COMMISSIONING AND USE OF CONVENTIONAL CT

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Outline

- Introduction and historical review
- CT-Technology
- Multislice Benefits
- Commissioning
- Conclusions
-

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Disclaimer: Our university uses Philips scanners in radiation therapy and I have easy access to their images which are used in this presentation. This should in no way be interpreted as our endorsement of these products.

CT in Radiation Therapy

1977, *British Journal of Radiology*, *50*, 294

Correspondence

(The Editors do not hold themselves responsible for opinions expressed by correspondents)

THE EDITOR—SIR,

TREATMENT SIMULATORS AND COMPUTER ASSISTED TOMOGRAPHY

The functions of the treatment simulator are localization of tumour volume and verification that the treatment fields include the tumour while sparing healthy tissue. For radiotherapy planning by computer the radiation beams are represented in digital form. We suggest that if accurate and detailed three-dimensional information on the relevant parts of the patient's anatomy, including the positions of reference markers on the skin, is available in digital form as well, it is feasible to verify the coverage of the treatment fields in the patient by computer calculation.

Advances in whole-body computer-assisted tomography (CAT) have led to new capabilities for tumour localization (Chernak *et al.*, 1975). In addition to their advantages for localization, CT scans provide the kind of information required for verification by computer. In this view a CAT scanner, linked to an interactive treatment planning system or with its own radiotherapy programs, can take over both functions of the treatment simulator, so that the treatment simulator as a separate entity is no longer necessary.

In the computerized version of verification, the path of each applied beam in the patient would be demonstrated by means of rays superimposed on the displays of the CAT scans. When needed, three-dimensional isodose distributions corrected for the measured patient contours and inhomogeneities could be calculated.

CAT scanners are expensive and it is hard to justify their purchase by a radiotherapy department for tumour localization alone. However, if one could acquire a radiotherapy oriented CAT system instead of buying separate units for treatment simulation and treatment planning, its price would become more competitive. We are investigating the requirements for the design of such a system, and the validity in practice of replacing the patient by a computer representation for the purpose of verifying radiotherapy fields.

Yours, etc.,

M. TATCHER.

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Haifa, Israel.

REFERENCES

CHERNAK, B. S., RODRIGUEZ-ANTUNEZ, A., JELDEN, G.L., DHALIWAL, R. S., and LAVIK, P. S., 1975. The use of computed tomography for radiation therapy treatment planning, *Radiology*, *117*, 613–614.

CT simulator history

- 1983 - Goitein and Abrams described multidimensional treatment planning based on CT images
  - Beams eye view (BEV)
  - film created from a divergent projection through the CT study data
- 1987-1990 - Sherouse et al – "software analog to conventional simulation"
  - Volumetric CT scan represents virtual patient
  - Software functions create a virtual simulator
- 1990 Nishidai et al and Nagata et al and 1994 Perez et al – CT simulator systems with laser beam projecting device
- 1993-1994 – Commercial systems introduced

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CT simulator

- CT scanner with external lasers
- Flat tabletop
- Virtual simulation software

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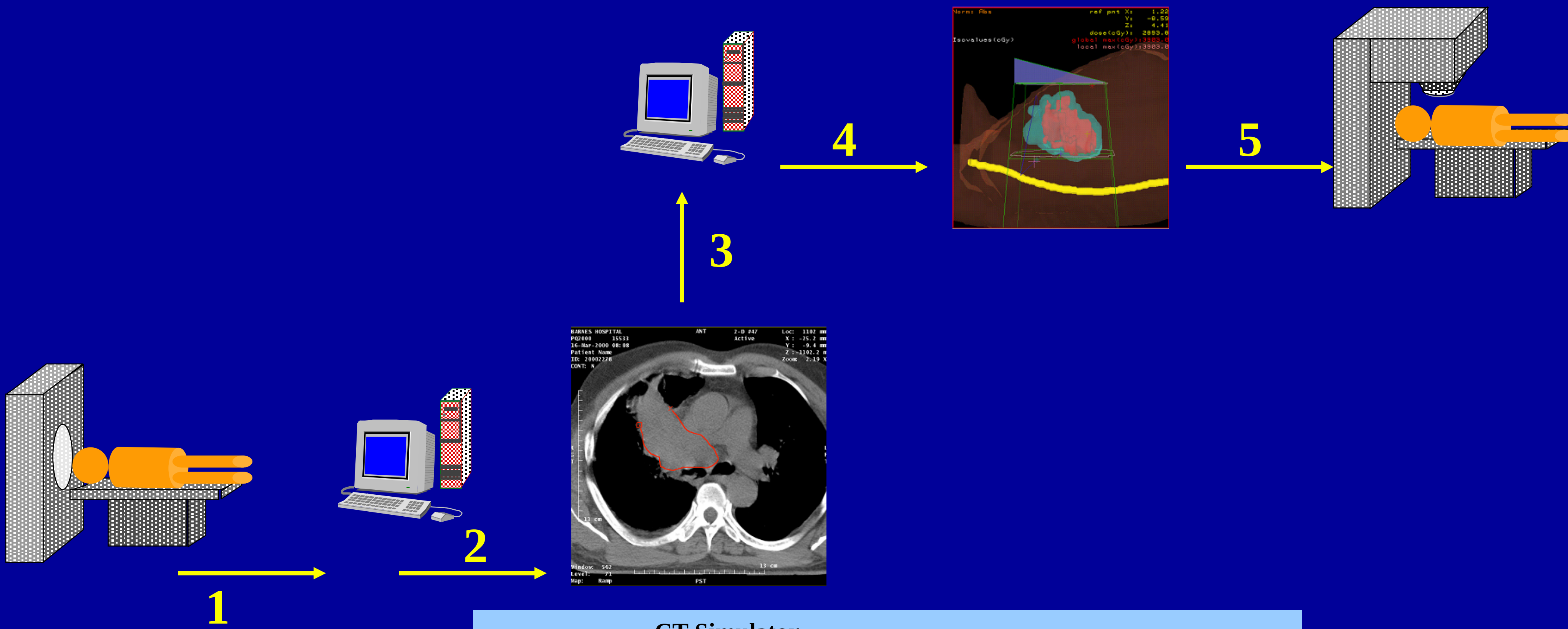
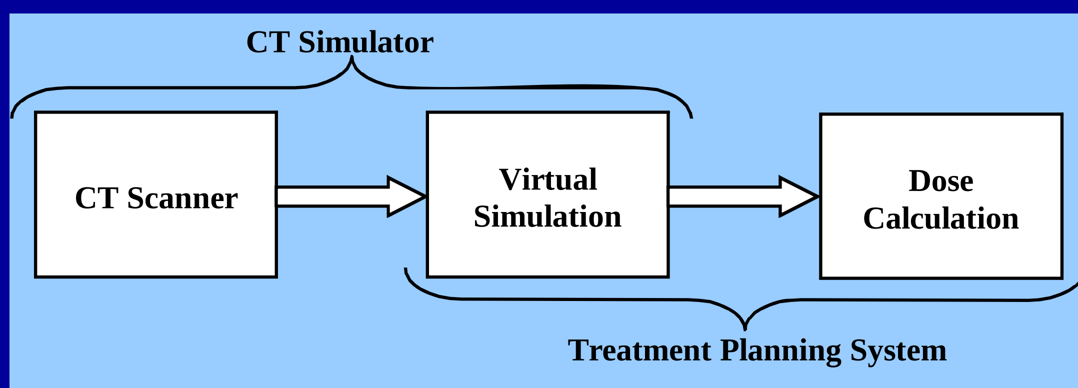
CT simulation process





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Technology

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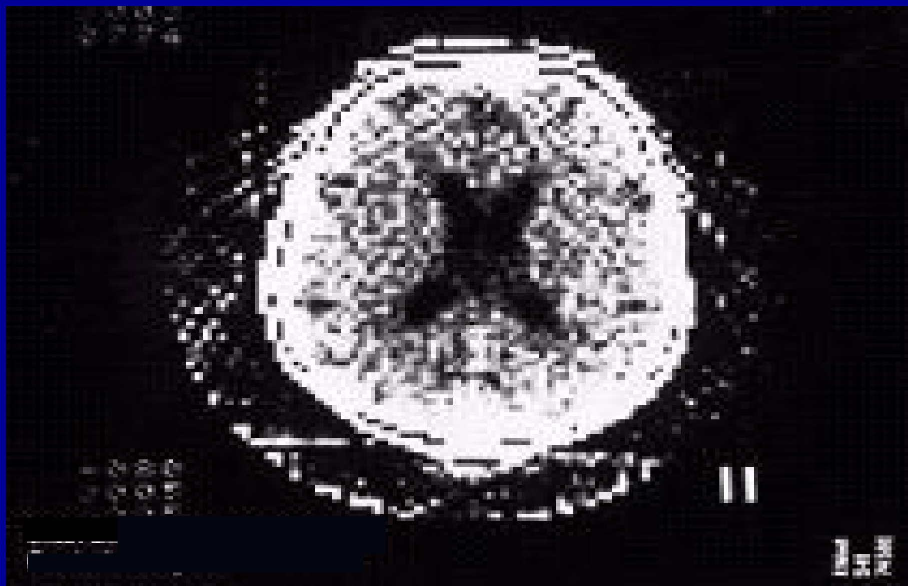

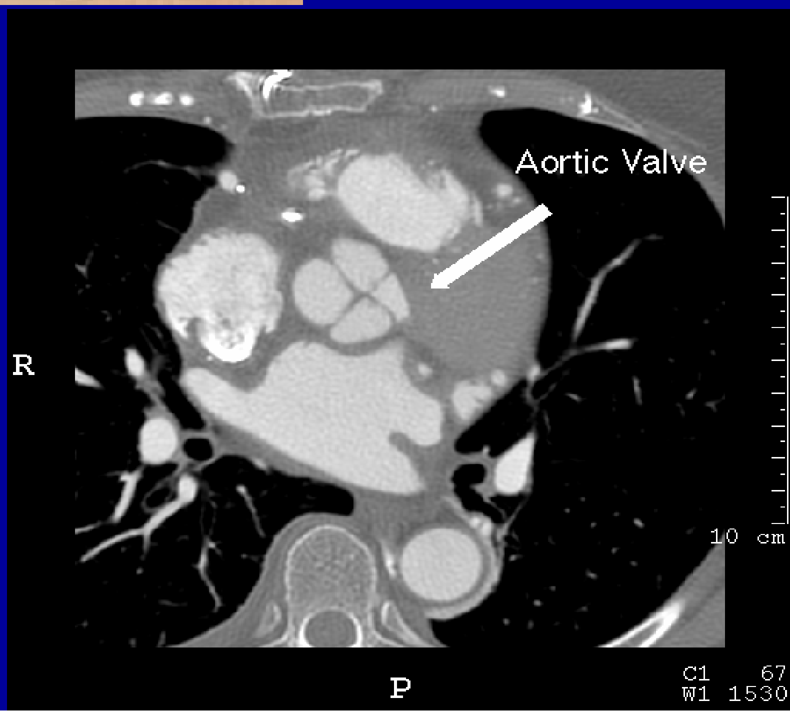

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CT Simulator Evaluation

- **Task**
  - Radiation and patient safety
  - CT dosimetry
  - Evaluation of electromechanical components
  - Evaluation of image quality
- **Solution?**
  - AAPM report number 39,
  - AAPM TG53 report
  - AAPM TG66 report
  - www.impactscan.org

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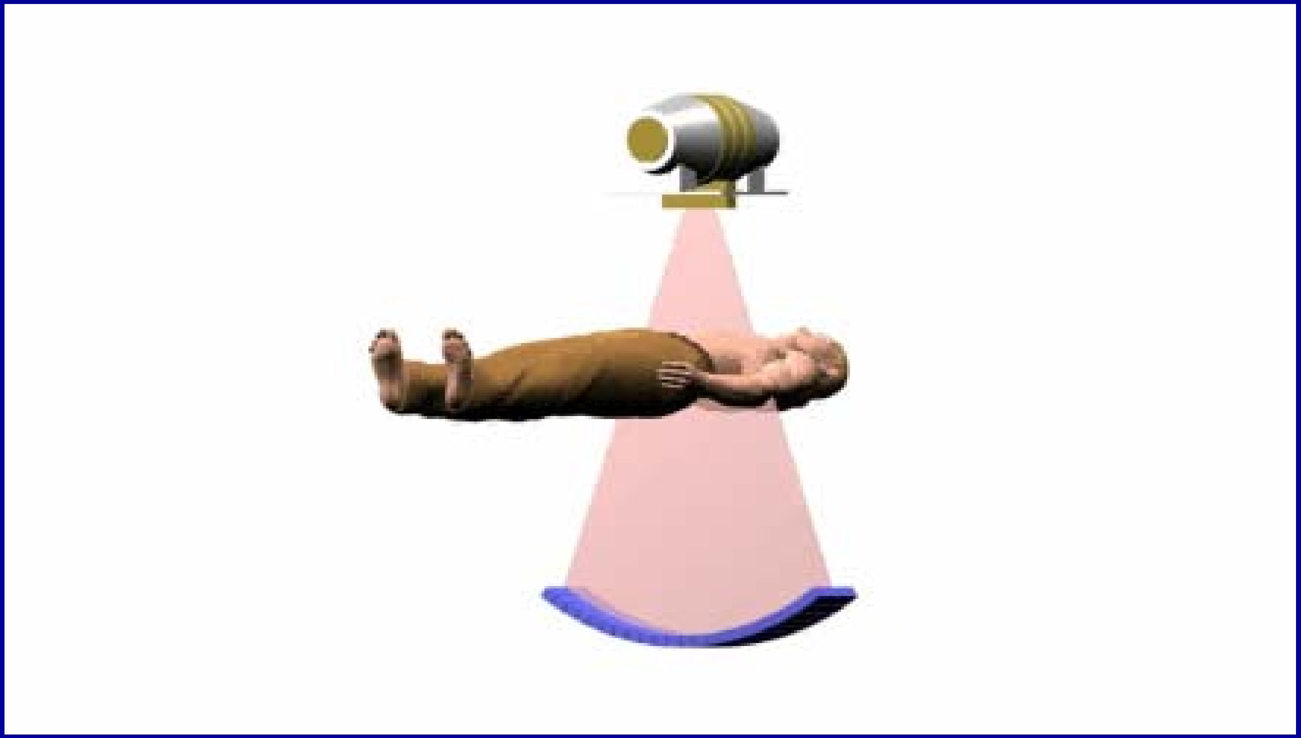
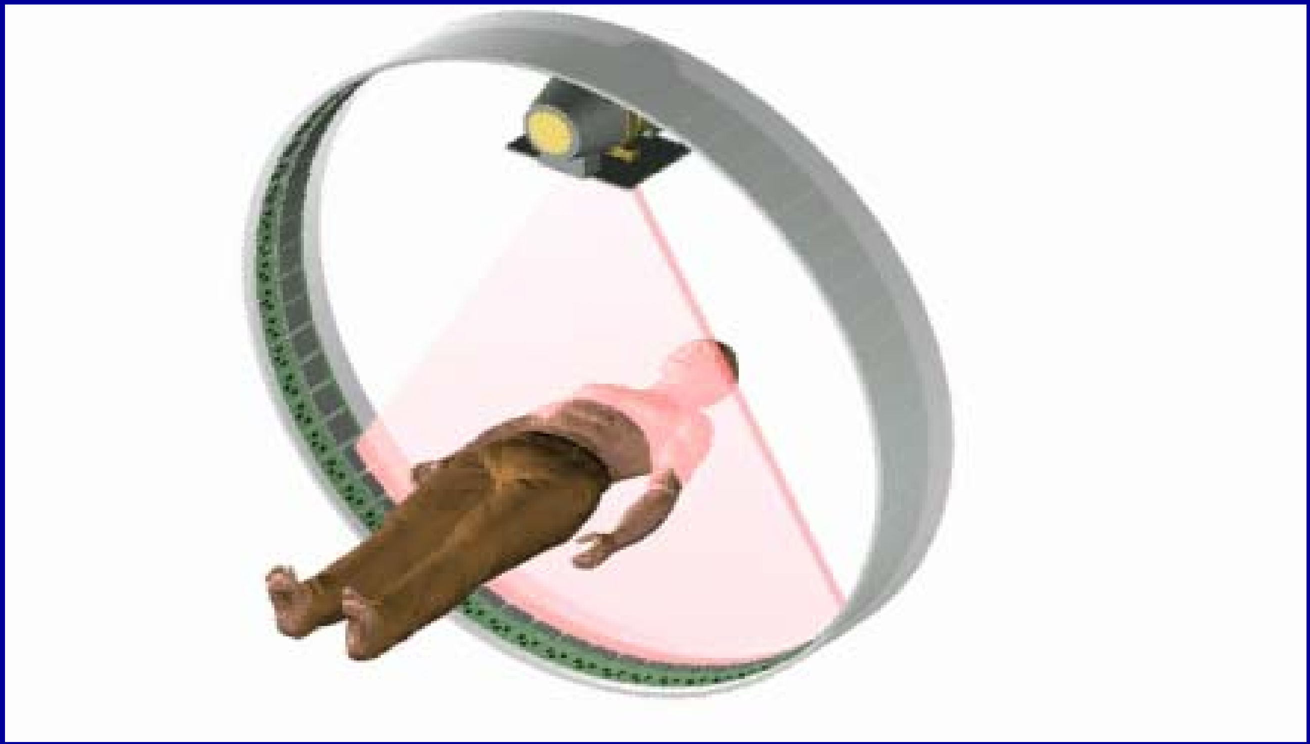
Generations



3rd Generation CT Scanner

- Fan Beam
- Rotate/Rotate

Generations



4th Generation CT Scanner

- Fan Beam
- Rotate/Stationary

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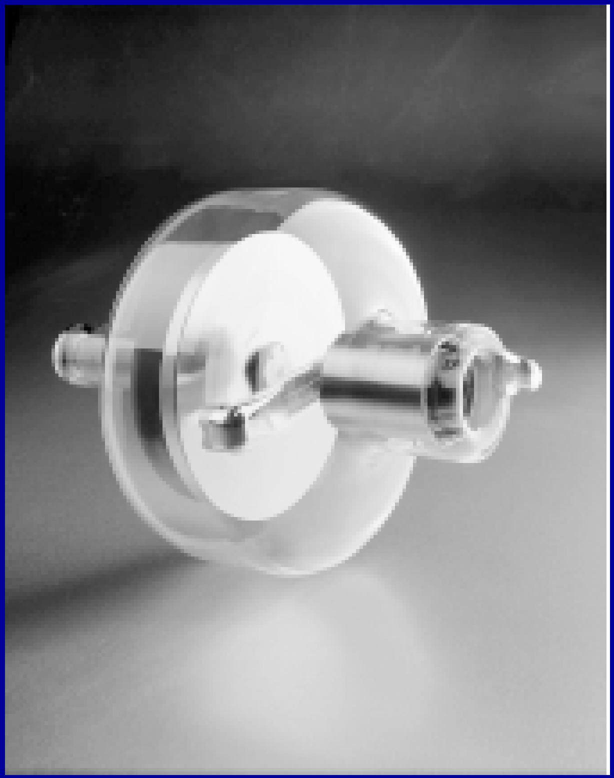
X-ray Tube – Historical Limitation



- Heat generation - inefficiency
- Large number of images per study
  - DRR quality
  - Target delineation
- Rapid study acquisition time
  - Spatial and temporal integrity
  - Motion artifacts
- Large heat anode storage ability (MHU): 5+ MHU tubes
- Fast anode cooling rate (MHU/min)

