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# Small photon field dosimetry

## Introduction to hospital exercise

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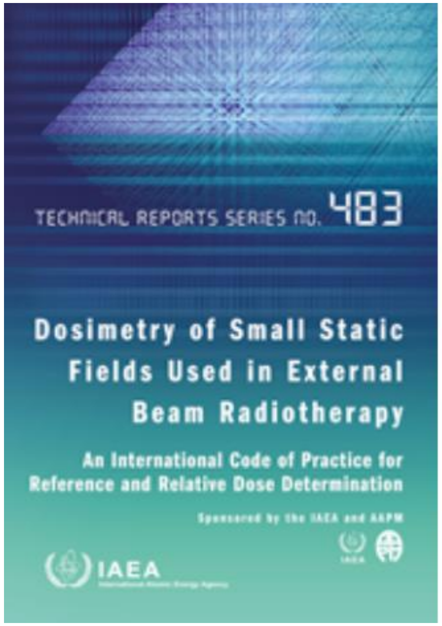
# What is small field?

1. There is a **loss of lateral charged particle equilibrium.**

2. There is **partial occlusion** of the primary photon source by the collimating devices.

3. The **size of the detector** is larger compared to the beam dimensions.



TECHNICAL REPORTS SERIES No. 483

Dosimetry of Small Static Fields Used in External Beam Radiotherapy

An International Code of Practice for Reference and Relative Dose Determination

Sponsored by the IAEA and AAPM

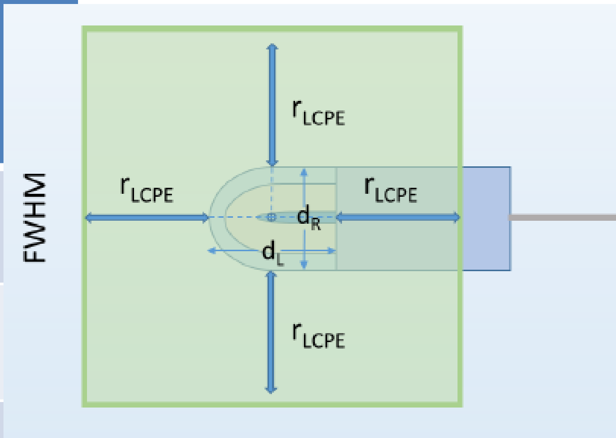
IAEA

# 1. Loss of lateral charged particle equilibrium

Beam radius to achieve complete lateral electron equilibrium in water: <u>measure of the range of laterally scattered electrons</u>

$$r_{LCPE}[cm] = 8.369 \cdot TPR_{20,10} - 4.382$$

| Beam energy (MV) | $TPR_{20,10}$ | $r_{LCPE}$ (cm) |
|---|---|---|
| 6 MV | 0.684 | 1.3 |
| 10 MV | 0.737 | 1.8 |
| 15 MV | 0.764 | 2.0 |



6 MV photons: $r_{LCPE} \approx 1.2$ cm

# 2. Partial source occlusion

- Partial occlusion of the primary source.
- The contribution of penumbra become negligible.

The output is reduced when the field size further decreases.

