

Automated Image Analysis Software for Quality Assurance of a Radiotherapy CT Simulator

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Overview

- Radiotherapy imaging
- RT Imaging QA: problems and solution
- Describe features of auto analysis software
- Demonstrate application to CT-Sim and Sim-CT
- Outline experience to date

Imaging Modalities for RT

- Common
 - Simulator (fluoroscopy)
 - CT-simulator
 - Digitally Reconstructed Radiographs (DRRs)
 - Simulator-CT (single slice and cone-beam)
 - Electronic Portal Imaging Devices (EPIDs)
- ‘Emerging’
 - Ultrasound
 - MRI
 - PET
 - On treatment cone-beam CT and kV radiography

Integrated System

RT Imaging QA: Essential Tests

- Geometric Accuracy in 3D
 - In and out of image plane (pixel size, couch travel)
 - Mechanical alignments
 - Laser alignment
- Image quality
 - Sufficient for purpose?
 - Consistent over time
- Accurate physical information
 - CT number / HU calibration -> electron density
- Testing of overall system
 - Geometrical co-registration
 - Transfer of image data

The Problems...

- Different tests are specified for different modalities
- Range of 'equivalent' test objects
- Most tests are only semi-quantitative
- Operator dependency
- Frequent (daily/fortnightly) comprehensive testing is required BUT most tests are time-consuming
- Some imaging equipment performs too well!
- Difficult to test integrated system.

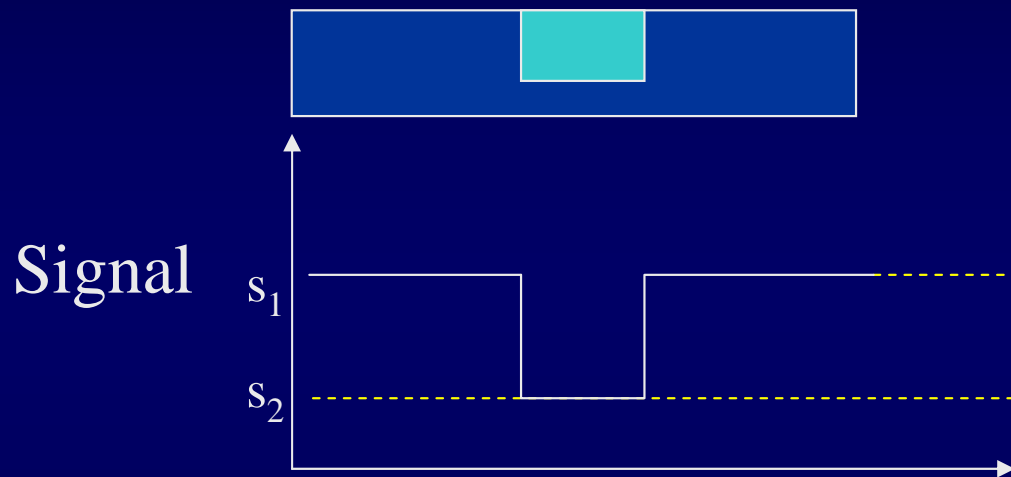
The Solution...

- Develop single, uniform approach for all RT imaging modalities
 - + display devices, film processors, etc.
- Robust, fully objective and quantitative
- Analysis performed by computer
- Results automatically stored in database for trend analysis, etc.

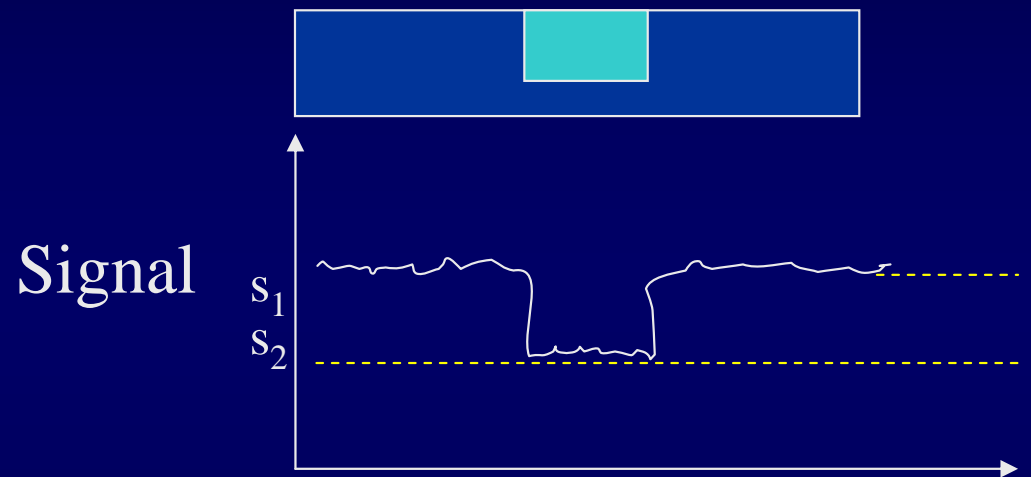
The Approach

1. Develop Appropriate Phantom

2. Acquire Image of Phantom



$$SNR_{in} = s_1 / s_2$$



$$SNR_{out} = s_1 / s_2$$

$$\left[\frac{SNR_{out}}{SNR_{in}} \right]^2 = DQE(f)$$

Determining the DQE

Modulation Transfer Function (Phantom)

$$DQE(f) = \boxed{K \cdot D} \cdot \frac{MTF^2}{NPS}$$

Dose and acquisition
setting dependent.

Noise Power Spectrum (Phantom)

