
بسم الله الرحمن الرحيم
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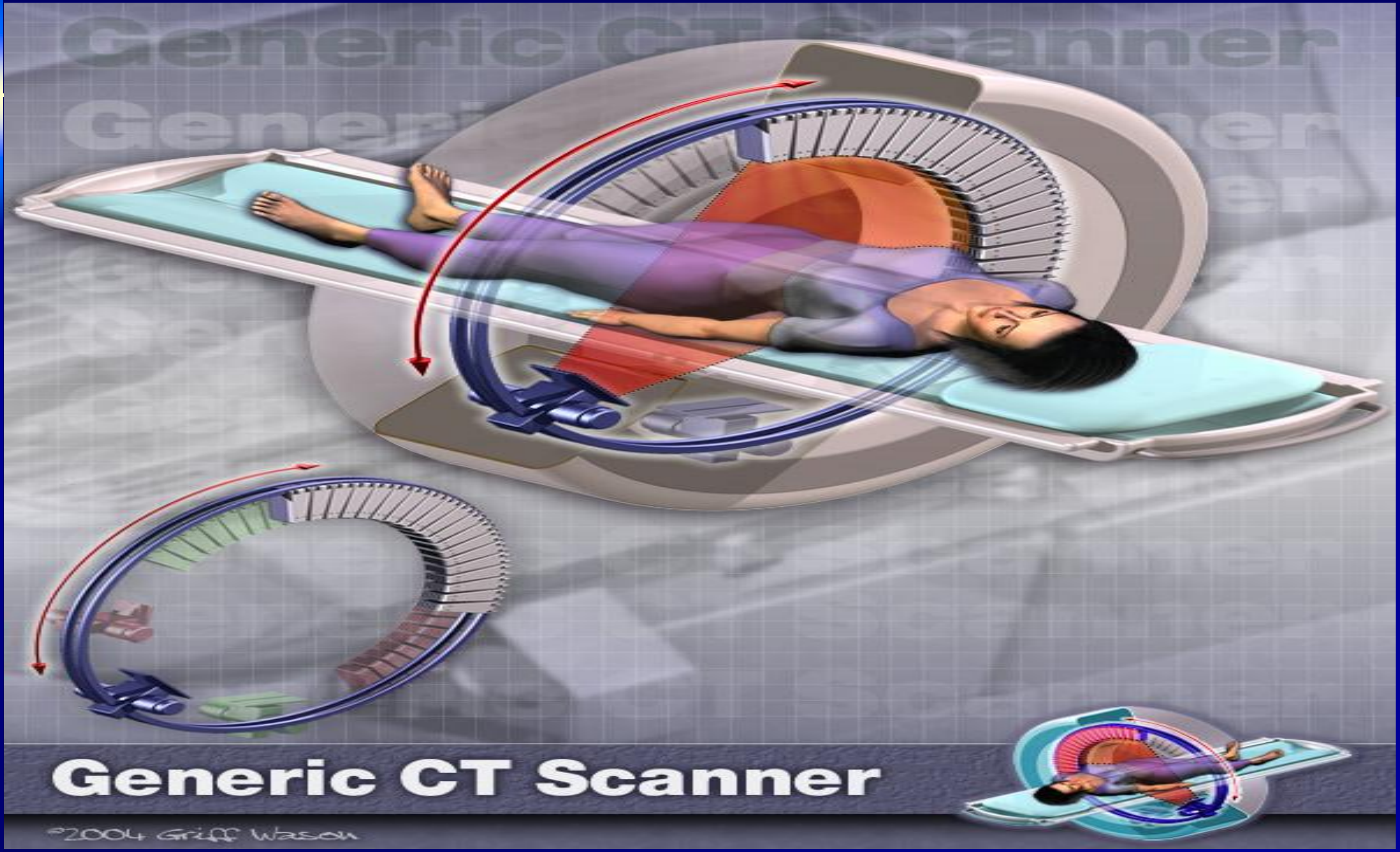
PHYSICAL PRINCIPLES OF COMPUTED TOMOGRAPHY



Presentation: **Mohamad Akbarnejad**

Radiobiology and Radiation Protection MSC

X-Ray Discovery

X-ray was discovered by a German scientist Roentgen 100 years ago. This made people for the first time be able to

- view the anatomy structure of human body without operation
- But it's superimposed
- And we couldn't view soft tissue

محدودیتهای اساسی رادیوگرافی:

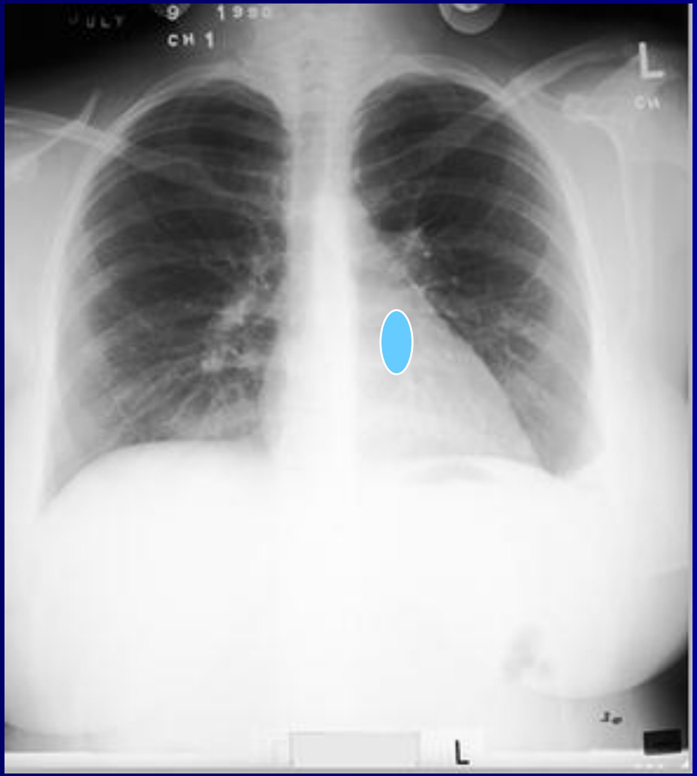
1-انطباق تصاویر اعضای مختلف بریکدیگر(SUPERIMPOSITION)

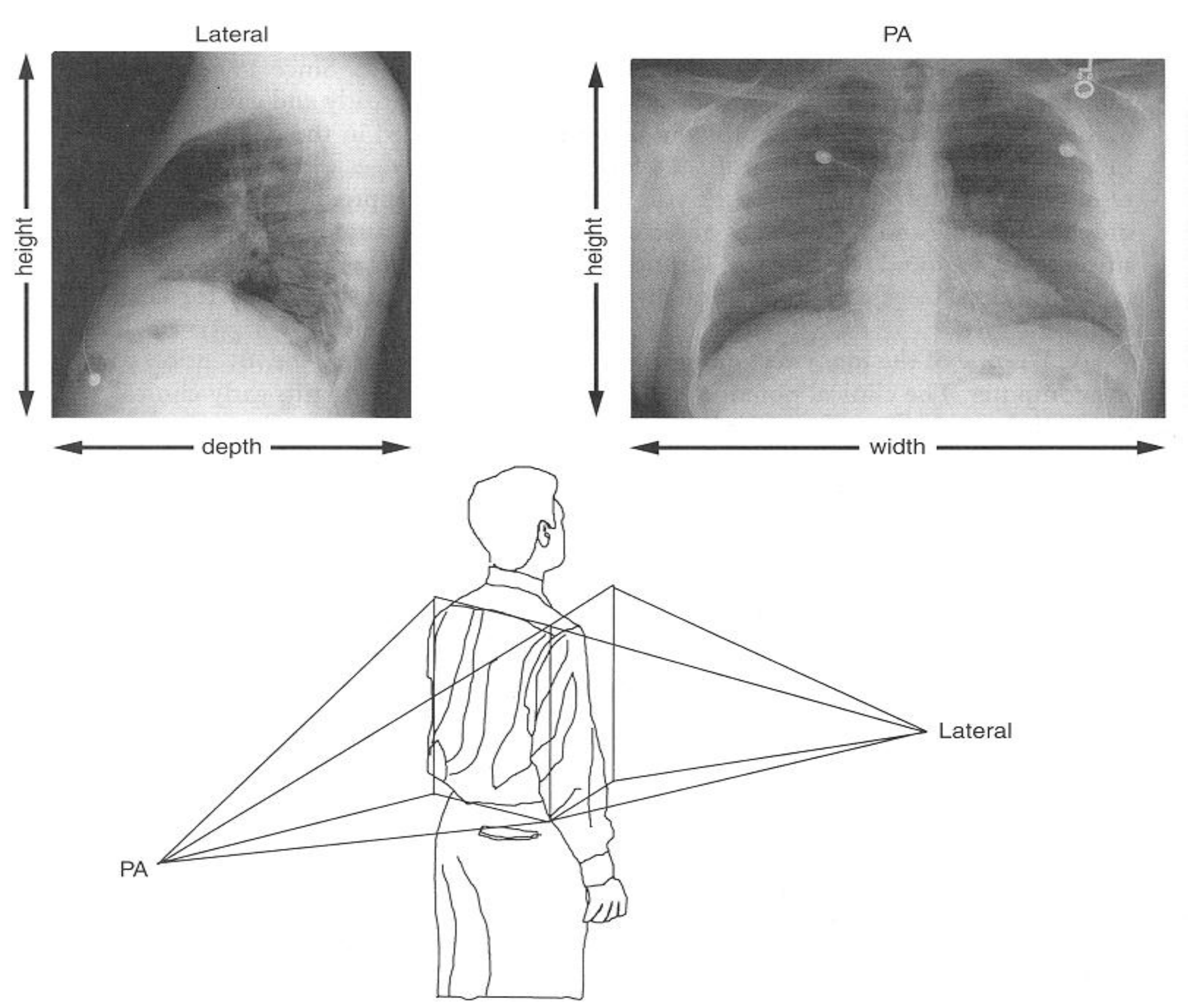
2-پایین بودن کنتراست در اختلاف جذبهای کم

3-رادیوگرافی معمولا اطلاعات را کیفی نشان میدهد(به جای کمی)

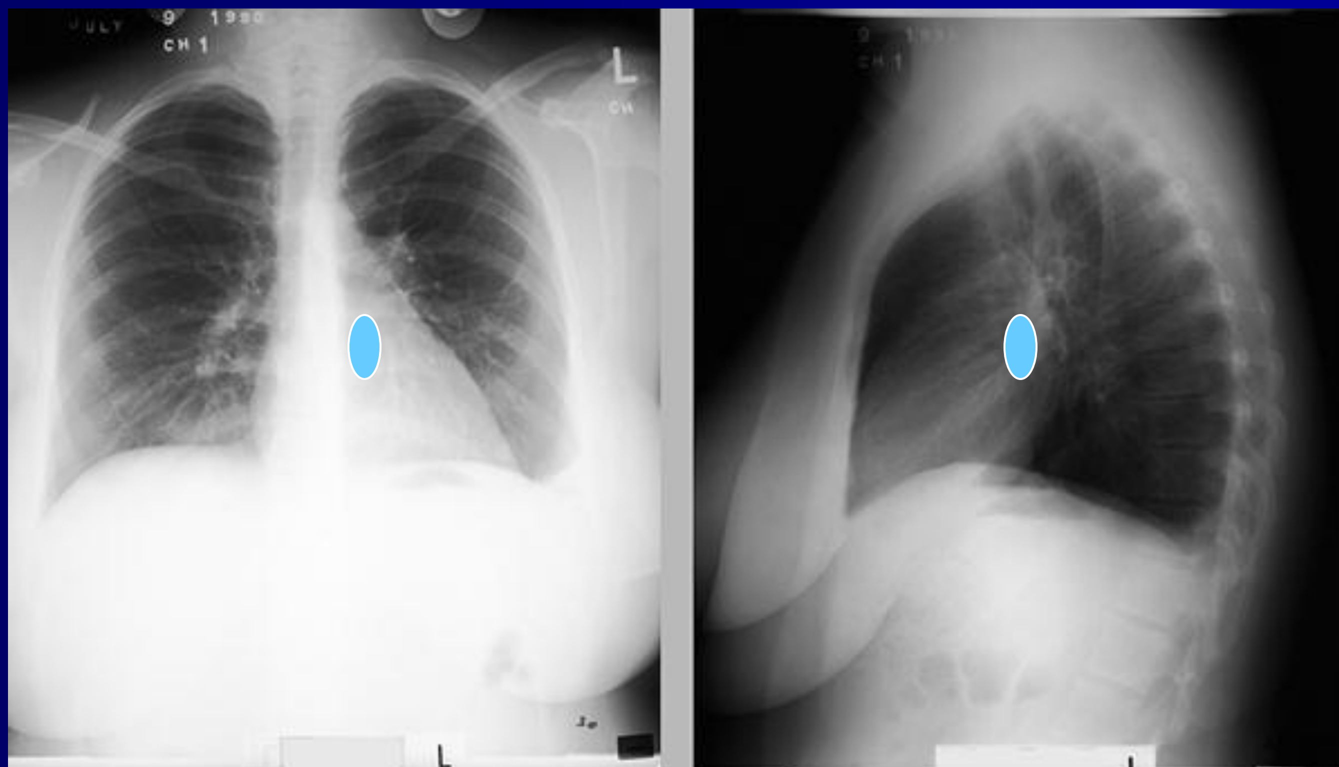
DIFFICULTY IN DISTINGUISHING BETWEEN HOMOGENOUS OBJECTS OF NON-UNIFORM THICKNESS.

1-SUPERIMPOSITION

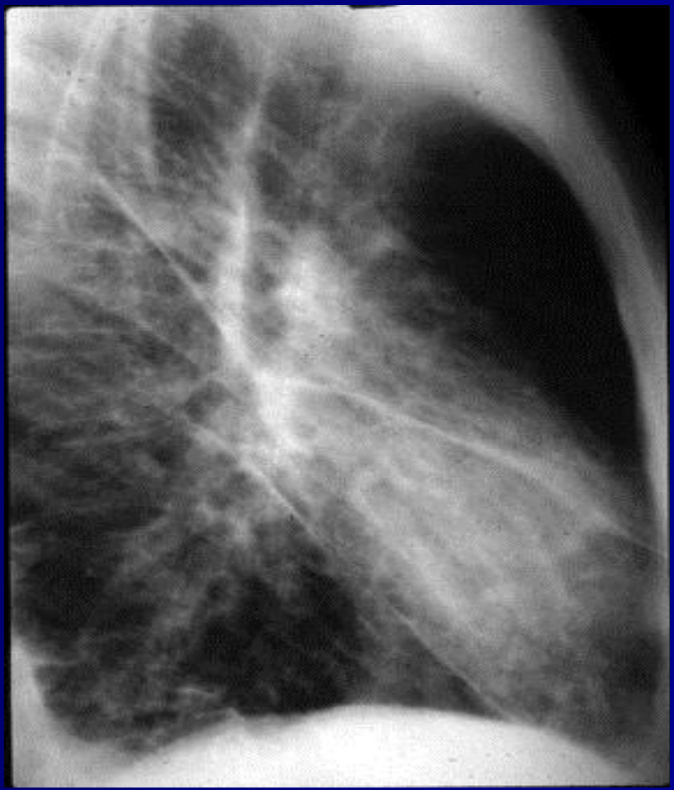




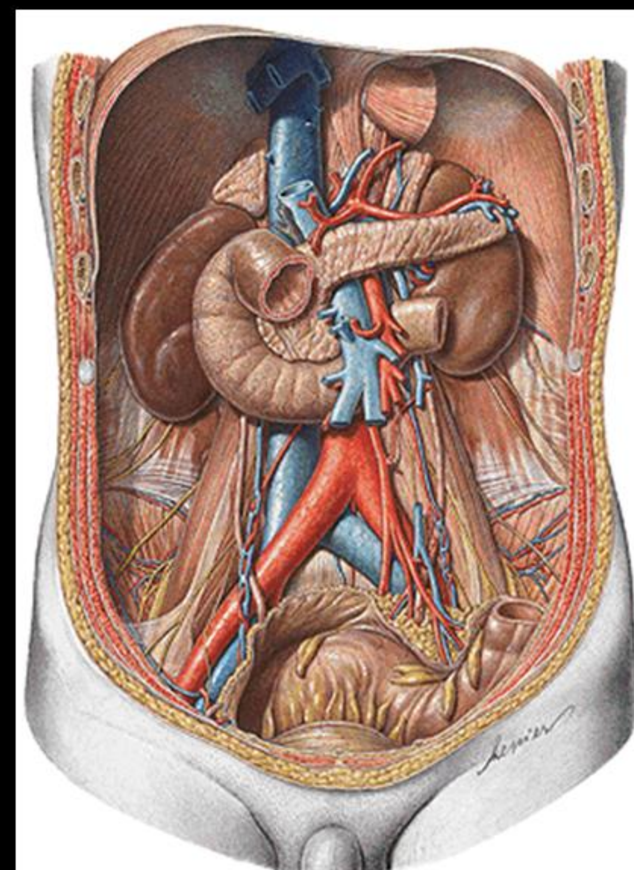
Lateral
PA
height
height
depth
width
Lateral
PA



2-TISUE DIFFERENCE SENSITIVITY
5%-10%



اختلاف جذب یا ضریب تضعیف:



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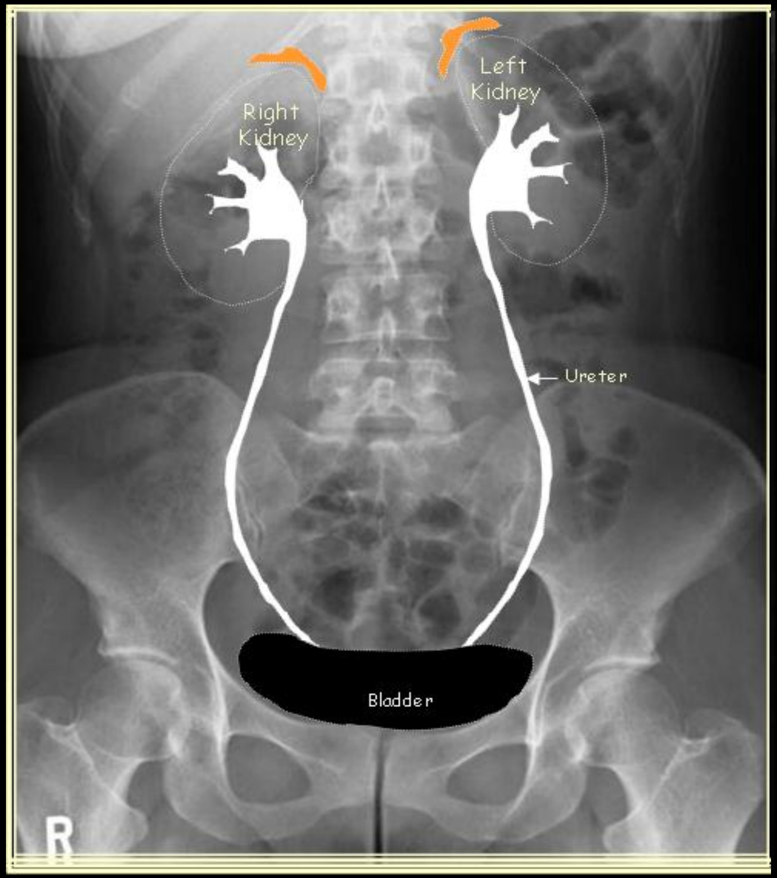
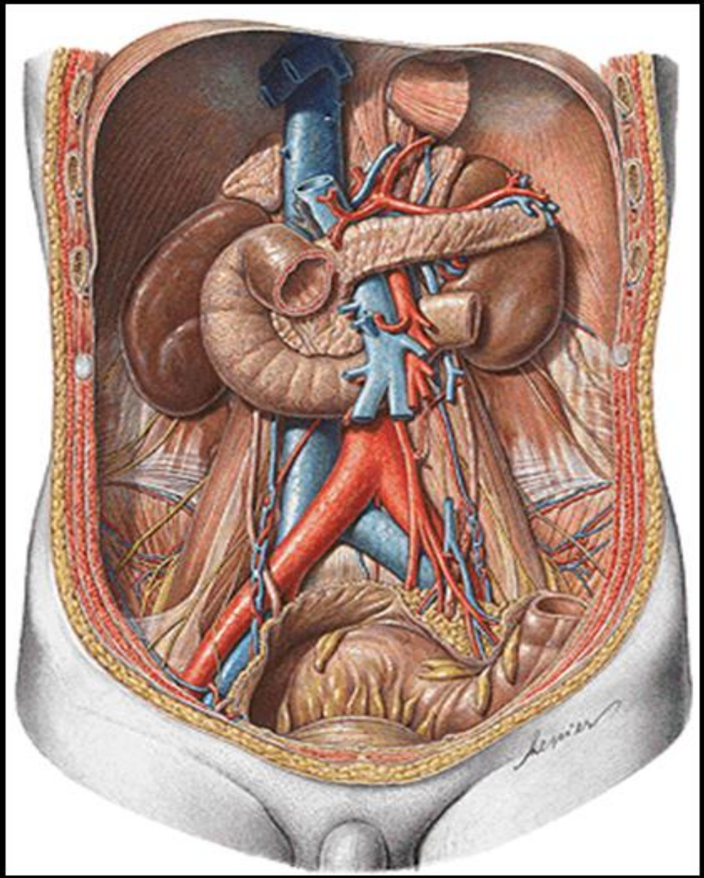


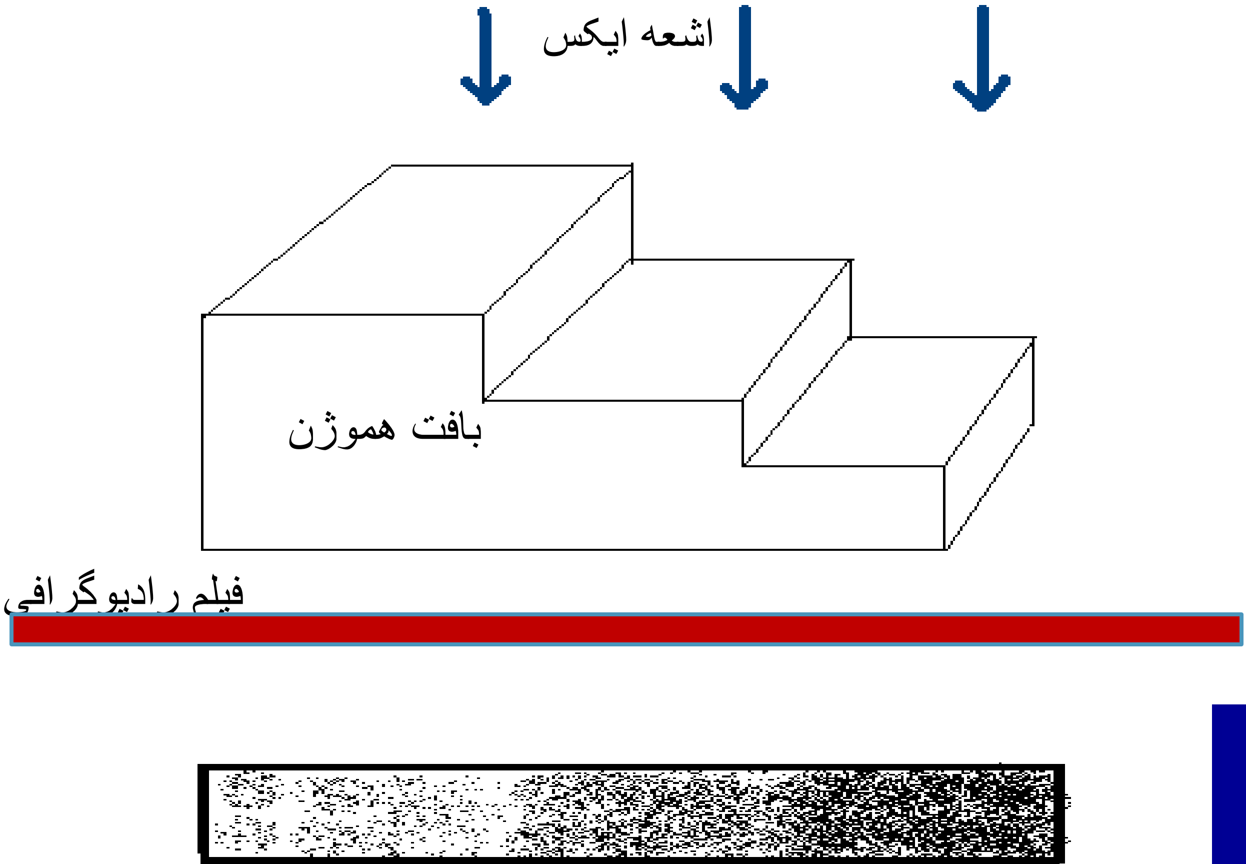


ضریب تضعیف خطی :

درصدی از پرتوها که به ازای عبور از واحد ضخامت بافت جذب میشود

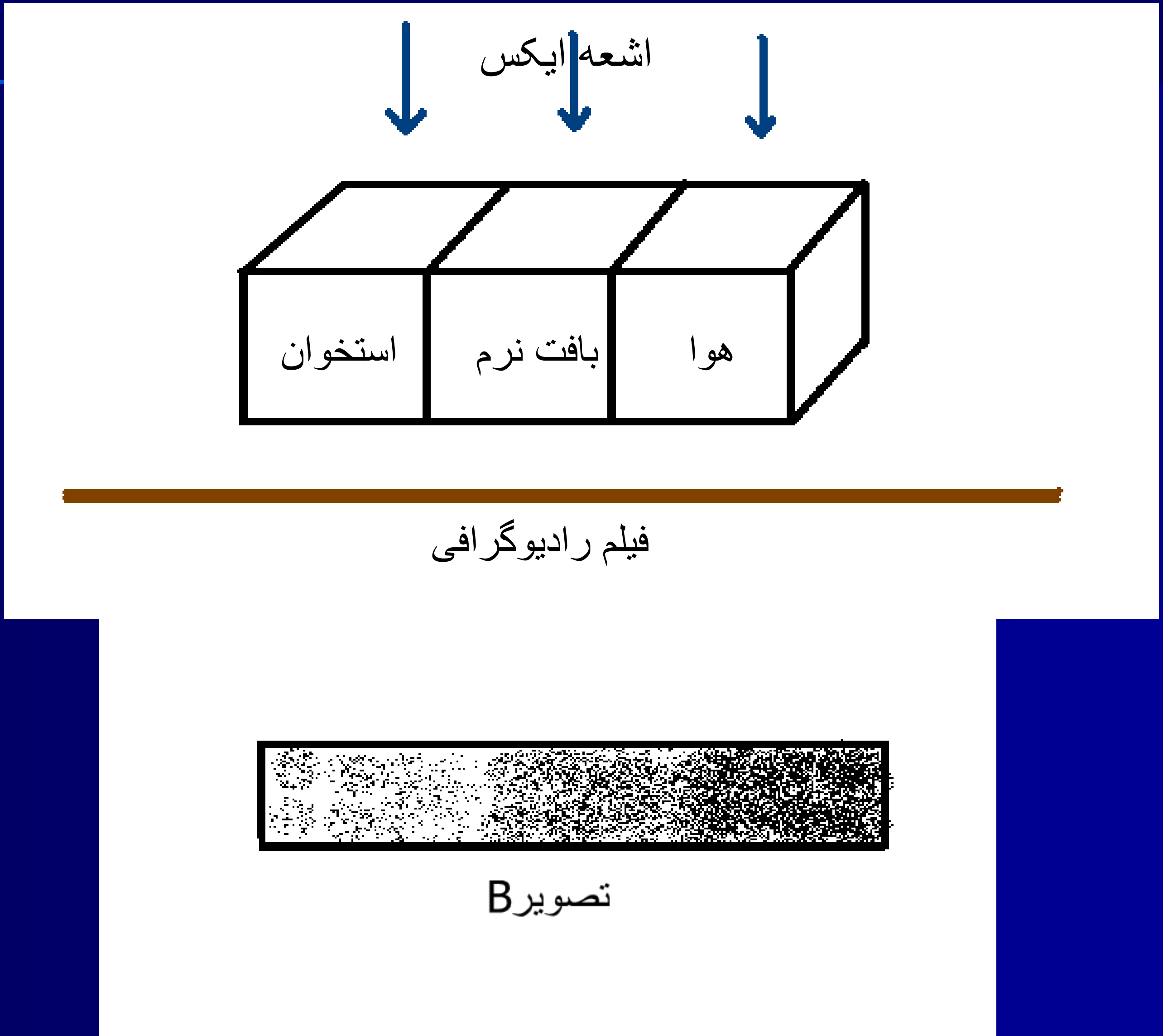
Blood	0/208
Gray matter	0/212
White matter	0/213
Cerebrospinal	0/207
Water	0/206
Fat	0/185
Air	0/0004

بافت هموژن با ضخامت مختلف:

