Development of the ICRP Reference Scanner

ICRP Task Group 113

Reference Organ Absorbed and Effective Dose Coefficients for Computed Tomographic Examinations

Chapter 3

Development of the ICRP Reference Scanner and Determination of Organ Absorbed Doses

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ICRP

Content of Development of ICRP Ref. Scanner

Development of virtual ICRP Reference CT Scanner

- **CT scanner model base from major manufacturer under NDA**
  - 12 different scanner models
  - Simulated 102 operating conditions for Adult Male and Adult Female
- **ICRP Reference CT scanner**
  - Beam shaping filter
  - Homogenous filter
- **CT Dosimetry phantoms**
  - Simulated CTDI for ICRP Reference scanner against physical scanners
  - Decision: ICRP Reference scanner requires 2 beam shaping filters and 4 tube voltages
- **ICRP Adult phantoms**
  - Comparison ICRP Reference scanner with physical scanners

CT scanner database

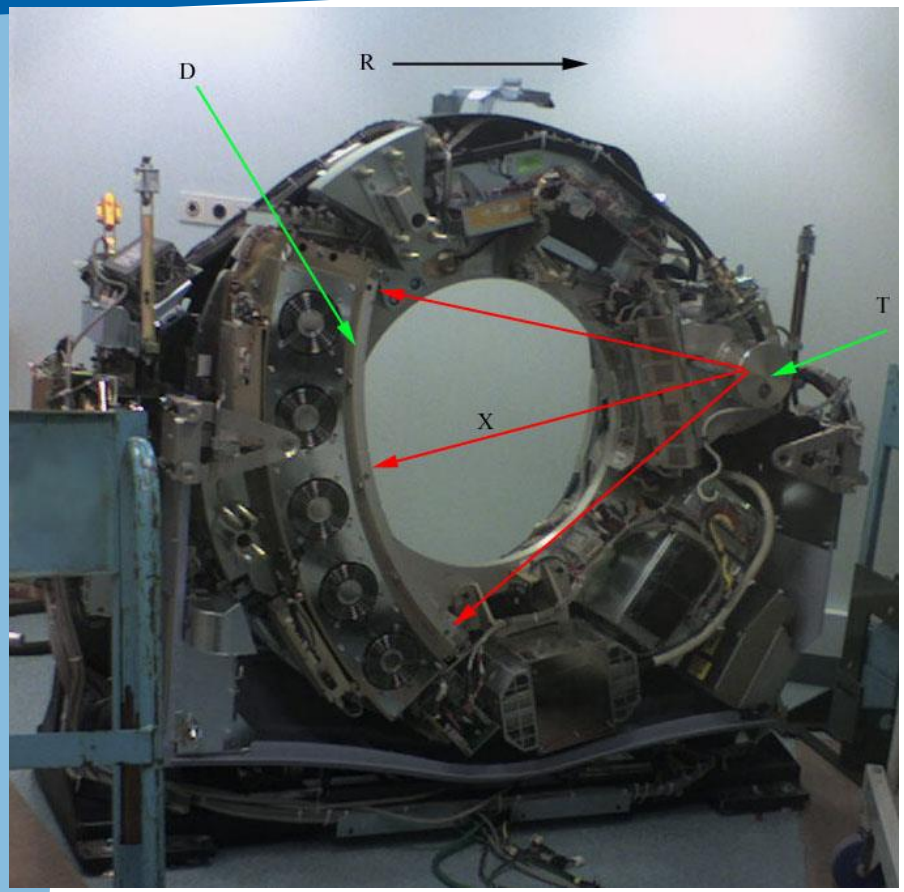
- **Manufacturers kindly supplied under Non-Disclosure Agreement (NDA) data about their CT scanner models including**
  - **Geometry**
    - Distances: X-ray focus to Centre of Rotation (CoR), X-ray focus to beam shaping filter, Detector to CoR, Collimation, Field of View
  - **X-ray tube**
    - anode material, anode angle, tube voltage, homogenous X-ray filter thickness, both internally and externally in thickness, density, and elementary material composition
  - **Beam Shaping Filter(s)**
    - Material(s) shape, thicknesses, density, and elementary material composition

