CT simulator

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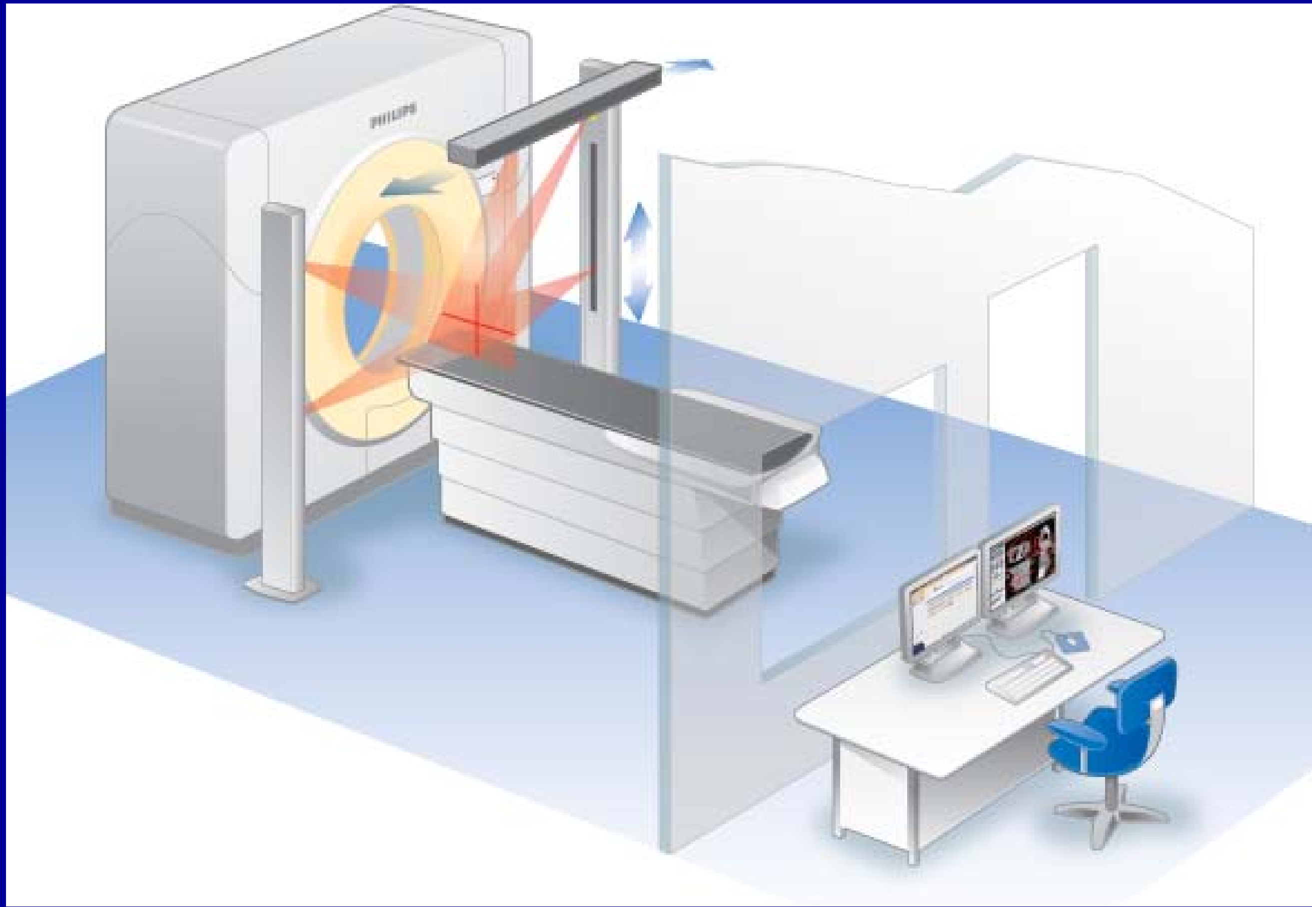
Outline

- What is a CT simulator?
- CT simulation process
- Functional performance characteristics of CT equipment
- QA of CT simulators
- QA for CT simulation software
- Evaluation of CT simulation process
- Conclusion

CT simulator

- CT scanner with flat table top
- Laser positioning and marking system (preferable with external lasers)
- Virtual simulation software
- Various hardcopy output devices



CT Simulation Process

- Varies from center to center
- 3 major categories:

1. CT-scan, patient positioning and immobilization
2. Treatment planning and CT-simulation
3. Treatment setup

CT Simulation Process

1. **CT-scan, patient positioning and immobilization**

- Scanner acquires volumetric scan of a patient, which represents a virtual or digital patient
- Scan is acquired with
  - the patient immobilized in treatment position
  - treatment specific scan protocols
  - often increased scan limits
  - use of contrast
  - placement of localization marks on the patient skin

CT Simulation Process

2. Treatment planning and CT-simulation

- The virtual simulation software provides virtual representations of the geometric capabilities of a treatment machine
- It also allows import, manipulation, display, and storage of images from CT and/or other imaging modalities

CT Simulation Process

2. Treatment planning and CT-simulation

- Beam placement and treatment design is performed using virtual simulation software
  - Contouring of target and OAR using information obtained from different imaging modalities
  - Treatment isocenter placement
    - » can be a final isocenter marked (needs physician presence)
    - » a reference point marked (does not need physician's presence)
    - » localization marks are placed on the patient's skin
  - Placement of the beams, design of treatment portals and communication of information to TPS
  - Printing of DRRs and patient setup instruction

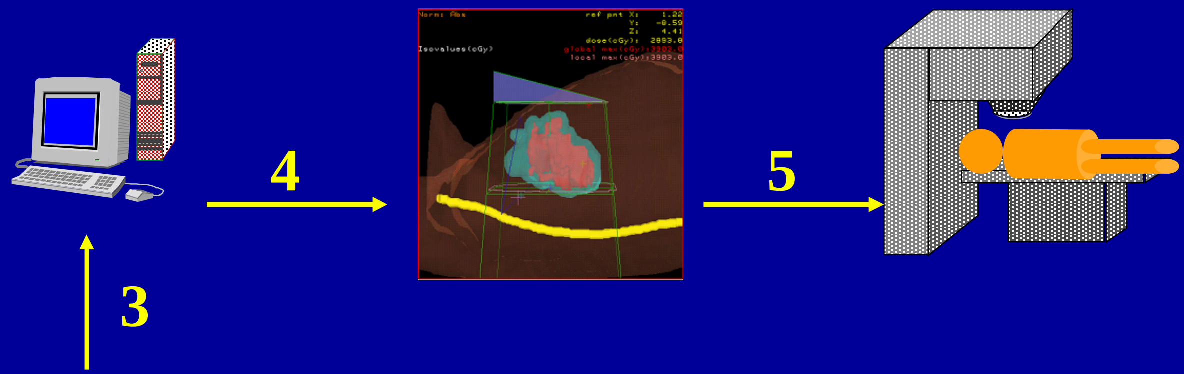
CT Simulation Process

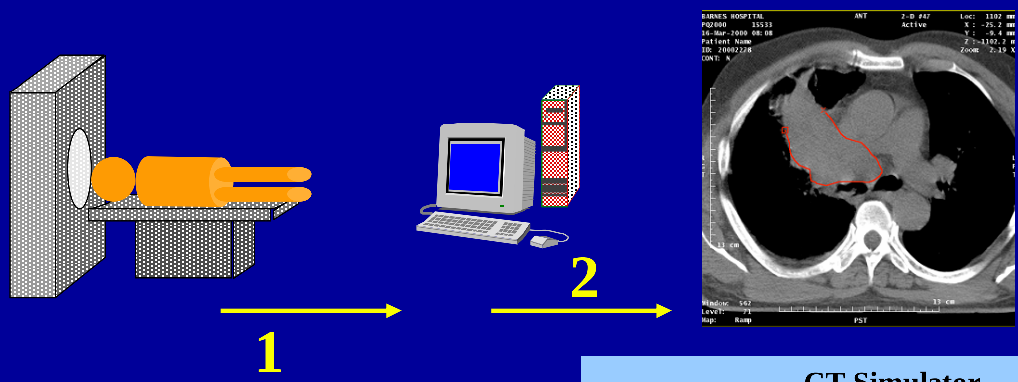
3. Treatment setup

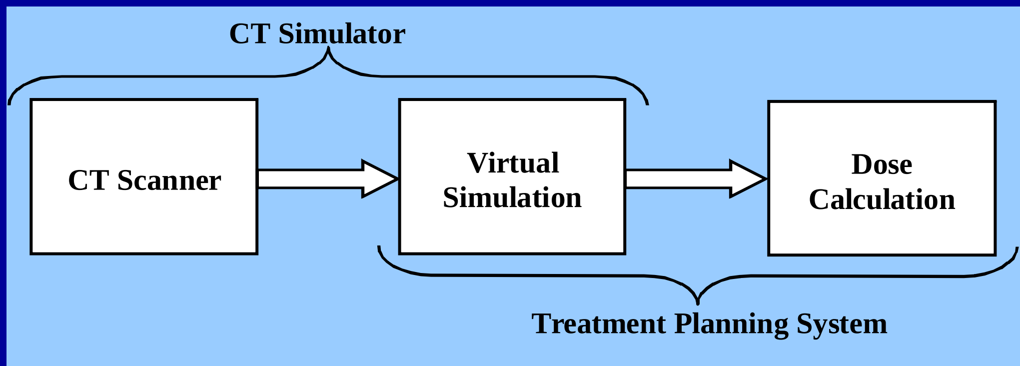
- Patient is setup on the treatment machine according to instructions created from the CT-sim software
- Port films are acquired and compared with CT-sim DRRs

CT simulation process

CT simulation includes the CT scanner and components of treatment planning system and provides input for dose calculation







Functional performance characteristics of CT equipment

A. CT scanner and virtual simulation system

- X-ray tube
  - » Large no of images and rapid data acquisition time requires the tube to withstand high heat and dissipate heat quickly
- Collimator and attenuator
  - » pre-patient collimator used to produce a narrow beam
  - » Post-patient collimator used to reduce scatter to detector
- Patient support table
  - » Must have a flat table top