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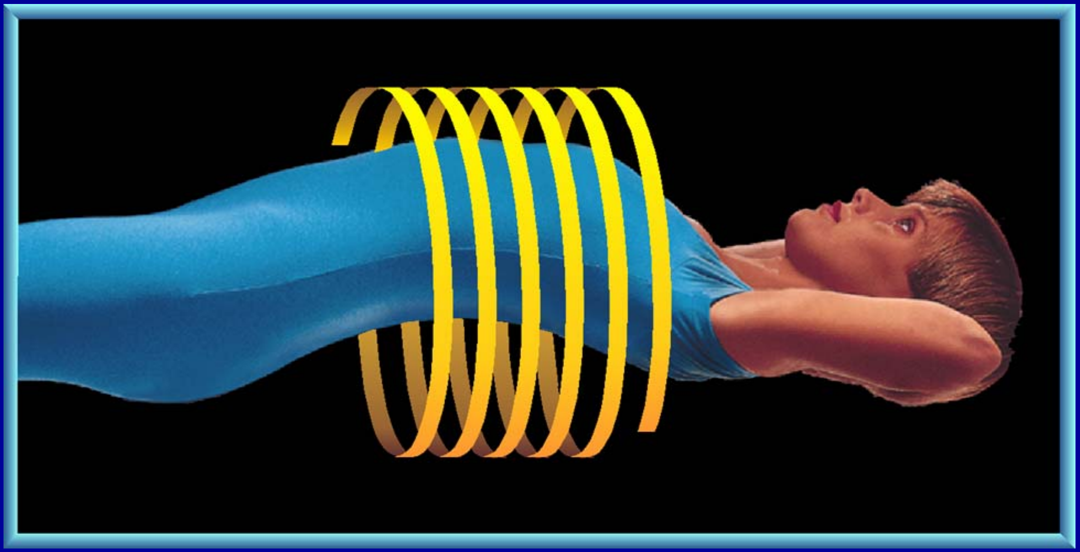
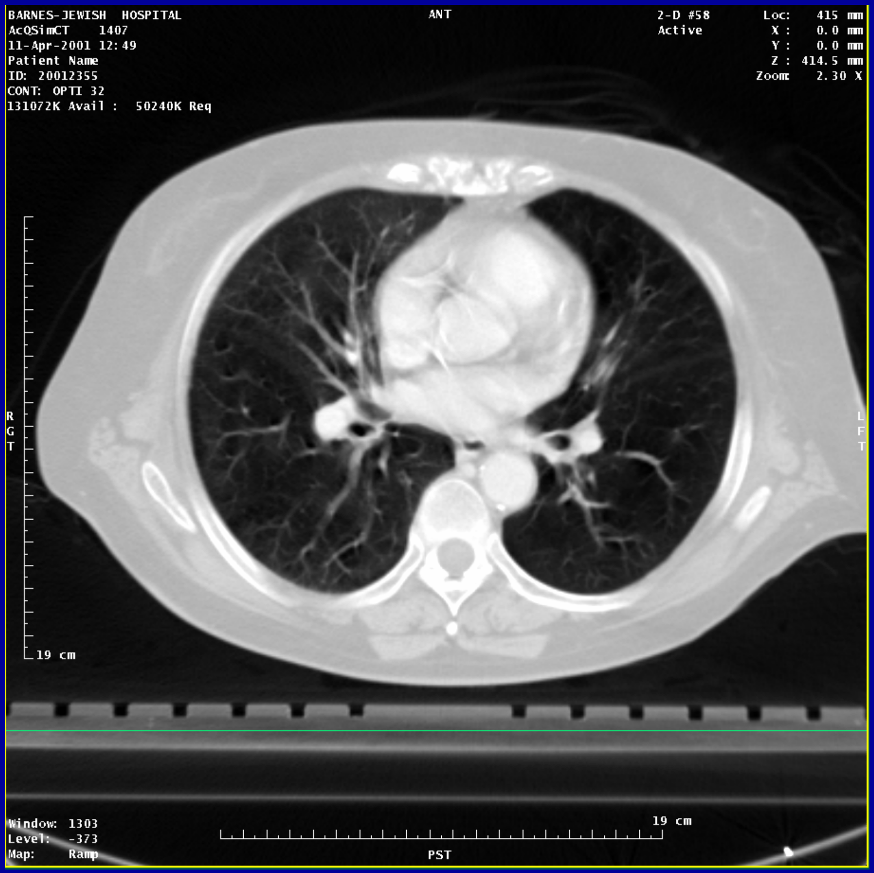
Image Generation – Single Slice



One Rotation – One Image



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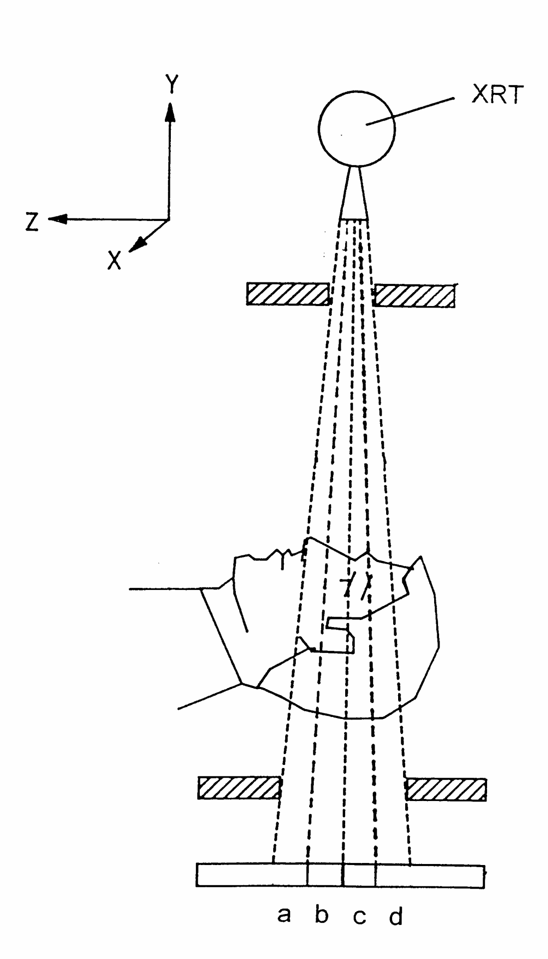
CT scanner – Single and multi-slice scanning



- Wider collimator widths
- Post patient collimation
- Multiple area detectors
  - **1992** - Elscint CT Twin - first CT scanner capable of simultaneously acquiring more than one transaxial slice
  - **1998** – Four major manufacturers introduce scanners capable of scanning 4 slices simultaneously
  - **Today** - 64+ slice scanners commercially available

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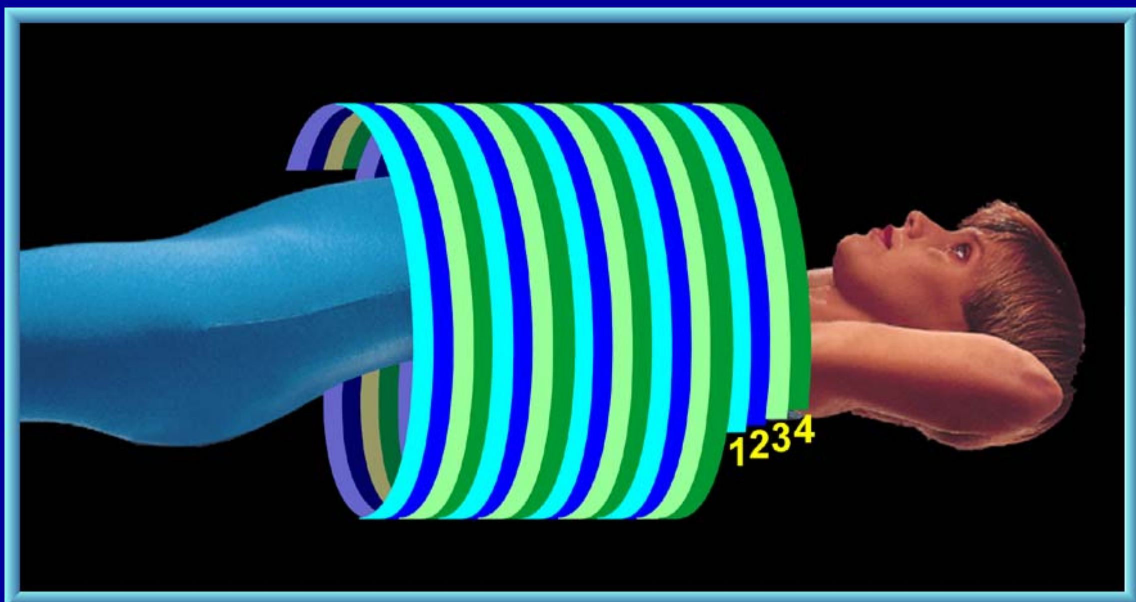
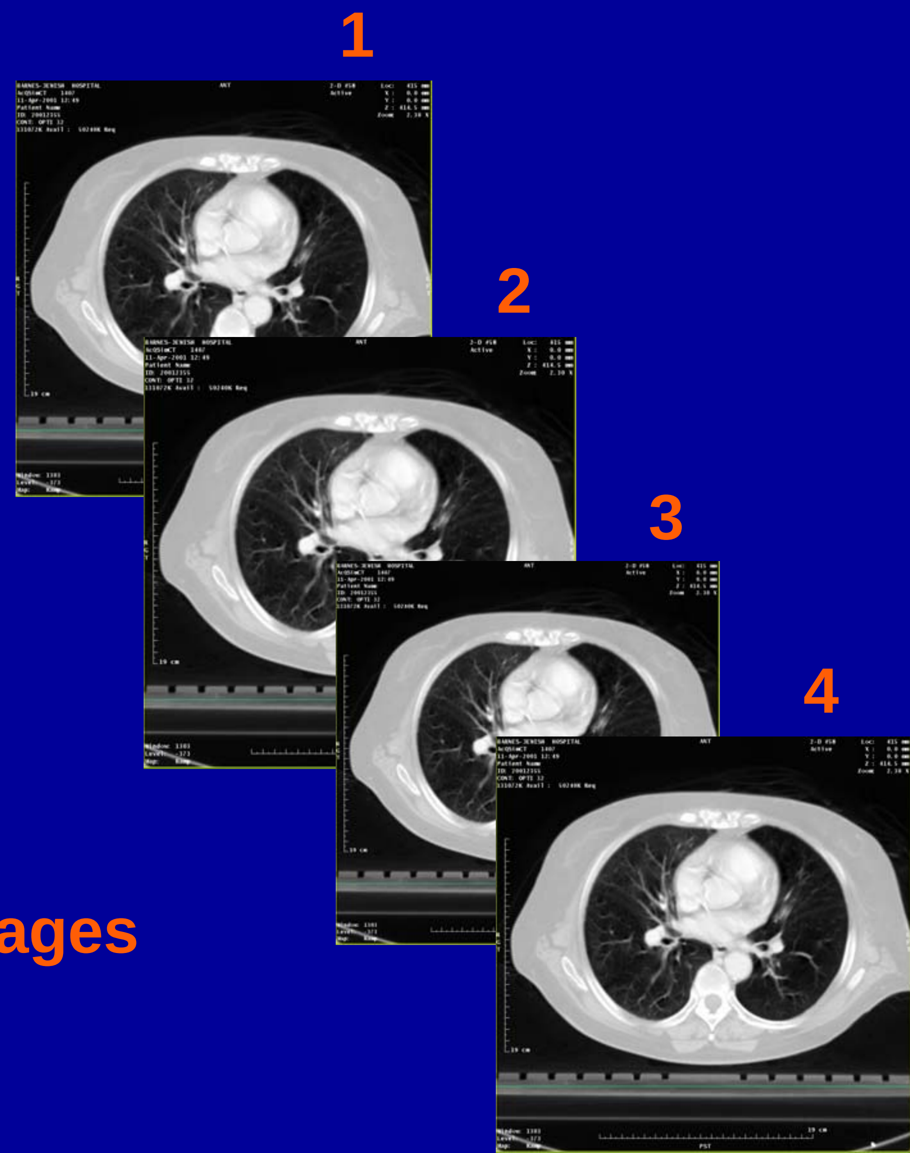
Multislice CT





One Rotation – Multiple Images

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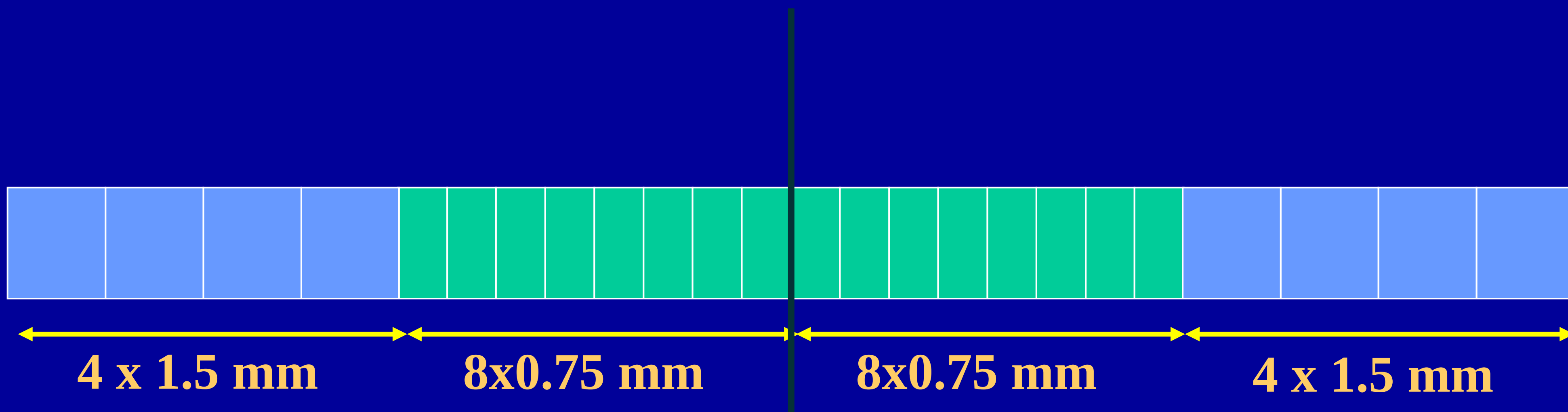
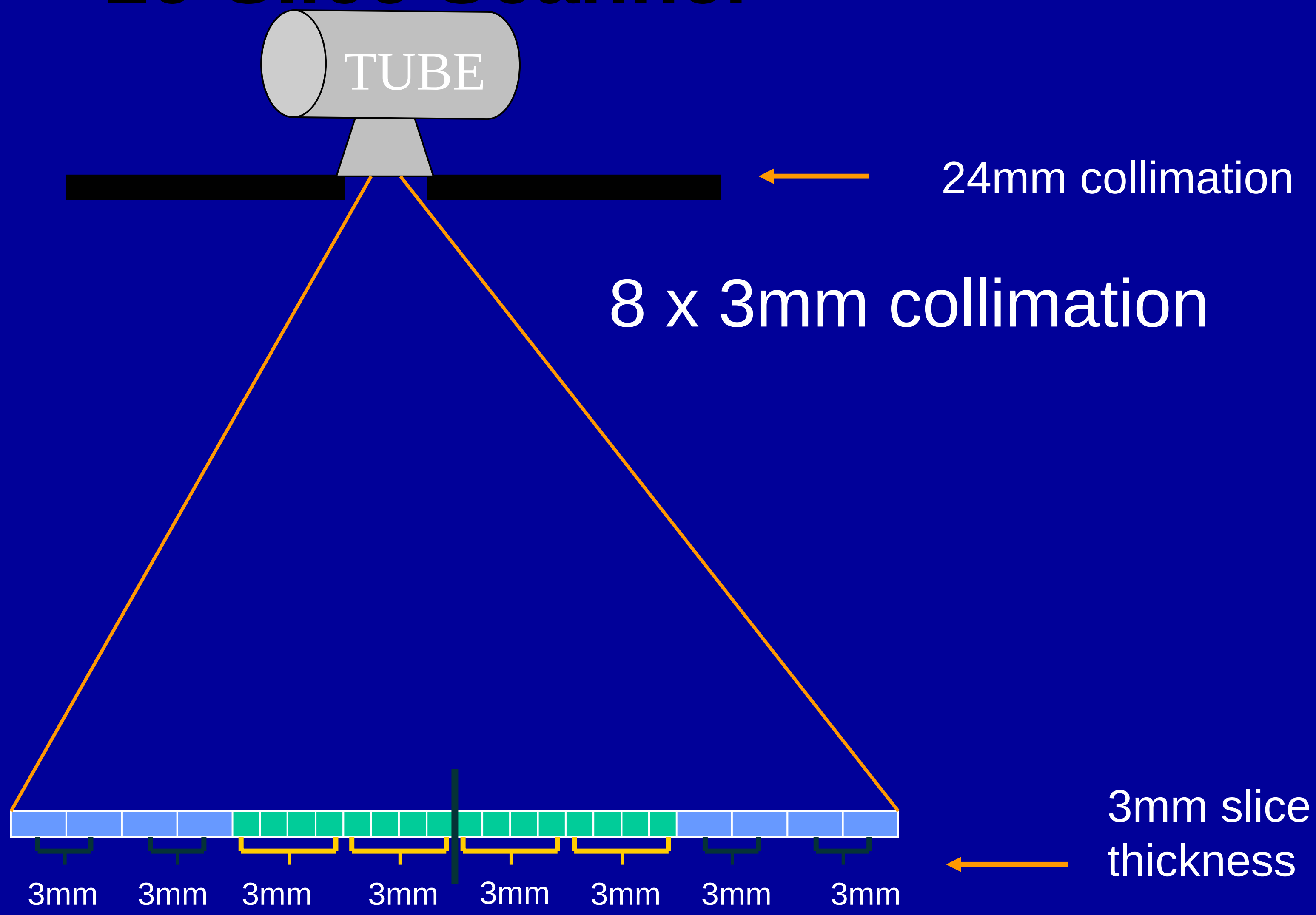
Detector Configuration
16-Slice Scanner



24 detector elements

Courtesy Philips Medical Systems, Inc.

