Monitor Unit Calculations for Photon and Electrons

AAPM Spring Meeting

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Outline

I. TG71 Formation and Charge
II. Photon Calculations
III. Electron Calculations
IV. Conclusions

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TG-71
Task Group Charge

- Emphasize the importance of a unified methodology
- Recommend of 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

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Monitor Unit Calculations Overview

- Accuracy within ±5%
- Absolute versus Relative Dosimetry
- Consistency with Treatment Plan
- QA program

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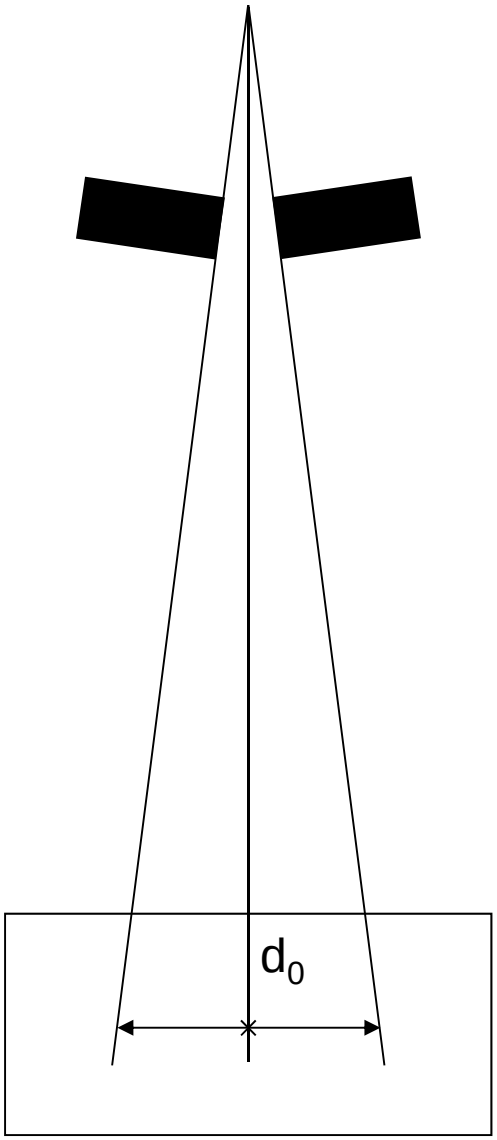
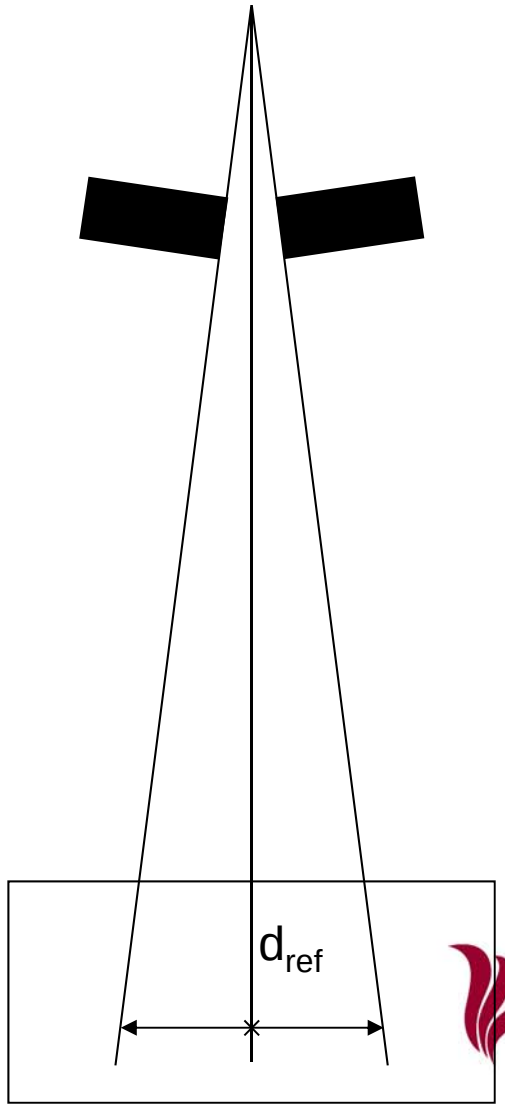
Reference and Normalization Depths

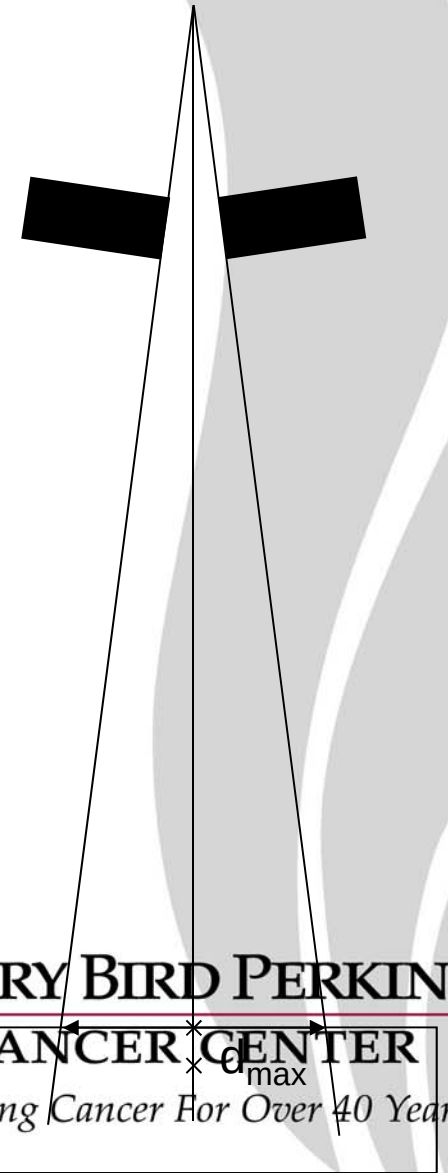
- Reference depth (d_{ref}): Defined within calibration protocols as the depth for measurement of absolute beam output.
  - TG51: d_{ref} = 10cm

