



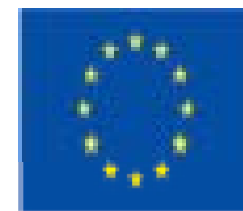
Τεχνολογικό Εκπαιδευτικό Ίδρυμα Αθήνας  
Σχολή Επαγγελματιών Υγείας & Πρόνοιας



## MDCT Principles and Applications



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2016



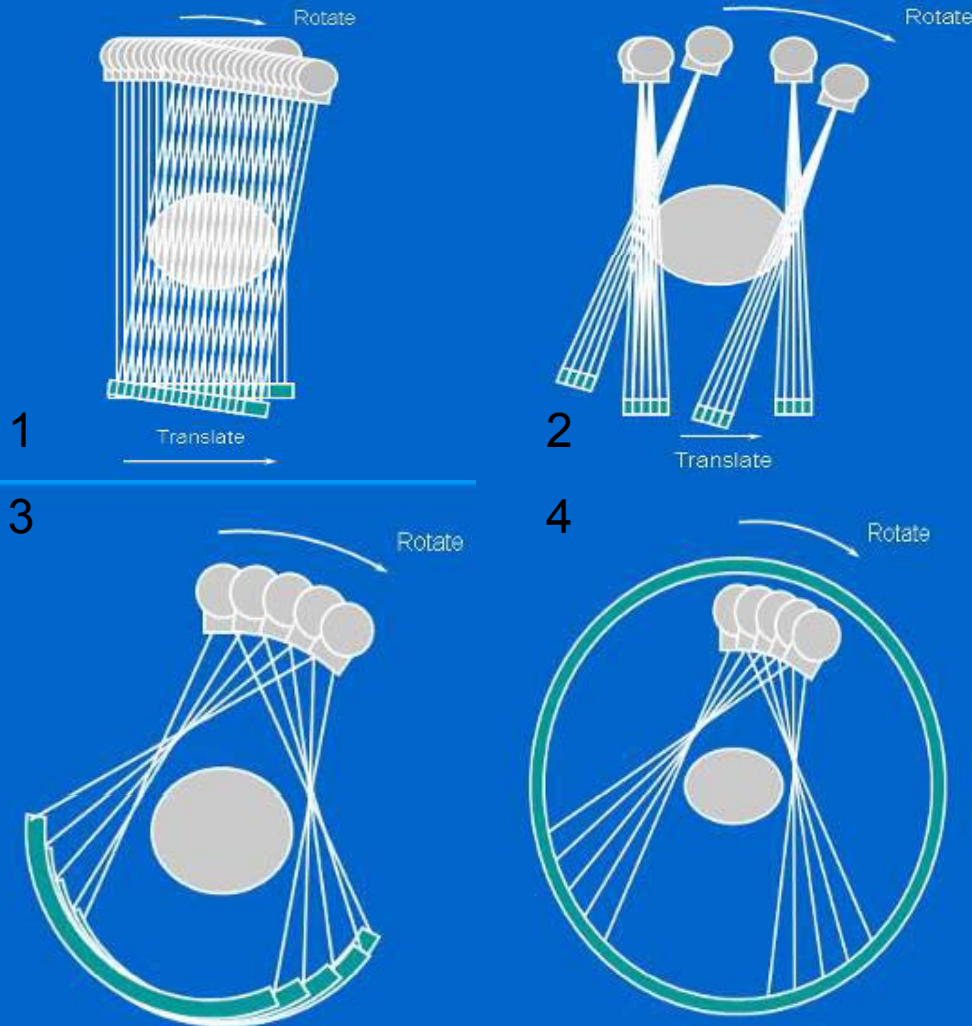
Erasmus+

# Aim

To understand recent technological advances in MSCT and how they can be effectively applied in daily practice.



# Introduction

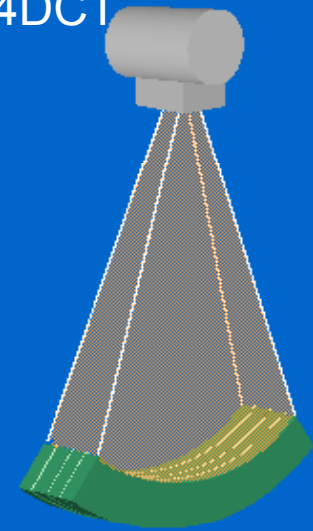


1. 1<sup>st</sup> generation Linear scanning and rotation, pencil beam
2. 2<sup>nd</sup> generation Linear and rotation, wider beam
3. 3<sup>rd</sup> generation Rotation only, fan beam
4. 4<sup>th</sup> generation Rotation fixed detectors

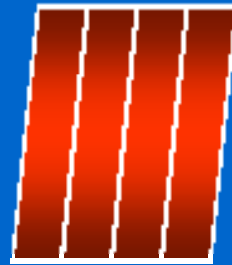
# HCT vs MDCT

1. Increased detector "face" on the z axis
2. Cone beam
3. Advanced software for rapid processing of increased data volume

