Intensity Modulated Radiation Therapy: Dosimetric Aspects & Commissioning Strategies

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Steps to Preparing for IMRT

1. Delivery System Commissioning
   1. Mechanical tasks
   2. Dosimetric tasks (3D)
   3. IMRT specific tasks
2. Treatment Planning System Commissioning
   1. 3D tasks *(IAEA Report TRS 430 (2004), ESTRO Booklet 7, Camargo 2007)*
   2. IMRT specific tasks *(Van Esch 2002, Sharpe 2003, Ezzell 2003)*
3. Dosimetric verification per plan / site
4. Independent verification / credentialing
5. Pre-treatment verification (per plan)

performed initially

Suggested Layers of Quality Assurance:

initial commissioning:

work up from bottom

introducing a new technique:

work from top down

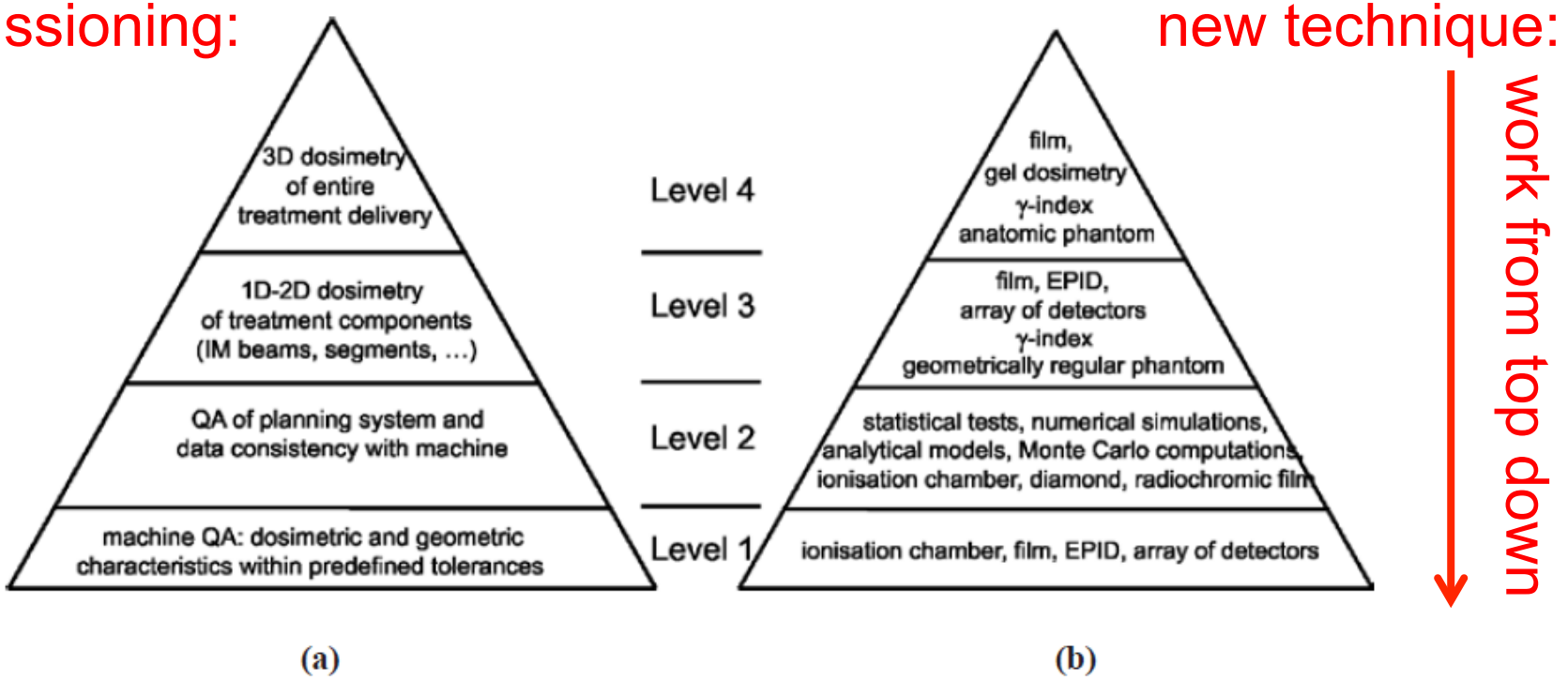

Figure 3.1 (a) Conceptual pyramid that correlates the various levels of dosimetric QA in IMRT. Like the situation for a real pyramid, each level is based on the stability of the underlying levels. The two lower levels can be part of the periodic QA procedures of equipment used for IMRT planning and delivery. For QA of a new clinical IMRT solution, one may start at the top by applying a 3D dosimetric verification of an entire treatment. One descends the pyramid to the lower levels if the 3D dosimetric verification reveals unacceptable discrepancies with treatment planning. (b) Methodology and tools appropriate for each of the levels. (Courtesy Carlos De Wagter, Ghent University Hospital, Ghent, Belgium, and the Institute of Physics).

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1. Delivery System Commissioning

IMRT Commissioning of Delivery System: General issues for IMRT using an MLC

- MLC Position Accuracy
  - Picket or Garden Fence / strip test
- Linac performance for small MU delivery
- MLC control issues & data transfer fidelity
- MLC physical (& dosimetric) characteristics
  - Dosimetric leaf gap (DLG)
  - Inter & Intra leaf leakage
  - Tongue & groove effect
- Additional issues specific to sliding window IMRT
  - Leaf position & leaf speed accuracy
  - Minimum leaf distance (to avoid collisions)

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MLC Position Accuracy

- 3D: MLC defines field edge
  - 1-2mm offset may be inconsequential to output & clinical outcome
- IMRT:
  - Consists of multiple small “segments”
  - Leaf edge moves to many positions within the treated area
  - Hence IMRT accuracy is much more sensitive to MLC edge position
- Rounded leaves: 0.4-1.1mm offset between light field edge & beam edge

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MLC Positional Accuracy: Proposed Test (AAPM Report 82):

- Proposed test procedure:
  - Measure offset between light field & radiation field as a function of distance from the central axis
    - often offset may be considered to be constant
  - Create test sequence that abuts irradiated strips at different locations across the field
    - account for offset so that 50% lines superimpose
  - Irradiate film & evaluate uniformity of dose
- Repeat at various gantry angles to assess effect of gravity
- Test over range of “carriage” motion for MLCs utilizing a carriage

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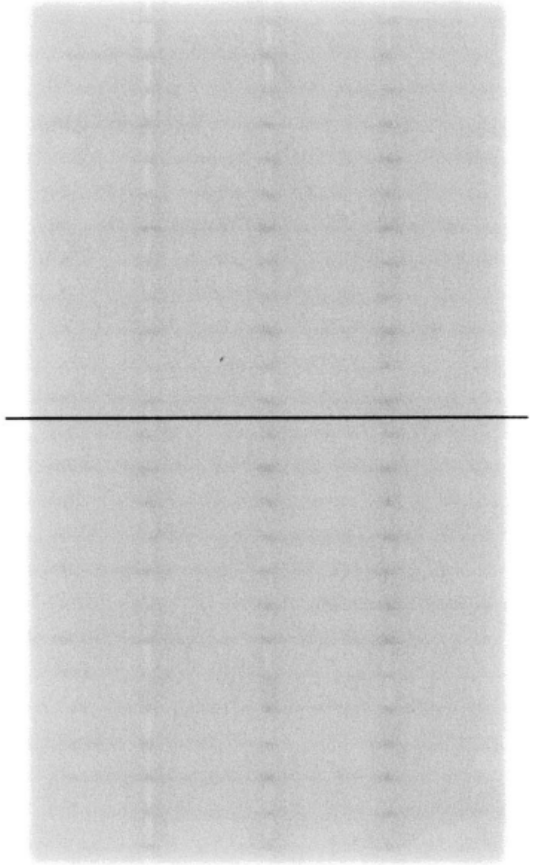
Abutting MLC Dose Uniformity Test

expected detectability = 0.2mm

±5% dose accuracy in the matchline



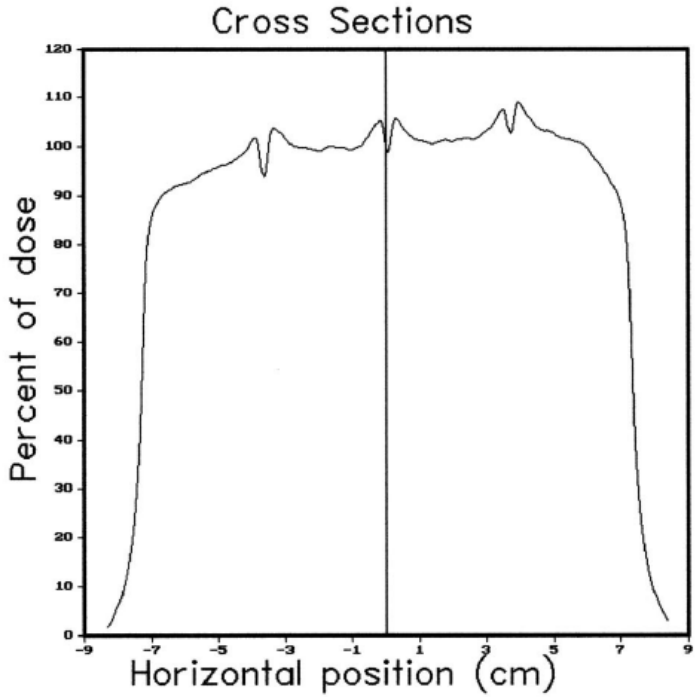


FIG. II.1. (a) MLC test pattern with a 2 cm wide strip. (b) QA film produced by moving the pattern in 2 cm intervals and irradiating in a step-and-shoot fashion. The strips should abut at the 50% decrement lines as described in Sec. II A 1. The line on the film shows the location of the scan (c), which is used to assess the quality of the matching. This MLC has a rounded leaf end design.

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MLC Positional Accuracy: Picket Fence Test

- Test sequence that creates 1mm strips at regular intervals
- Visual inspection can detect improper positioning of ~0.5mm
- Repeat at multiple gantry & collimator angles

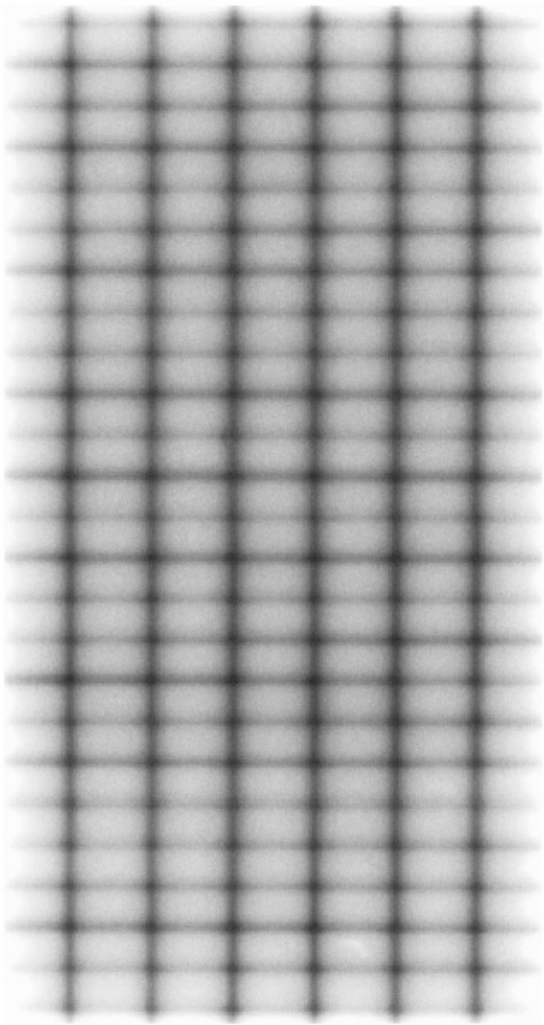

FIG. II.2. (a) MLC test pattern with a 1 mm wide strip. (b) QA film produced by moving the pattern in 2 cm intervals and irradiating in a step-and-shoot fashion. This MLC has a rounded leaf end design.