Detector Configuration
16-Slice Scanner



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CT scanner – Multi-slice scanning

- Faster scan times
  - 4 slice scanner example (8 times faster):
    - » multi: 0.5 sec/rotation and 4 slices/rotation
    - » single: 1 sec/rotation and 1 slice/rotation
- Lower tube heat loading
  - Longer volume covered per rotation
- Improved temporal resolution - faster scan times
- Improved spatial resolution – thinner slices
- Decreased image noise – more mA available

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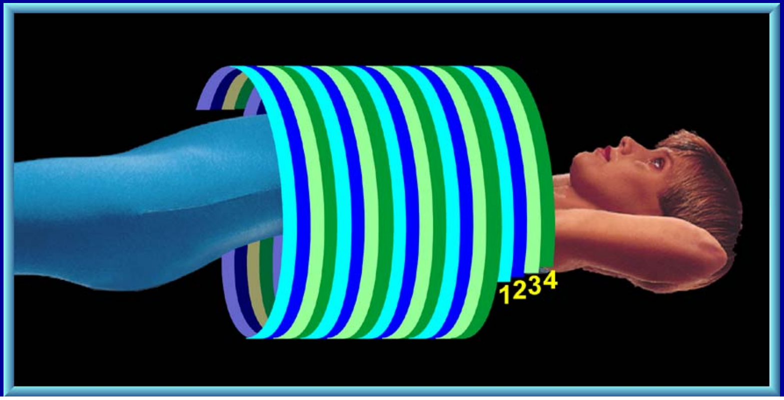
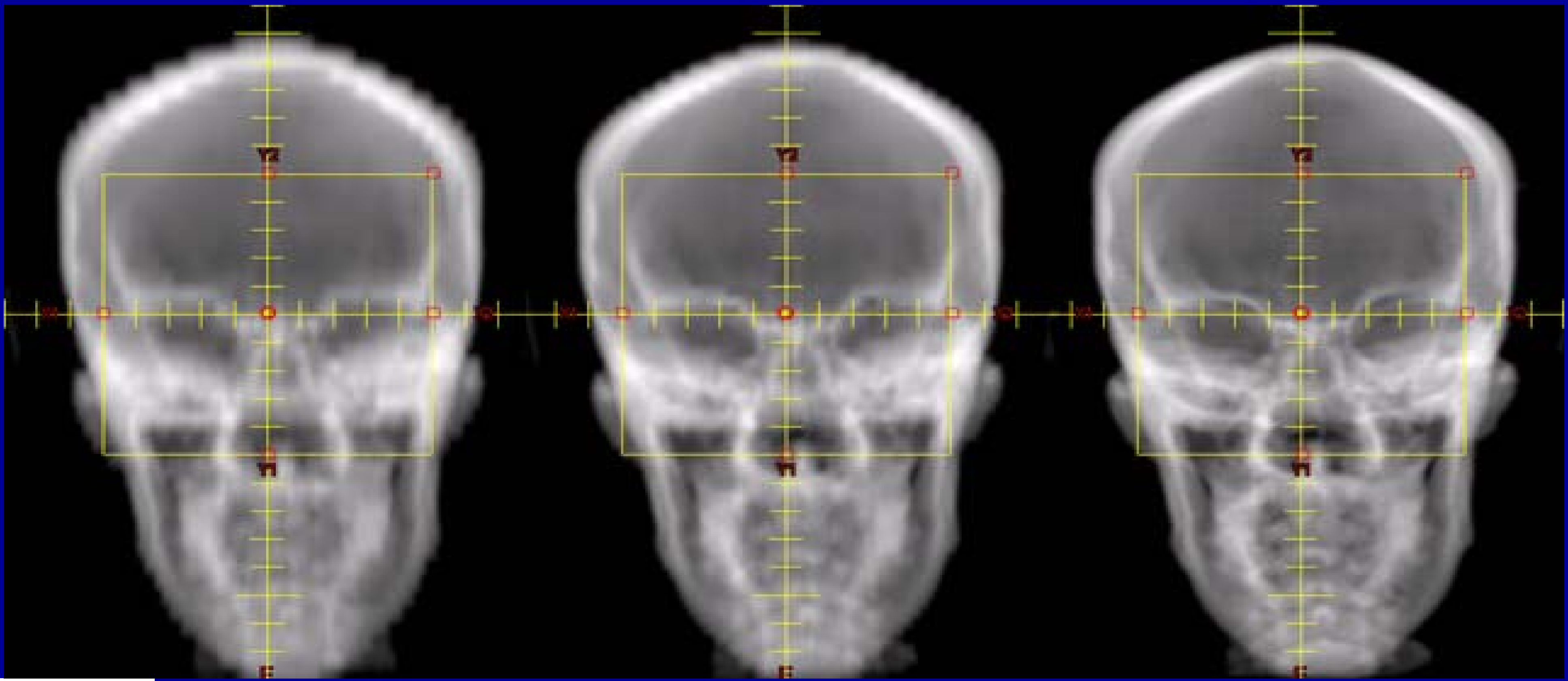


Resolution

- The lower limit on slice thickness for most single slice scanners in radiotherapy is 3 mm
- Often 5 and 8 mm slices were used
- Multislice scanners can acquire 0.75 mm thick slices with equivalent scan parameters
- Everything else being equal thinner slice thickness produces better DRRs

DRR Image Quality

- Everything else being equal, thinner slices produce better images
- Balance between large amounts of data and image quality



5mm Slices **3mm** **0.8mm**

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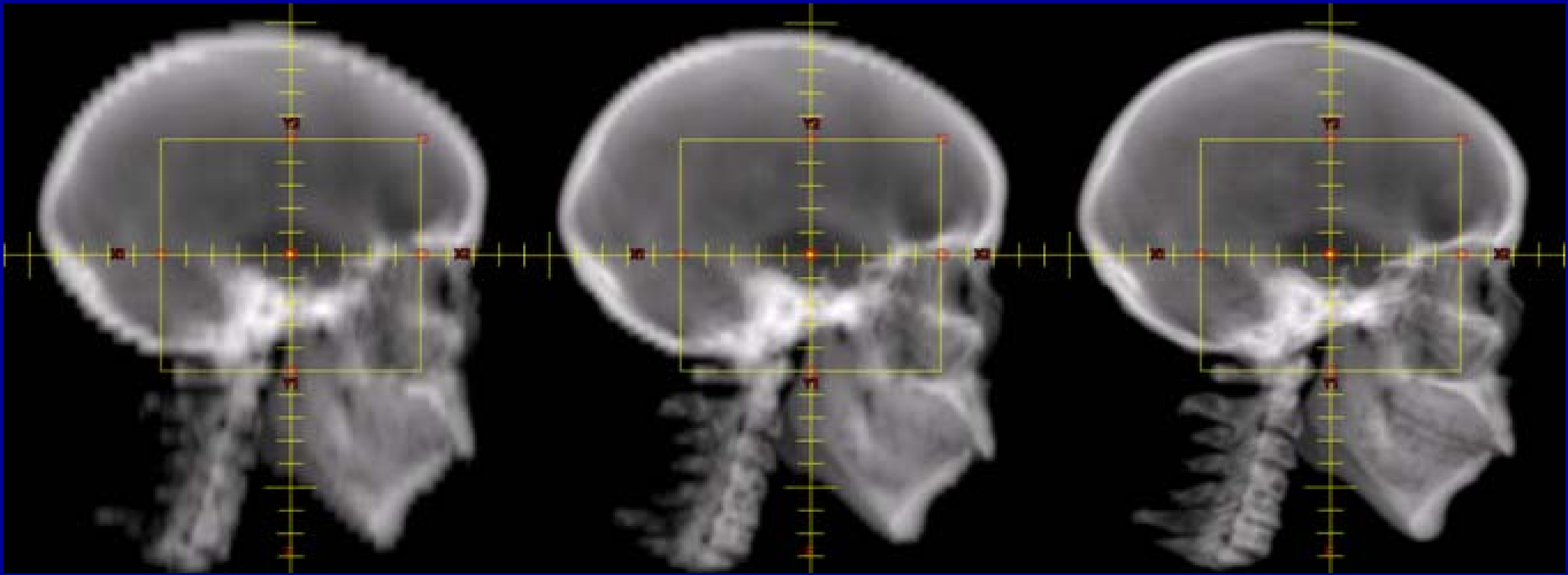
DRR Image Quality



5mm Slices **3mm** **0.8mm**

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DRR Image Quality

800 Images – 0.8 mm slice thickness

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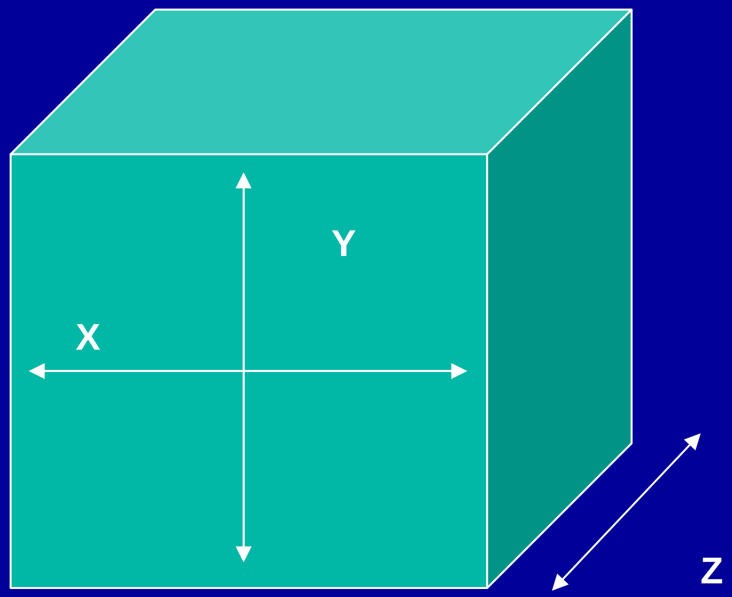
Image Reconstruction

- Voxel:
  - –Volume element representing the slice thickness or depth of the image.
  - –3 Dimensional
    - X
    - Y
    - Z



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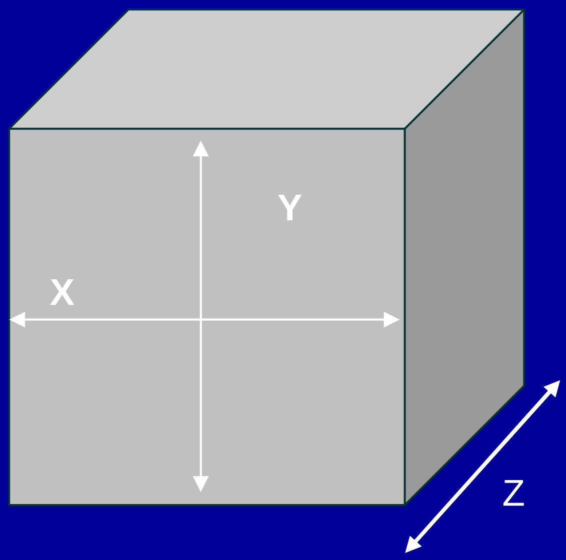
Isotropic Imaging

- Square isotropic voxels X = Y = Z
- Sub-millimeter slice thicknes
- Multi Planar Reconstruction
  - Sagittal
  - Coronal
- Multi Planar Contouring



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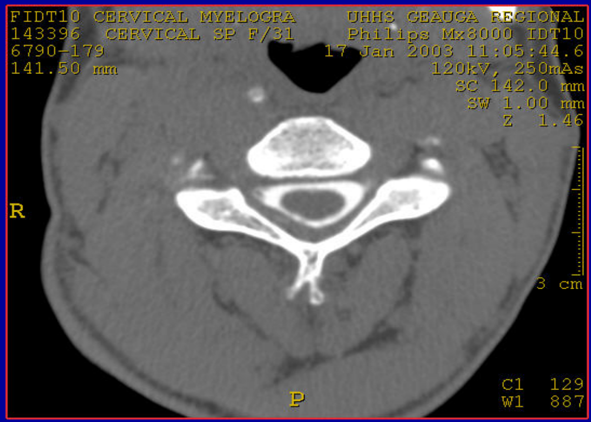
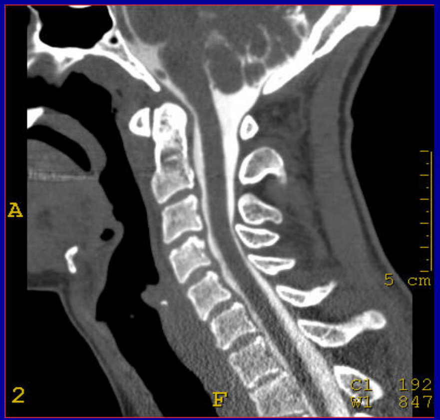
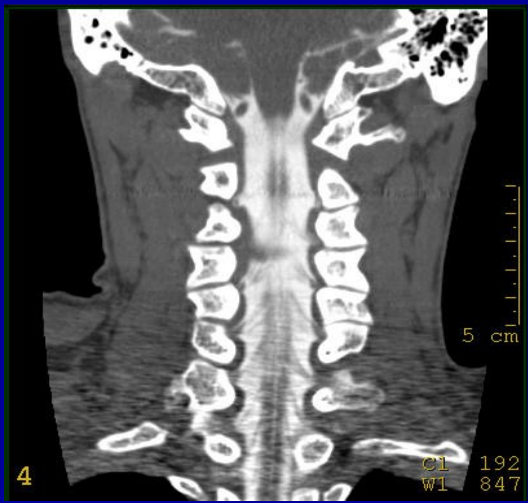
Isotropic Resolution

- Multi-planar contouring
  - Axial
  - Sagittal
  - Coronal
- Resolution the same in all three planes
- It does not matter which plane is used for contouring







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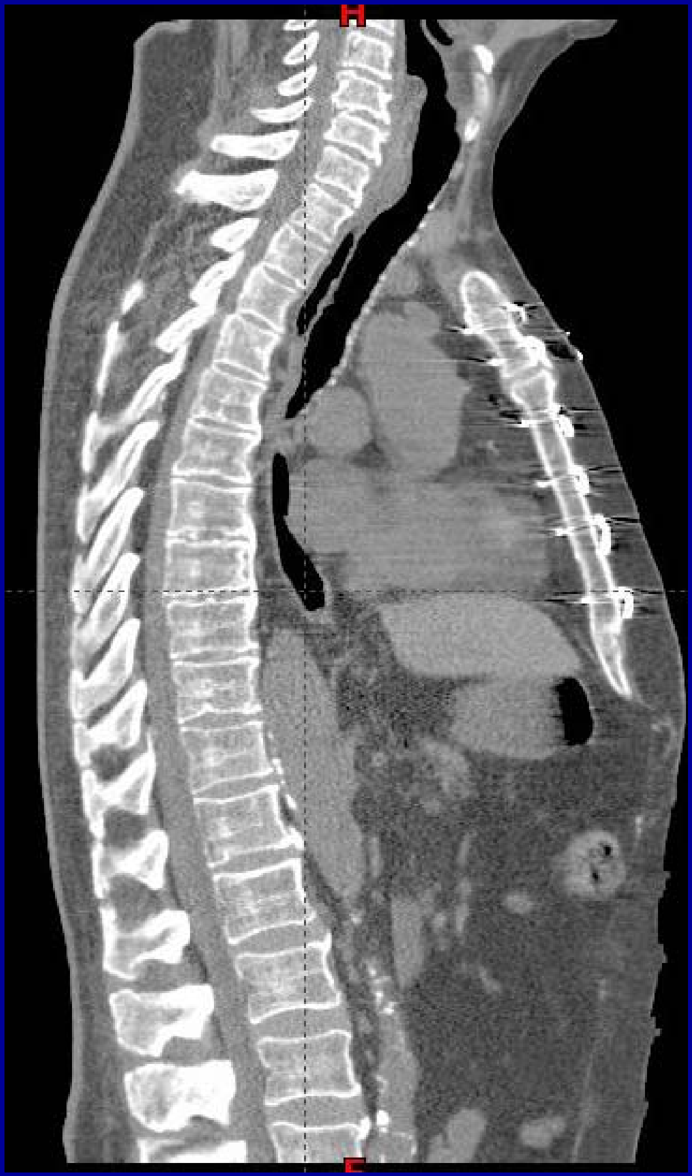
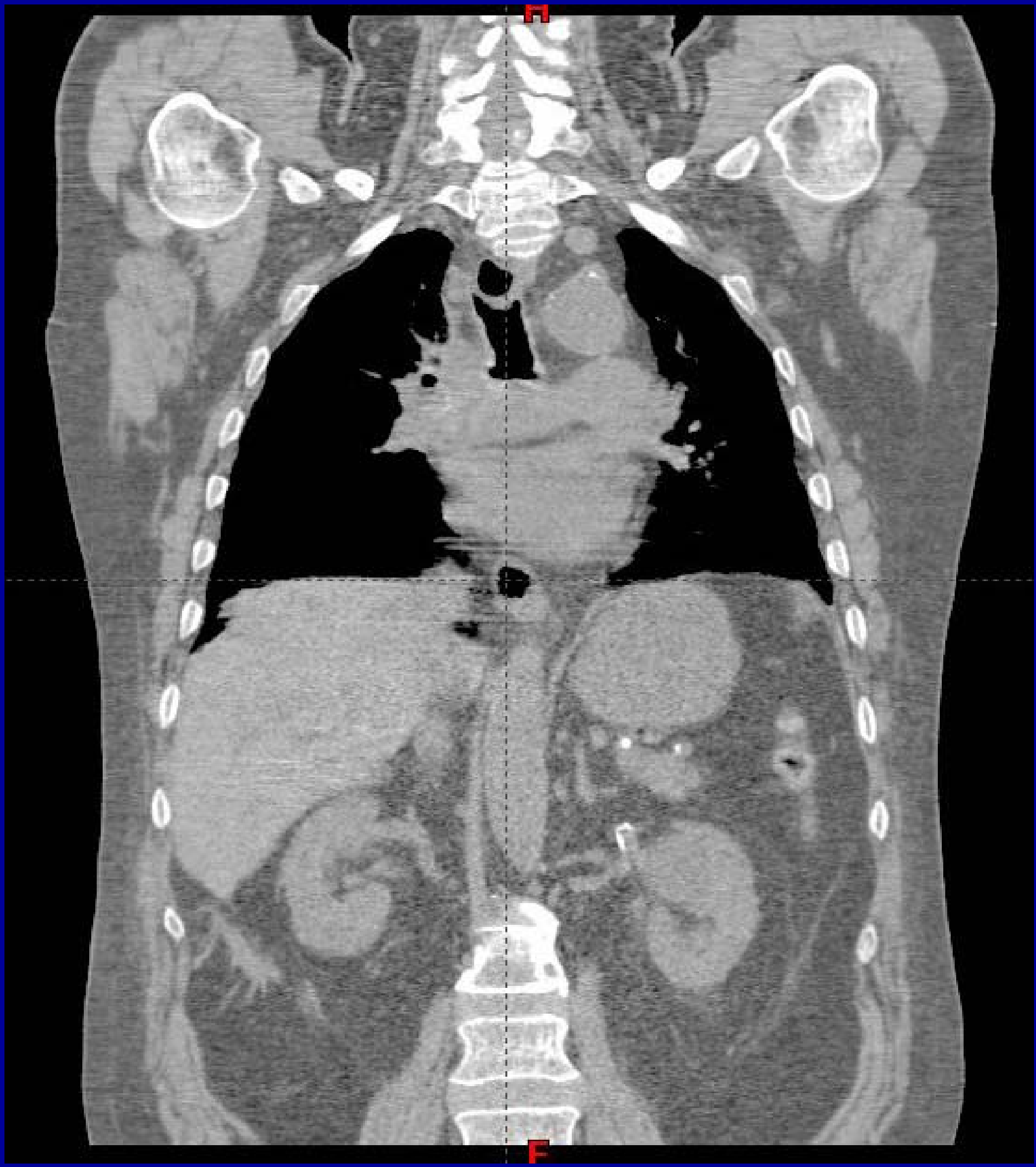
Isotropic Resolution





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Data Issues

- Image viewing speed
- Network Traffic
- Archiving
- Dose calculation
- Need tools to allow use of data without compromise in treatment planning speed

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Multi-slice CT - Speed

- Single slice scanner – 30 seconds
- Multi slice scanner – 2 to 4 seconds
- Dynamic CT
- 4D CT
- 5D CT
- Gating
- Tumor motion