4DCT



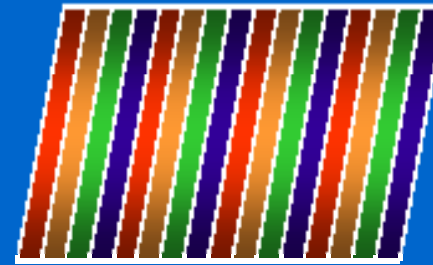
Axial: 40 sec



Helical: 20 sec

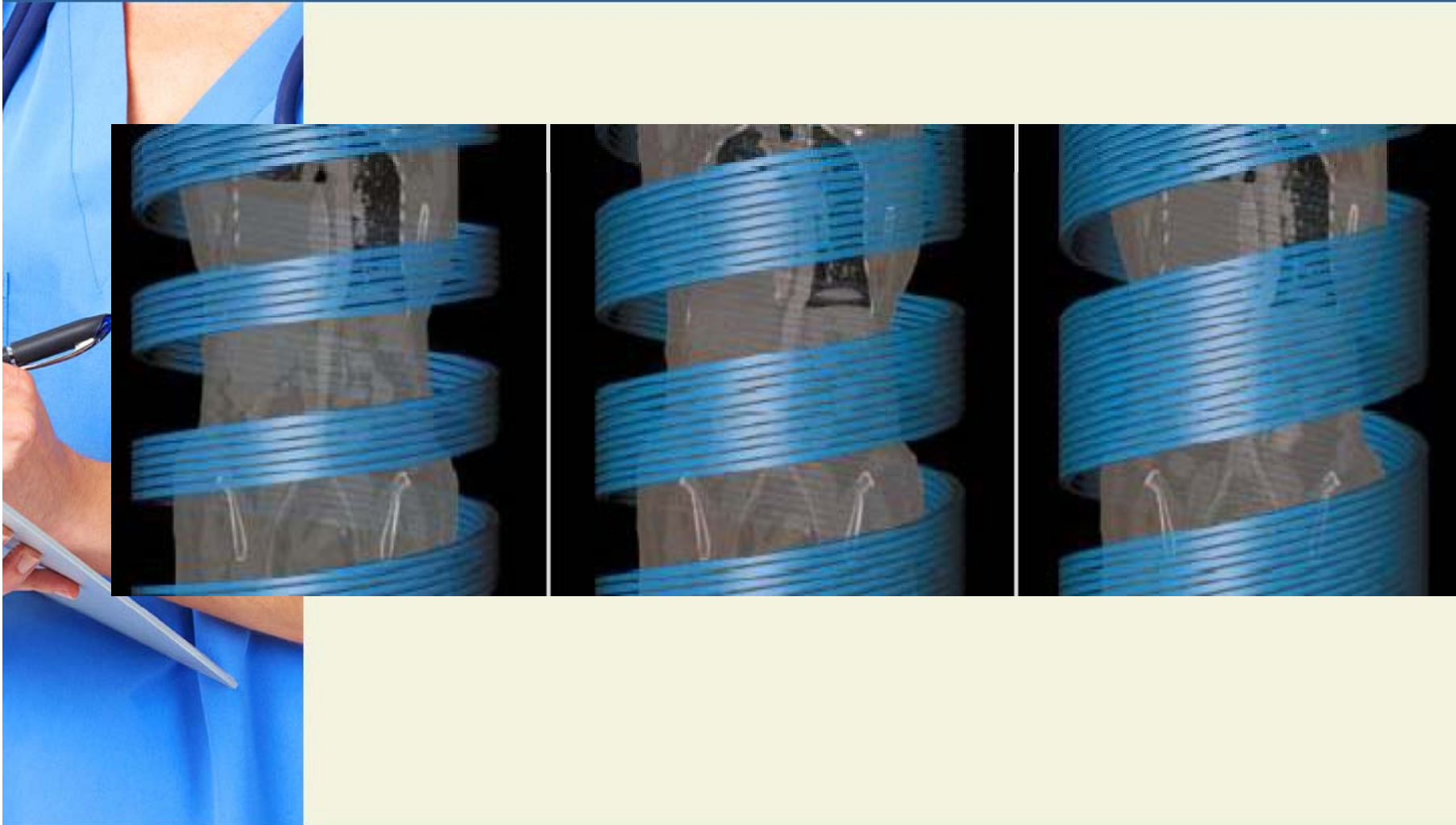


4DCT: 5 sec



16MDCT 2.5 sec

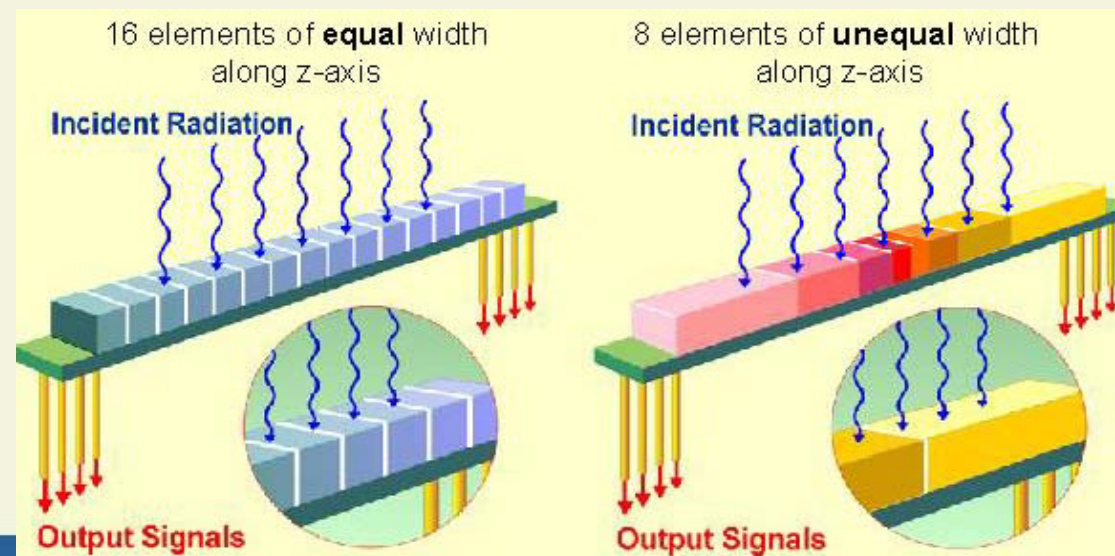
# MSCT



# MDCT

- Detector arrays consist of either
  - Fixed lengths
  - variable lengths

On the z axis



# A. Technical parameters influencing quality and dose



## Acquisition

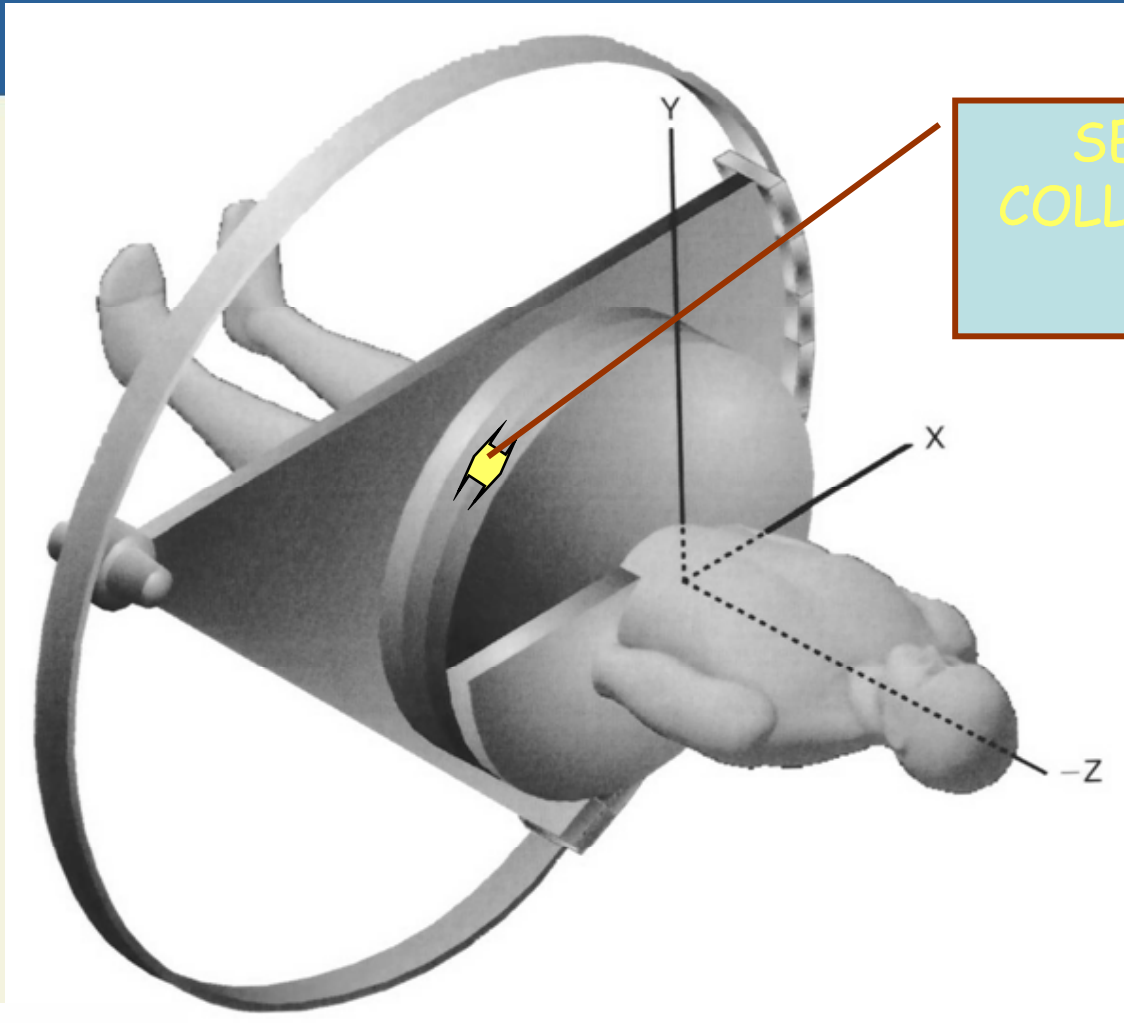
1. Section collimation/slice thickness
2. Table feed
3. Pitch
4. Total volume
5. Exposure factors έκθεσης kV, mA, s
6. Gantry tilt

# Protocol design

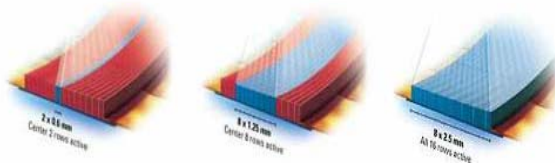
## TOPOGRAM ñ SCANOGRAM

- The first digital x-ray
- Required for our scanning plan
- It illustrates the position of the axial slices on an AP or LAT projection of ROI.
- Necessary for gantry tilting

# Section Collimation SC

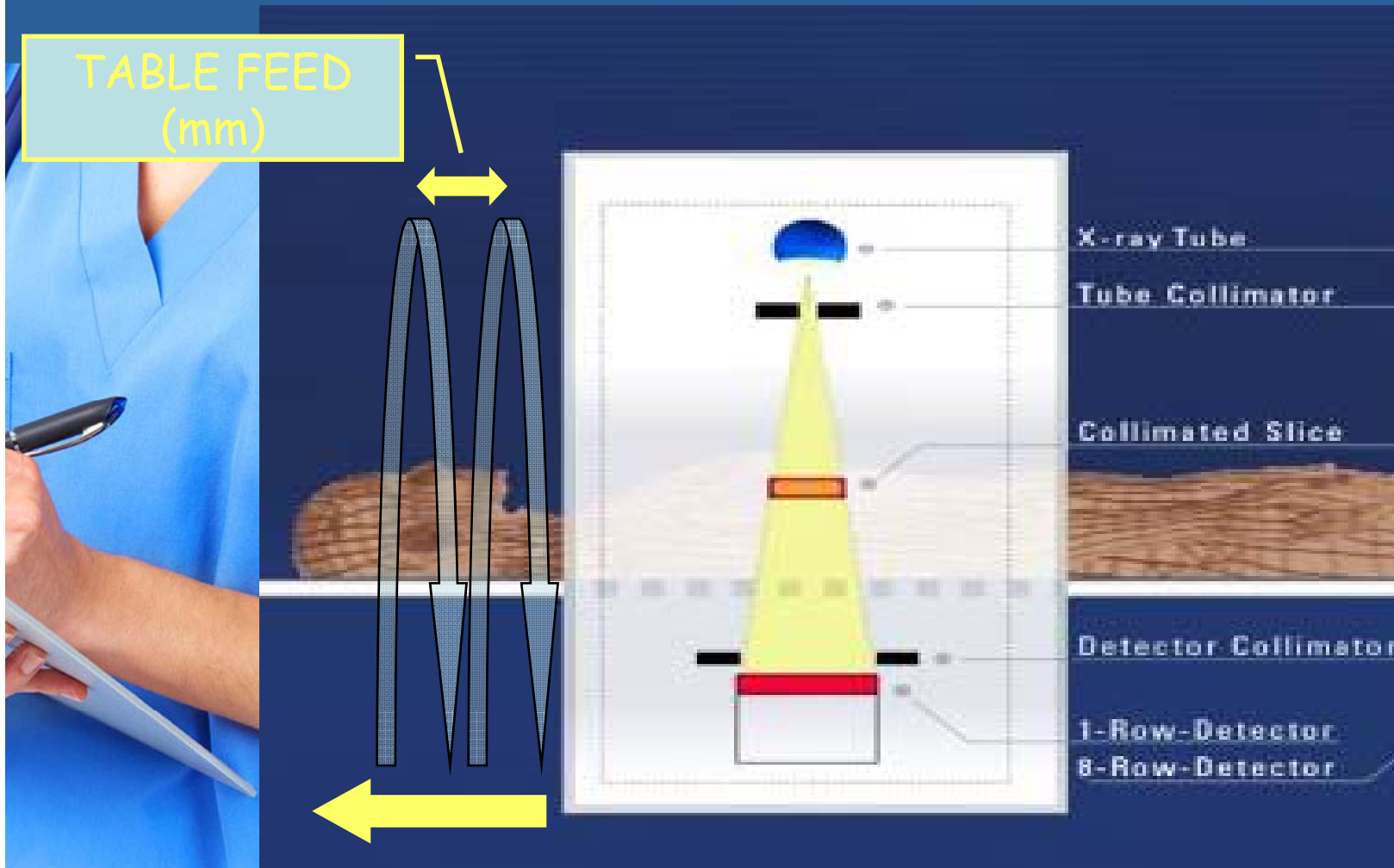


SECTION  
COLLIMATION  
(mm)



*Blanck.,C(1998) Understanding Helical Scanning*

# Table Feed TF



*Courtesy of Siemens Med A.G Library*

# Scan Length L

- Determines the length of a series of scan sections, expressed in **cm**.
- It depends on the scan time and table speed.
- Estimated by the formula:

$$L = TI \times TS$$

TI= scan time

TS=table speed

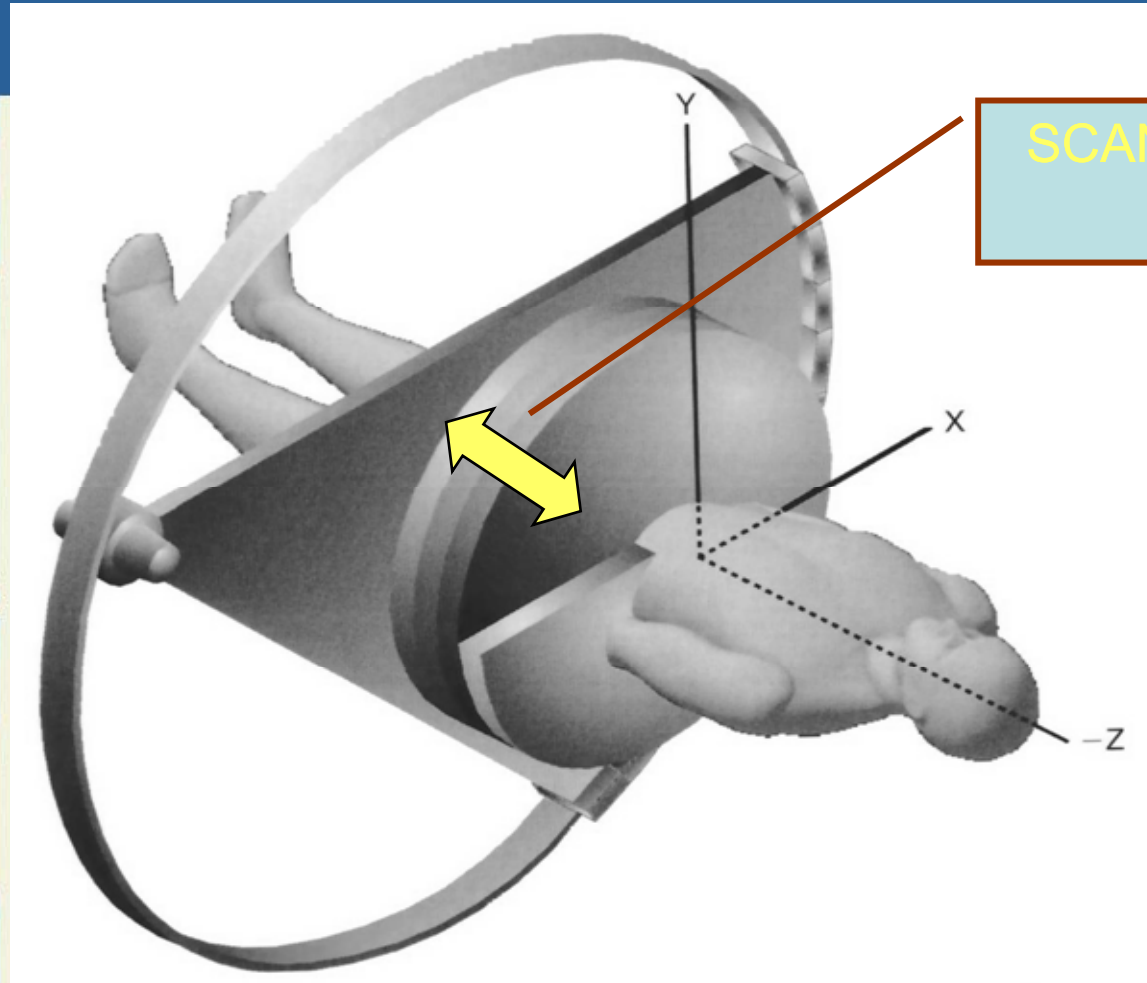


# Pitch ratio $P$



- Is the ratio:  
 $TF/RT : SC$
- For most clinical applications:  
 $P = 1.5-2.0$
- Artifacts appear when  $P > 2$ .


