CT Dose Measurements

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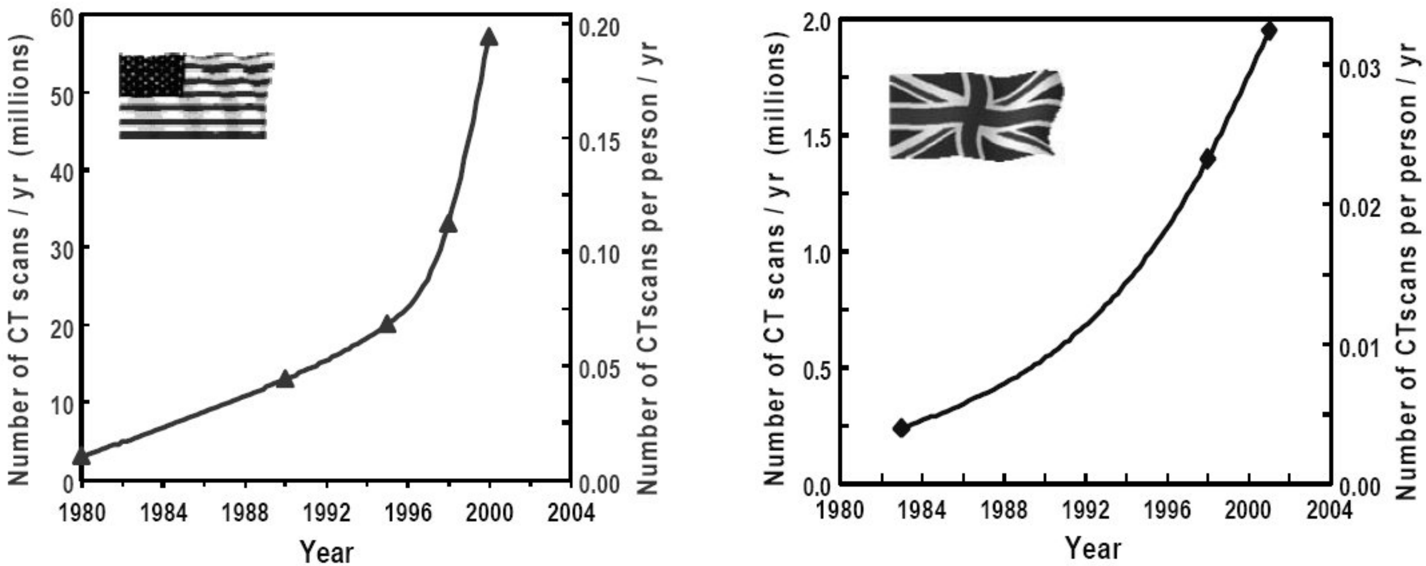
Number of CT exams increasing very rapidly…

Frequency of CT scans per year:



and typical organ doses from CT are much greater than most other common exams……

How many know someone who had a CT scan in the last year?

2007 NCRP

- US population collective effective dose
  - 1980, 0.54 mSv/person
  - 2006, 3.2 mSv/person
- Increase attributed to medical sources
- CT: 12% procedures, 45% eff. dose
- Nuc Med: 3% procedures, 23% eff. dose
- Substantial clinical benefits!

Abdomen/Pelvis CT protocol: 120kV, 280-300 mA, 1 sec/rotation, pitch = 1, image thickness = 5 mm

- How does the radiation dose from this study compare to the radiation dose from a chest x-ray?

a. CT $\simeq$ chest x-ray
b. CT $\simeq$ 10 chest x-rays
c. CT between 10-100 chest x-rays
d. CT between 100-250 chest x-rays
e. CT $\simeq$ 500 chest x-rays

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- How does the radiation dose from this study compare to the radiation dose from a chest x-ray?

	Radiologists' answers
a. CT ≃ chest x-ray	5%
b. CT ≃ 10 chest x-rays	56%
c. CT between 10-100 chest x-rays	15%
d. CT between 100-250 chest x-rays ***	13%
e. CT ≃ 500 chest x-rays	10%

Lee CI, et.al., Radiology 2004; 231:393-398

Radiation Dose - General Definitions

- **Exposure** - Ability of x-rays to ionize air;
  - **Roentgen (R)** is the unit of exposure
  - how much is ***present***;
  - Not how much is ***absorbed***.

MEASURED quantity

Radiation Dose - General Definitions

- **Absorbed Radiation Dose**
  - energy absorbed/unit mass at a point.
- Measured in rads (English) or Gray (SI).
  - 1 rad = 100 ergs/gram; 1 Gy = 1 J/kg
  - 1 rad = 10 mGy; 1 Gy = 100 rads.
- Absorbed Dose
  - How much ***is absorbed***;
  - Not ***where*** that dose is absorbed
  - NOR what the ***risk*** is to those tissues being irradiated

ESTIMATE for individual patients

Effective Dose

- $E = \Sigma_T(w_T * w_R * D_{T,R})$
- w_T= tissue weighting factor (next page)
- w_R= radiation weighting coefficient (1 for x-ray)
- $D_{T,R}$= average absorbed dose to tissue T
- Units are: SI - Sieverts (Sv); English - rem
- 1 rem = 10 mSv; 1 Sv = 100 rem