Functional performance characteristics of CT equipment

A. CT scanner and virtual simulation system

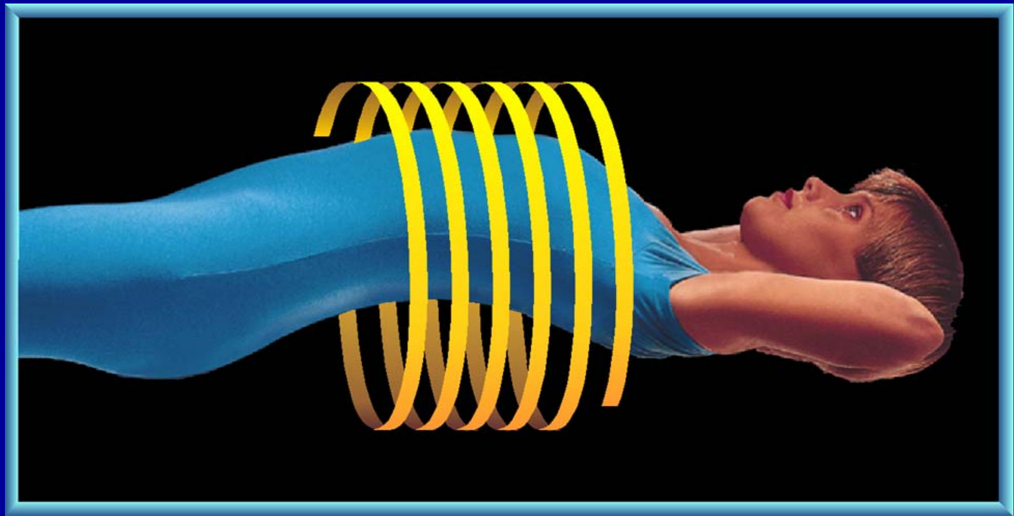
- Computer workstation
  - » Multiple microprocessors coordinate setup of the scan parameters, x-ray production, data acquisition, processing of transmission data and display of reconstructed image
- External patient marking/positioning lasers
  - » Used for marking for patients
  - » important that sagittal laser be mobile because the CT table cannot move laterally

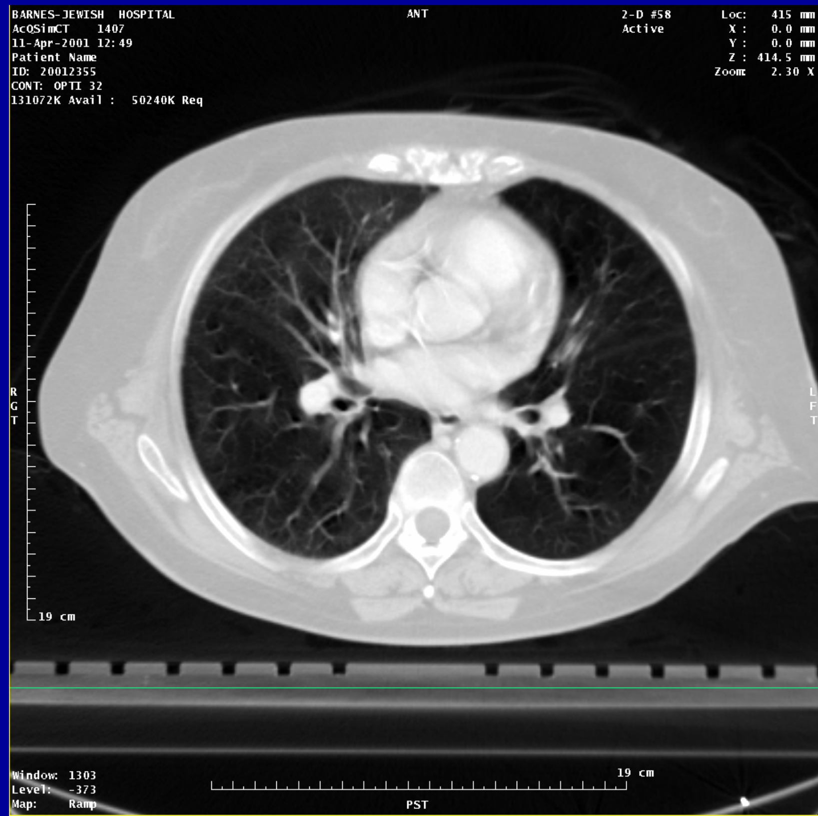
Functional performance characteristics of CT equipment

B. Conventional and spiral CT
   - Conventional CT acquires data one slice at a time
   - Spiral CT allows data to be acquired while the table translates and the tube rotates continuously. Path of the tube forms a helical pattern around the patient

C. Multislice scanners
   - Projection data from multiple slice is acquired simultaneously
   - Uses multiple row of detectors in the z axis
   - Enables acquisition of imaging studies faster than single slice scanners

