Current Approach in Clinical Electron Beam Dosimetry

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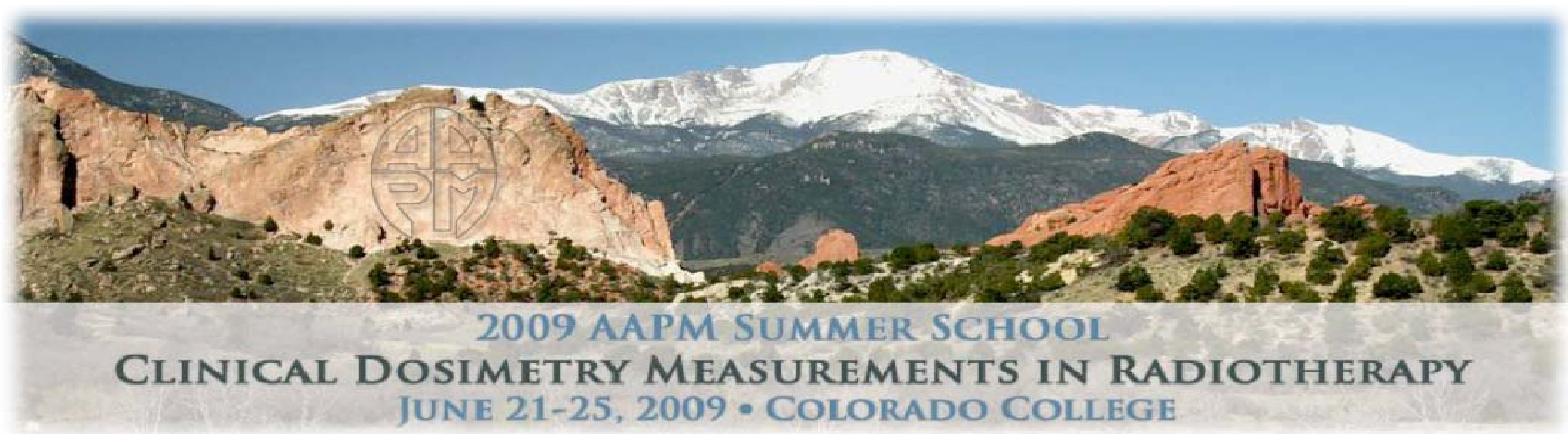
THANK YOU



Colorado Springs

Colorado

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OUTLINE

- Objectives
- Current calibration protocols
- E-beam quality specification
- Measurement of CA %DDs <u>in water</u>:
  - ion chambers, diodes, film
  - practical rules
- Output factors
- Non-water phantoms: Relative measurements
  - ion chambers, %DDs, film
- Small and irregular field dosimetry
- Extended treatment distances
- Electron algorithms
- Some data and examples

Objectives

- Address the issues that currently influence the dosimetry of clinical electron beams due to changes recently introduced by the new dosimetry calibration protocol (TG-51).
- Suggest how to appropriately modify and update the widely accepted TG-25 electron dosimetry protocol.
- Describe a detail procedure of converting measured depth-ionization curves with ion chambers into depth-dose curves making use of recently published stopping-power ratios and other conversion factors.
- Present the important points of the upcoming AAPM TG-70. *(Gerbi et al. Med. Phys. July 2009, issue!)*

Recommendations for clinical electron beam dosimetry: Supplement to the recommendations of Task Group 25

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TG70
In July Issue

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Objectives

- Describe the use of water equivalent phantoms to perform relative electron dosimetry based on recently published conversions factors.
- Discuss small and irregularly shaped electron field dosimetry using the concept of lateral buildup ratio (LBR) as an avenue to evaluate electronic equilibrium and compute dose per MU for those fields.
- Give some common clinical examples where electron beam dosimetry is applied.

Important reports to have

- TG-25 (Clinical electron beam dosimetry).
- TG-51 (protocol for clinical dosimetry for high-energy photon and electron beams).
- TG-69 (Radiographic Films for MV Beam Dosimetry).
- TG-39 (The calibration and use of plane-parallel ionization chambers for dosimetry of electron beams) .
- TG-53 (Quality assurance for clinical radiotherapy treatment planning).
- TG-106 (Accelerator beam data commissioning and procedures.
- **TG-70 (just published)**

Current calibration protocols

Current calibration protocols

- **TG-51 of AAPM (1999).**
- **TRS-398 of IAEA (2003).**

  "Absorbed Dose determination in External Beam Radiotherapy: An International Code of Practice based on Standards of Absorbed Dose to Water"
- **Code of practice of IPEM (2006).**

  "*Code of practice for electron dosimetry of radiotherapy beams with initial energy from 2 to 50 MeV based on air-kerma calibration***"**

Main objectives of TG-51

- Defines <u>Dose</u> at one point, d_{ref}.
- Proposes to do two things:
  1. Incorporate the new absorbed dose standard
     - Absorbed dose is more robust than the Air-Kerma Std.

$$N_{D,w}^{Q} = k_q N_{D,w}^{^{60}Co}$$

     - Dose to water is closer to the dose to tissue
  2. Simplify the calibration formalism (as much as possible)
- Makes use of <u>realistic</u> water-to-air restricted SPRs.

$$\left(\overline{L}/\rho\right)_{air}^{w}$$

Because of TG-51 (and other recent dosimetry data), do we need to modify TG-25 ?

YES! TG-70 was charged!

E-Beam Quality Specification

Electron Beam Quality Specification

New beam quality specifier*: R_{50} (depth in water at which dose falls to 50% of maximum for large field size (>10x10 cm^2) *(TG-51)*.

- First find I_{50} (50% of ionization maximum).

- $R_{50} = 1.029 I_{50} - 0.06$ cm for $2 \leq I_{50} \leq 10$ cm

or

$R_{50} = 1.059 I_{50} - 0.37$ cm for $I_{50} \geq 10$ cm

*(TG-25, beam quality specifier: $(E_p)_0$)

Energy at depth

Harder's Eq. still valid! *(Harder 1968)*

- Mean energy at depth: $$\overline{E}_d = \overline{E}_0 \left(1 - \frac{d}{R_p}\right) (MeV)$$
  - Mean energy at surface of phantom : *(IPEM 2003)*

$$\overline{E}_0 = 0.656 + 2.059 R_{50} + 0.022 R_{50}^2 (MeV)$$

or

$$\overline{E}_0 = 0.818 + 1.935 I_{50} + 0.040 I_{50}^2 (MeV)$$

- Practical range: *(Rogers 1996)*

$$R_p = 1.271 R_{50} - 0.23 (cm)$$

Energy at depth

Harder's Eq. still valid! *(Harder 1968)*

- Mean energy at depth:

$$\overline{E}_d = \overline{E}_0 \left(1 - \frac{d}{R_p}\right) (MeV)$$

?

?

Energy at surface and practical range

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or

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$$R_p = 1.271 R_{50} - 0.23 (cm)$$

Comment

Harder's Eq. still valid!

- Mean energy at depth: $$\overline{E}_d = \overline{E}_0\left(1 - \frac{d}{R_p}\right)(MeV)$$
- Use of (as of TG-25):

$$\overline{E}_0 = 2.33R_{50}(MeV)$$

or

$$\overline{E}_0 = 2.40R_{50}(MeV)$$

Task Group 25 recommends that either the AAPM (1983) protocol value for C_i of 2.33 or the HPA (1985) protocol value of 2.4 times either the depth of 50% ionization or 50% dose, corrected or uncorrected for divergence, are acceptable for estimating the incident mean energy to be used for the calculation of relative dose. This task group recommends that, within this framework, the physicist select the method consistent with his or her calibration protocol.