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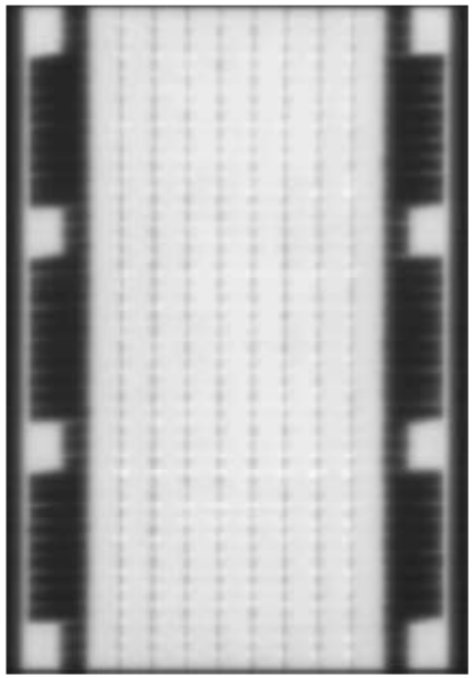
MLC Position Accuracy: Picket Fence Test



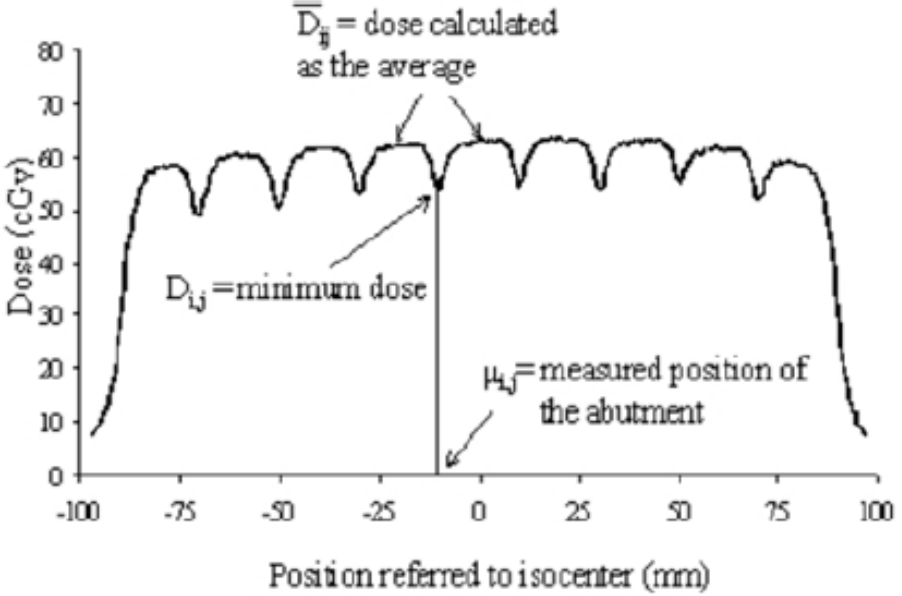


Figure 4.1 A strip-test design for MLC calibration purposes showing nine adjacent segments 2 cm wide with 1 mm gap, and two extra segments with 4 squares at the left and right side to determine the isocentre, measured with film. Dose profiles are taken for each leaf-pair. The right figure shows the profile of a central leaf. The dose variations of the abutments are used to determine the relative leaf positions, and the measured position of the abutments to determine the absolute leaf position (from D Sastre-Padro *et al.*, 2004).

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Linac performance for small MU delivery

- Step & Shoot IMRT consists of multiple small segments with few MU- requiring accurate dose linearity at low MU
- Recommended to verify output, along with flatness & symmetry

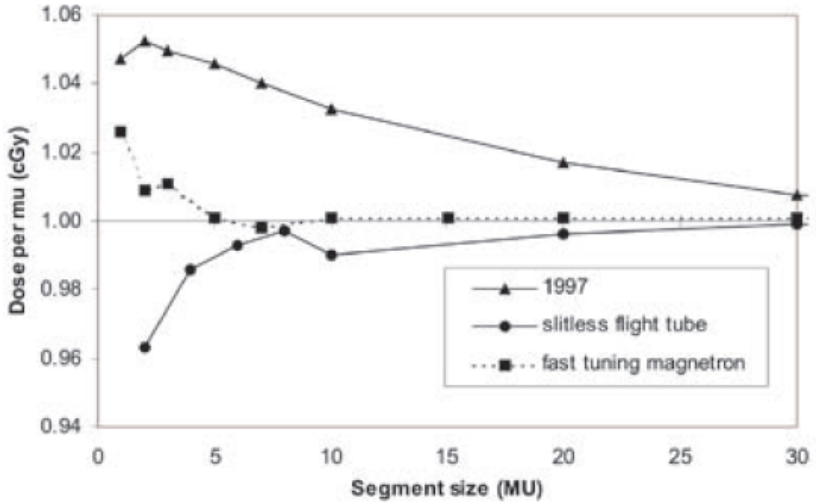

Figure 4.6 Beam calibration for a limited number of monitor units depending on the type of magnetron and steering technique for Elekta accelerators. In 1997 the feedback technique with slits was used. An improvement of this technique was the slitless flight tube, which was followed by a new design magnetron with faster tuning (Courtesy Geoff Budgell, Christie Hospital, Manchester, UK).

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MLC control issues

- Need to determine the following for specific equipment:
  - how MLC is calibrated
  - how MLC position is indexed to MU
  - how MLC position is measured
  - MLC tolerance applied (& can this be modified)
  - interlocks for MLC position
  - verification records & logs are created by the control system
  - how to respond when calibration has drifted
  - how to recover from delivery interruptions
- Vendor implementation of IMRT:
  - Segmental IMRT may be implemented as an extension of conventional treatment with each segment as a separate field (Siemens)
  - IMRT may utilize a dedicated linac & MLC control system (Elekta & Varian)

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Data Transfer Fidelity

- Visual verification that plan data has been transferred correctly between TPS and linear accelerator for representative plans
  - straightforward for basic machine settings & initial MLC shapes
- MLC motion is less straightforward to verify
  - dosimetric measurements may be a good surrogate
- After commissioning: it is a good idea to have a policy in place to verify this on a per-plan basis

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MLC physical (& dosimetric) characteristics

- MLC leakage
  - Leaf transmission is more critical for IMRT than 3DCRT because MLCs shadow the treatment area for a large portion of delivered MU
- MLC leaf penumbra
  - should be measured with high resolution detector (such as film or diode)
  - a beam model based on a chamber with an inner diameter >0.3cm may not produce accurate IMRT plans

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MLC Leakage

- Leakage types:
  - transmission through leaves
  - interleaf leakage
- Often the treatment planning system uses the "average leakage"
  - in this case, leakage should be measured with a detector large enough to provide an average value

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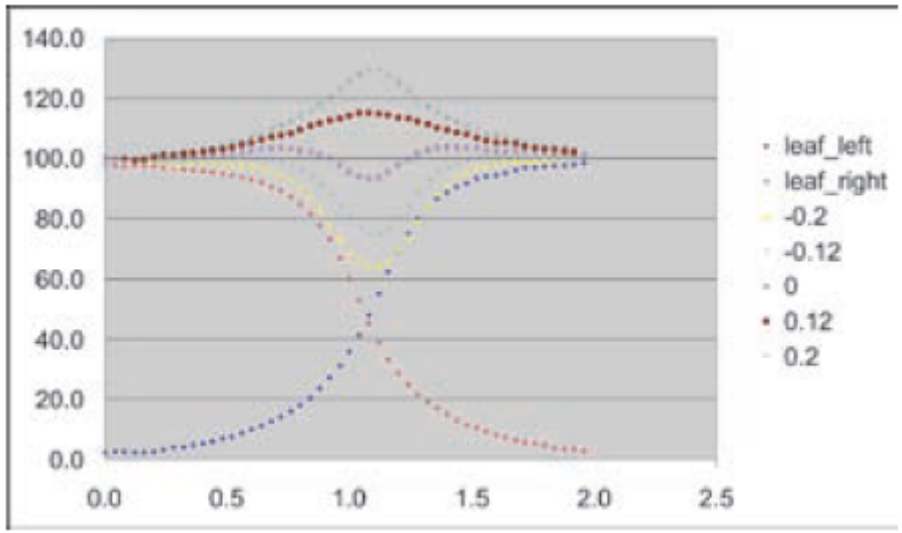
MLC Penumbra
Leaf position may be calibrated at:

- actual position
- 50% dose profile
  - Requires minimum leaf distance. Opposing leaves at same position would collide!
  - Calibration can be done in water phantom
- best position for abutting leaves
  - Gives optimal dose distribution with abutting segments
  - Slight difference from 50% dose profile
  - Calibration can be done using strip test

Figure 4.3 Dose profiles of leaves with rounded leaf ends with different gaps between opposing leaf positions. The calibration of the leaf position is at the 50% dose point. Dimensions are in cm.



most important: make sure linear accelerator & treatment planning system use same definition for leaf edge!

Dosimetric Leaf Gap (DLG) or Dosimetric Leaf Separation (DLS)

- DLG is a systematic offset introduced in the modeled leaf position
- Introduced into TPS to match the linear accelerator

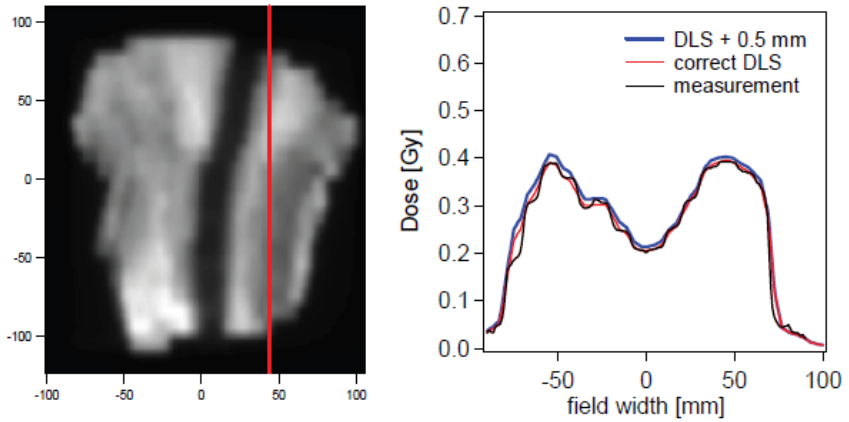


Figure 4.5 Film measurement of an IMRT field delivered using the sliding window technique of a head-and-neck treatment plan transferred to a phantom. The measured and calculated dose distributions along the red line have been compared. The correct value of the DLS parameter for this set-up was 2.6 mm. With this value the calculated and measured data agreed very well and are all within gamma criteria of 3% local dose difference and 2 mm DTA. The calculations were repeated by using a larger DLS of 3.1 mm. As a result 9 % of the area inside the 0.14 Gy isodose area had a gamma value larger than 1.

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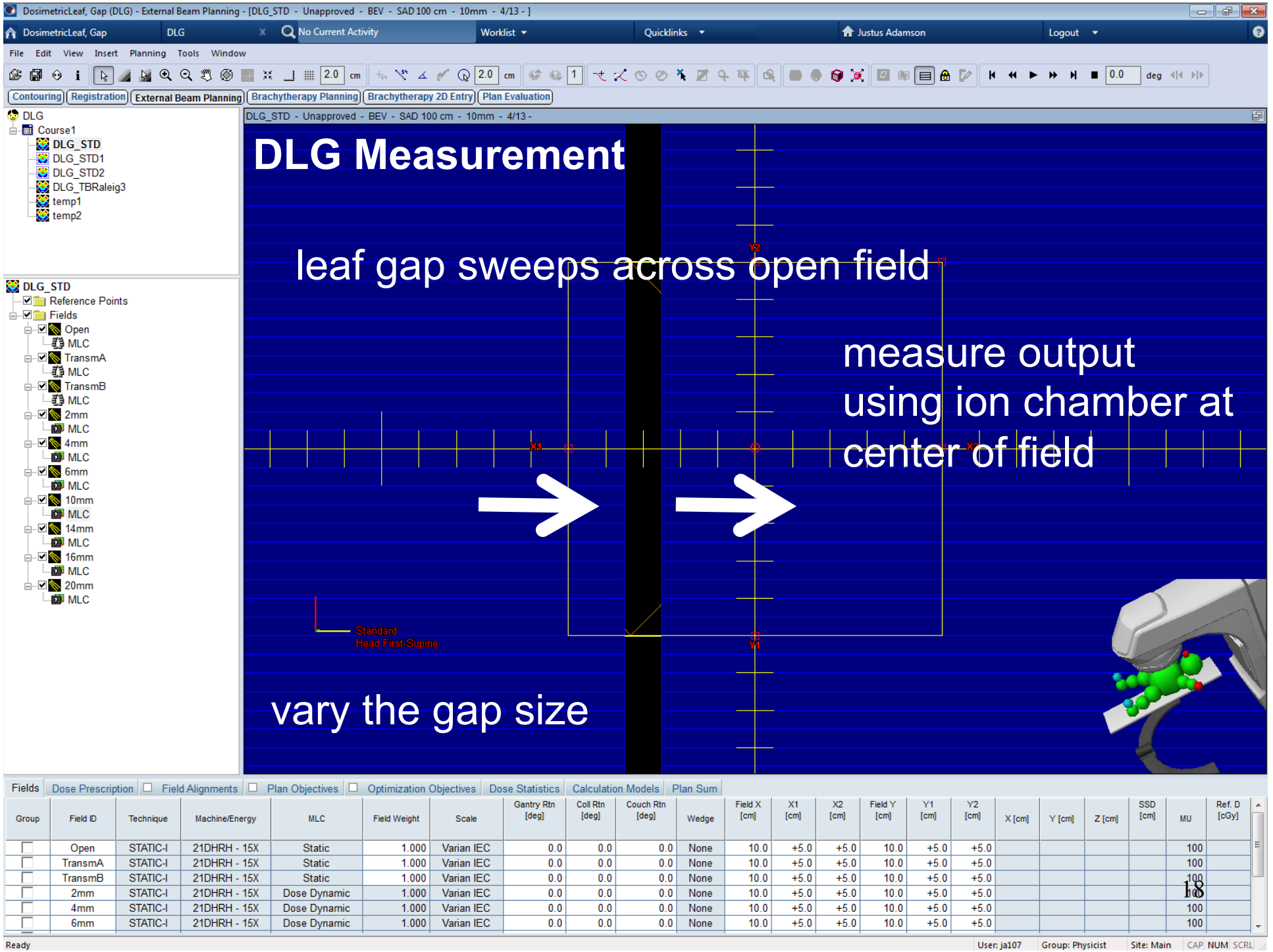
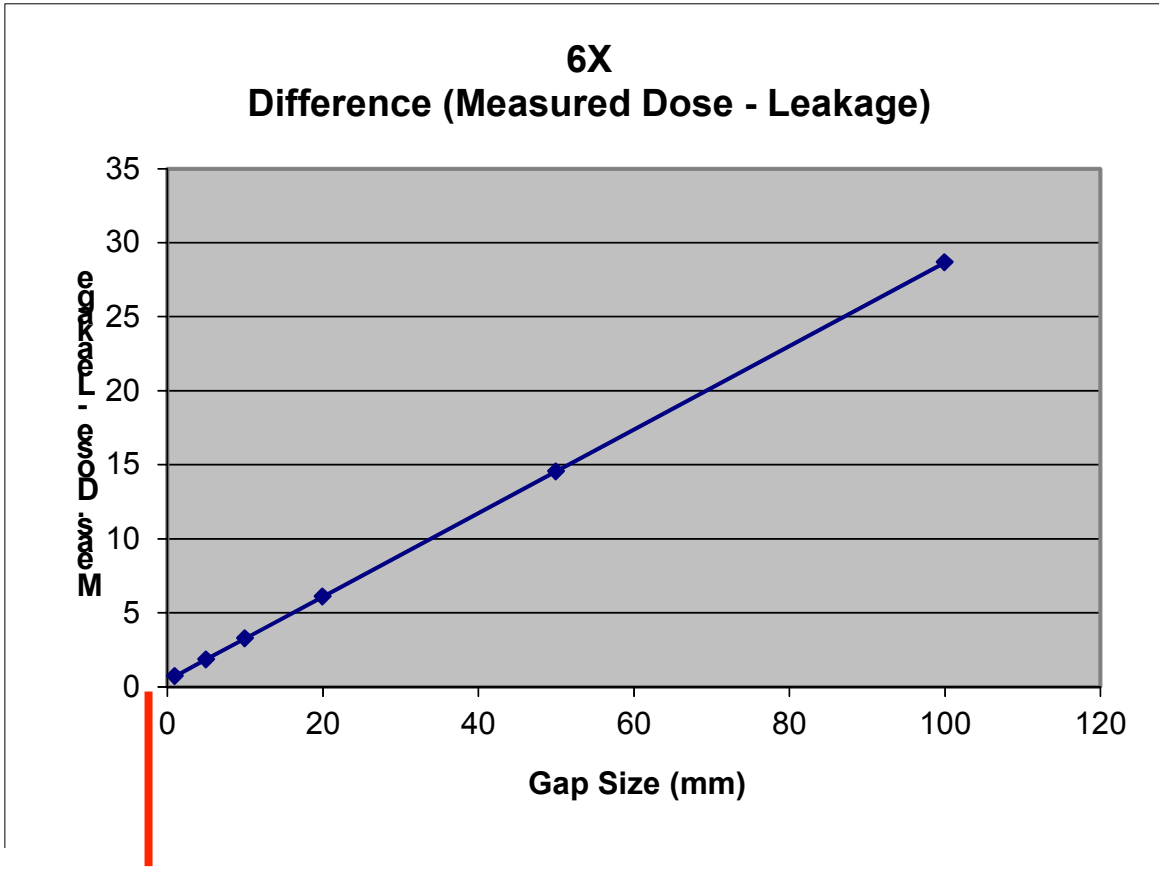