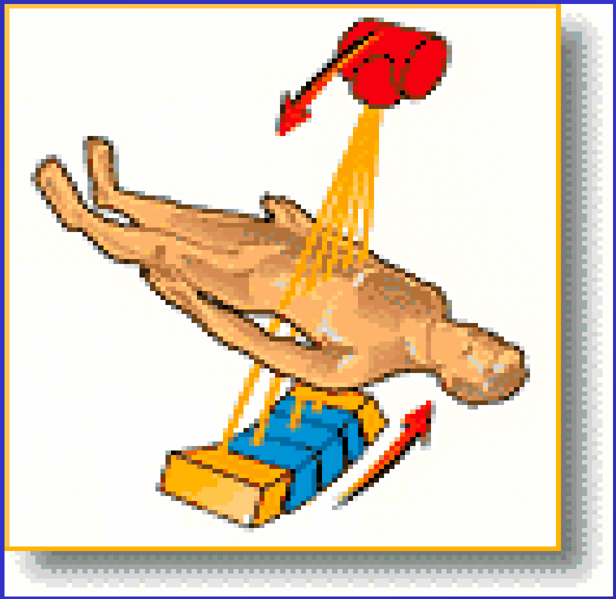
ESTIMATE for individual patients

Effective Dose

Tissue	Tissue weighting factor (w_T)	Proposed w_T
Gonads	0.20	.08
Red Bone Marrow	0.12	.12
Colon	0.12	.12
Lung	0.12	.12
Stomach	0.12	.12
Bladder	0.05	.04
Breast	0.05	.12
Liver	0.05	.04
Esophagus	0.05	.04
Thyroid	0.05	.04
Skin	0.01	.01
Bone Surface	0.01	.01
Brain	(Remainder)	.01
Salivary Glands	(Remainder)	.01
Remainder (Adrenals, etc.)	0.05	.12

CT -Specific definitions

- What is unique about CT?
  - Geometry and usage
  - Exposure is at multiple points around patient
  - Typically thin (0.5 - 40 mm) beam width
  - Multiple Scans (Series of Scans)



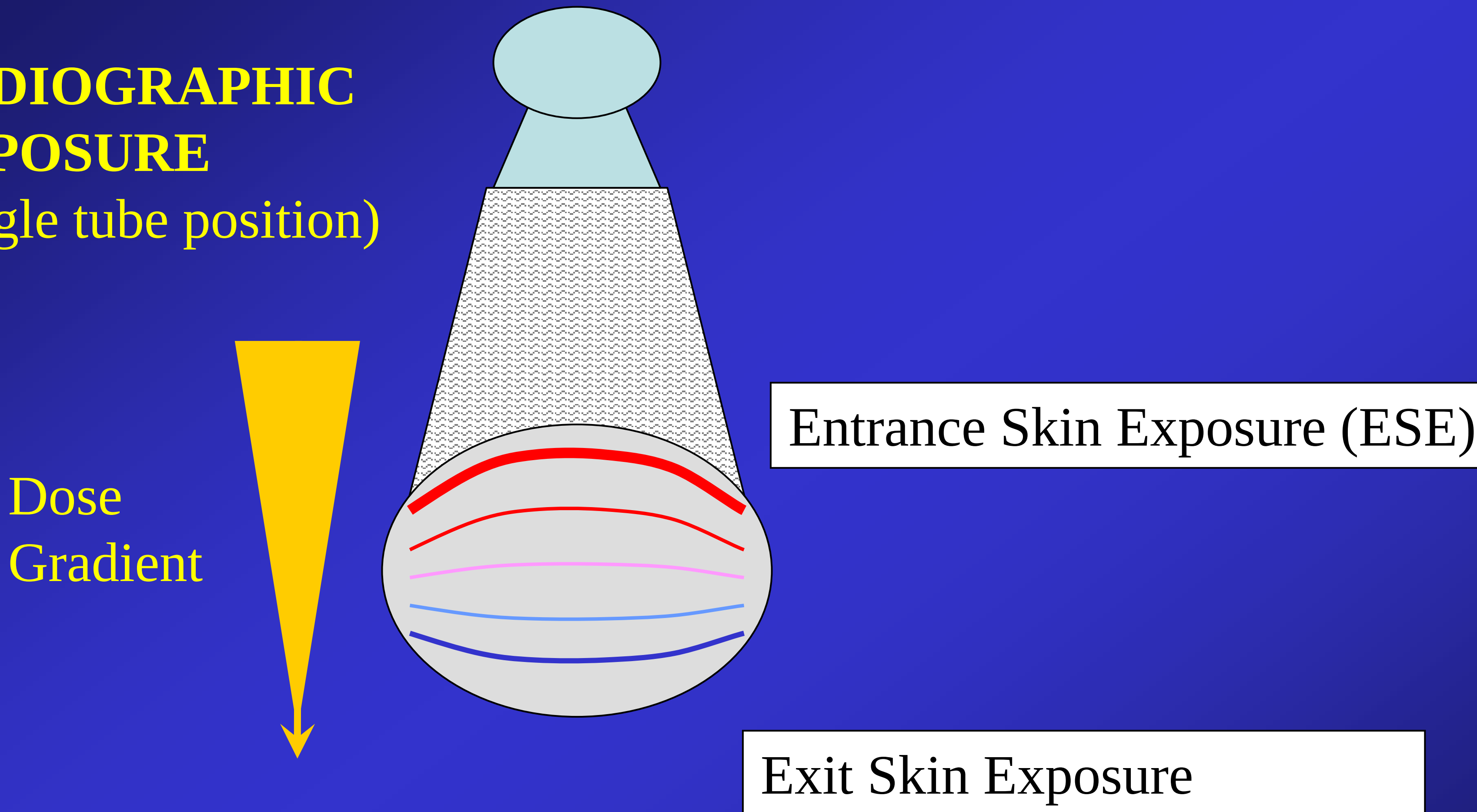
CT -Specific definitions

- Machine Specific
  - CTDI – defined, how to measure
  - $CTDI_w$- weighted
- Exam Specific
  - $CTDI_{vol}$
  - DLP
  - Effective Dose

