PHOTON BEAM DATA COMMISSIONING: TECHNIQUES, TIPS, AND LESSONS LEARNED

Gloria P. Beyer, Ph.D., DABR

Medical Physics Services LLC®

OUTLINE

1 Introduction

2 Detectors and Equipment

3 Beam data: PDDs and profiles

4 Small field data and output factors

1. INTRODUCTION

COMMISSIONING

Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM

Med. Phys. 35 (9), September 2008

Review of practical aspects and physics of commissioning

Radiation treatment outcome is directly related to the accuracy in the delivered dose to the patient that is dependent on the accuracy of beam data used in the treatment planning process. These data are obtained during the initial commissioning of the linear accelerator and …

COMMISSIONING CHANGES

- Tools and techniques (phantoms, detectors, software)
- Linear accelerators (matched, reference, or preconfigured data)
- Model commissioning process is, in some cases, "out-of-your hands" (Data used to validate instead of to configure a model)
- Does the treatment planning model that has been produced match my machine?

COMMISSIONING VS VALIDATION AND BEAM DATA

- Changes in radiation therapy equipment have led to the terms "commissioning" and "validation" becoming largely interchangeable
- If the TPS model was created from data acquired on a different linac, the commissioning data measurements will determine:
  - The adjustments to be performed on the machine to match the model
  - The certainty of how well the beam model matches your new machine
  - The limitations of the model for the types of treatments to be performed

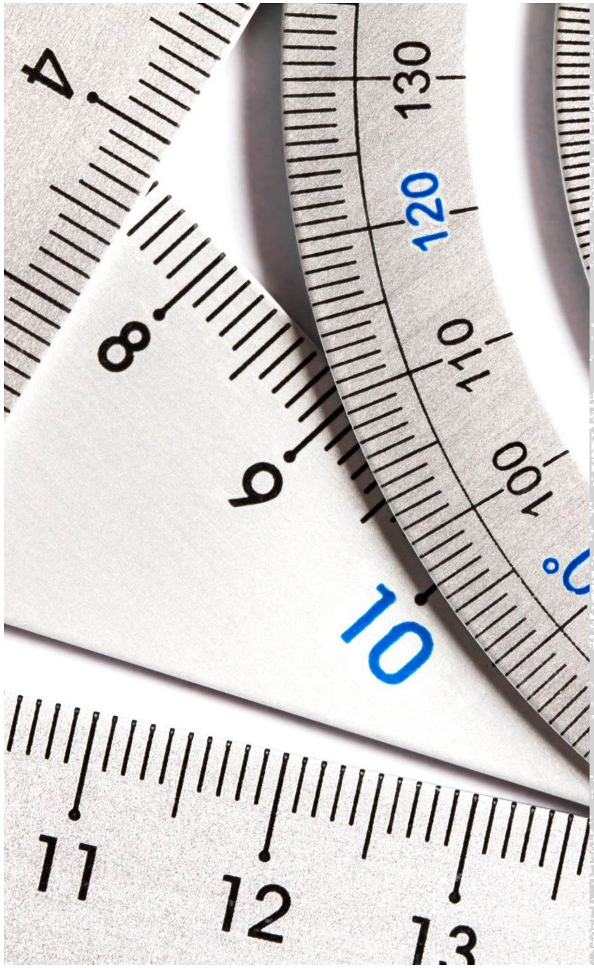
The data measurements taken during the commissioning process will determine the certainty of how well the beam model matches your new machine

COMMISSIONING VALIDATION

- **Beam data energy match:**
  - **False negative**: results indicate a mismatch with reference data
    - Secondary independent measurements showed a good match (<0.3% in PDDs, <1% profiles).
    - Errors in beam data measurements setup and techniques were found

- **Beam data energy match:**
  - **False positive**: results indicate a good match with reference data
    - Secondary independent measurements showed error of >0.5% in PDD and >2% in profile measurements.
    - Data originally acquired during acceptance or wrong equipment used
    - Acceptance ≠ Commissioning

Data measurements goals: true positives or negatives



2. DETECTORS & EQUIPMENT

DETECTOR SELECTION CONSIDERATIONS

Beam data measurement results can vary depending on detector used

Measurement Goals

- Point Dose
- PDD / Energy
- Profile / Penumbra

Field sizes and energies

- All fields
- Small fields
- Very-small fields
- Photons
- FFF photons
- Electrons

Detector Characteristics

Characteristic	Farmer-IC	Micro-IC	Diode	TLD/OSLD	Film
Energy dependence	Low	Low	Moderate	Moderate	Moderate
Angular dependence	Low	Low	Moderate	Moderate	Moderate
Lateral size	Moderate	Small	Small	Small	Small
Depth size	Moderate	Small	Small	Small	Small
Tissue equivalency	Depends	Depends	Diamond	***	No
Signal strength	Moderate	Low	High	Moderate	***
Electrometer/Bias	300 V	300 V	0*	N/A	N/A
Leakage/Dissipation	***	***	***	***	***
Maximum dose rate	***	***	***	***	***
Reading time	Fast	Fast	Fast	Slow	Slow
Waterproof or nor	Depends	Depends	Yes	Yes	Yes
Linearity w/ dose	Good	Good		***	***
Longevity due to Dose	Good	Good	MOSFET	***	***

DETECTOR CHARACTERISTICS

Sutlief, S: Introduction to Radiation Detectors.

2024 Spring Clinical Meeting Session: Detector Selection for External Beam Radiation Therapy Quality Assurance,

FFF ENERGIES

Phys. Med. Biol. 61 (2016) 8360 G Budgell *et al*

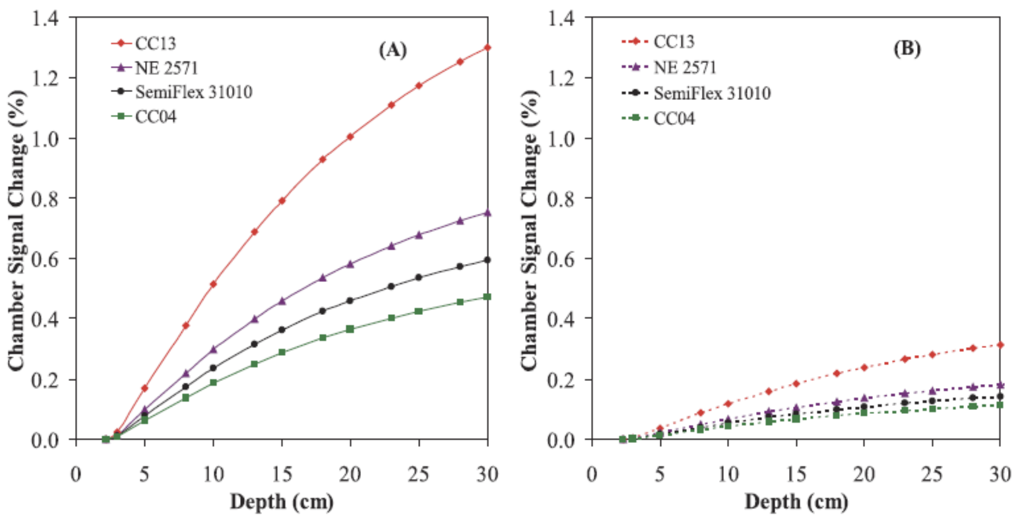


Figure 4. Effect on ionisation chamber signal at depth due to recombination losses for various detectors for (A) 10 MV FFF photons and (B) 10 MV flattened photons for a Varian TrueBeam. Measurements are for a 10 × 10 cm field at 100 cm SSD, using an operating potential of −350 V for all chambers. The ion chamber volumes are respectively: IBA CC13 0.13 cm^3, NE 2571 0.6 cm^3, PTW 31010 0.125 cm^3, IBA CC04 0.04 cm^3.

