CT dosimetry for Nuclear Medicine applications

John Le Heron

National Radiation Laboratory

Christchurch, NZ

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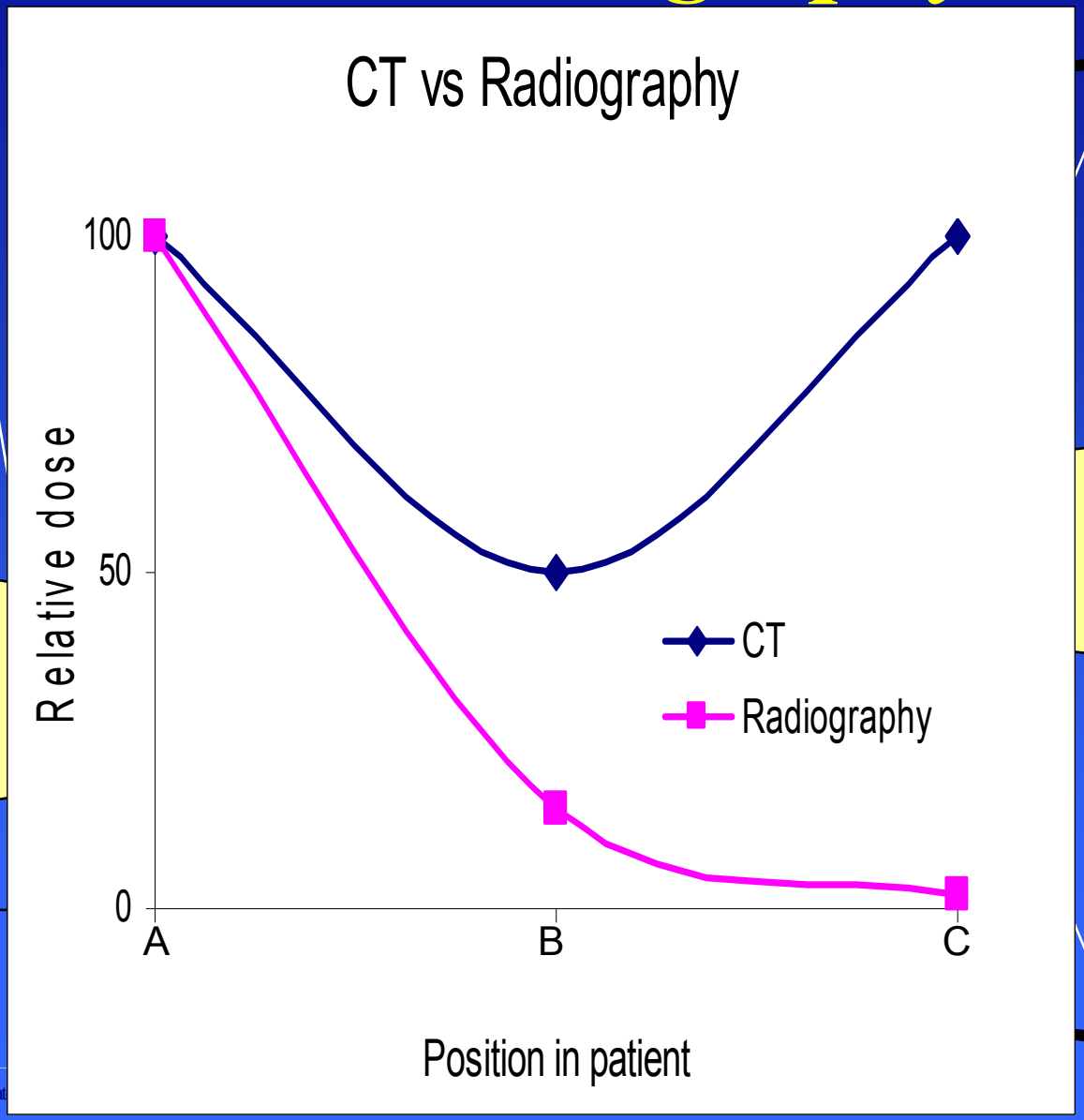
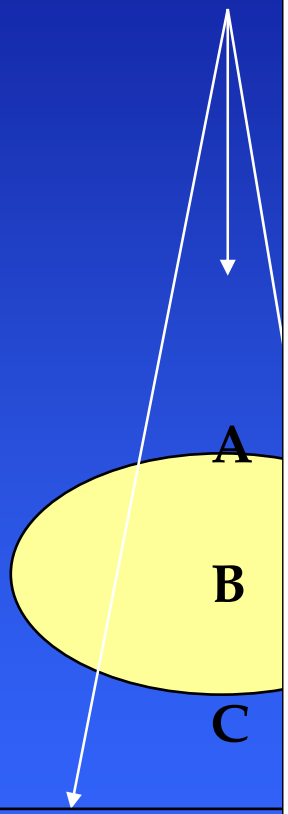
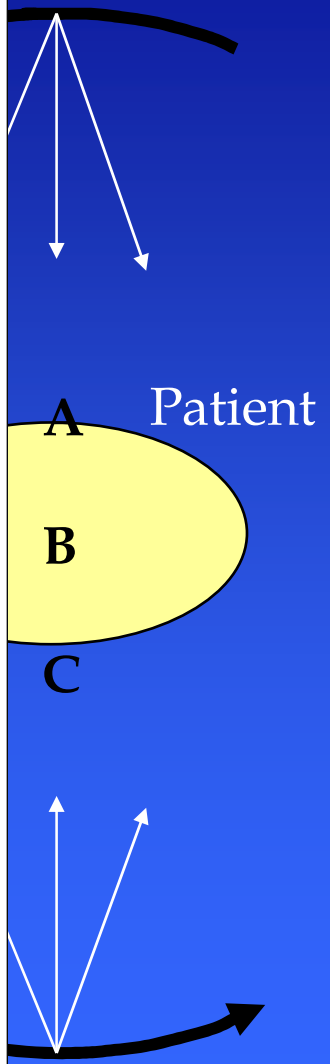
Outline

- Introduction to CT axial dose distributions
- CTDI and its many guises
- Effective dose for adults and children
- Factors affecting CT doses
- CT doses in PET

CT vs Radiography







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CT depth doses

- Within the scanned volume:
  - Much more uniform than for conventional x-ray
  - Uniformity depends on
    - Patient size
    - kVp
    - Patient position

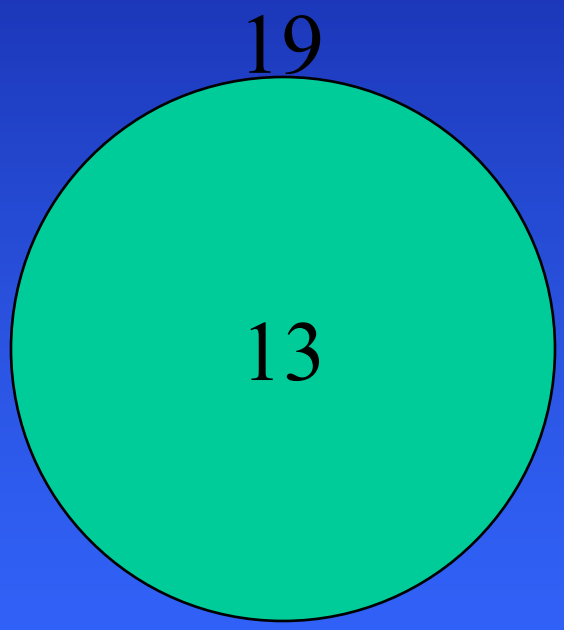
Patient size

- Two phantoms commonly used in CT dosimetry are:
  - 16 cm diameter perspex cylinder
    - Head phantom
  - 32 cm diameter perspex cylinder
    - Body phantom