# Total Volume V




SCAN VOLUME  
(mm)

*Blanck.,C(1998) Understanding Helical Scanning*

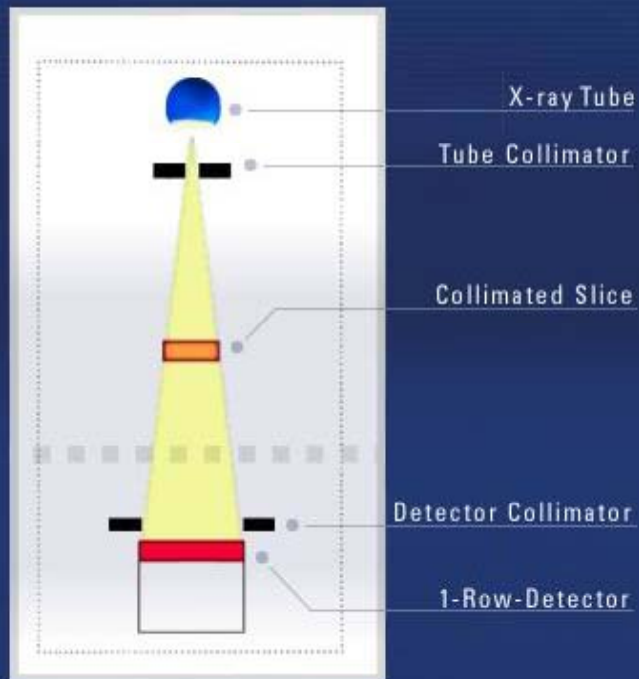
# Section Width $SW$

- 
- In helical scanning, unlike segmental the SC chosen is not what we get.
  - The effective section thickness is the result known as section width  $SW$ .
  - The  $SW$  is proportional to the pitch and depends on many factors including the interpolation algorithm.

# Exposure factors

- 
1. Tube voltage (kV) 70- 140 kV
  2. Tube current (mA)
  3. Exposure time (s)
- High kV recommended for HRCT kai QCT
  - mAs selection depends on scanner and pt size
  - Increase in mAs= increase in pt dose
  - They are selected based on the desired image quality at a minimum dose.

# Tube voltage kV



- A higher kV setting leads to:
  1. better penetration,
  2. less image noise
  3. rise in dose
- In clinical practice, 120kV is sufficient
- For obese patients 140 kV is suggested.

# Tube load mAs

- Tube current is expressed in mAs and is proportional to pt dose & detector dose
  1. Image noise is proportional to detector dose
  2. The patient dose is proportional to the effective mAs

$$mAs_{\text{eff}} = mAs / (RT \times P)$$

- Optimal mAs is very difficult to define

# Tube Rotation Time RT



- Represents the time required for a complete tube revolution around the patient.
- Large RT provide less volume coverage but produce better in-plane resolution

# Gantry Tilt GT



- Reduces dose to radiosensitive organs, e.g. the eye lenses in head scanning
- Causes image distortion
- Reformatted images will be out of 'true' plane.

# Rotation time **RT**



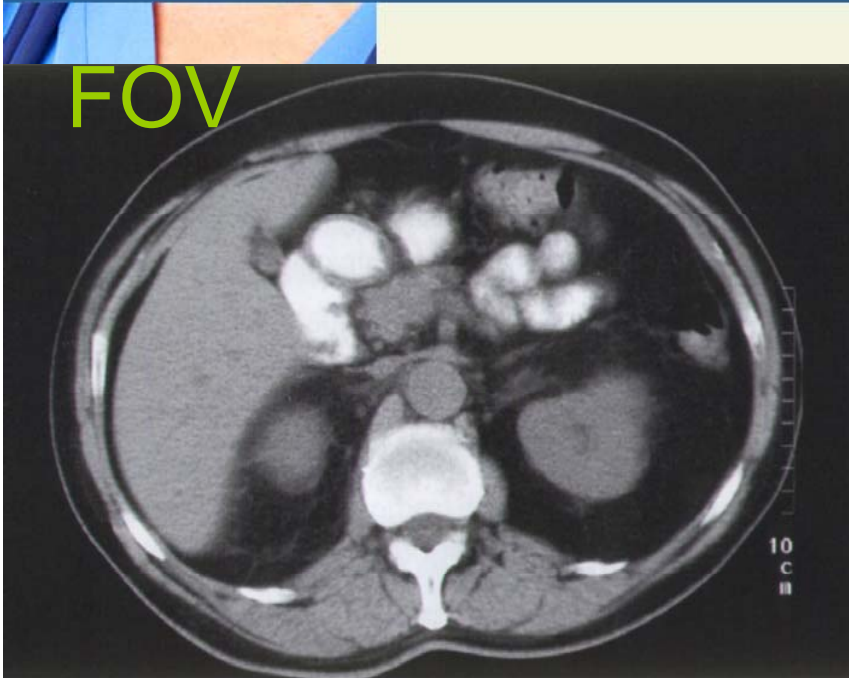
- The time required for a complete  $360^{\circ}$  around the examined volume.
- Longer time selection permits for shorter length scanning and higher resolution

# Gantry tilt GT



- May eliminate dose to radiosensitive organs i.e. lens during brain CT
- Selected to reduce high density artifacts i.e. teeth implants during facial bone CT
- Must be avoided when post processing is necessary

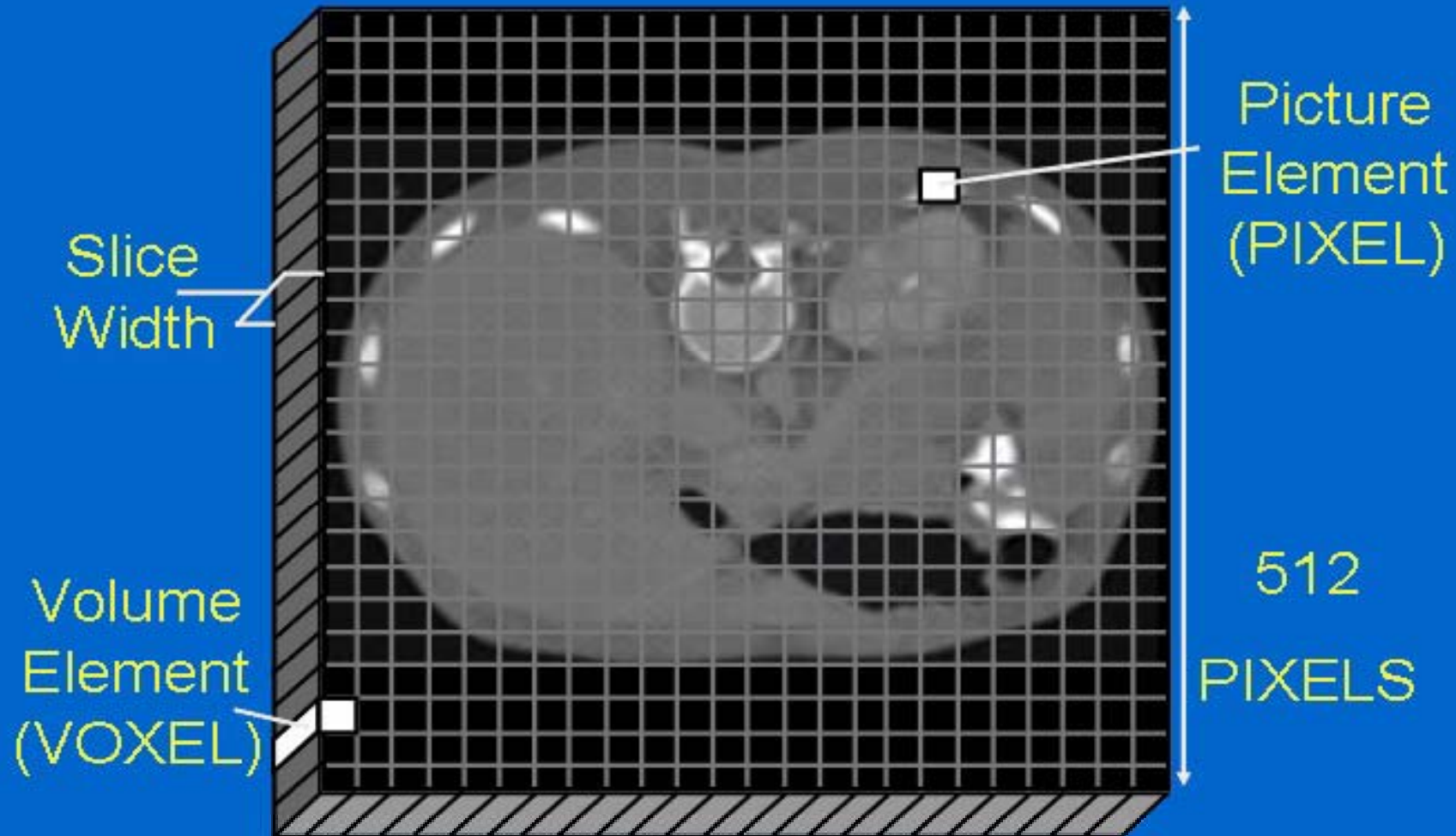
# A. Technical parameters influencing quality and dose



## Reconstruction & Image Presentation

1. FOV
2. Image Matrix size
3. Reconstruction Algorithms
4. Reconstruction Increment
5. Window level/centre
6. Window width

# Image matrix size



# Reconstruction Algorithms

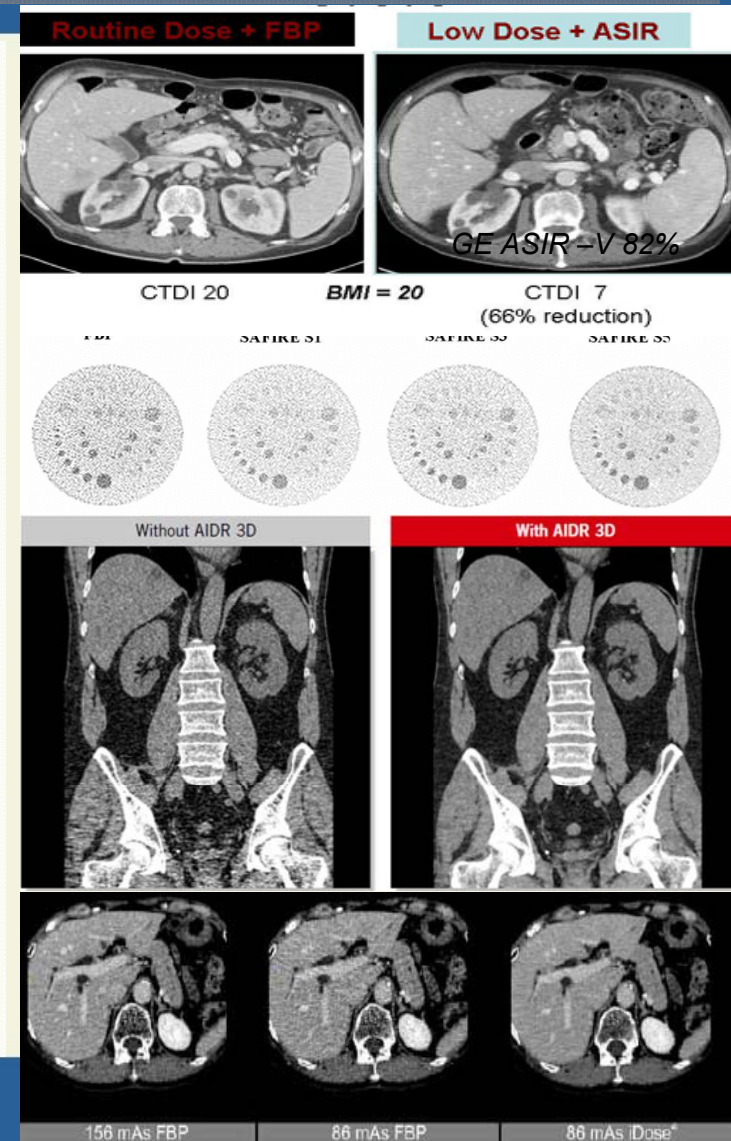
It's all maths...