- 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







Outline

I. Introduction

II. Photon Calculations

III. Electron Calculations

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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_{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=10cm
- Why d_0=10cm?
  1. Consistency with TG-51
  2. PDD(d_{max}) is inaccurate.
  3. Electron Contamination at d_m creates problems
- TG71 Formalism Valid for d_0= maximum d_m

Isocentric Calculations

Calculation to the Isocenter

$$MU = \frac{D}{D_0^{'} \cdot S_c(r_c) \cdot S_p(r_d) \cdot TPR(d, r_d) \cdot WF(d, r_d) \cdot TF \cdot \left(\frac{SSD_0 + d_0}{SAD} \right)^2}$$

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Isocentric Calculations

Calculations to Arbitrary Points

$$MU = \frac{D}{D_0^{'} \cdot S_c(r_c) \cdot S_p(r_d) \cdot TPR(d, r_d) \cdot WF(d, r_d) \cdot TF \cdot OAR(d, x) \cdot \left(\frac{SSD_0 + d_0}{SPD} \right)^2}$$

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Non-Isocentric (SSD) Calculations

$$MU = \frac{D \cdot 100\%}{D_0^{'} \cdot S_c(r_c) \cdot S_p(r_{d0}) \cdot PDD_N(d, r, SSD) \cdot WF(d, r) \cdot TF \cdot OAR(d, x) \cdot \left(\frac{SSD_0 + d_0}{SSD + d_0} \right)^2}$$

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Determination of Field Size
Method of Equivalent Square

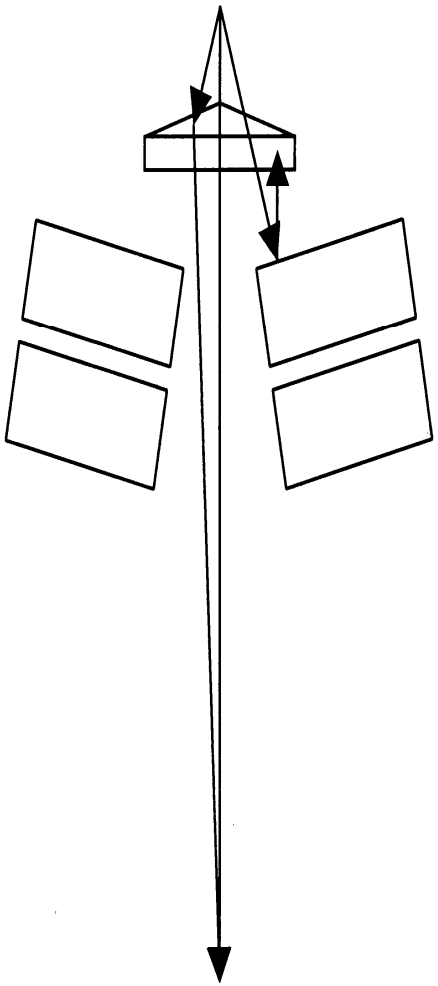
- Rectangular fields may be calculated using the dosimetric quantities for an equivalent square:
  - Equivalent Square Approximation: 4*A/P
  - Equivalent Square Tables (e.g, Day and Aird, '83)
- Highly irregular fields may be calculated using a Clarkson integration
- These relationships should be verified 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

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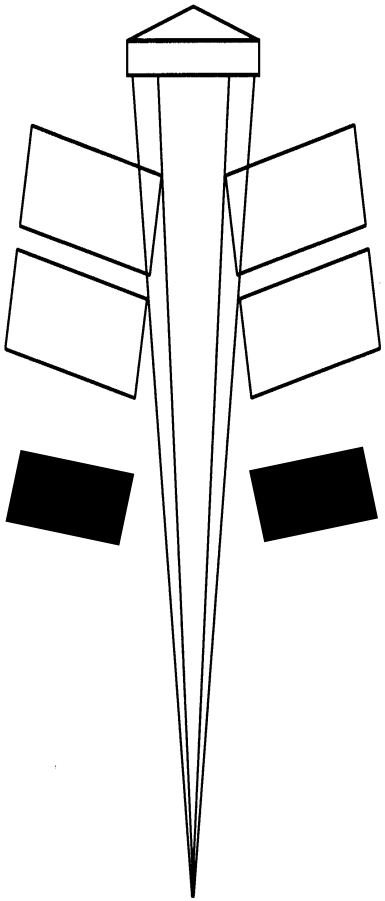
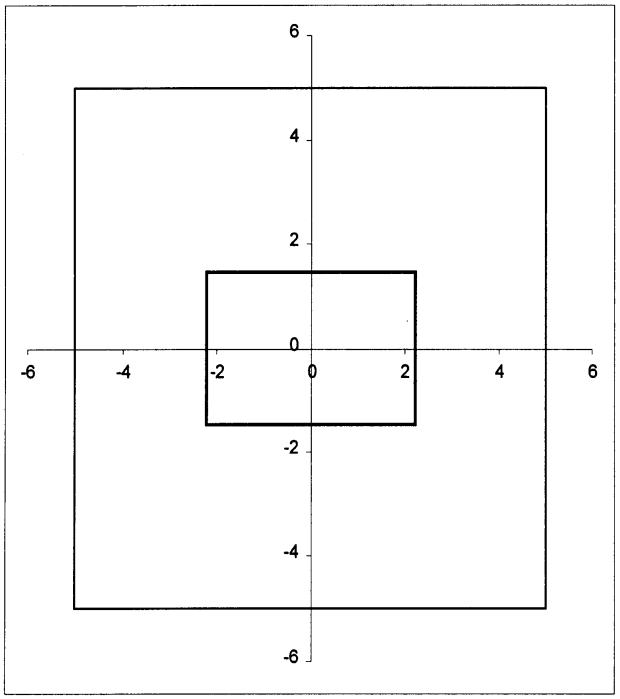
Determination of Field Size for S_c Points
Eye View Model





