COMPUTED TOMOGRAPHY (I)
Basic Principles of CT

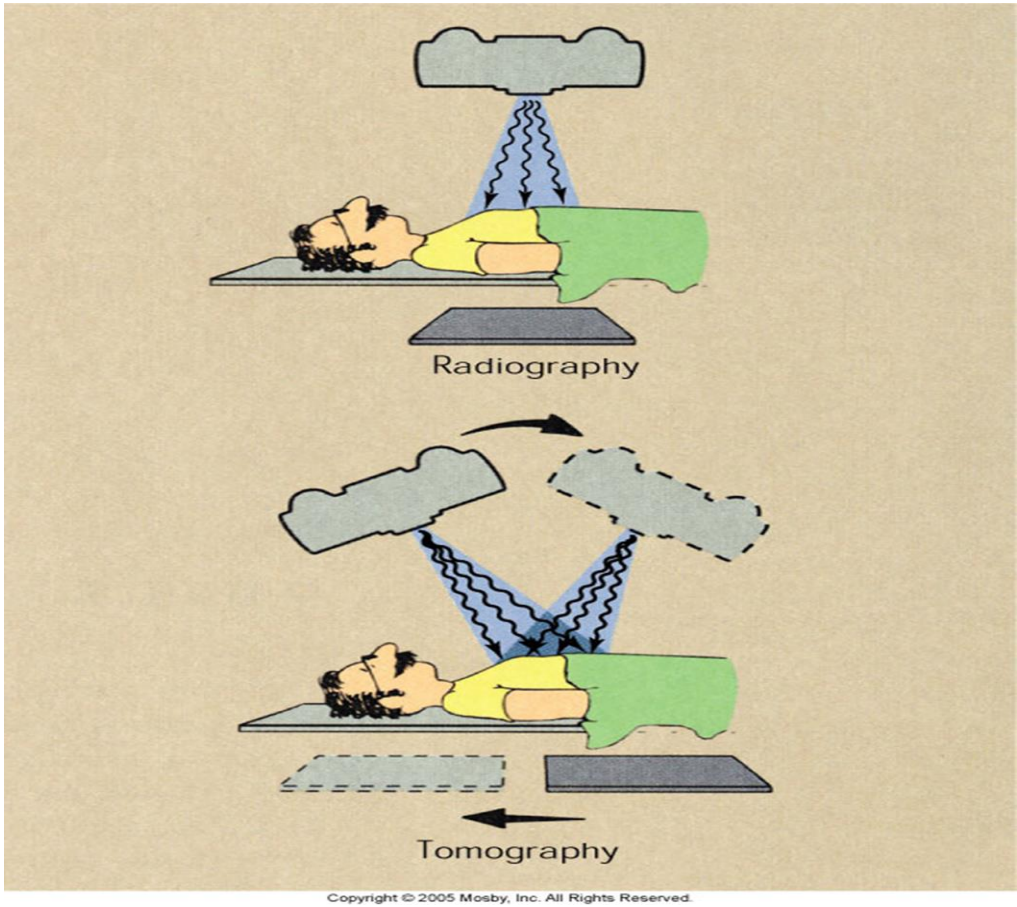
- Prepared By: Ahmed Jasem Abass
  MSC Medical Imaging

History

- ● CT scanners were first introduced in 1971 with a single detector for brain study under the leadership of Sir Godfrey Hounsfield, an electrical engineer at EMI (Electric and Musical Industries Ltd). After that, it has undergone multiple improvements, with an increase in the number of detectors and a decrease in the scan time.
- ● 1974 - first 3rd generation CT.
- ● 1979 - Nobel price (Cormack & Hounsfield).
- ● 1989 - single-row CT.
- ● 1994 - double-row spiral CT.
- ● 2001 - 16-row spiral CT.
- ● 2007 - 320-row spiral CT.

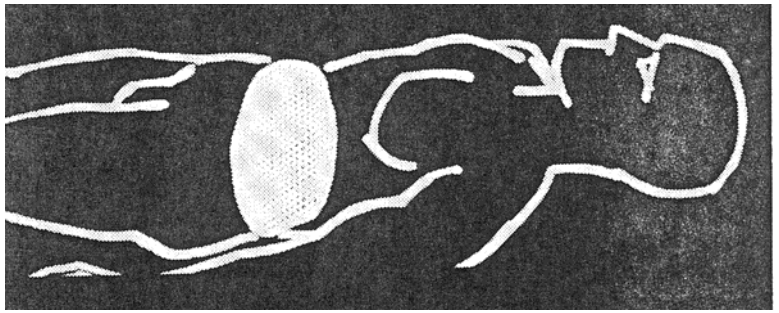
COMPUTED TOMOGRAPHY

- In conventional X-ray imaging, the entire thickness of the body is projected on a film:structures overlap and are difficult to distinguish). One of the problems is the loss of information about depth.
- It is a non-invasive medical imaging modality that combines the use of X-rays and computer processing to generate tomographic (‘slices’) of the area scanned.
- Tomography
- Tomos = slice; Graphein = to write
- Definition - imaging of an object by analyzing its slices.
- A CT Scanner is
- CAT: Computerized Axial Tomography
- Spiral CT.
- Multi-Slice CT or Multi-Detector.

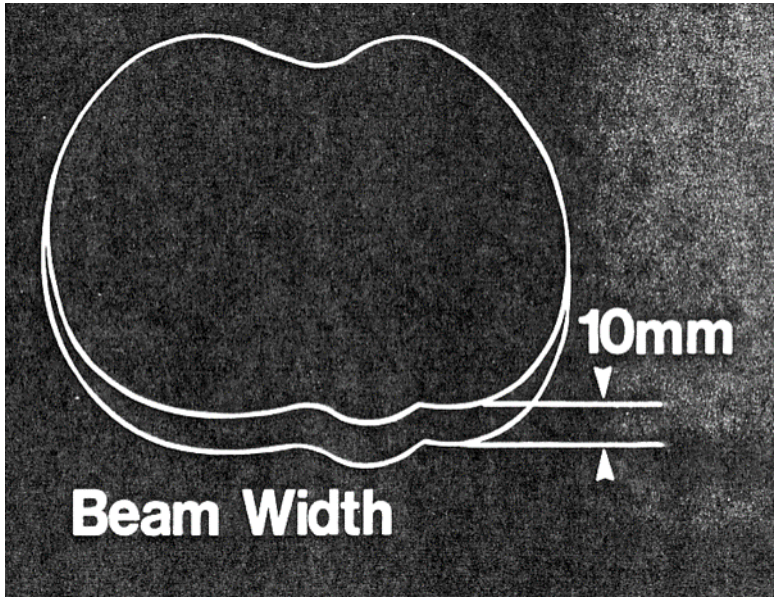


Slice / Cut

- The cross sectional portion of the body which is scanned for the production of CT image is called a slice.



- The slice has width and therefore volume.
- The width is determined by the width of the x-ray beam

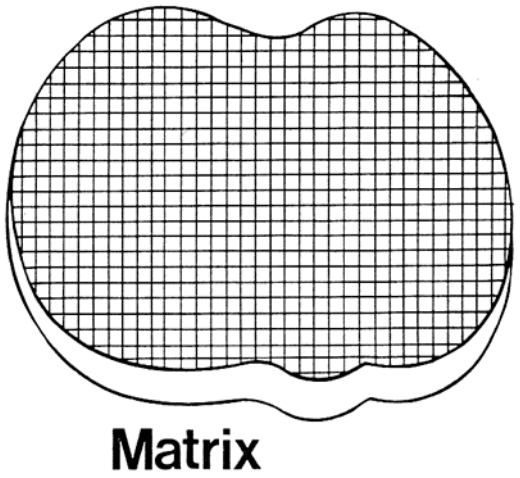


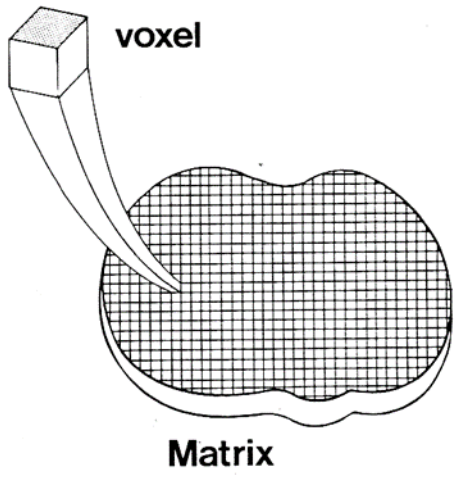
CT Imaging

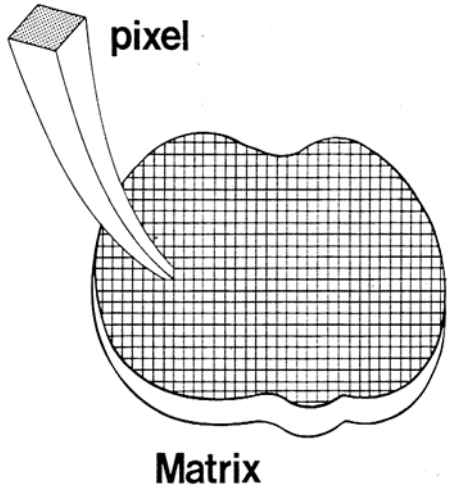
- Goal of x-ray CT is to reconstruct an image whose signal intensity at every point in region imaged is proportional to $\mu(x, y, z)$, where μ is linear attenuation coefficient for x-rays.
- In practice, μ is a function of x-ray energy as well as position and this introduces a number of complications that we will not investigate here.
- X-ray CT is now a mature (though still rapidly developing) technology and a vital component of hospital diagnosis.