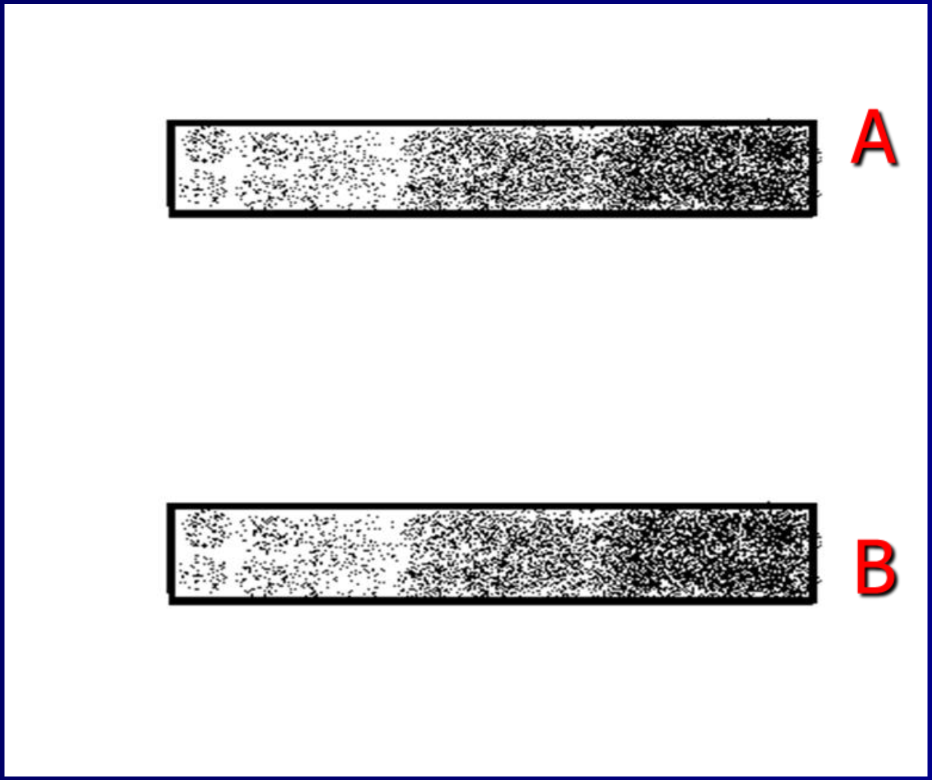


تصویر A

بافت غیرهموژن با ضخامت یکسان:



درهر دو فیلم چاپ شده از دوجسم با ضریب جذبهای متفاوت قبلی دانسیته های روی فیلمها شبیه بهم میباشد



هدف از بکارگیری CT:

- غلبه بر محدودیتهای رادیوگرافی

از طریق:

1- ایجاد تصاویربا کمترین میزان انطباق

2- بهبود کنتراست(تولید تصاویری با کنتراست بالاتر)

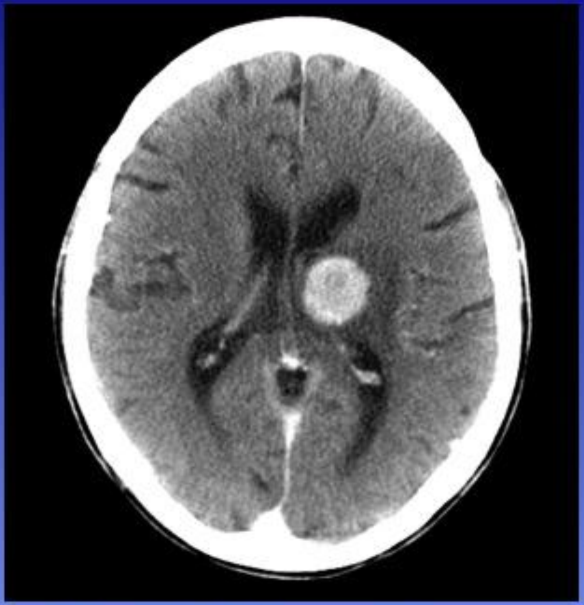
3- جمع آوری اطلاعات بصورت کمیت عددی

CT ADVANTAGES

CCT

Advantages of CT:

1. Three-dimensional image free of superimposition
2. More sensitive to differences in tissue type (1% compared with 10%)
3. Ability to manipulate and adjust image after scanning (digital technology)



Cranial CT demonstrating ventricles and calcified tumor

LIMITATIONS OF CT

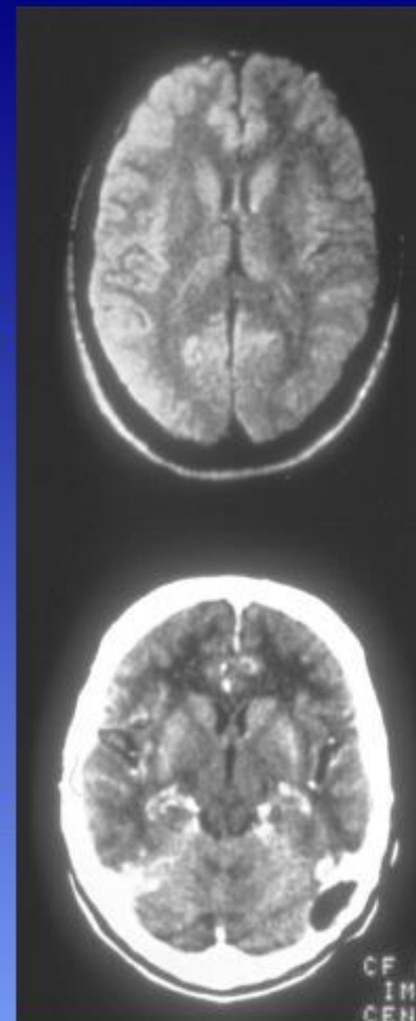
- UNABLE TO DIFFERENTIATE BETWEEN TISSUES WITH SLIGHT CONTRAST DIFFERENCES < 1%.

Comparison of MRI and CT

- Appearance of images
- MRI visualizes more soft tissue detail without contrast media

MR

CT



اصول فیزیکی وتکنیکی CT

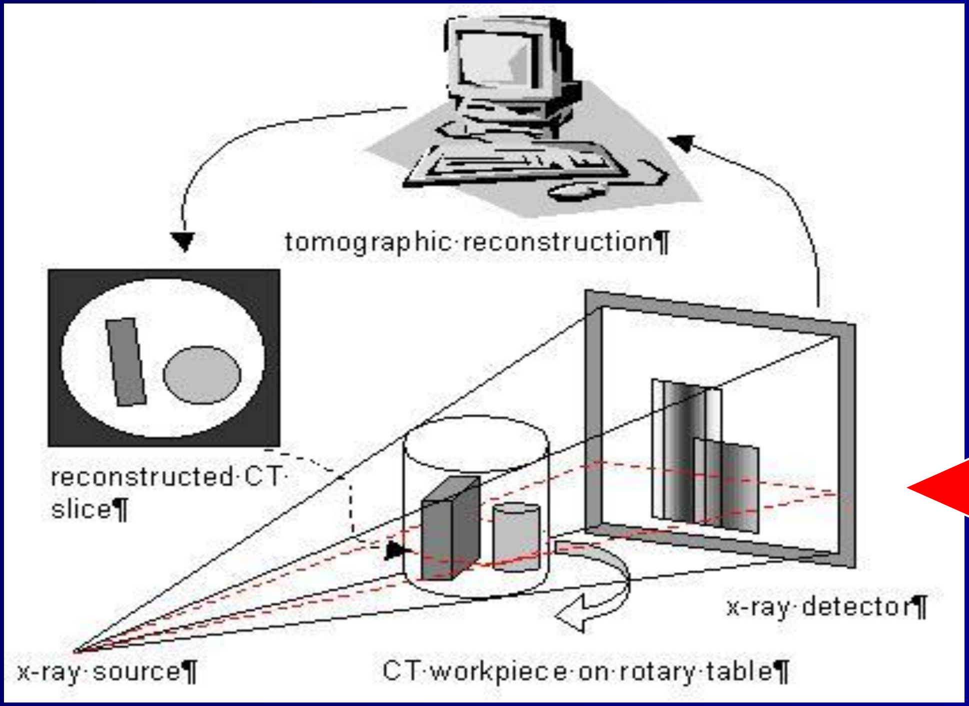
- **براساس 3 اصل استوار است:**

1- سبک خاص جمع آوری اطلاعات (Data acquisition)

2- سبک خاص پردازش اطلاعات (Data processing)

3- سبک خاص نمایش/ذخیره سازی/ مستند سازی تصاویر(Display/storage/document)

CT DATA AQUISITION



مهمترین واصلی ترین تفاوت بین نسلهای مختلف سی تی در نحوه وسبک خاص جمع آوری اطلاعات است .
تفاوتهای بعدی در نحوه پردازش داده هاست

اجزا و تجهیزات تشکیل دهنده :

گانتری

تیوب اشعه ایکس ولتاژ بالا

تخت بیمار

پنل کنترل

سیستم نمایش دهنده تصاویر

سیستم انتقال اطلاعات

ژنراتور ولتاژ بالا

این تجهیزات کمک میکند که به 3 هدف برسیم

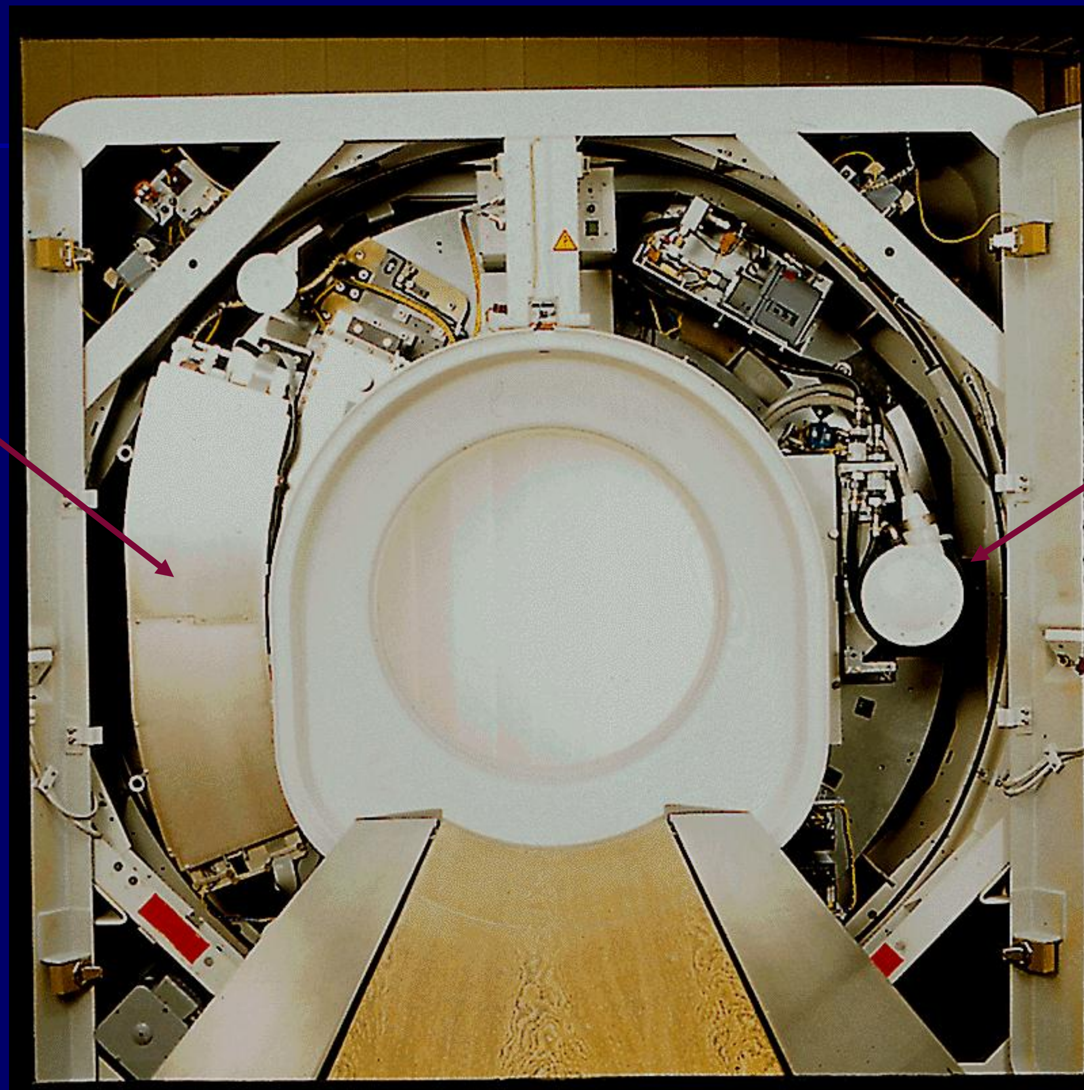
گانتری

گانتري

- شامل:
  - تيوب اشعه ايكس
  - كليماتور
  - آشكارسازها
  - سيستم جمع‌آوري اطلاعات (DAS)

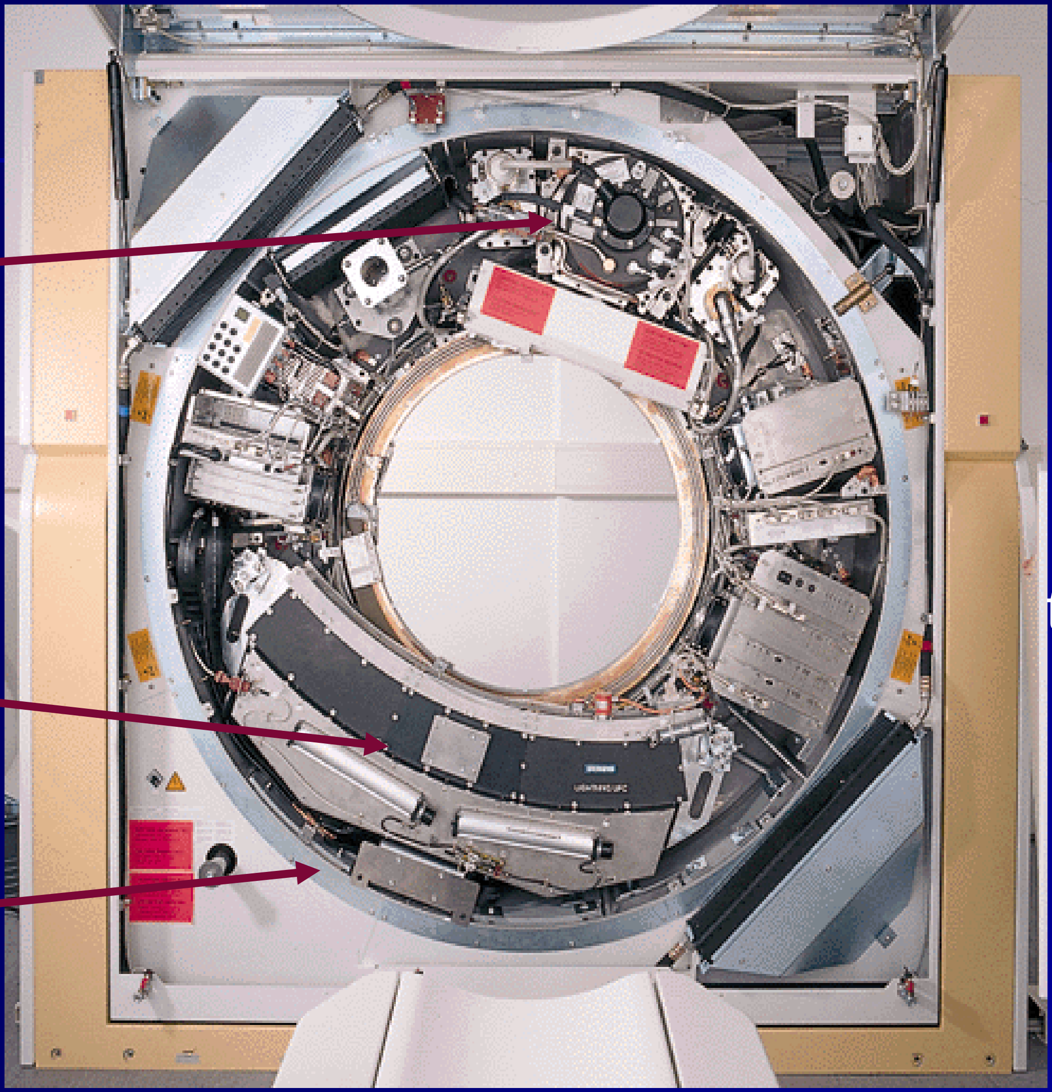
A look inside a rotate/rotate CT

Detector Array and Collimator



X-Ray Tube

A Look Inside a Slip Ring CT



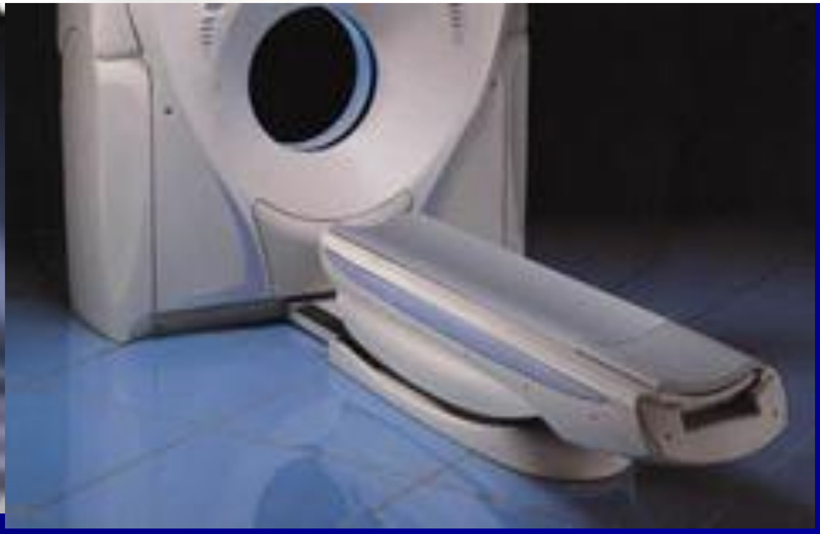
X-Ray Tube

Detector Array

Slip Ring

Note: how most of the electronics is placed on the rotating gantry

Multislice CT



• در اغلب دستگاه‌ها ، گانتري مي‌تواند نسبت به خط عمود ۳۰-۲۰± درجه زاويه پيدا کند.

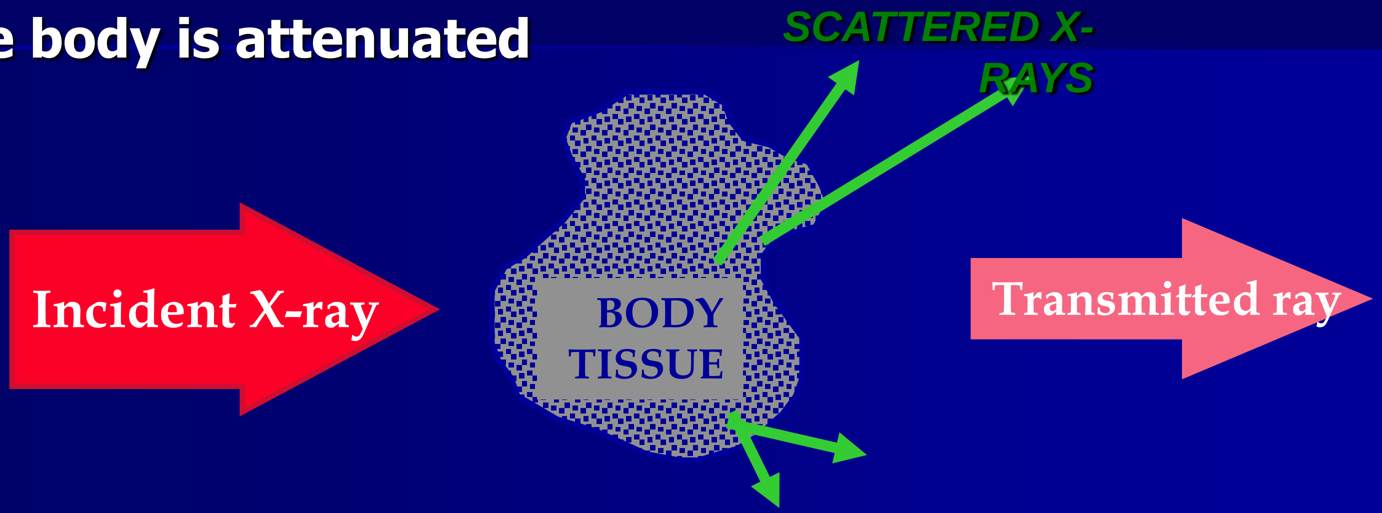
سيستم كامپيوتري و نمايش

- وظايف سيستم كامپيوتري:
  - كنترل و تنظيم حركات تخت و گانتري
  - كنترل و تنظيم فرآيند توليد اشعه و جمع‌آوري اطلاعات
  - بازسازي تصوير

How does CT Work?

Concept of X-ray Attenuation

An X-ray beam passing through the body is attenuated



Absorption by the tissue is proportional to the density

MORE ATTENUATION

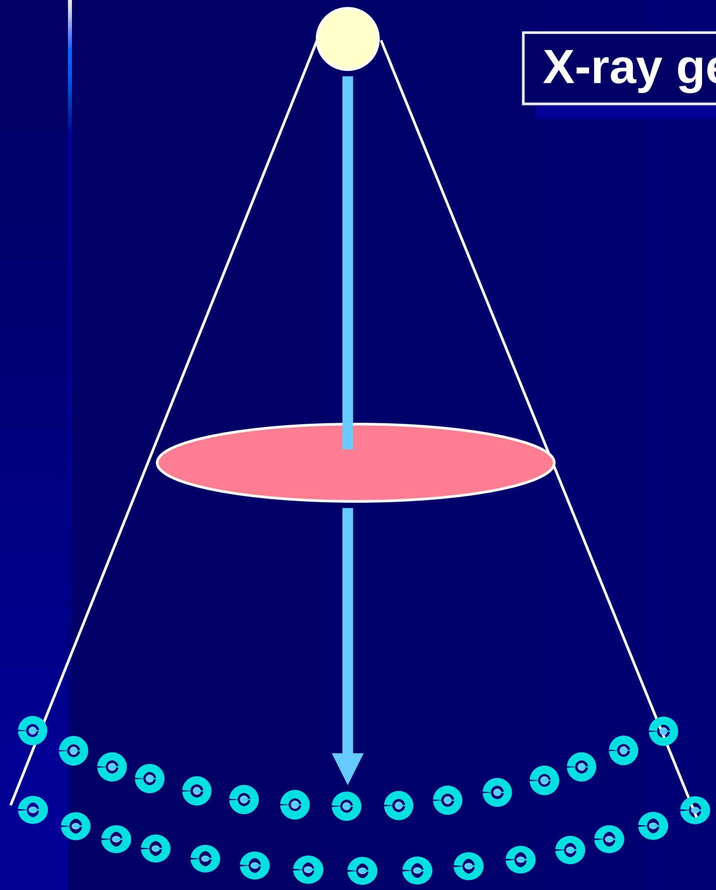
LESS ATTENUATION

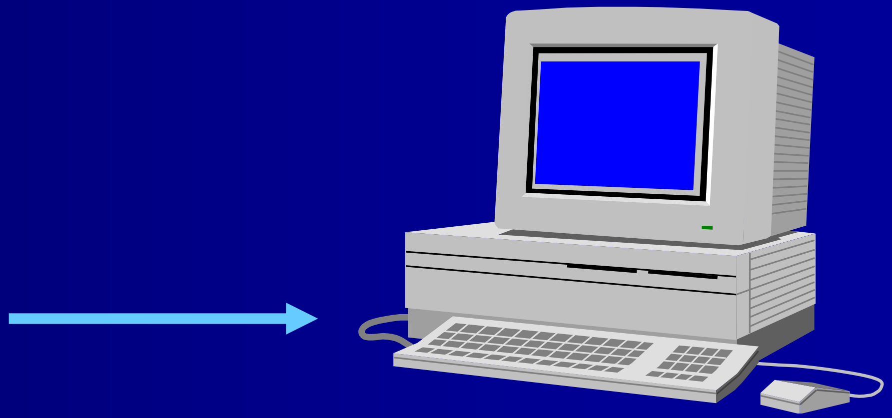
How does CT Work?

X-ray generation

Data acquisition

Recon. & postpro.

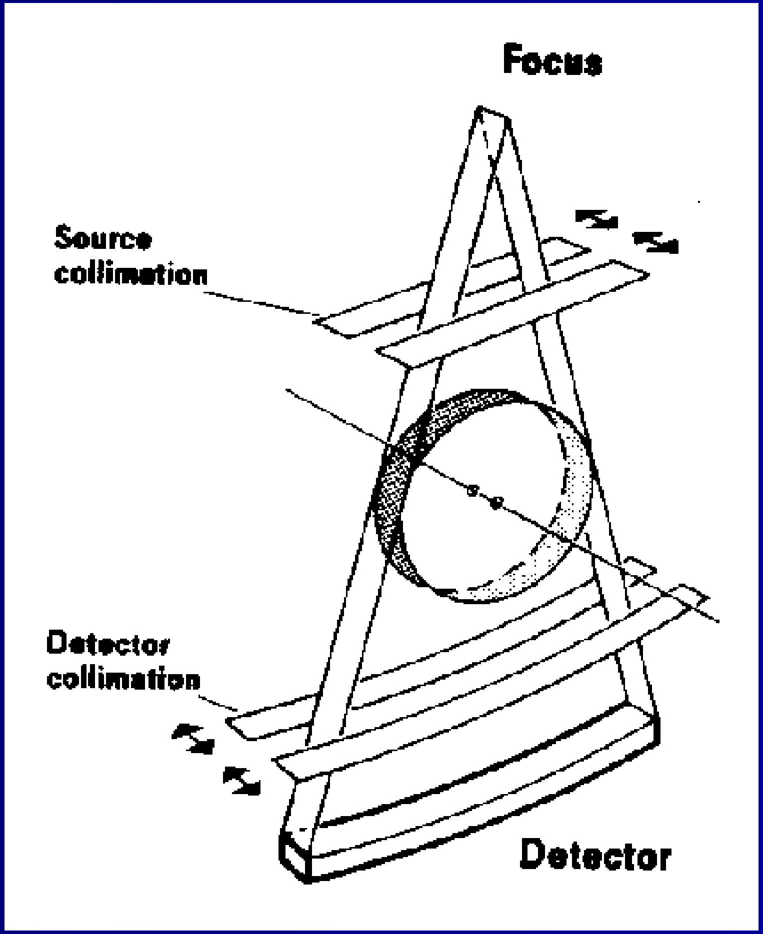




How does CT Work?

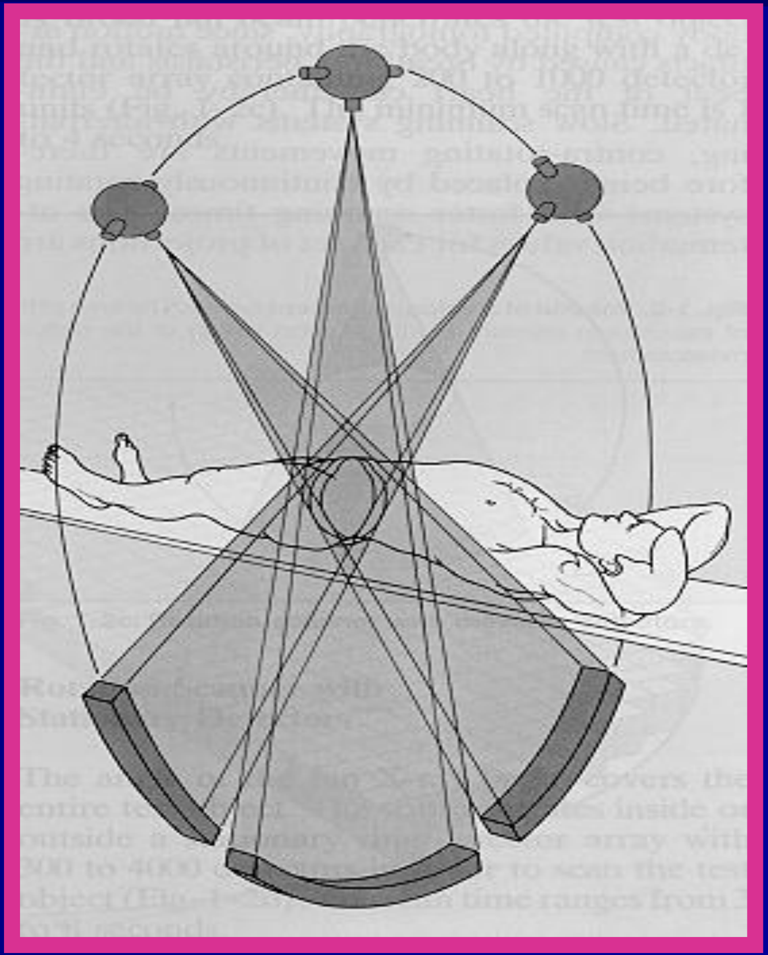
X-ray goes through collimator therefore penetrate only an axial layer of the object, called

"slice"



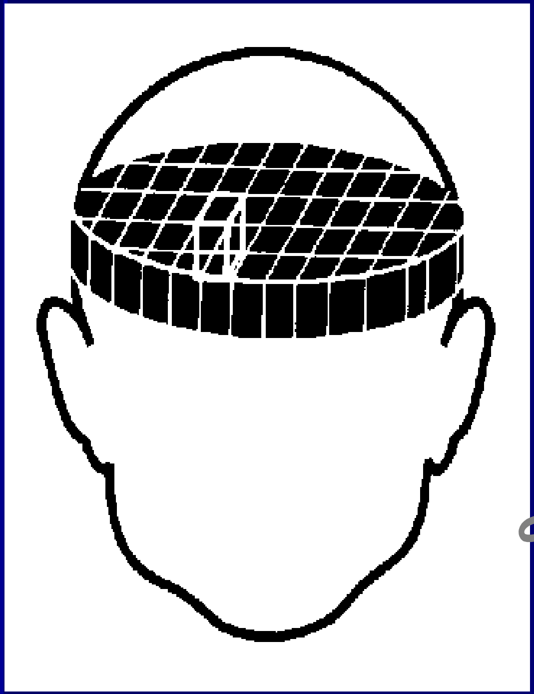
How does CT Work?