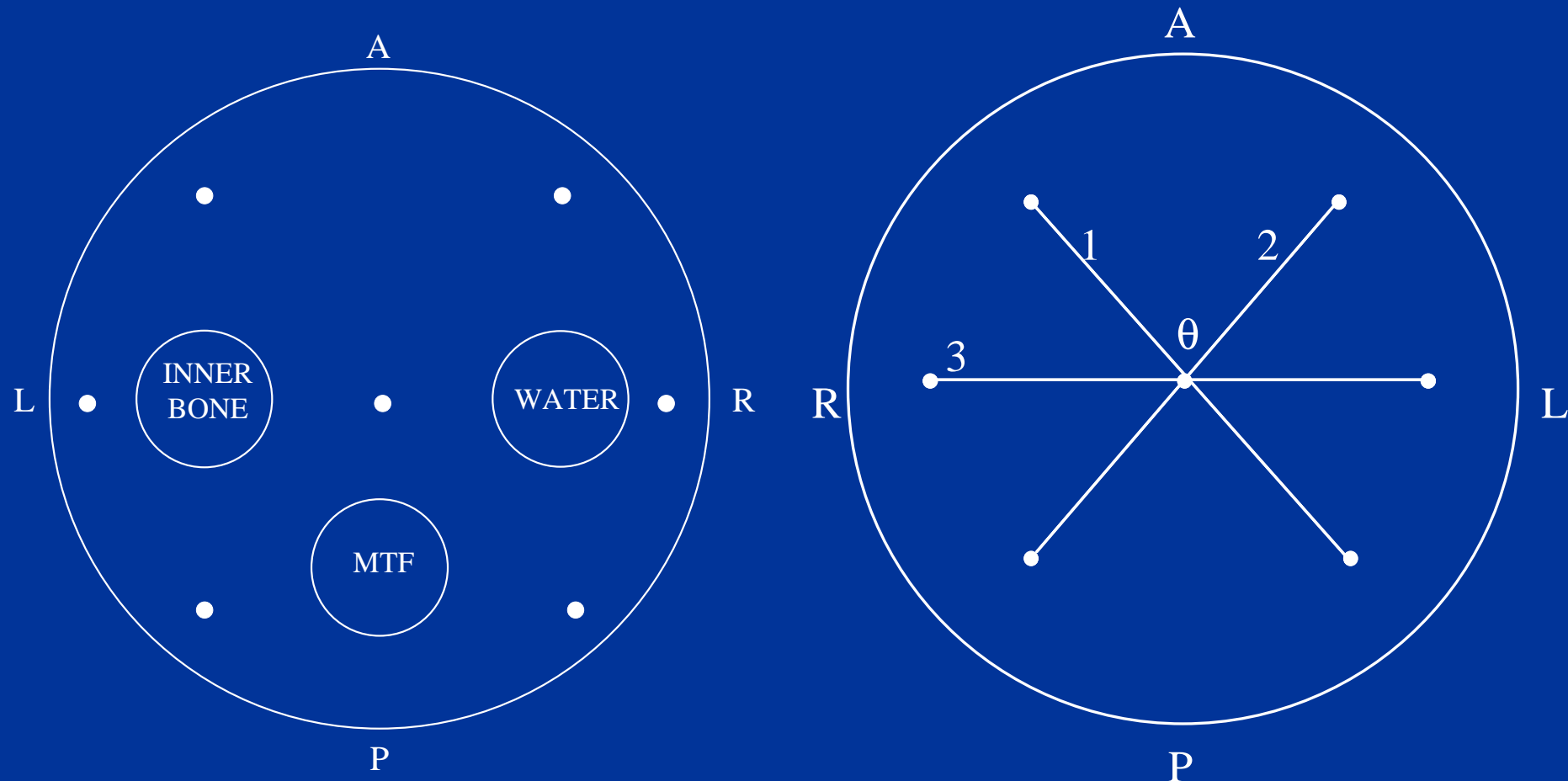


Varian Ximatron EX Sim-CT

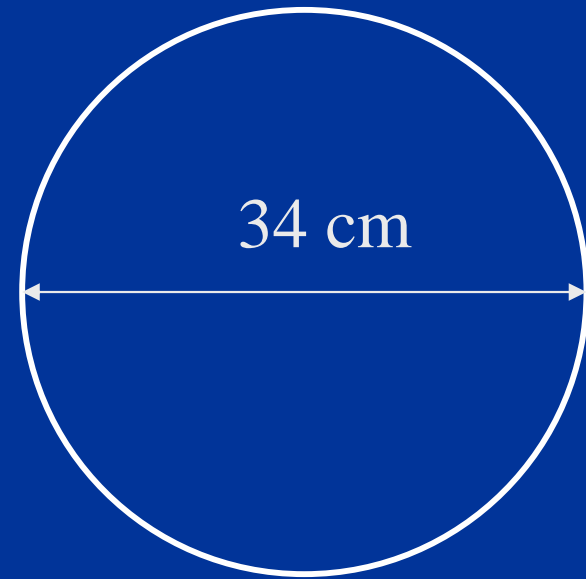
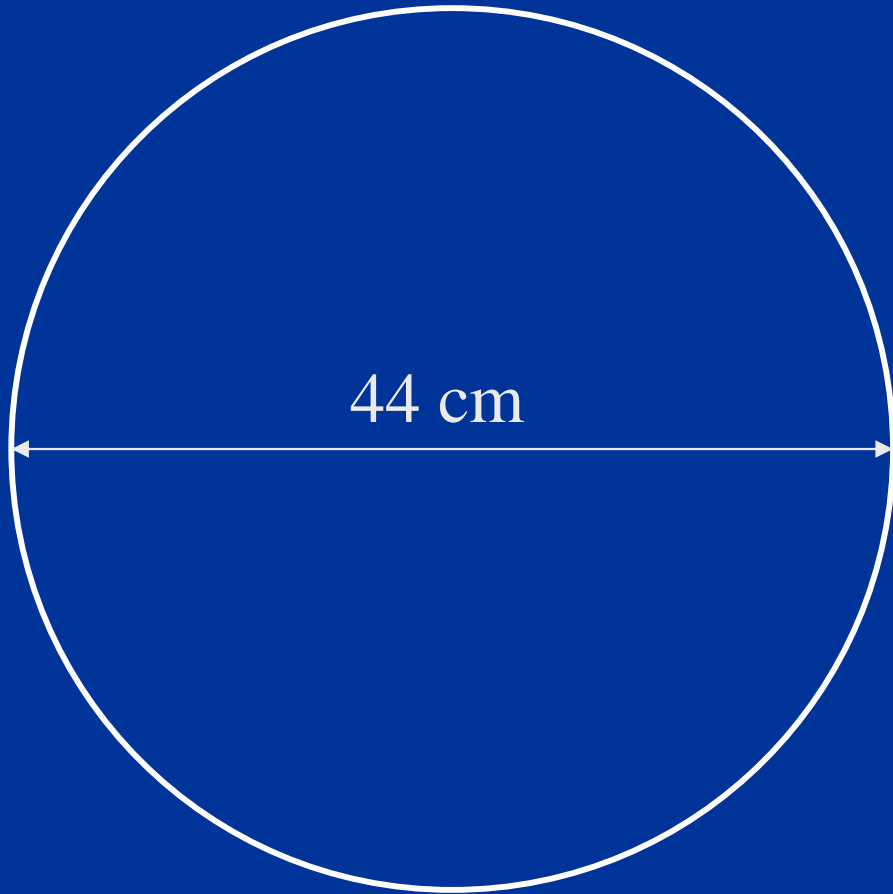
Additional
Collimators



Varian Performance Phantom



Varian Uniformity Phantoms

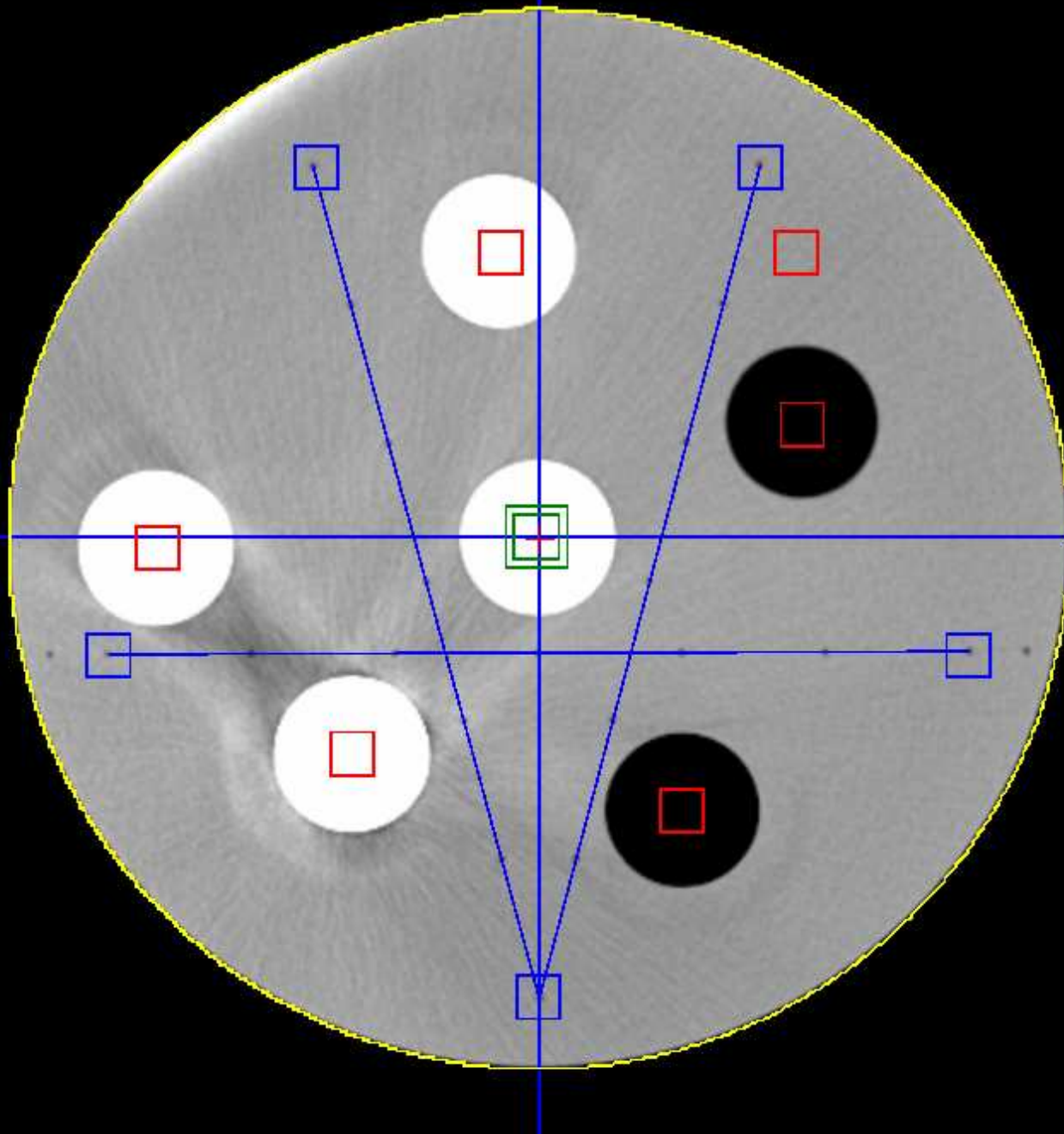


Polyurethane Casting
HU -580

Ge

nt

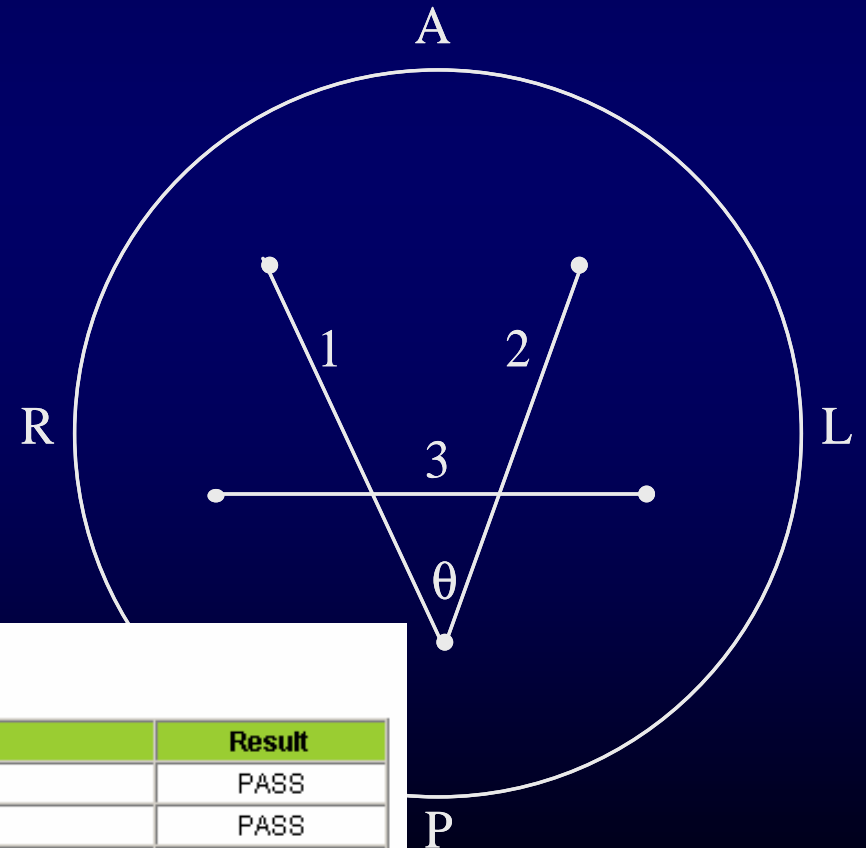
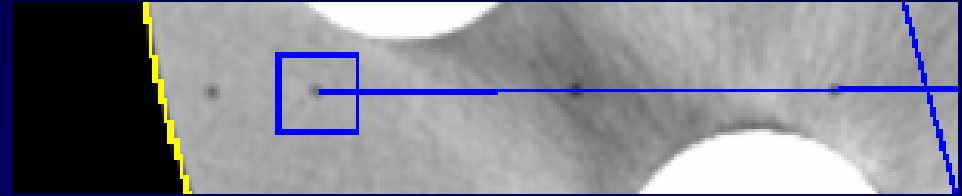
- Detect
 - Thru
 - Tra
 - cho
- Calcul
- Comp
- zero p