Matrix

- The image is represented as a MATRIX of numbers.
- Matrix: A two dimensional array of numbers arranged in rows and columns.
- Each individual element or number in the image matrix represents a three dimensional volume element in the object, called a VOXEL.
- The VOXEL is represented in the image as a two-dimensional element called PIXEL - (picture element).
- Field of view (FOV) is the diameter of the body region area being imaged (e.g., 25 cm for a head or 40 cm for an abdomen).
- CT pixel size is determined by dividing the FOV by the matrix size, which is generally 512 x 512 in CT.



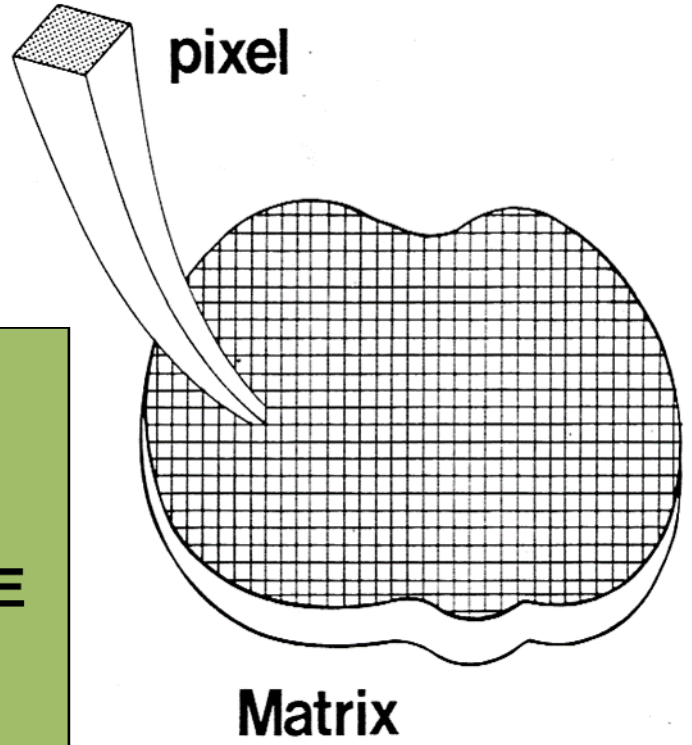




Pixel Size

- The Voxel is represented in the image as a two-dimensional element called Pixel - (picture element
- PIXEL SIZE