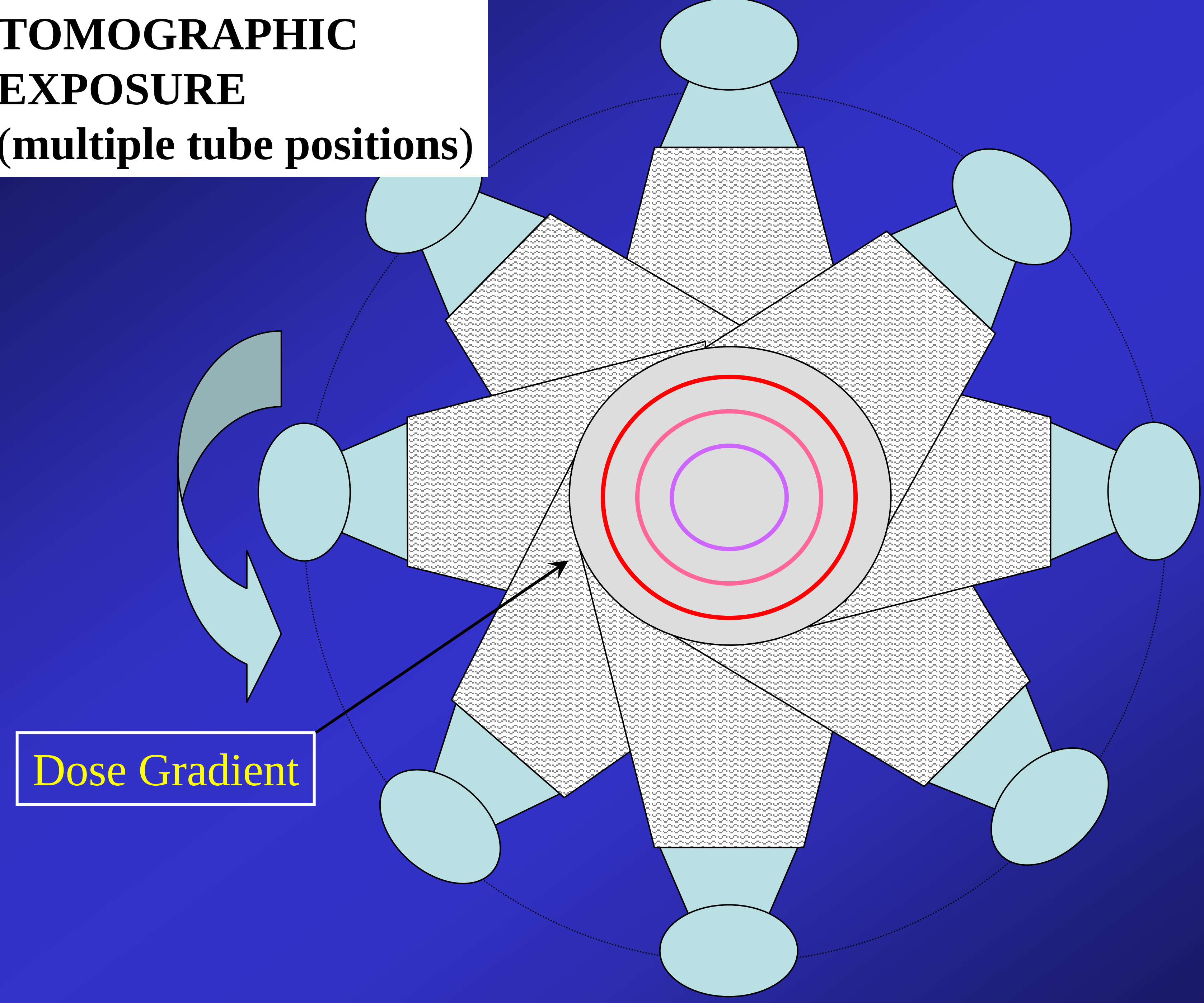
NO Patient Specific Dose Descriptors

RADIOGRAPHIC EXPOSURE

(single tube position)

