AAPM Task Group 51

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  - students,
  - attendees

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Traceability of Standards

- Dosimeters Traceable to National Standards
- National Protocol for calculation of Dose at a reference point (TG-21 & TG-51)
- National Protocol for Calculation of Dose to arbitrary point in a patient (relative to reference point dose) (EORTC)

Traceability to National Standards

Calibration of Ion Chamber by ADCL (NIST)
Chamber Calibration Factor

N_X : EXPOSURE CALIBRATION FACTOR: (Roentgen/ Charge)
Exposure at the chamber-center with the chamber removed.

N_K: AIR KERMA CALIBRATION FACTOR: (Gray/Charge)
Air Kerma at the chamber-center with the chamber removed
(never used seriously except maybe in a few European Centers.)

N_{gas}: CAVITY GAS CALIBRATION FACTOR: (Gray/Charge)
Absorbed dose to the gas in the chamber at chamber-center
[N_{gas} related to N_K (N_X) through calculational algorithm.]

$N_{D,w}$: ABSORBED DOSE (water) CALIBRATION FACTOR: (Gy/Charge)
Absorbed dose to water at chamber-center,
with chamber removed and replaced by water.

AAPM TG-51
Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams

- Based on an Absorbed dose to water (in Water) Standard (at reference energy ^{60}Co):
  - More robust standard than AIR-KERMA
  - Close to quantity needed (absorbed dose in tissue)

AAPM TG-51

- Conversion to absorbed dose - other energies
  - Photon: Single factor; $\mathbf{k_Q}$
  - Electron: 3 Factors; $P_{gr}^{Q}, k'_{R50}, k_{ecal}$
- Chamber specific corrections in “classes”
  few $\mathbf{k_Q}$ values
- Calibration in water (annually)
  Plastics - reference to water calibration

AAPM TG-51

- Photon:
  - ➢Beam Quality: %dd @ 10 cm (remove e^- contamination)
  - ➢Reference depth: 10 cm
- Electron:
  - ➢Beam Quality: R_{50}
  - ➢Reference depth: $d_{ref} \alpha R_{50}$

TG-51

- Based on Bragg Gray Cavity Theory
  - Chamber specific Corrections
    - TG-21 formalism
    - hidden in k_Q and k'_{R50}.
  - Determine k_Q and k'_{R50} directly
    - for chamber make & model
    - at National laboratories

Absorbed Dose Calibration Factor

Ideal: $$D = M \bullet N_{D,w}^{Q}$$

Where: $N_{D,w}^{Q}$ is the chamber Absorbed Dose Calibration Factor specific for the energy and modality of the beam being measured.

Absorbed Dose Calibration Factor

Ideal: $$D = M \bullet N_{D,w}^{Q}$$

- ***Too expensive to be practical***
- We understand the behavior of chambers in the megavoltage range.
- Cobalt 60 is still available, and very reproducible
- Cobalt 60 is a near perfect beam to use as the reference energy for chamber calibration.

Photon Equation

$$D_w^Q = M\, k_Q N_{D,w}^{^{60}Co} \text{ [Gy]} \qquad \text{(Eq 3)}$$

D_w^Q = Dose to water at beam quality Q

M = Corrected meter reading

k_Q = Energy correction factor

$N_{D,w}^{^{60}Co}$ = Absorbed Dose to Water calibration factor at Cobalt 60 energy

Chamber Calibration Factor $N_{D,w}^{^{60}Co}$

- Obtain from ADCL
- Chamber waterproofing material:
  - 1 mm Acrylic (PMMA) wall
  - Provided by ADCL
  - Waterproof chambers
- Obtain both N_K, (N_X), and $N_{D,W}$
  - Traceability to TG-21

$$M = P_{ion} P_{TP} P_{elec} P_{pol} M_{raw} \text{ [C or rdg]} \quad \text{(Eq 8)}$$

P_{ion} = Collection efficiency correction

P_{TP} = Temp-Press correction

P_{elec} = Electrometer factor

P_{pol} = Polarity Correction

M_{raw} = uncorrected charge reading

P_{elec}

- Electrometer Calibration factor [C/rdg]
- Previously included in Chamber calibration factor.
- Watch the powers of ten.

P_{ion} Pulsed Beam

$$P_{ion}(V_H) = \frac{1.00 - \left(\frac{V_H}{V_L}\right)}{\frac{M_{raw}^H}{M_{raw}^L} - \left(\frac{V_H}{V_L}\right)}$$

(Eq 11)

Pulsed

V_H = normal operating potential of chamber

V_L = reduced potential on chamber $V_L \leq V_H / 2$

M_{raw}^H = raw reading with full potential

M_{raw}^L = raw reading with reduced potential

Polarity Correction

$$P_{pol} = \left| \frac{M_{raw}^{+} - M_{raw}^{-}}{2M_{raw}} \right| \qquad \text{(Eq 9)}$$

M^{+}(M^{-}) is the charge collected with positive (negative) polarity on the collector

M_{raw} = charge collected with normal polarity

For Photons

$$K_Q = \frac{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \bullet P_{cel} \Big|_{\text{evaluated at the energy Q}}}{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \bullet P_{cel} \Big|_{\text{evaluated at cobalt energy}}}$$

- P_{repl} and P_{wall} same as for TG-21
- P_{cel} corrects for the influence of the Al center electrode
- P_{repl} is weakly dependent on chamber diameter
- P_{wall} is strongly dependent on thimble materials, less dependent on exact dimensions

