QA for Linac KV Imaging Systems

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Learning Objectives

- Understand the reasoning behind QA
  - Define quality metrics
  - Analyse metrics for quality improvement
- Apply to a device: cone-beam CT
- Apply to an existing RT process

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What is Quality?

- Several dimensions of quality
  - Technical specs
  - Staff/client education & credentials
  - Consistency of performance
  - Efficiency of service delivery
  - Continuity and timeliness
  - Safety
  - Human factors engineering

Applicable to devices and processes both

Quality Metrics

- Analyse a process or device in each of its dimensions
- For each dimension:
  - What is it that can go wrong?
  - How does this risk impact quality?
- Define an output that can be controlled, measured, or quantified

Quality Metrics

- ***Quantifiable measures of success***
  - Recommended maintenance performed
  - Error rate less than 0.5%
  - 1 mm objects can be seen
- Can be statistically analysed
- Can be tracked and monitored

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Risk Analysis

- Faulty mechanical design causing harm to patient?
  - FDA, EC, Health Canada
  - Preventative maintenance & daily visual checks
- System unreliable?
  - Buggy software, unstable components
  - R&D identifies these issues & report to users

Risk Analysis

- Fault resulting in poor image quality?
  - Portal imaging as a back-up system
- Excessive dose to the patient?
  - Validation of imaging techniques
  - Monitor tube output periodically
- Reports incorrect geometrical info?
  - Subtle, not immediately obvious
  - May impact success or failure of RT

Cone-beam CT: QA of a Device

- Safety
- Geometric
- System stability
- Image quality
- System infrastructure
- Dose

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Safety Tests

- Collision detectors on flat panels
  - Motion inhibits when activated
- X-ray tube deployment inhibit
- X-ray area monitors
- Grounding tests
- Visual inspection for electrical hazards

Cone-beam CT: QA of a Device

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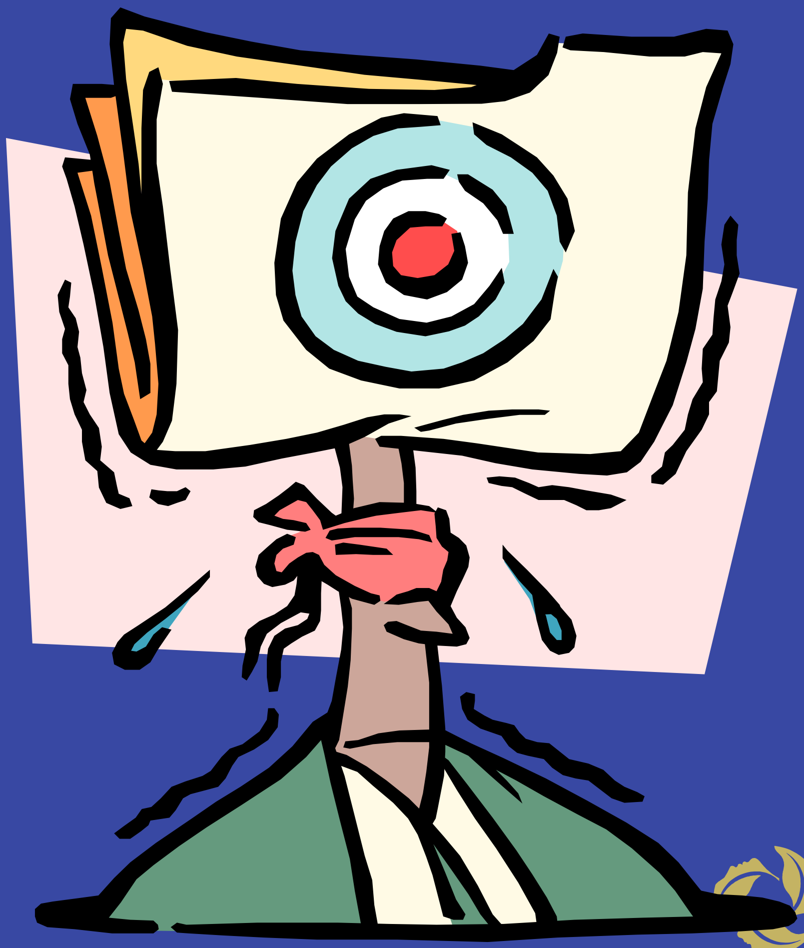
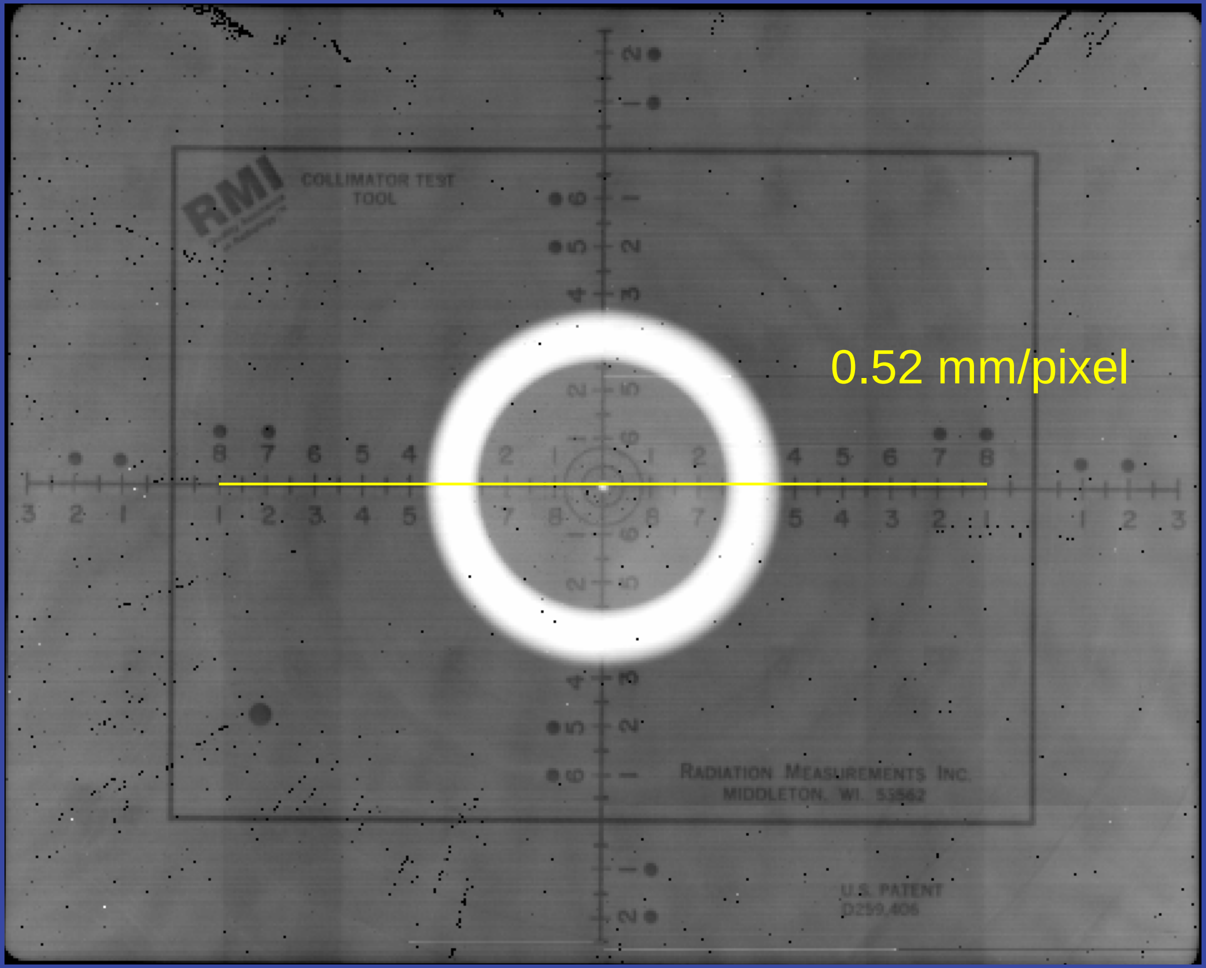
Geometry

- Pixel size calibration
- MV and kV source alignment
- Flexmaps
  - Refresh periodically
  - Repeatability
    - kV source positioning
    - Flat panel positioning
    - Each imaging position



Pixel Size at Isocentre



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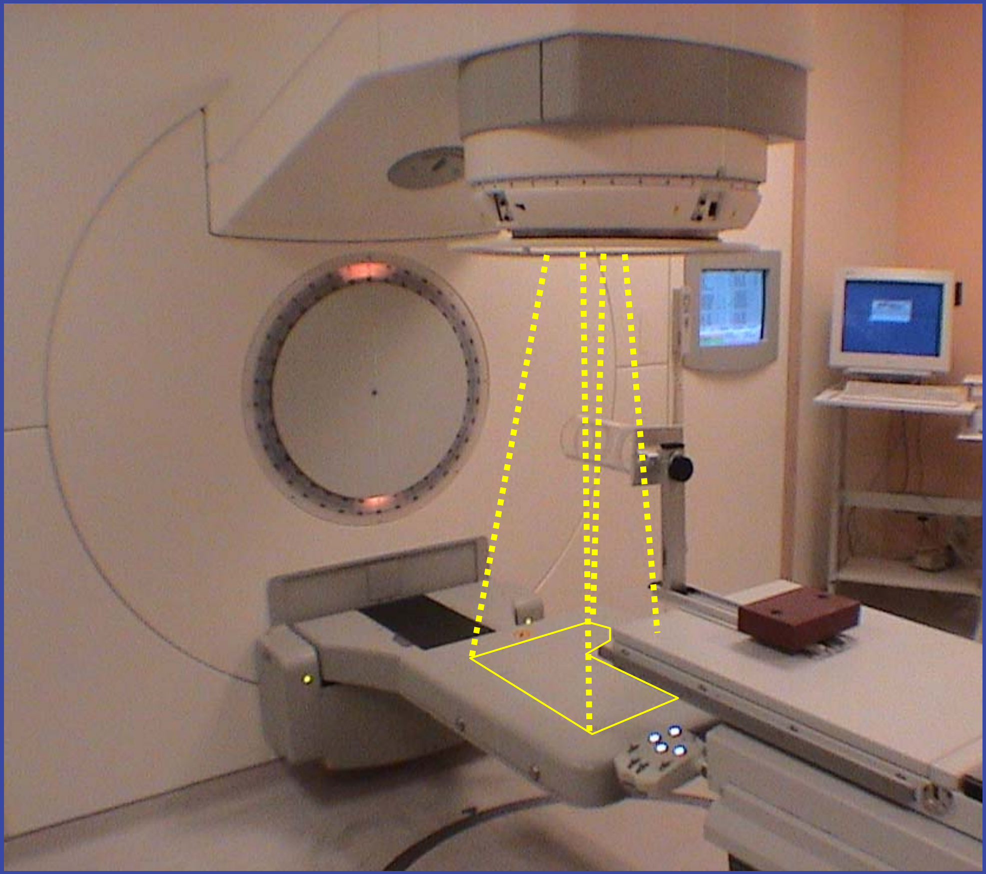
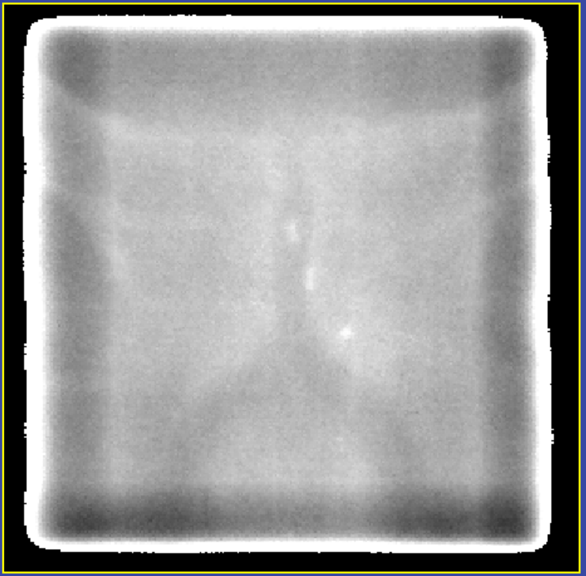
MV Geometry





- Imaging and treatment beams coincide

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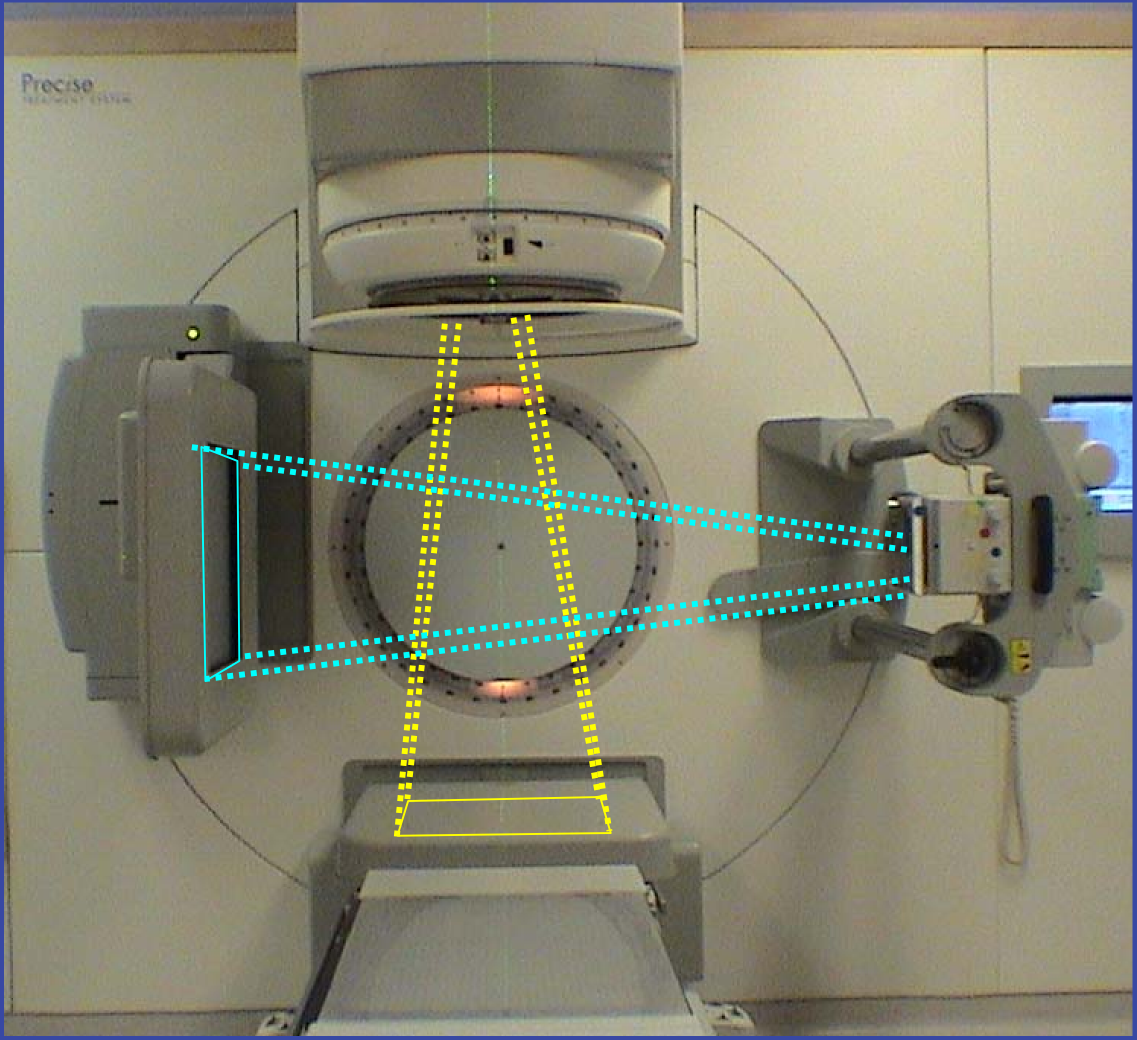
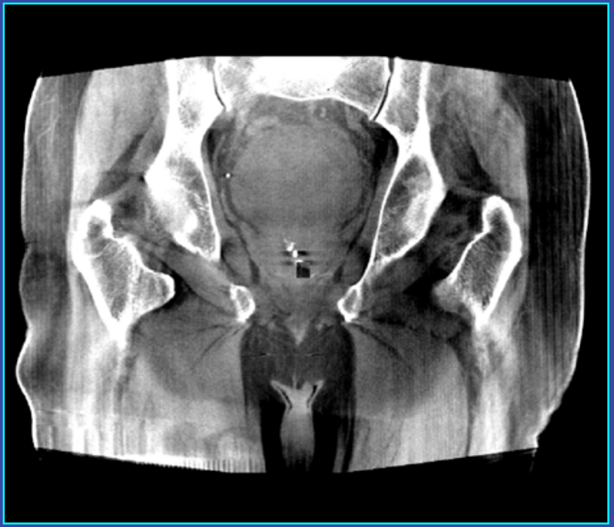
MV/kV Coincidence