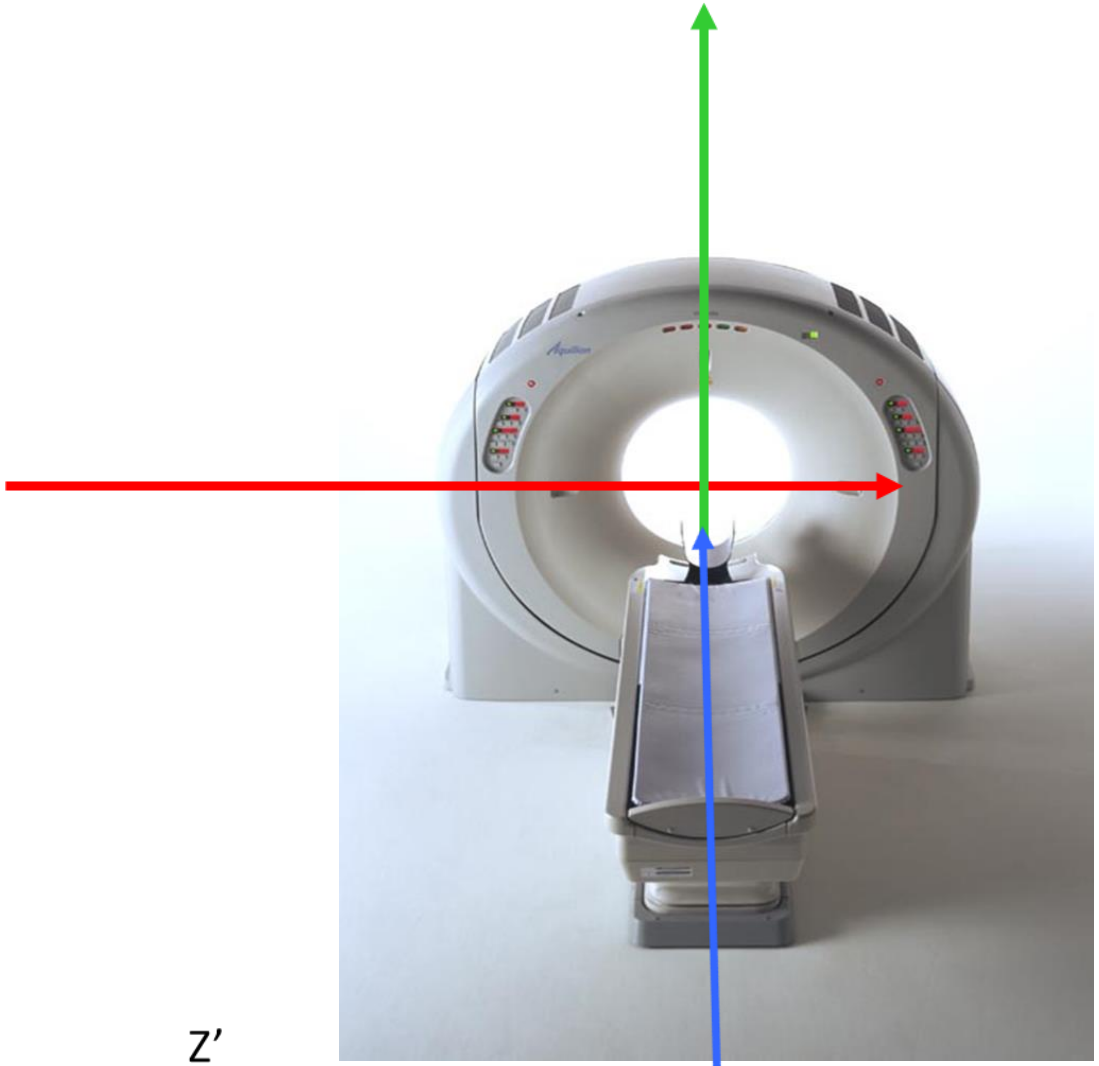
PIXEL SIZE= DFOV (mm)/ MATRIX SIZE



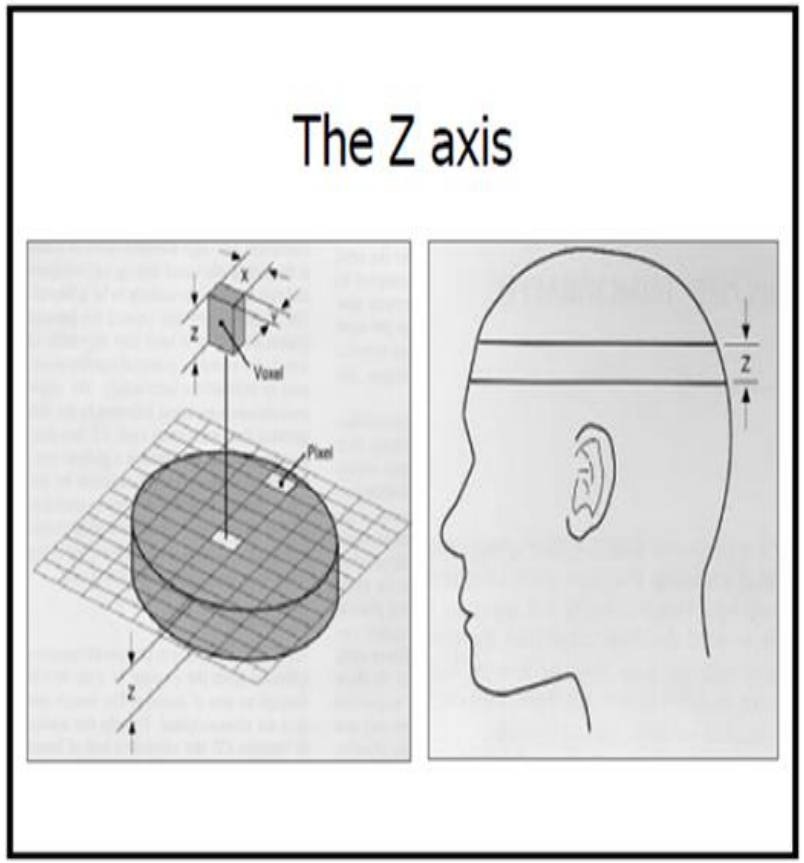
CT ‘X’ Axis

‘Y’
Axis

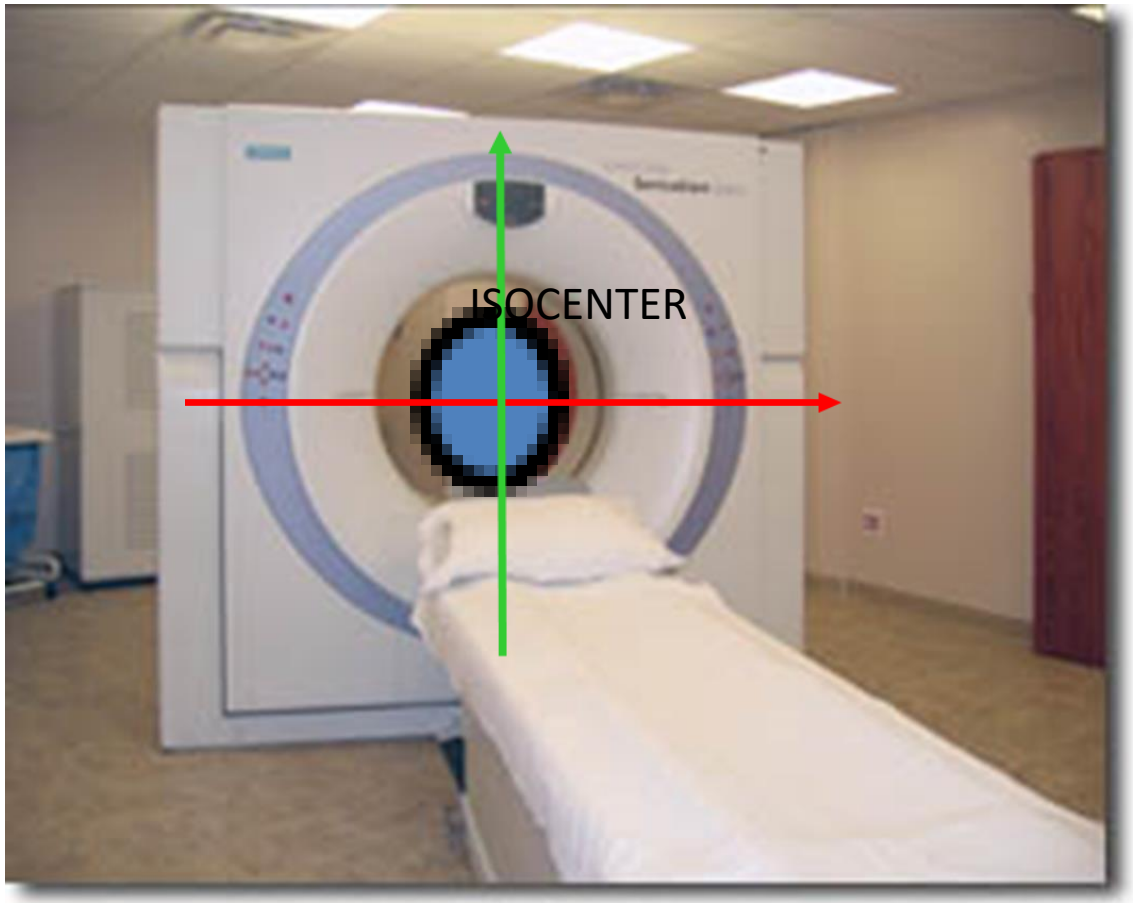
‘X’
Axis



Z’
Axis

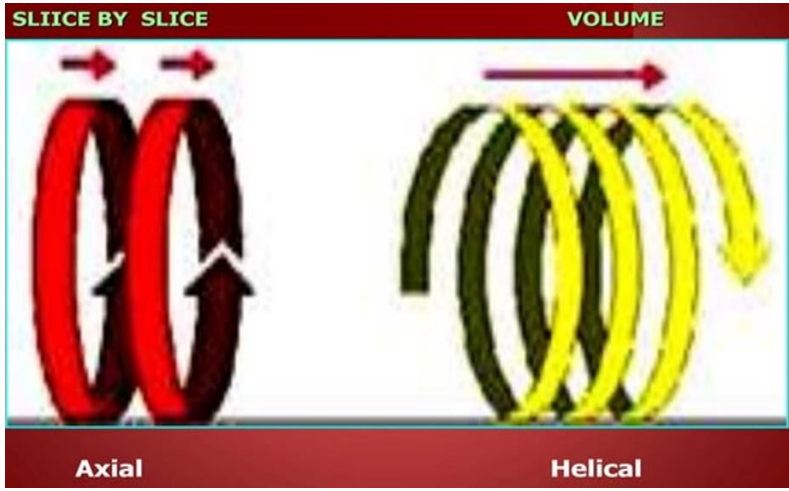


Isocenter



Axial Scan and Spiral

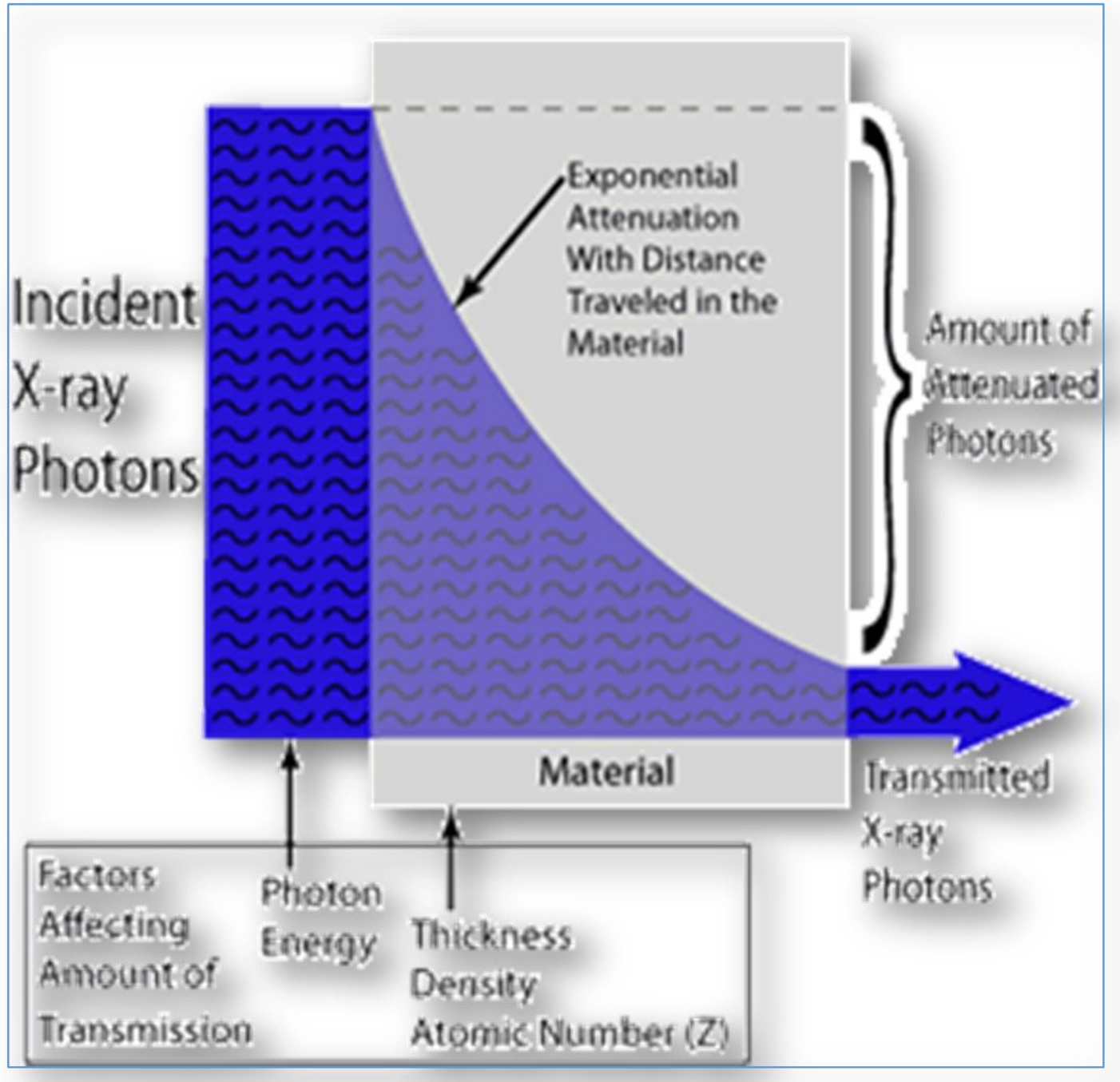
- TABLE STOPS AT THE SCANNING POSITION AND THE TUBE ROTATES AROUND A PATIENT.
- SPIRAL :PATIENT CONTINUOUSLY MOVES IN THE Z-AXIS DIRECTION WHILE THE TUBE ROTATES AROUND.



