Use of Small Field Correction Factors, Rapid Arc QA and FFF linac fields

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Outline

- Small Field Dosimetry
- IAEA TRS 483 Protocol
- Output Factors
- Small field correction factors
- Applications
- RapidArc QA
- Summary

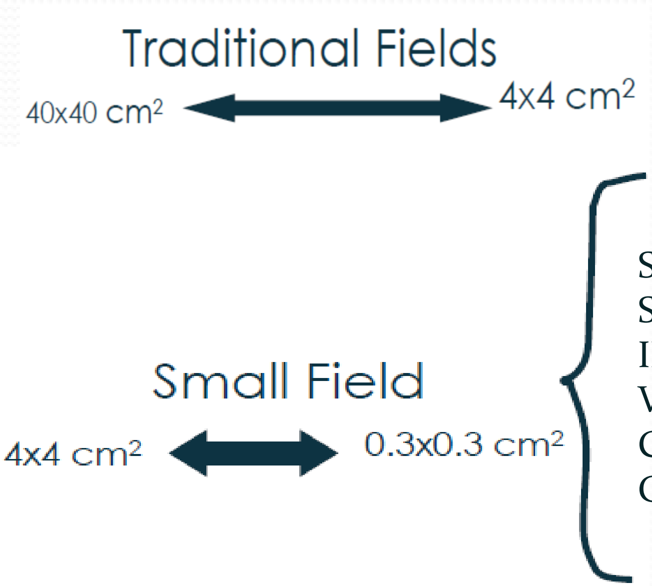
Small Field Dosimetry

Considerations

Under which conditions we consider a field “small”?

1- Field is smaller than approximately 4 x 4 cm^2

- detector size is comparable to field size



SRS/SRT
SABR
IMRT
VMAT
Cyberknife
GammaKnife

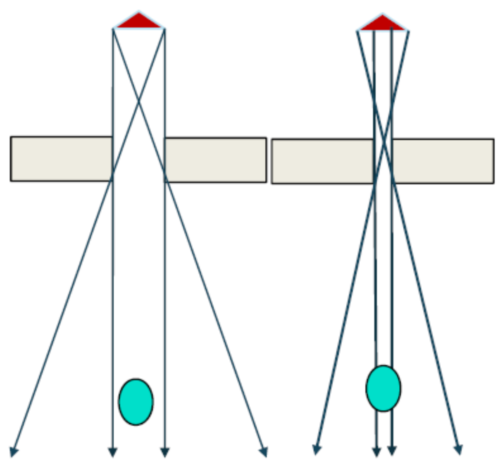
Small Field Dosimetry

Considerations

Under which conditions we consider a field “small”?

2-Focus is partially hidden by the collimators

- Partial geometrical shielding of primary photon source as seen from the point of measurement



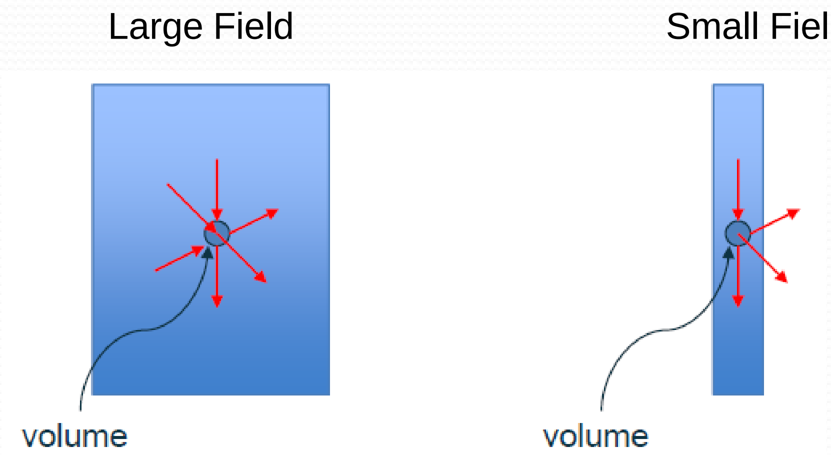
Small Field Dosimetry

Considerations

Under which conditions we consider a field “small”?

3-Lateral electron equilibrium is not given in the field

- Field with size smaller than range of charged particles
- Dependent on range of secondary electrons and energy



Small Field Dosimetry

Detectors for small field dosimetry

- Spectra and beam quality changes as field size decreases
- No ideal detector exists
- The response from different detectors will vary significantly for small fields
- Detectors perturb particle fluence in photon beams

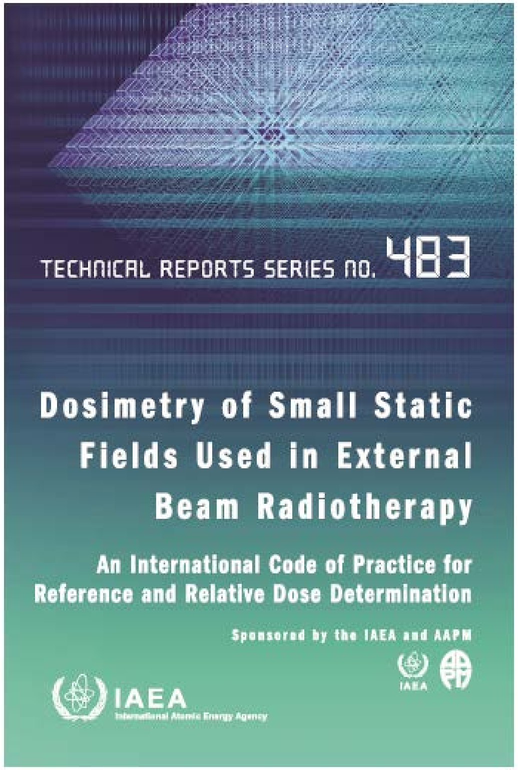
  -> correction factors

Small Field Dosimetry

Considerations

- Clinical medical physicists are responsible for verifying that the dose prescription is delivered accurately to a patient
- Quality Assurance “QA” protocols for small field treatment deliveries are more stringent due to the few treatment fractions and the need for high dose delivery accuracy
- Small field dose measurements can be challenging
- Recent protocol developed to standardize dose measurements for small fields

TRS 483: Dosimetry of Small Static Fields Used in External Beam Radiotherapy



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- Protocol for small field dosimetry:
  - Increase use of small photon fields has raised the need to standardize the dosimetry of small fields
  - Procedures for reference dosimetry in non-standard machine specific (f_{msr}) fields
  - Procedures for field output factors measurements
  - Correction factors as a function of field size for applying the measurement formalisms

