Dosimetry Metrology for IMRT Part I

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Outline

- Challenges of IMRT dosimetry
- Detectors
  - 1-D (point) detectors
  - 2-D
- Phantoms
  - Geometric
  - Anthropomorphic

Challenges of IMRT Dosimetry

- Importance of penumbral and peripheral field dose
- Complexity of the dose distribution
  - Numerous steep dose gradient regions, even within the target volume
- Dynamic dose delivery
  - Fluence shape and intensity vary during tx
  - Scan-based dose measurements impractical
  - IMRT limited to integrating dosimetric techniques

TG120 Recommendations

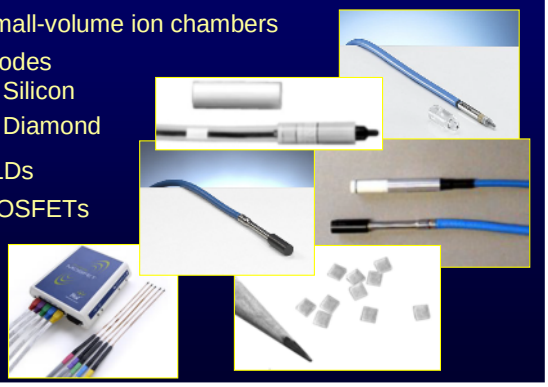
- QA should concentrate on cumulative delivered dose rather than only individual segments
- Verify dose at multiple locations
- Verify absolute position of the dose gradients

Detector Characteristics

- Stability
- Linearity of response
- Directional dependence
- Beam-quality dependence
- Absolute vs. relative
- Size
- Immediacy of results
- Stem and cable effects
- Cost and convenience

Point Detectors

- Small-volume ion chambers
- Diodes
  - Silicon
  - Diamond
- TLDs
- MOSFETs



Small-Volume Ion Chambers

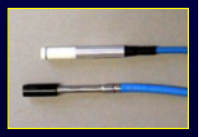
- Advantages
  - Stability
  - Linear dose response
  - Small directional dependence
  - Energy independence
  - NIST-traceable calibration
- Disadvantages
  - Volume averaging
  - Energy response dependence if central electrode of high Z material.
  - Stem effect

Small-Volume Ion Chambers

- Use for
  - Absolute dose measurements
- Do not use for
  - Penumbra of profiles used for modeling
  - Inter- and intra-leaf measurements
- Guidelines
  - If high-Z electrode, cross-calibrate under similar conditions
  - Dose heterogeneity < 5-10% across chamber
  - For comparisons, calculate average dose throughout active volume

Silicon Diodes

- Advantages
  - Very small active volume (smaller than IC)
  - High sensitivity
- Disadvantages
  - Over-responsive to low-energy photons
  - Some energy dependence
  - Dose-rate dependent
  - Angular dependence for non-normal incidence
  - Change in sensitivity over time due to radiation damage



Diamond Detectors

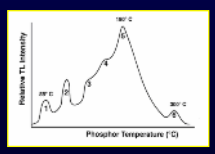
- Advantages
  - Very small active volume
  - High radiation sensitivity
  - Nearly tissue equivalent, though much more dense
  - Small directional dependence
  - High radiation hardness
- Disadvantages
  - May be dose-rate dependence
  - Expensive

Diodes

- Use for
  - Relative dose measurements
  - Regions of high dose gradient
- Do not use for
  - Peripheral region of profiles used for modeling
- Guidelines
  - Use unshielded silicon diode detectors
  - Don't use in-vivo diodes for phantom meas.
  - Monitor detector sensitivity
  - Consider/monitor orientation of diode to beam
  - Pre-irradiate diamond detectors to ~5 Gy

TLDs

- Advantages
  - Small size
  - Nearly tissue equivalent, density closer to tissue (LiF)
  - No cable
- Disadvantages
  - Nonlinear dose response
  - Some energy dependence
  - Labor-intensive
  - Delayed readout



TLDs

- Use for
  - Geometry which does not allow ion chambers
  - Multiple point measurements
- Do not use for
  - Absolute measurements needing precision <3%
- Guidelines
  - Use low-atomic number TLDs, e.g. LiF
  - Establish and follow strict handling, annealing, and calibration protocols
  - Use an automatic TLD reader

MOSFETs

- Advantages
  - Very small size
  - Linear dose response
  - Small directional dependence
  - Immediate readout
- Disadvantages
  - Not tissue equivalent
  - Some energy dependence
  - Limited lifetime
  - Change in sensitivity over time due to radiation damage