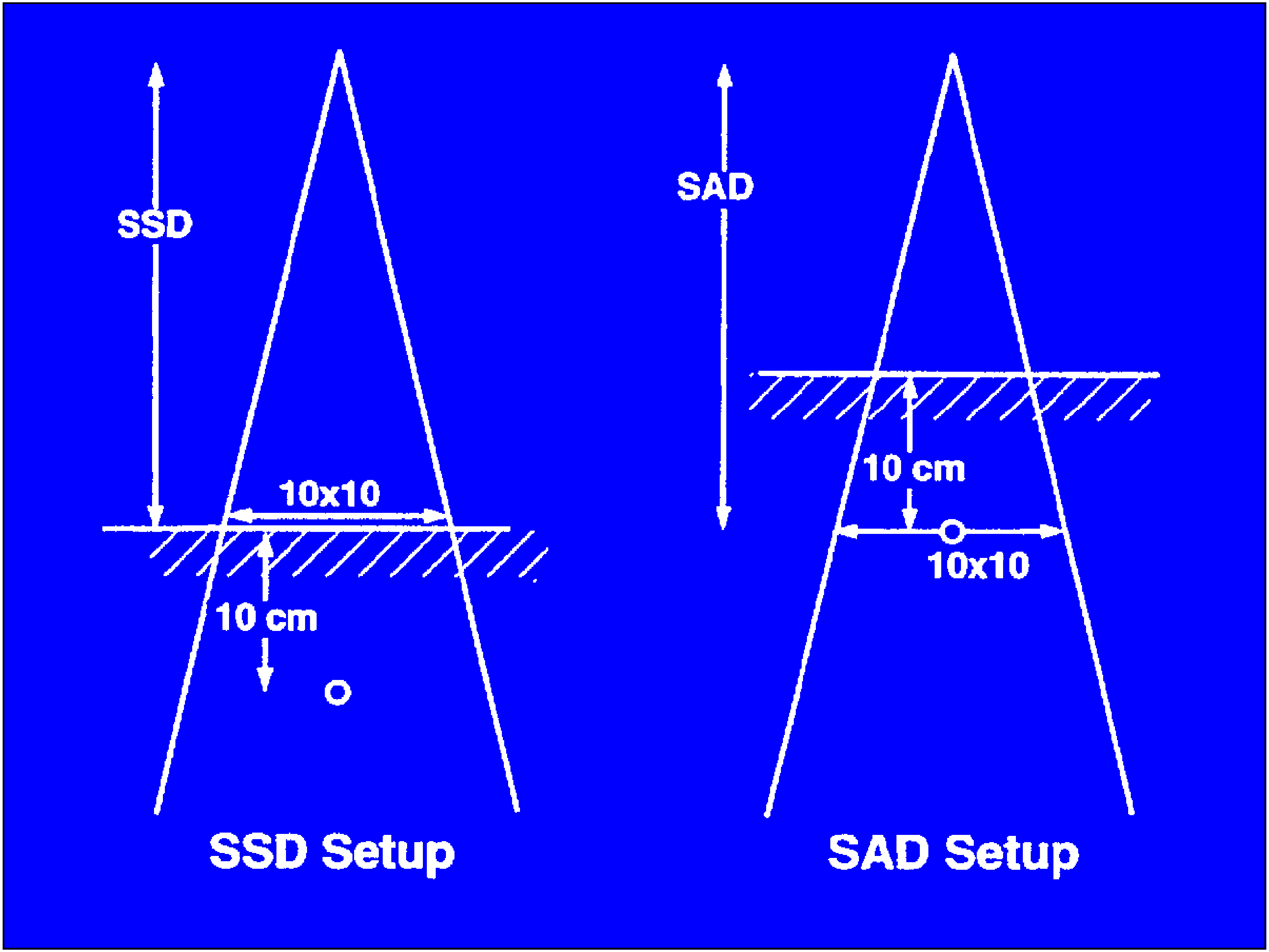
(See Table 1 and Figure 4 for values)

K_Q for photons

- Similar chambers have similar P_{wall} & $P_{cel,}$ so few k_Q needed.
- TG-51 does not list values for my Chamber ???
  - Choose chamber in Protocol that has
    - Same wall material
    - Same center electrode material
    - Approximately same wall thickness
    - Similar length and diameter -- weak depend

Reference Conditions (Photons)

- in Water
- On Central Axis
- 10 cm depth (chamber center)
- 10cm x 10 cm field
  - SSD (field size defined at surface)
  - SAD (field size defined at depth)


SSD
10x10
10 cm
SSD Setup
SAD
10 cm
10x10
SAD Setup

Electron Equation

$$D_w^Q = M\, k_Q\, N_{D,w}^{^{60}Co}$$

where $$k_Q = P_{gr}^Q\, k_{R_{50}}$$ (Eq 4)

and $$k_{R_{50}} = k'_{R_{50}}\, k_{ecal}$$ (Eq 5)

$$D_w^Q = M\, P_{gr}^Q\, k'_{R_{50}}\, k_{ecal}\, N_{D,w}^{^{60}Co}$$

For Electrons

P_{gr}^{Q} = correction for gradient at the point of calibration (d_{ref})

$$P_{gr}^{Q} = \frac{M\left(d_{ref} + 0.5r_{cav}\right)}{M_{raw}\left(d_{ref}\right)} \qquad \text{(Eq 21)}$$

NOTE: $M(d_{ref} + 0.5r_{cav})$ and $M(d_{ref})$ are the reading at the depth, (d_{ref}+05r_{cav} and d_{ref})

NOT the reading times the depth.

k_{ecal} Electrons

Modality conversion factor: Photon ⇒ electron

- carries $N_{D,w}^{60Co}$ into $N_{D,w}^{Q_{ecal}}$ [at R_{50} = 7.5cm]

- Allows for a specific electron-calibration factor to be introduced later.
- Includes L/ρ, P_{cel}, and P_{repl} for R_{50} = 7.5 cm & L/ρ, P_{repl}, P_{wall}, and P_{cel} for Cobalt 60.
- Energy independent (actually a fixed energy)

Table 3 (cyl)
Table 2 (pp)

$k'_{R_{50}}$

- Energy Dependent Factor - chamber specific

  (Includes ratio of $L/\rho \bullet P_{rep} \bullet P_{cel}$ for arbitrary electron energy to that for R_{50} = 7.5 cm)

- $k'_{R_{50}}$ well behaved (observed)

$$k'_{R_{50}} \text{(cyl)} = .9905 + 0.071e^{-(R50/3.67)} \qquad \text{(Eq 19)}$$

(cyl cham for 2cm < R_{50} < 9cm),
0.2% error for Farmer chambers.