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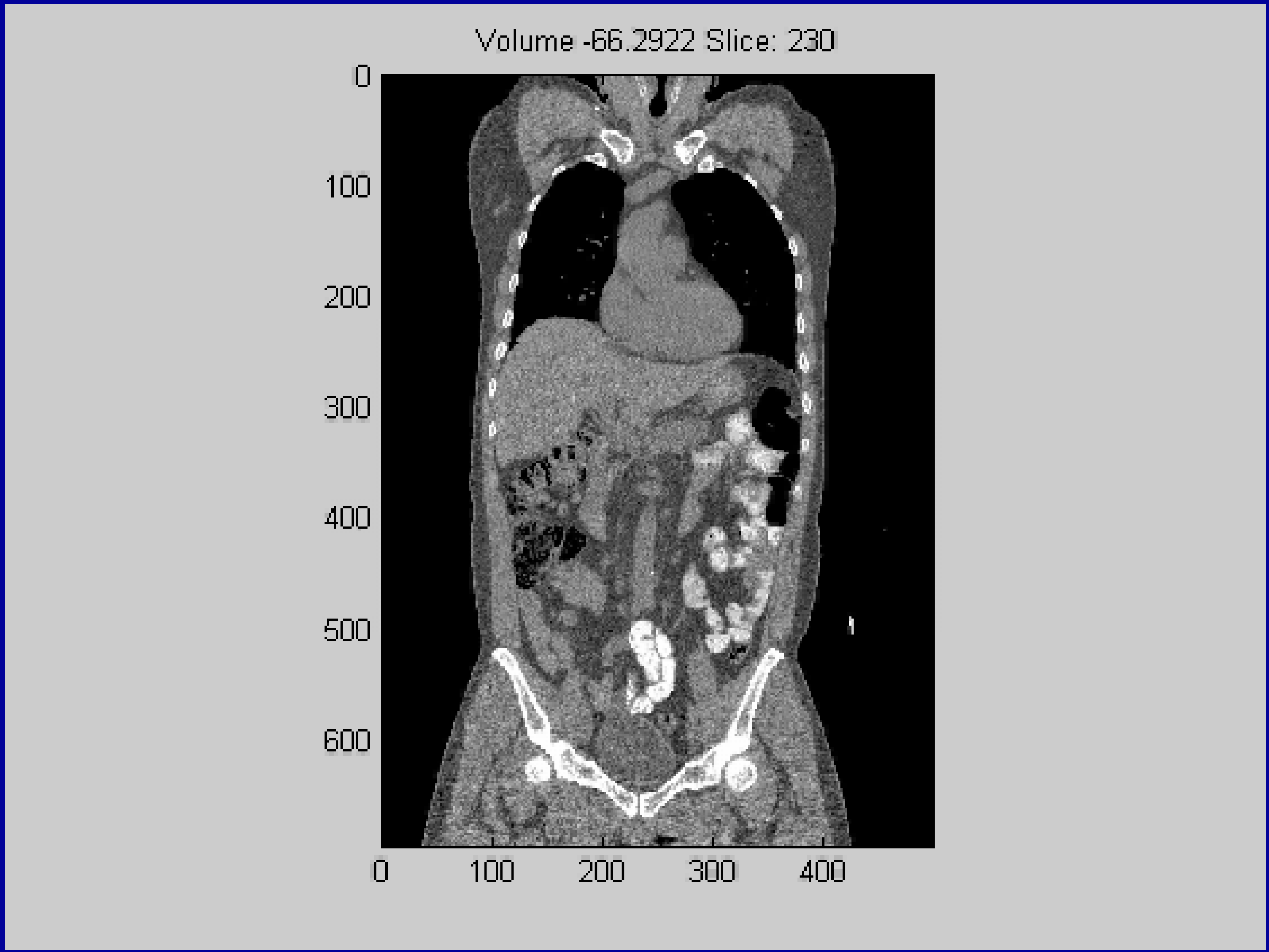
Multi-slice CT - Dynamic CT



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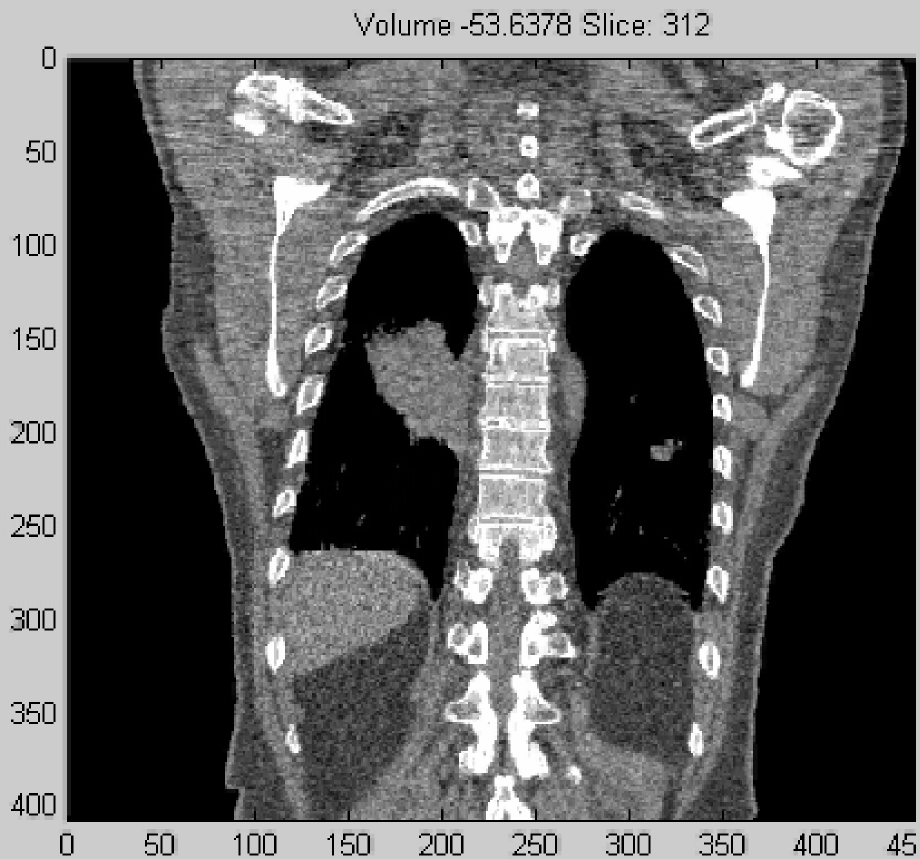
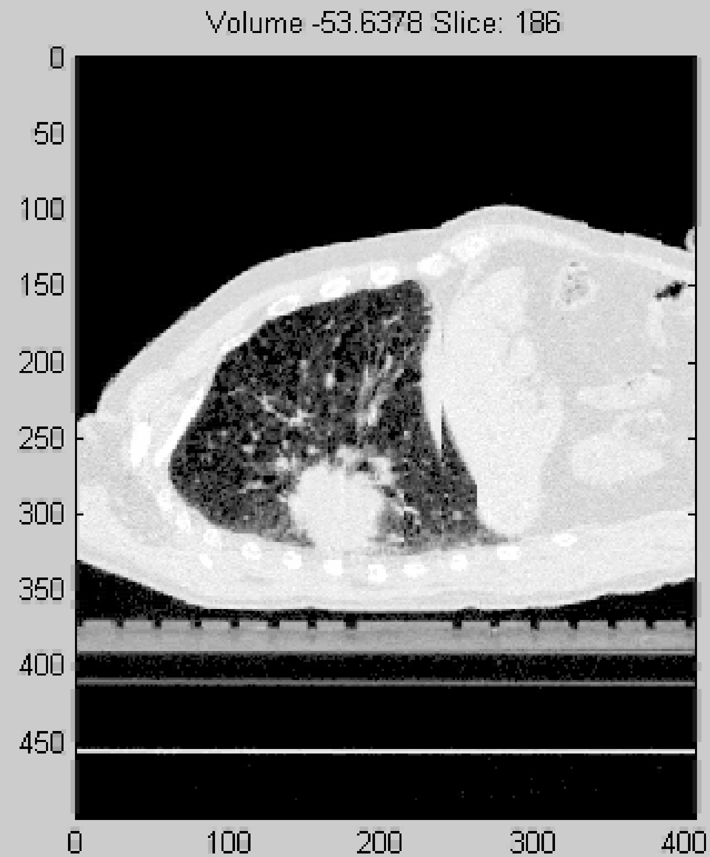
Approximately – 7000 images

Multi-slice CT - Dynamic CT





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Multi-slice CT- mAs

- mAs – proportional to number of photons
- Number of photons affects noise (image quality)
- Single slice scanner – 150 to 300 mAs
- Multi slice scanner – up to 2000 mAs
- Increasing mAs increases patient dose from a CT scan
- Increase in dose is a significant concern in diagnostic scanning
- Dose from a CT scan is insignificant compared to therapy dose
- Can take advantage of available mAs in radiotherapy scanning

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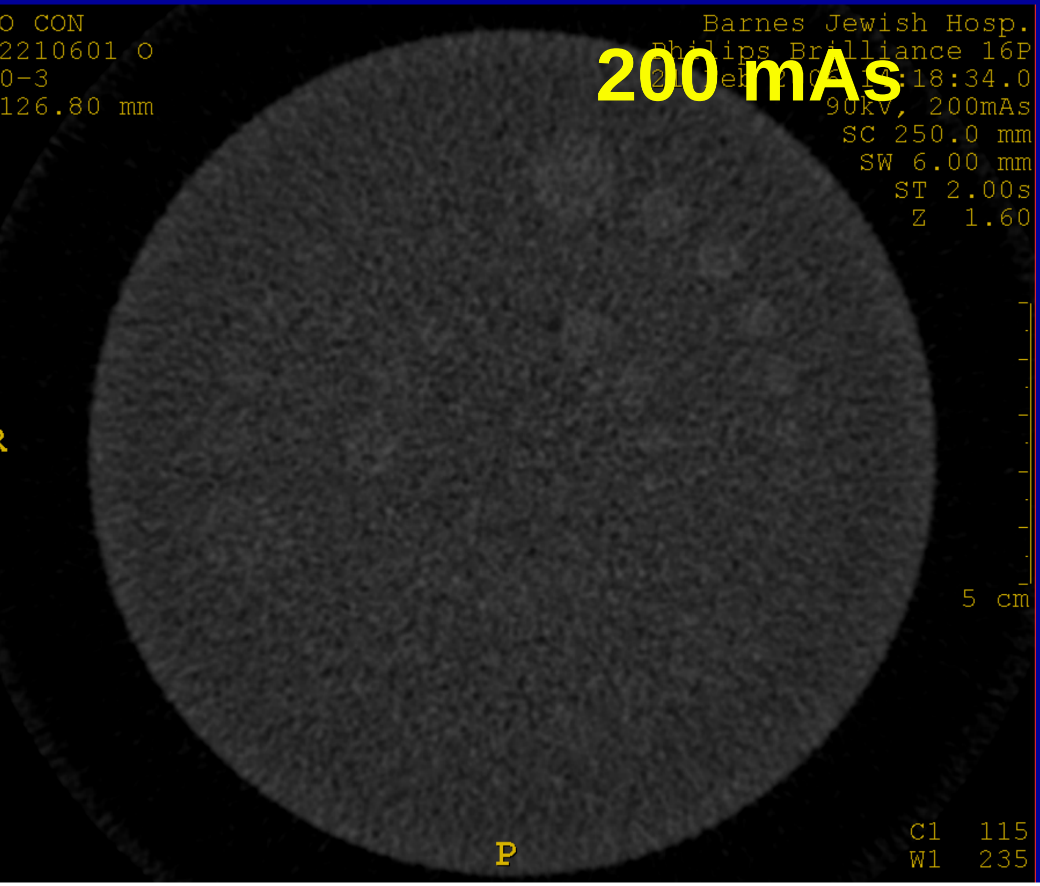
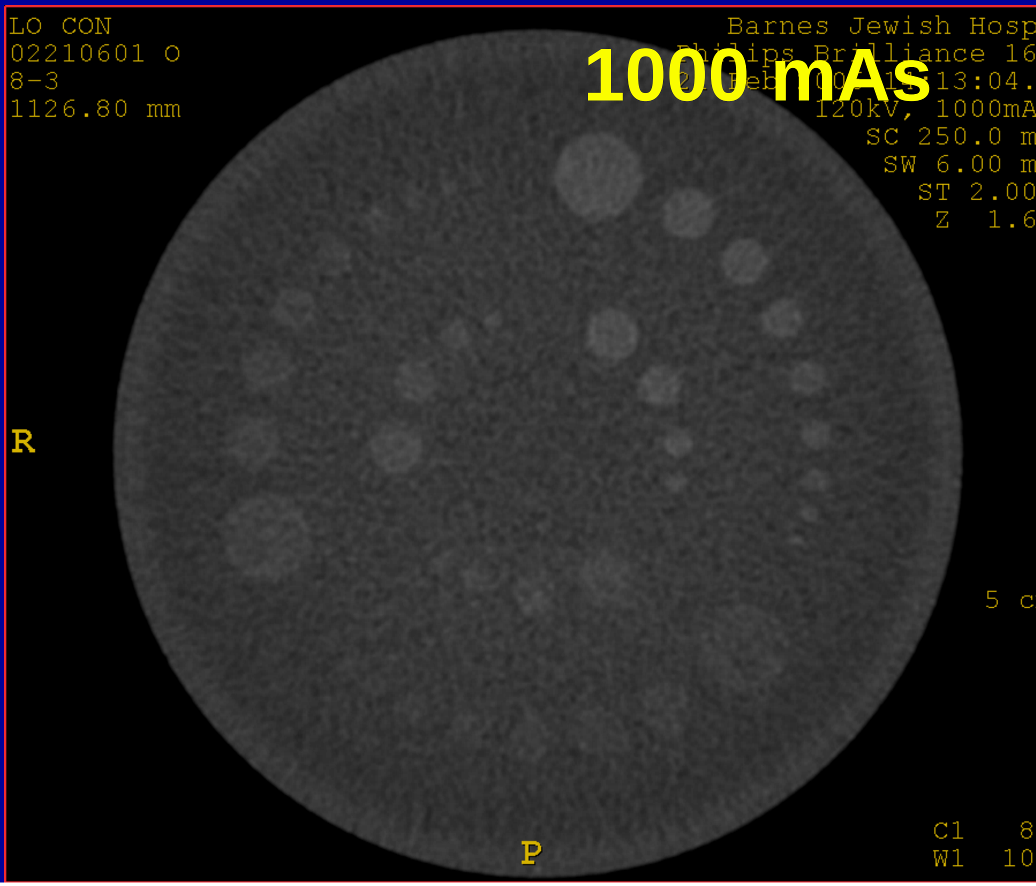
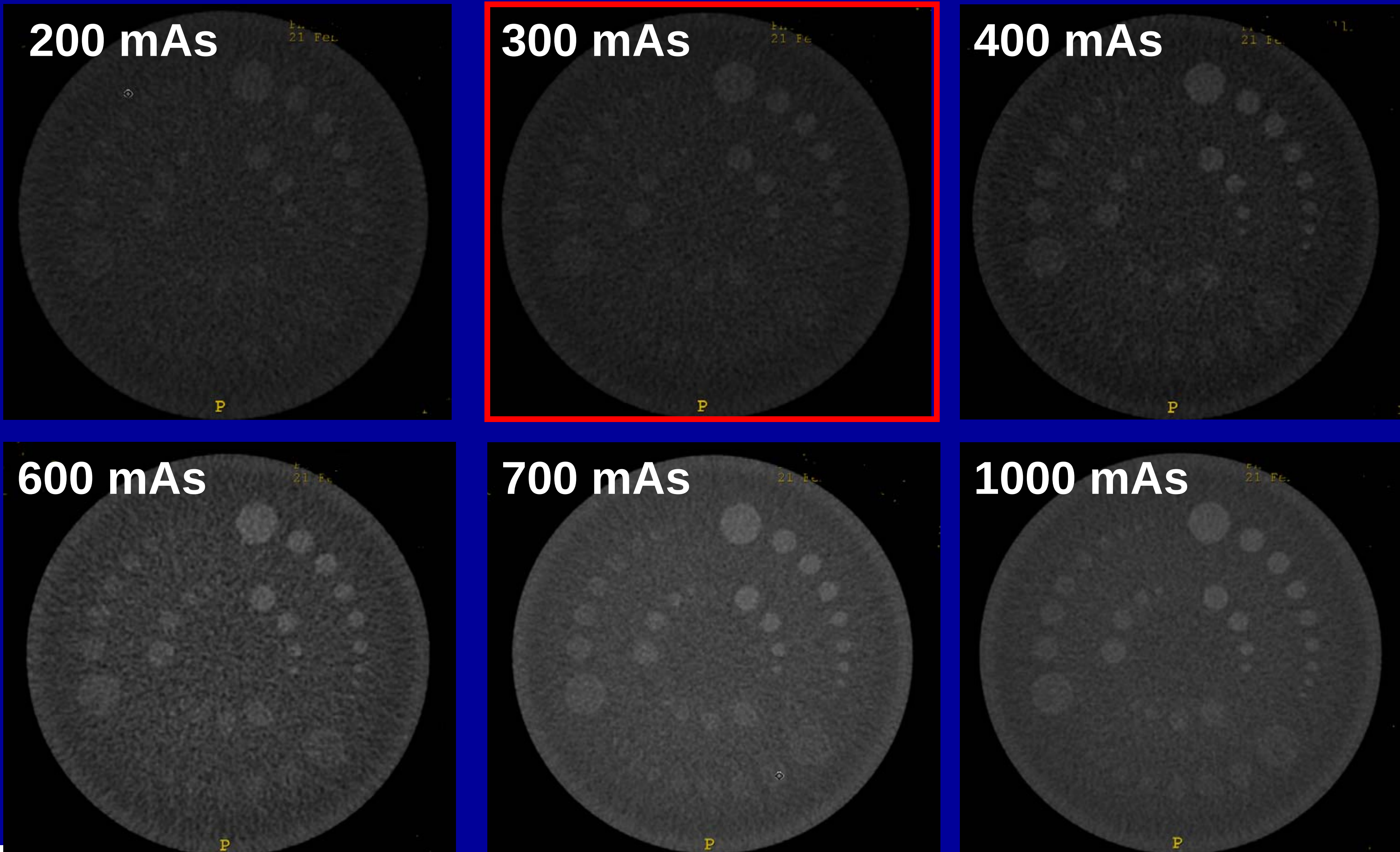
Contrast Resolution

- A measure of a scanners sensitivity, or the ability to discriminate small changes in density
- Soft tissue contrast
- Affects ability to contour structures