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- Dosimetric characterization of small fields requires:
  - Calibration of beam (reference conditions)
  - Measurement of PDD, TPR or TMR
  - Measurement of lateral profiles
  - Determination of **field output factors** or **field size dependency** for small field dose measurements

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Energy Spectrum of Small Fields

- Beam hardening effect and increase in average photon energy:
  - Reduced scattered low energy photons from linac head
  - Amount of phantom scatter decreases with small fields

Results:

- Change in ratio of mass energy absorption coefficients between water and material
- Change of water to air stopping power ratio

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Energy Spectrum of Small Fields

- MonteCarlo simulations -> charged particle spectrum produced in water is less affected from photon fluence spectrum changes
  - Influence of field size on water to air stopping power ratio decreases by no more than 0.5% for 6MV (10 cm) from 0.3x0.3 to 10x10 cm^2
  - For depths up to 30cm variation is <1%

- Changes in spectrum will affect response of certain detectors

  (silicon diodes)

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Beam Quality Specification

- Small variation of water to air stopping-power ratios with field size (photon beams of nominal energies ≤10 MV)
- For ionization chambers the beam quality index of broad field (10x10 cm^2) would be sufficient for all field sizes
- Variation of stopping-power ratios and perturbation factors with field size can then be incorporated into a field dependent output correction factor
- Machines that cannot achieve conventional 10x10 field the protocol introduces the msr field, f_{msr}

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Dose Measurement

- Dose to water for a clinical field with a known reference dose

$$D_{w,Q_{clin}}^{f_{clin}} = D_{w,Q_{msr}}^{f_{msr}} \Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}},$$

$\Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}}$ → Ratio of dose delivered to water in clinical field to dose delivered in reference field (output factor)

Output Factors

Standard fields

$$\Omega_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}} = \frac{D_{\mathrm{w},Q_{\mathrm{clin}}}^{f_{\mathrm{clin}}}}{D_{\mathrm{w},Q_{\mathrm{msr}}}^{f_{\mathrm{msr}}}}$$

Conventional fields → Independence of dosimetric quantities on field size → Ratio of detector readings

Output Factors

Small Fields

- Output factor requires a **correction factor** applied to the detector reading ratio
  - Field size, energy, and detector dependent => $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

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

Correction Factors

Output correction factors

$$k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}} = \frac{D_{\mathrm{w},Q_{\mathrm{clin}}}^{f_{\mathrm{clin}}} / D_{\mathrm{det},Q_{\mathrm{clin}}}^{f_{\mathrm{clin}}}}{D_{\mathrm{w},Q_{\mathrm{msr}}}^{f_{\mathrm{msr}}} / D_{\mathrm{det},Q_{\mathrm{msr}}}^{f_{\mathrm{msr}}}}$$

- Correction factor
  - Directly measured value
  - Experimental generic value
  - Monte Carlo calculated value

Correction Factors

Small field detector correction factors

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

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

K_d: differences between detector materials and water

K_{vol}: differences between point and volume-averaged doses

Output Factors

Energy response changes in detectors

- Intermediate field method or “daisy-chaining” for output factors measured with detectors exhibiting an energy dependent response:
  - Readings obtained with small detectors are renormalized to an intermediate field

$$Factor = \frac{M_{small\ detector}(SF)}{M_{small\ detector}(IF)} \times \frac{M_{Chamber}(IF)}{M_{Chamber}(Ref)}$$

SF: small field size or Cone ;
IF: Intermediate field size (4x4 cm^2)
Ref: Reference field size (10x10 cm^2)

Output Factors

- Small Field Output factor with intermediate field method:

$$\Omega^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} = \left[\Omega^{f_{clin},f_{int}}_{Q_{clin},Q_{int}}\right]_{det}\left[\Omega^{f_{int},f_{msr}}_{Q_{int},Q_{msr}}\right]_{IC}$$

$$\Omega^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} = \left[\frac{M^{f_{clin}}_{Q_{clin}}}{M^{f_{int}}_{Q_{int}}} k^{f_{clin},f_{int}}_{Q_{clin},Q_{int}}\right]_{det}\left[\frac{M^{f_{int}}_{Q_{int}}}{M^{f_{msr}}_{Q_{msr}}} k^{f_{int},f_{msr}}_{Q_{int},Q_{msr}}\right]_{IC}$$

$$\left[k^{f_{int},f_{msr}}_{Q_{int},Q_{msr}}\right]_{IC} \approx 1$$

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Corrections Factors $k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}$

- TRS483 tables 26 and 27 for linacs
- 6 MV and 10 MV WFF and FFF linacs
- MLC and SRS cones
- Equivalent square msr field of 10 cm
- Valid at 10 cm of water
- Include volume averaging effect

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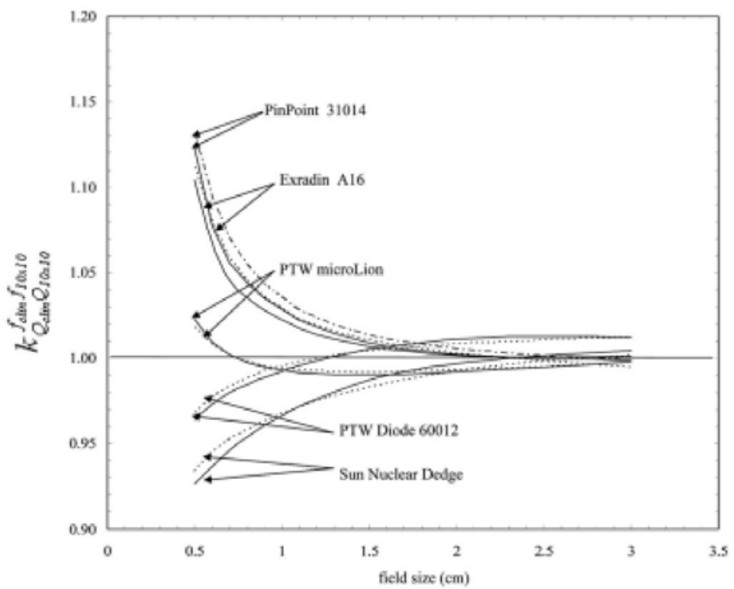
Corrections Factors $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

- If using intermediate field

$$\left[k_{Q_{clin},Q_{int}}^{f_{clin},f_{int}}\right]_{det} = \frac{\left[k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}\right]_{det}}{\left[k_{Q_{int},Q_{msr}}^{f_{int},f_{msr}}\right]_{det}}$$

Correction Factors

- In small fields:
  - Diodes over-respond
  - Microchambers under-respond



Correction Factors – TRS 483

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TABLE 26. FIELD OUTPUT CORRECTION FACTORS $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ FOR FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 6 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE (cont.)

