Dosimetry Metrology for IMRT II: Advanced Systems & Data Analysis

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Educational Objectives

- Learn about advanced dosimetry systems for IMRT measurements.
- Understand the benefits and limitations of different analysis tools for IMRT.
- Note: dosimeters and analysis tools must be matched to the task.

Outline

- Advanced dosimeters
  - EPIDs
  - 2D arrays in phantoms
  - 3D dosimeters
- 2D dose analysis techniques
  - Dose difference, distance to agreement
  - Gradient Analysis
  - Gamma Analysis
- Applications

System	Task
EPIDS	Verification only; With or without patient
2D phantom arrays	Limited commissioning if a fine spatial resolution
3D dosimeters	Commissioning

These systems should be validated against a known dosimetry system, e.g. ion chamber.

EPIDs
Task: QA Verification

- Advantages
  - Mounted to linear accelerator - known geometry with respect to the beam
    - Detector sag must be accounted for at different gantry angles
    - Positioning reproducibility important
  - Real time digital evaluation
- Challenges
  - Conversion of image response to "dose" is complex
  - Ghosting, lag

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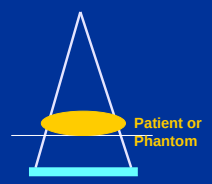
EPID Systems for Dosimetry

- Active matrix flat panel imagers (AMFPIs)
- Portal "dosimetry"
- Often a fluence or response verification



Transit Dosimetry

Pre-Tx 2-D Measurements

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Determination of Dose

- Imager response must be calibrated to a standard
- Absolute calibration to ion chamber at a point over a ROI
  - E.g. ion chamber in a mini-phantom or slab at same SDD as EPID
- 2-D calibration to actual beam distribution at the imager plane
  - Can be measured with film or a diode array

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Additional Factors for EPID Response

- Water-equivalent depth of the detector
- Field size dependence and scatter properties within the imager
- Short- and long-term reproducibility
- Dose rate
- Energy dependence
- Spatial integrity

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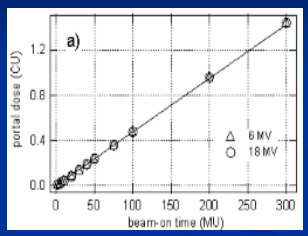
Imager response to Dose: AMFPI

- Example: Varian aS500
- Total area: 40 x 30 cm² (512x 384 pixels) with resolution of 0.784 x 0.784
- Water-equivalent thickness is 8 mm
- Continuous frame acquisition

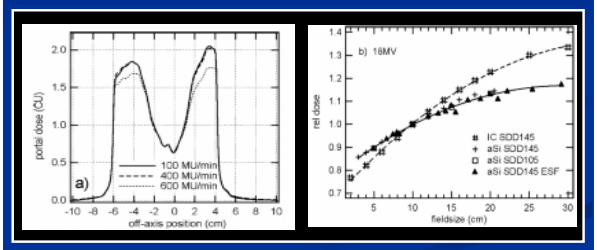


Van Esch et al Radiother Oncol 71: 223-234 (2004).

Dose Rate and Energy Considerations

6 MV
IMRT Prostate Field
SDD = 105 cm

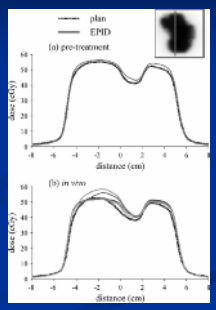
18 MV
Response as a function of field size



Van Esch et al Radiother Oncol 71: 223-234 (2004).

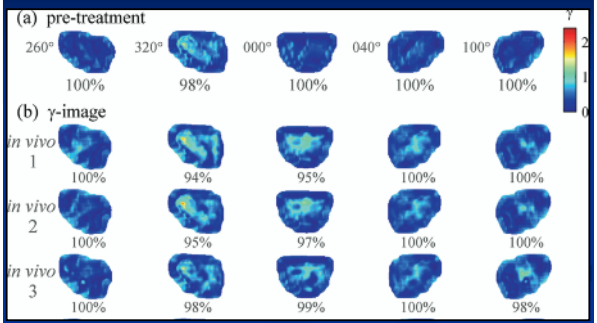
EPID for Transit Dosimetry

- Dose distributions are reconstructed from measured EPID images
  - Phantom
  - Patient – first 5 fractions
- Plans for 75 prostate patients were measured
- Elekta system
- 3%/3 mm Gamma criteria
- Degree of field modulation may affect applicability



McDermott et al, IJROBP 67: 1568-1577 (2007).

Example Gamma Results
1 patient



McDermott et al, IJROBP 67: 1568-1577 (2007).

3D Dosimetry
Task: Commissioning, End-to-end test, etc.

