

# Computed tomography Acceptance testing and dose measurements

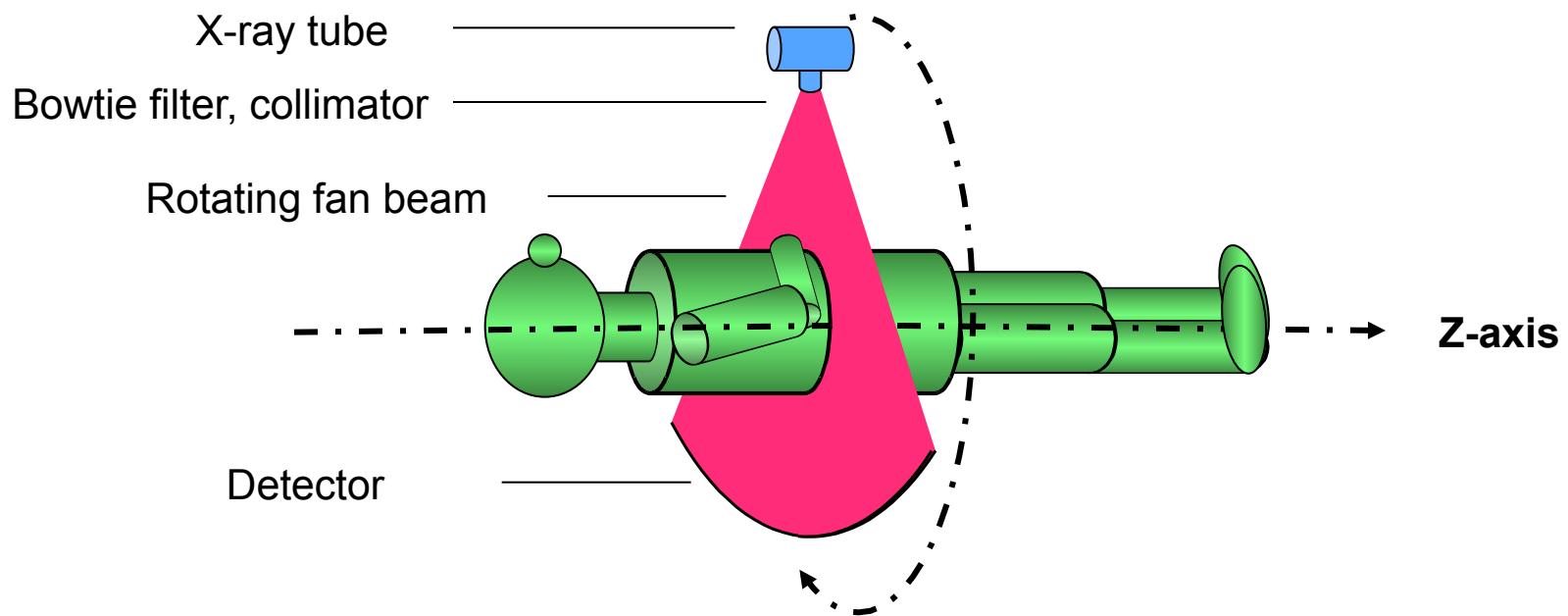
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# Contents

- The Computed Tomography Dose Index (CTDI)
- Acceptance tests for computed tomography
  - X-ray beam characteristics
  - Radiation output (CTDI)
  - Image quality
  - Examination protocol review
- Practical work beyond acceptance
  - Beam quality and dose in modulated X-ray beams
  - Beyond the CTDI formalism (AAPM Report No. 111)
  - Patient dosimetry (AAPM Report No. 204)

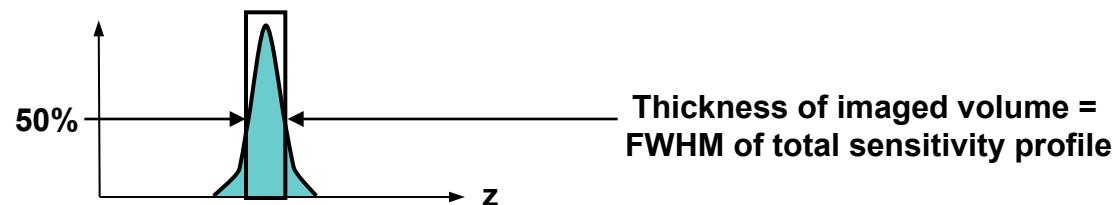
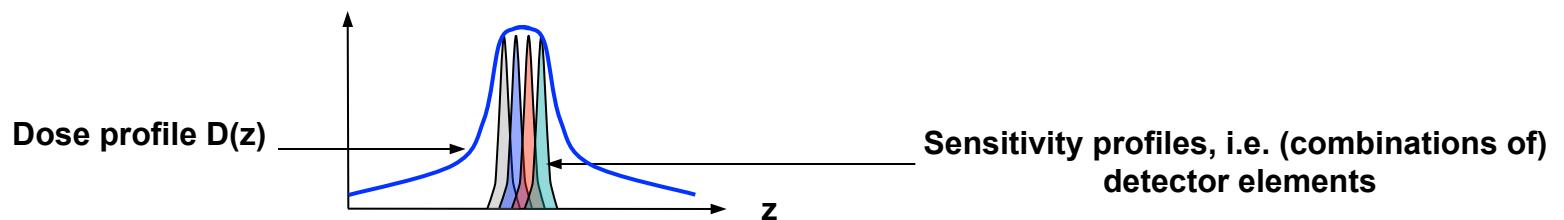
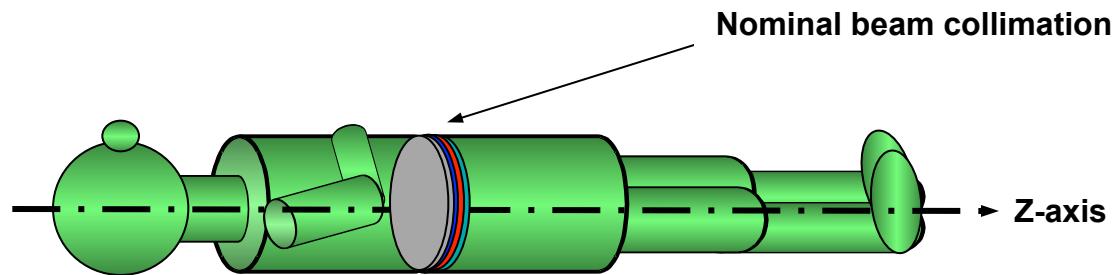
# Computed tomography

