Dosimetry Metrology for IMRT

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The Department of Radiation Oncology
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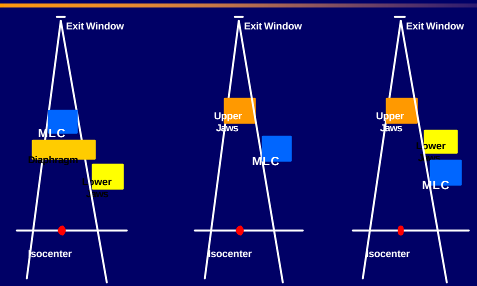
Outline

- Acceptance testing
- Detectors for commissioning
- Phantoms
- Dosimetry analysis tools
- Commissioning tests
  - Varying complexity and geometry
- Potential Pitfalls
- Summary

Acceptance

- Prior to purchase and installation, review manufacturer's acceptance tests
- If needed, adapt tests and tolerances with manufacturer in purchase order
- Test basic functionality of equipment
- Tests may be dependent on the MLC design

Collimator Designs

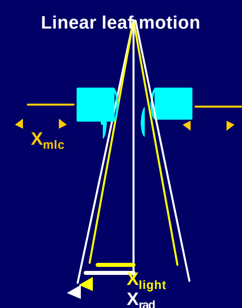


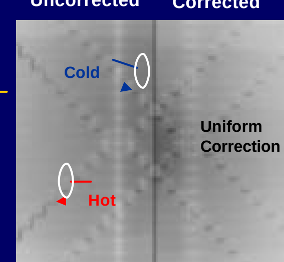
Elekta Siemens Varian

Physical MLC Characteristics

	Elekta	Siemens	Varian
Field Width	40x40 cm^2	40x40 cm^2 (40x27 cm^2)	40x40 cm^2
Leaf ends	Rounded	Divergent	Rounded
Leaf width	1 cm	1 and 6.5 cm	0.5 and 1 cm
Length	32.5 cm	31 cm	16 cm (14.5 cm Carriage)
Inter-digitation	No =1 cm gap	No	Yes

Effect of Rounded Leaf Ends & Linear Motion





Graves 2001

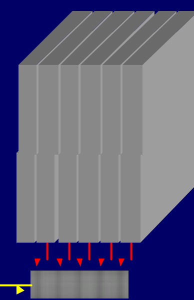
Leaf position offset = Xrad-Xlight

Static MLC Testing

- Carriage skew
  - Orientation of MLC carriages in the accelerator head
  - Determined by measurement with feeler gauges for very small field size
  - Important to prevent collisions especially for systems with interdigitation of leaves
  - Verify with film
- Alignment of each leaf bank to central axis
- Leaf position reproducibility and accuracy
  - Verify with graph paper

MLC Transmission

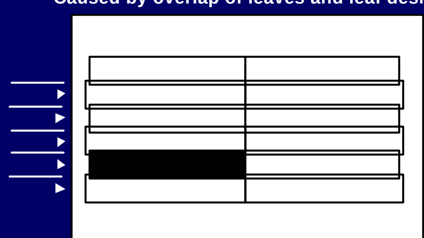
- Dependent on system design
- Values range from 1.5 to 3% for midleaf and interleaf transmission



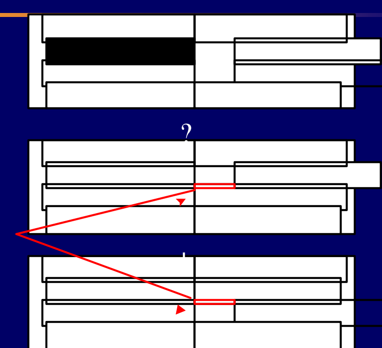
Film exposed under closed leaves
Evaluate compared to open field

Tongue and Groove Effect

Caused by overlap of leaves and leaf design

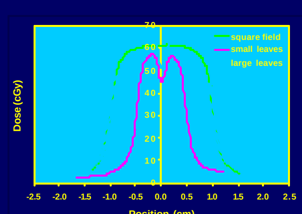


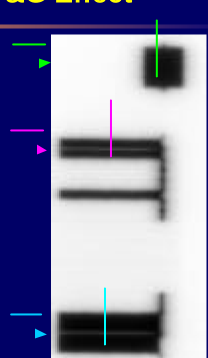
Uniform Square Field Illustration of TG Effect