- Treatment is orthogonal to imaging

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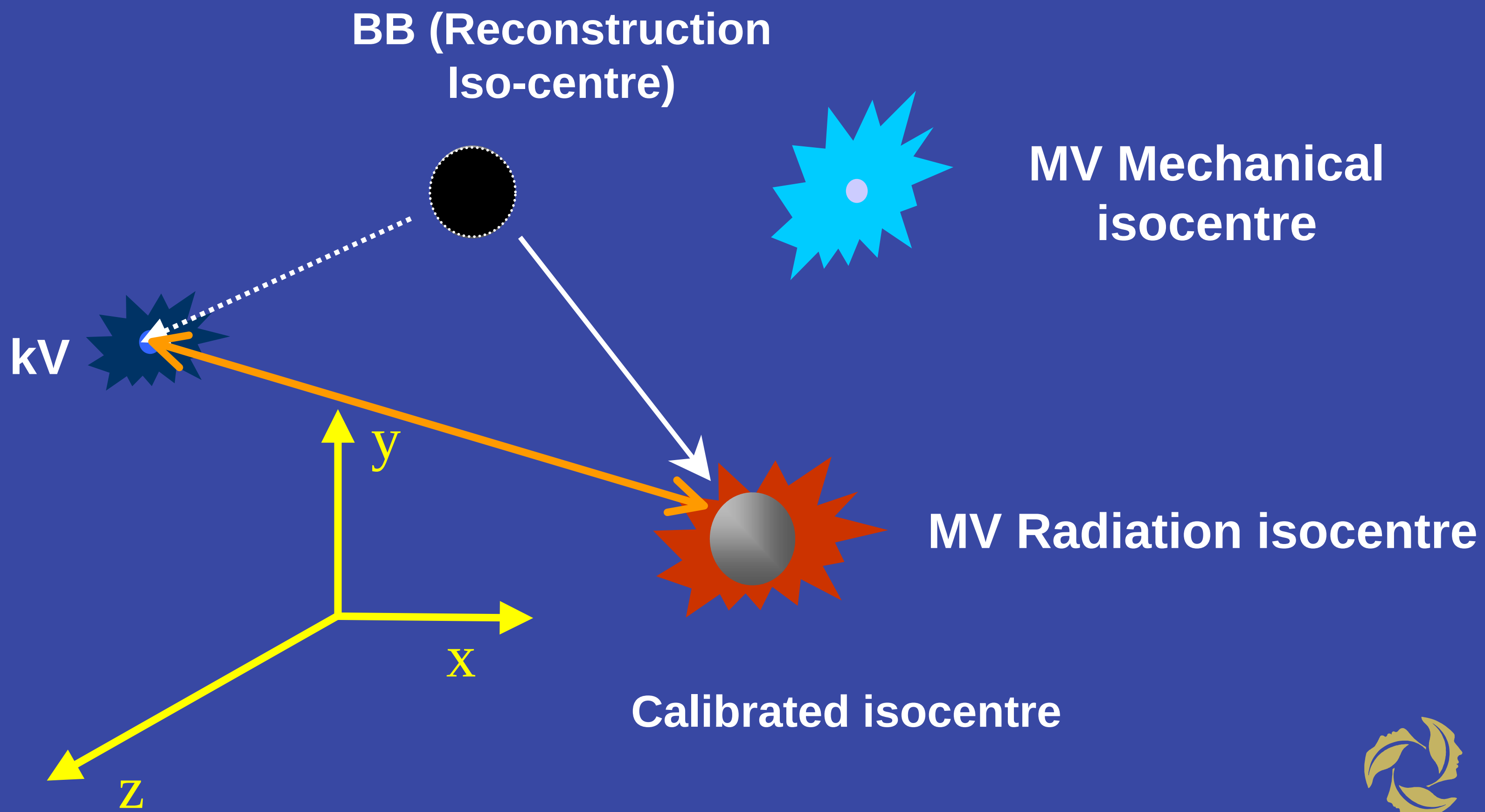
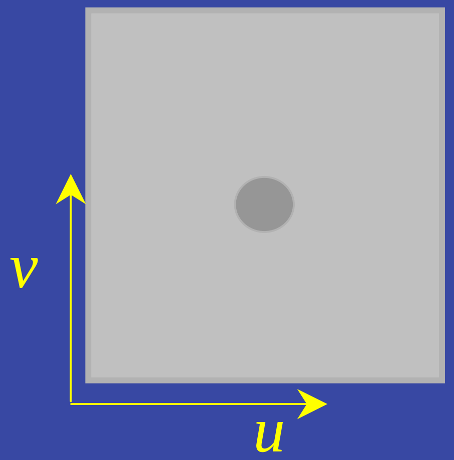
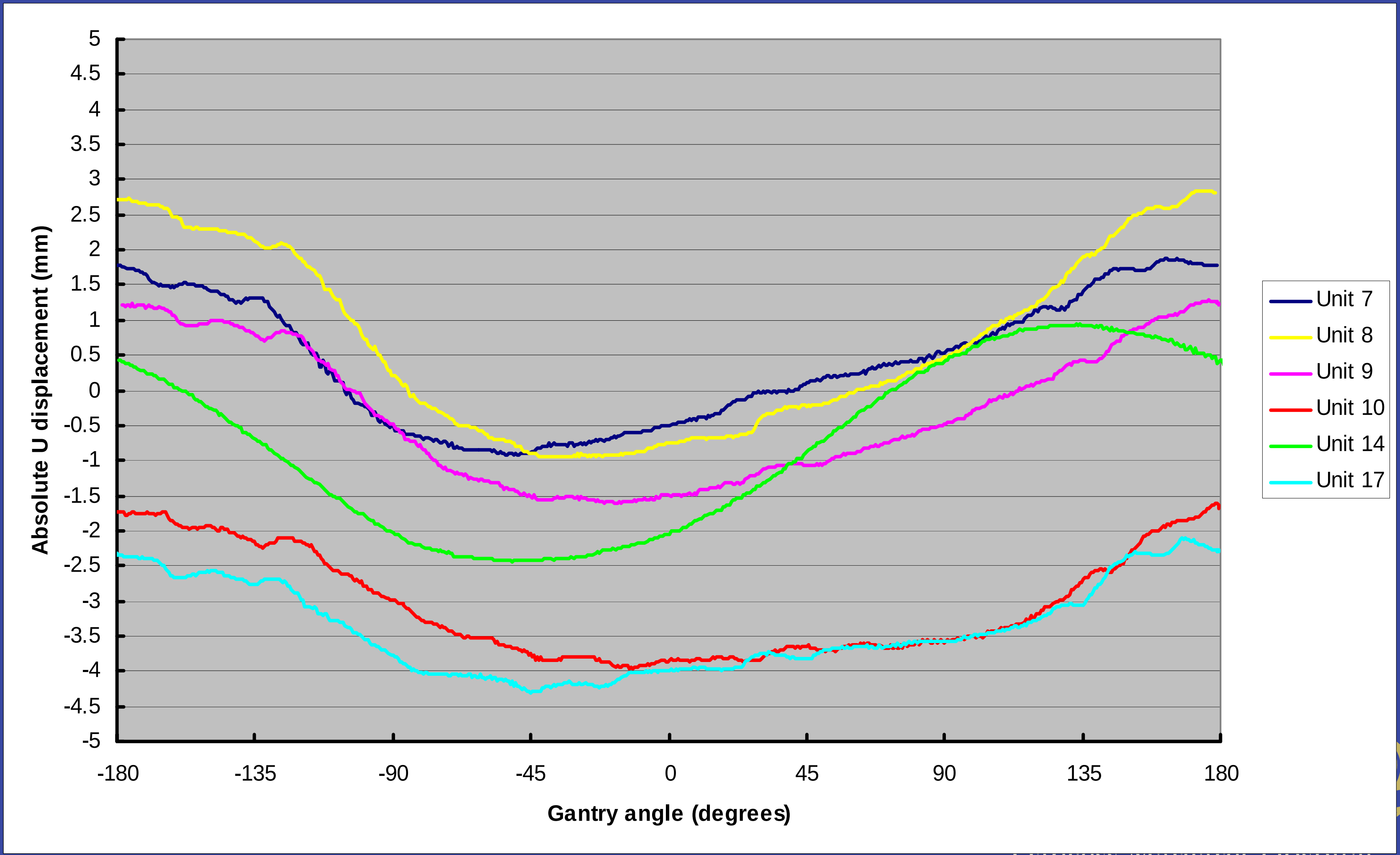
kV/MV Calibration Concept



MV/kV Calibration Procedure



Results for Six Units



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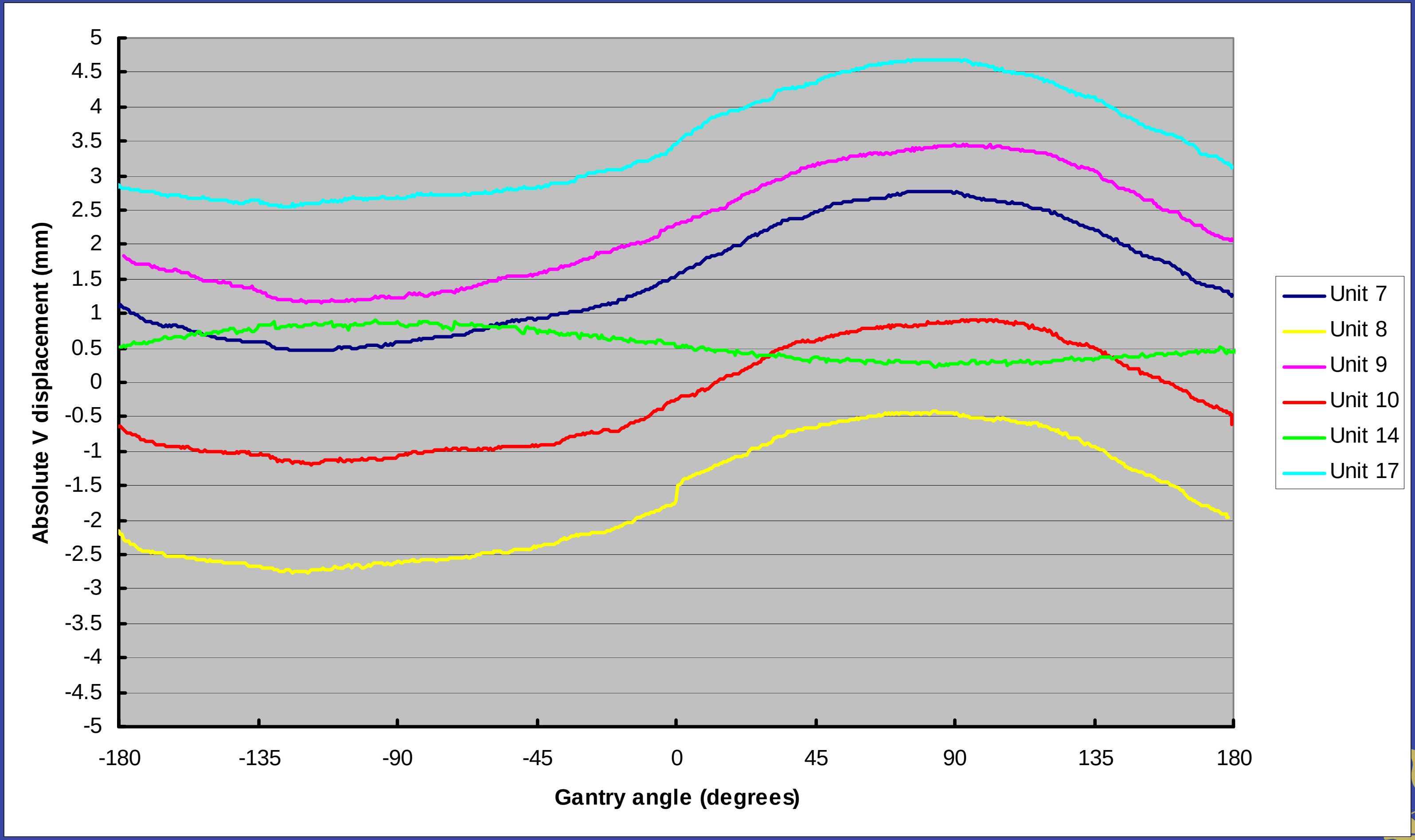

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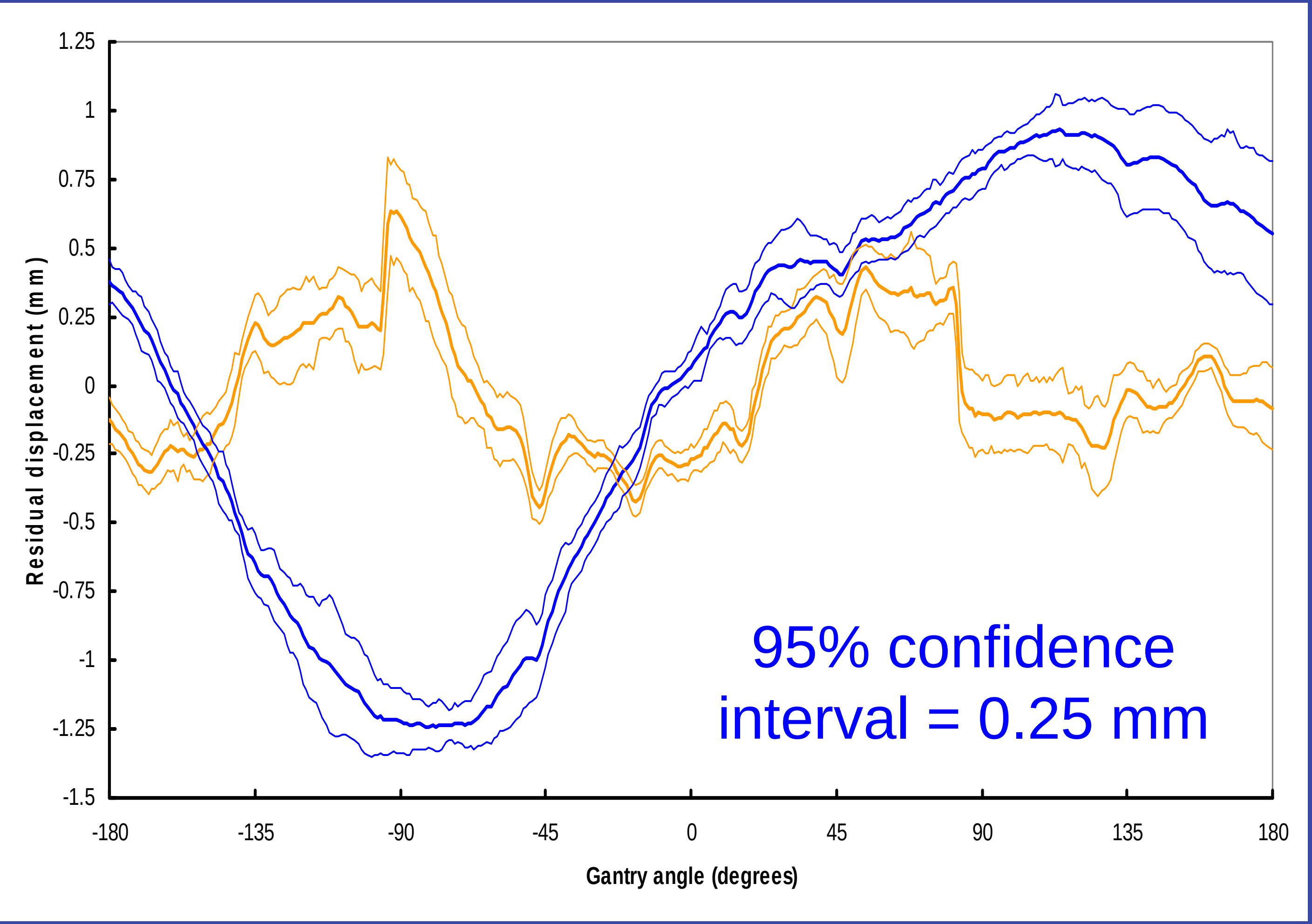
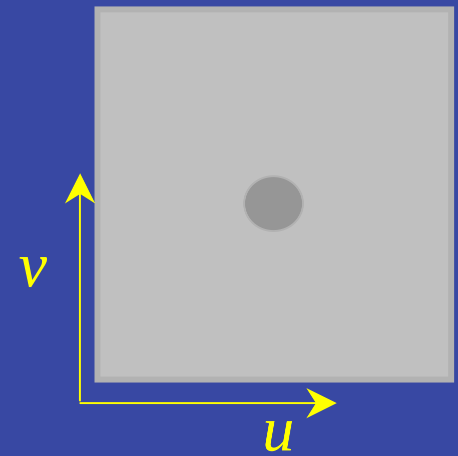
Long-term Stability: Flexmap