*Small Field Dosimetry*

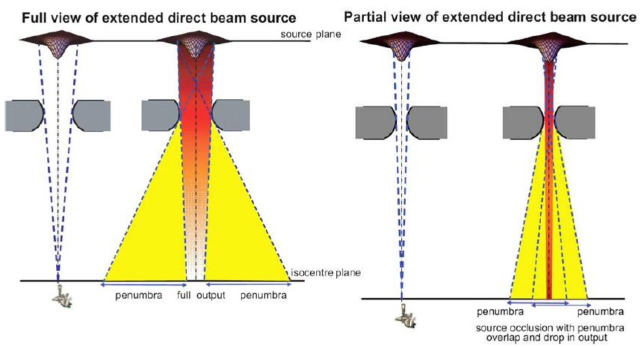
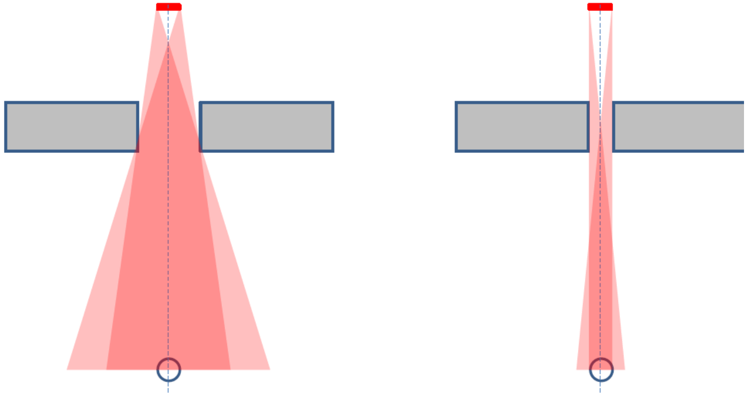
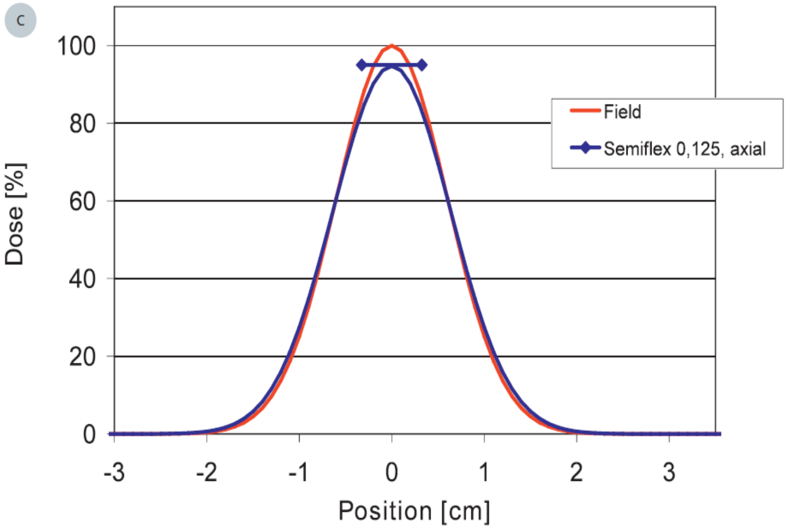


Figure 2.2. Schematic illustration of source occlusion. *Left*: the full, extended source can be "viewed" by an observer on the central axis. *Right*: only partial view of the source is possible by an observer on the central axis. (Adapted from IPEM Report 103 (Aspradakis *et al.* (2010).)



# 3. Size of detector vs field size

- **Several perturbation effects** occur when modulation or dose gradients exist over the chamber volume
- The most obvious one is **volume averaging**