Fig 5 & 7 (cyl)

Fig 6 & 8 (pp)

For Electrons

$$k_{ecal} = \frac{\left.\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{\mathrm{repl}} \bullet \mathrm{P}_{\mathrm{cel}} \Big|_{\text{evaluated at energy } \mathrm{R}_{50} = 7.5}}{\left.\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{\mathrm{repl}} \bullet P_{wall} \bullet \mathrm{P}_{\mathrm{cel}} \Big|_{\text{evaluated at Cobalt 60}}}$$

$$k'_{R_{50}} = \frac{\left.\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{\mathrm{repl}} \bullet \mathrm{P}_{\mathrm{cel}} \Big|_{\text{evaluated at the energy } \mathrm{R}_{50}}}{\left.\frac{L}{\rho}\right)_{air}^{water} \bullet \mathrm{P}_{\mathrm{repl}} \bullet \mathrm{P}_{\mathrm{cel}} \Big|_{\text{evaluated at energy } \mathrm{R}_{50} = 7.5}}$$

Electrons: Reference Conditions

- Field Size:

  $\geq$10 cm x 10 cm for R_{50} < 8.5 cm

  $\geq$ 20 cm x 20 cm for $R_{50} \geq$ 8.5 cm

- Reference Depth, d_{ref}

  $d_{ref} = 0.6R_{50} - 0.1$ [cm] (Eq 18)

- Nominal SSD (90 cm to 110 cm)

Beam Quality

Specification

Photon: Beam Quality Specification

$\%dd(10)_x$

- % depth dose due only to photons (excluding electron contamination) 10 cm x 10 cm at 100 cm SSD
- above 10 MV-- may be electron contamination. Need to remove the electrons (coming from collimators).

$\%dd(10)_x$ from $\%dd(10)_{Pb}$

- **Measure** %dd at 10 cm with 1 mm Pb foil:

- 50 cm from surface (± 5 cm)

$$\%dd(10)_x = [0.8905+0.00150\ \%dd(10)_{Pb}]\%dd(10)_{Pb}$$

- 30 cm from surface (± 1 cm)

$$\%dd(10)_x = [0.8116+0.00264\ \%dd(10)_{Pb}]\%dd(10)_{Pb}$$

(Where: $\%dd(10)_{Pb}$ measured with 1mm Pb foil)

DEPTHS ARE SHIFTED

$\%dd(10)_x$ from $\%dd(10)_o$

- **Interim solution** (error $\leq$ 0.4%)

$$\%dd(10)_x = 1.267\ [\%dd(10)_o] - 20.0$$

$$[75\% < \%dd(10)_o \leq 89\%]$$

Where: $\%dd(10)_o$ measured with open beam

ALL DEPTHS ARE SHIFTED TO EFFECTIVE POINT

Beam Quality Specification for Electron Beams

Specified by R_{50}

R_{50} = depth (cm) at which dose falls to 50% of max for a field with full side scatter.

10 x 10 or 20 x 20 (R50 > 8.5)

$$R_{50} = 1.029\, I_{50} - 0.06 \text{ (cm)} \quad [I_{50} \leq 10\text{cm}] \qquad \text{(Eq 16)}$$

$$R_{50} = 1.059\, I_{50} - 0.37 \text{ (cm)} \quad [I_{50} > 10\text{cm}] \qquad \text{(Eq 17)}$$

{I_{50} = depth of 50% ionization}

TG-51 Measurements

Photons:

- Search for I_{max}
- Place chamber at 10cm + 0.6 r_{cav} (with/without lead - for energy $\geq$ 10 MV)
- Determine k_Q from $\%dd(10)_x$
- Move chamber to calibration depth (physical 10 cm)
- Make measurements for M_{raw}, P_{pol}, and P_{ion}

TG-51 Measurements

Electrons:

- Look up k_{ecal} for your chamber.
- Search for I_{max} and I_{50} (use 0.5 r_{cav} shift)
- Determine R_{50}
- Determine d_{ref} and k'_{R50}
- Move chamber to physical d_{ref} (no shift)
- Measure P_{pol} and P_{ion}
- Move chamber to d_{ref} + 0.5 r_{cav}
- Calculate the gradient correction, P_{gr}

Regions of Confusion and Concern

- Water phantom
- 1 mm Acrylic cap
- Parallel Plate vs Cylindrical Chambers
- P_{pol}, P_{ion}
- Why d_{ref}
- Point of measurement
  - % dd
  - Beam Quality Specifications
  - Calibration

Phantoms

- Water only
  - Annual calibration (reference dosimetry)
- Plastics:
  - Weekly/Monthly
  - Compare with water at annual calibration.

Chamber Protection

- Waterproof Chambers
  - no protective sleeve needed
- Other Chambers
  - 1 mm thick ***Acrylic*** protective sleeve
- Cap correction: ????