Cold Spots from T&G Effect

~25% cold spot where leaves overlap





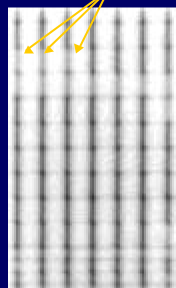
DMLC and/or SMLC Mode Tests

- Leaf speed
- Dose rate evaluation
- Leaf position tolerance and reproducibility
- Leaf acceleration and deceleration
- Rounded leaf tip transmission
- Beam stability (output, flatness, symmetry, linearity)
- Interrupted treatments

Example Test: FenceTest

- All leaves move across field and deliver dose to small field gap (0.1 or 0.2 cm)
- Sensitive to errors of 1 mm in leaf position

Multiple incorrect leaf positions



Equipment and Software for IMRT Commissioning

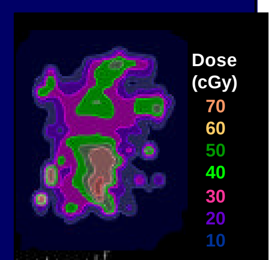
- Ideal measurement system:
  - Excellent spatial resolution, accuracy, tissue equivalent response, provide 3-D data, portable to multiple phantoms, and easy to use
- Multiple detectors required
  - Verifying IMRT fields is more complex than static fields
  - Profiles along major axes in a water phantom are insufficient for characterizing systems
  - Profiles are also time-consuming to obtain in water phantom for IMRT delivery

Equipment

- Depth dose and profiles in water
  - Ion chamber – required for absolute dose measurements
  - Ion chamber or linear diode array
  - Note: Depth dose curve measurements must be made with a repeat delivery for each datapoint on the curve (delivery stability)
- Detector arrays are useful for profile measurements in water but 2-D detectors are still required
- 2-D measurement methods
  - Film
  - Detector arrays

Detector Characterization

- Linearity
- Energy dependence
- Stem and cable effects
- Angular response
- Calibrated if for absolute measurements
- Small field detectors required for small field characterization
  - Sensitive to position
  - Detector should be smaller than homogeneous region of dose to be measured



1-D Detector Characteristics

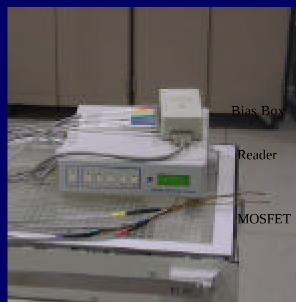
Detector	Measurement Volume (cm³)	Sensitive Area (cm²)	Diameter (cm)	Thickness (cm)	Effective Point of Measurement (cm)
Micro-chamber	0.009	0.24	0.6	NA	0.2
p-type Si diode	0.3	0.49	0.4	0.06	0.6
Stereotactic diode	NA	0.011	0.45	0.006	0.07
Pinpoint chamber	0.015	0.010	0.2	NA	0.06
MOSFET	NA	0.04	NA	0.1	NA
Diamond	0.0019	0.056/0.073	0.73	0.026	0.1

1-D Detectors

DETECTOR	DISADVANTAGES
Micro-chamber	Poorer resolution than diodes
p-type Si diode	Over-respond to low energy photons Martens et al. 2000
Stereotactic diode	
Pinpoint chamber	
MOSFET	Non-linear dose response for <30 cGy Chuang et al 2002
Diamond	< resolution than diodes, expensive, Rustgi et al, Laub et al

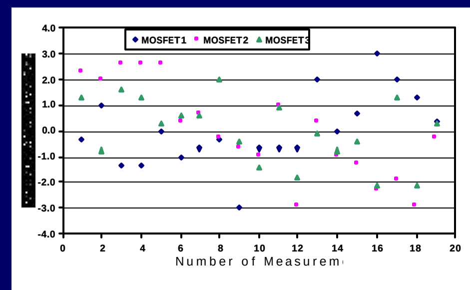
MOSFET System

- Excellent spatial resolution
- Automatic and immediate readout
- Can be re-used immediately
- Linear dose response
- Response independent of depth