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%

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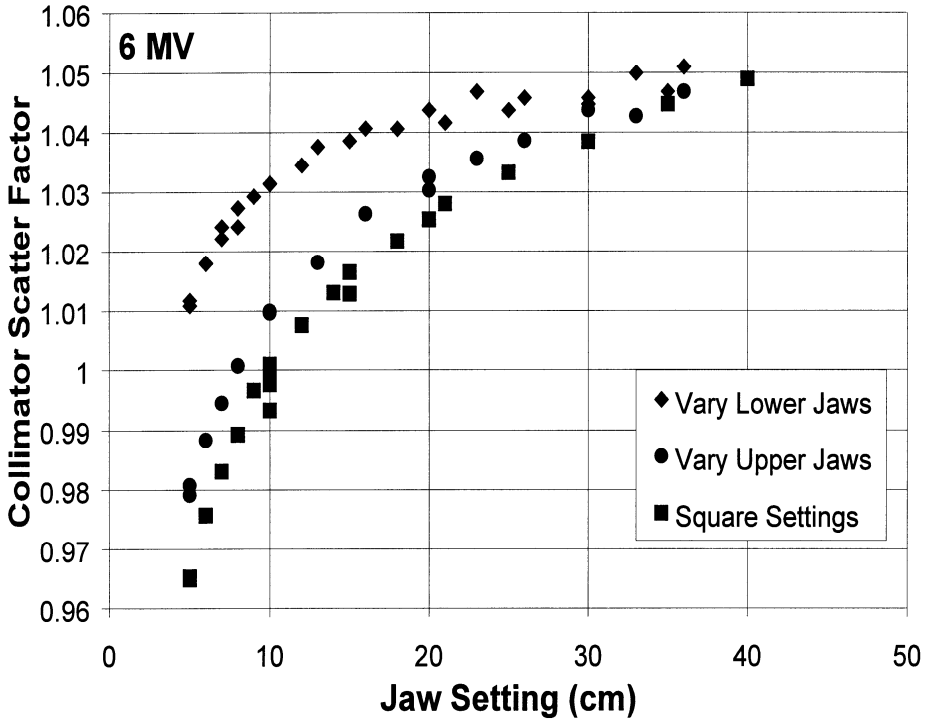
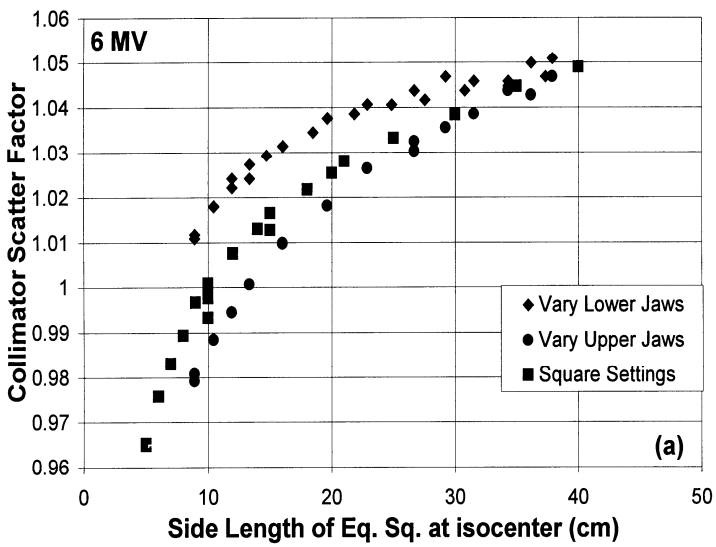
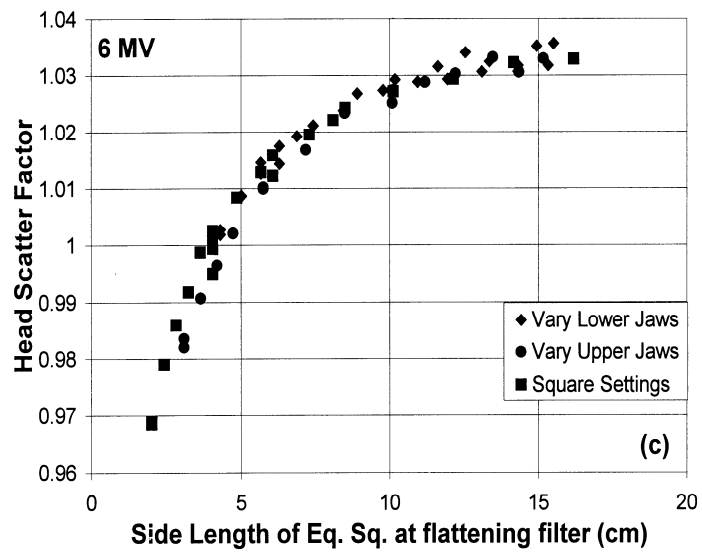
Determination of Field Size for S_c
Collimator Exchange Effect



Determination of Field Size for S_c Points
Eye View Model





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Determination of Field Size for S_c

- MLC Fields
  - Under PEV model, only apertures close to FF will effect Sc
  - 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 Sc best described by MLC field
- Lower Jaw Replacement:
  - Das found Sc best described by MLC field
- Tertiary Collimator:
  - Klein found Sc 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_{ref}
0%	4. Maximum $d_m < d_0 \leq 10$ cm
0%	5. Maximum $d_m \leq d_0$

