TG 120

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Disclosure

- I am on the scientific advisory board of ViewRay

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Objectives

- To understand the tradeoffs of different detectors
- To understand detector performance
- To understand dose evaluation tools

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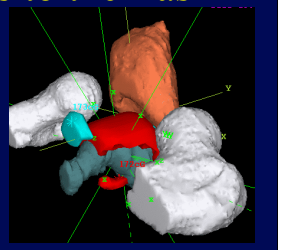
Matching Dosimeters to the Task

- Thoroughness
  - Quantitation
    - Spatial
      - Resolution
      - Registration accuracy
    - Dosimetric
      - Absolute vs relative, energy response
    - Evaluation
      - Thorough evaluation and analysis
  - Data density
    - 3D vs 2D vs 0D
  - Phantom geometry
- Commissioning versus routine QA
  - Efficiency versus thoroughness and relationship to patient dose



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"Point Detectors"

- Measure single volumetrically-averaged point
- Scanning provides multiple points

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1-D Detector Characteristics

Detector	Measurement Volume (cm^3)	Sensitive Area (cm^2)	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

Moran, "Dosimetry Metrology" AAPM Summer School Proceedings 2003

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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

Moran, "Dosimetry Metrology" AAPM Summer School Proceedings 2003

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Ionization Chamber

- Inconveniences
  - Acquire 1 measurement point for entire IMRT delivery
  - Relatively insensitive, large active volume
  - Volume average
- Convenience
  - Everyone has one
  - Calibration straightforward

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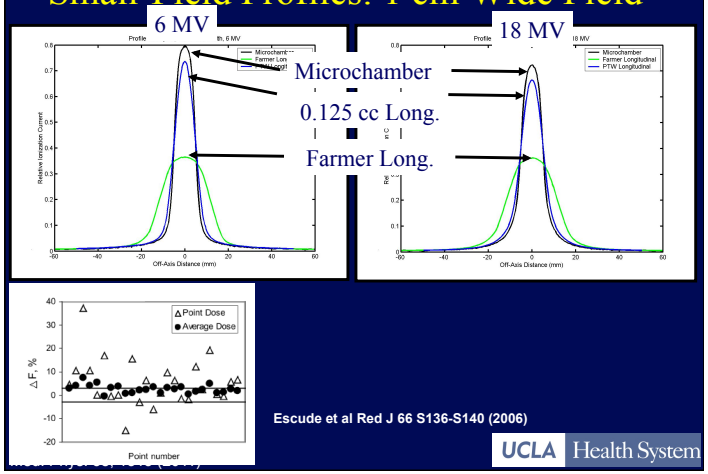
Small-Field Profiles: 1 cm Wide Field



Escude et al Red J 66 S136-S140 (2006)

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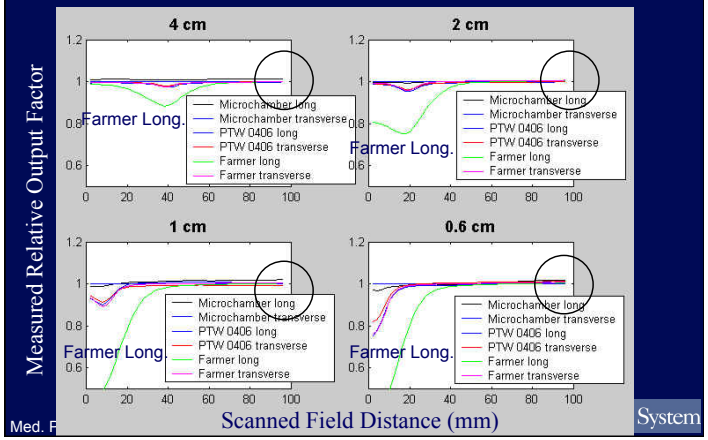
Integration Accuracy



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Ionization Chambers Can Be Used To Accurately Measure

20% 1. The dose from x-ray fields of any size.

20% 2. The beam penumbra.

20% 3. The dose from x-ray fields whose width is at least the same as the length of the chamber's active volume.

20% 4. The dose from fields at least 1.5 cm wider than the effective length of the chamber.

20% 5. Beam profiles for complex IMRT fields.

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10

Correct Answer: 4

- Source: TG120

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TLD Chips

- Advantage:
  - Larger number of simultaneous measurements
- Disadvantages
  - Delayed readings
  - Factors required for each chip (Pre-irradiation preparation)
  - Requires automated reader
  - Calibration for each measurement (subset of chips)
- <3% chip-to-chip reproducibility possible

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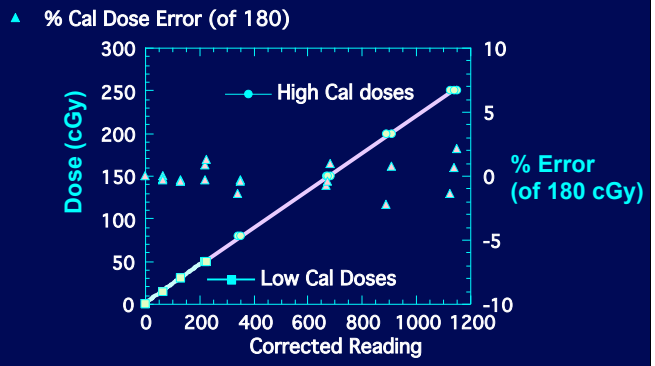
TLD Calibration



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2D Systems

- Radiographic film
- Radiochromic film
- 2-D detector arrays
- Portal imaging systems

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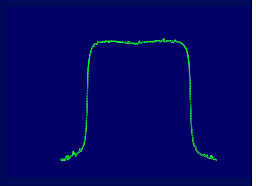
Radiographic Film

- Accuracy can be good for high-energy photons
  - Calibration fields/depths should be similar to the irradiated target size/depth
- Proper processing and normalization critical
  - Same batch
  - Process at same time
  - H&D curve every processing session
  - Nonlinear H&D fit necessary
  - Independent dose normalization desirable