FFF energies require detectors that minimize the ion recombination effect (smaller chambers have a lower effect)

EQUIPMENT

- Water phantom system
- Detectors
- Cables & connectors
- Electrometer

Medical Physics, Vol. 35, No. 9, September 2008

ELECTROMETER, CABLES, AND CONNECTORS

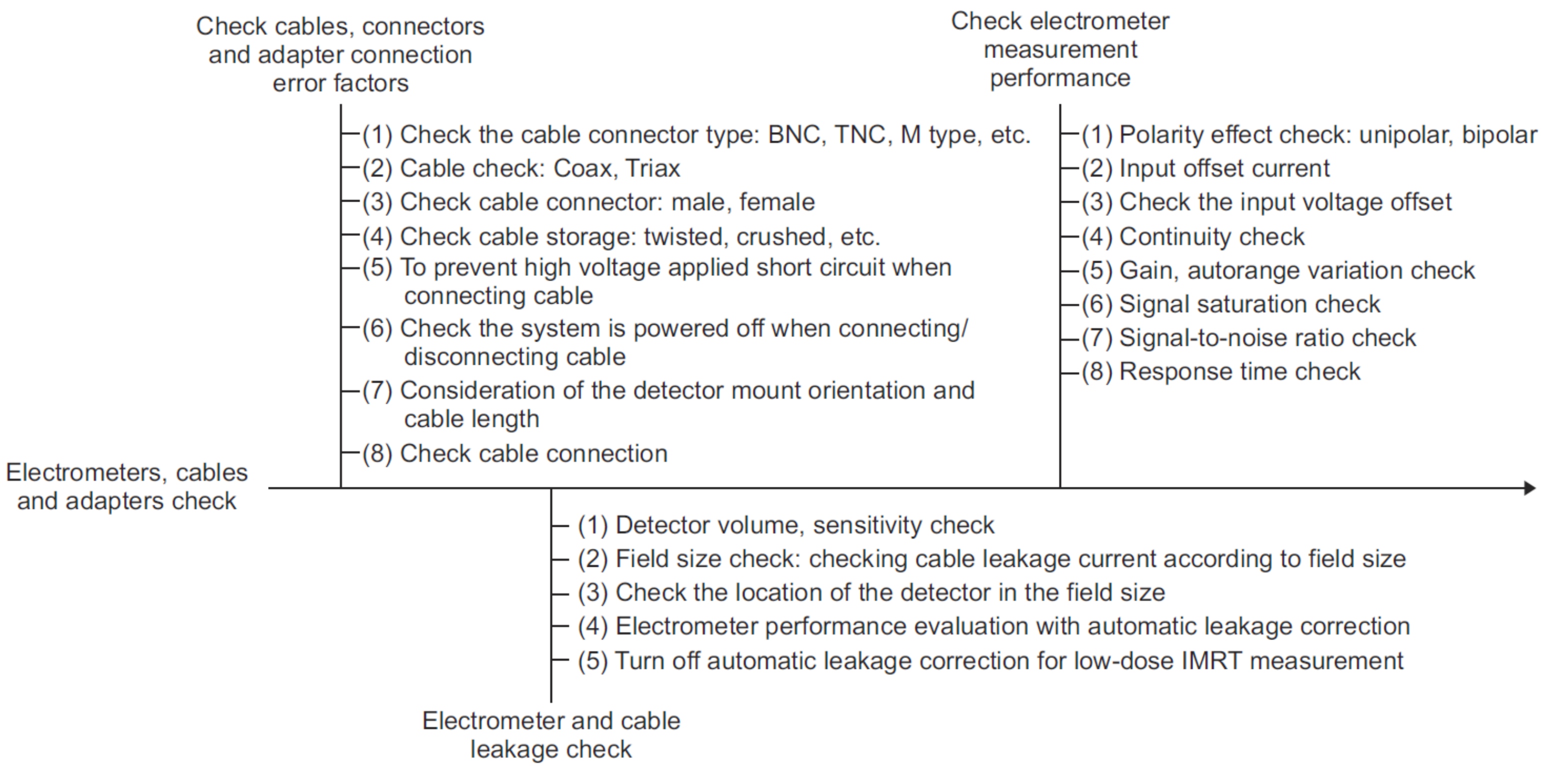


Fig. 2. The risk management items for electrometer, cable and connector check.

Progress in Medical Physics Vol. 29, No. 4, December 2018

DETECTORS AND EQUIPMENT

Learn

Learn the correct use and limitations of the detectors and equipment.

- Ex: using a large detector for small field measurements
- Ex: chamber with slightly longer cable affecting symmetry readings in large fields
- Ex: specific chamber offset requirements

Test

Test detectors or equipment prior to use

- Ex: limitation on field size for reference chamber
- Ex: electrometer reading extra-cameral signal during scanning
- Ex: electrometer settings and ranges
- Ex: cable functionality

Review

Review manufacturers' guidelines, publications, and release notes.

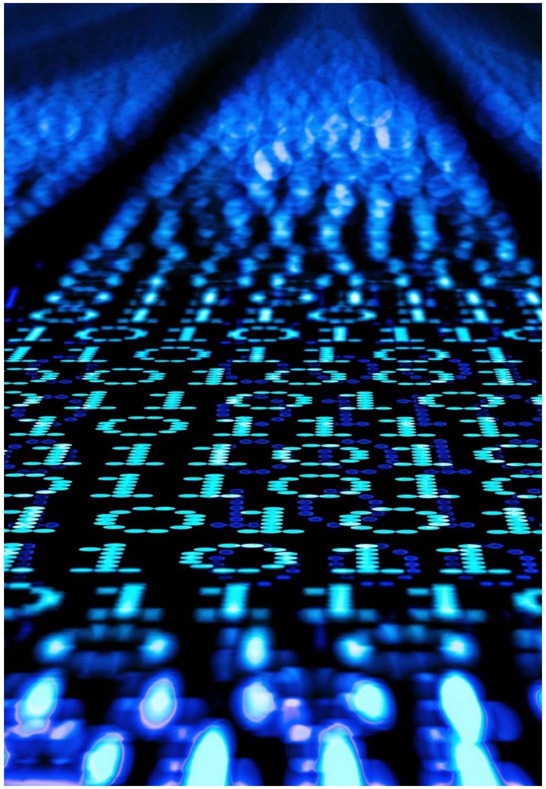
- Ex: error in applying background reading
- Ex: Electrometer position for scanning

Compare

Compare new and old detectors with a "trusted" detector

- Ex: older diodes (degradation may affect performance)
- Ex: older chambers (loose cables, bad connectors, materials)
- Ex: old cables (leakage)

DETECTORS AND EQUIPMENT SHOULD BE EVALUATED AND TESTED BEFORE USE



3. BEAM DATA: PDDS & PROFS

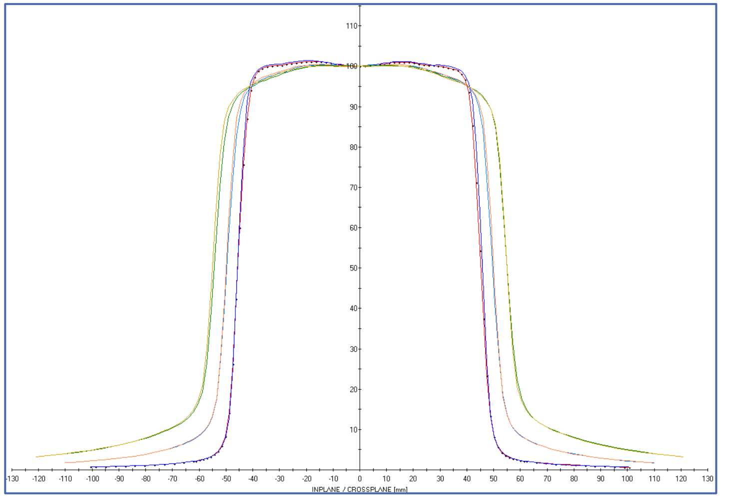
PDDS & PROFILES: APPLICATIONS

- Data for machine output calibration (PDD)
- Energy validation
- Beam matching evaluation
- Beam data configuration
- TPS data validation
- TPS modeling validation