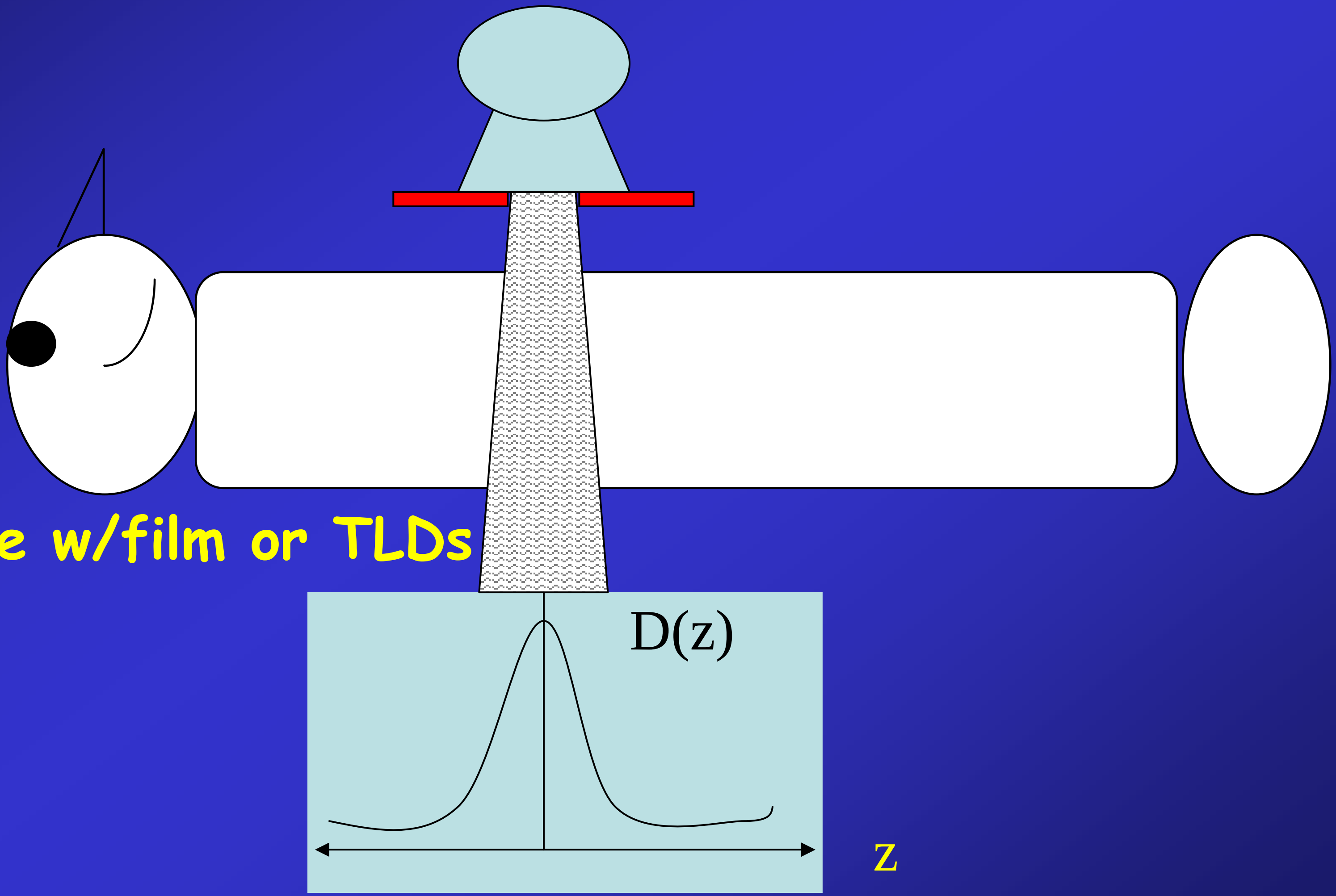


TOMOGRAPHIC EXPOSURE (multiple tube positions)



CT Dose Distributions

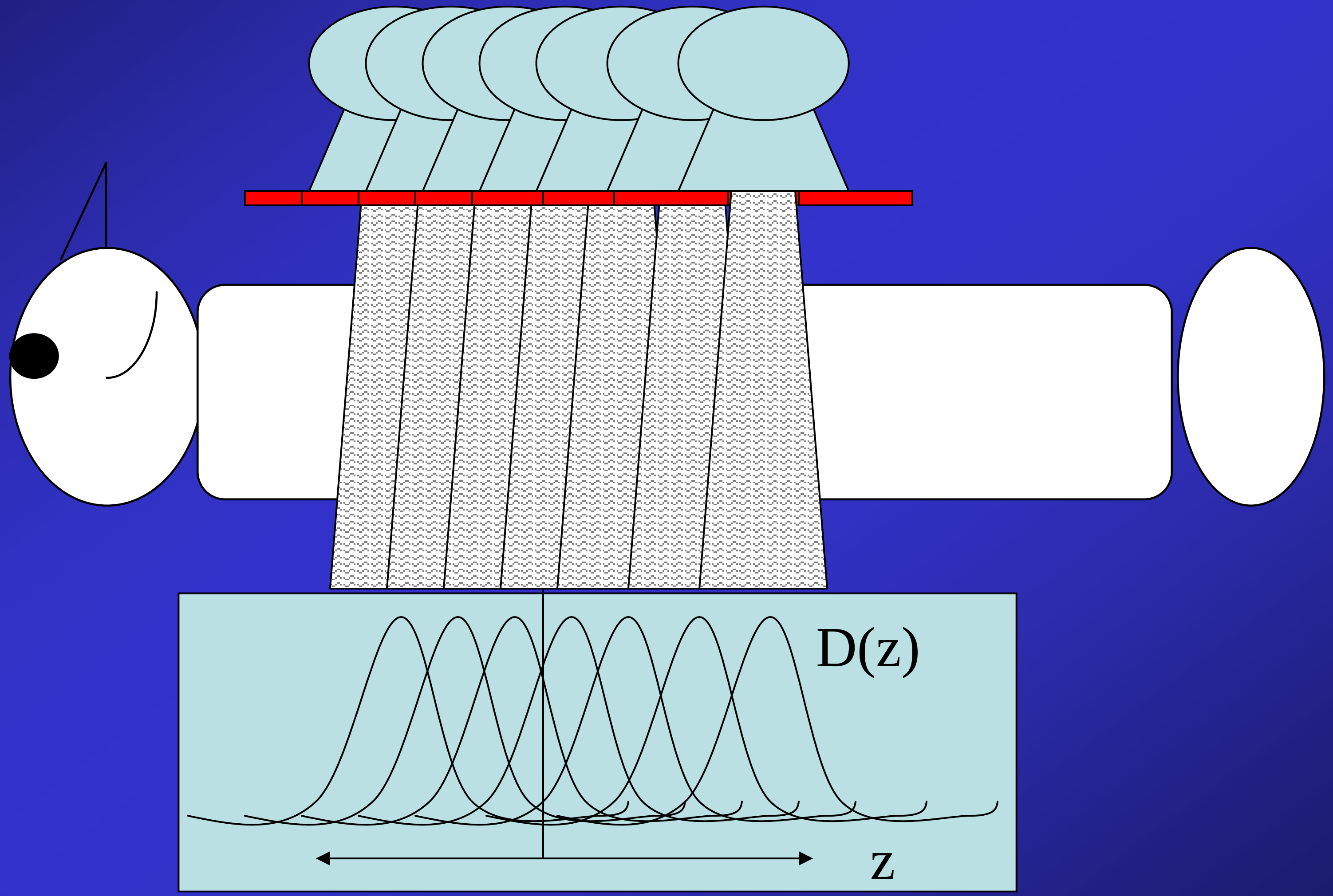
- D(z) = dose profile along z-axis from a single acquisition