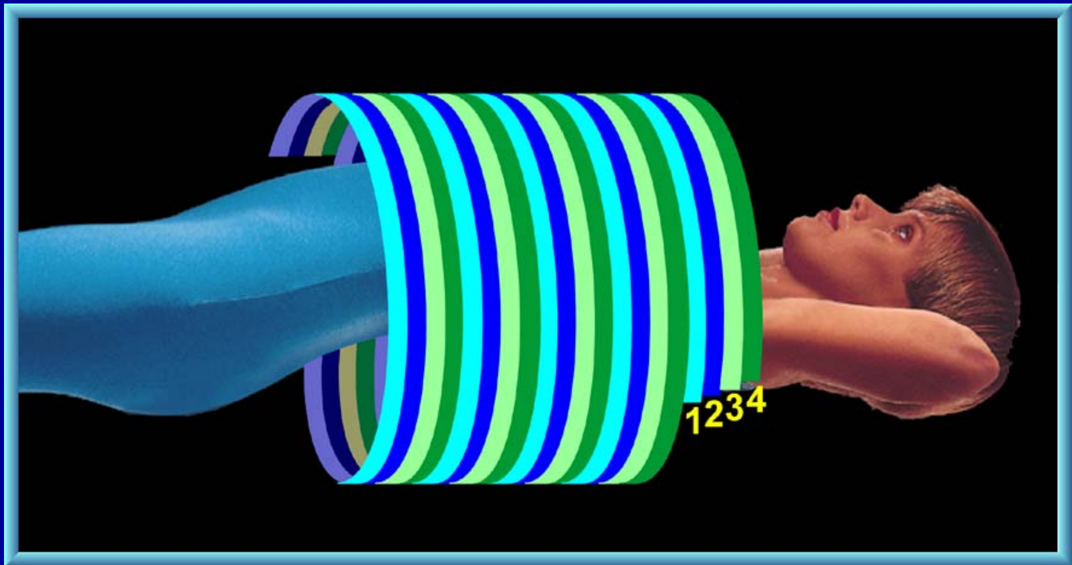
Image Generation – Single Slice

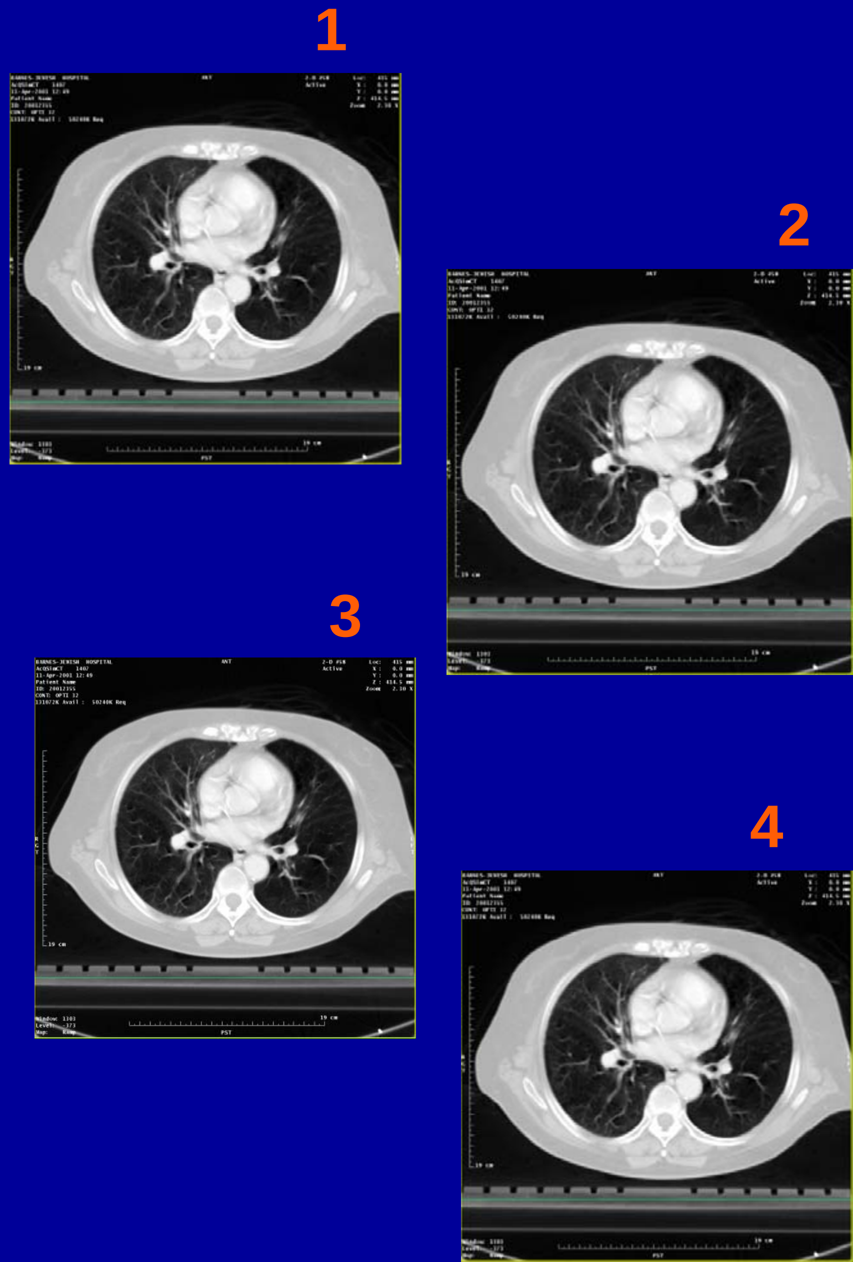




One Rotation – One Image

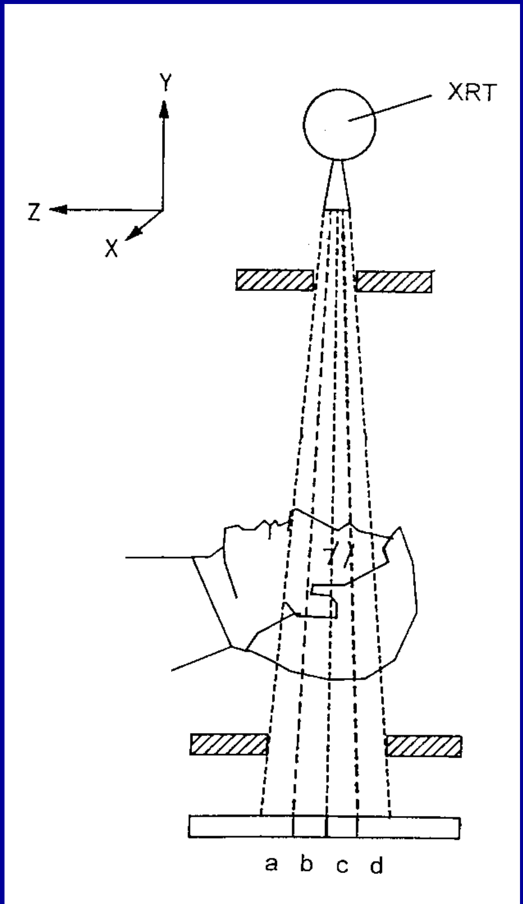
Multislice CT





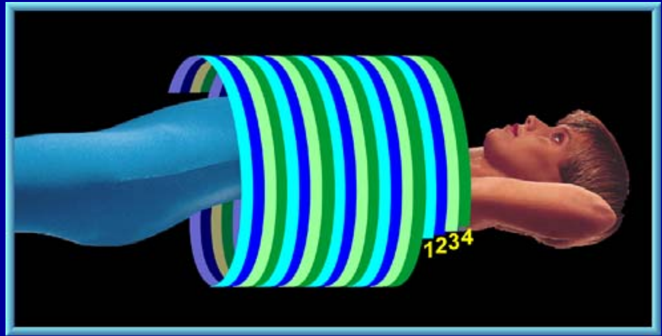
One Rotation – Multiple Images

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

CT scanner – Multi-slice scanning



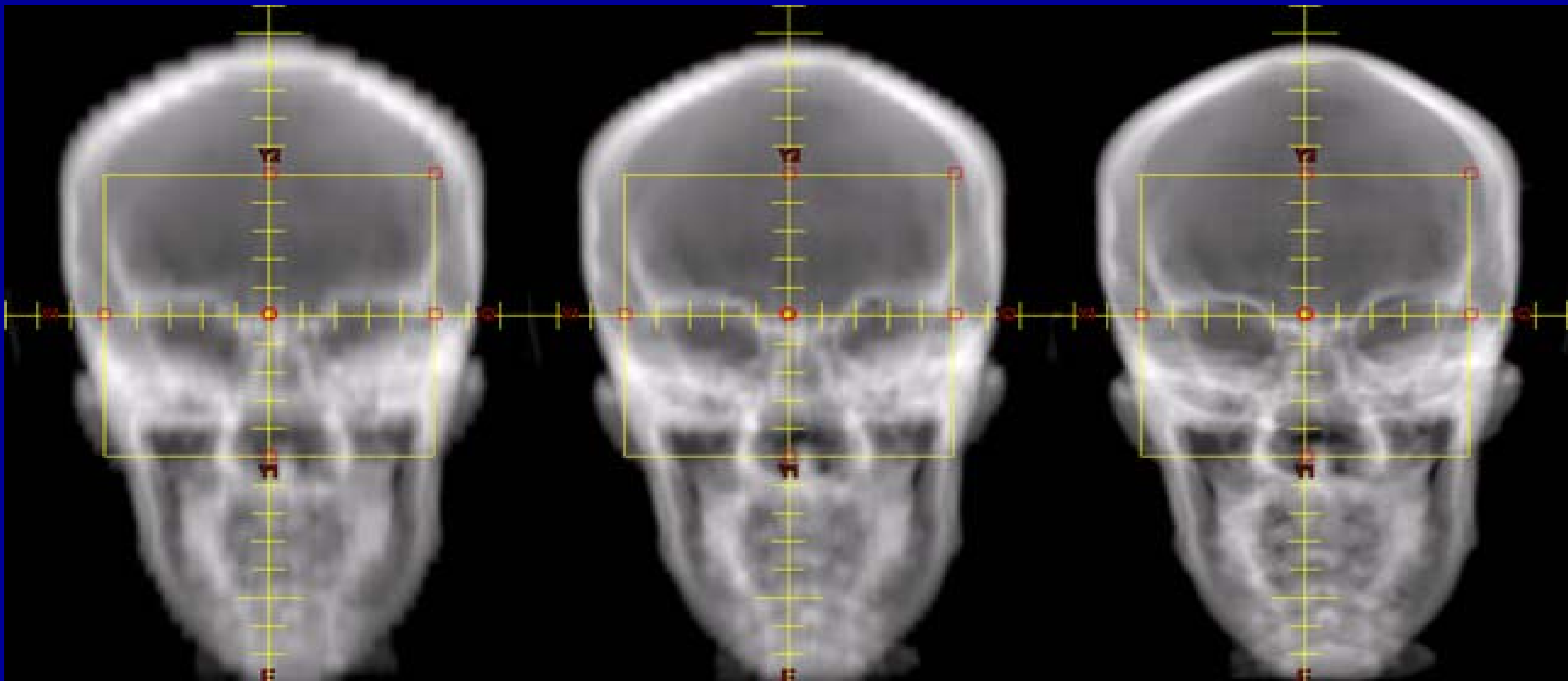
- Faster scan times
  - 4 slice scanner example (8 times faster):
    - » multi: 0.5 sec/rotation and 4 slices/rotation
    - » single: 1 sec/rotation and 1 slice/rotation
- Lower tube heat loading
  - Longer volume covered per rotation
- Improved temporal resolution - faster scan times
- Improved spatial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