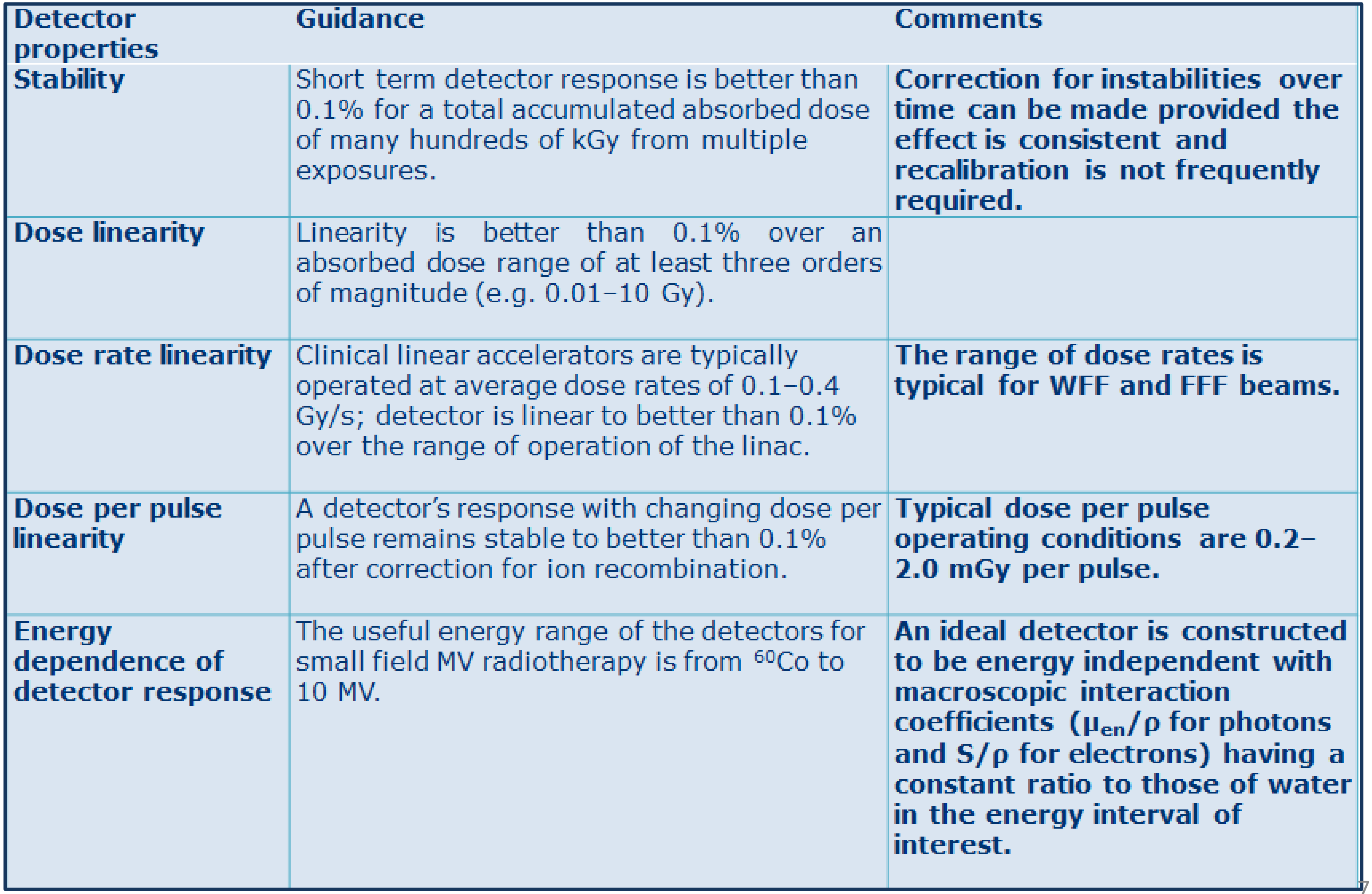


# Detector characteristics to consider in small field dosimetry

- **Spatial resolution** – output measurements & scans
- **Dimensions**
- Sensitivity – **signal/noise**
- **Density**
- Angular dependence
- **Energy dependence**
- Water-equivalence
- Dose linearity or known dose dependence

The **ideal detector** for measurement dosimetry would be a point detector that is energy indipendent and requires only a single calibration that is valid for all possible energies and irradiation scenarios.

# Detector characteristics to consider in small field dosimetry



| Detector properties | Guidance | Comments |
|---|---|---|
| **Stability** | Short term detector response is better than 0.1% for a total accumulated absorbed dose of many hundreds of kGy from multiple exposures. | **Correction for instabilities over time can be made provided the effect is consistent and recalibration is not frequently required.** |
| **Dose linearity** | Linearity is better than 0.1% over an absorbed dose range of at least three orders of magnitude (e.g. 0.01–10 Gy). | |
| **Dose rate linearity** | Clinical linear accelerators are typically operated at average dose rates of 0.1–0.4 Gy/s; detector is linear to better than 0.1% over the range of operation of the linac. | **The range of dose rates is typical for WFF and FFF beams.** |
| **Dose per pulse linearity** | A detector's response with changing dose per pulse remains stable to better than 0.1% after correction for ion recombination. | **Typical dose per pulse operating conditions are 0.2–2.0 mGy per pulse.** |
| **Energy dependence of detector response** | The useful energy range of the detectors for small field MV radiotherapy is from $^{60}$Co to 10 MV. | **An ideal detector is constructed to be energy independent with macroscopic interaction coefficients ($\mu_{en}/\rho$ for photons and $S/\rho$ for electrons) having a constant ratio to those of water in the energy interval of interest.** |

| | | |
|---|---|---|
| **Spatial resolution** | The choice of a suitable detector in terms of spatial resolution is usually based on a trade-off between a high signal to noise ratio and a small dosimeter size. | **The requirement for spatial resolution is set by the gradients in the quantity to be measured.** |
| **Size of detector** | The detector size is such that the volume averaging correction is not larger than 5%. | |
| **Orientation** | The response of a detector is ideally independent of the orientation of the detector with respect to the beam and the variation is less than 0.5% for angles of less than 60° between the beam axis and the detector axis. | **Detectors do not, in general, have an isotropic response, and either a correction is required to account for the angular response or, more commonly, the beam incidence is fixed (i.e. irradiation from end or side) to minimize the effect.** |
| **Background signal** | Any form of signal leakage that would contribute to increased background readings is at least three orders of magnitude lower than the detector response per Gy. | **The zero dose reading of a detector will affect the low dose limit of the device and the signal to noise ratio.** |
| **Environmental factors** | **Corrections over the full range of working conditions enables any influence to be reduced to better than 0.3%.** | **Measurements are ideally independent of temperature, atmospheric pressure and humidity changes or are corrected accurately for these influence quantities.** |