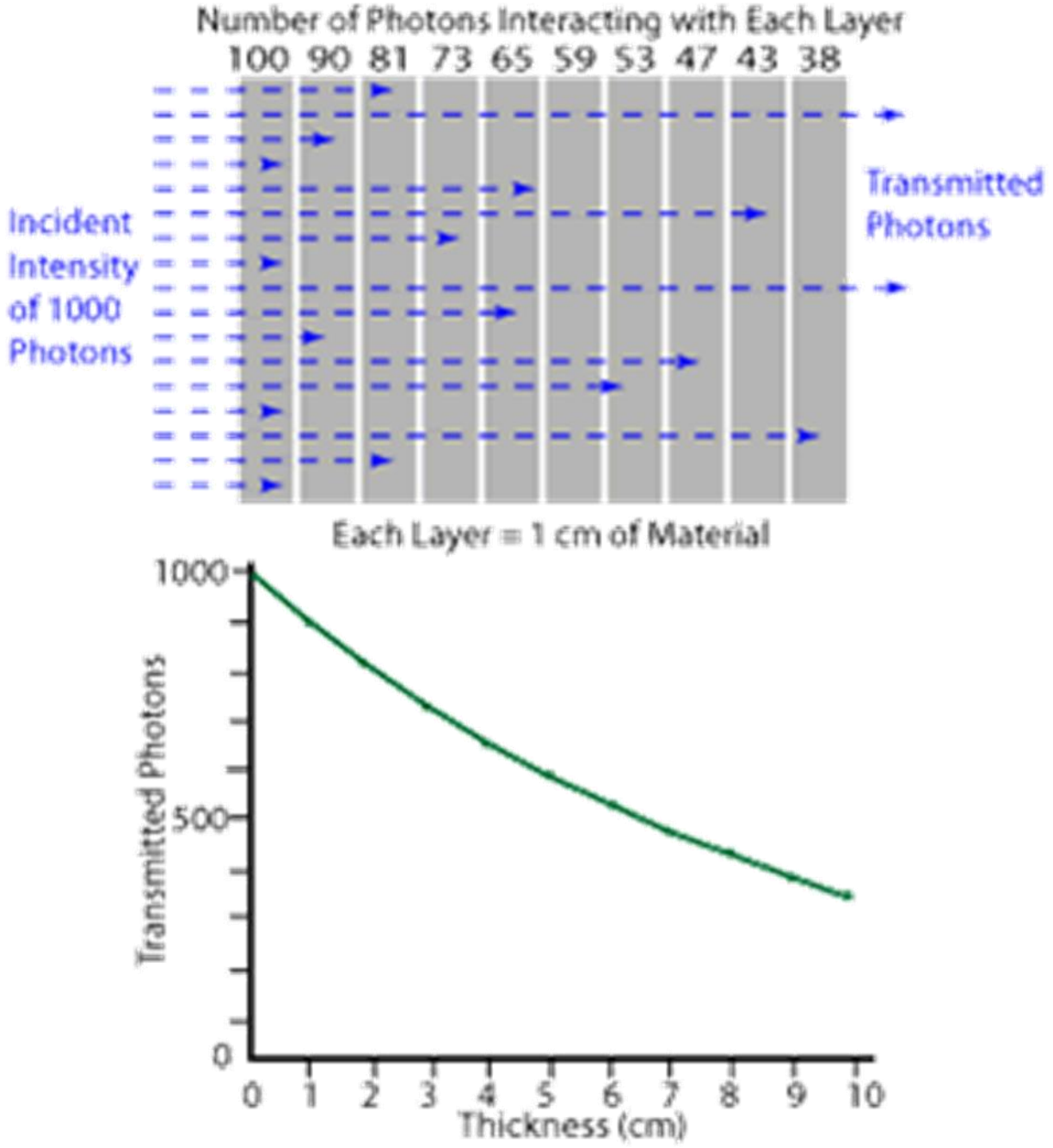
Interaction Between Penetrating Radiation and Matter

- When x-rays are directed into an object, some of the photons interact with the particles of the matter and their energy can be absorbed or scattered.
- This absorption and scattering is called attenuation.
- Other photons travel completely through the object without interacting with any of the material's particles.

- The number of photons transmitted through a material depends on the:
- 1. Thickness.
- 2. Density.
- 3. Atomic Number of the Material.
- 4. Energy of the Individual Photons.
- 5. The number of photons reaching a specific point within the matter decreases exponentially with distance traveled.


Incident
X-ray
Photons
Exponential
Attenuation
With Distance
Traveled in the
Material
Amount of
Attenuated
Photons
Material
Transmitted
X-ray
Photons
Factors
Affecting
Amount of
Transmission
Photon
Energy
Thickness
Density
Atomic Number (Z)

As shown in the graphic, if 1000 photons are aimed at ten 1 cm layers of a material and there is a 10% chance of a photon being attenuated in this layer, then there will be 100 photons attenuated. This leave 900 photos to travel into the next layer where 10% of these photos will be attenuated. By continuing this progression, the exponential shape of the curve becomes apparent.



The formula that describes this curve is:

$$I = I_0 e^{-\mu x}$$

The factor that indicates how much attenuation will take place per cm (10% in this example) is known as the linear attenuation coefficient, m.

Where:
I = the intensity of photons transmitted across some distance x
I0 = the initial intensity of photons
s = a proportionality constant that reflects the total probability of a photon being scattered or absorbed
μ = the linear attenuation coefficient
x = distance traveled

The Linear Attenuation Coefficient (μ)

The linear attenuation coefficient (μ) describes the fraction of a beam of x-rays that is absorbed or scattered per unit thickness of the absorber.

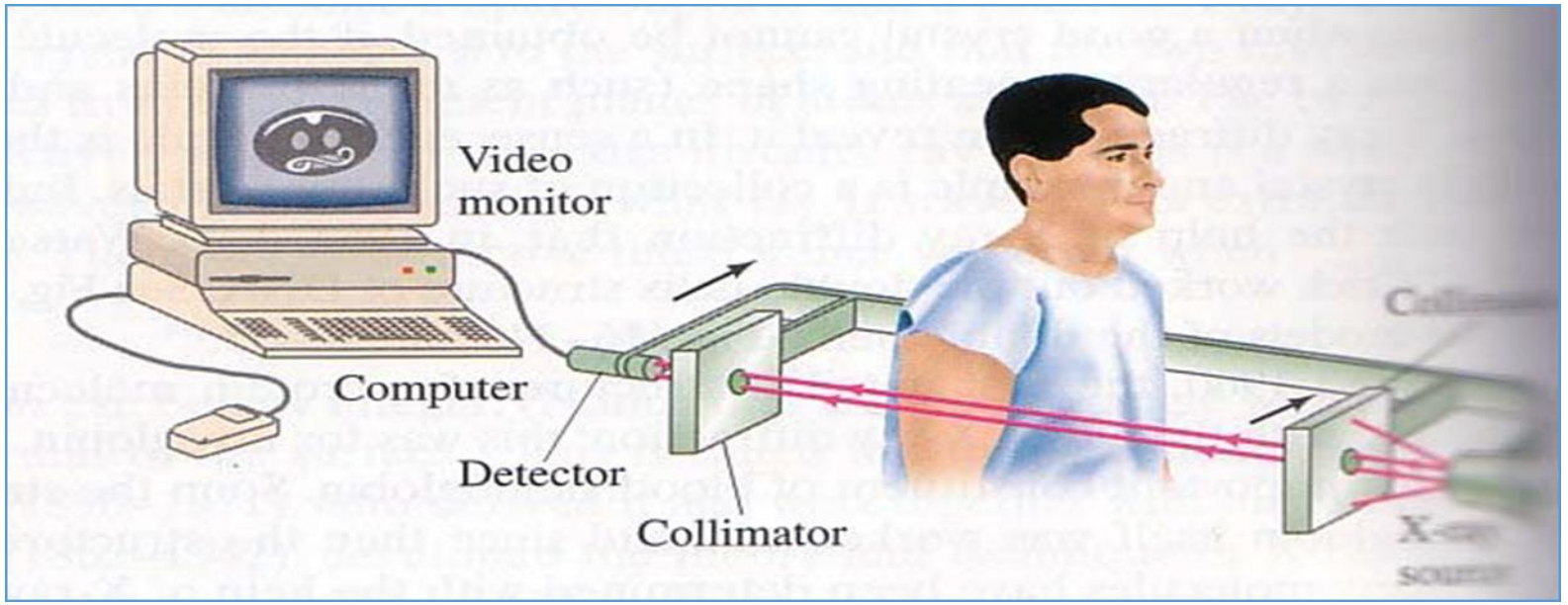
CT images are a display of the amount of attenuation that has occurred when the X-ray beam penetrates the body - this is known as the linear attenuation coefficient. The density measurement of this attenuated beam is assigned a CT number (Hounsfield Units) which are related to this linear attenuation coefficient. The selection of kVp has a direct effect on these linear coefficients values.

What is attenuation on CT?