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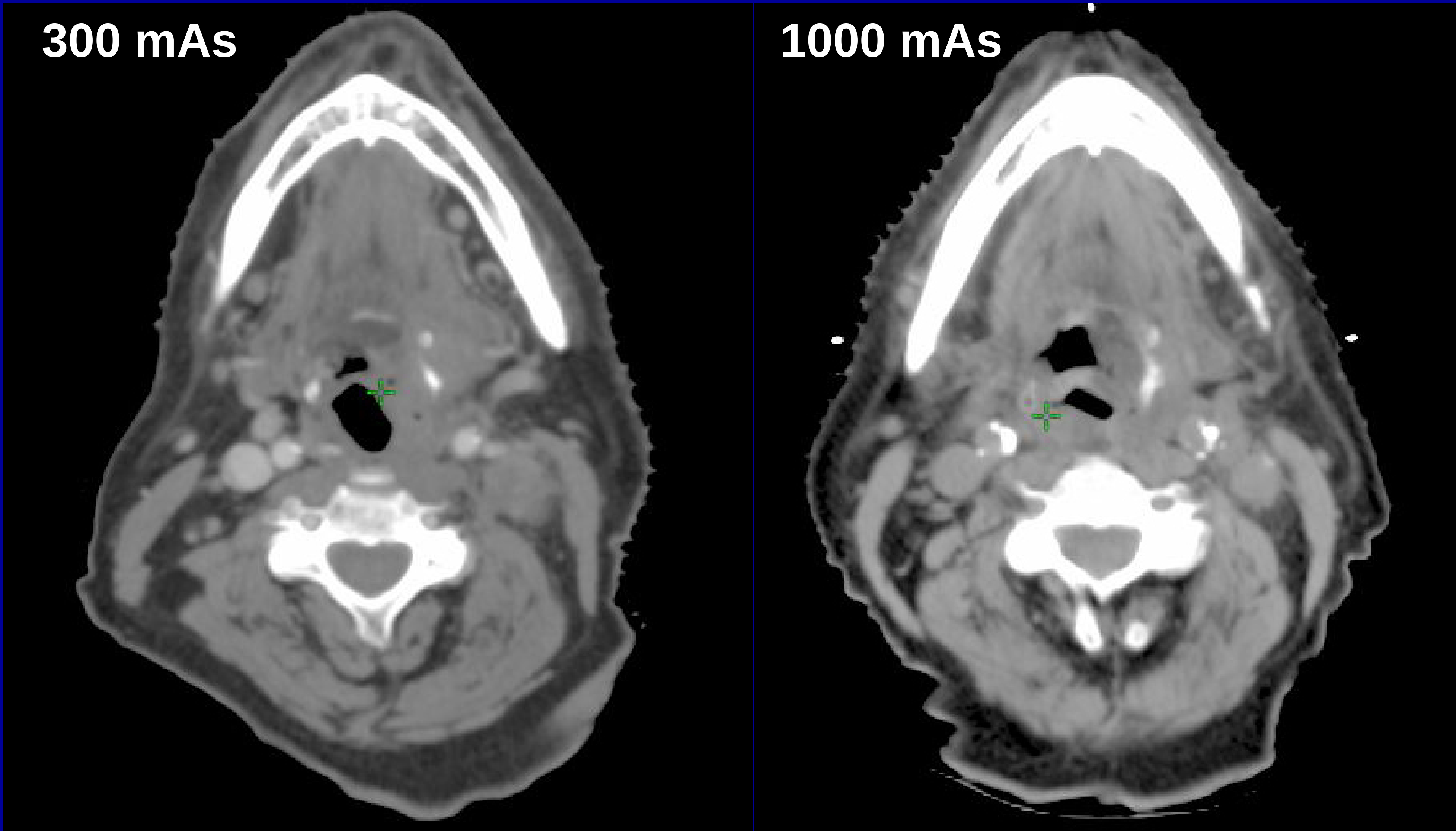

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Spatial Resolution

- Rows and columns form a matrix.
  - 512x512
  - 768x768
  - 1024x1024

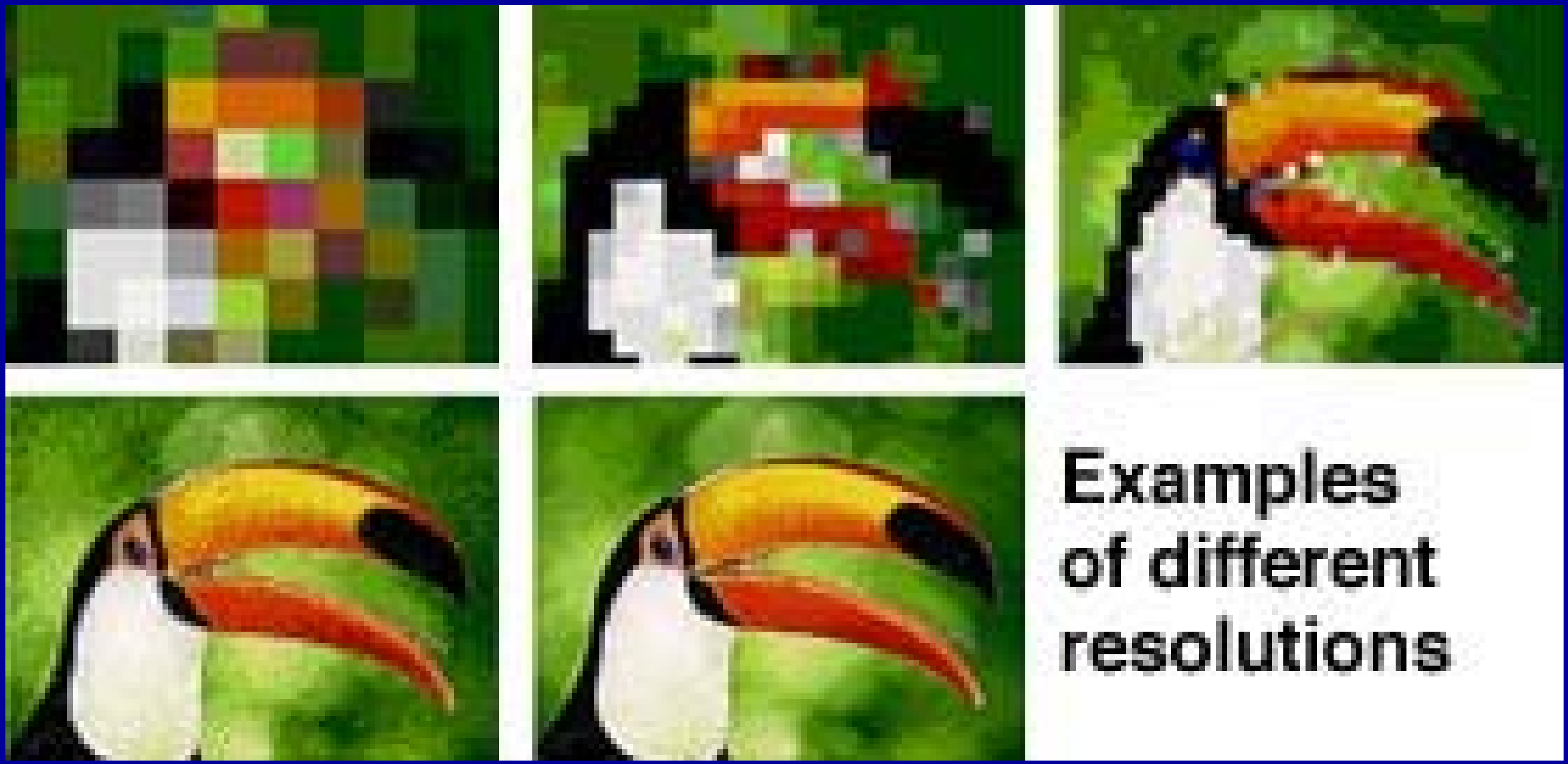

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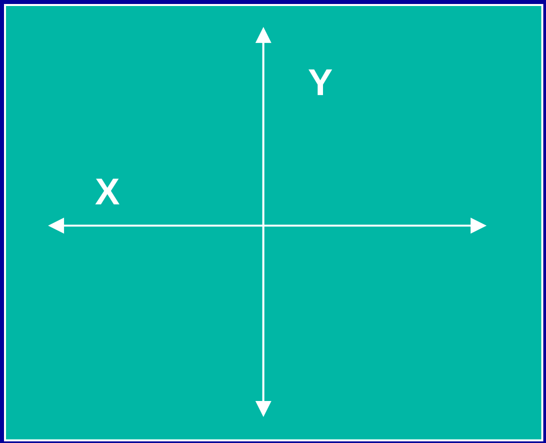
Image Reconstruction

- Pixel:
  - Picture element representing both the density and area of a small portion of the image.
  - Size is very important!
  - Pixel size = Field of View (FOC) divided by the display matrix.
  - 480/512 = 0.94 mm
  - 300/512 = 0.59 mm
  - 480/1024 = 0.47 mm
  - 300/1024 = 0.29 mm



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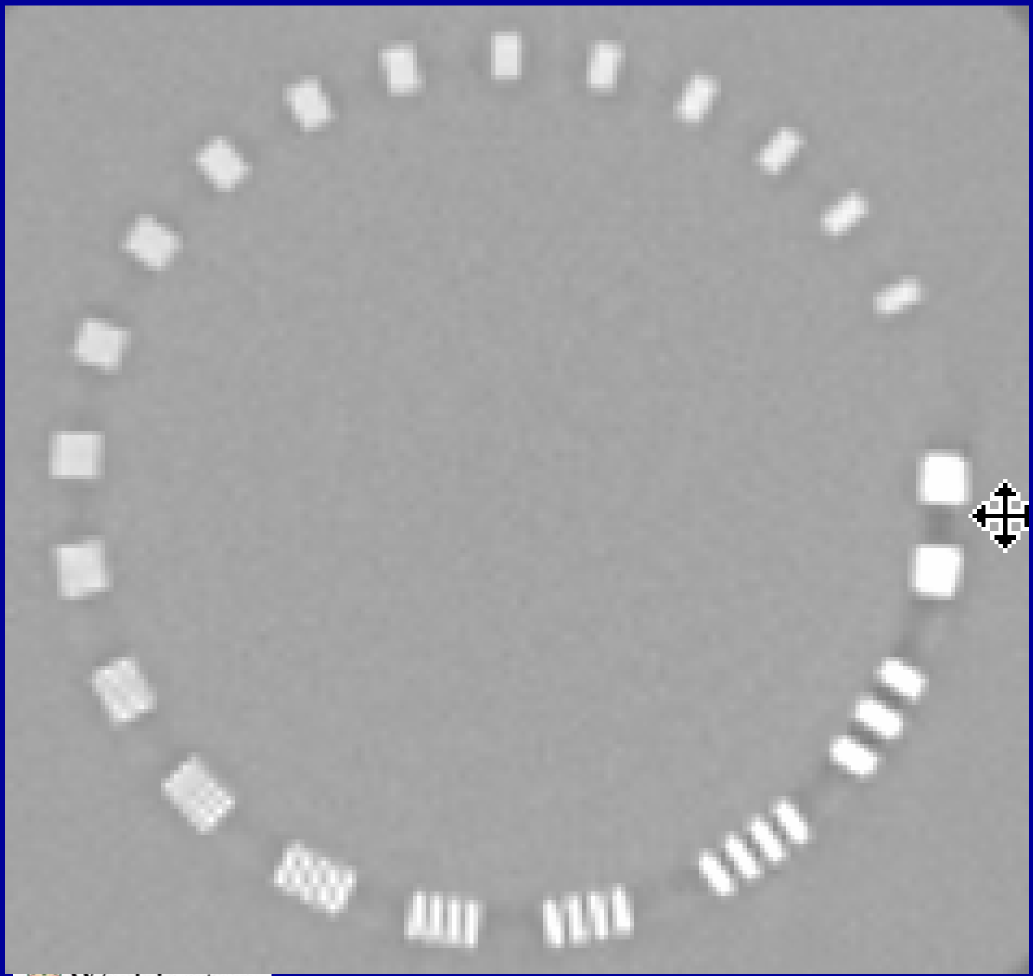
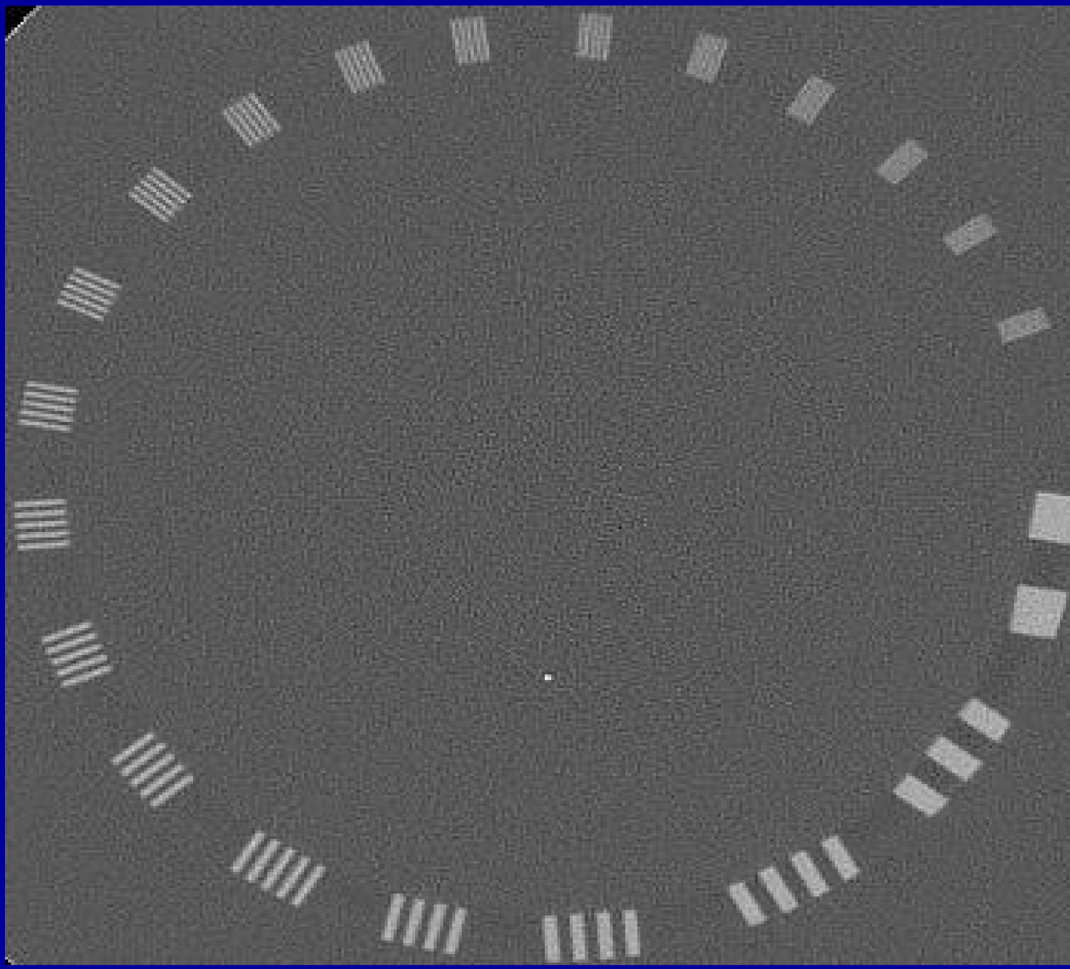
Resolution

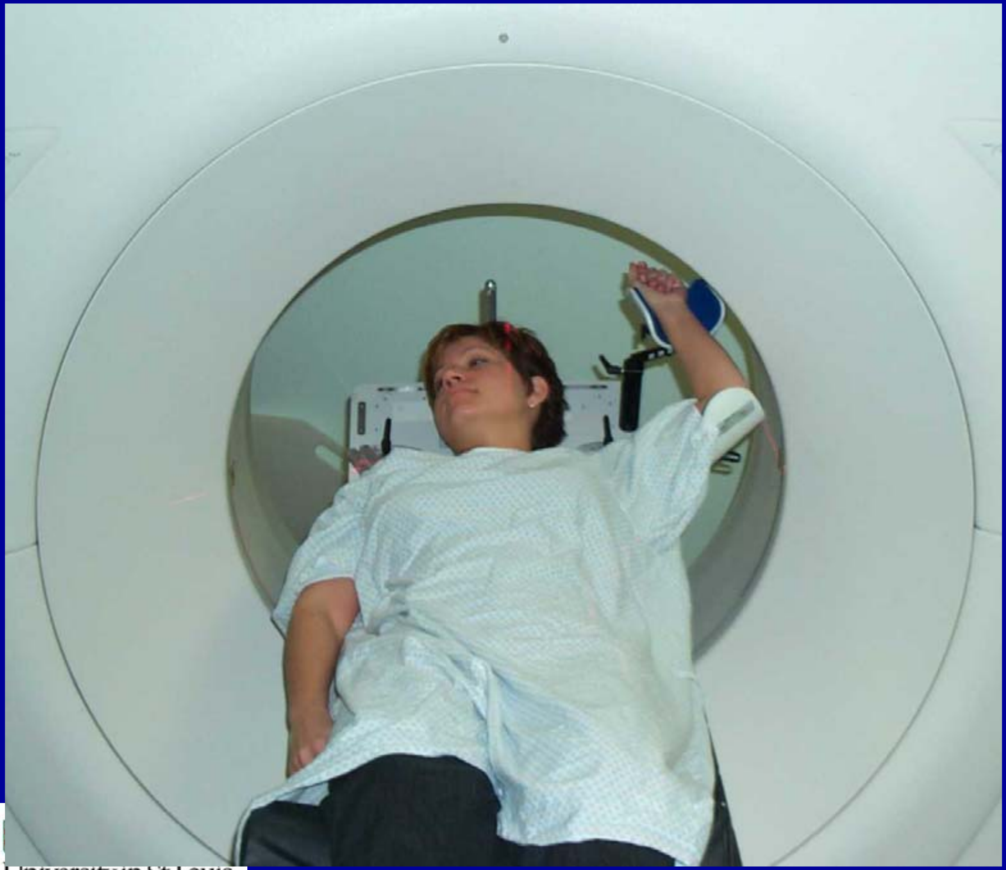




Low resolution **High resolution**

CT scanner – Bore size

85 cm Bore Opening



70 cm Bore Opening

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CT scanner – Bore size

Patient Size

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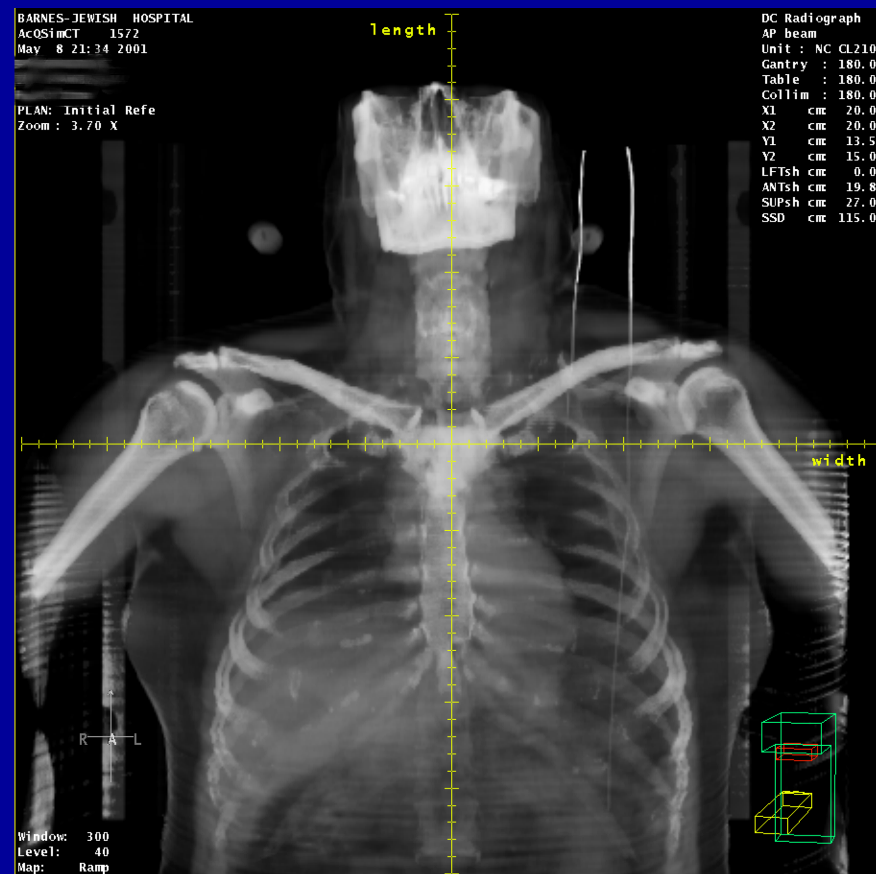
CT scanner – Bore size