www.2065

Geometry: Pixel Size

- Measure distance between holes
- Use centre of phantom and expected pixel size to identify 'seek area'
- Local minimum is centre of hole

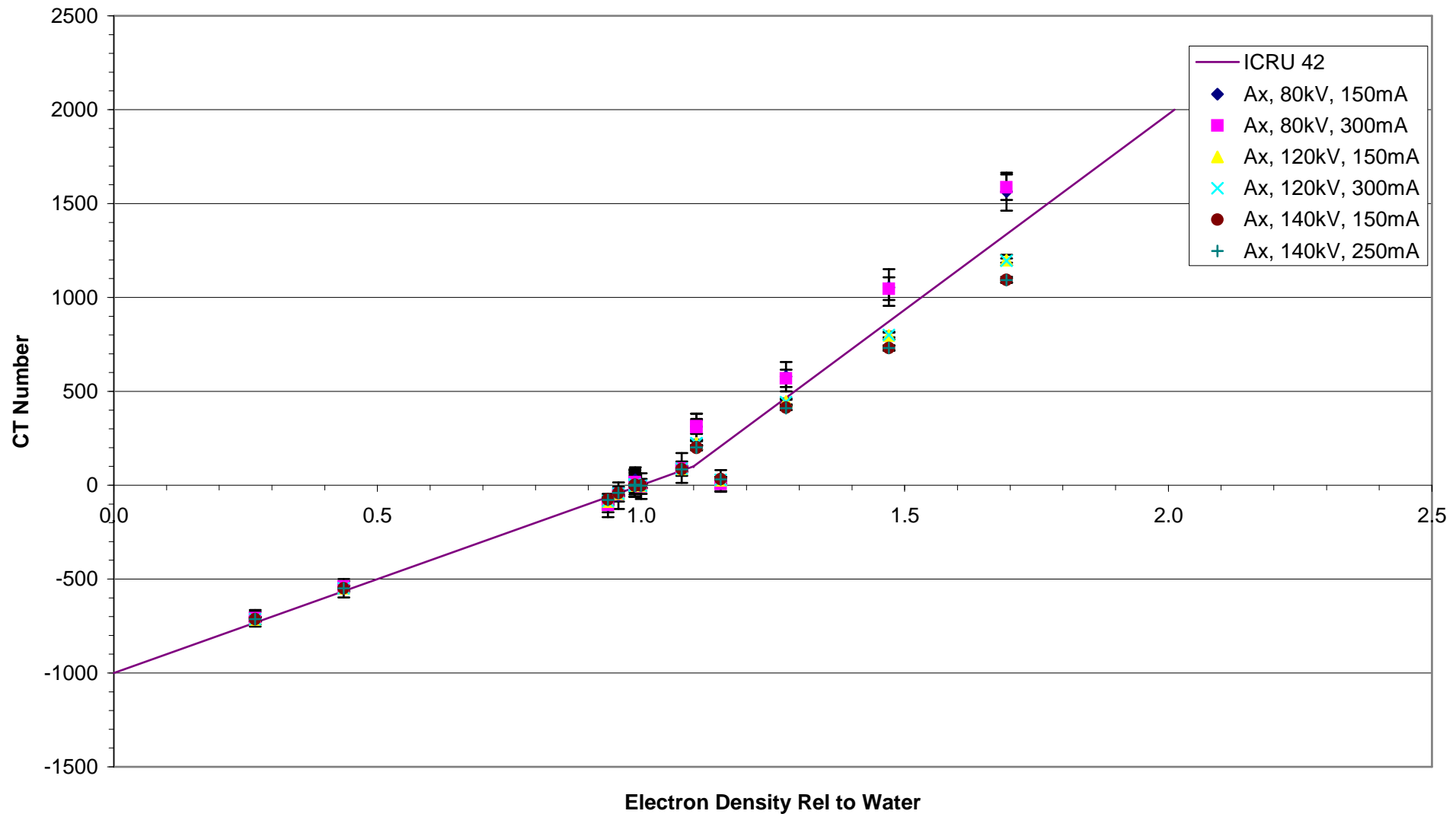


Geometric Distortion

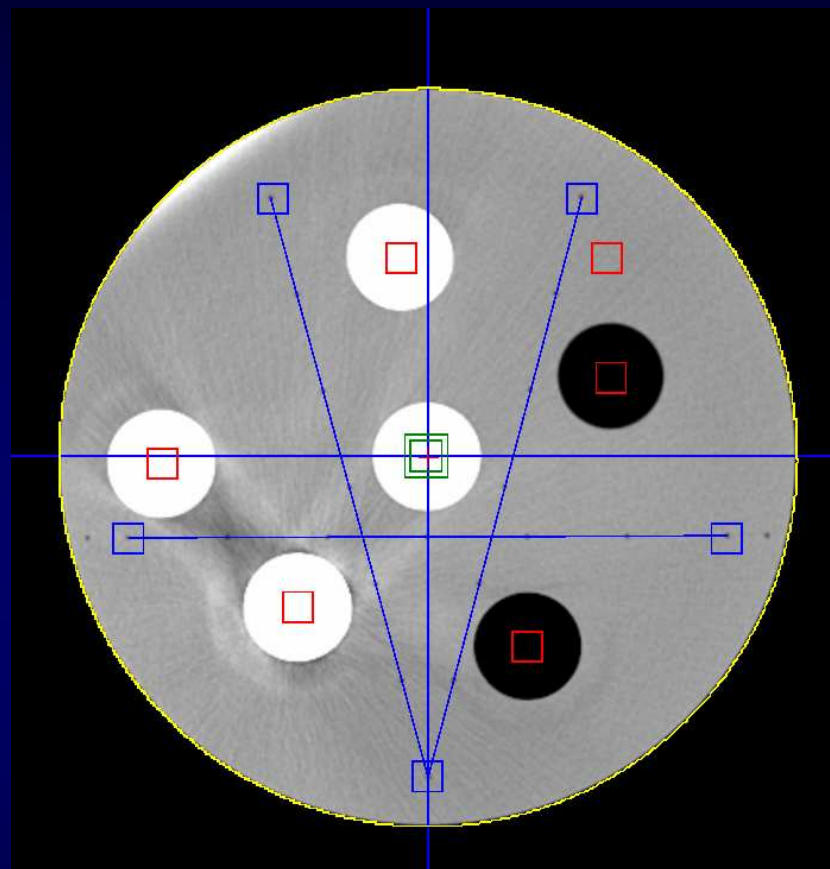
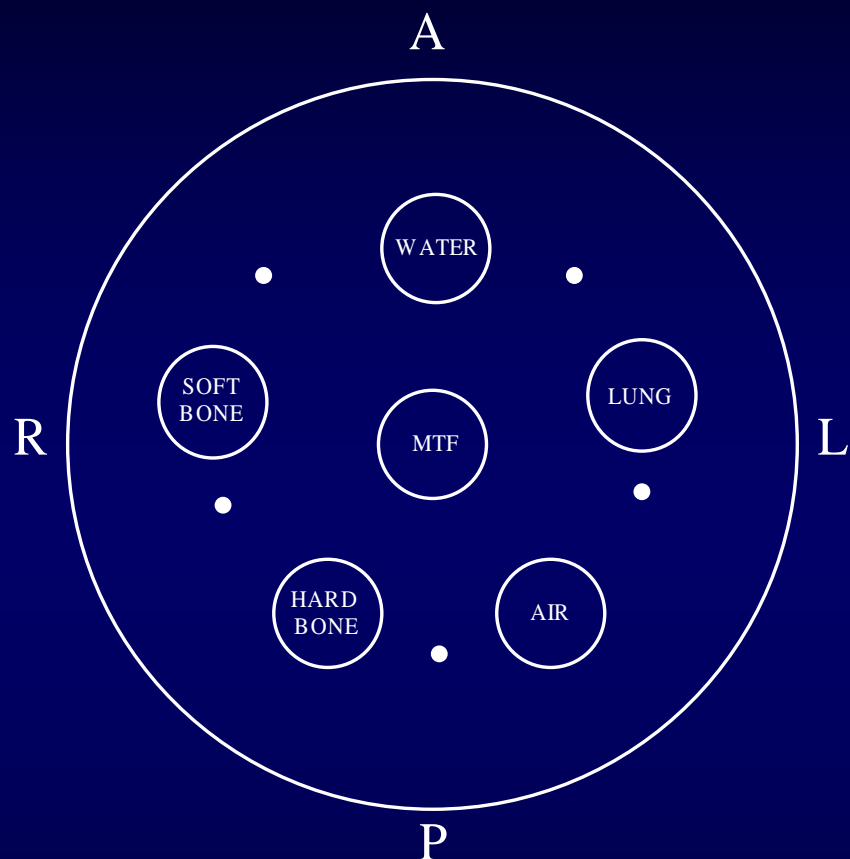
Line	Name	Length (mm)	Expected (mm)	Result
1	Line 1	301.6	300±2	PASS
2	Line 2	301.1	300±2	PASS
3	Line 3	300.8	300±2	PASS