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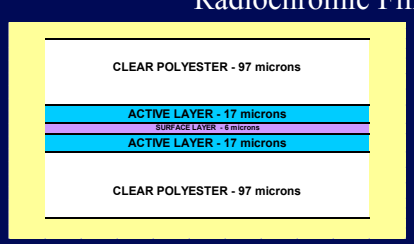
Radiochromic Film



- **Active component: micro-crystalline monomer**
  - **Turns blue upon exposure to radiation**
  - **Slow first order solid state topochemical polymerization reaction initiated by irradiation**
  - **results in homogenous, planar polyconjugation along the carbon-chain backbone**
- **The increase in absorbance is roughly proportional to the radiation absorption** Thanks to Jim Dempsey

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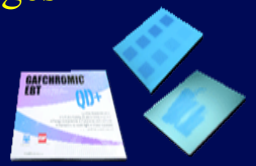
Advantages



- Tissue equivalence
- High spatial resolution (> 0.1mm)
- Large dynamic range (1cGy to 800cGy)
- Energy independence
- Insensitivity to visible light
- No need for chemical processing

Thanks to Jim Dempsey

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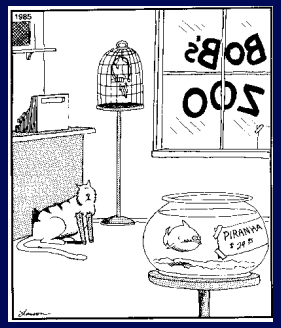
Quantitative Densitometry: an oxymoron?

- Most transmission film scanning equipment was designed for qualitative work
- For dosimetry we need quantitative results
  - At least <5% uncertainty
  - <2-3% would be better
- We have been using film scanners for a long time, but how well do they work?



Thanks to Jim Dempsey

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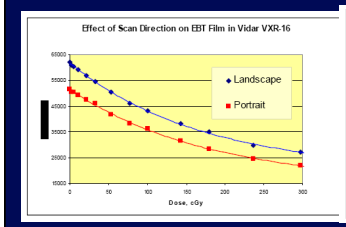
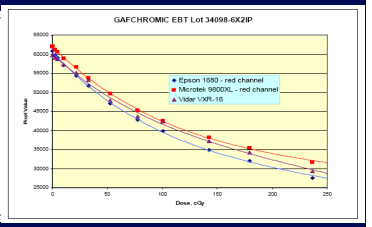
Commercial Support: Scan Direction Scanner and Light Color

- Many of the issues discovered by physicists are now managed by the manufacturer





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Commercial Support: Noise Effect on Dose

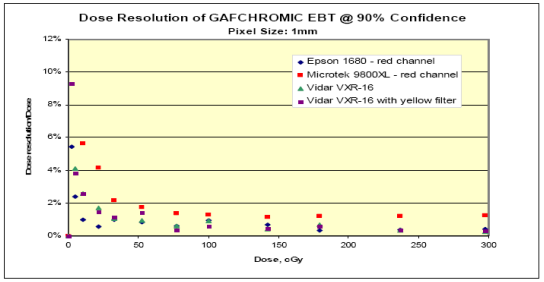

Figure 5.2: Dose Resolution of GAFCHROMIC® EBT Dosimetry Film with Film-Scanners

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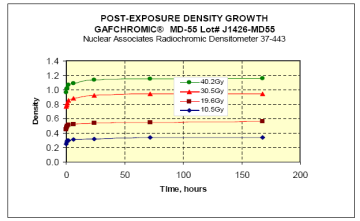
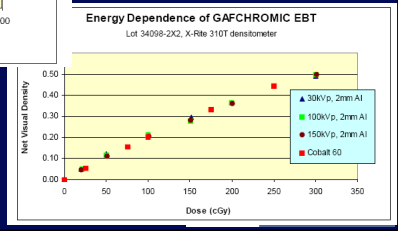
Commercial Support: Post Exposure Behavior Energy Dependence





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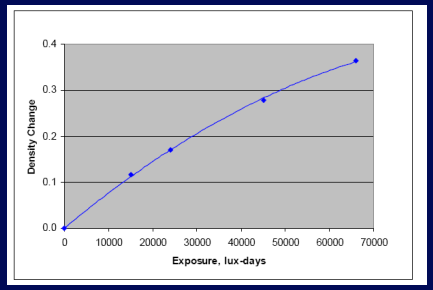
Commercial Support: White Light Sensitivity



Typical office space 600-1000 lux

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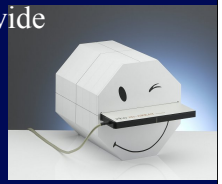
2D Detector Arrays

- Typically measure en-face beam deliveries
- Beam-by beam (or summed) evaluations
- Phantoms allow for integrated treatments
- Treatment planning systems provide prediction of planar doses for comparisons



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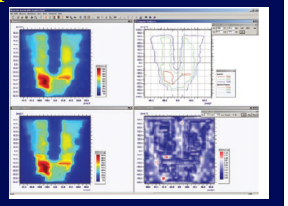
Scanditronix-Wellhofer I'mRT MatriXX

- 1020 ionization chambers (vented)
- 24.4 x 24.4 cm^2
- Even spacing (32 x 32 grid, 7.62 mm center spacing)
- Chamber size 4.5 mm diameter x 5 mm high (0.08 cm^3)



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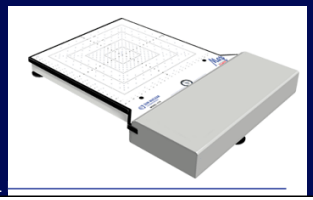
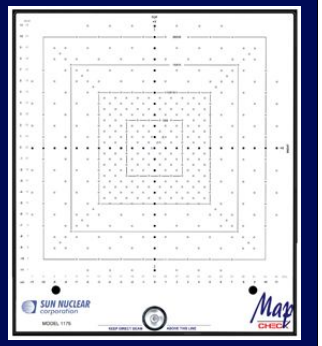
Sun Nuclear MapCheck

- 445 diode detectors
  - 0.707 cm (10x10) and 1.41 cm resolutions
  - 0.8 x 0.8 mm^2
- 22 x 22 cm^2





