Medical Image System

Computed Tomography 電腦斷層掃描

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FJU-EE

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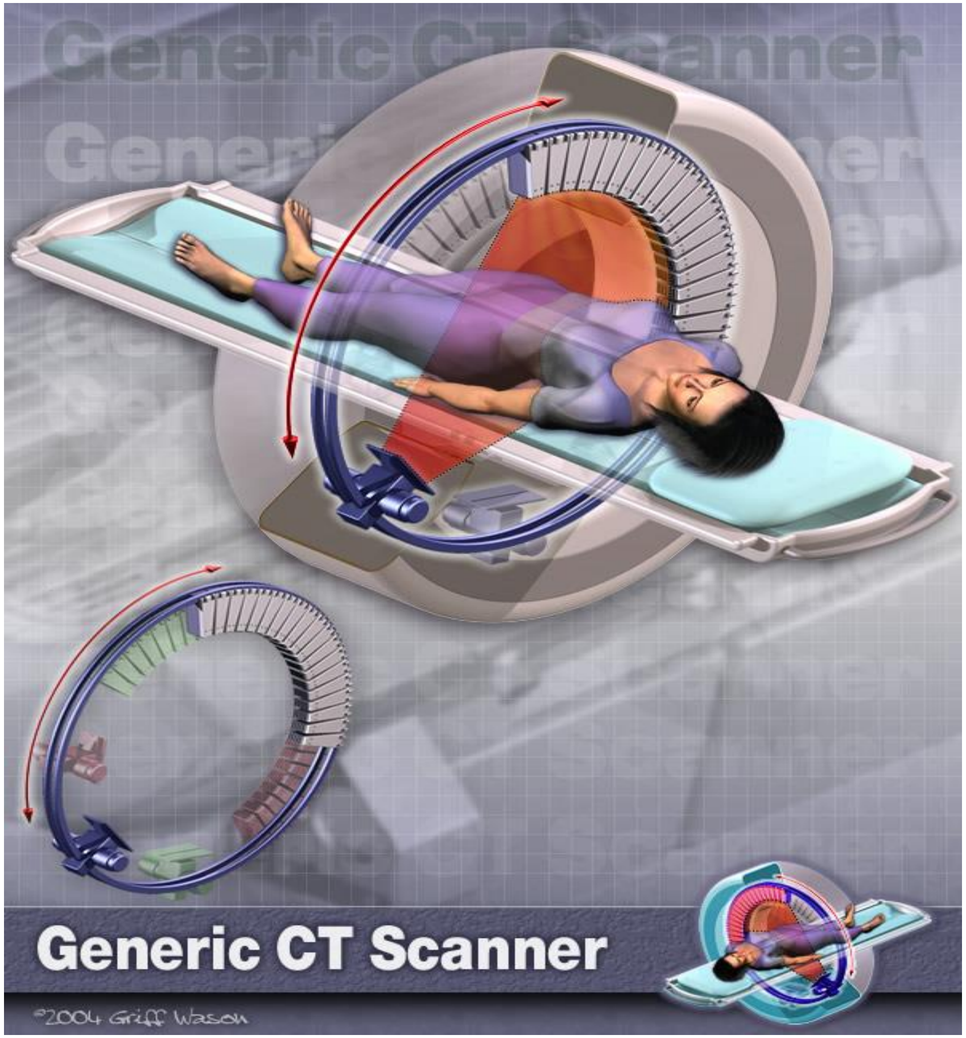
References:

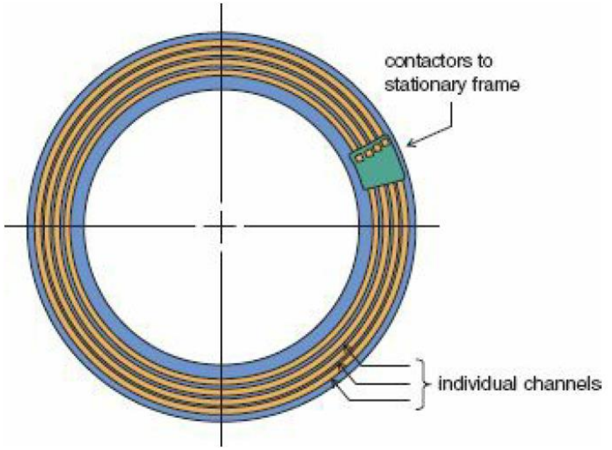
1. The Essential Physics of Medical Imaging, Jerrold T. Bushberg, ISBN-13: 978-0781780575
2. 醫學影像物理學，作者：莊克士，合記圖書出版社
3. Computed Tomography: Basic principles. V.G.Wimalasena. Principal School of Radiography
4. Computed Tomography. Dr. Wm. Hugh Blanton
5. Computed Tomography. Dr. Mohamed El Safwany.

Outline

- **Overview of Computed Tomography (CT)**
- History of Computed Tomography
- Data Acquisition
  - Tube and detector move
  - Multiple attenuation measurements are taken around the object
- Image Reconstruction
- CT Scan Examination

Overview of Computed Tomography



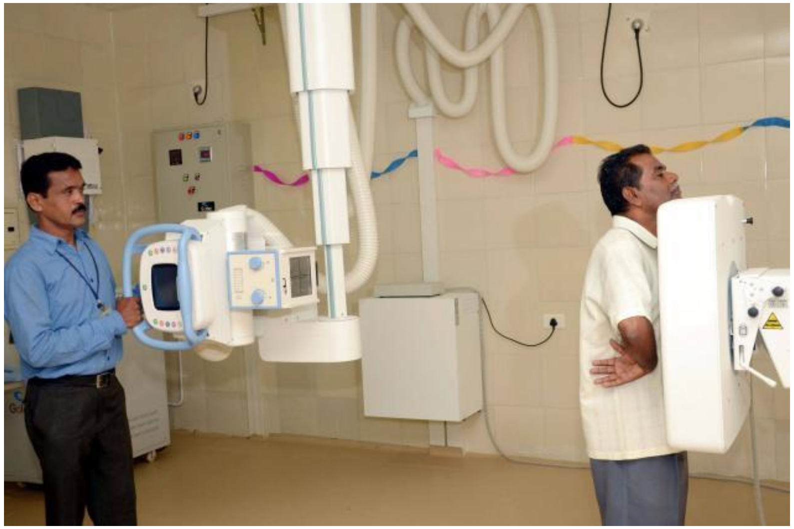


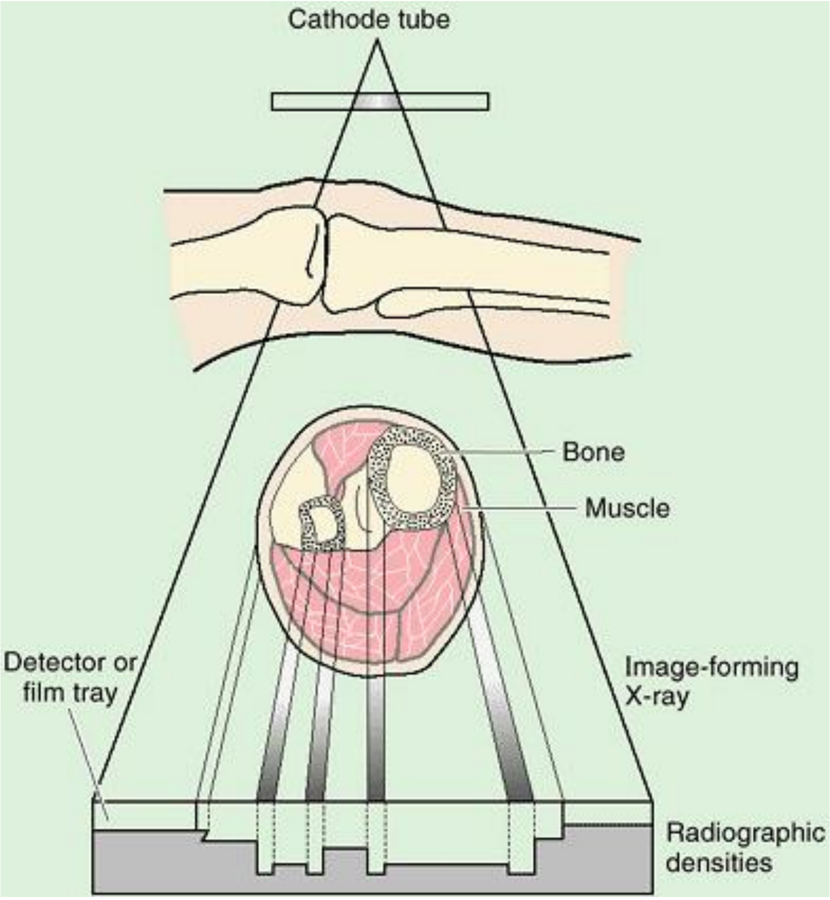
Tutorial for CT Scan

Philips Medical Systems "Brilliance iCT"

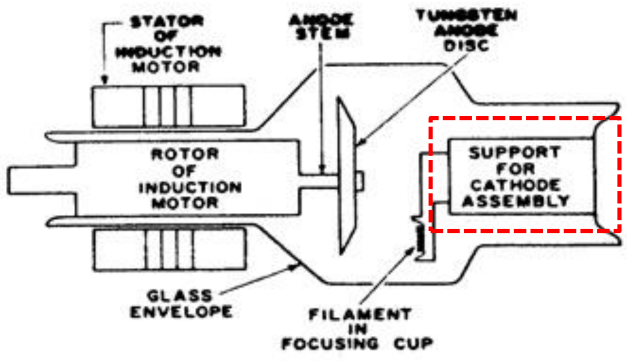
https://www.youtube.com/watch?v=9eJddBmOehA

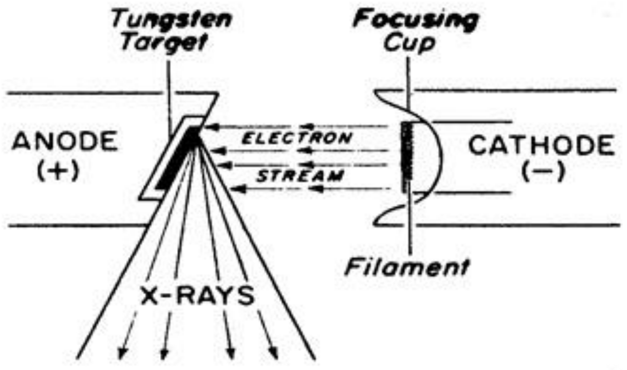
Source of CT --- X-Ray





Review - Major Components of a X-Ray Tube

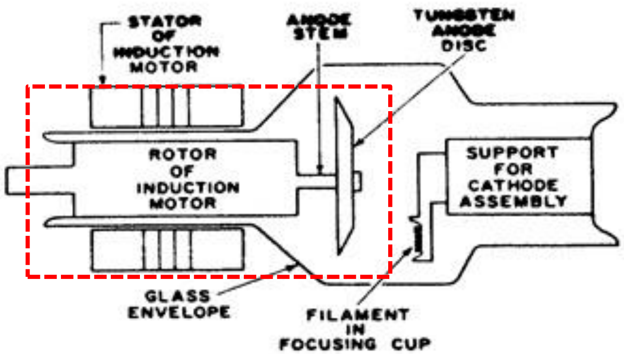


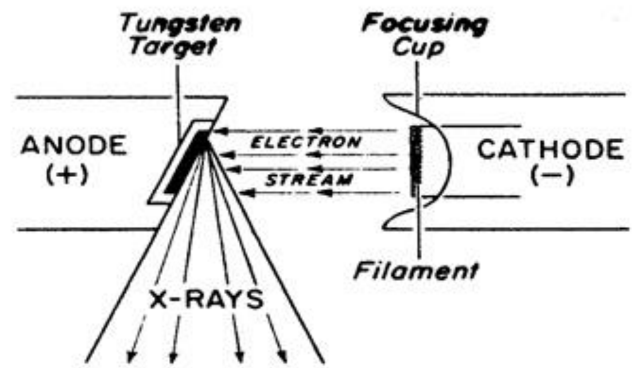


Cathode: negative terminal (source of electrons)

- filament: a spiral of tungsten wire, supply 10 V, 3-5 amps
- thermal emission: tungsten wire heated to 2,200°C emits electrons
- Tungsten is chosen because it can be drawn into a thin wire, a high melting point, and little tendency to vaporize.
- tube current: 100 mA (from cathode to anode travelling through the tube)
- focusing cup: to overcome the repulsive force among the electrons, which would result in bombardment of an unacceptable large area on the anode.

Review - Major Components of a X-Ray Tube

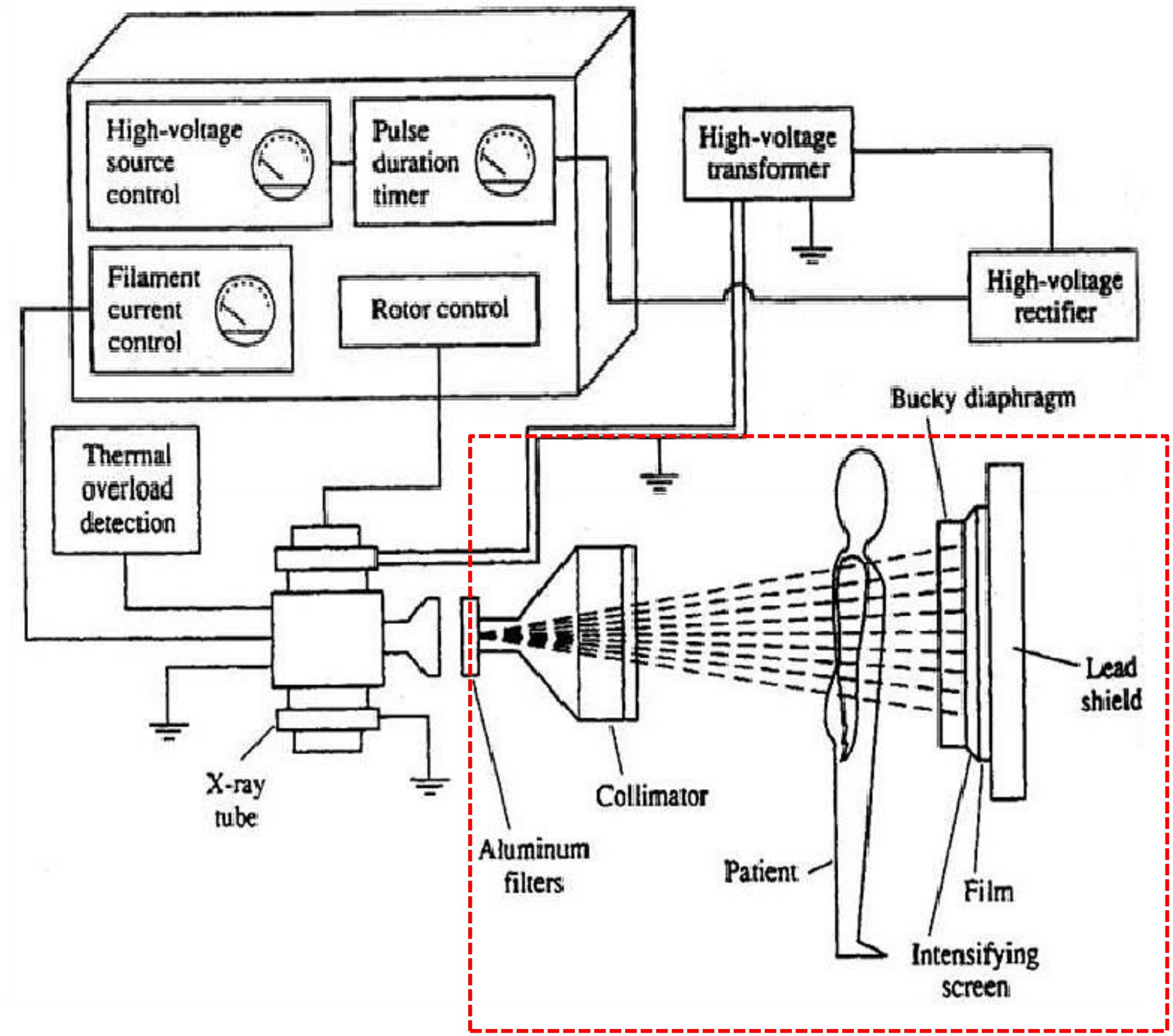




Anode: positive terminal (production of X-ray); *stationary or rotating*

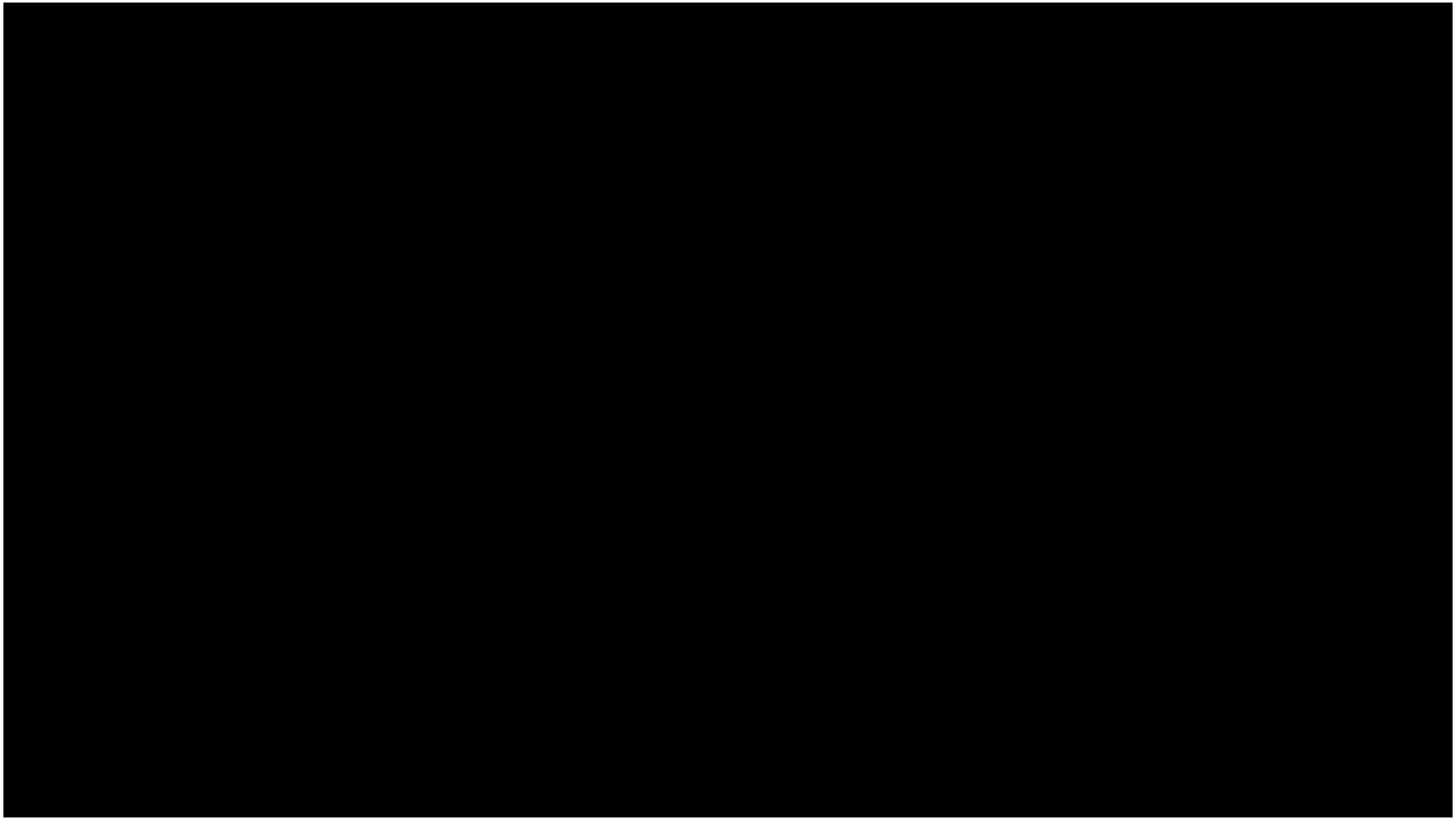
- Material: tungsten (90%, high efficiency of X-ray production, high temperature capacity) and rhenium (10%, ↑ resistant surface roughing
- Rotating anode: spreads the heat produced during an exposure over a large area, achieves higher x-ray output, which is limited by the heat generated
- structure: tungsten disk, anode stem (molybdenum, heat barrier), rotor
- heat dissipation: radiation through vacuum, glass envelope, surrounding oil
- roughening and pitting of the anode surface: bombardment by the electrons