12 calibrations over 28 months

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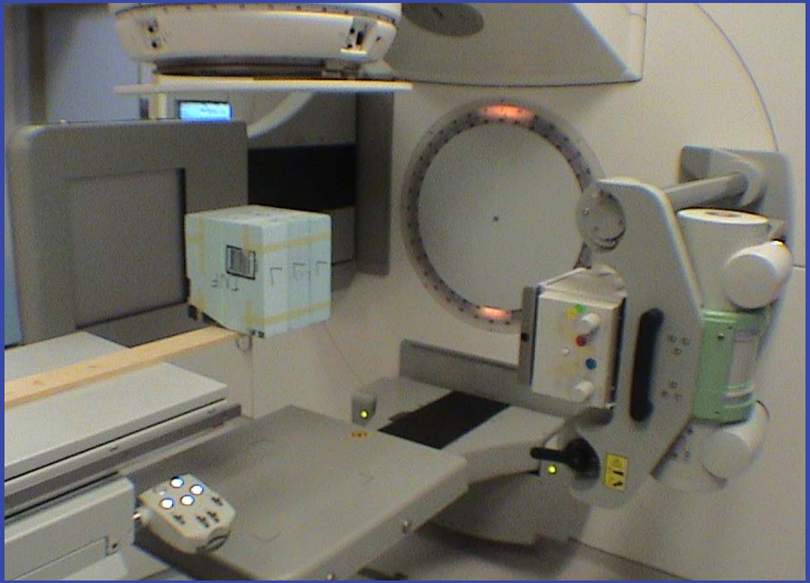
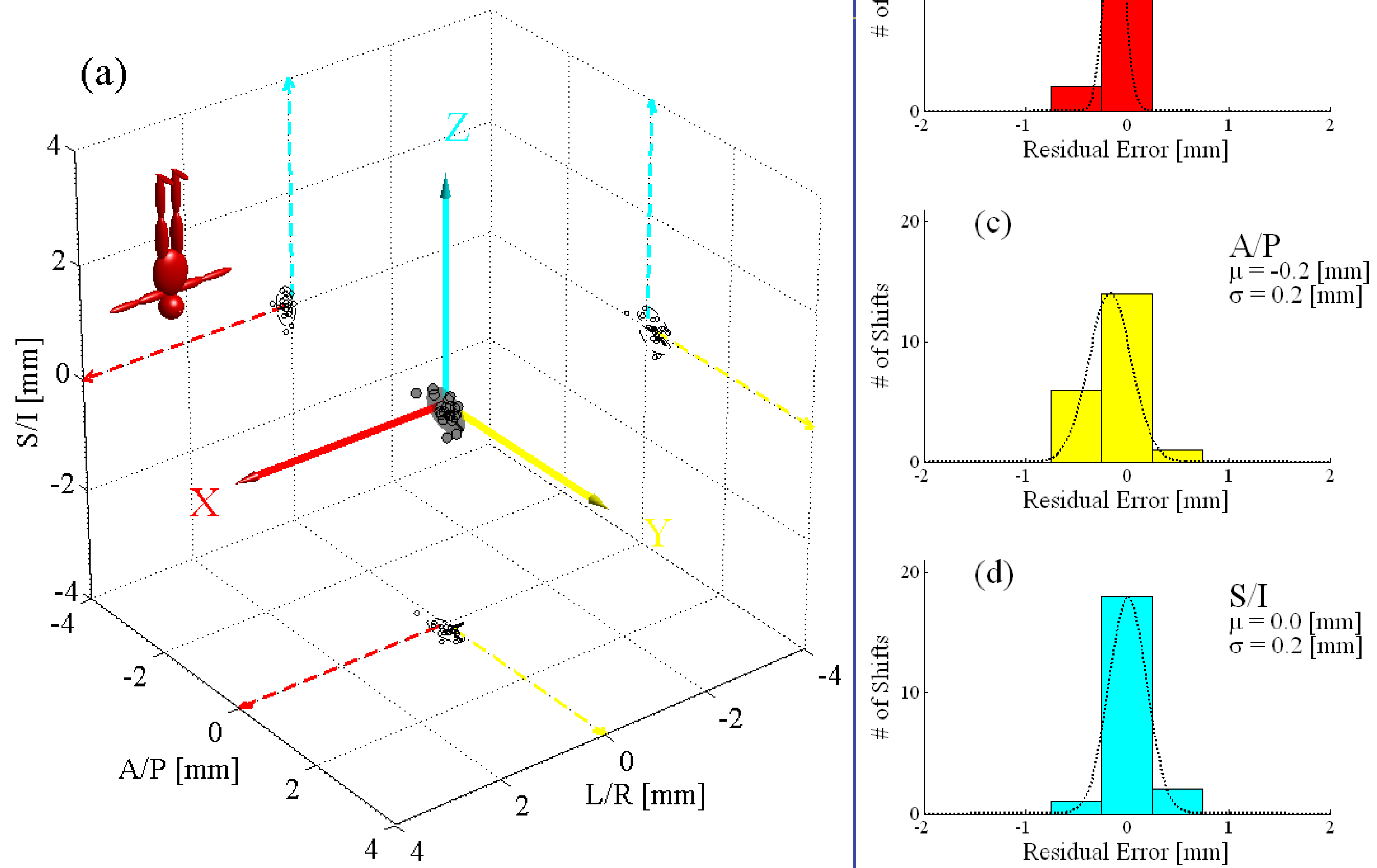
Targeting Study

- 21 sessions:
  - Over a 3 month period
  - Three different operators
  - Single calibration map

- Geometric calibration maps monitored weekly in parallel study.

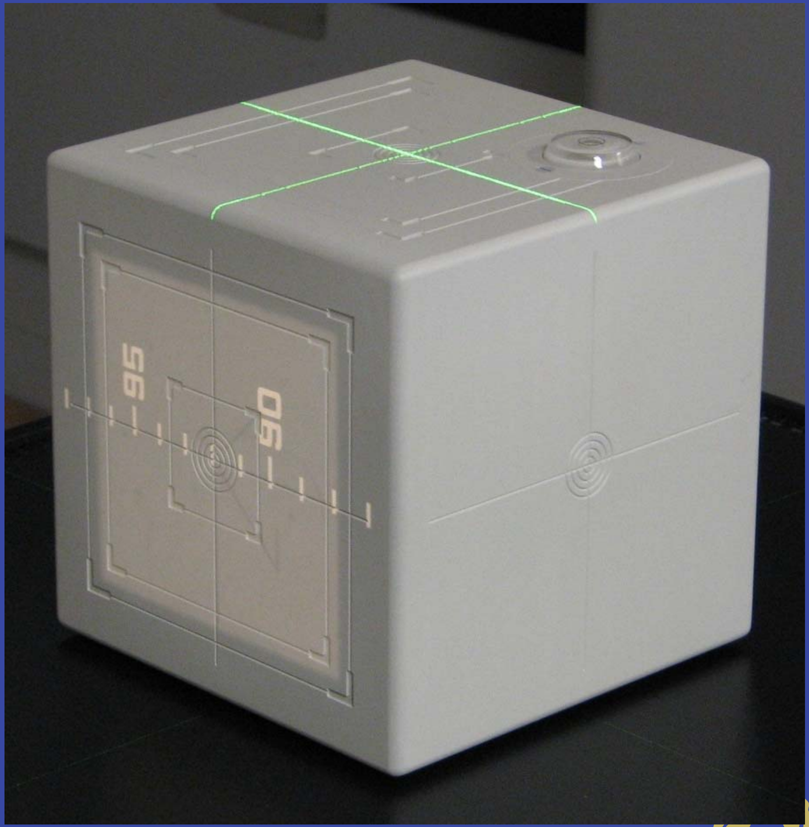


MV/kV Difference



Daily Geometry QA

- Align phantom with lasers
- Acquire portal images (AP & Lat) & assess central axis
- Acquire CBCT
- Difference between predicted couch displacements (MV & kV) should be < 2 mm



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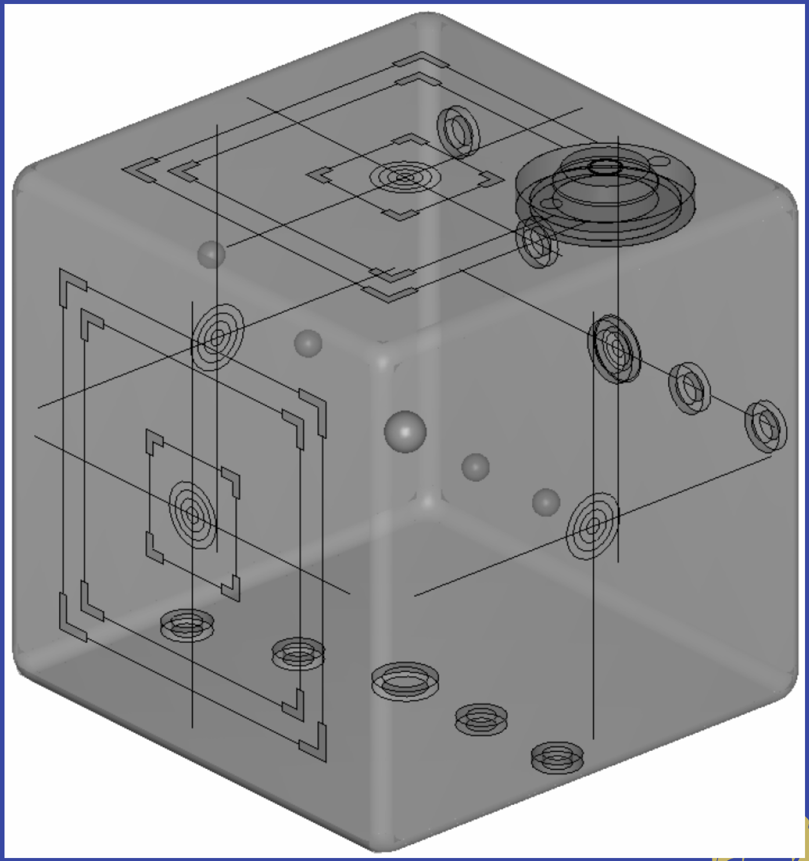