C. Chuang, UCSF

MOSFET Consistency

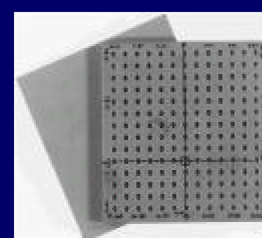


Cynthia Chuang, UCSF

TLDs

- TLDs must be characterized
  - Time consuming
- Reusable
- Achievable accuracy: 2-3%
- Automatic reader required for multiple TLD measurements

TLD Holder for Phantom Measurements



D.A. Low et al. "Phantoms for IMRT Dose Distribution Measurement and Treatment Verification, Int J Radiat Oncol Biol Phys 40: 1231-1235 (1998).

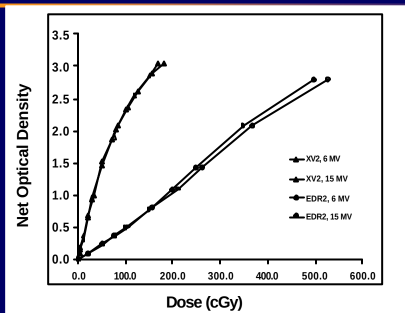
2-D Detectors

- Film
  - Radiographic: XV and EDR
  - Radiochromic
- Beam imaging system, CCD, SLIC, AMFPI
  - EPID systems attached to gantry
  - Investigated more for pre-treatment QA currently

Radiographic Film

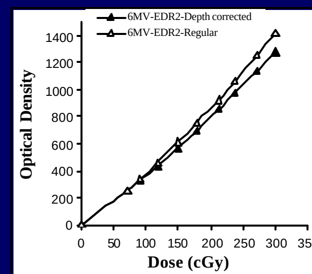
- Advantages
  - Excellent spatial resolution
  - Readily available
  - Less expensive than other 2-D systems
- Disadvantages
  - Over-response to low energies
  - Dependent on QA of film batch
  - Dependent on processor and digitizer QA
  - Sensitive to storage conditions
  - Need to measure the response to dose for each experiment

XV vs EDR Film



Chetty and Charland "Investigation of Kodak EDR film for megavoltage photon beam dosimetry" PMB 47: 3629-3641 (2002).

Depth Dependence of EDR Film



Dogan et al "Comparative evaluation of Kodak EDR2 and XV2 films for verification of intensity modulated radiation therapy," PMB 47: 4121-4130 (2002).

Radiochromic Film: Advantages

- Decreased sensitivity to low energy photons compared to radiographic film
- No processing
  - Film changes color with irradiation
- Insensitivity to visible light
- High spatial resolution

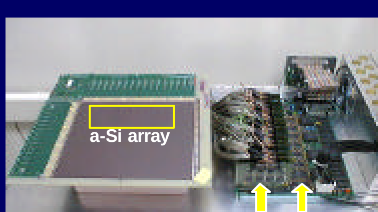
Niroomand-Rad et al. "Radiochromic film dosimetry: recommendations of AAPM Radiation Therapy Committee Task Group 55," Med Phys 25: 2093-2115.

Radiochromic Film: Disadvantages

- Non-uniform film response
  - Can be minimized by using double-exposure technique
- Response dependent on time and temperature
- More expensive than radiographic film
- Digitizer response is dependent on the light source of the digitizer and may need to be modified

Niroomand-Rad et al. "Radiochromic film dosimetry: recommendations of AAPM Radiation Therapy Committee Task Group 55," Med Phys 25: 2093-2115.

Active Matrix Flat Panel Dosimeter (AMFPD)



Preamplifiers AD converters

512 x 512 pixels

0.508 mm pitch

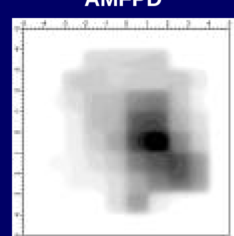
26.0 x 26.0 cm^2

Direct Detection
-No fluorescent screen

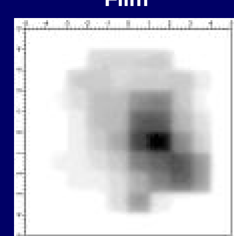
El-Mohri, et al. "Relative dosimetry using active matrix flat-panel imager (AMFPI) technology," Medical Physics 26, 1999.