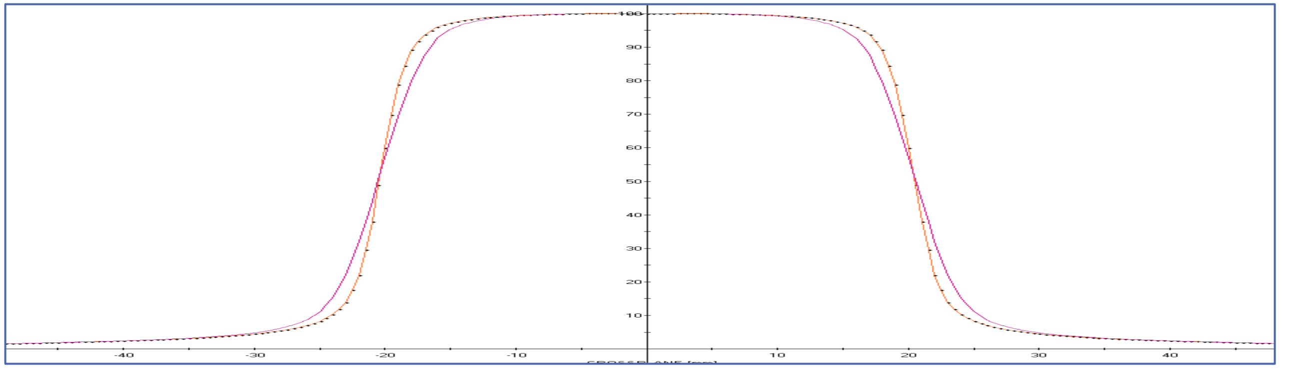
- Equipment:
  - 3D scanning systems (PDDs and Profiles)
  - 1D scanning systems (PDDs – some limitations)
  - 2D Array systems (Profiles – some limitations)

SCANNED DATA:

- CAX alignment should be consistent for all depths of measurements
- Consider the directional setup of the detector
- Scanning sequence settings will affect data measurements
- Reference detectors assist in minimizing noise in the signal

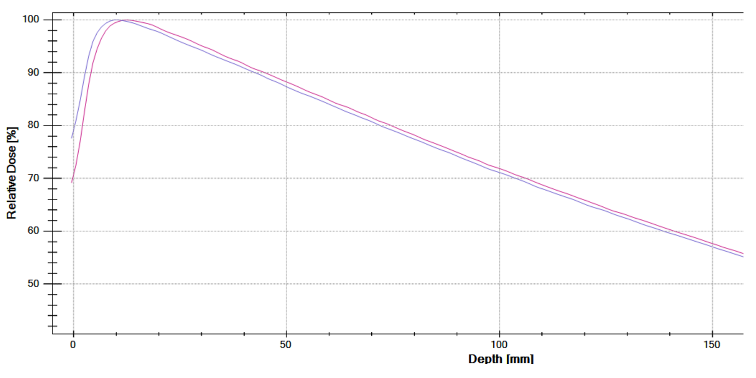


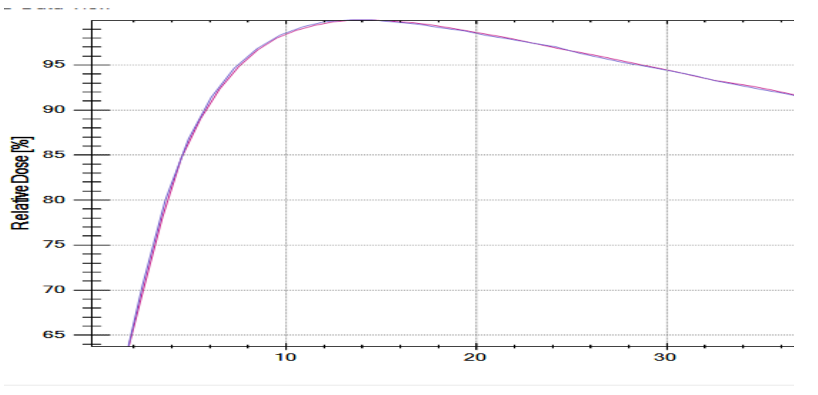
- Choose proper detector based on field size and beam data requirements



SCANNING WITH DIFFERENT DETECTORS

Field overlap with standard detector: check setup reproducibility and validate setup for detector shift.





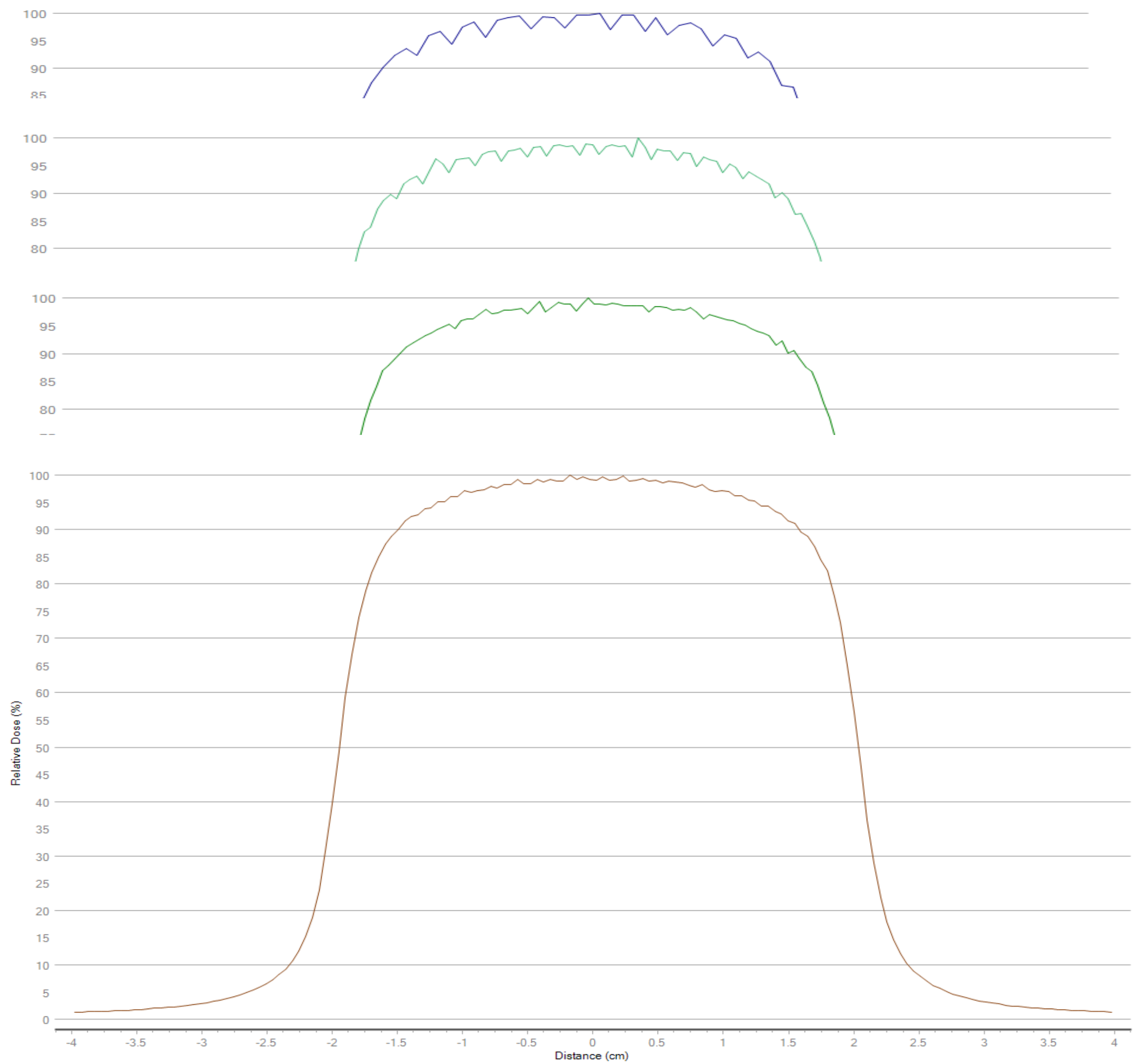
Some chambers may not comply to 0.6rcav shift with errors up to 1.6mm (within 0.5mm for standard chambers) [Med.Phys. 35(3), March 2008]