- Measure w/film or TLDs

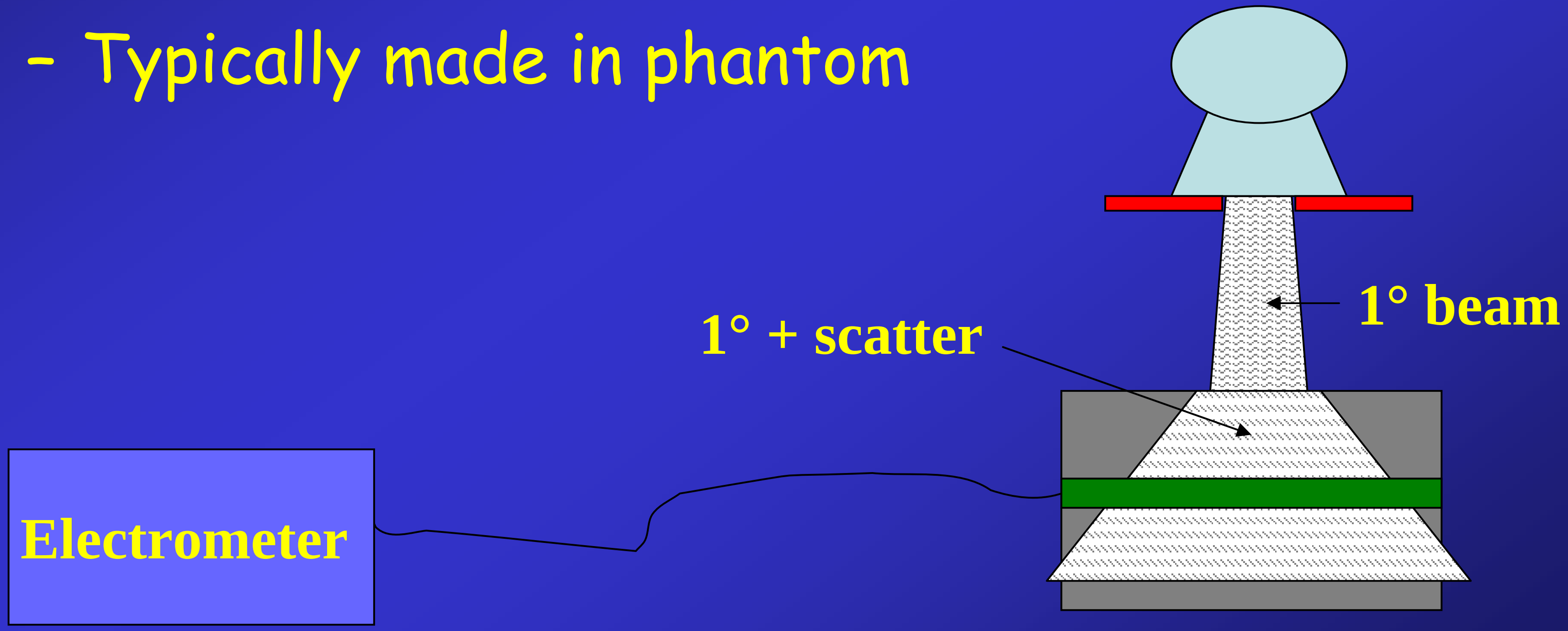
CT Dose Distributions

What about Multiple Scans?