Hounsfield Unit Calibration

Baseline Values Measured During Commissioning



Hounsfield Unit Calibration



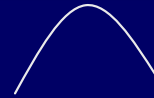
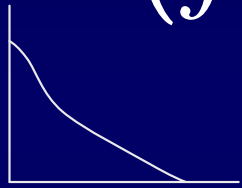
ROI Analysis

ROI	Name	Mean	Std Dev	Expected	Result
1	Water	-2.1	3.5	0±5	PASS
2	Lung	-732.1	2.4	-732±10	PASS
3	Air	-995.4	2.8	-1000±5	PASS
4	Cortical Bone	1298.7	8.6	1300±10	PASS
5	Inner Bone	185.5	5.0	189±10	PASS
6	Urethane	-579.8	2.6	-580±10	PASS

Modulation Transfer Function

- Calculate from impulse object

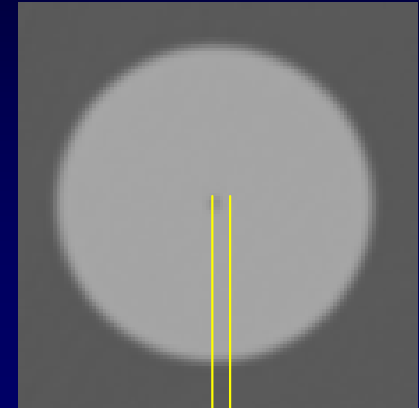
$$MTF(f) = |FT\{PSF(x)\}|$$



$$OSF(x) = PSF(x) \otimes DSF(x)$$

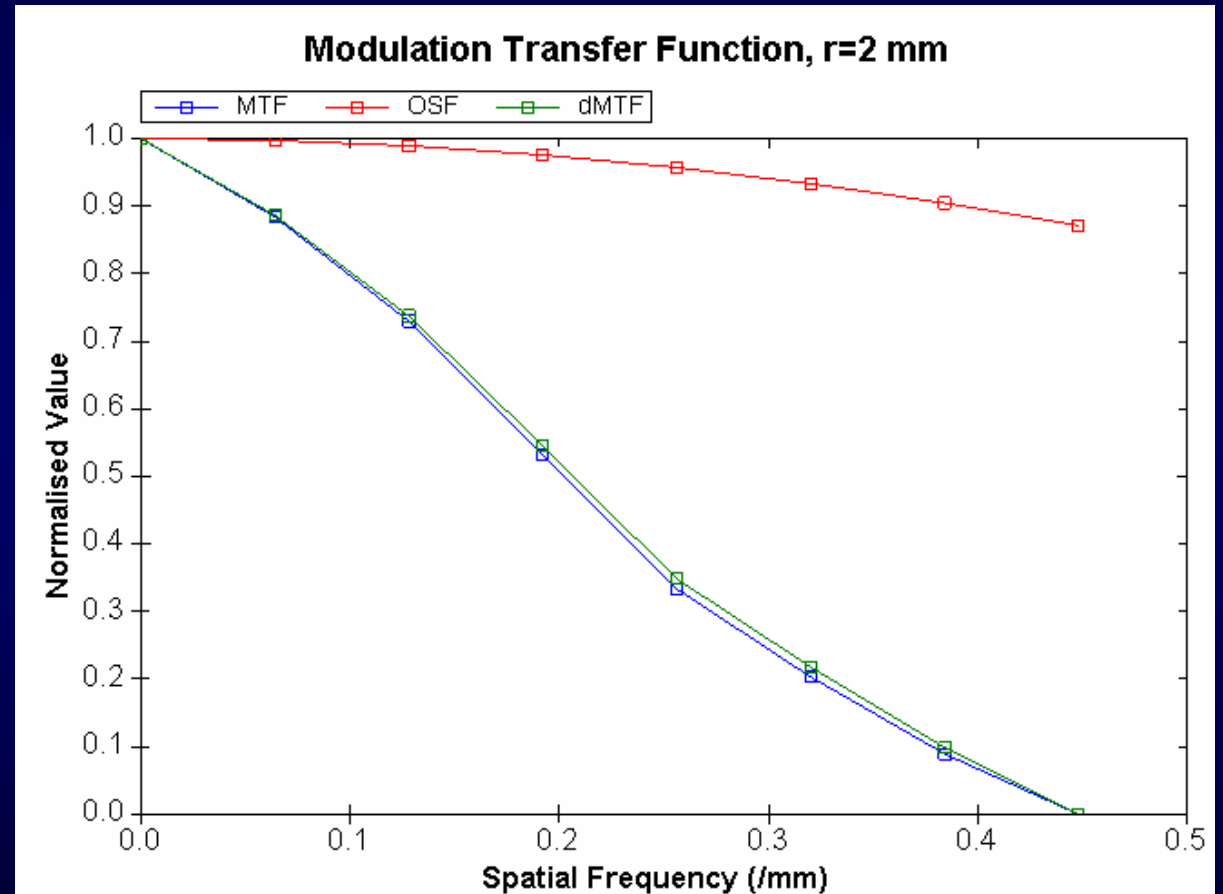
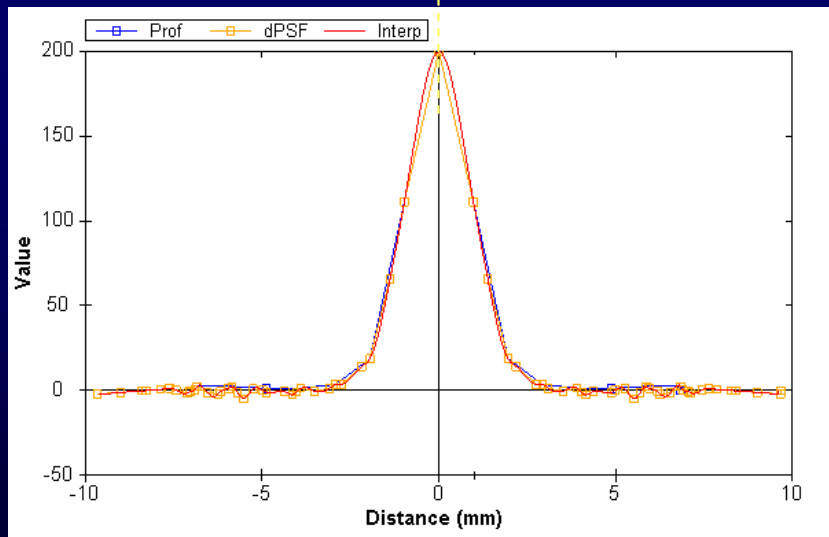
$$FT\{OSF(x)\} = FT\{PSF(x)\} \times FT\{DSF(x)\}$$