- 3D dosimetry has been an investigational topic for many years
- Such a dosimeter must have a stable response and a high spatial resolution
- 3D dosimeters continues to evolve as new formulations and refinements are developed

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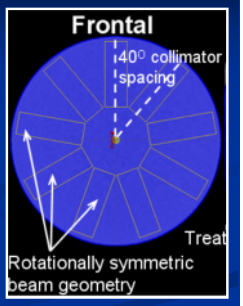
3D Dosimetry - Example

- Four PRESAGE dosimeters
- Read out multiple times with an optical CT reader
- Phantom: Irradiated with 9 1x3 cm beams
- Doses repeated
  - High, med, low, +penumbra
  - Extreme in-plane spatial variation
  - Low longitudinal variation
- Compared to EBT film



Sakhalkar, Adamovics, Ibbott, Oldham Med Phys 36: 71-82, 2009

Slide courtesy of Mark Oldham, Ph.D. – Duke University

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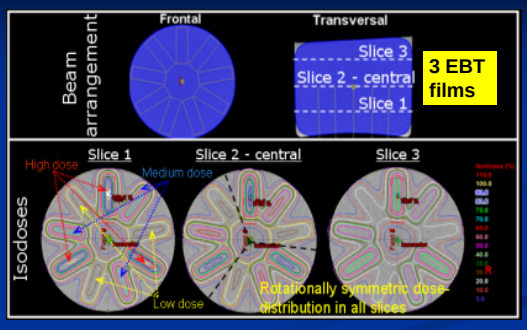
Multi-planar comparison



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Optical-CT Technique

- OCTOPUS 5X scanner from *MGS Research Inc*
- Acquisition Parameters:
  - 600 projections per slice over 360°
  - 168 pixels per projection (pixel size = 1 mm)
  - 15 slices per 3D scan (slice spacing = 5 mm)
- 3D attenuation reconstruction using an in-house MATLAB software.
  - Assume linear dose response
  - Prescans
  - Edge effects (RI matching)
  - Flood fields

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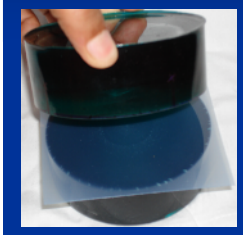
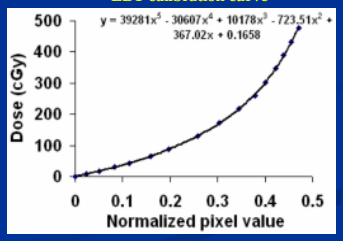
EBT film measurement

- EBT Gafchromic film scanned with an EPSON® Perfection 4990 flatbed scanner was used to scan the EBT film response.





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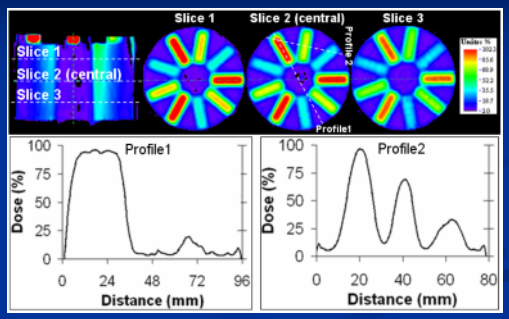
Results



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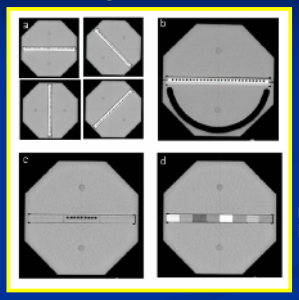
PTW Octavius Phantom Task: QA Verification

Multiple positions For 2D array

Multiple ion chamber insert



Cavity to compensate Chamber respons to arc delivery

Heterogeneous inserts

Van Esch et al Med Phys 34: 3825-3837, 2008.

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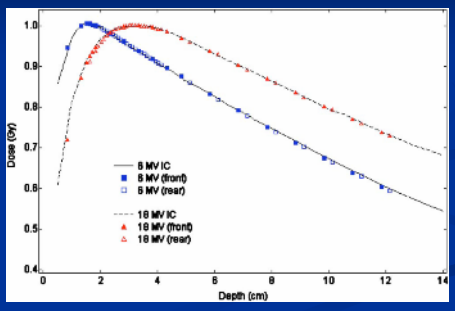
Depth dose validation – Array vs. ion chamber



Van Esch et al Med Phys 34: 3825-3837, 2008.