CT scanner model database

Manufacturer	CT Model	Operating Conditions		
		Potential (kV)	Beam shaping filter	Fan size
General Electric (GE)	Brightspeed 16 Elite	80, 100, 120, 140	Large, Small	–
	Discovery CT750 HD	80, 100, 120, 140	Large, Medium, Small	–
	Optima CT660	80, 100, 120, 140	Large, Small	–
	Lightspeed VCT	80, 100, 120, 140	Large, Medium, Small	–
Philips	Brilliance CT 64	80, 120, 140	Fixed	–
	Brilliance iCT 256	80, 100, 120, 140	Body, Head, Baby	–
Siemens^	Somatom Definition	80, 100, 120, 140	Body, Head	Full, Small
	Somatom Emotion 6	80, 110, 130	Fixed	–
	Somatom Sensation 16	80, 100, 120, 140	Body, Head	–
	Somatom Sensation 64	80, 100, 120, 140	Fixed	–
	Somatom Sensation Open	80, 100, 120, 140	Fixed	–
Toshiba*	Aquilion 16	80, 100, 120, 135	Dose reduction, Large, Small	–

^Siemens Healthineers *Toshiba now Canon

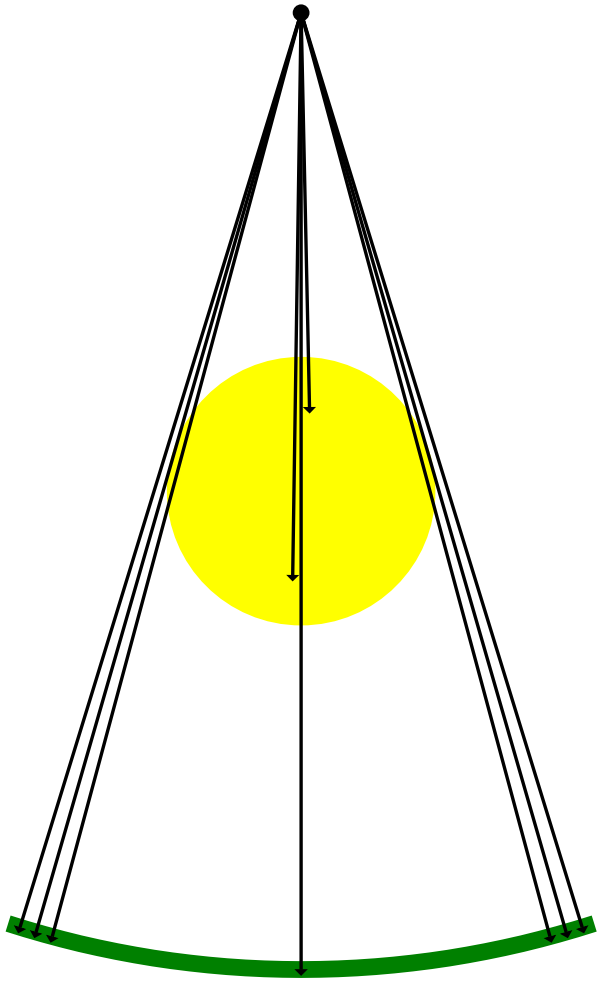
CT scanner model



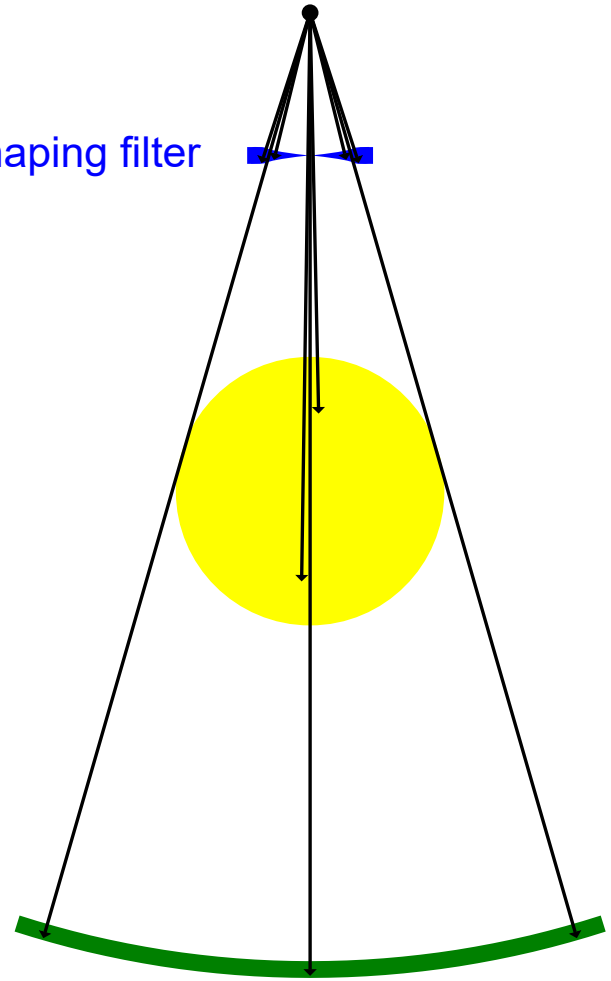
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T X-ray tube
X X-ray beam
D Detector
R Rotation direction