Produce values within 0.4 MeV of previous relationships

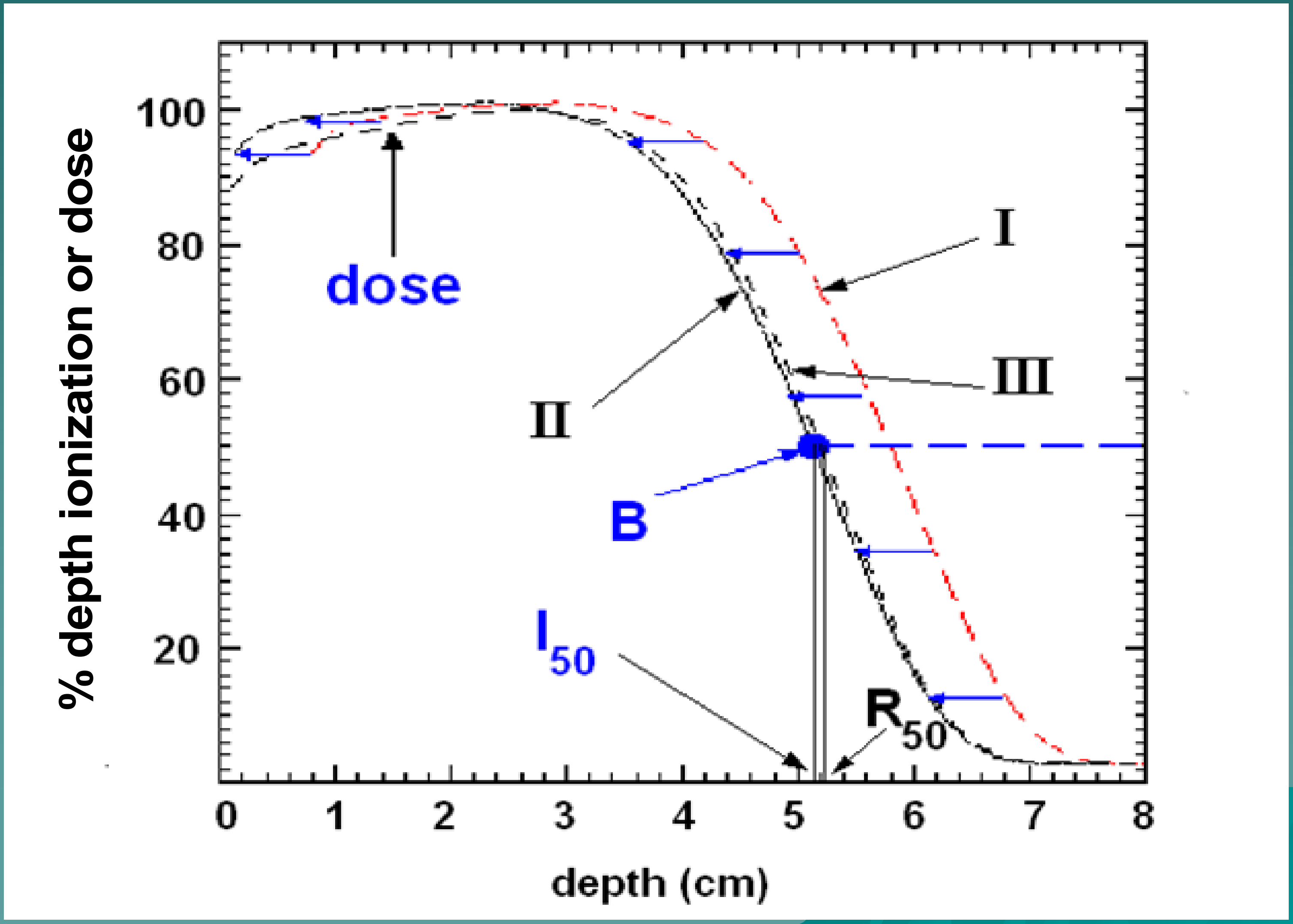
Measurements of %DDs

Phantoms and detectors

- **WATER** for relative measurements (%DDs, OFs, etc) such as large data collection.
- **Plastic (non-Water)** for limited relative measurements of clinical setups (%DDs, OF, etc).
- **Detectors** (cylindrical, p-p, diodes, film)

Cylindrical chambers in water

<u>Step 1</u>: Shift chamber deeper by $0.5r_{cav}$



Step 2: Correct reading for P_{ion}, P_{pol}

$$M(d) = M_{raw}(d) \cdot P_{ion}(d) \cdot P_{pol}(d)$$

- Apply TG-51 requirements for P_{ion} and P_{pol}

  (For %DD: measure at I_{50} and R_p depths)

$$\%di(d) = 100\,\frac{M(d)}{M(I_{\max})}$$

Step 3: Use realistic SPRs water/air

- From *Burns 1996* (in water)

$$\left(\frac{\overline{L}}{\rho}\right)_{air}^{w}(R_{50},z)=\frac{a+b(\ln R_{50})+c(\ln R_{50})^2+d\left(z/R_{50}\right)}{1+e(\ln R_{50})+f(\ln R_{50})^2+g(\ln R_{50})^3+h\left(z/R_{50}\right)}$$

Where:

a = 1.0752	**b = - 0.50867**	**c = 0.088670**	**d = - 0.08402**
e = - 0.42806	**f = 0.064627**	**g = 0.003085**	**h = - 0.12460**

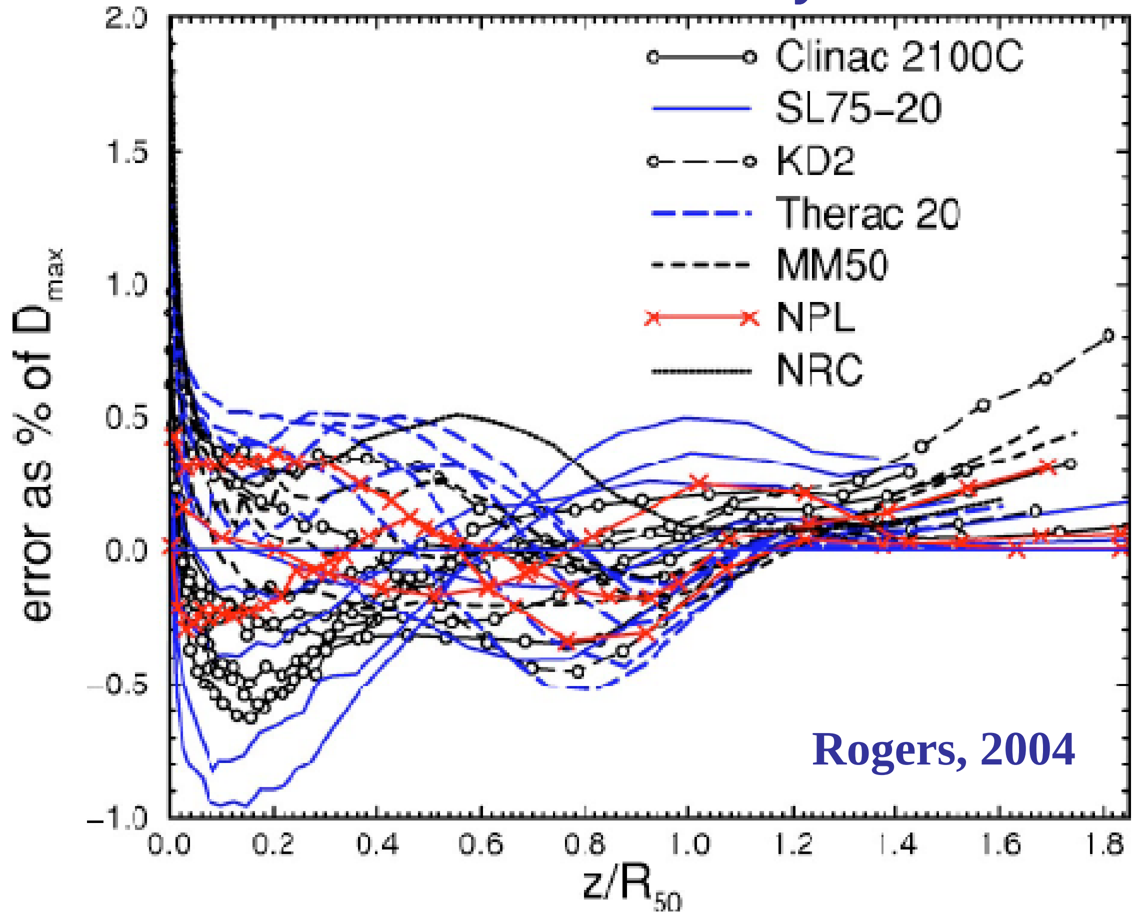
These coefficients give an rms deviation of 0.4% and a max. deviation of 1.0% for z/R_{50} between 0.02 and 1.1. The max. deviation increases to 1.7% if z/R_{50} values up to 1.2 are considered.

Step 4: a) Computation of %DD
b) Correct for P_{fl} and P_{wall}

$$\%dd_w(d) = \%id_w(d) \times \frac{\left(\frac{\bar{L}}{\rho}\right)_{air}^{w} (R_{50}, d) \cdot P_{fl}(\bar{E}_d) \cdot P_{wall}(d)}{\left(\frac{\bar{L}}{\rho}\right)_{air}^{w} (R_{50}, d_{\max}) \cdot P_{fl}(\bar{E}_{d_{\max}}) \cdot P_{wall}(d_{\max})}$$

Errors associated with SPRs

Fitted SPRs vs. individually calculated



Error:
% of Max dose= %error of the fitted SPRs vs. individually calculated values.

Rogers has shown that the %DD can be determined to within 1% of the dose at d_{max}.

(Rogers 2004)

<u>Reminder</u>: For electrons

$$P_{repl} = P_{gr} \times P_{fl}$$

P_{gr}: addressed with chamber shift

P_{fl}: Use Table V in TG-25

P_{fl} from TG-25

$\overline{E}_d$	Inner diameter (mm)			
(MeV)	3	5	6	7
2	0.977	0.962	0.956	0.949
3	0.978	0.966	0.959	0.952
5	0.982	0.971	0.965	0.960
7	0.986	0.977	0.972	0.967
10	0.990	0.985	0.981	0.978
15	0.995	0.992	0.991	0.990
20	0.997	0.996	0.995	0.995

*where $\overline{E}_d = \overline{E}_0\left(1 - d/R_p\right)$

P_{wall}

P_{wall}=1: for electron beams and low-Z thin-walled chambers *(Johansson 1978)*

P_{wall}: Recent data *(Buckley&Rogers 2006)* show change up to 2.5% at 0.5 cm-R_{50} for 6 MeV.

<u>Recommendation</u>: make sure your chamber introduces less than 2% error at depths by comparing its response to published data.

p-p chambers in water

Use of p-p chambers for %DD

- In general, front of window is *point of measurement*

  Front window thickness (1-2mm) should be taken into account.

  $P_{gr}=0$ for all p-p chambers.

  $P_{fl}=1$ for most chambers <u>except</u> Markus and Capintec PS-033 (use TG-39 for correction factors).

  P_{wall} corrections are considered negligible in most cases.

P_{wall}:

Recent data *(Buckley&Rogers 2006)* have shown strong depth dependence for NACP-02, Roos, Markus and Capintec PS-033.