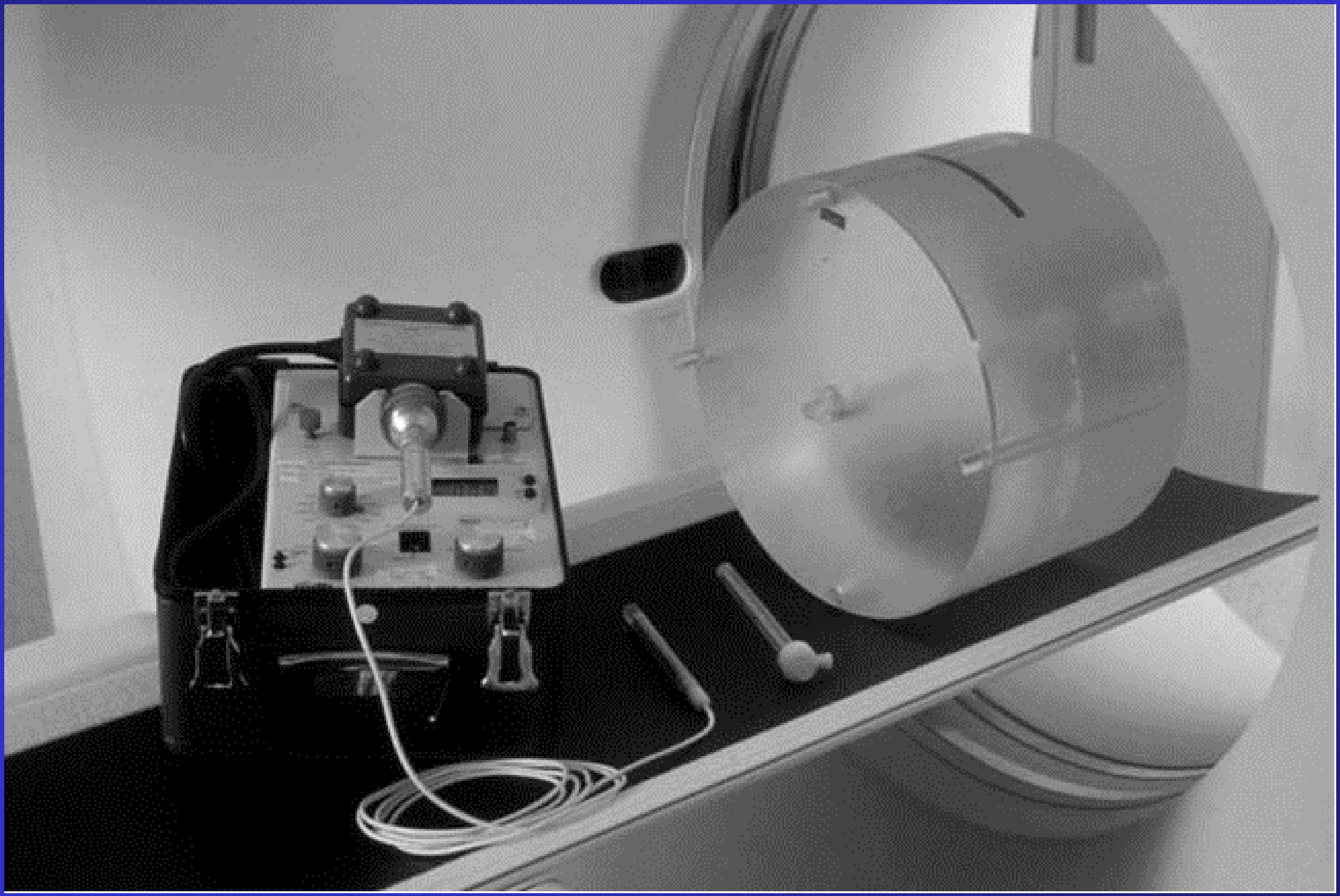


CT Dose Index (CTDI)

- How to get area under single scan dose profile?
  - Using a pencil ion chamber
  - One measurement of a transverse scan
  - Typically made in phantom

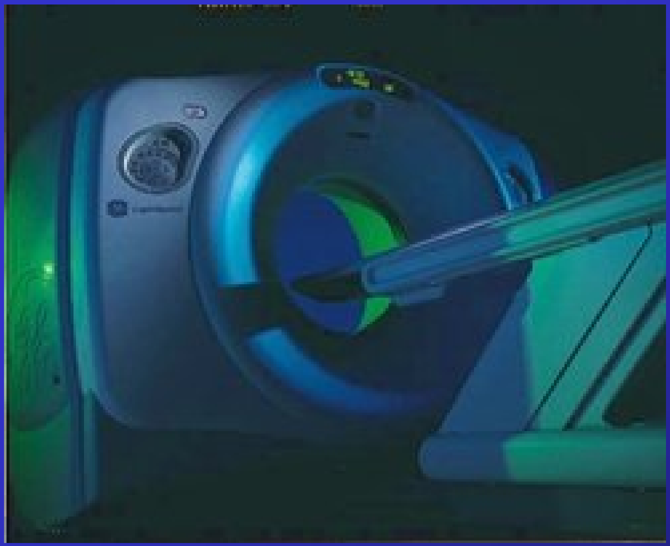


CT Dose Index (CTDI)



CT Dose Index (CTDI)

- CTDI Represents
  - **Average dose** along the z direction
  - At a given **point** (x,y) in the scan plane
  - Over the **central scan of a series of scans**
  - When the series consists of a **large number of scans**



CTDI Phantoms

- Body (32 cm diam), Head (16 cm diam)
- Holes in center and at 1 cm below surface

$CTDI_{100}$ (rad or Gray)