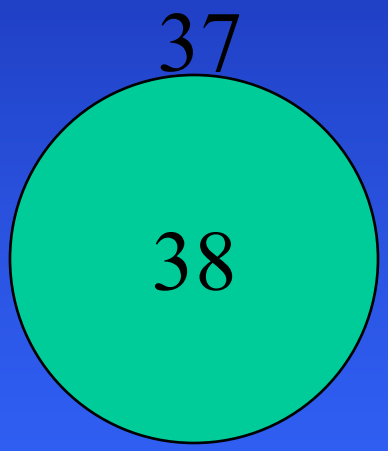
Uniformity vs phantom size

Eg. Surface dose and centre dose (mGy), 120 kVp & 300 mAs

- Less uniform as size increases



Body phantom



Head phantom

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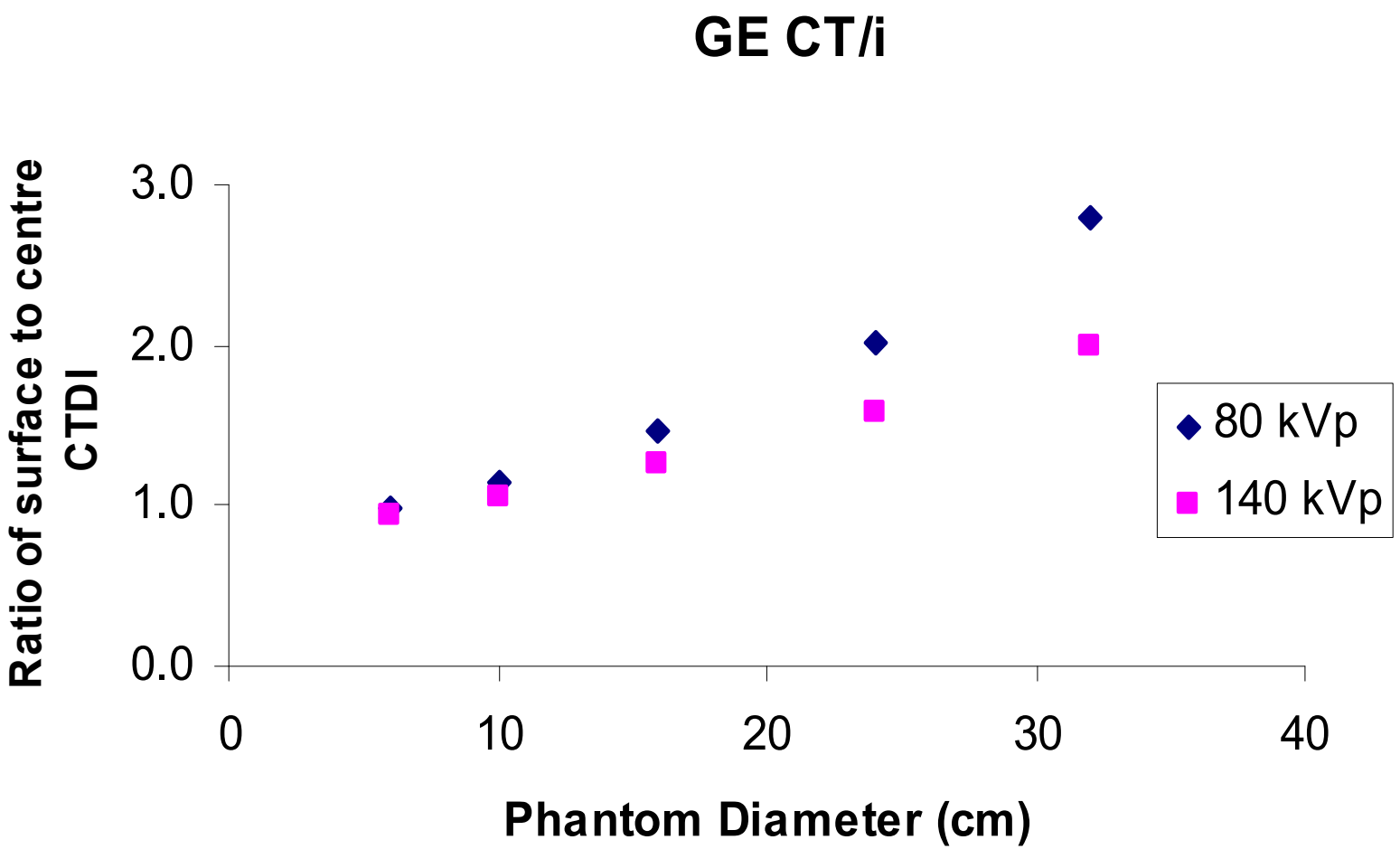
Uniformity vs kVp

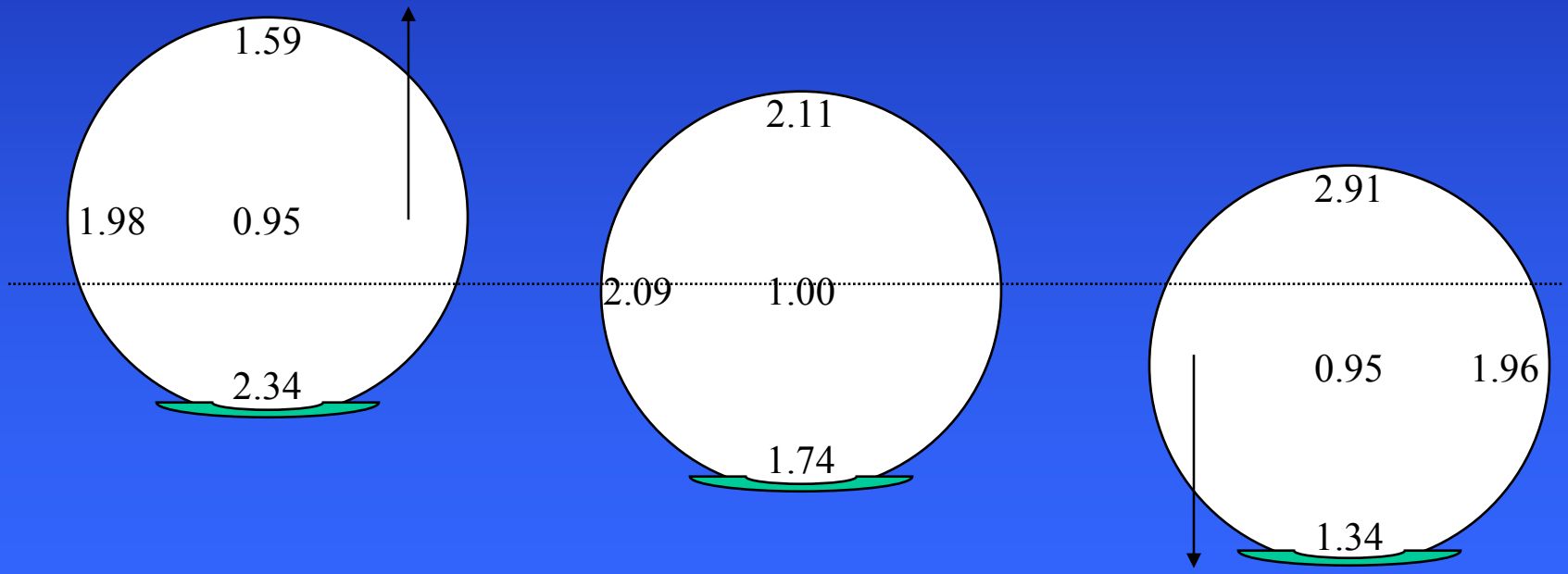
- Less uniform as kVp decreases



Uniformity vs patient position

Body phantom, moved ± 5 cm vertically (GE CT/I, 120 kVp)