Buckley&Rogers: p-p chambers

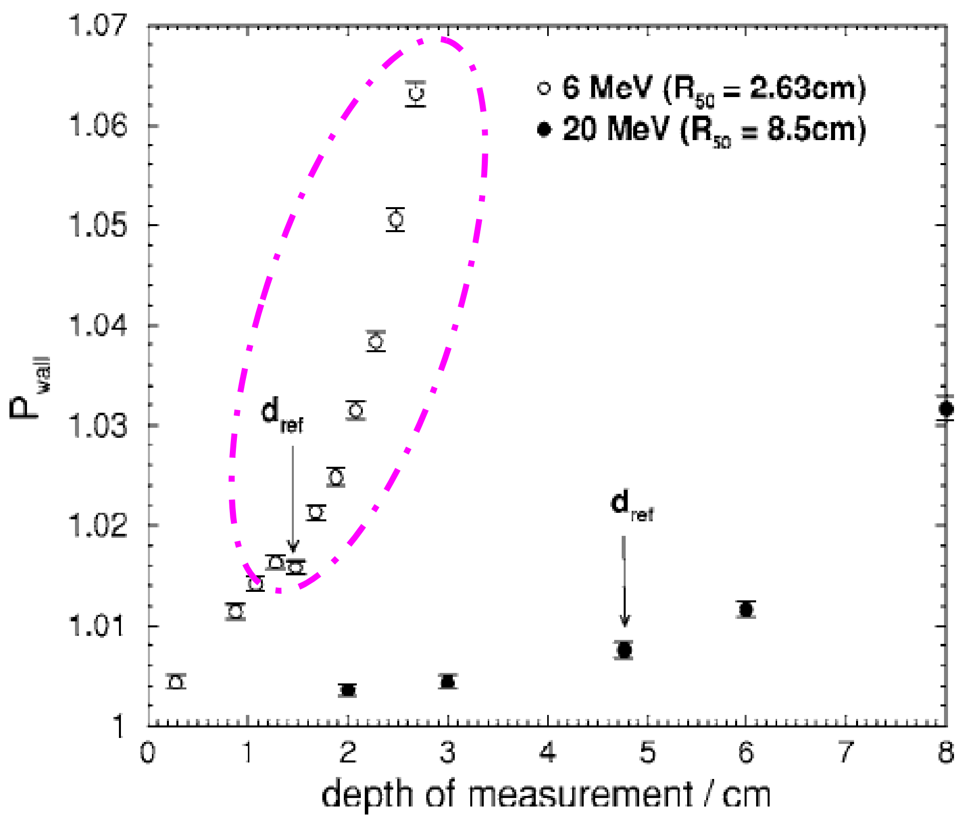


FIG. 4. P_{wall} as a function of depth of measurement for an NACP chamber in a water phantom. The calculations were performed using the CSnrc user-code for nominal beam energies of 6 MeV and 20 MeV. The reference depths for each beam, d_{ref}, specified by the standard dosimetry protocols, are indicated by the arrows.

Recommendation: Compare your chamber's response with data from literature to be <2%

Know your chamber!

diodes in water

Use of diodes for %DD

Diodes specifically designed for electron beams.

The effective point of measurement is the dye (get specs from manufacturer).

Validate %DDs measured with diodes against curves measured with chambers *(TG-25)*.

Have a QC program for diodes <u>before</u> taking large amount of data.

Use of diodes for %DD

1) Look at new TG-106 *(Das 2008)*

2) Look at this Summer School's chapter

QUESTION

In an open field, a bull mistakenly eats an explosive device. What word best describes this situation?

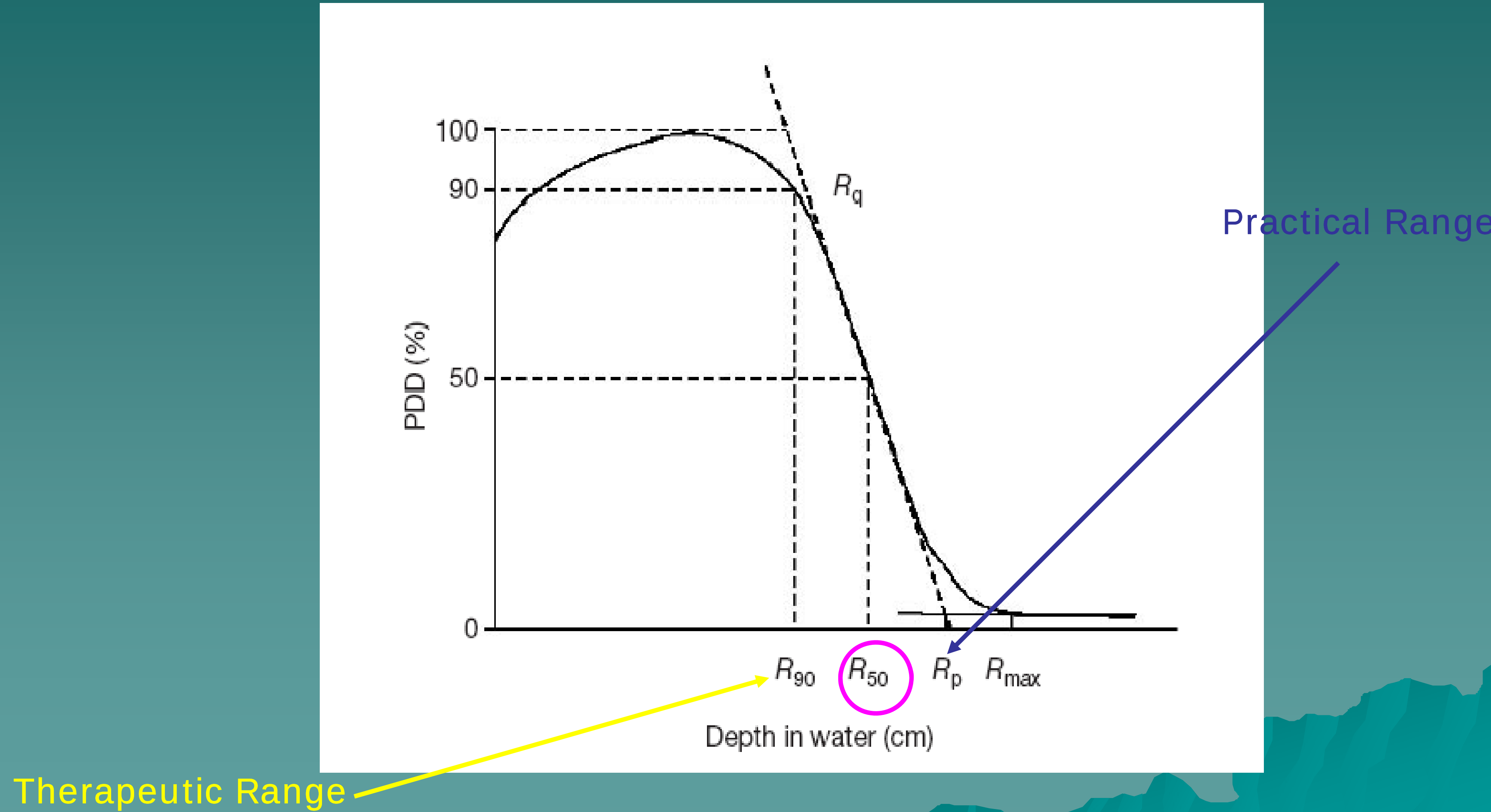
1. Ridiculous
2. Frightening
3. Horrific
4. Abominable
5. Hungry

ABOMINABLE (*A-Bomb-In-A-Bull*)

Courtesy of J. Gibbons, PhD

General Characteristics of E-%DDs

definitions….

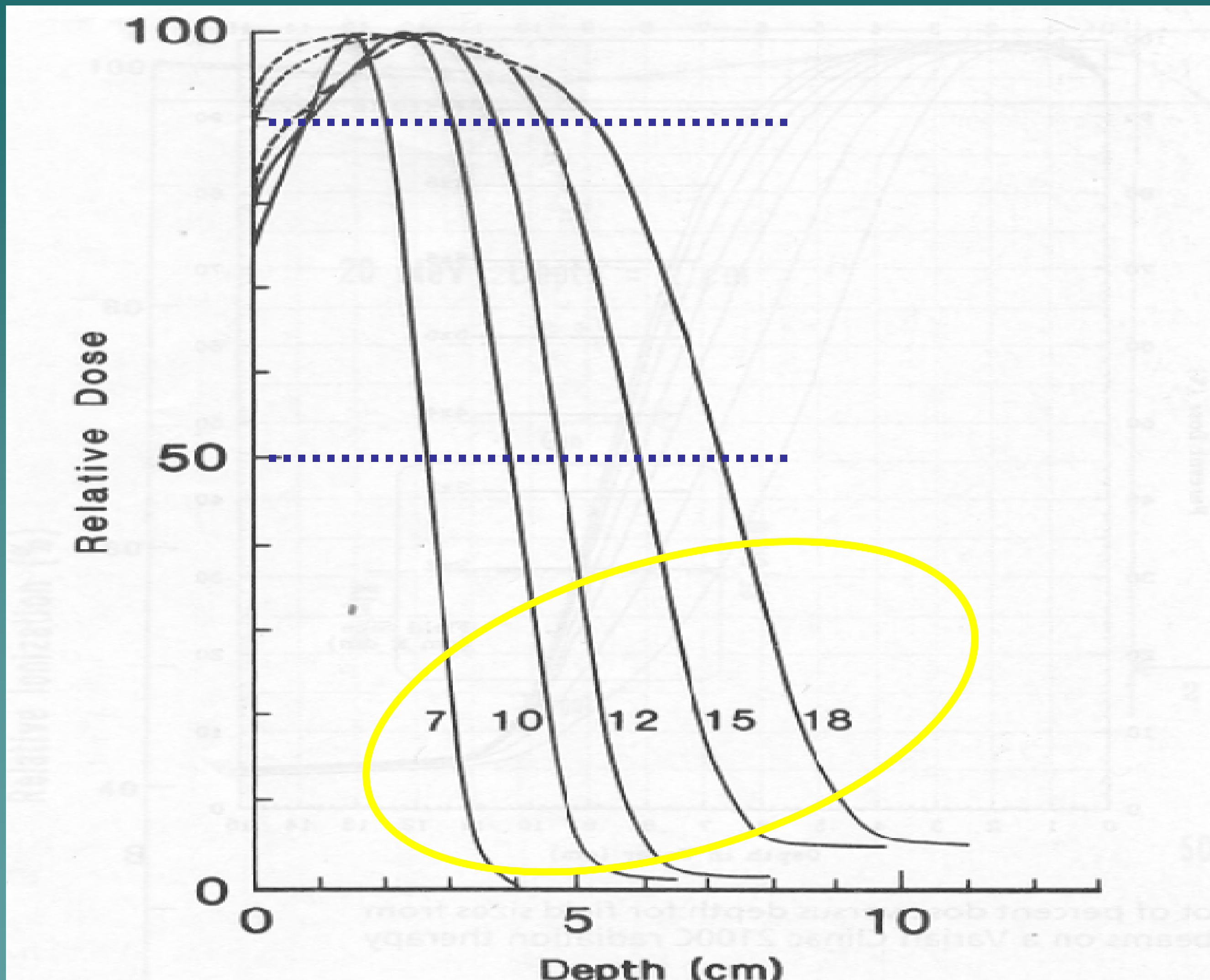


ICRU 35 (1984)

As Energy increases

- Surface dose (at 0.5mm) ↑.
- d_{max} ↑ for lower Es and stops at moderate/high Es.
- Beam penetration (d_{90}, d_{50} and R_p) ↑.
- Distance between d_{90}-d_{10} ↑.
- x-ray contamination ↑.