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

Correction Factors – TRS 483

TABLE 26. FIELD OUTPUT CORRECTION FACTORS $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ FOR FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 6 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE (cont.)

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
PTW 31018 liquid ion chamber	0.997	0.994	0.991	0.989	0.988	0.988	0.987	0.987	0.987	0.990	0.999	1.011	1.033
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

Note: The reference depth is 10 cm.

TABLE 27. FIELD OUTPUT CORRECTION FACTORS $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ FOR SMALL FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 10 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE (cont.)

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
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
PTW 31018 liquid ion chamber	0.998	0.996	0.994	0.994	0.993	0.993	0.992	0.992	0.993	0.995	1.005	1.017	1.039
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

Note: The reference depth is 10 cm.

Correction Factors

Considerations for use of correction factors tables

- Energy
- Machine model
- Field size
- Measurement setup
- Detector orientation

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Read table caption carefully

Correction Factors

Field size definition

- Detector response and perturbation depend on the irradiation of the field specified at 50% relative dose level (FWHM) at measurement depth
- FWHM should be used for selecting detector correction factors as a function of field size
- TRS-483 field size definition: irradiated field size or FWHM of the field
- Publications: nominal field size or irradiated field size

Correction Factors

Field size definition

- Area of the field at measurement distance
- *FWHM of lateral beam profile at depth sufficient to eliminate contaminating electrons*
- *Use of appropriate detector for beam profile measurements*
- Z_{ref} = 10 g/cm^2

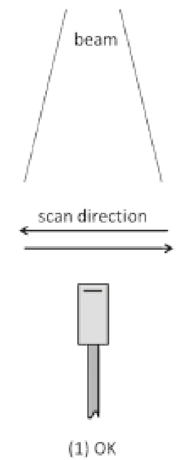
Equivalent Square field

- Rectangular
  - $S_{clin} = \sqrt{(AB)}$
- Circular
  - S_{clin} = 1.77 r

Correction Factors

Detector Position and Orientation

- Detector orientation influences:
  - shape of profiles
  - **output factors (correction factors)**
- Orientation:
  - smallest dimension of sensitive volume perpendicular to scanning direction
- Position:
  - Reference point at reference depth



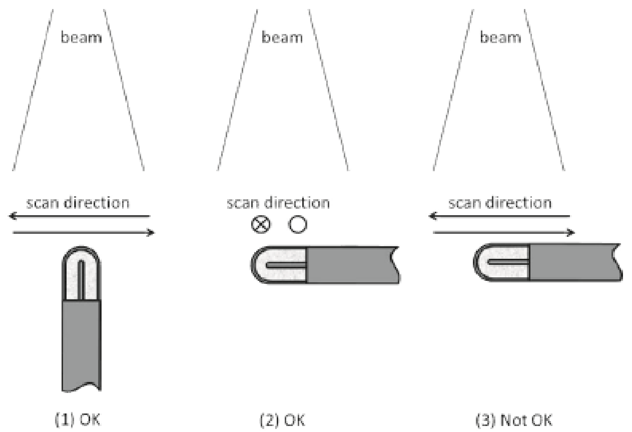


FIG. 18. Possible orientations of an ionization chamber for measurements of lateral beam profiles (arrows indicate scanning directions in the paper plane while circle and crossed circle symbols refer to scanning directions perpendicular to the paper plane).

Correction Factors

Detector Position and Orientation TRS 483

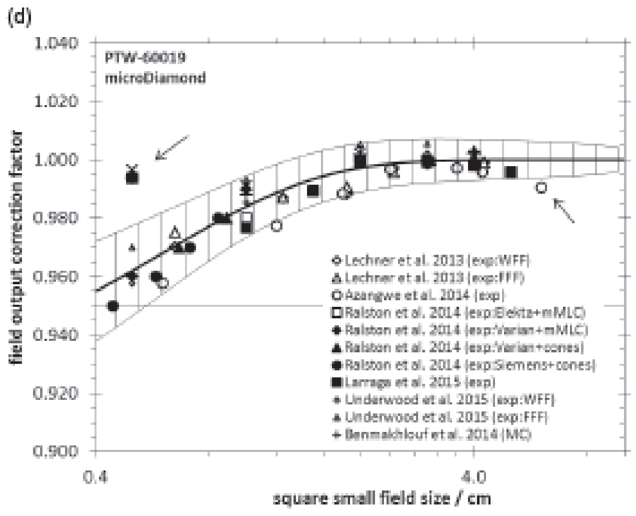
TABLE 22. DETECTOR ORIENTATION, WITH RESPECT TO THE BEAM CENTRAL AXIS, FOR RELATIVE DOSIMETRY IN SMALL PHOTON FIELDS

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

Correction Factors

Uncertainty TRS 483…

- Large amount of data available but:
  - Scattered for smallest field sizes
  - Majority for 6MV
  - Lack of homogeneity for SSD or SDD
  - Depth of measurement or calculation
  - Definition of field size differences
  - Lack of proper estimation of uncertainty in steps involved



Correction Factors

TRS 483 Uncertainty…

Appendix II

DETERMINATION OF FIELD OUTPUT CORRECTION FACTORS AND THEIR UNCERTAINTY ESTIMATES

Following the considerable amount of research in small megavoltage photon beam dosimetry during recent years, there is a large amount of experimental and Monte Carlo calculated data available for detector specific[15] output correction factors, $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$, particularly for certain solid state detectors and ionization chambers on the central axis of 6 MV beams. Unfortunately, the published data are rather scattered for certain field sizes, especially for the smallest fields, and lack homogeneity with regard to the SSD or SDD used, the depth of measurement or calculation, the definition of field size at the surface or at a reference depth, etc. To further complicate the determination of average values for the different detectors and their subsequent statistical analysis, most of the published data lack a proper estimation of the uncertainty in the various steps involved in the determination of the correction factors given by the different authors.