$$MTF(f) = \frac{FT\{OSF(x)\}}{FT\{DSF(x)\}}$$



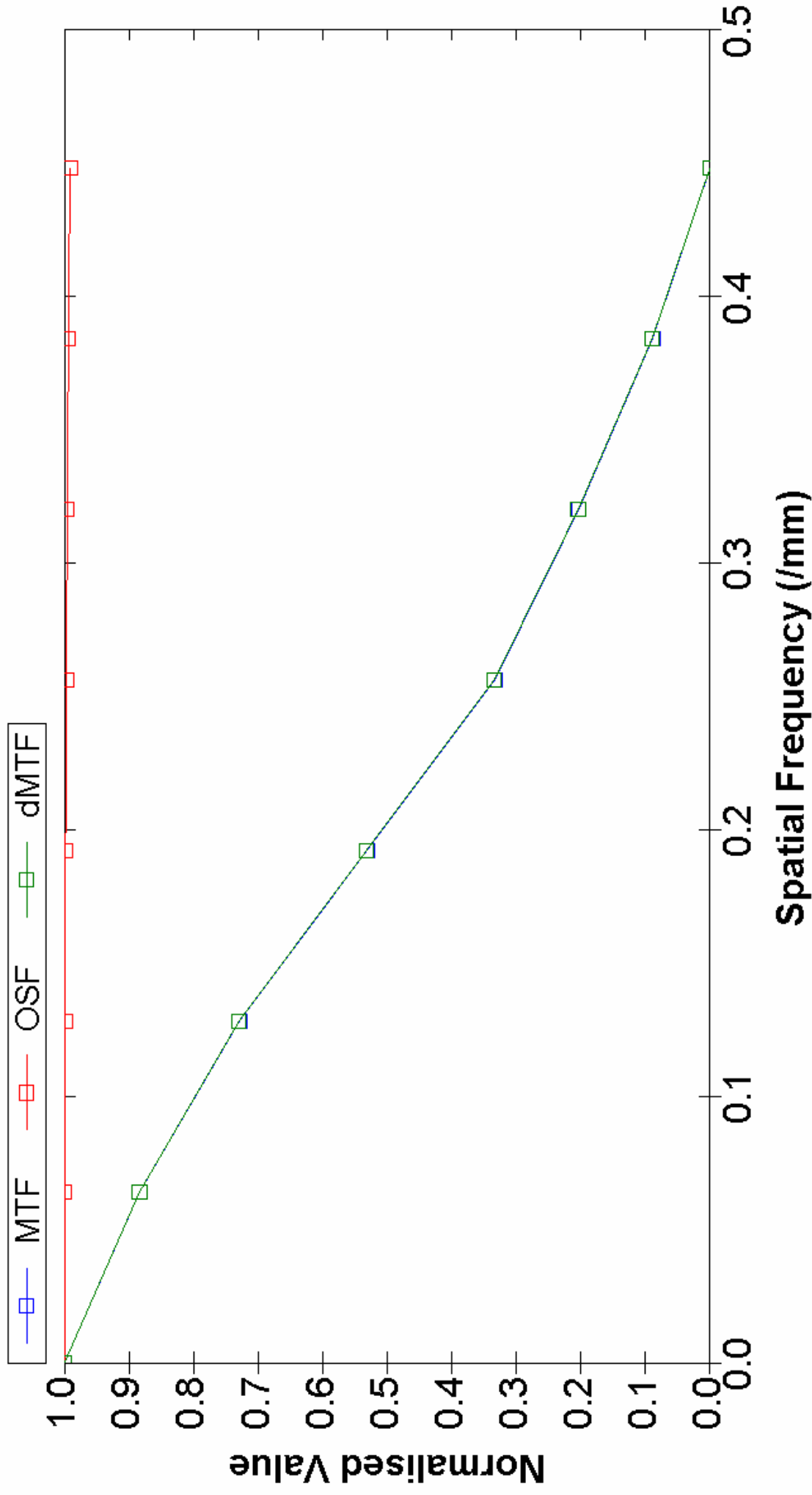
Finite size
(DSF)

Calculation from Impulse Object



Object Spread Function
(From ALL pixels in ROI)

Modulation Transfer Function, $r=0.5$ mm



Uniformity Phantom Analysis

- Define Useful FOV (UFOV) as 90% FOV
- Calculate:

$$\text{Coefficient of Variation, } CoV = \frac{\text{std dev}}{\text{mean}}$$

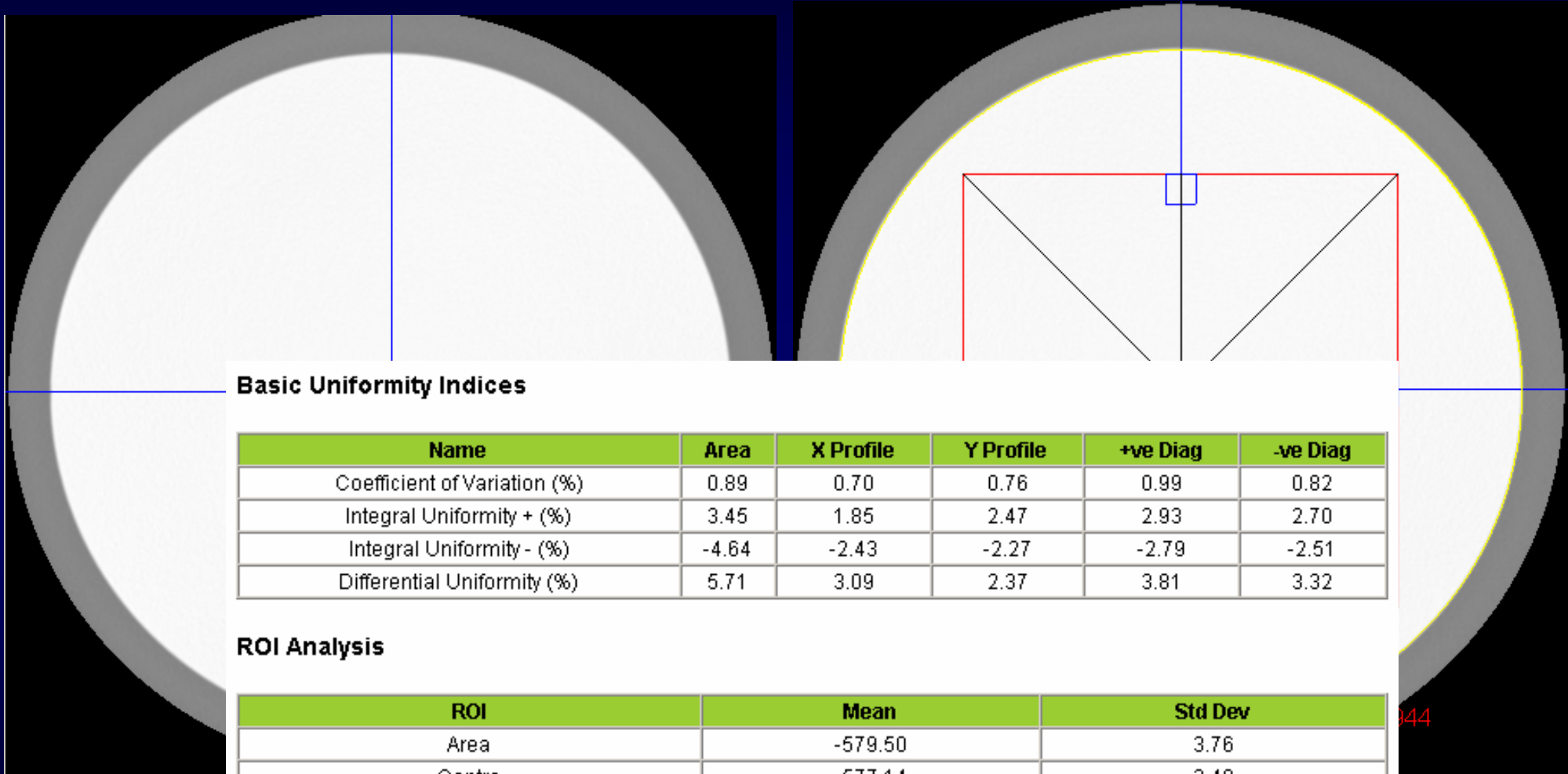
$$\text{Integral Uniformity, } U_+ = \frac{p_{\max} - \text{mean}}{\text{mean}}$$

$$\text{Integral Uniformity, } U_- = \frac{p_{\min} - \text{mean}}{\text{mean}}$$

$$\text{Differential Uniformity, } U_d = \frac{\Delta p_{\max}}{\text{mean}}$$

$$\text{Uniformity Index, } U_{CT} = \frac{\text{centre} - \langle \text{periphery} \rangle}{1000}$$

Uniformity Phantom Analysis



Basic Uniformity Indices

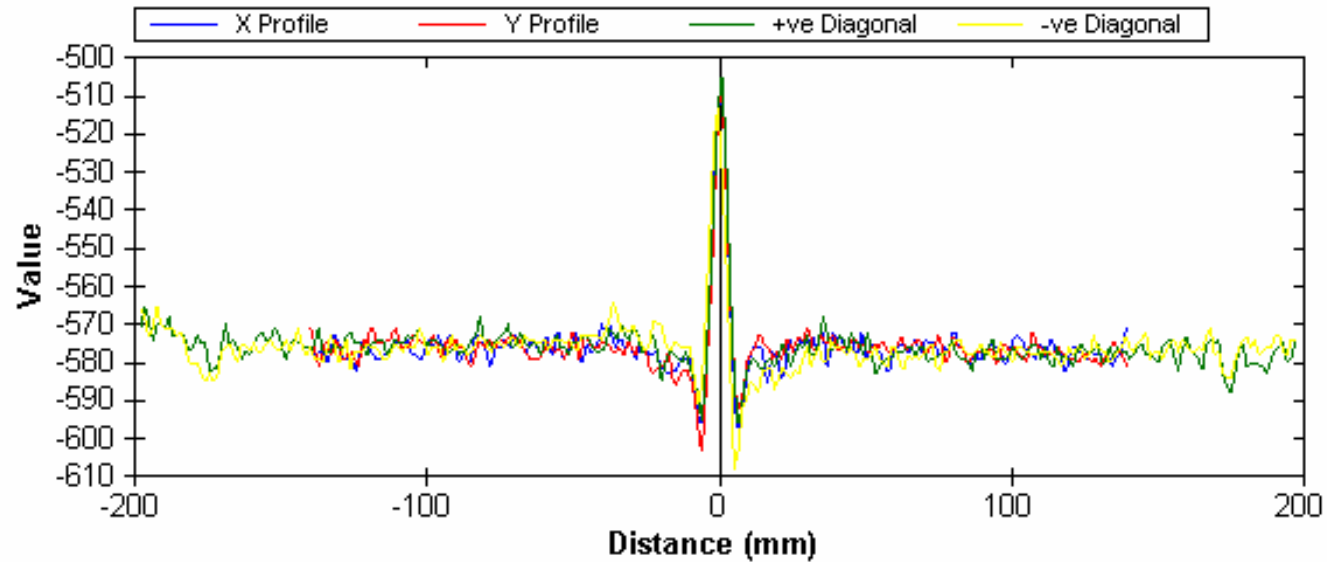
Name	Area	X Profile	Y Profile	+ve Diag	-ve Diag
Coefficient of Variation (%)	0.89	0.70	0.76	0.99	0.82
Integral Uniformity + (%)	3.45	1.85	2.47	2.93	2.70
Integral Uniformity - (%)	-4.64	-2.43	-2.27	-2.79	-2.51
Differential Uniformity (%)	5.71	3.09	2.37	3.81	3.32