Chambers: parallel plate vs cylindrical

- Photons:
  - Cylindrical Chambers: ***ONLY*** ***(effect of back scatter from insulator and body of P-P not understood)***
- Electrons:
  - Parallel Plate Chambers: ***RECOMMENDED***
  - Cylindrical Chambers: ***ACCEPTABLE***
  - ***P-P*** Chamber ***required*** for R_{50} < = 2.6 cm

Calibrate P-P Chamber

- ADCL's:
  - TG-39, in water
  - Cobalt 60
- User:
  - TG-39 in water/plastic(?)
  - high energy electron ($R_{50} \approx 7.5$ cm)
  - compare with cylindrical
- Traceability of Factor?????

Polarity Correction

Watch the sign

Some situations: pol > signal

ref depth -- not a problem

P_{pol} ~ 1.00

$$P_{pol} = \frac{\left|M_{raw}^{+}\right| + \left|M_{raw}^{-}\right|}{2\left|M_{raw}\right|}$$

P_{ion} Pulsed Beam

$$P_{ion}(V_H) = \frac{1.00 - \left(\frac{V_H}{V_L}\right)}{\frac{M^H_{raw}}{M^L_{raw}} - \left(\frac{V_H}{V_L}\right)} \qquad \text{(Eq 11)}$$

V_H = normal operating potential of chamber

V_L = reduced potential on chamber - $V_L \leq V_H / 2$

M^H_{raw} = raw reading with full potential

M^L_{raw} = raw reading with reduced potential

(Precision < 0.4%)

I Recommend Weinhous & Meli Med Phys 11, 846-849, 1984

Almond Med Phys 8, 901-904, 1980

TG-21 Curve for $V_L = V_H/2$

Equation for ^{60}Co in worksheet is wrong.

Why d_{ref} not d_{max} ??

- K'_{R50} is smooth curve with low gradient
  - remember L/ρ has high gradient at low energies.
- d_{ref} is close to d_{max} for low energy e^-
- %dd gradient is low for high energy e^-
- avoid 2-D interpolation of L/ρ
- WARNING: For clinical use, correct to d_{max} using ***clinical %dd*** data

Effective point of measurement,

%dd,

beam quality specifiers,

dose gradients

Effective Point of Measurement

$d_{eff} = d_{meas} - f\,(r_{cav})$

$f = 0.6\, r_{cav}$ for photons

$f = 0.5\, r_{cav}$ for electrons

$f = 0$ for parallel plate

inner surface of front window

Chamber Position

Cylindrical Chamber ($h\nu$ & e^-)

- Clinical depth dose:
  - ***effective*** pt of measurement
- Beam quality specification:
  - ***effective*** pt of measurement
- Calibration:
  - ***Physical*** center of chamber
  - gradient correction included in k_Q

For Photons

$$k_Q = \frac{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \cdot P_{cel} \Big|_{\text{evaluated at the energy Q}}}{\left(\frac{L}{\rho}\right)_{air}^{water} \bullet P_{repl} \bullet P_{wall} \cdot P_{cel} \Big|_{\text{evaluated at cobalt energy}}}$$

- P_{repl} = gradient correction

For Electrons

$$k_Q = P_{gr}^{Q}\, k'_{R50} \qquad \text{(Eq 4)}$$

P_{gr}^{Q} = gradient correction

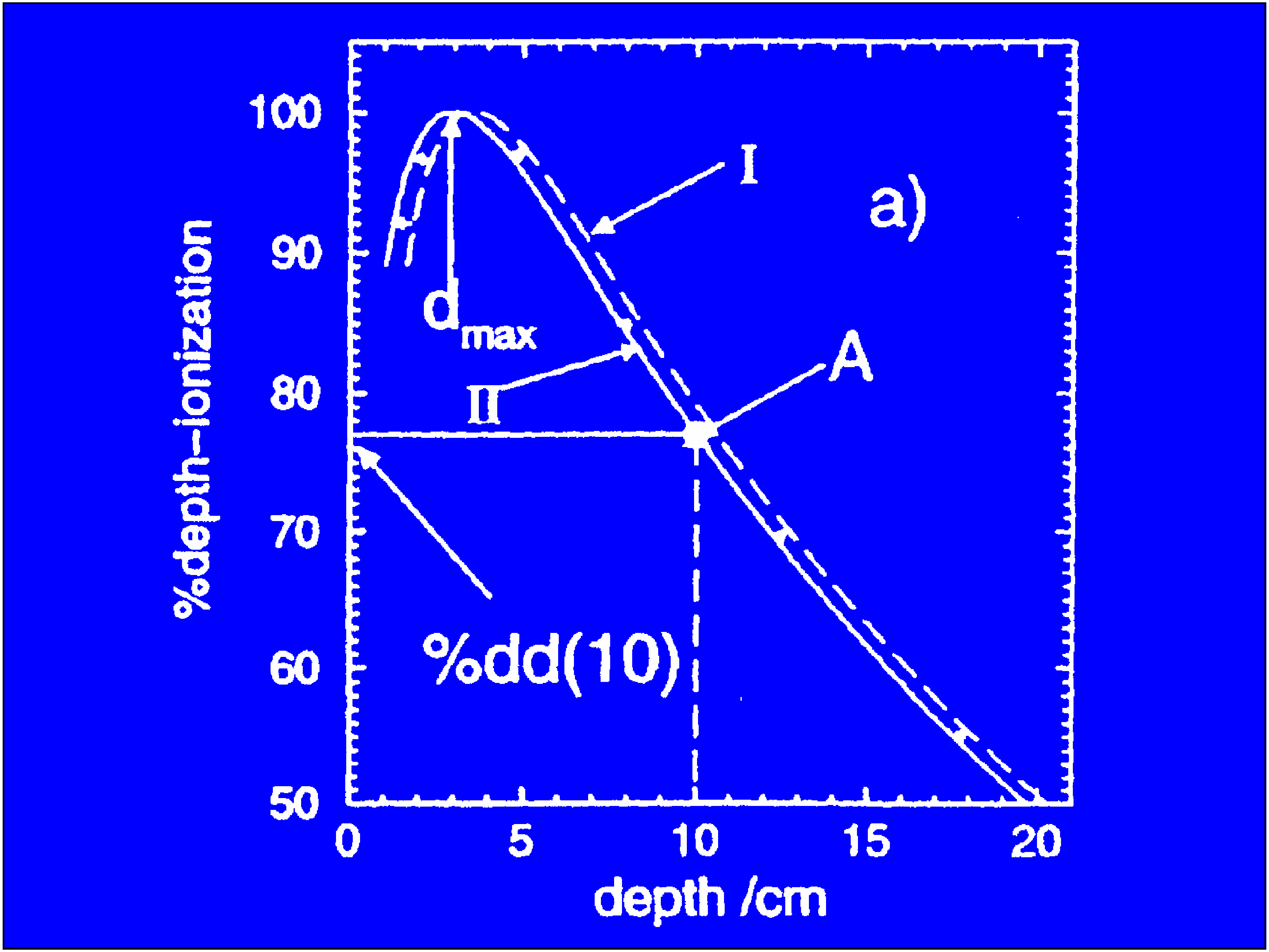
$$P_{gr}^{Q} = \frac{M(d_{ref} + 0.5r_{cav})}{M_{raw}(d_{ref})} \qquad \text{(Eq 21)}$$