Correction Factors

- Correction factors limitations:
  - Detectors, measurement depth, or machine configurations not included in the tables for TRS483 require an experimental or MonteCarlo determination
  - Extrapolation from correction factor tables is not recommended (limit correction factors <5%)

Correction Factors

- Correction factors variations?
  - Correction factors vary by detector and could vary in changes of detector manufacturing
    - These factors may vary by linear accelerator manufacturer and the beam spot size or beam characteristics
    - Sensitivity to interunit variations
    - Variability with detector orientation

Correction Factors

- Advantages:
  - Standardize small field measurements: Goal of TRS483
  - Reduce variation of small field output factors
  - Increase accuracy of small field dose measurements
  - Guide in selection of appropriate detectors

    (correction factors should remain <5%)

Applications

- Evaluation of correction factors
- Correction factors for non-listed detectors
- Dose measurements at different depths
- Simple small treatment fields dose measurements
- Small field IMRT and RapidArc (VMAT) QA for standard linear accelerators

Reference detector

- Which are suitable (optimal) detectors for small field measurements?
  - For fields down to 1x1 cm^2 most all detectors in general ok
  - For very small fields:
    - Synthetic microdiamond
    - Scintillator detector

Smallest corrections for all measurement types: OFs, PDDs, OARs

Reference detector

- Microdiamond
  - Lower sensitivity ➔ longer exposure times
  - Larger sensitivity volume but perturbation factor remains smaller than diode
  - Scatter and volume averaging largely cancel each other
  - High reproducibility

A suitable candidate for small field dosimetry (easy to use)

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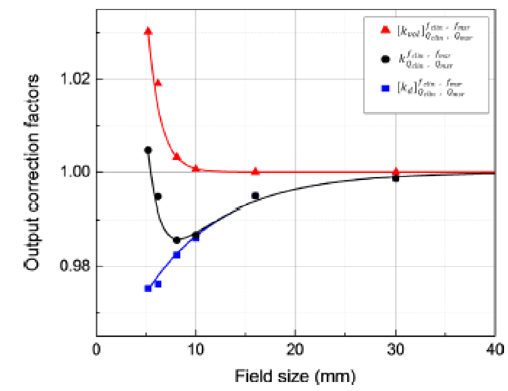


Figure 3. MC calculated MD correction factors as a function of the effective field size in the case of the VAR linac: $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ (black dots), volume averaging correction factors $[k_{vol}]_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ (red triangles) and $[k_{\rho}]_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ correction factors (blue squares).

Reference detector

- Non-homogeneity of results
- Agreement within 1.5% > 10 mm
- Differences may be due to:
  - Random MD fluctuations
  - Experimental setups
  - Measuring protocols
  - Modeling issues
  - Choice of reference detectors

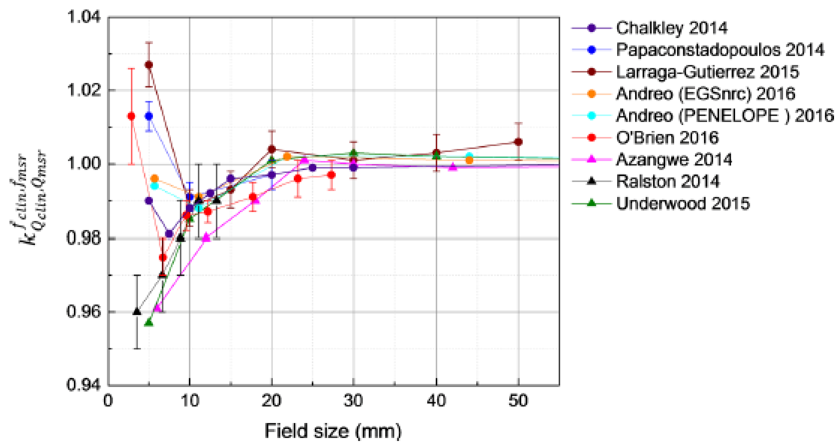
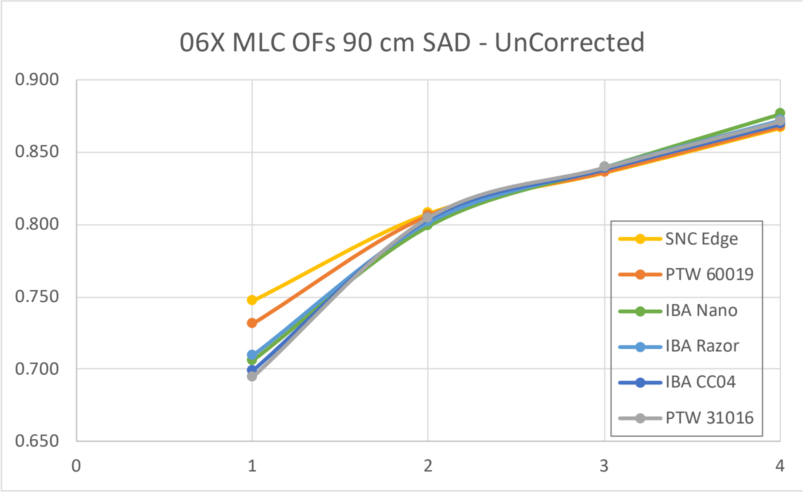
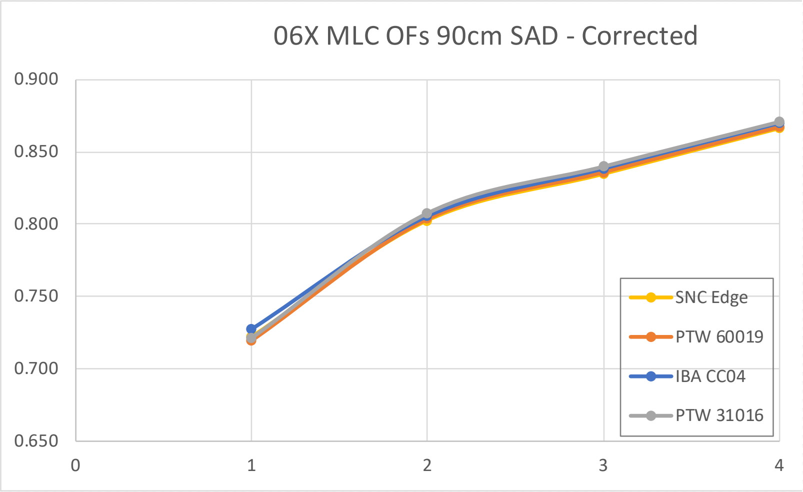


Figure 1. Summary of recently published data on MD output correction factors, in 6 MV small field photon beams.