DosimetricLeaf, Gap (DLG) - External Beam Planning - [DLG_STD - Unapproved - BEV - SAD 100 cm - 10mm - 4/13 -]
DosimetricLeaf, Gap
DLG
No Current Activity
Worklist
Quicklinks
Justus Adamson
Logout
File Edit View Insert Planning Tools Window
Contouring Registration External Beam Planning Brachytherapy Planning Brachytherapy 2D Entry Plan Evaluation
DLG
Course1
DLG_STD
DLG_STD1
DLG_STD2
DLG_TBRaleig3
temp1
temp2
DLG_STD - Unapproved - BEV - SAD 100 cm - 10mm - 4/13 -
DLG Measurement
leaf gap sweeps across open field
measure output using ion chamber at center of field
vary the gap size
Standard
Head First-Supine
DLG_STD
Reference Points
Fields
Open
TransmA
TransmB
2mm
4mm
6mm
10mm
14mm
16mm
20mm
MLC
Fields
Dose Prescription
Field Alignments
Plan Objectives
Optimization Objectives
Dose Statistics
Calculation Models
Plan Sum
Group
Field ID
Technique
Machine/Energy
MLC
Field Weight
Scale
Gantry Rtn [deg]
Coll Rtn [deg]
Couch Rtn [deg]
Wedge
Field X [cm]
X1 [cm]
X2 [cm]
Field Y [cm]
Y1 [cm]
Y2 [cm]
X [cm]
Y [cm]
Z [cm]
SSD [cm]
MU
Ref. D [cGy]
Open STATIC-I 21DHRH - 15X Static 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0 100
TransmA STATIC-I 21DHRH - 15X Static 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0 100
TransmB STATIC-I 21DHRH - 15X Static 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0 100
2mm STATIC-I 21DHRH - 15X Dose Dynamic 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0
4mm STATIC-I 21DHRH - 15X Dose Dynamic 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0 100
6mm STATIC-I 21DHRH - 15X Dose Dynamic 1.000 Varian IEC 0.0 0.0 0.0 None 10.0 +5.0 +5.0 10.0 +5.0 +5.0 100
Ready
User: ja107
Group: Physicist
Site: Main
CAP NUM SCRL

DLG Measurement



leaf gap = line intercept

Dynamic MLC IMRT:

- Tests developed by LoSasso (1998, 2001) & Chui (1996)
- Multi-institution report: Van Esch (2002)
- Tests include:
  - MLC speed test: deliver stepwise intensities with all leaf pairs moving at different speeds
    OR
  - ion chamber reading for 1cm sliding gap delivered with varied MU
    - MLC speed will vary given a different MU delivered for the same MLC sequence
    - chamber reading should be directly proportional to MU
    - chamber checks central leaves; film / EPID could be used to check multiple leaves

T. LoSasso, C. S. Chui, and C. C. Ling, "Comprehensive quality assurance for the delivery of intensity modulated radiotherapy with a multileaf collimator used in the dynamic mode," Med. Phys. **28**, 2209–2219 (2001).

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IMRT Commissioning: General issues for IMRT using physical attenuators

- Treatment planning system:
  - beam hardening
  - scatter from attenuator
- Delivery system:
  - Choice of attenuation material
  - Machining accuracy
  - Placement accuracy

Relevant References:

[22] W. U. Laub, A. Bakai, and F. Nusslin, "Intensity modulated irradiation of a thorax phantom: Comparisons between measurements, Monte Carlo calculations and pencil beam calculations," Phys. Med. Biol. **46**, 1695–1706 (2001).

[23] J. Meyer, J. A. Mills, O. C. Haas, E. M. Parvin, and K. J. Burnham, "Some limitations in the practical delivery of intensity modulated radiation therapy," Br. J. Radiol. **73**, 854–863 (2000).

[24] H. Thompson, M. D. Evans, and B. G. Fallone, "Accuracy of numerically produced compensators," Med. Dosim. **24**, 49–52 (1999).

[25] S. B. Jiang and K. M. Ayyangar, "On compensator design for photon beam intensity-modulated conformal therapy," Med. Phys. **25**, 668–675 (1998).

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Delivery System: Implications for IMRT

in many cases IMRT requires a stricter tolerance than 3D

TABLE II. Monthly.

Procedure	Machine-type tolerance		
	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy			
Electron output constancy		2%	
Backup monitor chamber constancy			
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy		1%	
Electron beam profile constancy		1%	
Electron beam energy constancy		2%/2 mm	
Mechanical			
Light/radiation field coincidence[b]		2 mm or 1% on a side	
Light/radiation field coincidence[b] (asymmetric)		1 mm or 1% on a side	
Distance check device for lasers compared with front pointer		1mm	
Gantry/collimator angle indicators (@ cardinal angles) (digital only)		1.0°	
Accessory trays (i.e., port film graticle tray)		2 mm	
Jaw position indicators (symmetric)[c]		2 mm	
Jaw position indicators (asymmetric)[d]		1 mm	
Cross-hair centering (walkout)		1 mm	
Treatment couch position indicators[e]	2 mm/1°	2 mm/1°	1 mm/0.5°
Wedge placement accuracy		2 mm	
Compensator placement accuracy[f]		1 mm	
Latching of wedges, blocking tray[g]		Functional	
Localizing lasers	±2 mm	±1 mm	<±1 mm
Safety			
Laser guard-interlock test		Functional	
Respiratory gating			
Beam output constancy		2%	
Phase, amplitude beam control		Functional	
In-room respiratory monitoring system		Functional	
Gating interlock		Functional	

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Klein *et al.*: Task Group 142 Report: QA of Medical Accelerators

2. Treatment Planning System Commissioning

IMRT Commissioning: Treatment Planning System

- Difficult to determine if differences between measurement & calculation are due to the planning system, delivery system, or measurement technique
  - Delivery system should be commissioned separate from the treatment planning system

Treatment Planning System Commissioning Aspects Requiring Special Attention for IMRT

- IMRT is an extension of 3D Treatment Planning
  - same commissioning requirements as for 3D planning + some IMRT specific tasks
- IMRT specific aspects:
  - inverse optimization
    - the optimization process requires more stringent accuracy of volume determinations, beam modelling and DVHs, including the effect of dose grid on these parameters
    - Guidelines & reports describe verification tests for DVH calculation, etc.
    - These details can be verified collectively by a “users group” for a specific planning software
  - leaf sequencer
    - Leaf sequencing algorithm is commissioned together with the planning process (rather than separately)
    - need to perform some verification if & when a new leaf sequence algorithm is introduced
  - dose calculation

TPS Verification:
Dose Calculation Considerations

- definition of leaf positions in TPS
- beam profiles of small segments & abutting fields (step & shoot)
- beam profiles of small fields (sliding window)
- tongue & groove effect
- leaf transmission
- small field output factors & depth dose curves
- dose distributions in inhomogeneous phantoms irradiated with small fields
- dose distributions for typical site specific fields
- dose distributions for representative test patients

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TPS Verification Procedure

- Start simple & then advance to more complex tests.
- Example:
  - single beam on flat phantom with controlled intensity pattern
  - multiple beams on flat phantom with controlled intensity pattern
  - multiple beams treating hypothetical targets in flat phantom
  - multiple beams treating hypothetical targets in anthropomorphic phantom

increasing complexity

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[17] M. Essers, M. de Langen, M. L. Dirkx, and B. J. Heijmen, "Commissioning of a commercially available system for intensity-modulated radiotherapy dose delivery with dynamic multileaf collimation," Radiother. Oncol. **60**, 215–224 (2001).

[110] X. Wang, S. Spirou, T. LoSasso, J. Stein, C. S. Chui, and B. Mohan, "Dosimetric verification of intensity-modulated fields," Med. Phys. **23**, 317–327 (1996).

[111] L. Xing, Y. Curran, R. Hill, T. Holmes, L. Ma, K. M. Forster, and A. L. Boyer, "Dosimetric verification of a commercial inverse treatment planning system," Phys. Med. Biol. **44**, 463–478 (1999).