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10

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:

0% 1. Equivalent area method

0% 2. 4A/P method, where A, P are the area, perimeter of the irregular field

0% 3. 4A/P method, where A, P are the area, perimeter of an equivalent rectangle to the irregular field

0% 4. PEV model for non-tertiary MLC fields

0% 5. PEV model for all fields

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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")

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:

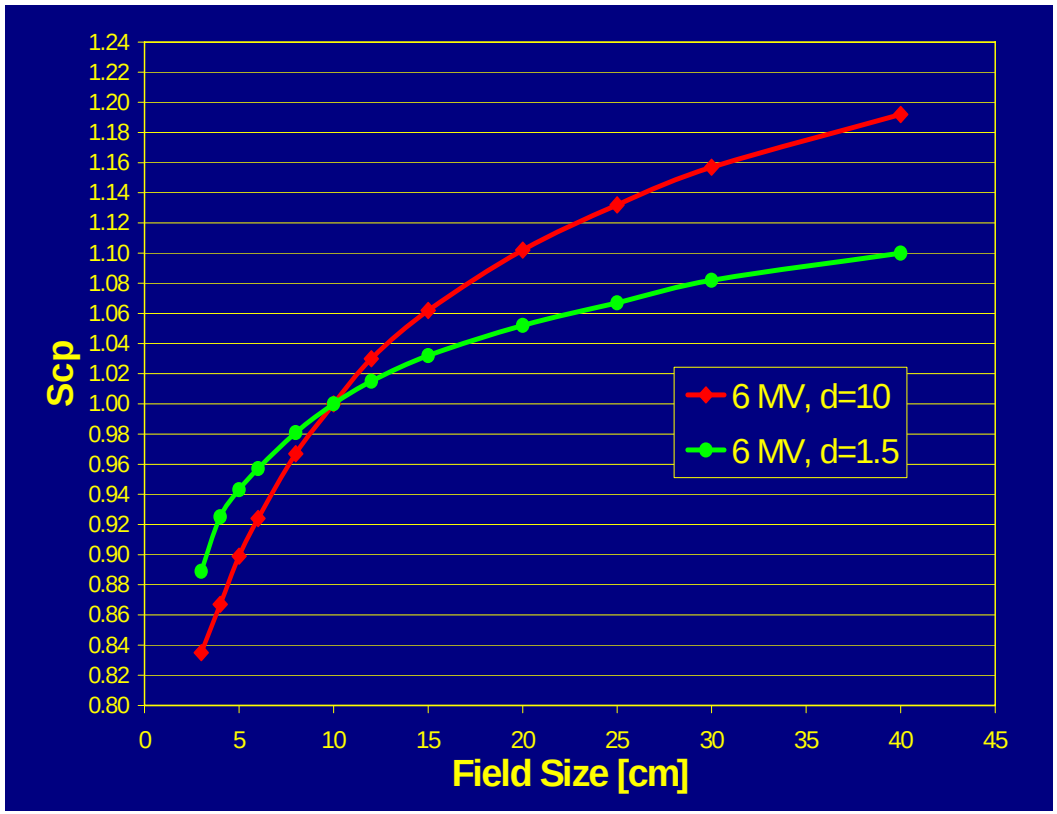
$$S_p = \frac{S_{c,p}}{S_c}$$

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



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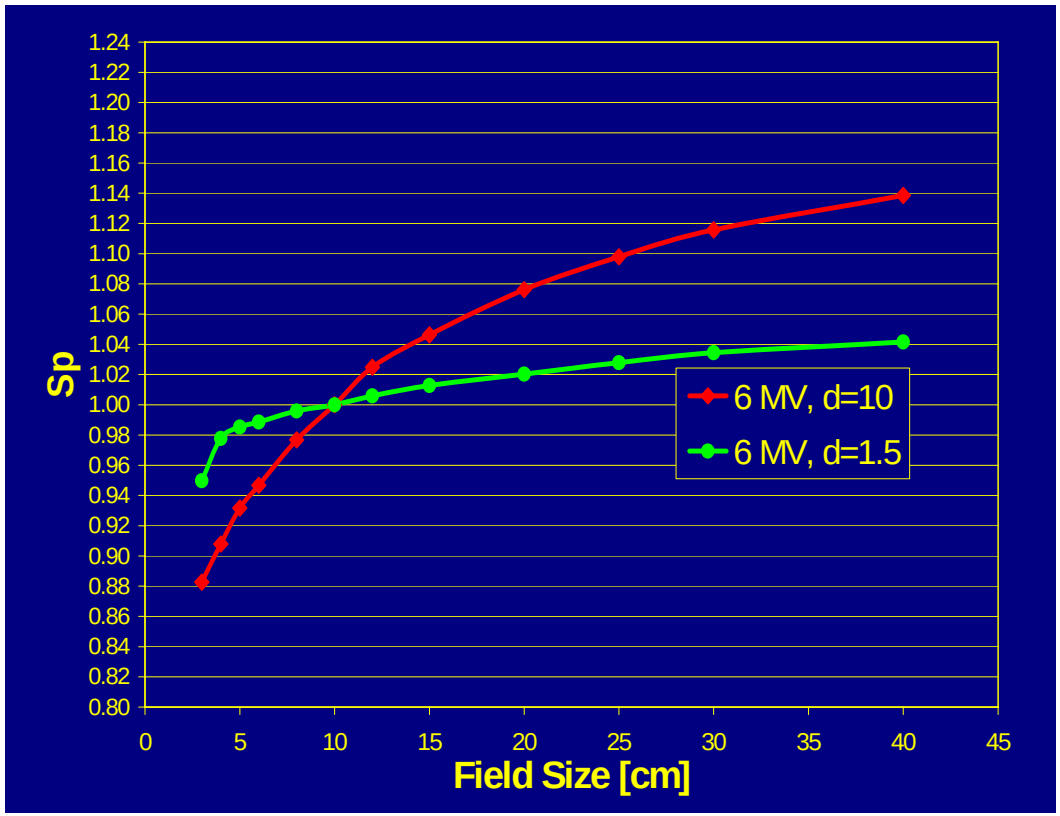
Measuring Dosimetric Parameters