Applications

- Evaluation of correction factors
- Correction factor for other detectors



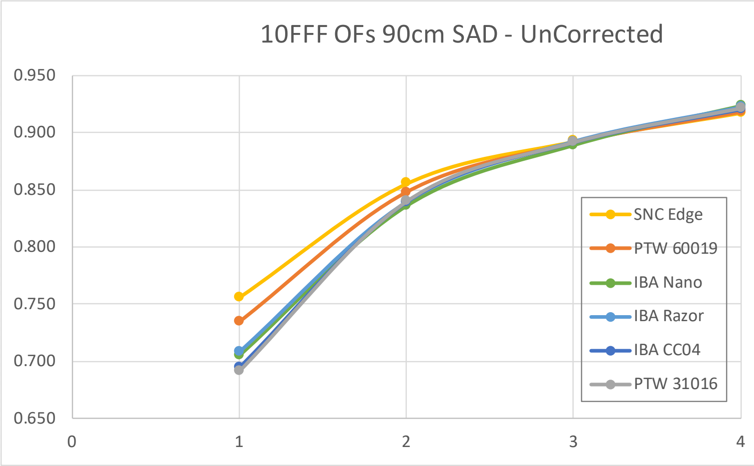


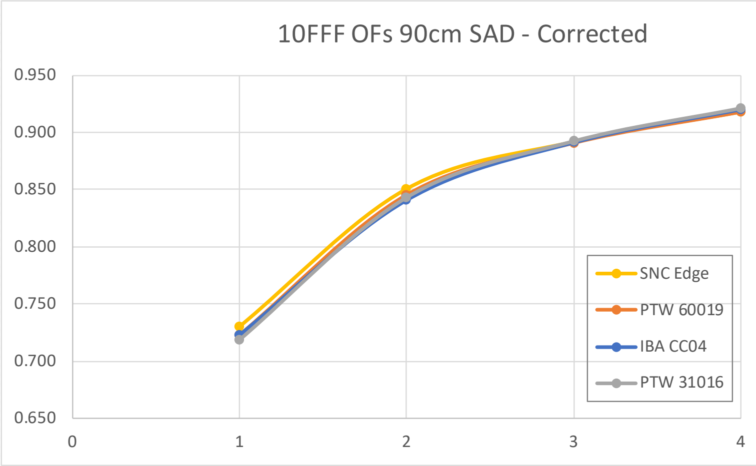
6X	IBA CC04	PTW 60019	PTW 31016	SNC Edge	IBA Razor	IBA Nano
4x4	0.869	0.867	0.871	0.866	0.871	0.876
3x3	0.838	0.836	0.839	0.835	0.839	0.839
2x2	0.804	0.806	0.804	0.807	0.801	0.799
1x1	0.699	0.732	0.694	0.747	0.709	0.706

6X	IBA CC04	PTW 60019	PTW 31016	SNC Edge
4x4	0.869	0.867	0.871	0.866
3x3	0.838	0.836	0.840	0.835
2x2	0.805	0.804	0.808	0.802
1x1	0.727	0.720	0.721	0.722

Applications

- Evaluation of correction factors
- Correction factor for other detectors





10FFF	IBA CC04	PTW 60019	PTW 31016	SNC Edge	IBA Razor	IBA Nano
4x4	0.921	0.918	0.922	0.918	0.922	0.924
3x3	0.891	0.891	0.892	0.893	0.892	0.889
2x2	0.839	0.848	0.840	0.856	0.839	0.836
1x1	0.694	0.734	0.691	0.756	0.709	0.705

10FFF	IBA CC04	PTW 60019	PTW 31016	SNC Edge
4x4	0.921	0.918	0.922	0.918
3x3	0.891	0.891	0.893	0.892
2x2	0.841	0.845	0.843	0.851
1x1	0.723	0.723	0.718	0.730

Applications

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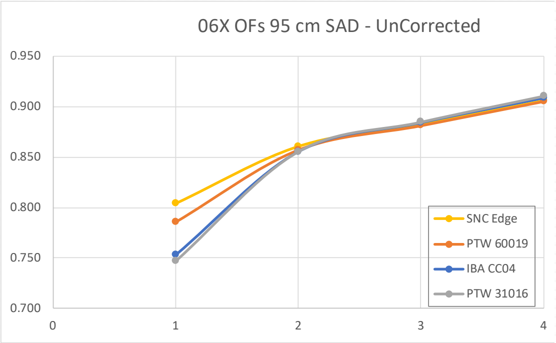
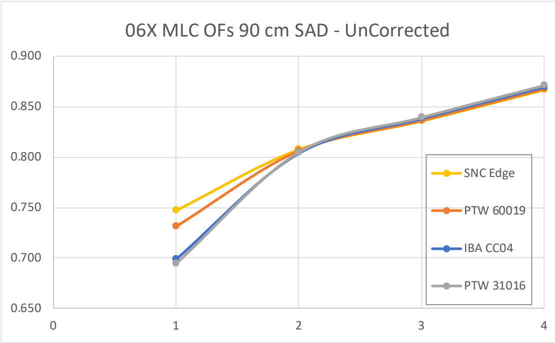
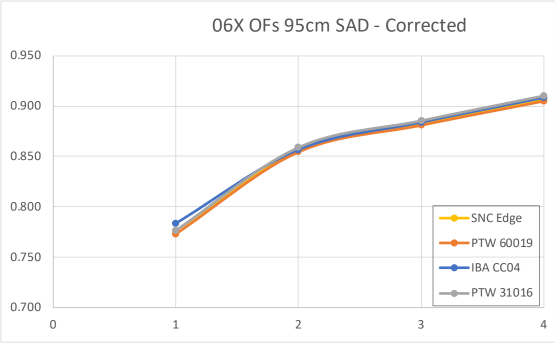
- Linac correction factors based on depth of 10 cm
- Appendix II:
  - Data assumed to apply to depth of 10 cm
  - Values obtained at d_{max} were not considered
  - Detectors not showing substantial field size above 3 cm, published data obtained at 5 cm assumed valid at 10 cm