- Spiral Convolution algorithms
- Body algorithms
- Head algorithms
- Soft tissue/Smooth algorithms
- Mid/mild algorithms
- Bone/lung/High resolution algorithms
- FBP algorithms
- Advanced reconstruction algorithms
  - Iterative algorithms
  - Noise reduction algorithms

# Advanced Reconstruction Algorithms

- Algorithms **alone** do not reduce dose!!!!
- They are selected when the image quality level desired at a minimum dose has been established in order to reduce the noise level.

Vendor	Algorithm	Noise reduction
GE	ASIR	66%
PHILIPS	iDose4 IRA	50%
SIEMENS	SAFIRE	66%
TOSHIBA	AIDR 3D	50%




# Reconstruction Increment RI



- The fundamental advantage of HCT is the overlapping of axial sections without increase in exposure.
- It defines the degree of overlapping between axial sections.
- GENERAL RULE: RI selected must generate images with at least 30% section overlap

# Window level & width **WL/WC & WW**

- 
1. **WL/WC**, Determines the median density /brightness of structures visualized
  2. **WW**, Determines the average contrast of structures visualized.
- Selection is based on the specific diagnostic requirements.

# TISSUE & ORGAN DENSITIES

Table 12.1a Density of all tissues

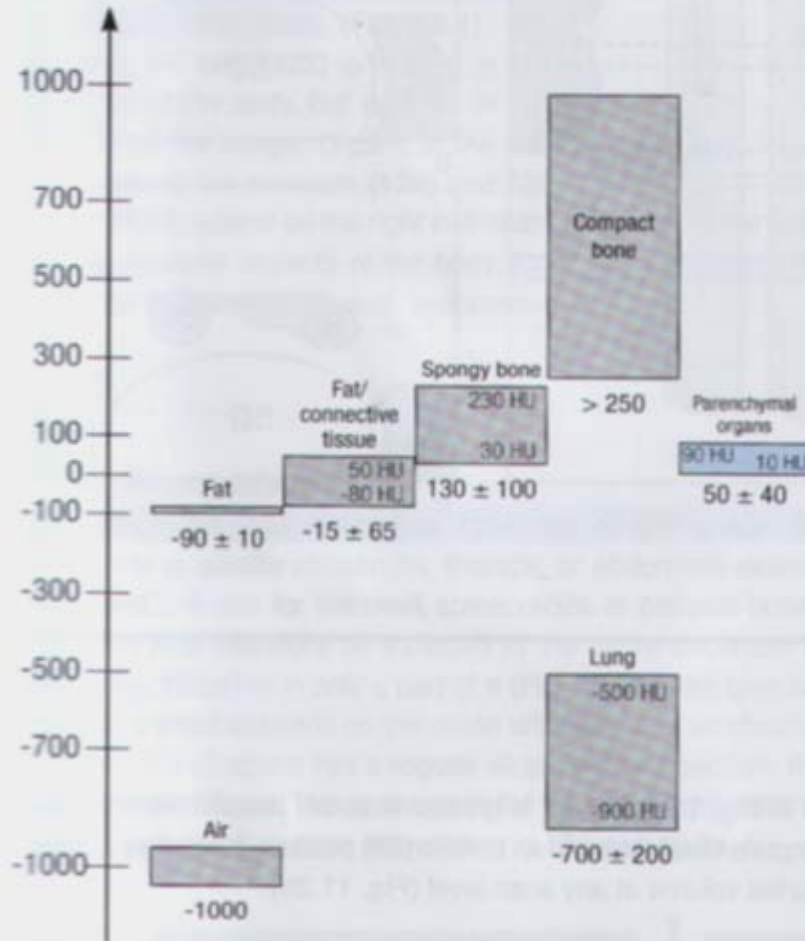
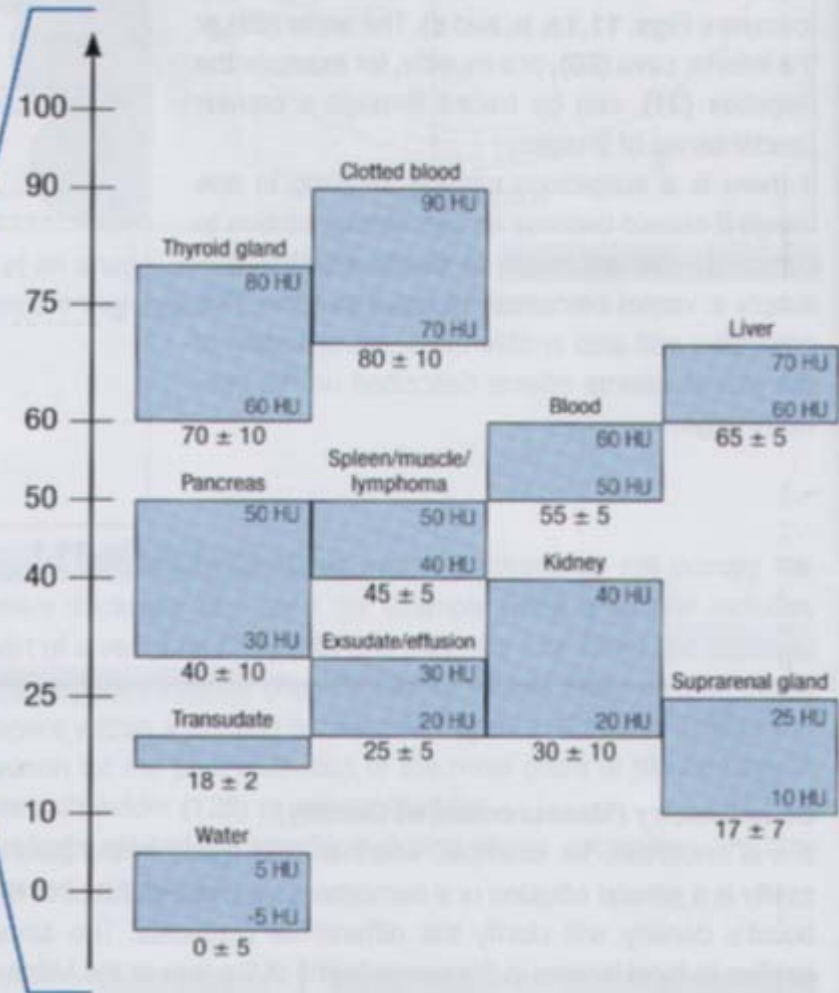
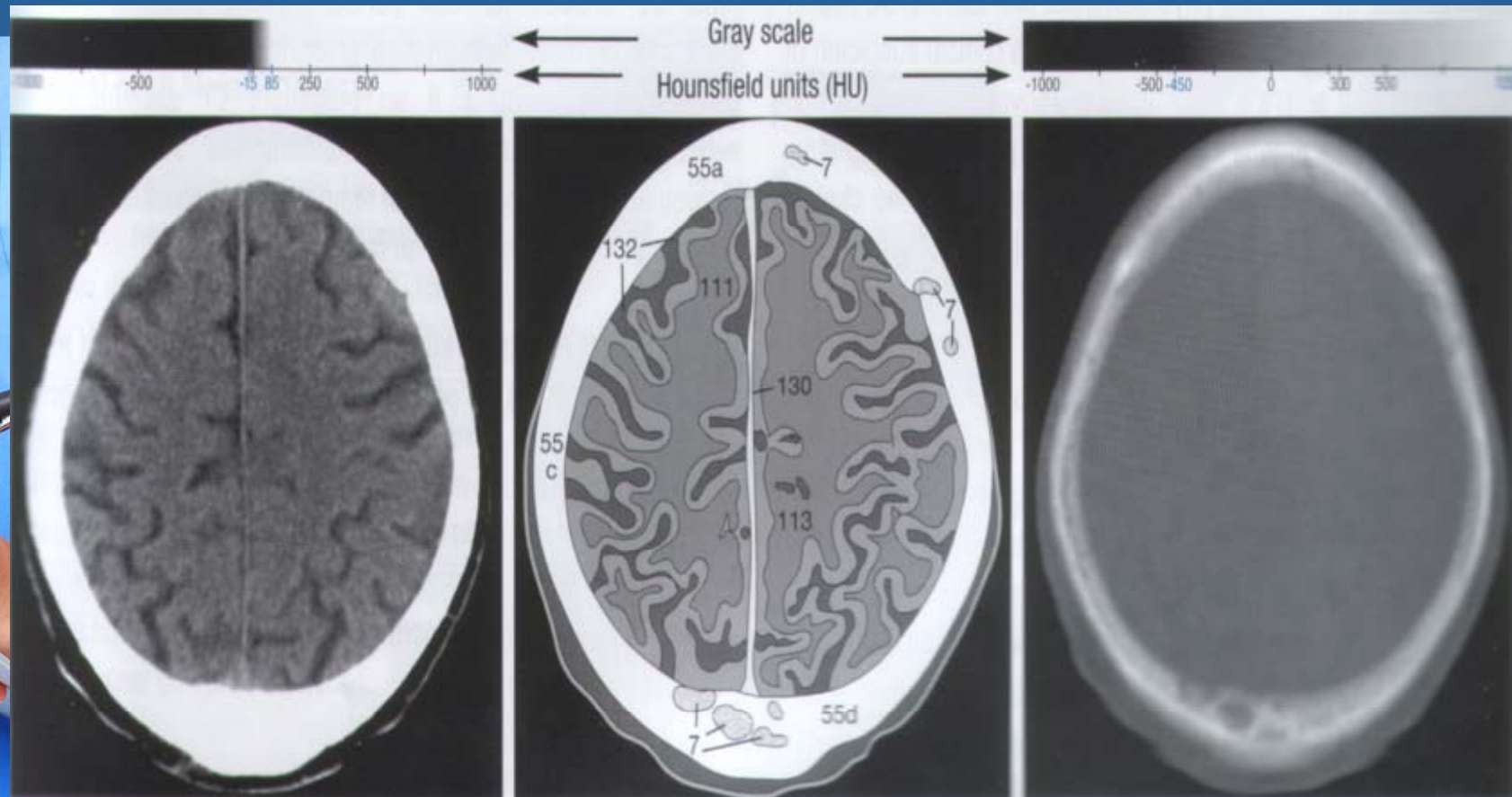