Example: SMLC Delivery

AMFPD



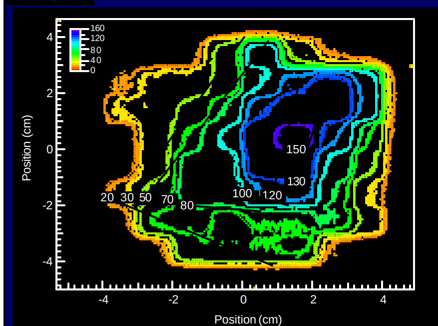
Film



Non-commercial system
AMPFD at 10 cm depth in solid water

184 mu
600 mu/min
d=10 cm

Example: SMLC Delivery



Film
AMFPD

184 mu
600 mu/min
d=10 cm

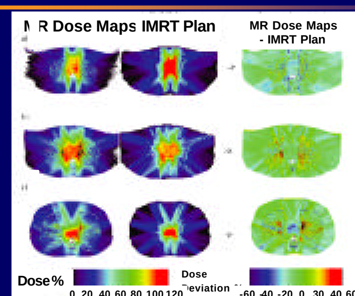
Gel Dosimetry: Advantages

- Obtain 3-D information in one irradiation
- Gels can be prepared with different density therefore ideal for heterogeneous measurements
- Gel can be used in containers of different shapes
- Ideal for anthropomorphic phantoms

Gel Dosimetry: Disadvantages

- Sensitive to many factors such as time, preparation, temperature
- Optical reader requires cylindrical container for gel
- MR time is often limited and expensive (unless dedicated scanner)
  - Long scan times are required to increase accuracy of readout
  - E.g. 5% accuracy over 10 hr scan time (Gum et al 2002)
- Interface of gel and container results in less accurate readout at edges of the gel
- Not ready for routine use in the community

Gel Dosimetry



Gum et al. "Preliminary study on the use of an inhomogeneous anthropomorphic Fricke gel phantom and 3D magnetic resonance dosimetry for verification of IMRT treatment plans" PMB 47: N67-N77 (2002).

Considerations for Phantoms

- Fiducials for reproducible setup of phantom and detectors
- Flexibility to accommodate different detectors
- Simple vs. anthropomorphic
- Homogeneous or heterogeneous

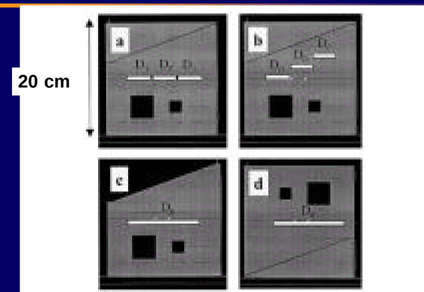
Water Tank

- Restricted to gantry at 0 degrees
  - Unless mylar window for 90 degrees
- Flexibility in chamber position
- Important for basic depth dose and profile measurements
- Output, flatness, symmetry, and linearity assessment

Water-equivalent Plastics

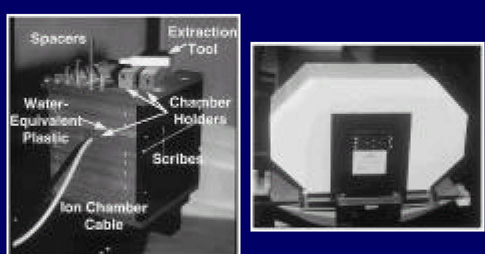
- Flat phantoms with custom chamber inserts
  - Accommodate film at multiple depths
  - Detector position only varies with depth
- Cylindrical phantoms (plastic or water filled)
  - Ion chamber at single position
  - Possibly hold films
- Can be customized to hold various detectors and have multiple positions

Simple Geometric Phantom



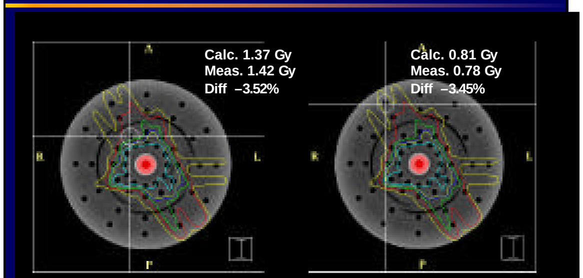
Van Esch et al. "Acceptance tests and QC procedures for the clinical implementation of IMRT using inverse planning and the sliding window technique: experience from five radiotherapy departments," Radiother Oncol 65: 53-70 (2002).