- Less uniform as moved away from iso-centre



Measurable dose quantities in CT

- Practical issues include:
  - Tube rotation
  - Thin (single slice) fan beam
  - Fairly thin (multislice) fan beam
  - Patient (table) feed

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CTDI

- Computed Tomography Dose Index

$$CTDI = \frac{1}{nT}\int_{-\infty}^{\infty} D(z)dz$$

D(z) = dose profile, in the z direction, from a single rotation

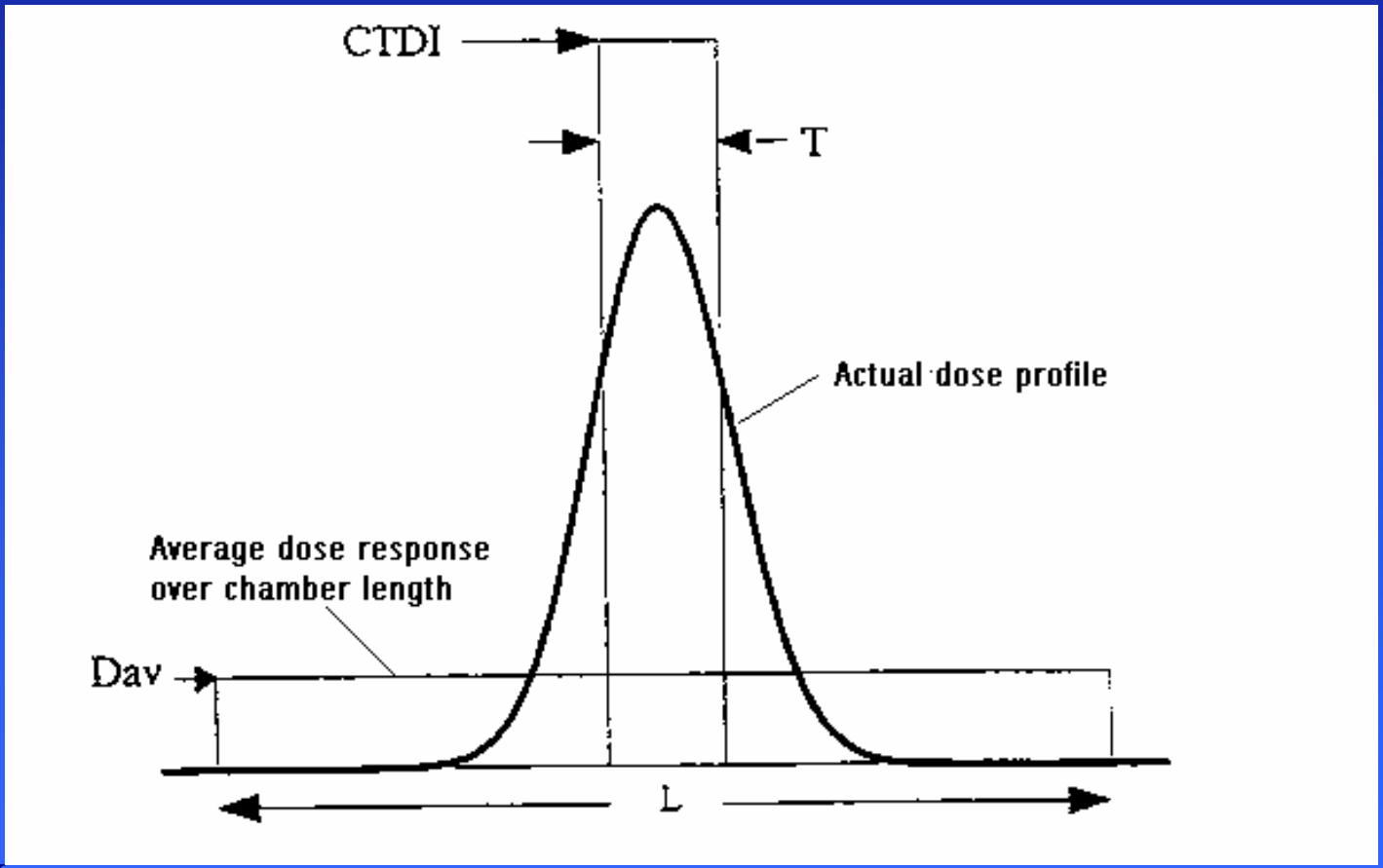
T = nominal slice width

n = number of slices in that rotation

What does CTDI really mean?

- It re-assigns the actual dose profile to a rectangular dose profile
  - Width of rectangle = nominal slice width
  - Height of rectangle = CTDI

Measuring CTDI with a pencil chamber



$$CTDI_{100} = D_{av} \times L / T$$

Are all CTDIs equal?

- Integration length
  - 100 mm, $CTDI_{100}$
  - 14 times the nominal slice width, $CTDI_{FDA}$
- Where it is measured
  - Free-in-air, $CTDI_{air}$
  - In a perspex dosimetry phantom
- Medium for dose
  - Air
  - Perspex
  - Muscle

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Measuring $CTDI_{100}$

- Usually measured with a pencil chamber
  - Active length of 100 mm

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$_{n}CTDI_{100,air}$

- On axis, free-in-air
- Normalised values, /mAs or /100 mAs
- Radiation output for use in CT dose programs
  - Typical normalised values
    - 10 to 40 mGy per 100 mAs

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CTDI in phantoms

- Dosimetry phantoms – perspex cylinders
  - Head, 16 cm diameter
  - Body, 32 cm diameter
  - Length > active volume of pencil chamber
  - Holes to accept pencil chamber
    - Centre
    - Periphery, 10 mm below surface
- Purpose – measurement of local dose

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Head and body dosimetry phantoms

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More CTDIs in phantoms

- Weighted CTDI: $CTDI_w$

$$CTDI_W = \frac{1}{3} CTDI_{100,C} + \frac{2}{3} CTDI_{100,P}$$

$CTDI_{100,C}$ = $CTDI_{100}$ at the centre of the dosimetry phantom

$CTDI_{100,P}$ = $CTDI_{100}$ at the periphery of the dosimetry phantom

$CTDI_w$ represents average dose in the phantom, in the irradiated slice

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Effective $CTDI_W$

- $CTDI_{w,eff}$
- Also known as $CTDI_{vol}$

$$CTDI_{W,eff} = \frac{1}{p} CTDI_W$$

p = pitch = table feed per rotation/beam collimation

$CTDI_w$ or $CTDI_{w,eff}$ – displayed on modern CT consoles

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Dose length product, DLP

- Characterises the overall radiation exposure for the CT examination
- Displayed on the CT console

$$DLP = CTDI_W \times T \times N$$

$$DLP = CTDI_{W,eff} \times L$$

T = slice width

N = total number of rotations in the exam

L = scan length

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But what about effective dose and organ doses in CT?