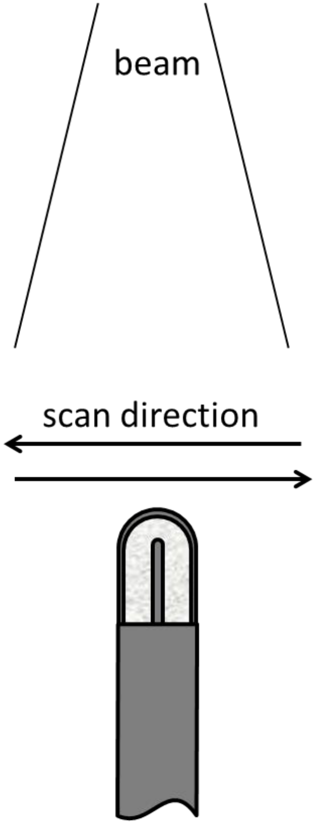
# Detector orientation

TABLE 22. DETECTOR ORIENTATION, WITH RESPECT TO THE BEAM CENTRAL AXIS, FOR RELATIVE DOSIMETRY IN SMALL PHOTON FIELDS

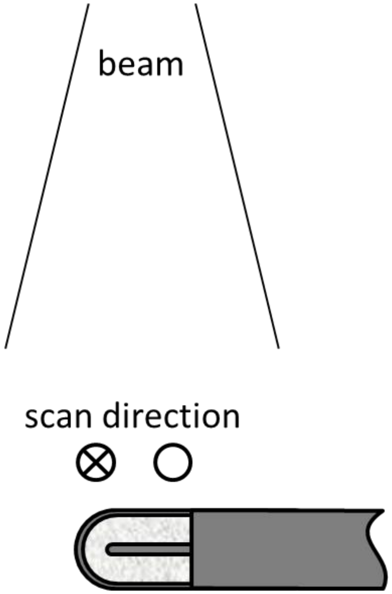
| Detector type | Detector’s geometrical reference | | Lateral beam profiles | Field output factors |
|---|---|---|---|---|
| **Cylindrical micro ion chamber** | **Axis** | | **Parallel or perpendicular** | **Perpendicular** |
| Liquid ion chamber | Axis | | Perpendicular | Parallel |
| Silicon shielded diode | Axis | | Parallel | Parallel |
| **Silicon unshielded diode** | **Axis** | | **Parallel** | **Parallel** |
| **Diamond detector** | **Axis** | | **Parallel** | **Parallel** |
| Radiochromic film | Film surface | | Perpendicular | Perpendicular |