Review - X-Ray



High-voltage source control
Pulse duration timer
High-voltage transformer
Filament current control
Rotor control
High-voltage rectifier
Bucky diaphragm
Thermal overload detection
Lead shield
X-ray tube
Collimator
Aluminum filters
Patient
Film
Intensifying screen

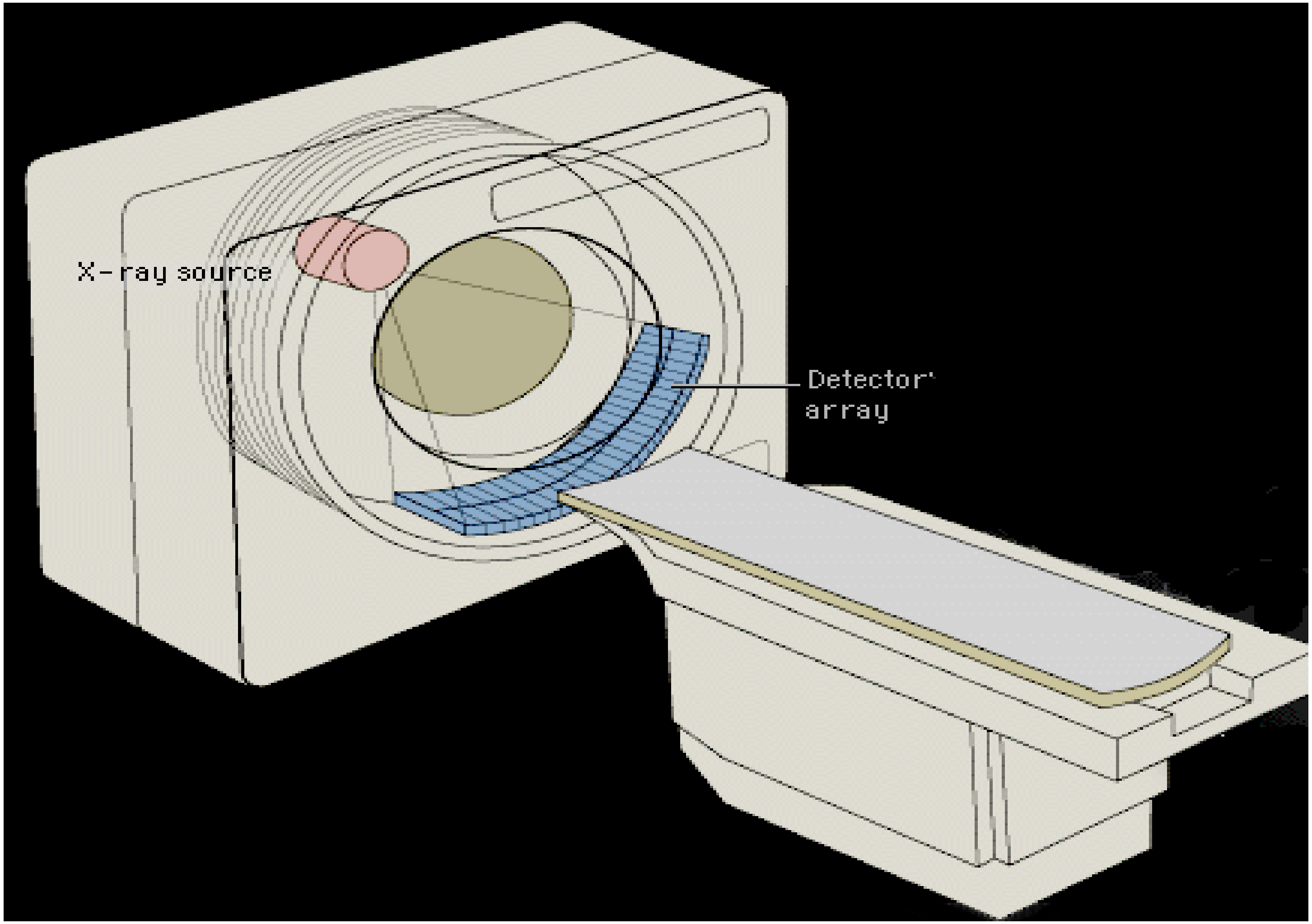
X-Ray Tutorial



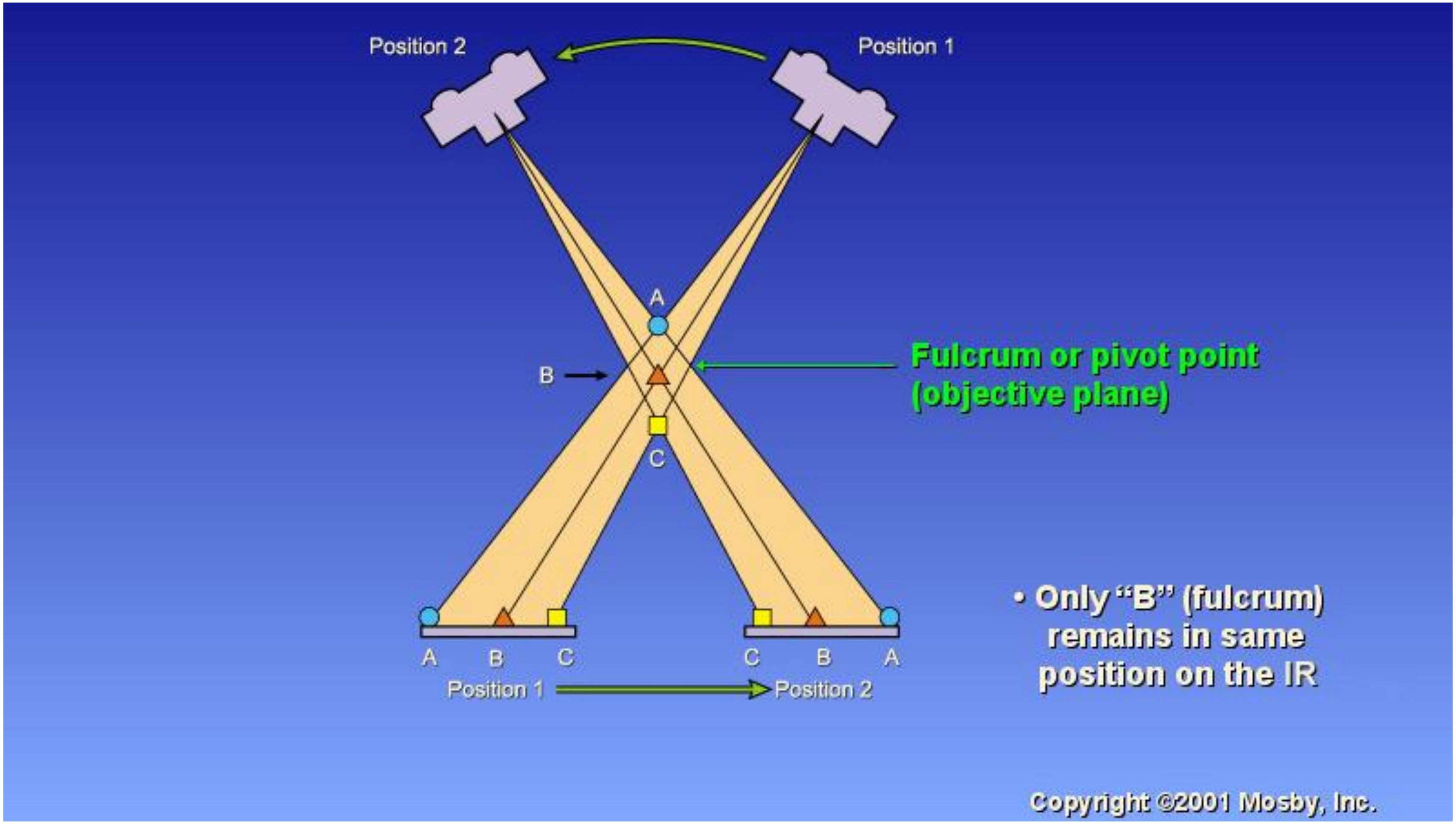
from Ted-Ed

https://www.youtube.com/watch?v=gsV7SJDDCY4

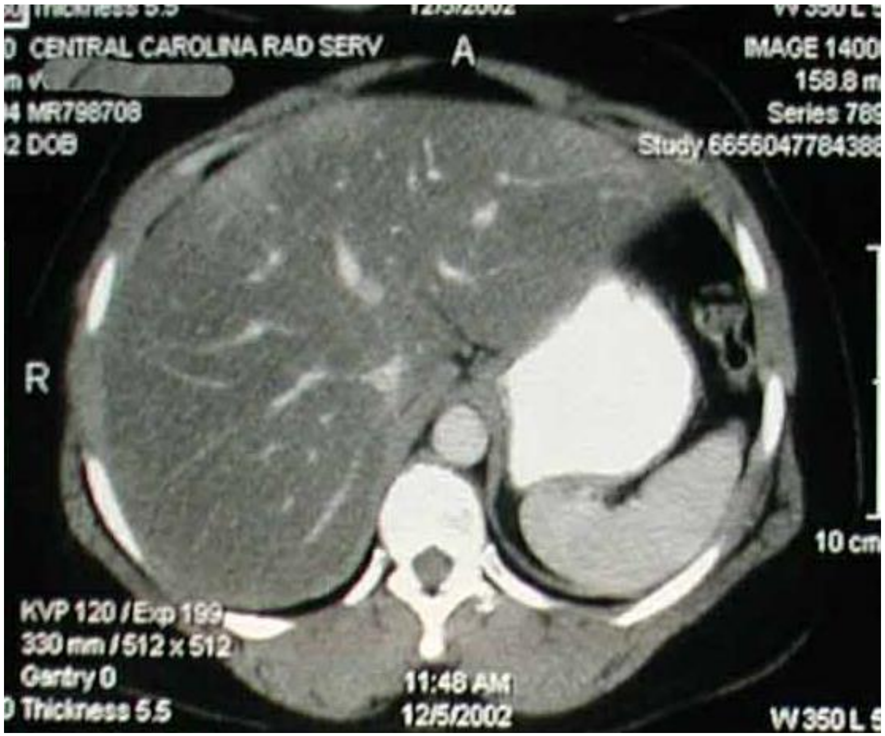
Computed Tomography (CT)

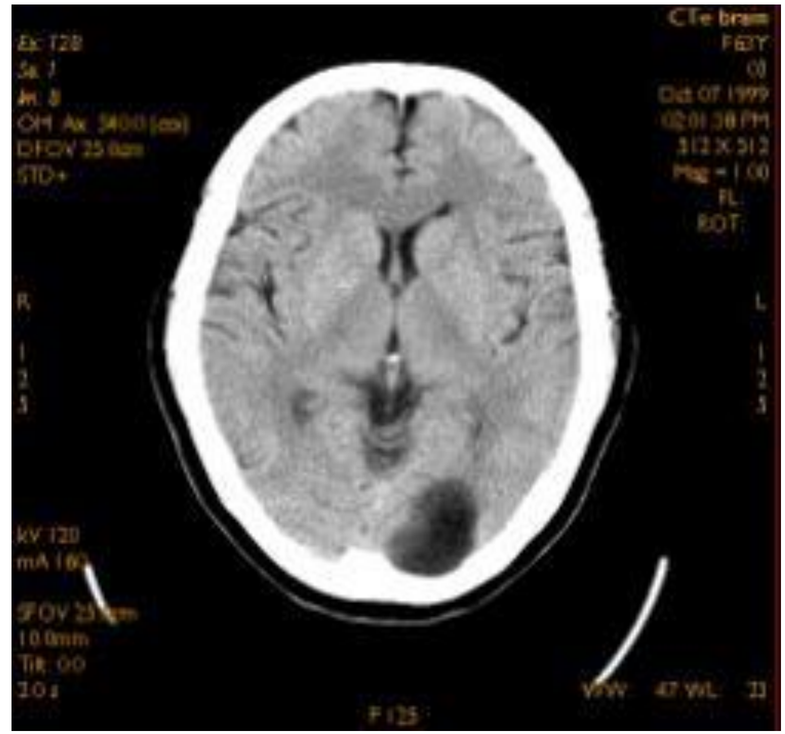


Tomographic Blurring Principle



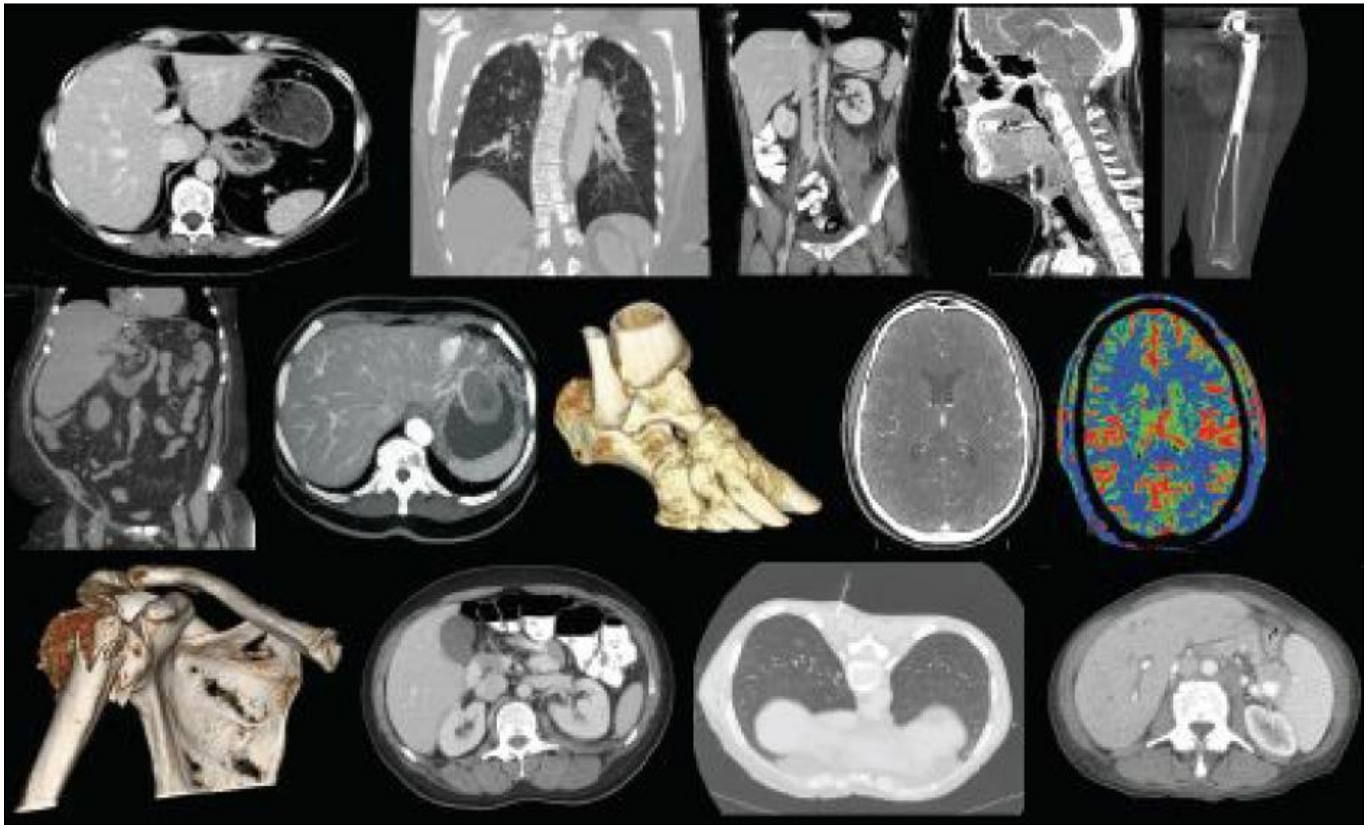
Tomographic Blurring Principle





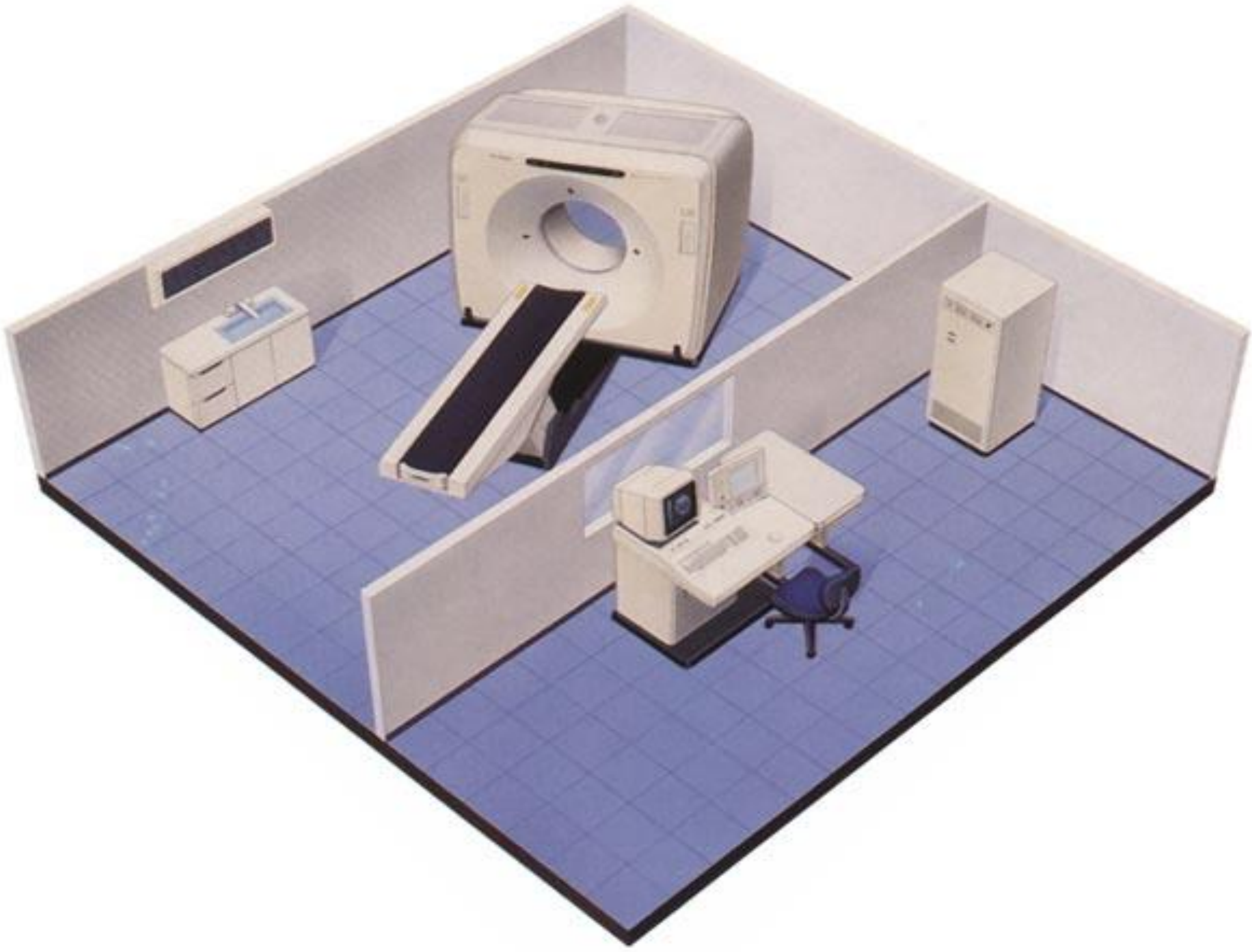
An image of an unknown object could be produced if one had an <u>**infinite number of projections**</u> through the object