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

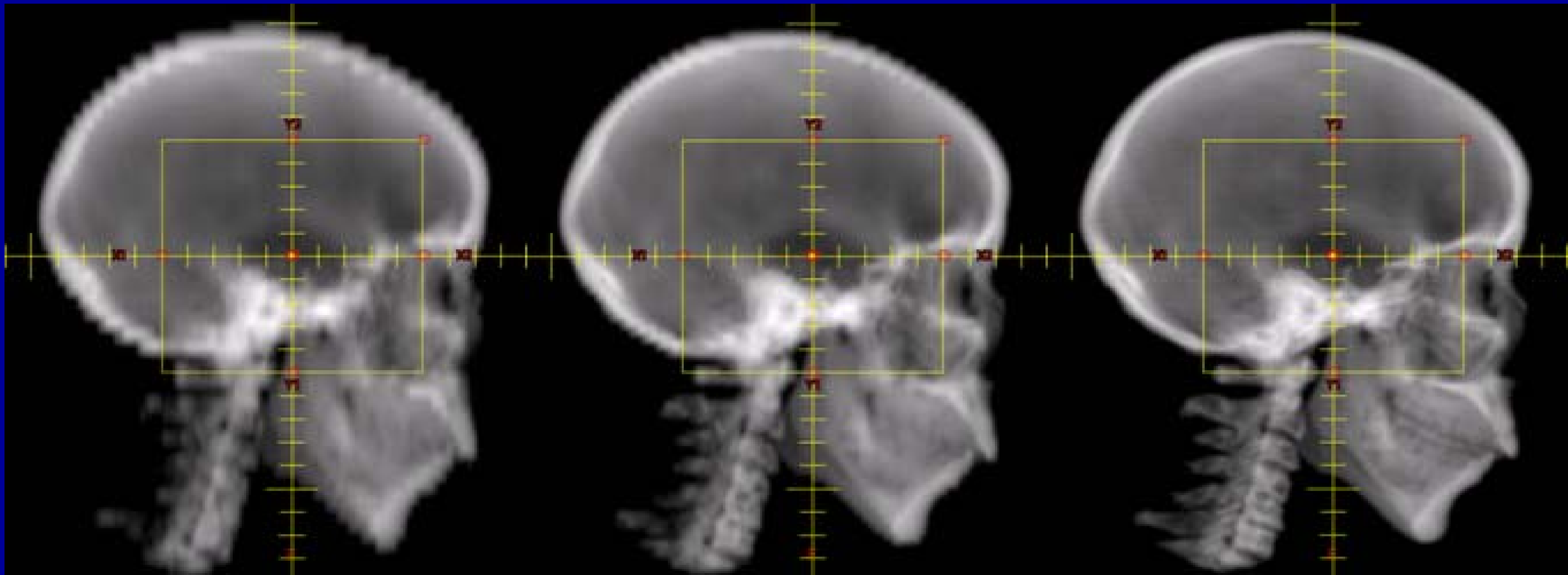
DRR image quality

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



5mm Slices 3mm 0.8mm

DRR Image Quality



5mm Slices 3mm 0.8mm

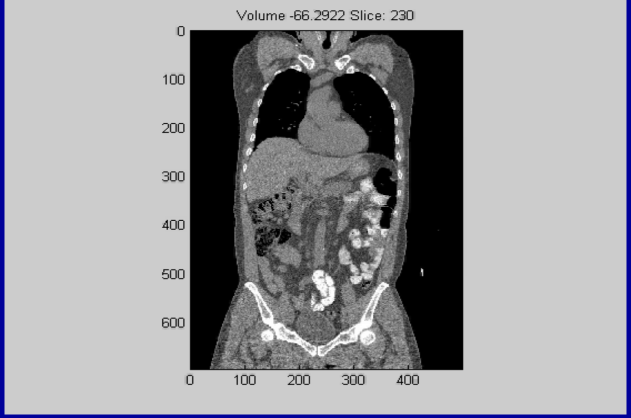
DRR Image Quality

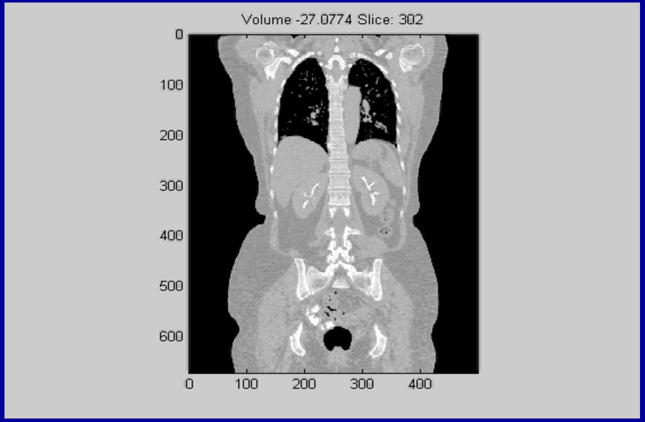
800 Images – 0.8 mm slice thickness

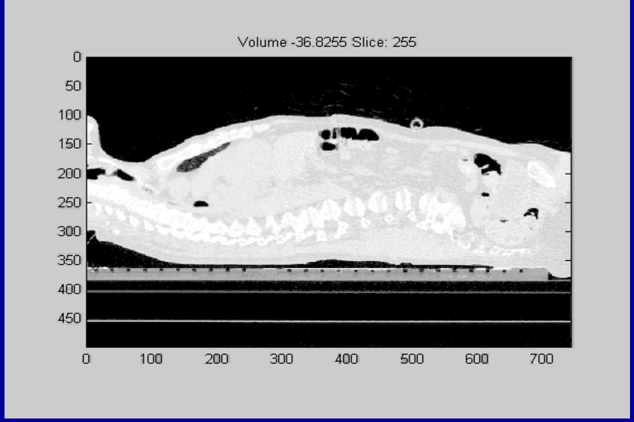
Multi-slice CT - Speed

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

Multi-slice CT - Dynamic CT







Approximately – 7000 images

Functional performance characteristics of CT equipment

D. Large bore scanners

85 cm Bore Opening

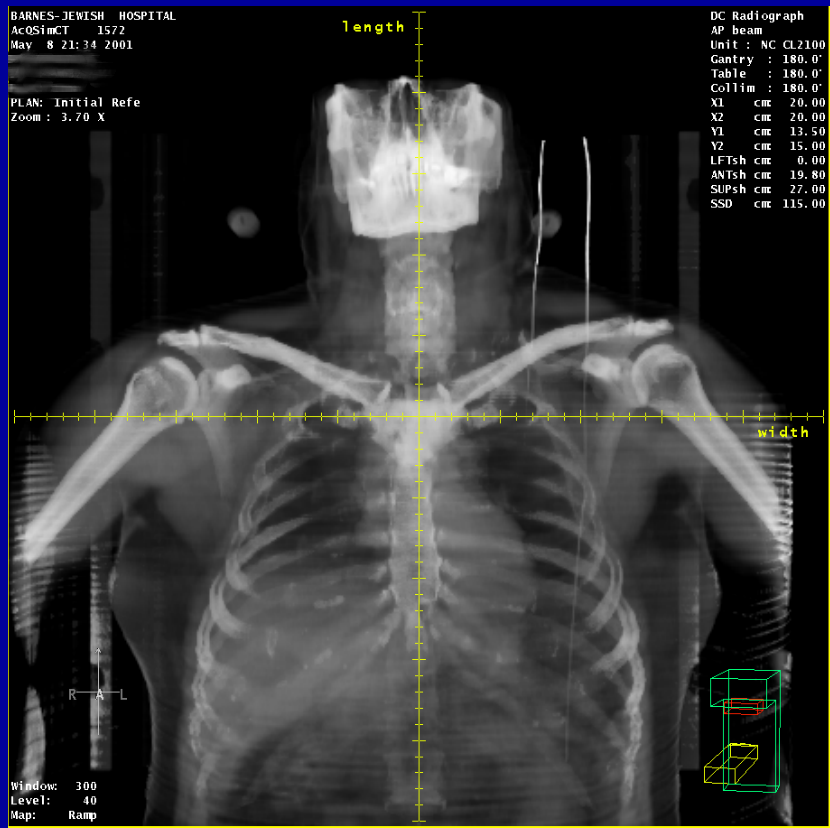
70 cm Bore Opening

CT scanner - Bore size

Patient Size

CT scanner – Bore size

Mantle Field



Functional performance characteristics of CT equipment

E. CT performance parameters

- X-ray system calibration
- Collimator assessment
- Localization laser alignment
- Slice width and sensitivity profile
- Radiation exposure and dose

E. CT performance parameters

- Image uniformity and noise
- Spatial resolution
- Contrast resolution
- CT number calibration and linearity
- Artifact evaluation

Quality assurance of CT simulators

Commissioning

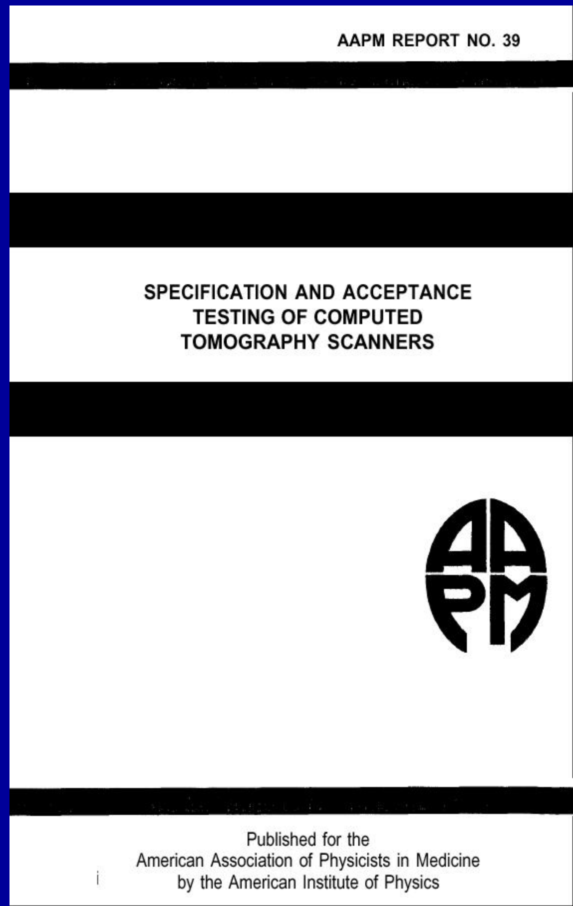
- Ensure that the equipment performs within the specifications agreed on by the vendor and user
- Establish a record of baseline performance
- An opportunity for a physicist to become an expert user
- Develop clinical procedures and policies
- Develop a quality assurance program

CT Sim QA – AAPM TG66

- QA recommendations and guidelines for diagnostic radiology and radiation therapy for CT-Simulators
- Equipment description
- Tests for
  - CT scanners
  - Virtual simulation software
  - Image registration
  - Overall CT-Simulation process
- Test frequencies, methods, and tolerances

Quality assurance of CT scanners

- The AAPM Report Number 39- “Specification and acceptance testing of computed tomography scanners”
  - Radiation safety
  - CT Dosimetry
  - Electromechanical tests
  - X-ray Generator
  - Image performance tests


AAPM REPORT NO. 39

SPECIFICATION AND ACCEPTANCE
TESTING OF COMPUTED
TOMOGRAPHY SCANNERS

Published for the
American Association of Physicists in Medicine
by the American Institute of Physics

QA program

- Purpose
  - To assure proper equipment and program operation
  - To assure safety of patient, staff, and public
- Should include
  - specification of tests
  - test frequency
  - tolerance limits
  - corrective actions
  - QA assignments

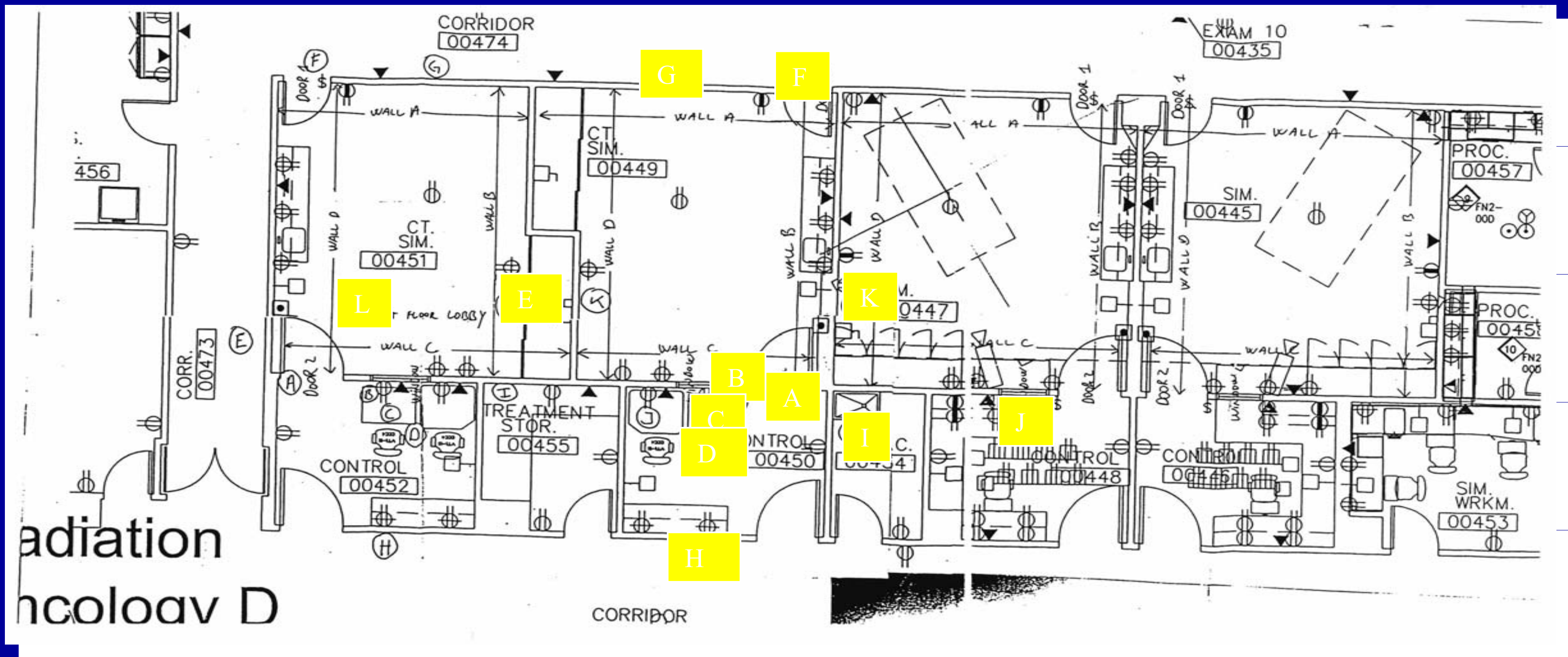
QA components

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

Radiation Safety/Interlocks

- Exposure Measurements
  - Two shielding design methods commonly employed
    - » direct use of isoexposure contours
    - » NCRP Report No. 49 & 147
- Interlocks (x-ray interruption, dead man)
- Patient Dose (CTDI, MSAD)