IMRT Verification Phantom



D.A. Low et al. "Phantoms for IMRT Dose Distribution Measurement and Treatment Verification, Int J Radiat Oncol Biol Phys 40: 1231-1235 (1998).

Cylindrical Phantom: Ion Chamber and MOSFETs



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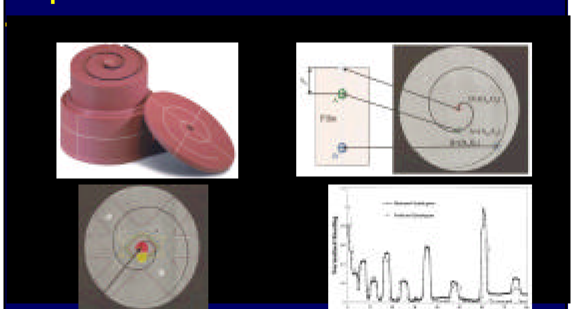
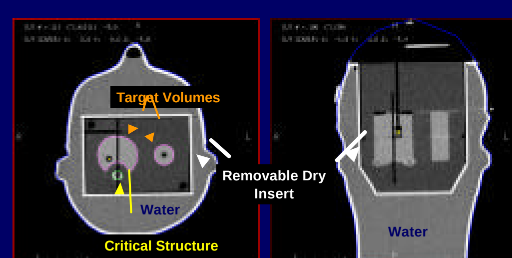
Spiral Phantom for Dosimetric Verification



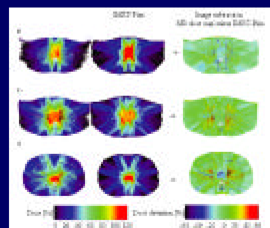
Paliwal et al "A spiral phantom for IMRT and tomotherapy treatment delivery verification" Medical Physics pp. 2503-2507 (2000).

RPC Head Phantom



TLDs in Target Volumes
Radiochromic film through multiple plans
Delivery is required by RTOG for participation in IMRT trials

Anthropomorphic Phantom for Gel Dosimetry



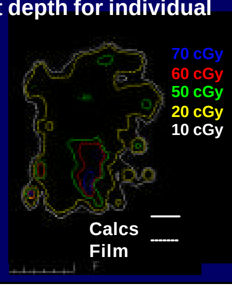
Gum et al. “Preliminary study on the use of an inhomogeneous anthropomorphic Fricke gel phantom and 3D magnetic resonance dosimetry for verification of IMRT treatment plans” PMB 47: N67-N77 (2002).

Dosimetry Analysis Software

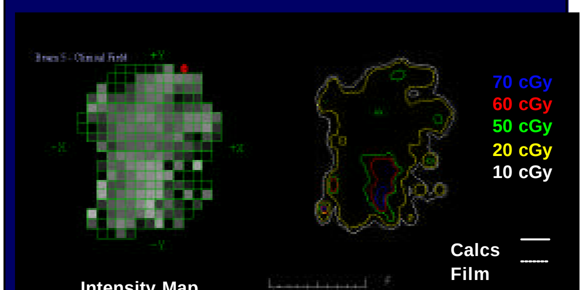
- Transfer patient fluence maps and beam geometry to phantom geometry
- 2-D dose difference displays with colorwash
- DVHs
- Highlight of differences
- Gamma analysis
  - % agreement and distance-to-agreement

Phantom Measurements

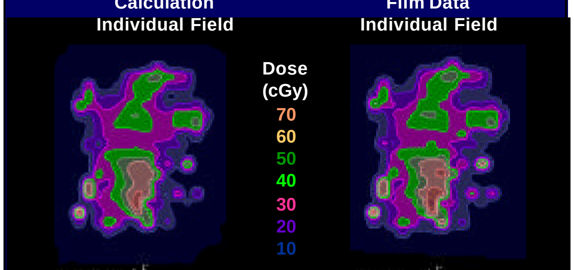
- Calculate IMRT plan for each field in measurement geometry
- Film measurement at depth for individual field at gantry=0