MOSFETs

- Use for
  - Geometry which does not allow ion chambers
  - Multiple point measurements
  - Situations needing real-time readout
- Do not use for
  - Absolute measurements needing precision <3%
- Guidelines
  - Monitor detector sensitivity
  - Monitor total lifetime exposure

2-D Detectors

- Film
  - Radiographic
  - Radiochromic
- Array detectors
  - Diodes
  - Ion chambers

Radiographic Film

- Advantages
  - High spatial resolution
  - Relatively inexpensive
- Disadvantages
  - Light sensitive
  - Oversensitive to low-energy photons
  - Dependence on film batch, processor conditions, digitizer
  - Need to measure response curve for each measurement session

Radiographic Film

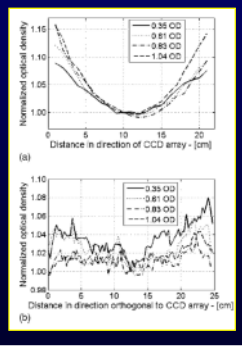
- Use for
  - Relative planar dose measurements
  - Penumbra of profiles used for modeling
  - Relative output factors for small fields
- Do not use for
  - Absolute measurements
- Guidelines
  - Choose a film with appropriate speed (EDR2)
  - Measure response curve for every experiment
  - Follow recommendations of TG69 (Med Phys **34**, 2228-2258 ;2007)

Radiochromic Film

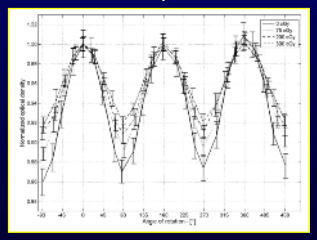
- Advantages
  - High spatial resolution
  - Does not require processing
  - Not sensitive to indoor light
  - Nearly tissue-equivalent
  - Decreased sensitivity to low-energy photons
- Disadvantages
  - Low OD at clinical doses
  - Susceptible to scanner artifacts
  - Post-irradiation coloration

Radiochromic Film

Scanner non-uniformity



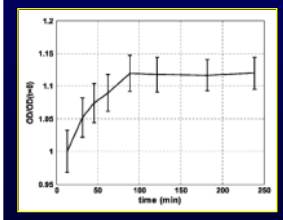
Orientation dependence



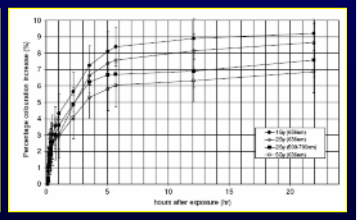
Lynch et al., Med Phys 33:4551-6;2006

Radiochromic Film

OD change after exposure



Zeidan et al., Med Phys 33:4064-72;2006



Cheung et al., PMB 50:N281-5;2005

Radiochromic Film

- Use for
  - Relative planar dose measurements
  - Penumbra of profiles used for modeling
  - Relative output factors for small fields
- Do not use for
  - Absolute measurements
- Guidelines
  - Characterize scanner response and establish consistent scanning protocol
  - Wait ≥2 hour after irradiation before scanning
  - Measure response curve for every experiment

2D Arrays

- Advantages
  - Immediate readout
  - Absolute or relative dose
  - Ease of use
- Disadvantages
  - Lower spatial resolution
    - (detector spacing ≥0.7 cm)
  - Limited active area
  - Require normal incidence beam delivery
    - Do not give "true" composite results

2D Arrays – Diode vs. Ion Chamber

	MapCHECK with TPS		*MatriXX with TPS (Original)*		*MatriXX with TPS (Convolved)*	
	3%/3 mm	**2%/2 mm**	**3%/3 mm**	**2%/2 mm**	**3%/3 mm**	**2%/2 mm**
6 MV Field A	98.3%	94.4%	98.1%	93.3%	100.0%	96.1%
6 MV Field B	100.0%	96.8%	97.6%	90.5%	99.2%	94.8%
6 MV Field C	99.6%	96.1%	97.9%	92.7%	98.8%	95.3%
Average (6 MV)	**99.3%**	**95.8%**	**97.9%**	**92.2%**	**99.3%**	**95.4%**
18 MV Field A	97.8%	94.9%	96.3%	91.4%	96.9%	94.3%
18 MV Field B	95.3%	93.2%	93.6%	89.8%	95.2%	93.9%
18 MV Field C	99.7%	96.1%	95.8%	90.7%	97.6%	95.1%
Average (18 MV)	**97.6%**	**94.7%**	**95.2%**	**90.6%**	**96.6%**	**94.4%**