Survey Sites



Staff and Public Weekly Exposure

NCRP 49:

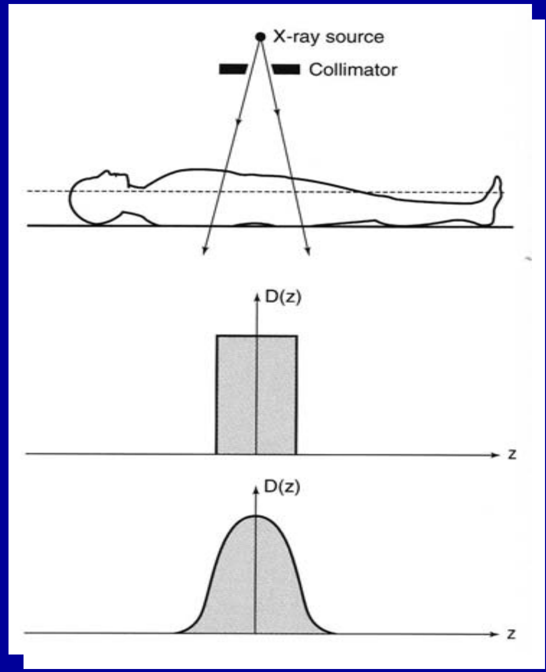
Controlled Areas: 100 mR/week

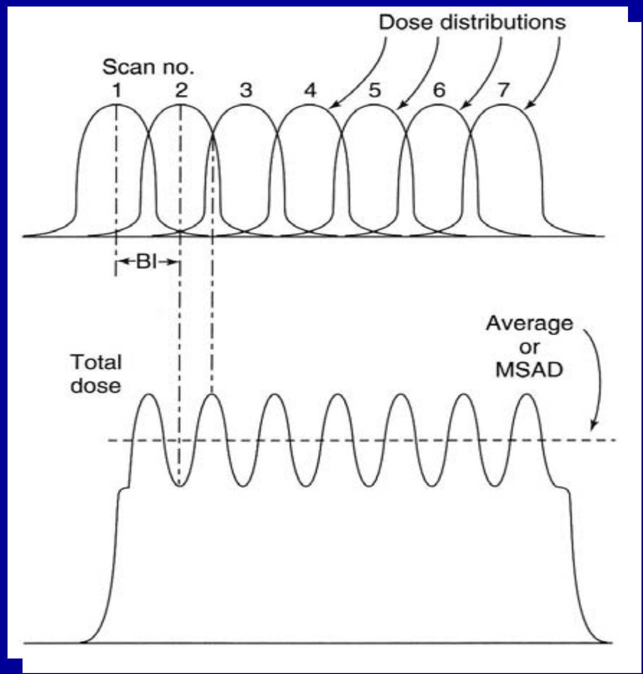
Non-Controlled Areas: 10 mR/week

			Brilliance	AcQSim
Location	Measured Instantaneous Exposure Rate (mR/hr)	Occupancy Factors	Weekly Exposure Based on Workload (mR/week)	Weekly Exposure Based on Workload (mR/week)
A. Room 450 Door	0.18	1.00	0.026	0.645
B. Room 450 Window	0.30	1.00	0.043	1.075
C. Room 450 Countertop	0.33	1.00	0.047	1.183
D. Room 450 Chair	0.22	1.00	0.031	0.788
E. Room 451	0.23	0.25	0.008	0.206
F. Corridor 474 Door	0.10	0.25	0.004	0.090
G. Corridor 474	0.17	0.25	0.006	0.152
H. Corridor 362	0.15	0.25	0.005	0.134
I. Room 454	0.10	0.25	0.004	0.090
J. Room 448	0.10	1.00	0.014	0.358
K. Room 447	0.10	0.25	0.004	0.090
L. First floor lobby	background			

Patient Dose

- CTDI - Computed Tomography Dose Index represents average dose per slice
- MSAD - Multiple Scan Average Dose represents average dose per scan
- Body Dose from CT Scans ~ 1 cGy



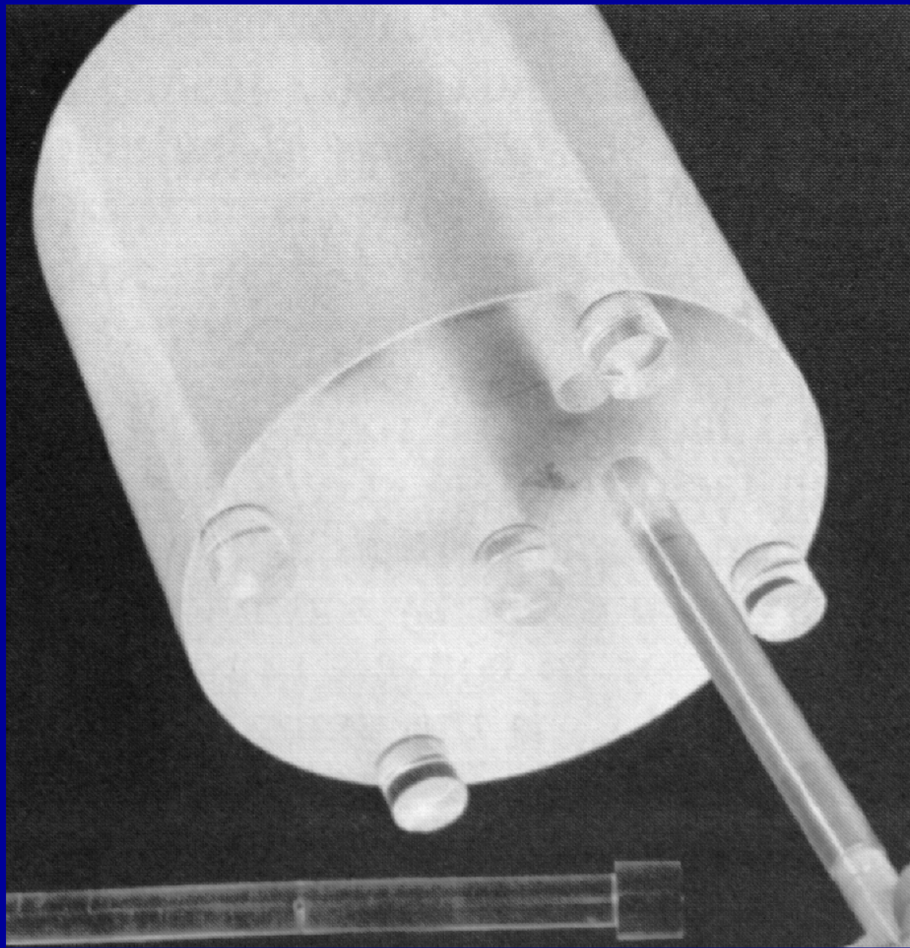


Continually evolving concept – due to multislice technology

CTDI

CTDI Measurement Technique

- Pencil Ionization Chamber (long cylindrical ionization chamber)
- TLD array
- "Body" and "Head" phantom
- Technique
  - kVp
  - mAs
  - Slice Width
  - Index
  - Other parameters



CTDI

- CT dose Index (CTDI)
- For axial scan only
- Ideally from ±∞, in reality 10 cm
- f_{med} = 0.78 cGy/R (acrylic)
- n is number of slices
- T is slice width

$$CTDI_{100} = \frac{Rdg * C_{tp} * k_{el} * N_x * f_{med} * 100\text{mm}}{\text{n*T (mm)}} [\text{cGy}]$$

$$CTDI_{100} = \frac{1}{nT} \int_{-50mm}^{+50mm} D(z)\,dz$$

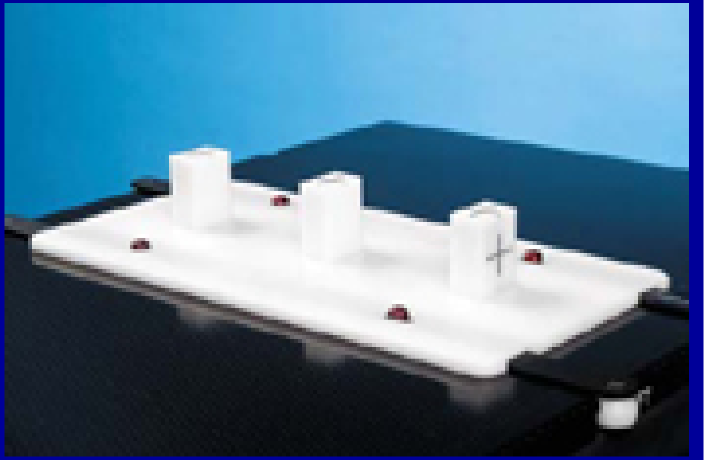
Electromechanical Tests

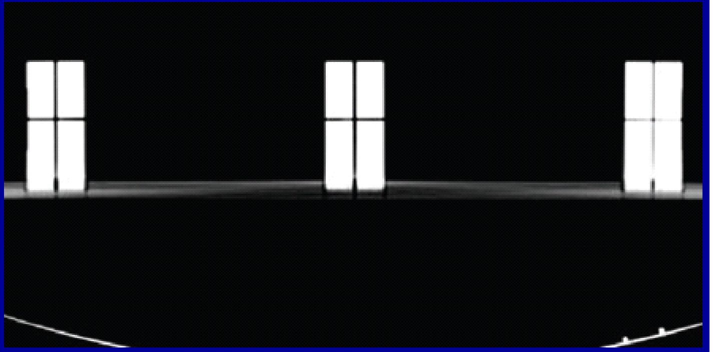
- Localization Laser Accuracy
- Table/Image Plane Orthogonality
- Gantry Tilt
- Slice Localization from Scout Image (Topogram, Pilot Image)
- Table Indexing