- Basic function



# Computed tomography

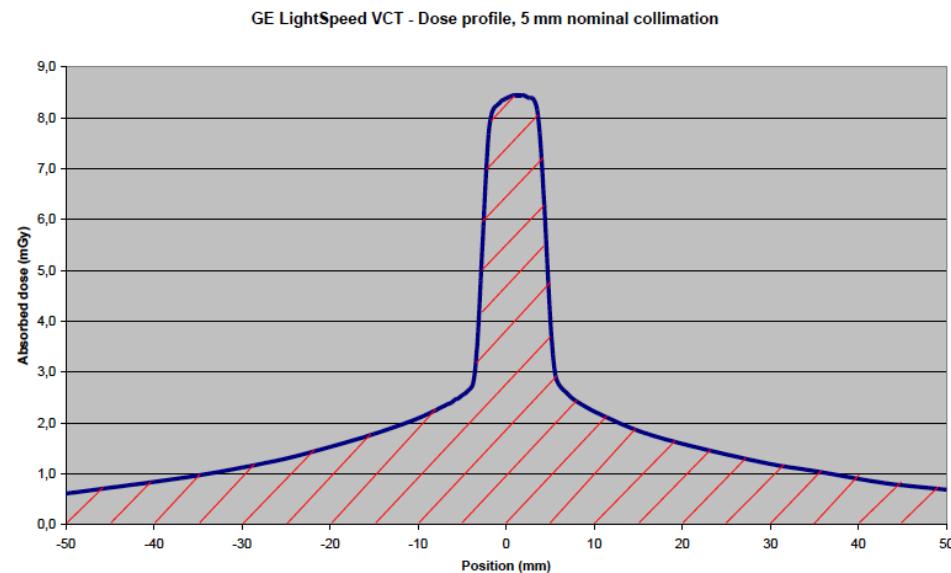
- Basic function



# The CTDI formalism (I)

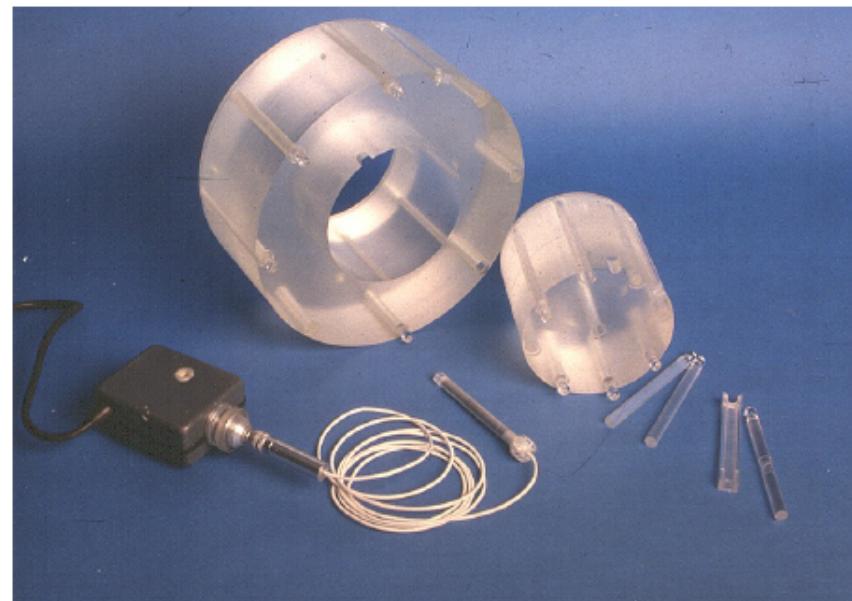
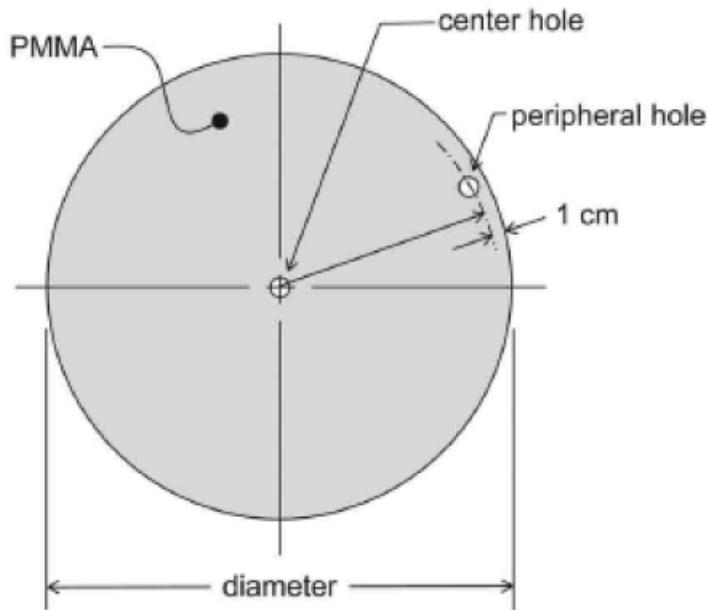
- The Computed Tomography Dose Index (CTDI)
  - One rotation, i.e. single axial scan
  - Integrate dose profile  $D(z)$  over 100 mm
  - Normalize to the nominal collimation ( $N \times T$ ), i.e. spatial average of dose

$$CTDI_{100} = \frac{1}{NT} \int_{-50\text{ mm}}^{50\text{ mm}} D(z) dz$$



# The CTDI formalism (II)

- CTDI phantoms for dose measurements
  - PMMA cylinders, central and peripheral holes
  - Head 16 cm diameter
  - Body 32 cm diameter