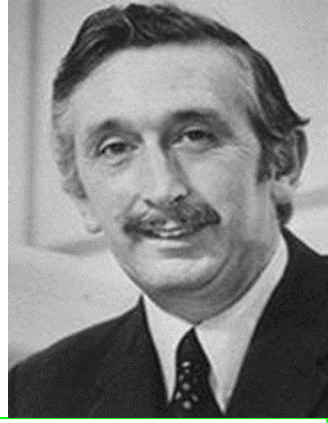
- Attenuation is the measurement of energy absorbed and deflected as it passes through a medium. In simpler terms, attenuation is how much stopping power a material has on energy.
- CT is basically a specialized X-Ray
- We talk about “density” or “attenuation”
- The image is a measure of absorption of X-rays through different angles through a given tissue and then transformed mathematically

How is the image formed?

- We can think of the slice to be imaged as being divided into many tiny picture elements or pixels, which could be squares. For CT, the width of each pixel is chosen according to the width of the detectors and/or the width of the X-ray beams.
- An X-ray detector measures the intensity of the transmitted beam after it has passed through the body. Subtracting this value from the intensity of the beam at the source, we get the total absorption. To form an image, we need to determine how much radiation is absorbed at each pixel. We can then assign a 'grayness value' to each pixel according to how much radiation was absorbed. The image, then, is made up of tiny spots (pixels) of varying shades of grey, as is a black-and-white television picture.

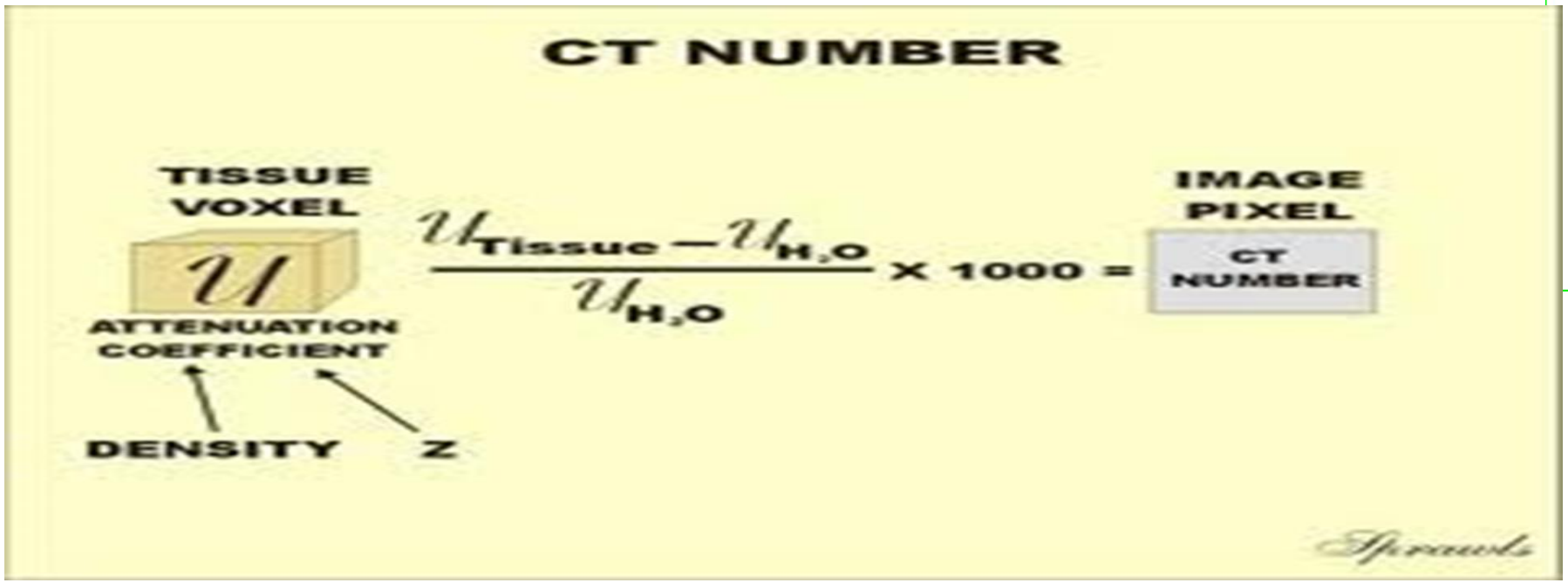


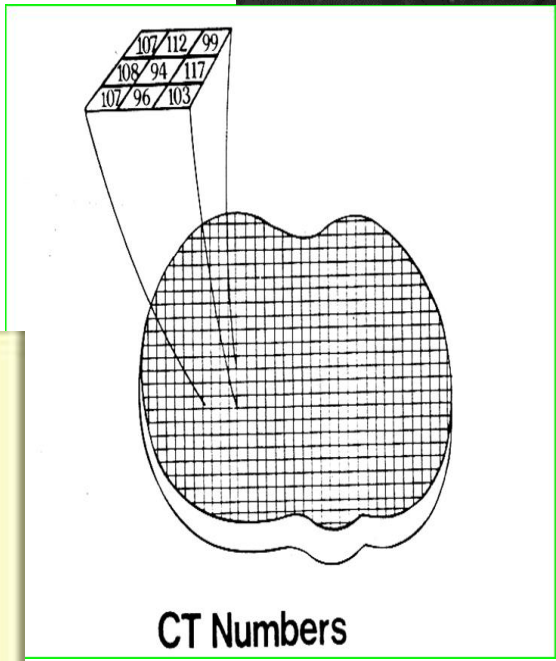
CT numbers



- The numbers in the image matrix are called CT numbers.

- Each pixel has a number which represents the x-ray attenuation in the corresponding voxel of the object





CT number for water can calculated

$$CT_{water} = \frac{\mu_{water} - \mu_{water}}{\mu_{water}} \cdot K$$

$$= \frac{0.19 - 0.19}{0.19} \cdot 1000$$

$$= \frac{0}{0.19} \cdot 1000$$

$$= 0$$

Thus the CT number for water is 0.

Hounsfield units represent logarithmic scale of CT density.

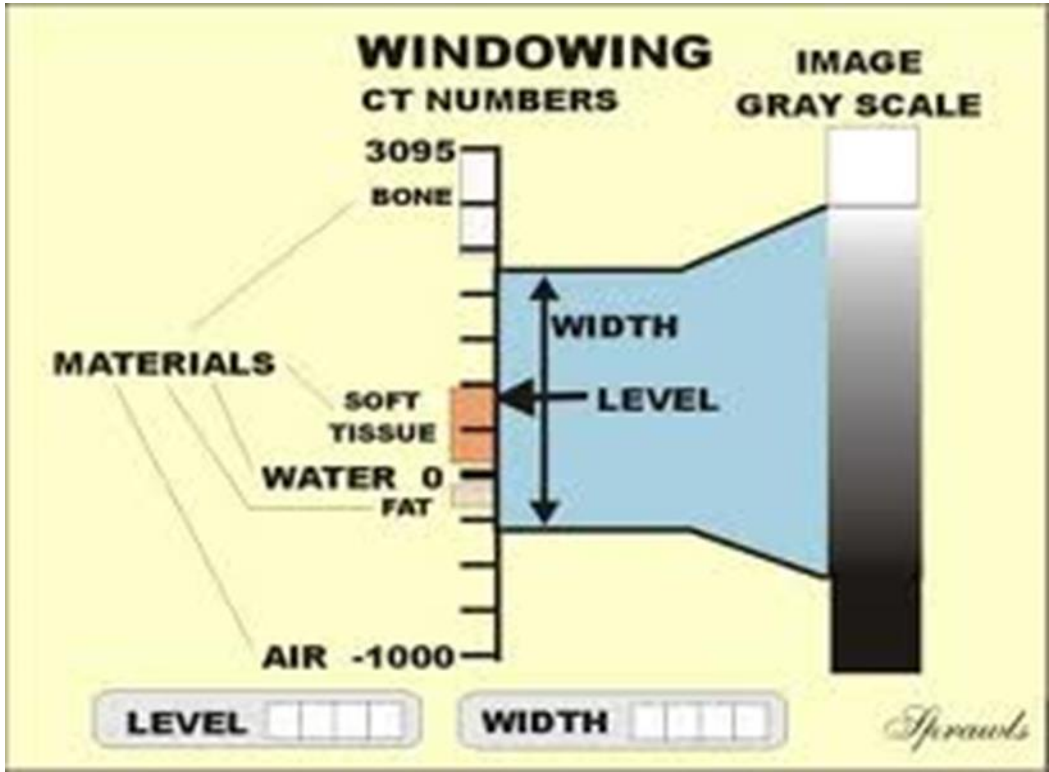
DESCRIPTION	Approx. HU	DENSITY
Calcium	> 1000	Hyperdense
Acute blood	60-80	Hyperdense
Grey matter	38 (32-42)	Hyperdense
White matter	30 (22-32)	Hyperdense
CSF	0-10	ISODENSE
Fat	-30 to - 100	Hypodense
Air	- 1000	Hypodense