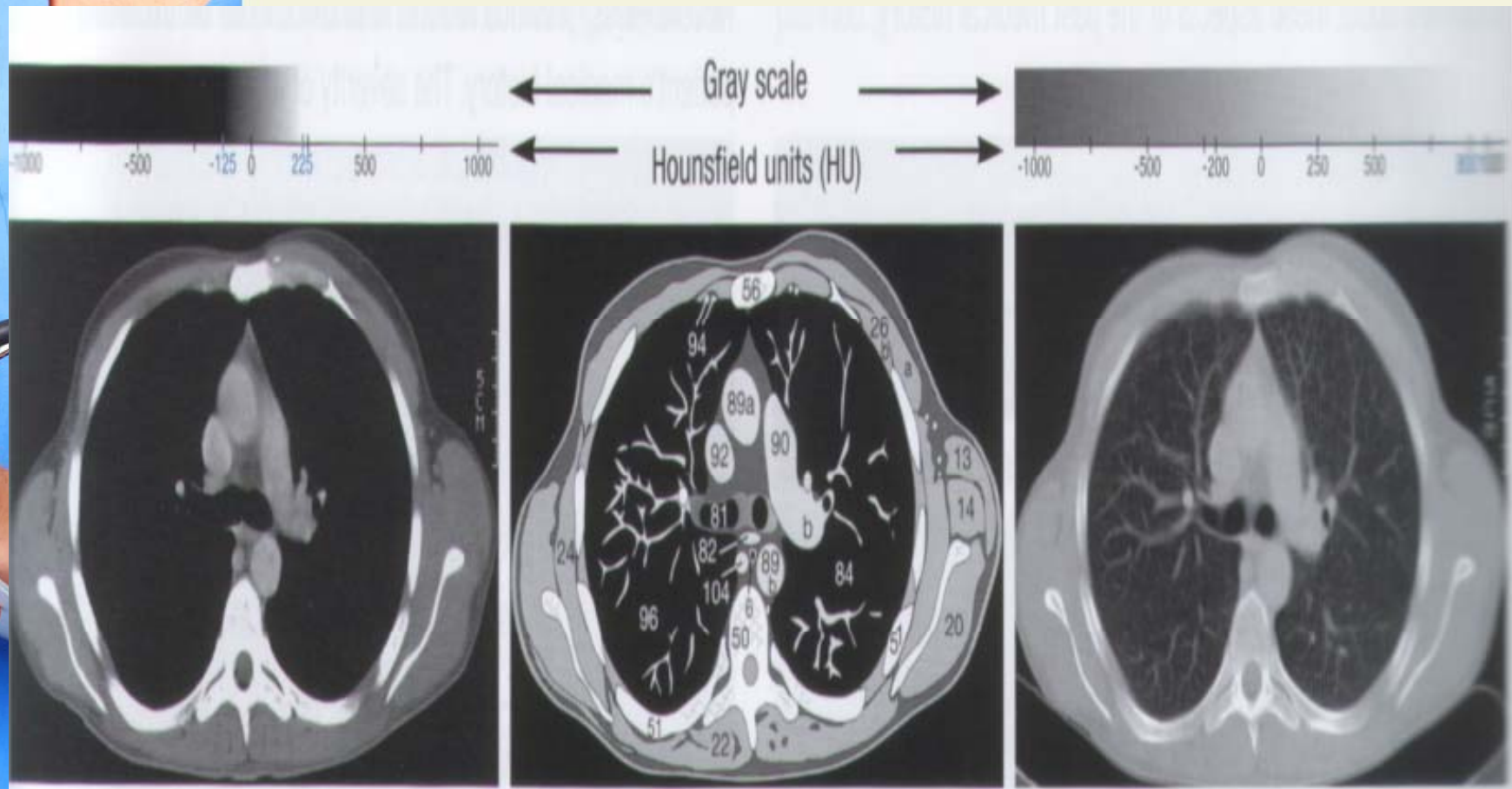
Table 12.1b Density of parenchymal organs and fluids



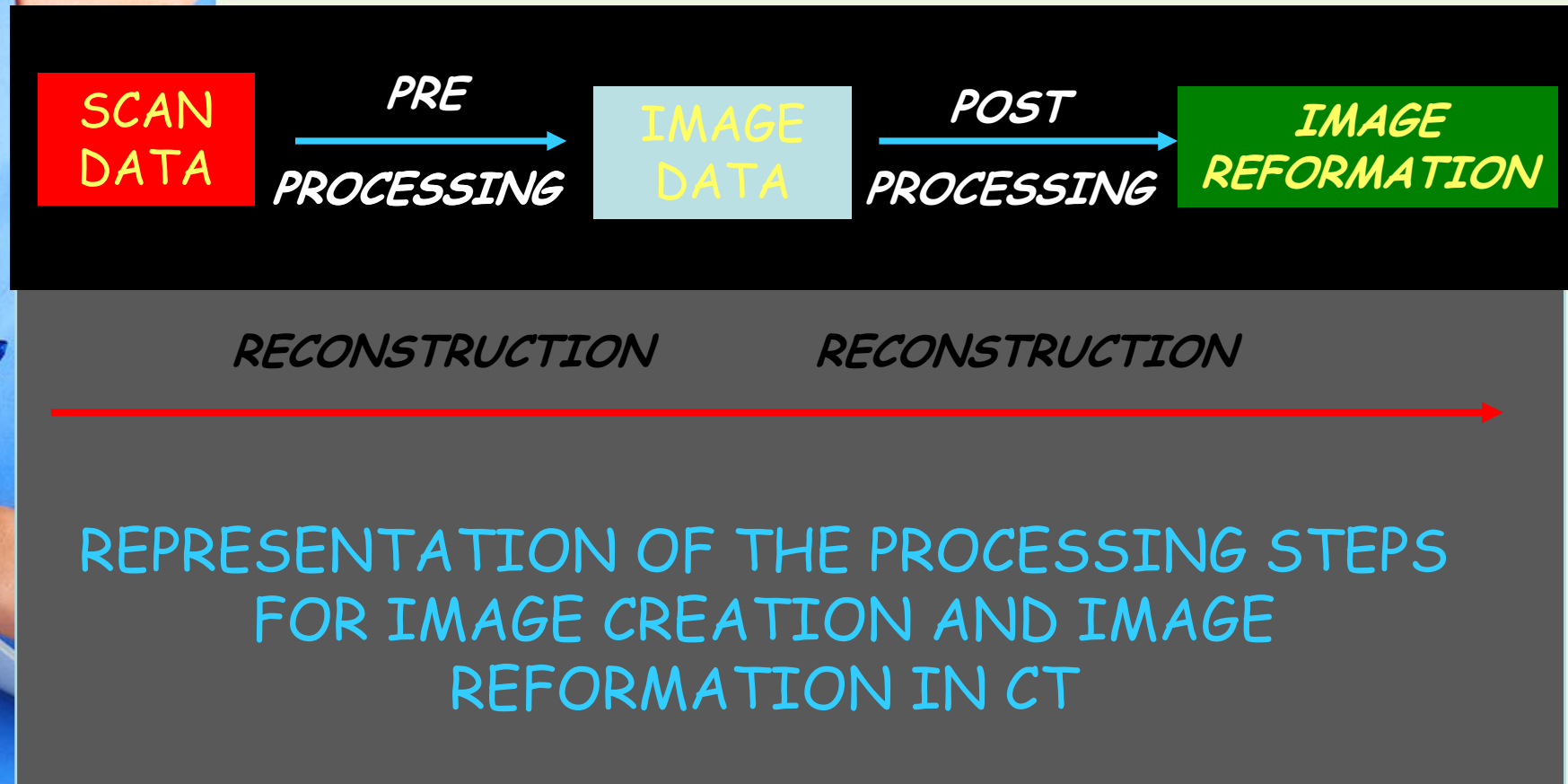
# HEAD CT windows



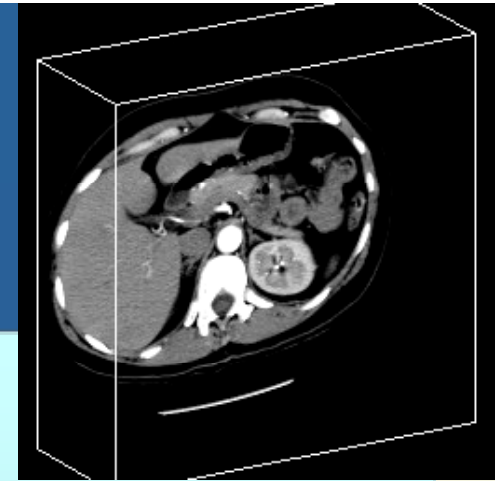
# Chest CT: Mediastinum and Lung windows



# Advanced image reconstruction



# Post processing



1. Max intensity projn(MIP)
2. Min intensity projn (mIP)
3. MultiPlanar Reconstruction (MPR) & (CurvedMPR)
4. 3D Reconstruction  
Surface Shaded Display (SSD)  
Volume Rendering Technique (VRT)

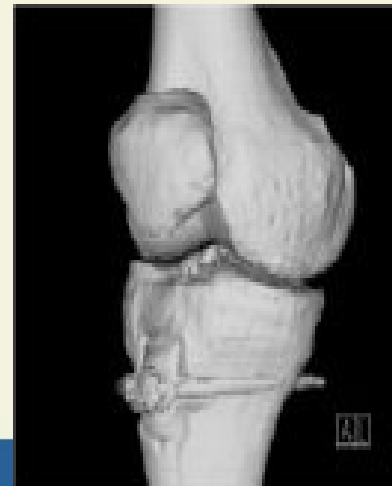
MIP



MPR



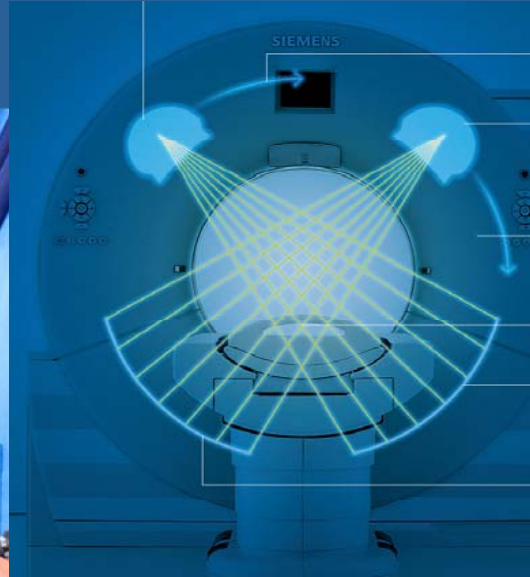
SSD



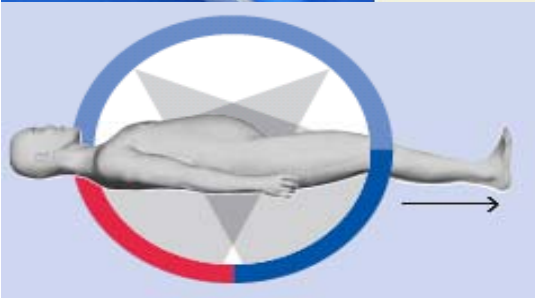
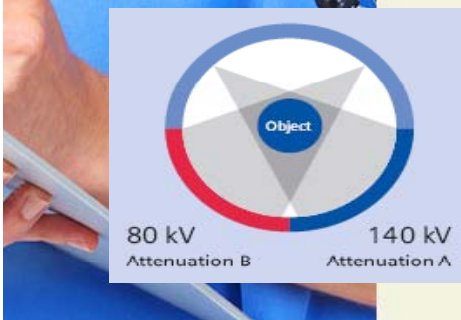
VRT




# DSCT



- Dual source CT:
  1. Tissue differentiation
  2. Immediate bone and vessel subtraction
  3. Mass and plaque characterization
  4. Fluid differentiation



# References

- 
- Agadakos E., (2009), *CT Principles and Applications*, CPD - CT notes GEN Hospital Nikaia
  - Bushong S.C., (1988), **Radiologic Science for Technologists**, (4<sup>th</sup> Ed.), C.V. Mosby Co: Washington D.C. USA.
  - Curry III T.S., Dowdey J.E., Murray Jr R.C., (1984), **Christensen's Introduction to the Physics of Diagnostic Radiology**, (3<sup>rd</sup> Ed.), Lea and Febiger: Philadelphia USA.
  - **EC European Guidance on Quality Criteria for Computed Tomography.** (May 1999), EUR 16262.
  - Hofer M., (2000), **CT Teaching Manual**, Thieme: New York USA.
  - Prokop M., Galanski M., (1998), **Spiral and Multislice Computed Tomography of the body**, Thieme: New York.
  - Wegener O. H., (1994), **Whole Body Computed Tomography**, (2<sup>nd</sup> Ed.), Blackwell Scientific Publications: Cambridge USA.
  - Whitehouse G.H., Worthington B.S., (1990), **Techniques in Diagnostic Imaging**, (2<sup>nd</sup> Ed.), Blackwell Scientific Publications: VIC. Australia.