Estimating effective doses in CT

- Methods for adults well developed
  - Normalised organ dose data sets
    - NRPB-SR250 (1991)
      - CTDOSE
      - CTDosimetry.xls
    - GSF
      - CT-Expo (effective dose, uterine dose)

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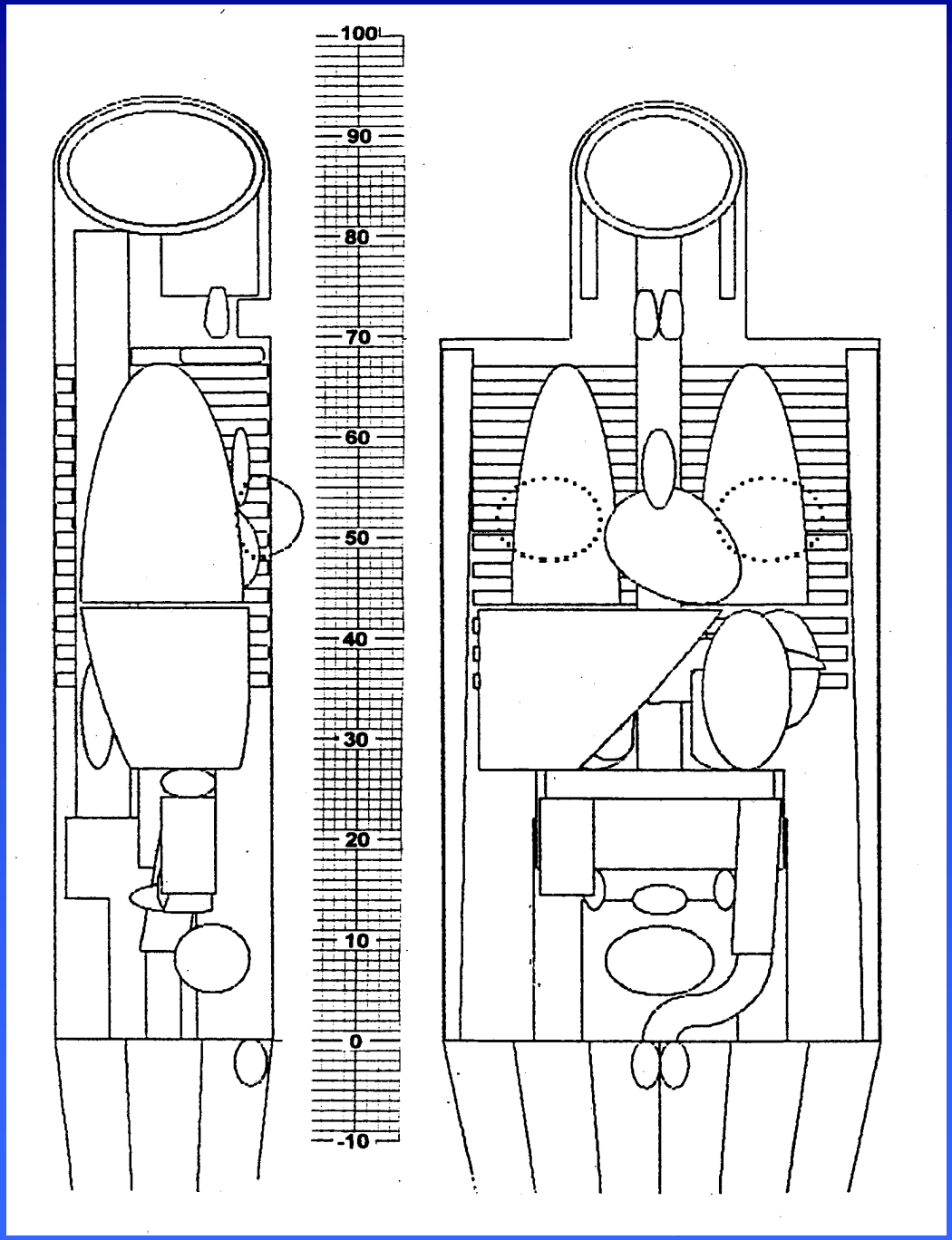
Phantom used by the NRPB for MC simulations of CT examinations



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Organ dose datasets from NRPB MC calculations

- CT – adult

Group	*Phantom*	*Reference quantity*	*No of slabs*	*No of spectra*	*No of organs*
NRPB	Cristy hermaphrodite	Axial $CTDI_{air,\ muscle}$	208	23	23

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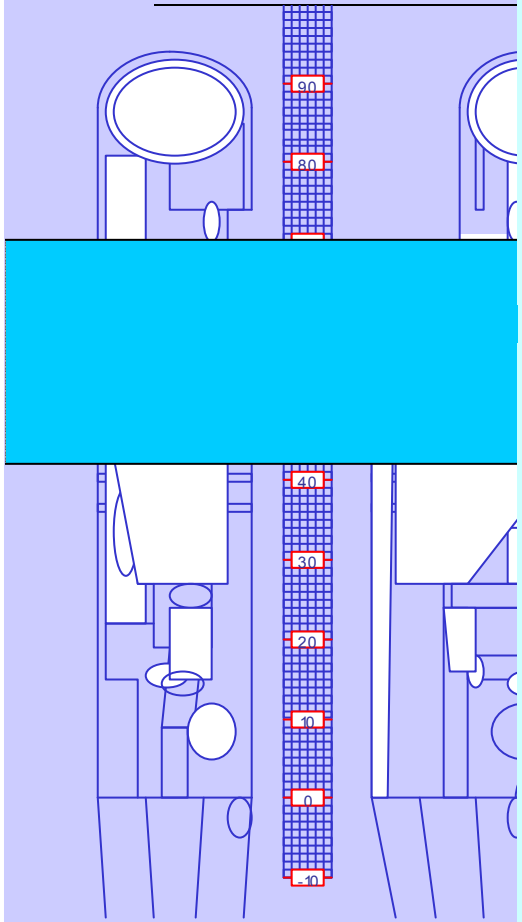
ImPACT CT Patient Dosimetry Calculator

version 0.99t, 24/07/2003



Scanner Model:			
Manufacturer:	Siemens		
Scanner:	Siemens Sensation 16		
kV:	120		
Scan Region:	Body		
Data Set	MCSET16	Update Data Set	
Current Data	MCSET16		
Scan range			
Start Position	42.5	cm	Get From Phantom Diagram
End Position	70.5	cm	
Patient Sex:			

Acquisition Parameters:			
mA	300	mA	
Rotation time	0.5	s	
mAs / Rotation	150	mAs	
Collimation	24	mm	
Slice Width	1.5	mm	
Pitch	1.5		
Rel. CTDI	Look up	1.11	at selected collimatic
CTDI (air)	Look up	18.7	mGy/100mAs
CTDI (soft tissue)		20.0	mGy/100mAs
${}_nCTDI_w$		7.6	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	0.0087	0.0017
Bone Marrow (red)	0.12	3.2	0.39
Colon	0.12	0.021	0.0025
Lung	0.12	12	1.4
Stomach	0.12	1.3	0.16
Bladder	0.05	0.0046	0.00023
Breast	0.05	9.8	0.49
Liver	0.05	2	0.1
Oesophagus (Thymus)	0.05	13	0.64
Thyroid	0.05	3.6	0.18
Skin	0.01	2.4	0.024
Bone Surface	0.01	6.2	0.062
Remainder1	0.025	13	0.32
Remainder 2	0.025	2.2	0.056
Total Effective Dose (mSv)			**3.8**