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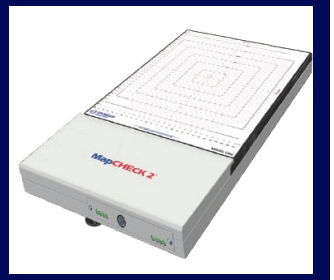
Sun Nuclear MapCheck 2

- 1536 diode detectors
  - Octagonal array
  - 0.707 cm spacing
- 32 x 26 cm^2



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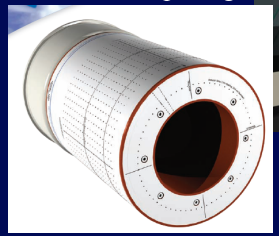
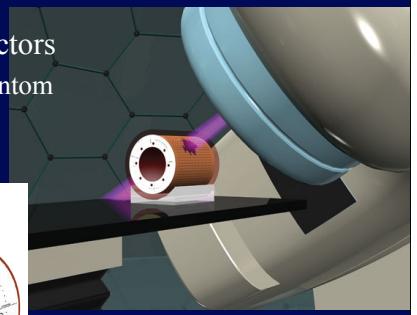
Sun Nuclear Arc Check

- 1386 diode detectors
  - Cylindrical Phantom
  - 32 x 26 cm^2
  - 1.0 cm spacing





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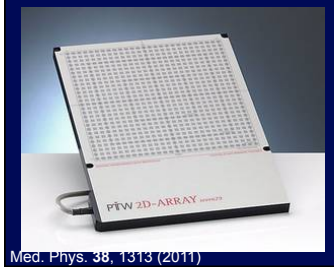
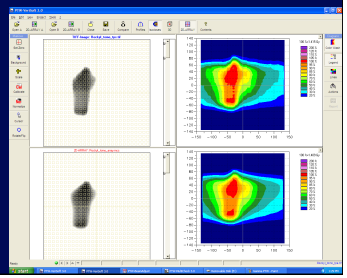
PTW 2D-Array: seven29

- 729 Ionization chambers (vented)
  - 5 x 5 x 5 mm^3
  - 5 mm spacing





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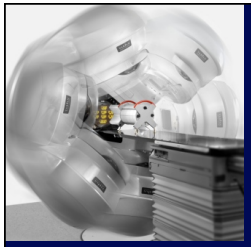
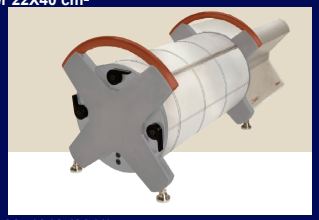
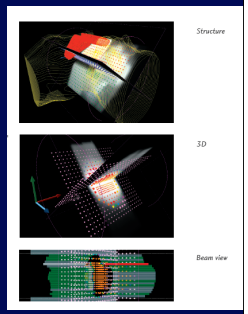
ScandiDos



Crossed array of 1069 p-Si diode detectors
20x20 cm^2 planes, 5 mm spacing central 6 cm, 1 cm other
Cylinder 22X40 cm^2





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Regarding diode detector arrays:

20% 1. they can be used to acquire beam profile data for commissioning.

20% 2. they can be used for absolute calibrations.

20% 3. they are convenient for routine quality assurance, but care needs to be taken when interpreting the results.

20% 4. they have no place in modern radiation therapy quality assurance.

20% 5. they come in only one general shape; flat and therefore have limited utility in arc-based quality assurance.

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Correct Answer: 3

- Source: TG 120

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IMRT QA Tools

EPIDS - Advantages

- Many centers have installed EPIDs for patient localization
  - Logical extension to investigate dosimetric applications
- 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
  - No processor, data acquisition takes less time

Med. Ph Jean Moran, U Michigan

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IMRT QA Tools

EPIDS - Challenges

- However, EPIDs were primarily designed for patient localization
  - High resolution, good contrast images
  - Additional dose to the patient should be minimized
- The conversion of imager response to dose is complex
  - Imaging system dependent
- Other problems
  - Ghosting
  - Lag

Jean Moran, U Michigan

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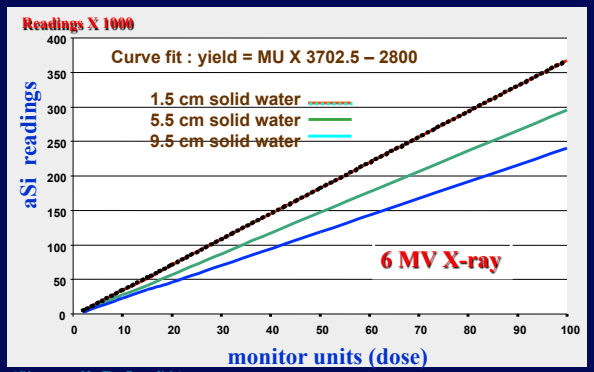
Linear Dose Response for aSi EPID



(slide courtesy of Joe Ting, Emory Univ.)

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QA Software

- Critical component of IMRT QA is the software!
- Many commercial vendors providing software solutions
- Evaluations are 2D, 3D, many evaluation tools

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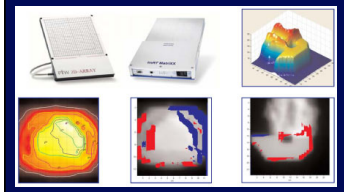
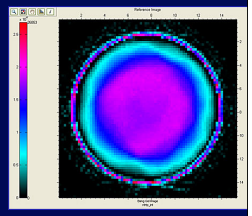
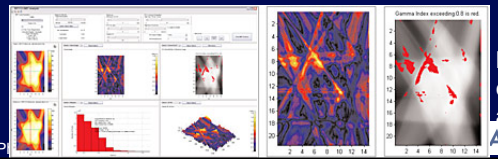
QA Software: RIT

Multiple input support





3D dosimetry



Dose comparison analysis

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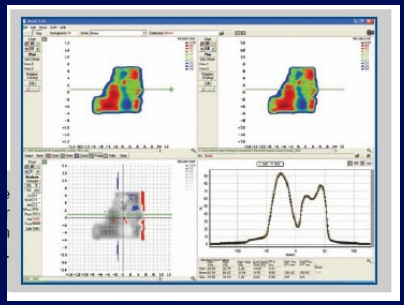
QA Software: Sun Nuclear