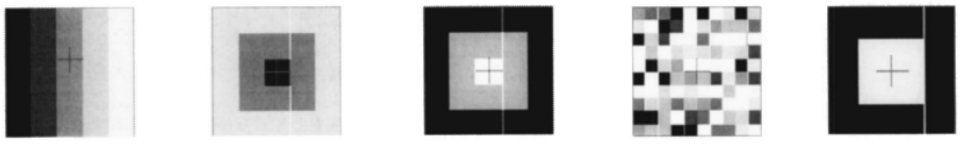

FIG. III.3. Examples of user-controlled intensity shapes used for commissioning tests.

goals:
-verify accuracy of beam parameters in simple, easily analyzed situations
-determine level of accuracy to be expected in clinical situations

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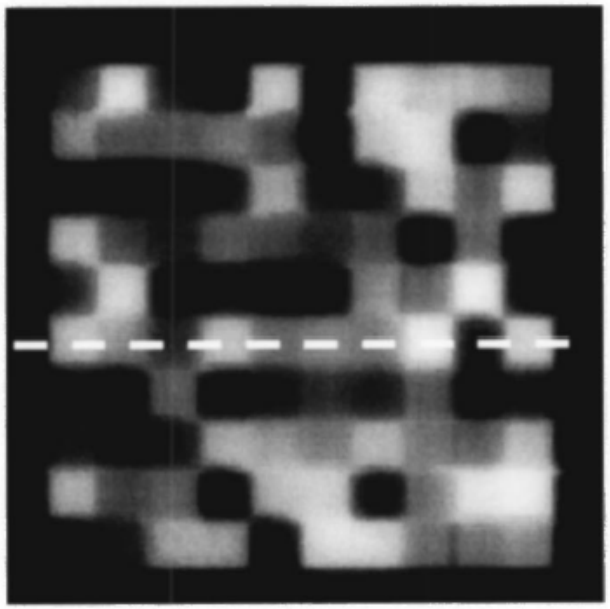
Example:



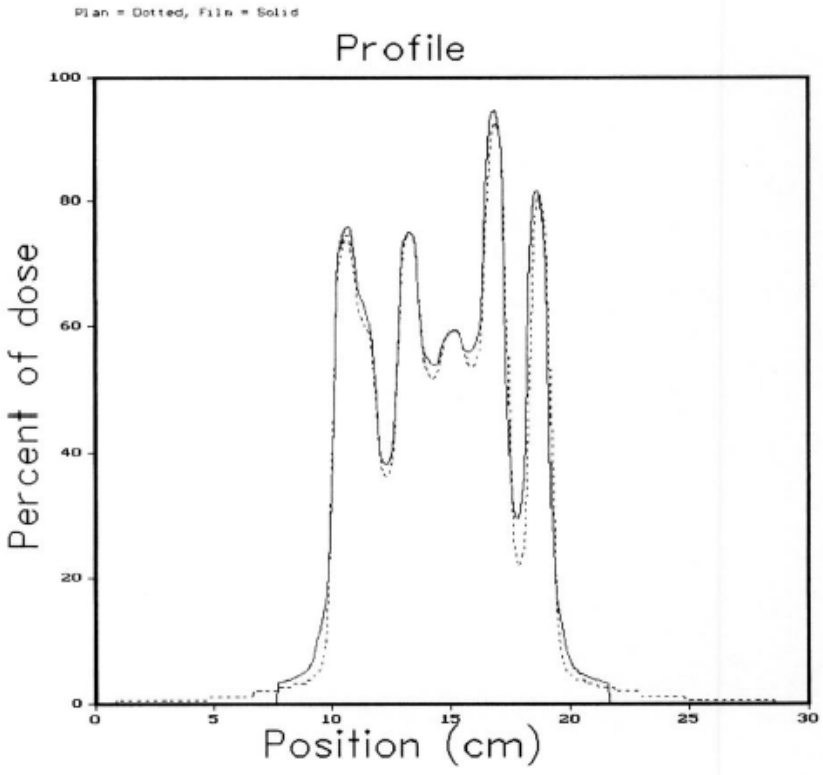


FIG. III.4. The dose profile measured with film across one line of a random intensity pattern (plan= dotted, film= solid), showing some systematic differences in low intensity regions.

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IMRT "Test Suite"

AAPM Task Group 119 Report on IMRT Commissioning includes:

- a "test suite" of treatment planning geometries to verify the treatment planning & delivery system
  - structures on square (solid water) phantom
  - optimization constraints
- agreement rates from multiple institutions as a baseline
  - point dose measurements (ion chamber)
  - planar dose measurements (film)

Medical Physics, Vol. 36, No. 11, November 2009

IMRT “Test Suite”

- AAPM TG119 Test Suite:
  - AP-PA
  - Bands
  - Multi-target
  - Prostate
  - Head & Neck
  - C-shape (easy)
  - C-shape (hard)

different optimization criteria / constraints

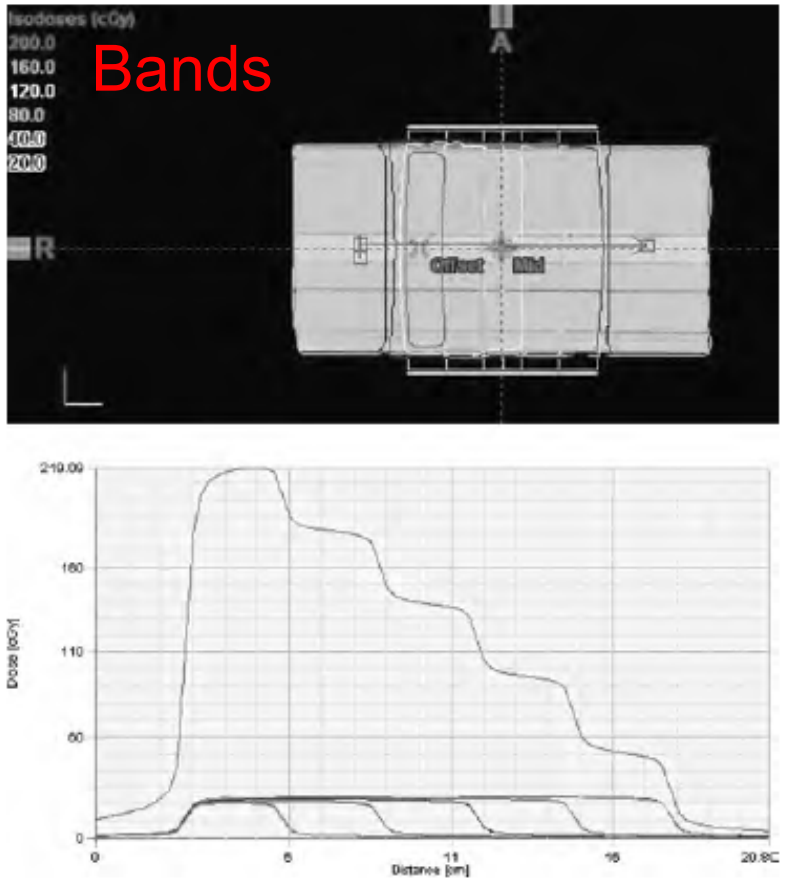

FIG. 1. Dose profile through central plane for bands. The lower curves are the individual contributions from each subfield (band); the upper curve is the summation.

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IMRT "Test Suite"

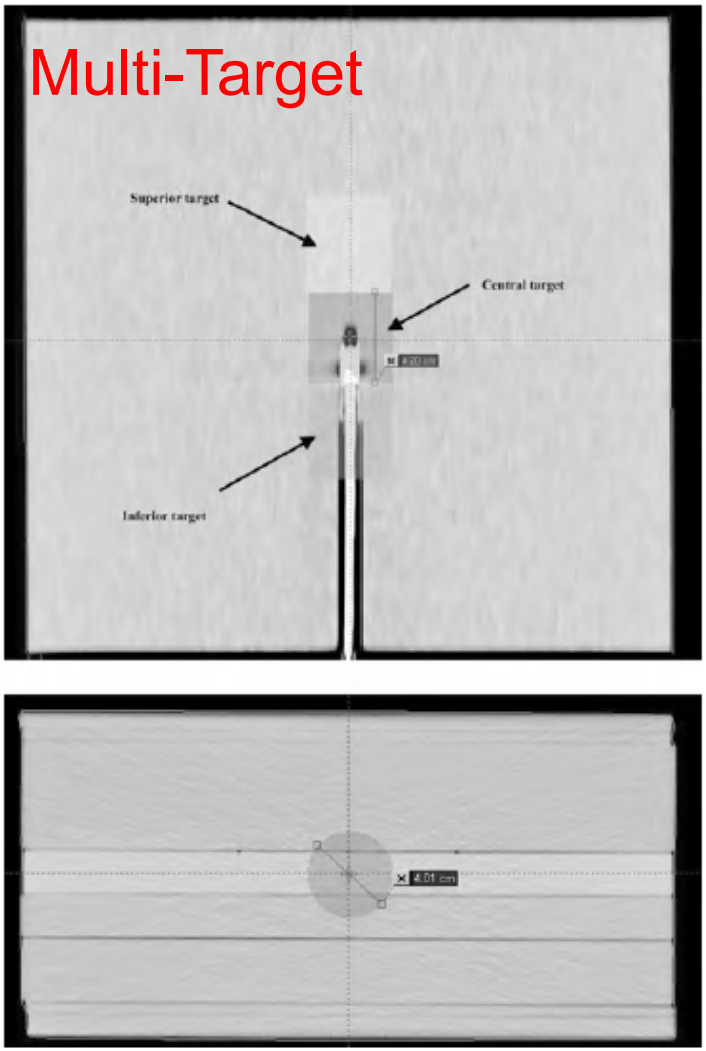

FIG. 2. Multitarget structures: Central target, superior target, and inferior target. These three cylindrical targets are stacked along the axis of rotation. Each has a diameter of approximately 4 cm and length of 4 cm. Coronal and transverse views are shown.

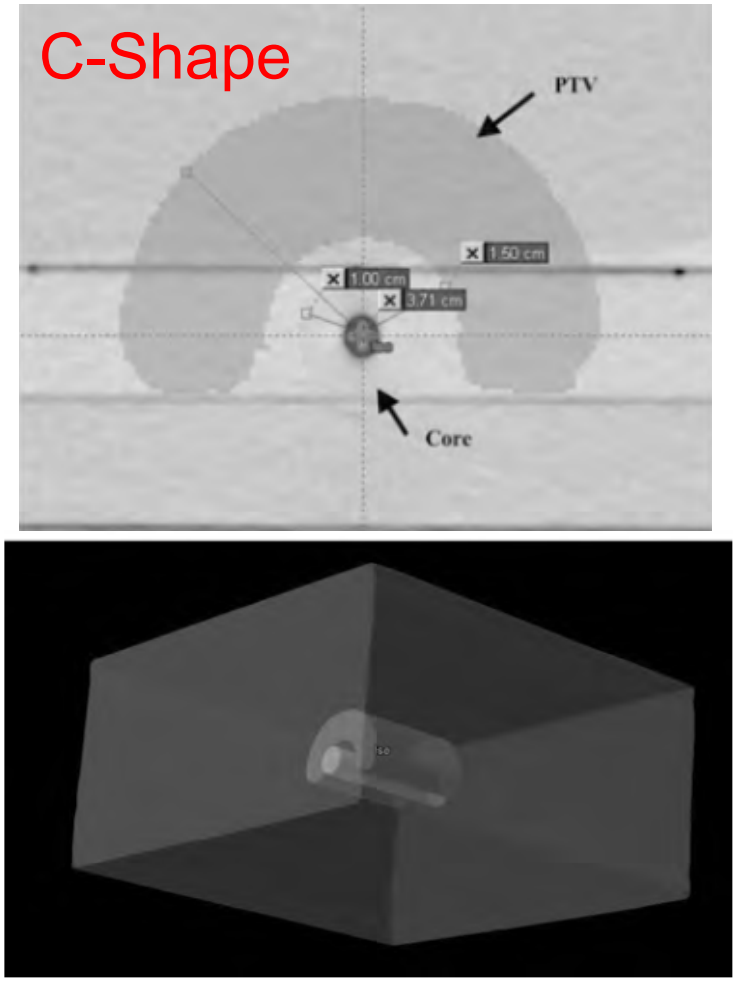

FIG. 5. CShape structures: CShape PTV and core. The center core is a cylinder 1 cm in radius. The gap between the core and the PTV is 0.5 cm, so the inner arc of the PTV is 1.5 cm in radius. The outer arc of the PTV is 3.7 cm in radius. The PTV is 8 cm long and the core is 10 cm long. Transverse and 3D views are shown.

IMRT "Test Suite"

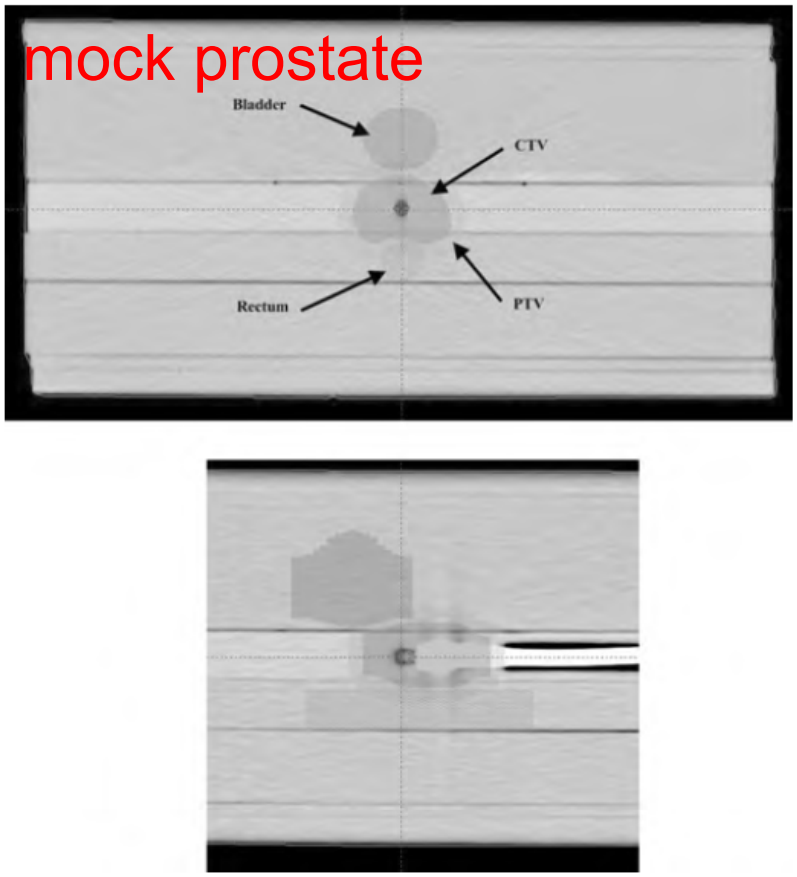

FIG. 3. Mock prostate structures: The prostate CTV, PTV, rectum, and bladder. The prostate CTV is roughly ellipsoidal with RL, AP, and SI dimensions of 4.0, 2.6, and 6.5 cm, respectively. The prostate PTV is expanded 0.6 cm around the CTV. The rectum is a cylinder with diameter of 1.5 cm that abuts the indented posterior aspect of the prostate. The PTV includes about 1/3 of the rectal volume on the widest PTV slice. The bladder is roughly ellipsoidal with RL, AP, and SI dimensions of 5.0, 4.0, and 5.0 cm, respectively, and is centered on the superior aspect of the prostate. Transverse and coronal views are shown.