Photons:
Clinical % dd
(new procedure)

- Measure % ionization
- Shift to effective point of measurement.
  - – L/ρ and P_{wall} are ~ independent of depth

Use this value to correct dose from
depth of calibration to
other depths in phantom.

NOTE: This changes %dd values and shifts your d_{max} but does not change the gradient.



100
90
80
70
60
50
%depth-ionization
0
5
10
15
20
depth /cm
I
a)
d_{max}
II
A
%dd(10)

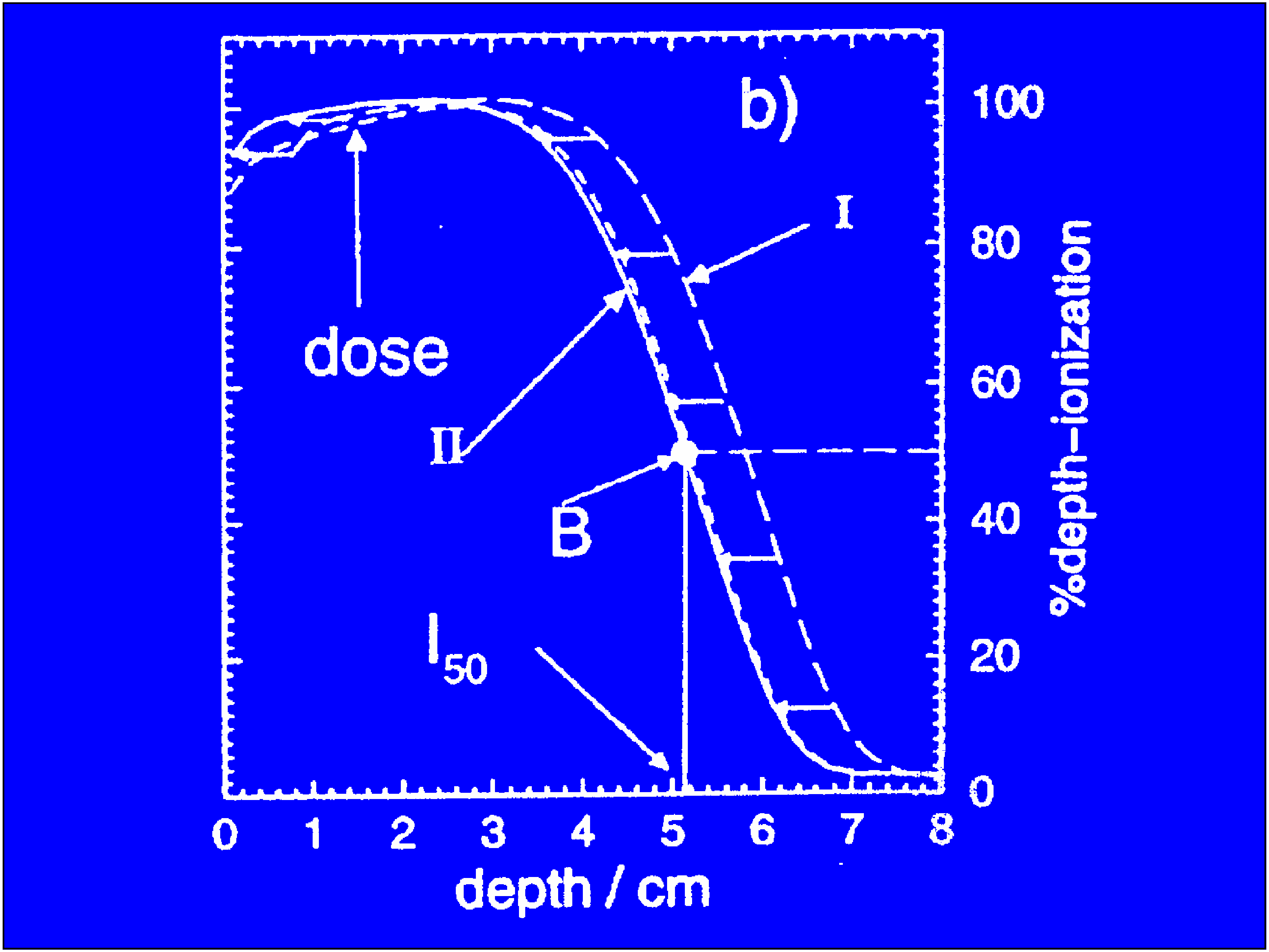
Electrons
Clinical % dd

Same as before

- Measure % ionization
- Shift to effective point of measurement
- Convert to dose -- using TG-25 (revised L/ρ)
- Use this value to shift from d_{ref} to d_{max}

Parallel Plate and *diode* need *no shift*

Figure 1



b)
dose
I
II
B
I50
100
80
60
40
20
0
%depth-ionization
0
1
2
3
4
5
6
7
8
depth / cm

Depth Dose Without Electron Contamination

- Measure %dd at 10 cm with 1 mm Pb foil:
  - 50 cm from surface

$\%dd(10)_x = [0.8905 + 0.00150\ \%dd(10)_{Pb}]\ \%dd(10)_{Pb}$

Use ***percent*** depth dose, %dd,

not ***fractional*** depth dose, fdd.

