Small Field Dosimetry
Relative dosimetry: detector choice and corrections

Relative dosimetry
Measurement tasks:
- Rel. profiles (OARs)
- Rel. depth dose
- Tissue phantom ratios (TPR)
- Total scatter factor (output measured in phantom, $S_{cp}$)
  - Head scatter factor (output measured in air $S_c$)
  - Phantom scatter factor $S_p$

Desired detector properties
- High spatial resolution
- High signal, low noise
- Low energy dependence
- Low directional dependence
- Low perturbation
- Dose (rate) linearity
- High stability, robust
- Easy to use in a clinic

Some detectors
- Ionization chamber PTW 31010, 0.125cc
- Ionization chamber PTW 31006, PinPoint, 0.015cc
- Shielded Si-diode Sc.-Welthöfer PFD Photon, 0.0003cc
- Mini Si-diode Sc.-Welthöfer SFD stereotactic, 0.00017cc
- Si-MOSFET Thomson & Nielsen TN-502 RD
- Diamond detector PTW 60003, ca. 0.0052cc
- microLion Chamber 0.0017cc

Detector response
$$D(r) = \prod k(r) \cdot NM(r)$$
M: measured value
N: calibration factor
k: correction factor

Reference dosimetry:
- Product of correction factors should be known (use dosimetry protocol)

Relative dosimetry:
- Product of correction factors $k$ should be constant
  or the relation $k_{meas}/k_{ref}$ should be known
Influence factors on detector response

- Volume averaging
- Perturbation of the radiation field displacement of water
- Energy dependence of stopping power \( \frac{dE}{dx} \) and energy absorption coefficient \( \mu_{\text{en}} \) ratios
- Temperature, pressure, dose rate, dose, age ...

Detectors, pros and cons

- Polymer gel
  - 3D, high spatial resolution, difficult readout, calibration, preparation
- Radiochromic film
  - 2D, difficult calibration, stability of scanning
- Micro ionization chamber
  - Volume effect, signal/noise, background, energy dependence
- TLD, alanine, MOSFET, all non direct reading 1D detectors
  - Position uncertainty
- Diamond
  - Dose rate dependence, volume effect, robustness
- Si-diodes
  - High spatial resolution, energy & field size dependent response

Gafchromic Film

- EBT3
- EBT2
- EBT

- Brown et al: Dose response curve of EBT EBT2 and EBT3 radiochromic films, MP2013, 7412

Ionization chamber – energy dependence

- High volume effect
  or
- Low current
  but
- Low energy dependence:
  \( \delta_{\text{FS}}=\frac{0.5\text{cm}}{w,a} < 1\% @ 6\text{MV} z=10\text{cm} \)

Figure from Andreo & Brahme
Ionization chamber - Volume effect

- Mean relative dose on the sensitive area of the detector perpendicular to the beam axis
- PinPoint, FS=2cm → ε ≈ 0.5%
- (assumption: constant sensitivity → volume effect is overestimated)

OAR: off-axis ratio

Volume effect (2)

- Deconvolution with the detector response function K
- D_m: measured dose
- D: “true” dose
- F: Fourier transform

\[ D_m(x) = \int D(u)K(u-x)du \]


Measured and calculated LSF for a IC

- FIG. 7. Calculated ~solid lines! and measured ~dashed lines! line spread functions ~LSFs! of an IC15 ionization chamber based on 0.2 and 0.4 mm slit beams, respectively, in a 6 MV (a) and 25 MV (b) x-ray beam. The points represent the calculated LSF after the application of Eq. 3 using a maximum likelihood iterative reconstruction (MLIR) algorithm; the lines represent the LSFs after a fit according to Eq. 4. The calculated and fitted LSFs have been normalized to a central value of 1.0; the other LSFs were normalized to the same area under the curves.

- van’t Veld et al.: Detector line spread functions, Medical Physics, Vol. 28, No. 5, May 2001

Dose rate dependence

- Determine by 1/r²-law
A diamond detector
- may have a huge dose rate dependence
- is not really small (> 3mm)
- has a huge production spread
- has low energy dependence

Detector response for different dose rates in a 6 MV bremsstrahlung beam expressed as ratios of detector response and dose rate, determined by a Farmer ionization chamber, and normalized at the lowest dose rate. The error bars represent the statistical uncertainty (1SD).
Silicon - Energy dependence, Perturbation, no B-G Cavity

Silicon detector
- Small: width < 1mm
  - hardly any volume effect
- Sensitive →
  - Dimension not small against electron range
  - General cavity theory applies
  - strong increase of response below $h\nu = 200$ keV
  - over response in regions with high scatter fraction
- High density displacement of water perturbation of the local field