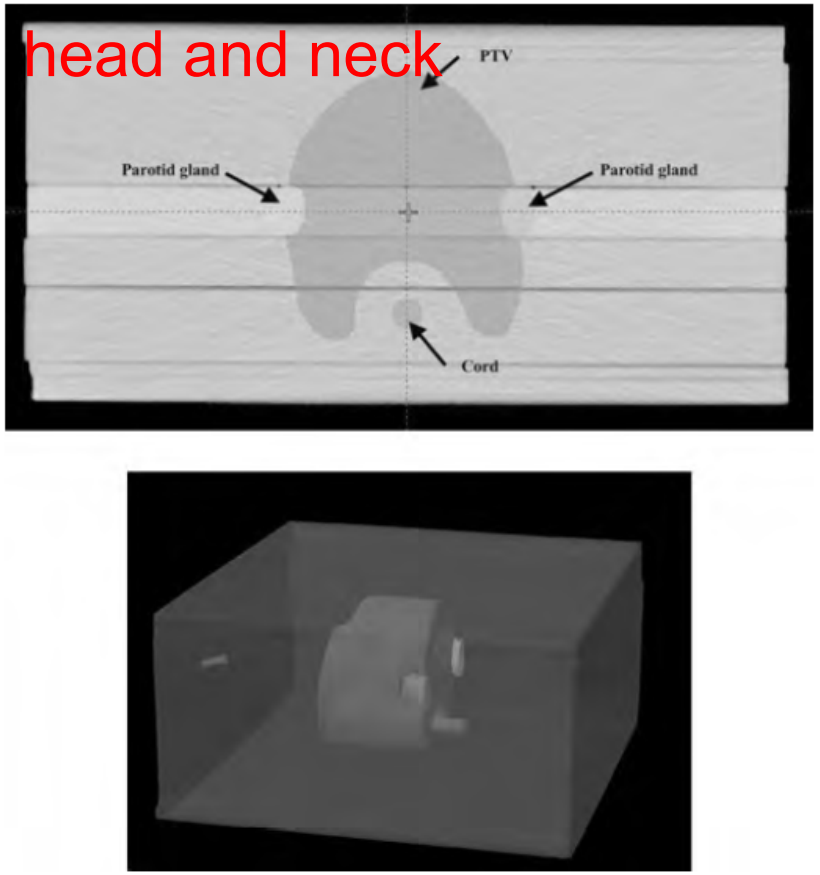

FIG. 4. Mock head/neck structures: HN PTV, cord, and parotid glands. The PTV is retracted from the skin by 0.6 cm. There is a gap of about 1.5 cm between the cord and the PTV. The parotid glands are to be avoided and are at the superior aspect of the PTV. Transverse and 3D views are shown.

TG119 Multi-Institutional Baseline

TABLE I. List of participating institutions and the systems utilized. Manufacturer's identifications are listed below the table. "DMLC" refers to dynamic MLC, sometimes called "sliding window." "SMLC" refers to static MLC, sometimes called "step and shoot" (Varian, ECLIPSE: Varian Medical Systems, Milpitas, CA; Siemens: Siemens AG, Healthcare Sector, Erlangen, Germany; Elekta, CMS: Elekta Inc., Norcross, GA; PINNACLE: Philips Healthcare, Andover, MA; TOMOTHERAPY: TomoTherapy Inc., Madison, WI).

Institution	Accelerator	Delivery technique	Planning system
Mayo Clinic Arizona	Varian 21EX	DMLC	ECLIPSE V7.5
Thomas Jefferson University Hospital	Elekta Synergy S	SMLC	CMS XIO V3.1
Robert Wood Johnson University Hospital	Varian 21EX	DMLC	ECLIPSE V7.5
Memorial Sloan Kettering Cancer Center	Varian Trilogy	DMLC	In-house
Karmanos Cancer Center/Wayne State University	Varian 23EX	DMLC	ECLIPSE V7.5
Karmanos Cancer Center/Wayne State University	Tomotherapy Hi-Art	BinaryMLC	TOMOTHERAPY V3.0
University of California at San Francisco	Siemens Oncor C	SMLC	PINNACLE V8.0d
University of Florida	Elekta Synergy	SMLC	PINNACLE V8.0d
Virginia Commonwealth University	Varian Trilogy	DMLC	PINNACLE V8.0d
Charleston Radiation Therapy Consultants	Siemens Primus	SMLC	PINNACLE V7.4f

variety of linear accelerators, delivery techniques, & planning systems

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Medical Physics, Vol. 36, No. 11, November 2009

TG 119 Multi-Institutional Baseline: Point Dose

TABLE VII. High dose point in the PTV measured with ion chamber: [(measured dose) − (plan dose)]/prescription dose, averaged over the institutions, with associated confidence limits.

Test	Location	Mean	Standard deviation (σ)	Maximum	Minimum
Multitarget	Isocenter	0.001	0.017	0.030	−0.020
Prostate	Isocenter	−0.001	0.016	0.022	−0.026
Head and neck	Isocenter	−0.010	0.013	0.011	−0.036
CShape (easier)	2.5 cm anterior to isocenter	−0.001	0.028	0.038	−0.059
CShape (harder)	2.5 cm anterior to isocenter	−0.001	0.036	0.054	−0.061
Overall combined		−0.002	0.022		
Confidence limit = (|mean| + 1.96σ)				0.045	

σ = ~2-3.6%

largest uncertainty for most complicated plans

TABLE IX. Low dose point in the avoidance structure measured with ion chamber: [(measured dose) − (plan dose)]/prescription dose, averaged over the institutions, with associated confidence limits.

Test	Location	Mean	Standard deviation (σ)	Maximum	Minimum
Multitarget	4 cm inferior to isocenter	−0.008	0.019	0.014	−0.050
Prostate	2.5 cm posterior to isocenter	0.000	0.018	0.030	−0.025
Head and neck	4 cm posterior to isocenter	0.004	0.024	0.061	−0.017
CShape (easier)	Isocenter	0.010	0.024	0.050	−0.037
CShape (harder)	Isocenter	0.009	0.025	0.055	−0.021
Overall combined		0.003	0.022		
Confidence limit (|mean| + 1.96σ)				0.047	

σ = ~2% of prescription

TG 119 Multi-Institutional Baseline: Film

TABLE XI. Composite film: Percentage of points passing gamma criteria of 3%/3 mm, averaged over the institutions, with associated confidence limits.

Test	Location	Mean	Standard deviation (σ)	Maximum	Minimum	Number of submissions
Multitarget	Isocenter	99.1	0.9	100	97.5	8
Prostate	Isocenter	98.0	2.24	99.8	94.2	7
	2.5 cm posterior	93.2	7.6	99.9	85	3
Head and neck	Isocenter	96.2	3.0	100	92.4	8
	4 cm posterior	97.6	1.5	98.9	95.6	4
CShape (easier)	Isocenter	97.6	3.9	100	88.9	7
	2.5 cm anterior to isocenter	93.9	5.0	99.6	87.9	5
CShape (harder)	Isocenter	94.4	6.0	99.4	86.2	5
	2.5 cm anterior to isocenter	93.0	7.2	99.9	81.3	5
Overall combined		96.3	4.4			
Confidence limit = (100 − mean) + 1.96σ				12.4 (i.e., 87.6% passing)		

TABLE XIII. Per-field measurements: Average percentage of points passing the gamma criteria of 3%/3 mm, averaged over the institutions, with associated confidence limits.

Test	Mean	Standard deviation (σ)	Maximum	Minimum
Multitarget	97.8	3.5	99.8	90.8
Prostate	98.6	2.4	100	93.3
Head and neck	98.1	2.0	100	94.2
CShape (easier)	97.4	2.8	99.8	93.0
CShape (harder)	97.5	2.6	99.9	94.0
Overall combined	97.9	2.5		
Confidence limit = (100 − mean) + 1.96σ		7.0 (i.e., 93.0% passing)		

3. Dosimetric verification per plan / site

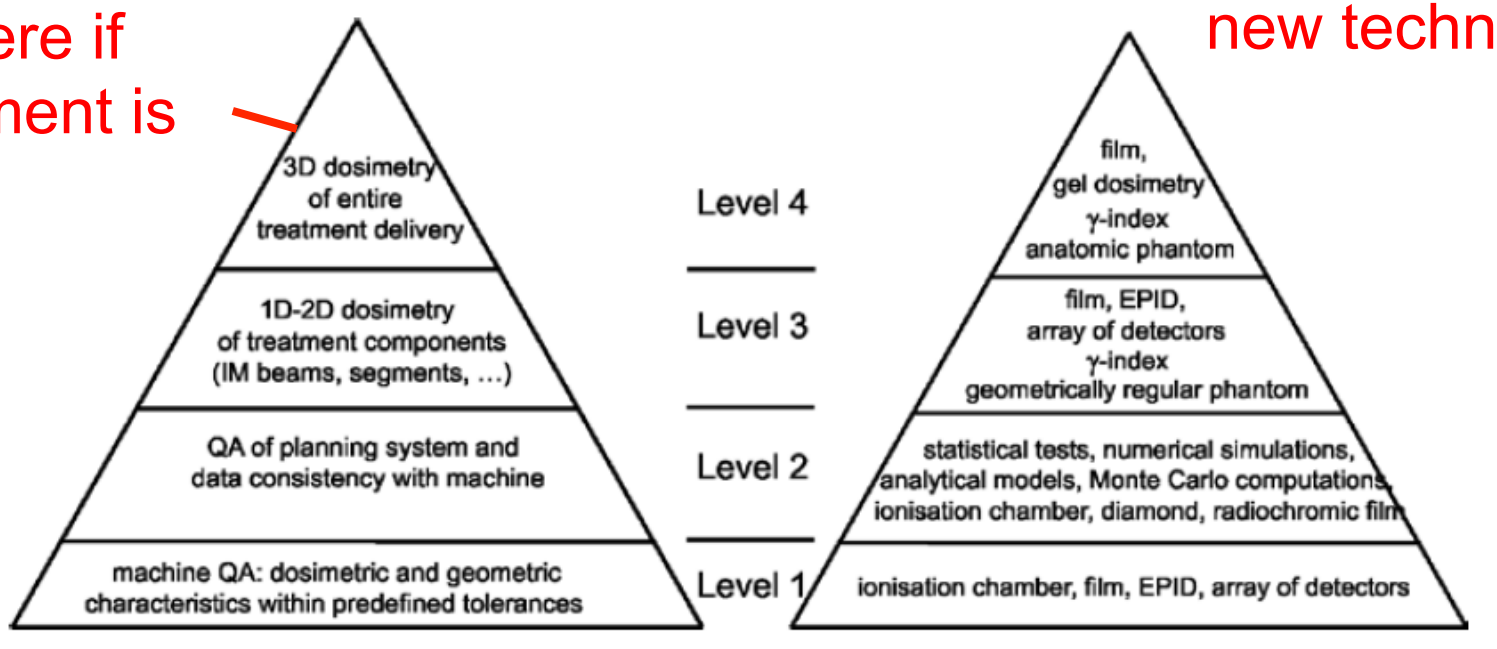
Dosimetric verification per planning site

What to do when a new IMRT treatment technique is to be introduced (if it is relatively unique from current practice):

- prepare a sample of representative treatment plans
  - solidify details for treatment planning, delivery, & QA processes
- make a thorough set of verification measurements for the sample plans
- *goal is be confident of the robustness & dosimetric accuracy for the new technique*

Suggested Layers of Quality Assurance:

stop here if agreement is good



introducing a new technique:

work from top down

if discrepancies exist, move down the list until the problem is resolved

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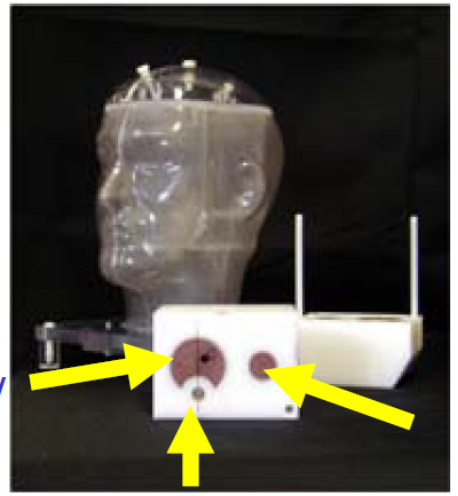
4. Independent QA / Credentialing

Independent QA / Credentialing

- Imaging and Radiation Oncology Core (IROC) (formerly RPC) offers independent QA services
  - absolute dose output check
  - IMRT phantoms (point dose & film measurement) used to credential for clinical trials
- Alternative: cross check absolute dose measurement with another (nearby) radiation oncology center

Head and Neck Phantom



The head and neck phantom consists of the following:

Primary PTV containing 4 TLD

Secondary PTV containing 2 TLD

Organ at risk containing 2 TLD

GafChromic® film in axial and sagittal planes

IMRT Head and Neck Phantom Irradiations: Correlation of Results with Institution Size

Andrea Molineu, Nadia Hernandez, Paola Alvarez, David S. Followill, and Geoffrey S. Ibbott
Department of Radiation Physics
The University of Texas, M.D. Anderson Cancer Center, Houston, Texas

RPC Radiological Physics Center

5. Pre-treatment verification

Preparing for Pre-Treatment Verification

- Determining a pre-treatment verification procedure should be performed as part of IMRT commissioning
- Similar measurement tools can be used as those used to verify dose during IMRT commissioning

Pre-treatment verification

Commissioning: need to determine methods & criteria for per-plan pre-treatment verification

1. what detector & geometry? phantom / air?
    1. is the measurement noise at an acceptably low level?
    2. is the detector & geometry adequately sensitive to dose discrepancies
2. what comparison analysis to be used?
    1. dose difference (1D, 2D, & 3D)
    2. distance to agreement (2D & 3D)
    3. gamma analysis (1D, 2D, & 3D)
    4. others?
3. what acceptance criteria is acceptable / expected?