As beam energy increases….

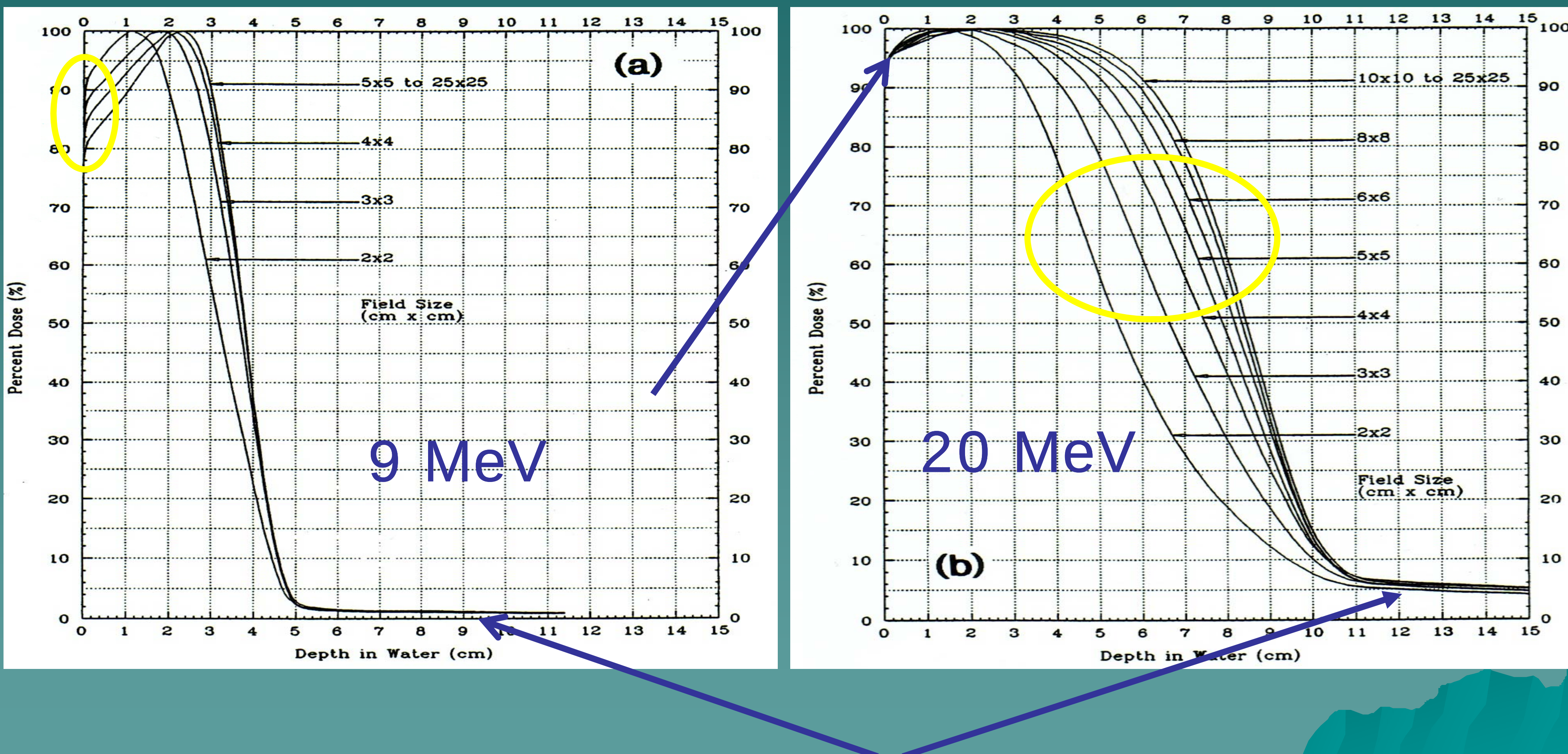


Hogstrom (2003)

As field size decreases

- Surface dose (at 0.5mm) ↑.
- d_{max} and d_{90} ↓ (shift to surface).
- Distance between d_{90}-d_{10} ↑.
- R_p unchanged.

As field size decreases….



Hogstrom (2003)

Output factors

Definition

$$S_e\left(d_{\max}\left(r_a\right), r_a, SSD\right) = \frac{\dot{D}\left(d_{\max}\left(r_a\right), r_a, SSD_{treat}\right)}{\dot{D}\left(d_{\max}\left(r_0\right), r_0, SSD_{nom}\right)}$$

r_a: treatment field at SSD_{treat}

r_0: reference / cal field at SSD_{nom}

Non-water phantoms
Relative measurements

Use of non-water phantoms

- Water substitutes should mimic water across the whole electron energy range
  - mainly in stopping and scattering powers
    - thus, both the electron density and the effective atomic number should be matched to water
    - in practice for some phantoms, this is difficult to achieve (due to the carbon in plastics)
  - off-the-shelf material can have large variations in density and scattering power
    - Must be careful in using these materials

SO:

USE WATER WHENEVER POSSIBLE!

Use of non-water phantoms discussion of corrections

- Depths need to be scaled.
- Chamber readings need to be multiplied by an appropriate fluence-ratio correction.
- Stopping-power ratios should be taken at the scaled depth.
- Charge storage effects should be kept in mind using polystyrene and PMMA.

Corrections needed

Depth correction:

$$d_w = d_{med}\,\rho_{eff} = d_{med}\left(\frac{R_{50}^{w}}{R_{50}^{med}}\right)$$

***Corrected dose** (Ding 1997):*

$$D_w(d_w^{\max}) = D_{med}(d_{med}^{\max})\left[\left(\bar{L}/\rho\right)_{coll}\right]_{med}^{w}\,\phi_{med}^{w}$$

Electron fluence correction factor

Depth correction factors

Material	Mass density (g cm^{-3})	Recommended effective density, ρ_{eff}
Water*	1.00	1.00
Clear polystyrene*	1.045	0.975
High-impact polystyrene (white)*	1.055	0.99
Electron solid water*	1.04	1.00
Polymethylmethacrylate (PMMA)*	1.18	1.115
Epoxy resin water substitute, photon formulation**	1.02	0.98

*from TG-25, Table VII, p. 84.
**From IPEM 2003, p. 2945.

Output in non-water phantom

$$S_{e,w}(d_w^{\max}, r) = S_{e,med}(d_{med}^{\max}, r) \cdot \frac{\left[\phi(d_{med}^{\max}, r)\right]_{med}^{w}}{\left[\phi(d_{med}^{\max}, r_0)\right]_{med}^{w}}$$

ϕ_{med}^{w} ***: Use data from Ding 1997.***

NOTE: Since corrections appear as RATIOS <u>might be</u> neglegible. CHECK it!

Measurements PDDs in non-water Phantoms

- The SSD and field size are not to be scaled.

- Chamber must be positioned with its effective point of measurement at the <u>equivalent-scaled depth</u> in the non-water phantom.

- Correct for electron fluence ϕ_{med}^{w}

PDDs in non-water phantoms

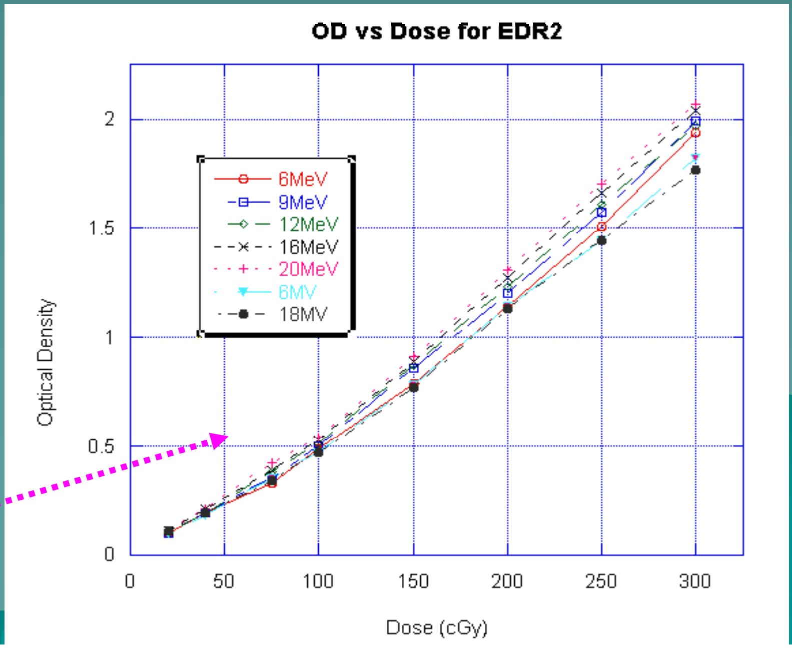
- Cylindrical chambers

$$\%dd_w(d^w) = \%di_{med}(d^{med}) \times \frac{\left(\frac{\bar{L}}{\rho}\right)_{air}^{w}(R_{50}^{w}, d^{w}) \cdot P_{fl}(E_{d^{med}})}{\left(\frac{\bar{L}}{\rho}\right)_{air}^{w}(R_{50}^{w}, d_{\max}^{w}) \cdot P_{fl}(E_{d_{\max}^{med}})} \times \frac{\phi_{med}^{w}(d^{med})}{\phi_{med}^{w}(d_{\max}^{med})}$$

- p-p chambers: $P_{fl}=1$

- Film XV-2 (TG-25)

Large energy dependence



Dosimetry of small and irregular fields

Dose determination in small/irregular fields

- Inherent problems in dosimetry of small electron fields
  - depth of d_{max} becomes shallower.
  - the output factor may be <u>significantly</u> different than the cone factor if the field size is small enough for lateral scatter equilibrium (LSE).
  - isodose coverage is reduced in all directions as the field shrinks.