Scanner without beam shaping filter



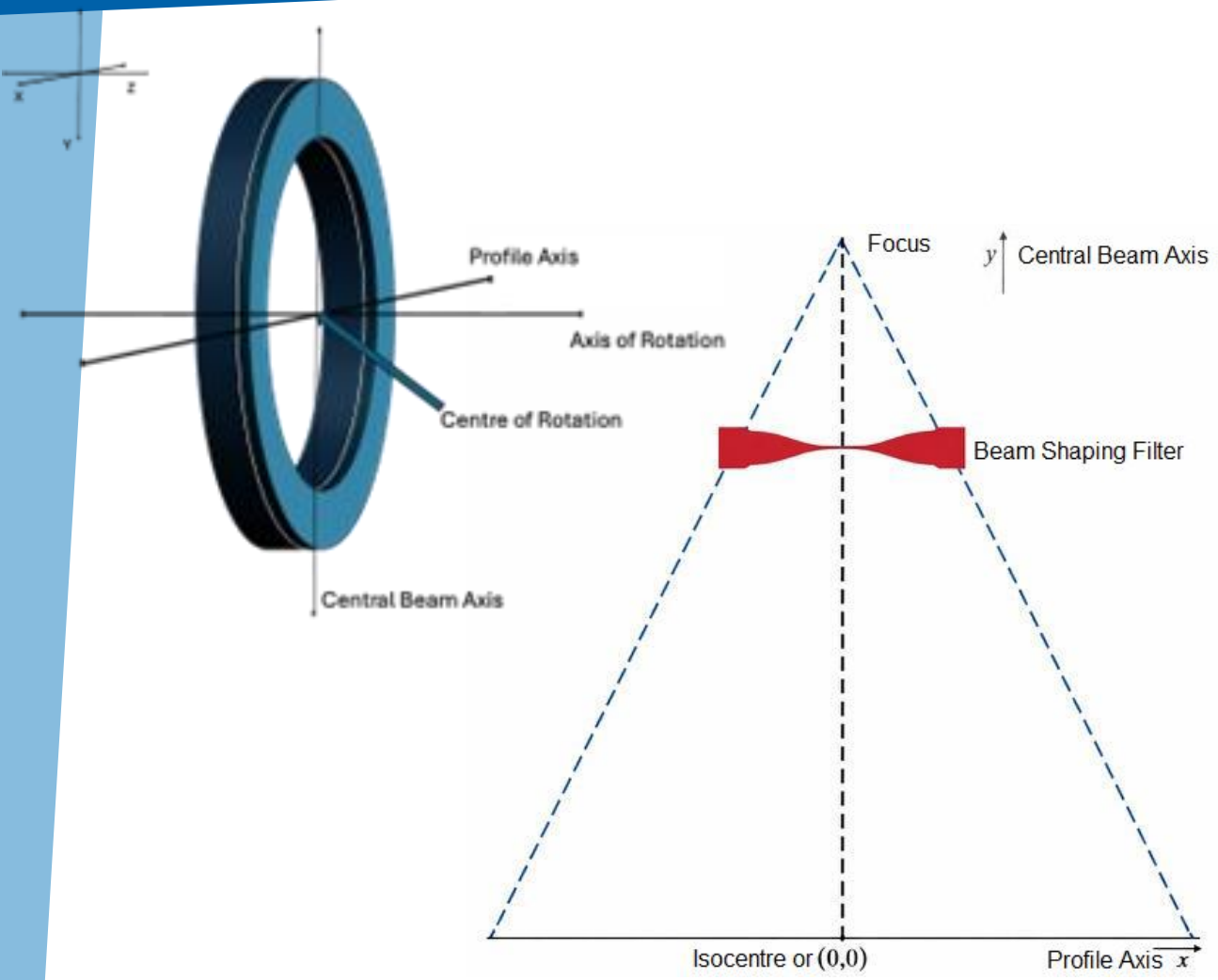
Scanner with beam shaping filter



Construction ICRP Reference CT scanner

- **Geometric parameters**
  - Focus to isocentre distance
  - Focus to beam shaping filter distance
- **Dose profile axis**
  - Calculation of dose profiles for Body and Head beam shaping filters at 60 keV
- **Beam shaping filters**
  - Derive Body and Head beam shaping filters made of aluminium
- **Homogeneous X-ray filter**
  - Homogeneous aluminium filter was interpolated from various added filter thicknesses to match the physical CT scanners averaged $CTDI_{centre,32}$ / $CTDI_{free\text{-}in\text{-}air}$ at 120 kV tube voltage with the Head beam shaping filter

Construct Beam Shaping Filter



- **Calculate point detector dose in air-kerma per starting photon with 60 keV monoenergetic photons**
  - from X=0 cm to 37 cm and X= -0.5 cm to -37.5 cm, in 1 cm steps
  - for each CT scanner model with Body and Head filter
- **Average**
- **Correct for increased distance and incident angle towards boundaries**
- **Convert attenuation to aluminium thickness**
- **Linear scale beam shaping filter to the location**

Adjust homogeneous filter

- **Calculate $CTDI_{centre,32}$ / $CTDI_{free\text{-}in\text{-}air}$ for tube voltage exactly 120 kV, Head filter for each model and average the results**
- **Generate with IPEM SR 78 spectra† with 3, 5, 7, 9, 11 mm aluminium filter, 120 kV tube voltage and 7 degree target angle for the ICRP reference scanner with Head beam shaping filter**
- **Interpolate these 5 ICRP reference CT scanner results to the average physical scanner**
- **Homogeneous filter thickness of 8.2 mm aluminium.**