6MV Output Comparisons



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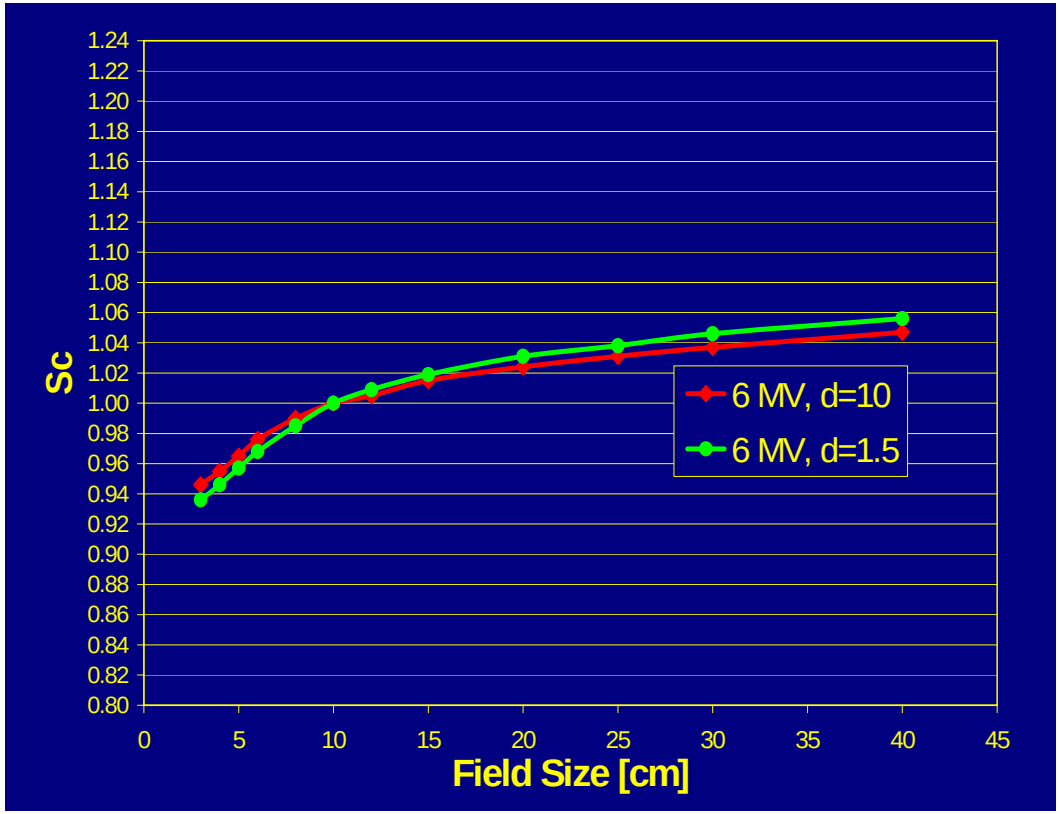
Measuring Dosimetric Parameters

6MV Output Comparisons



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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

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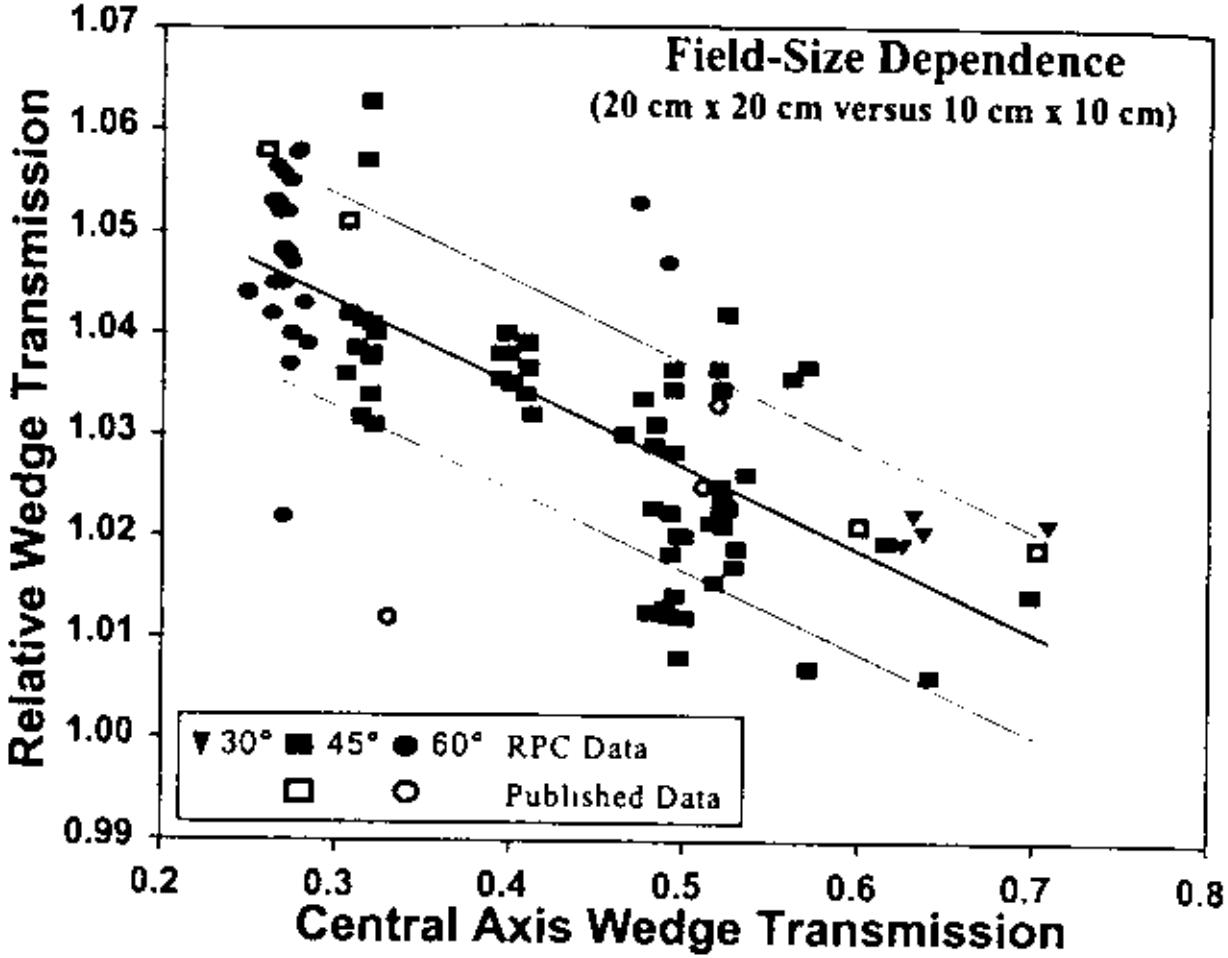