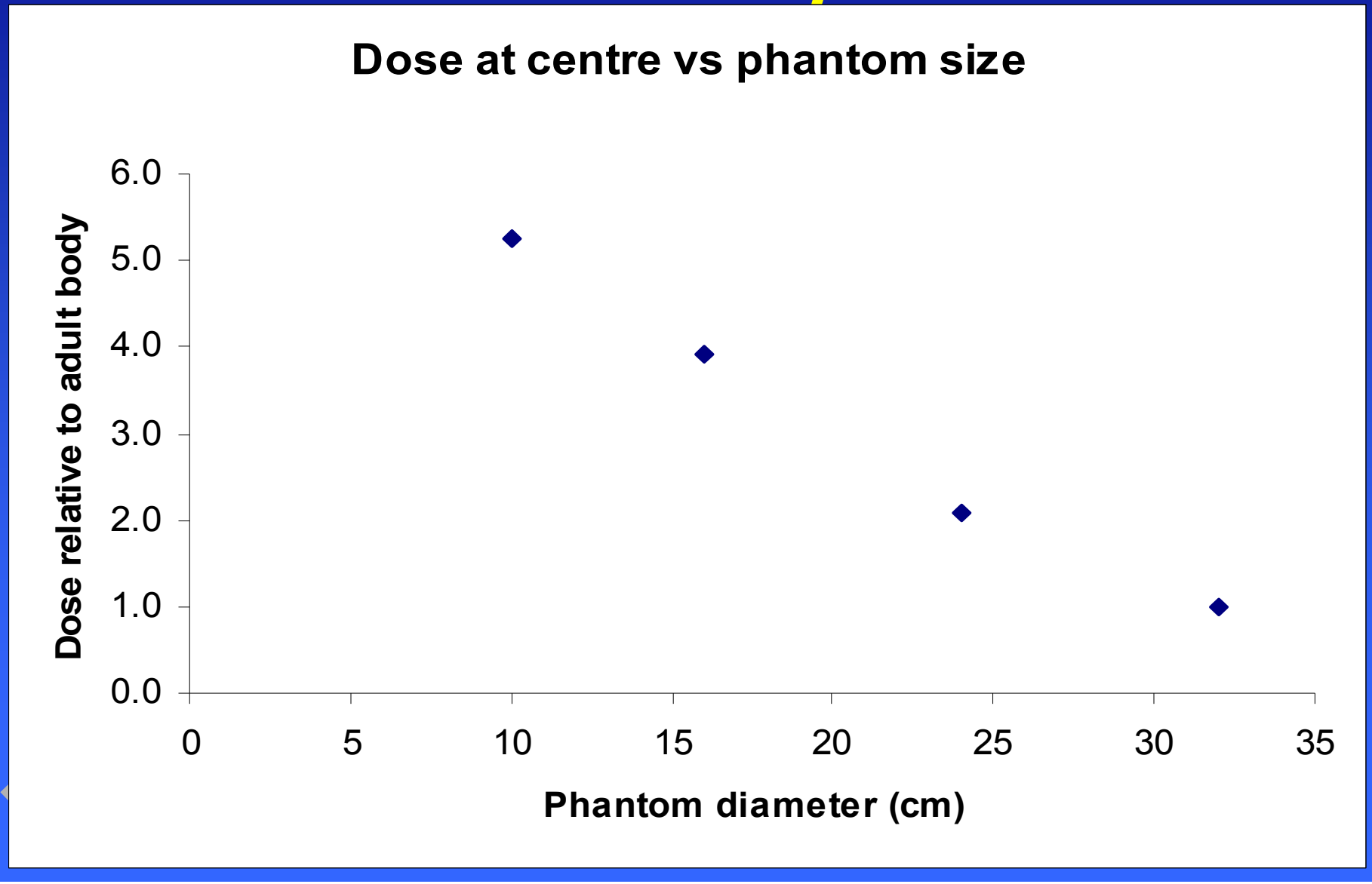
Remainder Organs	H_T
Adrenals	2.4
Brain	0.14
Upper Large Intestine	0.11
Small Intestine	0.084
Kidney	0.51
Pancreas	1.8
Spleen	1.5
Thymus	13
Uterus	0.023
Muscle	2.4

${CTDI_w}$ (mGy)	11.4
${CDTI_{vol}}$ (mGy)	7.6
DLP (mGy.cm)	213

And for children?

- Methods for children less well developed
  - Normalised organ dose data sets
    - GSF
      - Limited data
      - CT-Expo (new born and 7 year old)
  - Specific cases
    - Eg. 14 year-old with a particular scanner
      - Caon et al
  - Energy imparted to cylindrical phantoms

Dose vs phantom size – constant exposure



Relative normalised effective dose

- Calculate the effective dose to an adult for the given CT exam, matching:
  - the anatomy scanned
  - the "delivery of the radiation"
    - Scanner, kV, mAs per rotation, pitch, CTDI, etc
- Scale by a factor dependent on:
  - the ratios E/AAK for the child vs an adult
    - the given body region
      - *Data presented*
        - *EPSM2000 – Le Heron*
        - *BJR 2002 - NRPB*