# Dose Management in CT

**ALARA**

(As Low As Reasonably Achievable)

**Radiation Protection**

**Diagnostic Reference Levels DRLs**

# Dose control strategy

- Clinical indication
- Decrease beam energy (mA)
- Increase pitch
- Accurate scanning of volume
- Apply AEC
- Raw data storage

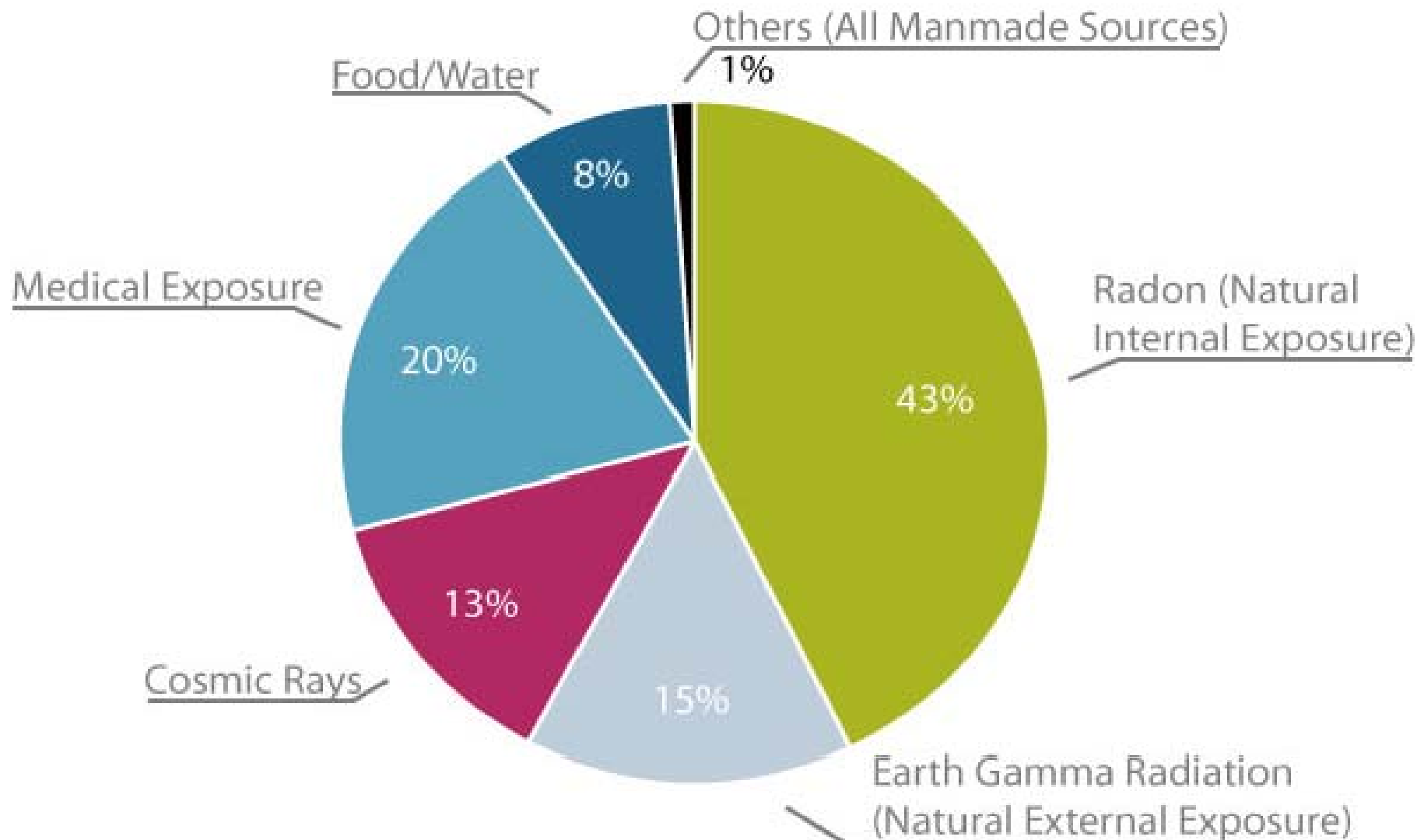


# Reasoning...



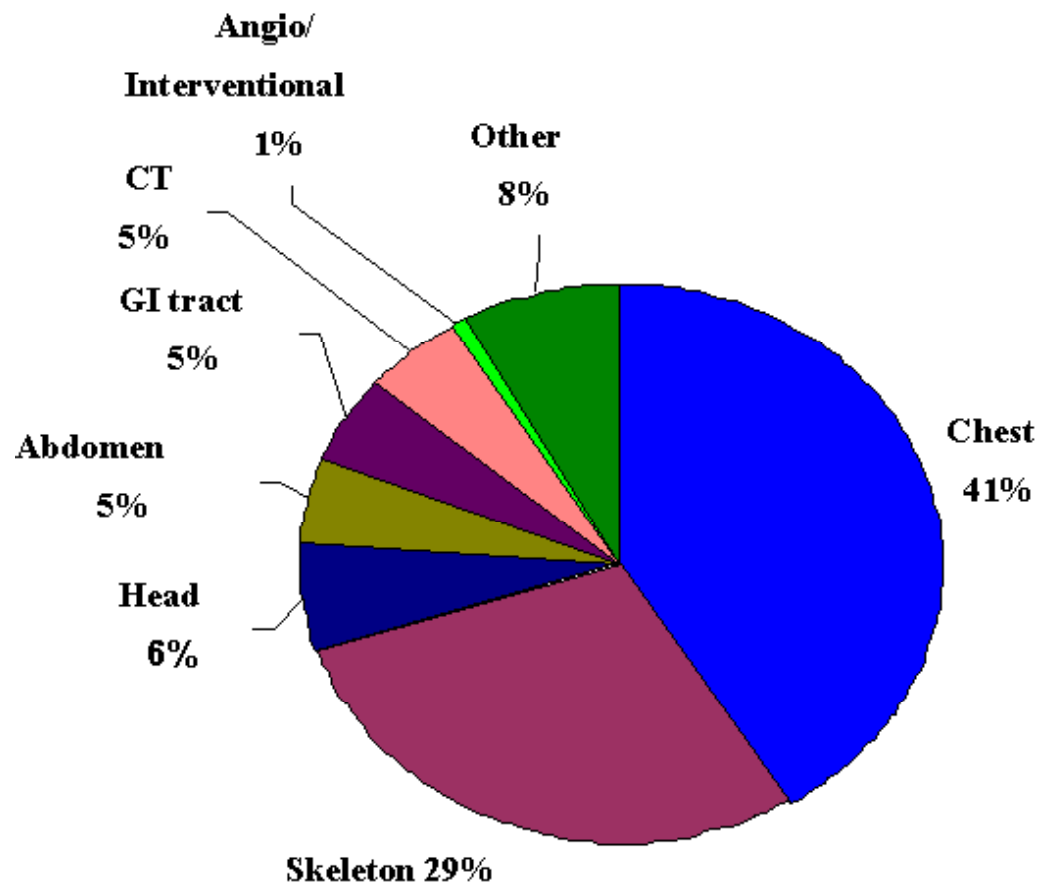
- Situation analysis
- Why increased frequency?
- Why increased dose?
- Is the dose really high? How high?
- What can be done to manage patient dose?
  - What can RGs do?
  - Action for manufacturer
  - Action for physician & radiologist

# Sources and distribution of average radiation exposure to the world's population

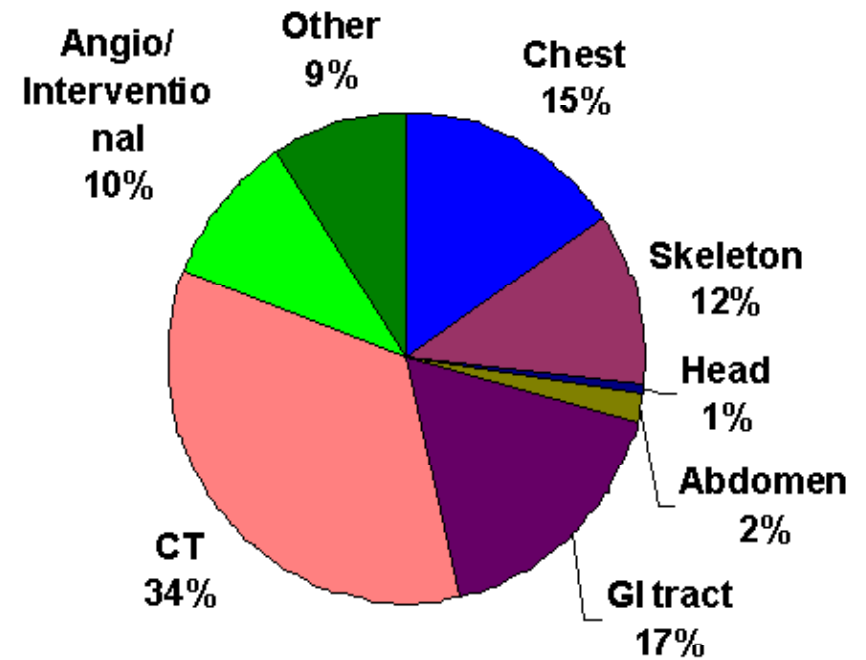


# UNSCEAR 2000

## (a) Contributions to frequency



## (b) Contributions to collective dose



# Why increased frequency?




- 20 years ago, a standard CT of the thorax took several minutes while today similar information can be accumulated in a single breath hold making it attractive, patient & user friendly
- Advances in CT technology have made possible CT fluoroscopy and interventional procedures, in some cases replacing ultrasound guided interventions
- Recently CT screening is picking up

# Why increased dose...



- Unlike radiography where over-exposure results in blackening of film, better image quality is obtained with higher exposures in CT
- There is a tendency to increase the volume covered in a particular examination
- Modern helical CT involves volume scanning with no inter-slice gap and with possibility of overlapping scans
- Repeat CT examinations

# Why increased dose (cont'd)

- 
- A person wearing blue scrubs is shown from the chest down, holding a clipboard and a pen. A stethoscope is visible around their neck.
- Same exposure factors used for children as for adult
  - Same exposure factors for pelvic (high contrast region) as for abdomen (low contrast region)

# What is the dose from CT? How high?




- The effective dose in chest CT is in the order of 8 mSv (around 400 times more than chest radiograph dose) and in some CT examinations like that of pelvic region, it may be around 20 mSv
- The absorbed dose to tissues from CT can often approach or exceed the levels known to increase the probability of cancer as shown in epidemiological studies