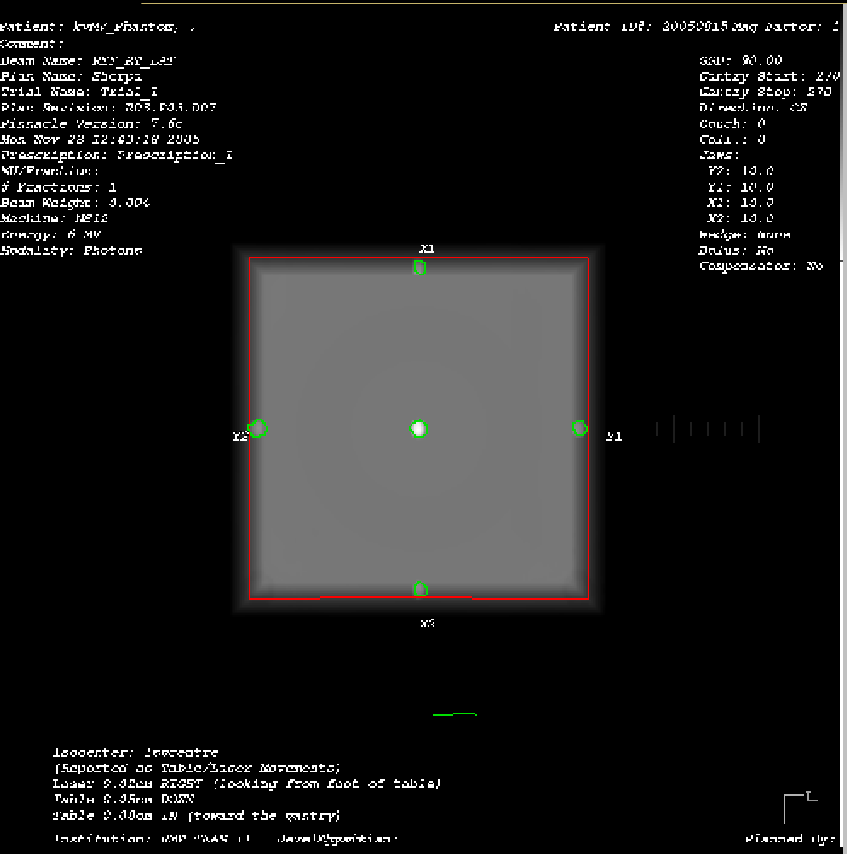

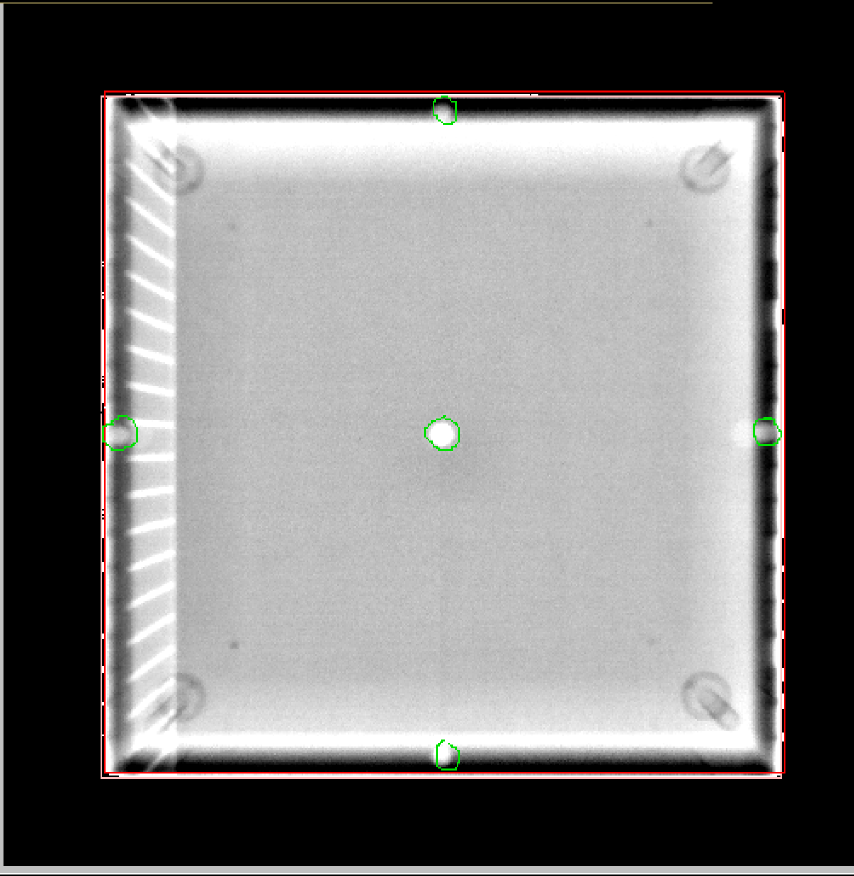

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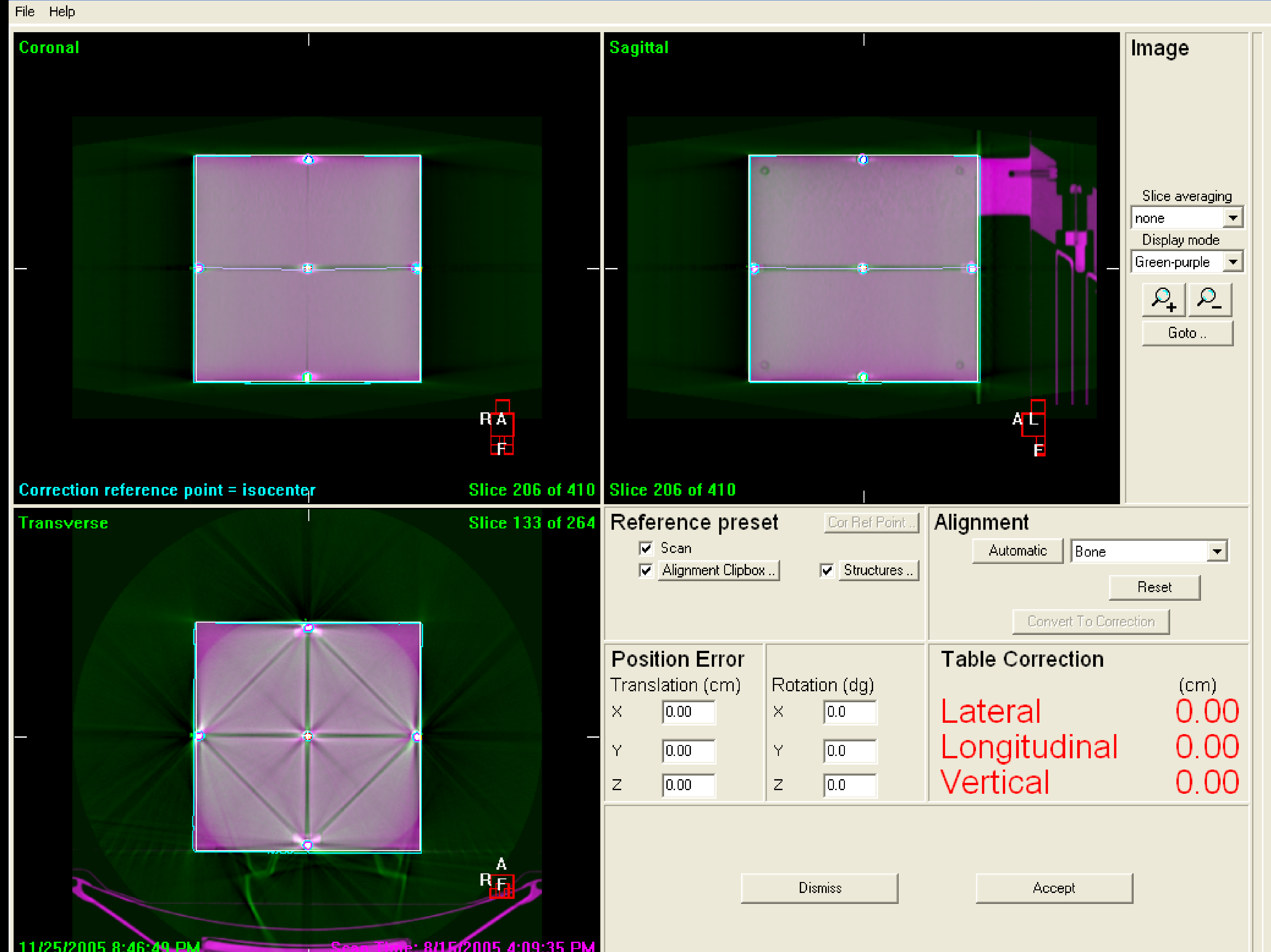
File Help
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Correction reference point = isocenter
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Slice 206 of 410
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Structures ..
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Position Error
Translation (cm)
X 0.00
Y 0.00
Z 0.00
Rotation (dg)
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35	Error	E1					E2			E3		
36												
37	Date	MV-AP		MV-R.LAT			kV - Volume View			kV-MV Error (<2mm)		
38		x	y	x	y	S/I	Lateral	Longitudinal	Vertical	x (L/R)	y(S/I)	z(A/P)
39		[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]
40	01-Jul-06					0.00				0.00	0.00	0.00
41	02-Jul-06					0.00				0.00	0.00	0.00
42	03-Jul-06					0.00				0.00	0.00	0.00
43	04-Jul-06	-0.07	-0.02	0.1	0.02	0.00	0	0	0	-0.07	0.00	0.10
44	05-Jul-06	0.00	-0.15	0.15	-0.15	-0.15	0.05	0.00	0.00	0.05	-0.15	0.15
45	06-Jul-06	0.05	-0.12	0.17	-0.17	-0.15	0.00	0.00	0.03	0.05	-0.15	0.14
46	07-Jul-06	0.01	-0.10	0.02	-0.07	-0.09	0.00	0.00	0.00	0.01	-0.09	0.02
47	08-Jul-06					0.00				0.00	0.00	0.00
48	09-Jul-06					0.00				0.00	0.00	0.00
49	10-Jul-06	0.00	-0.12	0.15	-0.15	-0.14	0.00	0.00	0.00	0.00	-0.14	0.15
50	11-Jul-06	0.00	-0.10	0.12	-0.05	-0.08	0.00	0.00	0.08	0.00	-0.08	0.04
51	12-Jul-06	0.00	-0.12	0.17	-0.12	-0.12	0.00	-0.04	0.04	0.00	-0.16	0.13
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55	16-Jul-06					0.00				0.00	0.00	0.00
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57	18-Jul-06	-0.01	-0.01	0.17	-0.01	-0.01	0.08	-0.05	0.05	0.07	-0.06	0.12
58	19-Jul-06	0.15	0.00	0.07	-0.05	-0.03	0.00	-0.08	0.00	0.15	-0.11	0.07
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69	30-Jul-06					0.00				0.00	0.00	0.00
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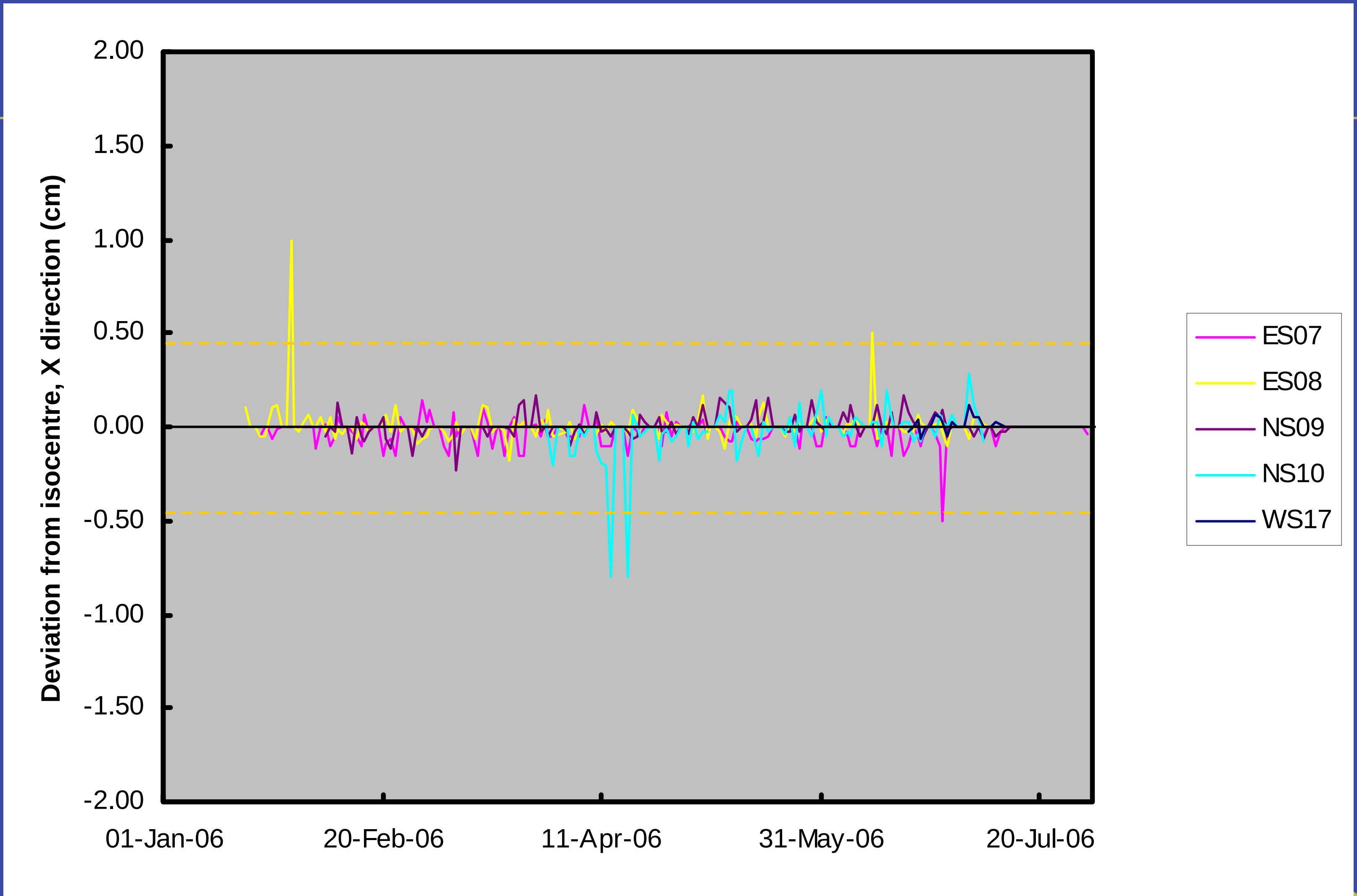
71												

June 2006 (3) / January 2006 / February 2006 / March 2006 / April 2006 / May 2006 / June 2006 / July 2006 / August 2006



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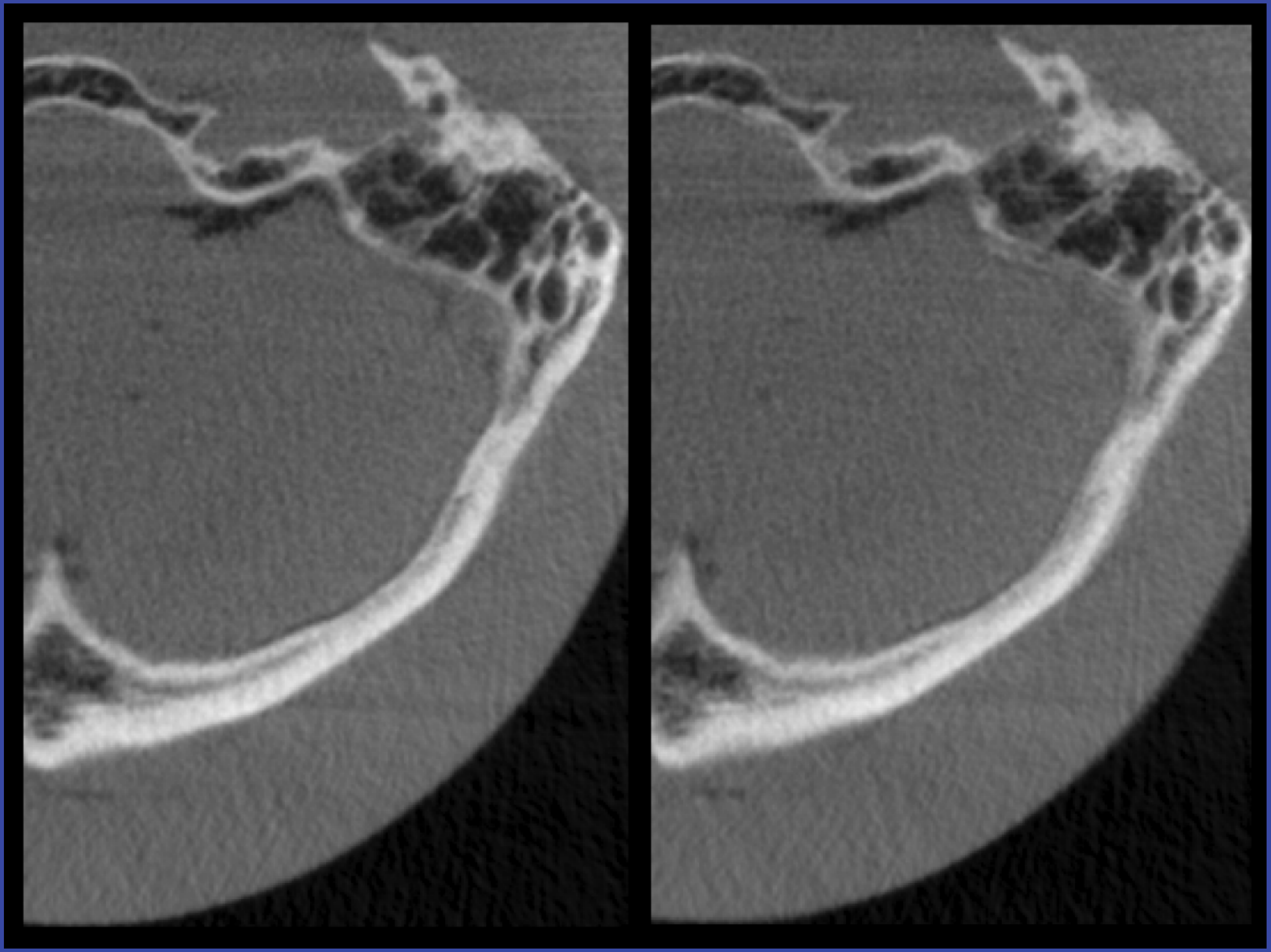
Effect of Incorrect Calibration



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Cone-beam CT: QA of a Device

- Safety
- Geometric
- System stability
- Image quality
- System infrastructure
- Dose

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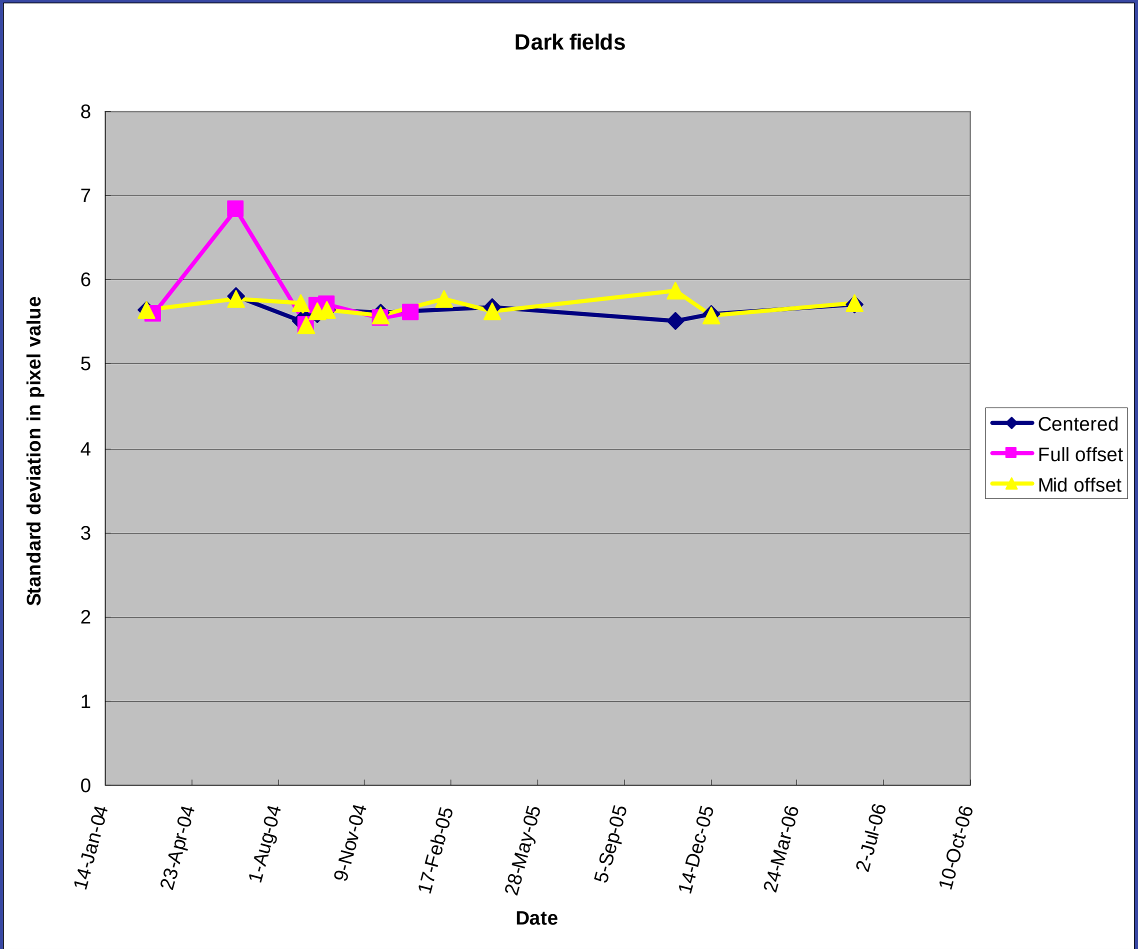
System Stability