# Detector orientation for lateral profiles

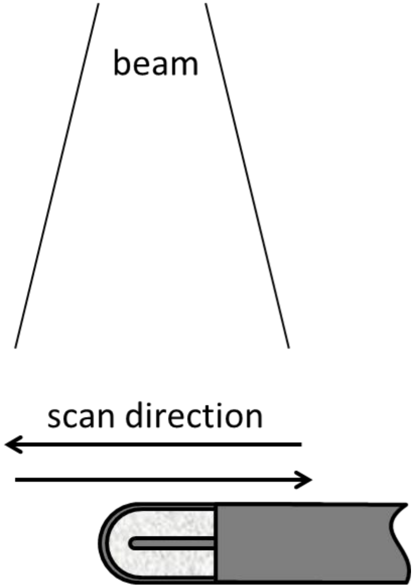
**ion chamber**



(1) OK

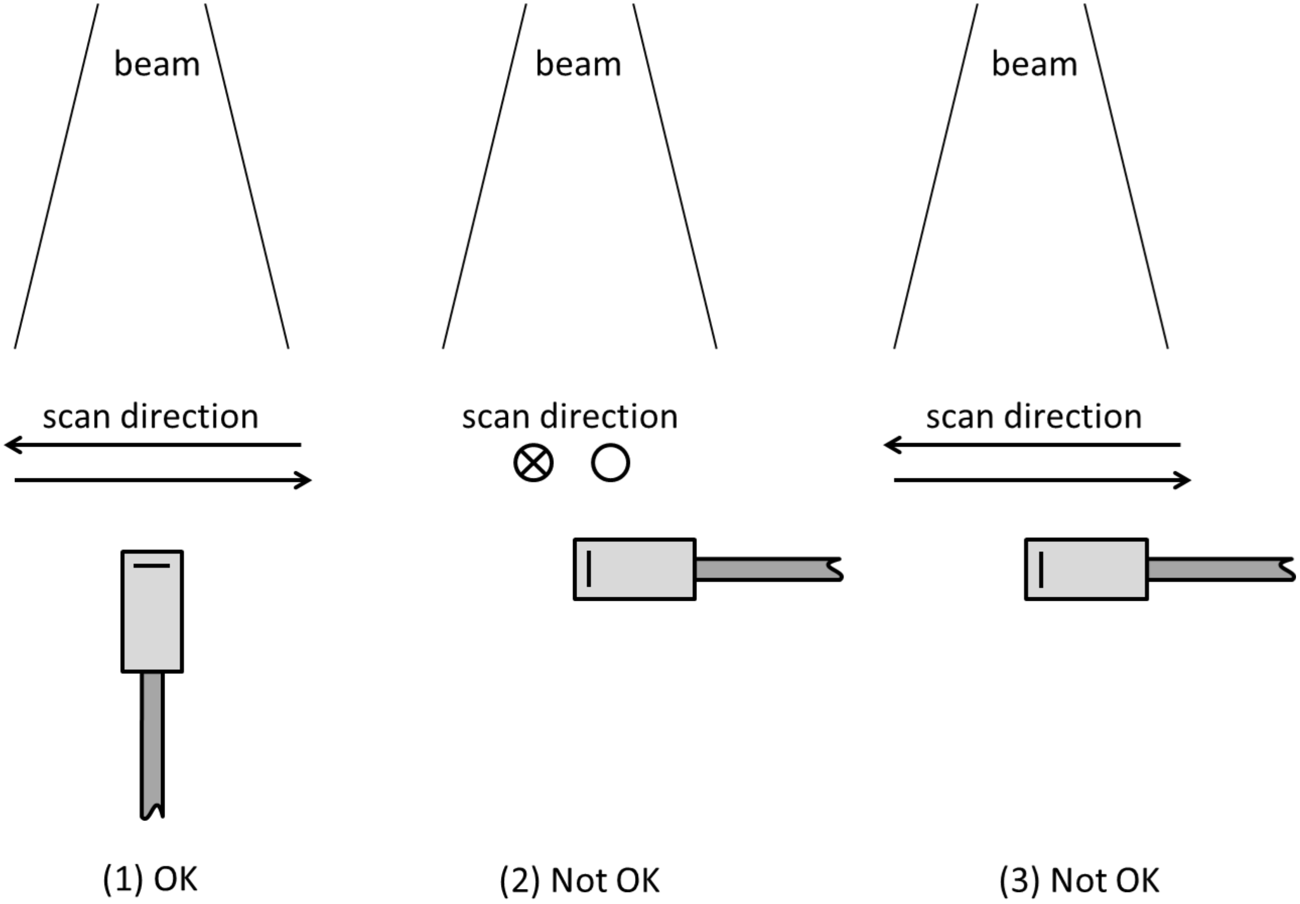


(2) OK



(3) Not OK

# Detector orientation for lateral profiles



**diode**
**or**
**diamond detector**

# Output factors - definition

$$\Omega^{f_{\mathrm{clin}},f_{\mathrm{msr}}}_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}} = \frac{D^{f_{\mathrm{clin}}}_{w,Q_{\mathrm{clin}}}}{D^{f_{msr}}_{w,Q_{msr}}} = \frac{M^{f_{\mathrm{clin}}}_{Q_{\mathrm{clin}}}}{M^{f_{msr}}_{Q_{msr}}} \cdot k^{f_{\mathrm{clin}},f_{\mathrm{msr}}}_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}$$