Square-Root Method

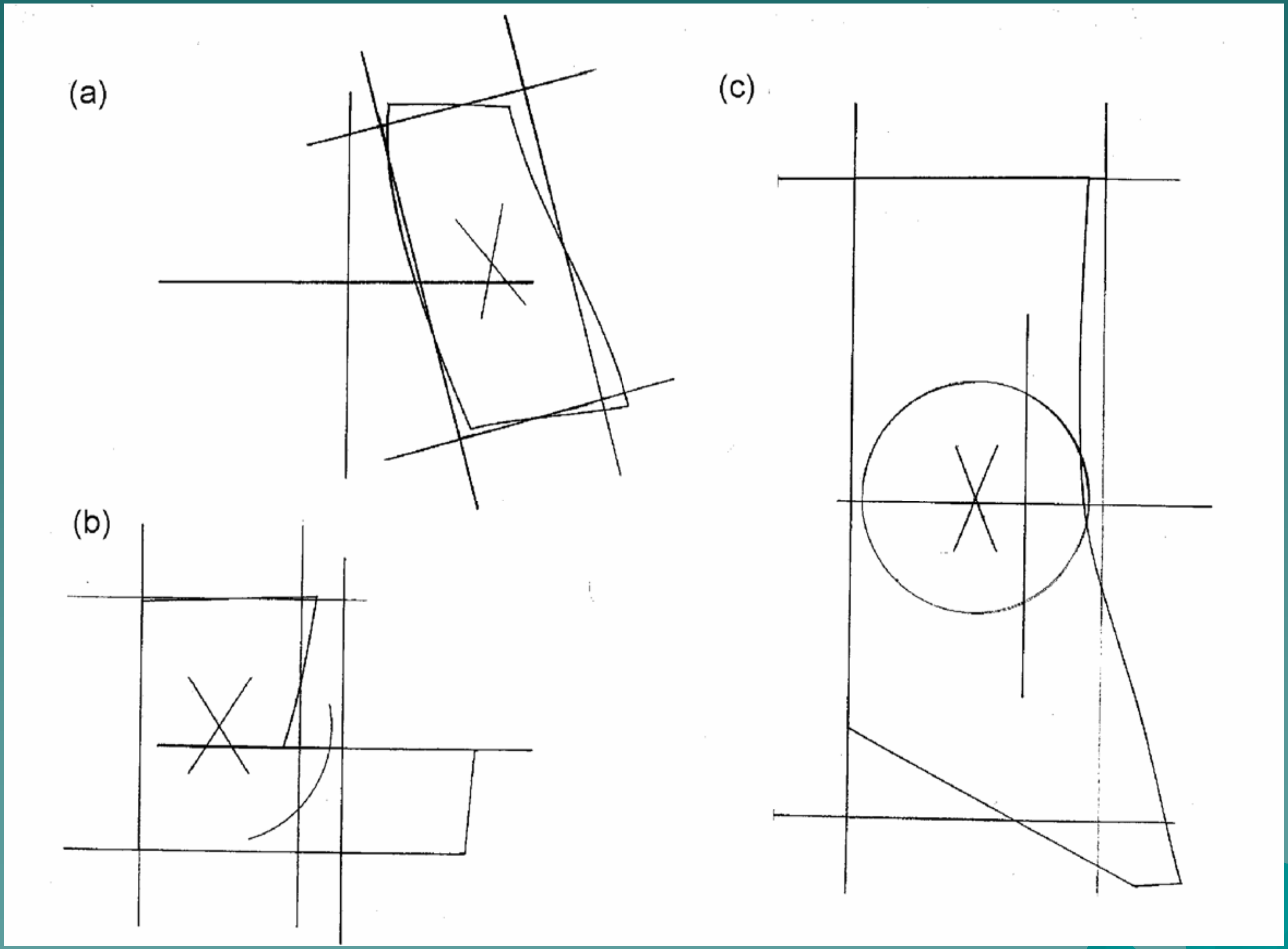
- For rectangular fields of X & Y dimensions:

$$\%dd(d, r_{X,Y}) = [\%dd(d, r_{X,X}) \times \%dd(d, r_{Y,Y})]^{1/2}$$

$$S_e(d_m, r_{X,Y}) = [S_e(d_m, r_{X,X}) \times S_e(d_m, r_{Y,Y})]^{1/2}$$

(Hogstrom (1981) & Mills (1982))

Approximate irregular shapes with rectangles



Hogstrom (2000)

Comparison of the percent difference between measured and calculated output factors for common methods of calculation in the literature. The measured and calculated output factors were for cutout shields that were shaped as squares, rectangles, circles, ellipses, and arbitrary shapes used in the clinic

Calculation method	Percent difference (≤±%)
Equivalent square	2.7*, 5.9*, 3.0*
Square root	3.0*, 2.3*, 4.6*, 3.0*
One-dimensional	3.0*, 2.0*, 2.1*
Pencil beam	2.7*, 2.0*
Sector integration	3.0, 1.5, 1.0*

(Jursinic 1997)

Lateral Buildup Ratios (LBRs) Model

(Khan et al. 1999)

THE WRATH OF KHAN

When is special dosimetry required?

- When the minimum field dimension <u>is less than</u> the minimum radius of a circular field that produces **lateral scatter equilibrium** (LSE)

$$R_{eq} = 0.88\sqrt{E_{p,0}}$$

or

$$a \cong 1.58\sqrt{E_{p,0}}$$

(Khan&Higgins 1999)

where

$$E_{p,0} = 0.22 + 1.98\,R_p + 0.0025\,R_p^2$$

Do you remember what it has been?

- From *Lax&Brahme (1980)* we have been using the criterion for LSE:

$$R_{eq} \cong \frac{E_0}{2.5}$$

$$where$$

$$E_0 = \overline{E}_0$$

$$or$$

$$E_0 = E_{p,0}$$

(also in Khan's book)

Pencil beam…

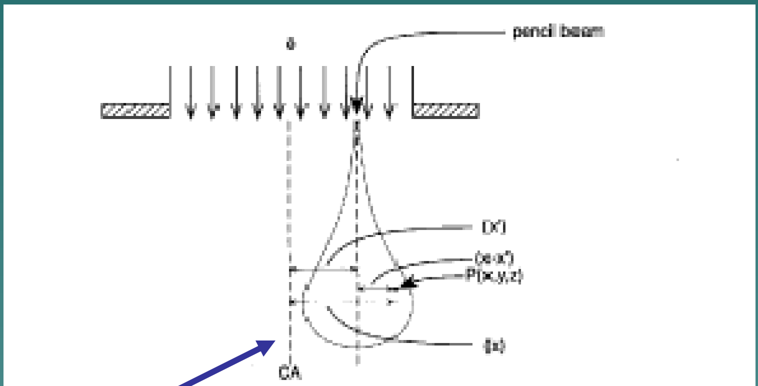


FIG. 14.49. A pencil beam coordinate system. (From Khan FM. Dose distribution algorithms for electron beams. In: Khan FM, Potish RA, eds. *Treatment planning in radiation oncology.* Baltimore: Williams & Wilkins, 1998:113–122, with permission.)

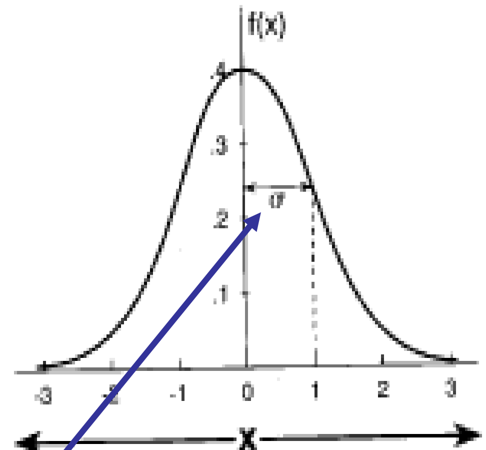


FIG. 14.50. A plot of normal distribution function given by Equation 14.29 for $\sigma = 1$. The function is normalized to unity for limits $-\infty$ to ∞. (From Khan FM. Dose distribution algorithms for electron beams. In: Khan FM, Potish RA, eds. *Treatment planning in radiation oncology.* Baltimore: Williams & Wilkins, 1998:113–122, with permission.)

Broad field-same surface fluence as pencil beam

$$d_p(r,z) = D_\infty(0,z) \cdot \frac{\exp\left(-r^2 \big/ \sigma_r{}^2(z)\right)}{\pi \sigma_r{}^2(z)}$$

Due to multiple Coulomb Scattering

Khan et al. (1998)

LBR definition

- LBRs are related to $\sigma_r^2(d)$ mean square radial spread of pencil beam (independent of field size).