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Measuring Dosimetric Parameters

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

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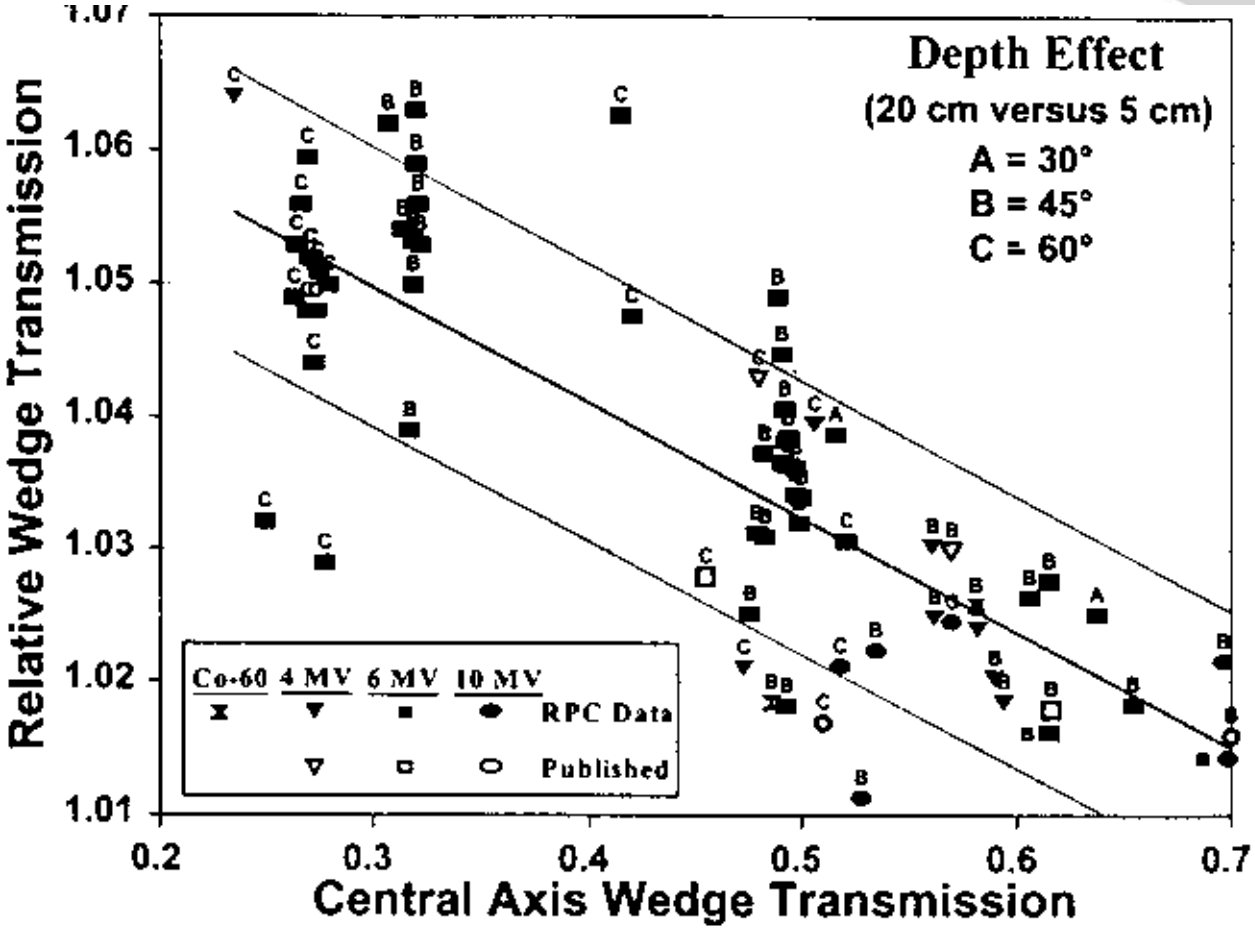