Computed Tomography

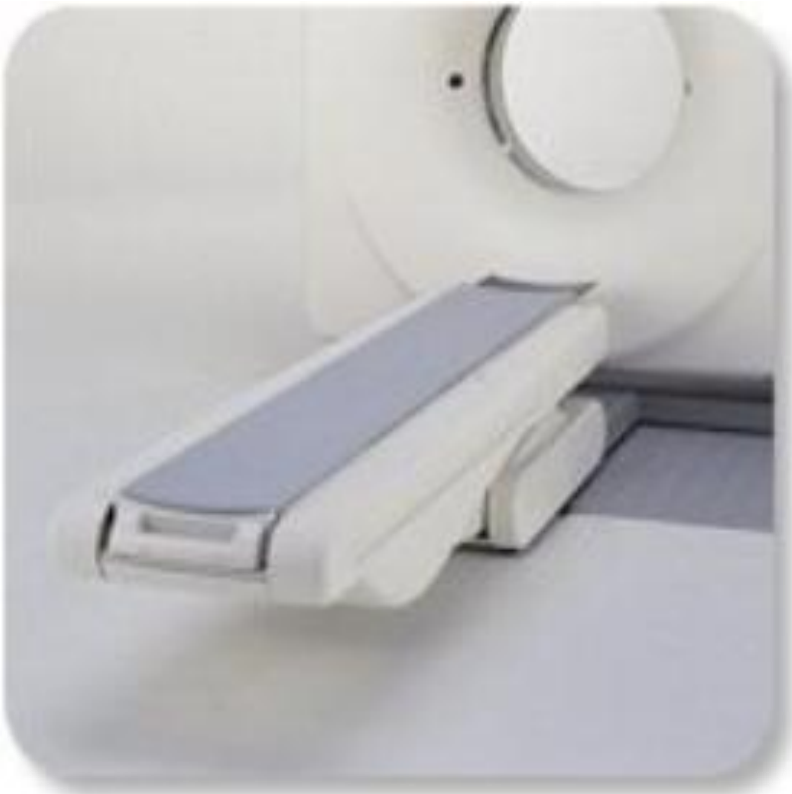


The wide use of CT and the excellent anatomical detail that CT provides

CT Room Layout



Computed Tomography



Gantry and Table

Operation Console

Computed Tomography

Feet first

Head first

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- Overview of Computed Tomography (CT)
- **History of Computed Tomography**
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    - Tube and detector move
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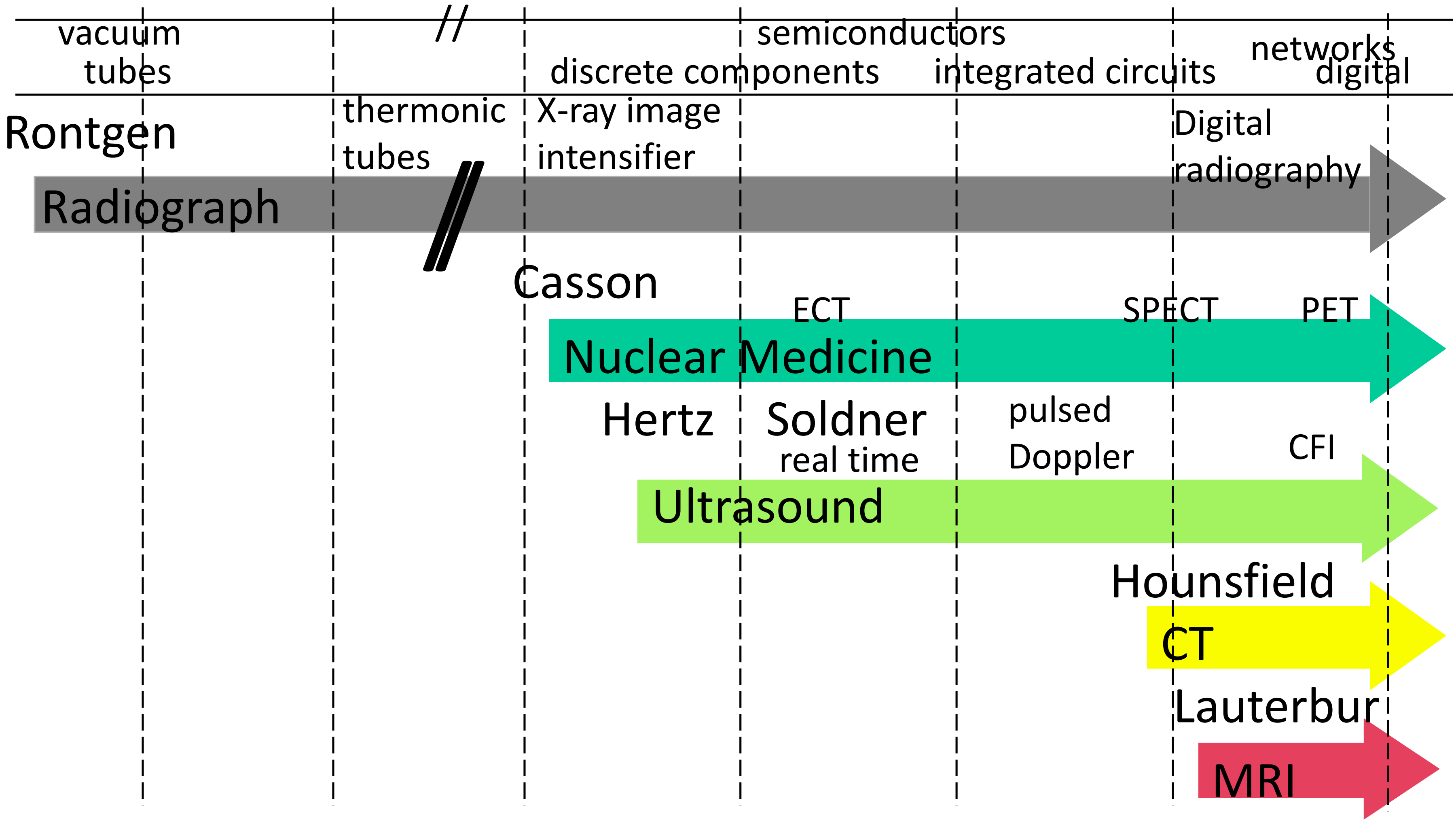
Modalities Evolution

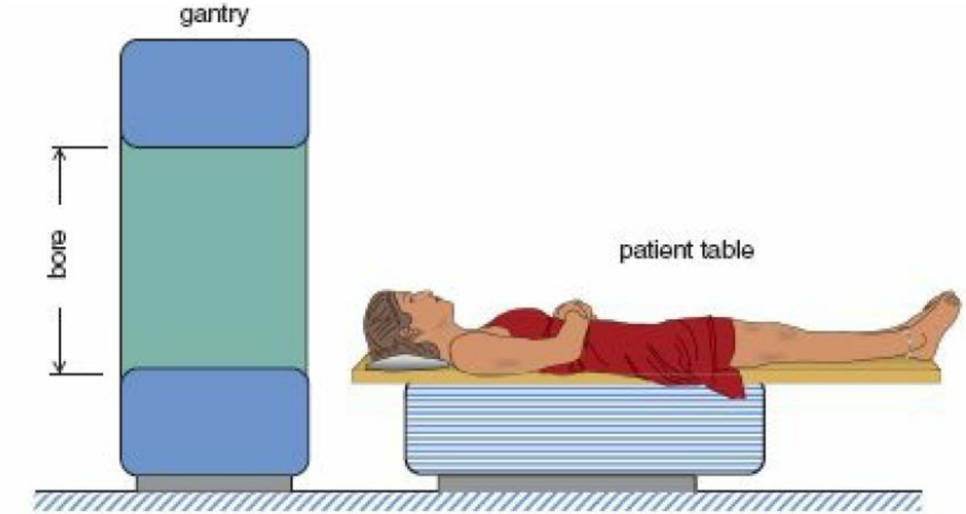


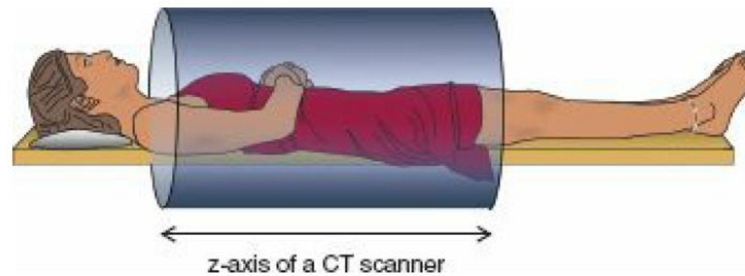
Source: Brueckner E.K., Siemens Medical Systems Erlangen

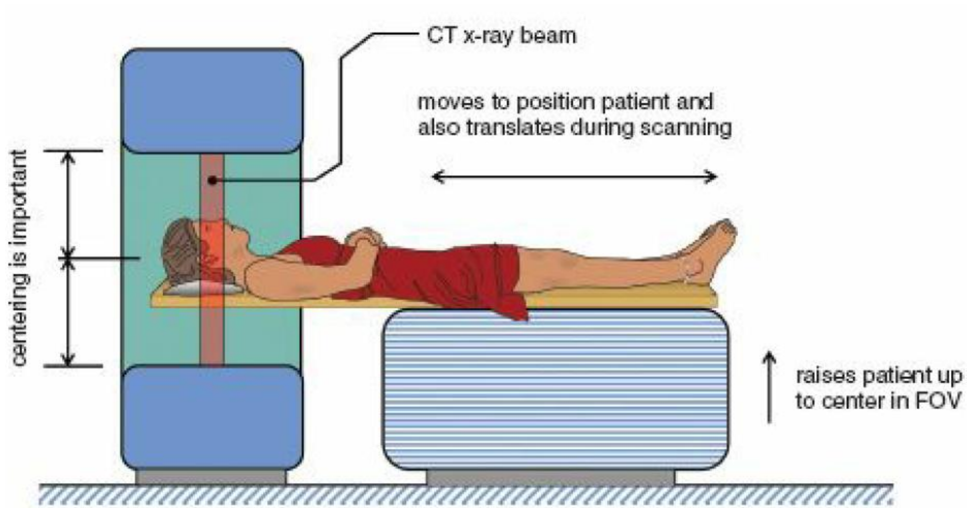
Introduction

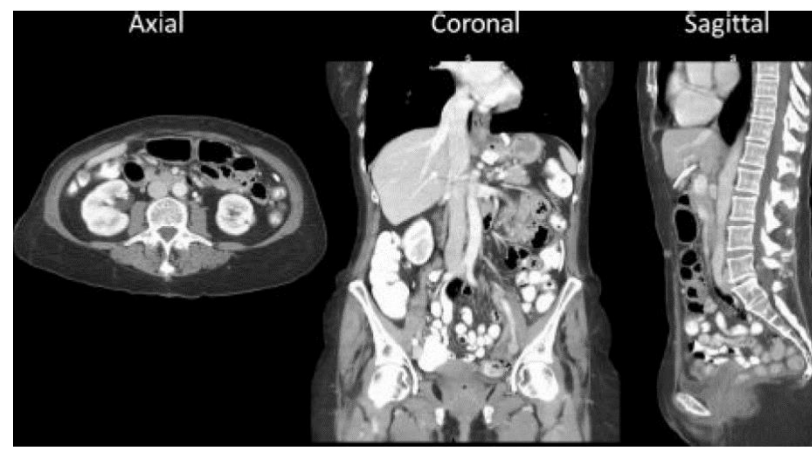
- Computed tomography (CT) is a **medical imaging** method employing **tomography (斷層攝影術)**.
- The word "**tomography**" is derived from the Greek tomos (slice) and graphein (to write).
- A large series of two-dimensional **X-ray** images (slices) of the inside of an object are taken around a single **axis of rotation**.
- Digital geometry processing is used to generate **three-dimensional images** of the object from those slices.

Introduction









Computed Tomography (CT)

- The first CT (computerized axial tomography scan, CAT) scanner was built by ***Godfrey Hounsfield*** in 1971, designed to only ***take pictures of the brain***.
- He shared the 1979 Nobel Prize for Physiology or Medicine with ***Allan Cormack*** for developing the CT diagnostic technique.

Godfrey Hounsfield
(28 August 1919 – 12 August 2004)

EMI Head CT scanner 1974

Allan Cormack
(February 23, 1924 – May 7, 1998)

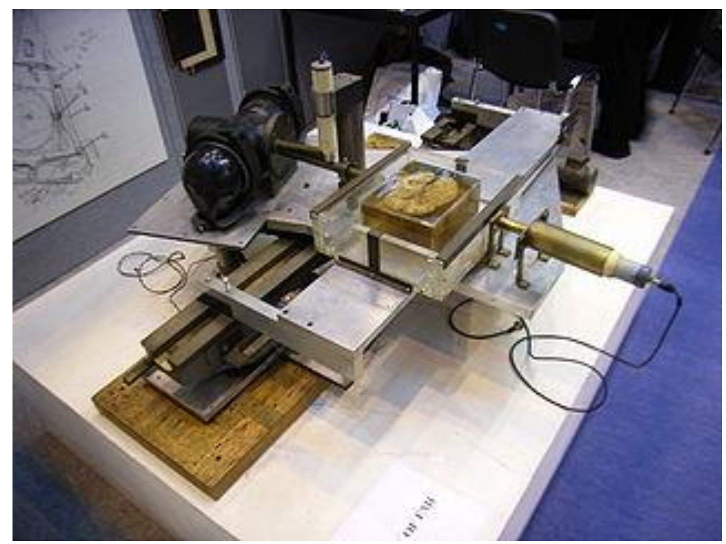
Ref: http://www.imaginis.com/

How the Beatles funded the CT scan?

- EMI's full name was ***Electric and Musical Industries*** and was as much into electrics as it was into music in 1960s.
- By 1967, Beatles sales earned 30 percent of the company's profits.
- Godfrey Hounsfield is an electrical engineering worked at EMI.
  - weapon systems and radar (1949)
  - computer (1958)
  - CT scanner (1960)
  - EMI first released in 1972
  - Nobel Prize in 1979

No Beatles, No CT scanner?