DEFINITION of LBR:

$$LBR(d,r) = \frac{D(d,r_x)}{D(d,r_\infty)} \cdot \frac{\Phi_i(r_\infty,E)}{\Phi_i(r,E)}$$

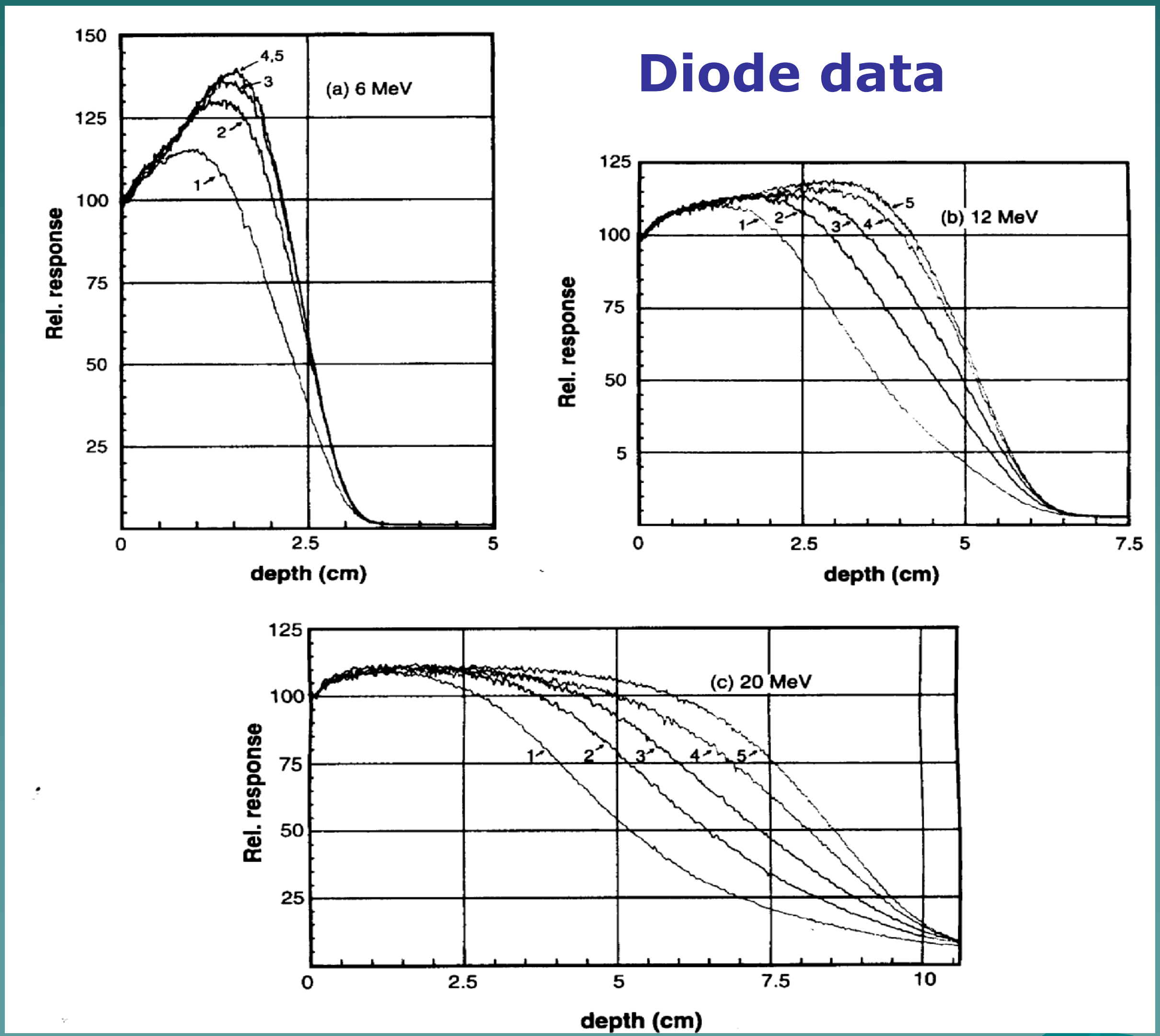
r_x: small field (e.g., 2 cm radius)

r_∞: broad field (e.g., 20x20 cm^2)

Φ(...): incident fluence (normalize at 0.5 mm depth)

(Khan et al. 1998)

Measured PDDs normalized at 0.5 mm depth (surface)



1: 2 cm
2: 2.8 cm
3: 3.7 cm
4: 5.8 cm

Khan et al. (1998)

Determine $\sigma_r^2(d)$

- Take a small circular field r_x=2 cm diam. to measure PDDs and ratio those to PDDs from a 20x20 cm^2 ,normalized both at 0.5 mm, to determine LBRs.

$$\sigma_r^2(d) = \frac{r_x^2}{\ln\left[\frac{1}{1 - LBR(r_x, d)}\right]}$$

with LBR<1

(Khan et al. 1998)

Sigma vs. field size and energy

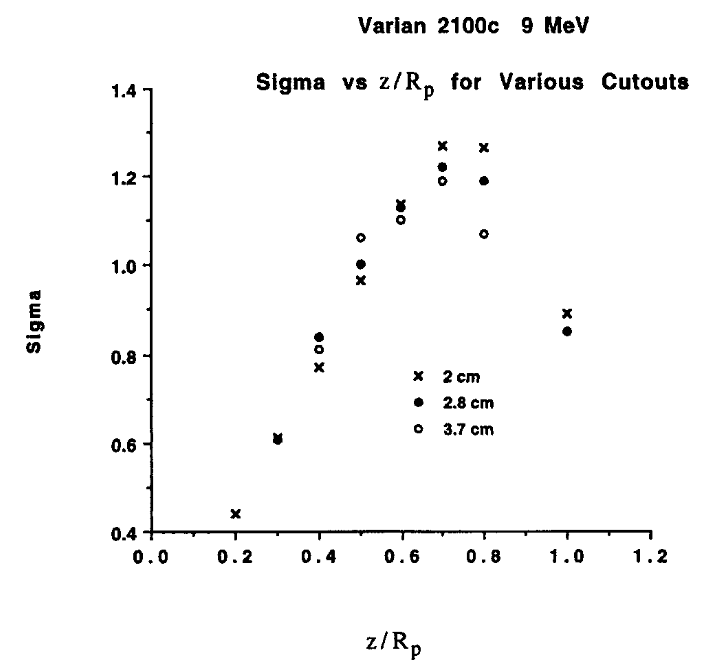
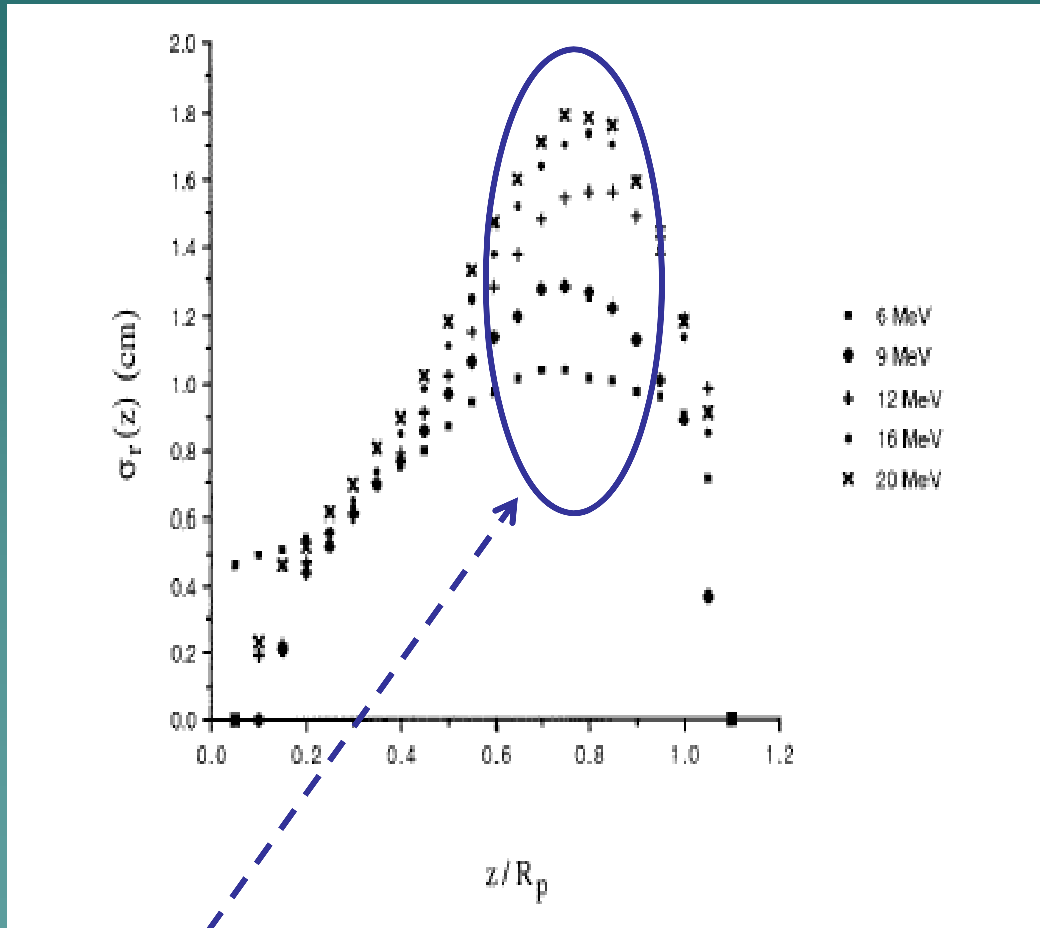
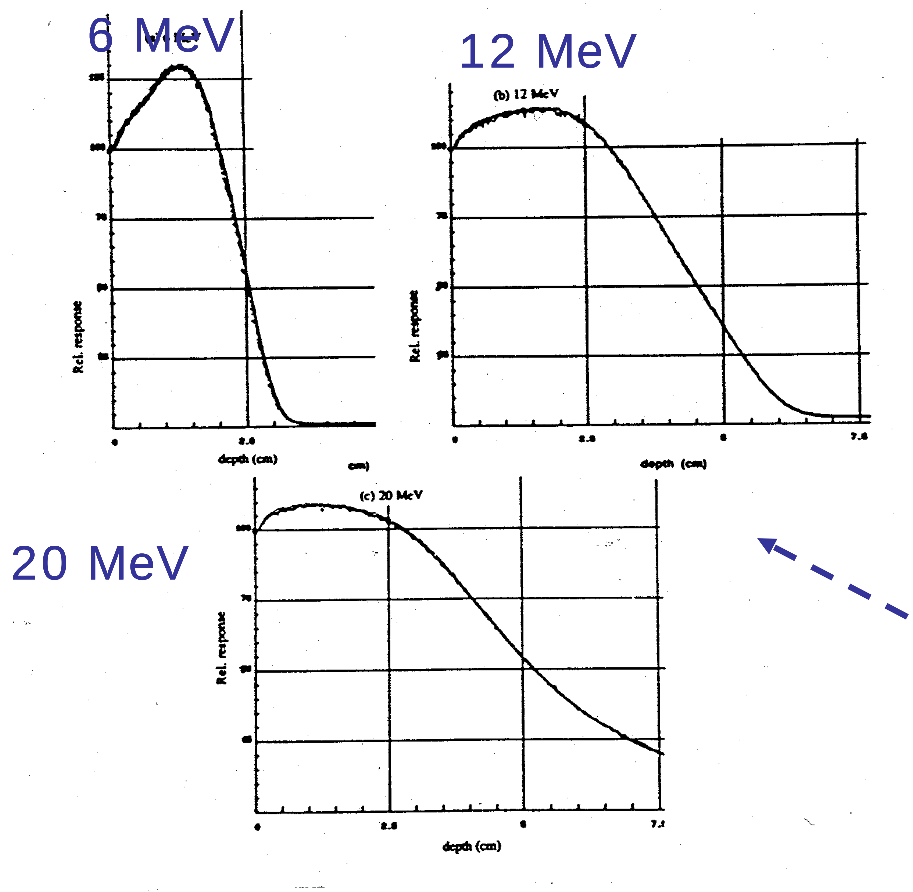