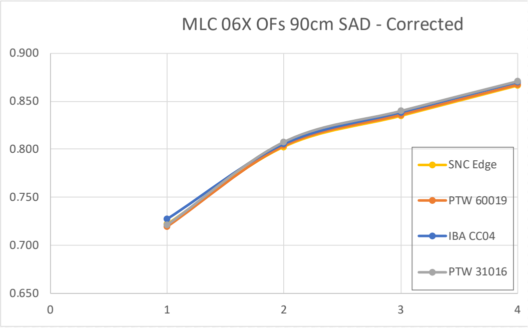
Applications

- Evaluation of correction factors
- Correction factor for different depths



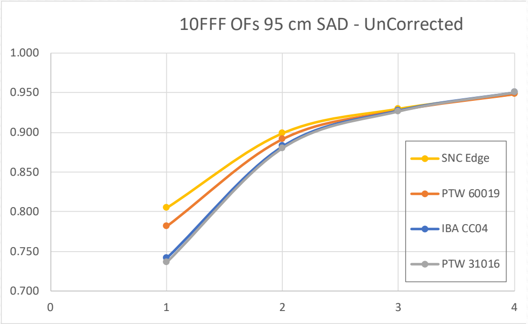


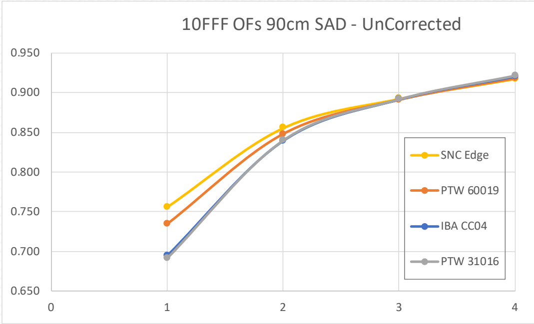


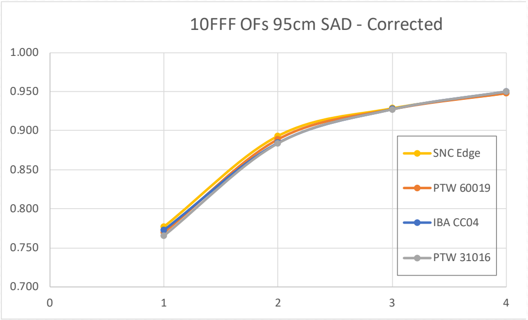


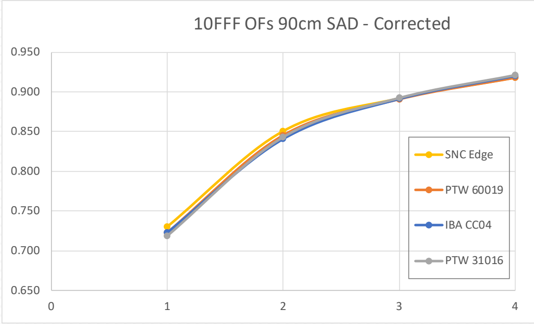
Applications

- Evaluation of correction factors
- Correction factor for different depths









Applications

TRS 483

- Simple small field dose measurements
- Evaluate accuracy of treatment plan dose calculation
- Correction factors for standard and FFF energies

Applications

- Simple small field dose measurements
- Small MLC fields at d=5 cm (two detectors)
- Standard and FFF energy

6X	Measured vs Predicted Dose		
MLC field	PTW31016	Eclipse Acuros	% Diff
3x3	0.833	0.829	**0.5%**
2x2	0.805	0.802	**0.4%**
1x1	0.703	0.722	**-2.7%**

6FFF	Measured vs Predicted Dose		
MLC field	PTW31016	Eclipse Acuros	% Diff
3x3	0.831	0.830	**0.1%**
2x2	0.803	0.801	**0.2%**
1x1	0.713	0.730	**-2.3%**

6X	Measured vs Predicted Dose		
MLC field	PTW31016 Corr.	Eclipse Acuros	% Diff
3x3	0.834	0.829	**0.6%**
2x2	0.808	0.802	**0.8%**
1x1	0.730	0.722	**1.1%**

6FFF	Measured vs Predicted Dose		
MLC field	PTW31016 Corr.	Eclipse Acuros	% Diff
3x3	0.832	0.830	**0.2%**
2x2	0.806	0.801	**0.6%**
1x1	0.741	0.730	**1.5%**

6X	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.833	0.829	**0.5%**
2x2	0.812	0.802	**1.3%**
1x1	0.744	0.722	**3.1%**

6FFF	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.831	0.830	**0.2%**
2x2	0.808	0.801	**0.9%**
1x1	0.748	0.730	**2.4%**

6X	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.833	0.829	**0.5%**
2x2	0.810	0.802	**1.0%**
1x1	0.732	0.722	**1.4%**

10FFF	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.831	0.830	**0.2%**
2x2	0.806	0.801	**0.6%**
1x1	0.736	0.730	**0.8%**

Applications

- Simple small field dose measurements
- Small MLC fields at d=5 cm (two detectors)
- FFF energies

6FFF	Measured vs Predicted Dose		
MLC field	CC01	Eclipse Acuros	% Diff
3x3	0.888	0.896	-0.9%
2x2	0.854	0.867	-1.5%
1x1	0.771	0.792	-2.6%

10FFF	Measured vs Predicted Dose		
MLC field	CC01	Eclipse Acuros	% Diff
3x3	0.920	0.918	0.2%
2x2	0.876	0.878	-0.3%
1x1	0.749	0.756	-0.9%

6FFF	Measured vs Predicted Dose		
MLC field	CC01 corrected	Eclipse Acuros	% Diff
3x3	0.895	0.896	-0.1%
2x2	0.861	0.867	-0.7%
1x1	0.785	0.792	-0.9%

10FFF	Measured vs Predicted Dose		
MLC field	CC01 corrected	Eclipse Acuros	% Diff
3x3	0.925	0.918	0.7%
2x2	0.881	0.878	0.3%
1x1	0.760	0.756	0.5%

6FFF	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.897	0.896	0.1%
2x2	0.868	0.867	0.1%
1x1	0.803	0.792	1.4%

10FFF	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.926	0.918	0.9%
2x2	0.888	0.878	1.1%
1x1	0.781	0.756	3.3%

6FFF	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.897	0.896	0.1%
2x2	0.865	0.867	-0.2%
1x1	0.790	0.792	-0.2%

10FFF	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.926	0.918	0.9%
2x2	0.885	0.878	0.8%
1x1	0.768	0.756	1.6%

Applications

- Simple small field dose measurements
- Small MLC fields at d=5 cm (two detectors)
- FFF energies

6FFF	Measured vs Predicted Dose		
MLC field	Edge	Eclipse Acuros	% Diff
3x3	0.829	0.831	-0.2%
2x2	0.806	0.803	0.4%
1x1	0.759	0.737	2.9%

10FFF	Measured vs Predicted Dose		
MLC field	Edge	Eclipse Acuros	% Diff
3x3	0.924	0.914	1.0%
2x2	0.895	0.871	2.8%
1x1	0.806	0.756	6.7%