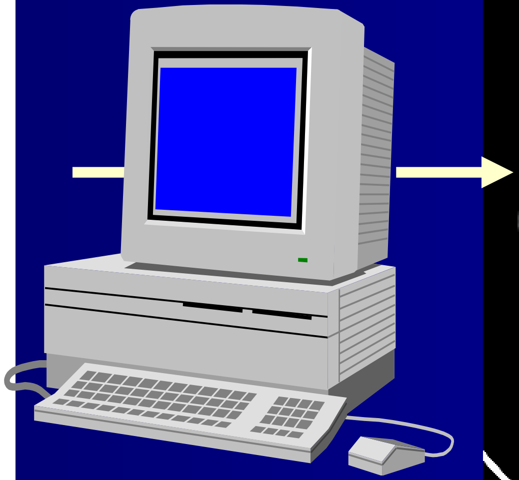
- Patient is placed in the center of the measurement field
- X-ray is passed through the patient’s slice from many direction along a 360˚ path
- The transmitted beams are captured by the detectors which digitizes these signals
- These digitized signals called raw data are sent to a computer which create the CT image

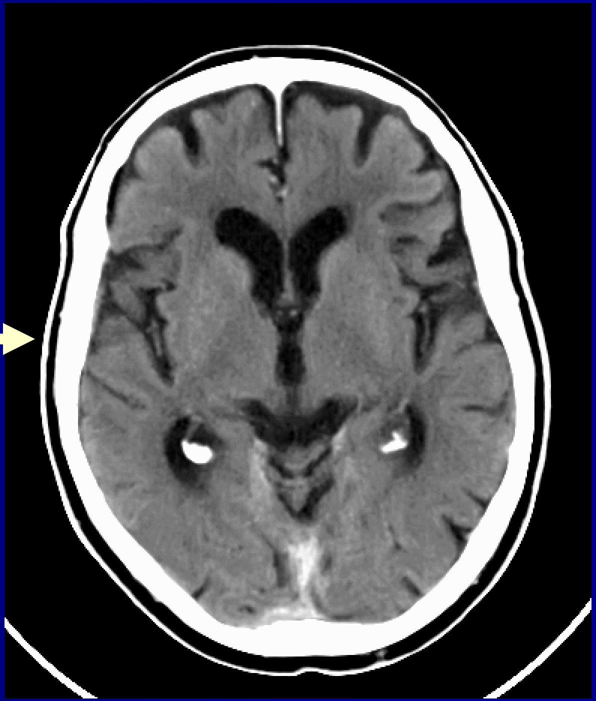


How is CT Image generated?

The attenuation values are transferred to the computer where they are coded & used to create a slice image







CT Broke the Barrier

For the first time we could view:

- Tomographic or "*Slice*" anatomy
- Density difference

⌨ But it's time consuming

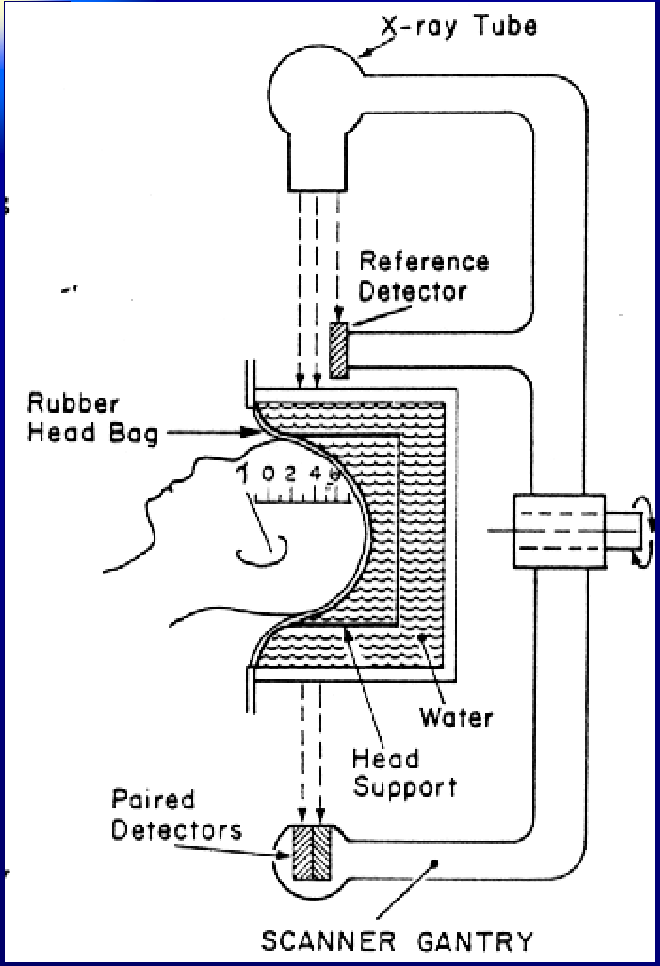
⌨ And resolution needs to be improved

History of Computed Tomography

1963 - Alan Cormack developed a mathematical method of reconstructing images from x-ray projections

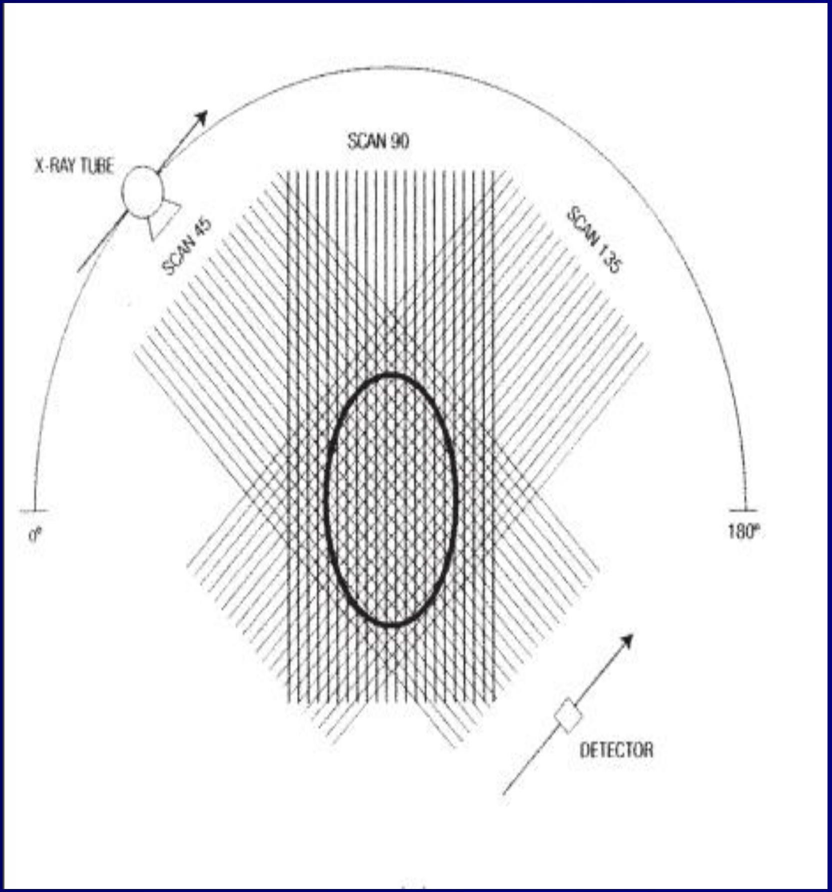
- ***My name is Godfrey Hounsfield***
- ***I work for the Central Research Labs. of EMI, Ltd in England***
- ***I developed the the first clinically useful CT scanner in 1971***

نسلهای CT



- نسل اول:
- در سال1971 توسط هانسفیلد ساخته شد
- دسته پرتو باریک (pencil beam)
- مخصوص سر
- دتکتور دوگانه ثابت
- 12 مقطع با ضخامت 13میلیمتر
- ماتریکس 80*80
- 180 حرکت خطی
- 180 حرکت چرخشی
- حدود 36 دقیقه زمان کل اسکن

نسل اول:



- نسل اول:
- در سال1972 توسط هانسفیلد ساخته شد
- دسته پرتو باریک (pencil beam)
- مخصوص سر
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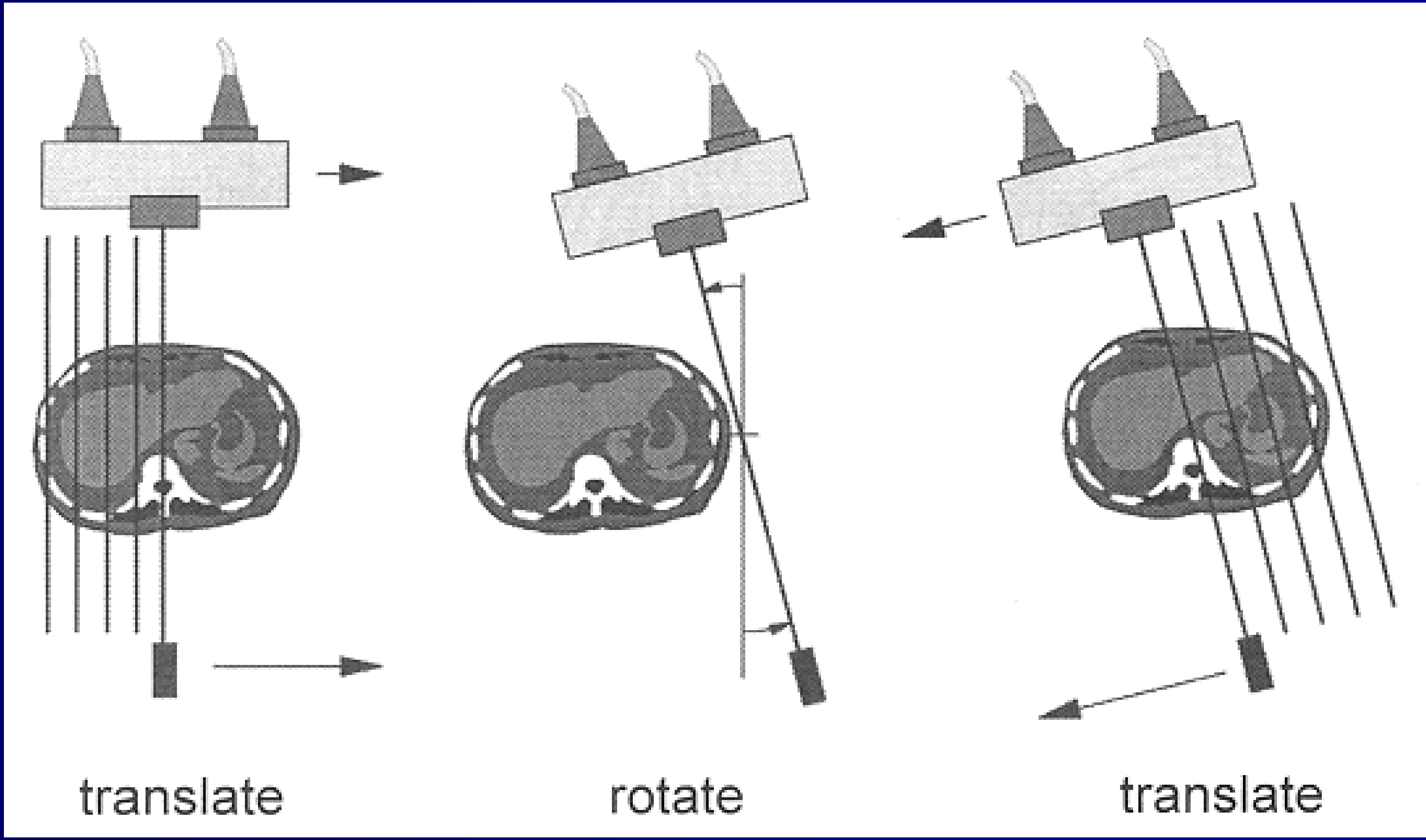
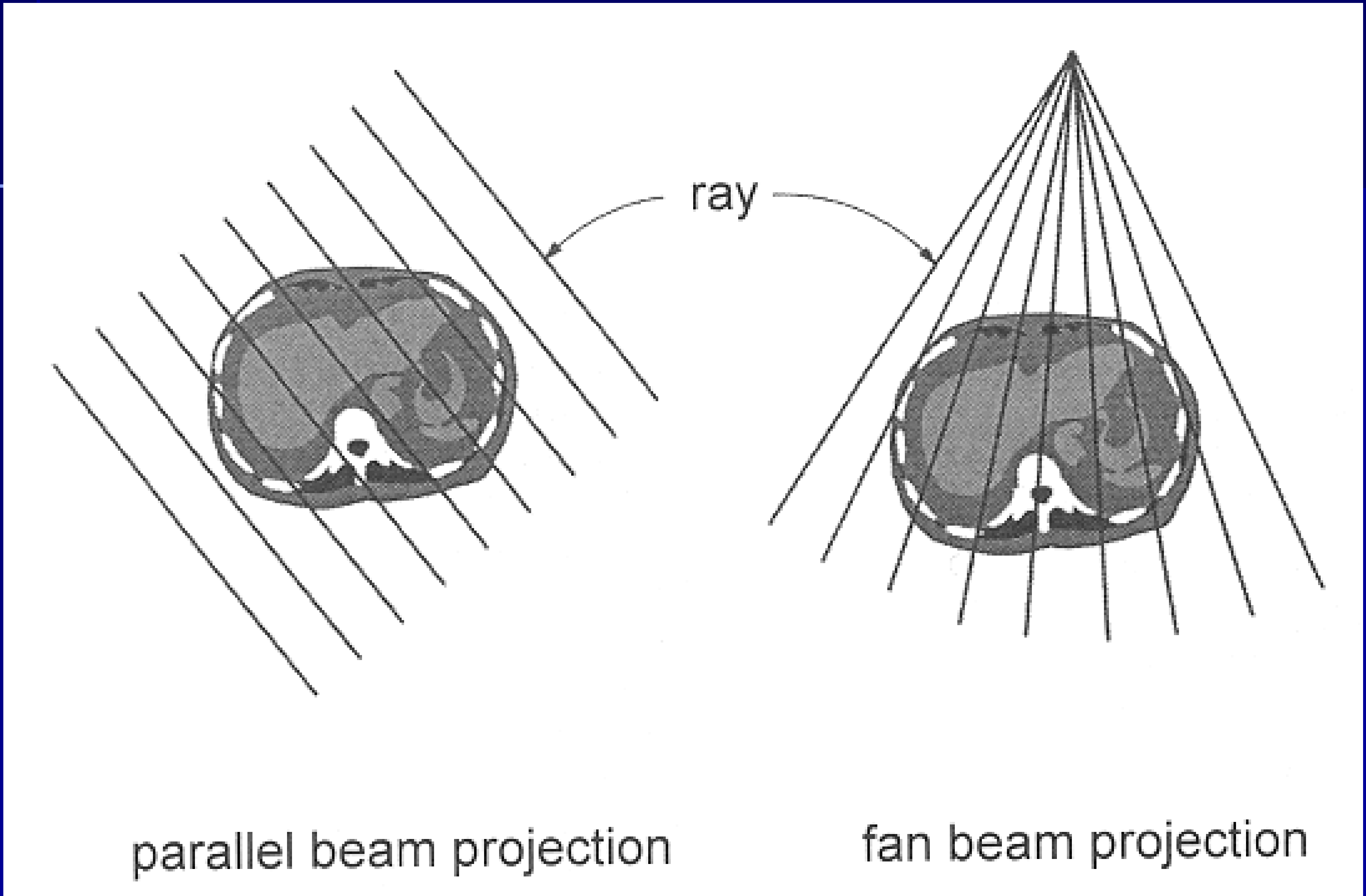
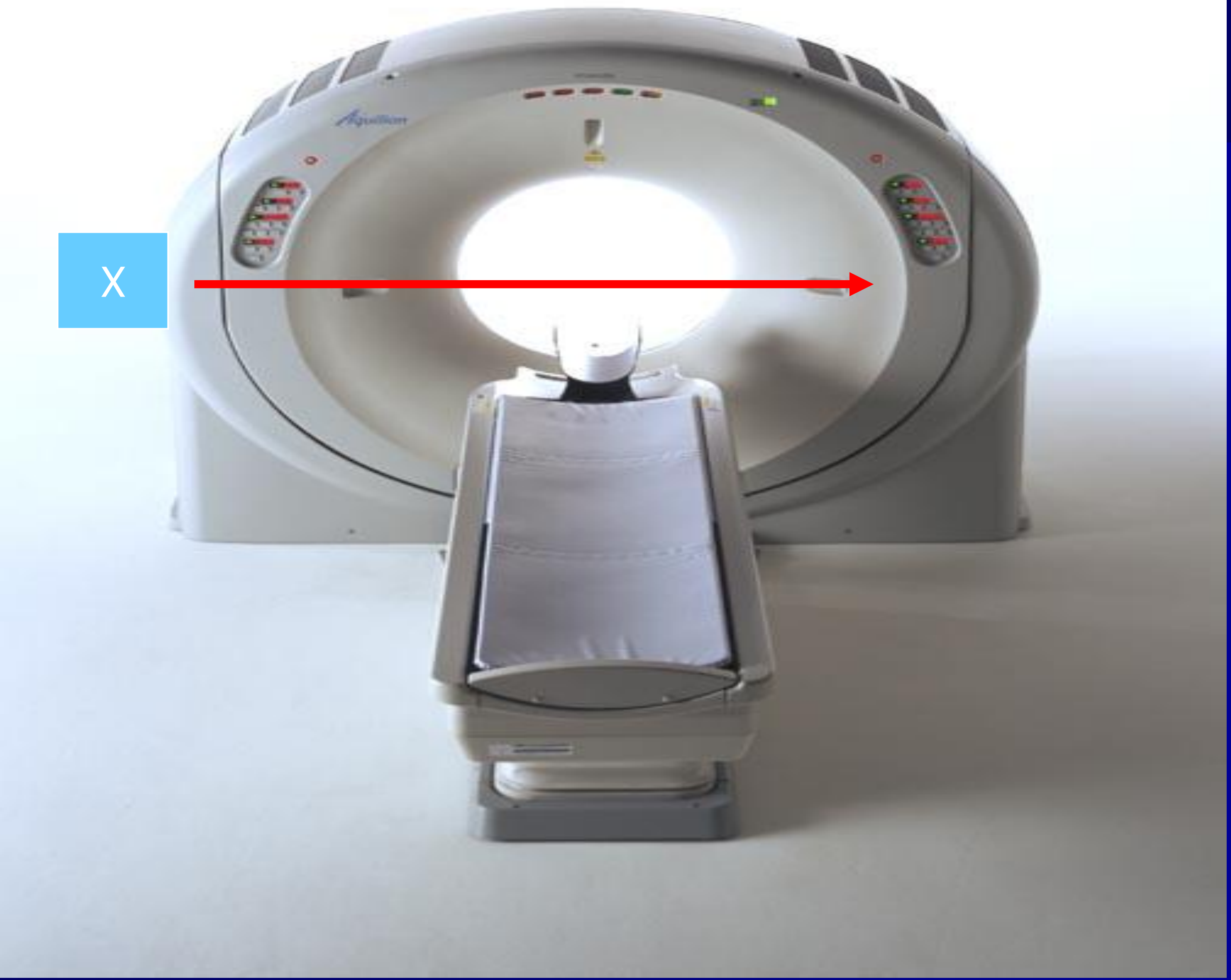

translate
rotate
translate

معایب:

- زمان طولانی اسکن
- باریک بودن دسته اشعه
- امکان حرکت بیماران
- کیفیت پایین تصاویر
- محدود بودن به ناحیه سر


ray
parallel beam projection
fan beam projection

محورها در CT



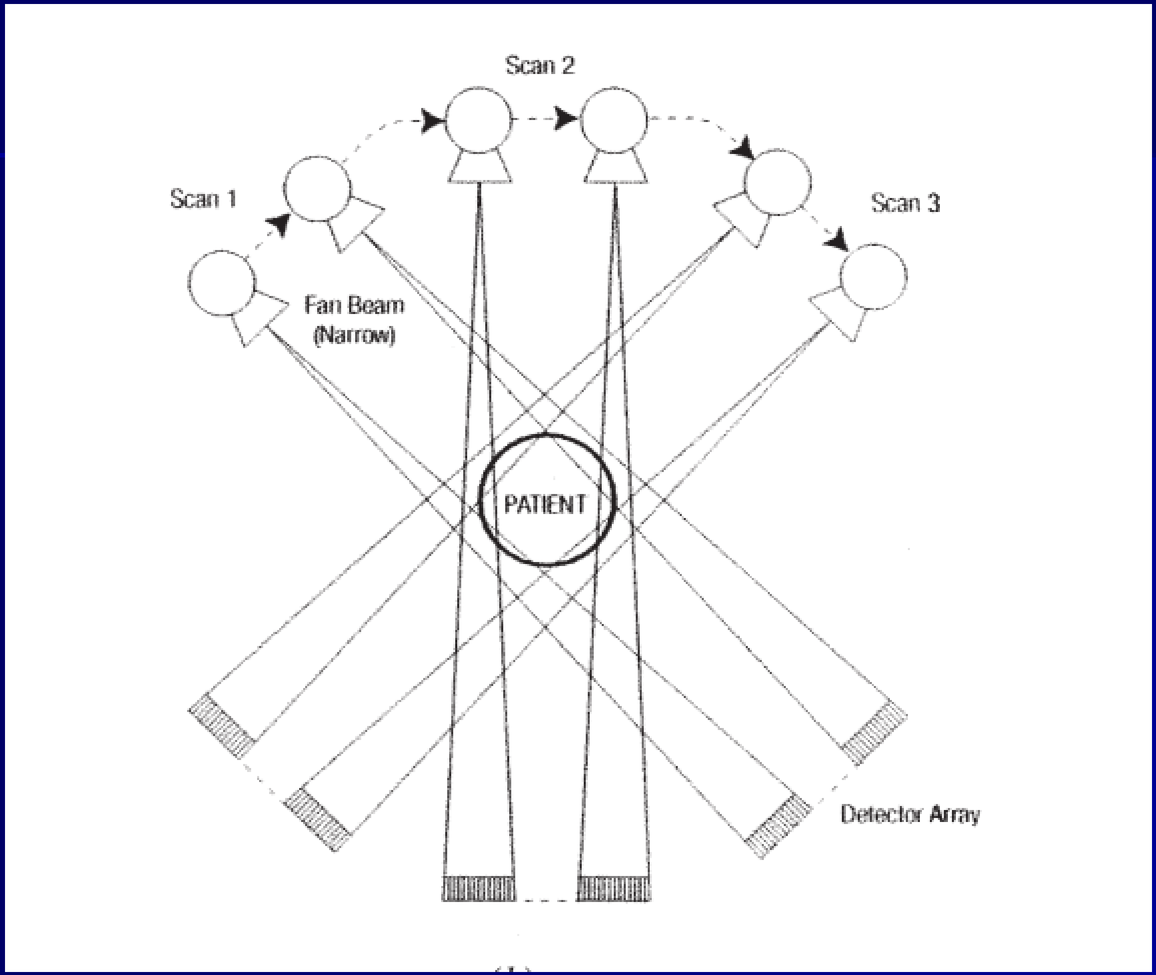
محورها در CT

محورها در CT


ISOCENTER

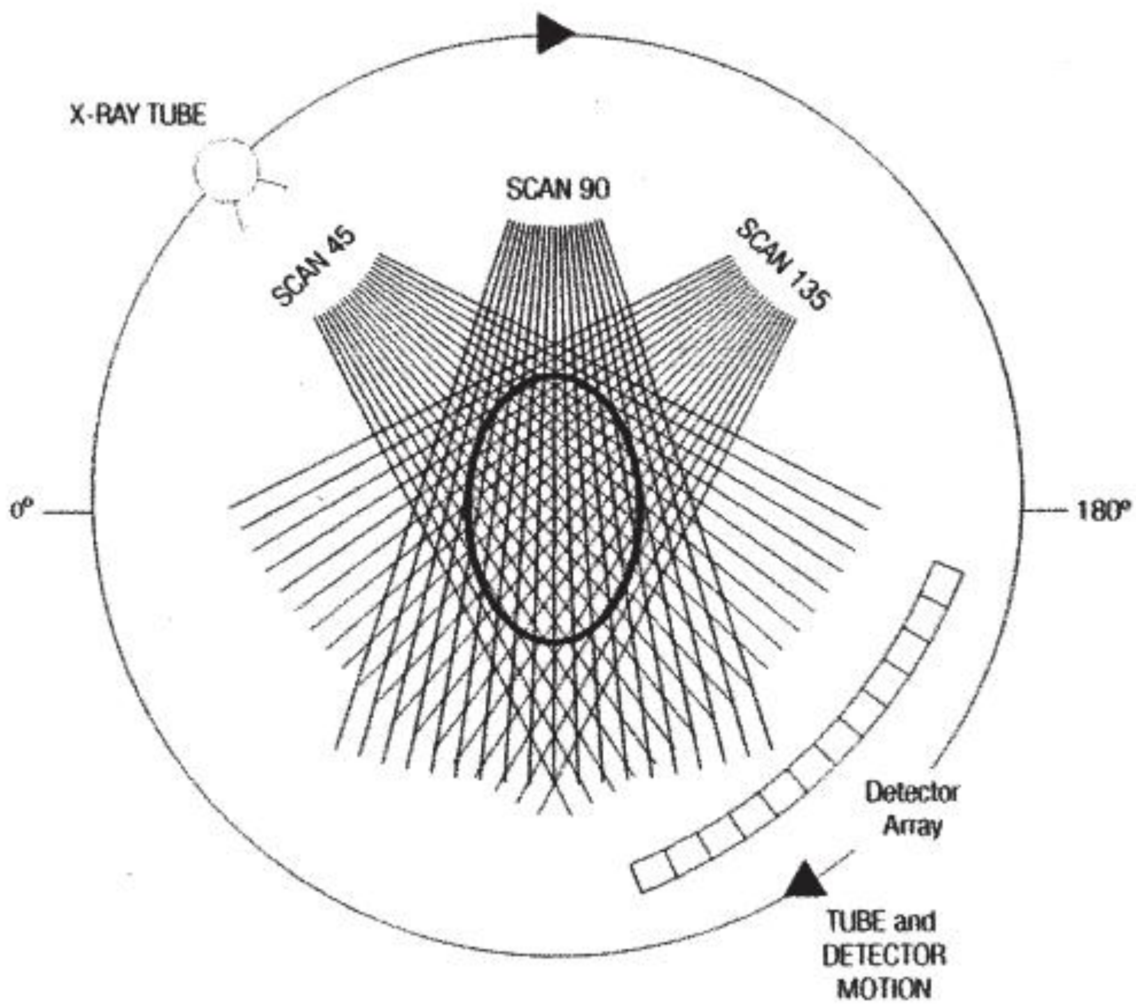
2nd generation: rotate/translate, narrow fan beam

- Incorporated linear array of 30 detectors
- More data acquired to improve image quality (600 rays x 540 views)
- Shortest scan time was 18 seconds/slice
- Narrow fan beam allows more scattered radiation to be detected (~10 degree)
- 6 Liner movement & 6 rotary movement