Dose Delivery Verification Methods

Phantom based verification:

1. IMRT plan is recalculated on the “phantom” geometry to be used for verification measurements
2. Plan is delivered in phantom geometry & dose measured
3. Planned & delivered dose are compared

- 1D:
  - Point dose & dose profiles measurements
  - Ion chambers
- 2D:
  - Radiographic film
  - Radiochromic film
  - Computed radiography
  - Detector arrays
    - Ion chamber / diode detector arrays
    - EPIDs
- 2D+:
  - Detector arrays in multiple planes
- 3D:
  - Gel dosimeters
  - Polyurethane dosimeters

Point Dose Verification with Ion Chamber: Procedure

1. Measure charge at known conditions (Q_{ref}) (10x10cm field, reference SSD & depth, etc.)
2. Measure charge at point in IMRT plan (Q_{IMRT})
3. $D_{IMRT} = D_{ref} \times Q_{IMRT} / Q_{ref}$
4. Compare measured D_{IMRT} to D_{IMRT} from the TPS

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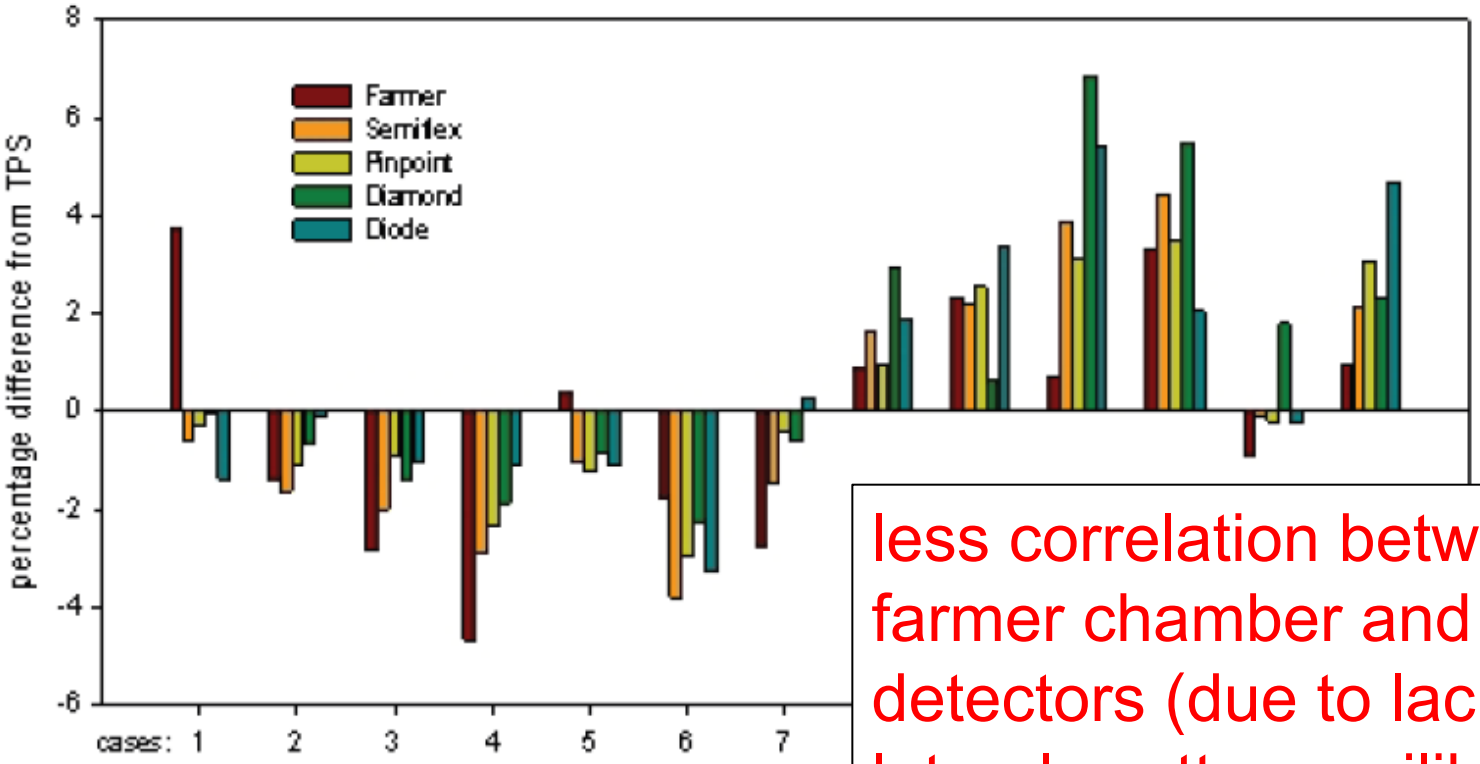
Point dose verification via ion chamber



less correlation between farmer chamber and other detectors (due to lack of lateral scatter equilibrium)

Figure 3.2 Relative differences between dose values measured with various types of detectors and calculations performed with two types of TPS. Cases 1-7 were irradiated with step-and-shoot techniques, while cases 8-13 represent sliding window IMRT treatments

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Point Dose Verification with Ion Chamber: Uncertainties

- Differences in stopping power ratios (between IMRT & reference conditions) can be assumed to be negligible
- Dose differences up to 9% can exist for measurements in penumbra region & small IMRT segments
- Minimize errors by:
  - Using small volume ion chamber
  - calculating dose to a volume rather than a point in the TPS
  - avoid measurement in areas with large dose gradient
- Using a small volume chamber, standard uncertainty is 1.0-1.5%

Point Dose Verification: Other Detector Choices

Solid state detectors:

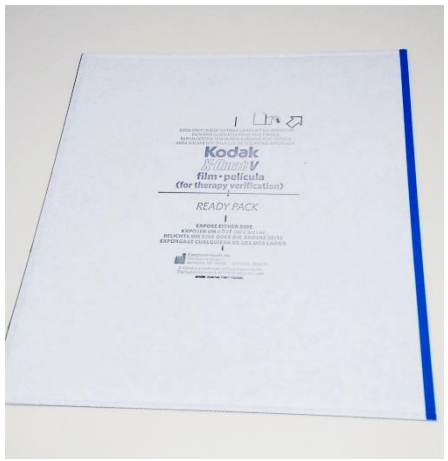
- energy & dose rate dependence cause uncertainties
- diamond detectors not recommended for IMRT verification due to required pre-irradiation dose

2D Verification: Measurement Options

- Integrating Measurements
  - Radiographic film (silver halide)
  - Radiochromic film (radiation sensitive dye, e.g. diacetylene monomer)
  - Computed radiography
- 2D Arrays
  - Diode / ion chamber arrays
  - Electronic Portal Imaging Devices

2D Verification: Radiographic Film

- High spatial resolution
- EDR2 preferred over XV2 due to increased dose range
  - XV2 saturates above 2Gy
- Uncertainties exist due to lack of water equivalence & energy dependence
  - can be minimized by measuring perpendicular to beam at set depth
- Requires measurement of sensitometric calibration curve



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2D Verification: Radiochromic Film

- Nearly tissue equivalent-> eliminates energy & directional dependence
- Auto processing
- Scanned with flatbed scanner-> maximum absorption in red, hence red channel often used exclusively
- GafChromic EBT dose range: 2-800cGy

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2D Verification: Radiochromic Film

Table 3.1 Working protocol for EBT radiochromic film dosimetry using a flatbed scanner (from Stuertewagen *et al*., 2008).

EPSON scanner protocol	EBT Gafchromic film protocol
Use a positioning frame to position the films on the same place	Use gloves to handle the films
Remove the positioning frame during scanning	Use tight-light envelopes for storage
Perform at minimum 5 successive scans before real measurements	Cut film pieces at minimum one day prior to irradiation
Turn the scanner off between the measurements	Use the films in portrait orientation
Use the same specifications in the EPSON software: professional mode, transparent document type, set 48-bit. colour correction off; select 150 dpi resolution	Scan the films before and after irradiation and use the net optical density for dosimetric evaluation
	After irradiation wait at least 4 hours to scan the films
	Use/select the red colour channel
	Use MatLab software to obtain and process the measured pixel-values; including a 2D correction for scanner inhomogeneities (due to variations in light scattering).

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2D Verification: Radiochromic Film

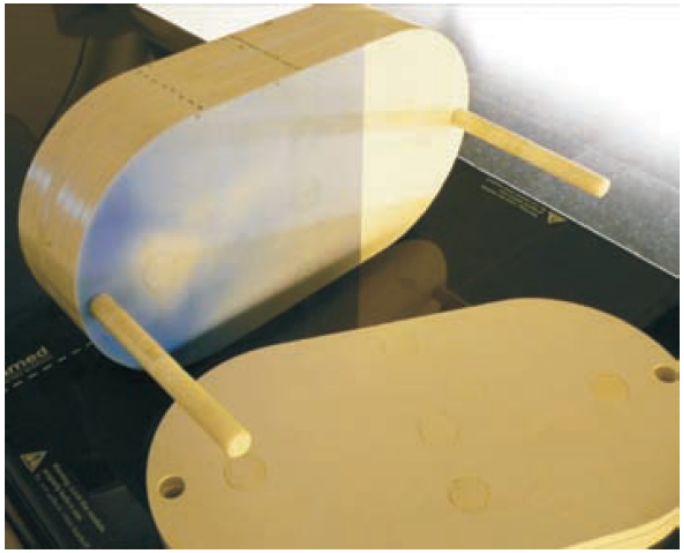

Figure 3.6 QUASIMODO CarPet phantom with Gafchromic EBT film after the delivery of a 5-arc IMAT treatment of an elongated tumour adjacent to the thorax wall.

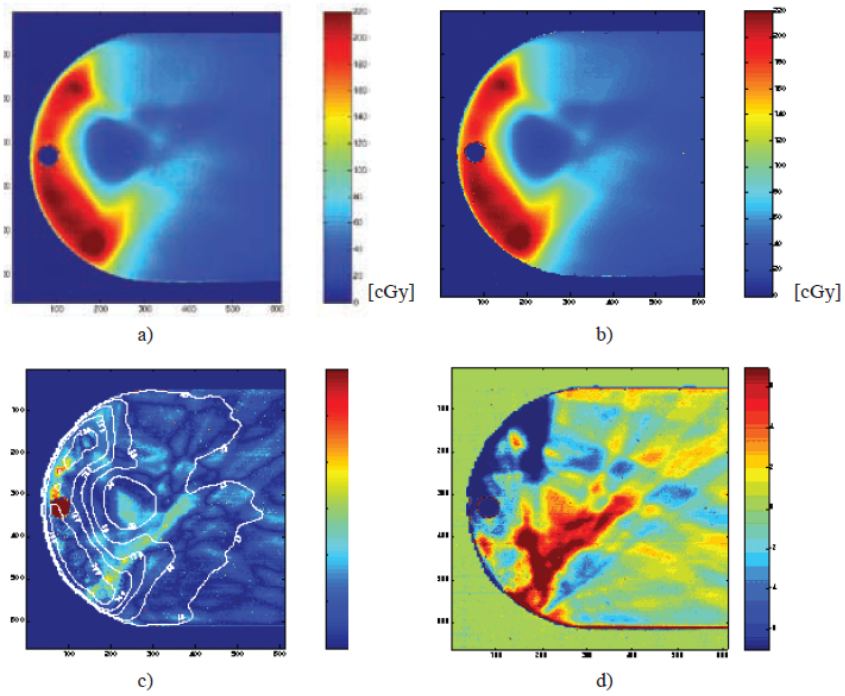

Figure 3.7 Comparison of a) computed and b) measured dose distribution using radiochromic film in the transverse plane through the isocentre. Panel c) shows the distribution of gamma values (3%, 3 mm) on which computed isodose lines have been superimposed. Panel d) shows the film-measured dose (panel b) minus the computed dose (panel a) expressed as a percentage of the reference dose (200 cGy).