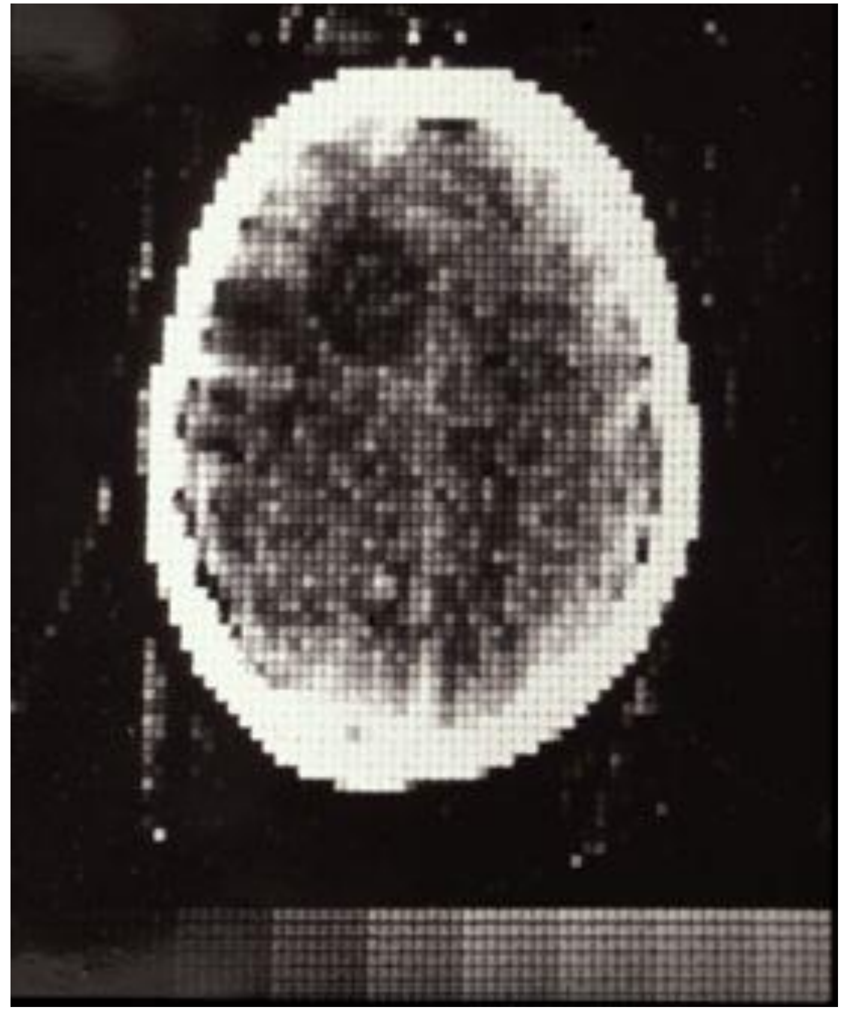
The Beatles arrive at JFK International Airport, 7 February 1964. Ref: CNET.com



The prototype CT scanner Ref: Wiki

First CT Scan Image

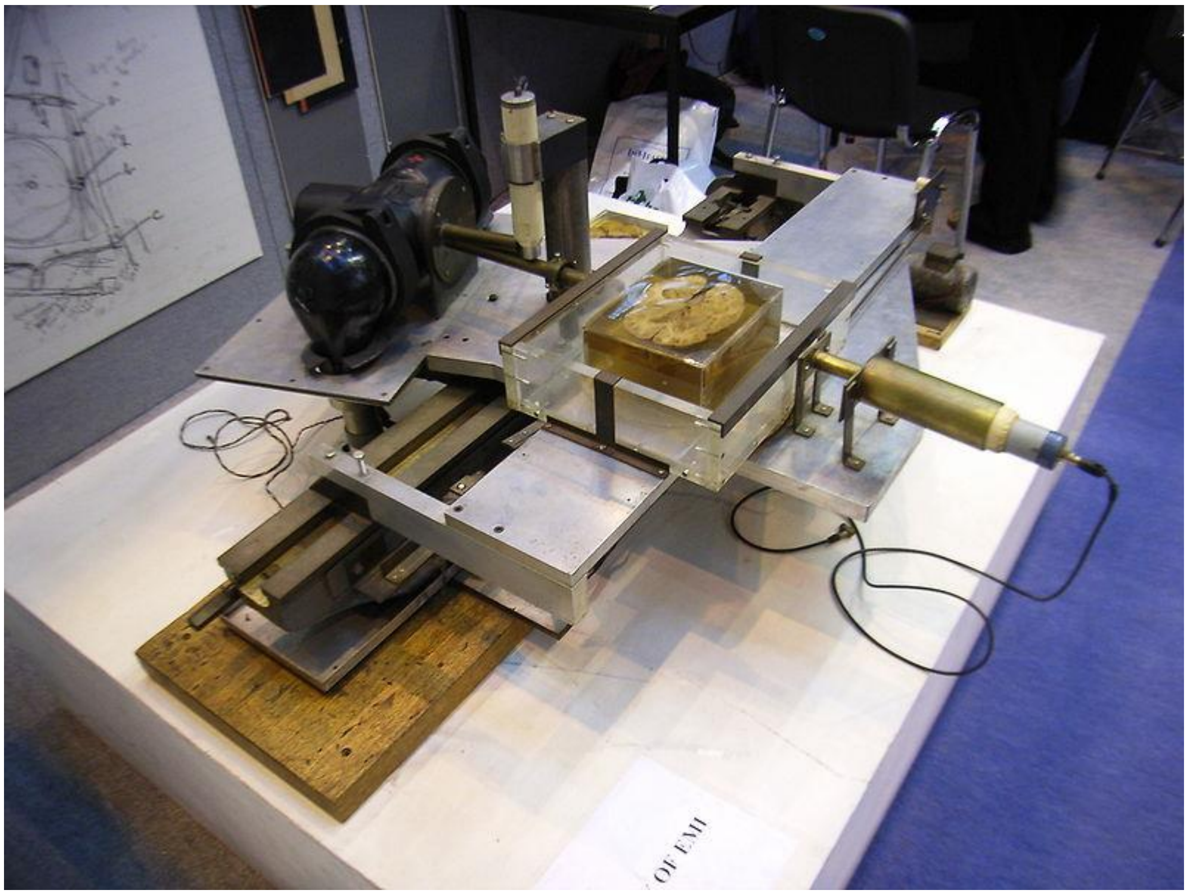
- The 1st scanner produces an image:
  - with an 80 x 80 matrix
  - taking about 5 minutes for each scan
  - taking 2.5 hours to be processed by algebraic reconstruction techniques on a large computer
- Current CT scanners can produce images
  - with an 1024 x 1024 matrix
  - taking a slice in less than 0.3 seconds



The first clinical scan: The patient, a lady with a suspected frontal lobe tumor, Atkinson Morley's Hospital, October 1971.

Ref: http://www.impactscan.org/

Prototype CT Scanner



The initial prototype CT scanner used in clinical trials shown here had some less than inspiring specifications:

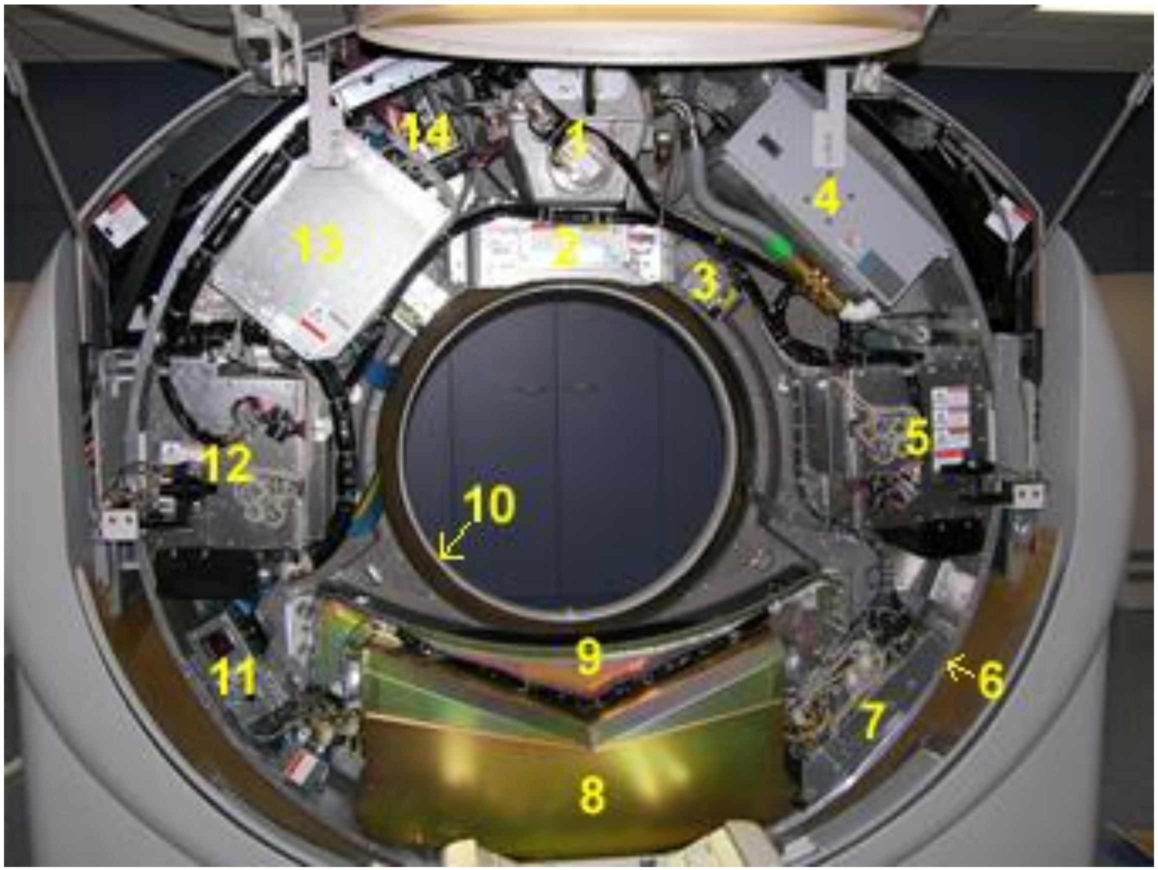
Scan time 9 days
Reconstruction 2.5 hours
Print Image 2 hours
Resolution 80 x 80

http://www.bioclinica.com/blog/evolution-ct-scan-clinical-trials

Modern CT Scanner

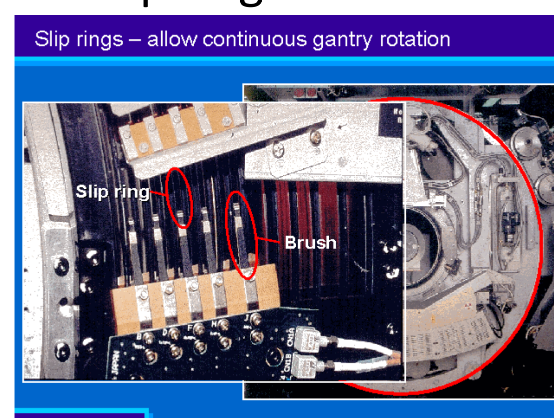
1. Gantry aperture (720mm diameter)
2. Microphone
3. Sagittal laser alignment light
4. Patient guide lights
5. X-ray exposure indicator light
6. Emergency stop buttons
7. Gantry control panels
8. External laser alignment lights
9. Patient couch
10. ECG gating monitor

CT Gantry –Internal Structure

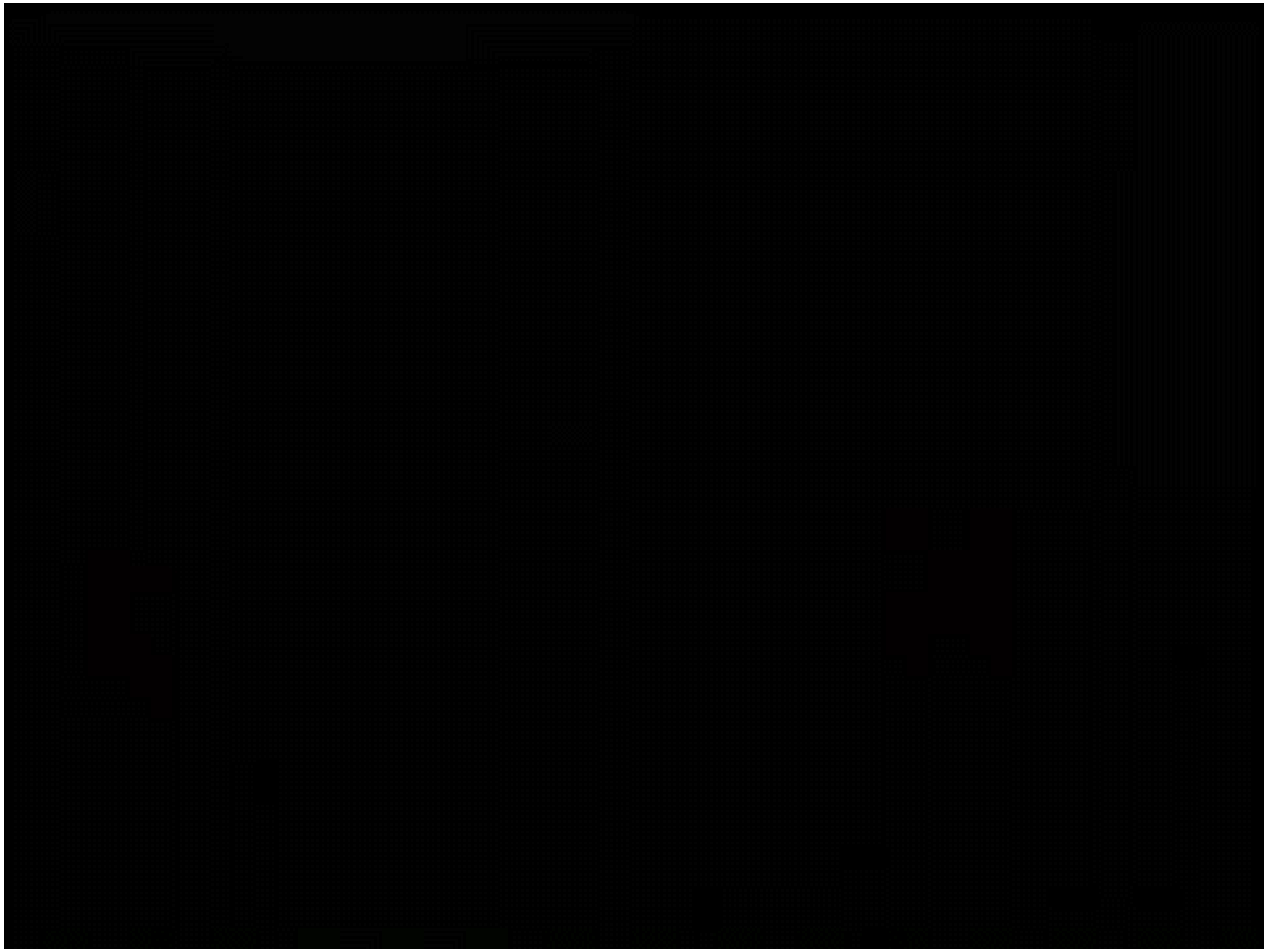


https://www.youtube.com/watch?v=cjtHNxf01tQ

1. X-ray tube
2. Filters, collimator, and reference detector
3. Internal projector
4. X-ray tube heat exchanger (oil cooler)
5. High voltage generator (0-75kV)
6. Direct drive gantry motor
7. Rotation control unit
8. Data acquisition system (DAS)
9. Detectors
10. Slip rings



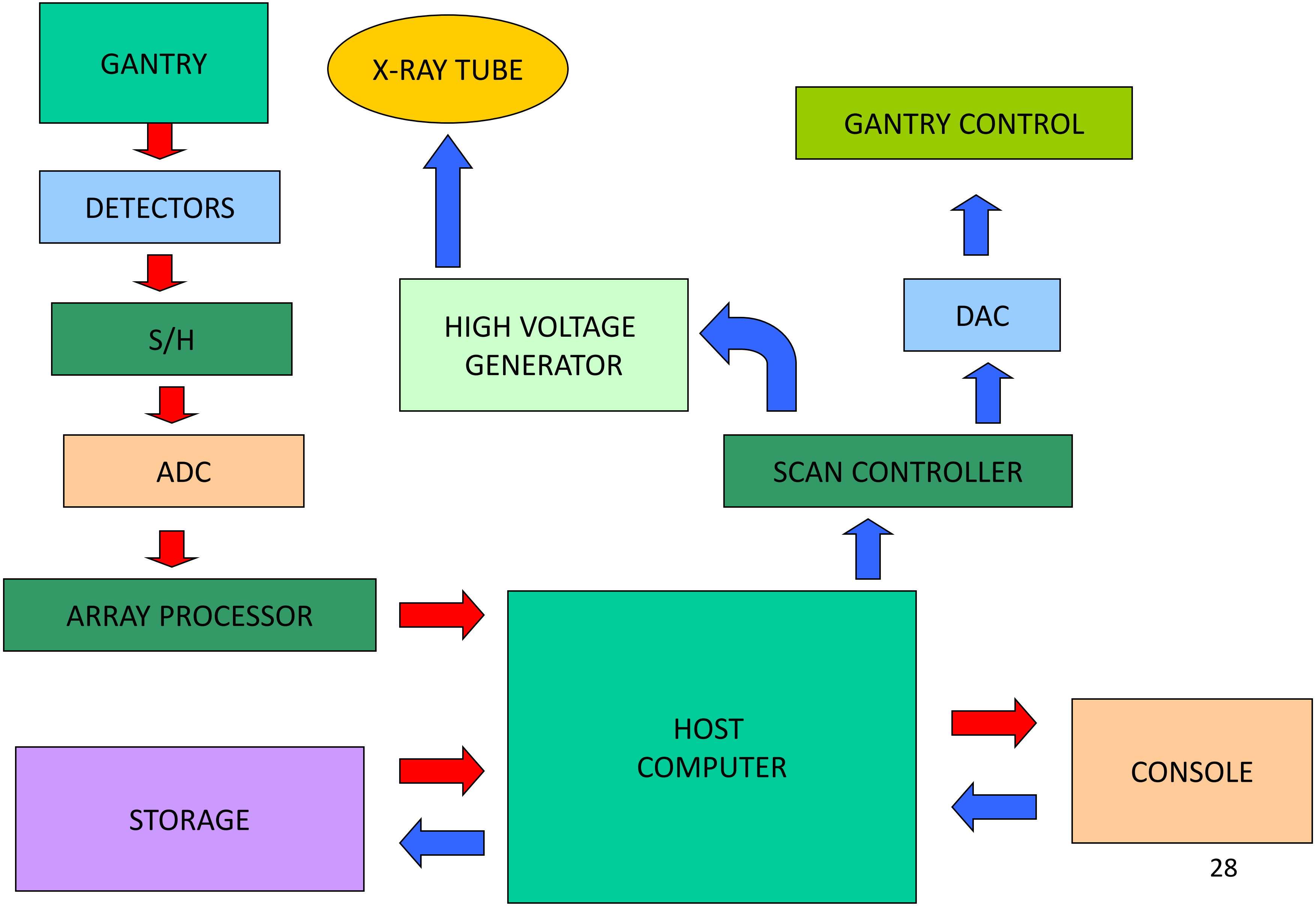
Tutorial for CT Scanner Rotating



Philips CT 256 slice scanner rotating at highspeed

https://www.youtube.com/watch?v=CWnjqeB7Mk8

CT System


GANTRY
X-RAY TUBE
GANTRY CONTROL
DETECTORS
S/H
HIGH VOLTAGE GENERATOR
DAC
ADC
SCAN CONTROLLER
ARRAY PROCESSOR
HOST COMPUTER
CONSOLE
STORAGE