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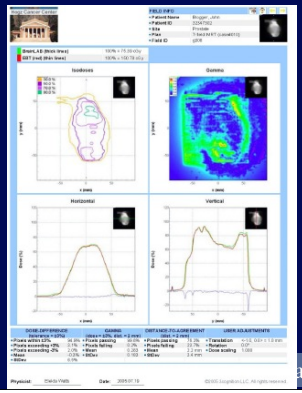
QA Software: 3cognition



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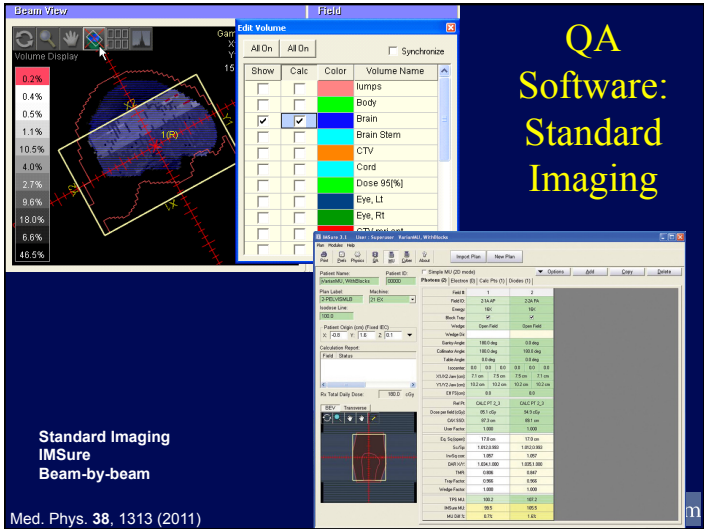
QA Software: Standard Imaging



Standard Imaging
IMSure
Beam-by-beam

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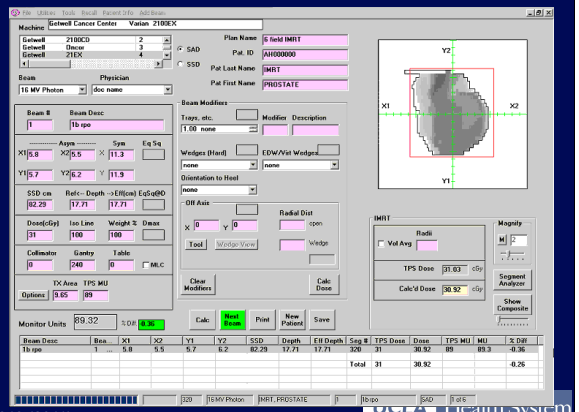
QA Software: MUcheck



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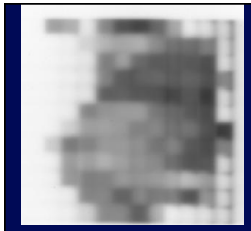
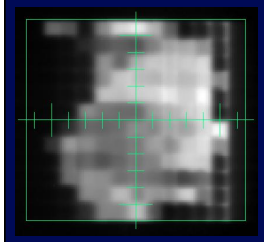
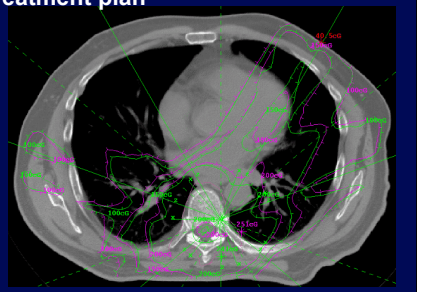
QA Software: MRSS

Film or EPID-based input
3D dose calculation compared against treatment plan







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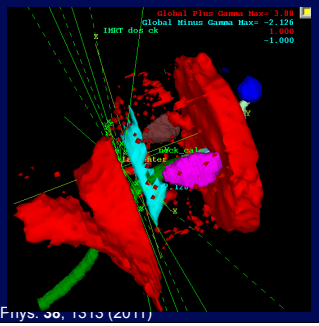
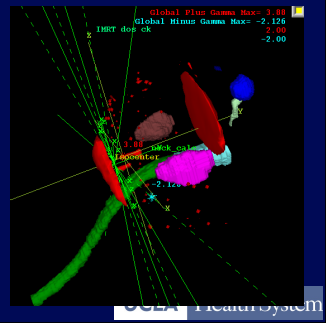
MRSS

Gamma evaluations
gamma >1 (left) gamma >2 (right)





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Commercial Phantoms

BIT web site

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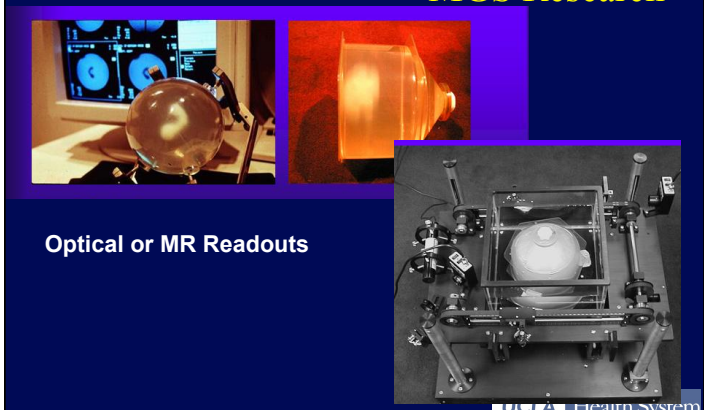
3D Dosimetry MGS Research



Optical or MR Readouts

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Dose Evaluations and Comparisons

- Each system has tools to evaluate dose distributions
- Effective use of the tools requires understanding of how the tools work
  - Point comparisons
  - Superimposed dose distributions
  - Dose difference
  - Distance-to-agreement
  - "Composite failure analysis"
  - "γ"

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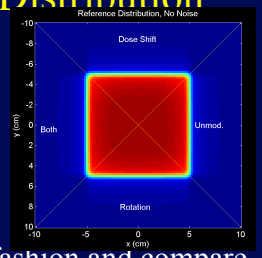
Example Dose Distribution