Measurement is made w/100 mm chamber:

$$CTDI_{100} = (1/NT) \int_{-5cm}^{5cm} D(z)\, dz$$

$$= (f*C*E*L)/(NT)$$

f = conversion factor from exposure to dose in air, use 0.87 rad/R

C = calibration factor for electrometer (typical = 1.0, 2.0 for some)

E = measured value of exposure in R

L = active length of pencil ion chamber
(typical= 100 mm, 160 mm for some)

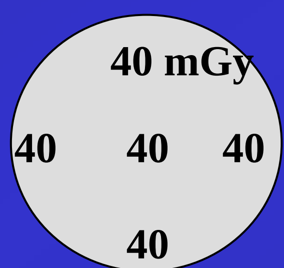
N = number of *active* data channels used during one transverse scan

T = channel width (active detector surface)

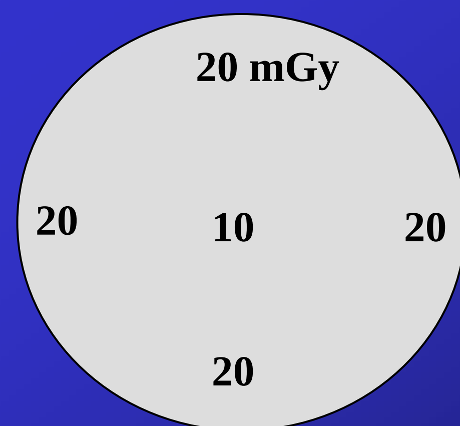
[Note: NT = total x-ray beam width]

$CTDI_{100}$ (rad or Gray)

- $CTDI_{100}$ Measurements are done:
  - In Both Head and Body Phantoms
  - Using ONLY TRANSVERSE scan techniques (CTDI = Area under the single scan dose profile)
  - At isocenter and at least one peripheral position in each phantom



Head 16 cm diameter



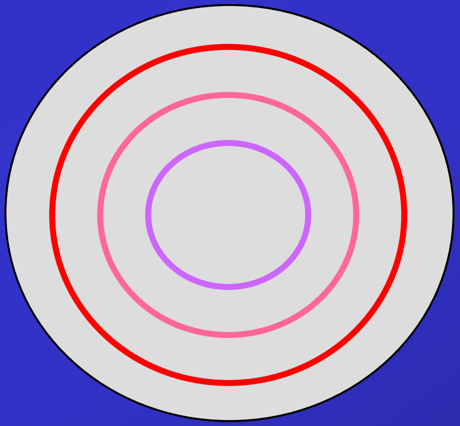
Body 32 cm diameter

$CTDI_w$ (Gray)

- CTDIw is a **weighted average** of center and peripheral $CTDI_{100}$ to arrive at a single descriptor

- **$CTDI_w = (1/3)CTDI_{100,center} + (2/3)CTDI_{100,peripheral}$**

Intended to reflect dose gradient



CTDI $_{vol}$ (Gray) – EXAM-related

- Exam parameters such as beam width, spacing between slices (transverse) or table speed (helical)
- $CTDI_{vol} = CTDI_w \ {}^*NT/I$
- where N= number of active data channels,

  T= data channel width

  I = spacing or table feed/rotation for helical

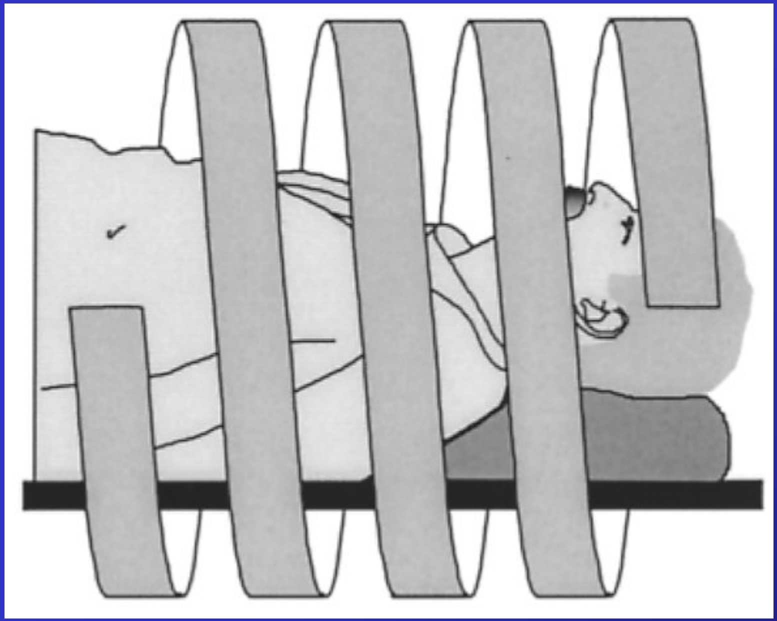
Note: NT = total x-ray beam width

Also pitch= I/NT, so **$CTDI_{vol} = CTDI_w/pitch$**

Pitch?