SCANNING AND NOISE

-

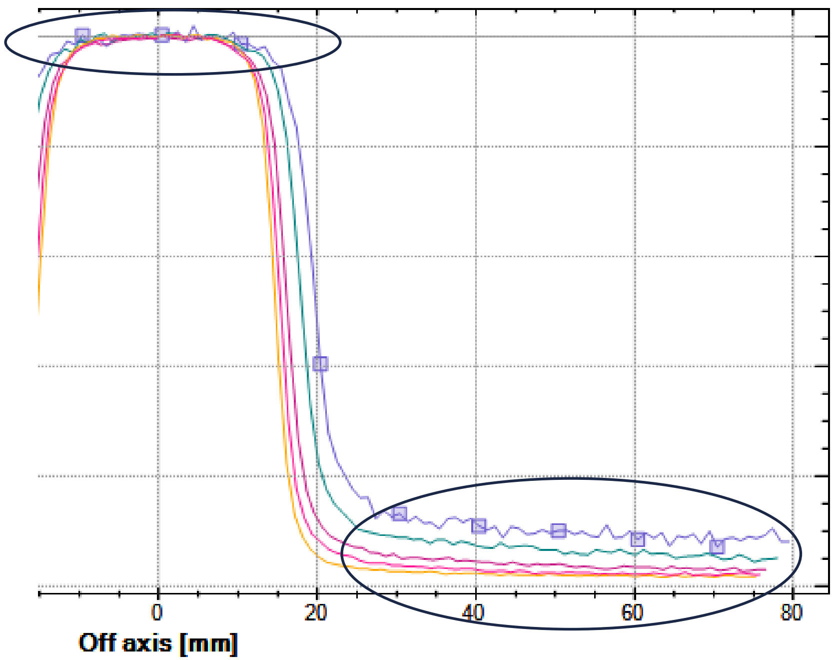
- Phantom:
  - Setup
  - Alignment
  - Functionality
- Scanning techniques:
  - Speed
  - Continuous or step-by-step
  - Measurement time
  - Direction of scanning
- Cable:
  - Positioning
  - Connections
- Detector:
  - Orientation
  - Alignment
  - Temperature
- Electrometer:
  - Positioning
  - Resolution
  - Voltage

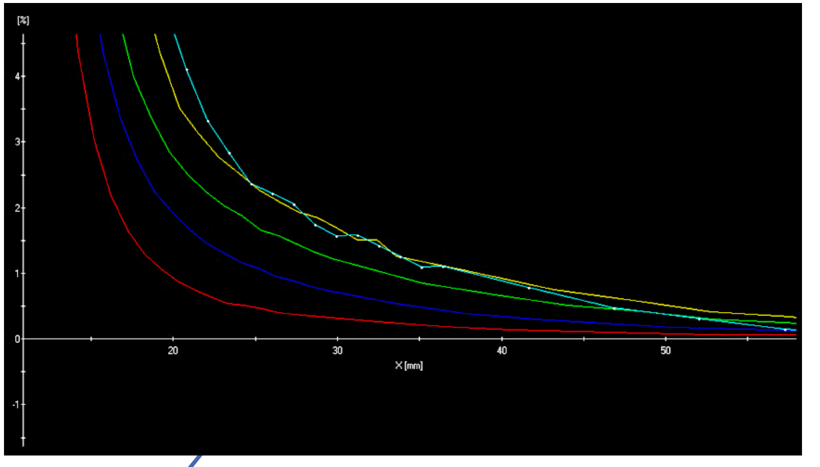
SCANNING TECHNIQUES AND NOISE

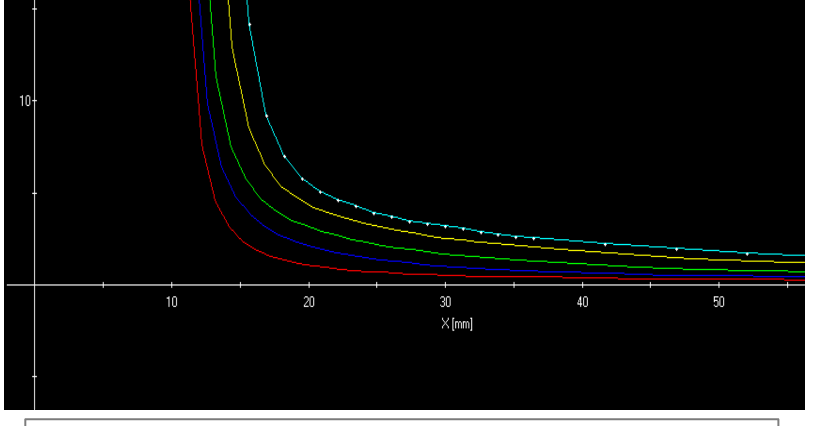


NOISE IN SCANS AND DATA PROCESSING

- Processing noisy scans will potentially alter the data
- Evaluate data before and after processing