ROI Analysis

ROI	Mean	Std Dev
Area	-579.50	3.76
Centre	-577.14	2.49
3 O'Clock	-580.22	3.59
6 O'Clock	-580.86	3.81
9 O'Clock	-578.91	4.12
12 O'Clock	-579.87	3.46

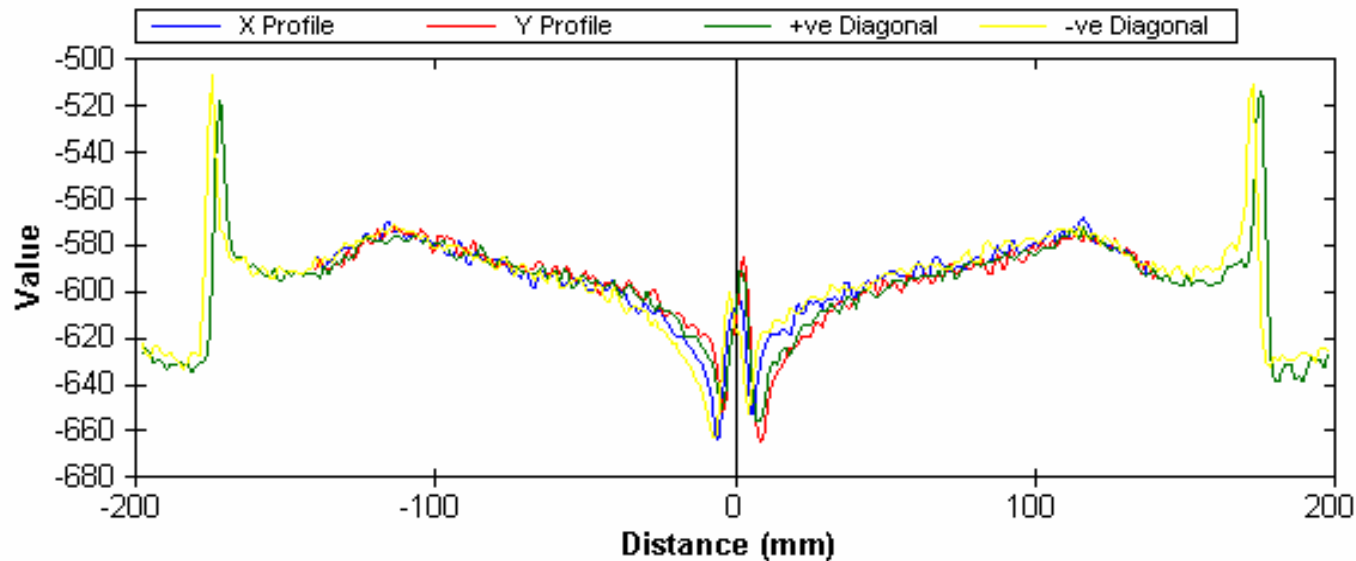
Index of Uniformity: 0.28 %

Uniformity Profiles



Sim-CT

Urethane Norm



Air Norm

Noise Power Spectrum

- Region of Interest from Uniformity Phantom
- Remove DC component (subtract mean value)
- Perform 2D FFT

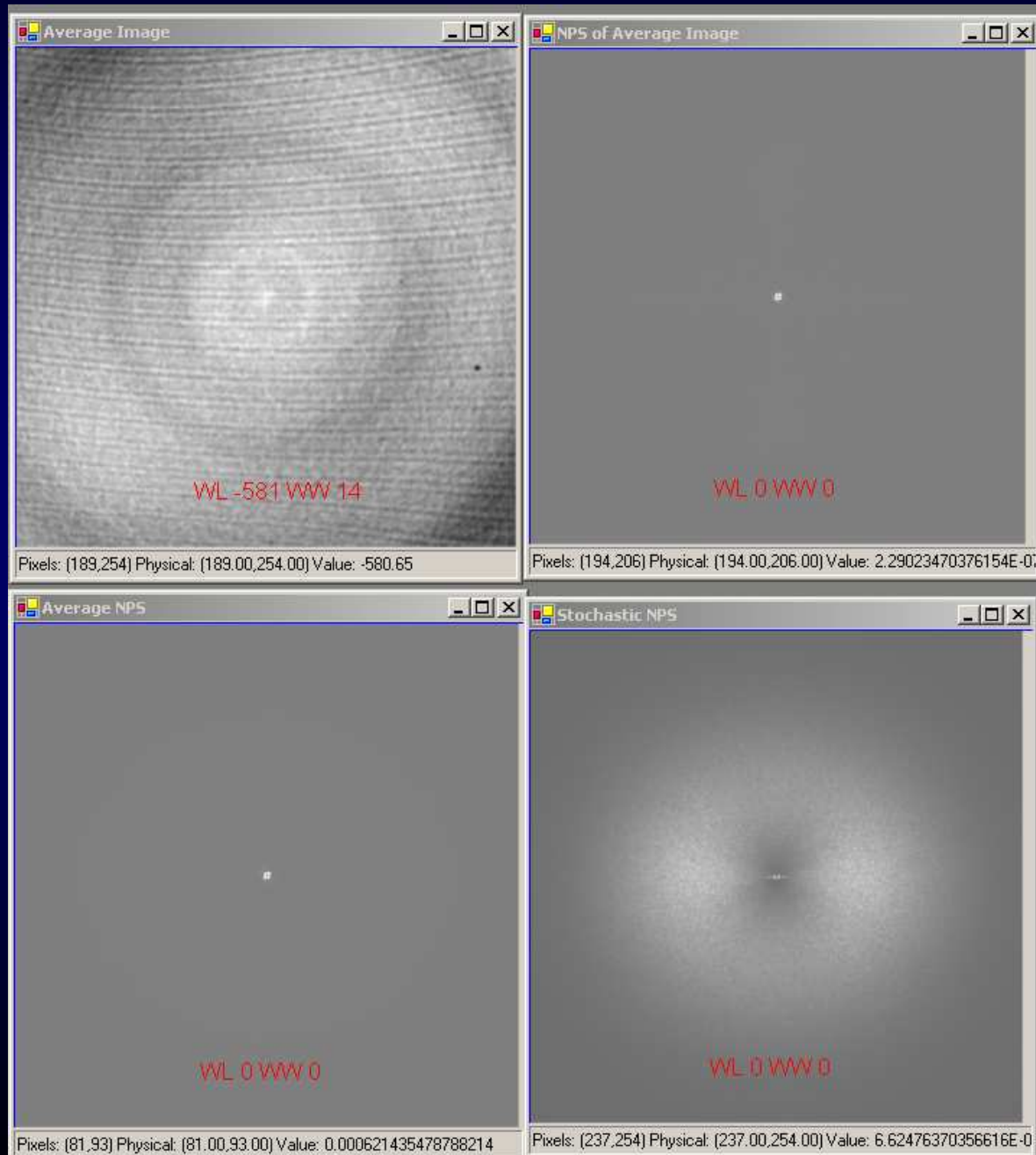
$$NPS(u, v) = \frac{\text{Re}(u, v)^2 + \text{Im}(u, v)^2}{\text{area}}$$

- Separation of stochastic noise

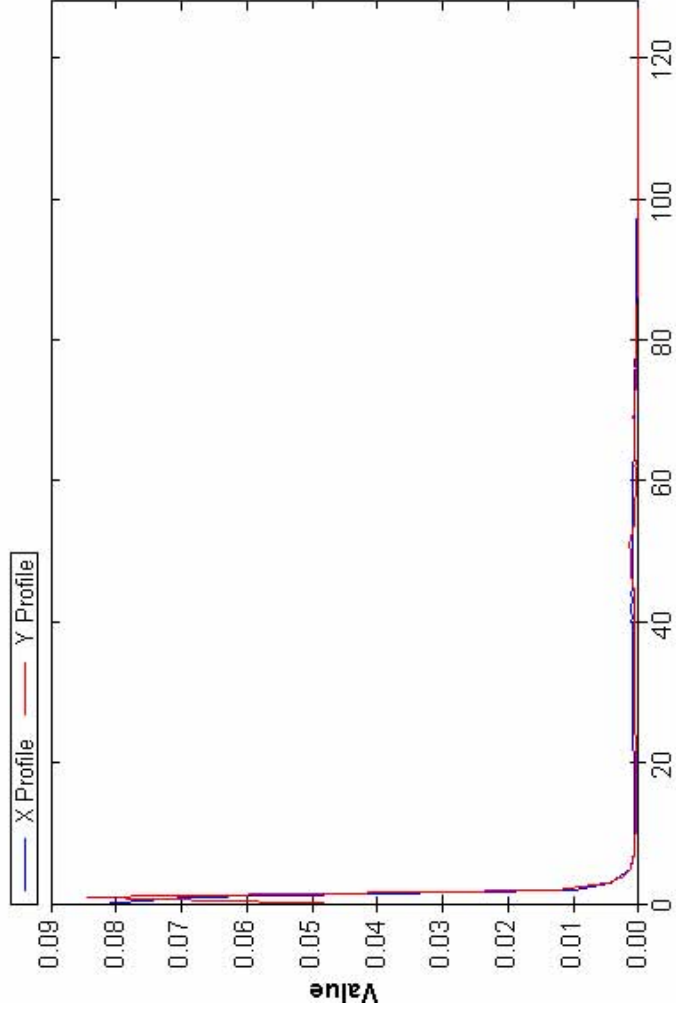
$$NPS_s = \frac{\sum NPS}{n} - NPS \left(\frac{\sum ROI}{n} \right)$$