Li et al., JACMP 10:62-74;2009

2D Arrays

- Use for
  - Relative and absolute planar dose measurements
  - linac and patient-specific QA
- Do not use for
  - initial commissioning
- Guidelines
  - Evaluate array calibration stability before use
  - Pass/fail criteria must take spatial resolution into account

Phantom Characteristics

- Material
  - Water-equivalent or known electron-density
- Homogenous or heterogeneous
- Geometric or anthropomorphic
- Allowable detectors
- Flexibility in detector positioning
- Fiducials for setup accuracy and reproducibility
- Light tight, internally opaque for radiographic film
- CT characterization

Water Tank

- Allows great flexibility in detector position
- Can accommodate variety of detectors
  - Must be water-proof or have water-proof sleeves
- Restricted to gantry oriented straight down (0°)
- Use for
  - Initial commissioning
    - Depth dose, profiles, output factors
  - Beam assessment
    - Flatness/symmetry

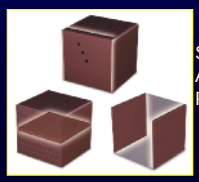
Slab Phantoms

- Water-equivalent plastic
- Can include heterogeneities
- Custom cutouts for IC or other detectors
- Limited flexibility in detector position
- Allow film
- May be scribed with lines for setup accuracy
- Use for single or composite beams
- Ease of use

Slab Phantoms

Gammex 473 Planar Phantom

CIRS Cube Phantom



Standard Imaging ACE IMRT Phantom

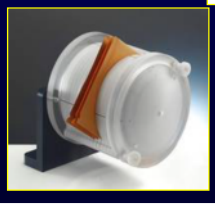
PTW IMRT Body Phantom

Cylindrical Phantoms

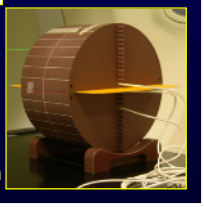
- Same properties as slab phantoms but usually not as flexible in detector/film position
- Convenient geometry for composite beams
  - more "realistic" than slab phantom

Cylindrical Phantoms

Modus Medical QUASAR verification phantom



PTW Verification H&N Phantom

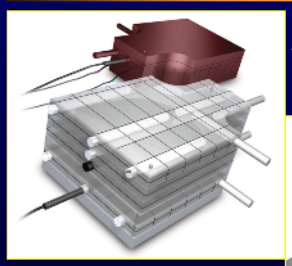


Tomotherapy "Cheese" Phantom

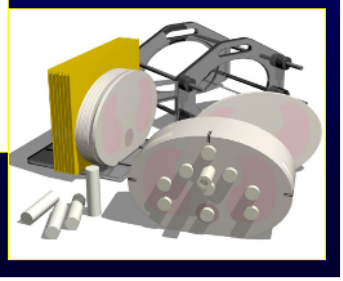
Anthropomorphic Phantoms

- Useful for assessing overall IMRT planning and delivery process
  - Better simulation of human setup and irradiation
- Limited flexibility in detector and film placement
- More difficult to set up accurately
- Difficult to determine causes of dose distribution discrepancies
  - May require additional measurements in simpler geometric phantoms

Anthropomorphic Phantoms



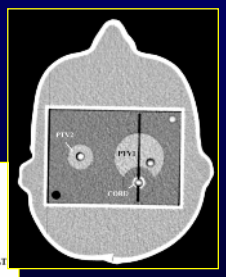
Standard Imaging Dose Verification Phantom

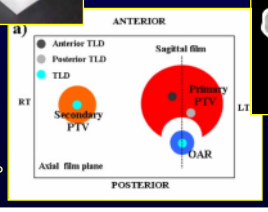


CIRS IMRT Thorax Phantom

RPC Phantoms

RPC website





Babic et al., IJROBP 70:1281-91;2008

Cadman et al., PMB 47:3001-10;2002

Summary

- Main challenges for IMRT dosimetry are
  - small fields
  - complex dose distributions with steep gradients
  - dynamic dose delivery
- No one detector or detector system is adequate for all IMRT commissioning and QA
- No one phantom is adequate for all IMRT commissioning and QA
- Select the appropriate chamber/phantom combination for each measurement situation