6FFF	Measured vs Predicted Dose		
MLC field	Edge Corrected	Eclipse Acuros	% Diff
3x3	0.829	0.831	-0.3%
2x2	0.802	0.803	-0.2%
1x1	0.733	0.737	-0.6%

10FFF	Measured vs Predicted Dose		
MLC field	Edge Corrected	Eclipse Acuros	% Diff
3x3	0.923	0.914	0.9%
2x2	0.890	0.871	2.2%
1x1	0.779	0.756	3.0%

6FFF	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.834	0.831	0.4%
2x2	0.811	0.803	1.0%
1x1	0.755	0.737	2.4%

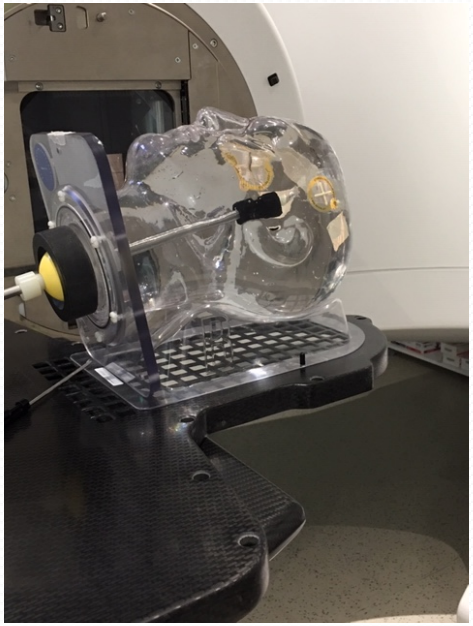
10FFF	Measured vs Predicted Dose		
MLC field	PTW60019	Eclipse Acuros	% Diff
3x3	0.922	0.914	0.8%
2x2	0.888	0.871	1.9%
1x1	0.788	0.756	4.2%

6FFF	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.834	0.831	0.4%
2x2	0.809	0.803	0.7%
1x1	0.743	0.737	0.8%

10FFF	Measured vs Predicted Dose		
MLC field	PTW60019 corr.	Eclipse Acuros	% Diff
3x3	0.922	0.914	0.8%
2x2	0.885	0.871	1.6%
1x1	0.775	0.756	2.6%

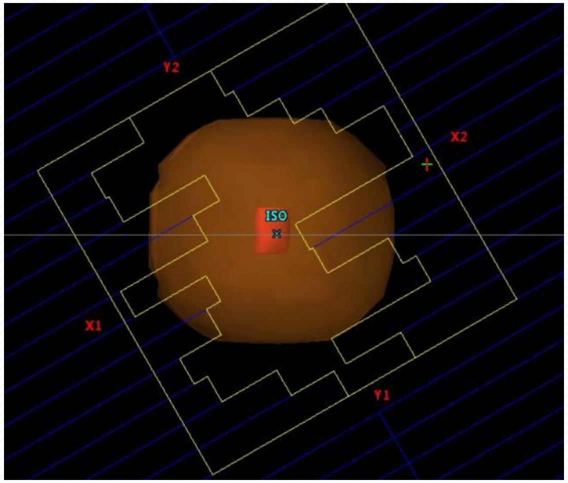
Applications

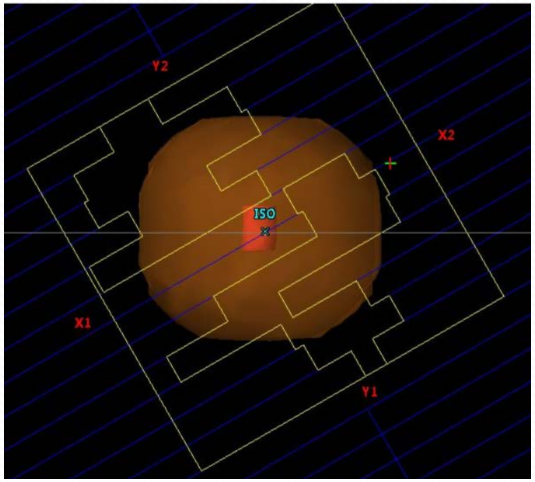
- IMRT and RapidArc (VMAT) QA dose measurements



Applications

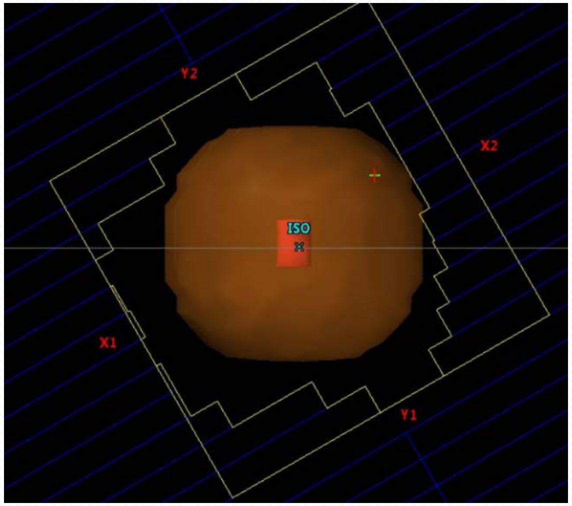
- IMRT and RapidArc (VMAT) QA dose measurements
  - Complex delivery field shape and variable irradiated field size

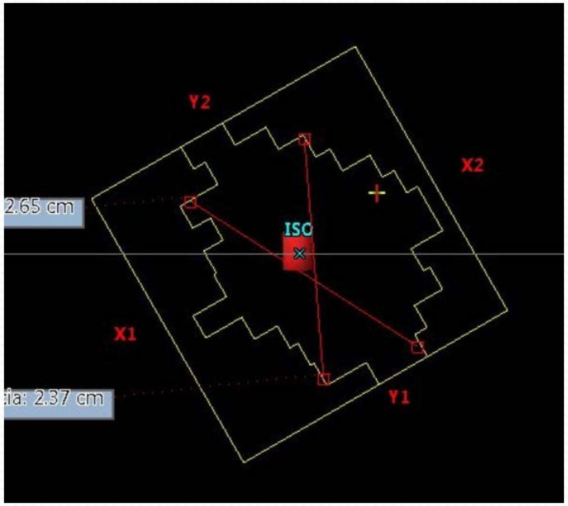




Applications

- IMRT and RapidArc (VMAT) QA dose measurements
  - Complex delivery field shape and variable field size
  - Determination of field size for correction factors?