- **Collimation**
  - **Radiation Profile Width**
  - **Sensitivity Profile Width**
- **X-ray Generation**
  - **kVp**
  - **HVL**
  - **Timer accuracy**
  - **mAs Linearity**
  - **mAs Reproducibility**

Electromechanical components
Laser Alignment/Accuracy

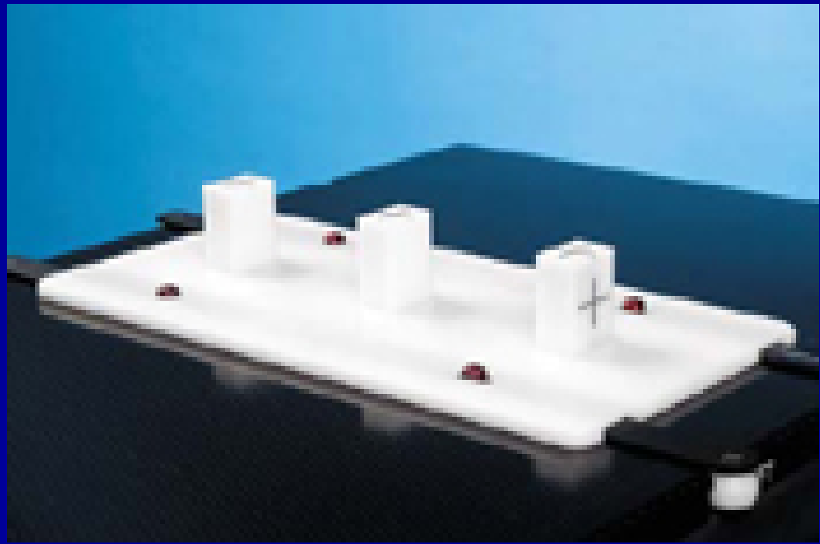
- Gantry lasers should accurately identify scan plane within the gantry opening
- Gantry lasers should be parallel and orthogonal with the scan plane and should intersect in the center of scan plane
- Vertical side-wall lasers should be accurately spaced from imaging plane
- Wall lasers should be parallel and orthogonal with the scan plane, and should intersect at a point which is coincident with the center of the scan plane
- The overhead (sagittal) laser should be orthogonal to the imaging plane
- The overhead (sagittal) laser movement should be accurate, linear and reproducible

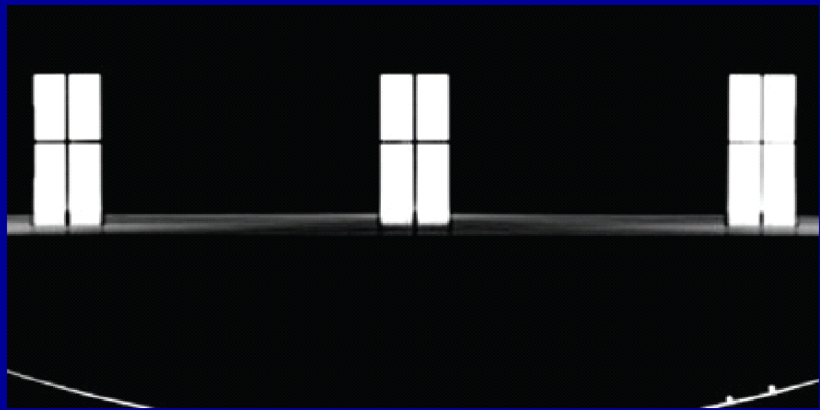




Electromechanical components
Table Alignment/Accuracy

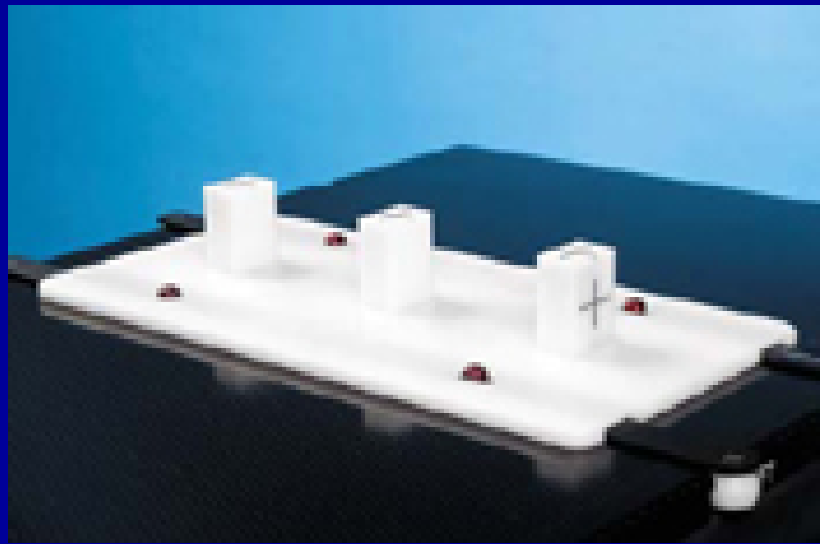
- The tabletop should be level and orthogonal with respect to the imaging plane
- Table vertical and longitudinal motion according to digital indicators should be accurate and reproducible
- Table indexing and position under scanner control should be accurate
- Flat tabletop should not contain any objectionable artifact producing objects

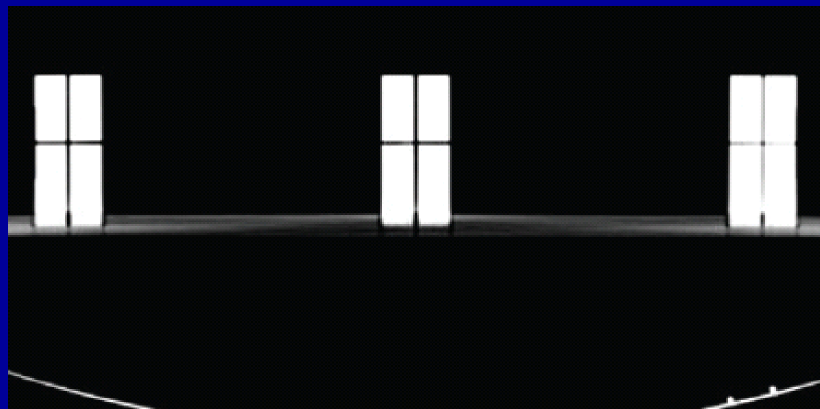




Electromechanical components
Gantry Alignment/Accuracy

- The angle of the gantry tilt with respect to nominal vertical imaging plane should be accurate
- After the tilt, the gantry should return to the nominal vertical imaging plane





Electromechanical Components
x-ray Generator

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

X-ray Generation

- As many possible modes as practical should be verified:
  - kVp, time, HVL - non-invasive tests device
  - mA Linearity - inferred indirectly using a mAs linearity measurement. For a constant tube potential and slice width, the integral exposure should be a linear function of mAs.
  - mAs Reproducibility