Beam Quality Specification
Photons

Specified by [$\%dd(10)_x$]

- ***X-ray only*** %dd, 10 cm depth, 10 square
- Measure I_{max} and I_{10} at 10cm + $f*r_{cav}$
- Use ***only*** to determine k_Q
- Use lead sheet for energies > 10MV (vague)
  - 1mm ± 20% (1/32" - 3/64")
  - Place at 30 (± 1) cm or 50 (± 5) cm from SSD
  - Last material between collimator and phantom
  - remove lead and throw away $\%dd(10)_x$
  - Interim equation to use without lead

Beam Quality Specification
Electrons

Specified by $\boldsymbol{R_{50}}$

R_{50} ~ depth (cm) at which dose falls to 50% of max for full scatter field.

$R_{50} = 1.029\ I_{50} - 0.06$ (cm) $[I_{50} \leq 10\text{cm}]$

$R_{50} = 1.059\ I_{50} - 0.37$ (cm) $[I_{50} > 10\text{cm}]$

$\{I_{50}$ = depth of 50% ionization$\}$

- May not agree with clinical depth dose
- Use ***only*** to determine d_{ref} and k'_{R50}

Implementation

- Do Homework:
  - Make measurements
  - Determine Change in Dose to patient
  - If change exceeds 2.5% -- ***contact RPC***
  - Choose a good date to change
- Inform everyone involved
- Make change

Expected Changes

- TG-51/TG-21 at ^{60}Co
- TG-51/TG-21 at other energies/modalities

Calculation of $N_{D,w}/N_K$ for Cobalt-60

$$D(^{60}Co) = M \cdot N_{D,w} = M \cdot N_{gas} \cdot L/\rho \cdot P_{repl} \cdot P_{wall}$$

$$N_K = 0.8791\ [Gy/R]\ N_X$$

$$\frac{N_{D,w}}{N_K} = \left[\frac{1}{0.879}\right]\left[\frac{N_{gas}}{N_x}\right]\left[P_{repl}\right]\left[P_{wall}\right]\left[\frac{L}{\rho}\right]_{air}^{water}$$

Comparison of Absorbed Dose and Air Kerma Calibration Factors

Chamber	$N_{D,w} / N_k$ (Meas.)	$N_{D,w} / N_k$ (Calc.)	Meas. / Calc.
NEL (SN 1864)	1.100	1.088	1.011
NEL (SN 1503)	1.102	1.088	1.013
PTW (SN 1516)	1.099	1.086	1.012
PTW (SN 1483)	1.099	1.086	1.012
Capintec PR06C	1.095	1.079	1.015
Exradin A12	1.106	1.093	1.012

Dose (TG-51)/Dose (TG-21)

Chamber	^{60}Co	6 MV hν	18 MV hν	9 MeV e$^-$	16 MeV e$^-$
NEL (2 chambers)	1.012	1.010	1.007	1.015	1.021
PTW N23333/ N30001	1.012	1.010	1.006	1.014	1.017
Capintec PR06C	1.015	1.011	1.004	1.014	1.015
Exradin A12	1.012	1.008	1.002	1.014	1.016

Note: The measurement uncertainty (1 SD) is less than ± 0.4%.

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CAVEATS ABOUT DEPTH DOSE MEASUREMENTS

- Effective point of measurement:

$$d_{eff} = d_{meas} - f\,(r_{cav})$$

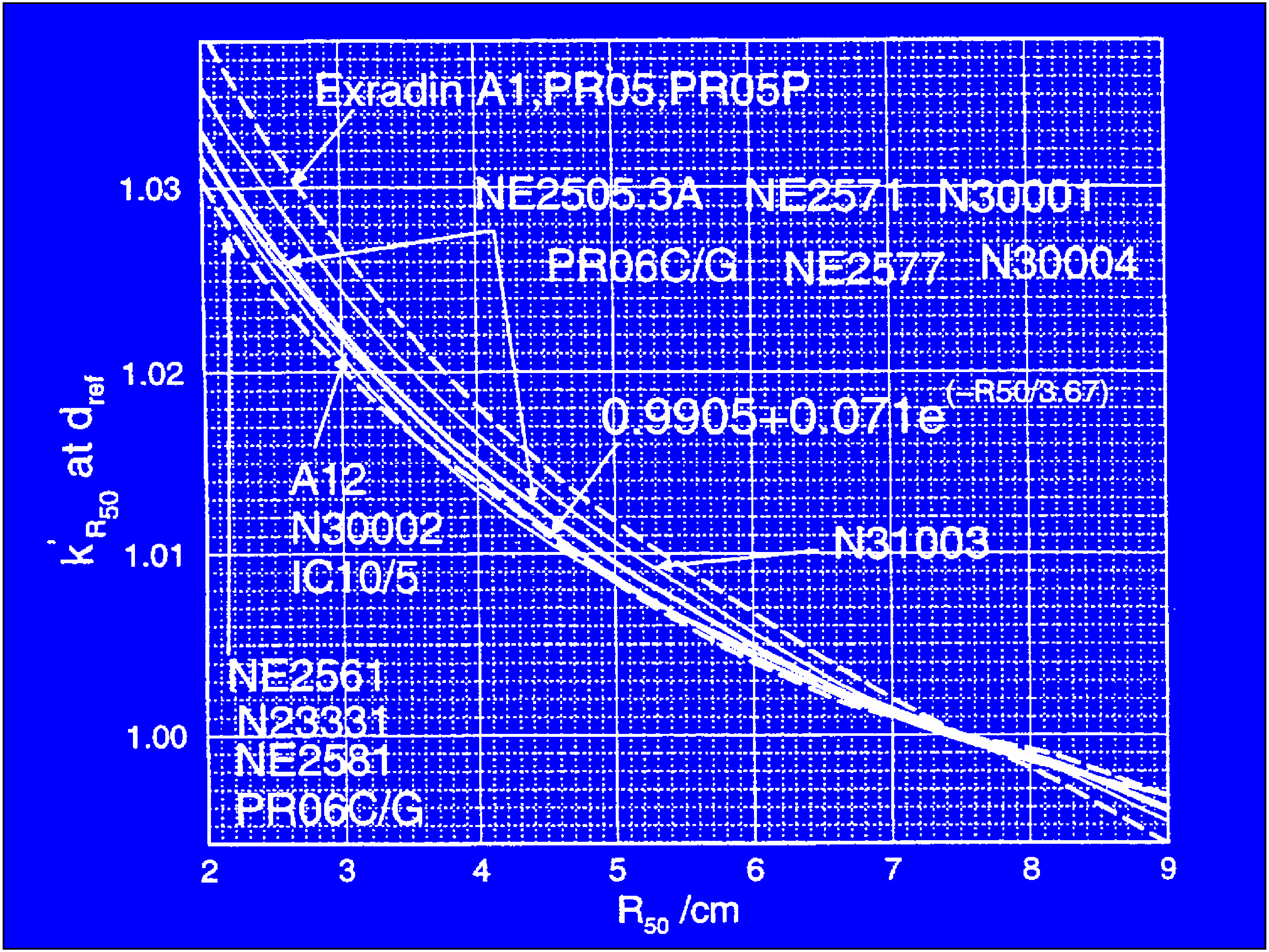
$$f = 0.6\, r_{cav} \text{ for photons}$$

$$f = 0.5\, r_{cav} \text{ for electrons}$$

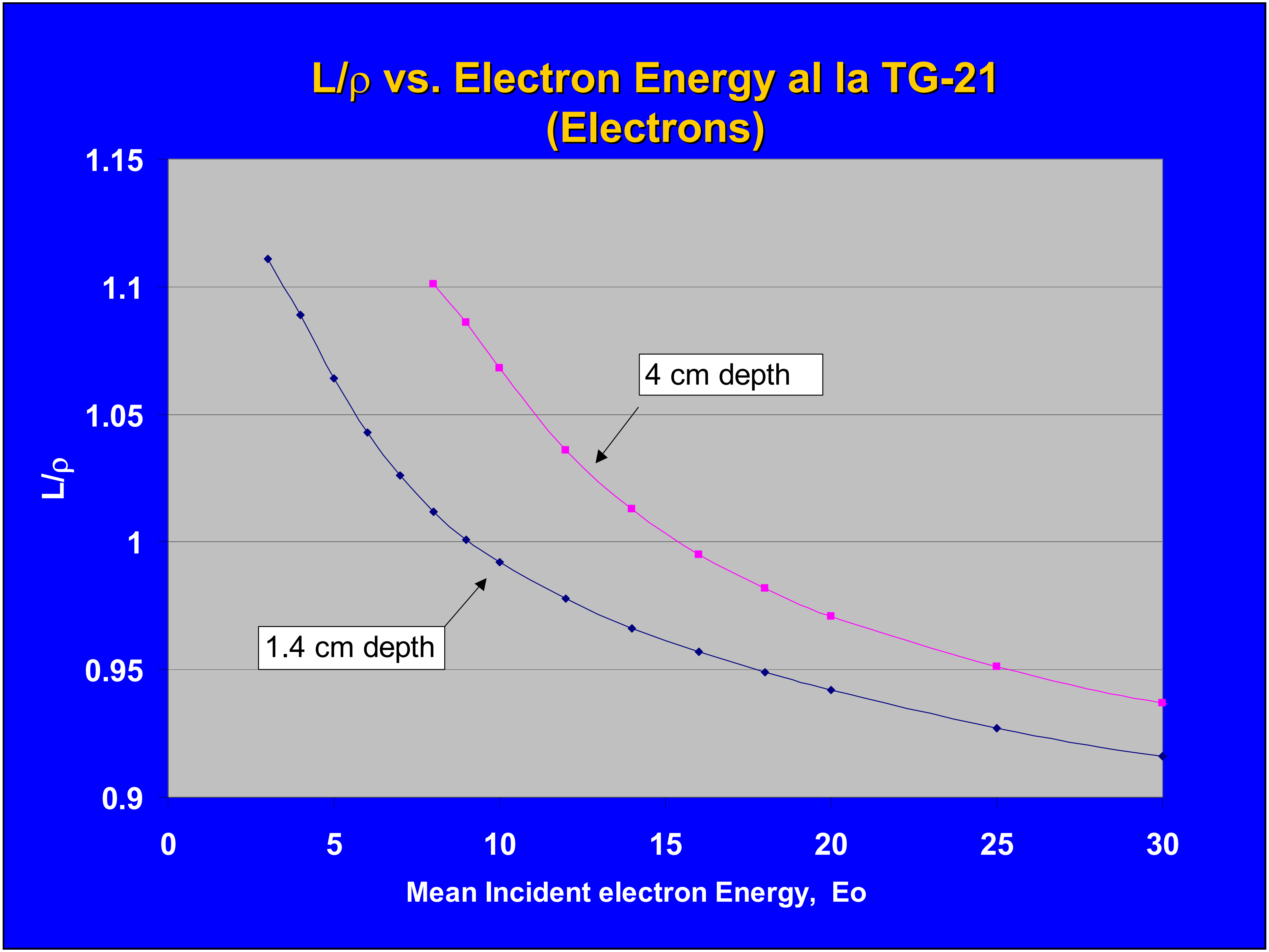
- effective point of measurement is used to calculate %dd used for clinical data and for energy specification.
- for calibration: do not shift point of measurement, gradient is corrected for in $k_{Q.}$