**ratio of detector readings**

**output correction factor**

# Output correction factors

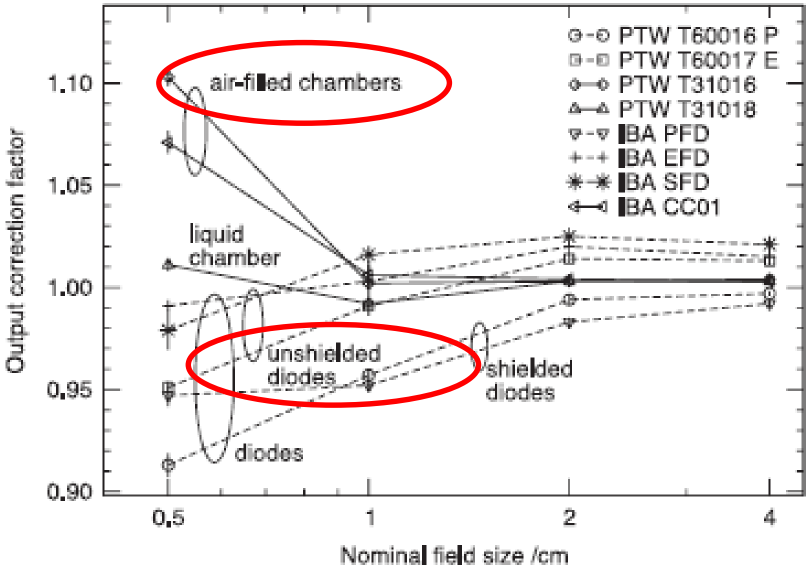


Figure 2.10. Output correction factors, $k^{f_{\text{clin}},f_{\text{msr}}}_{Q_{\text{clin}},Q_{\text{msr}}}$, for eight detector types in small fields from the Varian IX series for 5 mm, 1, 2, and 4 cm field openings normalized to a 10 × 10 cm$^2$ field size. Three types of detectors are involved: air-filled ionization chambers (PTW T31016, IBA CC01), liquid ionization chamber (PTW T31018), and diodes (PTW T60016, PTW T60017; IBA PFD, IBA EFD, IBA SFD). The diode data is shown in two classes (*unshielded*: under-response in intermediate field sizes 2–4 cm and over-response in small fields; *shielded*: over-response in fields 4 cm and smaller). The field size is specified as the nominal side of a square field. The data is an average of several studies Monte Carlo and measurements. (Benmakhlouf *et al.*, 2014) and references therein.

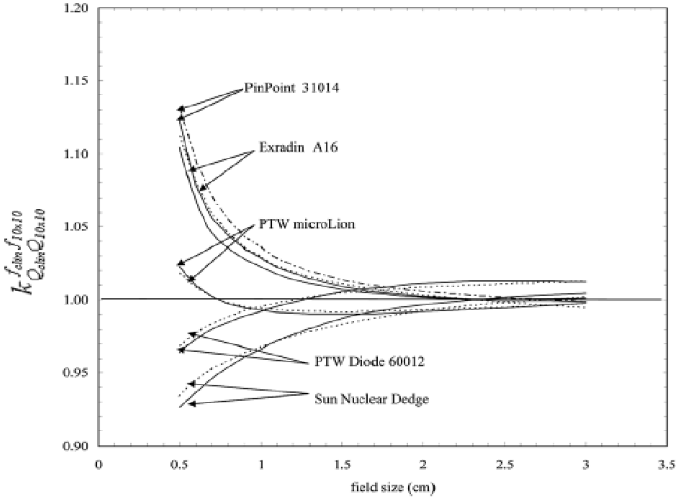


FIG. 7. Correction factor $k^{f_{\text{clin}},f_{10\times10}}_{Q_{\text{clin}},Q_{10\times10}}$ for five detectors as a function of the field size, for 6 MV beams of Siemens (dotted line) and Elekta (continuous line) linacs.

Francescon et al 2011, Med Phys 38:6513

# Hospital practical experience: output factors measurements

- Beam lasers are not always *exactly on central axis*
  - Do inplane and crossplane-profile scan
  - Set detector to maximum profile in either direction
  - Repeat profile scan
- Set jaws to reflect clinical plans
- Field sizes: 10 cm x 10 cm, 4 cm x 4 cm, 2 cm x 2 cm and 1 cm x 1 cm for the 6MV photon energy