# The CTDI formalism (III)

- The weighted CTDI ( $CTDI_W$ )
  - Weighted average, reflect dose distributions in head and body phantoms and different tube voltages

$$CTDI_W = \frac{1}{3} CTDI_{100,centre} + \frac{2}{3} CTDI_{100,peripheral}$$

- The volume CTDI ( $CTDI_{vol}$ )
  - Extended definition for spiral scan mode, employing the spiral pitch factor ( $p$ )

$$CTDI_{vol} = \frac{CTDI_W^{avg}}{p} \quad p = \frac{\Delta d}{NT}$$

- $\Delta d$  represents table travel per rotation

# The CTDI formalism (IV)

- The volume CTDI ( $CTDI_{vol}$ )
  - The most common QA metric and dose descriptor
  - Used to derive the Dose Length Product (DLP)

$$DLP_{spiral} = CTDI_{vol} \cdot L$$

$$DLP_{axial} = CTDI_{vol} \cdot \Delta d \cdot n$$

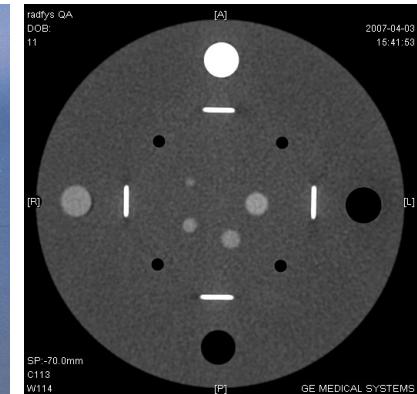
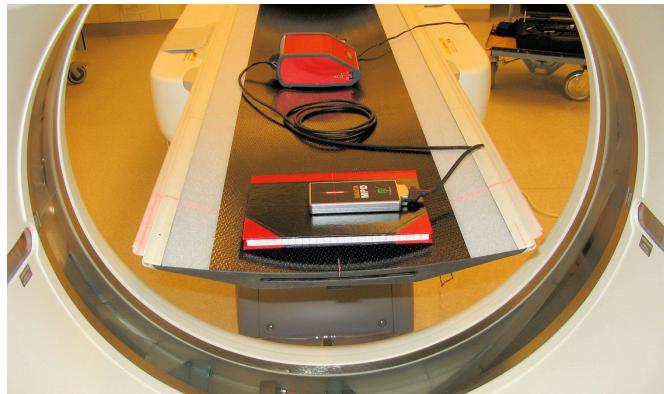
- Reported in various formats
  - Secondary capture, DICOM, RDSR
- Robustness as a QA metric
  - Depends on all technique factors

# The CTDI formalism (V)

DICOM tag	Value (Parameter)	Description	Comments and units
(0018,0060)	120	kVp	Peak kilo voltage output of the x-ray generator used.
(0018,1150)	500 ( $t$ )	Exposure Time	Time of x-ray exposure in msec.
(0018,1151)	187 ( $I$ )	X-Ray Tube Current	X-ray Tube Current in mA.
(0018,1160)	FLAT	Filter Type	Label for the type of filter inserted into the x-ray beam.
(0018,9307)	12 ( $N \cdot T$ )	Total Collimation Width	The width of the total collimation (in mm) over the area of active x-ray detection.
(0018,9310)	6.6 ( $\Delta d$ )	Table Feed per Rotation	Motion of the table (in mm) during a complete revolution of the source around the gantry orbit.
(0018,9311)	0.55 ( $p$ )	Spiral Pitch Factor	Ratio of the Table Feed per Rotation (0018,9310) to the Total Collimation Width (0018,9307).
(0018,9345)	31.9	$CTDI_{vol}$	Computed Tomography Dose Index ( $CTDI_{vol}$ ), in mGy according to IEC 60601-2-44, Ed.2.1

# Acceptance testing

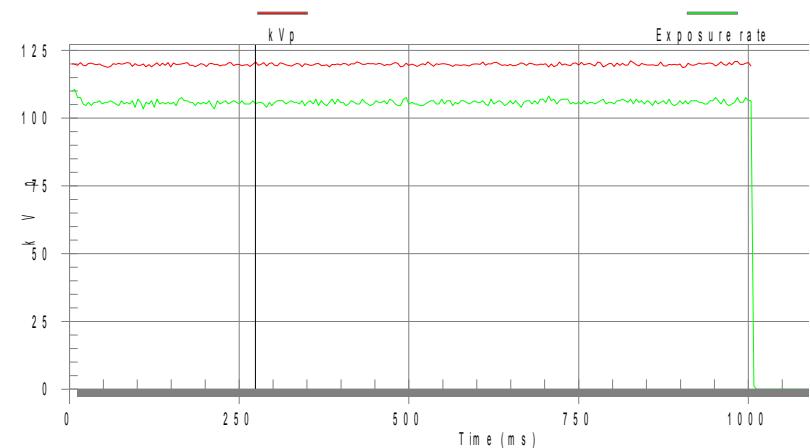
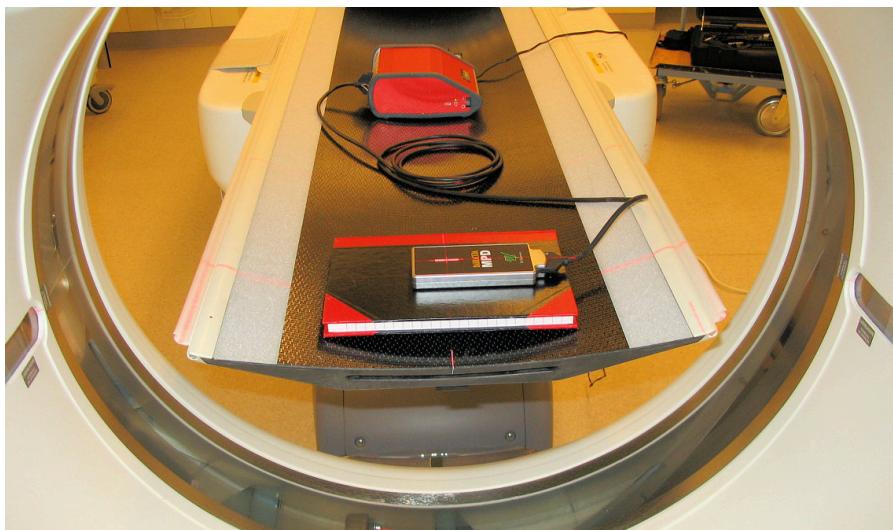
- Verification of technique factors
- Basic system functionality checks
- Required equipment
  - Diode system, e.g. Unfors XI, RTI Barracuda
  - Pencil ionization chamber (100 mm long)
  - CTDI phantoms (head and body)
  - Image quality phantom