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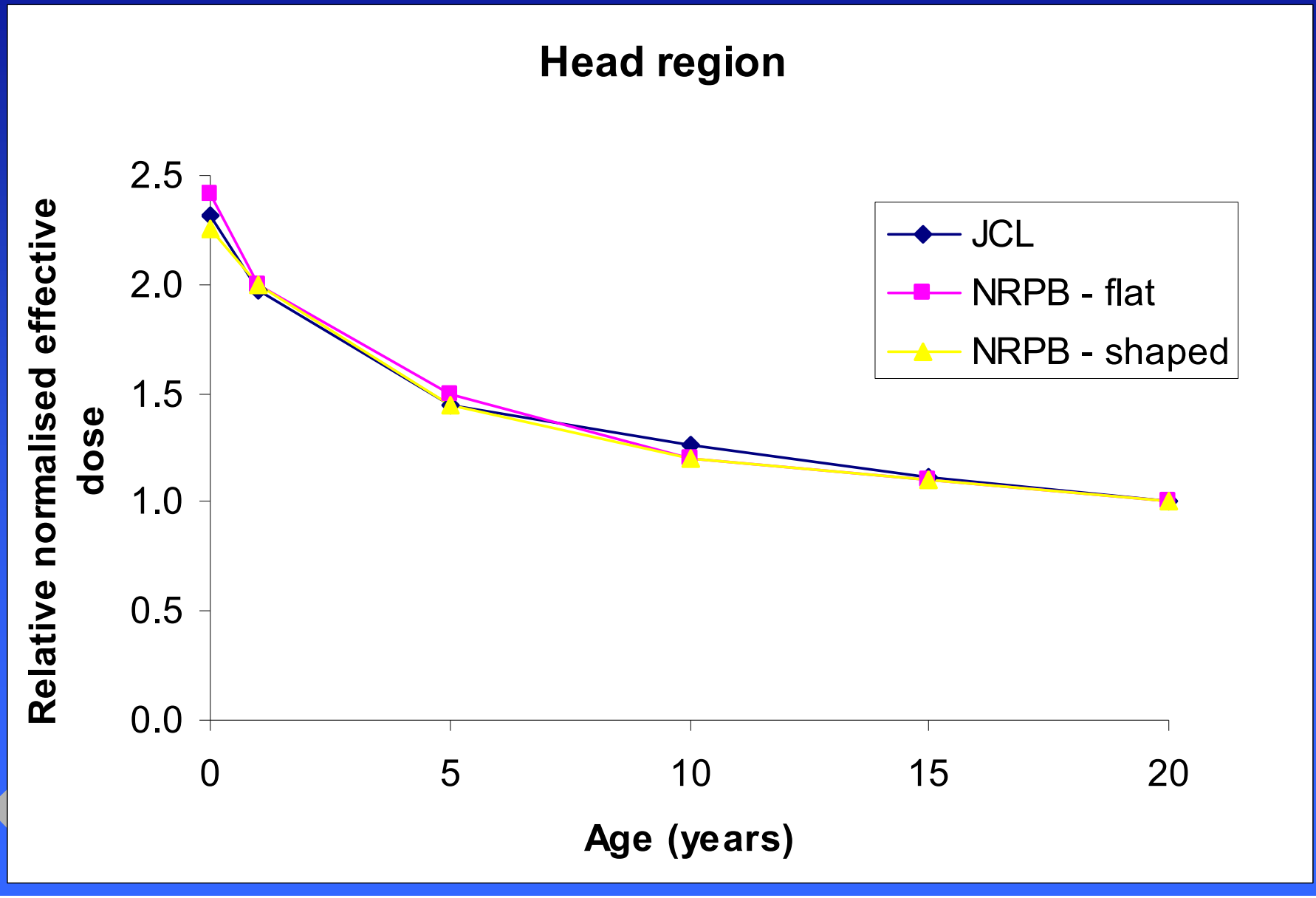
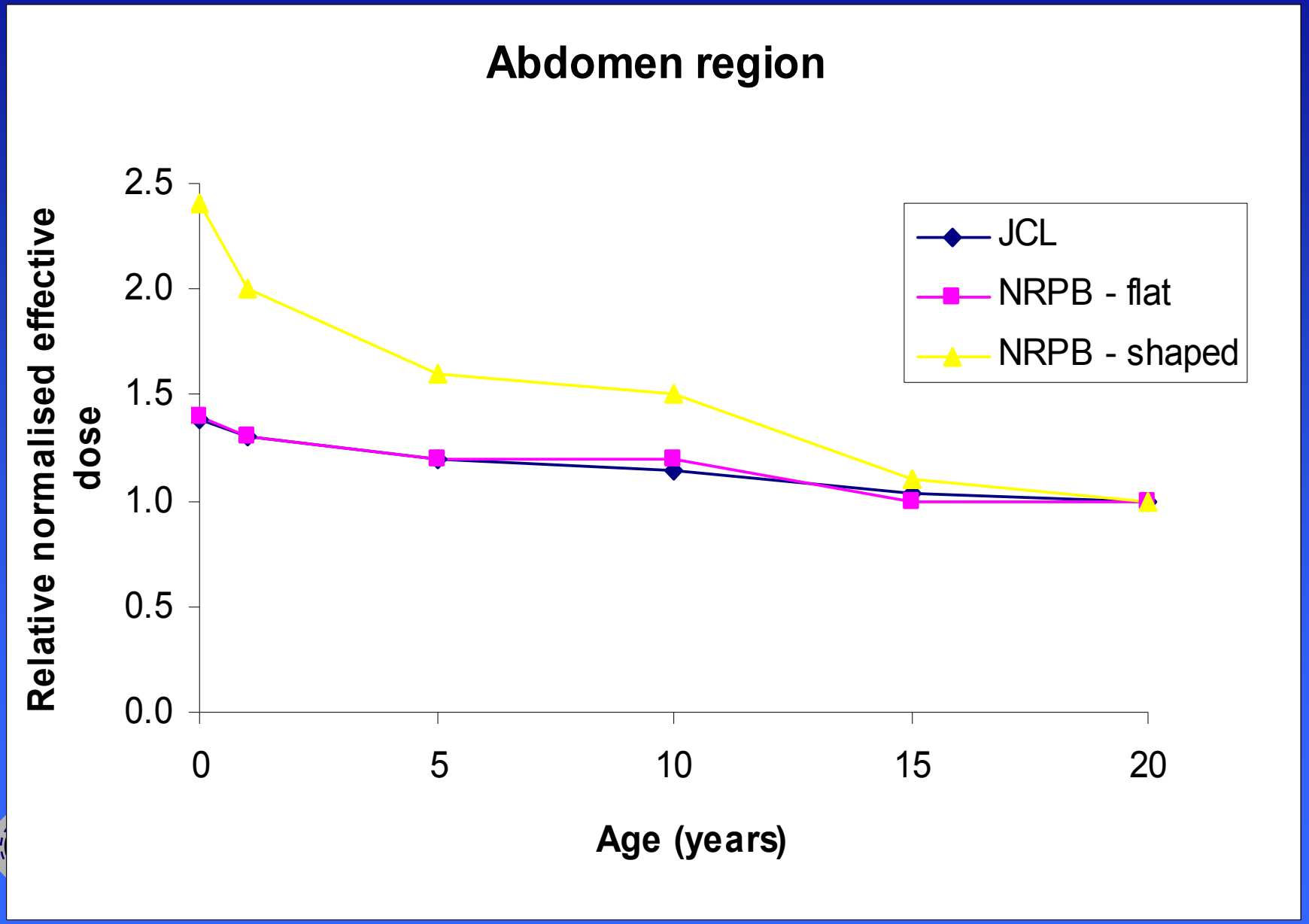
Child vs adult



Child vs adult



Effective doses for CT – adult factors

	Baby	Adult
	Effective dose (mSv)	
Head	6.5	2.7
Abdomen	15.4	11.0

CTDI per mAs = 0.2 mGy/mAs, flat filtered beam
400 mAs per rotation for Head exams
200 mAs per rotation for Abdomen exams

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Optimised paediatric CT

- mAs
  - should be significantly lower

	Abdomen	
	mAs	Effective dose (mSv)
Baby	50	4
Adult	200	11

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Factors affecting CT doses

- Patient dose depends on
  - Machine factors
  - Examination factors

Machine factors affecting patient dose

- Include:
  - beam filtration
  - beam shaping
  - focus to axis distance
  - detector efficiency
  - beam collimation

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Exam factors affecting patient dose

- Examination factors
  - Volume scanned
    - scan length
    - use of contrast
      - multi-phase
  - Exposure factors
    - mAs per rotation
      - patient size
      - slice width
      - reconstruction filter
    - pitch
    - kVp

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Automatic exposure control

- Adapting mA to the attenuation of the patient
  - Longitudinal dose modulation
    - Slice by slice modulation
  - Circular dose modulation
    - Modulation within a rotation
  - Temporal dose modulation
    - Heart studies