# Procedure

- Set the chamber at 10 cm depth for the SAD=100cm configuration for 10 cm × 10 cm field
- Measure lateral and longitudinal ionization profiles for the 10 cm × 10 cm field to centre the chamber
- Set default bias voltage. Register P and T. Make a warm-up reading (400 MUs), then record 3 readings, 100 MUs each
- For the square field sizes with 4, 2 and 1 cm side, measure lateral and longitudinal ionization profiles

# Procedure

- For the square field sizes with 4, 2 and 1 cm side, measure lateral and longitudinal ionization profiles
- Centre the chamber, then record 3 readings, 100 MUs each for each field size (readings should not differ by more than about 0.5%). Register P and T for each field size
- Set field size at 10 cm × 10 cm and record 3 readings, 100 MUs each
- **Determine field output factors**

| Depth z (cm) | Square field size ($cm^2$) | Reading1 (cGy/100MU) | Reading2 (cGy/100MU) | Reading3 (cGy/100MU) | Medium value (cGy/100MU) |
|---|---|---|---|---|---|
| 10 | 10*10 | | | | |
| | 4*4 | | | | |
| | 2*2 | | | | |
| | 1*1 | | | | |

# Hospital practical experience

**Small field** relative dosimetry:

- Equipment
- Small field Profiles (detector alignment, FWHM)
- Small field Output factors (pinpoint IC, micro diamond, diode)