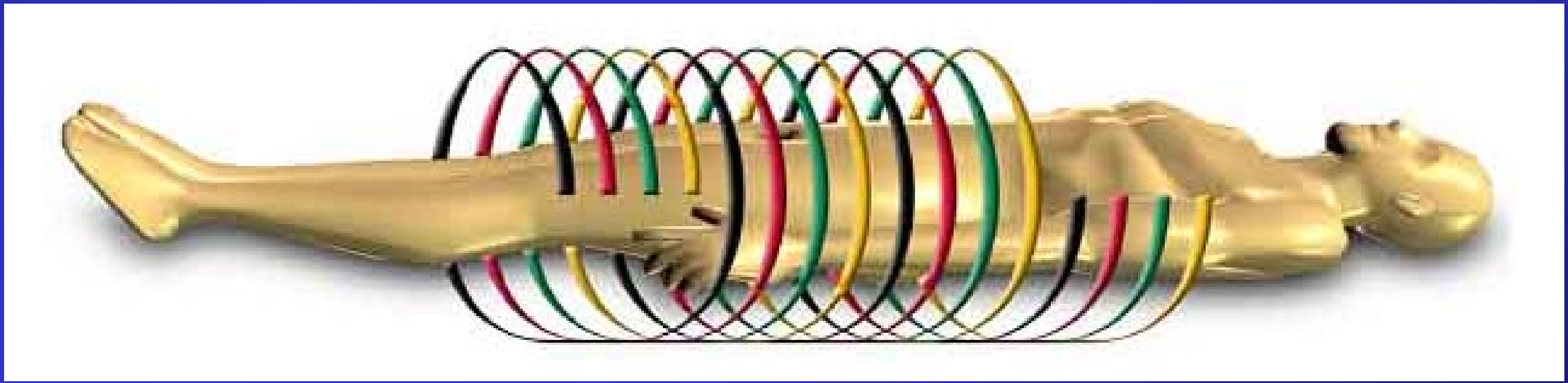
- Definition:

$$\text{Pitch} = \frac{\text{distance table travels during one rotation}}{\text{total x-ray beam width}}$$



Dose Length Product (mGy·cm)

- Accounts for extent of scan
- Nose to toes, or very limited study?
- DLP = [CTDIvol (mGy)] x [Scan extent (cm)]



Dose information display

CTDI$_{vol}$

DLP

Dose Information

Images	CTDIvol mGy	DLP mGy·cm	Dose Efficiency %
1-73	5.94	234.94	97.40
SmartPrep	43.95	43.95	

Projected series DLP: 278.89 mGy·cm

Accumulated exam DLP: 1934.43 mGy·cm

Add Group | Split Current Group | Delete Selected Group | Biopsy Rx | Smart Prep Rx | Preview | Optimize not Needed | Gating | Prior | Next

Images	Scan Type	Start Location	End Location	No. of Images	Thick Speed	Interval (mm)	Gantry Tilt	SFOV	kV	mA	Total Exposure Time	Prep Group (sec)	ISD (sec)	Breath Hold (sec)	Breathe Time (sec)	Voice Lights Timer	Cine Duration (sec)
1-20	Helical Full 0.8 sec.	I50.00	I38.03	20	0.63 1.25 HQ	0.63	S10.0	Large	120	200	8.6	1.0	1.3	N	N	N	2.0
21-31	Helical Full 0.8 sec.	S21.25	S46.25	11	2.5 7.5 HQ	2.50	S10.0	Large	120	200	4.1	1.0	1.3	N	N	N	2.0
32-42	Helical Full 0.8 sec.	S96.25	S146.25	11	5.0 15.0 HS	5.00	S10.0	Large	120	200	3.8	1.0	1.3	N	N	N	2.0

Effective Dose (mSv)

- Accounts for RISK to sensitive tissues
- Table of weighting factors
- Estimate by using k-factor approach
- Units mSv/mGy·cm

Eff. Dose = DLP · k

Region	k-factor
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

European Guidelines on Quality, EUR 16262 EN, May 1999

Estimating Effective Dose

- To estimate effective dose, you need to ESTIMATE DOSE TO EACH RADIOSENSITIVE ORGAN !!! ($E = \Sigma_T w_T * D_{T,R}$) ; $w_R = 1$
- Difficult to do accurately –
  - How do you know how much a specific organ (e.g. the kidney) received from a specific exam? In a specific patient?

Estimating Effective Dose

- Computer Software - CTDOSE and WinDose
  - Based on Monte Carlo simulations
  - ImPACT calculator

- Factors based on DLP
  - E = DLP * k (k in mSv/(mGy*cm))
  - k= .0023 for head exams , k =0.015 for abdomen

"Typical" CT Effective Dose Values

- **Background radiation ~ 3.60mSv/year**
- **Typical effective doses**
  - **Head** **1 to 2 mSv**
  - **Chest** **5 to 7 mSv**
  - **Abd** **5 to 7 mSv**
  - **Pelvis** **3 to 4 mSv**
  - **Abd/Pelv** **8 to 11 mSv**
- **Typical scan ~ 1 – 2 x avg annual background**

Limitations of CTDI approach

- Underestimates dose by ~15% (Boone, 2007)
- Inappropriate for:
  - Cone beam CT
  - C-arm CT
  - Dental 3D-CT

Limitations of Effective Dose

- C.J. Martin, British J Radiology, 2007
- Examined uncertainties is estimated effective dose values
- Effective dose uncertainty for medical exposures ± 40% in reference patient
- Estimated cancer risk a factor of three higher or lower for reference patient
- Recommends use of organ dose estimates when assessing dose to individual subject

Emerging methodology…

- 3 Tier system for dose measurement:
  - Simple in air site measurement (R)
  - Point dose measurement in suitable phantom
  - Application of standard size Monte-Carlo voxelized 'patient' models