- Dark image calibration
  - Acquired prior to each scan
- Gain stability & defect maps
  - Refresh floods every month

Dark image performance



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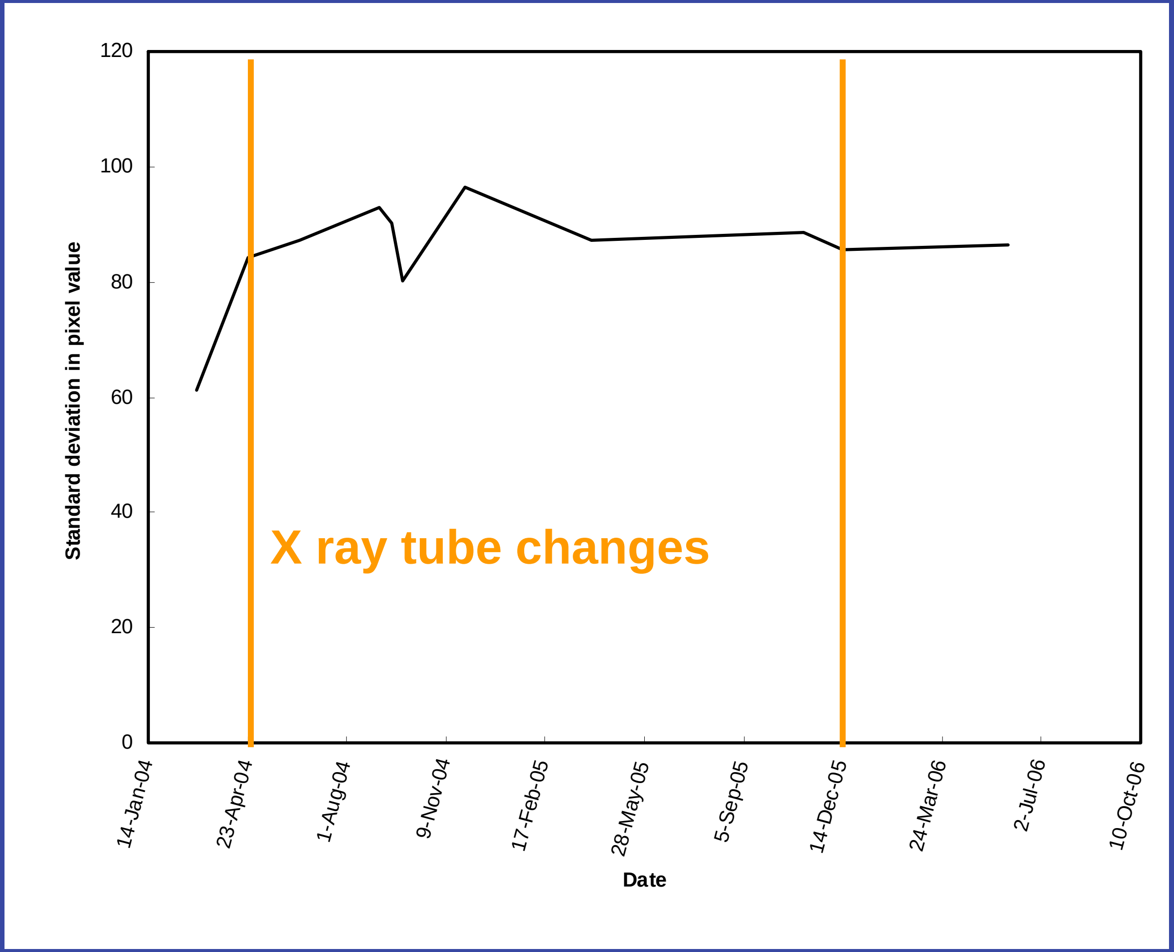
Flood Fields: image SNR



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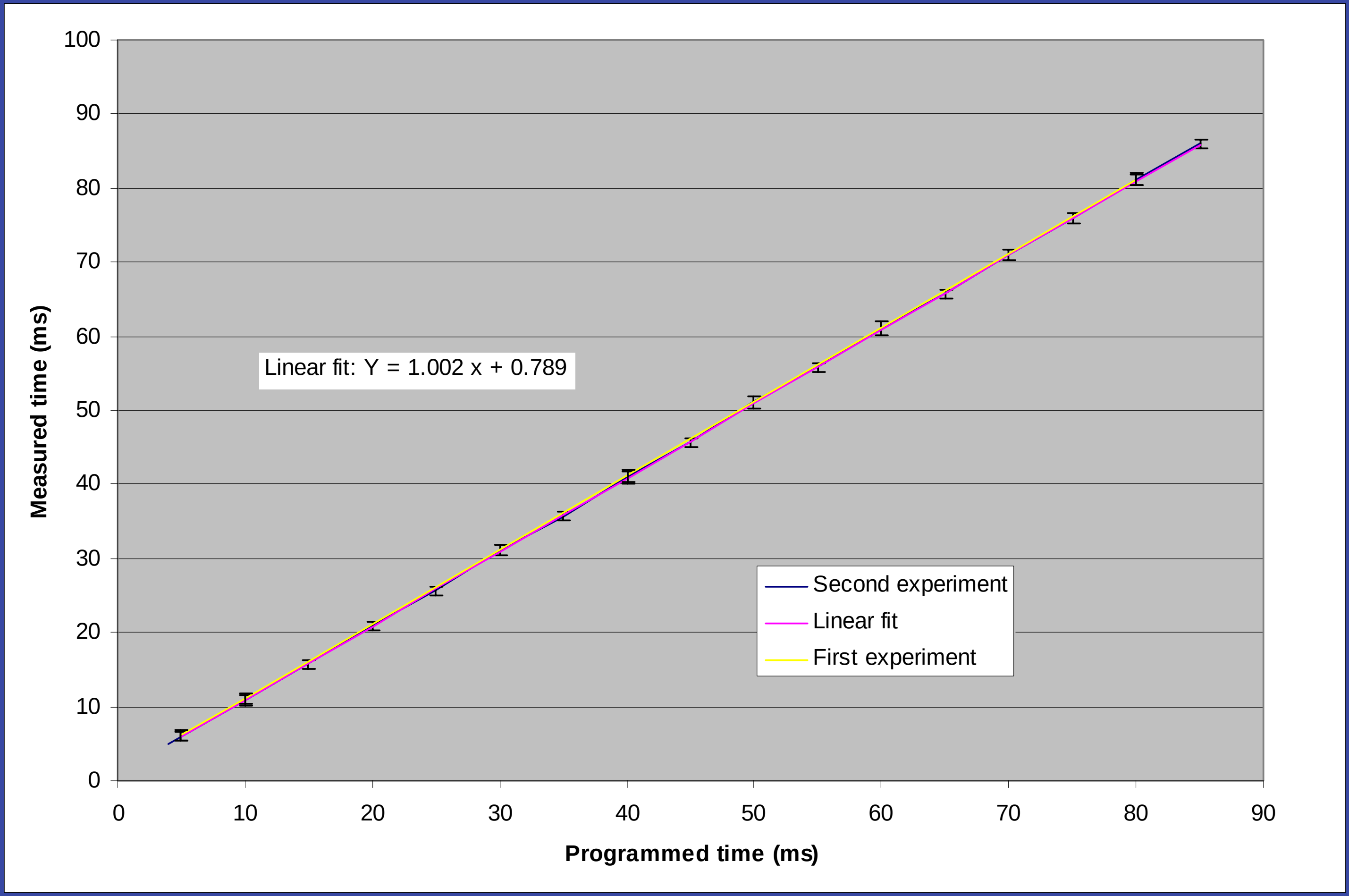
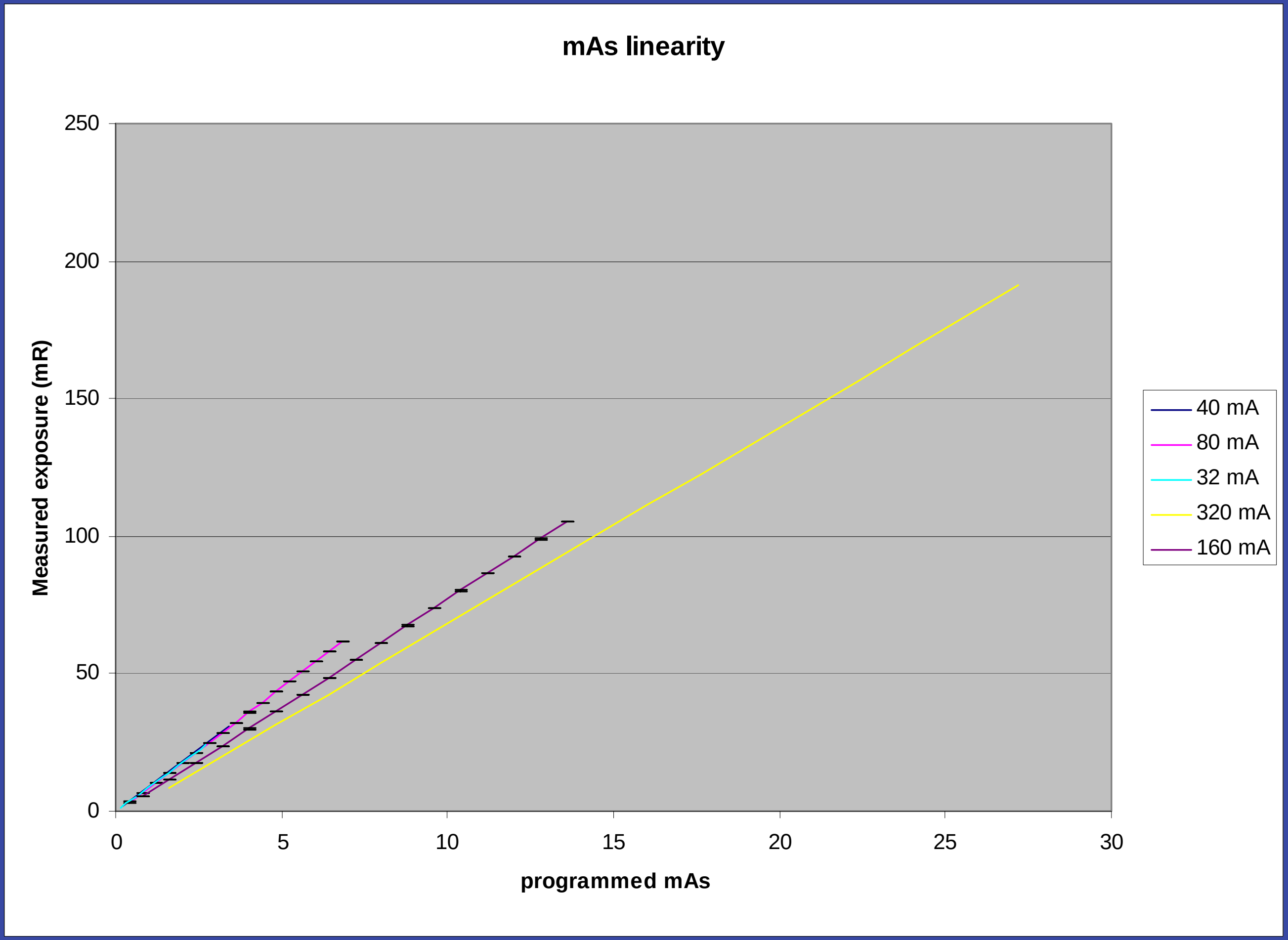
X ray Generator Stability

- Reproducibility and Accuracy
  - kV_p, mA, ms

X-ray Generator: ms Accuracy



mAs linearity: fixed current



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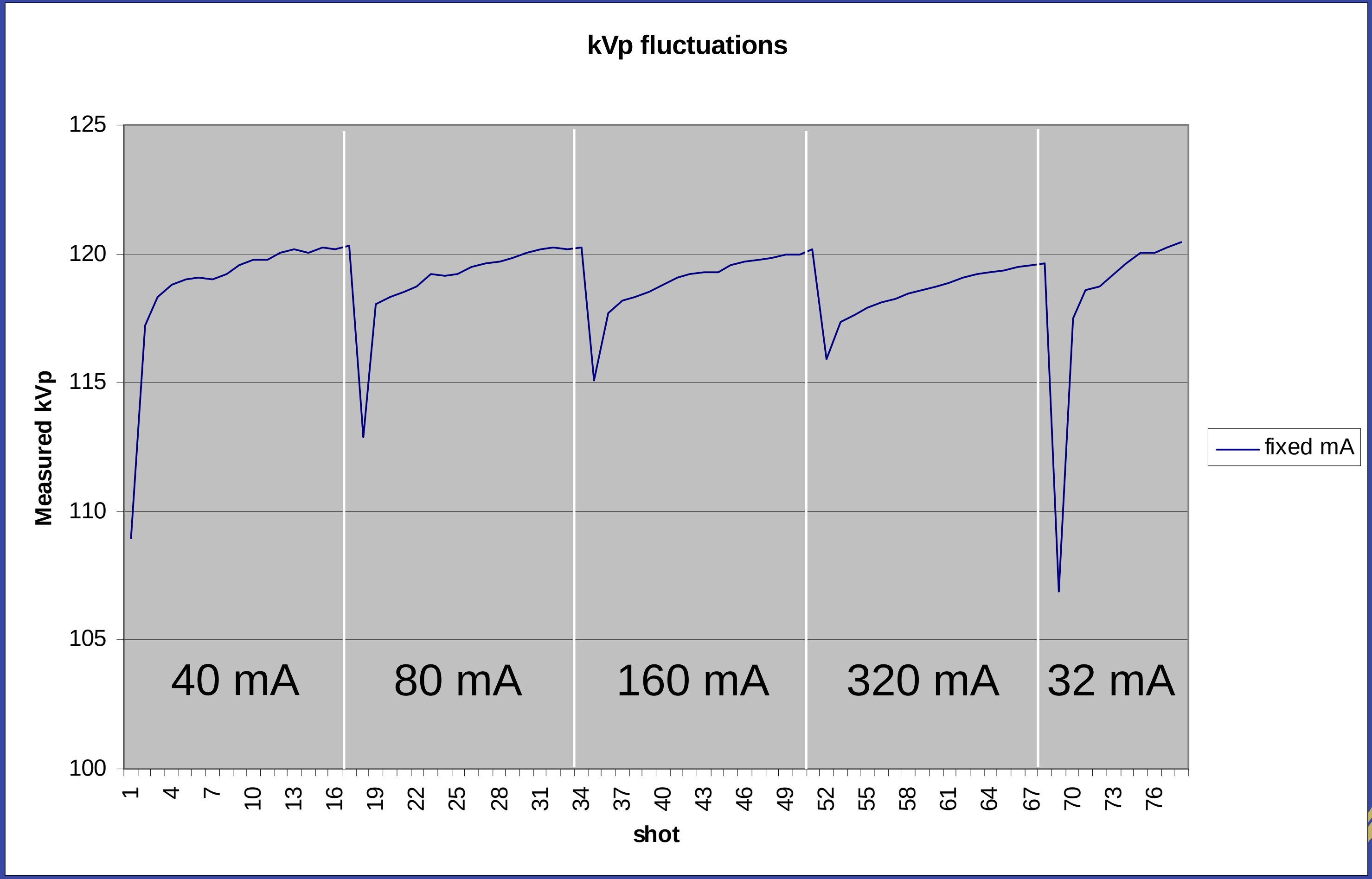
kV_p accuracy & stability