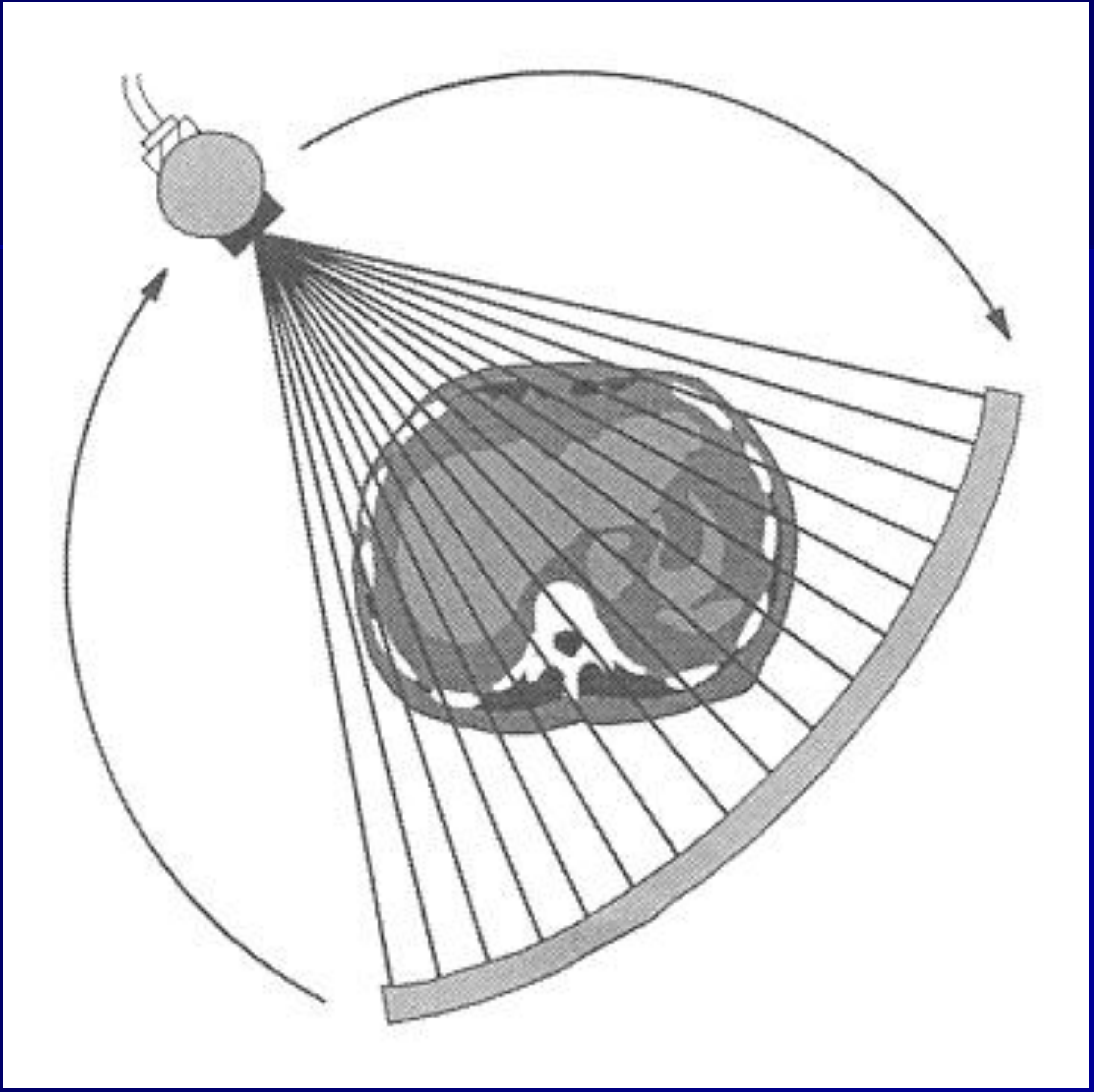

Scan 2
Scan 1
Scan 3
Fan Beam
(Narrow)
PATIENT
Detector Array

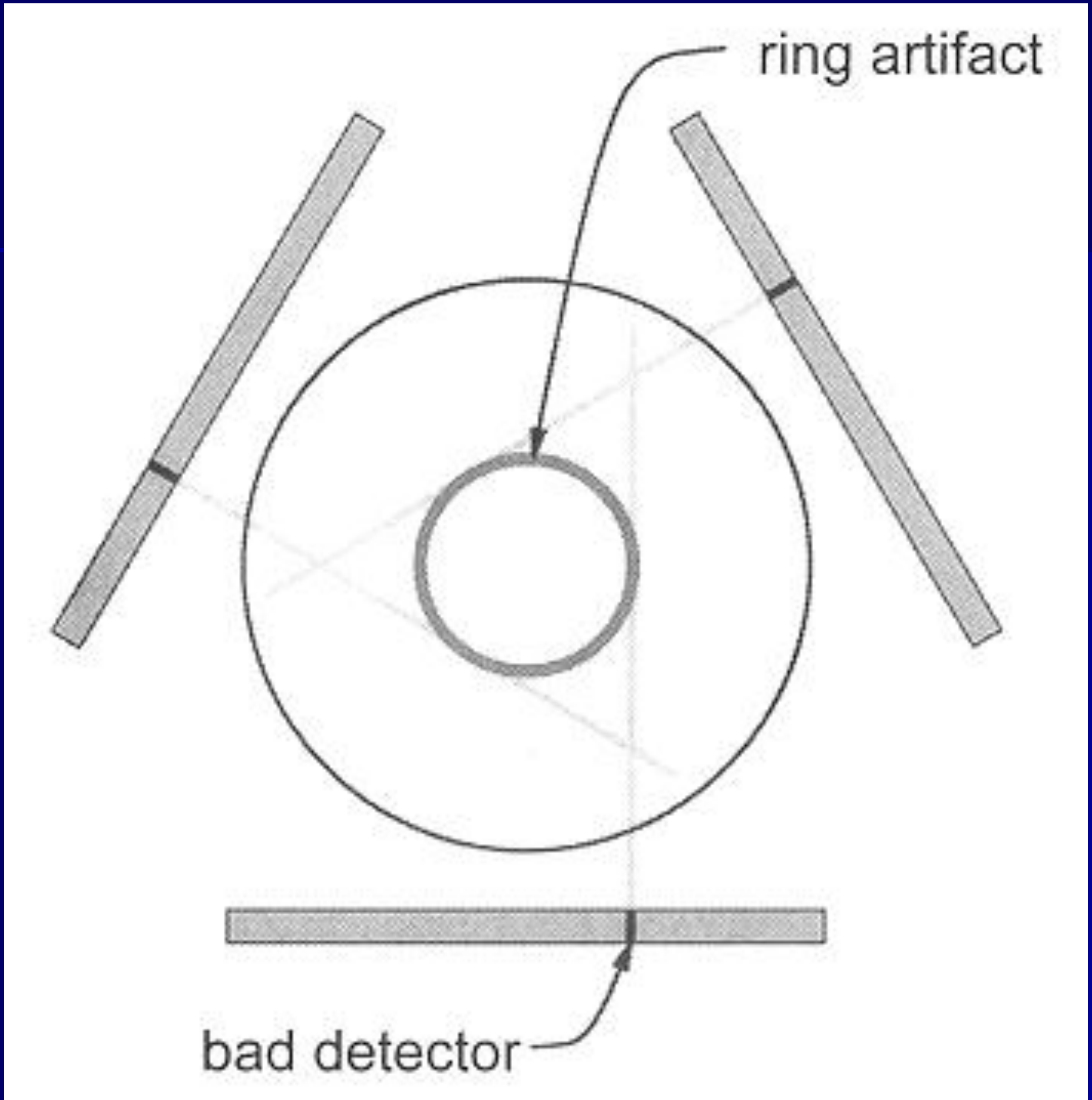
3rd generation: rotate/rotate, wide fan beam

- Number of detectors increased substantially (to more than 800 detectors)
- Angle of fan beam increased to cover entire patient
  - Eliminated need for translational motion
- Mechanically joined x-ray tube and detector array rotate together
- Newer systems have scan times of ½ second



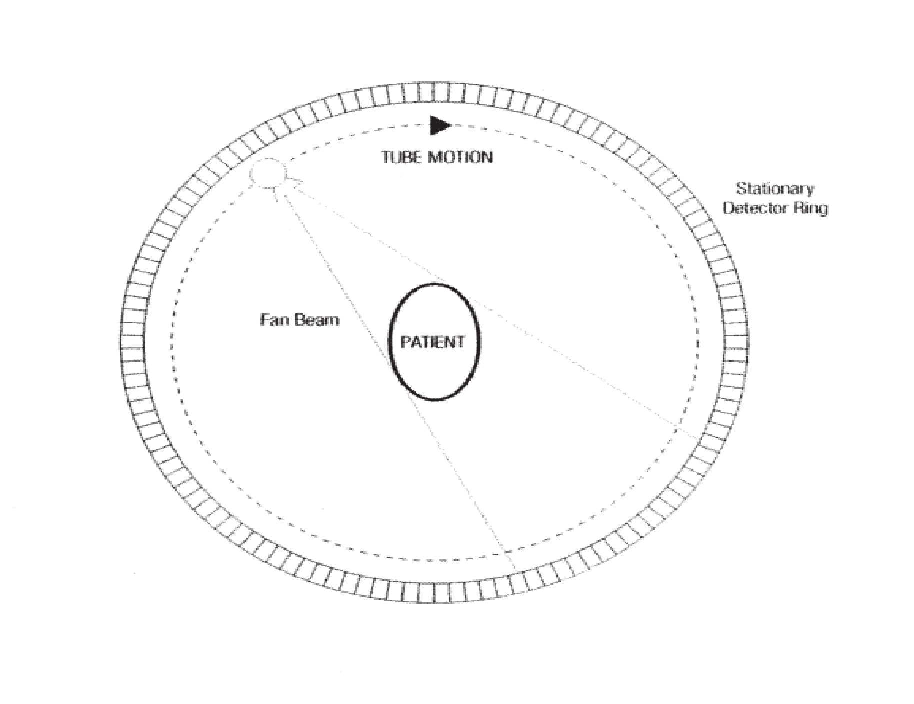
X-RAY TUBE
SCAN 45
SCAN 90
SCAN 135
0°
180°
Detector
Array
TUBE and
DETECTOR
MOTION

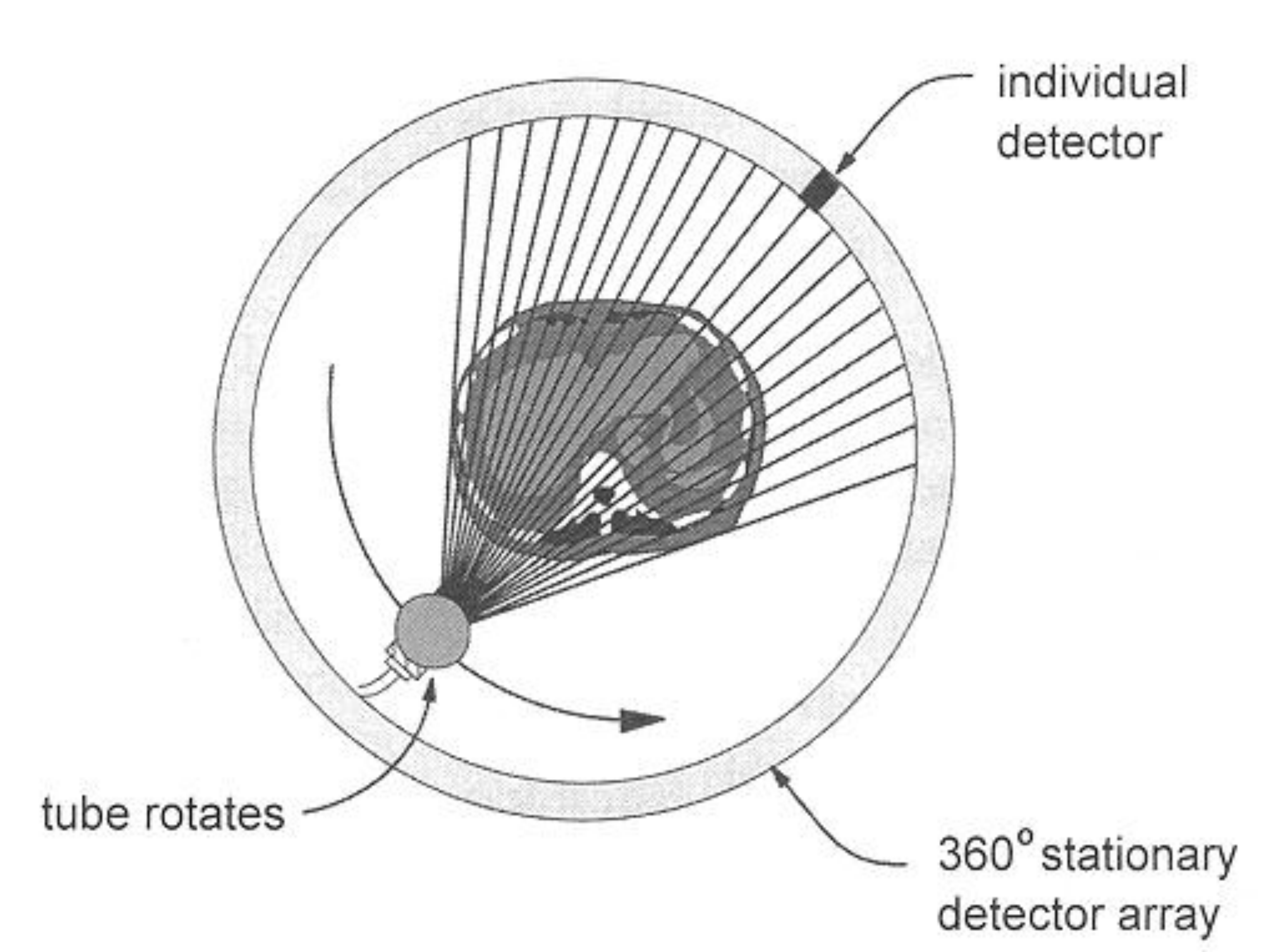



ring artifact
bad detector

4^{th} generation: rotate/stationary

- Designed to overcome the problem of ring artifacts
- Stationary ring of about 4,800 detectors




individual
detector
tube rotates
360° stationary
detector array

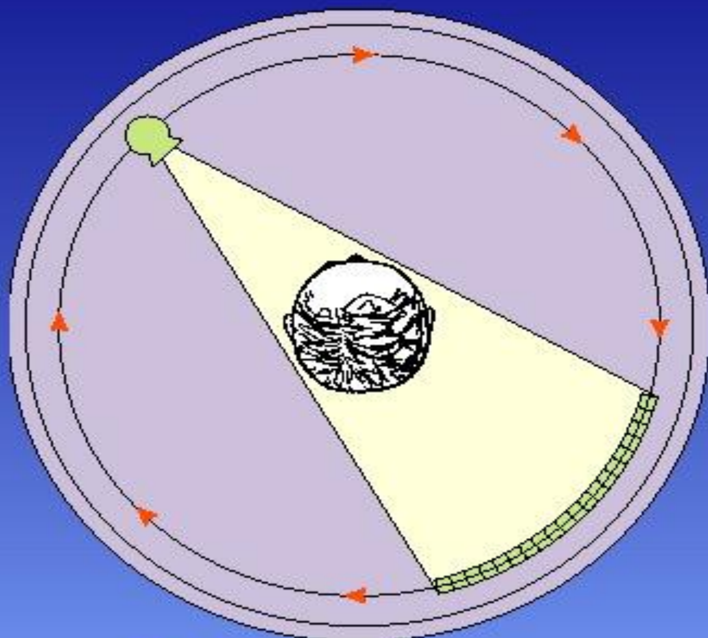
DATA AQUSITION GEOMETRIES

- CONTINUOUS
- STATIONARY

CONTINUOUS

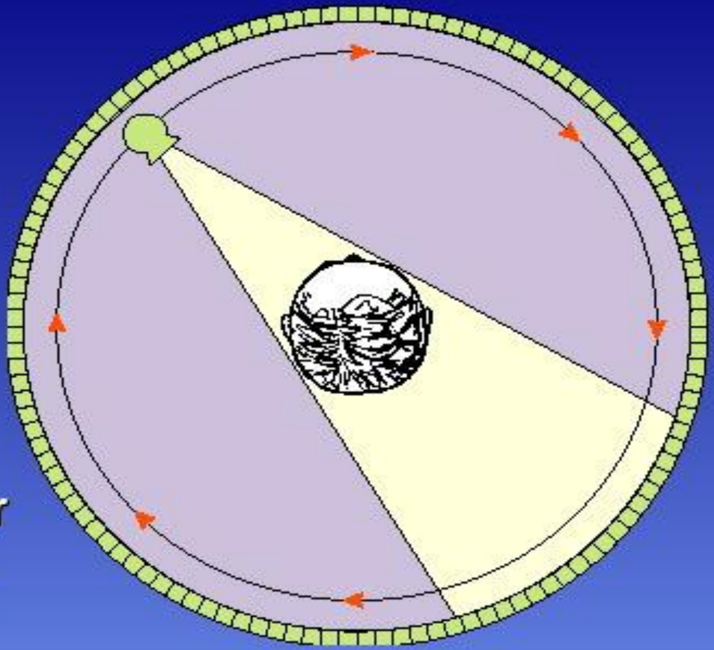
Changes and Advances in CT Systems

- First generation scanner:
  - One or two detectors
  - 4-1/2 minute scan
- Second generation scanner:
  - 30 or more detectors
  - 40 slices in 10 minutes
- Third generation scanner:
  - Up to 960 detectors
  - 360° rotation of x-ray tube and detectors



Third generation scanner

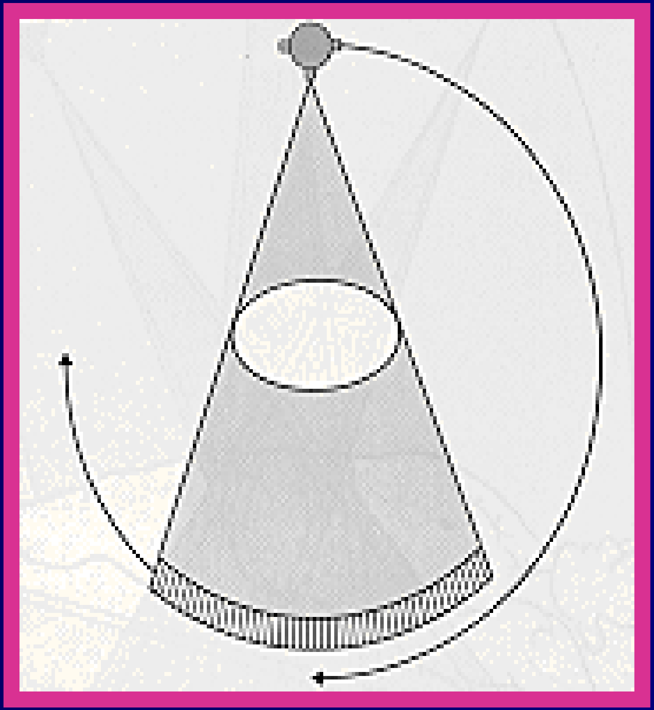
STATIONARY



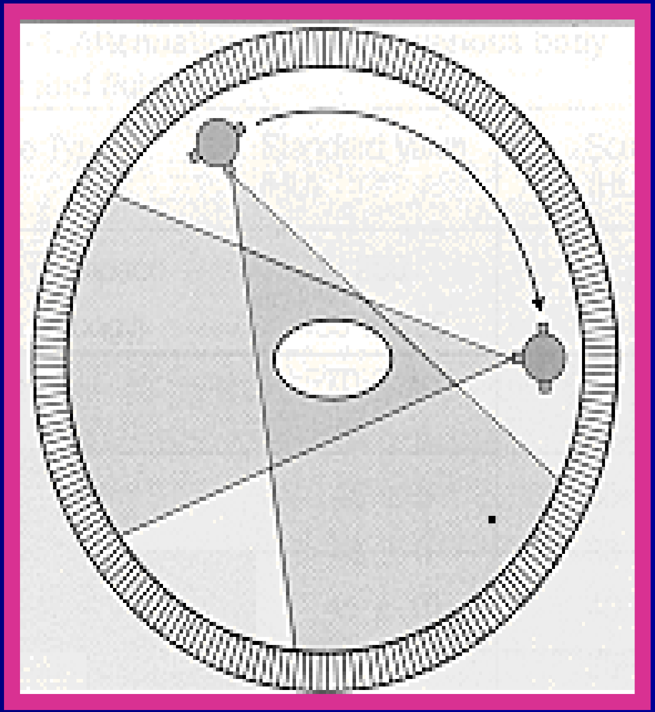
- Fourth generation scanner
  - Up to 4800 detectors on a fixed ring
  - X-ray tube rotates 360°

CT Generations & Design

"Generation" is used to label CT tube-detector designs



3rd Generation Design
Rotating tube & detector

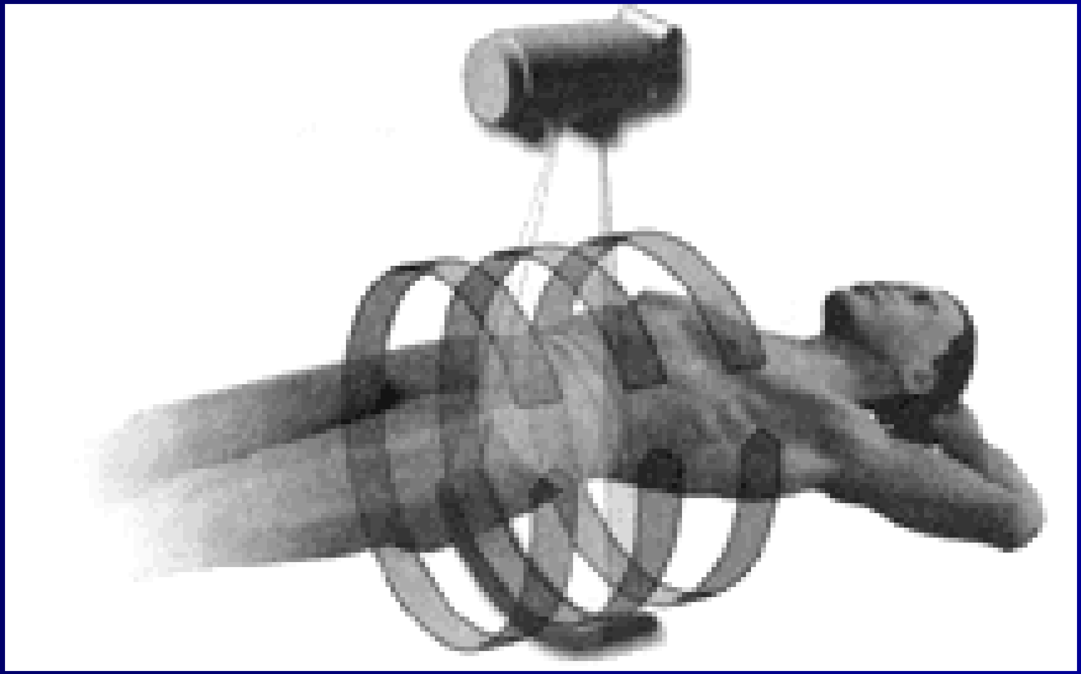


4th Generation Design
Fixed ring detector

مقایسه زمان اسکن در نسلهای CT

	زمان اسکن	زاویه چرخش
نسل اول	6 دقیقه	180
نسل دوم	18 ثانیه	180
نسل سوم	0/5 ثانیه	360
نسل چهارم	؟	؟

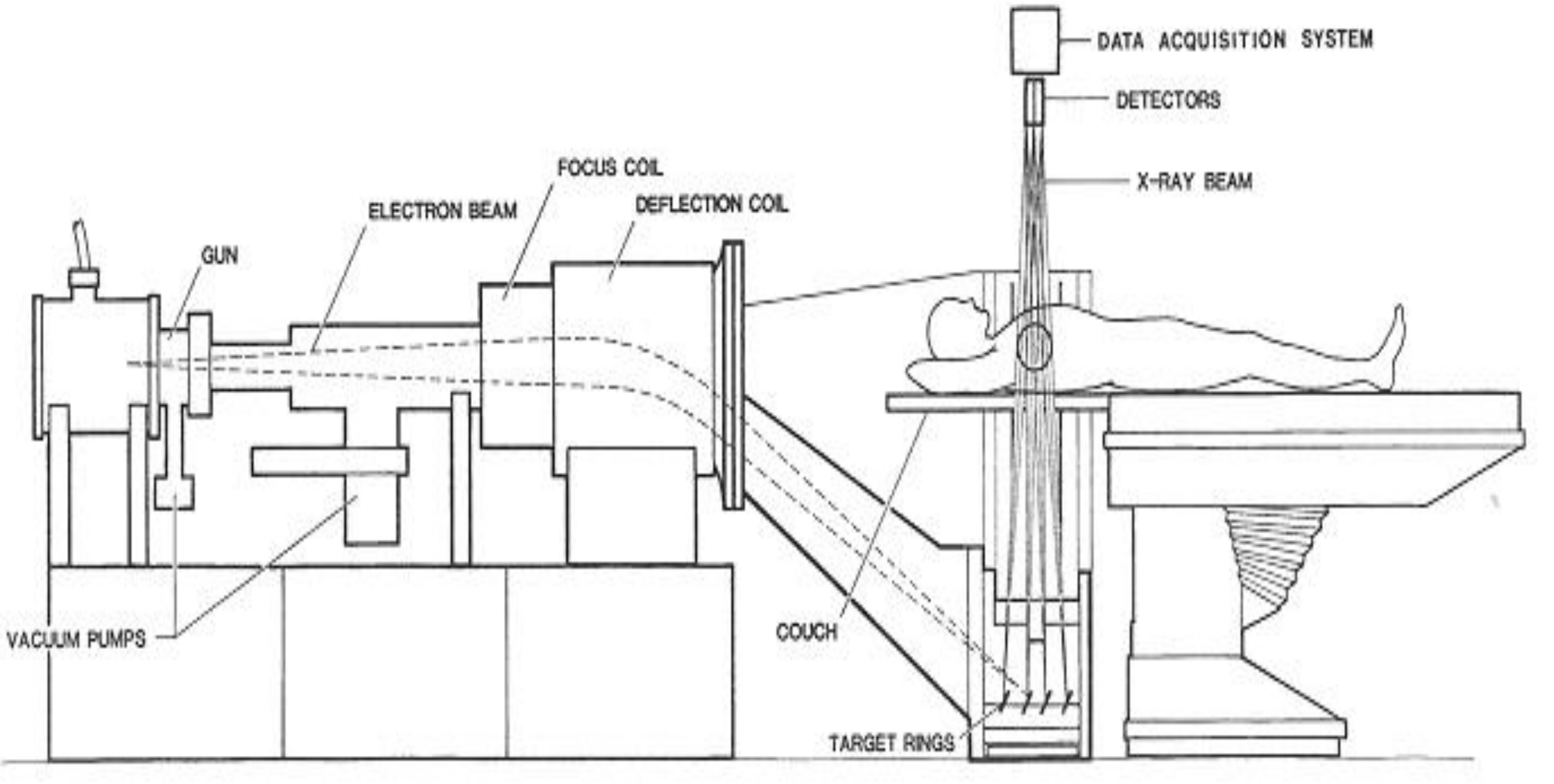
SEQUENTIAL-SLICE BY SLICE SCANNING



5th generation: stationary/stationary

- Developed specifically for cardiac tomographic imaging
- No conventional x-ray tube; large arc of tungsten encircles patient and lies directly opposite to the detector ring
- Electron beam steered around the patient to strike the annular tungsten target
- Capable of 50-msec scan times; can produce fast-frame-rate CT movies of the beating heart

5th generation

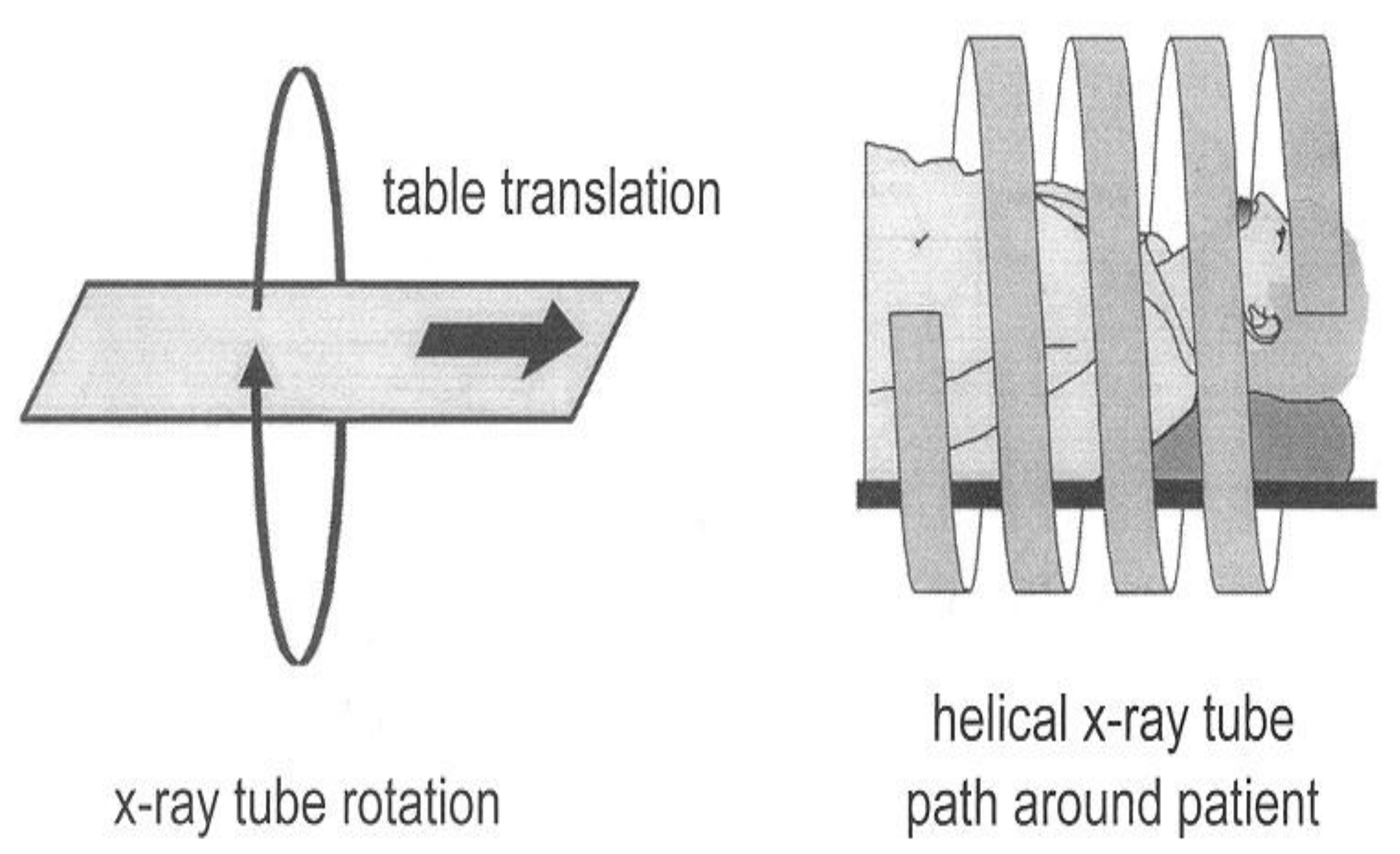


Helical/Spiral:

6th generation: helical

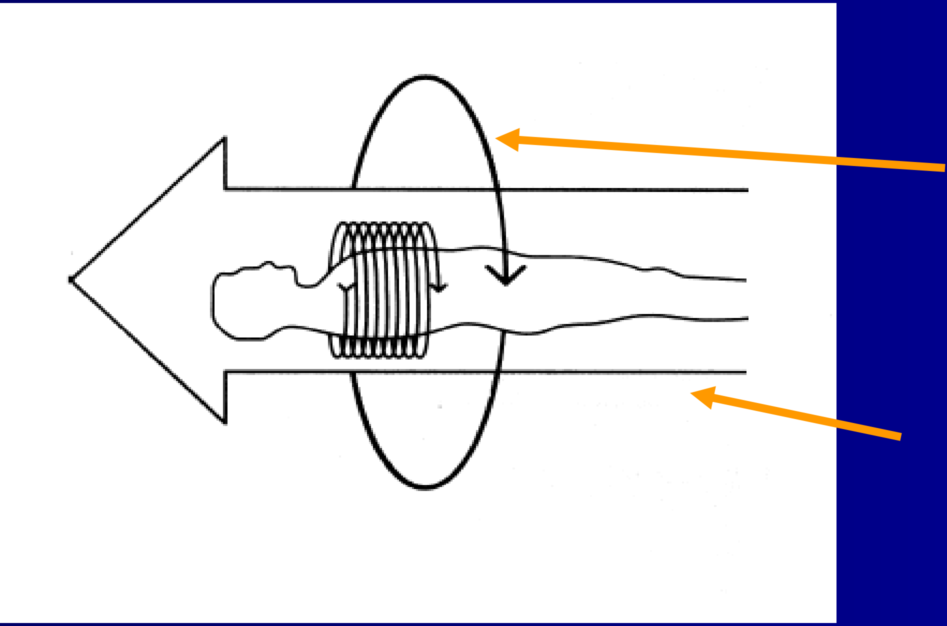
- Helical CT scanners acquire data while the table is moving
- By avoiding the time required to translate the patient table, the total scan time required to image the patient can be much shorter
- Allows the use of less contrast agent and increases patient throughput
- In some instances the entire scan be done within a single breath-hold of the patient

Spiral / Helical



Helical Scan Principle

Scanning Geometry

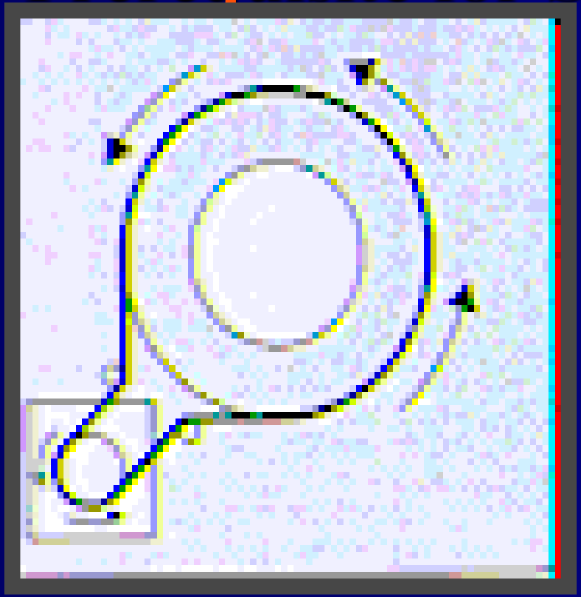


Continuous Data Acquisition and Table Feed

Slip-ring Technology

Power is transmitted through parallel sets of conductive rings instead of electrical cables

- Continuous Gantry Rotation
- Prerequisite for Spiral CT



Non Slip-ring Scanner

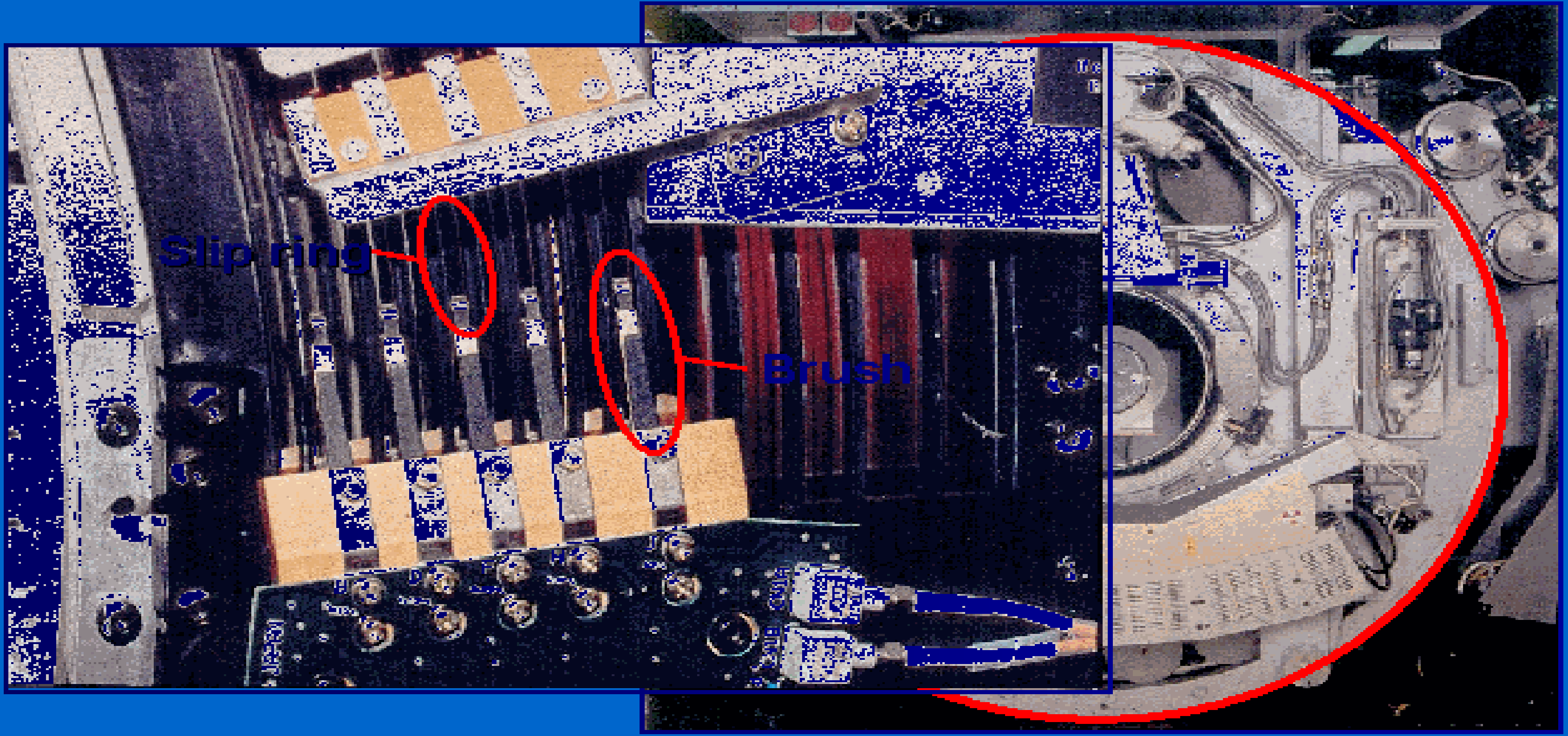
Slip-ring Scanner

What is Spiral Scan? -- just 4"C"

- **C**ontinuously rotating tube/detector system
- **C**ontinuously generating X-ray
- **C**ontinuously table feed
- **C**ontinuously data acquisition

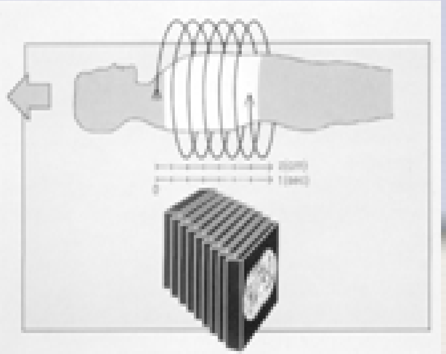
SLIP RINGS

Slip rings – allow continuous gantry rotation



Slip-ring

Spiral (helical) CT



Spiral CT and Spiral multislice CT:

Volume acquisition may be preferred to serial CT

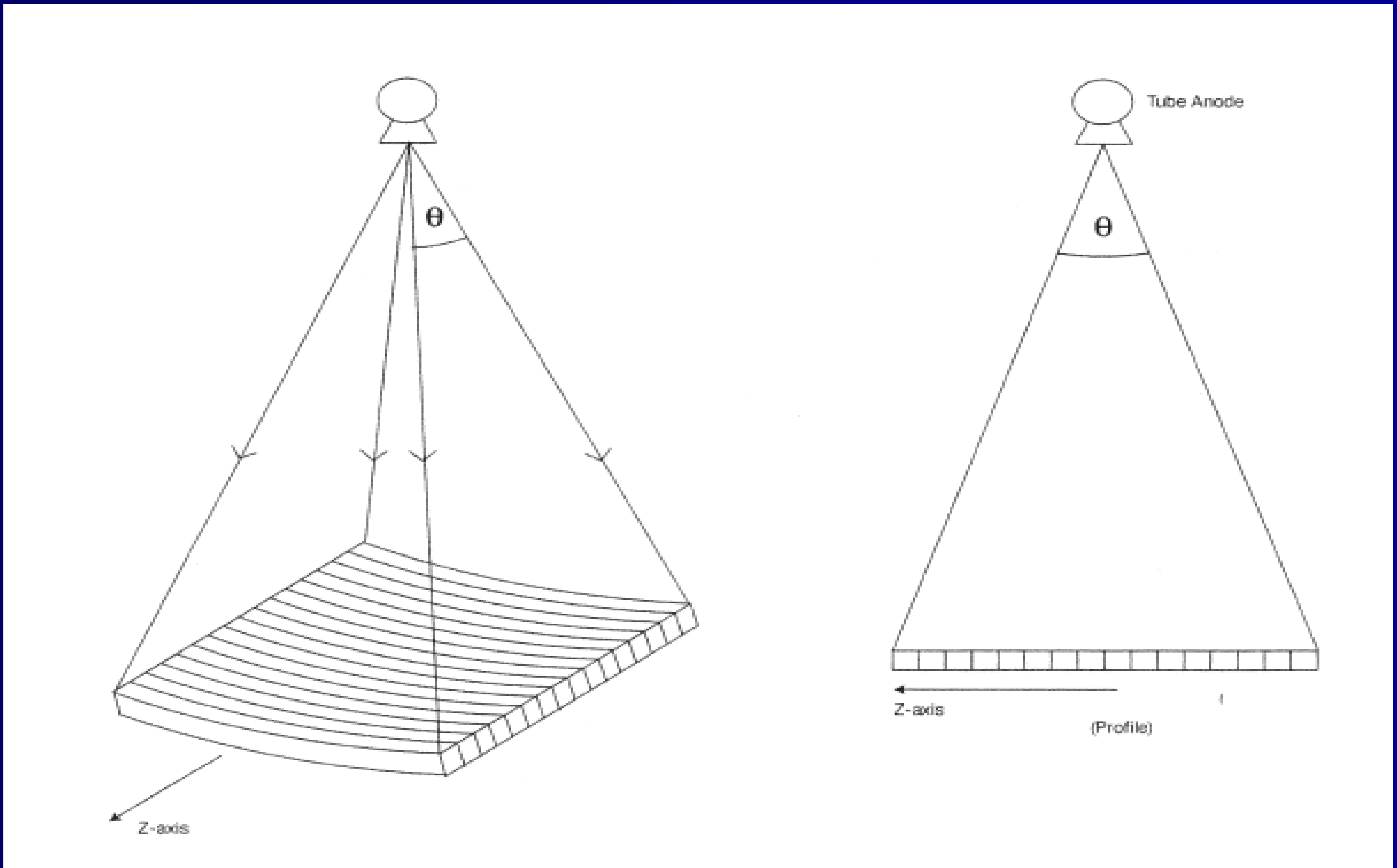
- Advantages:
  - dose saving:
    - reduction of single scan repetition (shorter examination times)
    - replacement of overlapped thin slices (high quality 3D display) by the reconstruction of one helical scan volume data
    - use of pitch > 1
  - no data missing as in the case of inter-slice interval
  - shorter examination time
    - to acquire data during a single breath-holding period avoiding respiratory disturbances
    - disturbances due to involuntary movements such as peristalsis and cardiovascular action are reduced

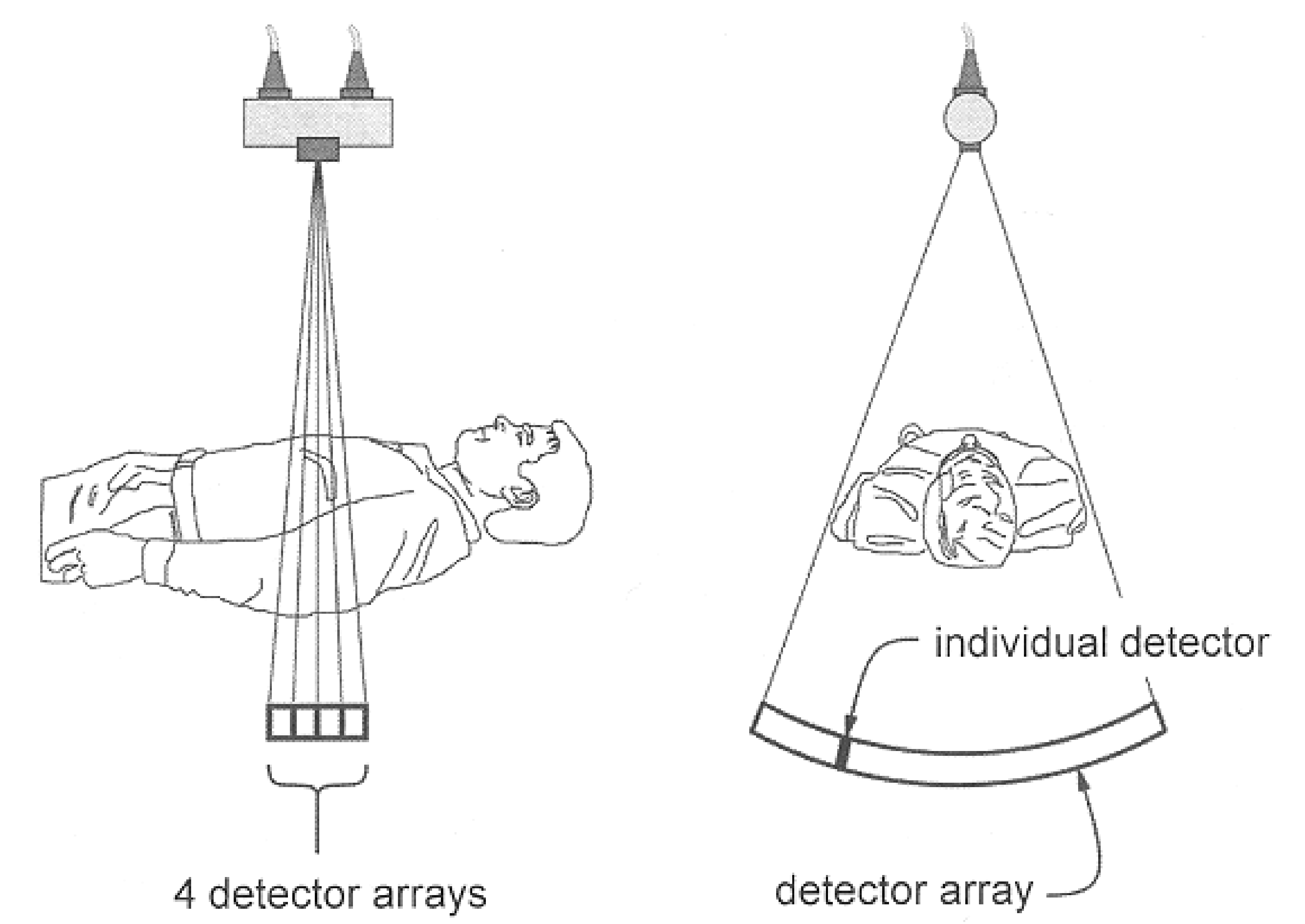
7^{th} generation: multiple detector array

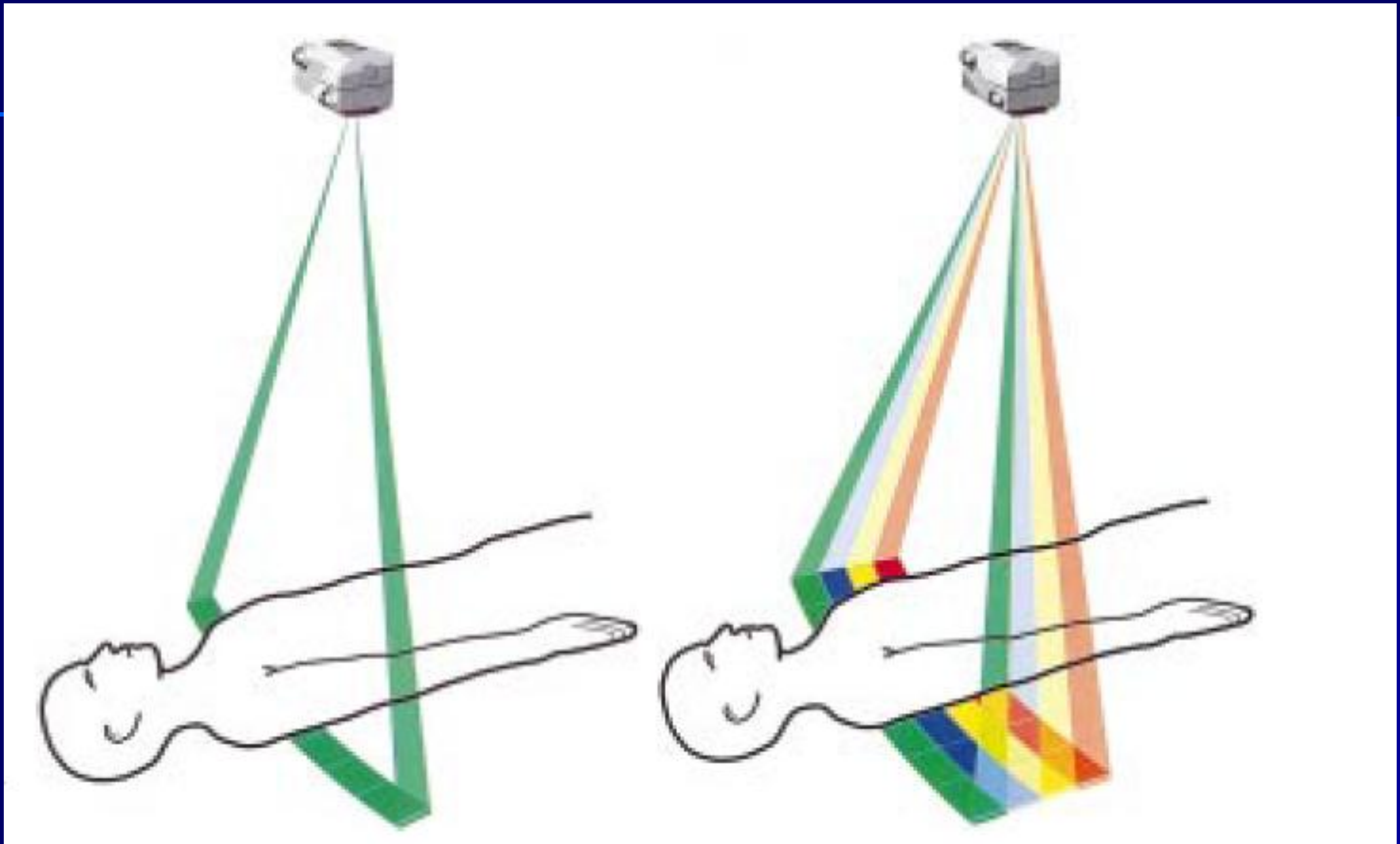
When using multiple detector arrays, the collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data

- Opening up the collimator in a single array scanner increases the slice thickness, reducing spatial resolution in the slice thickness dimension
- With multiple detector array scanners, slice thickness is determined by detector size, not by the collimator

Detector array




individual detector
4 detector arrays
detector array

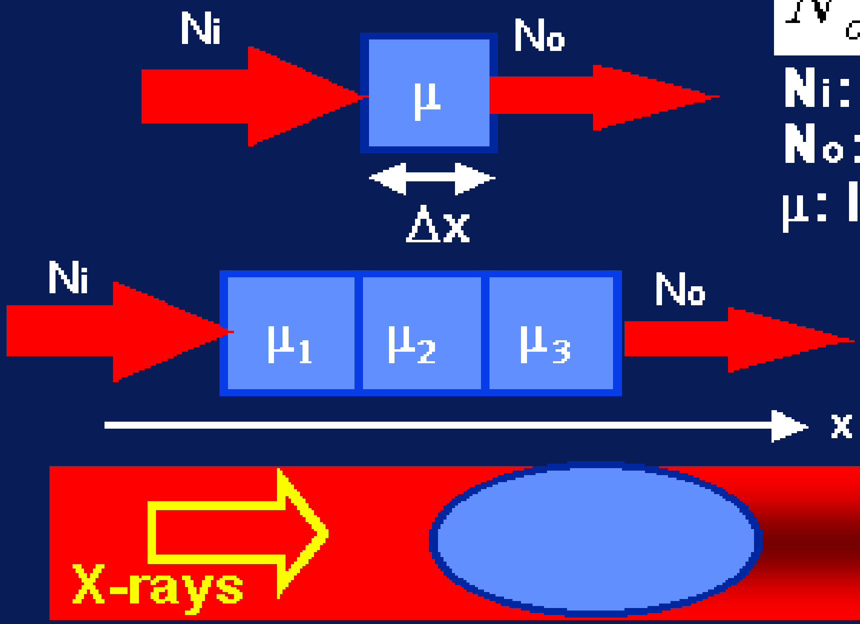


TRANSMISSION

RELATIVE TRANSMISSION=Io/I

ATTENUATION

Exponential Attenuation of X-ray



$$N_o = N_i e^{-\mu \Delta x}$$

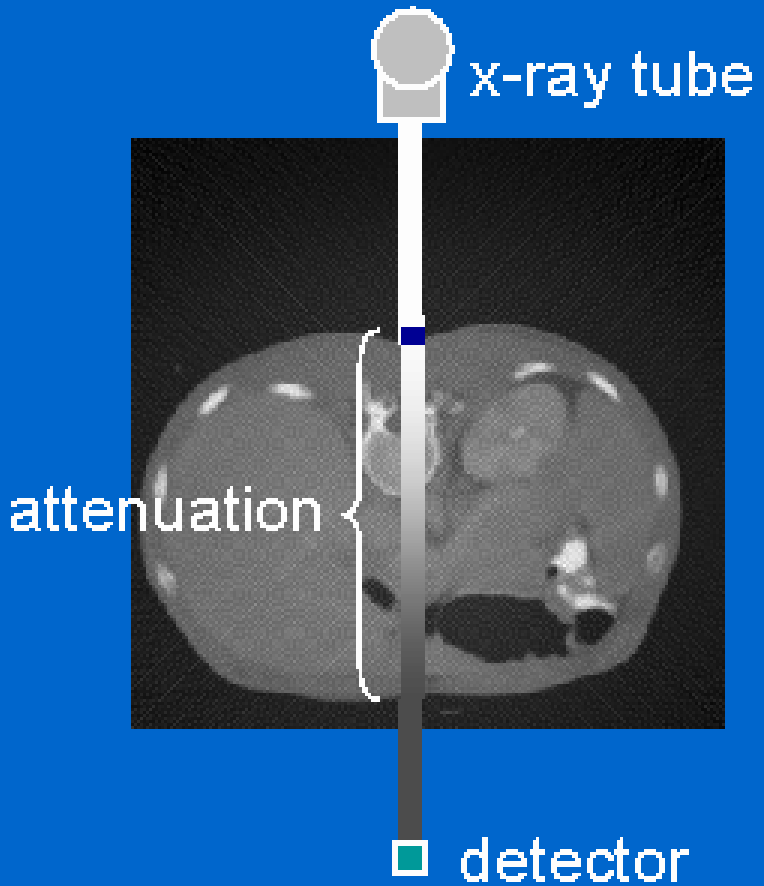
Ni: input intensity of X-ray
No: output intensity of X-ray
μ: linear X-ray attenuation

$$N_o = N_i e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

Attenuated more

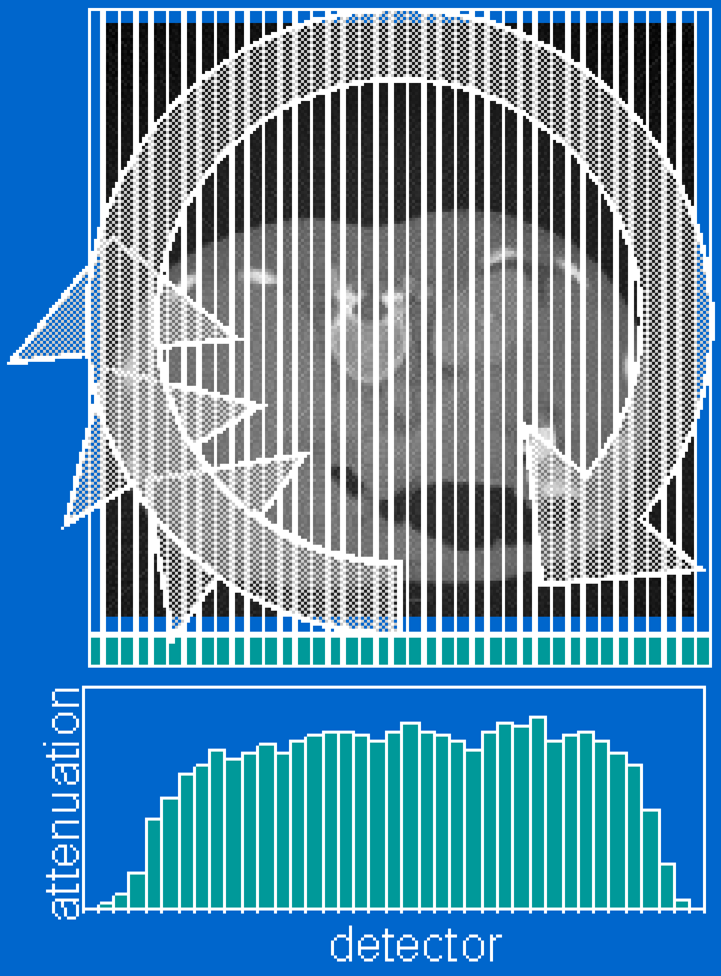
What are we measuring?