NPS Example

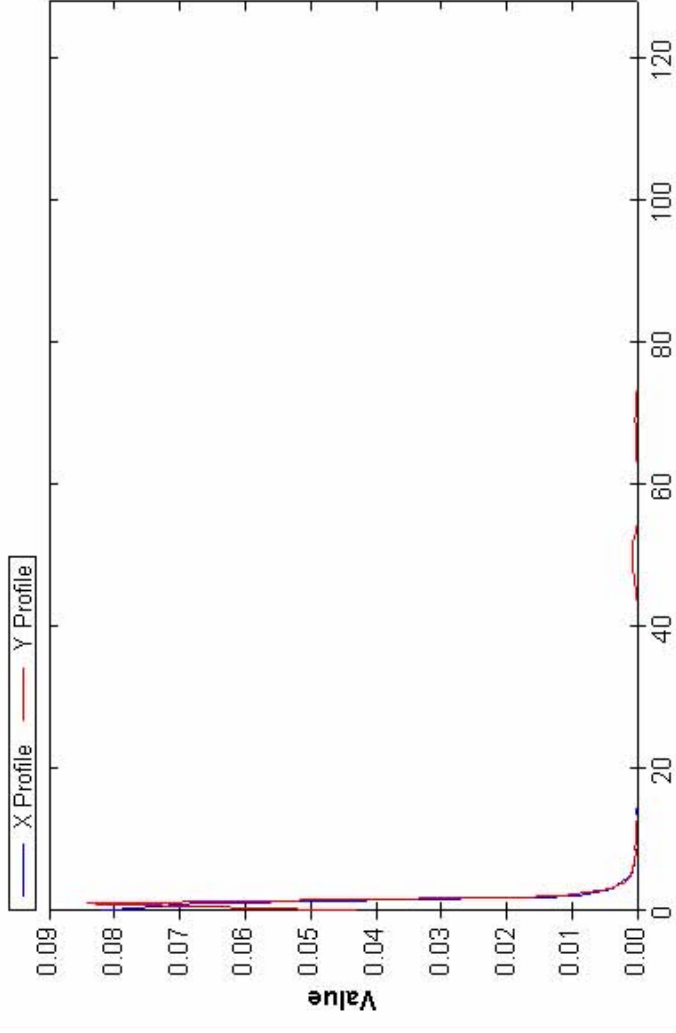
- 100 images of Uniformity Phantom, 50 cm FOV



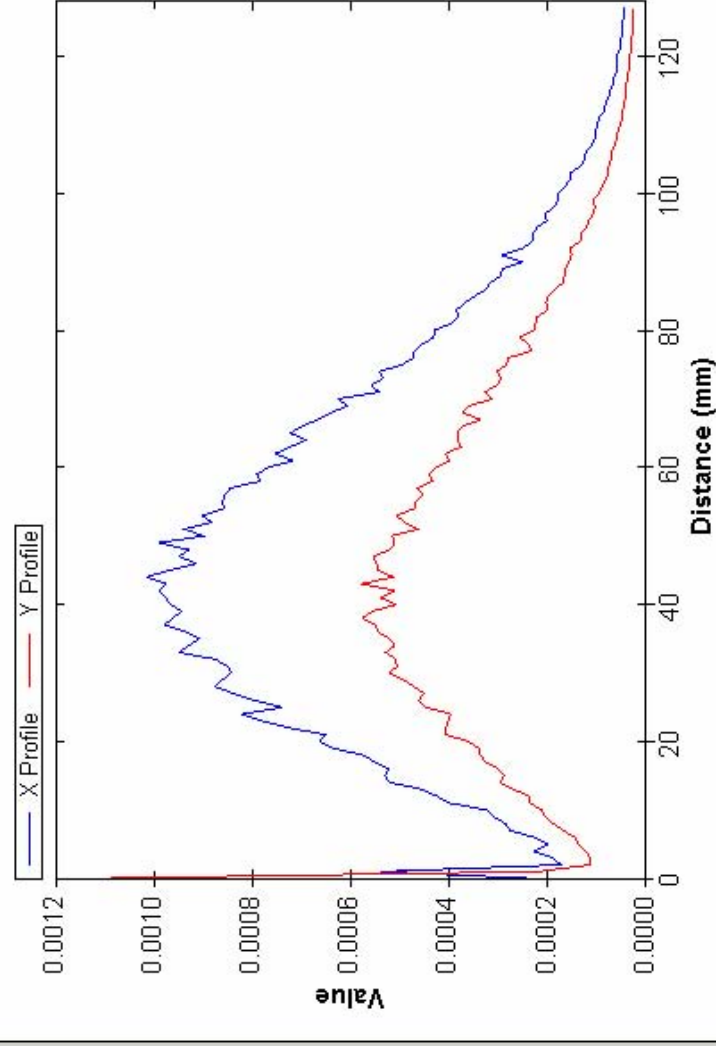
Profiles of Average NPS



Profiles of NPS of Average Image

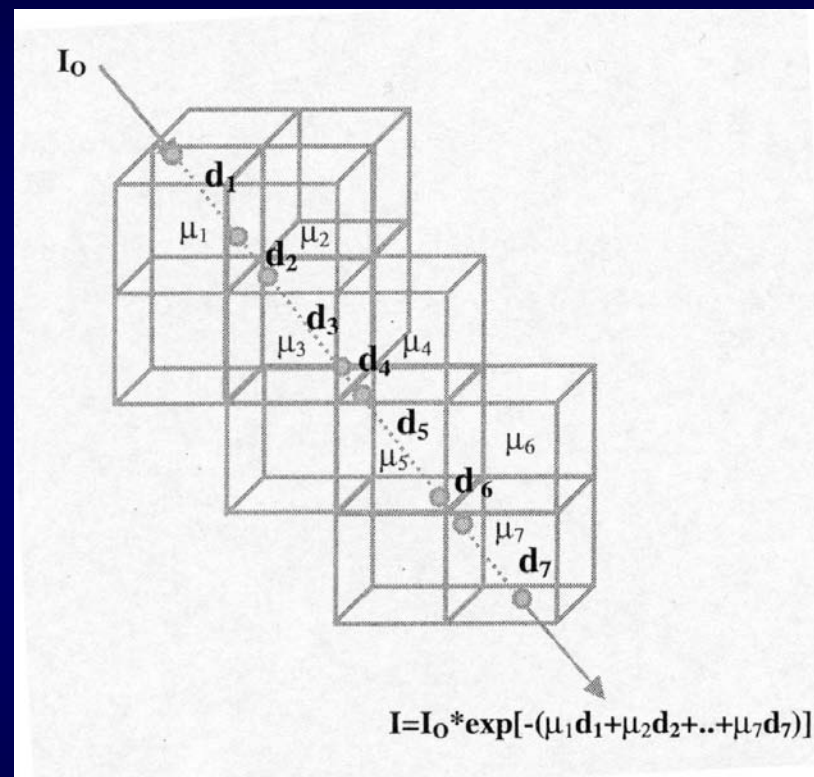
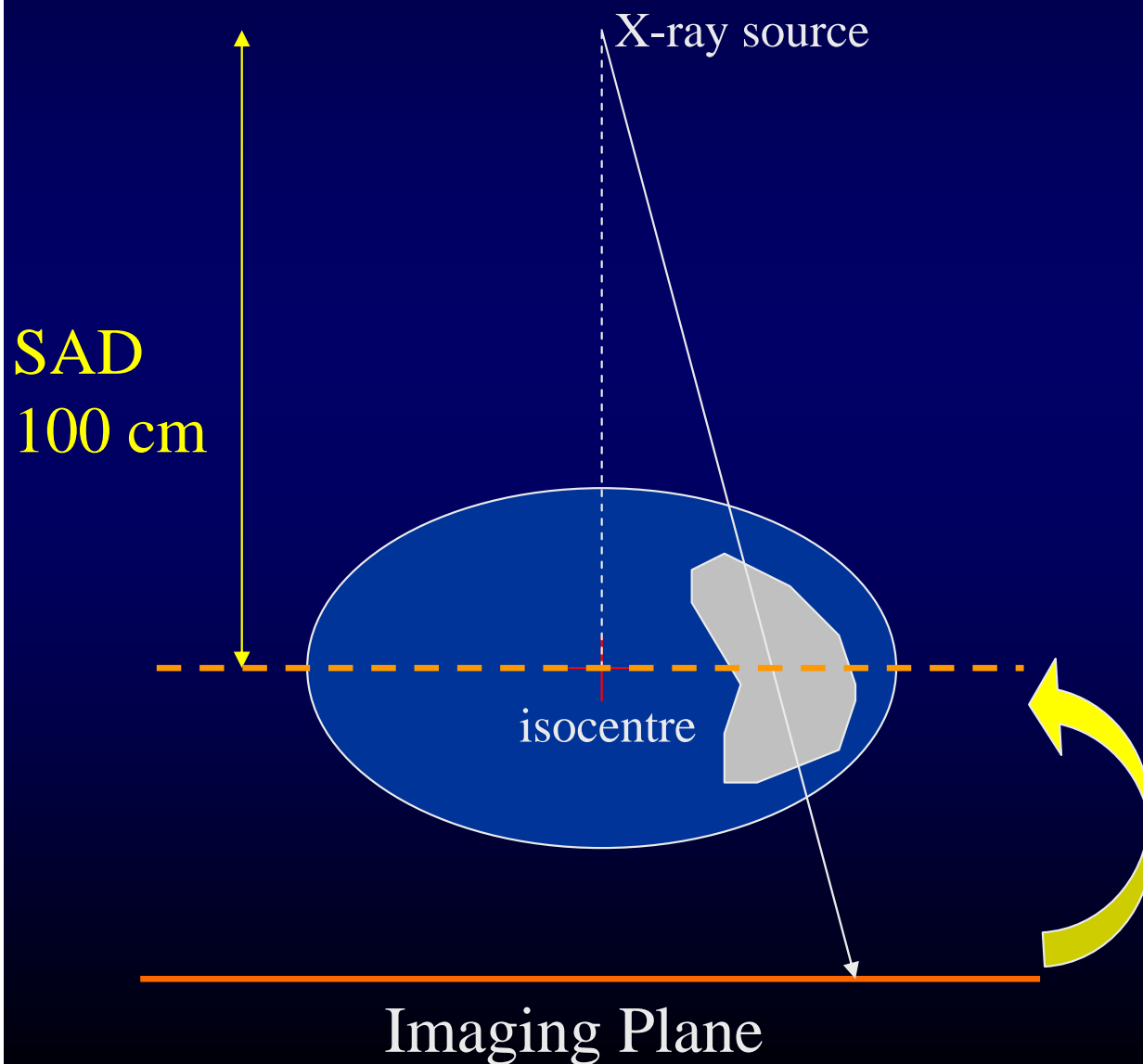