- Two 10 x 10 fields
- 6 MV
- Coronal
- 3%, 3mm criteria
- Skew one in a smooth fashion and compare doses



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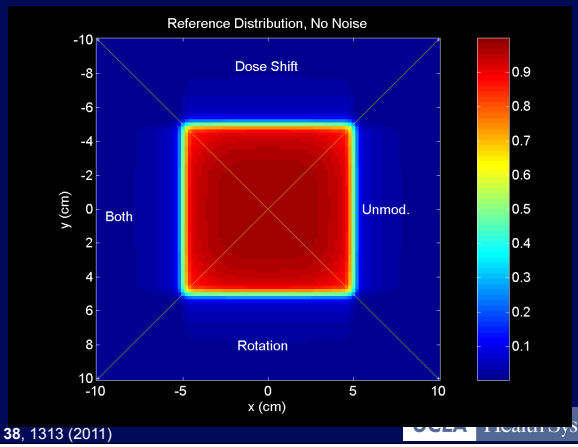
Reference Distribution (10x10 cm²)



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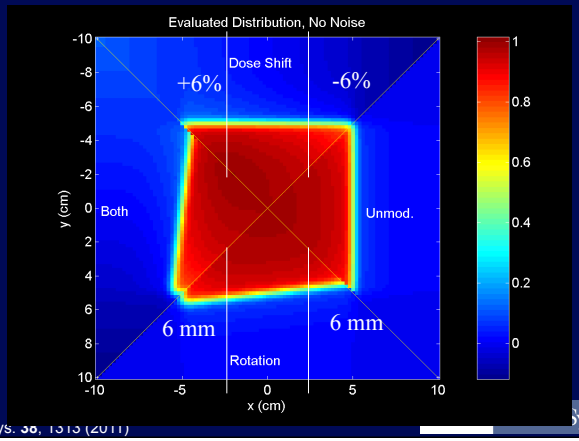
Evaluated Distribution



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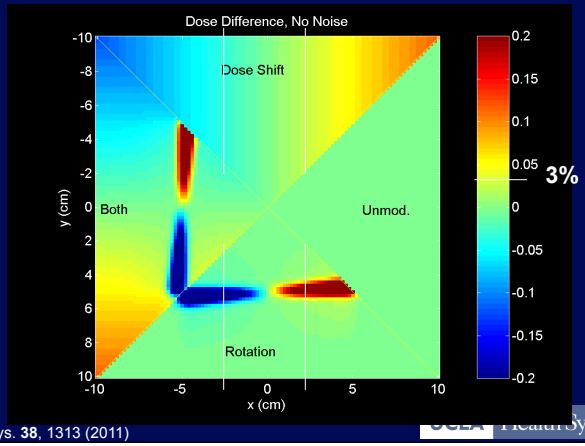
Dose Difference



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Steep Dose Gradients provide a challenge for dose distribution comparisons because

20% 1. Slight shifts between the two compared doses cause the dose differences to appear smaller than they actually are.

20% 2. Rotations between the two compared doses have no effect in steep dose gradient regions.

20% 3. The selected dose difference criteria have a big impact on the dose differences in steep dose gradients.

20% 4. The dose difference is overly sensitive in steep dose gradient regions.

20% 5. The gradients occur only in the centers of tumors.

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Correct Answer : 4

- Source TG 120

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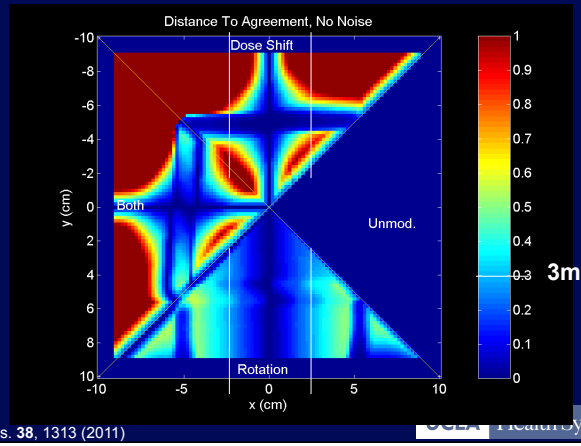
Distance-to-Agreement



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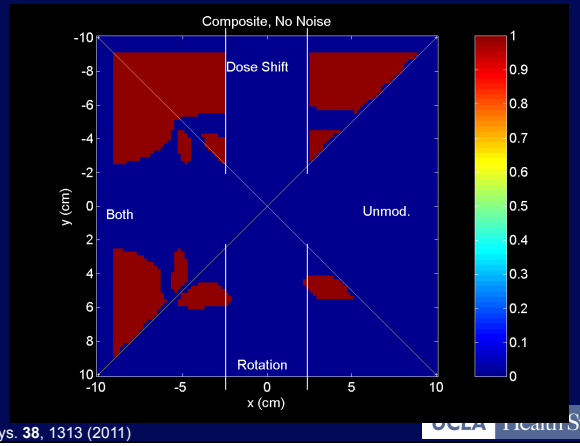
Composite



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What is γ?

- γ is the rescaled Euclidean distance between an evaluated distribution and each point in a reference distribution
- Each spatial and dose axis is normalized by a criterion
- Renormalized "distance" defaults to distance to agreement and dose difference in shallow and steep dose gradient regions, respectively.