- The average linear attenuation coefficient, μ, between tube and detectors
- Attenuation coefficient reflects the degree to which the x-ray intensity is reduced by a material

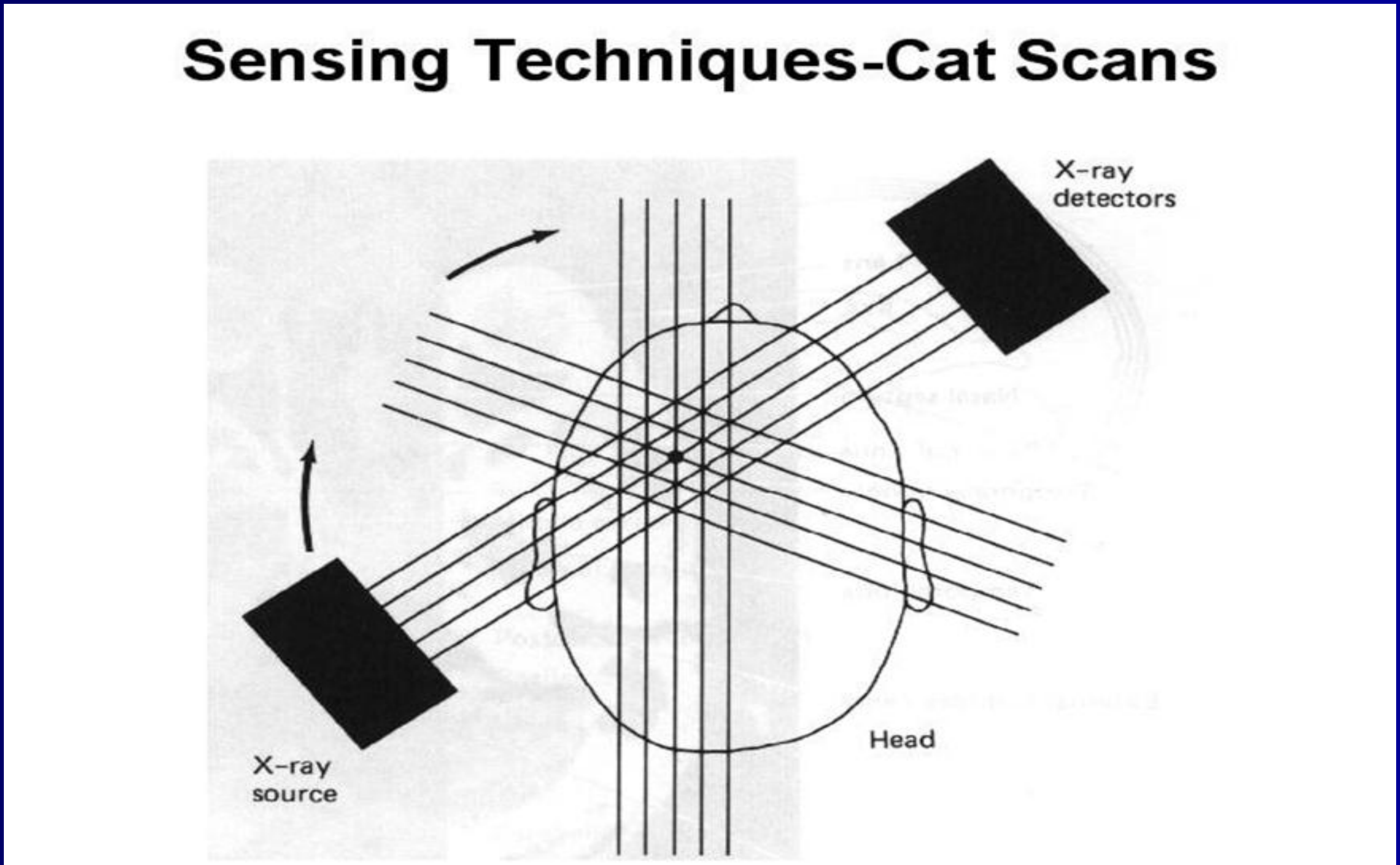


Projections

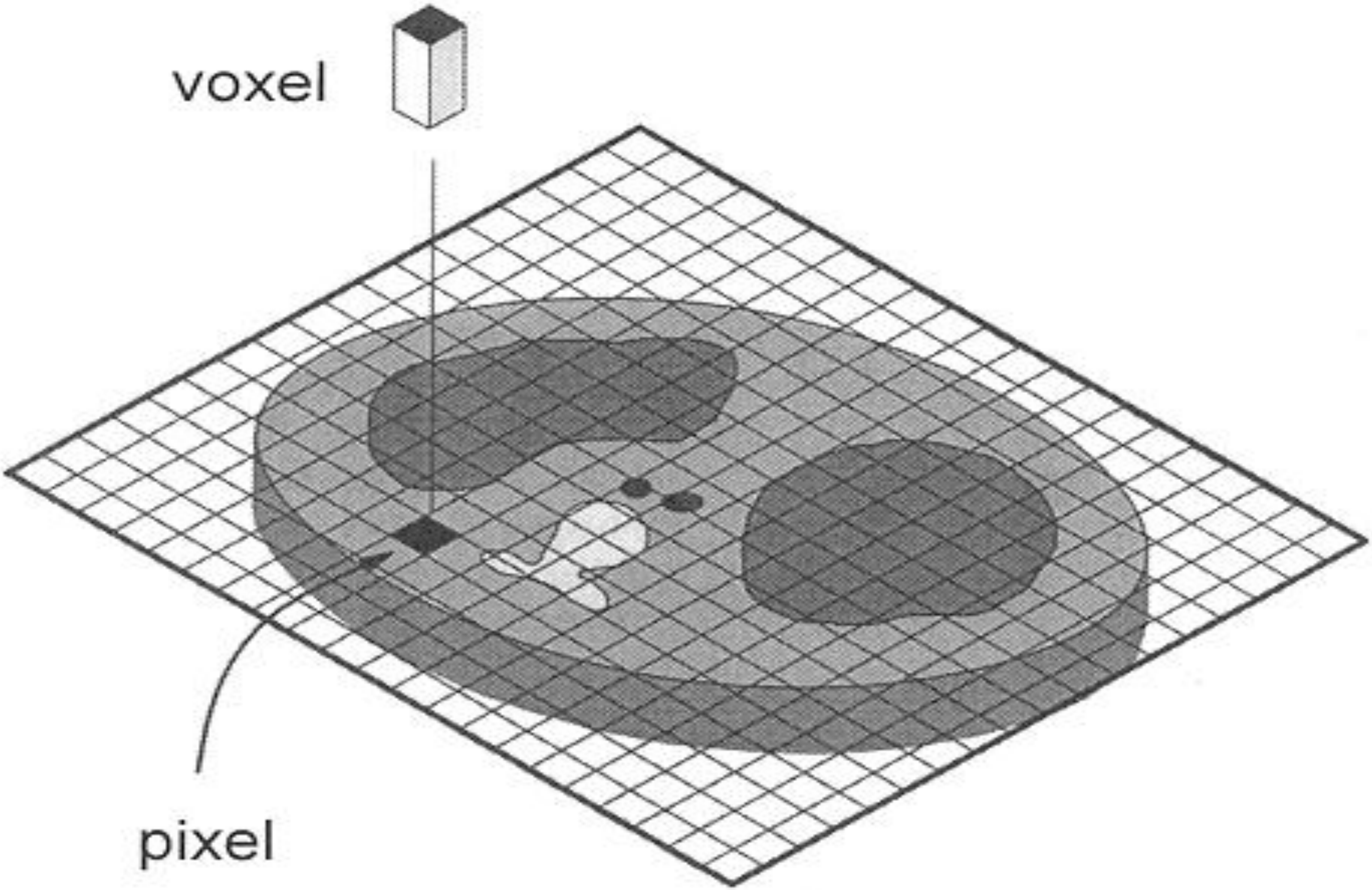
- 2D views - 'projections' at angles all the way round the patient
  - sample μ at each detector to generate a projection
  - rotate tube and detectors a small amount and repeat the measurements



SCANNING

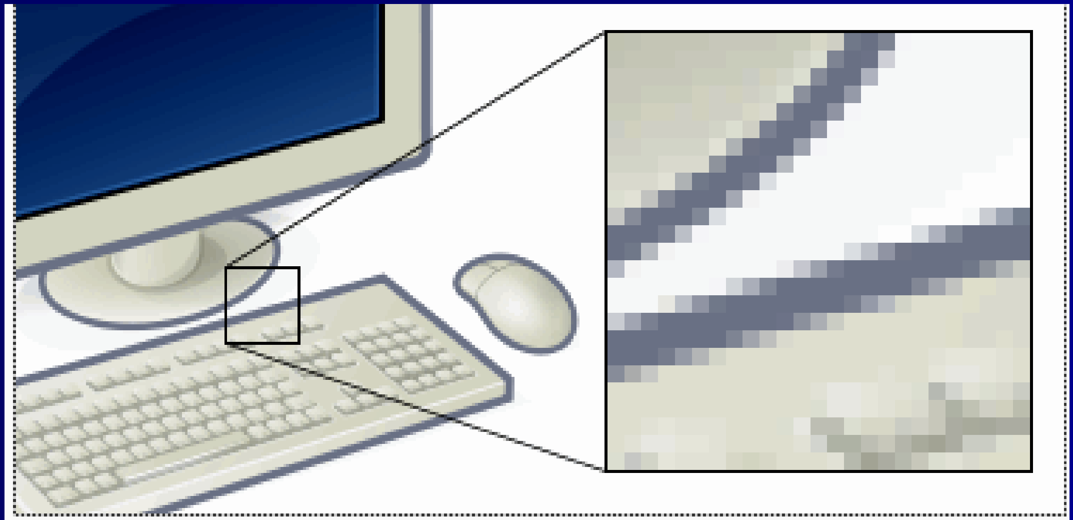


Sensing Techniques-Cat Scans
X-ray detectors
X-ray source
Head


voxel
pixel

پیکسل (Pixel):

در تصاویر دیجیتالی پیکسل (Pixel) کوچکترین جزء ساختاری (element) یک تصویر را گویند. پیکسل را بعضاً در مباحث مربوط به گرافیک و تصویر، نقطه نامیده و آن را کوچکترین نقطه تشکیل دهنده تصویر نیز می خوانند.



نمونه فوق، تصویری را نمایش میدهد (سمت چپ) که بخشی از آن به میزان قابل توجهی بزرگ گردیده (سمت راست)، در این بخش پیکسل های تشکیل دهنده تصویر به شکل مکعب های کوچکی قابل مشاهده میباشند

وکسل (voxel):

واکسل یا وکسل (Voxel) کوچکترین جز ساختاری(element) یک تصویر ۳ بعدی را گویند

از این لحاظ، وکسل مشابه ۳ بعدی یک پیکسل است.

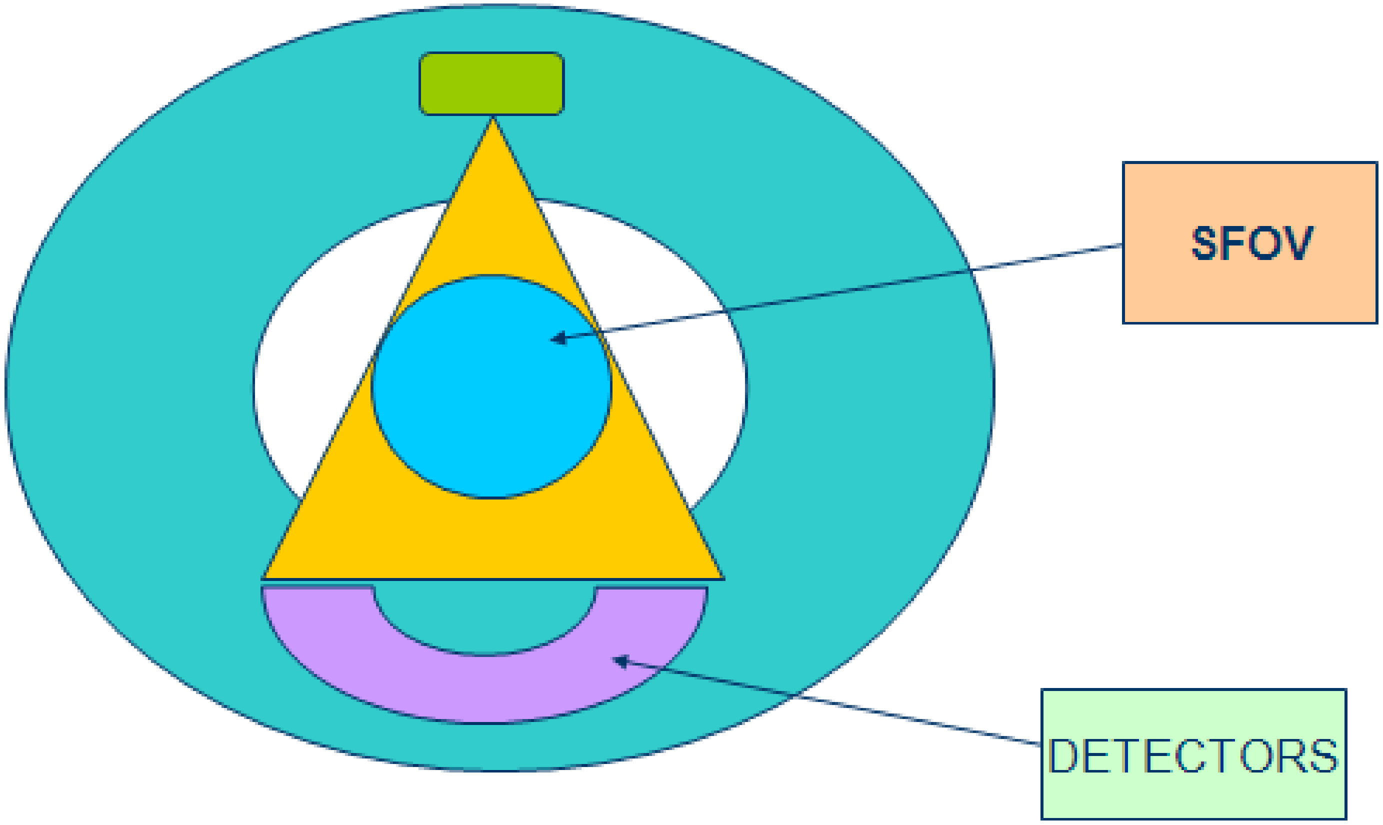
FOV:

- وسعت ناحیه آناتومیکی که به تصویر کشیده میشود

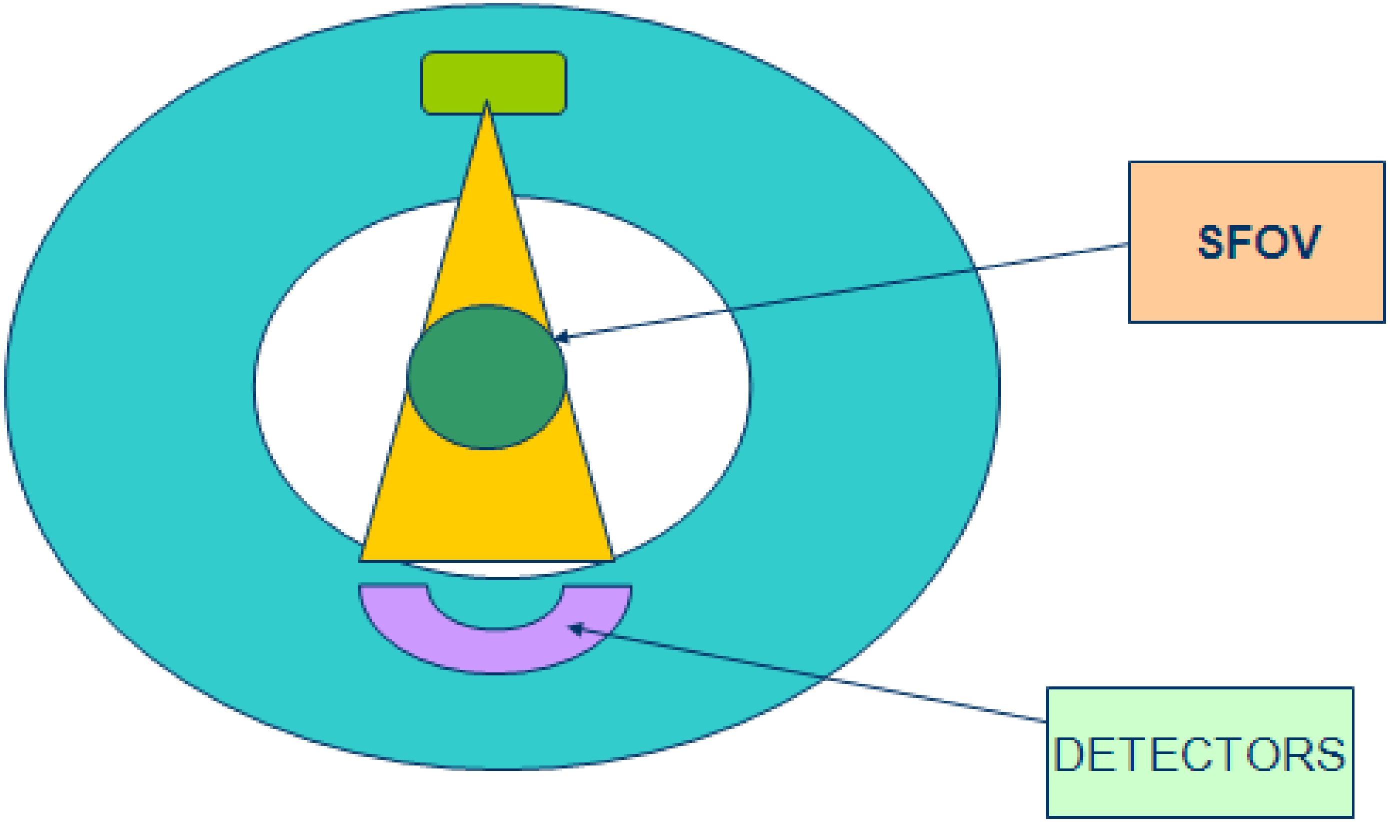
DISPLAY FOV vs SCANNING FOV

- **SFOV** – AREA OF MEASUREMENT DURING SCAN
- **DFOV** - DISPLAYED IMAGE
- **DFOV** CAN BE EQUAL OR LESS OF **SFOV**

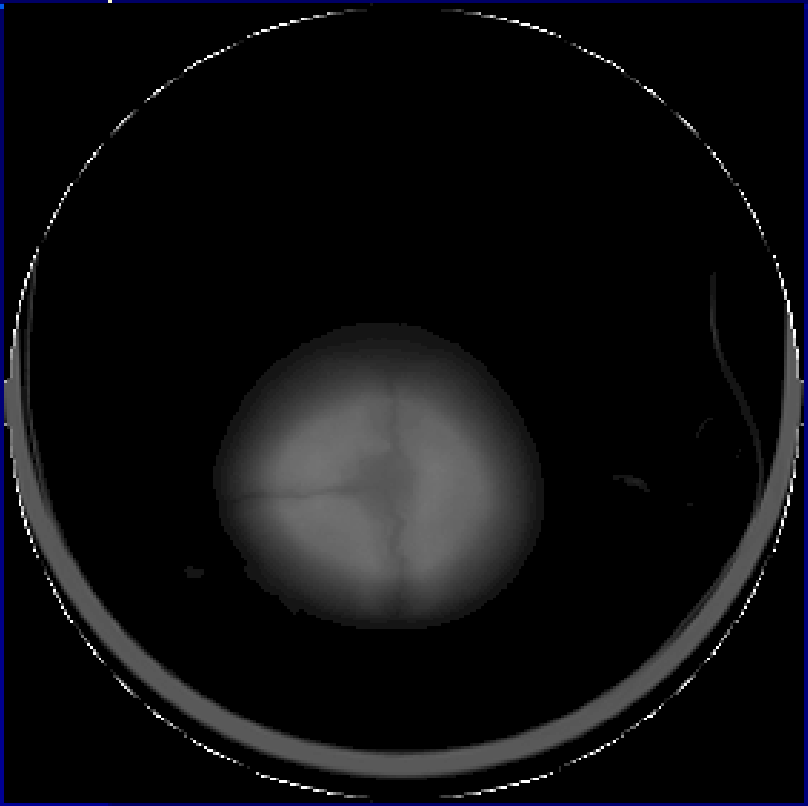
SCAN FOV

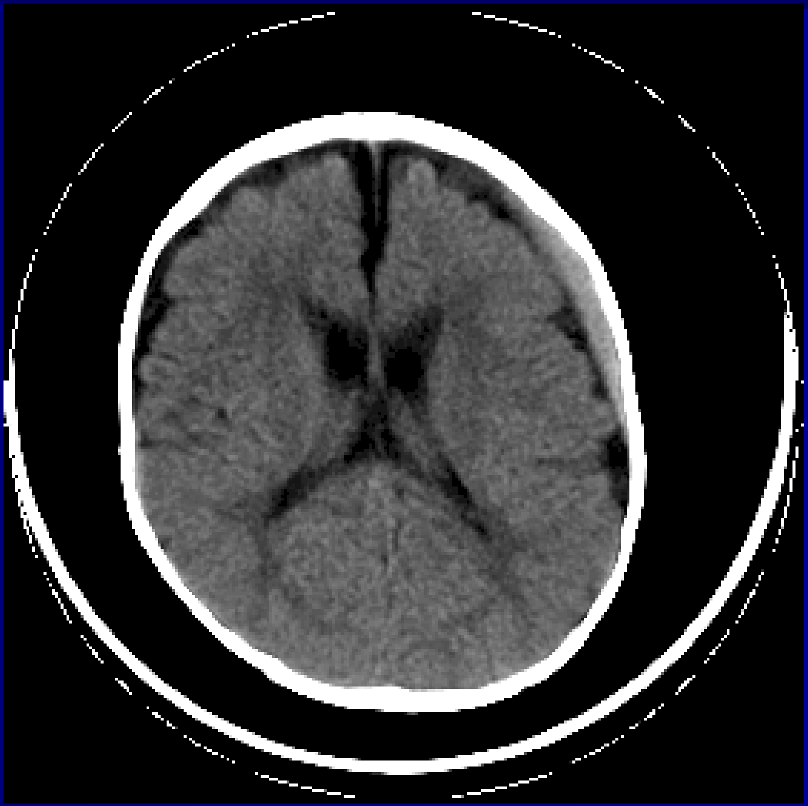


SCAN FOV-SMALL

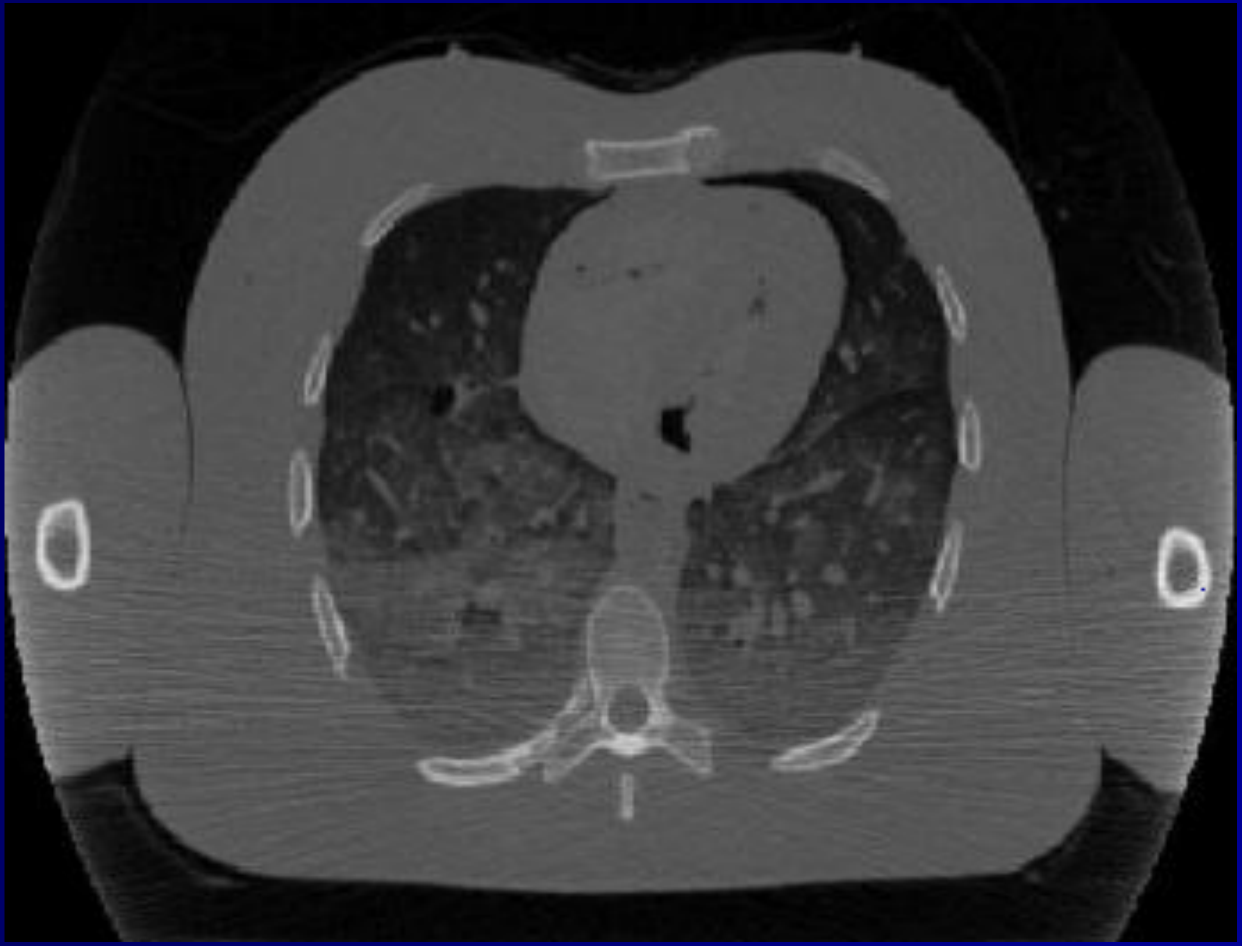


SFOV - HEAD

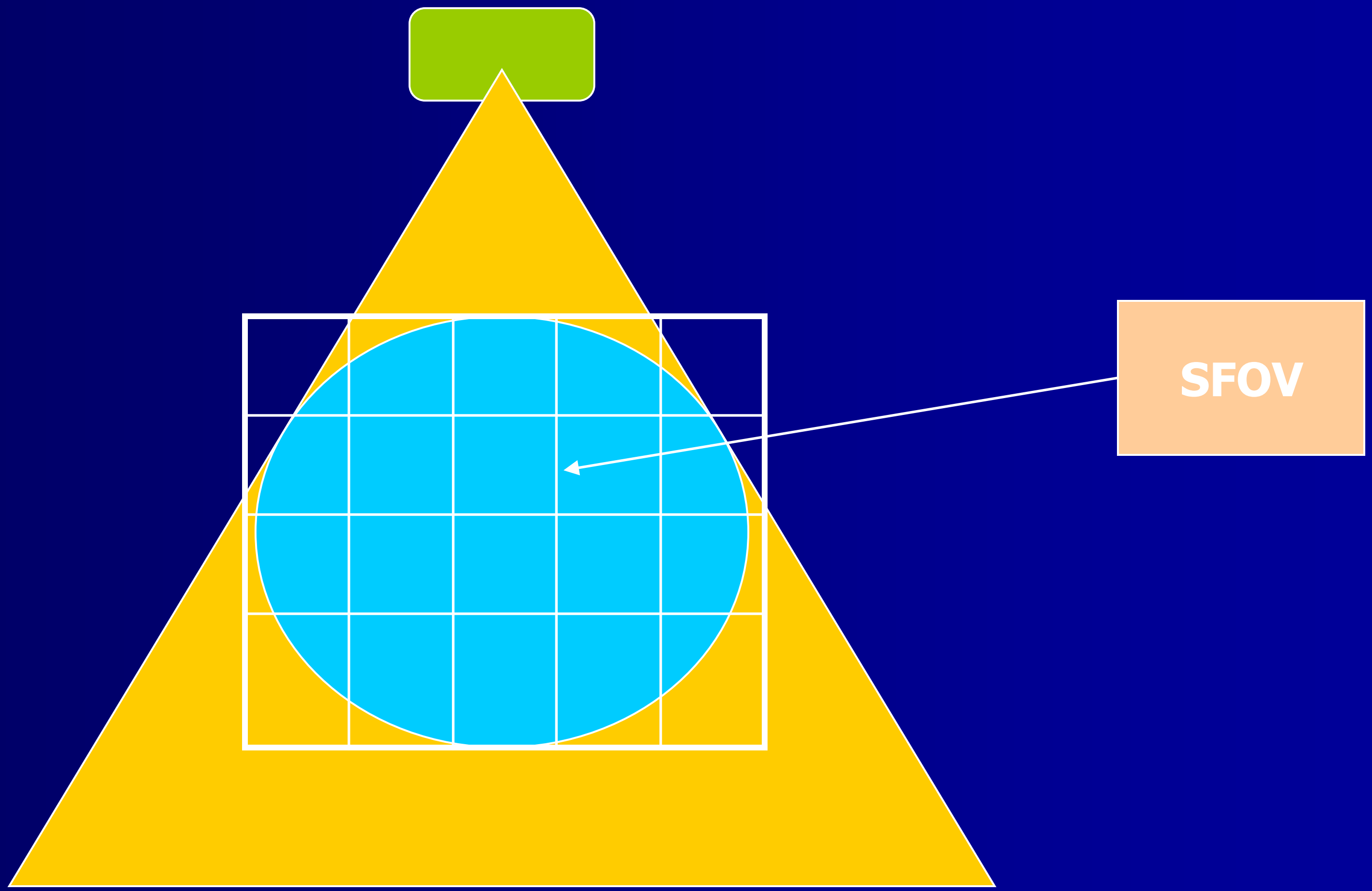




TOO SMALL OF SFOV – OUT OF FIELD ARTIFACT



SCAN FOV-RESOLUTION



MOST SCANNERS PIXEL SIZE

1 TO 10mm

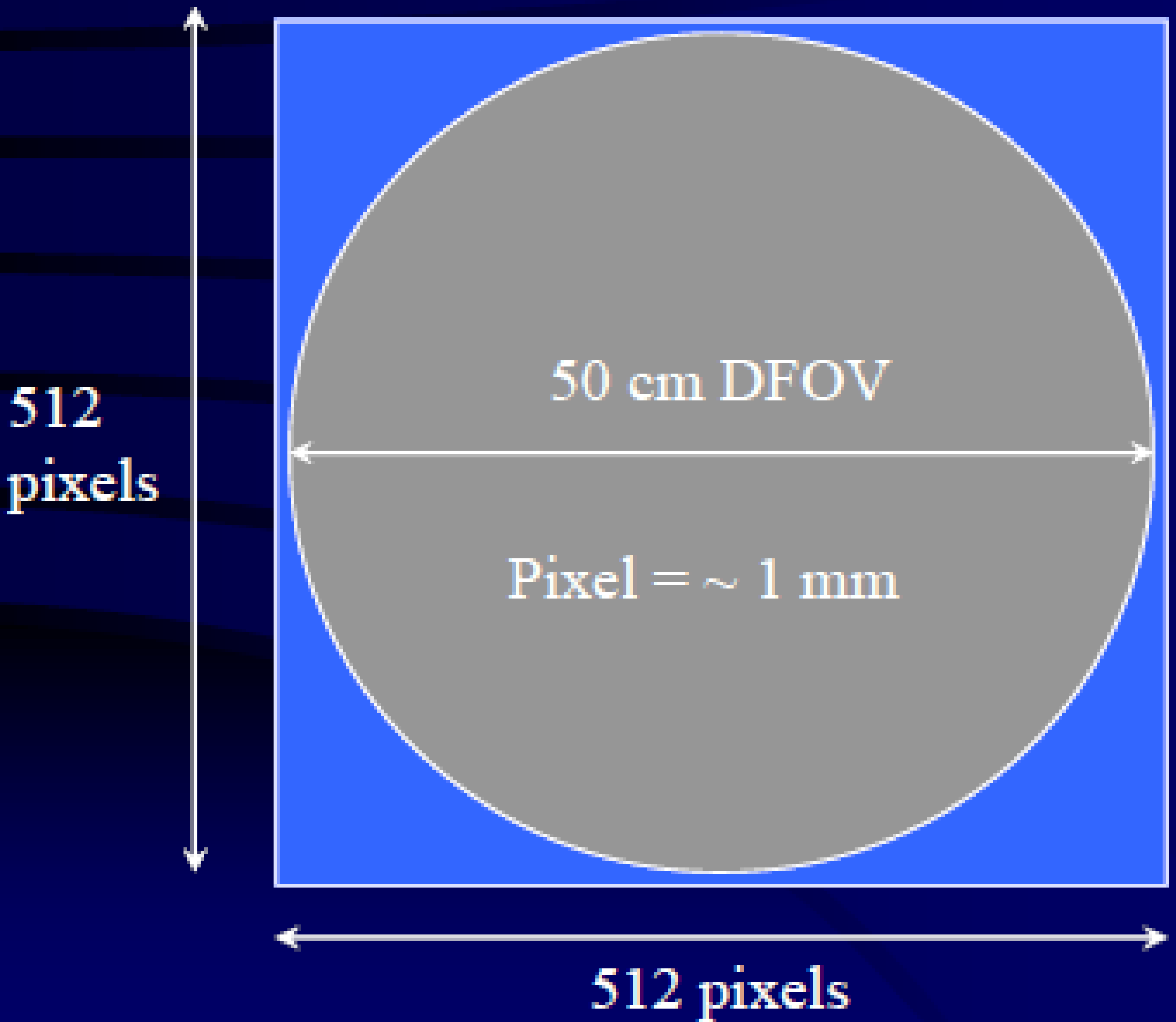
EXAMPLE:

- FOV= 40 CM= 40 X 10 MM=400 mm
- MATRIX= 512 X 512 = 512^2

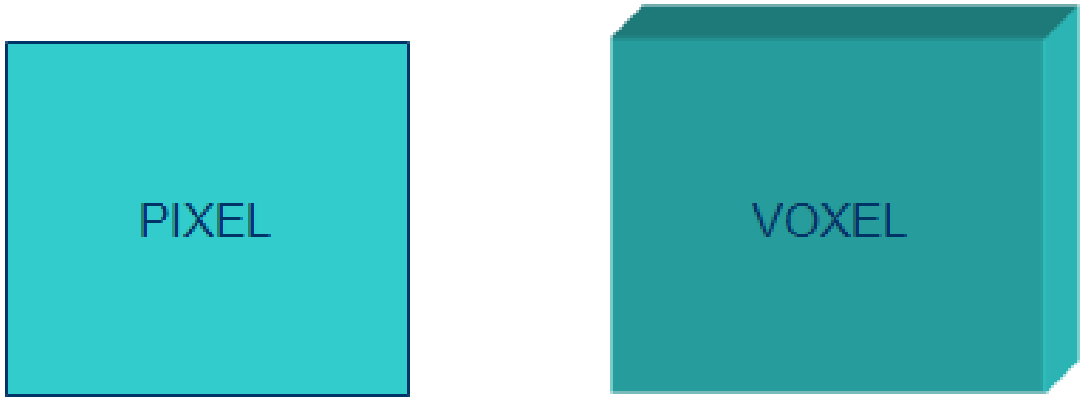
400/512 = 0.78 mm

0.8 mm

X-Y Voxel Size



PIXEL vs VOXEL

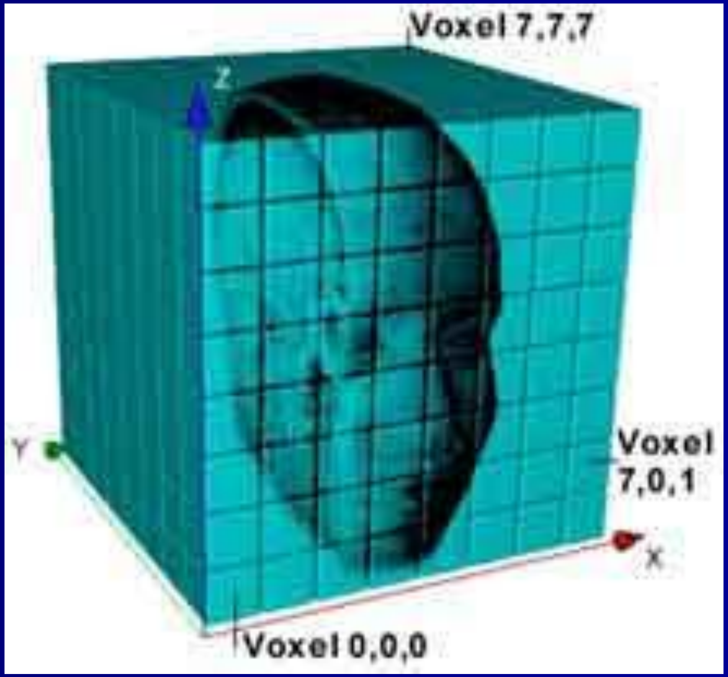


PIXEL SIZE DEPENDS ON:

- MATRIX SIZE
- FOV

VOXEL SIZE DEPENDS

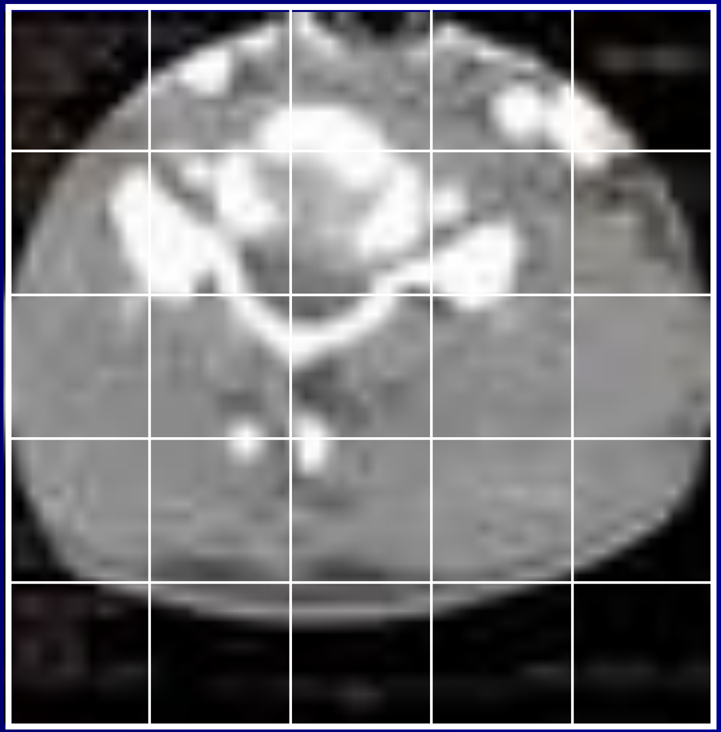
- FOV
- MATRIX SIZE
- SLICE THICKNESS



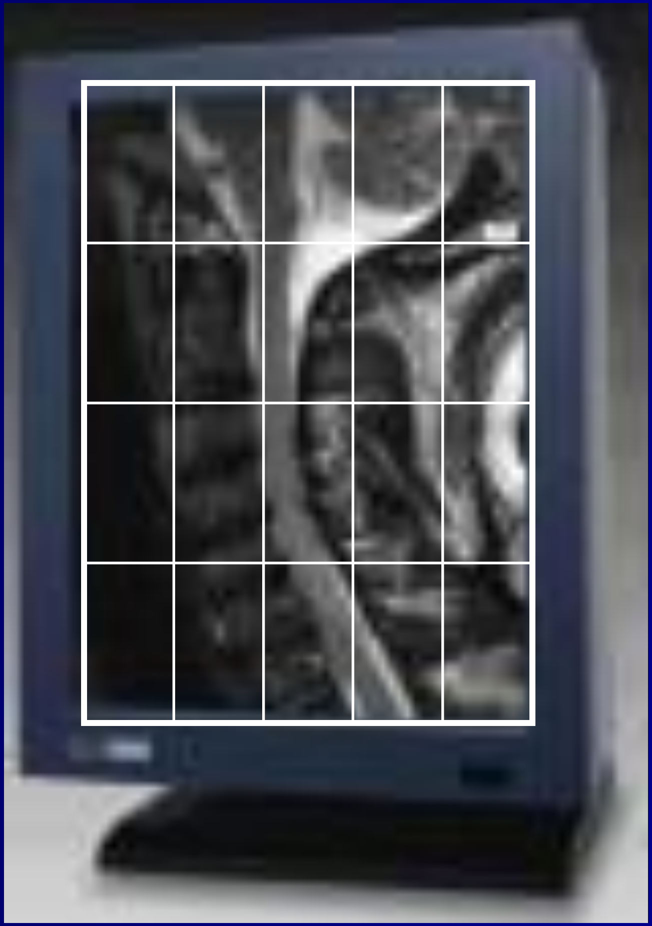
GRAY SCALE DISPLAY MONITOR RESOLUTION IS RELATED TO THE SIZE OF THE PIXEL MATRIX

- 64 X 64
- 128 X 128
- 256 X 256
- 512 X 512
- 1024 X 1024
- 2048 X 2048 (HIGH PERFORMANCE MONITORS)

MATRIX



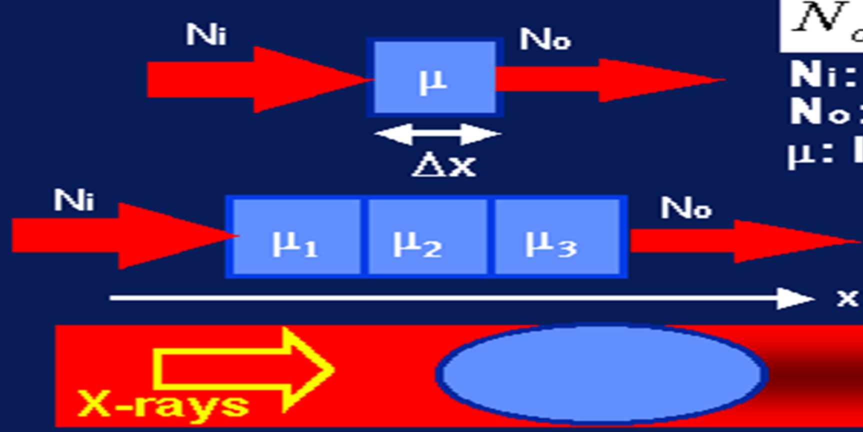
PIXEL MATRIX



در رادیوگرافی ضریب تضعیف خطی میانگین محاسبه میشود ولی در **CT** نمیتوانیم از ضریب تضعیف خطی میانگین استفاده کنیم بنابراین یک ماتریس ریاضی بازسازی را روی **FOV** منطبق میکنیم که شامل ردیف وستون می باشد

وقتی یک ماتریس ریاضی بازسازی را روی **FOV** منطبق میکنیم اصطلاحا آنرا پیکسیلیت کرده ایم

بنابراین وقتی میخواهیم ضریب تضعیف خطی **(μ)** را برای یک طول وهر پیکسل حساب کنیم فرمول بصورت زیر در می آید



$$N_o = N_i e^{-\mu \Delta x}$$

Ni: input intensity of X-ray
No: output intensity of X-ray
μ: linear X-ray attenuation

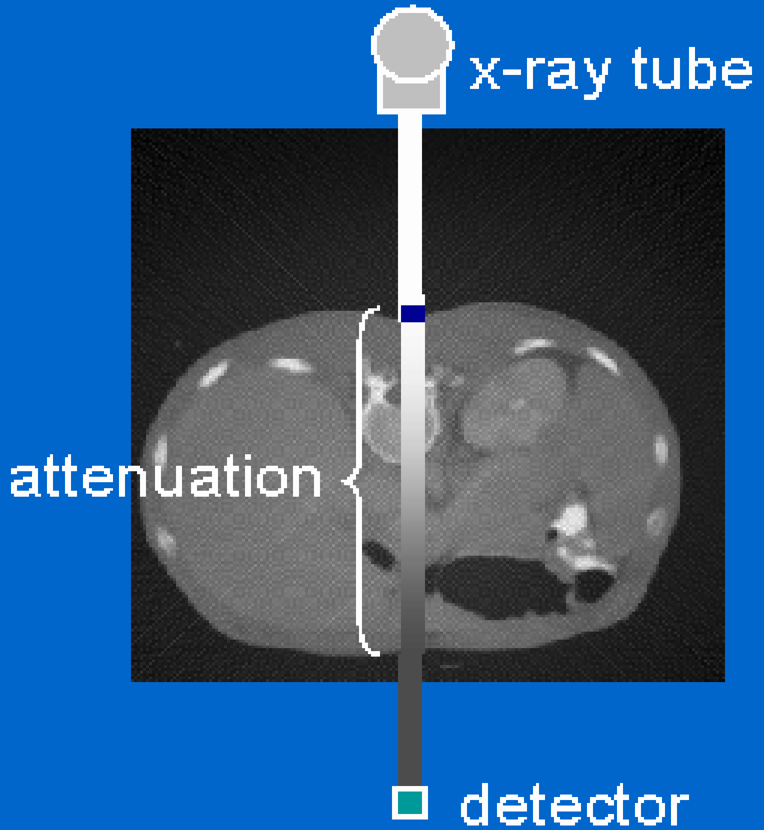
$$N_o = N_i e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

Attenuated more

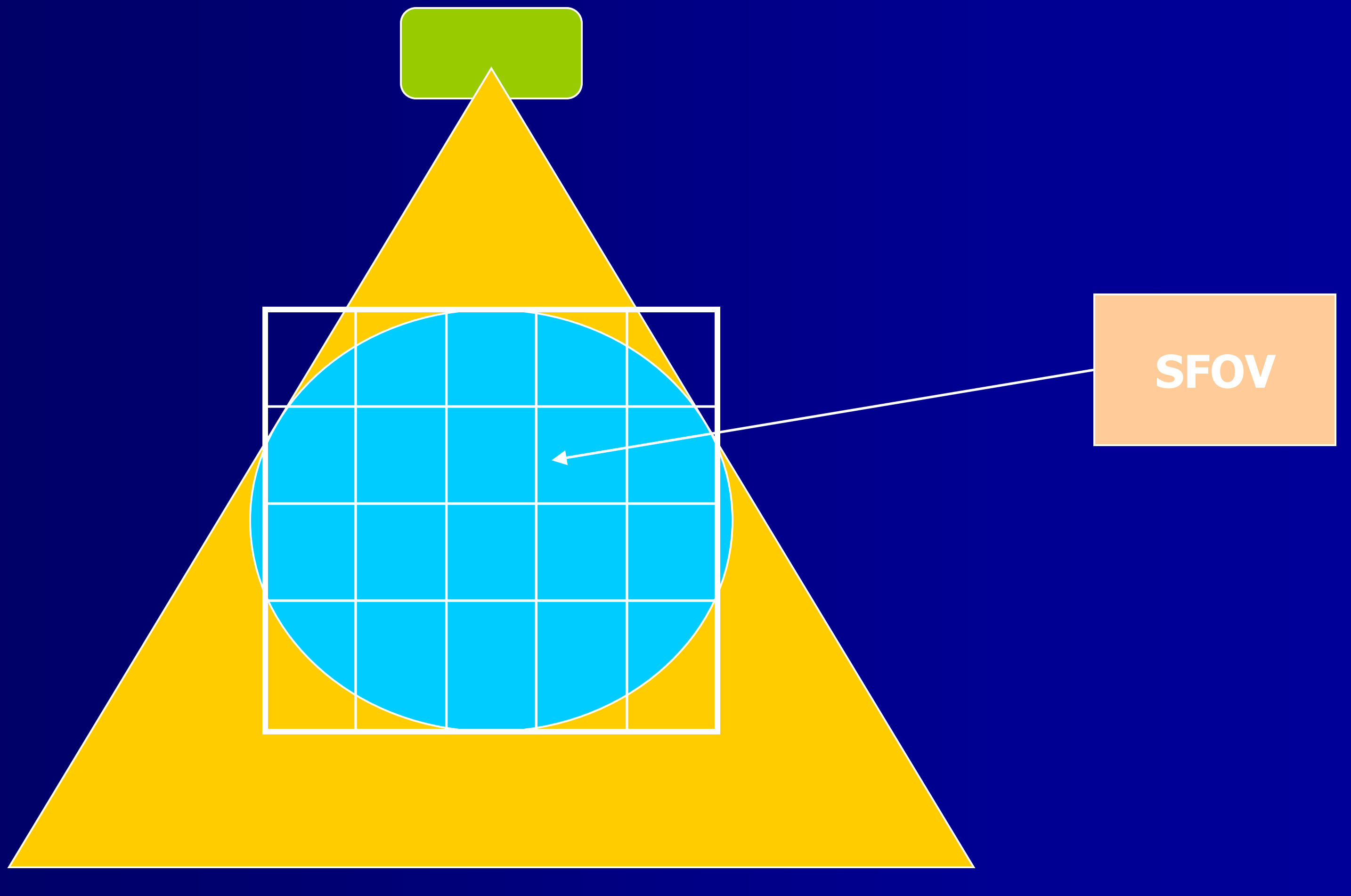
- یعنی برای هر پیکسل به صورت جدا یک μ محاسبه میکنیم
- پس در CT در هر زاویه ای از 0 تا 360 تعدادی معادله سنگین را بدست میاوریم وحل میکنیم این مجموعه عظیم داده ها که بدست میاید به ما کمک میکند تا بتوانیم μ را برای یک به یک پیکسلها در داخل FOVبطور دقیق محاسبه کنیم.
- حاصل این امر بدست آوردن μ برای یک به یک پیکسل ها در مسیر تابش است
- حال که برای هر پیکسل μ را بدست آورده ایم انگار که اطلاعات جذبی توسط هر پیکسل را بطور دقیق حساب کرده ایم ودر مرحله بعد با استفاده از μهایی که برای پیکسل محاسبه کردیم، عدد CT را برای هر پیکسل یا وکسل حساب کنیم

What are we measuring?

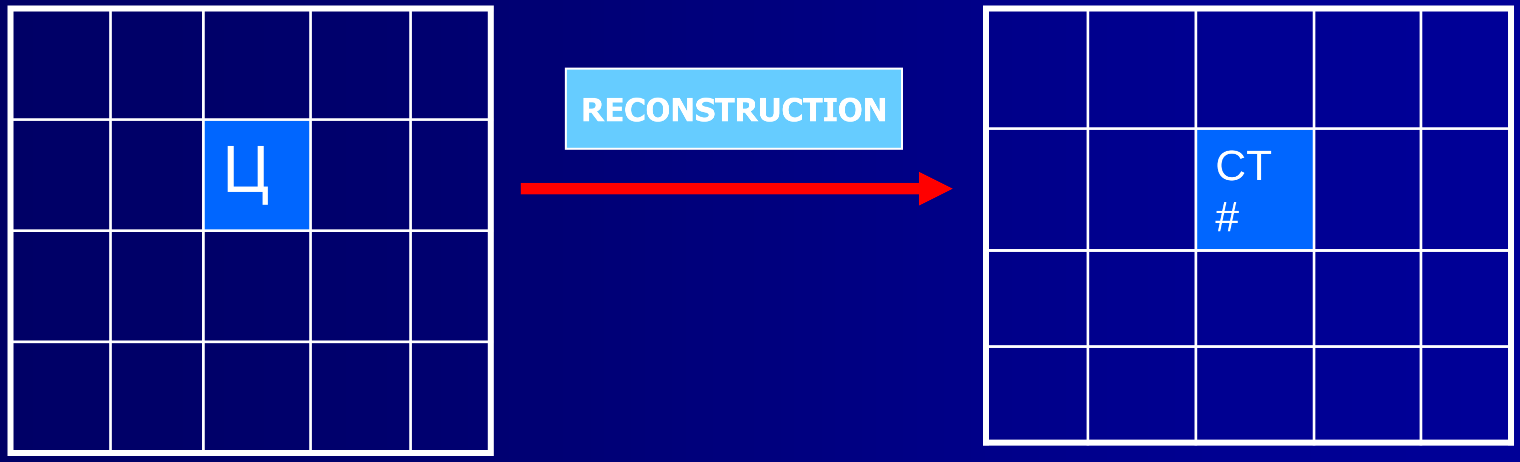
- The average linear attenuation coefficient, μ, between tube and detectors
- Attenuation coefficient reflects the degree to which the x-ray intensity is reduced by a material



SCAN FOV



RECONSTRUCTION



CT NUMBER

μ to CT number

- Originally measured was the distribution of μ
- μ values are scaled to that of water to give the CT number
- CT number = $$\frac{\mu_{tissue} - \mu_{water}}{\mu_{water}} \times 1000$$
- Water = 0
  Air = -1000
  Bone = ~1000

CT Number

- Pixel bit-depth of $2^{12} = 4096$ values
- Contrast scale

  $$HU = \text{Constant}\,(\mu_m - \mu_{water}) / \mu_{water}$$

  – CT number for water = 0 at all energies

  – CT number range –1024 to +3072
- CT number affected by kVp

  – Reduce kVp, increase contrast

Computed Gray Scale and CT Numbers

TISSUE TYPE AND CT NUMBERS		
TISSUE TYPES	**CT NUMBERS**	**APPEARANCE**
Cortical bone	+1000	White
Muscle	+50	Gray
White matter	+45	Light gray
Gray matter	+40	Gray
Blood*	+20	Gray
CSF	+15	Gray
Water	0 (Baseline)	
Fat	-100	Dark gray to black
Lung	-200	Dark gray to black
Air	-1000	Black

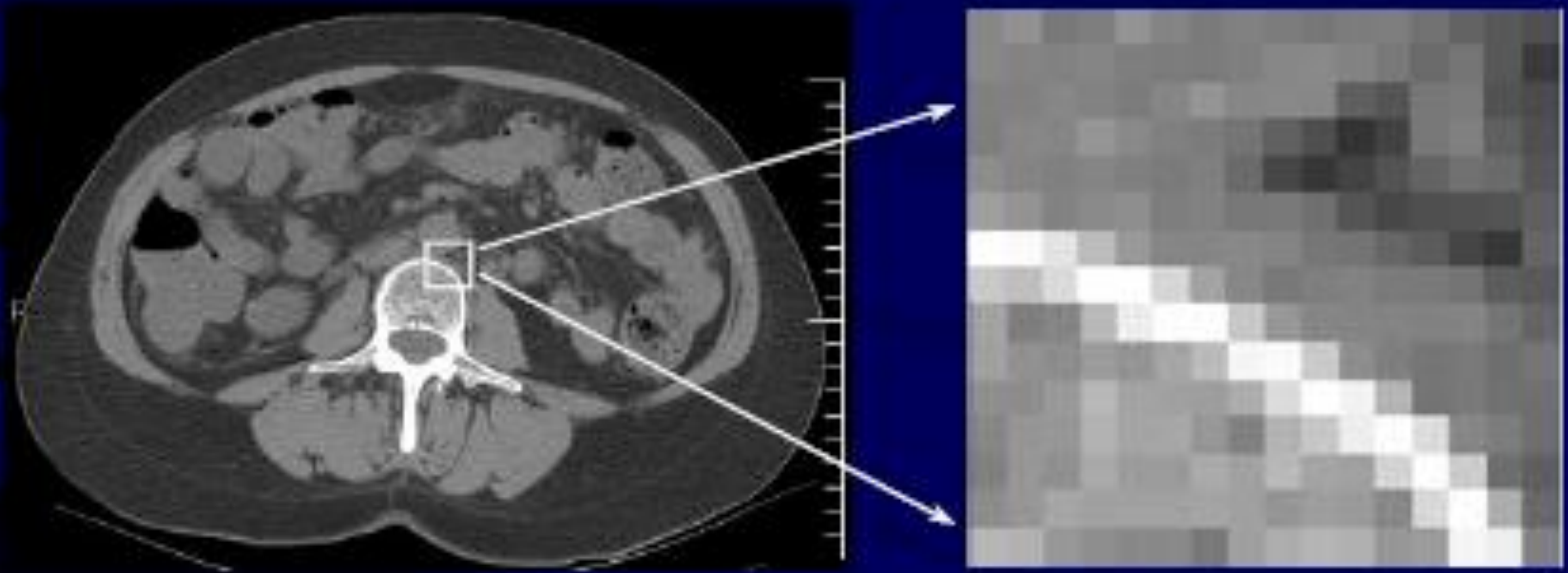
*White if iodinated contract media is present.

Relative attenuation (shades of gray) is based on CT numbers (Hounsfield units).

LINEAR ATTENUATION COEFFICIENT (cm^{-1})

BONE	0.528
BLOOD	0.208
G. MATTER	0.212
W. MATTER	0.213
CSF	0.207
WATER	0.206
FAT	0.185
AIR	0.0004

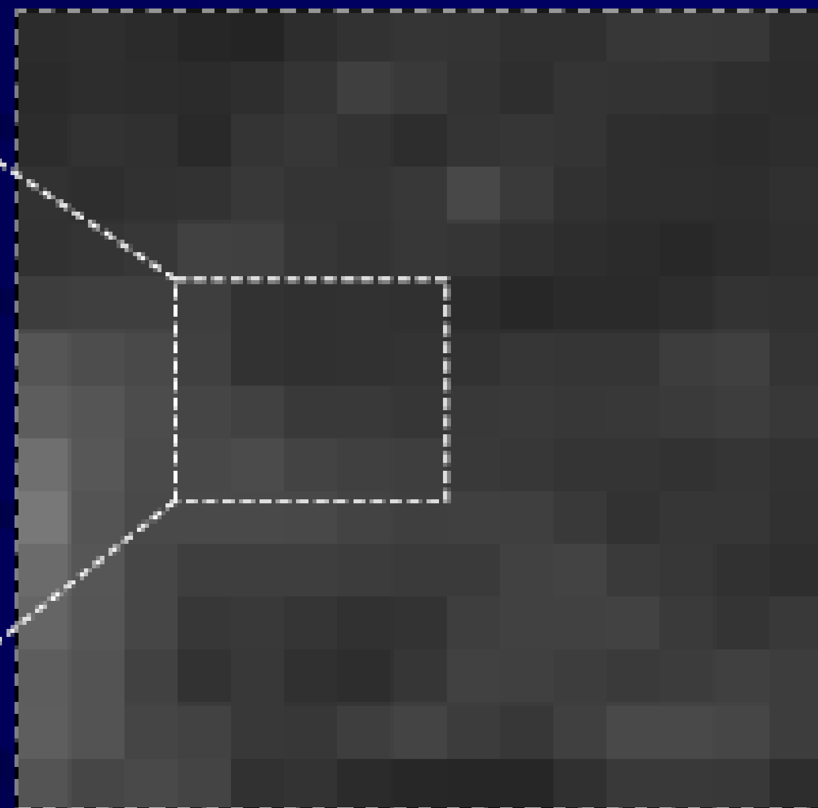
Pixels and Image Matrices



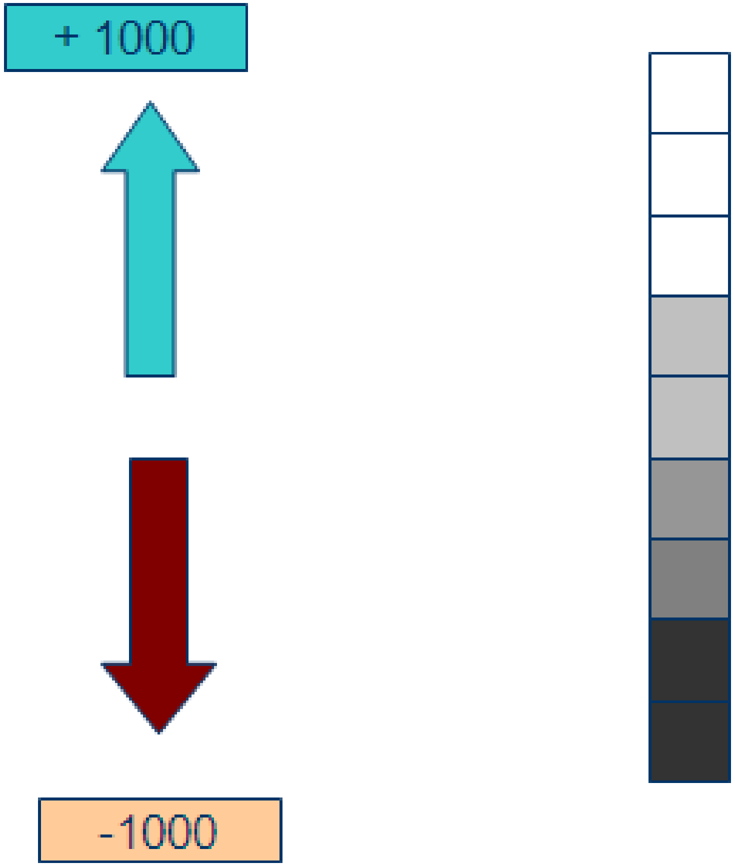
Pixels and Image Matrices

222	220	200	146	103
200	158	127	96	73
207	131	103	82	86
202	126	112	124	133

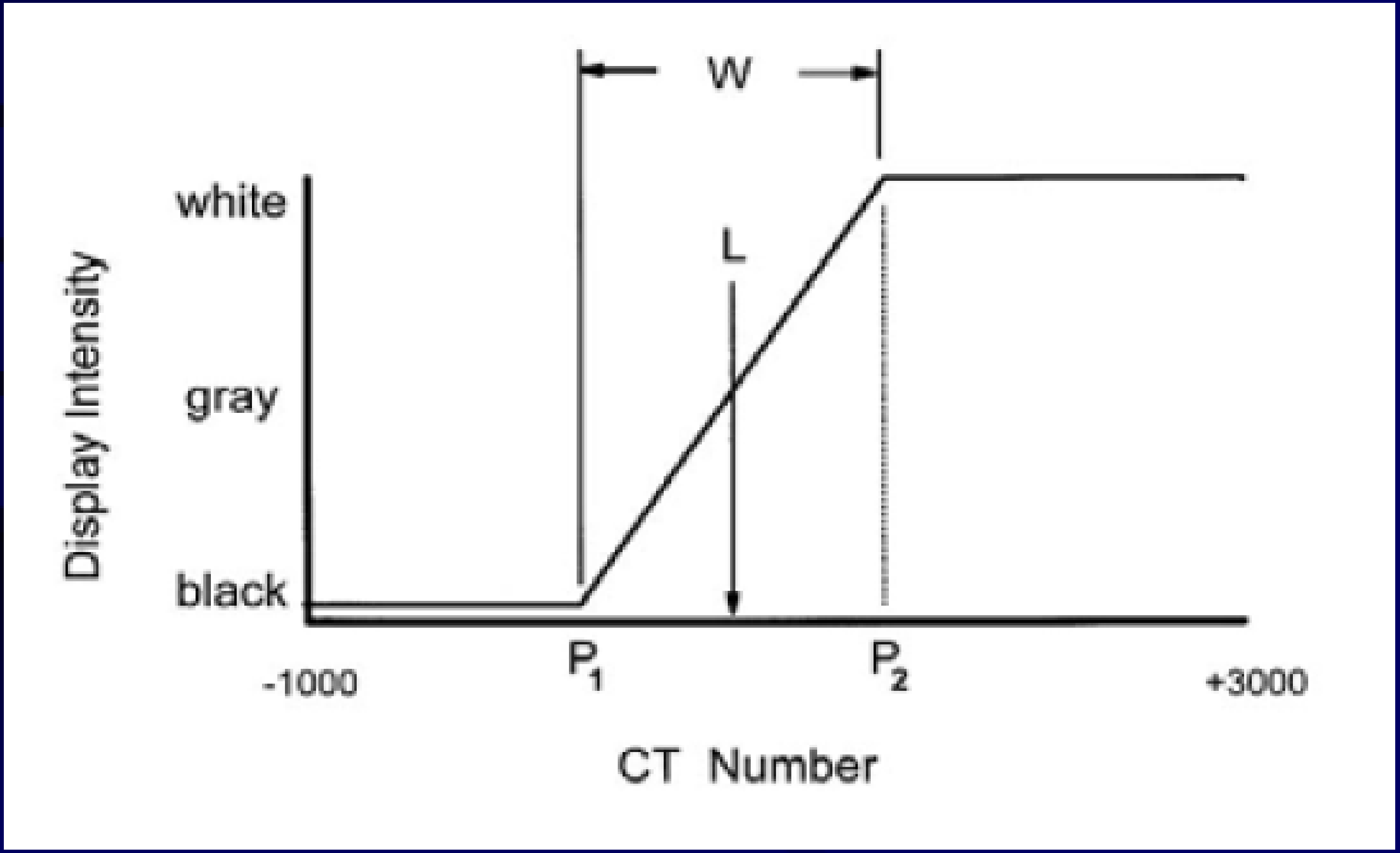
Pixel Values (HU)