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Dosimetry Analysis Software

- Transfer patient fluence maps and beam geometry to phantom geometry
- 2-D dose difference displays with colorwash
- Dose volume histogram of detector volume
- Highlight of differences
- Gradient evaluation – dose & distance
- Gamma analysis
  - % agreement and distance-to-agreement

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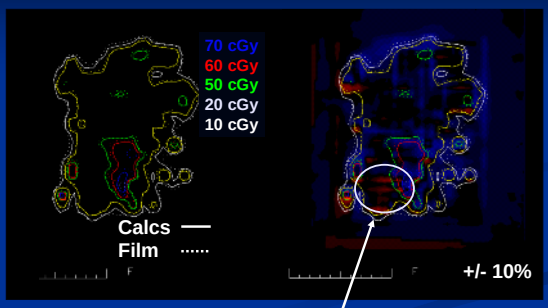
Isodose lines - Dose Difference Displays



Differences due to tongue-and-groove

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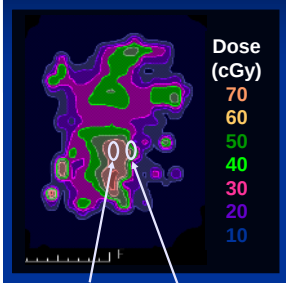
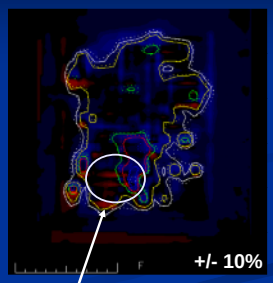
Dose Distributions

Colorwash of dose distribution

Dose Difference Display





More stable measurement point

Steep gradient

Differences due to tongue-and-groove

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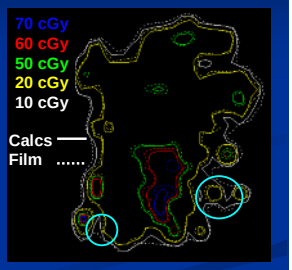
Limitations of Current Tools

The steep dose gradients in IMRT fields make it difficult to interpret dose differences with standard comparison tools.

Isodose lines agree within 2 mm except for small regions of 10 cGy



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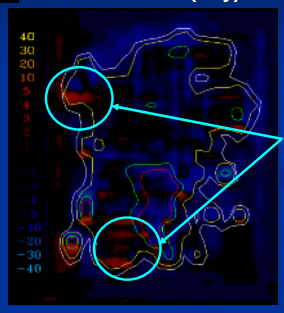
Limitations of Current Tools

Calculation (cGy) – Film (cGy)



Multiple regions where the calculation is greater than the measurement

Differences are not seen on isodose line comparison

Are these differences significant?

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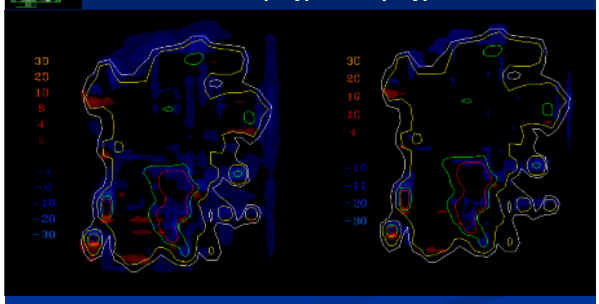
Limitations of Current Tools

Calculation (cGy) – Film (cGy)



+/- 2 cGy agreement in black

+/- 4 cGy agreement in black

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Initial Gradient Calculation

For each dose grid point:

- Calculate dose difference between point and nearest neighbors on the calculation grid
- Divide by respective grid distance(s)

$$Gradient = \sqrt{\sum \left(\frac{Dd}{Dx} \right)^2}$$

For example:
D = 10 cGy
Nearest points = 1 cGy
3 mm calculation grid
Gradient is ≈ 7.4 cGy/mm

Moran et al JACMP 6(2): 62-73 2005.

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Gradient Compensation

- Start with dose difference between 2 plans
- Decrease the displayed dose difference by Gradient • Dx where Dx is a distance (in mm) chosen for analysis
- Display remaining dose difference
- This highlights differences which cannot be explained by a geometrical error of Dx mm

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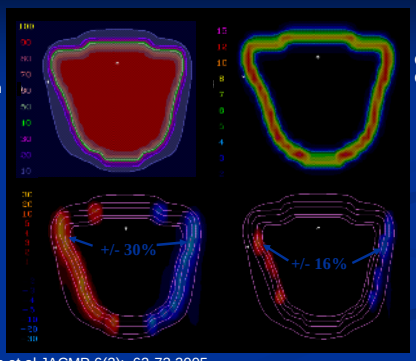
Static Field Example

Dose Distribution

Gradient Calculation

Dose Difference

1mm grad applied



Moran et al JACMP 6(2): 62-73 2005.