Outline

- Overview of Computed Tomography (CT)
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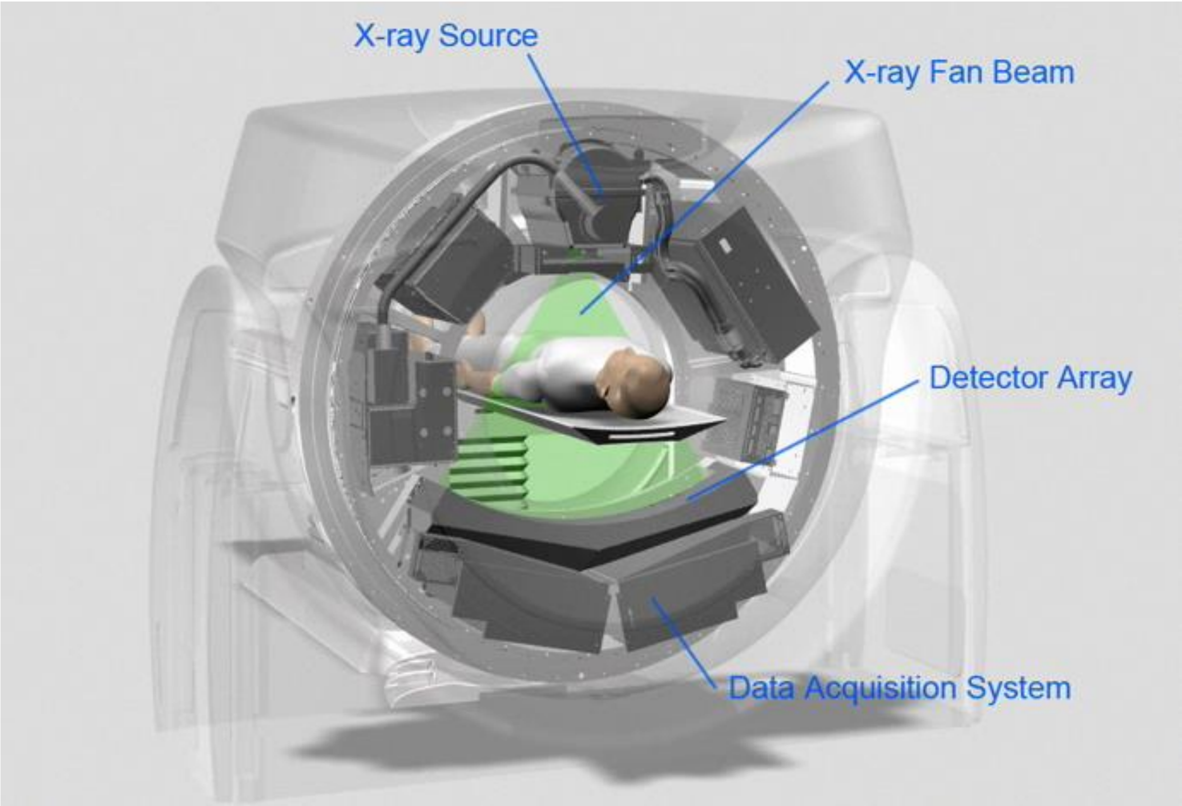
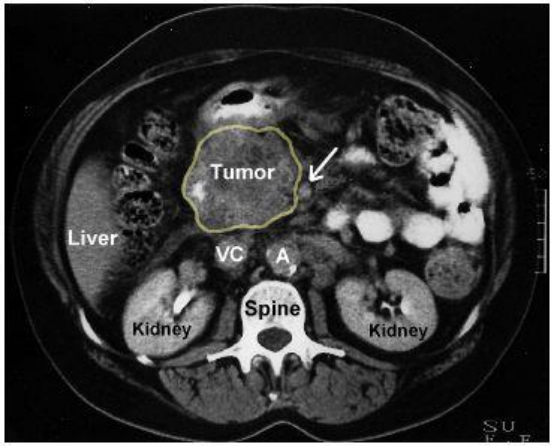
Computed Tomography (CT)

A CT scan (called X-ray computed tomography or computerized axial tomography scan) makes use of computer-processed ***combinations of many X-ray images taken from different angles*** to produce cross-sectional images of specific areas of a scanned object.





From http://www.pathology.jhu.edu/

From http://www.analogic.com/

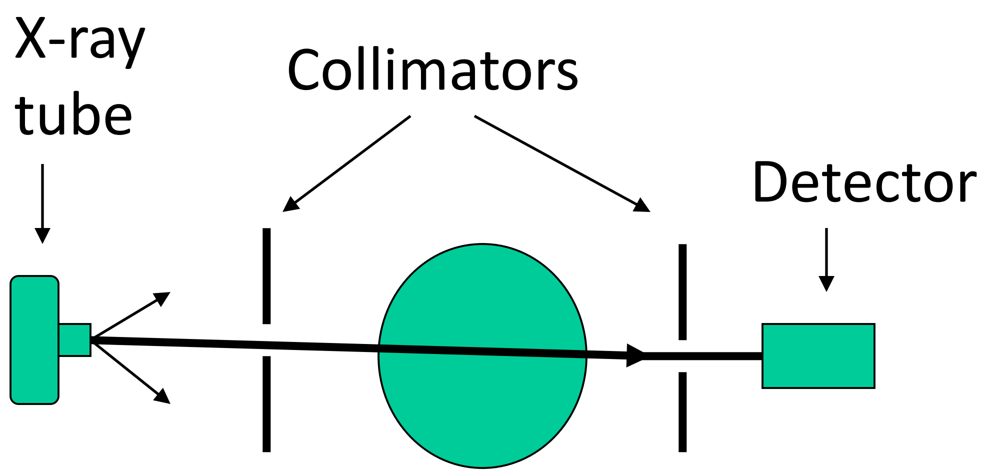
Tomographic acquisition

Basic components

- **X-ray tube**
- **Collimators**
- **Detector/s**

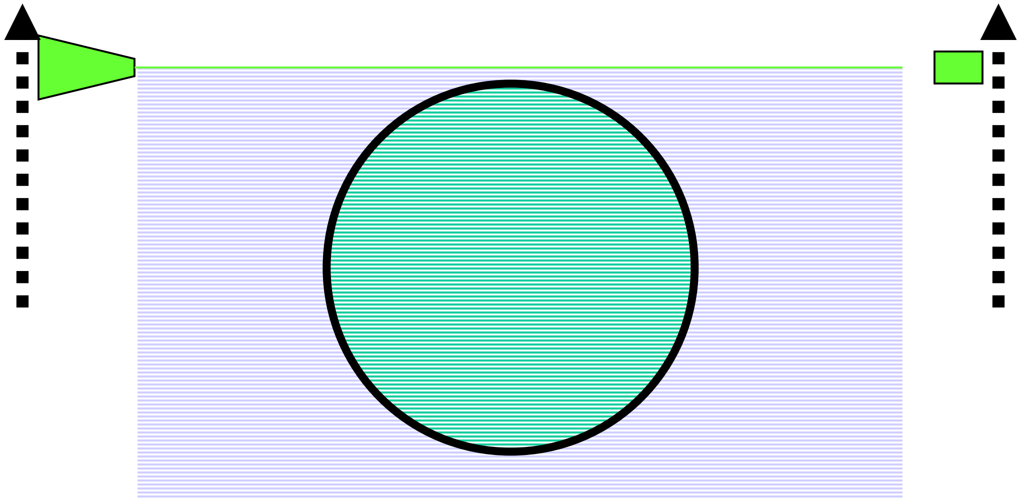
Collimated x-ray beam traverses the object and enters the detector.

The **attenuation** is determined from the **difference between incident intensity** and **transmitted intensity**



Translate Rotate System

In the basic CT system the x-ray tube and detector are **translated linearly** so that the beam scans the object (eg. A disc of uniform density)



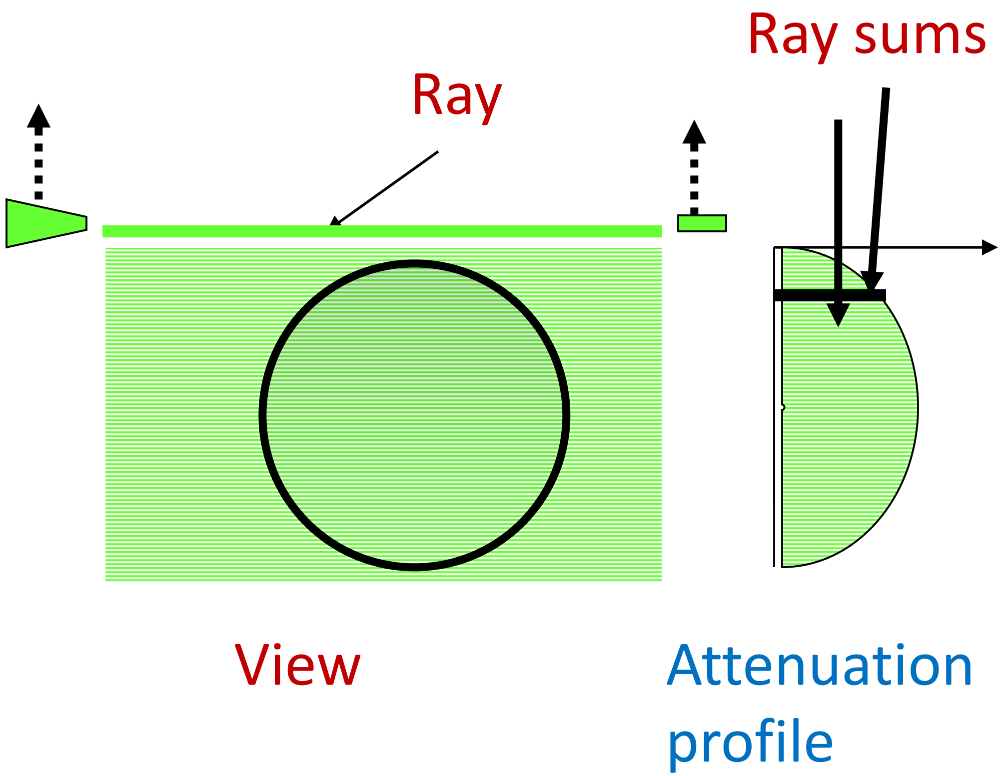
Ray, Ray Sum, View & Attenuation Profile

Ray – Imaginary line between Tube & Detector

Ray Sum – Attenuation along a Ray

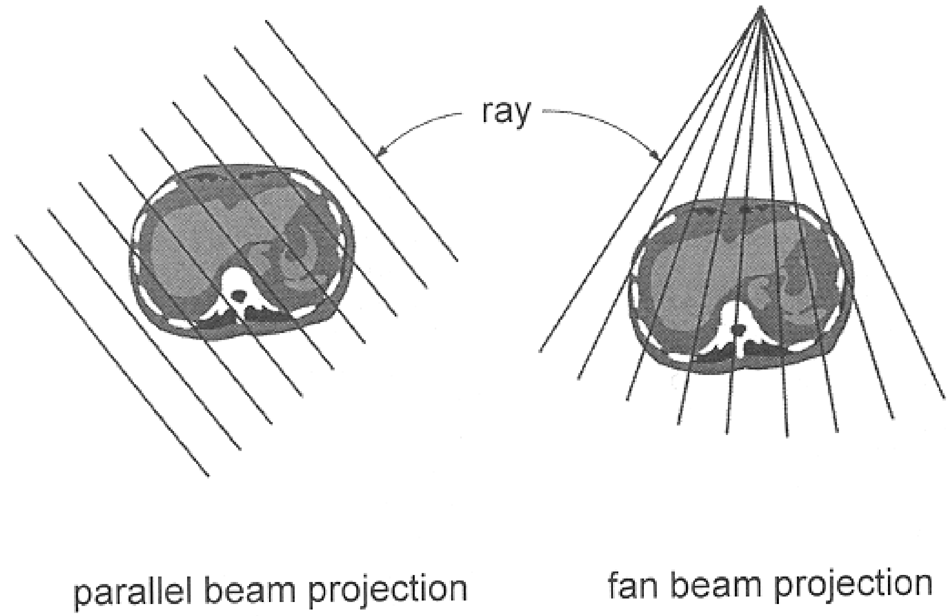
View – The set of ray sums in one direction

The attenuation for each ray sum when plotted as function of its position is called an attenuation profile



Tomographic Acquisition

- Single transmission measurement through the patient made by a single detector at a given moment in time is called a ***ray***
- A series of rays that pass through the patient at the same orientation is called a ***projection* or *view***
- Two projection geometries have been used in CT imaging:
  - ***Parallel beam geometry*** with all rays in a projection parallel to one another
  - ***Fan beam geometry***, in which the rays at a given projection angle diverge

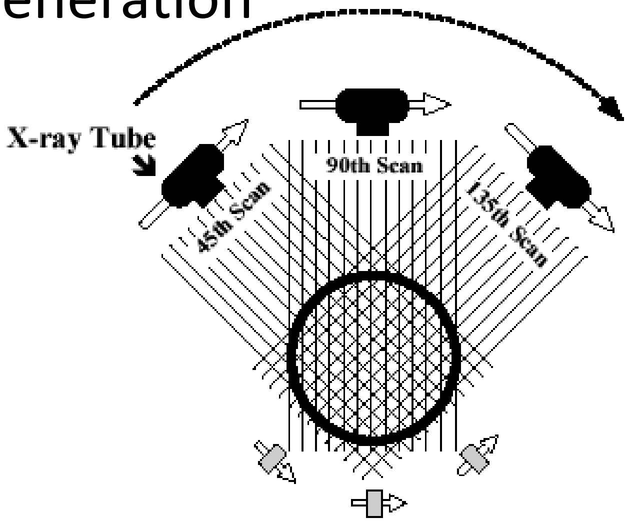


Tomographic Acquisition

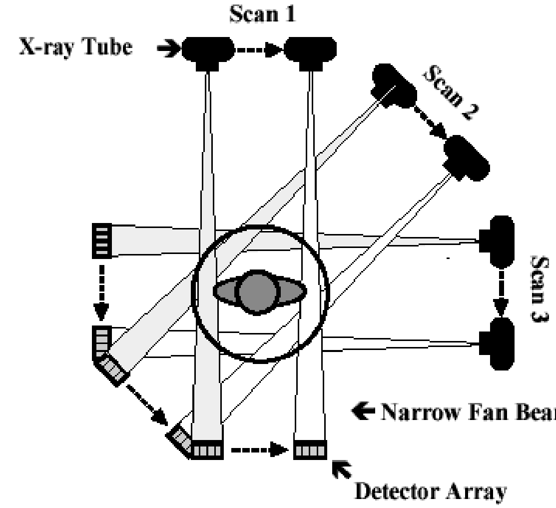
- Purpose of CT scanner hardware is to acquire a ***large number of transmission*** measurements through the patient at ***different positions***
- Single CT image may involve approximately 800 rays taken at 1,000 different projection angles
- Before the acquisition of the next slice, the table that the patient lies on is moved slightly in the ***cranial-caudal direction*** (the “z-axis” of the scanner)