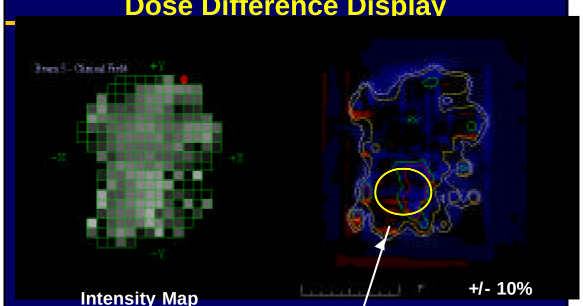
Dosimetric Analysis: Overlay of Isodose Lines



Dosimetric Analysis : Dose Color Wash

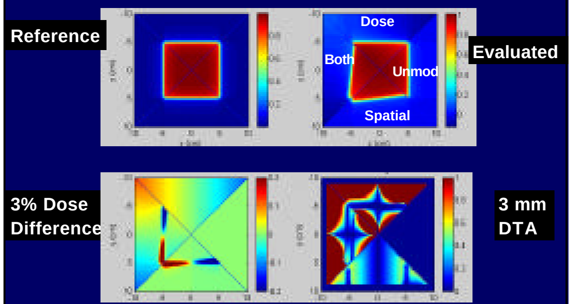


Dosimetric Analysis: Dose Difference Display



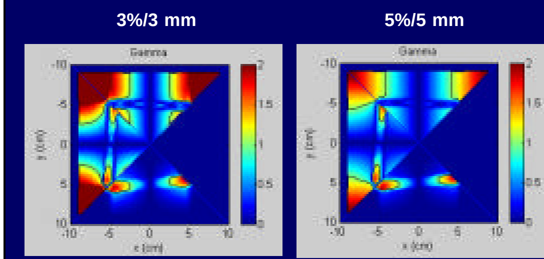
Differences due to tongue-and-groove

Dosimetric Analysis: Dose Difference and DTA



D. A. Low – Washington University

Dosimetric Analysis: Gamma Evaluation



D. A. Low – Washington University

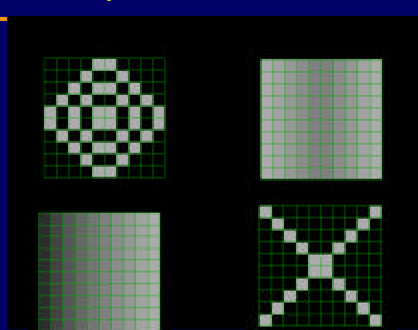
Simple Geometry Tests

- Leaf position reproducibility in dynamic or step-and-shoot mode
- Effect of gravity on leaf position accuracy and reproducibility
- Sweeping gap test
- Fence test

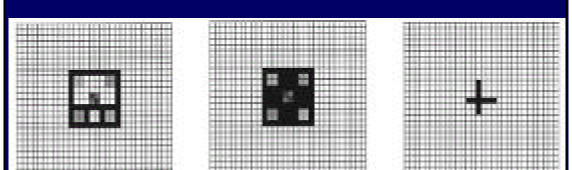
Simple Geometry Tests

- Leaf speed stability
- Leaf acceleration/deceleration
- Output checks for small to large fields
  - Including smallest field size – 1 x 1 cm^2
- MLC limits (field size restrictions)
- Depth dose curve measurements