# X-ray beam characteristics

- Tube voltage (kVp), HVL (and exposure time)
  - In isocenter (center of bowtie filter)
  - kVp tolerance  $\pm 5\%$  (IEC)
  - Diode system

Indicated (kV)	Time (ms)	Measured (kV)	Deviation (%)	Measured HVL (mm Al)
80	1005	81	0,7	4,3
100	1005	102	1,7	5,4
120	1005	122	1,3	6,4
140	1009	144	2,7	-

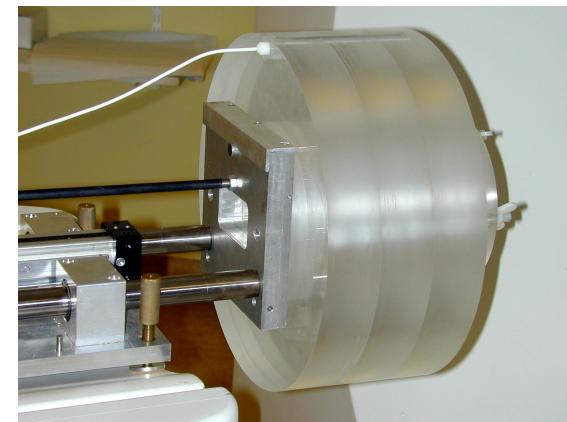


# Radiation output

- The weighted average CTDI ( $CTDI_w$ )
  - Nominal collimation, bowtie filter and tube voltage
  - Typical/maximum tolerance  $\pm 20\%/\pm 40\%$  (MITA)
  - CTDI phantom, pencil ionization chamber

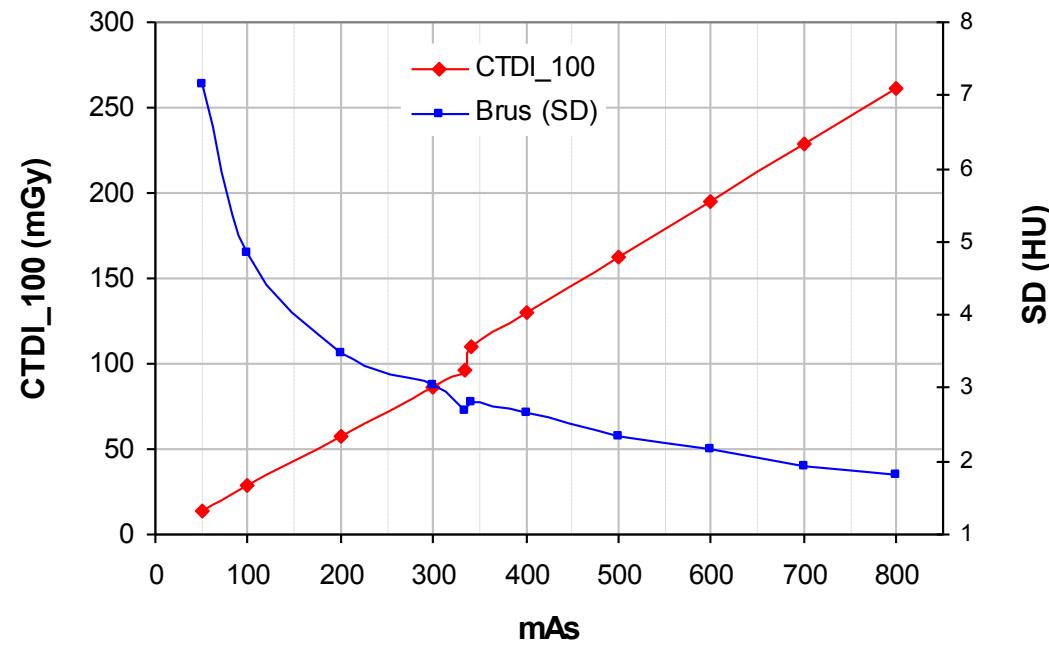
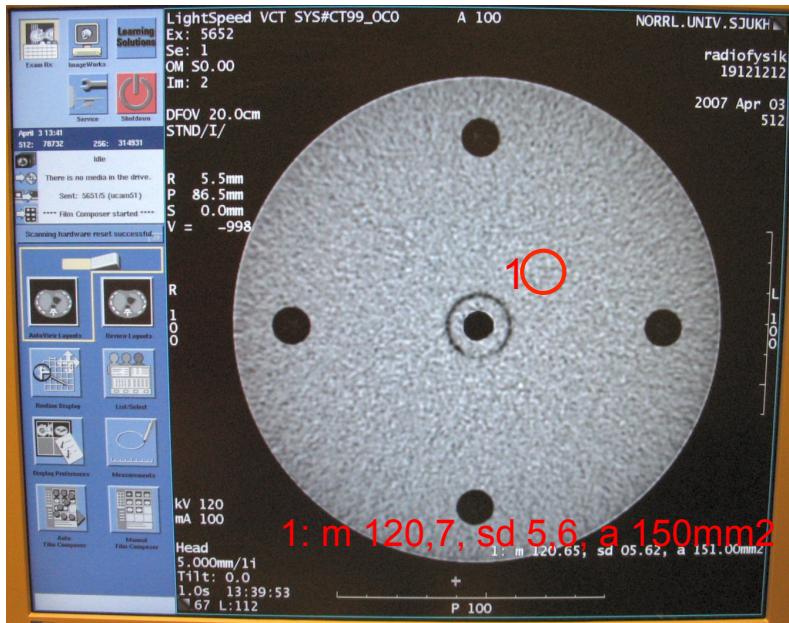
Electrometer reading (pC)	Measurement	Central	Top (12)	Lateral (3)	Peripheral	Bottom (6)	Lateral (9)
1		-134	-260	-259	-256	-259	
2		-134	-263	-259	-257	-259	
3		-134	-265	-263	-259	-260	
4		-134	-271	-258	-258	-267	
Mean (C)		-1,34E-10	-2,65E-10	-2,60E-10	-2,58E-10	-2,61E-10	
CTDI_100 (mGy)		24,9	49,1	48,2	47,8	48,5	