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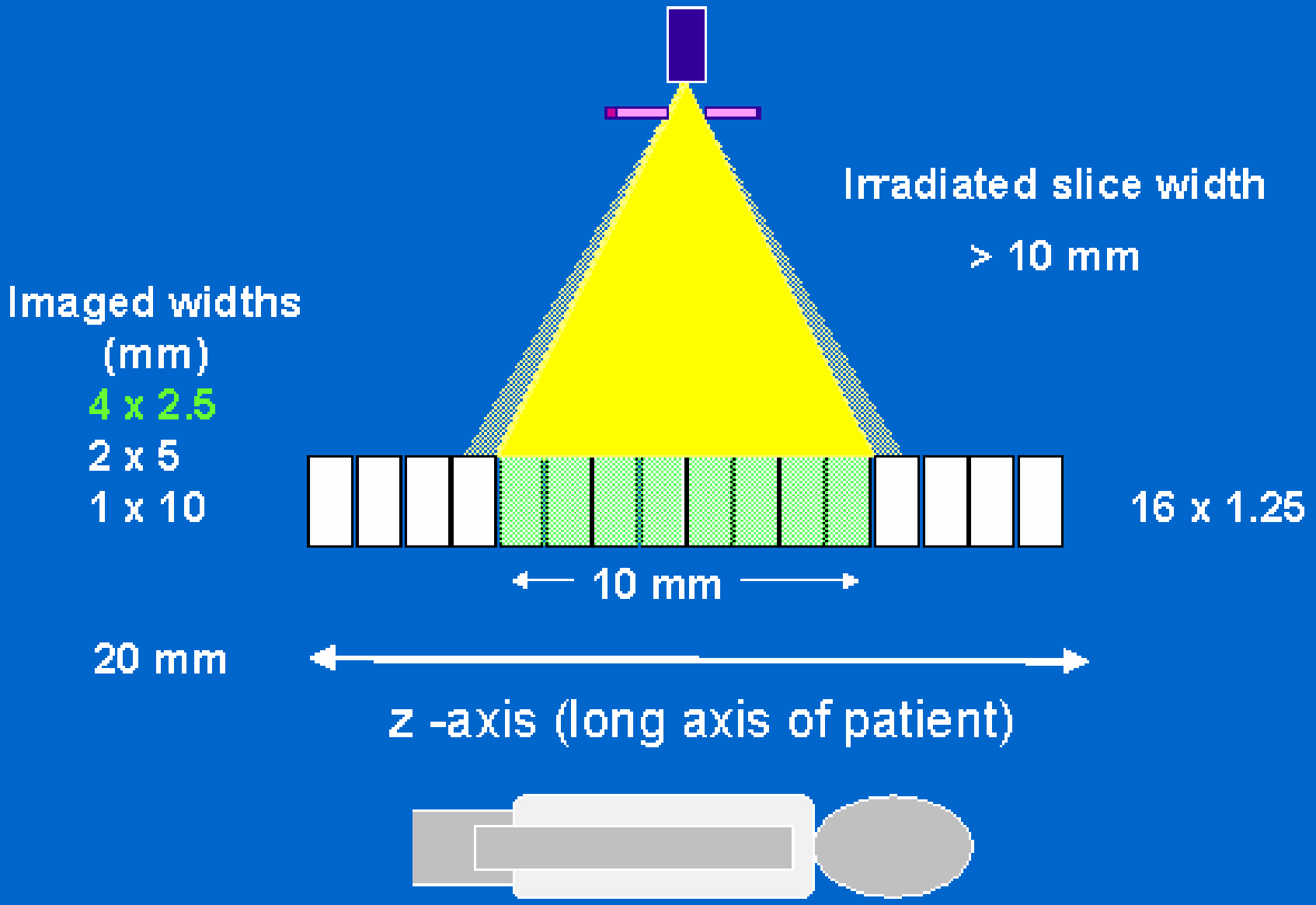
Multi-slice CT

- Overbeaming
- Additional rotations

Geometric efficiency – overbeaming



Additional rotations

- Needed for reconstruction of the beginning and end slices
- Depends on interpolation method
- More significant for short scan lengths

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CT in PET applications

- Attenuation corrections
- Simple anatomical registration
- Full CT diagnostic information

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So what doses arise from the CT component?

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Scan projection radiograph

- Scout view, topogram, scanogram
- Dose depends on “mAs” used to image a given point
- Eg. SPR for imaging the trunk
  - Effective dose
    - 0.1 – 1 mSv, for 1-5 “mAs”

Attenuation/registration

- Typical protocol
  - Whole body
  - Lower mAs per rotation
- Eg.
  - GE LightSpeed Plus
    - 4 x 3.75 mm
    - Pitch = 1.5
    - 40 mAs per rotation, 140 kVp
    - Pelvic floor to cerebellum – 870 mm

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ImPACT CT Patient Dosimetry Calculator

version 0.99t, 24/07/2003

Scanner Model:			
Manufacturer:	GE		
Scanner:	GE QX/i, LightSpeed, LightSpeed Plu		
kV:	140		
Scan Region:	Body		
Data Set	MCSET19	Update Data Set	
Current Data	MCSET19		
Scan range			
Start Position	0	cm	Get From Phantom Diagram
End Position	87	cm	
Patient Sex:			

Acquisition Parameters:			
mA		80	mA
Rotation time		0.5	s
mAs / Rotation		40	mAs
Collimation		15	mm
Slice Width		3.75	mm
Pitch		1.5	
Rel. CTDI	Look up	0.99	at selected collimatic
CTDI (air)	Look up	41.0	mGy/100mAs
CTDI (soft tissue)		43.9	mGy/100mAs
${}_{n}CTDI_{w}$		14.3	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	3.2	0.63
Bone Marrow (red)	0.12	4.4	0.53
Colon	0.12	4.8	0.58
Lung	0.12	6.5	0.79
Stomach	0.12	6	0.72
Bladder	0.05	5.9	0.29
Breast	0.05	5.2	0.26
Liver	0.05	5.8	0.29
Oesophagus (Thymus)	0.05	6.9	0.35
Thyroid	0.05	9.3	0.46
Skin	0.01	3.5	0.035
Bone Surface	0.01	8.1	0.081
Remainder1	0.025	4.1	0.1
Remainder 2	0.025	4.1	0.1
Total Effective Dose (mSv)			**5.2**

Remainder Organs	H_T
Adrenals	5.5
Brain	3.5
Upper Large Intestine	5.7
Small Intestine	5.5
Kidney	6.3
Pancreas	5.4
Spleen	5.7
Thymus	6.9
Uterus	5.5
Muscle	4

$CTDI_w$ (mGy)	5.7
$CDTI_{vol}$ (mGy)	3.8
DLP (mGy.cm)	332

Full diagnostic CT

- Typical protocol
  - Whole body
  - Higher mAs per rotation
- Eg.
  - GE LightSpeed Plus
    - 4 x 3.75 mm
    - Pitch = 1.5
    - 125 mAs per rotation, 140 kVp
    - Pelvic floor to cerebellum – 870 mm

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ImPACT CT Patient Dosimetry Calculator

version 0.99t, 24/07/2003

Scanner Model:			
Manufacturer:	GE		
Scanner:	GE QX/i, LightSpeed, LightSpeed Plu		
kV:	140		
Scan Region:	Body		
Data Set	MCSET19	Update Data Set	
Current Data	MCSET19		
Scan range			
Start Position	0	cm	Get From Phantom Diagram
End Position	87	cm	
Patient Sex:			

Acquisition Parameters:			
mA		250	mA
Rotation time		0.5	s
mAs / Rotation		125	mAs
Collimation		15	mm
Slice Width		3.75	mm
Pitch		1.5	
Rel. CTDI	Look up	0.99	at selected collimatic
CTDI (air)	Look up	41.0	mGy/100mAs
CTDI (soft tissue)		43.9	mGy/100mAs
${}_nCTDI_w$		14.3	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	9.9	2
Bone Marrow (red)	0.12	14	1.6
Colon	0.12	15	1.8
Lung	0.12	20	2.5
Stomach	0.12	19	2.3
Bladder	0.05	18	0.92
Breast	0.05	16	0.81
Liver	0.05	18	0.91
Oesophagus (Thymus)	0.05	22	1.1
Thyroid	0.05	29	1.4
Skin	0.01	11	0.11
Bone Surface	0.01	25	0.25
Remainder1	0.025	13	0.32
Remainder 2	0.025	13	0.32
Total Effective Dose (mSv)			**16**