Windowing

- Selective display of a restricted range of gray scale of selected tissues (tissues of interest).
- Tissues with CT no outside this window un displayed.
- Manipulated by selection of :

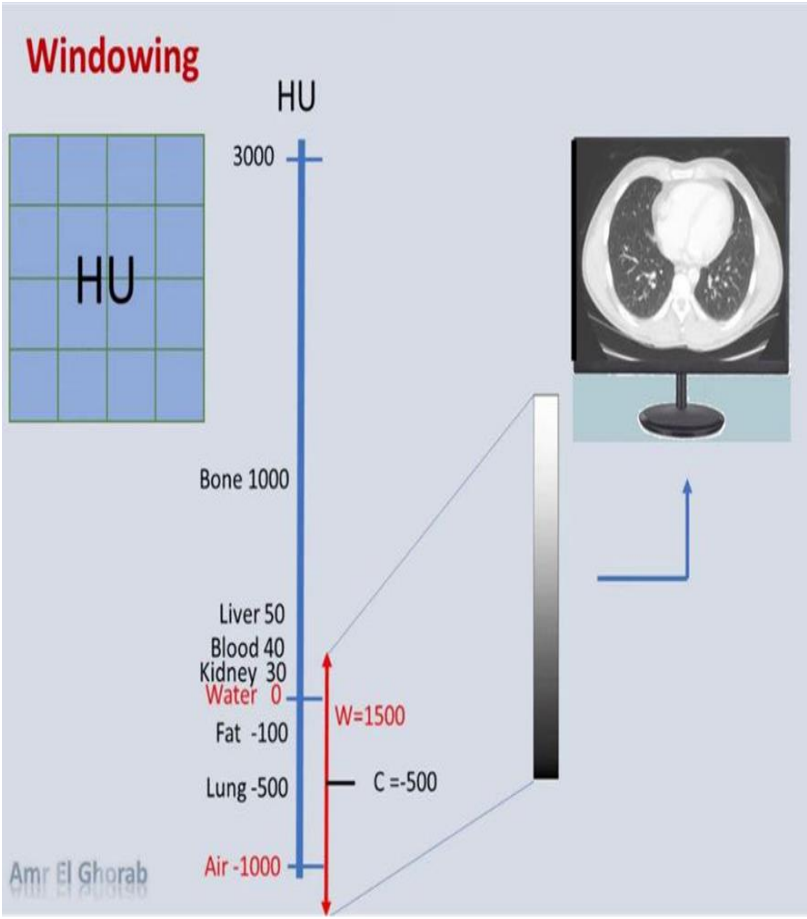
- window center.

- window width



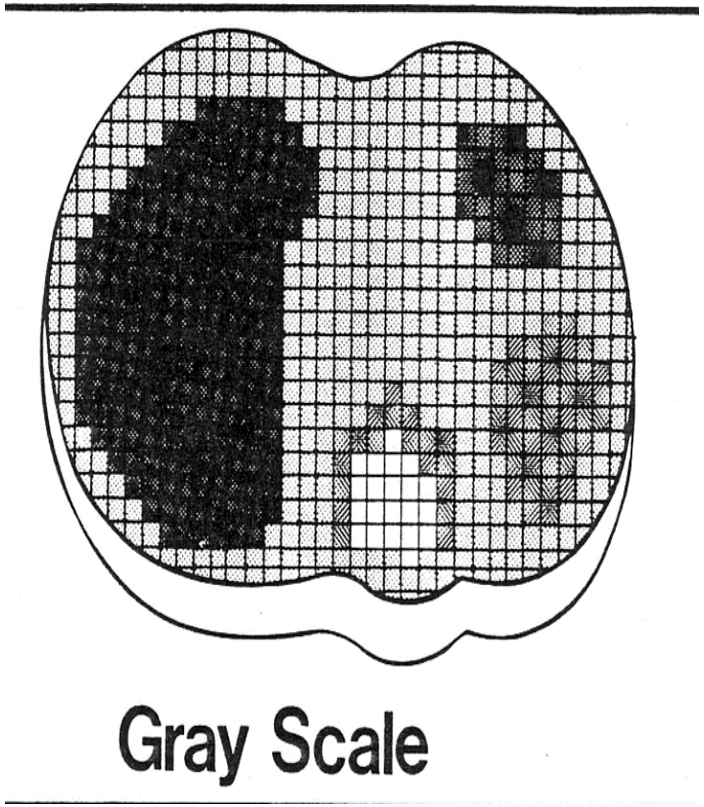
Windowing

- Window level is CT number selected for centre of the range of numbers displayed on the image.
- Window width is total range of values selected.
- Width determines contrast.
- A narrow window enhances inherent contrast.
- Window level determines the brightness



Visual image & Gray Scale

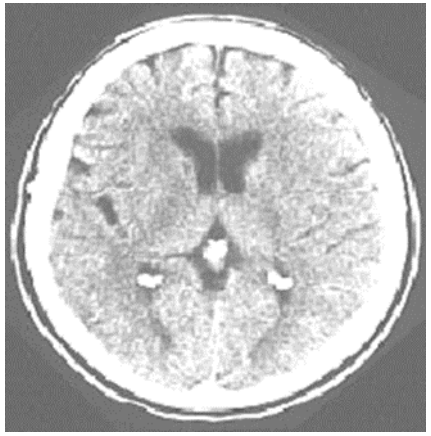
- To obtain a visual image, the CT numbers are assigned different shades of gray on a gray scale.
- Each shade of gray represents the x-ray attenuation within the corresponding voxel