# Effective doses in CT and radiographic examinations

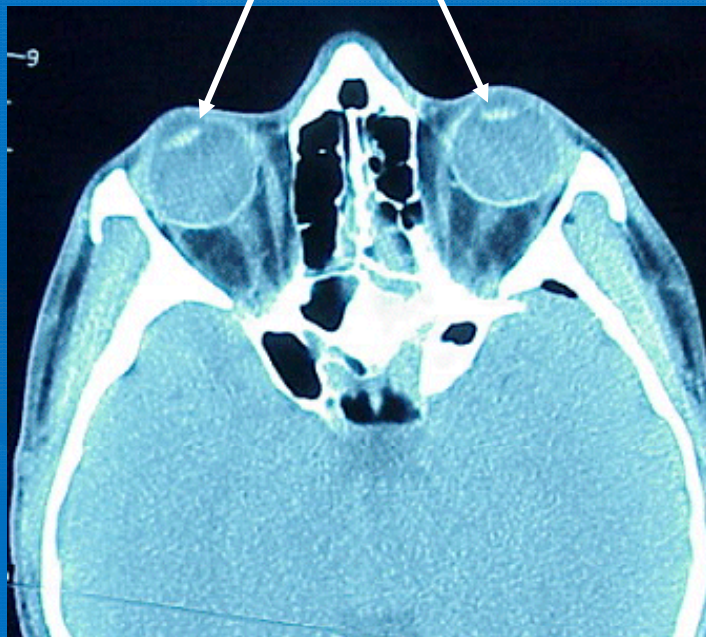
CT examination	Effective dose (mSv)	Radiographic examination	Effective dose (mSv)
Head	2	Skull	0.07
Chest	8	Chest PA	0.02
Abdomen	10-20	Abdomen	1.0
Pelvis	10-20	Pelvis	0.7
		Ba swallow	1.5
		Ba enema	7

# Organ doses in CT

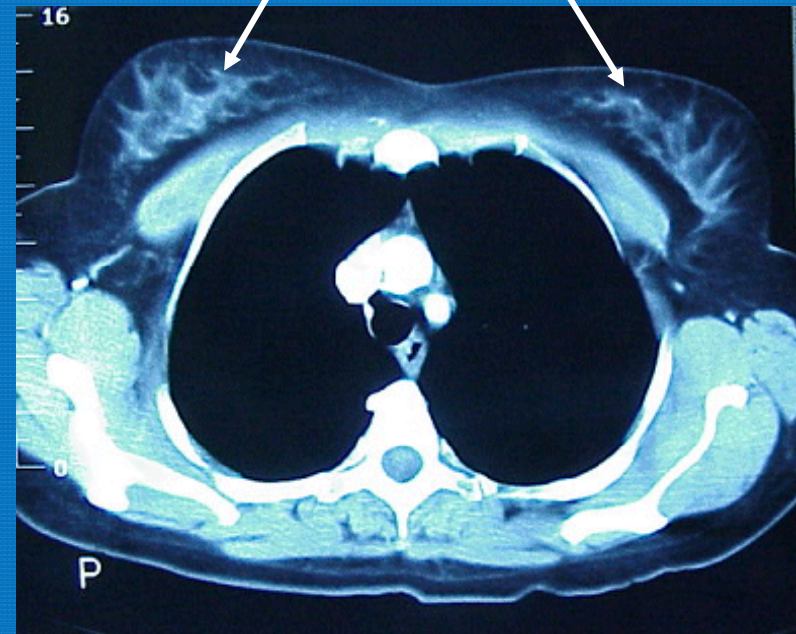
- 
- Breast dose in thorax CT may be as much as 30-50 mGy, even though breasts are not the target of imaging procedure
  - Eye lens dose in brain CT, thyroid in brain or in thorax CT and gonads in pelvic CT receive high doses

Tissues in the field although they are not the area of interest for the procedure

Lens of the eye



Breast tissue



# Typical doses in mGy during CT in adults (Shrimpton et al. 1991)

Examination	Eyes	Thyroid	Breast	Uterus	Ovaries	Testes
Head	50	1.9	0.03	*	*	*
Cervical spine	0.62	44	0.09	*	*	*
Thoracic spine	0.04	0.46	28	0.02	0.02	*
Chest	0.14	2.3	21	0.06	0.08	*
Abdomen	*	0.05	0.72	8.0	8.0	0.7
L. spine	*	0.01	0.13	2.4	2.7	0.06
Pelvis	*	*	0.03	26	23	1.7

The symbol \* indicates that dose is  $< 0.005$  mGy

# Does spiral CT give more or less radiation dose?



- It depends upon the choice of factors
- Even though it is possible to perform a spiral CT with lower radiation dose than slice-by-slice CT, in practice the patient gets higher dose due to the factors chosen (scan volume, mAs, pitch, slice width)

# Does multi-slice CT impart more or less radiation dose?



- An increase by 10-30% may occur with multi-slice detector array

# Some observations...

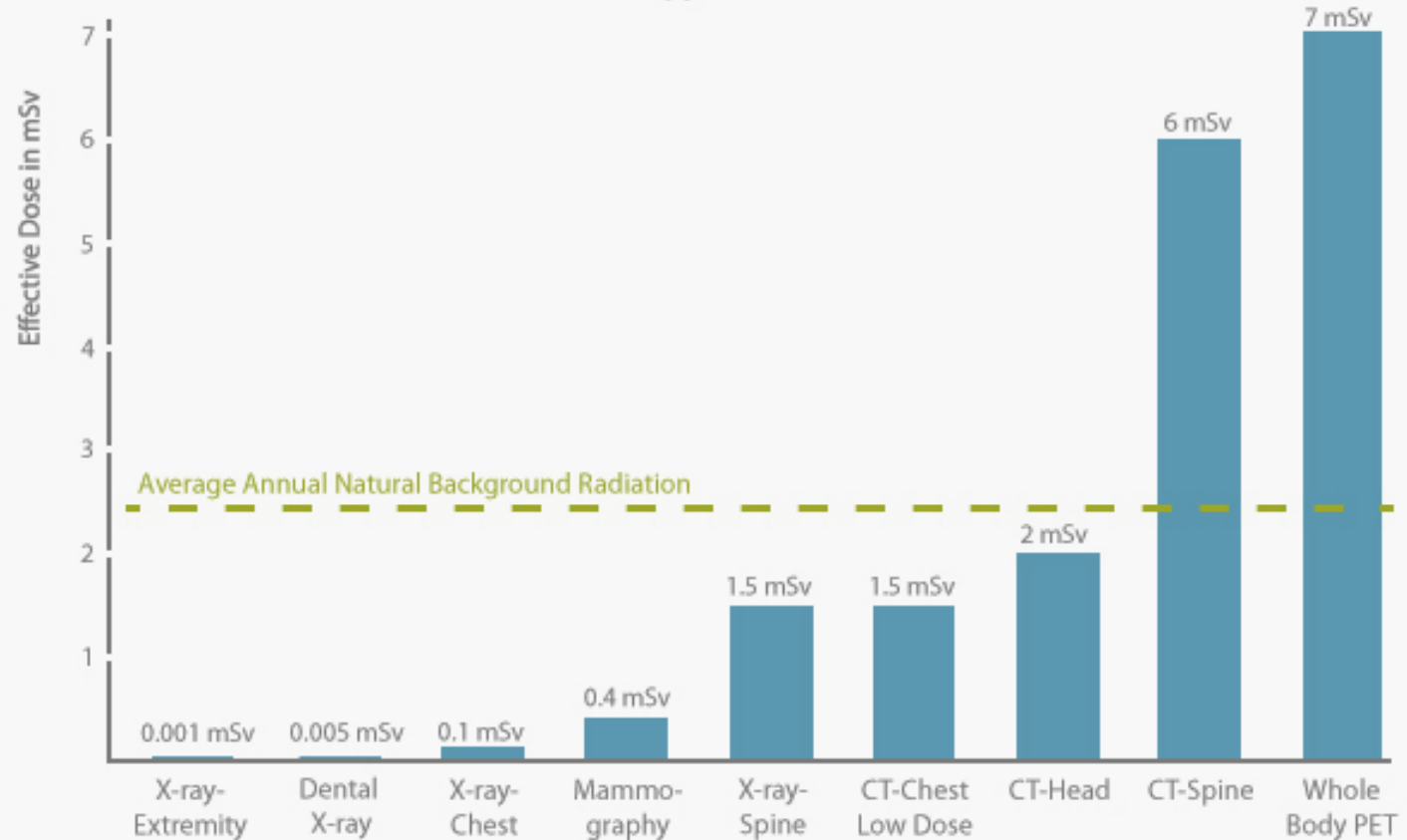


- Most doctors, including many radiologists have a feeling that modern CT scanners which are very fast give lesser radiation dose
- Unfortunately 'time' and 'radiation dose' are not proportional in such a situation
- Over the years the x-ray tubes are becoming more and more powerful such that they can give high bursts of x-rays which can give satisfactory image in shorter exposure time

# *In brief...*



Radiation Doses of Typical Medical Examinations

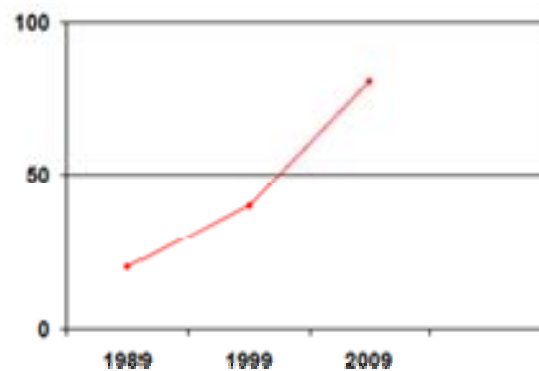


All information from radiologyinfo.org except "Whole Body PET" (Source: Radiation Exposure of Patients Undergoing Whole-Body Dual-Modality 18F-FDG PET/CT Examinations, Brix G et al., JNM, 46:4, 4/2005) and "Average Annual Background Radiation" (Source: <http://www.iaea.org/Publications/Factsheets/English/radlife.html>)

*In brief...*

## CT contribution to Radiation Collective Dose

Year	% Xray procedures	% of total collective doses
1989	2	20
1999	4	40
2009	8	80



ICRP *Publication 87*

# New directive: EURATOM 2013/59

## Official Journal of the European Union



Legislation

Legislation

ISSUE L 13

Volume 57  
17 January 2014

Contents

II Non-legislative acts

DIRECTIVES

- Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2000/113/Euratom ..... 1

# Dose Management



## Objectives

1. To become familiar with CT Dose indicators
2. To incorporate national DRLs
3. To utilize dose reduction tools
4. To tailor protocols accordingly

# Computer Tomography Dose Index Volume (CTDI<sub>vol</sub>)

- Reflects the total of average doses CTDI<sub>w</sub> for a given section of a total L

$$\text{CTDI}_{\text{vol}} = \text{CTDI}_w \times \text{SC} / \text{TF}$$

TF = table feed

SC = section collimation

$$\frac{\text{TF/RT}}{\text{SC}} \left. \vphantom{\frac{\text{TF/RT}}{\text{SC}}} \right\} \text{P} = \text{pitch}$$