$CTDI_w = (1/3)*CTDI_{100,Central} + (2/3)*CTDI_{100,Peripheral}$       40,5 mGy  
Indicated  $CTDI_w$       38,6 mGy  
 $CTDI_w / 100 \text{ mAs}$       13,5 mGy  
Ratio, central/peripheral      0,51



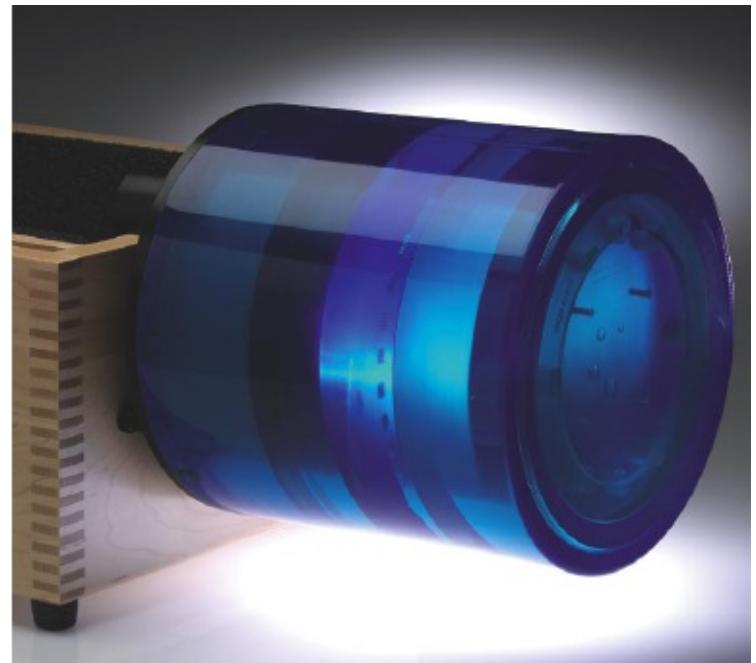
# Radiation output

- Linearity (dose/mA) and image noise/mA
  - Measured CTDI<sub>100</sub>, image noise (SD), tube load (mAs)
  - CTDI phantom, pencil ionization chamber



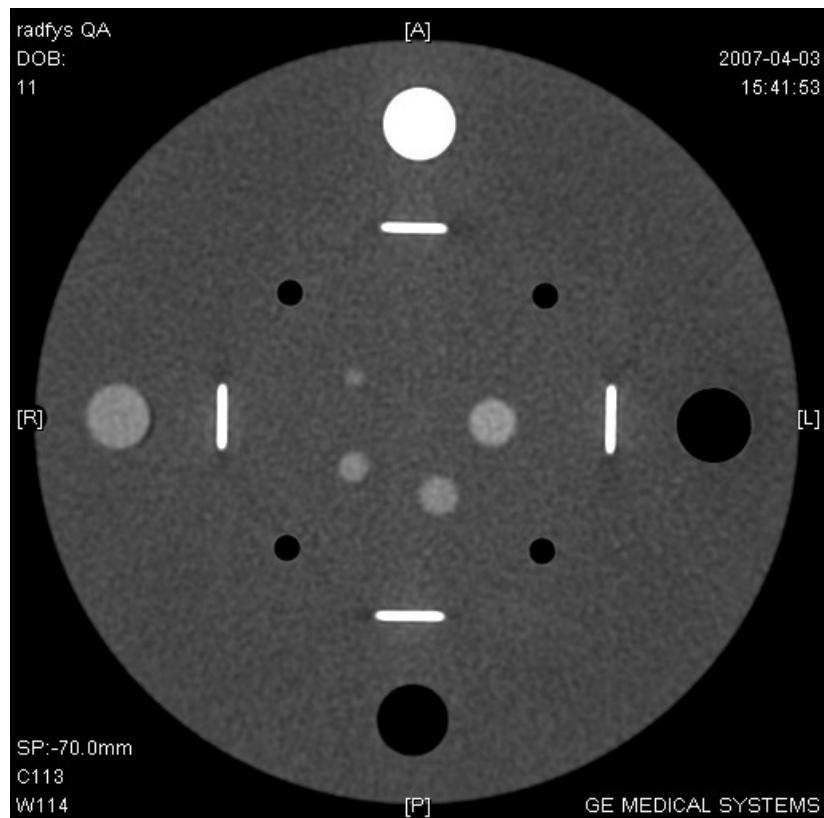
# Image quality phantoms

- The Phantom Laboratory Catphan, ACR Phantom
  - Uniformity
  - Detail resolution (MTF)
  - Low contrast resolution
  - CT number accuracy
  - Image artifact evaluation
- Tolerance levels (IEC)
  - Uniformity
  - CT number accuracy



# Image quality

- Verification beyond image quality (Catphan)
  - Alignment lasers
  - Table travel
  - Sensitivity profile (FWHM)
- Automatic evaluation
  - CT AutoQALite
  - Custom solutions (Matlab)