Evolution of CT Scanners

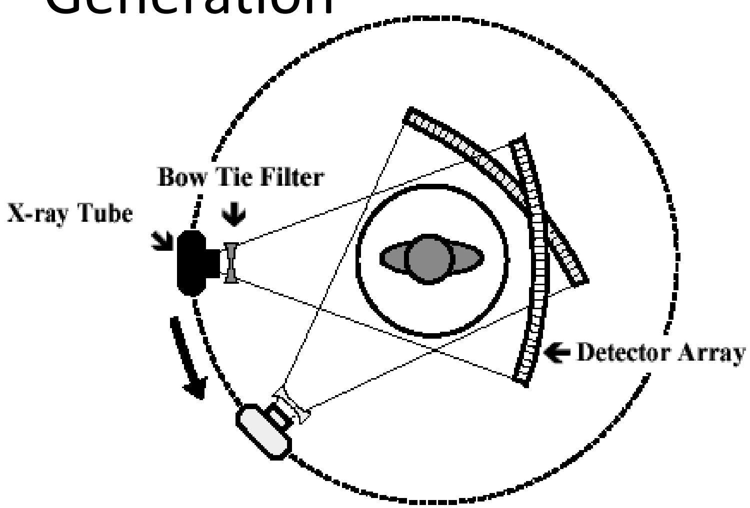
1st Generation



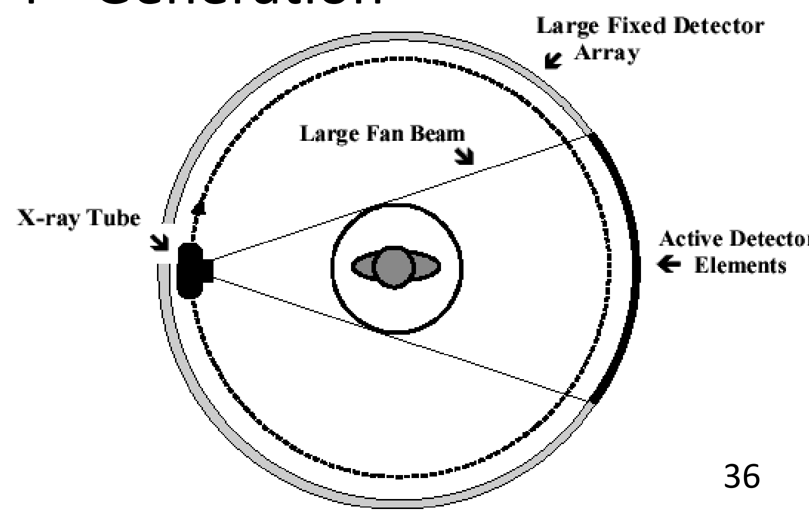
2nd Generation



3rd Generation

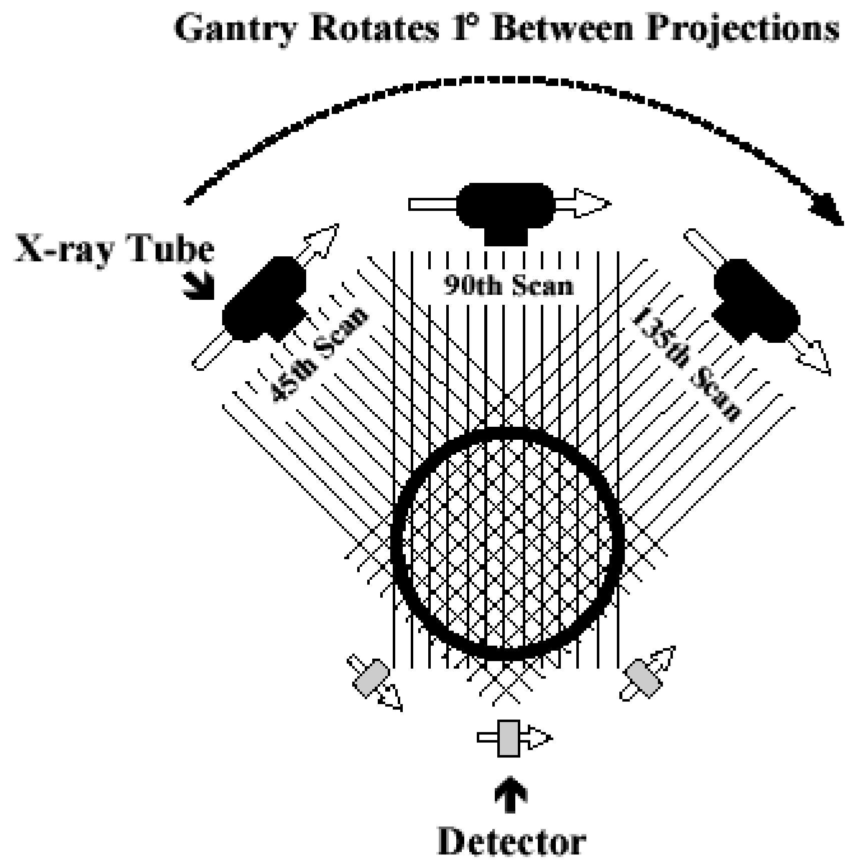


4th Generation



CT Scanning Geometries-1st Generation

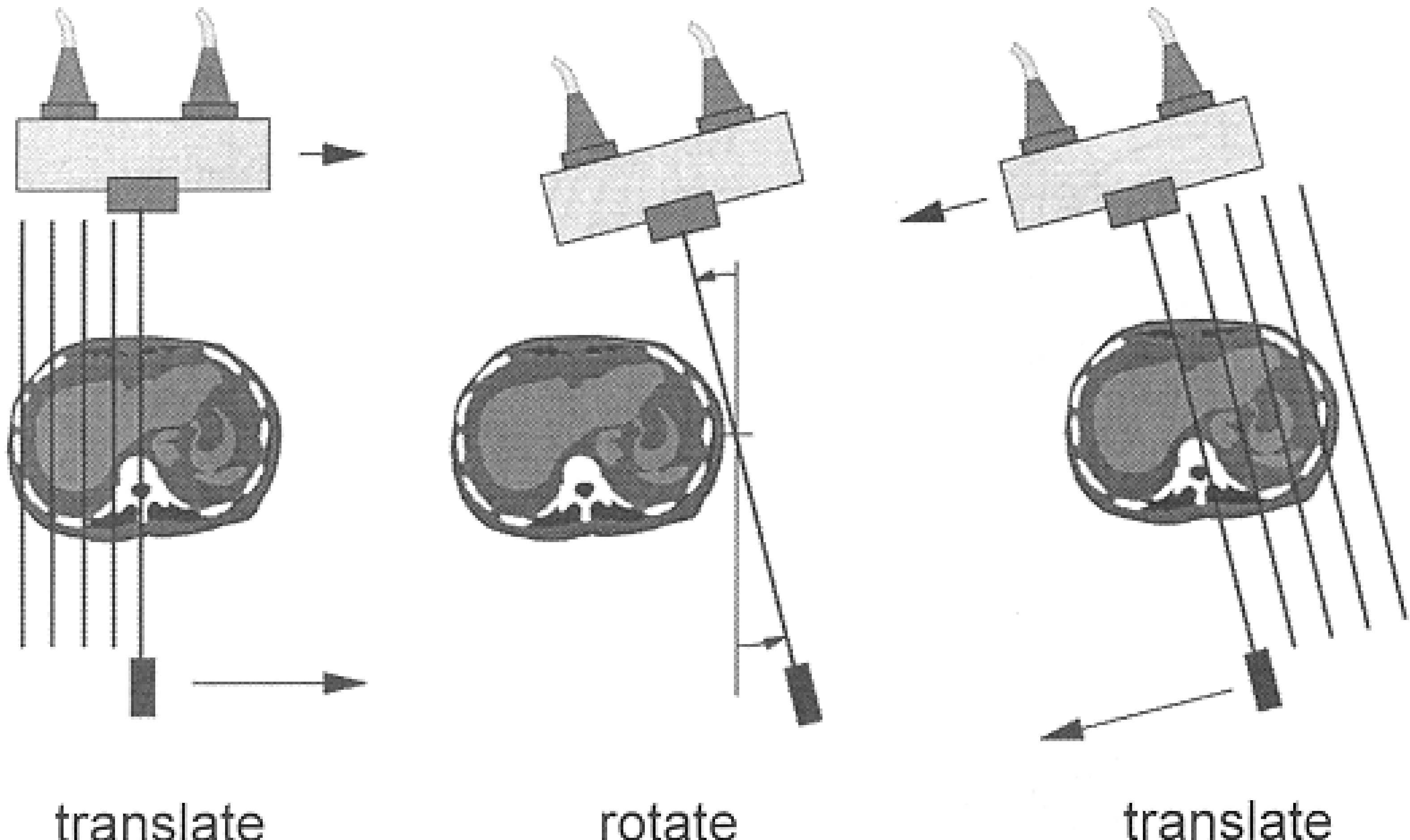
- The first generation of CT scanner used what is referred to as ***Translate-Rotate geometry*** (a pencil X-ray beam and a single detector)
  - ***Translation***: X-ray beam was sampled 160 times to produce a single profile.
  - ***Rotation***: through 1 degree with the X-ray beam for a new profile.
  - This procedure was completed after scanning by 180 different angles (~ 5mins)



First generation CT scanner design

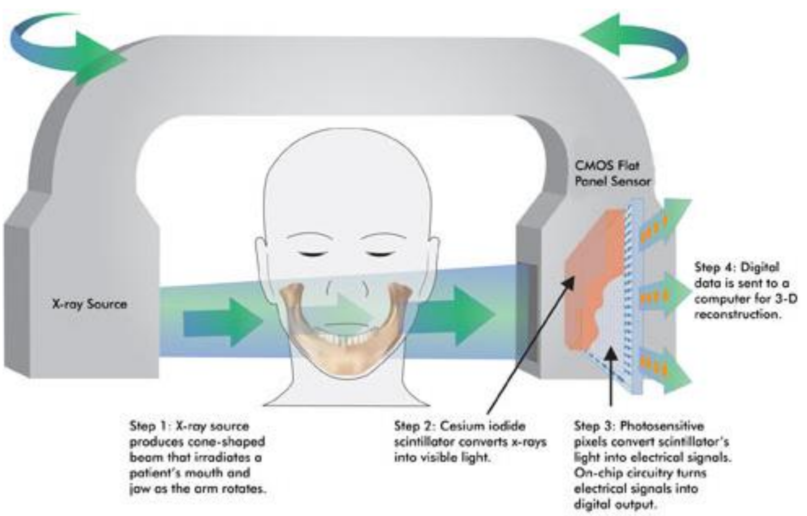
From https://en.wikibooks.org/

1^{st} Generation: Rotate/Translate, Pencil Beam



1st Generation: Rotate/Translate, Pencil Beam

- Only **2 x-ray detectors** used (two different slices)
- **Parallel** ray geometry
- Translated linearly to acquire 160 rays across a 24 cm FOV
- **Rotated** slightly between translations to acquire 180 projections at **1-degree** intervals
- About **4.5 minutes/scan** with 1.5 minutes to reconstruct slice

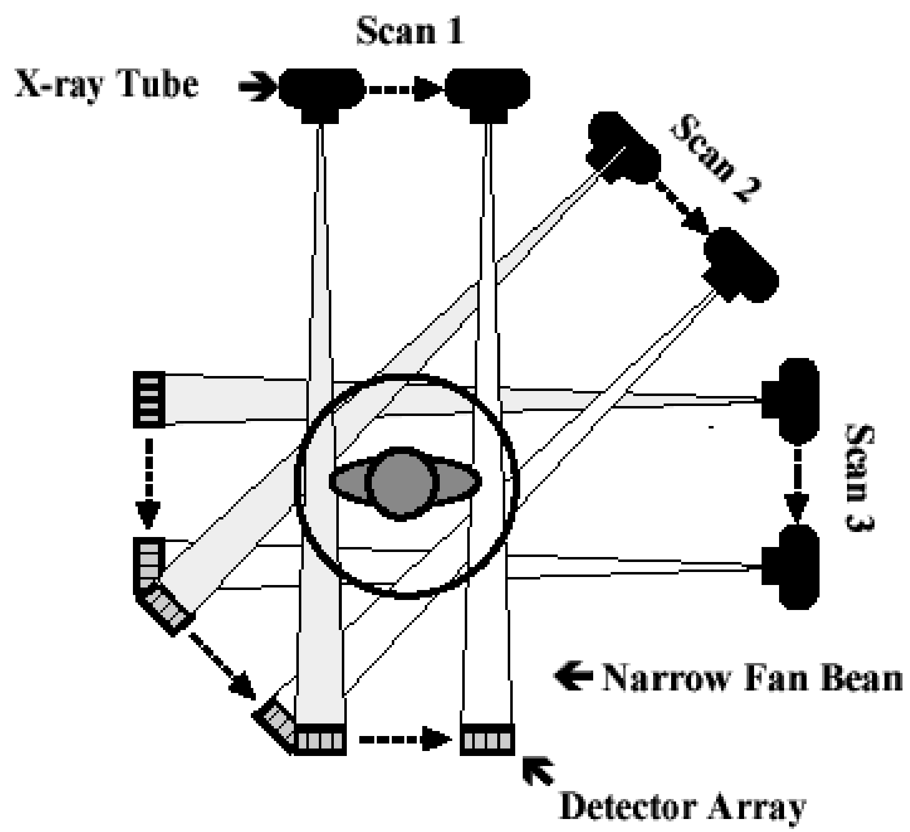


1st Generation: Rotate/Translate, Pencil Beam

- Large change in signal due to **increased x-ray flux outside of head**
  - Solved by pressing patient's head into a flexible membrane surrounded by a water bath
- Sodium iodide (NaI) **detector** signal **decayed slowly**, affecting measurements made temporally too close together
- **Pencil beam** geometry allowed very efficient **scatter reduction**, best of all scanner generations

CT Scanning Geometries-2nd Generation

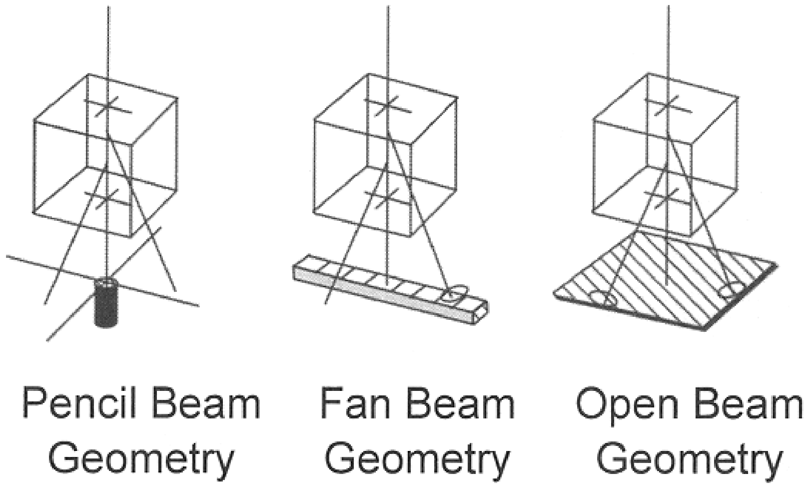
- The second generation of scanner decreases the scan time by using a **small fan beam** with **multiple detectors** (***Translate-Rotate geometry***).
  - ***Translation***: Each of the detectors (up to 30) collects its own limited profile during each translation.
  - ***Rotation***: 30 degrees was employed between translational movements.
  - only ***six rotational movements*** were required to obtain the data for one slice (5-90 sec)

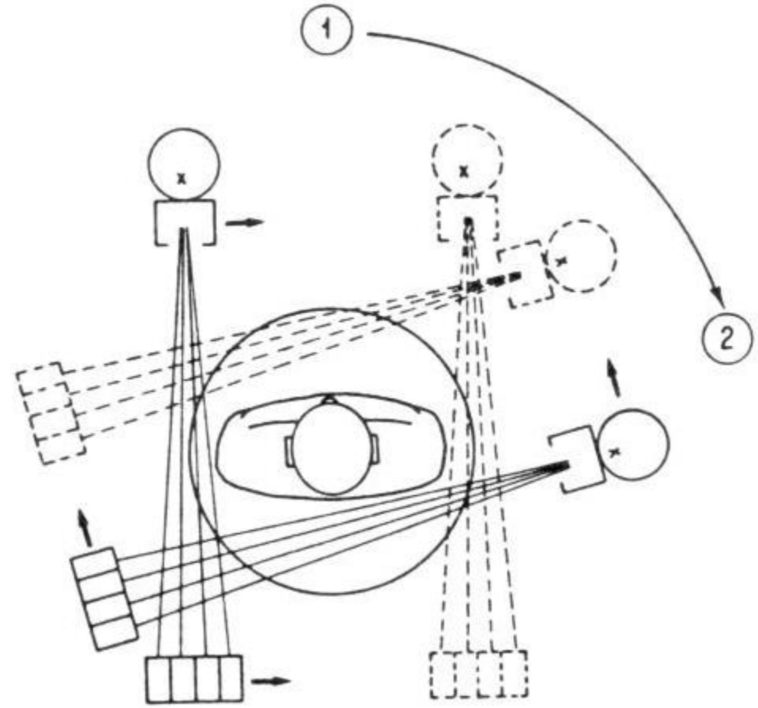


Second generation CT scanner design

From https://en.wikibooks.org/

2nd Generation: Rotate/Translate, **Narrow Fan Beam**



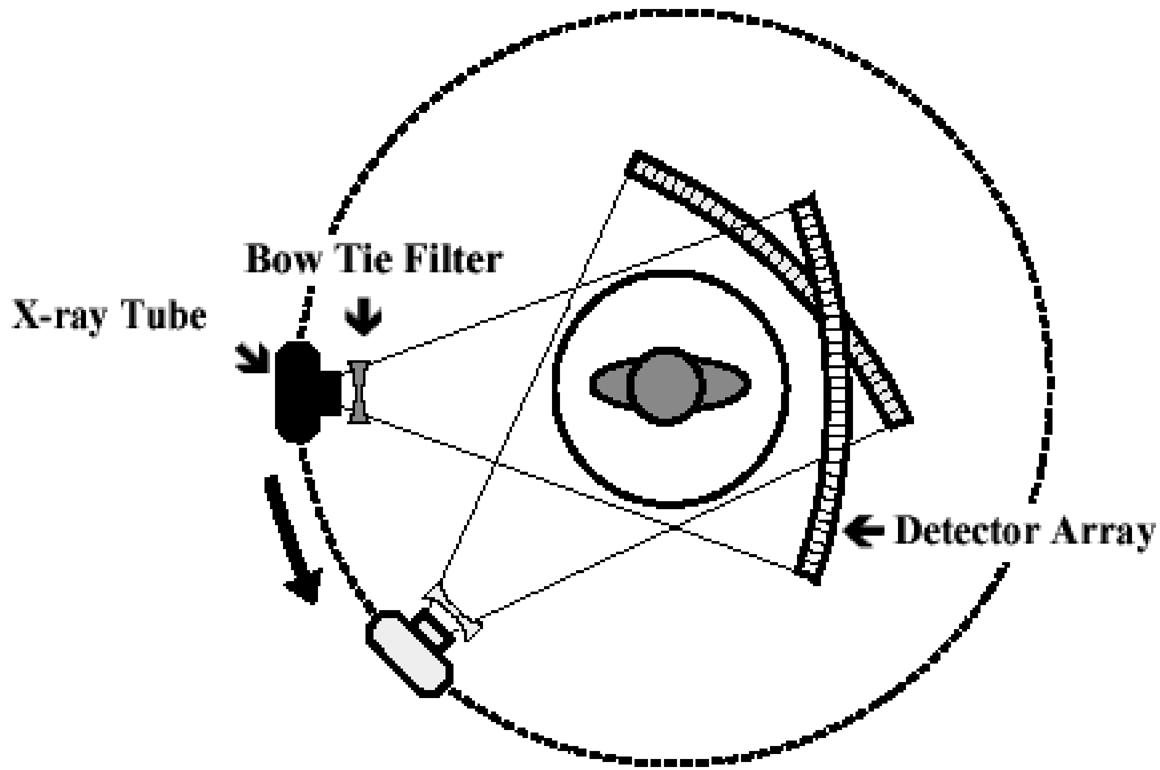


- More data acquired to improve image quality (600 rays x 540 views)
- Narrow fan beam allows more scattered radiation to be detected

CT Scanning Geometries-3rd Generation

- The third generation of CT scanner decreased scan times even further by using a ***Rotate-Rotate geometry*** (**a large fan beam** and **detectors in hundreds**).

- Most scanners today are of the third generation type).
  - ***Rotation***: The X-ray tube and detector array rotate as one through 360 degrees.
  - Scan times can be as low as a second.