CT # vs BRIGHTNESS LEVEL

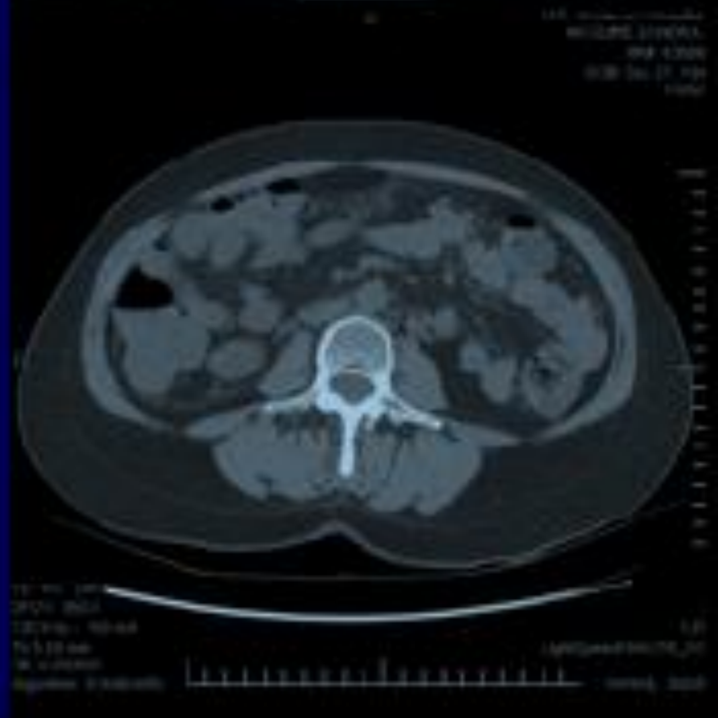


Select CT#'s with WW WL

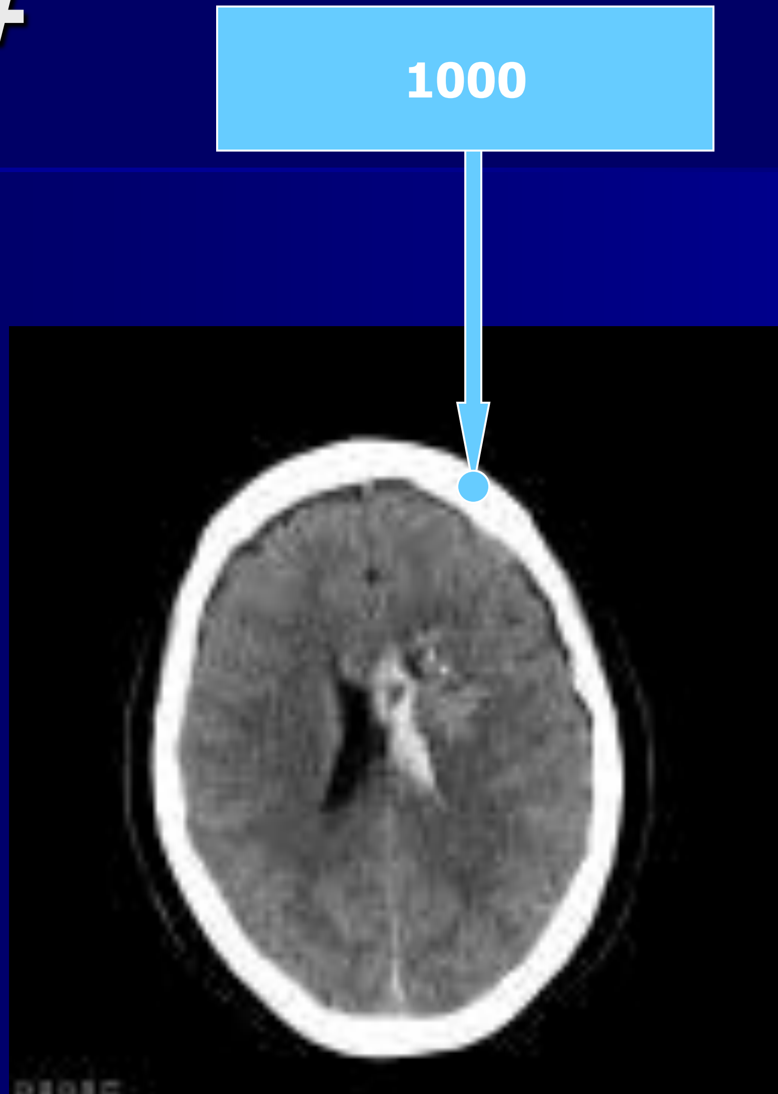


Typical CT Numbers

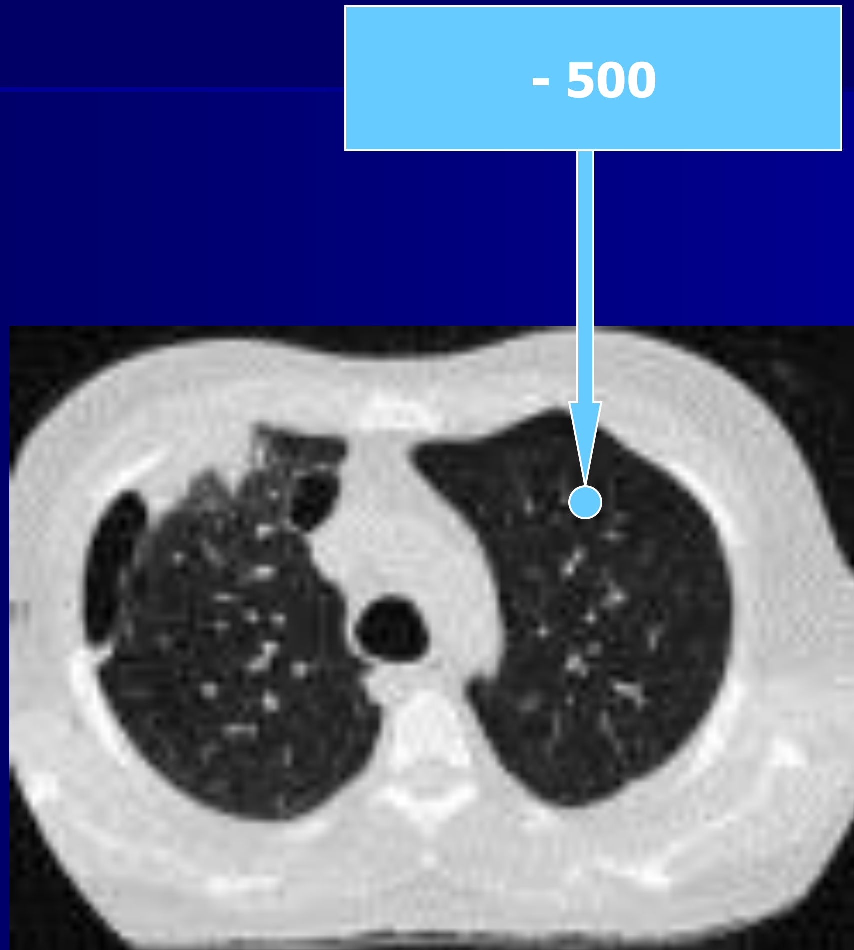
- Air -1024
- Lung ~ -700
- Fat ~ - 120 to ~ -80
- Water 0 +/- 5
- Brain ~ 40
- Soft Tissue ~ 40 to ~ 100
- Bone 200 to > 600
- Metal > 1000



CT

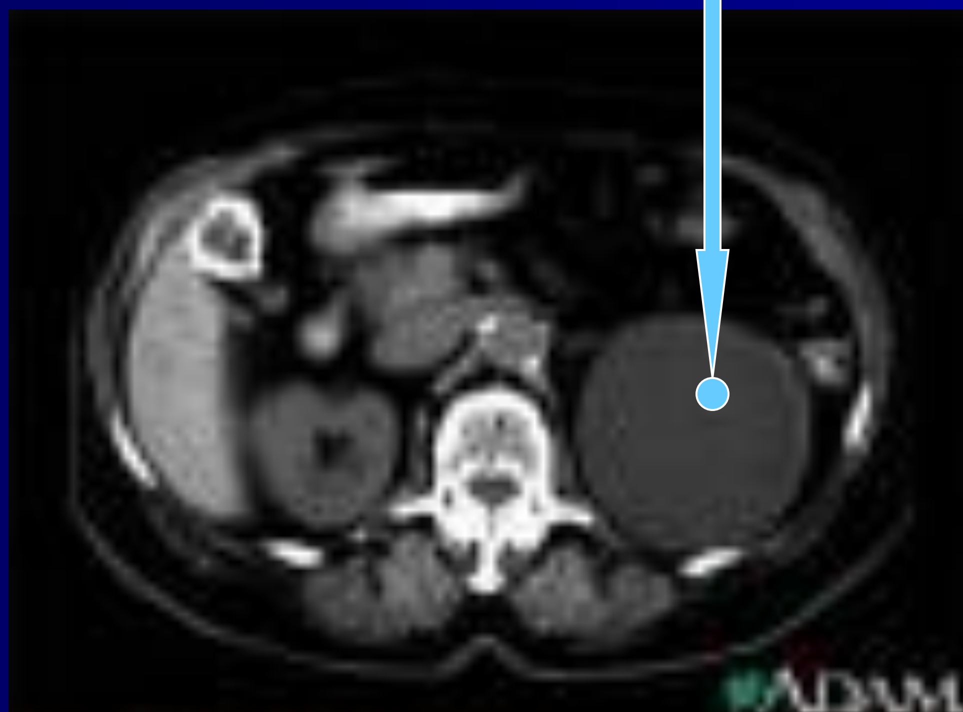


CT

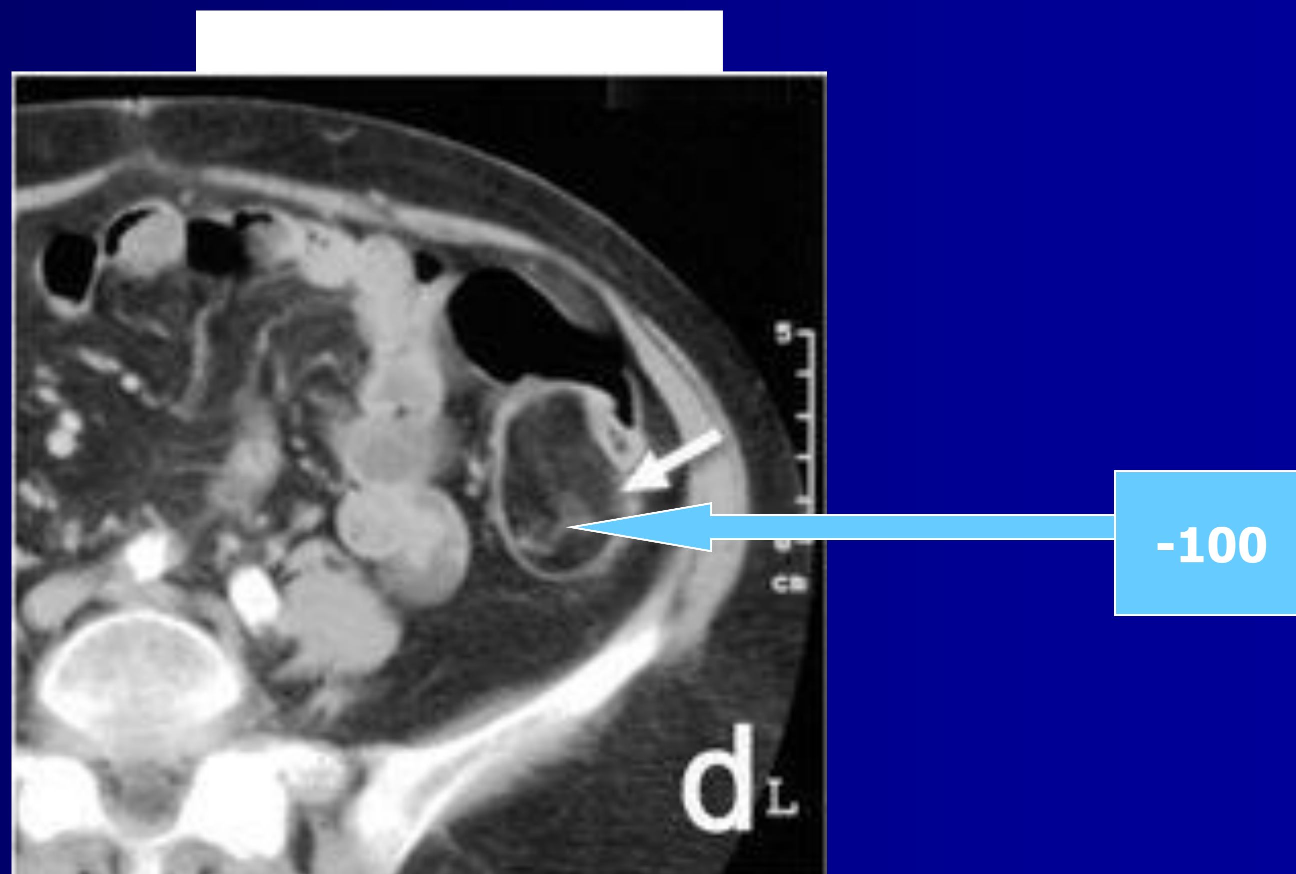


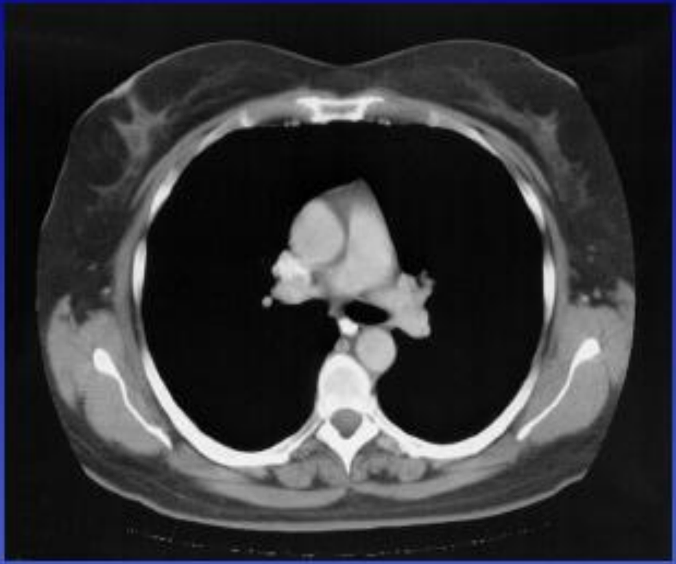
CT # OF CYST

5



CT # OF LIPOMA (FATTY TUMOR)

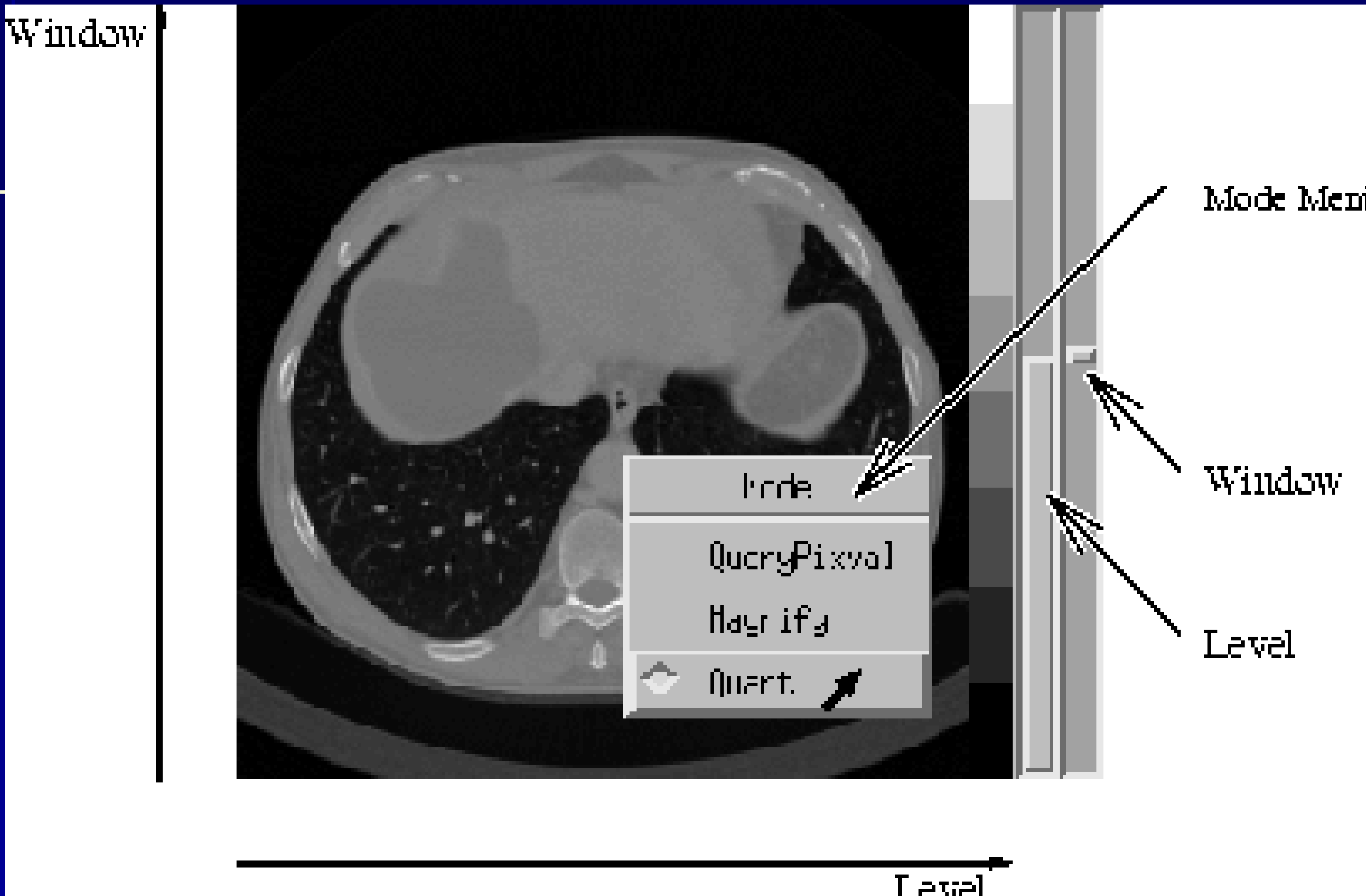


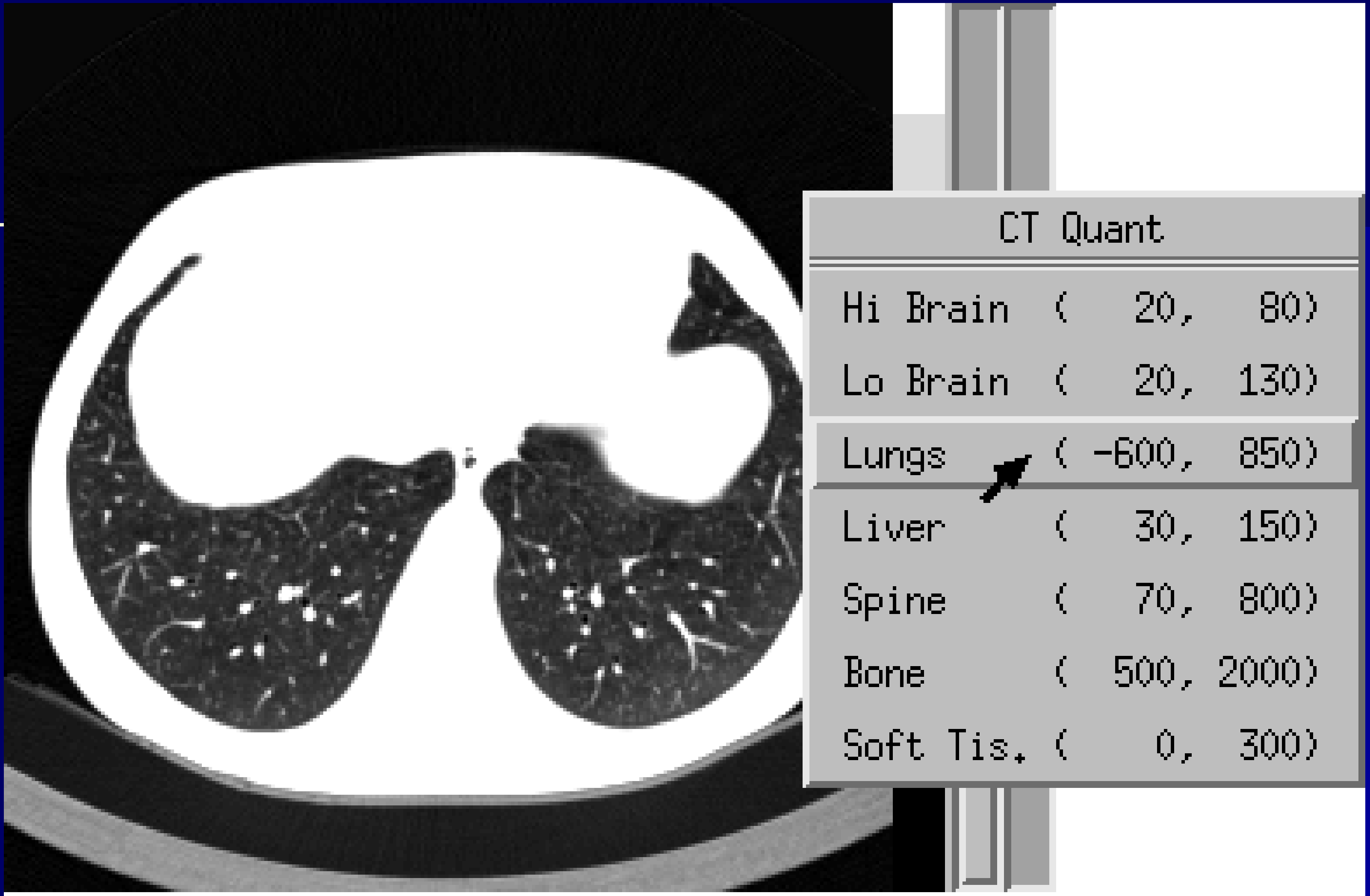


Narrow (high) contrast

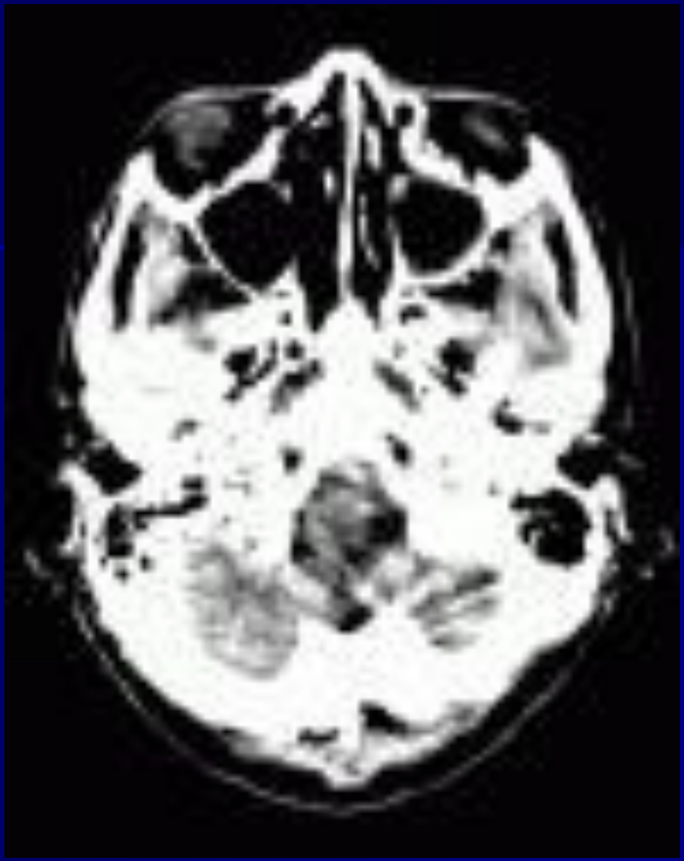
Wide (low) contrast

- Window width (WW)
  - Range of CT numbers displayed as shades of gray
  - Controls image **contrast**
- Window level (WL) or window center
  - Determines CT number to be in the center of window width
  - Controls image **density**


Window
Mode Men
Window
Level
Level

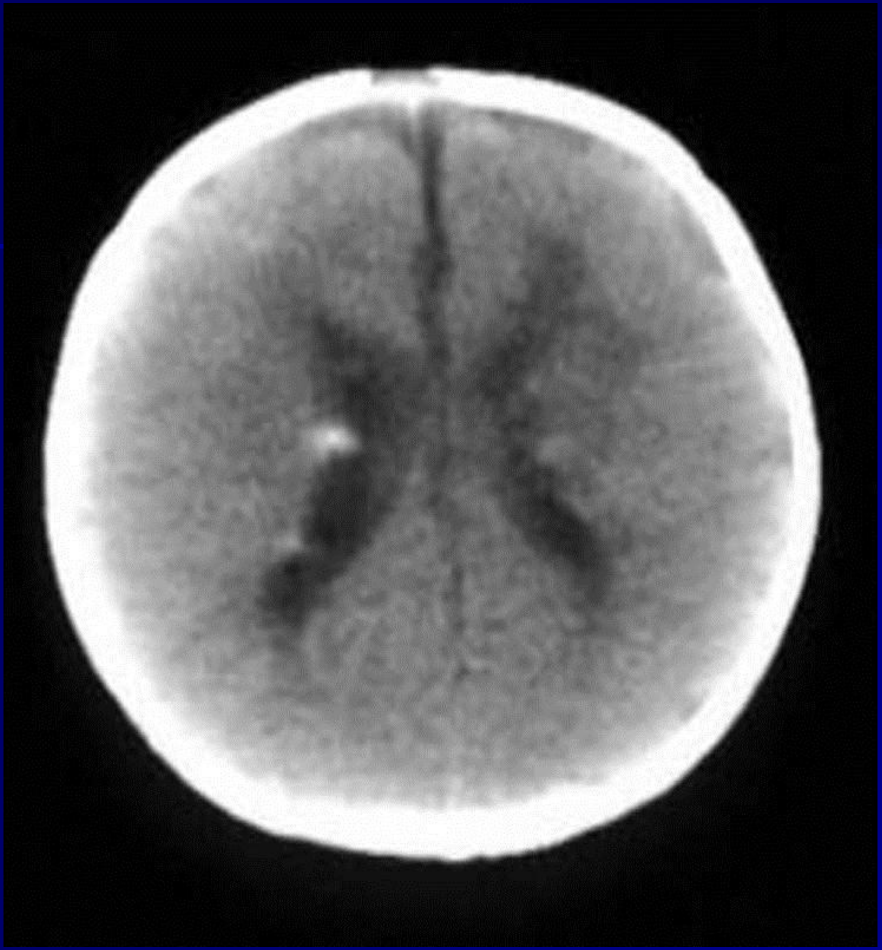


(Einstellung auf den Bereich Lunge)



W 120

L 40



W 80
L 40