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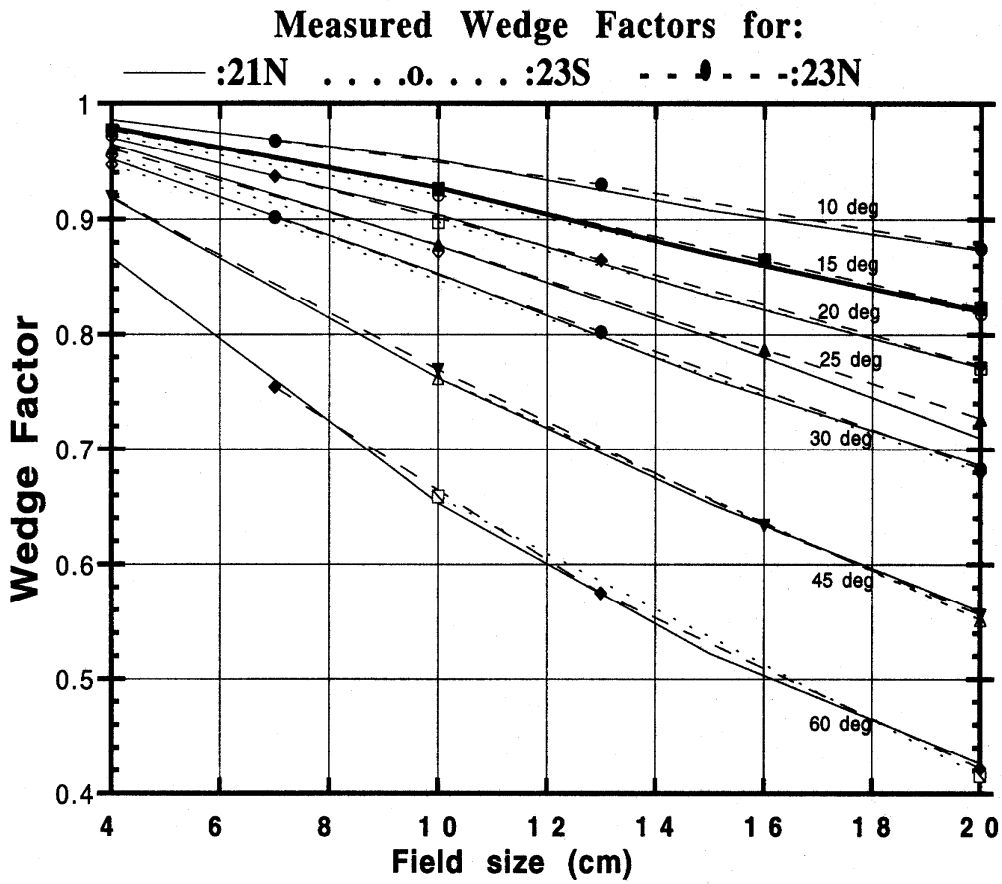
Determining Dosimetric Parameters
Filterless Wedge Factors

- EDW Factors
  - Direct Inspection of Final 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



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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:

[6, 24MV photons at 5,10,15cm OADs/depths]

	Average (Max) Error
Large Field Profiles:	2.5% (6.7%)
POARs:	0.8% (1.8%)
Analytic Equation:	0.5% (1.7%)

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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

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In MU calculations, wedge factors are

1. Field size and depth dependent if WF<0.65

Reference: "A first order approximation of field size and depth dependence of wedge transmission", Tailor et al., Med Phys 25(2), 1998

Outline

I. Introduction
II. Photon Calculations
III. Electron Calculations

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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_{eff} Effective Source to Surface Distance

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Nomenclature
Electron Calculations
Dependent Variables

- f_{air} Air gap correction factor
- S_e Electron Output Factor

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Electron Calculations
(SSD_0=100cm)

$$MU = \frac{D}{D_0^{'} \cdot S_e\left(r_a, r\right)}$$

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Electron Calculations
(SSD>SSD_0)

Method 1: SSD_{eff} Technique

$$MU = \frac{D}{D_0^{'} \cdot S_e(r_a, r) \cdot \left((SSD_{eff} + d_0) / (SSD_{eff} + d_0 + g) \right)^2}$$

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Electron Calculations
(SSD>SSD$_0$)

Method 2: Air Gap Technique

$$MU = \frac{D}{D_0^{'} \cdot S_e(r_a, r) \cdot \left((SSD + d_0)/(SSD + d_0 + g)\right)^2 \cdot f_{air}(r, SSD)}$$

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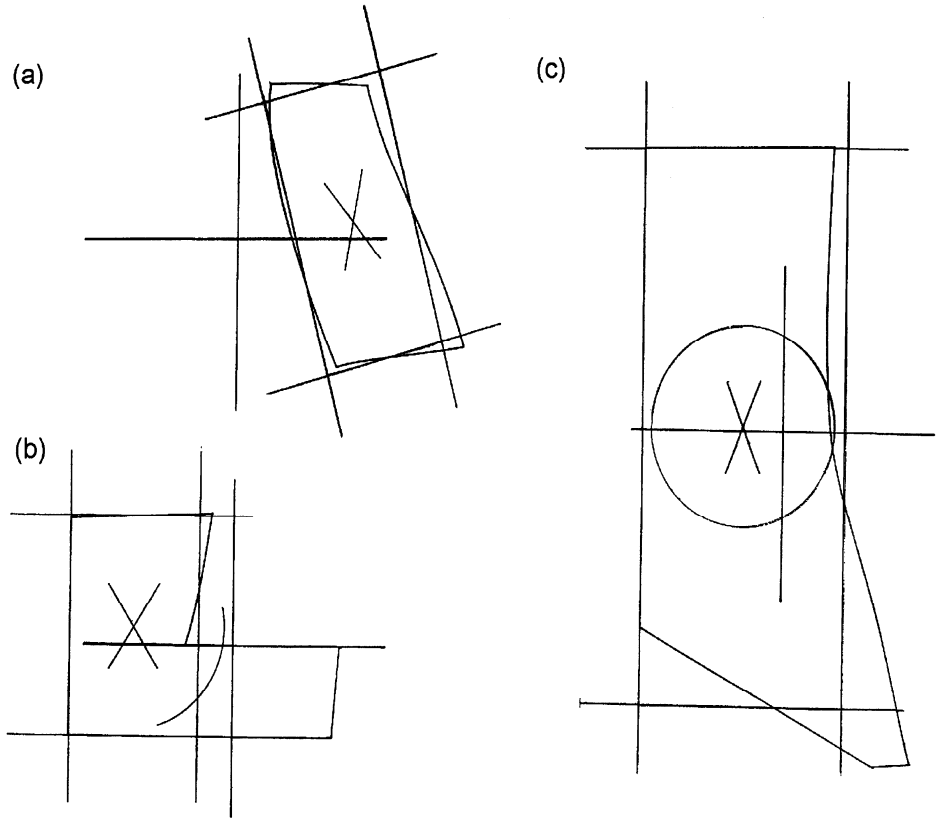
Electron Output Factors