Applications

- RapidArc (VMAT) QA dose measurements

Rapid Arc small target (˜1.5 cm opening MLC)

RapidArc Measured vs Predicted Dose (Eclipse Acuros)			
6FFF	**Arc 1**	**Arc 2**	**Composite**
Meas	1.64	1.13	2.77
Predicted	1.63	1.06	2.69
% Diff	0.7%	6.5%	**3.0%**

RapidArc Measured vs Predicted Dose (Eclipse Acuros)			
10FFF	**Arc 1**	**Arc 2**	**Composite**
Meas	1.71	1.21	2.92
Predicted	1.69	1.14	2.83
% Diff	1.0%	6.4%	**3.2%**

RapidArc Measured vs Predicted Dose (with correction factors)			
6FFF	**Arc 1**	**Arc 2**	**Composite**
Meas	1.66	1.14	2.80
Predicted	1.63	1.06	2.69
% Diff	1.8%	7.7%	**4.1%**

RapidArc Measured vs Predicted Dose (with correction factors)			
10FFF	Arc 1	Arc 2	**Composite**
Meas	1.72	1.22	2.94
Predicted	**1.69**	**1.14**	2.83
% Diff	1.7%	7.2%	**3.9%**

Applications

- RapidArc (VMAT) QA dose measurements

RA Measured vs Predicted Dose (Eclipse Acuros)		
6X	**Plan 1 (std)**	**Plan 2 (smooth)**
Meas	10.35	10.22
Predicted	10.27	10.23
% Diff	**0.8%**	**-0.1%**

RA Measured vs Predicted Dose (Eclipse Acuros)		
6FFF	**Plan 1 (std)**	**Plan 2 (smooth)**
Meas	10.01	9.94
Predicted	9.98	9.96
% Diff	**0.4%**	**-0.2%**

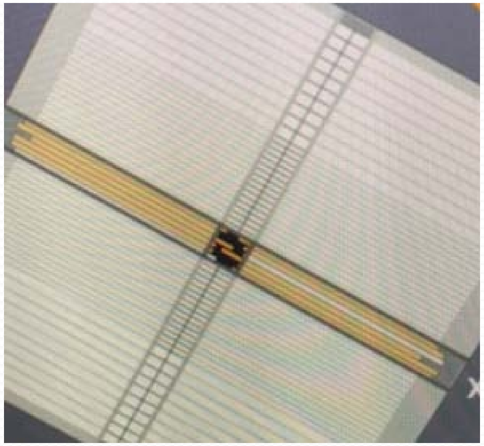
RA Meas. vs Pred. Dose (w correction factors)		
6X	**Plan 1 (std)**	**Plan 2 (smooth)**
Meas	10.49	10.35
Predicted	10.27	10.23
% Diff	**2.1%**	**1.2%**

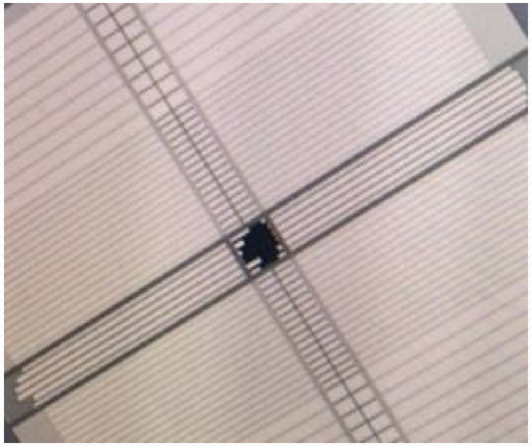
RA Meas. vs Pred. Dose (w correction factors)		
6FFF	**Plan 1 (std)**	**Plan 2 (smooth)**
Meas	10.14	10.07
Predicted	9.98	9.96
% Diff	**1.7%**	**1.1%**

Rapid Arc small target (1.5 cm)

1.013 1.5cm
1.039 1 cm

Applications





Applications

Rapid Arc small target (˜1.5-2.0 cm opening MLC)

RA Measured vs Predicted Dose (Eclipse Acuros)		
6FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	8.76	9.94
Predicted	8.50	9.77
% Diff	**3.1%**	**1.8%**

RA Measured vs Predicted Dose (Eclipse Acuros)		
10FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	10.34	11.67
Predicted	9.91	11.32
% Diff	**4.4%**	**3.1%**

RA Meas. vs Pred. Dose (w correction factors)		
6FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	8.80	9.98
Predicted	8.50	9.77
% Diff	**3.5%**	**2.2%**

RA Meas. vs Pred. Dose (w correction factors)		
10FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	10.38	11.72
Predicted	9.91	11.32
% Diff	**4.8%**	**3.5%**

RA Meas. vs Pred. Dose (w correction factors)		
6FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	8.88	10.07
Predicted	8.50	9.77
% Diff	**4.5%**	**3.1%**

RA Meas. vs Pred. Dose (w correction factors)		
10FFF	Plan 1 (std)	Plan 2 (smooth)
Meas	10.47	11.82
Predicted	9.91	11.32
% Diff	**5.7%**	**4.5%**

1.004 2.0 cm
1.013 1.5 cm
1.039 1.0 cm

Summary: Small Field Dosimetry

- The response from different detectors can vary significantly for small fields
- No ideal detector exists: correction factors
- Follow protocol guidelines:
    - Suitable small detector
    - Careful setup
    - Correct for volume averaging and energy dependence of detector
    - Use two or more detectors if possible
    - Share data with peers

Summary: Small Field Correction Factors

- Correct for effects of volume average and density perturbation in small field measurements
- Need to be considered for small field dose measurements to prevent large errors
- Several publications available
- Review data prior to implementation

Summary: TRS 483 and Correction Factors

- Provides clear procedures for small field measurements
- Provides correction factors for a limited number of detectors
- Current recommendation is to use the published factors to standardize the small field dosimetry measurements
- Probable updates in the corrections factors will be seen in the near future
- Stimulates further research to measure or calculate missing data according to the defined procedures

Summary: Correction Factors Implementations

- More data for different detectors relating to differences in correction factors with FF vs FFF energies
- Further investigation is needed on machine-specific correction factors to clarify any differences in detector response
- Definition of field size in complex dynamic treatment deliveries
- Guidelines and research will be beneficial for applications in IMRT and RapidArc (VMAT) linac QA dose measurements

Although there are no machine specific correction factors and the protocol correction factors have some uncertainty, significant errors may result if detector correction factors are not applied in small field dosimetry

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&

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Questions and Discussions