Mantle Field



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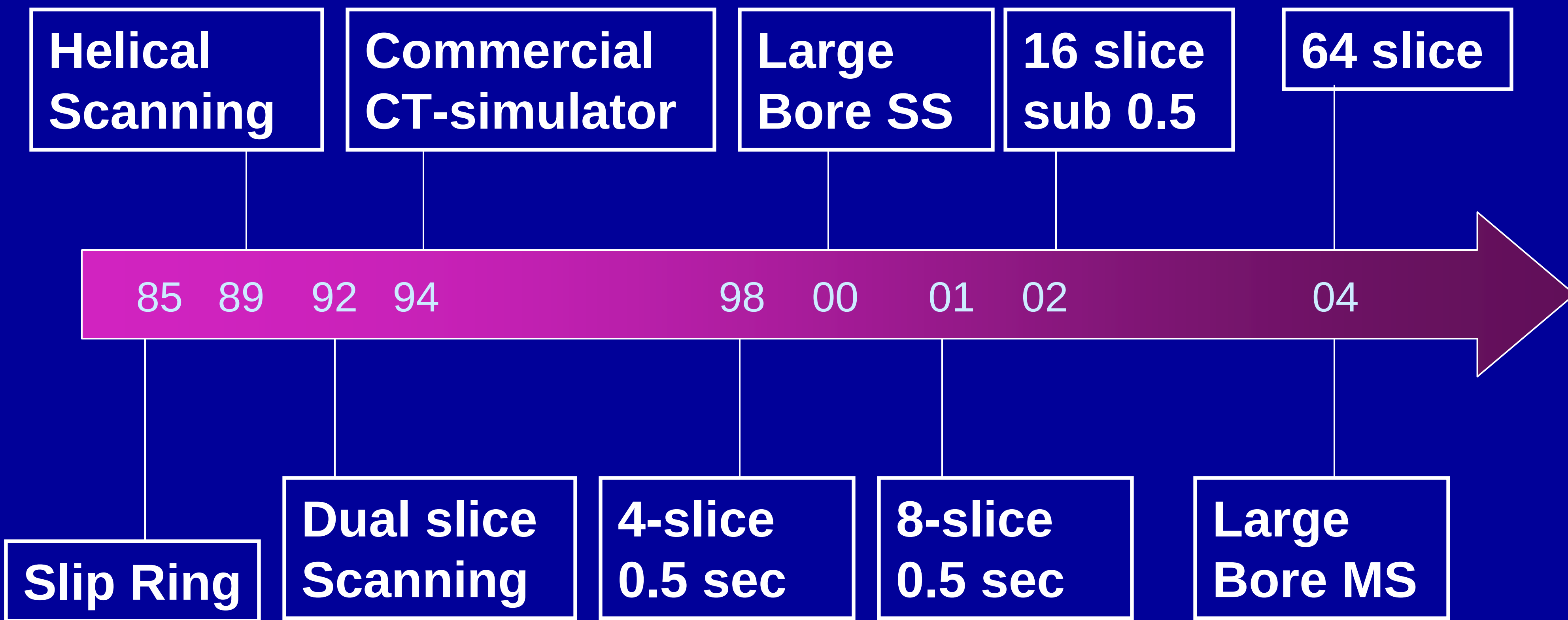
CT Time Line


Helical Scanning
Commercial CT-simulator
Large Bore SS
16 slice sub 0.5
64 slice
85 89 92 94 98 00 01 02 04
Slip Ring
Dual slice Scanning
4-slice 0.5 sec
8-slice 0.5 sec
Large Bore MS

Paradigm Shift

- CT scanners used to be made for diagnostic radiology and then modified for radiotherapy
- There are new CT scanners that were specifically designed for radiotherapy
- Or they have special features that are designed for radiotherapy

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CT Scanner Selection

- Small Bore vs. Large Bore
  - Patient population
  - Conventional simulator availability
  - The question will (has) become:
    - » How large? (80, 82, or 85 cm)
- Single Slice vs. Multi Slice
  - DRR quality
  - Image quality
  - 4D CT
  - The question will (has) become:
    - » How many? (2, 4, 6, 10, 16, 40, … cone beam)

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Commissioning and QA

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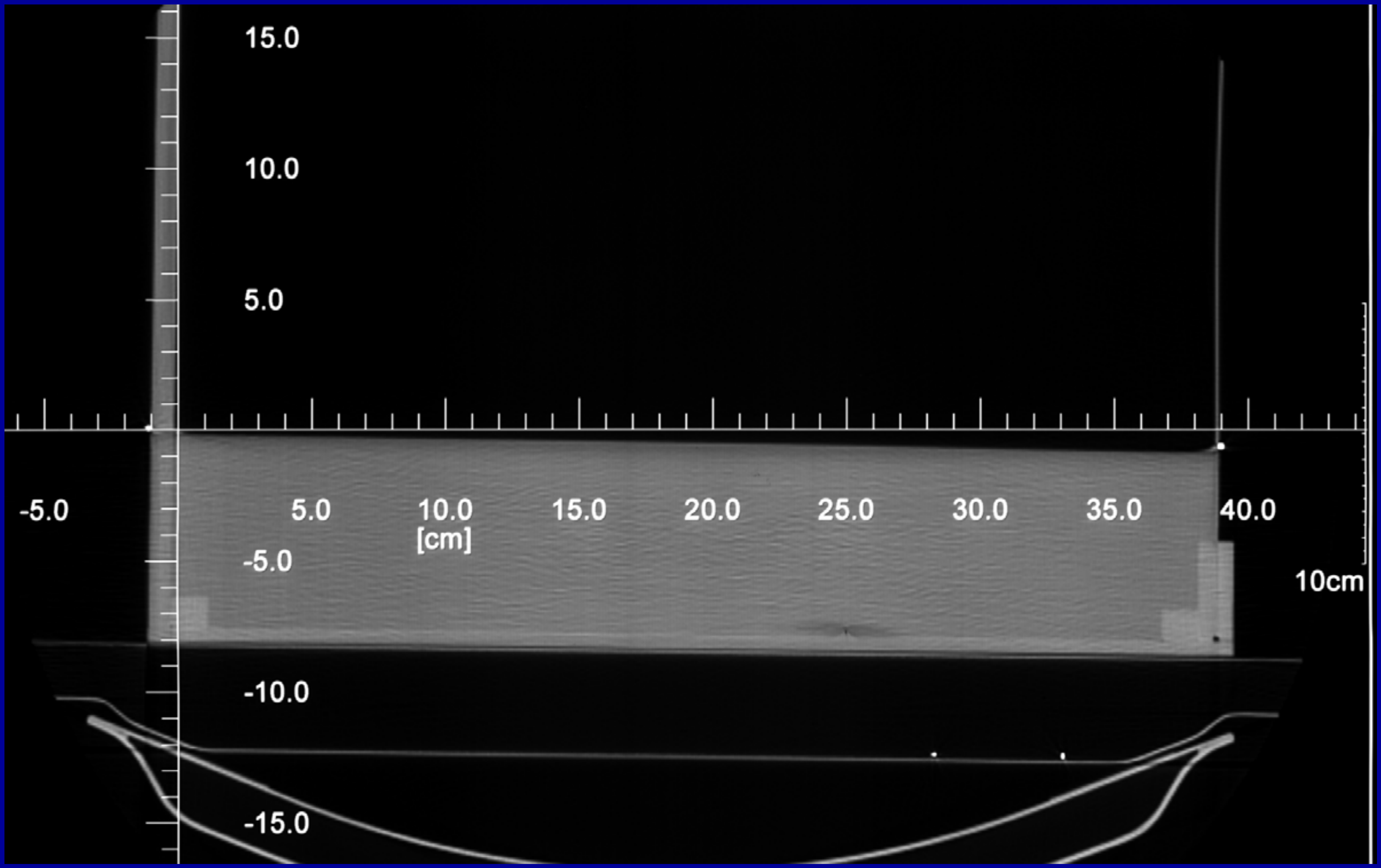
Geometric Accuracy



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Tasks

- Radiation and patient safety
- CT dosimetry
- Evaluation of electromechanical components
- Evaluation of image quality

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Radiation and Patient safety

- **Patient Safety**
  - Interlocks
  - Electromechanical
  - Door Interlock
  - CTDI
    - » Definition
    - » Multislice CT

- **Radiation Safety**
  - Workload – potential pitfall
    - » Significant increase
    - » Shielding design
    - » NCRP 147
    - » Radiation survey

$$X = 60^{-1} \cdot \dot{X} \cdot W \cdot T$$

$$W = N_{CT} \cdot mA_{CT} \cdot t_{CT} + N_{4D} \cdot mA_{4D} \cdot t_{4D}$$

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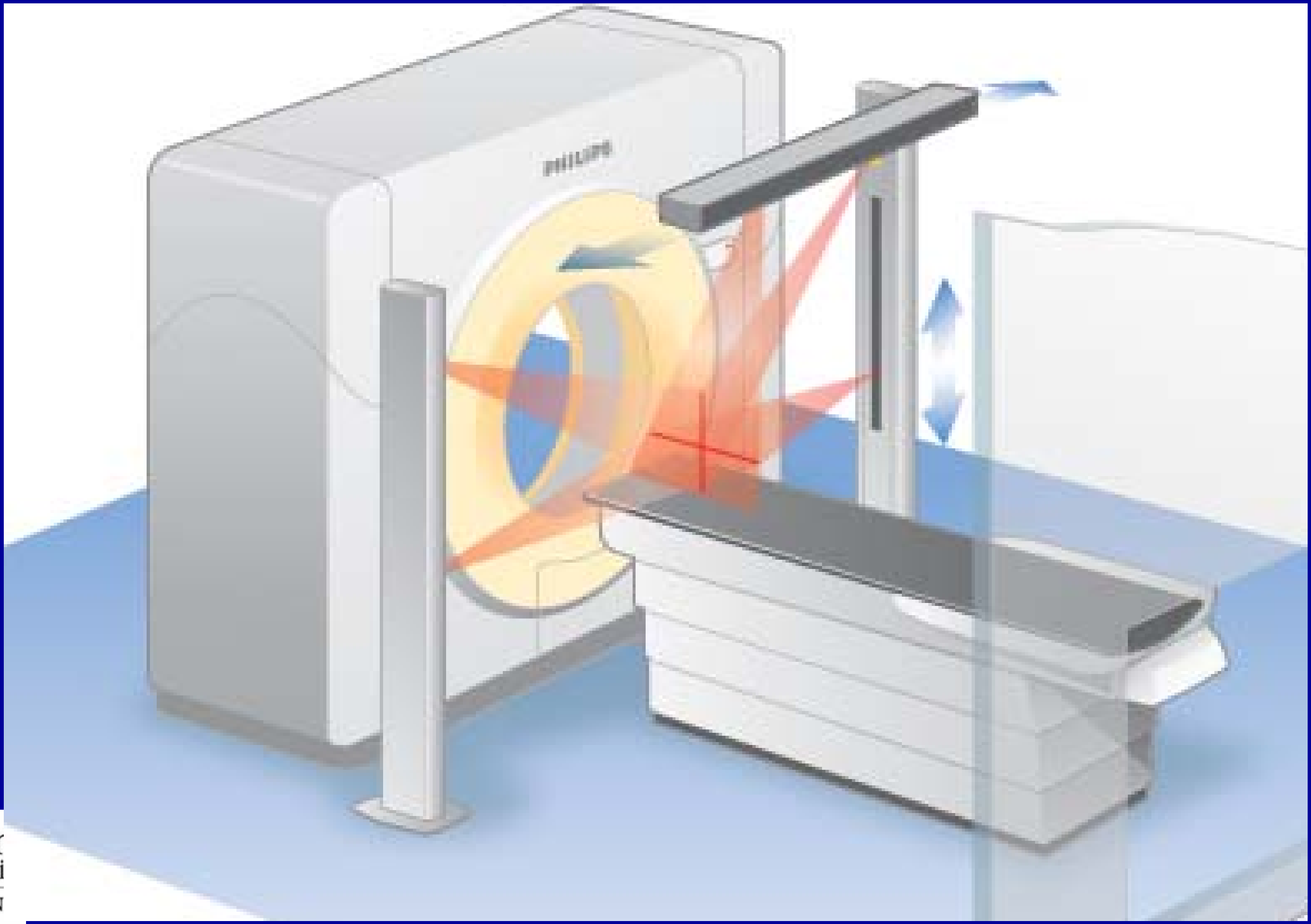
Electromechanical Components

- X-ray Generator
- Gantry Alignment
- Table Alignment/Accuracy
- Laser Alignment/Accuracy

Electromechanical Components x-ray Generator

- Need a non-invasive meter
  - kV accuracy
  - Timer accuracy
  - mA linearity
  - HVL measurements

CT Simulator Mechanical Alignemnt



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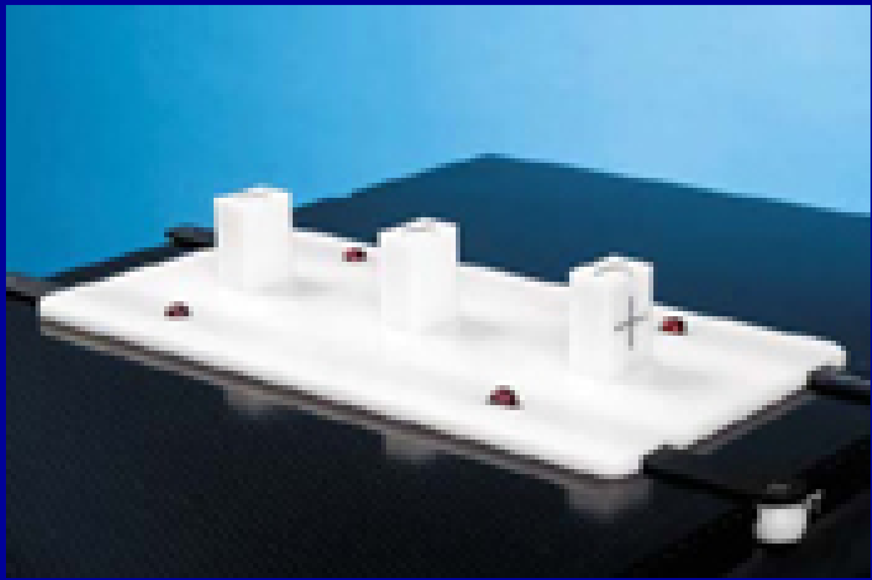
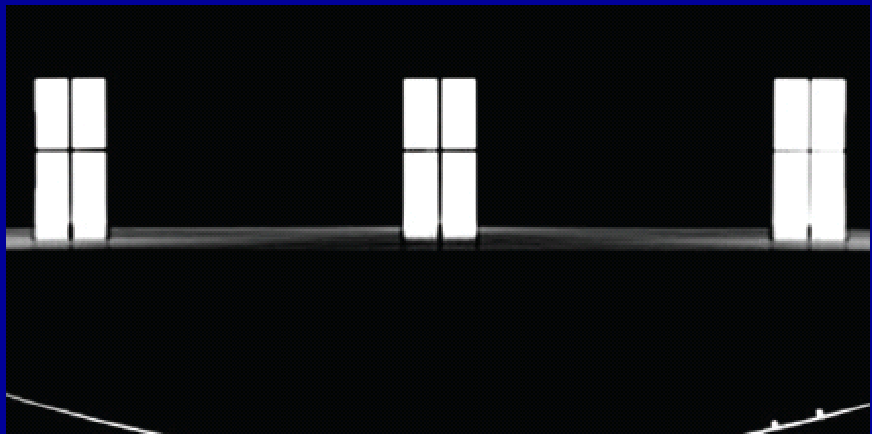
Electromechanical Components
Gantry Alignment/Accuracy

- **Gantry tilt accuracy**
- **Gantry vertical**
  - **Imaging plane orthogonal to the couch top**
- **Gantry vertical placement reproducibility**
  - **Especially important for dual purpose scanners**





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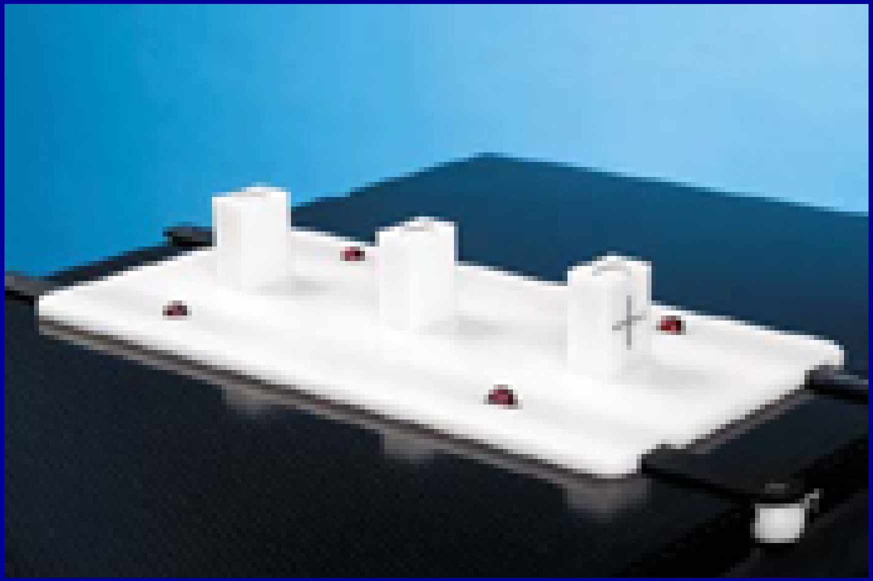
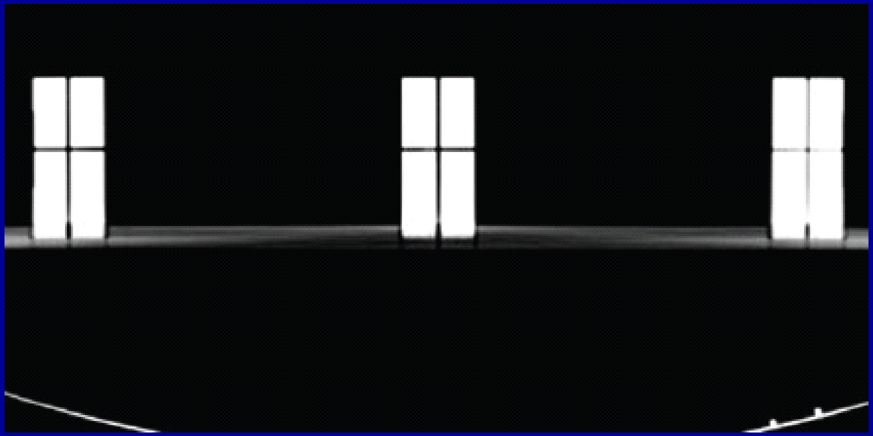
Electromechanical Components
Table Alignment/Accuracy

- Tested with weight
  - Settle
  - Sag
- Tabletop motion orthogonal/parallel with the imaging plane
- Table positional accuracy/reproducibility
  - Vertical
  - Longitudinal





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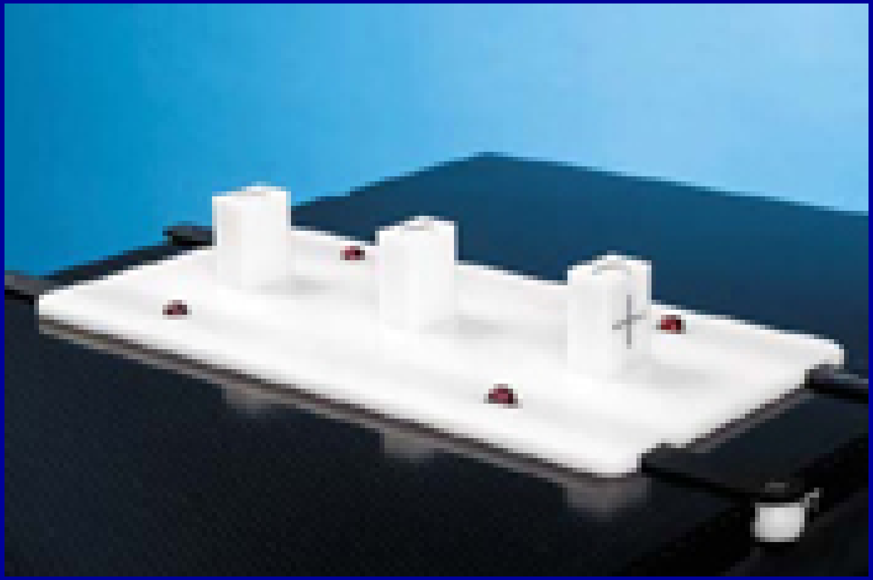
Electromechanical Components
Laser Alignment/Accuracy