# Examination protocol review

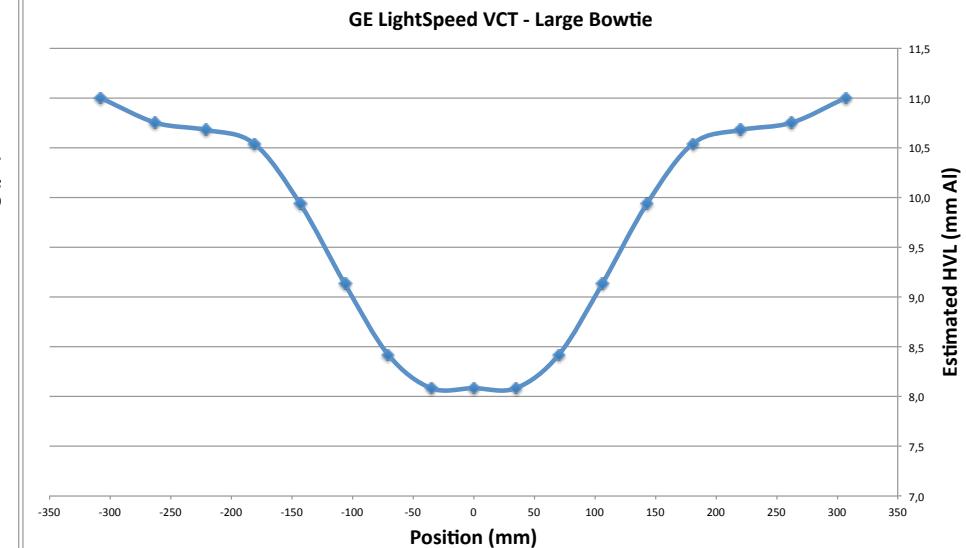
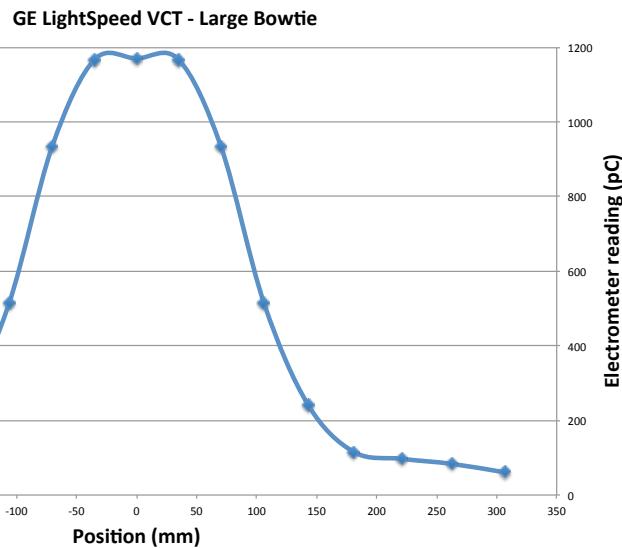
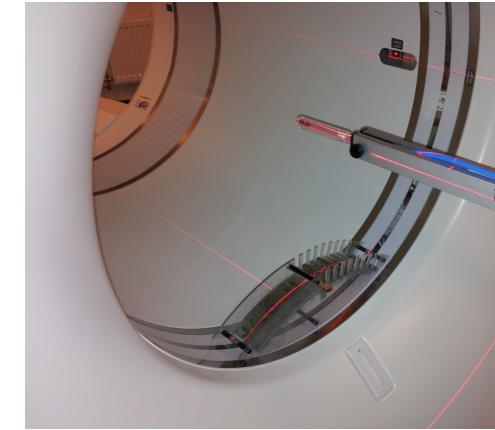
- Protocols (ACR/AAPM recommendations)
  - Head and abdomen for adult and pediatric patients
  - Very high dose rate procedures, e.g. brain perfusion
- Technique factors used and radiation output
  - kVp, mA, rotation time, detector configuration, pitch, reconstructed image thickness, AEC and IQ settings
  - Indicated CTDI<sub>vol</sub>
- Evaluation
  - Protocol management mode
  - DICOM information in PACS
  - RDSR information

# Practical work beyond acceptance

- Understanding the system
  - Optimization of procedures
  - Modeling (Monte Carlo)
- Beam quality and dose in modulated X-ray beams
  - Bowtie filter
  - Tube current modulation (TCM)
  - Adaptive collimation (spiral scans)
- Required equipment
  - Non-standard phantoms
  - Detector with small measurement volume

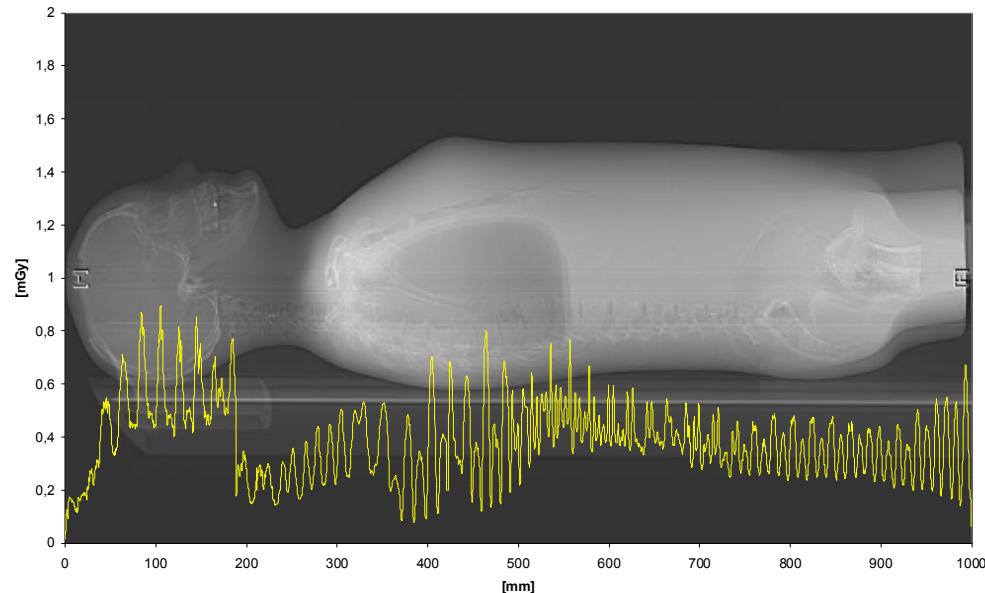
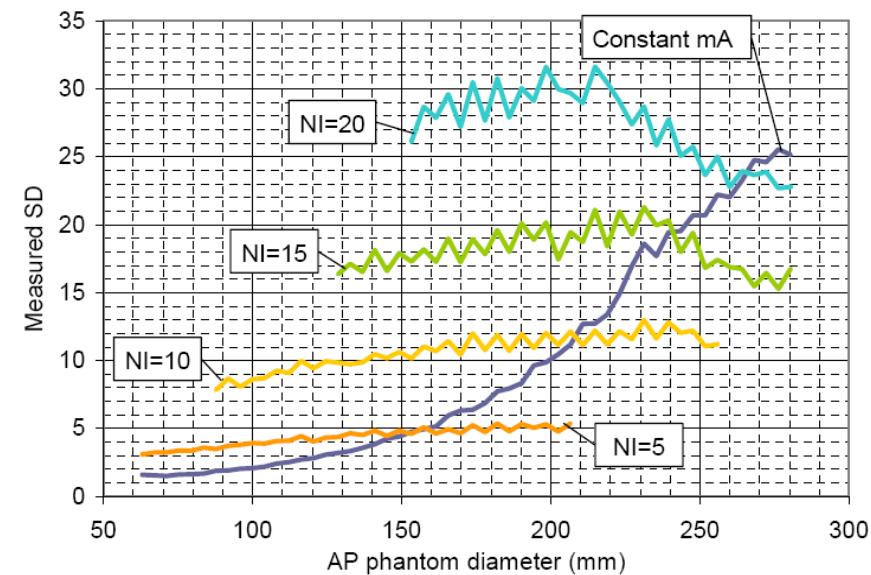
# Characterization of X-ray beam