Figure 3. A plot of σ_r as a function of Z/R_p, for σ_r values extracted from LBR data for field sizes of 2, 2.8 and 3.7 cm diameter and beam energy of 9 MeV.



Khan et al. (1998)

In which applicator to use the r_x field?



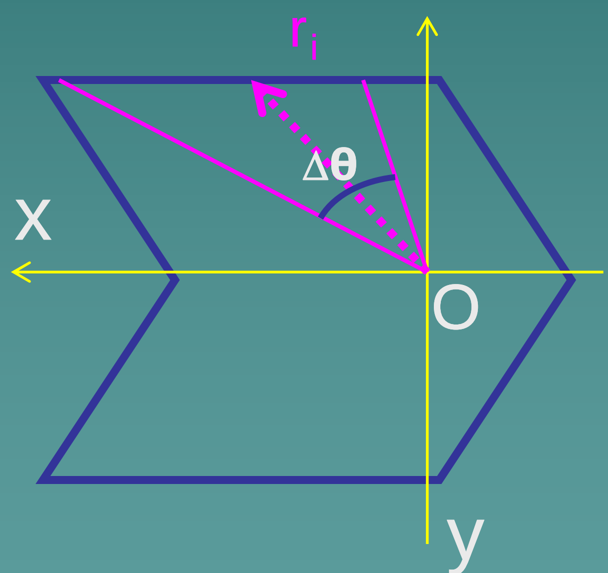
It does NOT matter!

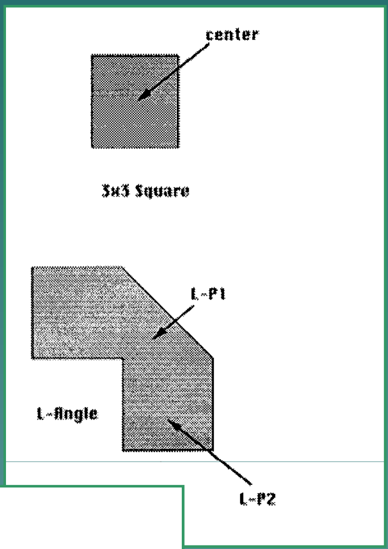
2 cm diam. insert in 10x6, 10x10 and 20x20 cm^2 applicators

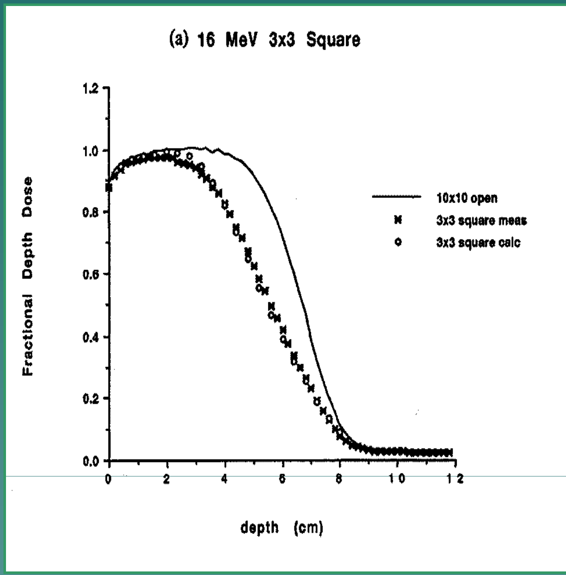
For irregularly shaped fields…

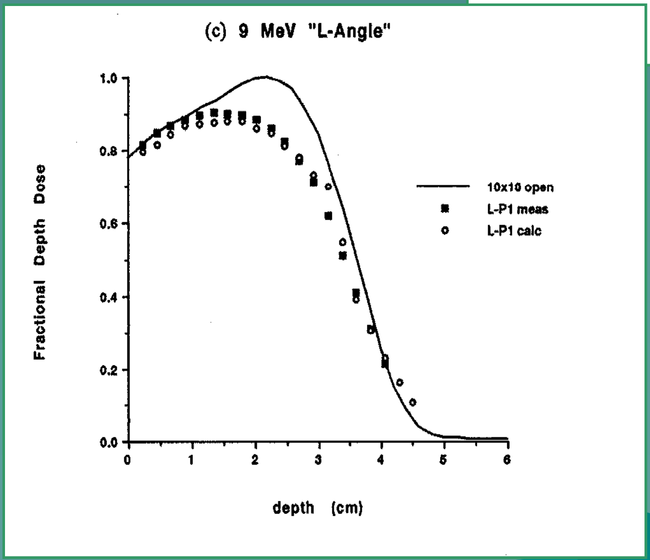
- Sector integration summing the pencil beam contributions.

$$LBR_{eff}(d,r) = 1 - \left(\frac{\Delta\theta}{2\pi}\right)\sum_{i=1}^{n} \exp\left[\frac{-r_i^2}{\sigma_r^2(d)}\right]$$









(Khan&Higgins 1999)

Can we predict d_{max} for small fields?

- Circular fields as example, within ±0.5% of maximum dose.

$$d_{\max}^{r_x} \cong \left(0.174 r_x^{\ 0.67} E_{p,0}^{1.67} - 0.0625 E_{p,0}^{\ 2}\right)^{0.33} \qquad r_x \le R_{eq}$$

For broad field

$$d_{\max}^{R_{eq}} \cong 0.46 E_{p,0}^{0.67} \qquad r_x \ge R_{eq}$$

Compute output factor:

Relative applicator

Output Factor

$$S_e(d, r_j) = S_e \times LBR_{eff}(d, r_j) \times \% dd_{\infty}(d, r_{\infty})$$

(Khan&Higgins 1999)

Data vs. predictions for small circular fields

d_{max}

Table 1. Depths of maximum dose, z_{max}, for circular and rectangular fields. Calculated values are given by equation (7) for circular fields and by equation (8) for rectangular fields. R_{eq} is given by equation (2).

Energy (MeV)	Field radius or size (cm)	z_{max} measured† (cm)	z_{max} calculated (cm)
6	1.0	0.9–1.1	1.1
(R_{eq} = 2.2 cm)	1.4	1.1–1.3	1.3
	1.9	1.3–1.5	1.4
	3×3	1.3–1.5	1.5
	3×5	1.4–1.5	1.5
	$\geqslant R_{eq}$	1.4–1.5	1.5
9	1.0	1.0–1.2	1.2
(R_{eq} = 2.6 cm)	1.4	1.4–1.7	1.5
	1.9	1.7–2.0	1.8
	3×3	1.7–2.1	1.8
	3×5	1.9–2.1	2.0
	$\geqslant R_{eq}$	1.9–2.1	2.0
12	1.0	1.0–1.2	1.3
(R_{eq} = 3.0 cm)	1.4	1.0–2.2	1.7
	1.9	1.4–2.6	2.0
	3×3	1.3–2.5	2.0
	3×5	1.5–2.7	2.0
	$\geqslant R_{eq}$	2.2–3.0	2.4
16	1.0	0.7–1.5	1.2
(R_{eq} = 3.5 cm)	1.4	1.3–2.0	1.8
	1.9	1.5–2.7	2.2
	3×3	1.5–2.7	2.1
	3×5	1.5–2.7	2.2
	$\geqslant R_{eq}$	2.0–3.2	2.9
20	1.0	0.8–1.5	1.0
(R_{eq} = 3.9 cm)	1.4	0.8–2.4	1.9
	1.9	1.0–2.7	2.4
	3×3	1.0–2.7	2.3
	3×5	1.0–2.8	2.5
	$\geqslant R_{eq}$	1.0–3.5	3.4

† Range of depths within ±0.5% of maximum dose.

(Khan&Higgins 1999)

Data vs. predictions for small circular fields

Table V. Calculated vs. Measured dose per monitor unit for rectangular fields using equivalent radius method.