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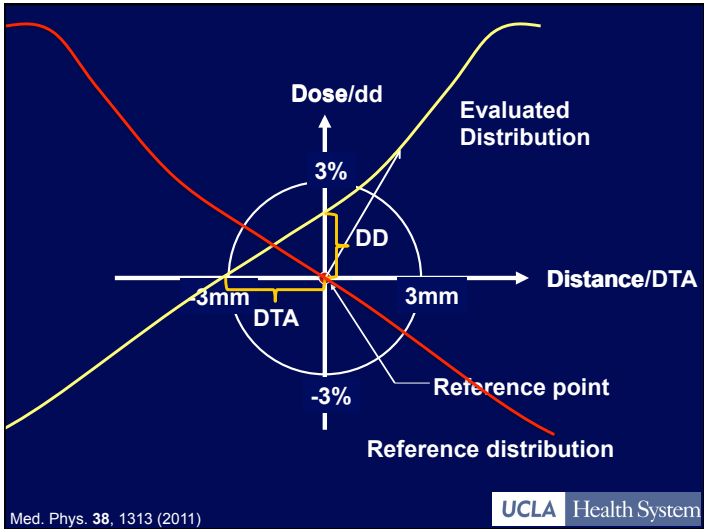

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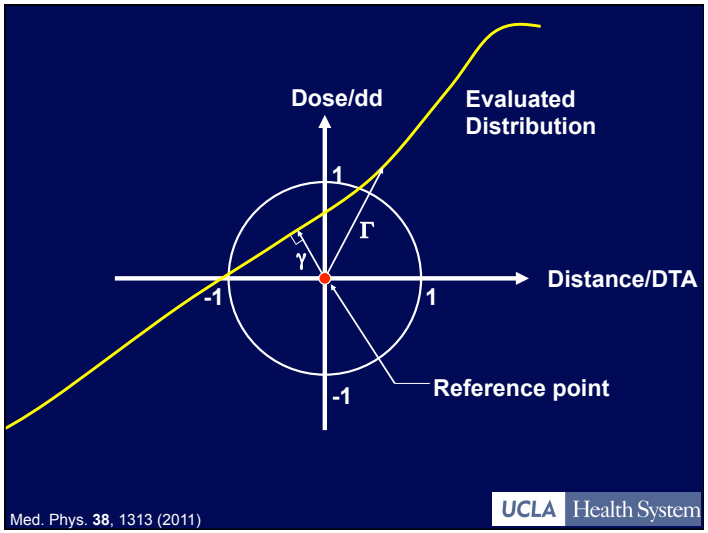
Dose/dd
Evaluated Distribution
Distance/DTA
Reference point
Γ
γ
1
-1
1
-1
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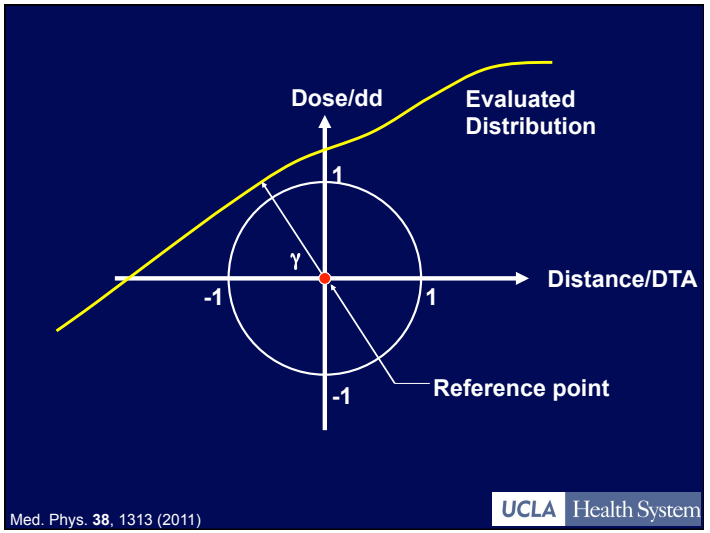
Dose/dd
Evaluated Distribution
Distance/DTA
Reference point
γ
1
-1
1
-1
Med. Phys. 38, 1313 (2011)
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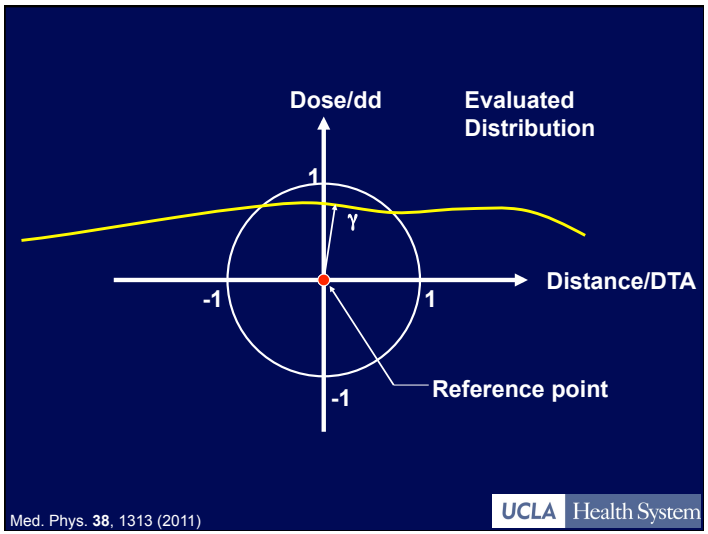
Dose/dd
Evaluated Distribution
Distance/DTA
Reference point
γ
1
-1
1
-1
Med. Phys. 38, 1313 (2011)
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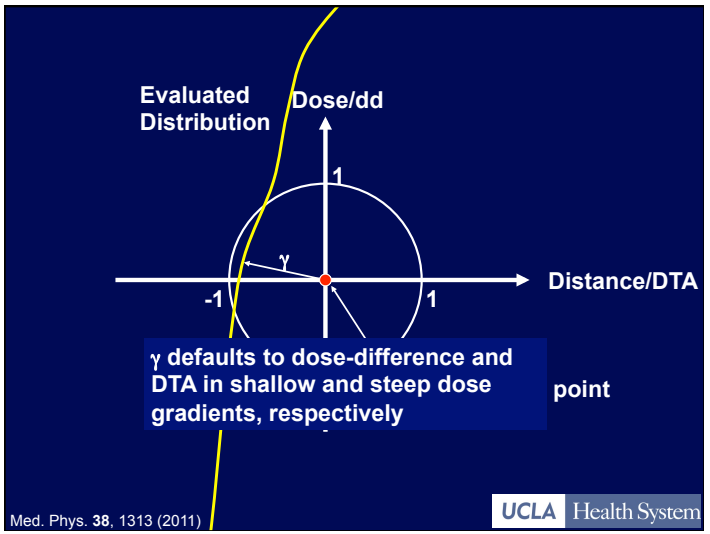
Evaluated Distribution
Dose/dd
Distance/DTA
γ defaults to dose-difference and DTA in shallow and steep dose gradients, respectively
point
γ
1
-1
1
Med. Phys. 38, 1313 (2011)
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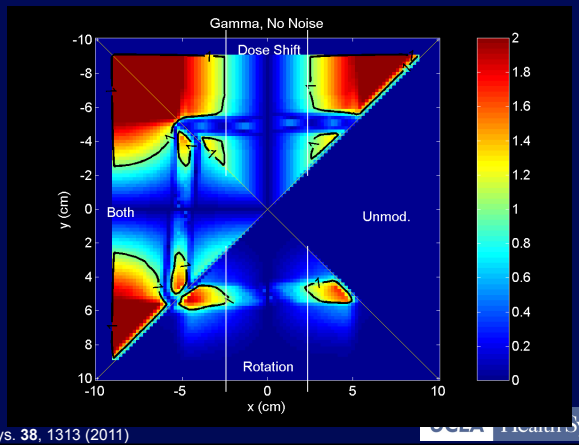
Gamma