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Application of Gradient Tool to IMRT

- Algorithm and leaf sequencer verification
  - Gradient across field
  - Transmission
  - Split fields
- Routine QA
  - Pre-treatment patient QA
- Goal: To delineate planning and delivery differences not due to simple geometric misalignment or grid resolution issues

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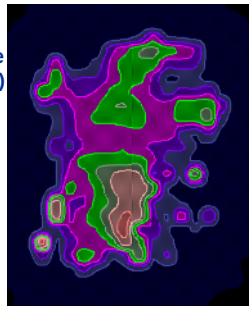
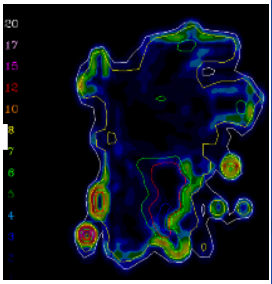
IMRT Example

Calculation (cGy)

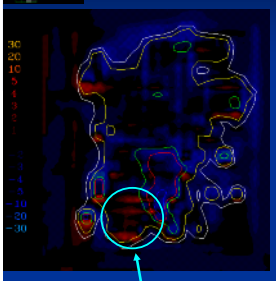
Gradient Map (cGy/mm)

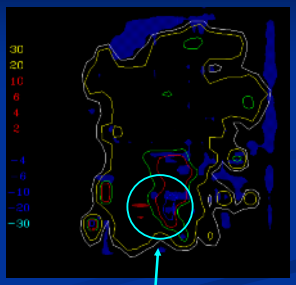
Dose (cGy)
70
60
50
40
30
20
10





Calculation – Measurement (cGy)





Differences due to tongue-and-groove

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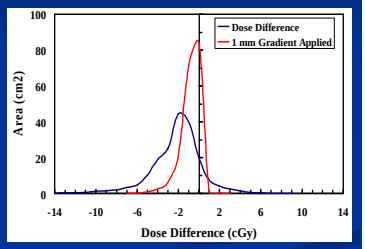
Dose Area Histogram of Dose Difference

- Can evaluate the # of points within a given criteria
- Approach can be applied with any dosimeter



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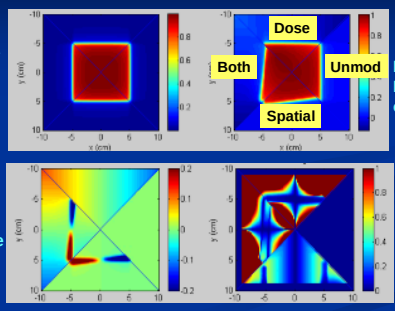
Dosimetric Analysis: Dose Difference and DTA

Reference



Evaluated Dose: +/-6% or 6 mm skew

3% Dose Difference

3 mm DTA

Slide courtesy of Dan Low, Ph.D. – Washington University

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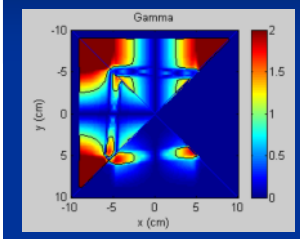
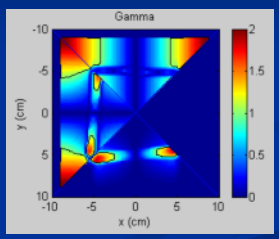
Dosimetric Analysis: Gamma Evaluation

3%/3 mm



5%/5 mm



Slide courtesy of Dan Low, Ph.D. – Washington University

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Conclusions

- The detector or system must be matched to the task
- QA verification: EPID and array systems
  - Multiple phantom configurations for 2D arrays provide additional flexibility for new applications.
- Commissioning and end-to-end tests: 3D dosimeters.
  - Still under development
  - Not seen in many clinics at this time

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Conclusions (continued)

- 2D analysis: the tool depends on the need
  - Gamma analysis technique by Low et al. is often to combine dose and distance criteria
    - Parameters for % difference and distance should be chosen with care.
  - Dose difference and gradient compensation techniques help to identify differences and their clinical significance.

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Status of Task Group 120 Report

- The report has been reviewed by the Therapy Physics Committee.
- We expect to submit the report to Medical Physics for publication in August.
- Members: Dan Low (chair), James Dempsey, Lei Dong, Mark Oldham, Jean Moran

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Future Developments

- With dynamic arc therapy, a new generation of dosimetry equipment is being developed.
- We continue to need electronic systems with automated analysis because of the additional workload requirements for advanced technologies.
- Many of the new systems for arc therapy may provide valuable information for IMRT QA as well.

Tools for IMRT Commissioning: Static & Rotating Gantries
Gary Ezzell, Fang-Fang Yin, and Ying Xiao
Wed 8:30 am Ballroom C