Simple Geometric Tests

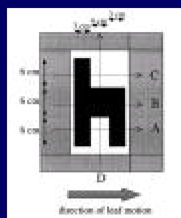


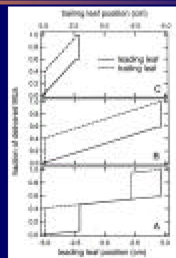
Geometric Tests



L. Xing et al. "Dosimetric verification of a commercial inverse treatment planning system" PMB 44: 463-478 (1999).

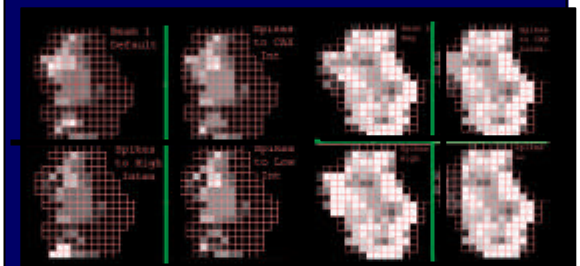
Geometric Tests





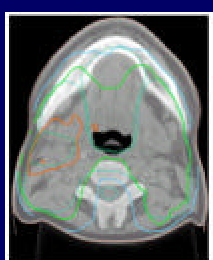
Acceptance tests and quality control (QC) procedures for the clinical implementation of intensity modulated radiotherapy (IMRT) using inverse planning and the sliding window technique: experience from five radiotherapy departments Van Esch et al Radiotherapy Oncology 65: 53-70 (2002).

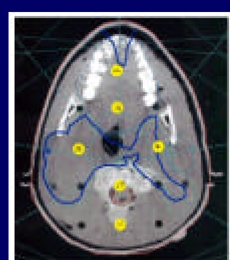
Complex Cases – Simple Geometry



Evaluate dose across field as a function of regional beamlet intensity

Complex Geometry: Anthropomorphic phantom





M. A. MacKenzie et al. “Dosimetric verification of inverse planned step and shoot MLC fields from a commercial planning system,” J Appl Clin Med Phys 3: 97-109 (2002)

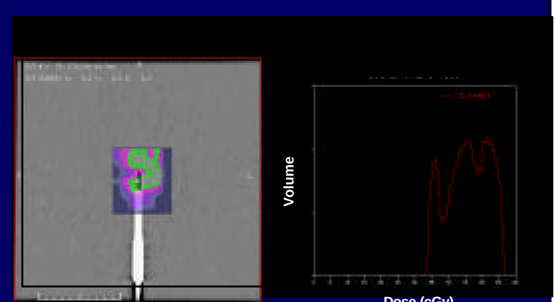
Potential Pitfalls

- Limit number of monitor units per segment to verified Linac behavior
- Limit field width for IMRT
- Overshoot-undershoot phenomenon
- Incorrect tolerance value
- Integration with record-and-verify system

Potential Pitfalls: Prior to Measurements

- Verify all equipment is functioning properly
  - Film processor, digitizer
  - Detectors, cables, electrometers (automatic leakage correction)
  - TLD reader, ovens
- Input/output to treatment planning system
- Standardize measurement setup when possible
- Monitor software and hardware changes and QA

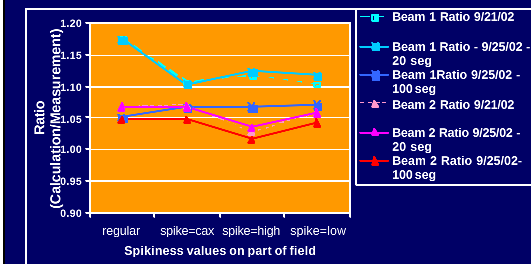
Detector Issues



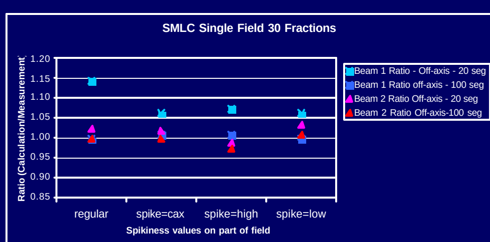
Detector Position

- Small ion chambers are very sensitive to position
- Position should be considered with respect to MLC design
  - Example: CAX of Varian MLC is a junction of four 0.5 cm wide leaves