CT simulator mechanical alignment

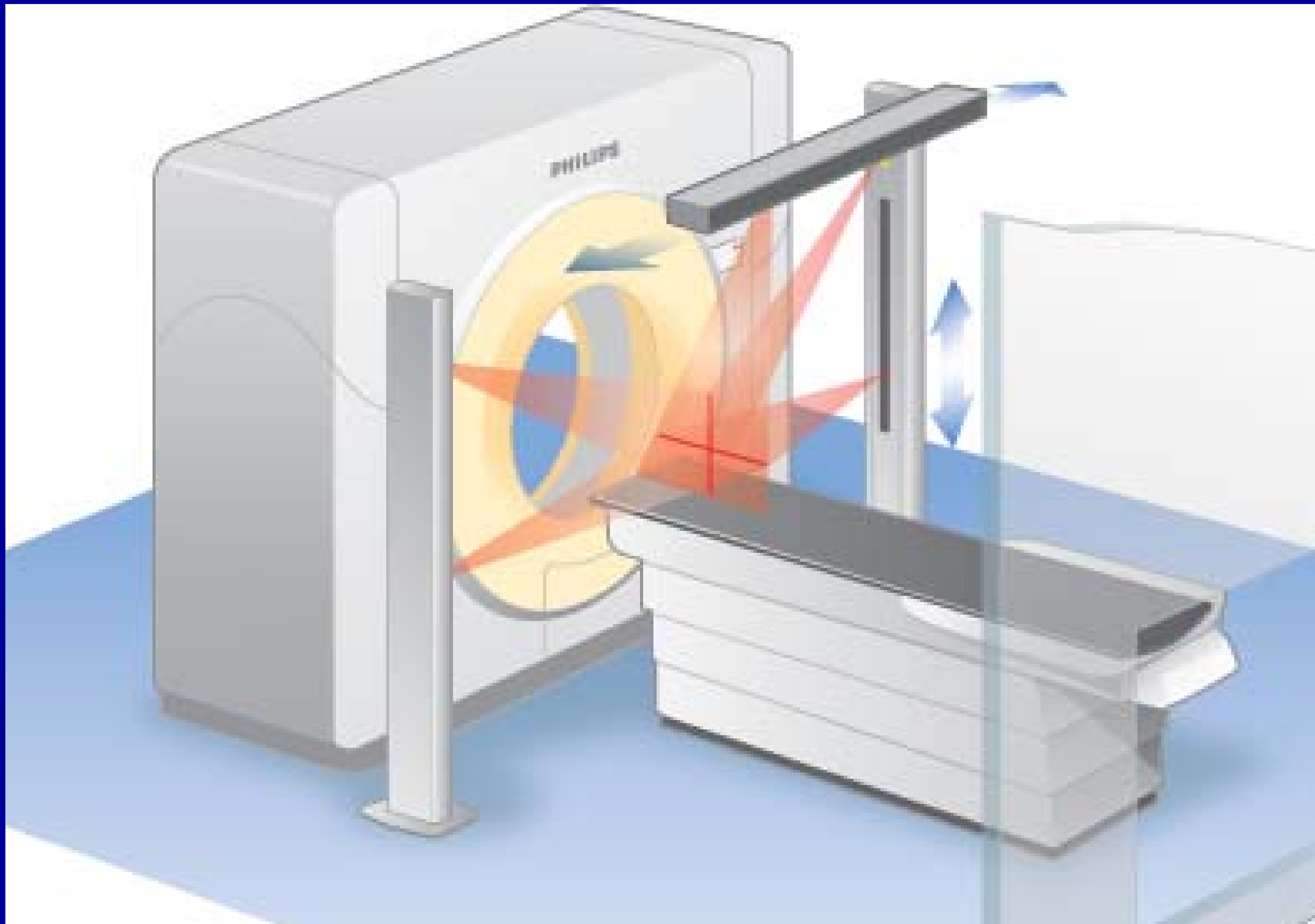
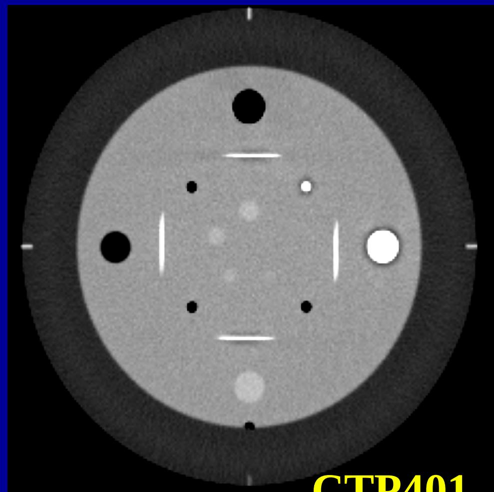


Image quality indicators

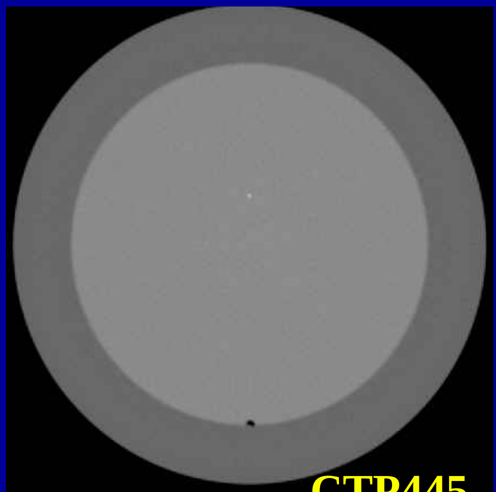
- <u>Quantitative</u>
  - Phantom Measurements
    - » High Contrast
    - » Low Contrast
    - » Uniformity
    - » Spatial Integrity
    - » Artifacts
    - » Slice thickness
    - » CT # accuracy
- <u>Qualitative</u>
  - Physician Preferences
    - » Tumor
    - » Normal Structures
    - » DRR/DCR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