- Lasers orthogonal/parallel with the imaging plane
- Lasers spacing
- Laser positional accuracy
  - Absolute
  - Linearity
  - Reproducibility
- Coordinate system orientation



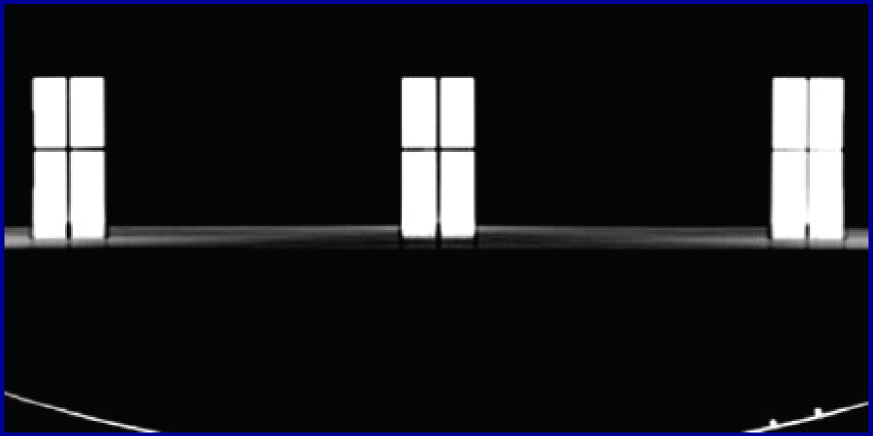


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Image Quality Indicators

- **Quantitative**
  - Phantom Measurements
    - » High Contrast
    - » Low Contrast
    - » Uniformity
    - » Spatial Integrity
    - » Artifacts
    - » Slice thickness
    - » CT # accuracy
- **Qualitative**
  - Physician Preferences
    - » Tumor
    - » Normal Structures
    - » DRR/DCR Objects
    - » Workflow
    - » Customized protocols

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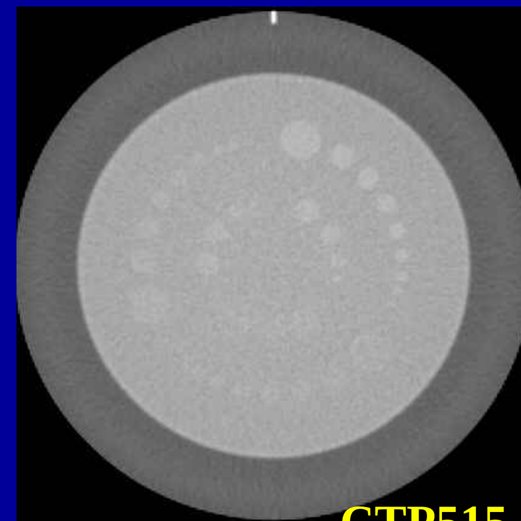
Image Performance

Catphan 500

CTP401



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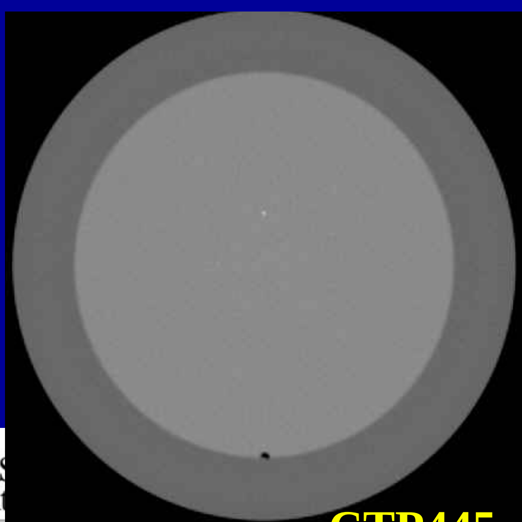
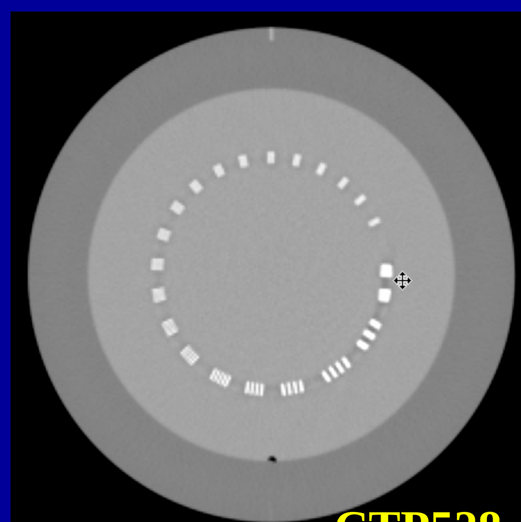
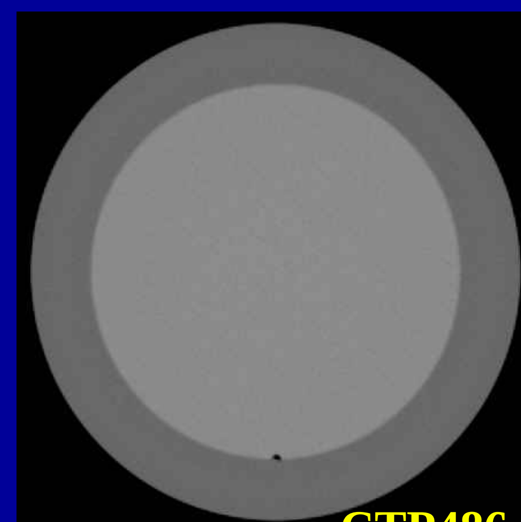


CTP445



CTP528



CTP486

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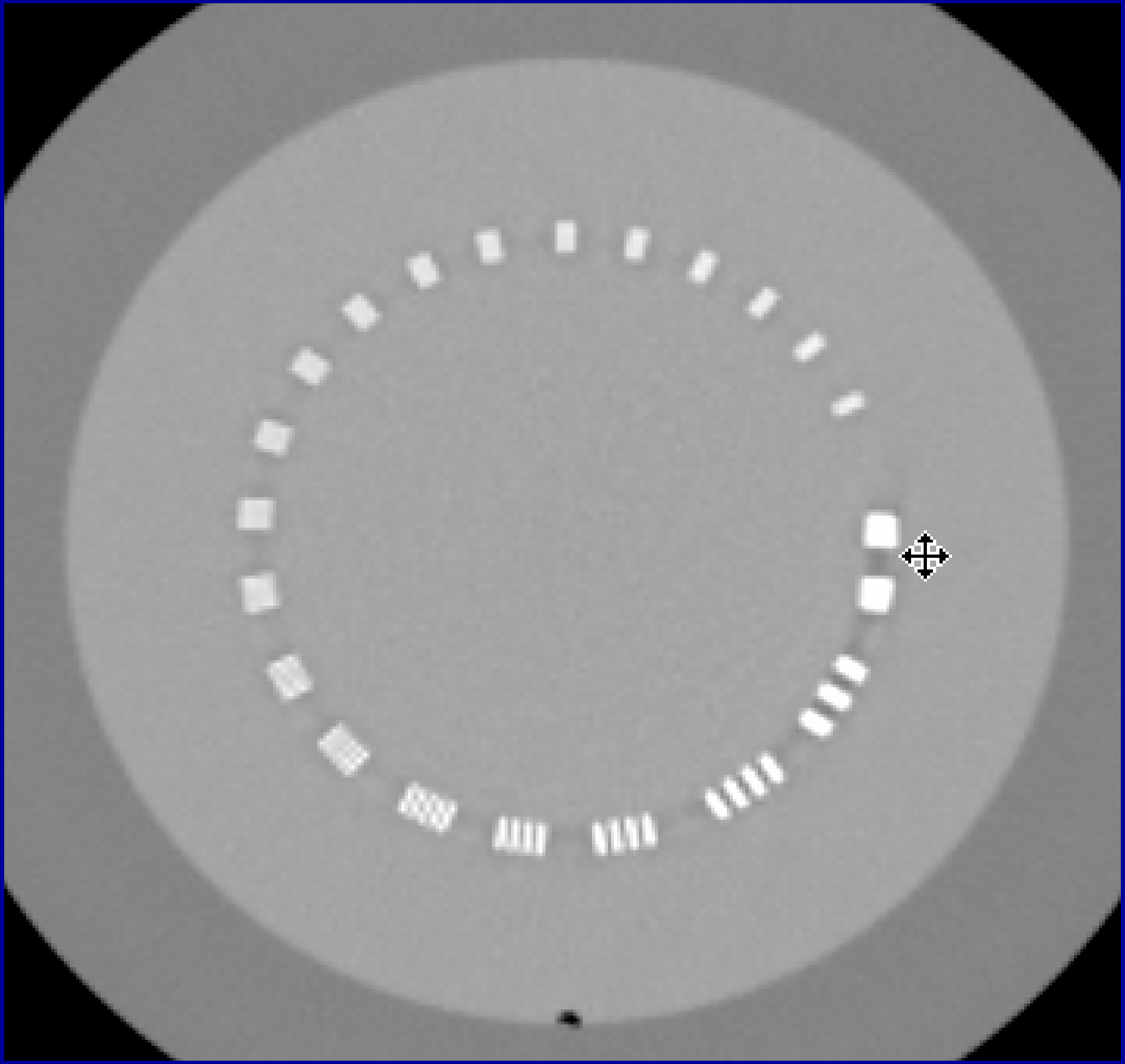
Resolution (High Contrast)

- **Ability of the system to record separate images of small objects that are placed very close together**



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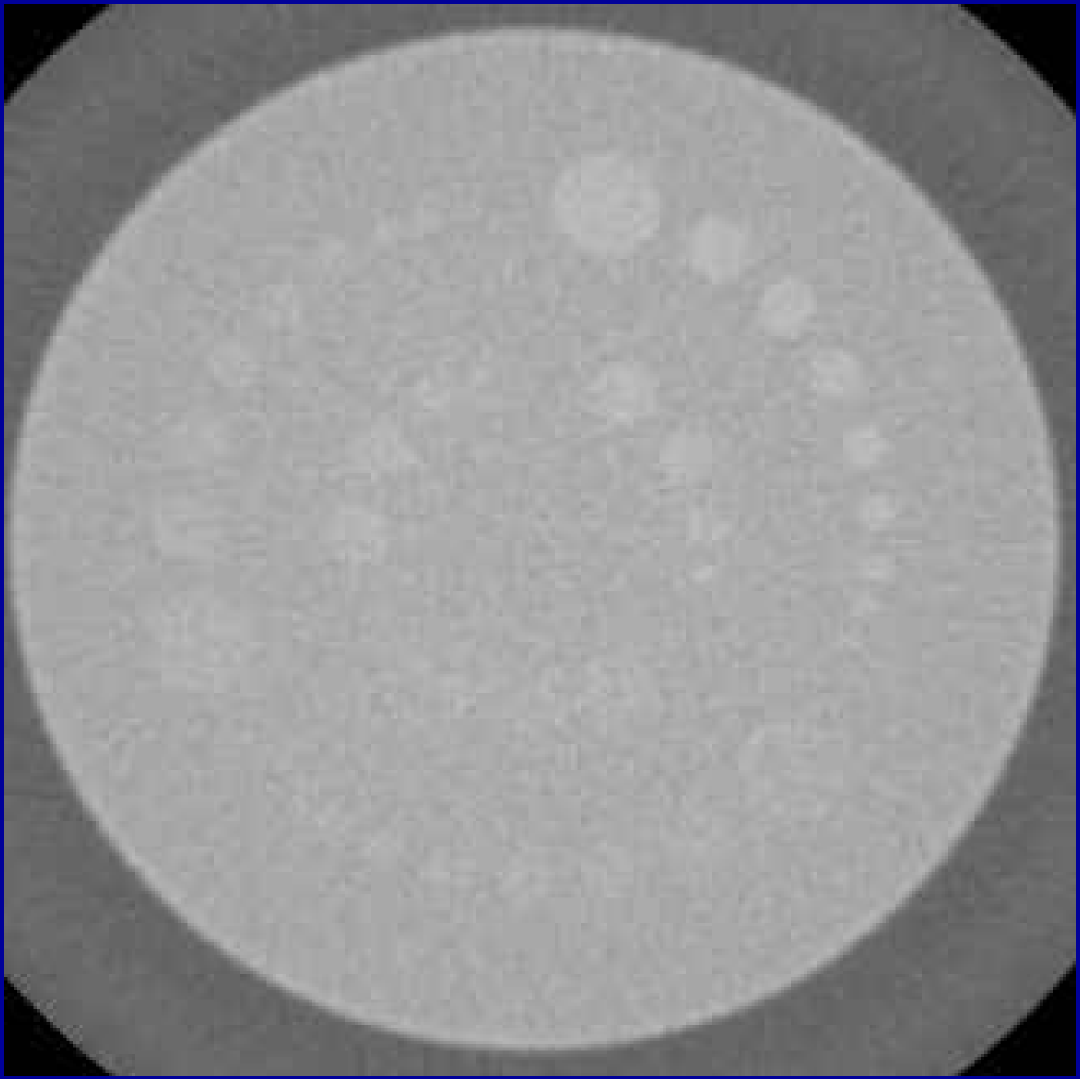
Subject Contrast (Low Contrast)

- Ability of a system to resolve adjacent objects with small density differences
- Noise limited



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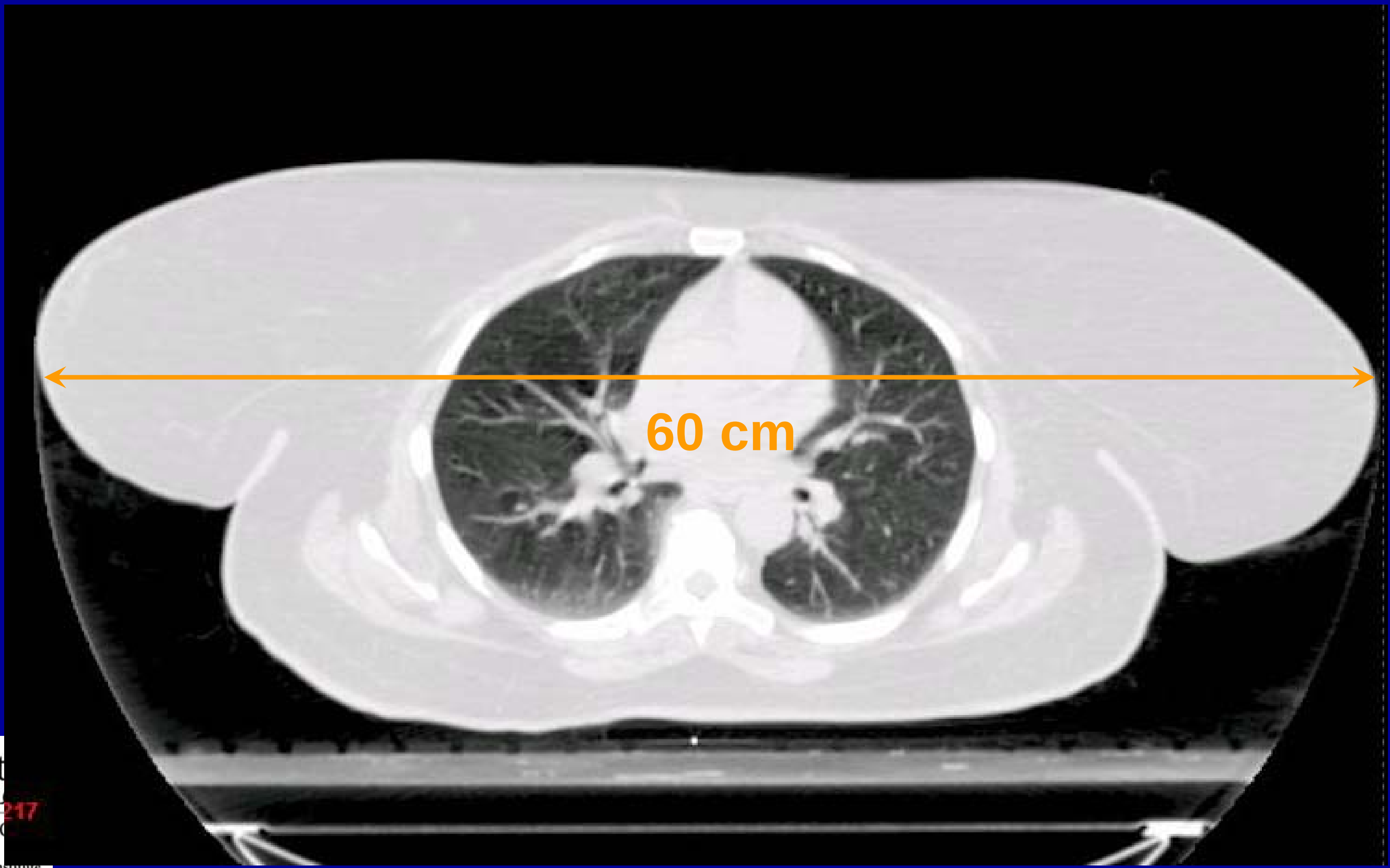
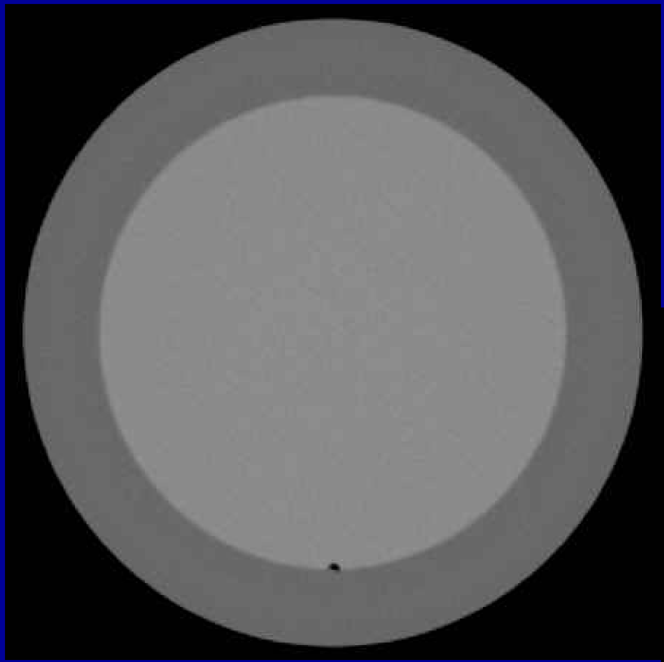
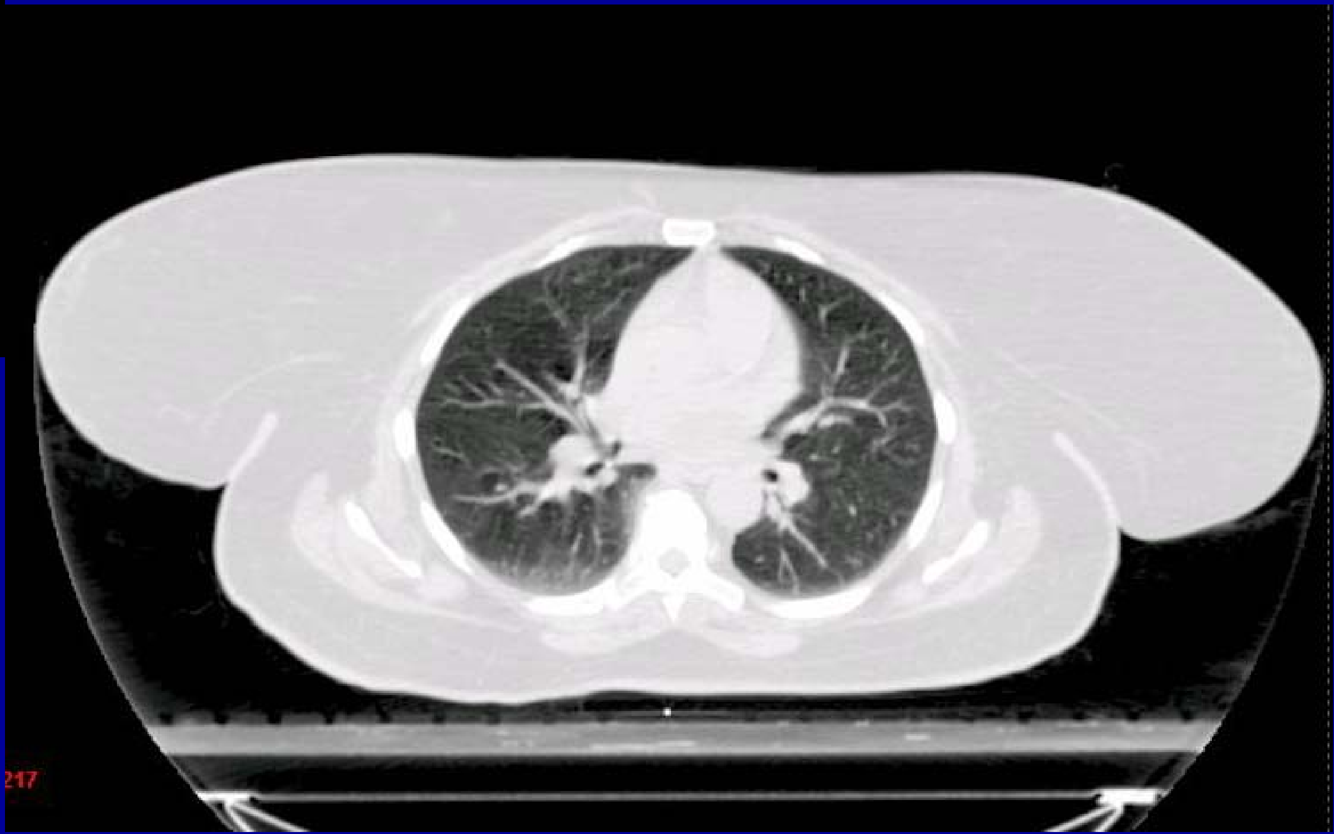
Field of View (FOV)