Learning Curve

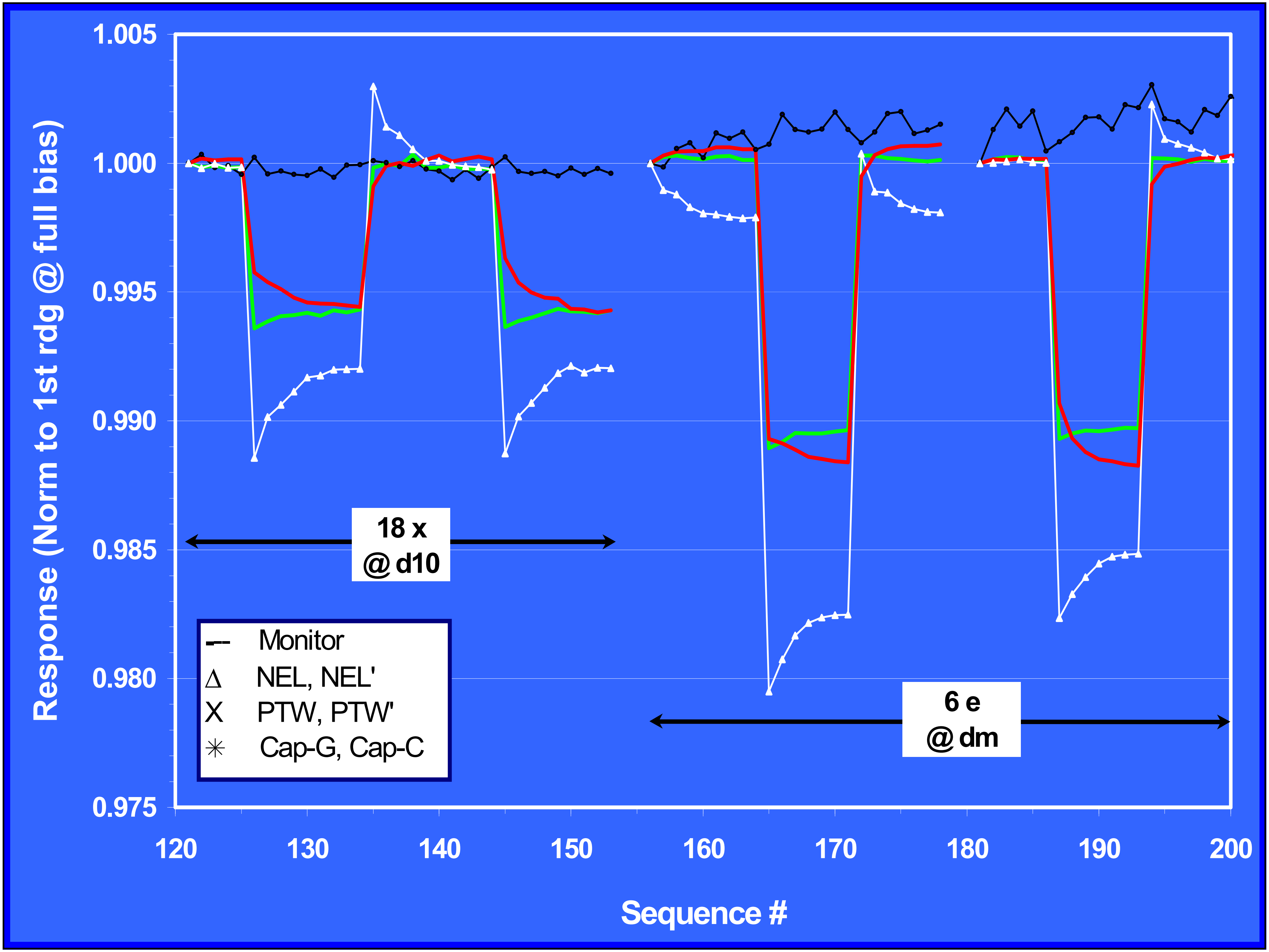
- Photons --- rather short:
  - One night of concentration
- Electrons --- somewhat longer
  - Several sessions to become comfortable



Exradin A1,PR05,PR05P
NE2505.3A NE2571 N30001
PR06C/G NE2577 N30004
0.9905+0.071e(−R50/3.67)
A12
N30002
IC10/5
N31003
NE2561
N23331
NE2581
PR06C/G
1.03
1.02
1.01
1.00
2
3
4
5
6
7
8
9
k'R50 at dref
R50 /cm



L/ρ vs. Electron Energy al la TG-21
(Electrons)
1.15
1.1
1.05
1
0.95
0.9
L/ρ
4 cm depth
1.4 cm depth
0
5
10
15
20
25
30
Mean Incident electron Energy, Eo


1.005
1.000
0.995
0.990
0.985
0.980
0.975
Response (Norm to 1st rdg @ full bias)
120
130
140
150
160
170
180
190
200
Sequence #
18 x
@ d10
6 e
@ dm
Monitor
NEL, NEL'
PTW, PTW'
Cap-G, Cap-C