- Radiation output and beam quality
  - Bowtie filter modulation
  - Important for modeling (Monte Carlo)
  - Custom filter holder (Aluminum)
  - Ionization chamber (SSDL)



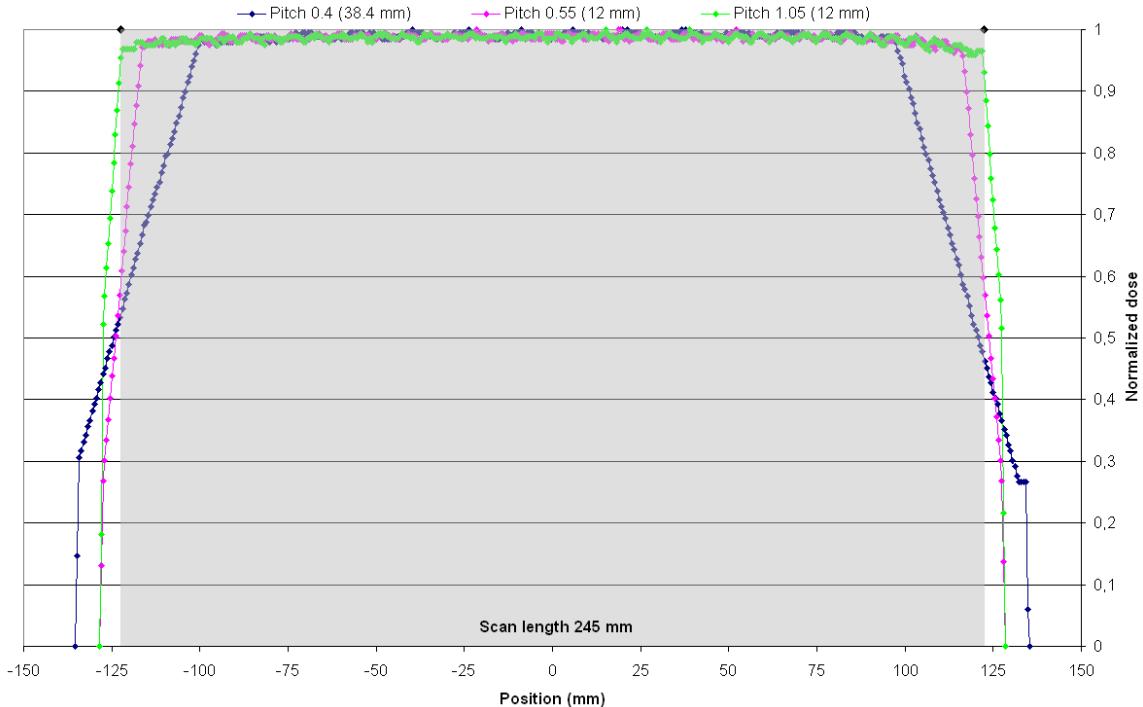
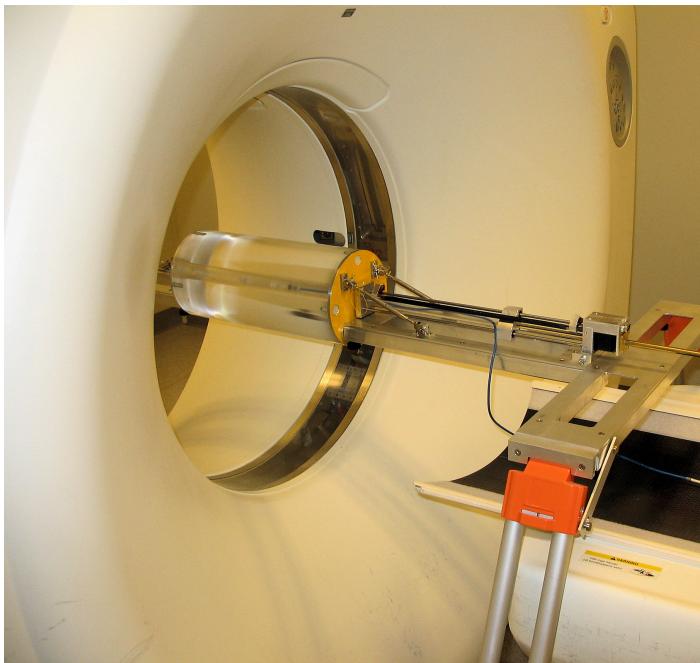
# Functionality of Tube Current Modulation

- Radiation output and image noise
  - Different TCM settings
  - Anthropomorphic phantom
  - Ionization chamber (SSDL)
  - High frequency electrometer



