivalent Square

• Rectangular fields may be calculated using the dosimetric quantities for an equivalent square:
  – Equivalent Square Approximation: $4 \times \frac{A}{P}$
  – Equivalent Square Tables (e.g., Day and Aird, ‘83)
• Highly irregular fields may be calculated using a Clarkson integration
• These relationships should be verified for $S_c$
Determination of Field Size for $S_c$

- Open or Blocked (Cerrobend) Fields
  - Protocol uses Equivalent Square of Collimator Field Size
  - More accurate methods (e.g., PEV model) may be required if:
    - Rectangular Fields of large aspect ratio
    - Highly Irregular Fields
Determination of Field Size for $S_c$

Sources of Head Scatter

- Backscatter to monitor chamber
- Head Scatter
  - Adjustable Collimators
  - Flattening Filter
Determination of Field Size for $S_c$ Points
Eye View Model
Determination of Field Size for $S_c$ Collimator Exchange Effect

- Defined: $S_c(a,b) \neq S_c(b,a)$
- Demonstrated for Open and Wedged Fields
- Magnitude is typically $< 2\%$
Determination of Field Size for $S_C$
Collimator Exchange Effect
Determination of Field Size for $S_c$ Points
Eye View Model

(a) 6 MV Collimator Scatter Factor

(b) 6 MV Head Scatter Factor
Determination of Field Size for $S_c$

- MLC Fields
  - Under PEV model, only apertures close to FF will affect $S_c$
  - Thus Field Size depends on MLC model
    - Upper Collimator Replacement
    - Lower Collimator Replacement
    - Tertiary MLC
Determination of Field Size for $S_c$
Collimator Scatter with MLCs

• Upper Jaw Replacement:
  – Palta found $S_c$ best described by MLC field

• Lower Jaw Replacement:
  – Das found $S_c$ best described by MLC field

• Tertiary Collimator:
  – Klein found $S_c$ best described by collimator jaws
Determination of Field Size

• Other parameters are affected by the amount of scatter within the phantom material.

• Define the “Effective Field Size” as the equivalent square of the field size incident on the phantom. This field size is reduced by
  – Custom Blocking/MLCs
  – Missing Tissue (“Fall Off”)
Determination of Field Size

- $S_p$
  - Use effective field size at depth (isocentric) or at the normalization depth (SSD)

- TPR, WF
  - Use effective field size at depth

- $PDD_N$
  - Use effective field size on the surface
For Photon Beams, the depth of normalization is:

0%  1.  10 cm
0%  2.  \(d_m\)
0%  3.  \(d_{\text{ref}}\)
0%  4.  Maximum \(d_m < d_0 \leq 10\) cm
0%  5.  Maximum \(d_m < d_0\)
For Photon Beams, the depth of normalization is:

5. Maximum $d_m \leq d_0$

Reference: AAPM Task Group 71 Report
The equivalent square for irregular fields may be approximated by:

1. Equivalent area method
2. 4A/P method, where A, P are the area, perimeter of the irregular field
3. 4A/P method, where A, P are the area, perimeter of an equivalent rectangle to the irregular field
4. PEV model for non-tertiary MLC fields
5. PEV model for all fields
The equivalent square for irregular fields may be approximated by:

3. 4A/P method, where A, P are the area, perimeter of an equivalent rectangle to the irregular field

Reference: AAPM TG-71 Report
Determination of Depth
Use of Heterogeneity Corrections

- Not universally used
- Importance of physician awareness
- Two possible methods for manual calculations
  - Ratio of TAR (RTAR) method
  - Power law TAR (“Batho Method”)

MARY BIRD PERKINS CANCER CENTER
Fighting Cancer For Over 40 Years.
Measuring Dosimetric Parameters

Photon Output Factors

- $S_{c,p}$ measured in phantom at reference depth
- Important to separate collimator and phantom scatter
- $S_p$ usually determined indirectly:

\[ S_p = \frac{S_{c,p}}{S_c} \]
Measuring Dosimetric Parameters
Photon Output Factors

- $S_c$ measured in air at reference depth.
  - Traditionally, measured with buildup cap
  - Larger $d_o$ will require mini-phantoms
- Should avoid scatter from surrounding structures (support stands, floor, wall)
Measuring Dosimetric Parameters
6MV Output Comparisons

![Graph showing 6 MV output comparisons for field sizes up to 45 cm, with lines for 6 MV, d=10 and 6 MV, d=1.5.]
Measuring Dosimetric Parameters
6MV Output Comparisons

![Graph showing field size vs. Sp for 6MV output comparisons with different depths (d=10 and d=1.5).]
Measuring Dosimetric Parameters

6MV Output Comparisons

![Graph showing field size vs. output ratio for 6MV radiation]
Measuring Dosimetric Parameters

Wedge Factors

• **Internal (Motorized) Wedges**
  - Single, large (e.g., 60°) wedge placed above jaws
  - Universal wedge concept

• **External Wedges**
  - Wedge placed below jaws by user
  - Selection of wedge angles available
Measuring Dosimetric Parameters

WF Field Size Dependence

• Extensively studied (>20 papers)

• RPC Review:
  $WF = WF(R)$ if $WF < 0.65$
Field-Size Dependence

(20 cm x 20 cm versus 10 cm x 10 cm)

Relative Wedge Transmission

Central Axis Wedge Transmission

30° ▼ 45° ■ 60° ● RPC Data

Published Data
Measuring Dosimetric Parameters
WF Depth Dependence

• McCullough et al.,
  • Introduced RWF(d)
  • No significant effect >2% for d<10cm

• RPC Review:
  WF=WF(d) if E<10MV or
  if WF<0.65
Depth Effect
(20 cm versus 5 cm)