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TG69: Radiographic film for megavoltage beam dosimetry (2007)
ESTRO Guidebook 9: GUIDELINES FOR THE VERIFICATION OF IMRT (2008)

Computed Radiography Film

- Active layer: photostimulable phosphor ($BaSrFBr:Eu^{2+}$)
- Inserted in light tight envelope to avoid signal decay from room light exposure
- semi-logarithmic dose response up to 150cGy
- energy dependent leads to over-response of low energy scatter

2D Arrays:

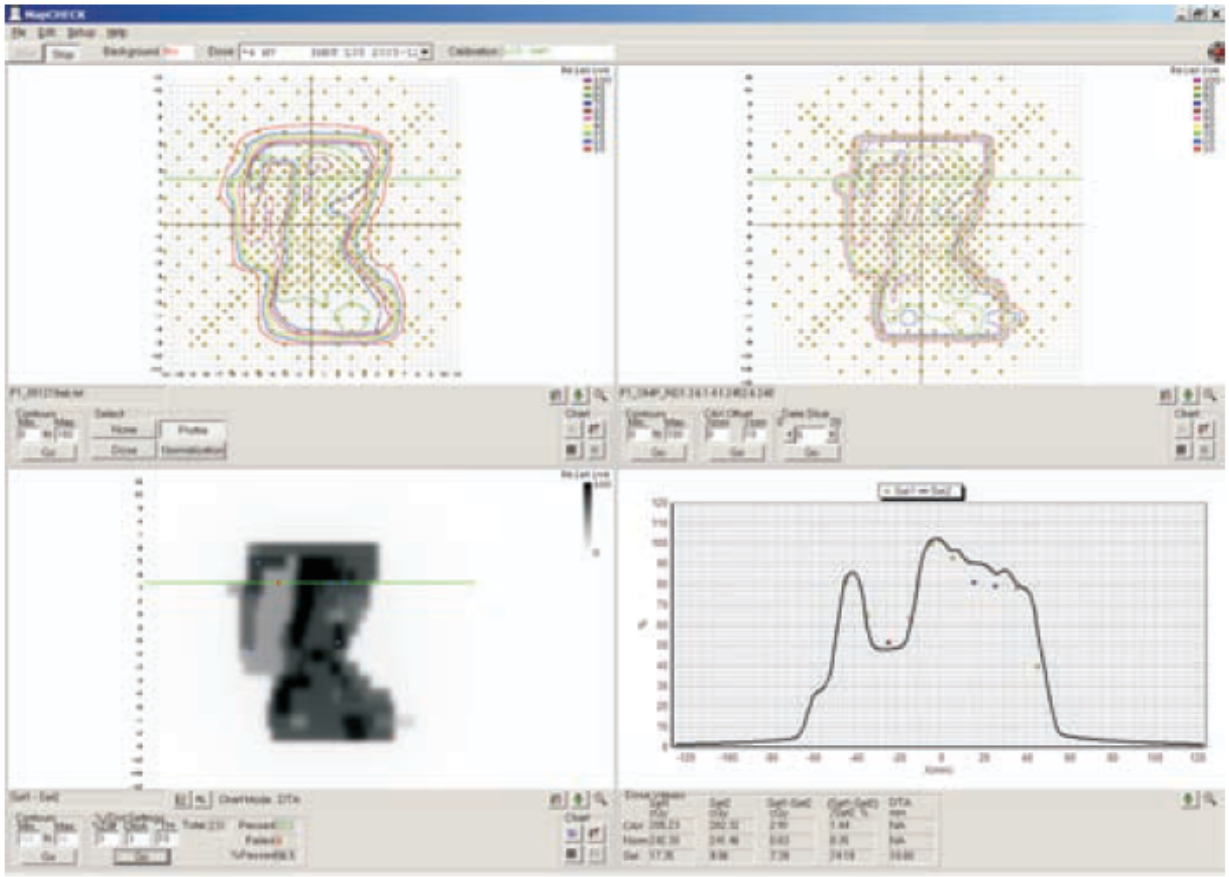

Figure 3.9 Verification of an IMRT treatment using a 2D detector array. Top left: measured isodose lines; top right: isodose lines calculated by the TPS. Bottom left: gamma evaluation of the two dose distributions; bottom right: beam profiles along the horizontal green line. At some points differences between the measured dose and the dose calculated by the TPS can be observed due to the finite spatial resolution of the detector array.

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2D Detector Arrays

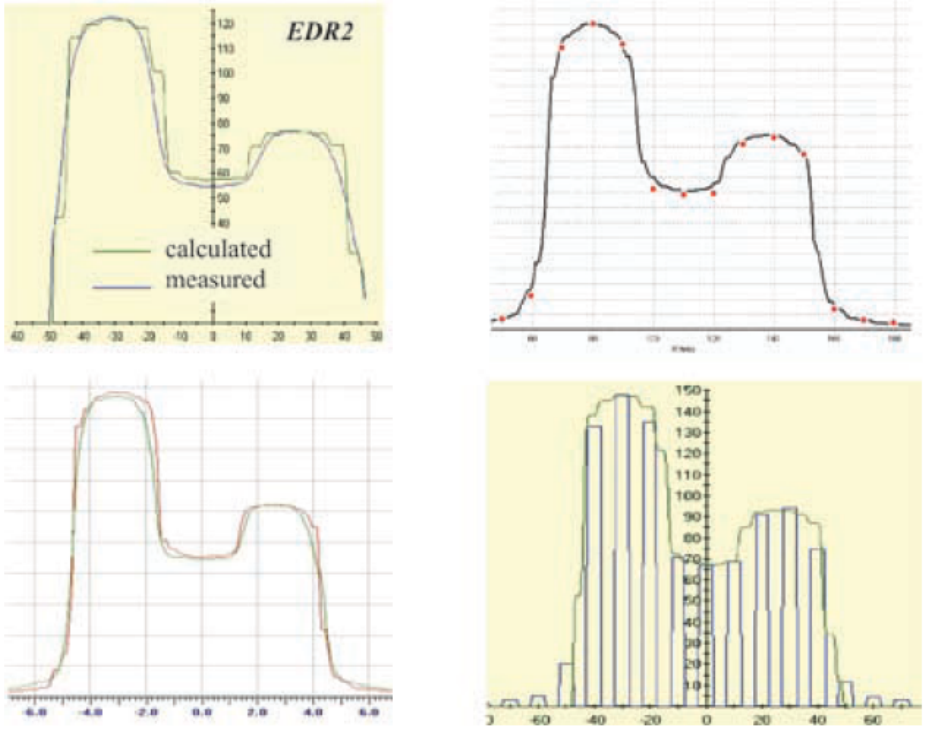

Figure 3.8 Example of an IMRT verification (for the same intensity profile) performed with different commercial 2D detector arrays. All intensity profiles marked as "calculated" refer to IM profiles obtained with the TPS. Measurements were made at 10cm water equivalent depth with radiochromic film (EDR2, left upper), a diode array (Mapcheck, right upper), a scintillation detector (I'mRT, left lower) and an ionisation chamber array (Seven29, right, lower). The 10 cm water equivalent depth included the inherent build-up of the 2D detector arrays. For comparison EDR2 film measurements are shown as well (from Wiezorek *et al.*, 2005).

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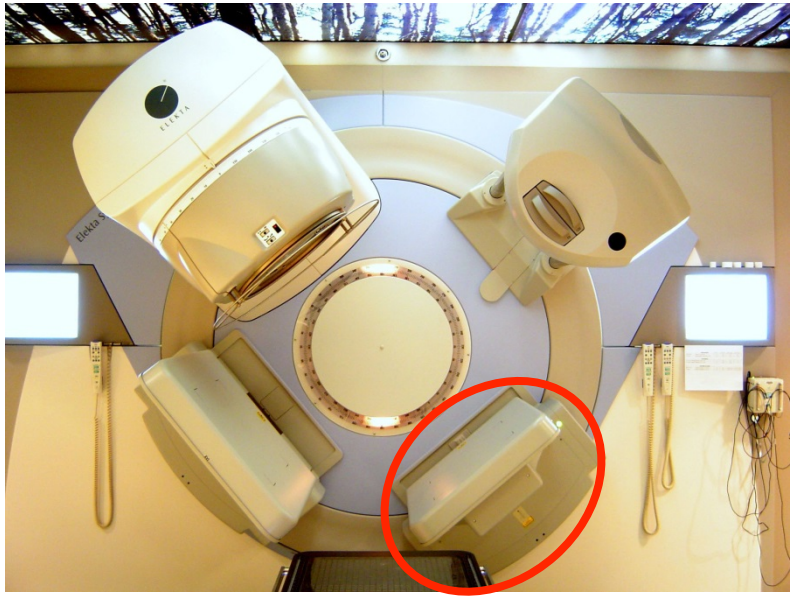
EPIDs

- CCD camera based systems (Philips SRI-100)
- Liquid filled matrix ion chamber (Varian, old design)
- **Amorphous Silicon (a-Si) flat panel**
  - Fast response
  - High spatial resolution
  - Subject to ghosting artifacts
  - Energy dependence



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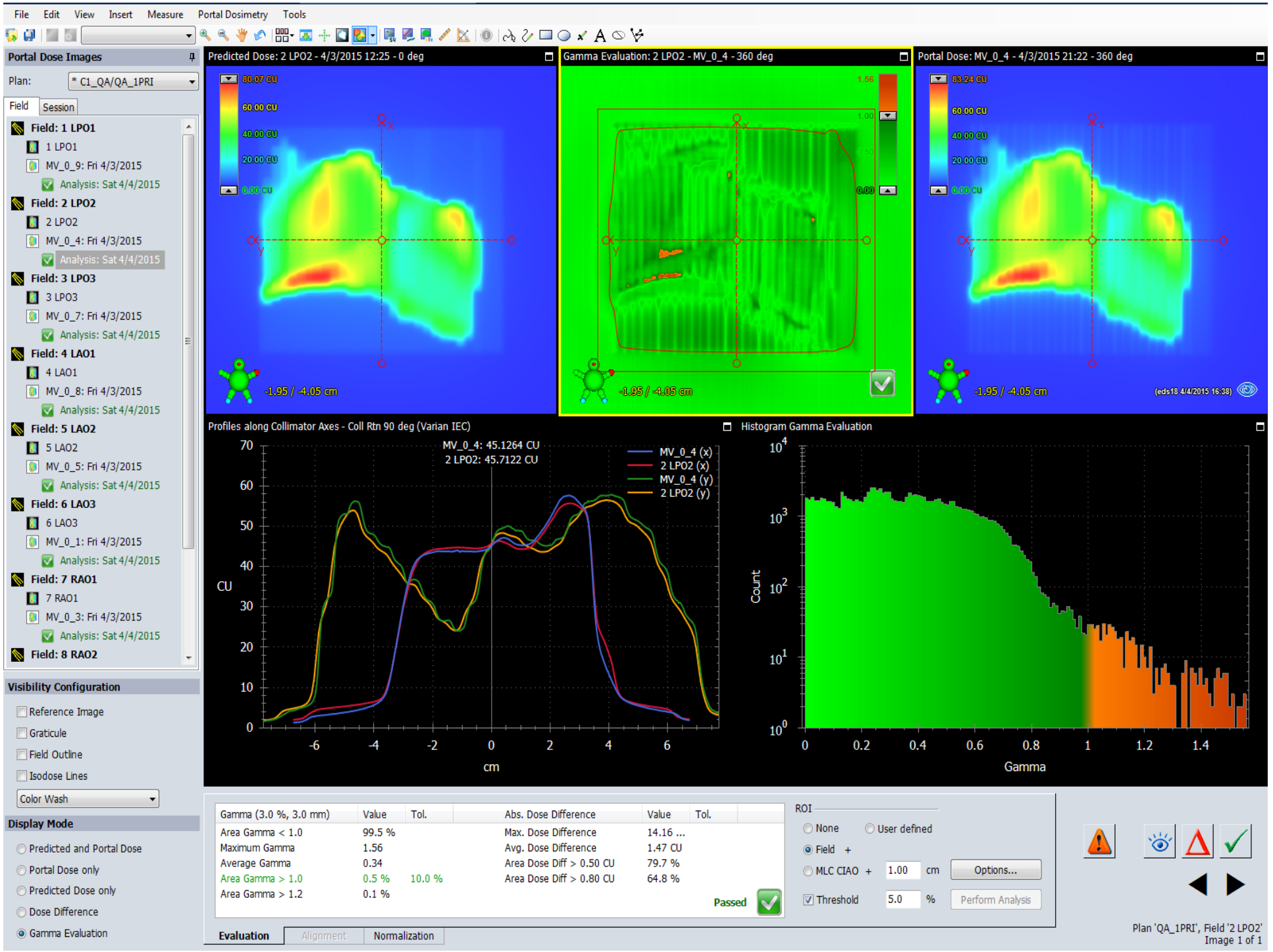
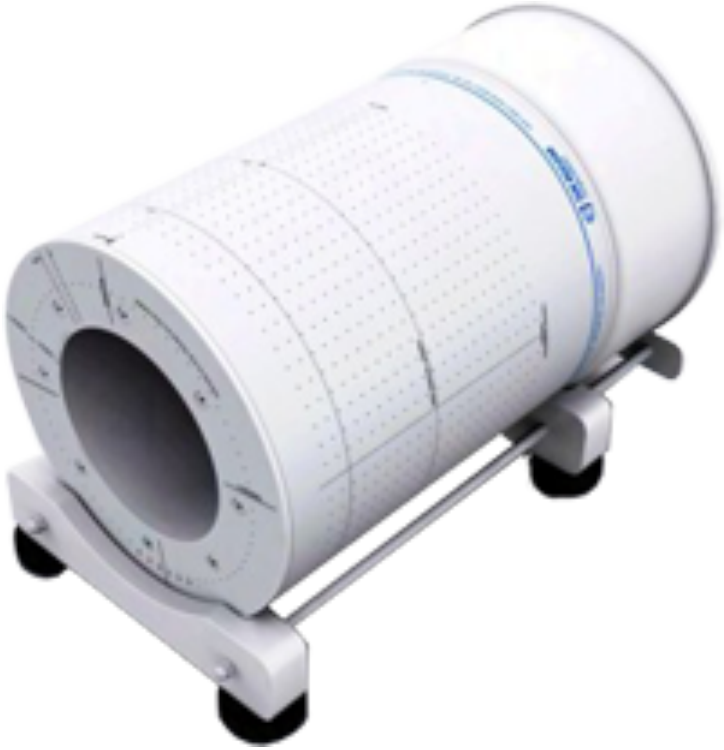
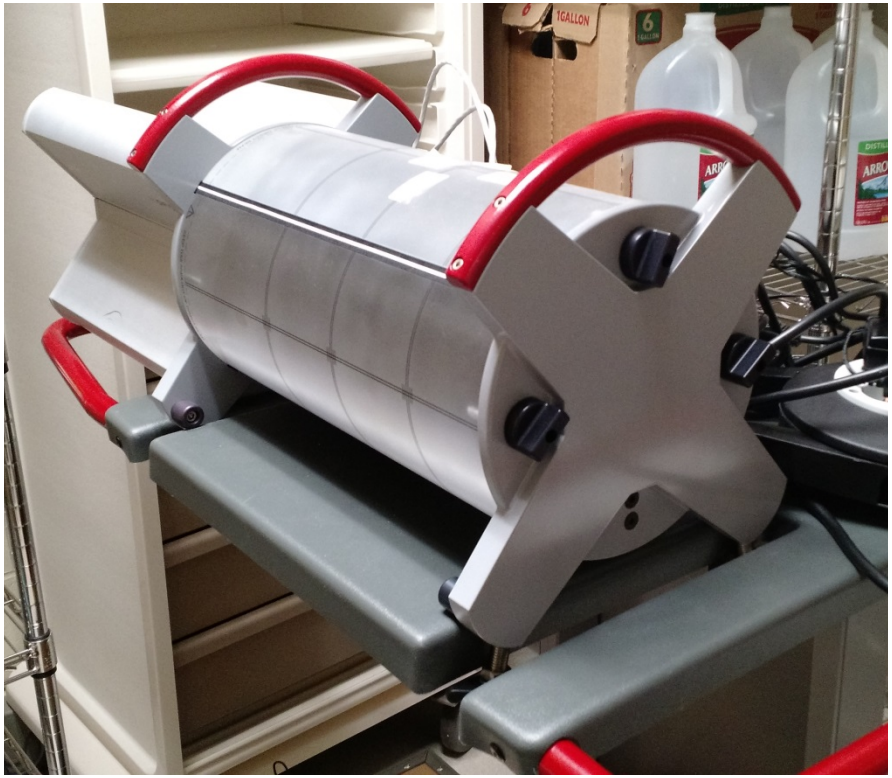
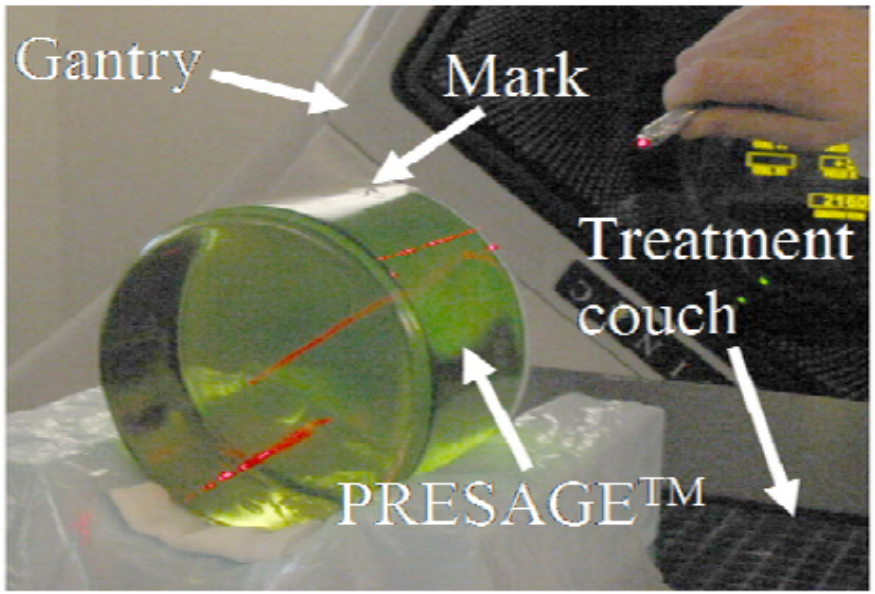