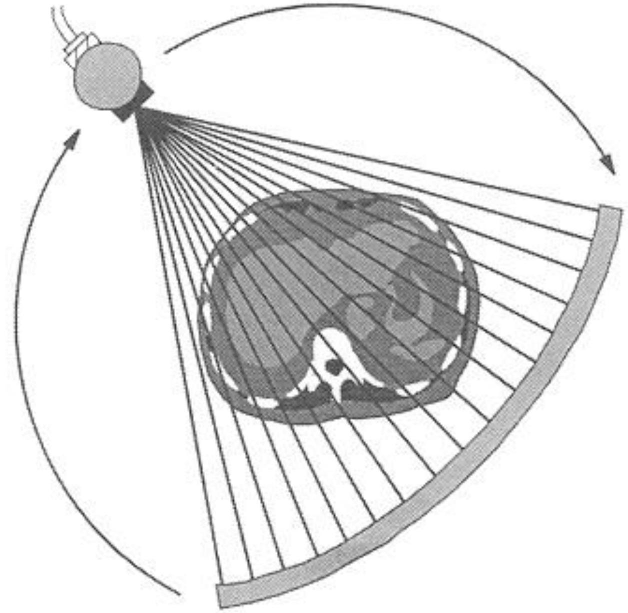


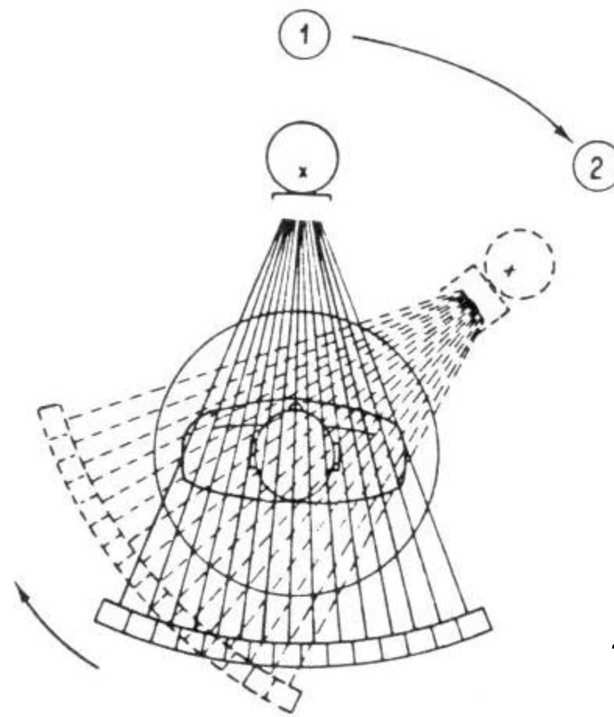
Third generation CT scanner design

From https://en.wikibooks.org/

3rd Generation: Rotate/Rotate, **Wide Fan Beam**

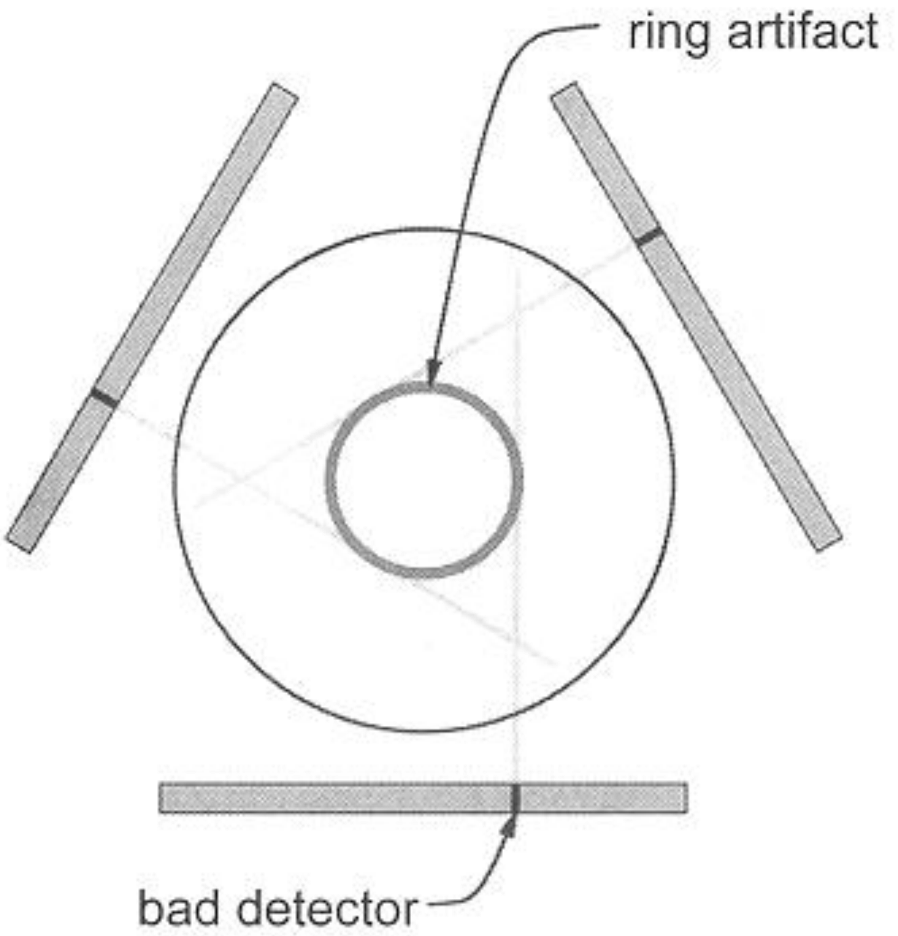
- **Number of detectors increased** substantially (to more than 800 detectors)
- Angle of fan beam increased to **cover entire patient**
  - Eliminated need for translational motion
- Mechanically joined x-ray tube and detector array **rotate** together
- Newer systems have scan times of **½ second**





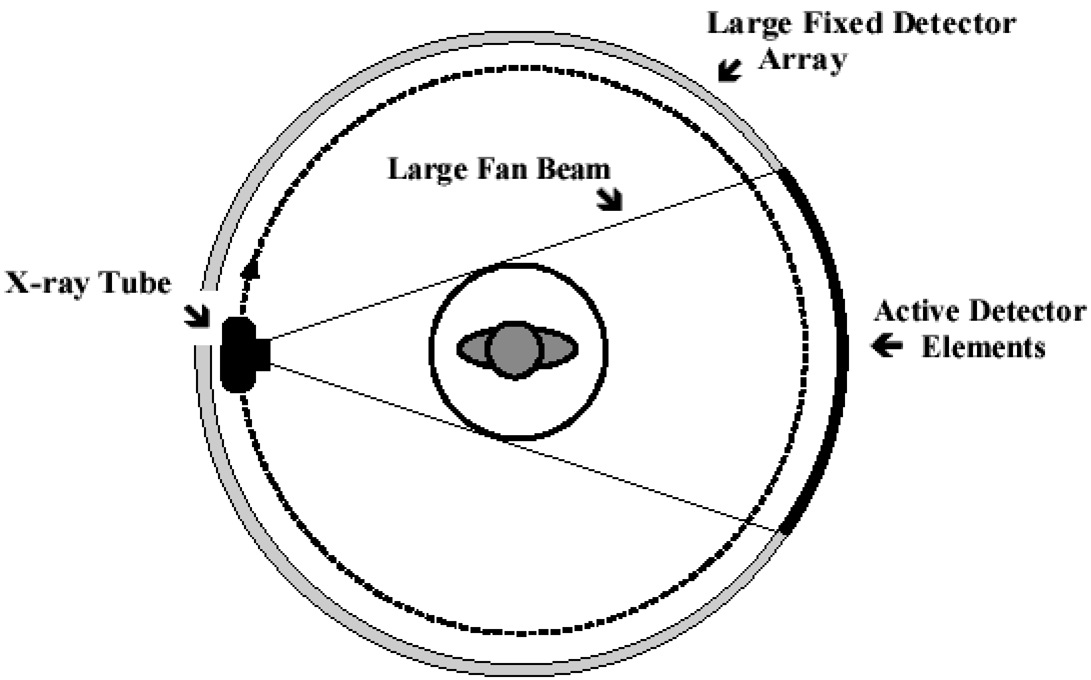
3rd Generation: Ring artifacts

- The rotate/rotate geometry of 3rd generation scanners leads to a situation in which **each detector is responsible for the data corresponding** to a ring in the image
- **Drift in the signal levels of the detectors** over time affects the μt values that are backprojected to produce the CT image, causing **ring artifacts**



CT Scanning Geometries-4th Generation

- The fourth generation of CT scanner uses a ***Rotate-Fixed Ring geometry*** where a ring of fixed detectors completely surrounds the patient (**a wide fan beam** and **a fixed ring detector**).
- ***Rotation***:
    - The X-ray tube rotates inside the detector ring through a full 360 degrees with a wide fan beam.
    - Only those detectors which see the beam are activated at any one time.
    - Scan time is comparable with third generation scanners.

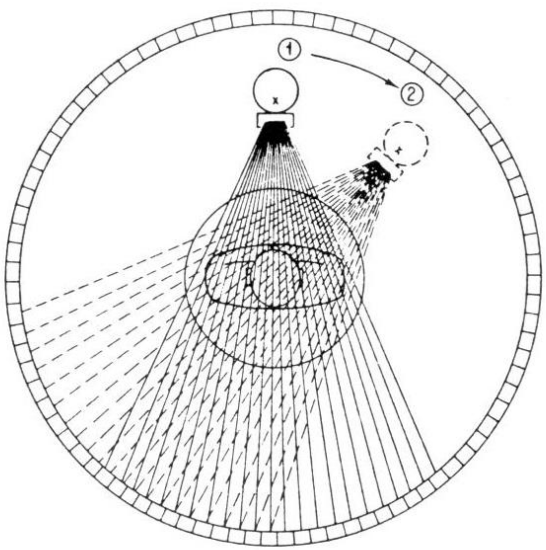


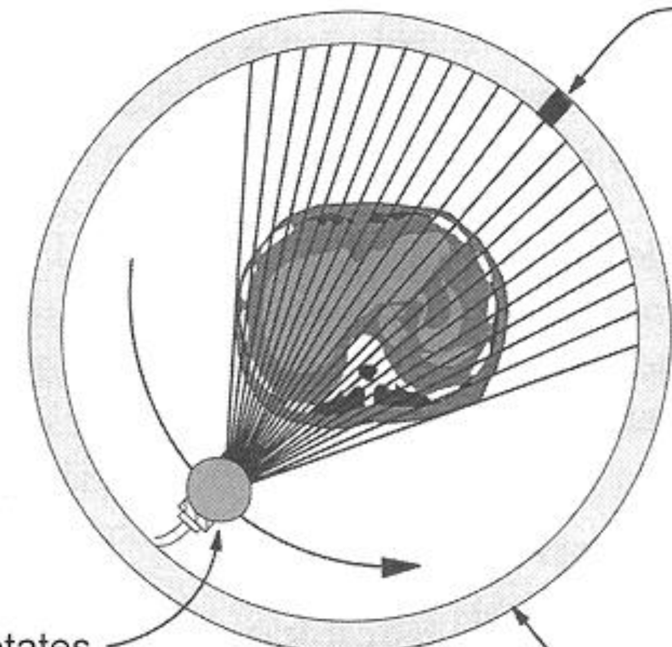
Fourth generation CT scanner design

From https://en.wikibooks.org/

4^{th} Generation: Rotate/Stationary

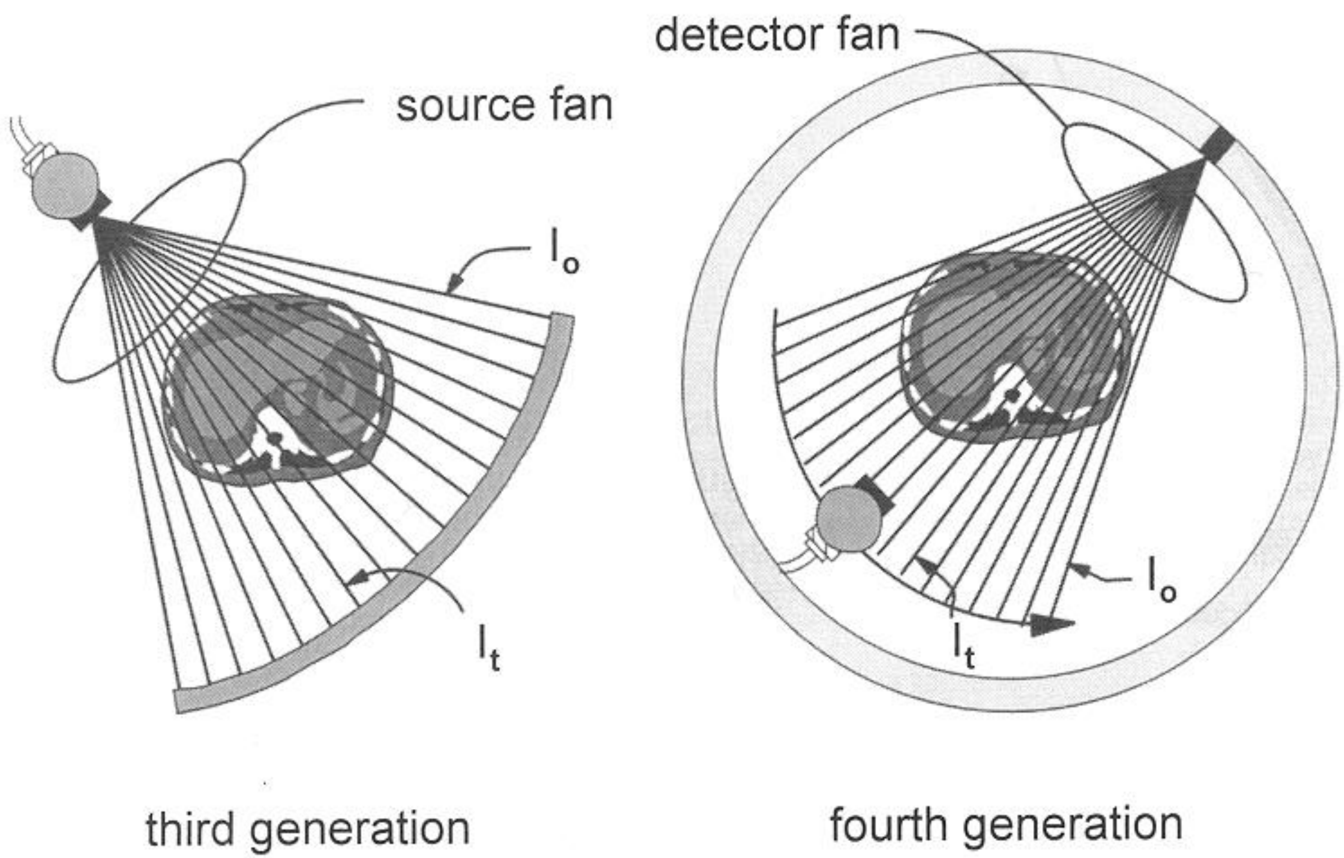
- Designed to **overcome the problem of ring artifacts**
- Stationary ring of about 4,800 detectors





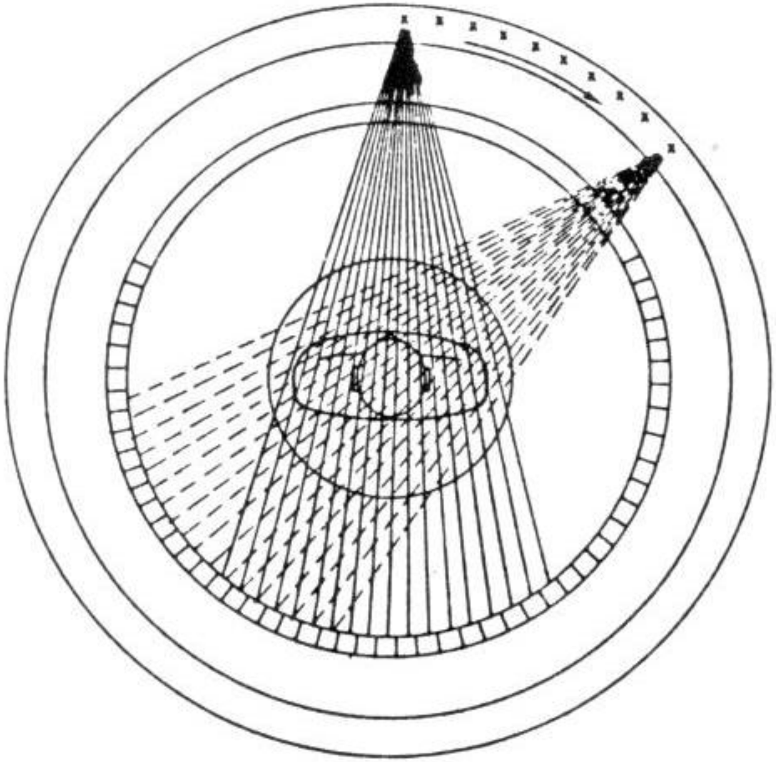
3^{rd} and 4^{th} Generation

- 3^{rd} generation fan beam geometry has the x-ray tube as the apex of the fan; 4^{th} generation has the individual detector as the apex



CT Scanning Geometries-5th Generation

- The fifth generation of CT scanner uses a ***Stationary-Stationary geometry*** (**a fixed beam ring and a fixed detector ring**).
- ***Rotation***:
  - 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 and ***can produce fast-frame-rate CT movies of the beating heart***.
  - ***Developed specifically for cardiac tomographic imaging.***

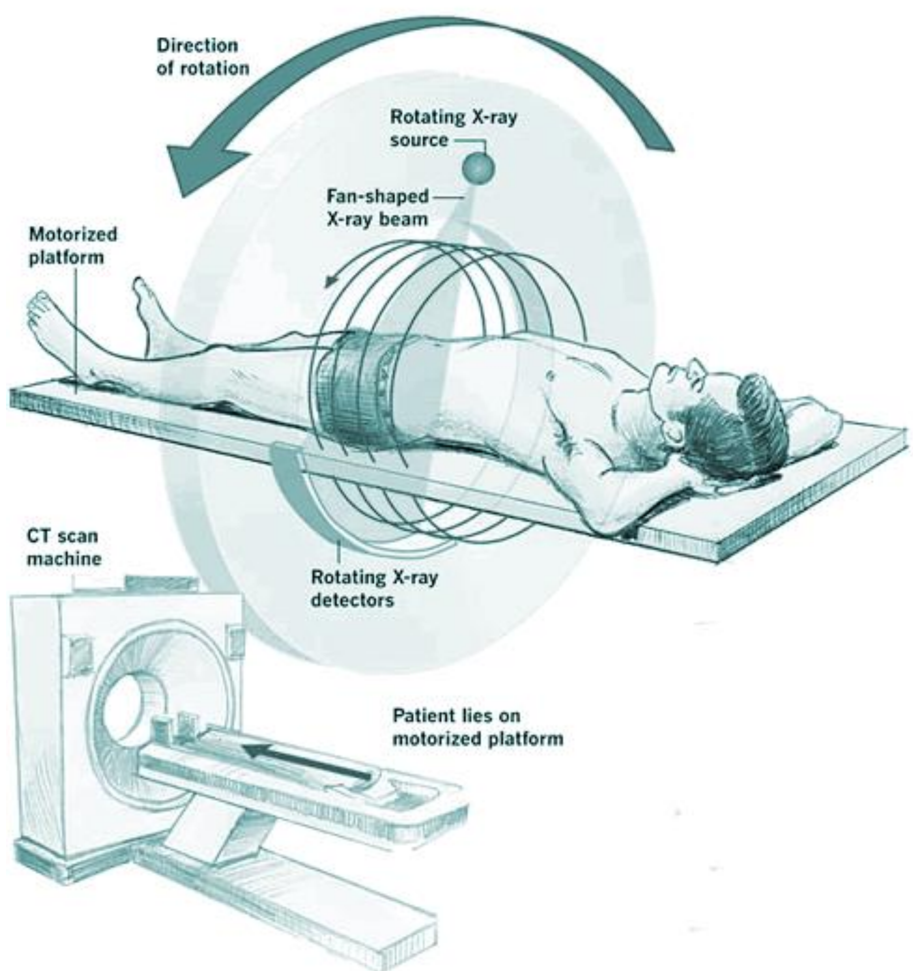


Fifth generation CT scanner design

From https://en.wikibooks.org/

CT Scanning Geometries-6th Spiral CT

- **Helical** (**spiral,螺旋**), CT was introduced in the early 1990s with the development led by Willi Kalender and Kazuhiro Katada.
- Helical CT scanners ***acquire data while the table is moving.***
- This allows more images to be made in a ***shorter time*** than with older CT methods, which is currently adopted by most modern hospitals.