†: https://www.ipem.ac.uk/resources/all-ipem-guidance/

CT Dosimetry phantom simulations

CT Dosimetry phantoms



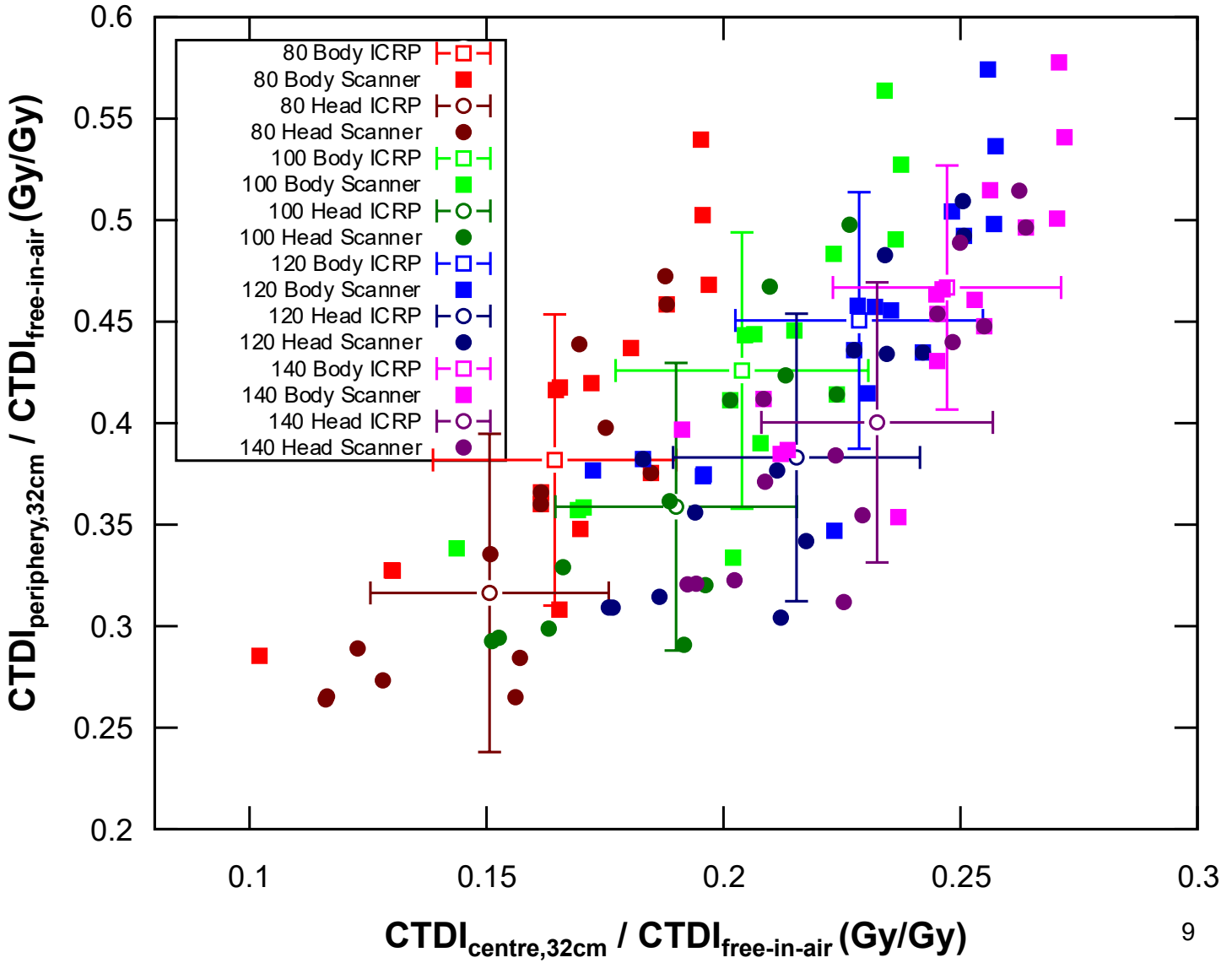
Image courtesy PTW