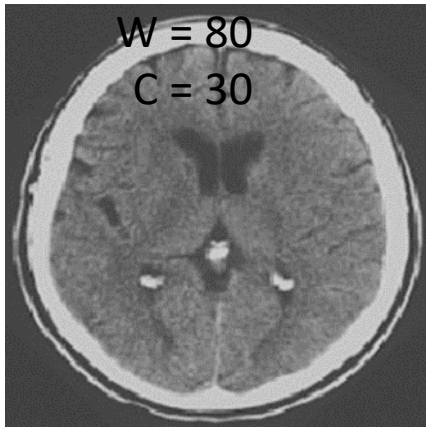
W = 80
C = 40

Centre average gray
<centre lighter gray
>centre darker gray

W = 80
C = 50



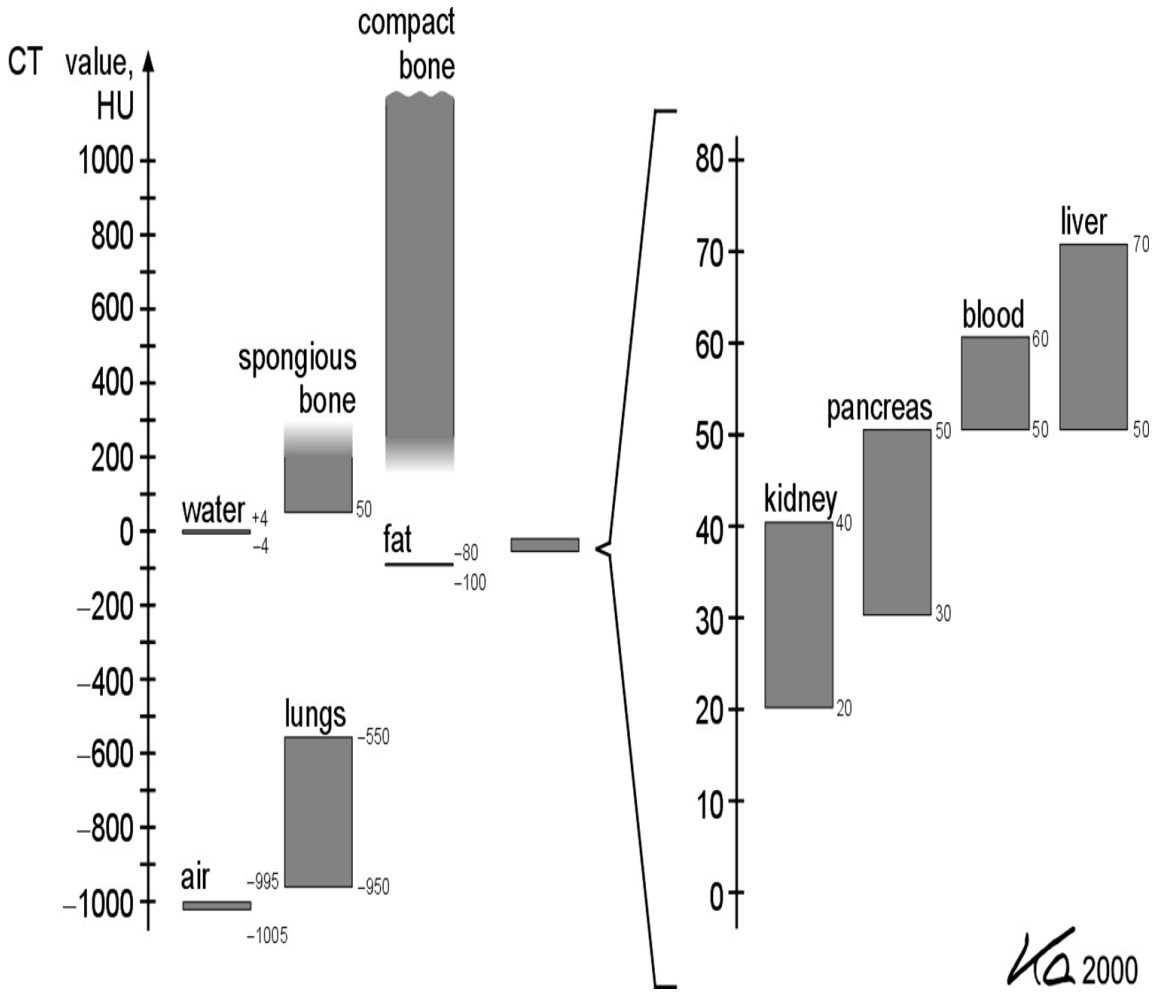
W = 80
C = 20

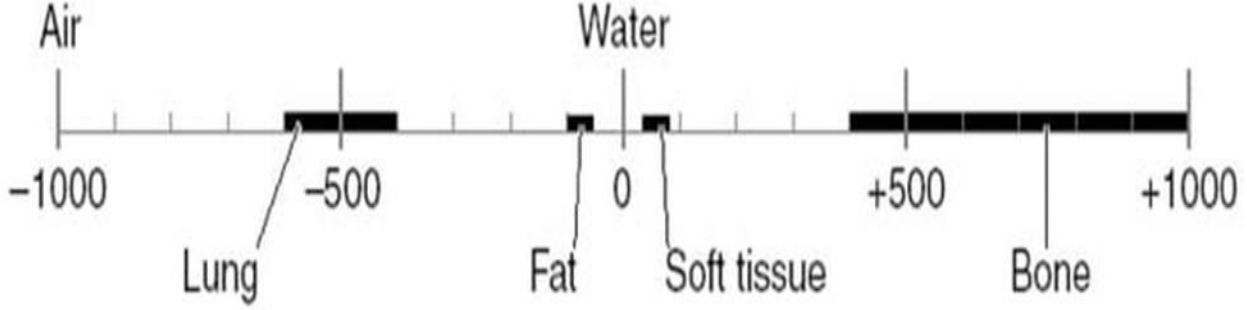


W = 200
C = 30

W = 50
C = 30

Display:Windowing

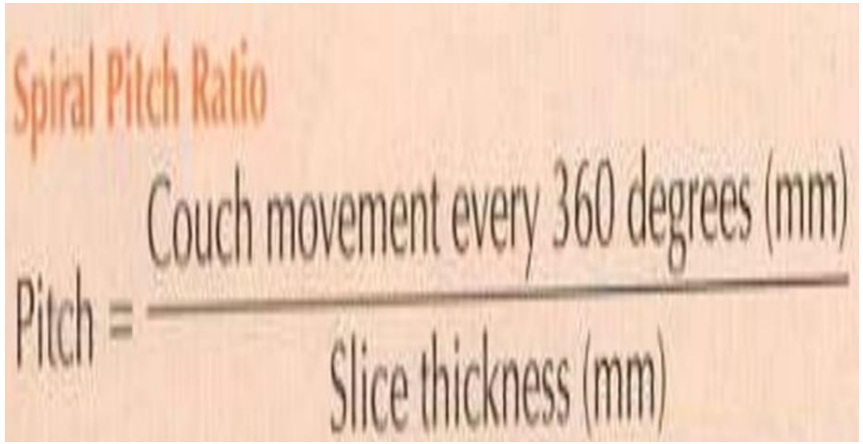


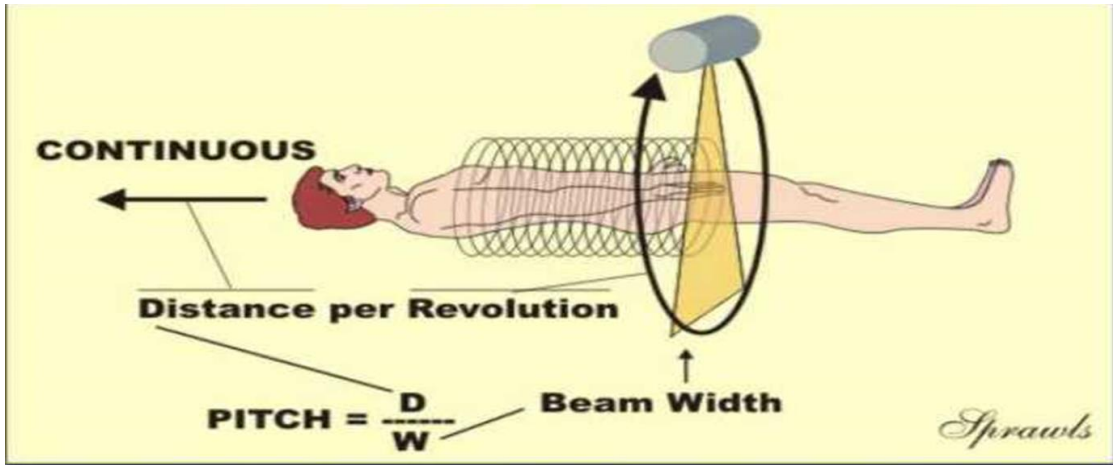


Bone	+400 → +1000
Soft tissue	+40 → +80
Water	0
Fat	−60 → −100
Lung	−400 → −600
Air	−1000

What is pitch?

- Pitch is the distance in millimeters that the table moves during one complete rotation of the X-ray tube, divided by the slice thickness (millimeters).
- Increasing the pitch by increasing the table speed reduces dose and scanning time, but at the cost of decreased image resolution.

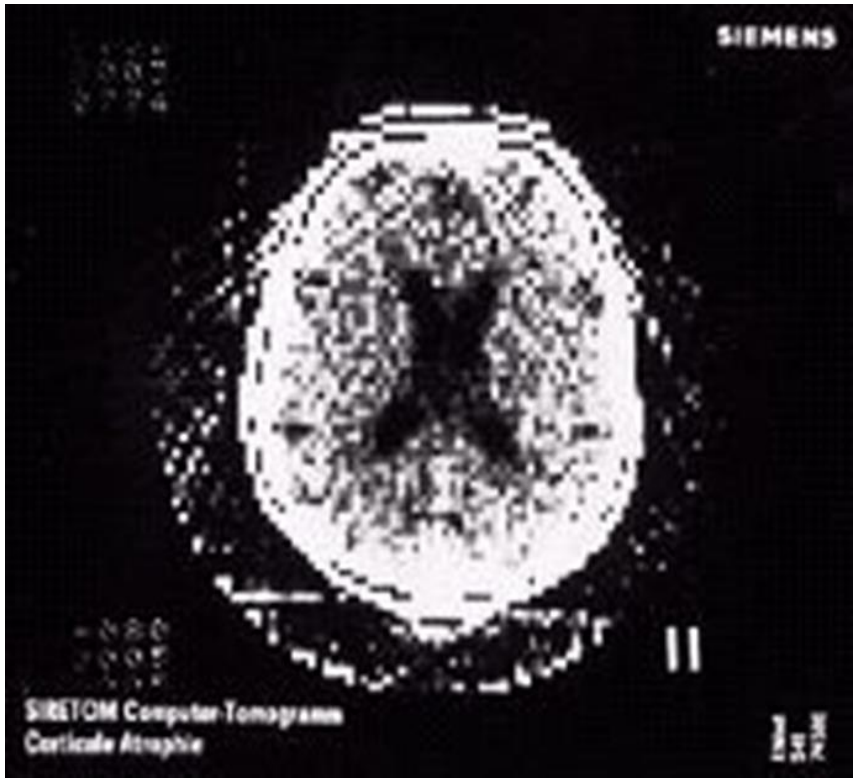




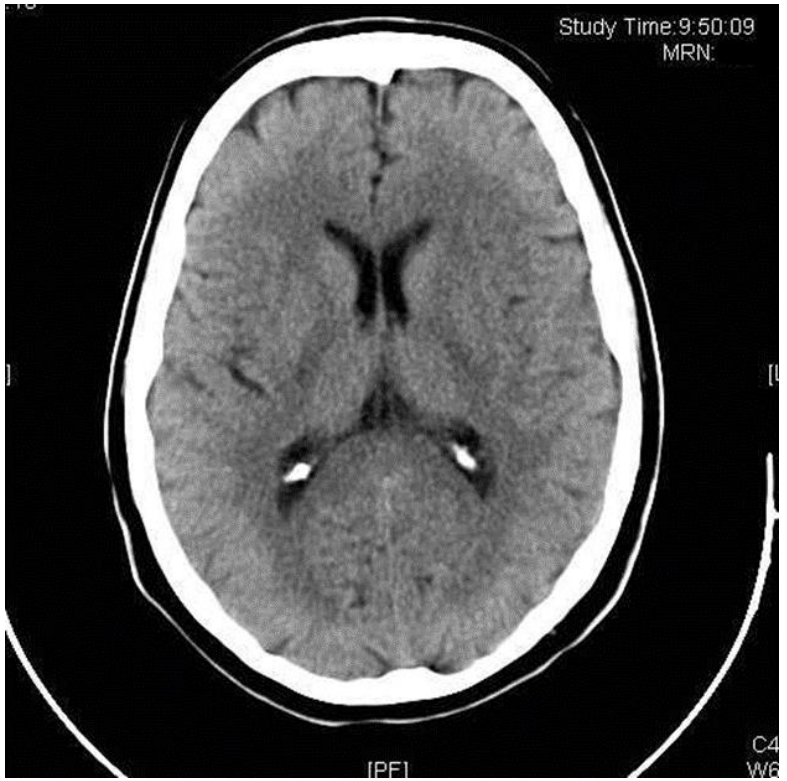
USUALLY MATRIX IS PERMANENTLY SET AT 512 X 512