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$117.6 \pm 4.6\ kV_p$

Cone-beam CT: QA of a Device

- Safety
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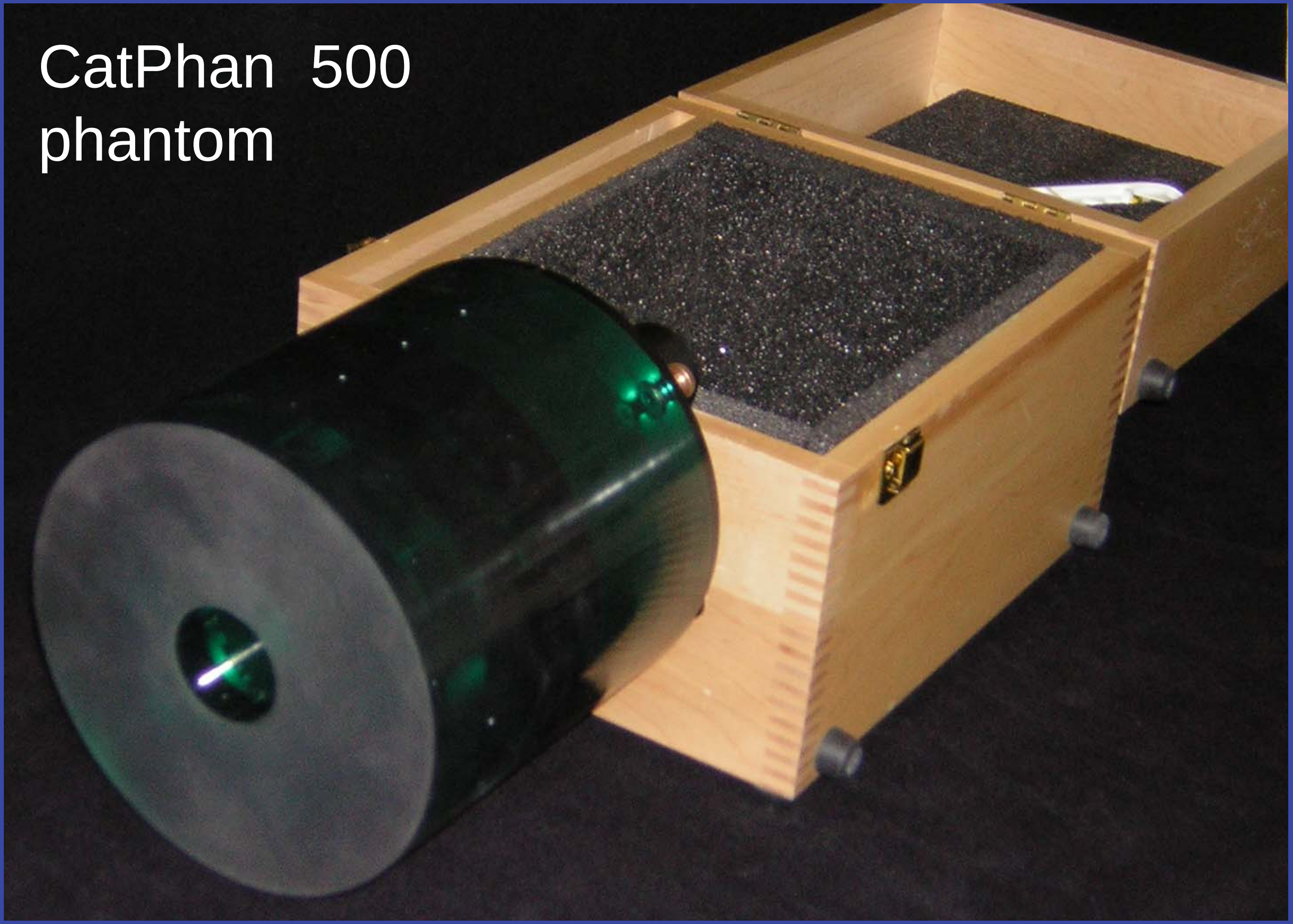
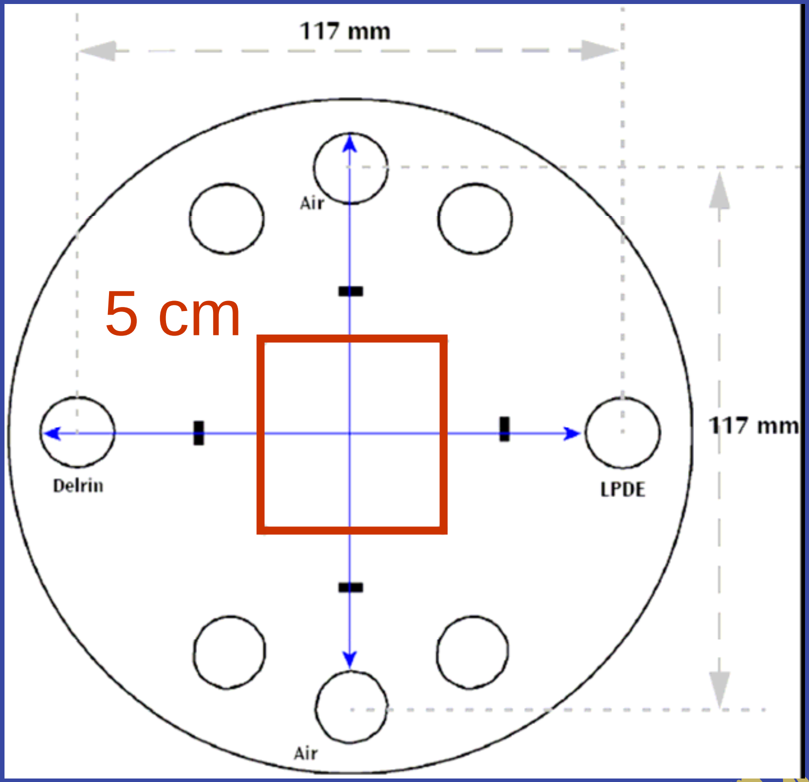
Image Quality



Scale

- Geometric calibration to tie isocentre to centre of volumetric reconstruction
- Scale to relate all pixels to isocentre



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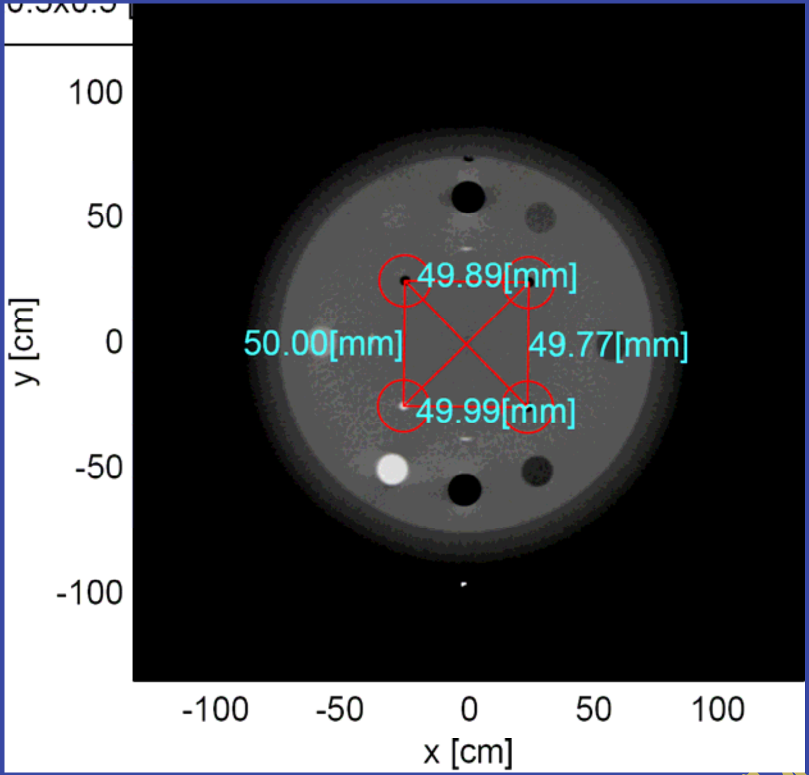

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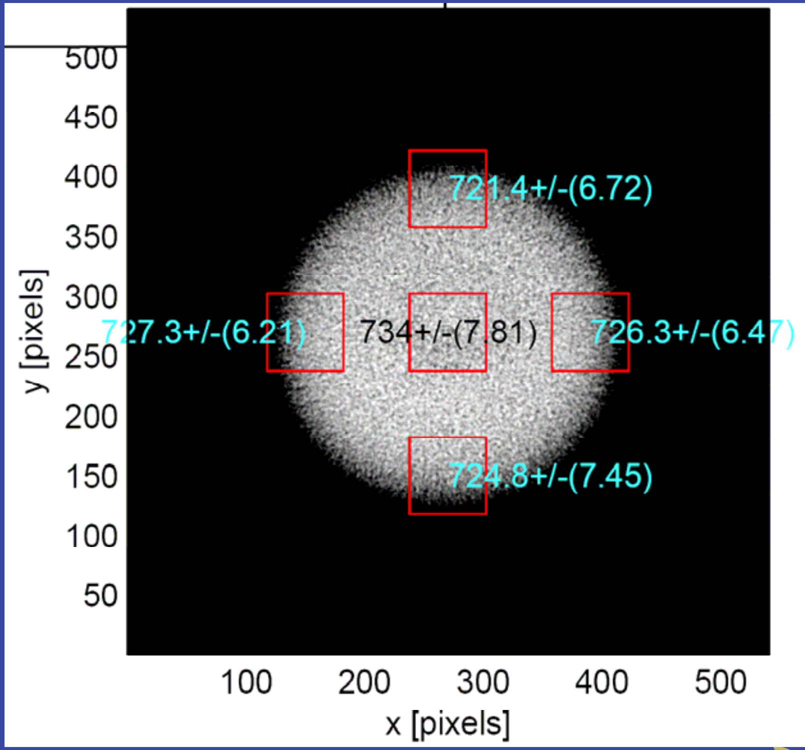
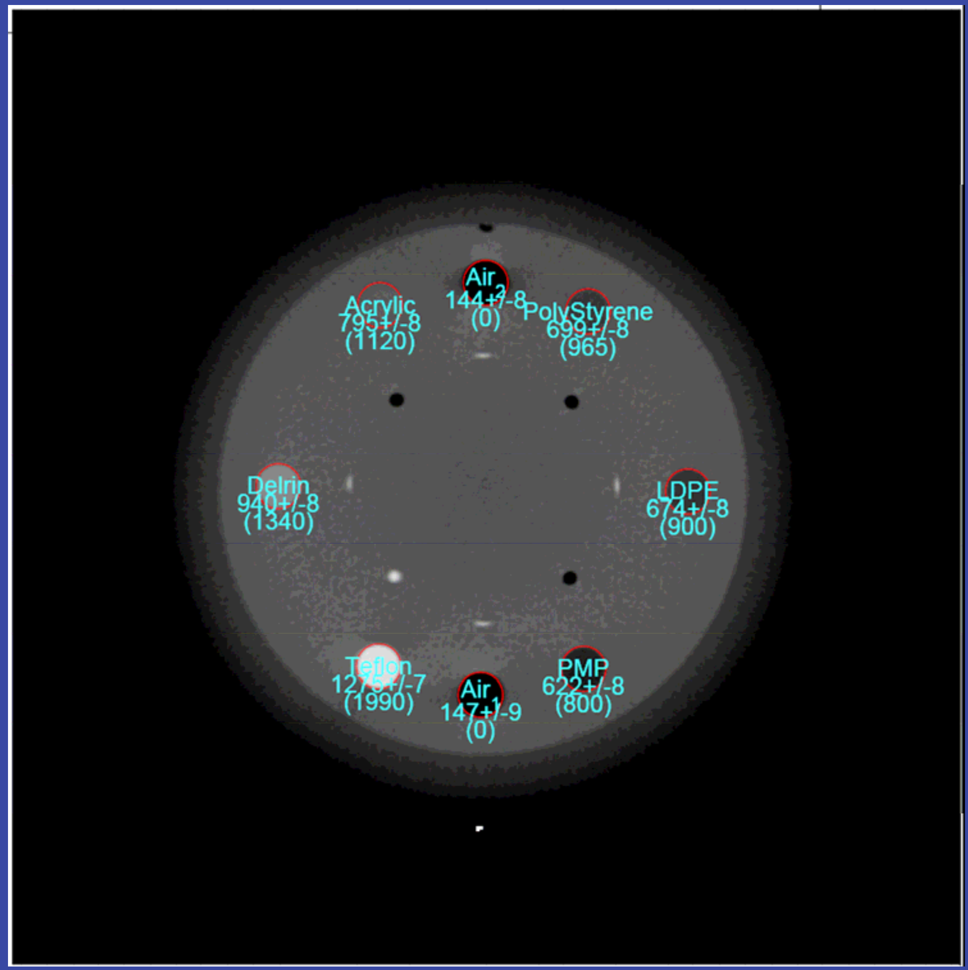
Uniformity

- Standard CT tests
  - Cupping, capping
- Baseline non-uniformity index:

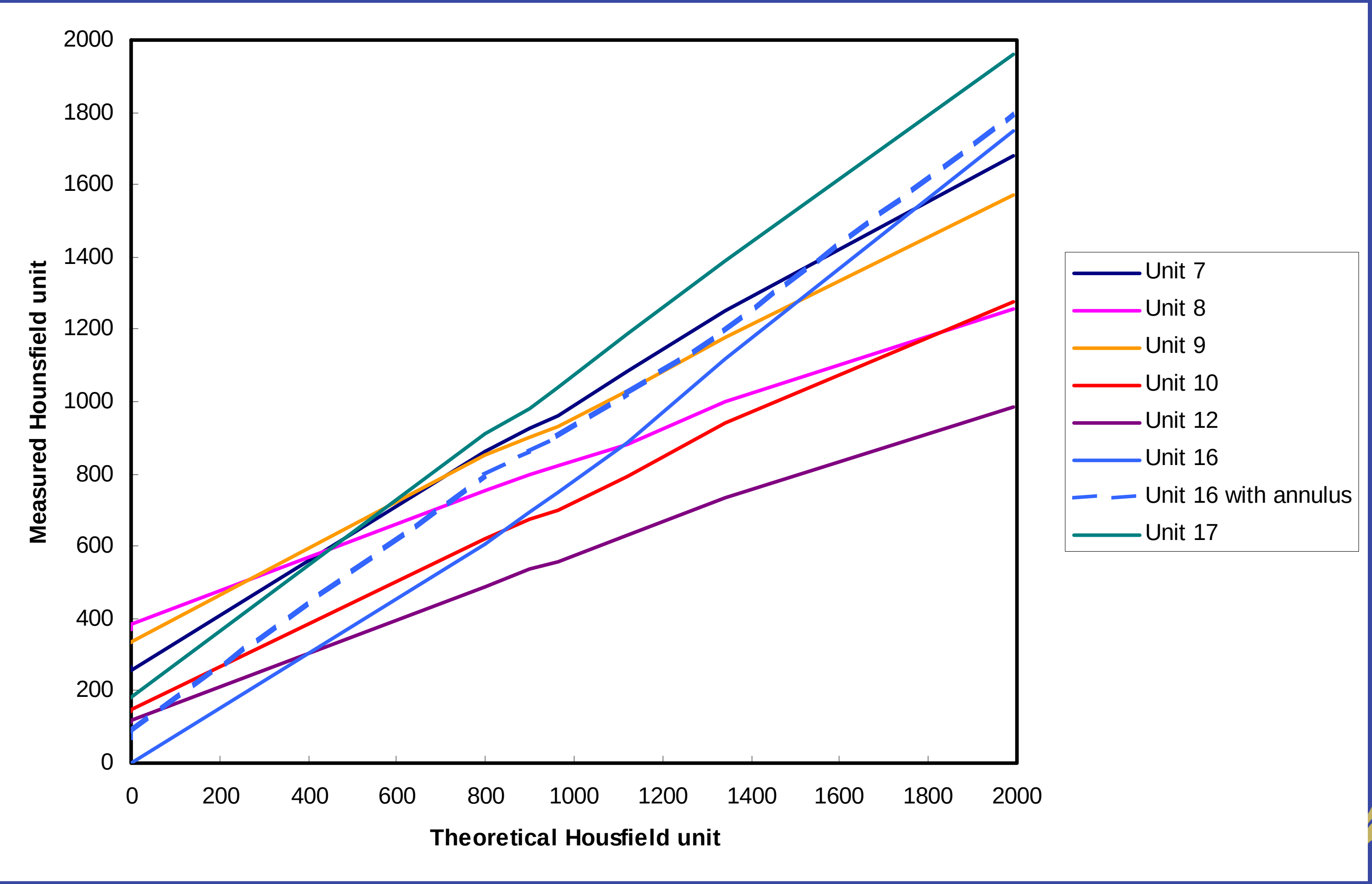
$$\frac{CT_{max} - CT_{min}}{CT_{max} + CT_{min}}$$