Energy (MeV)	Field Size (cm^2)	Equivalent Diameter[a] (cm)	Depth (cm) z100	Depth (cm) z90	Dose/MU (cGy/MU) Measured at z100	Measured at z90	Calculated[b] at z100	Calculated[b] at z90
9	3x3	3.4	2.0	2.6	0.93	0.84	.95	0.87
	3x5	4.0	2.2	2.8	0.95	0.86	0.97	0.85
	4x4	4.4	2.3	2.9	0.99	0.89	0.99	0.86
	4x10	5.0	2.3	2.9	1.00	0.90	1.00	0.89
16	3x3	3.4	2.0	3.9	0.97	0.87	0.98	0.89
	3x5	4.0	2.5	4.2	1.00	0.90	1.00	0.92
	4x4	4.4	2.7	4.4	1.00	0.90	1.00	0.92
	4x10	5.4	3.0	4.7	1.00	0.90	1.00	0.92

a. Equivalent diameter calculated by Eq. 12 and Eq. 9.

b. Calculated by Eq. 2; LBR was determined for the equivalent radius by using Eq. 6 and Eq. 8.

$$\frac{Dose}{MU}$$

(Khan et al. 1998)

Treatments at extended distances

Electron beam features at extended SSDs

- Differences in PDDs resulting from InvSq. effect are small because electrons do not penetrate that deep and because the significant increase of penumbra width with SSD restricts the SSD to 115 cm or less in clinical practice *(Hogstrom 2003)*.
- The depth of d_{max} at extended SSD is a complex function of field size and beam energy. For small field sizes, the d_{max} depth changes little. As the field size increases (>10x10 cm^2), the d_{max} depth increases very slowly for electron energies below 12 MeV. For higher energies, the d_{max} depth increases with increasing SSD *(Das et al. 1995, Cygler et al. 1997).*
- However, this effect is clinically insignificant since higher electron energies have broad d_{max} ranges. In addition, beam flatness decreases and penumbra width increases at extended SSD, an effect more pronounced at smaller field sizes and lower electron energies. *(also in Khan's book)*

Treatment planning systems (without Monte Carlo) differ in their ability to accurately depict the effects of extended SSD and individual institutions should investigate the limitations of their planning systems before use on patients.

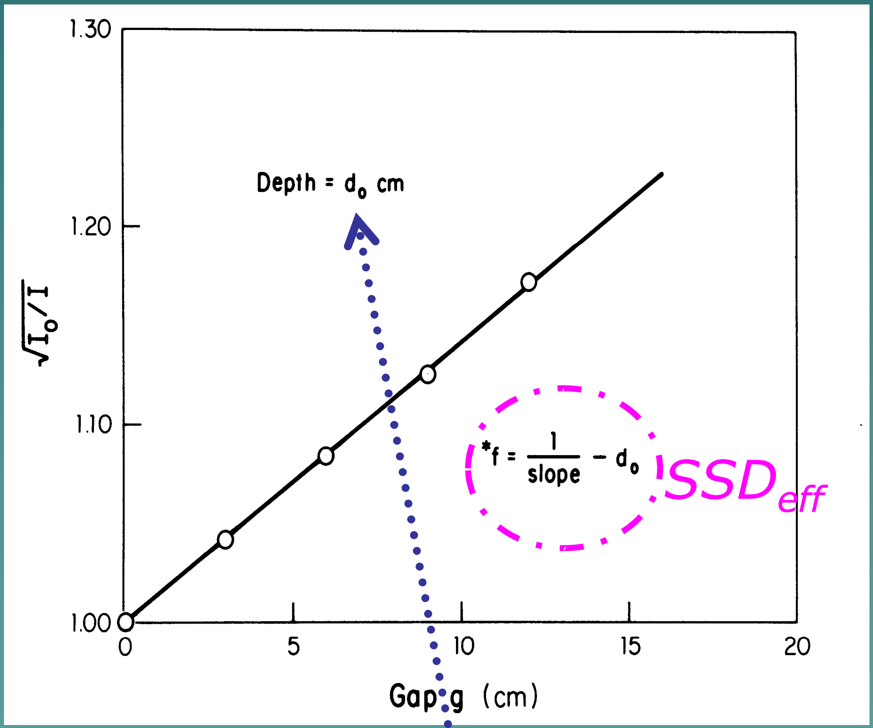
Use TG-25 recommendations.

Beam output
at
extended distances

The *Effective-SSD* (SSD_{eff}) method

How to determine SSD_{eff}

- For every applicator and energy plot:



Typically d_{max}

Gap: $\boxed{g = SSD_{ext} - SSD_{nom}}$

I_o: Rdg at SSD_{nom}

I: Rdg at SSD_{ext}

SSD_{ext}: extended SSD (typically <115 cm)

SSD_{nom}: 100 cm

(TG-25 & in Khan's book)

Data from Siemens Primus

7 MeV

CONE SIZE	INSERT SIZE	d_{max} [cm]	S	SSD_{eff} [cm]
10x10	2x2	0.9	0.791	**33.1**
"	3x3	1.2	0.870	**46.6**
"	4x4	1.4	0.957	**55.4**
"	6x6	1.4	1.001	**61.5**
"	8x8	1.6	0.998	**73.6**
5cm	5cm	1.5	0.817	**57.3**
10x10	10x10	1.6	1.000	**83.9**
15x15	15x15	1.6	0.998	**99.4**
20x20	20x20	1.6	1.001	**100.4**
25x25	25x25	1.6	0.992	**106.0**

14 MeV

CONE SIZE	INSERT SIZE	d_{max} [cm]	S	SSD_{eff} [cm]
10x10	2x2	1.2	0.893	**58.7**
"	3x3	1.6	0.918	**66.4**
"	4x4	2.0	0.944	**62.5**
"	6x6	2.6	0.987	**71.5**
"	8x8	2.9	0.995	**79.1**
5cm	5cm	2.7	0.922	**82.0**
10x10	10x10	2.9	1.000	**94.2**
15x15	15x15	2.9	0.984	**103.5**
20x20	20x20	2.9	0.957	**104.6**
25x25	25x25	2.9	0.957	**106.9**

(Mihailidis, et al.)

Weak dependence of SSD_{eff} on applicator size
(Varian 2100 Data)

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	$\boxed{83.5}$	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	$\boxed{82.0}$	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	$\boxed{84.2}$	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

Insert size (cm^2)	Beam Energy (MeV) 6	9	12	16	20
4	46.2	61.1	72.5	76.4	76.6
6	62.2	74.7	80.2	81.8	80.6
8	77.6	83.8	**83.2**	83.6	82.7
10	82.9	85.9	86.8	85.5	83.8
15	90.7	90.9	90.1	90.0	89.7
20	90.0	91.8	91.4	90.9	92.0
25	90.7	91.9	91.0	92.5	93.3

Average

(Roback et al. 1995)

Output at extended distances

$$S_e(d_m, SSD_{ext}) = S_e(d_{m,} SSD_{nom}) \times GF$$

with
$$GF = \left(\frac{SSD_{eff} + d_{\max}}{SSD_{eff} + d_{\max} + g} \right)^2$$

Monitor Units:
$$MU = \frac{D_{prescription}}{S_e(d_m, SSD_{ext})}$$

(Khan et al. 1998)

QUESTION

The bomb exploded. What word best describes this situation?

1. Sad
2. Disgusting
3. Noble
4. Horrific
5. Silly

NOBLE (*No-Bull)*

Courtesy of J. Gibbons, PhD

Electron Beam Algorithms

(Simple discussion)

General Comments

- What should be done to commission these algorithms (being consistent with TG53)
  - know the pitfalls and limitations of electron algorithms
  - careful with normalization of dose distributions for electron algorithms
    - Restricted field
    - Extended treatment distance
    - Plans involving inhomogeneities
- Attention to how data should be entered into the program.

Some clinically relevant tests

- Inhomogeneities in electron treatments
  - The effects of inhomogeneities on dose distributions
  - Computer representation of the effects of dose inhomogeneities
- Use of bolus
- Field abutment
  - Electron-electron, with same or different energies
  - Electron-photon, with standard or extended distances
  - Tertiary shielding for field abutment
- Library of clinical treatment examples

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- Members of TG-70 group.
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- Ken Hogstrom.
- Bruce Gerbi (Chair of TG-70).

Not done yet
Stay where you are!

The Duke

Problem

- A small area will be treated with 16 MeV electrons and a custom circular field of 5.5 cm diameter (average), at 100 SSD. What are the necessary dosimetric parameters to be measured in order to determine the output of such field?

2.25 cm radius

1) See if there is LSE:

In practice: $R_p \simeq \frac{16 MeV}{2} = 8 cm$

$E_{p,o} = 16.2 MeV$ then: $\boxed{R_{eq} = 0.88\sqrt{16.2} = 3.5 cm \text{ radius}}$

Thus: NO LSE $\Rightarrow$ δ_{max} would be shifted towards surface.

2) Find new d_{max} for the 5.5cm diam field with

a) Film dosimetry - film parallel to beam in solid water.

b) or pp chamber in solid water and thin sheets of 1mm thickness

To estimate the new d_{max}: $\boxed{d_{max}^{(5.5cm)} \simeq \left(0.174\, r_x^{0.67} E_{p,o}^{1.67} - 0.0625 E_{p,o}^{2}\right)^{0.33}}$

$d_{max}^{(5.5cm)} \simeq 2.8 cm$ instead of $d_{max} = 3.4 cm$ for 10x10 field.

3) Measure output factor of 5.5cm field @ new d_{max} relative to 10x10 @ 3.4cm depth, both at 100SSD

4) From Film or p-p chamber measurements find d_{90}, d_{80} and at those depths measure isodose lines with film perpendicular to beam. Scan films cross/in plane to find the width of

95%, 90%, 80% & 50% isodose lines @ d_{max}, d_{90}, d_{80} depths.

Solution

- Check for LSE first. In practice cm and $E_{p,0}$=16.2 MeV (from (12.19)). Then, R_{eq}=3.5 cm (eq. (12.18)), thus no LSE since a diam=7 cm will be required.
- Need to find new d_{max} that is shifted towards the surface. Use either film dosimetry with film placed parallel to electron beam in solid water or plane-parallel chamber in solid water with thin sheets of 1 mm to measure the d_{max}. An estimate of expected d_{max} for the 5.5 cm diam. field is: 2.8 cm (from (12.24)).
- Measure the output factor of 5.5 cm field at 2.8 cm (new d_{max}) relative to the reference 10x10 at 3.4 cm, both at 100 SSD.
- From film or plane-parallel chamber dosimetry find d_{max}, d_{90}, d_{80} and at those depths measure isodose lines with film perpendicular to beam in solid water. Scan films in-plane and cross-plane to get the widths of 95%, 90%, 80% and 50% isodose lines at the above depths.

THANK YOU!

Now, let’s go for a brew or two!