# Dose Indicators

## Volume Computed Tomography Dose Index (CTDI<sub>vol</sub>)

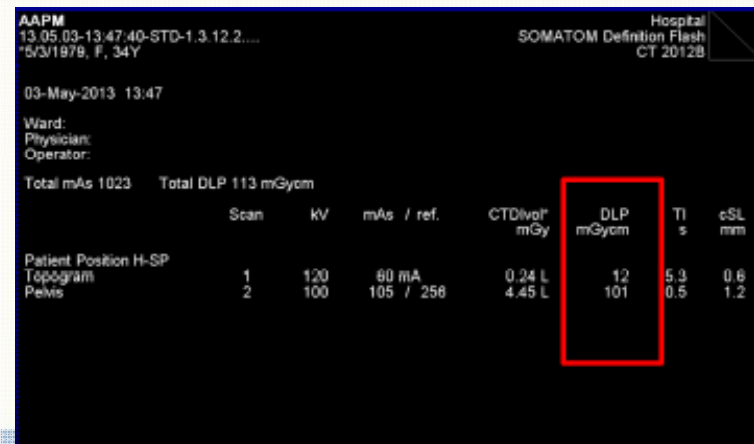
- Measures radiation output of the scanner
- **CTDI<sub>vol</sub> is NOT DOSE!!!!**
- SI Unit : mGy
- Is different for diameters of 16cm and 32cm
  - eg for equal exposure & scanning parameters, CTDI<sub>vol</sub> is doubled for 16cm diameter compared to 32 cm diameter.
- The CTDI<sub>vol</sub> presented is according to vendors' measurements.
- Dosimetry controls CTDI<sub>vol</sub> accuracy.
- CTDI<sub>vol</sub> vs Dose is influenced by many factors and by patient factors

# Dose Indicators

## Dose Length Product (DLP)

- Is calculated by the system and is presented on screen.
- Expressed in mGy.cm
- Is the product of the total length, L of the volume scanned and the CTDIvol.

$$\text{DLP} = \text{CTDI}_{\text{vol}} \times L$$
$$\text{DLP} = \text{CTDI}_{\text{w}} \times P \times L$$



AAPM  
13.05.03-13:47:40-STD-1.3.12.2....  
\*531978, F, 34Y

Hospital  
SOMATOM Definition Flash  
CT 2012B

03-May-2013 13:47


Ward:  
Physician:  
Operator:

Total mAs 1023 Total DLP 113 mGy.cm

	Scan	KV	mAs / ref.	CTDIvol <sup>a</sup> mGy	DLP mGy.cm	Tl s	cSL mm
Patient Position H-SP	1	120	80 mA	0.24 L	12	5.3	0.6
Topogram	2	100	105 / 258	4.45 L	101	0.5	1.2

# Dose Indicators

## Effective Dose



Region	L (cm)	E/DLP* <i>Conversion factor</i>	E (mSv)
Chest	30	0.017	11.05
Liver	20	0.012	10.80
Pelvis	20	0.019	10.83
Abdomen	40	0.015	20.25
Chest upper abdo	60	0.014	22.88

# Dose Indicators

## Size Specific Dose Estimate (SSDE)

- The American Association of Physicists in Medicine – AAPM (Report 204) has introduced a newer indicator that involves both,
  - $CTDI_{vol}$  and
  - patient body type.



**RPOP**  
Radiation  
Protection of  
Patients

# 10 Pearls: Radiation protection of patients in CT

<https://rpop.iaea.org/RPOP/RPoP/Content/Documents/Whitepapers/poster-ctradiation-protection.pdf>



## 10 Pearls: Radiation protection of **patients** in CT

### 1. Perform scan only if it is indicated!

It is estimated that a significant number of imaging examinations are unnecessary  
Consultation between the referring physician and the radiologist is recommended



**US**

Ultra Sound

**MRI**

Magnetic Resonance Imaging

2. Encourage use of alternative non-ionizing imaging (MRI,US) when appropriate especially in younger patients

### 3. Always check if patient may be pregnant

Use special signs and informative material notifying patients that they **MUST** disclose any possibility of pregnancy



Please notify staff if you think you might be pregnant!

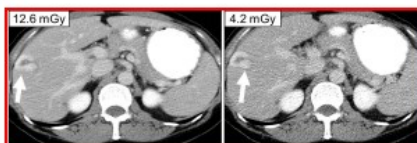


Image Quality: Unnecessarily high      Image Quality: Adequate for diagnosis

4. High quality /Crisp images may look nice but they impart higher radiation dose to patients  
Start using images with some noise without loss of diagnostic information

Images courtesy of: MK Kaifa, S. Singh, MGH Webster Center for Advanced Research and Education in Radiation

5. Use indication-specific CT protocols for each body region, e.g. for lung nodule follow up or kidney stones, diagnostic images can be obtained at 50-75% lower radiation dose compared to routine or general use protocols




**RPOP**  
Radiation  
Protection of  
Patients

Related Poster!  
10 Pearls: Appropriate referral of CT examinations  
<https://www.iaea.org/RPOP/RPoP/Content/Documents/Whitepapers/poster-ct-radiation-protection.pdf>

<http://rpop.iaea.org>

Page 1 of 2  
Computed Tomography  
Patient Radiation Protection

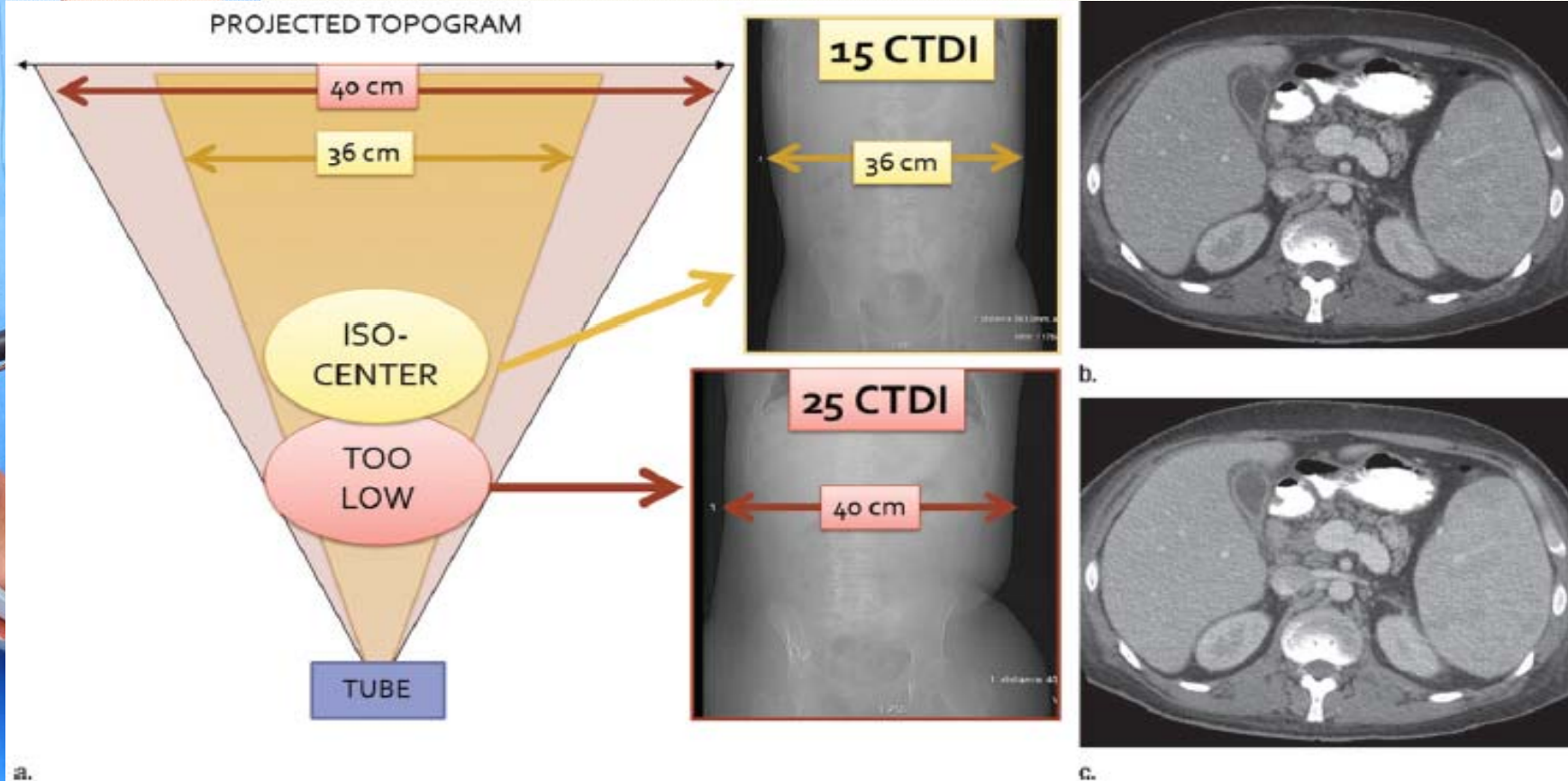
# DRLs : NCRP Report No172 vs Greek National DRLs, Gazette 3176/B/26-11-2014



Examination	<i>*NCRP Report No. 172</i>	Reference Levels (CTDIvol)*	
CT head		75 mGy	(67mGy)
CT adult abdomen		25 mGy	(16mGy)
CT adult chest		21 mGy	(14mGy)
CT paediatric abdomen (5 y old)		20 mGy	(-)
CT paediatric head (5 y old)		34 mGy	(-)

*Greek Gazette 3176/B/26-11-2014*

# Pt positioning & AEC



# Dose alert

**DOSE NOTIFICATION**


One or more group result in a projected dose exceeding the Notification Value set. Select Cancel to go back to Viewedit and adjust scan parameters if clinically appropriate to set below the Notification Value. Selecting Confirm will proceed to scan and log user confirmation of scan parameters exceeding the Notification Value.

Series#	1	Series Description	A/P Onocology
	Images	NV	Projected
CTDIvol (mGy)	1 - 9	30	31.09

Diagnostic Reason

**Dose Alert**

A dose value will be exceeded!

 The accumulated CTDIvol (1177.41 mGy) will locally exceed the alert value (1000 mGy for Adult). Please reconsider the current examination procedure.

Hint: The currently used scan protocol can not be saved!

User name (mandatory)

Diagnostic reason

Password

**DOSE NOTIFICATION**

One or more elements in this exam plan will exceed the dose notification level that has been set.

Element	Predicted CTDIvol	Predicted DLP	Notification CTDIvol	Notification DLP
Helical	11.4 mGy	342 mGy.cm	30 mGy	1000 mGy.cm
Helical	34.6 mGy	1038 mGy.cm	30 mGy	1000 mGy.cm

# Summary



- Clinical indications for CT **must** be confirmed.
- Other modalities with less or no radiation dose **must** be considered. (e.g. Ultrasound, MRI)
- Optimisation of acquisition protocol

# Conclusion

1. The competent RG is the sole health professional who knows or must be aware of the capabilities, limitations and the technological innovations of the CT system and accessory equipment
2. Must utilize these new tools effectively and must record DLPs
3. Ought to be actively involved in CT protocol tailoring with the medical physicist and radiologist.





Visit [IMAGEGENTLY.ORG](http://IMAGEGENTLY.ORG) for pediatric protection information.

## Web sites on Radiation Protection



[WWW.IMAGEWISELY.ORG](http://WWW.IMAGEWISELY.ORG)

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<http://www.eurosafeimaging.org/>  
ESR Eurosafe Imaging



<https://rpop.iaea.org/RPoP/RPoP/Content/index.htm>

IAEA Radiation Protection Of Patients RPOP

## • Rad Protn Publications

- IAEA 1996 BSS - Guidance levels
- ECRP109EC 1999b DRL
- ICRP 103 2007 New recommendations (Education-Training)
- ICRP 105 2007b New recommendations (Education-Training)
- UNSCEAR 2000 Report Annex D Medical radiation exposures
- Rad Protection EN 118 2000
- UNSCEAR 2008 Report Annex A Medical radiation exposures
- IAEA IBSS Edition 2011
- Hellenic Radiology Society Diagnostic – Therapeutic Protocols 2011