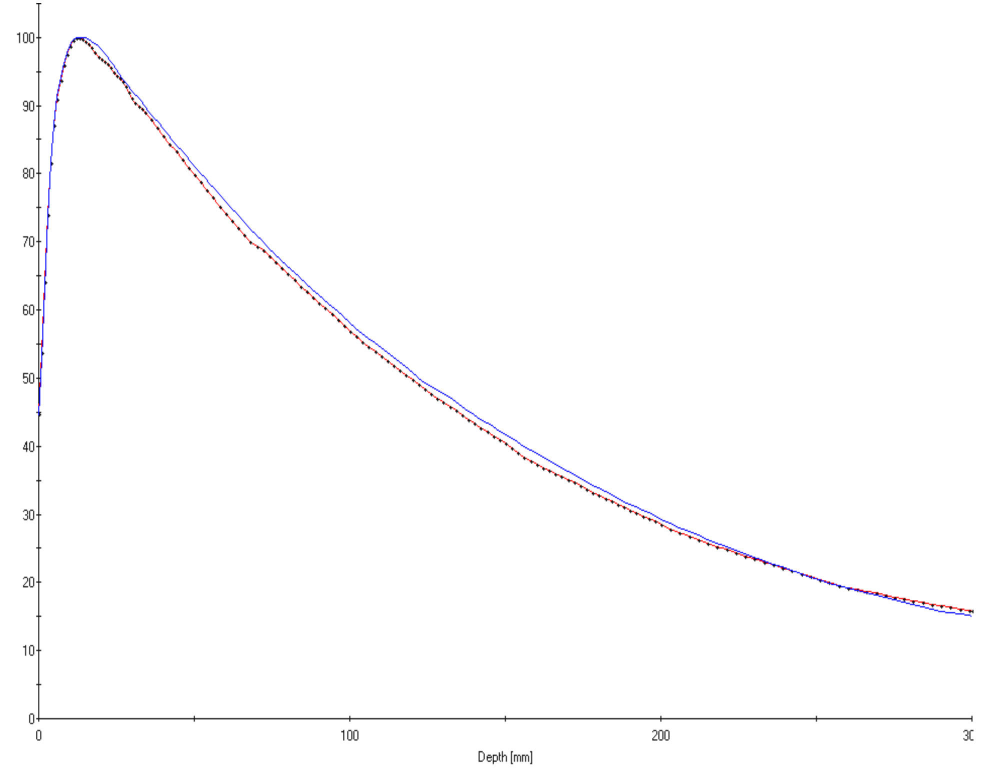




Processed profiles with and without noise

NOISE IN SCANS AND DATA PROCESSING

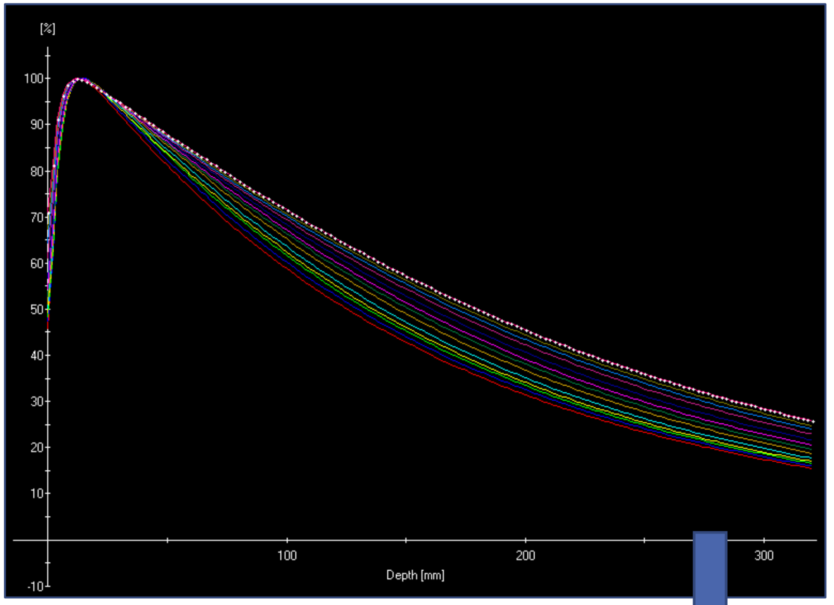
Noise in scans may yield incorrect data.
PDD data may result in incorrect energy values
Processing noisy scans may further distort the data
Good quality scans will improve the measurement accuracy

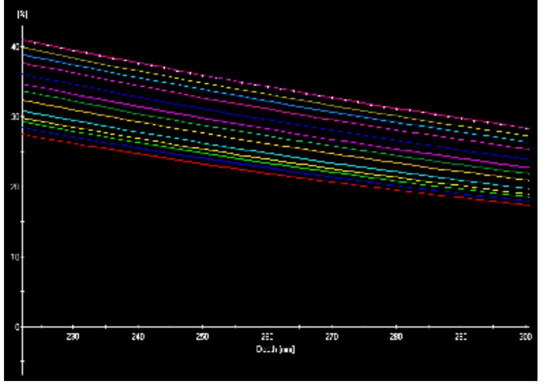


PDDS: VALIDATION

- Combine and evaluate PDDs for all field sizes for each energy

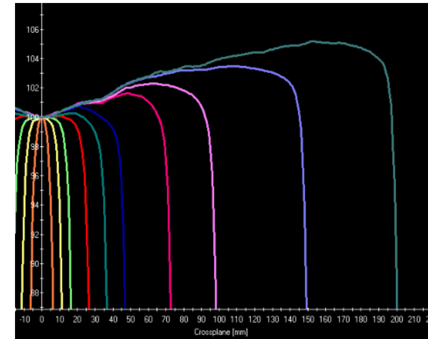
- Check PDDs do not cross at depth for all field sizes

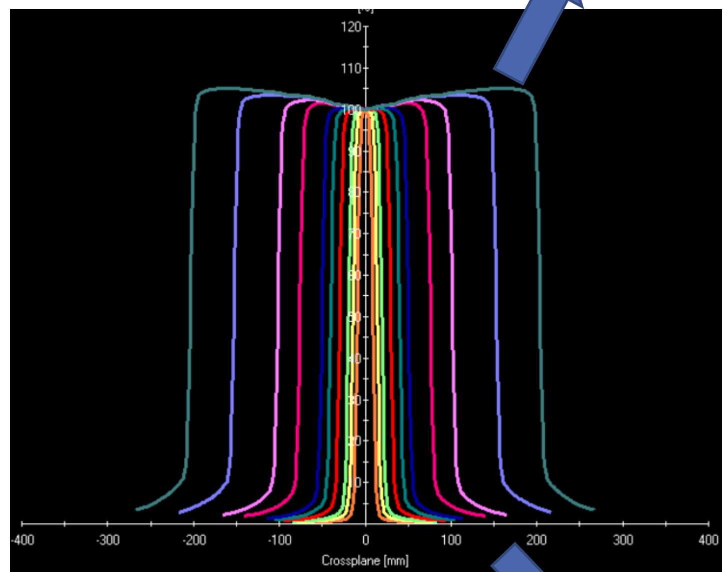


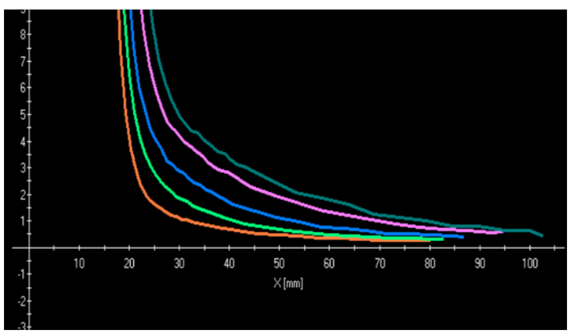


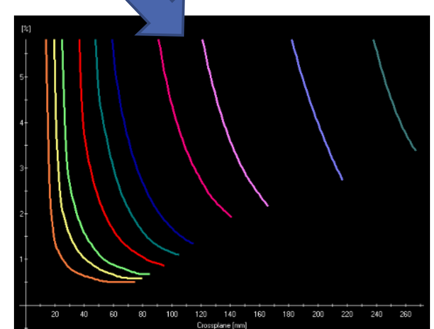
PROFILES: VALIDATION

- Profile shape for multiple field sizes at a depth
- Evaluate profiles at different depths for each field size: out-of-field region









PROFILES: ARRAYS

2D arrays can be used to measure profiles

Flatness and symmetry checks

Constancy checks

Some limitations exist:

Resolution

Effects of electronic components

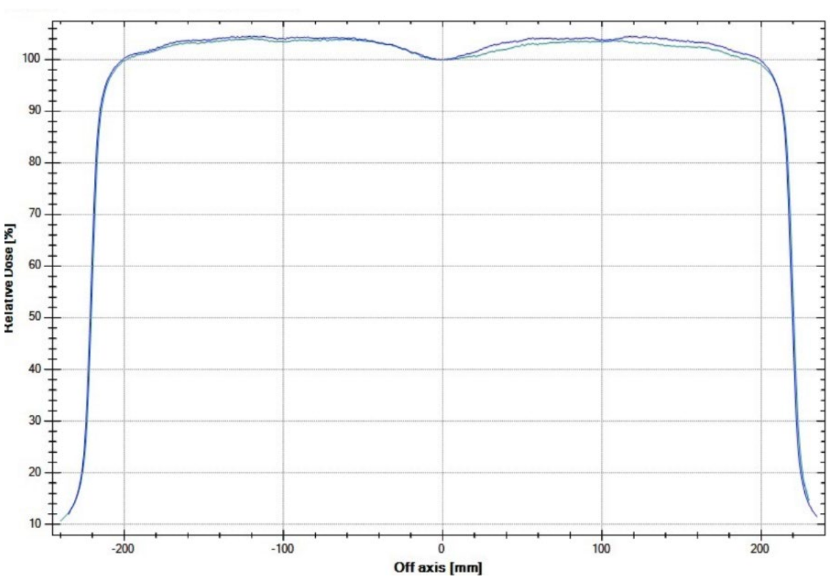
Buildup material used

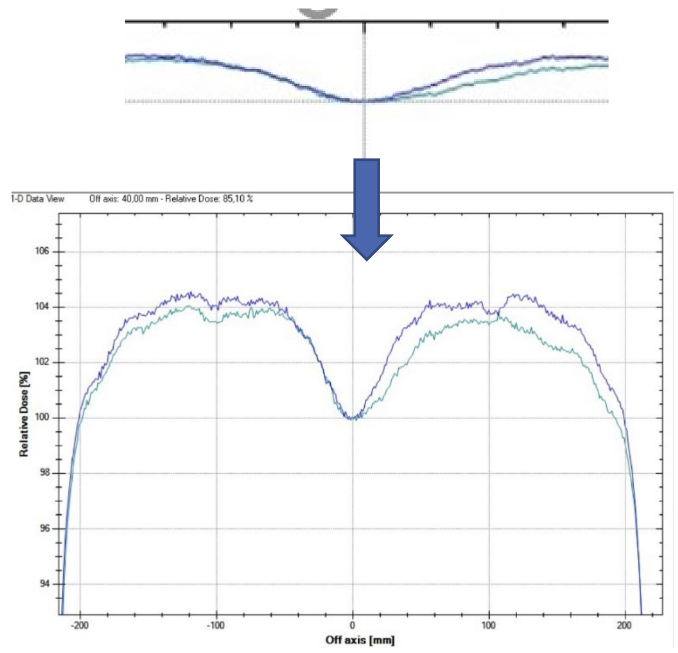
Small field profiles

Detector type

PROFILES MEASUREMENTS

- Beam shape can provide valuable information (beyond numerical parameters) and higher measurement resolution may be necessary

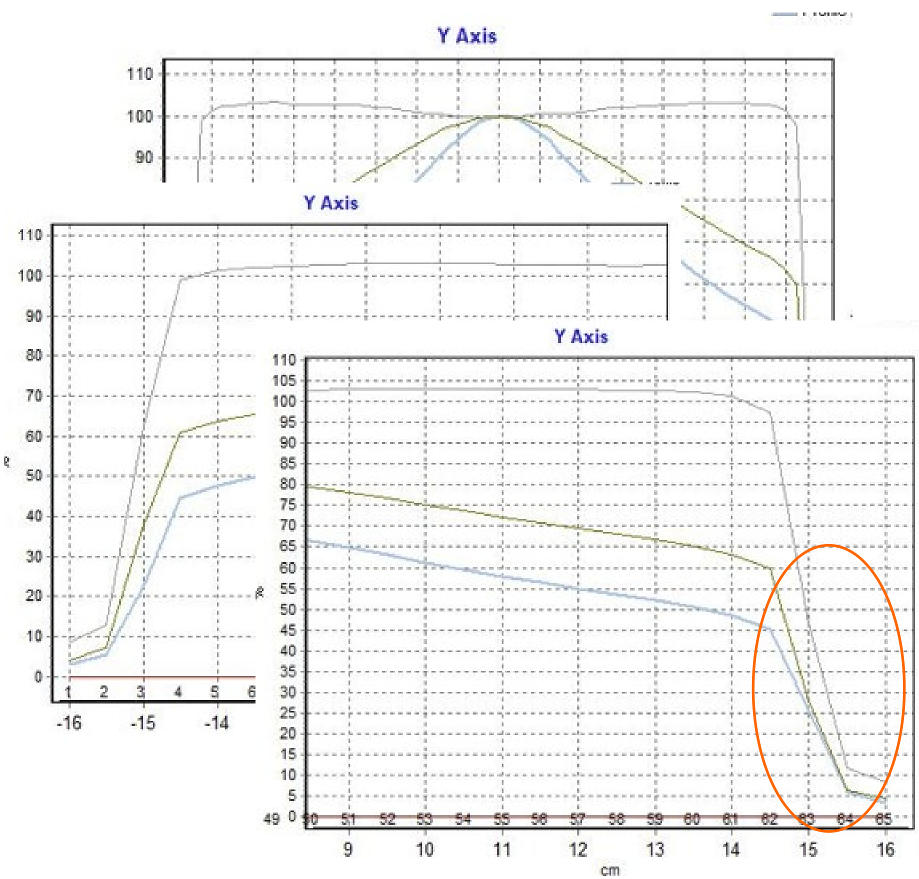


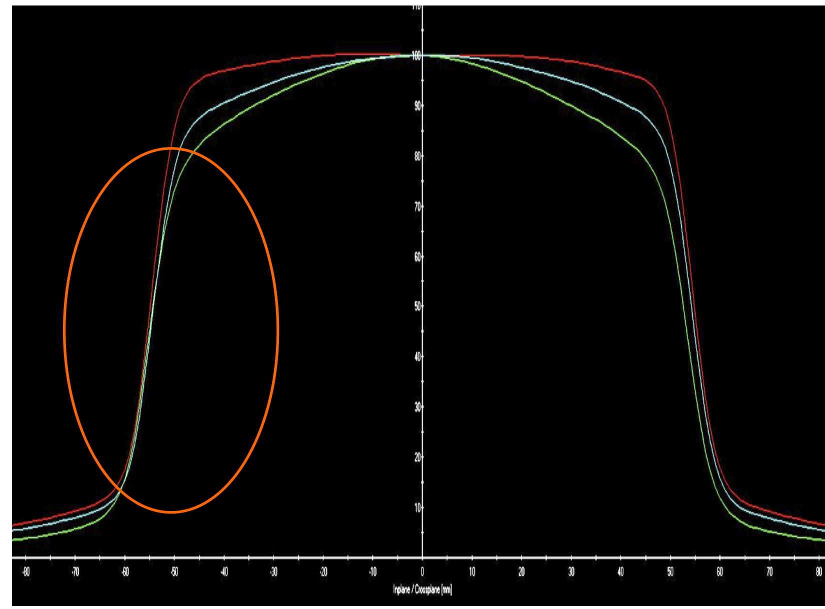


Symmetry changes: 1.6%/1.4% to 0.6%/0.6% after flattening filter replacement

PROFILES: SCANNER VS ARRAYS

- Beam center misalignment





4. SMALL FIELD DATA

SMALL FIELD DATA MEASUREMENTS:

- Potential for a large magnitude effect in the detector misuse or using an inappropriate detector.
- The need for quality data measurement increases as the field size decreases
- The choice of a proper detector is crucial for small field quality data

Selection
Selection of the appropriate detector for measurement goals

Positioning
Positioning accuracy of the detector (setup and effective point of measurement)

Alignment
Correct alignment of the detector (CAX and vertical alignment)

Procedures
Measurement procedures: equipment settings, scanning sequences, background, noise, etc.

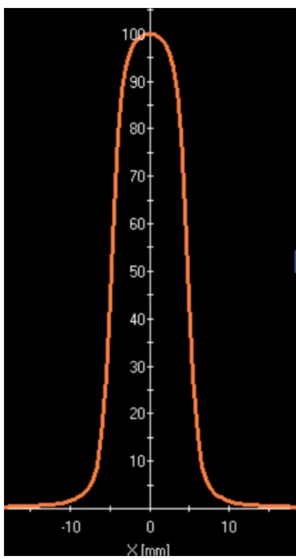
Multiple
Use of multiple detectors to measure data (validate and overlap data for certain field sizes)

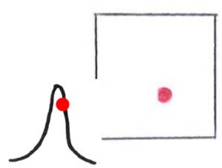
Corrections
Correction factors for dosimetric data (volume and perturbation effect, and assist in detector selection)

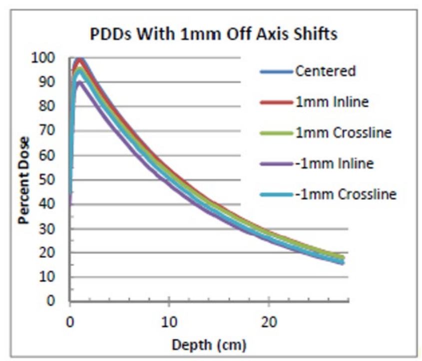
POSITIONAL ACCURACY

Position of detector off central axis can lead to errors due to the beam shape

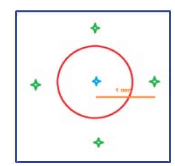
Ex: Errors in positioning can result in smaller OFs and incorrect PDDS and profiles