Linearity of CT Numbers



Linearity of CT numbers



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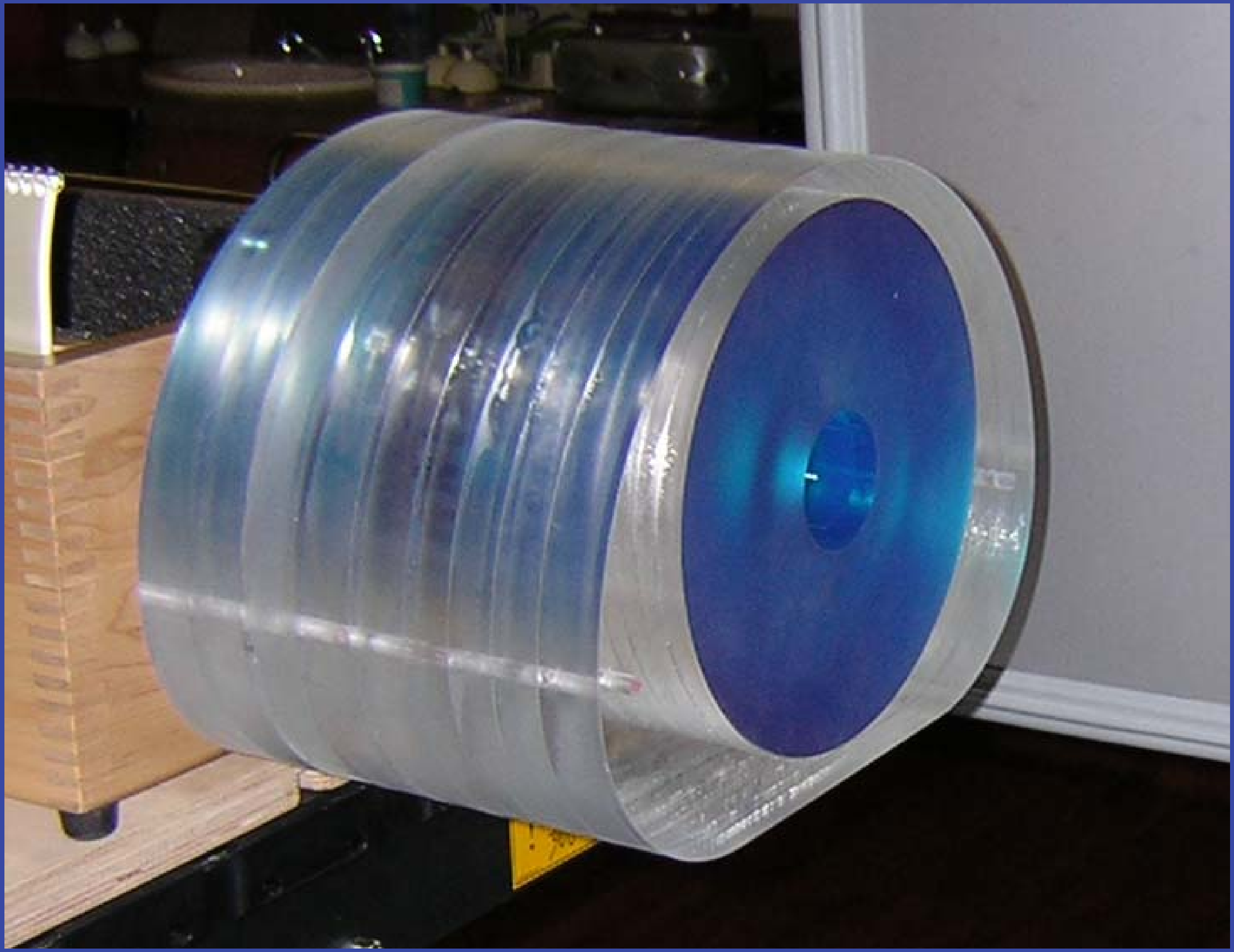
Add Scatter



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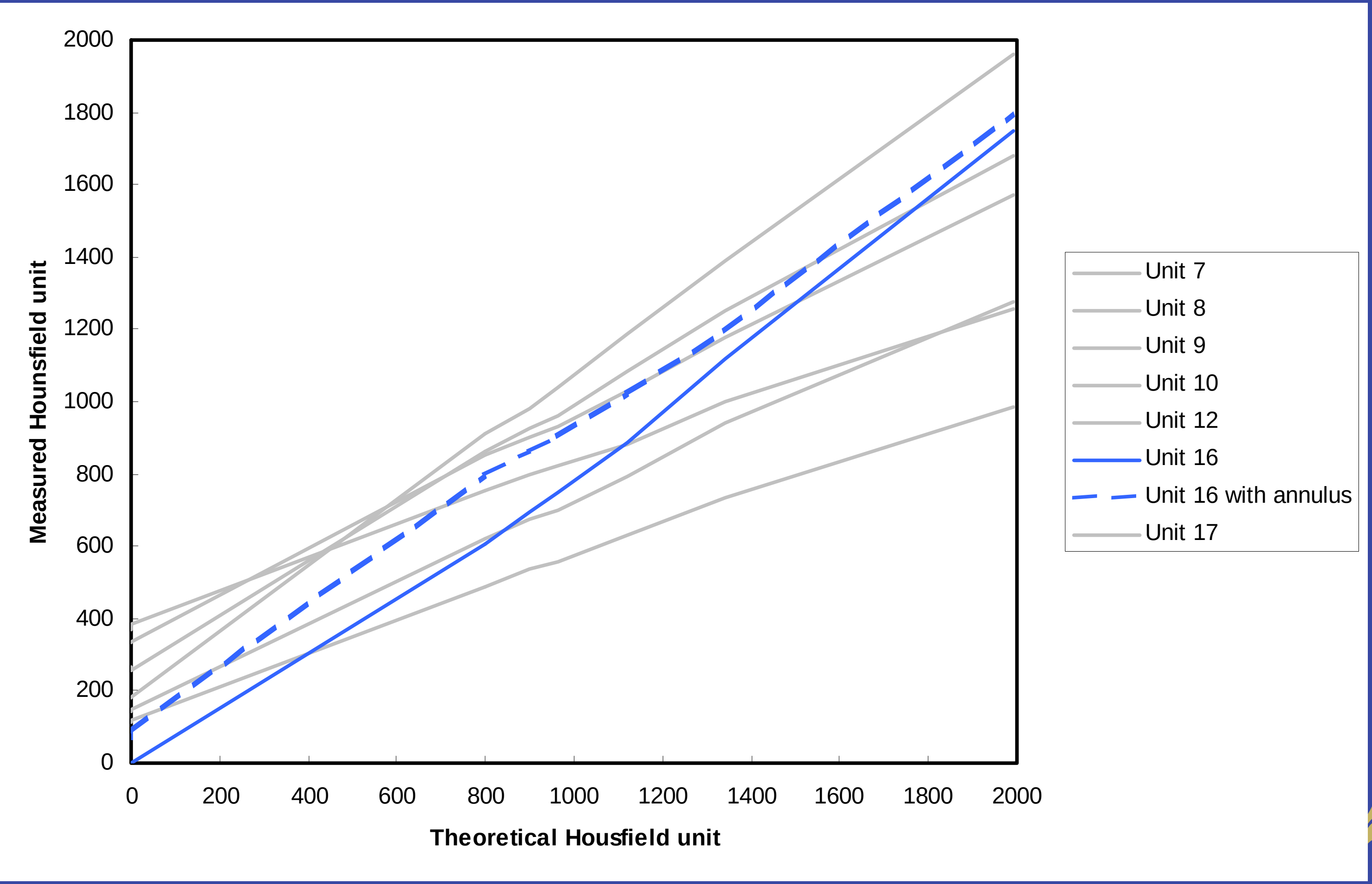
IEC standard 61675-1

Linearity of CT numbers



Linearity of CT Numbers

- Fairly linear ($\chi^2 > 0.99$) for all systems
- Beam hardening
- Scatter conditions
- Non-standard metric; use only as a baseline

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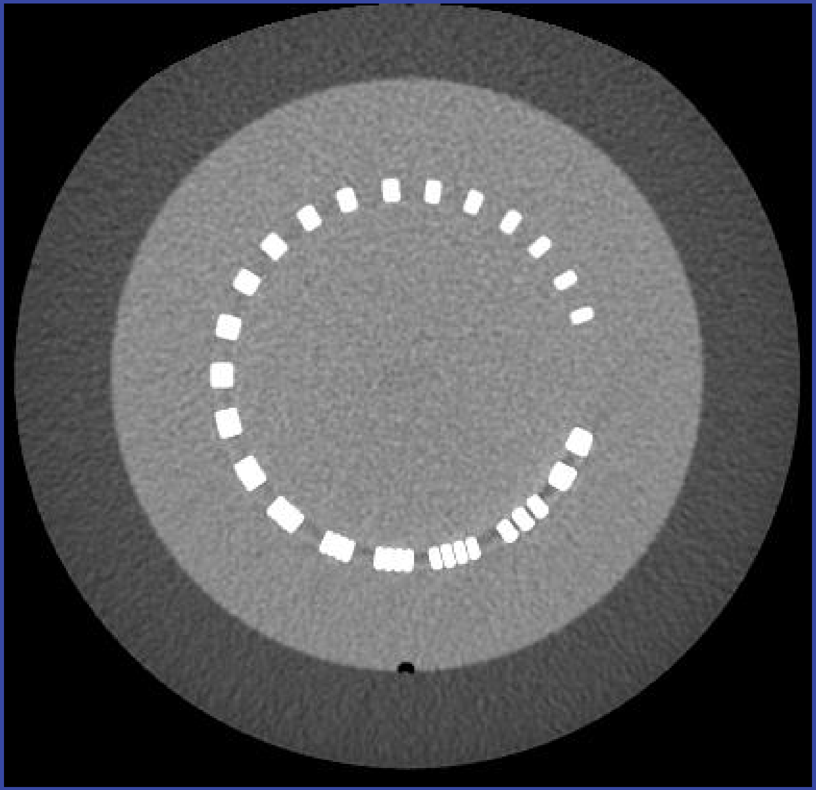
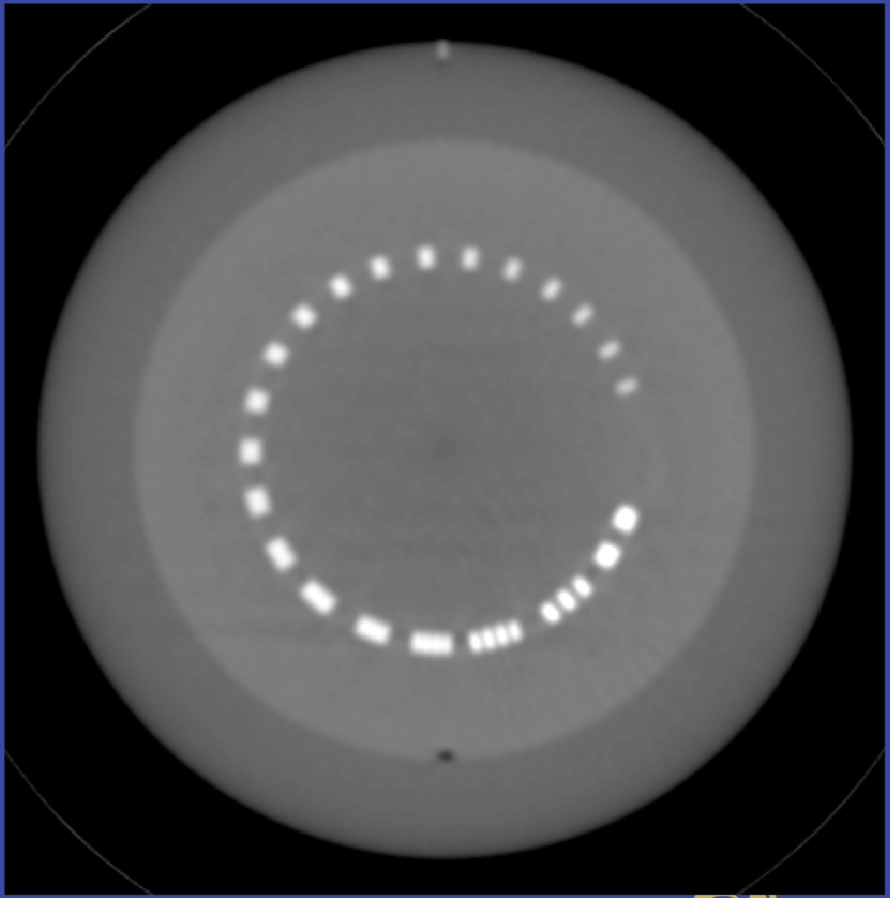
Spatial Resolution



GE CT scanner
2.5 mm slices



0.5 mm pixels

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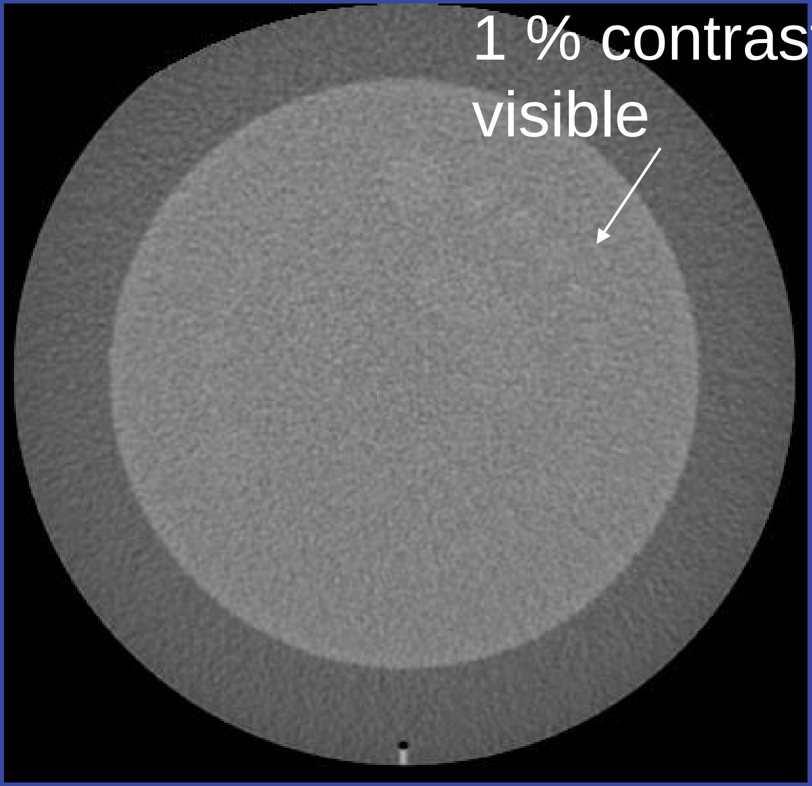
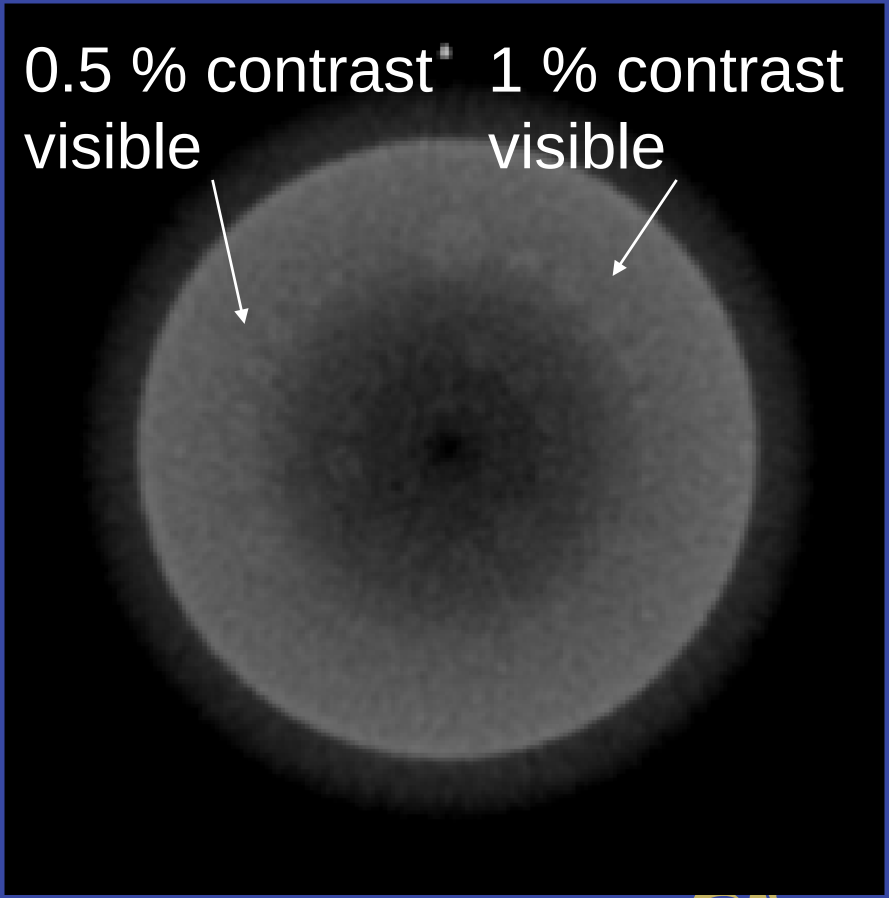
120 kVp, 100 mA