32 cm and 16 cm diameter of PMMA

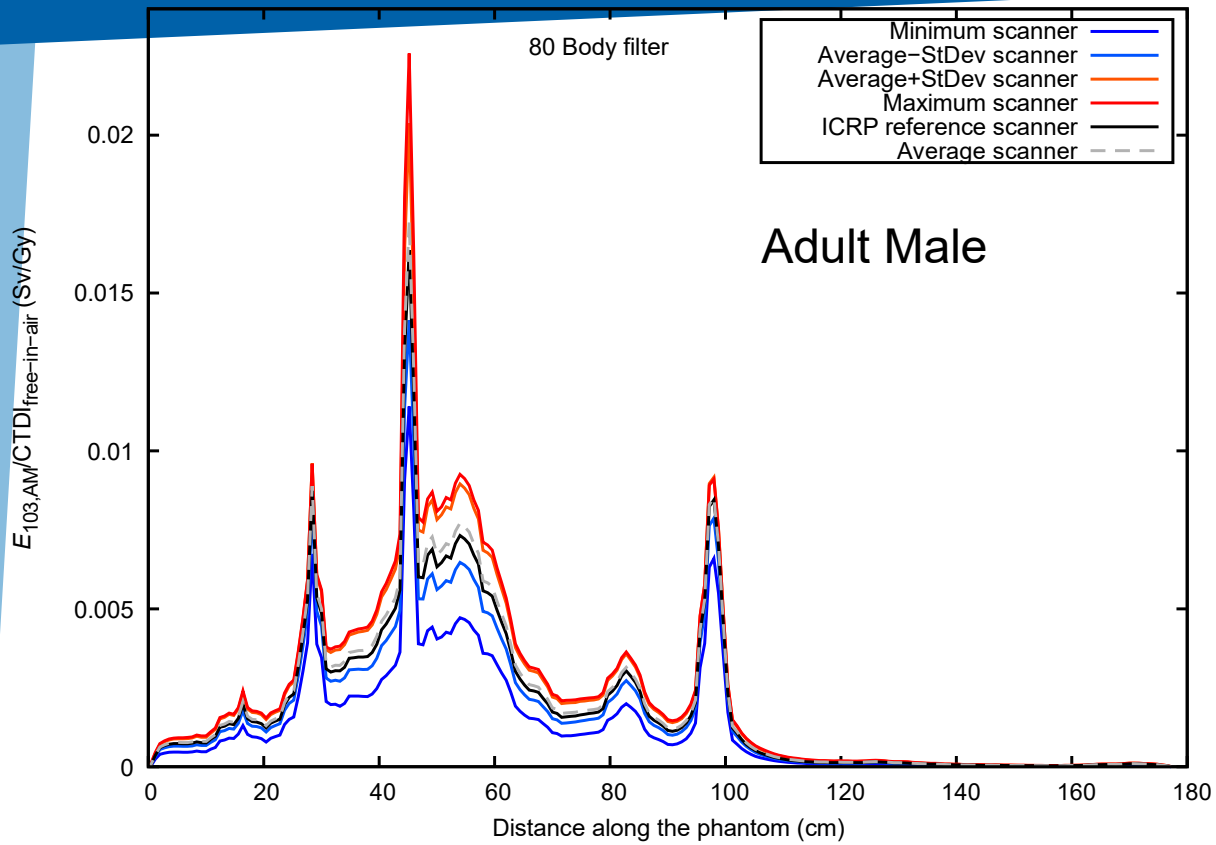
Scanners: ICRP scanner and database scanners

Simulations: 102 operating conditions (database) + 8 (ICRP)