File Edit View Insert Measure Portal Dosimetry Tools
Portal Dose Images
Plan: * C1_QA/QA_1PRI
Field Session
Field: 1 LPO1
1 LPO1
MV_0_9: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 2 LPO2
2 LPO2
MV_0_4: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 3 LPO3
3 LPO3
MV_0_7: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 4 LAO1
4 LAO1
MV_0_8: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 5 LAO2
5 LAO2
MV_0_5: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 6 LAO3
6 LAO3
MV_0_1: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 7 RAO1
7 RAO1
MV_0_3: Fri 4/3/2015
Analysis: Sat 4/4/2015
Field: 8 RAO2
Predicted Dose: 2 LPO2 - 4/3/2015 12:25 - 0 deg
80.07 CU
60.00 CU
40.00 CU
20.00 CU
-1.95 / -4.05 cm
Gamma Evaluation: 2 LPO2 - MV_0_4 - 360 deg
1.56
1.00
0.50
0.00
-1.95 / -4.05 cm
Portal Dose: MV_0_4 - 4/3/2015 21:22 - 360 deg
83.24 CU
60.00 CU
40.00 CU
20.00 CU
-1.95 / -4.05 cm
(eds18 4/4/2015 16:38)
Profiles along Collimator Axes - Coll Rtn 90 deg (Varian IEC)
MV_0_4: 45.1264 CU
2 LPO2: 45.7122 CU
MV_0_4 (x)
2 LPO2 (x)
MV_0_4 (y)
2 LPO2 (y)
CU
cm
Histogram Gamma Evaluation
Count
Gamma
Visibility Configuration
Reference Image
Graticule
Field Outline
Isodose Lines
Color Wash
Display Mode
Predicted and Portal Dose
Portal Dose only
Predicted Dose only
Dose Difference
Gamma Evaluation
Gamma (3.0 %, 3.0 mm) Value Tol.
Area Gamma < 1.0 99.5 %
Maximum Gamma 1.56
Average Gamma 0.34
Area Gamma > 1.0 0.5 % 10.0 %
Area Gamma > 1.2 0.1 %
Abs. Dose Difference Value Tol.
Max. Dose Difference 14.16 ...
Avg. Dose Difference 1.47 CU
Area Dose Diff > 0.50 CU 79.7 %
Area Dose Diff > 0.80 CU 64.8 %
Passed
ROI
None
User defined
Field +
MLC CIAO + 1.00 cm
Options...
Threshold 5.0 %
Perform Analysis
Evaluation
Alignment
Normalization
Plan 'QA_1PRI', Field '2 LPO2'
Image 1 of 1

2D+ Arrays:
Detector arrays in multiple axes





3D Dosimetry



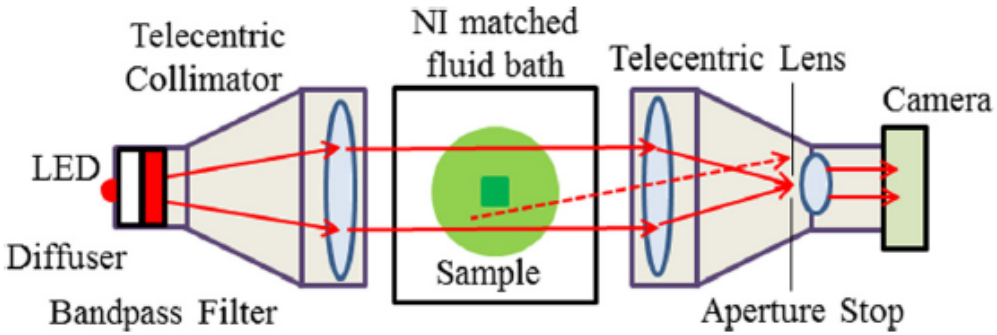


FIG. 1. Duke large field-of-view optical-CT scanner (DLOS). Light is collected by the matched telecentric imaging lens, which forms a precise image only from light rays that are parallel to the optic axis (with a 0.1° tolerance due to the aperture stop). Note rejected light rays due to the aperture such as the dashed scattered line. Each pixel in the image, measures the line-integral of optical attenuation through the dosimeter, with negligible scatter contamination upstream of the imaging lens.

New 3D dosimeters have overcome many of the challenges of prior 3D dosimeters: rigid, high resolution, no signal dispersion, no oxygen dependence

Dose can be read out quickly with new telecentric lens optical CT

DukeMedicine

Medical Physics, Vol. 38, No. 8, August 2011

Journal of Physics: Conference Series **56** (2006) 221–224

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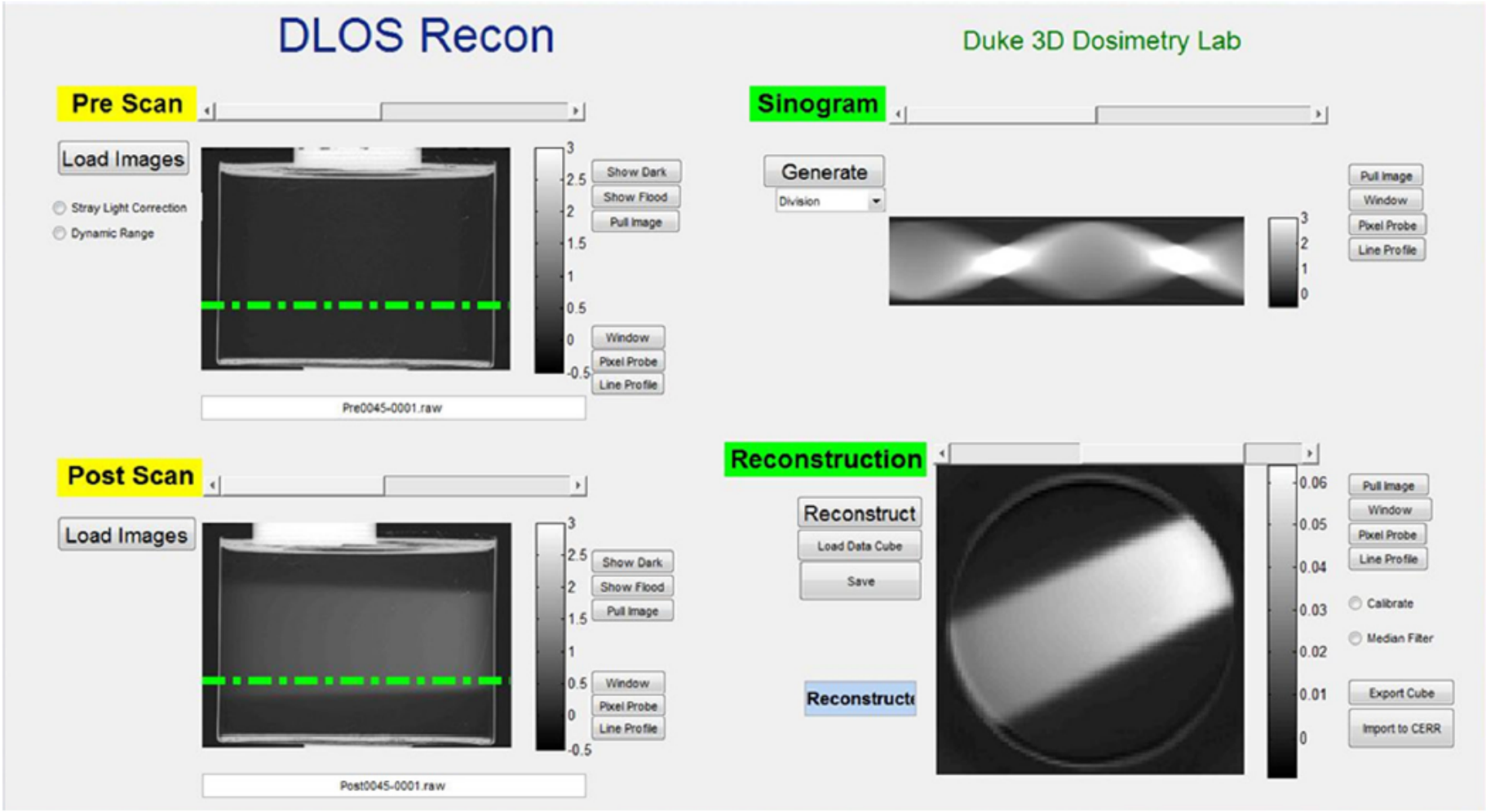
3D Dosimetry



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Medical Physics, Vol. 38, No. 8, August 2011

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- ESTRO Guidebook 9: GUIDELINES FOR THE VERIFICATION OF IMRT (2008)
- AAPM:
  - Report 82: Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee (2003)
  - TG119: IMRT commissioning: Multiple institution planning and dosimetry comparisons (2009)
  - TG120: Dosimetry tools and techniques for IMRT (2011)