Profiles of Stochastic NPS



Production of DRRs

- Ray trace from virtual source of x-rays through stack of CT slices and model attenuation of beam.

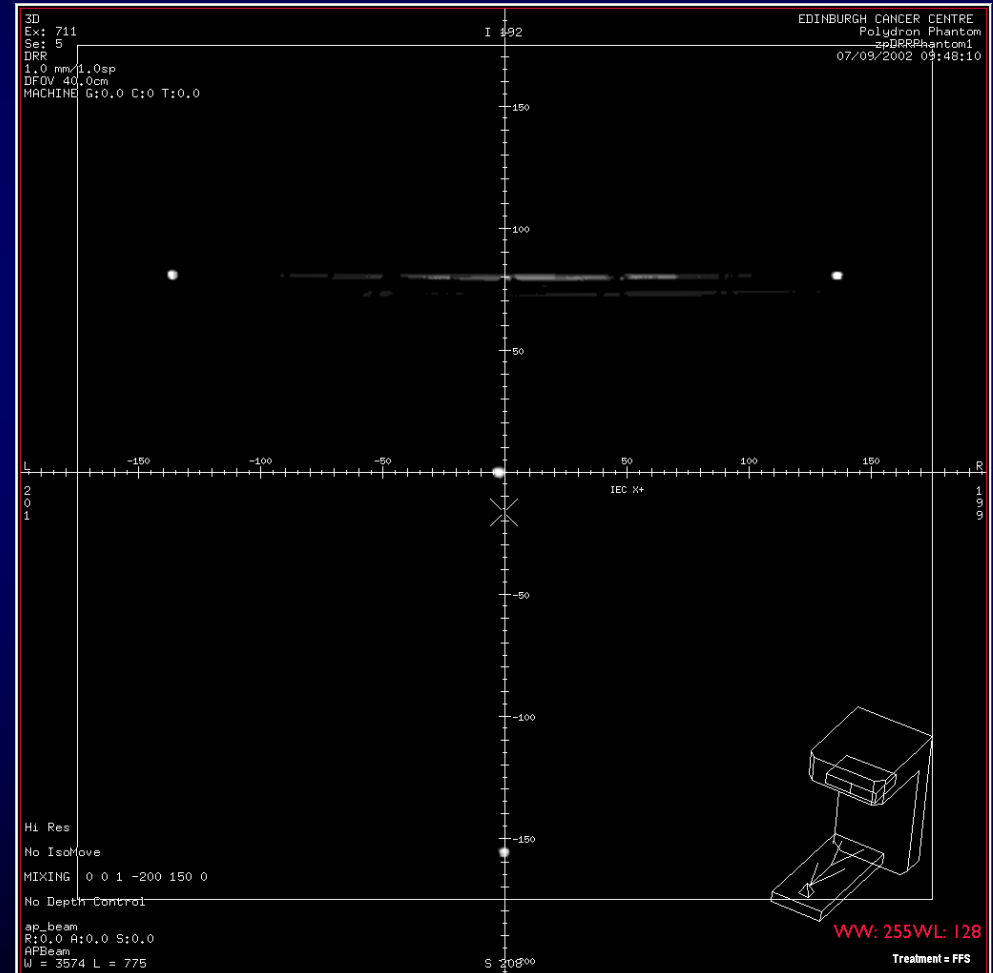
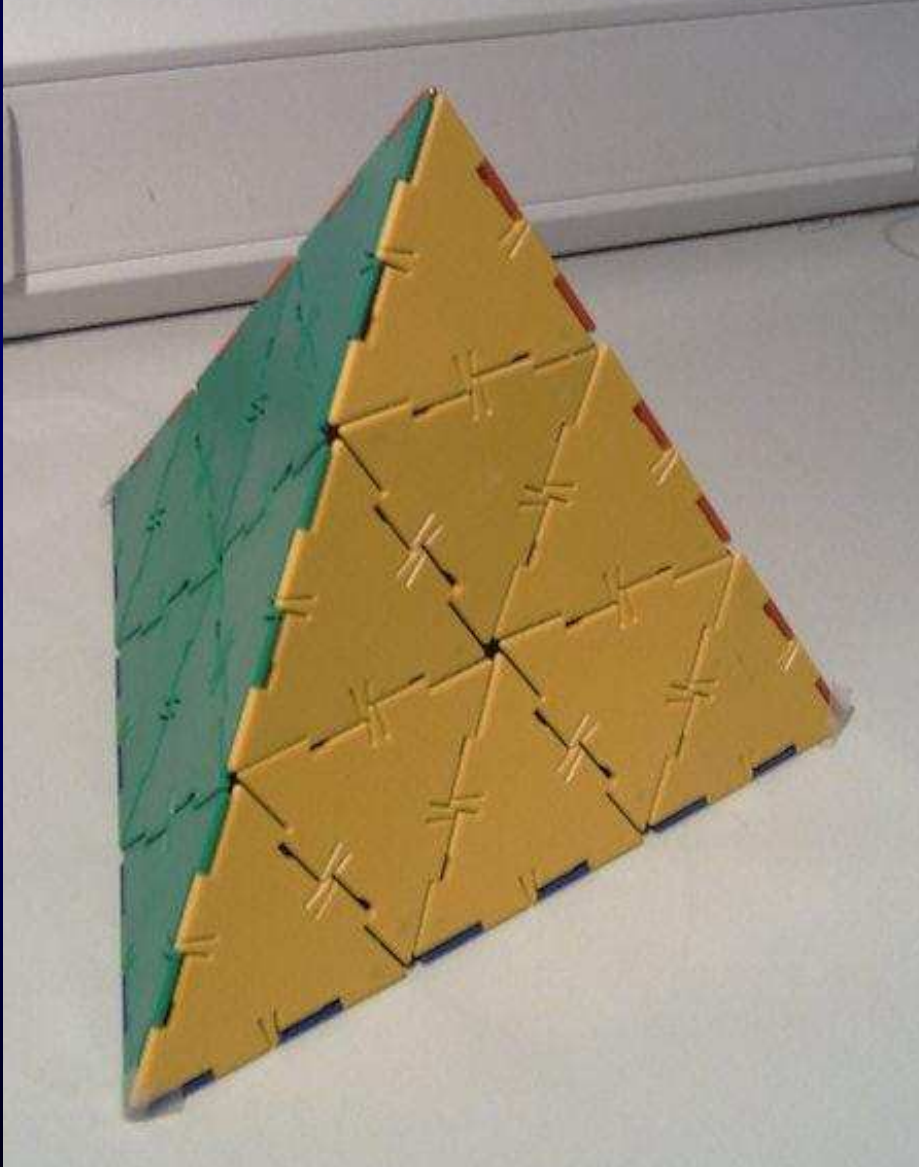


Reference: Milickovic *et al*,
Physics in Medicine and Biology (2000) 45:10;2787-2800

DRR Production Example



Edinburgh DRR Phantom



Software Demo

Experience & Conclusions

- New approach appears complicated, but...
- Significantly faster than previous methods
- More robust, fully objective and quantitative
- Greater confidence in results
- New ability to follow trends

- Need to finalise DRR phantom
- Expand to include other RT imaging modalities