- For square fields, S_e measured at commissioning
- For rectangular fields, use Square Root Method:

$$S_e(r_a, LxW) = [S_e(r_a, LxL) \cdot S_e(r_a, WxW)]^{1/2}$$

- 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

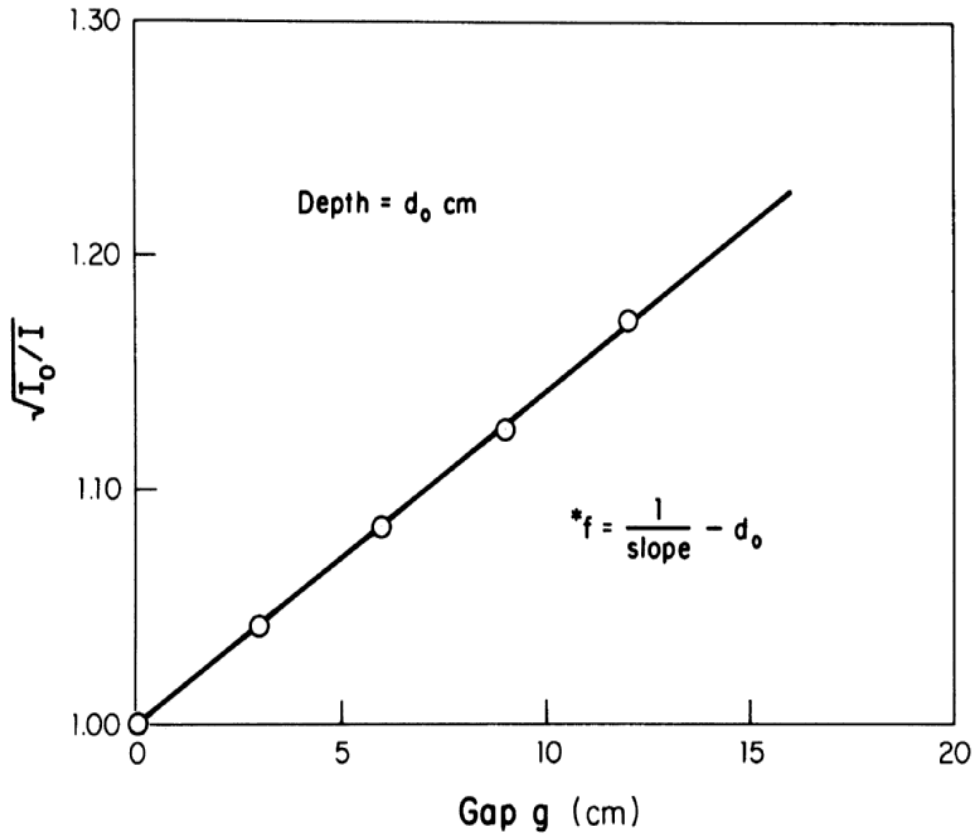
- Special considerations required if FS very small ($r < E/2.5$)
- For these conditions, S_e may be determined by
  - Special Dosimetry
  - Method of Lateral Buildup Ratio (LBR)

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



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Electron Extended SSDs

Aperture size (cm^2)	Inert size (cm^2)	Energy (MeV)				
		6	9	12	16	20
10×10	4×4	44.1	60.1	72.8	76.6	74.3
	6×6	62.5	74.6	80.2	81.8	78.4
	8×8	77.7	82.8	83.5	85.7	83.0
	10×10	83.6	88.3	89.1	87.5	84.8
20×20	4×4	44.9	61.3	72.9	75.9	77.8
	6×6	62.1	74.1	79.4	81.8	82.1
	8×8	78.6	82.2	82.0	81.4	82.4
	10×10	83.7	84.7	86.5	84.1	83.4
	15×15	90.6	90.1	89.8	89.2	89.8
	20×20	90.6	91.5	91.8	91.9	92.9
25×25	4×4	49.5	61.9	71.8	76.6	77.8
	6×6	63.3	75.5	81.1	81.8	81.3
	8×8	76.6	86.3	84.2	83.7	82.7
	10×10	81.4	84.8	84.8	85.0	83.3
	15×15	90.7	91.6	90.3	90.8	89.6
	20×20	89.3	92.1	91.0	89.9	91.1
	25×25	90.7	91.9	91.0	92.5	93.3

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_{ref}

For electron beams, the depth of normalization is

2. R_{100} for the given field

Reference: TG-71 and AAPM Task Group 70 Report, "Recommendations for Clinical Electron Beam Dosimetry", Gerbi et al., Med Phys 36(7), 2009

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%	
0%	4. Depend primarily on applicator field size
	5. Calculated using lateral build-up ratios

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Electron output factors at extended SSDs are

3. Calculated either using effective SSDs or air-gap methods

Reference: TG-71 and AAPM Task Group 70 Report, "Recommendations for Clinical Electron Beam Dosimetry", Gerbi et al., Med Phys 36(7), 2009

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