Uniformity





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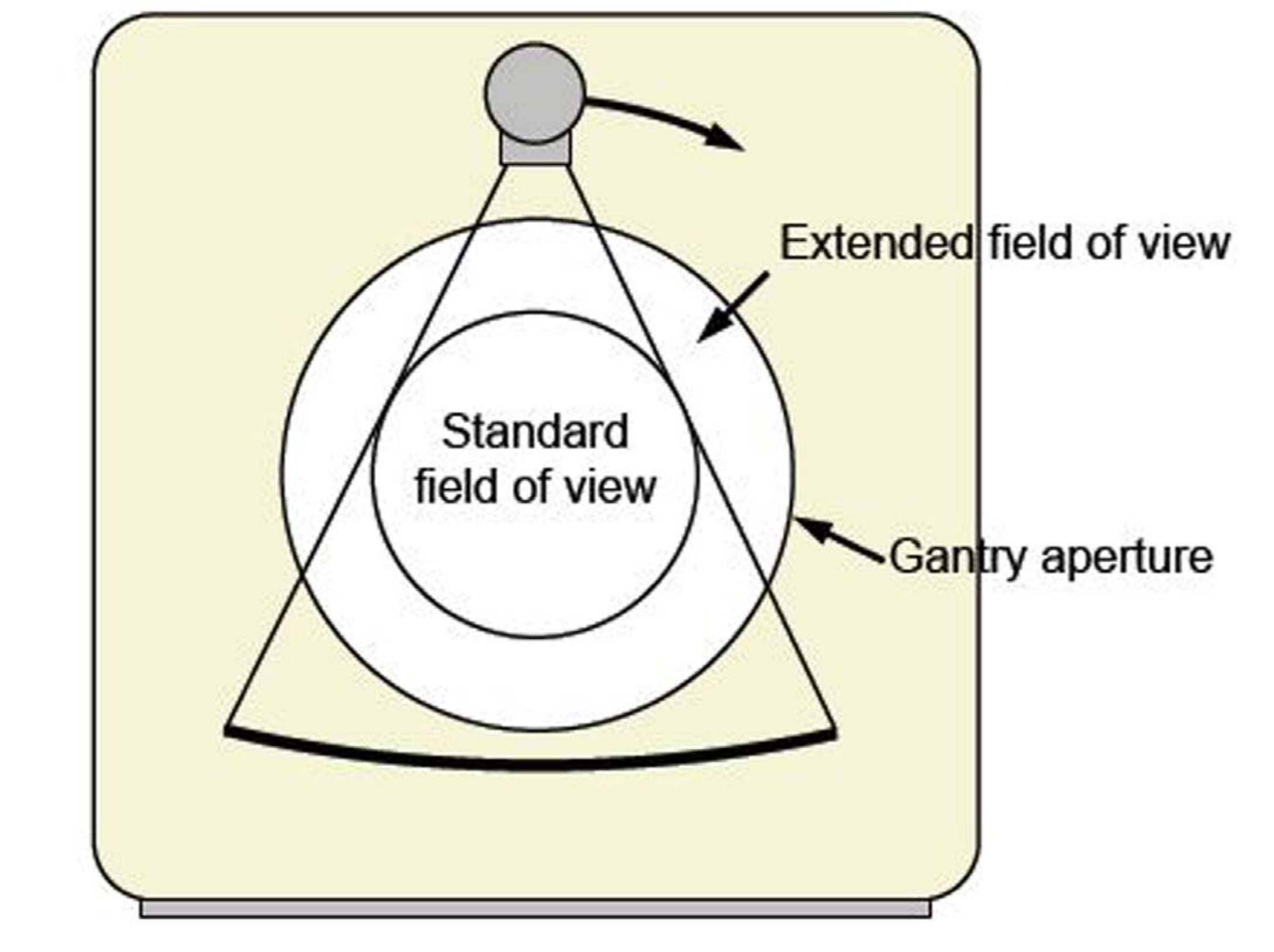
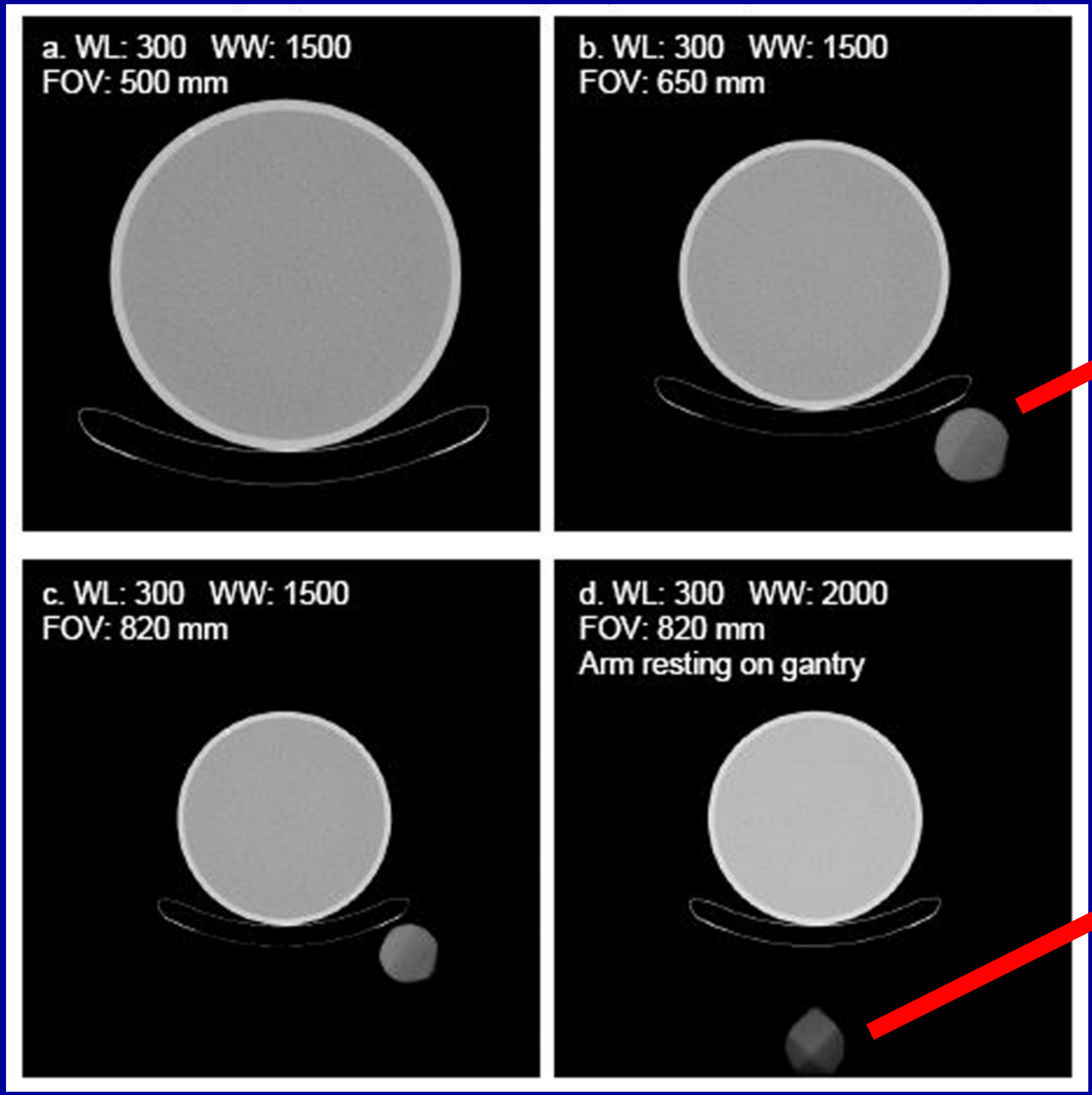
True vs. Extrapolated FOV



From impactscan.org report 05071

Evaluation of Extrapolated FOV



From impactscan.org report 05071

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Image Performance Evaluation

Performance Parameter	Tolerance Limits
CT number accuracy	For water, 0 ± 5 HU
Image noise	Manufacturer specifications
In plane spatial integrity	±1 mm
Field uniformity	within ±5 HU
Electron density to CT number conversion	Consistent test phantom manufacturer specifications
Spatial resolution	Manufacturer specifications
Contrast resolution	Manufacturer specifications

Evaluation of CT Simulation Software

- What is CT-simulation Software
- Image input verification (data transfer)
  - Orientation
  - Spatial accuracy
- Structure delineation
- Isocenter calculation and movement
- Output parameters and connectivity

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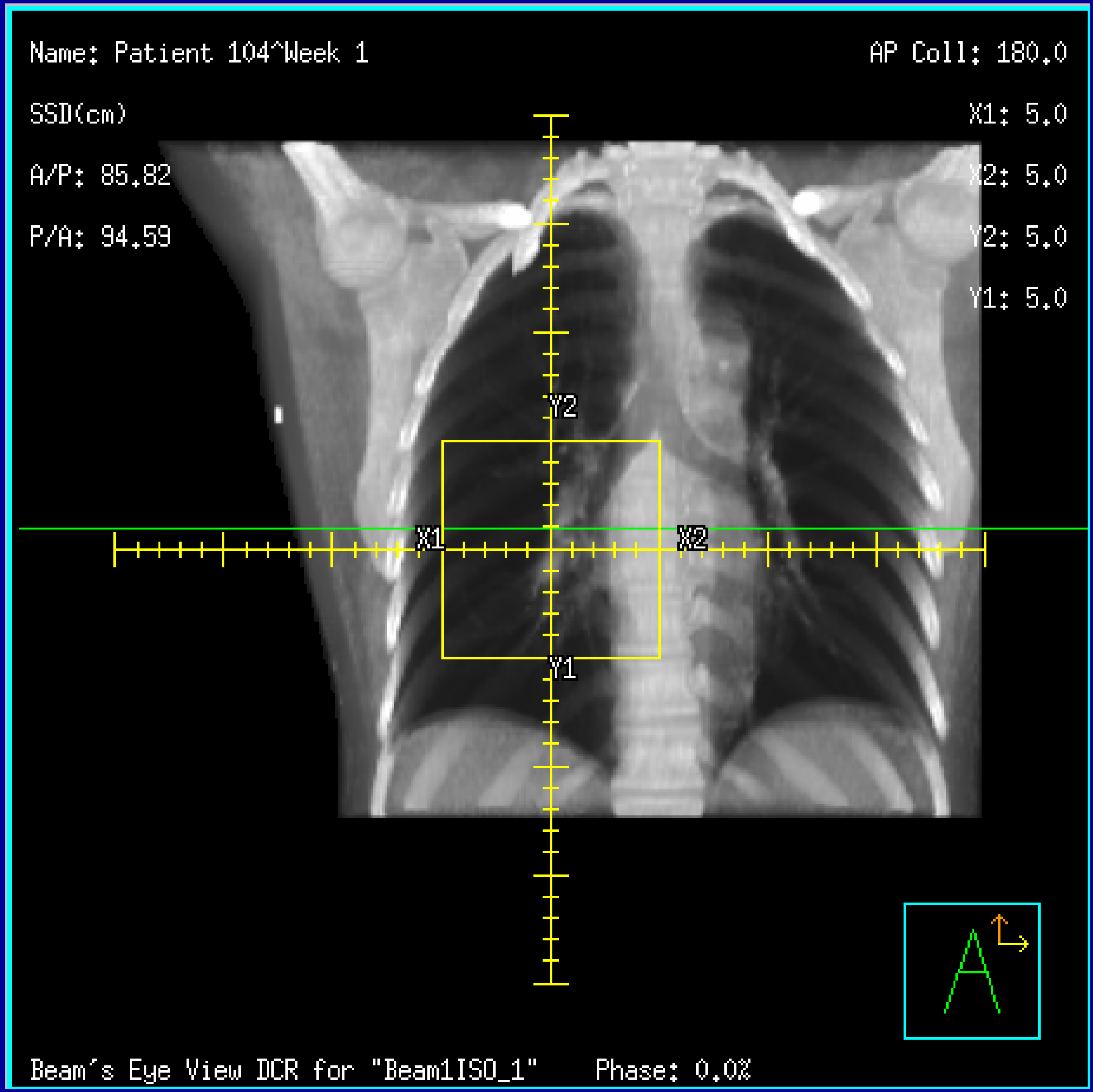
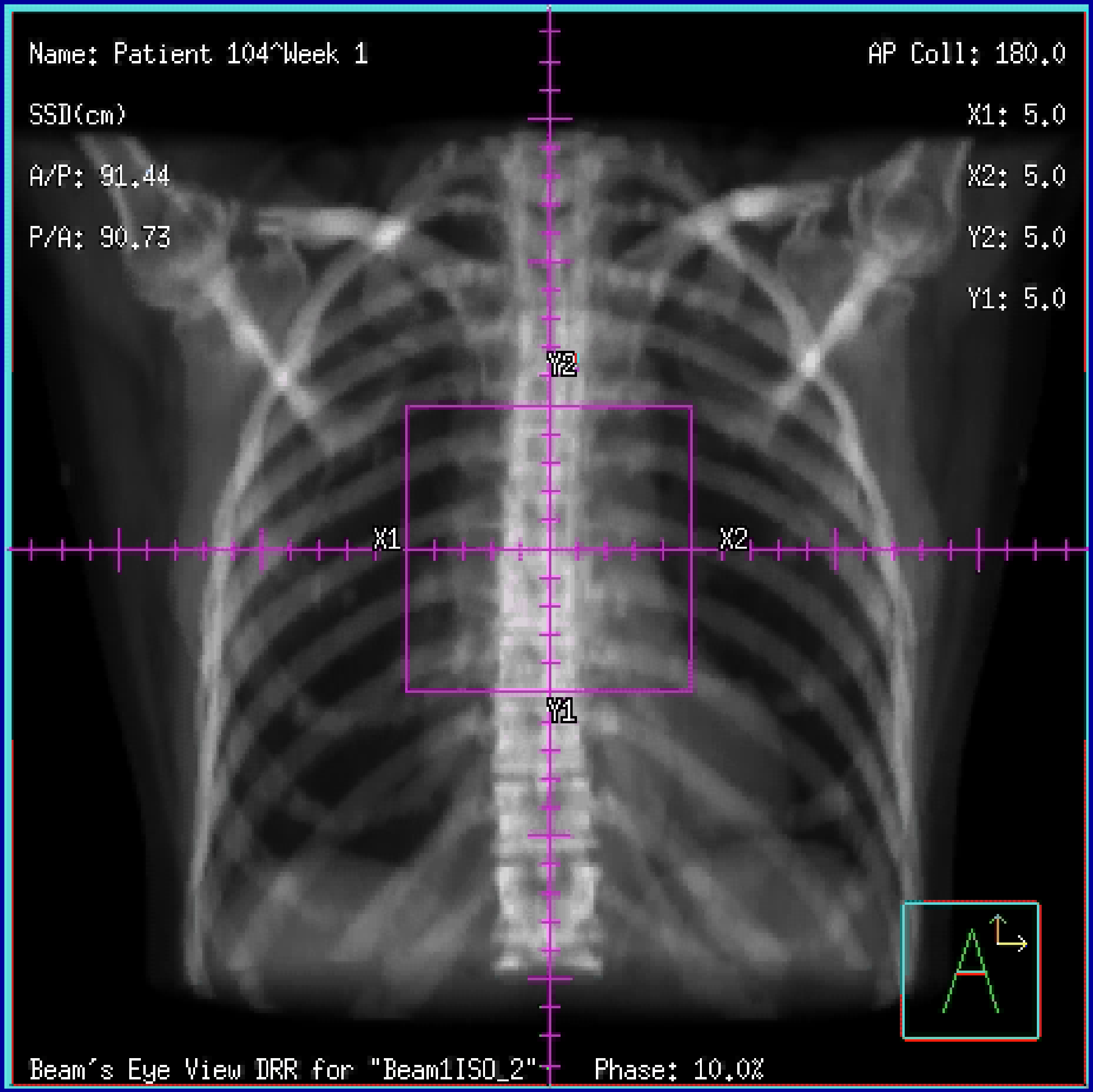
Dynamic DCRs



Dynamic DRR



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Conclusions

- CT will remain the primary imaging modality in radiotherapy
- CT simulator only departments
- Large bore multislice CT will become standard scanners for radiotherapy
- Existing documents (Report #39, tG66, TG53) are a good foundation
- New CT scanning capabilities/parameters can be evaluated with the existing recommendations

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