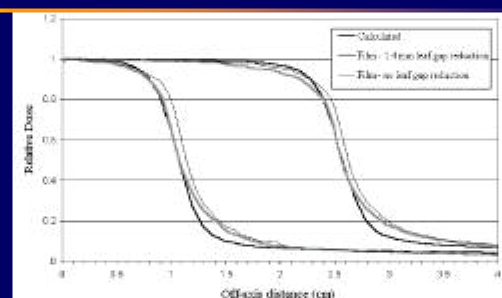
Ratio Calc/Ion Chamber - CAX



Ratio Calc/Ion Chamber - -0.5, -0.5 cm from CAX

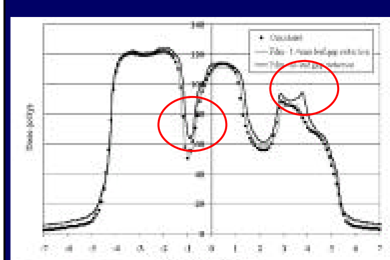


Effect of Leaf Position Offset on IMRT



Cadman et al "Dosimetric considerations for validation of a sequential IMRT Process with a commercial treatment planning system" PMB: 3001-3010 (2002).

Effect of Leaf Position Offset on IMRT

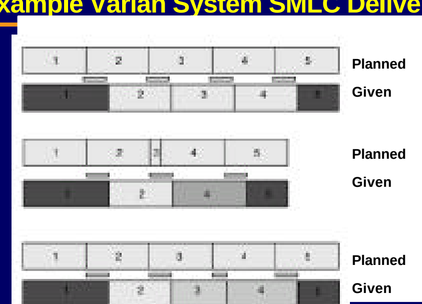


No leaf offset correction -3-12% errors

With leaf offset corrected +/- 5%

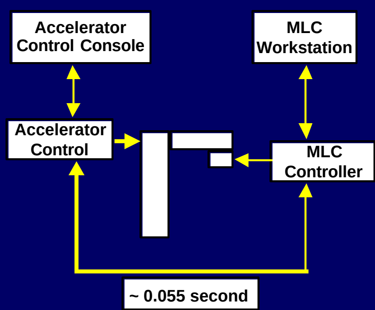
Cadman et al "Dosimetric considerations for validation of a sequential IMRT Process with a commercial treatment planning system" PMB: 3001-3010 (2002).

Overshoot Phenomenon: Example Varian System SMLC Delivery



Ezzell and Chungbin, "The overshoot phenomenon in step-and-shoot IMRT Delivery," J Appl Clin Med Phys 2: 138-148 (2001).

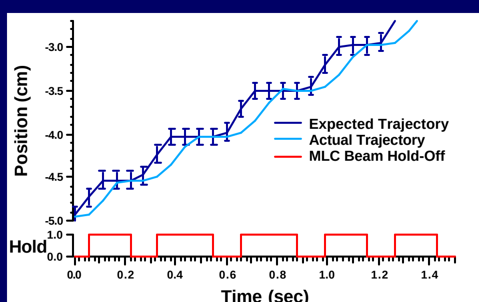
System Communication Delay



MLC Dynamic Log File (Dynalog)

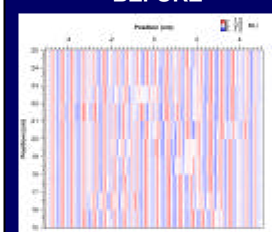
- Varian 21 EX
- Expected and actual leaf positions
- Beam hold-off events
- Position tolerance setting
- Recorded approximately every 55 ms
- Information can be compared to imported 2-D information

Deviation in Leaf Trajectory



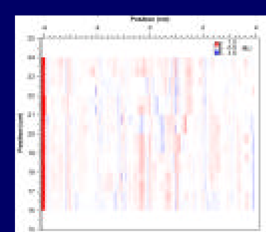
DMLC: Effect of Incorporating Machine Limitations

BEFORE



44 mu, tolerance 0.1 mm
no gap: 137 beam hold-offs

AFTER



54 mu, tolerance 0.25 mm
gap 1.1 mm: No beam hold-offs

Summary

- Basic MLC characteristics should be tested in static mode prior to IMRT testing
- IMRT tests should be specific to delivery mode and device
- Be aware of potential issues with delivery systems that may need further investigation
- Multiple detectors and phantoms are typically required for IMRT commissioning
- Quantitative dose analysis tools are required for proper evaluation of delivery

Summary

- Measurements may show dosimetric – mechanical differences that planning systems may not model at this time
- Need to know the limits of the mechanical systems and combination of software + delivery
- Continued need to improve software for delivery system, measurement devices, phantoms, and dose analysis tools

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