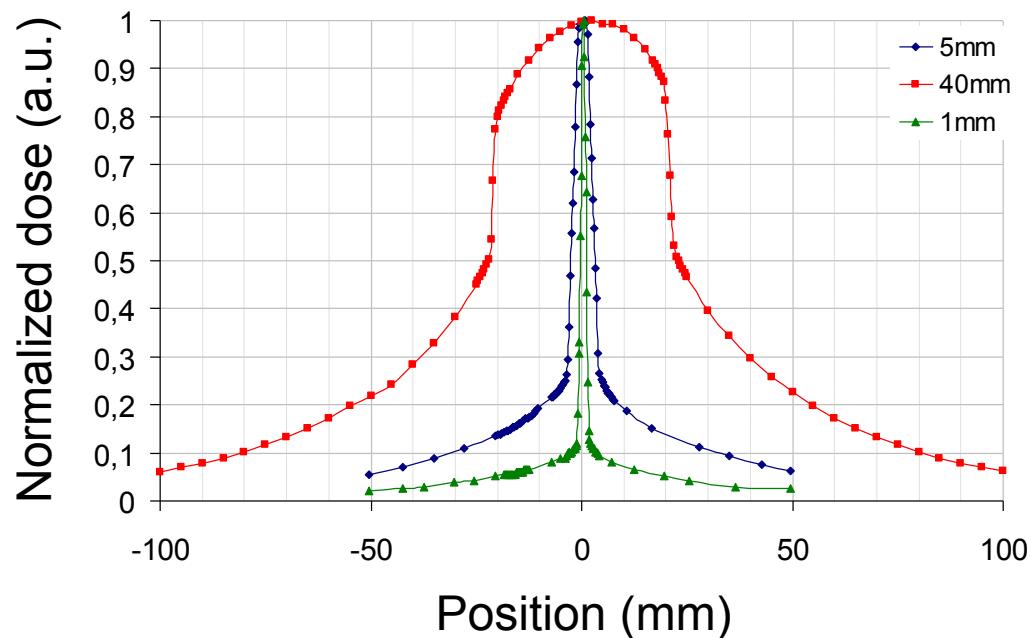
# Functionality of adaptive collimation

- Radiation output
  - Stationary phantom in isocenter, spiral scan mode
  - Different settings of pitch and nominal collimation
  - Ionization chamber (SSDL), high frequency electrometer



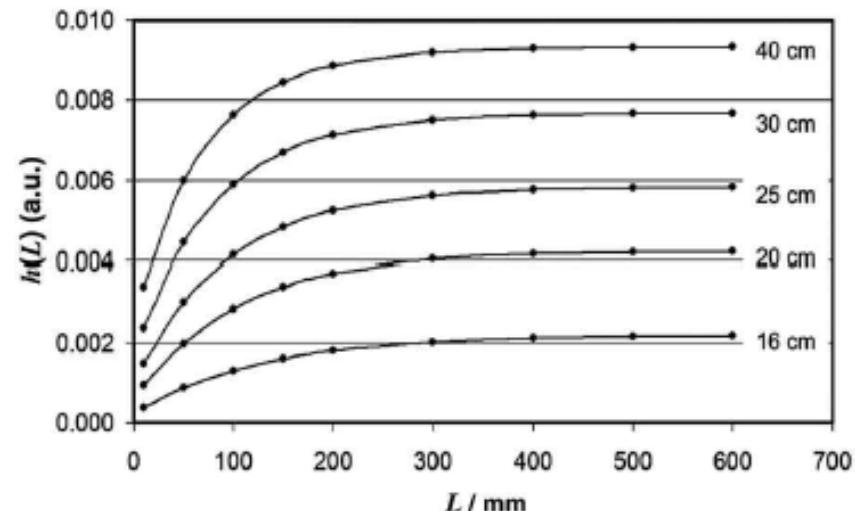
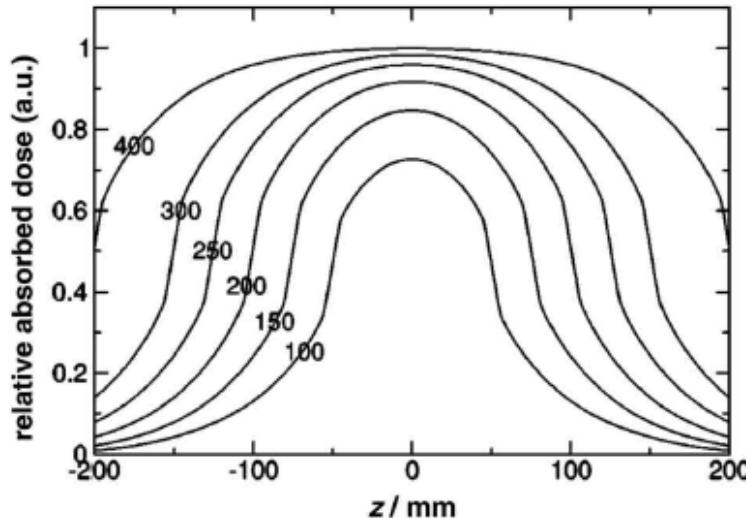
# Beyond the CTDI formalism

- The CTDI formalism
  - Robust for QA
  - Intrinsically poor for patient dosimetry
  - CTDI phantoms, axial scan mode, narrow beams



# Beyond the CTDI formalism

- Spiral scan mode and scan length
  - DLP scales linearly with scan length ( $\text{CTDI}_{\text{vol}} \times L$ )
- Dose equilibrium concept (AAPM Report No. 111)
  - Scatter makes dose distribution scan length dependent
  - Small measurement volume detector and large phantom



# Patient dosimetry

- Size Specific Dose Estimate (AAPM Report 204)
  - Patient size, geometry (basic) or attenuation (refined)
  - Conversion factors ( $f$ ) for different patient sizes
  - $SSDE = CTDI_{vol} \times f$
  - Includes scatter correction (dose equilibrium)
- Size and CT Specific Dose Estimate?
  - DICOM/RDSR – typical/maximum tolerance  $\pm 20\%/\pm 40\%$
  - Dosimetry code of practice, e.g. IAEA TRS 457
  - Robust dosimetry for a specific CT