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The γ dose comparison tool requires

20% 1. Only one dose distribution and two criteria.

20% 2. Two dose distributions and one criterion.

20% 3. Two dose distributions measured or calculated from different source types (e.g. film versus calculation).

20% 4. Two criteria: any combination of dose difference and DTA.

20% 5. Two criteria: one dose difference and one DTA.

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Correct Answer: 5

- Source TG 120

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Spatial Resolution

- γ is calculated independently for each reference point
- Reference distribution can be a single point
- Evaluated distribution 1D-3D
- Resolution challenge

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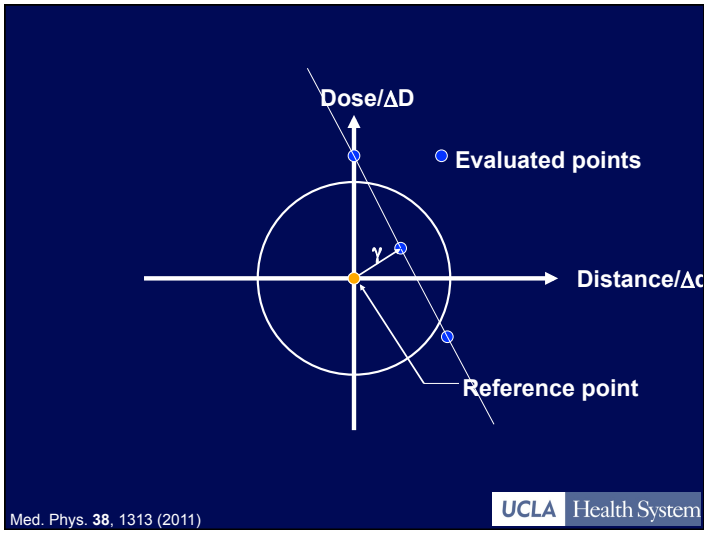

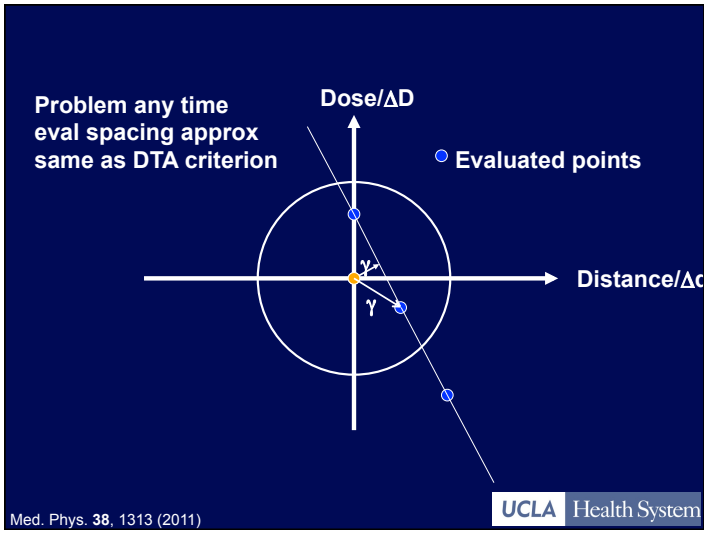

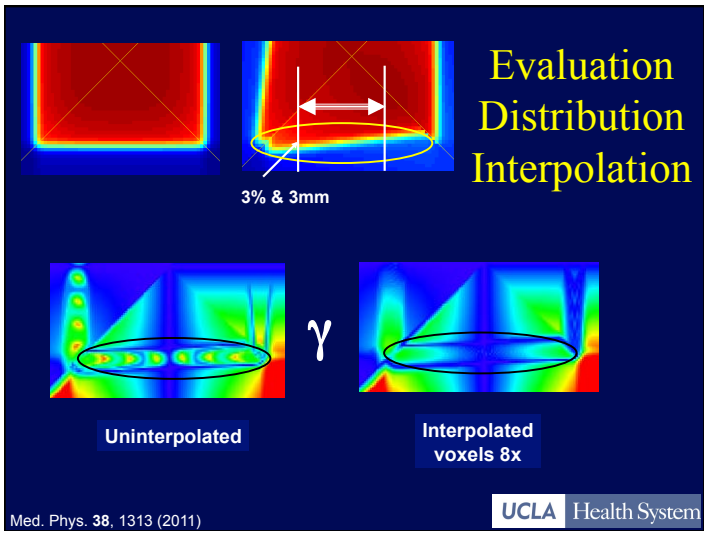

Interpolation

- Fixes resolution problem with evaluated distribution
- Cost in computation time
- Think of interpolation as geometric problem
  - Closest distance between line, surface, volume and one point
- Fast computation provided by computer gaming
- Ju et al. Med. Phys. 35, 879-887 (2008).