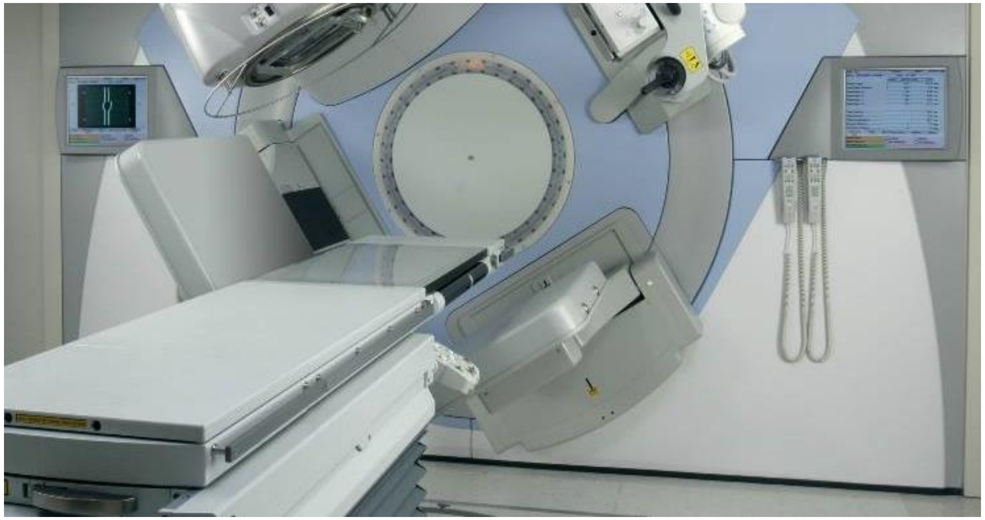
# Hospital practical experience

## Small field relative dosimetry:

Equipment

Elekta Synergy Agility, **WFF** 6MV

*MP3 water phantom (PTW)*



# Hospital practical experience

## **Small field** relative dosimetry:

### Equipment

Electrometers PTW UNIDOS E

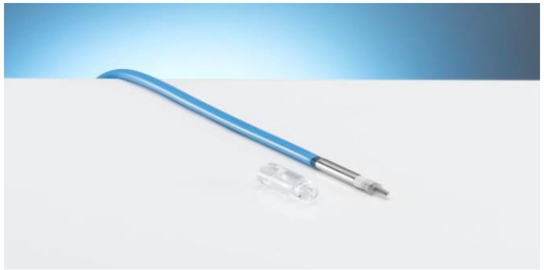
PTW pin point 31014

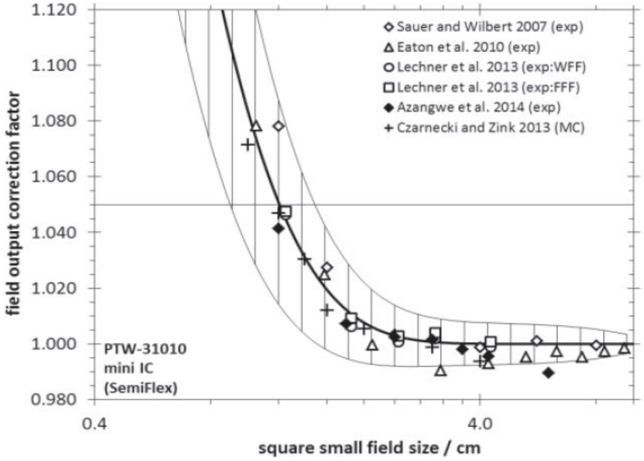
PTW 60019 microDiamond

PTW 60017 non-shielded (EFD) diode

# Hospital practical experience

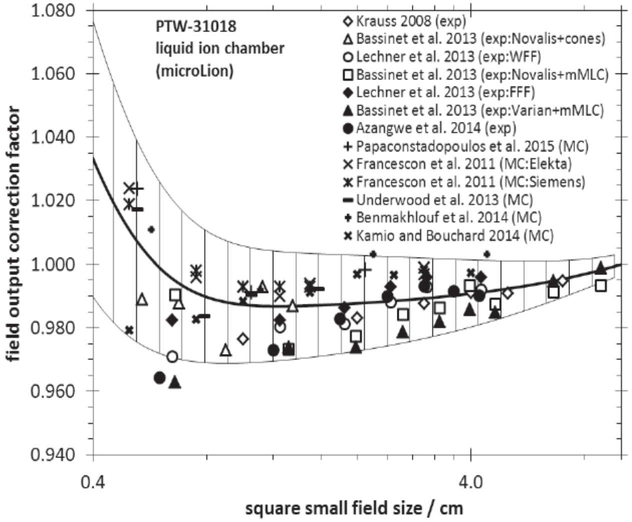
**PTW pin point 31014**





Air-filled

- Good stability
- Sensitivity puts lower size limit->volume averaging
- Stem and cable currents
- Polarity effects



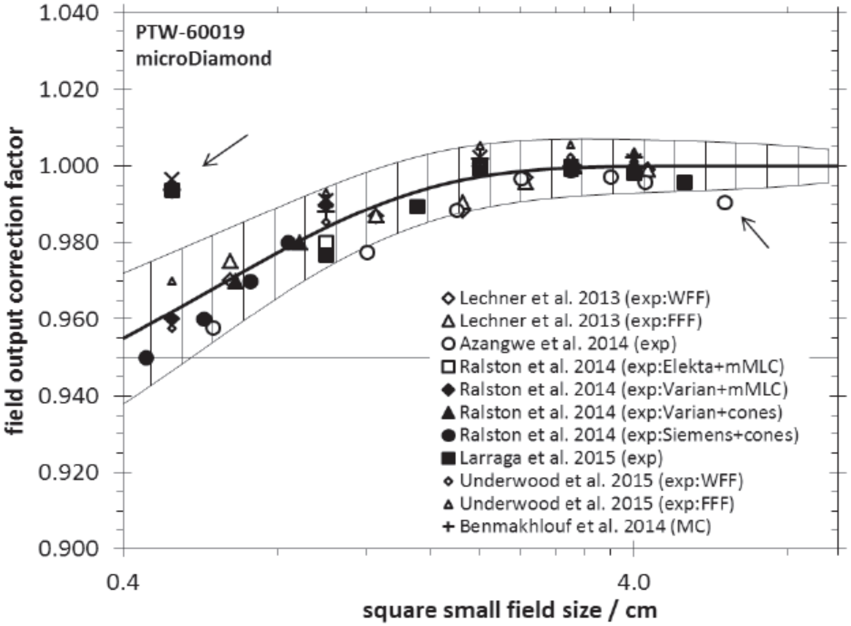
Liquid-filled

- Higher sensitivity
- Smaller volume
- Density close to water
- Less stable (deterioration liquid, leaking, etc.)
- Dose rate dependence

# Hospital practical experience

**PTW 60019 microDiamond**

- ✓ Small
- ✓ Sensitive
- ✓ No pre-irradiation needed
- ✓ Small temperature dependence
- ✓ Stopping power ratio diamond/water almost independent of energy
- ✓ Recombination (single-crystal natural diamond) -> dose rate dependence
- ✓ Expensive



# Hospital practical experience

**PTW 60017 non-shielded (EFD) diode**

- ✓ Small
- ✓ Sensitive
- ✓ Small temperature dependence
- ✓ Unshielded diodes: over respond in large fields
- ✓ Shielded diodes: large perturbations in small fields
- ✓ Angular dependence
- ✓ Radiaton damage