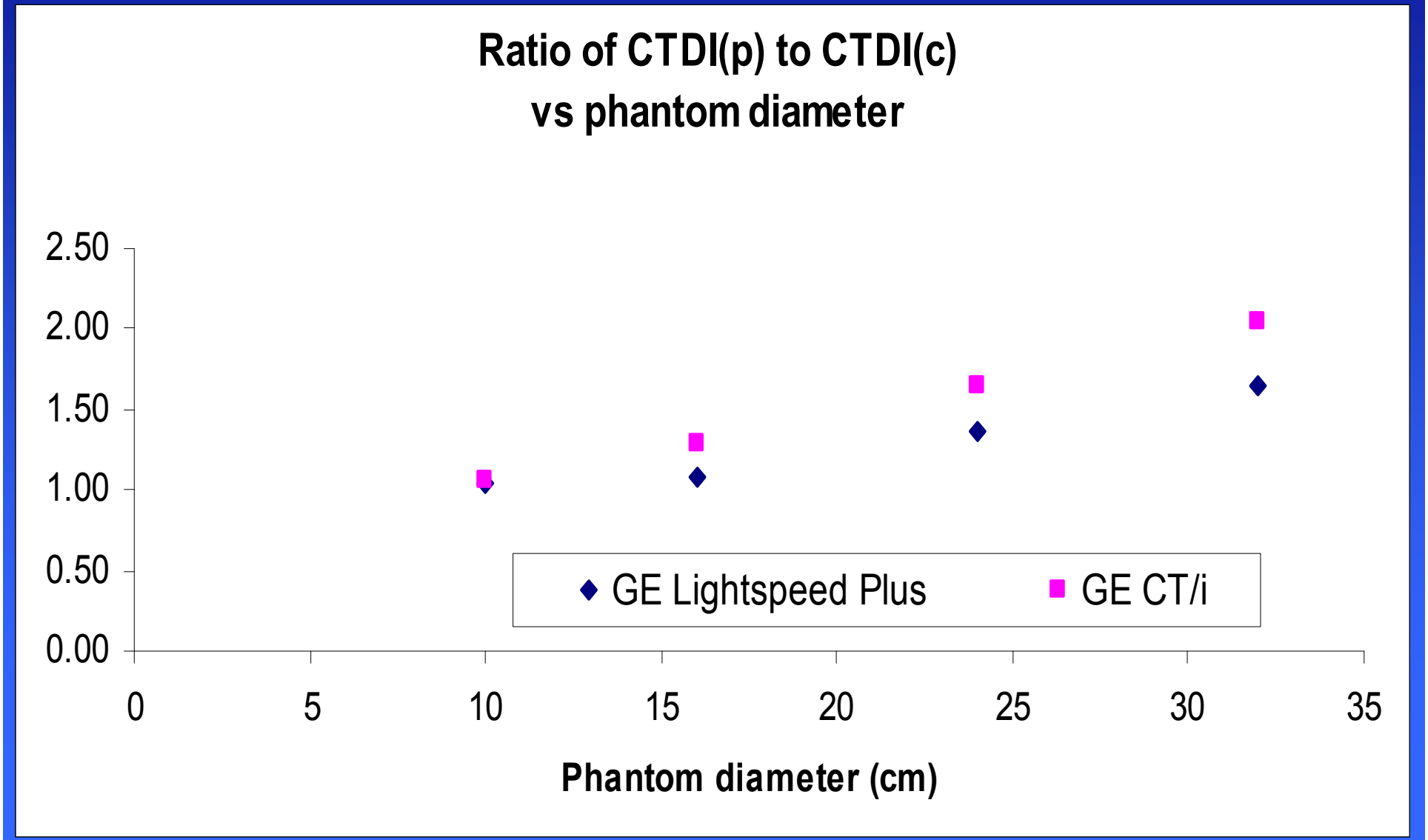
Remainder Organs	H_T
Adrenals	17
Brain	11
Upper Large Intestine	18
Small Intestine	17
Kidney	20
Pancreas	17
Spleen	18
Thymus	22
Uterus	17
Muscle	13

$CTDI_w$ (mGy)	17.9
$CDTI_{vol}$ (mGy)	11.9
DLP (mGy.cm)	1037

Conclusion - CT doses in PET

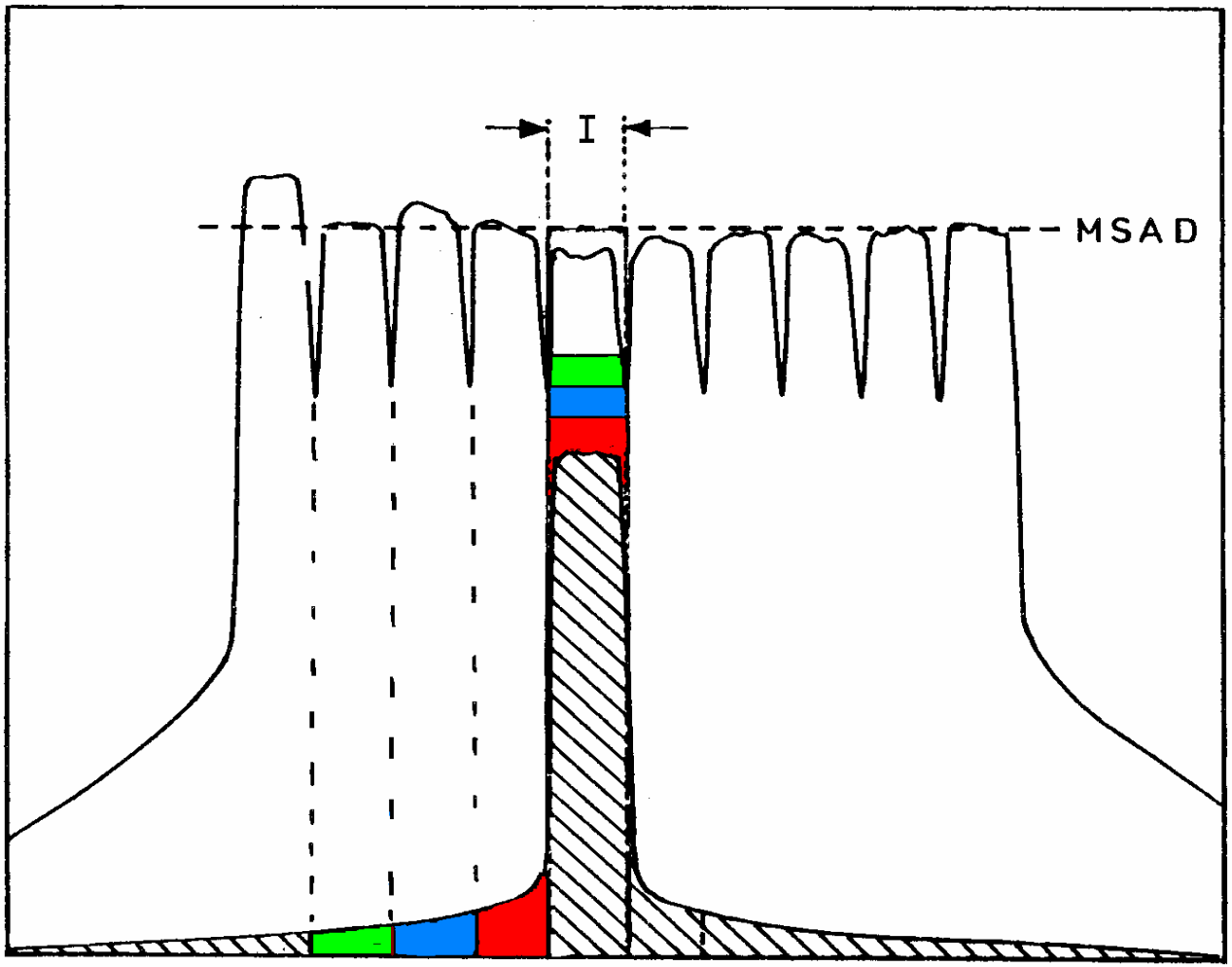
- Effective dose
  - 5 to 20 mSv, depending on role & protocol
- Organ equivalent doses
  - 5 to 50 mSv, depending on role & protocol
- Optimisation of protocol is important

Uniformity vs phantom size



Contiguous axial slices

CTDI = multiple scan average dose



DRLs in CT

- Europeans
  - $CTDI_W$
    - Constraint on dose per rotation
  - DLP
    - Constraint on dose per examination