DIFFERENT MATRICES

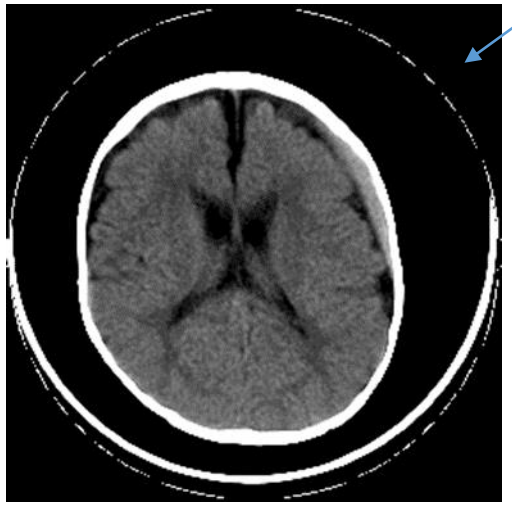
80 X 80 mat

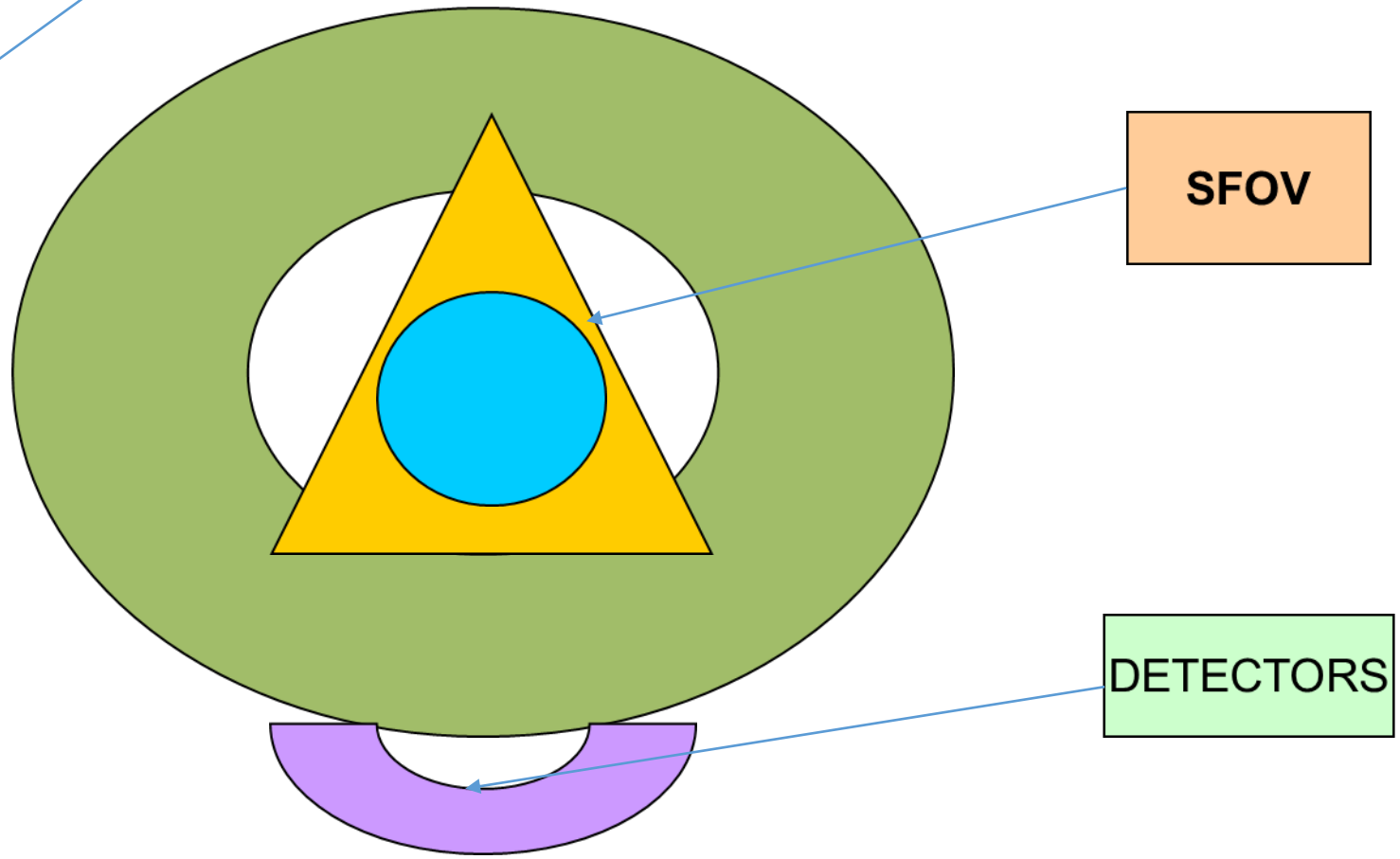


512 X 512

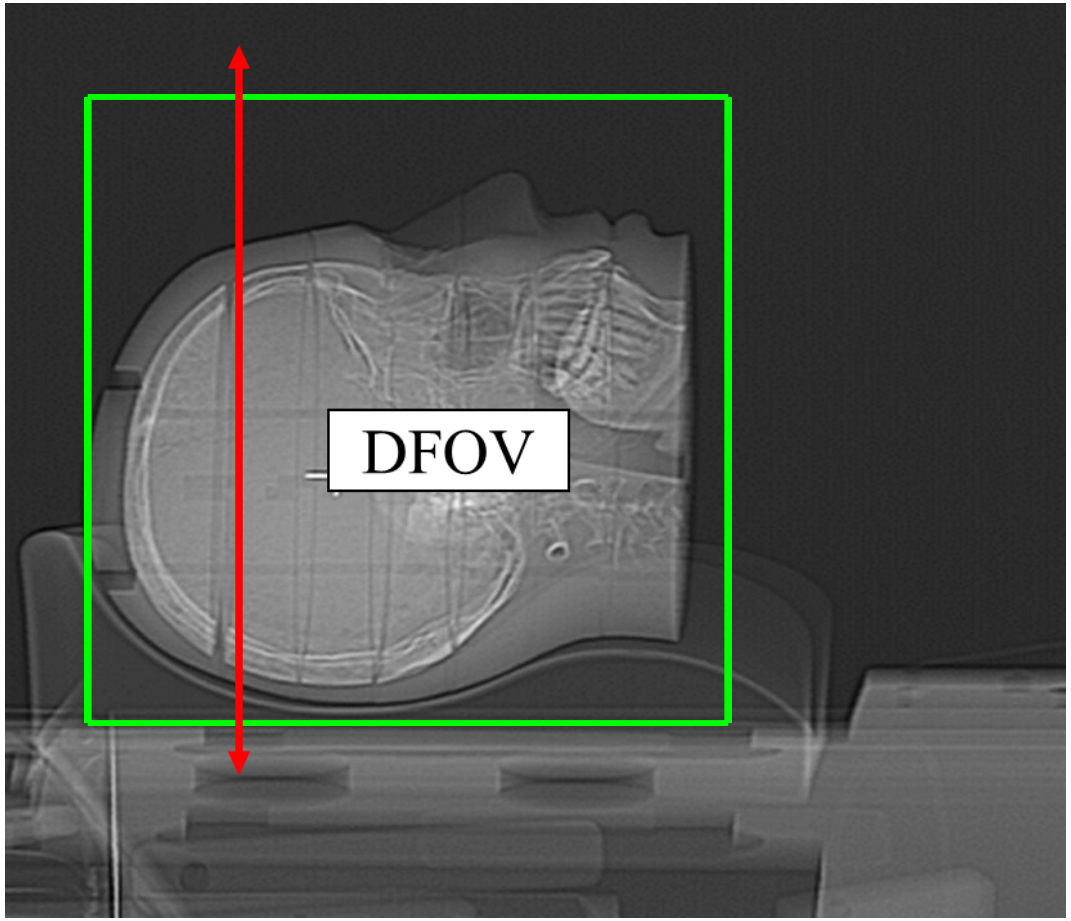


SCAN FOV-DFOV –





Display Field Of View



QUESTIONS

- Define; window level & width?
- What is the CT number of bone, air and water?
- What is the difference between u and CT number of the tissue?