Low Contrast Resolution





GE CT scanner
2.5 mm slices

1 mm pixels

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120 kVp, 100 mA

Cone-beam CT: QA of a Device

- Safety
- Geometric
- System stability
- Image quality
- System Infrastructure
- Dose

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System Infrastructure

- Data safety
- Storage space available
- Review of QA data

Daily CBCT QA Program

Dimension	Procedure	Tolerance
Detector stability	Dark image calibration	
Geometry	Localising lasers	< 1 mm
	MV/kV/laser alignment	< 1 mm
	Accuracy of shifts	< 1 mm
Safety	Interlocks: interrupts or prevents irradiation	Functional
	Warning lights	Functional
Warm-up	Generator operation	Functional
	Detector operation	Functional
	Detector signal	Within expected range
	Collimator operational	Functional
Clinical process issues	Database integrity	
	Storage space availability	

Monthly CBCT QA Program

Dimension	Procedure	Tolerance
Imaging system performance	Gain stability	Replace or refresh
	Defect maps	Replace or refresh
Image quality	Scale and distances	± 0.5 mm
	CT number linearity & stability	Baseline
	Image uniformity	Baseline
	High contrast spatial resolution	Baseline
	Artefacts	Absence
Geometric	Geometric calibration	Replace / refresh
	Accuracy of couch shifts	< 1 mm
Clinical process issues	Review of daily test results	

Annual CBCT QA Program (service)

Dimension	Procedure	Tolerance
X-ray generator stability	kV_p accuracy	Baseline
	mAs linearity	Baseline
	Radiation quality (HVL)	Baseline
	Accuracy of mA & mAs	Baseline
Geometry	Couch scales	1 mm
	Couch motion accuracy (manual or remote)	1 mm
	Detector tilt	Baseline
	Detector skew	Baseline
	Detector scale	Baseline

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Annual CBCT QA Program (upgrades)

Dimension	Procedure	Tolerance
Data transfer	Link to treatment planning	Functional and accurate
	Long term and short term storage	Functional
Dosimetry	Axial and skin doses	Baseline
Clinical process issues	Database integrity and maintenance	Baseline
	Documentation of imaging procedure	Up-to-date
	Review of daily and monthly test results	Completeness

Radiation Therapy Process

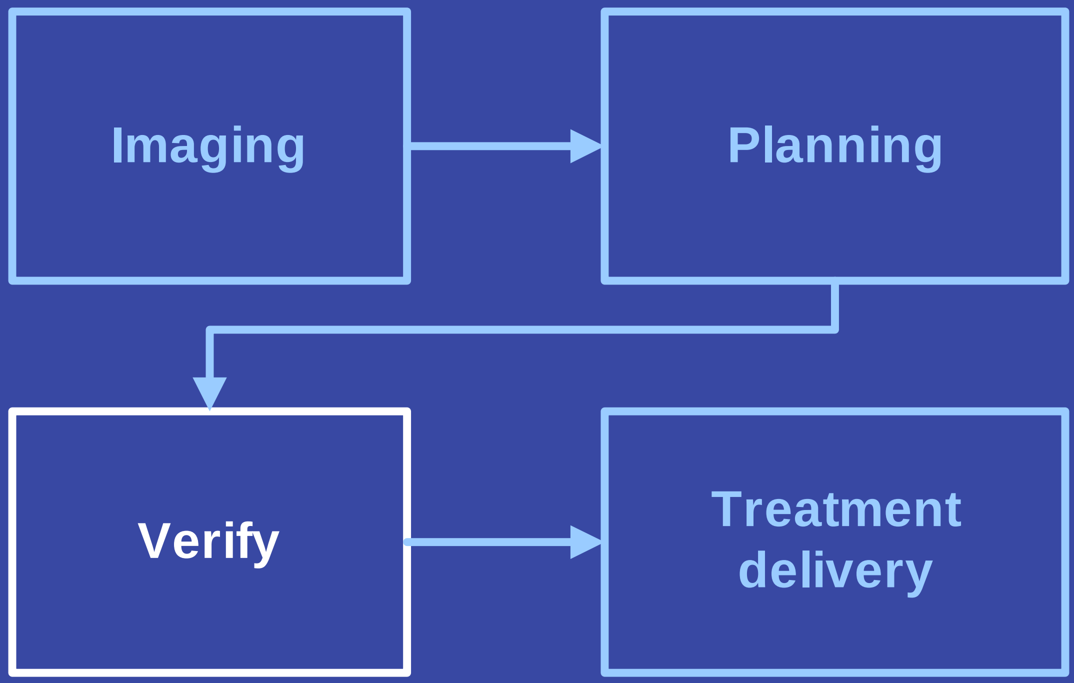
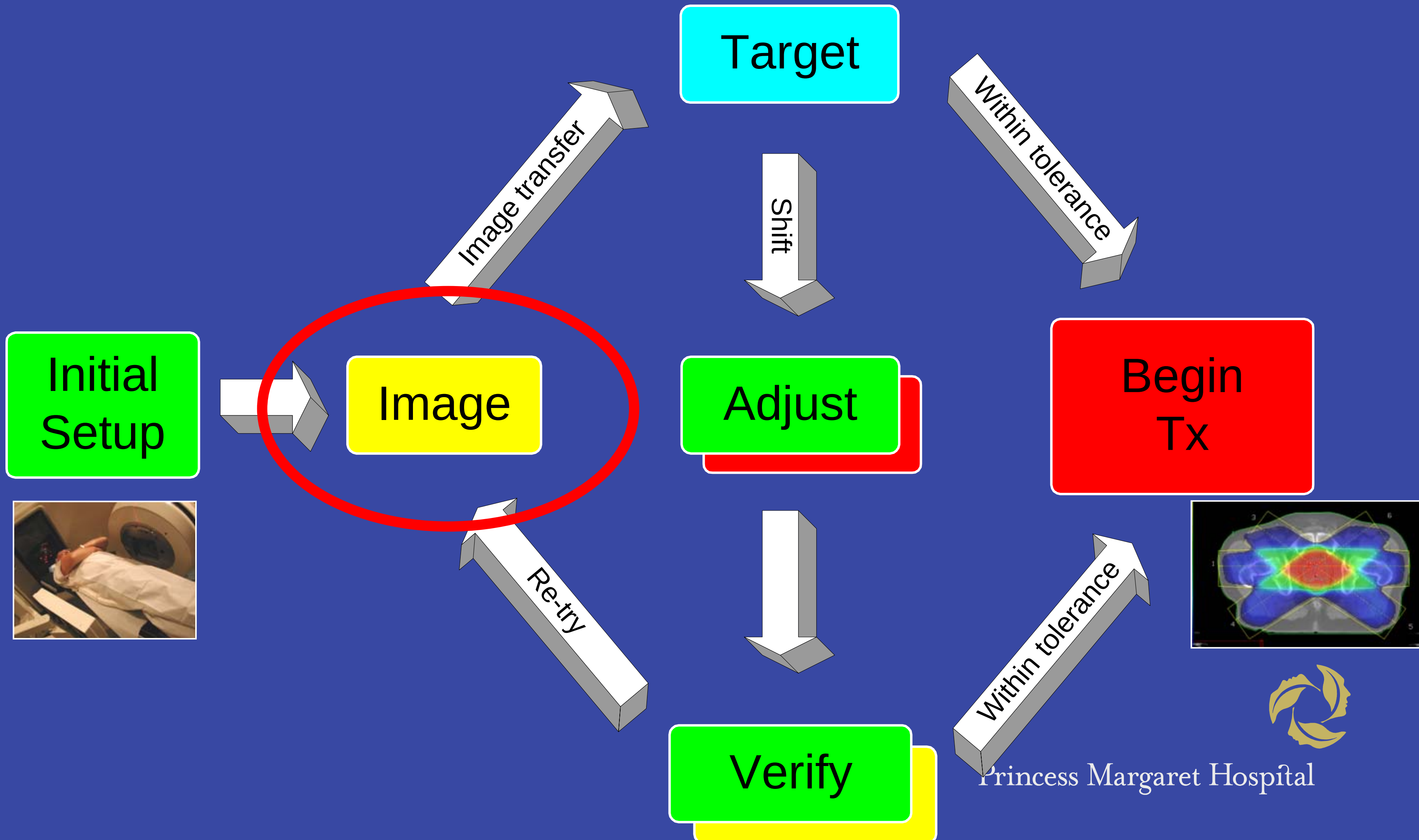


Image-Guided RT: Process



Verify: Quality Metrics

- Patient ID
- Prescription
- Location
- Patient set-up

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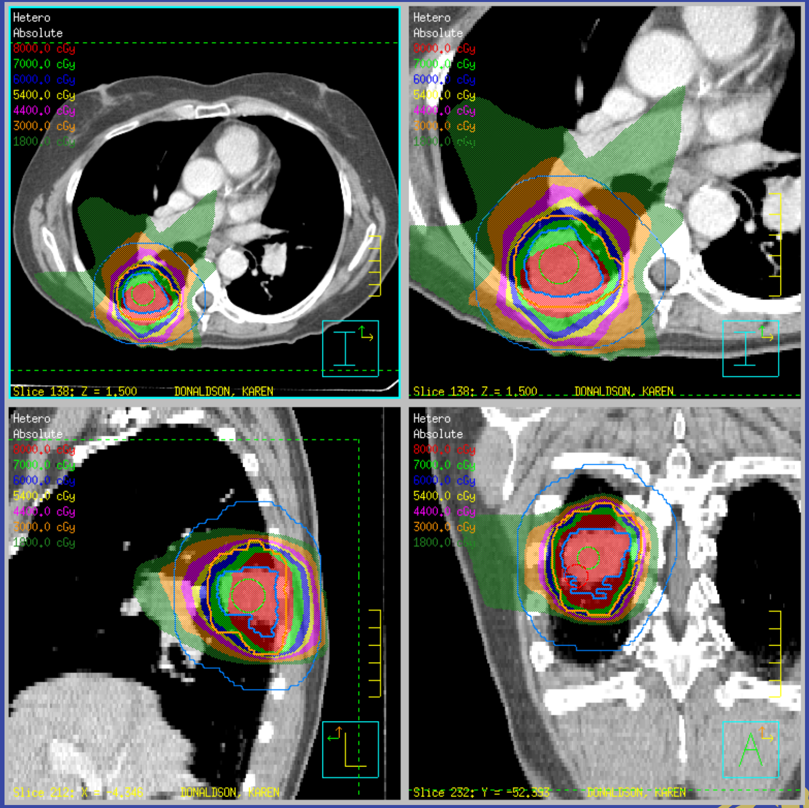
Illustrative Example: SBRT Lung

- Small, inoperable lung lesions
- Radio ablative doses (60 Gy in 3 fx)
- High level of confidence
  - Targeting
  - Planning
  - Treatment



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Method: Lung SRT Process

Patient consent and education

Immobilisation

Steretactic frame for abdominal compression

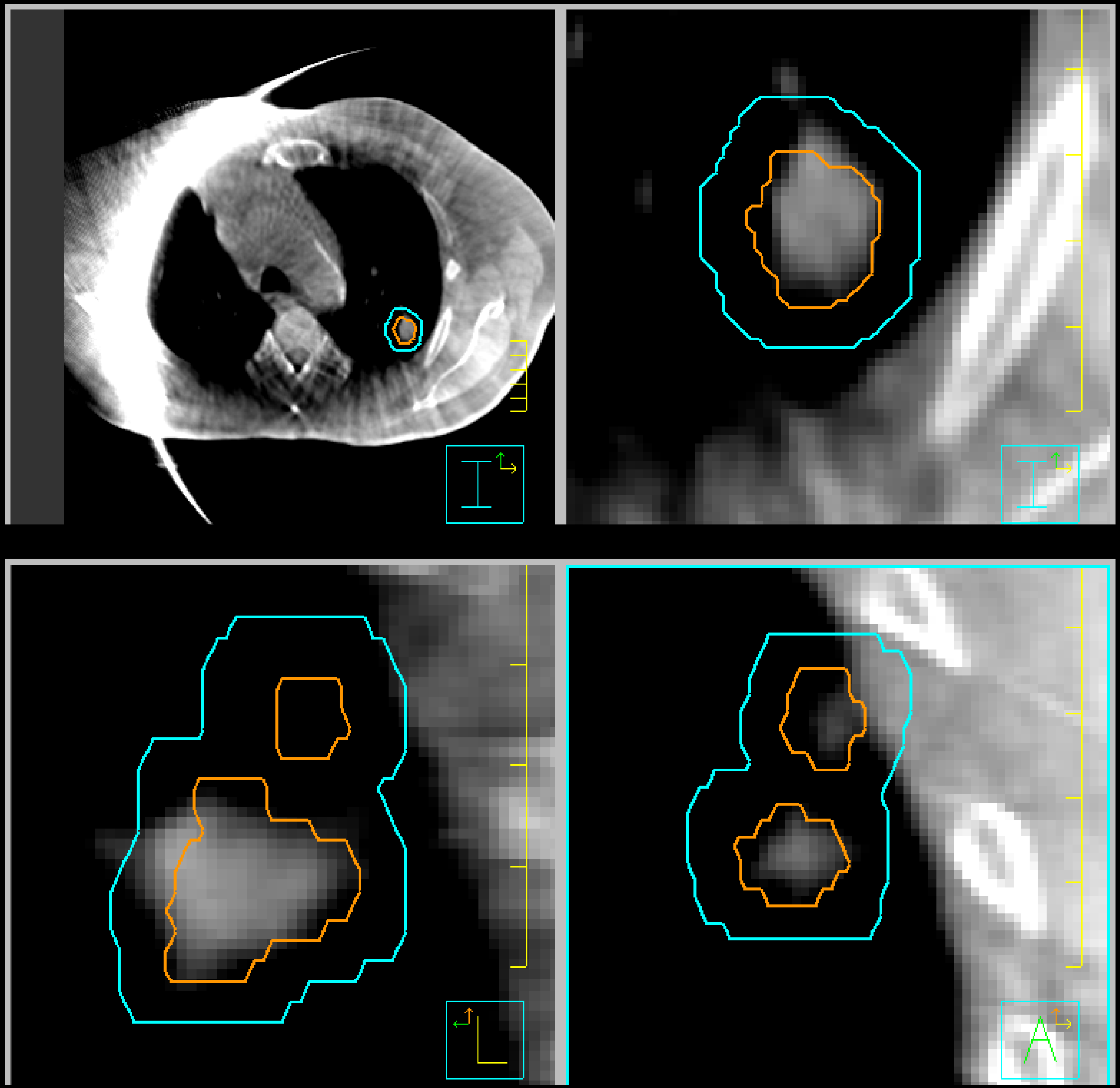
Helical and 4DCT imaging: derive GTV

Planning

Image guided positioning at the treatment unit CBCT
± 3 mm

Treat

Image Guidance: CBCT



Planning CT

CBCT Fx #1

CBCT Fx #2

CBCT Fx #3

GTV

PTV

CBCT Image Guidance Accuracy

Displacements (mm)		
Medio-lateral	Antero-posterior	Cranio-caudal
4.7 ± 5.3	7.3 ± 9.4	5.6 ± 4.8

Residual Error (mm)		
Medio-lateral	Antero-posterior	Cranio-caudal
2.0 ± 1.8	2.7 ± 2.2	2.1 ± 2.3

10 patients

Observations

- IGRT clearly reduces both the systematic and random errors.

- Residual errors reflect our current tolerance (± 3 mm).

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Radiation Therapy

- Who?
  - Record & verify / electronic file
- What?
  - Planning CT, diagnostic work-up
- When?
  - Record & verify / electronic file

Radiation Therapy

- How?
  - Treatment plan
- Where?
  - Daily CBCT

IGRT is a QA tool for external beam radiation therapy

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Summary and Conclusions

- Introduced framework for a QA program
  - Goal: reduce errors and uncertainties
    - Devices
    - Processes

Summary and Conclusions

- Quality has several dimensions
  - Dimensions can be formulated as *metrics*
    - Quantifiable
    - Traceable
  - Use quality metrics
    - Assess performance
    - Improve quality with time

Summary and Conclusions

- Have applied QA framework to a *device*
  - Cone-beam CT
- Have applied QA framework to a *process*
  - SBRT lung

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Conclusions

- Demonstrated that IGRT is routinely used to reduce systematic and random errors & uncertainties
- In this sense, IGRT is a QA tool

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