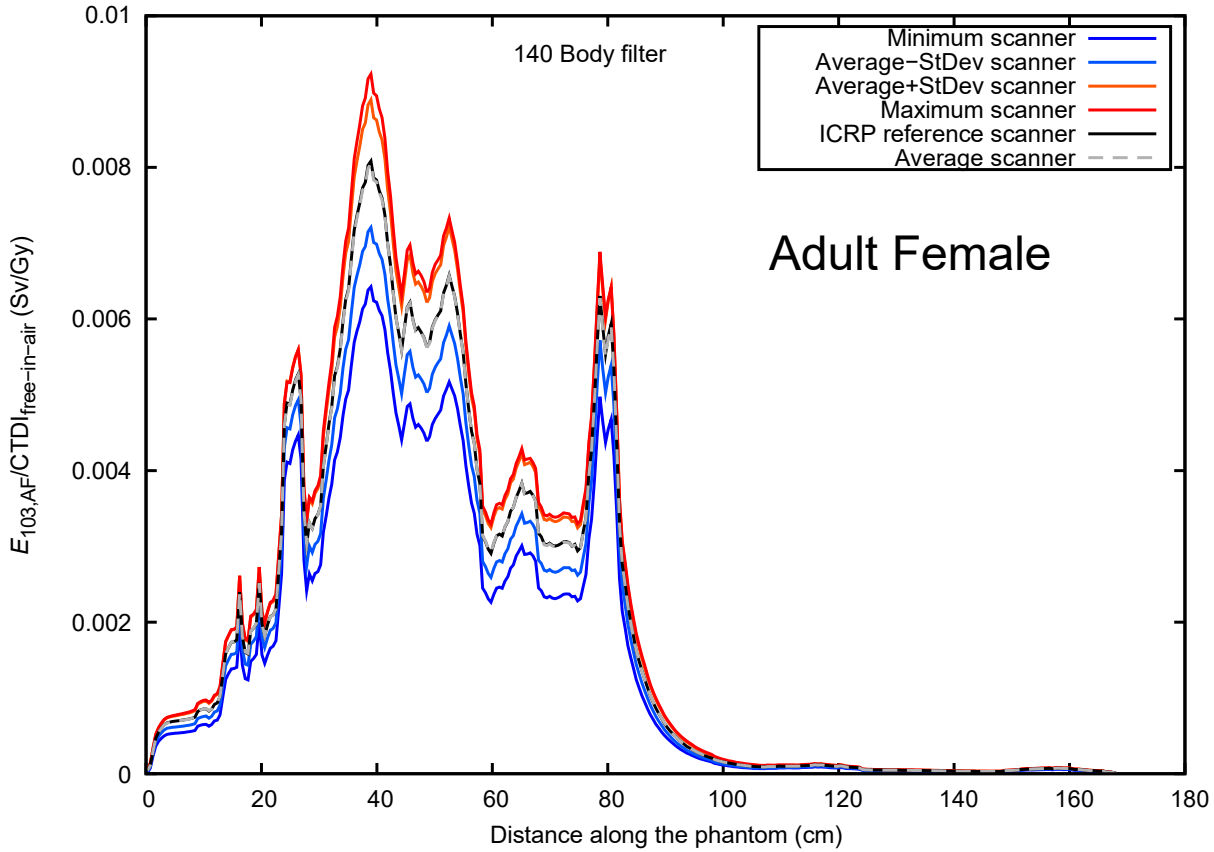
Conclusion: ICRP Reference scanner requires 4 tube voltages and 2 beam shaping filters.

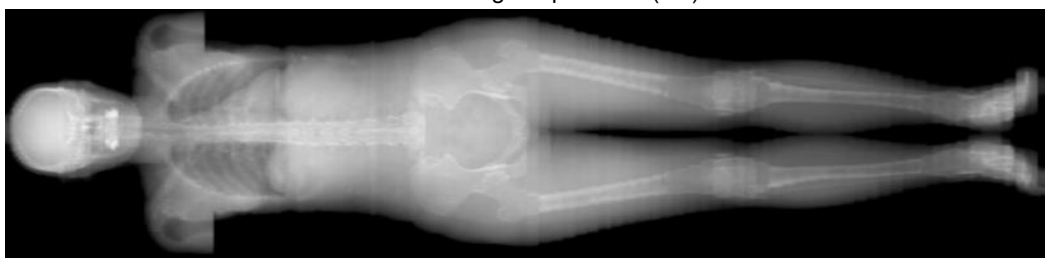


Comparison ICRP Reference CT Scanner









Summary

Development of the ICRP Reference CT scanner

- **Database of CT scanners**
- **Dose profiles are used the determine the beam shaping filter thickness of aluminium at various positions**
- **$CTDI_{centre,32}$ / $CTDI_{free\text{-}in\text{-}air}$ is used to determine the homogeneous filter thickness at 120 kV for the Head beam shaping filter**
- **ICRP reference CT scanner needs 80, 100, 120, and 140 kV with beam shaping filter Body and Head**
- **$D_{T,i}$ / $CTDI_{free\text{-}in\text{-}air}$ and $E_{103,AF\ or\ AM,i}$ / $CTDI_{free\text{-}in\text{-}air}$ are used to compare the ICRP reference CT scanner with the database CT scanners.**



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