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Noise and γ

- Dose distribution noise has profound impact on γ calculations
- The impact depends on whether the noise is in the reference or evaluated distributions

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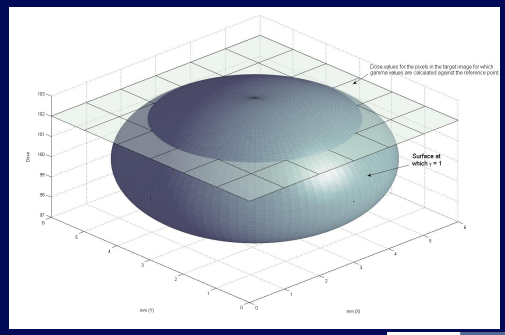
Why Noise Impacts γ



Thanks to Matt Whitaker, RIT

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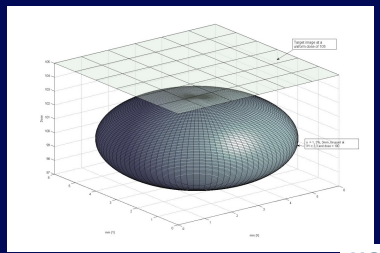
- Ideal case with a constant 5% difference between the point to be evaluated and the target image surface.
- With no noise a 3mm, 3% gamma will evaluate to 1.667 for this situation (fail).



Thanks to Matt Whitaker, RIT

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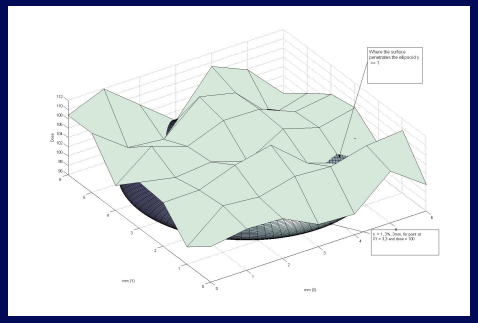
- If we add Gaussian noise with 0 mean and 3.16 standard deviation we see that the ellipsoid is penetrated.
- Anywhere the ellipsoid is penetrated γ <= 1 (pass)



Thanks to Matt Whitaker, RIT

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- Impact of noise depends on whether it is in the reference or evaluated distribution!
  - Evaluated: Typically underestimates γ (γ is the **minimum** distance!)
  - Reference: Noise is reflected in γ

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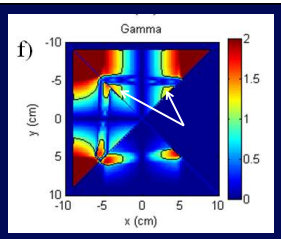
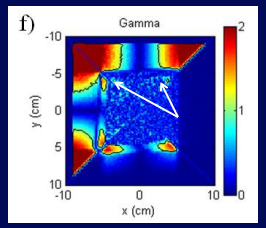
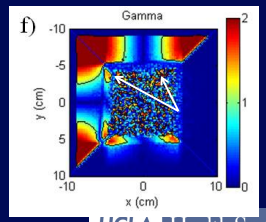
No Noise



3% Evaluated



3% Reference



Low and Dempsey Med. Phys. 30, 2455-2464 (2003).

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Clinical Issues

- Spatial resolution in evaluated distribution is important unless some type of interpolation is used
- Dose difference criterion is intuitive
- DTA criterion
  - Spatial uncertainty (measurements)
  - Spatial allowance (margins)
- How do we interpret γ failures?

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γ failures

- 100% passing would be nice!
- Not practical
- Caution: γ tool should be used as an indicator of problems, not as a single indicator of plan quality
- Passing Rate (Nelms): passing rate not correlated with clinically relevant errors

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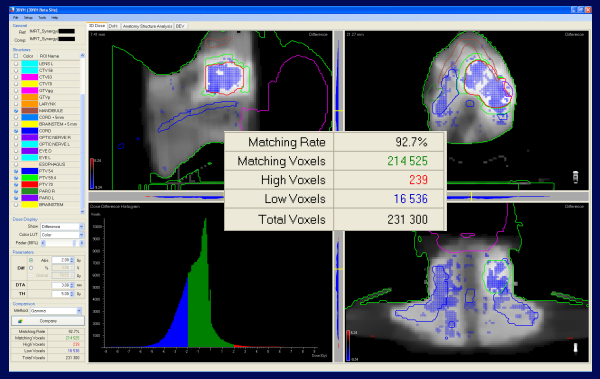

Thanks to Geneviève Jarry, HMR, Montre

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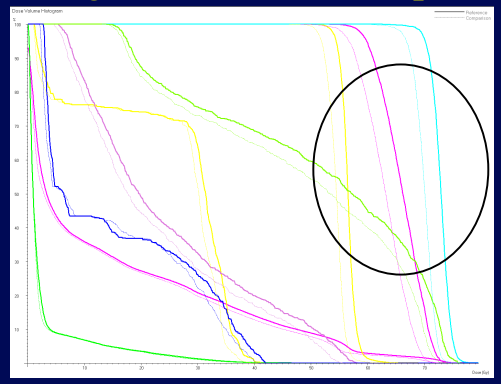
Target Volume Cold Spots



Thanks to Geneviève Jarry, HMR, Montre

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Criteria

- Spatially varying criteria (both dd and DTA
  - Anatomical (target versus muscle)
  - Dose (high versus low)
- This may be very useful with new back-projected and independently calculated 3D dose distributions
- Medically appropriate criteria will make interpretation of γ more straightforward

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γ Histograms

- γ histograms provide more information than just pass/fail percentages
- Maximum γ indicates magnitude of agreement
- Mean γ may also indicate relative quality of plan

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2D versus 3D

- Gradients exist in all 3 dimensions
- 2D γ provides less information than full 3D γ
- If measurement is 2D, calculation is typically 3D, so no reason not to use 3D γ (3D γ will always provide smaller values than 2D)

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Modern IMRT QA:

20% 1. Is adequate by itself to guarantee safe IMRT treat
20% 2. Will identify most major sources of error.
20% 3. Catches many but not most errors.
20% 4. Is accurate, but inadequate.
20% 5. Does not play a significant role in improving radi therapy safety.

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Correct Answer: 2

- Source TG 120

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Conclusions

- Dosimetry for IMRT is complicated
- Many opportunities for making a mistake
- TG-120 provides guidance for selection and use of most common detectors

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