A = 30°
B = 45°
C = 60°
Determining Dosimetric Parameters
Filterless Wedge Factors

- EDW Factors
  - Direct Inspection of Final Segmented Treatment Tables (STT)
  - Use of Normalized Golden STT
  - Analytic Equations

- VW Factors
  - Very close to unity for all Wedge Angles, Field Sizes
  - Exponential Off-Axis Relationship
Determining Dosimetric Parameters
EDW Factors
Measuring Dosimetric Parameters
Off Axis Ratios

Calculations to off-axis points may be performed in two methods:

1. Use of off-axis dosimetry functions
2. Use of CA dosimetry functions with a off-axis ratio: $OAR(x,d,r)$
Measuring Dosimetric Parameters
Off-Axis Ratios

Off-Axis Ratios have been determined in several ways

1. Large field profile data
2. Primary Off-Axis Ratios (POAR(x,d))
3. Analytic Equations
Measuring Dosimetric Parameters
Off-Axis Ratios

OAR Comparisons:

<table>
<thead>
<tr>
<th></th>
<th>Average (Max) Error</th>
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<tbody>
<tr>
<td>Large Field Profiles</td>
<td>2.5% (6.7%)</td>
</tr>
<tr>
<td>POARs:</td>
<td>0.8% (1.8%)</td>
</tr>
<tr>
<td>Analytic Equation</td>
<td>0.5% (1.7%)</td>
</tr>
</tbody>
</table>

[6, 24MV photons at 5,10,15cm OADs/depths]
In MU calculations, wedge factors are

0% 1. Field size and depth dependent if WF<0.65
0% 2. Always larger for physical wedges
0% 3. Defined at d = 10 cm
0% 4. Defined at d = dm
0% 5. Field size dependent only for internal wedges
In MU calculations, wedge factors are

1. Field size and depth dependent if WF<0.65

Outline

I. Introduction

II. Photon Calculations

III. Electron Calculations
Nomenclature
Electron Calculations

*Independent Variables*

- $r_a$ Applicator size for electron beams
- $r$ Effective field size on the surface
- $g$ Difference between treatment SSD and normalization SSD ($SSD_0=100$)
- $SSD_{\text{eff}}$ Effective Source to Surface Distance
Nomenclature
Electron Calculations

*Dependent Variables*

- $f_{air}$: Air gap correction factor
- $S_e$: Electron Output Factor
Electron Calculations
(SSD\(_0\)=100\,\text{cm})

\[ \text{MU} = \frac{D}{D_0' \cdot S_e(r_a, r)} \]
Electron Calculations
(SSD > SSD₀)

Method 1: SSD_{eff} Technique

\[ MU = \frac{D}{D'_0 \cdot S_e (r_a, r) \cdot \left(\frac{(SSD_{eff} + d_0)}{(SSD_{eff} + d_0 + g)}\right)^2} \]
Electron Calculations
(SSD>SSD₀)

Method 2: Air Gap Technique

\[ MU = \frac{D}{D₀ \cdot S_e (r_a, r) \cdot \left( (SSD + d₀) / (SSD + d₀ + g) \right)^2 \cdot f_{air} (r, SSD)} \]
Electron Output Factors

• For square fields, $S_e$ measured at commissioning
• For rectangular fields, use Square Root Method:
  $$S_e(r_a,LxW) = \left[ S_e(r_a,LxL) \cdot S_e(r_a,WxW) \right]^{1/2}$$
• Many irregular fields can be approximated by rectangular fields.
Electron Cone Inserts

From Hogstrom et al., “MU Calculations for Electron Beams”, 2000
Electron Irregular Fields

• Special considerations required if FS very small \((r < E/2.5)\)

• For these conditions, \(S_e\) may be determined by
  – Special Dosimetry
  – Method of Lateral Buildup Ratio (LBR)
Electron
Extended SSD Calculations

- Many treatment geometries require extended SSDs

- The *Air Gap Factor* may be determined
  - Using inverse square correction with virtual SSD
    - requires air gap scatter correction term
  - Using inverse square correction with effective SSD
Electron Extended SSDs

\[ \sqrt{\frac{I}{I_0}} \]

Depth = \( d_0 \) cm

\[ \*f = \frac{1}{\text{slope}} - d_0 \]

Gap \( g \) (cm)
## Electron Extended SSDs

<table>
<thead>
<tr>
<th>Aperture size (cm²)</th>
<th>Inert size (cm²)</th>
<th>Energy (MeV)</th>
</tr>
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<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>10×10</td>
<td>4×4</td>
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<td>89.3</td>
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<td></td>
<td>25×25</td>
<td>90.7</td>
</tr>
</tbody>
</table>

*From Roback et al., “Effective SSD for Electron Beams …”, Med Phys 1995*
For electron beams, the depth of normalization is

0% 1. 10 cm
0% 2. \( R_{100} \) for the given field
0% 3. \( R_{90} \) for the given field
0% 4. \( R_{100} \) for the open cone
0% 5. \( d_{\text{ref}} \)
For electron beams, the depth of normalization is

2. $R_{100}$ for the given field

Electron output factors at extended SSDs are:

- 0% 1. Independent of electron energy
- 0% 2. Calculated using the square root method
- 0% 3. Calculated either using effective SSDs or air-gap methods
- 0% 4. Depend primarily on applicator field size
- 0% 5. Calculated using lateral build-up ratios
Electron output factors at extended SSDs are 3. Calculated either using effective SSDs or air-gap methods

Conclusions

• Task Group 71 of the RTC was formed to create a consistent nomenclature and formalism for MU Calculations

• For photon beams, TG71 recommends a normalization depth of 10cm, although the formalism is valid for (maximum) $d_m$.

• For electron beams, TG71 allows for both effective SSD or Air Gap correction methods for extended SSD calculations