PDDs measured at central axis and off axis



Measurement of Output and PDD for SRS Cones with Semiconductor and Microdiamond Detectors

E. Lief[1], G. Dawson[1], J. Restrepo[1], G. Beyer[2], P. Jeffe[1], A. Cheuk[1]

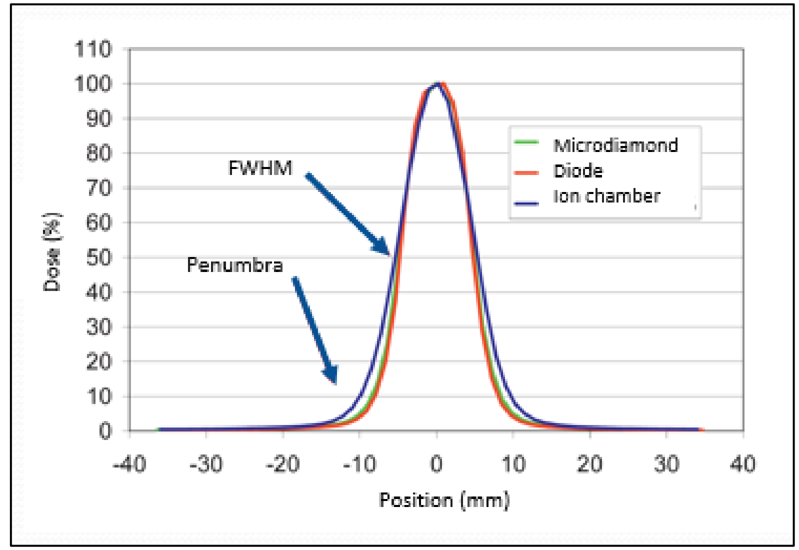
1.J.J. Peters VA Medical Center, Bronx, NY
2.Medical Physics Services, LLC, Miami, FL

DETECTOR CHOICE

Received: 2 April 2021 | Revised: 6 May 2021 | Accepted: 2 June 2021
DOI: 10.1002/mp.15030

AAPM SCIENTIFIC REPORT
MEDICAL PHYSICS

Report of AAPM Task Group 155: Megavoltage photon beam dosimetry in small fields and non-equilibrium conditions



Detector choice considerations:

- Detector with known correction factor preferably close to one

Field sizes ≤1cmx1cm

Electron diode
Unshielded SRS diode
Plastic scintillator
Microdiamond

Field sizes >1cmx1cm

Very small ion chambers

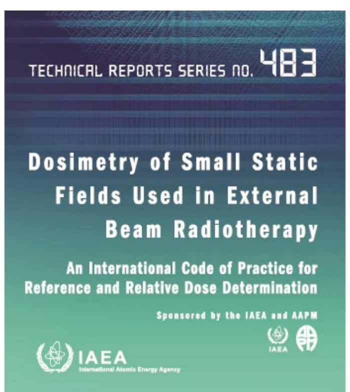
SMALL FIELD CORRECTION FACTORS

- Volume averaging effect
- Density difference between detector material and water

$$k_{Q_{\text{clin}},Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}} = [k_{\text{vol}}]_{Q_{\text{clin}},\ Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}} \cdot [k_{\text{d}}]_{Q_{\text{clin}},\ Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}}$$

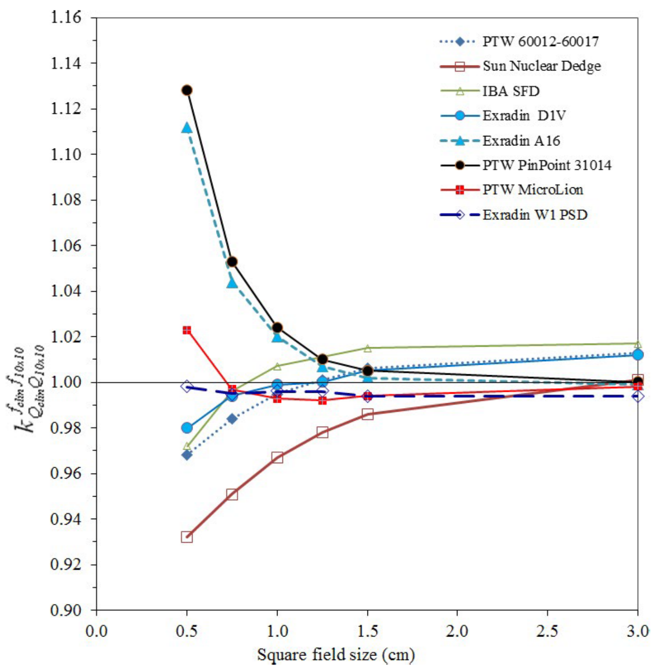
K_d: density perturbation
K_{vol}: volume effect

$$\Omega_{Q_{\text{clin}},Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}} = \frac{M_{Q_{\text{clin}}}^{f_{\text{clin}}}}{M_{Q_{\text{msr}}}^{f_{\text{msr}}}} k_{Q_{\text{clin}},Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}}$$



TRS-483:
- Correction factor tables
  - Linac type
  - Detector type
  - Field size
  - Energy

- For small fields:
  - Ion-chambers under-respond
  - Diodes over-respond



Das et. al, Medical Physics, 2021; 48 (10): e886-e921

TRS-483: CORRECTION FACTORS TABLES

Detector	Equivalent square field size, S_{clin} (cm)												
	8.0	6.0	4.0	3.0	2.5	2.0	1.5	1.2	1.0	0.8	0.6	0.5	0.4
Real time solid state dosimeters													
IBA PFD3G shielded diode	1.000	1.000	0.998	0.995	0.992	0.986	0.976	0.968	0.961	0.952	—	—	—
IBA EFD3G unshielded diode	1.005	1.009	1.014	1.016	1.016	1.015	1.012	1.008	1.004	0.998	0.988	0.983	0.976
IBA SFD unshielded diode (stereotactic)	1.008	1.017	1.025	1.029	1.031	1.032	1.030	1.025	1.018	1.007	0.990	0.978	0.963
PTW 60008 shielded diode	1.000	1.000	1.000	0.998	0.995	0.990	0.977	0.962	—	—	—	—	—
PTW 60012 unshielded diode	1.005	1.010	1.015	1.017	1.017	1.016	1.010	1.003	0.996	0.985	0.970	0.960	—
PTW 60016 shielded diode	1.000	1.000	0.999	0.995	0.991	0.984	0.970	0.956	—	—	—	—	—
PTW 60017 unshielded diode	1.004	1.007	1.010	1.011	1.011	1.008	1.002	0.994	0.986	0.976	0.961	0.952	—
PTW 60018 unshielded diode (stereotactic)	1.004	1.007	1.010	1.011	1.009	1.006	0.998	0.990	0.983	0.973	0.960	0.952	—
PTW 60003 natural diamond	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.003	1.009	1.026	1.045	—
PTW 60019 CVD diamond	1.000	1.000	1.000	1.000	0.999	0.997	0.993	0.989	0.984	0.977	0.968	0.962	0.955
Sun Nuclear EDGE Detector	1.000	1.000	1.000	0.999	0.998	0.994	0.986	0.976	0.966	0.951	—	—	—
Standard Imaging W1 plastic scintillator	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

APPLICATION OF SMALL FIELD CORRECTION FACTORS

Considerations for application of correction factors:

- Energy
- Machine model
- Measurement setup
- Detector orientation
- Reference field normalization
- Field size definition TRS-483:

  Rectangular

  - $S_{clin} = \sqrt{(AB)}$

  Circular

  - $S_{clin} = 1.77\ r$

TRS 483

Read table caption carefully

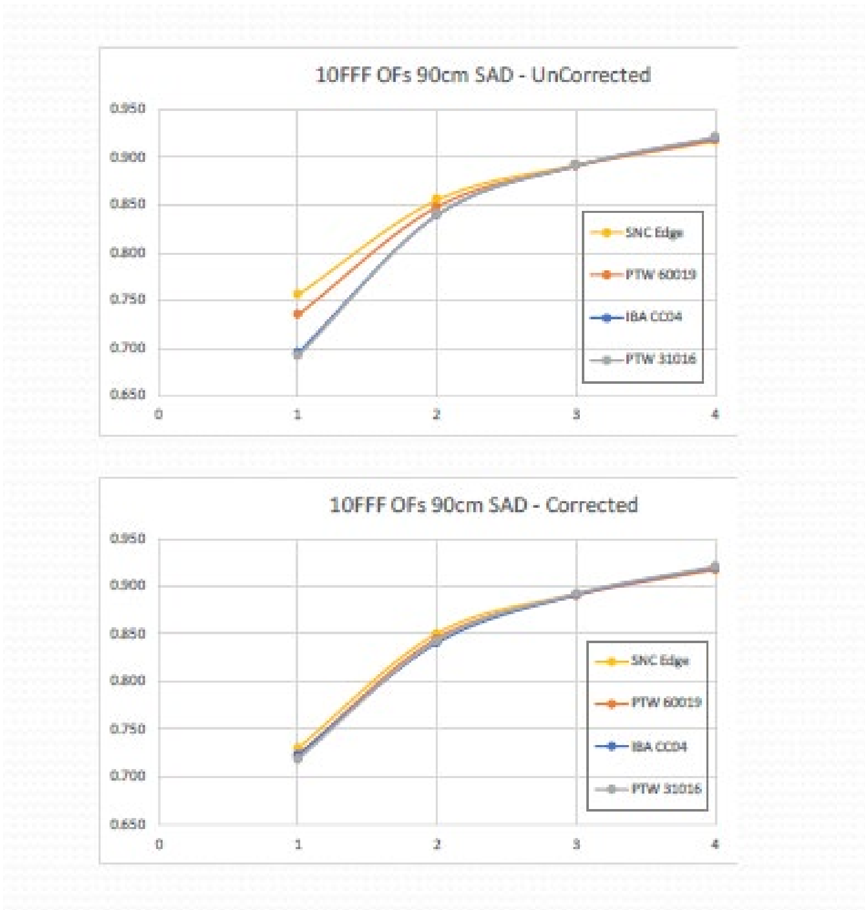
Published data

Evaluate reference field size and measurement conditions

Beyer, G.P.: Small Field Detectors and Measurement Uncertainty.

2024 Spring Clinical Meeting Session: Detector Selection for External Beam Radiation Therapy Quality Assurance,

SMALL FIELD OUTPUT FACTORS

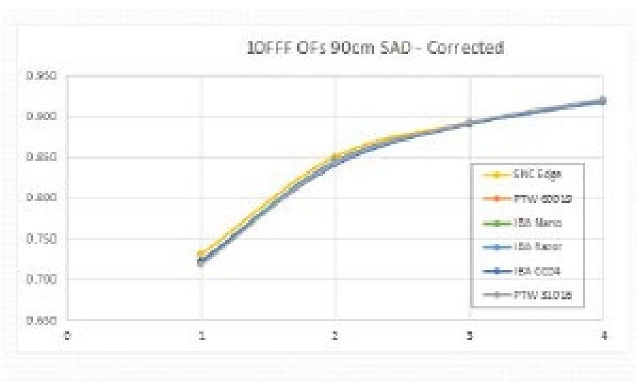


Challenges and opportunities within practical small field dosimetry
G.P, Beyer, 9th May 2019 Queen Elizabeth Hospital, Birmingham, UK

Correction Factors and New Detectors

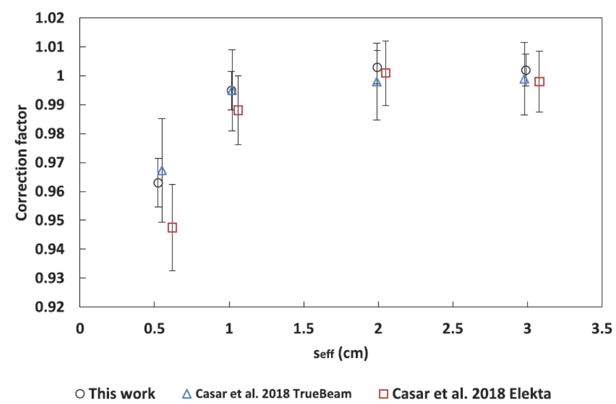
- Data provided by manufacturer
- Published data
- Experimental determination

Use of corrected output factors for one detector included in TRS-483



Beyer G.P. et al, PO-1332, Estro 2020

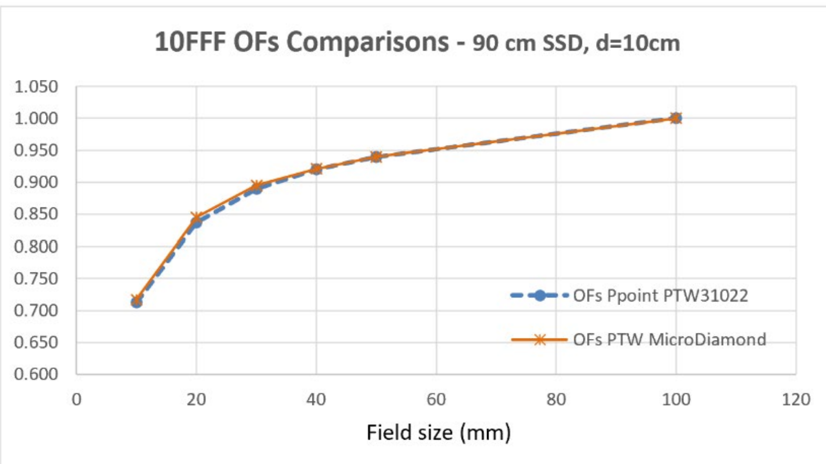
Use of corrected output factors for five detectors included in TRS-483



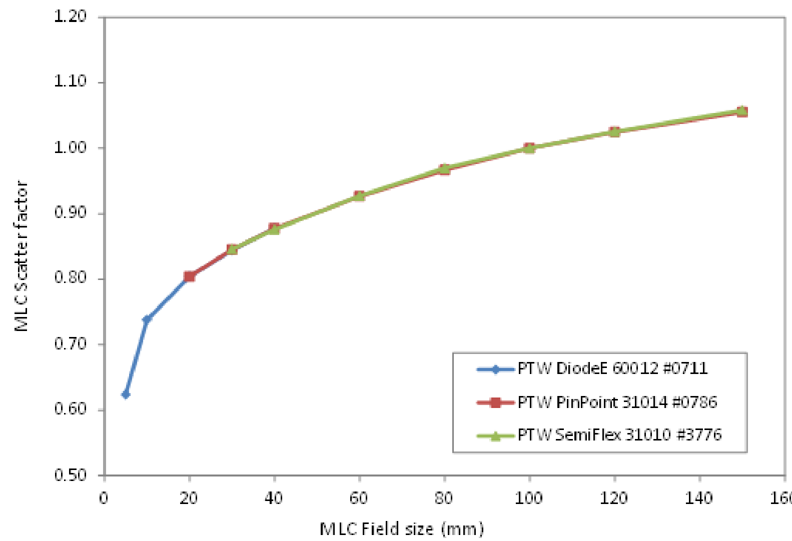
McGrath et. al. J App Clin Med Phys. 2022

OUTPUT FACTORS : VALIDATION

Overlap OFs measured with detectors with IAEA and vendor compiled factors



Overlap OFs measured with different detectors for all field sizes measured



THANK YOU!

- Q&A at the end of the session
- Contact:
  - gpbeyer@MedicalPhysicsServices.com