% dose from photons below 200 keV for $^{60}$Co

- Field size = 5cm x 5cm

Profile measurements: Energy-response of diodes

- To detect the penumbra correctly use a small diode
- Check the detector response outside the geometrical field
- Correct for over/under-response or use an appropriate detector. [e.g. shielded diode or radiographic film]
Depth dose and TPR measurements

- Use a small diode for small fields and BU, an IC otherwise
- Estimate the changing volume effect with depth
- Carefully align CAX with scan direction
- Measure TPR directly
- Examine data
  - Fit to a function
  - Corroborate by different means
- Energy dependence, i.e. depth dependence of response is low for small fields

Change of correction factors with depth

<table>
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<tr>
<th>Depth dependence</th>
<th>PTW60012</th>
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<td>Cramer-Sargison</td>
<td>Raiston 12</td>
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<table>
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<th>5</th>
<th>0.5</th>
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<td>depth /cm</td>
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<td>0.98</td>
<td>1</td>
<td>0.96</td>
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<td>1.5</td>
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<td>Mean</td>
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<td>Std. dev.</td>
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<td>0.005</td>
<td>0.000</td>
<td>0.006</td>
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Depth dependence is negligible also for unshielded diodes
At which field size will it start to be relevant?

Output measurement $S_{cp}$: Field size dependence of $k_{NR}$

$$S_{cp} = \frac{D_x(A,z_{ref})}{D_x(A_{ref},z_{ref})}$$

- Perturbation correction factor $k_P$
- Energy correction factor $k_E$
- Volume averaging correction factor $k_V$

Output terminology: conventional vs. AAPM/IAEA

- Calibration conditions $\rightarrow$ reference conditions $\rightarrow$ measurement conditions
- Output factor $=$ total scatter factor $=$ collimator scatter $\times$ phantom scatter

$$D_x(A) = k(A)D_{ref} = k(A)NM_{det}(A)$$

$$S_{cp} = \frac{k(A)M_{det}(A)}{k_{ref}M_{det}(A_{ref})}$$

$$D_{ref} = \frac{Q_{ref}Q_{det}Q_{w}}{Q_{ref}Q_{det}Q_{w}}$$

$$S_{cp} = \frac{k(A)M_{det}(A)}{M_{det}(A_{ref})}$$

$$\Omega_{ref}Q_{det}Q_{w} = \frac{M_{ref}}{M_{det}}k_{ref}Q_{w}Q_{det}$$
Behavior of $k_{\text{NonReference}}$ with field size?

Response versus field size: influence of photon energy

- Signal of various detectors relative to ionization chamber PTW31010 with 0.125cm³
- Decreasing response of Si-detectors with decreasing field size
- Reason: depletion of low energy photons
- For small fields volume averaging of the 0.125 cm³ large IC is dominant

Signal ratios (= RF for SES>4cm) vs. SES / cm

![Graph showing signal ratios vs. SES/cm](image)


Lateral electron equilibrium and lateral electron range

- Only for field sizes larger than the lateral electron range approximate LEE exists

Causes of perturbation

Ionization chamber:
- wall, central electrode, air cavity,
  - (low density: blurring or rising of the isodose volume)

Diode:
- housing, shielding, contacting silicon chip,
  - (high density: shrinkage or ebbing of the isodose volume)

Field size dependence of perturbation factors

Li et al MP 22, 1995, 1167-1170

Li et al MP 22, 1995, 1167-1170

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Response versus field size: Density effect


Otto Sauer: small field dosimetry

Monte Carlo determination of correction factors


Monte Carlo determination of correction factors


Figure 8. The change in k as a function of field size shown for various source widths (left) and energies (right) calculated using the simplified models.

- k doesn't contain kV
- Simplified model sufficient
- Influence of FWHM and energy marginal
Monte Carlo determination of correction factors

- stereotactic field diode (SFD) (IBA/Scanditronix)
- T60016 shielded (PTW) and T60017 unshielded (PTW) diodes


Using polymer gel, EBT, alanine, and TLD to determine corrections for diodes

1% difference between shielded/unshielded diode correction

Experimental derivation

- Largest correction for SFD at 4mm cone size
- Low (<2%) differences between shielded and unshielded detectors

Comparison of data from different resources

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<th>Method</th>
<th>Machine</th>
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</table>

Otto Sauer: small field dosimetry

Conclusions

- Output:
  - For very small photon fields, detector response is not known with high certainty
  - Contemporary literature shows over-response, likely due to density effects
  - But, volume effect, photo-effect and possibly intrinsic effects counteract

- Use a detector needing a low correction
  - E.g. unshielded diode, radiochromic film

- Profiles:
  - Determine dependence of response on energy for each detector
    - Good detectors are e.g. shielded diodes or radiochromic film

- Depth dose:
  - Any detector works, if small enough

- Corroborate the measurements by
  - Using different types of detectors