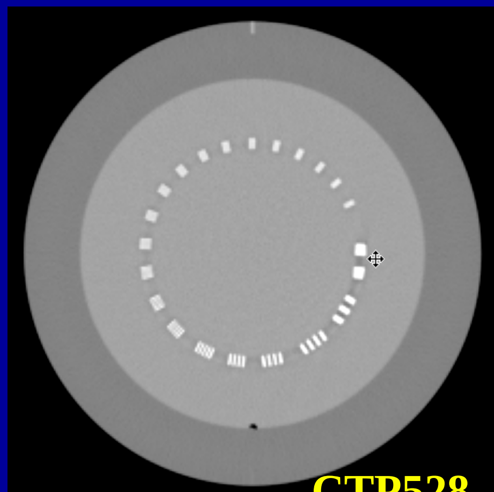
Image performance

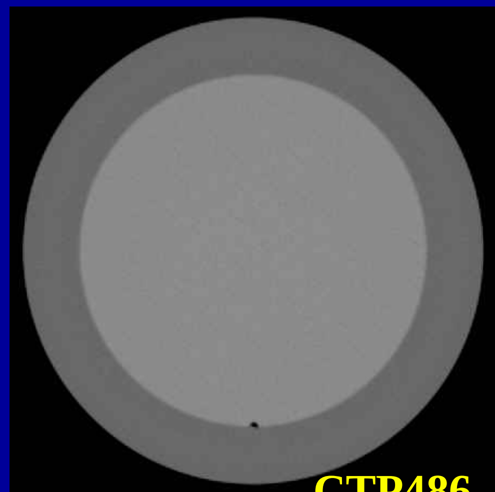

Catphan 500


CTP401


CTP515

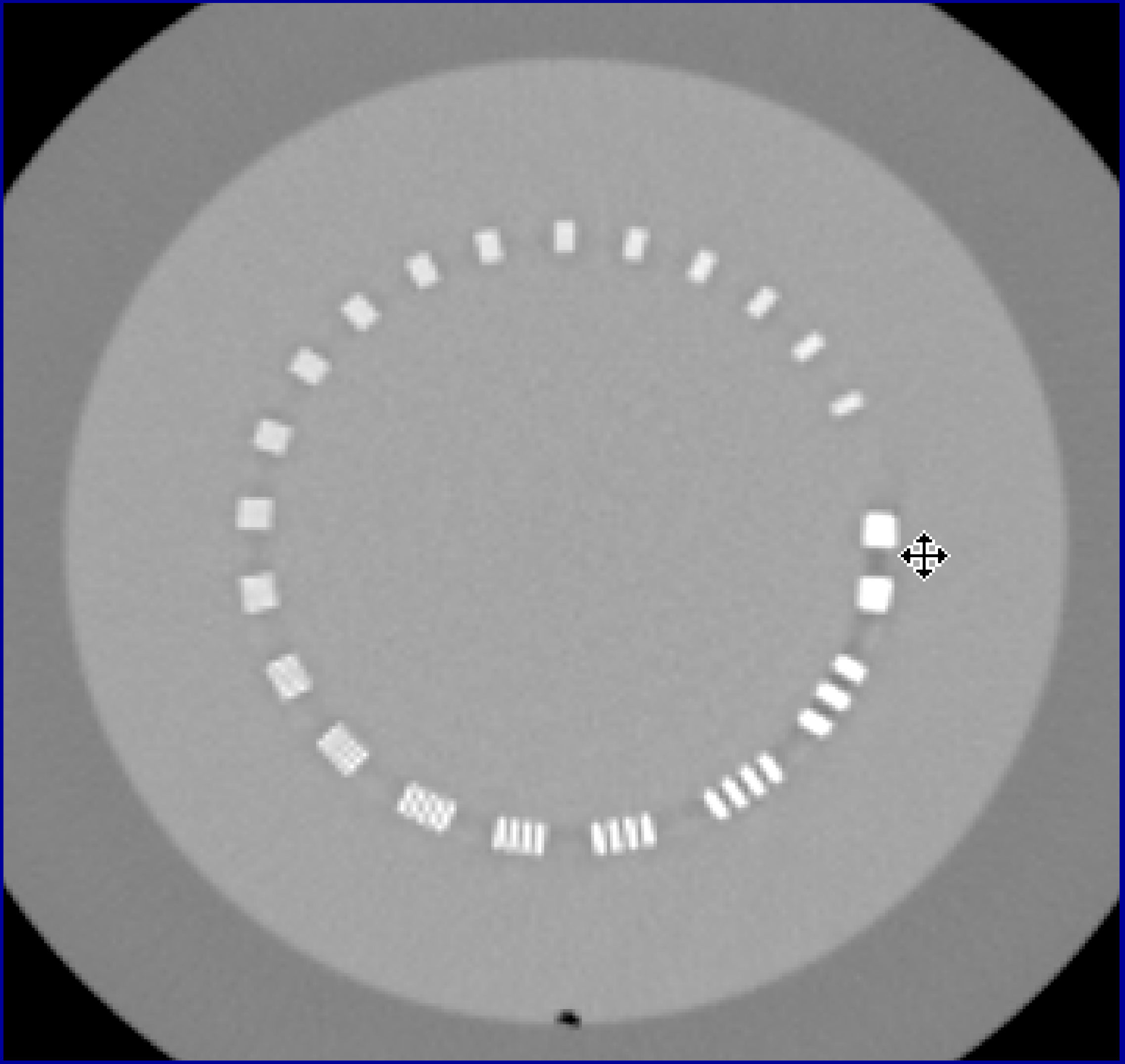

CTP445


CTP528


CTP486

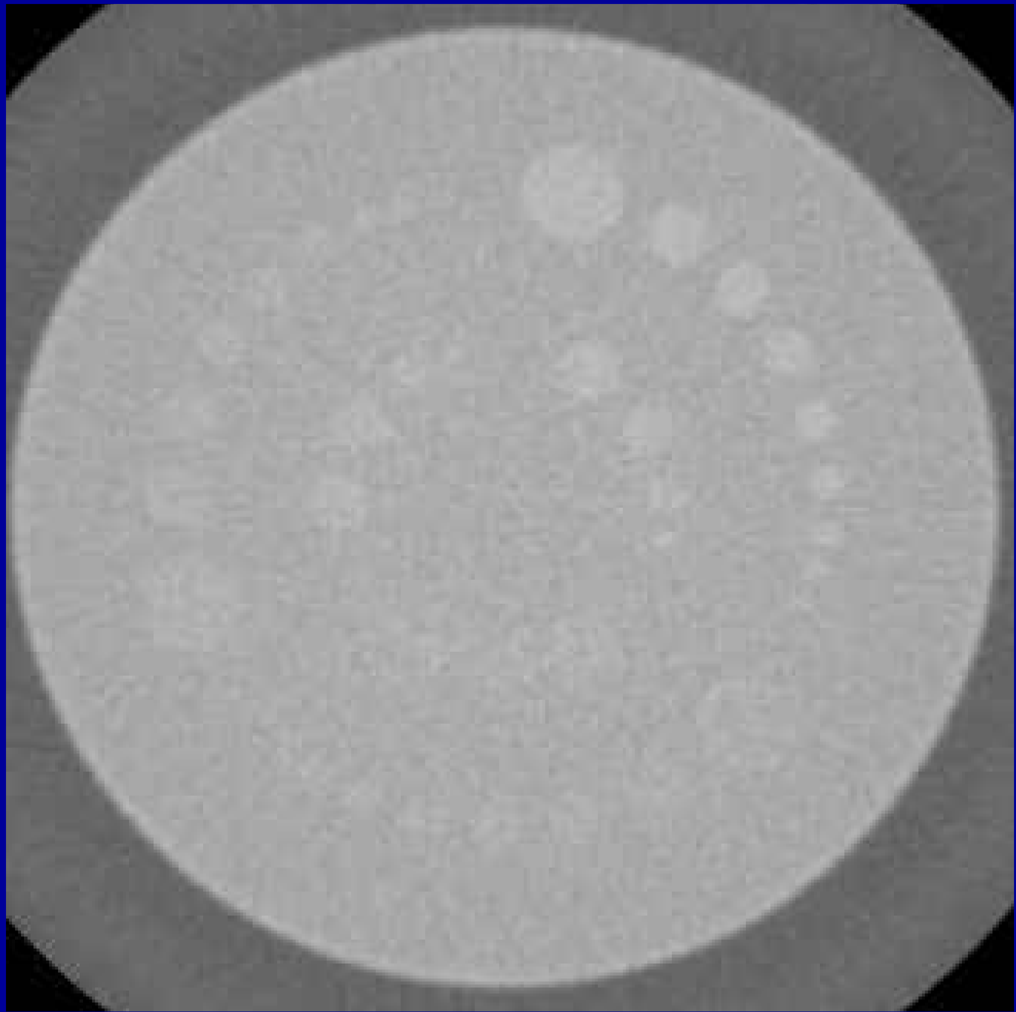
Resolution (High Contrast)

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



Subject contrast (Low Contrast)

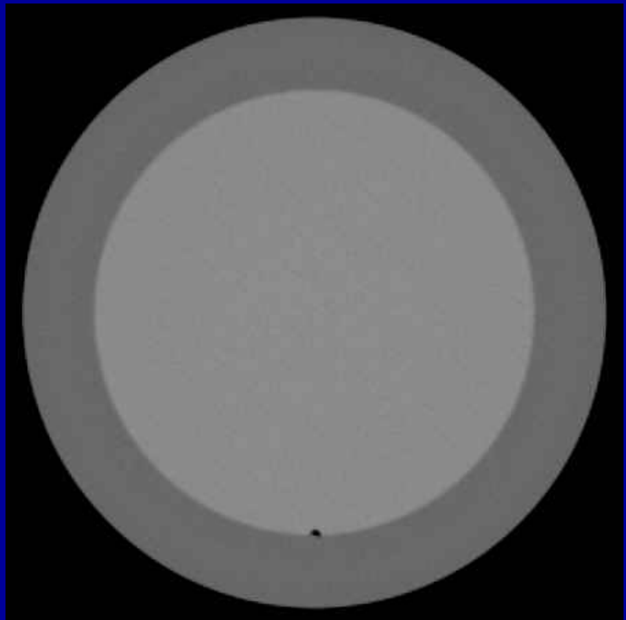
- Ability of a system to resolve adjacent objects with small density differences
- Noise limited



Field uniformity

- The average CT number of water should always be 0, independent of the position within the homogeneous phantom
- Measurements are performed using head and body uniformity phantoms
- Measure average CT numbers in center and at the periphery (several locations) of the phantom

Uniformity



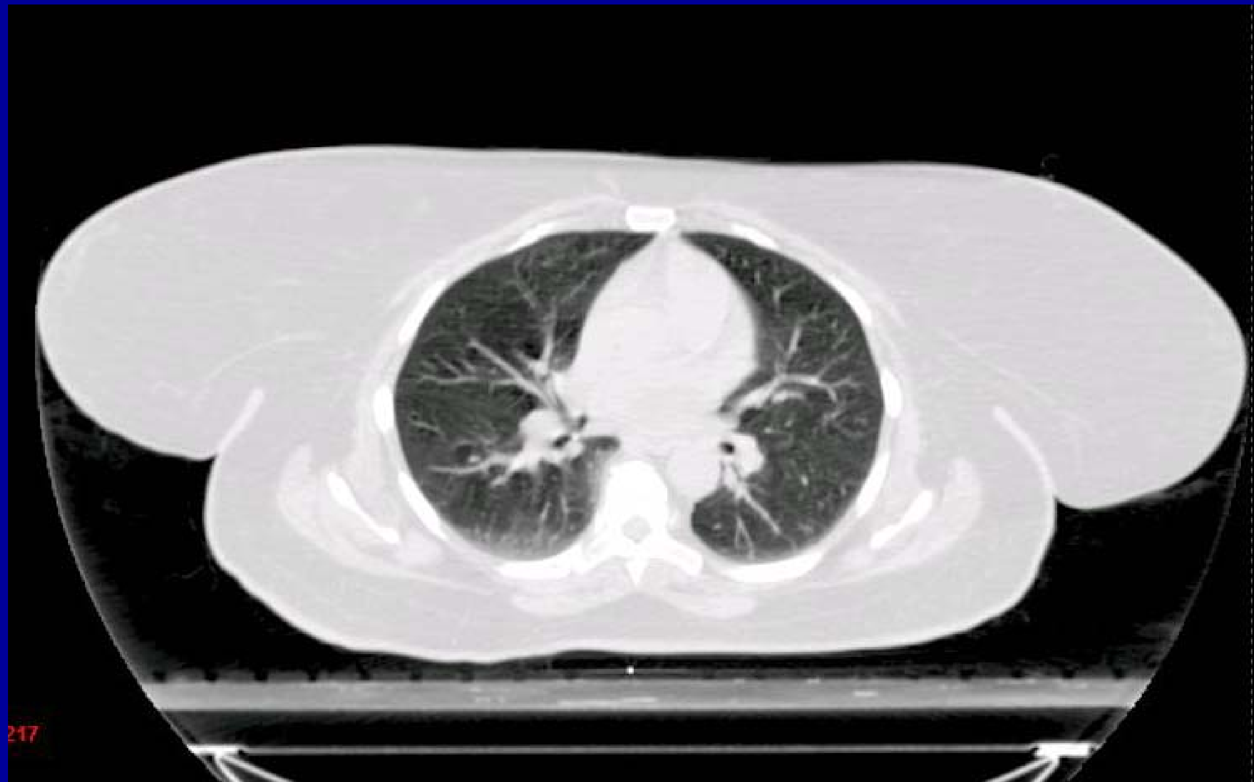


Image performance evaluation

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

Quantitative CT

- Phantom with sections of known electron densities
- Determine CT numbers for each section
- Compare measured CT numbers with vendors specifications
- Should be independent of phantom size
- CT numbers are a function of kVp
- Edge enhancement algorithms should be avoided

CT Number Accuracy
(MIR with Manufacturer's Phantom)

Material	Big Bore (HU)	Std Bore (HU)	Manufacturer (HU)
Polyethylene	–70.9	–75.1	–75 ± 15
Water	–2.5	–2.5	0 ± 4
Nylon	100.0	100.5	100 ± 15
Lexan	114.0	117.5	116 ± 15
Acrylic	136.0	137.5	140 ± 15
Teflon	1020.0	1033.0	1016 ± 50

Both scanners exhibited CT number accuracy well within manufacturer's specifications

Spatial accuracy

- Spatial accuracy within the image plane can be verified by imaging a convenient object of known dimensions

Virtual simulation software tests

- Beam geometry
- Target localization
- Target contour verification (using BEV)
- Isocenter calculation
- Isocenter movement
- Virtual field size
- Virtual gantry, collimator, and table rotation
- Evaluation of digitally reconstructed radiographs (DRRs)

Virtual simulation software QA

- Fraass et al. AAPM TG 53: Quality assurance for clinical radiotherapy treatment planning. Med Phys,25:1773-1829,1998
- Spatial and geometric accuracy
  - contour delineation
  - isocenter localization
  - treatment port definition
  - virtual treatment machine operation
- Evaluation of DRRs and DCRs
- Accuracy of the multimodality image fusion and registration

QA for the CT simulation process

- CT scan
- transfer of images
- isocenter localization
- treatment plan design
- multimodality image fusion
- transfer of virtual simulation data for calculation of dose distributions
- DRR generation
- transfer of the plan to treatment machine
- treatment of the patient
- treatment verification

Quality assurance frequency

- Daily (Therapists)
- Weekly (Therapists)
- Monthly (Clinical Engineering)
- Annual (Medical Physics)

Daily QA
(Sim Therapists)

- Radiographic Uniformity
  - Most important - look for noise and distortions in CT image
- Laser Alignment and Tracking
  - Critical for patient setup
  - Most critical - Couch in/out 500 mm tracking
- Audio/Visual System

Weekly Inspection (ok, not ok)
(Sim Therapists)

- Scanner couch
- Couch and gantry controls
- Gantry lasers
- Wall lasers
- Overhead laser
- General image quality
- Control console
- Software functions
- Networking and archiving
- Audio communication
- Machine operation during scanning
- Room condition
- Treatment aids condition

Monthly QA
(Clinical Engineering)

- Couch Digital Position Accuracy
- Laser Digital Position Accuracy
- Laser Alignment
- Slice Thickness
- Spatial Resolution
- Contrast resolution
- CT# Accuracy, Uniformity, and Noise
- MTF
- Distance Measuring Tool Accuracy

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

Acknowledgements

I would like to thank Sasa Mutic for giving me many of the slides that I presented in this talk