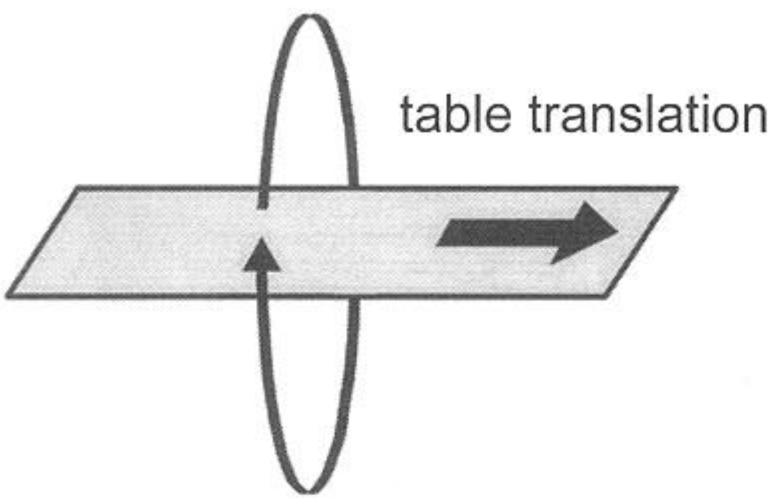


Spiral CT scanner design

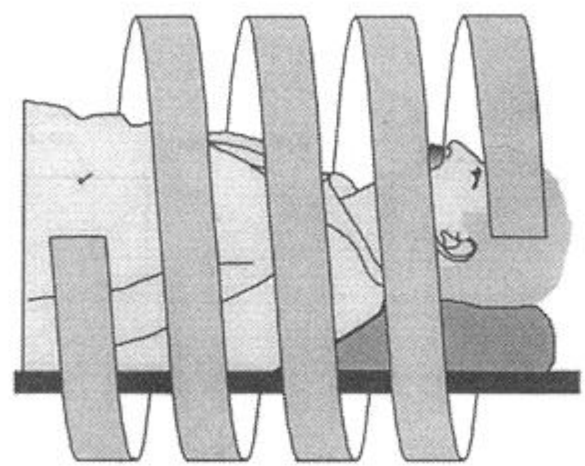
From https://www.quora.com/

CT Scanning Geometries-6th Spiral CT

- 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



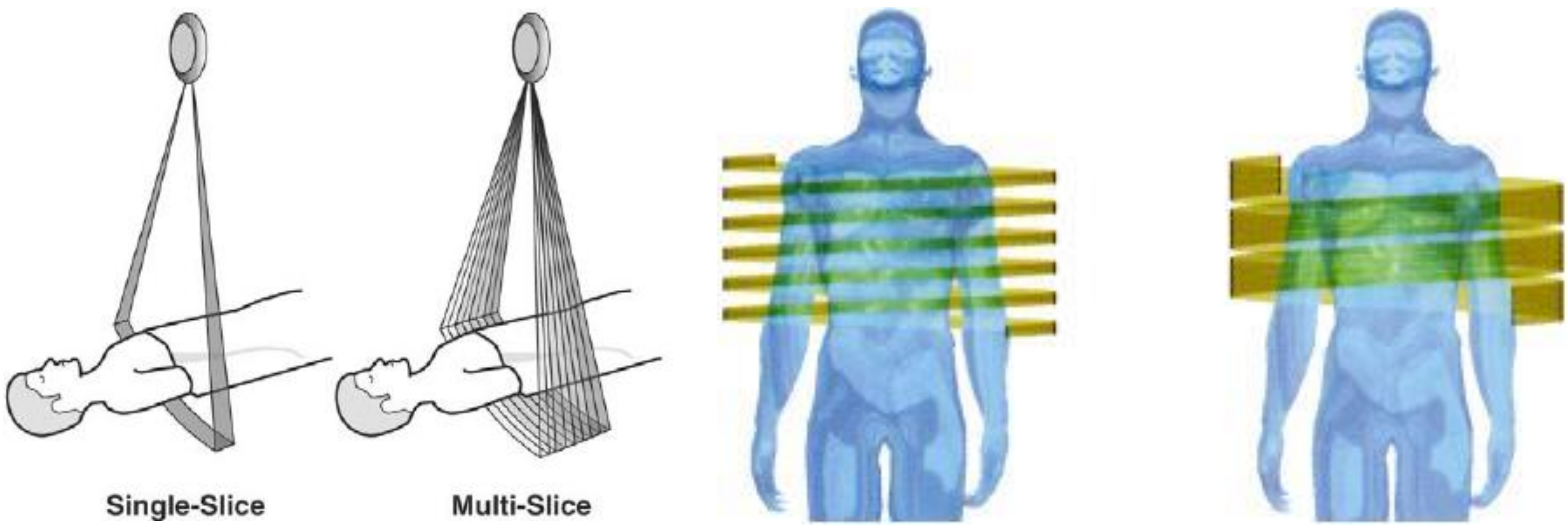
x-ray tube rotation



helical x-ray tube path around patient

CT Scanning Geometries-7th **Multi-slice** Spiral CT

- A single-slice CT scanner has only one detector row.
- In multislice CT, the detector consists of multiple rows that are stacked longitudinally and can be configured in one of several topologies for various choices of slice thickness.
- The x-ray source illuminates ***multiple rows simultaneously***, *e.g.*, a 16-slice scanner can read out 16 slices simultaneously.



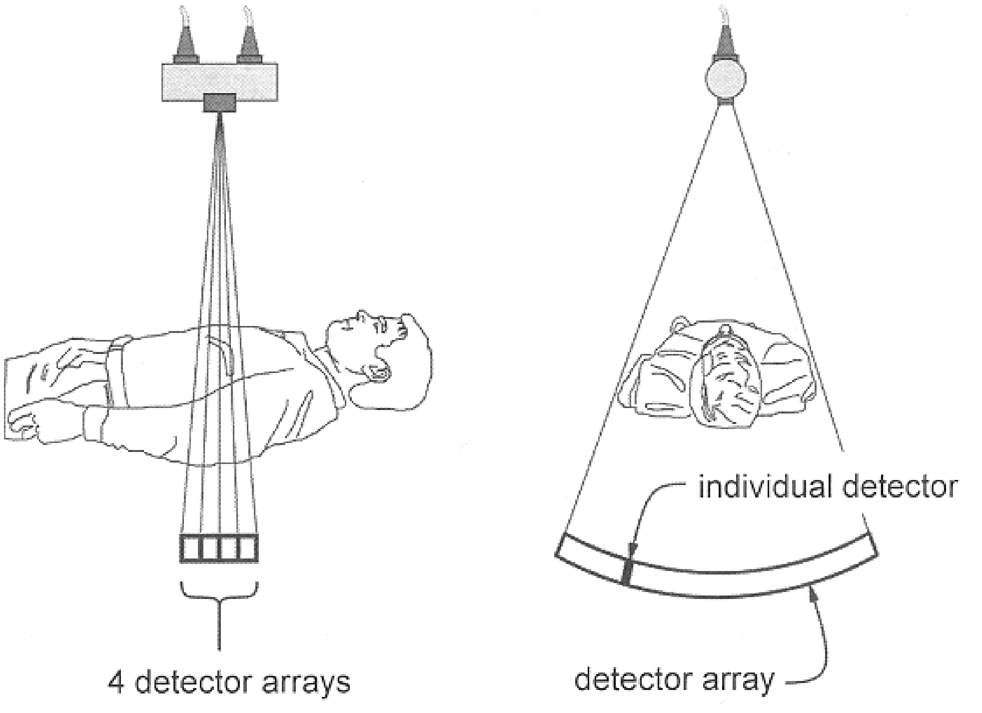
Multislice spiral CT scanner design

From https://www.researchgate.net/ From http://homepage.hispeed.ch/

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

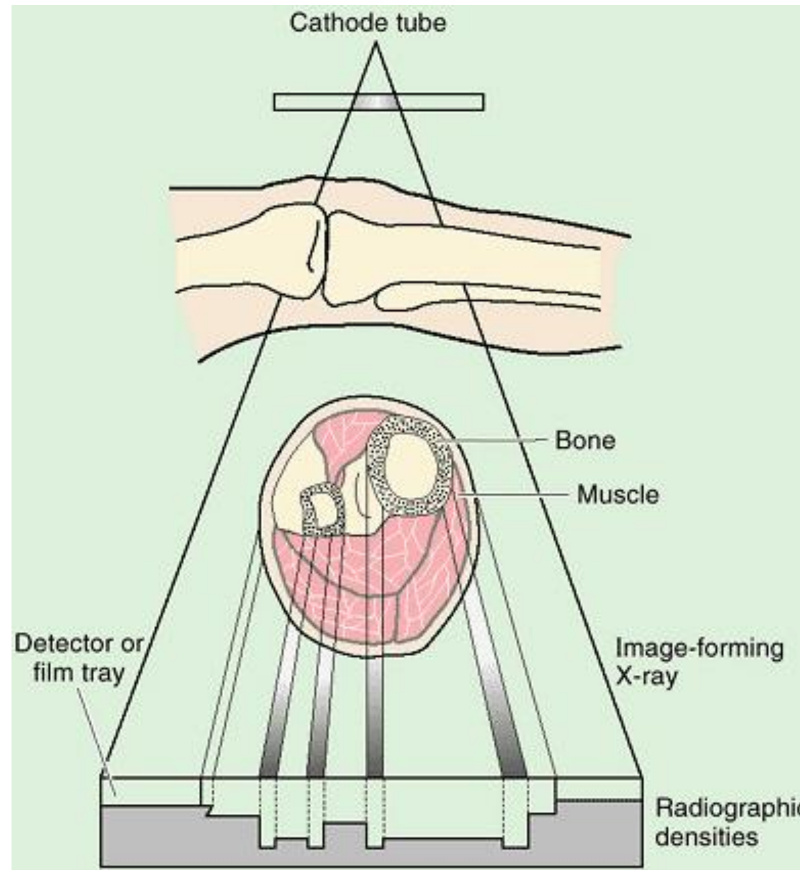


Outline

- Overview of Computed Tomography (CT)
- History of Computed Tomography
- **Data Acquisition**
    - Tube and detector move
    - **Multiple attenuation measurements are taken around the object**
- Image Reconstruction
- CT Scan Examination

Basic Principles

- Plain film imaging reduces the **3D** patient anatomy to a **2D** projection image
- **Density** at a given point on an image represents the **x-ray attenuation properties** within the patient along a line between the x-ray focal spot and the point on the detector corresponding to the point on the image



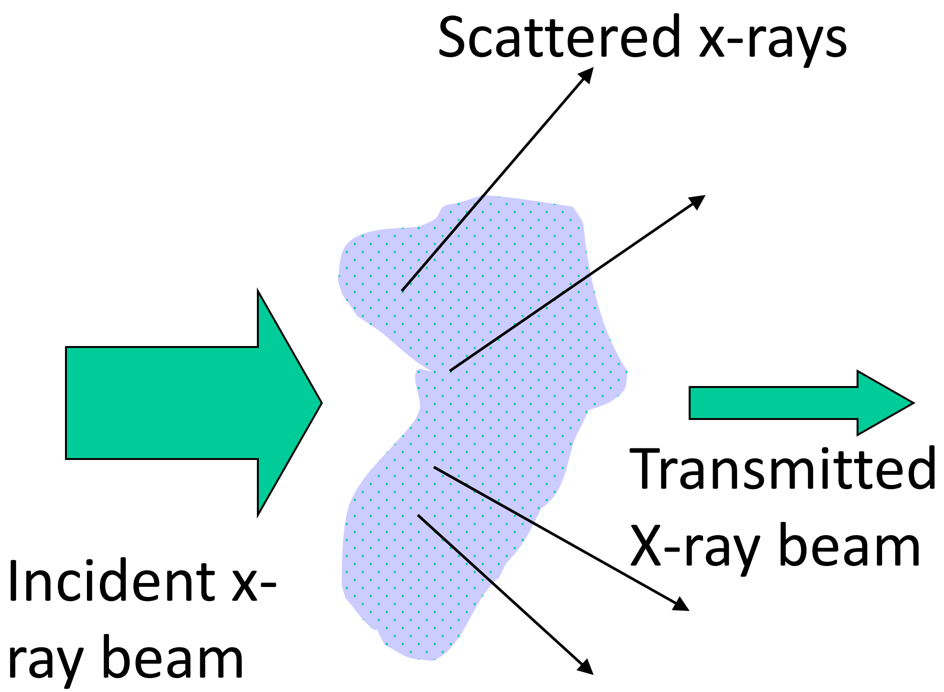
Understanding Basic factors

Absorption: stopping of x-rays with transfer of energy

Scatter: deflection of x-rays

Incident Intensity: Number of x-ray photons falling on an object

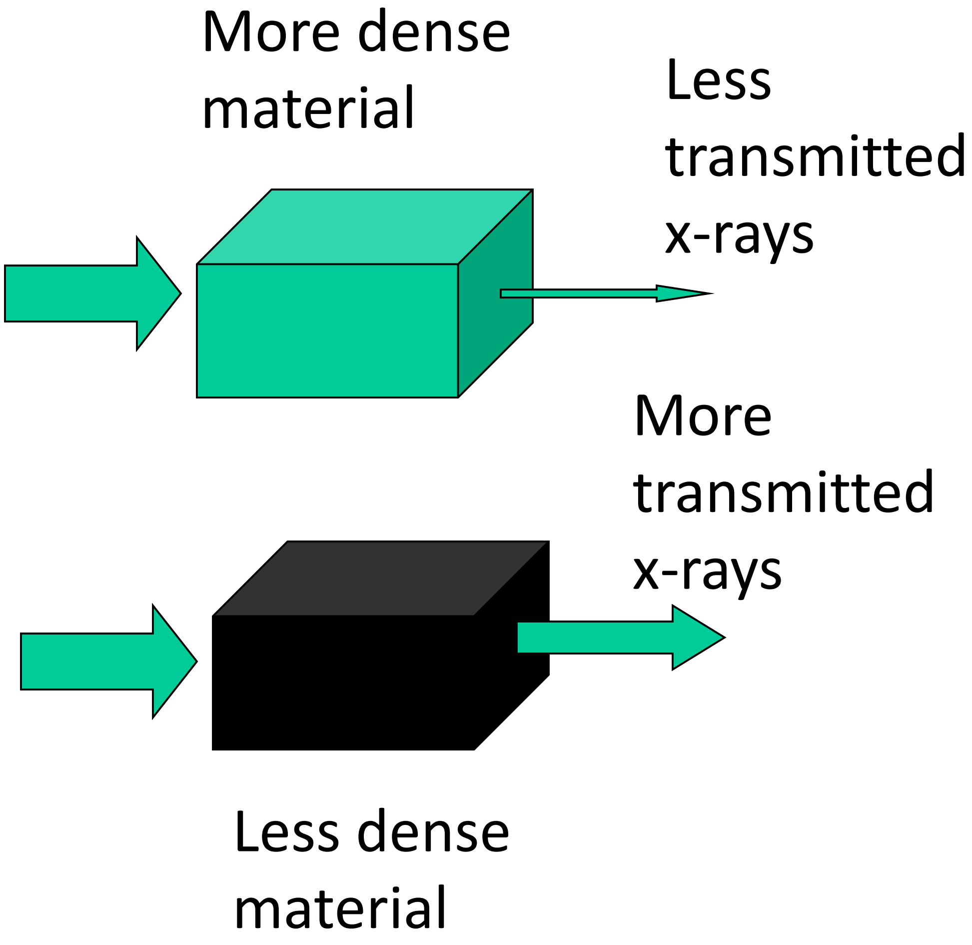
Transmitted Intensity: Number of photons passing through



Attenuation

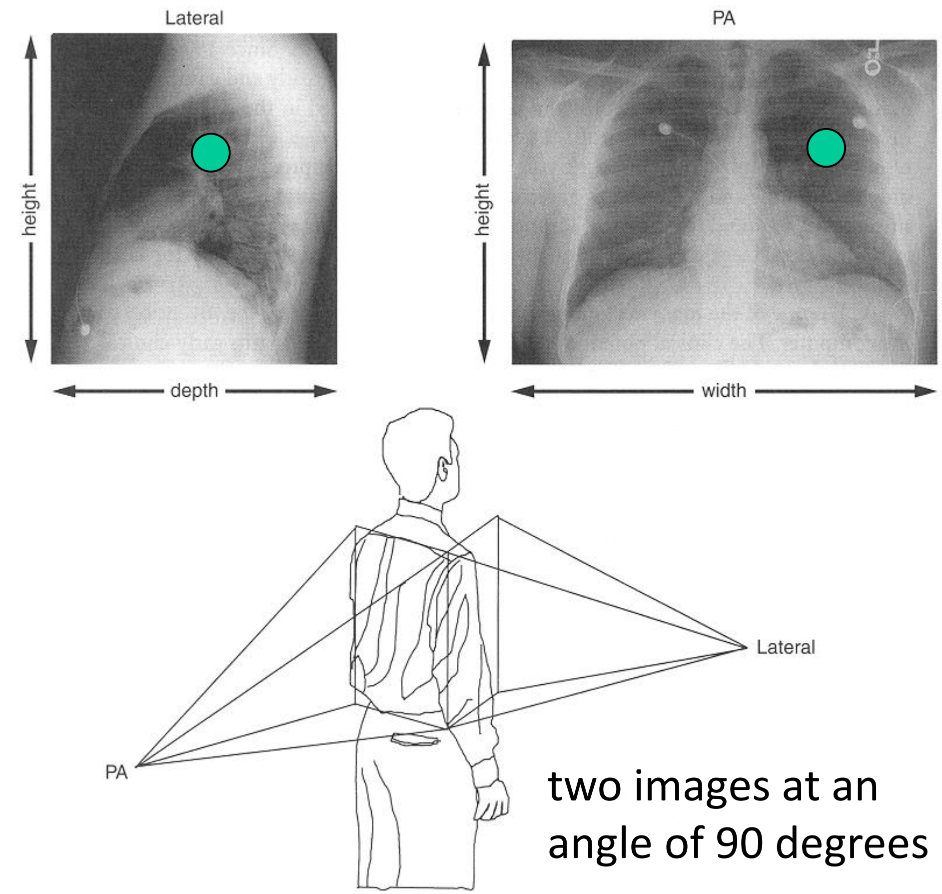
The reduction of the beam intensity on passing through the material due to **absorption plus scatter**

The degree of attenuation is obtained by measuring and comparing the **incident and transmitted intensities**



Basic Principles

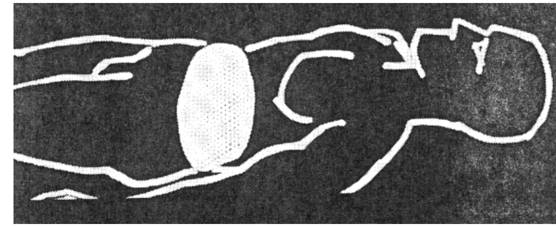
- With a conventional radiograph, information with respect to the dimension **parallel to the x-ray beam is lost**
- Limitation can be overcome, to some degree, by acquiring **two images at an angle of 90 degrees** to one another
- For objects that can be identified in both images, the two films provide **location information**

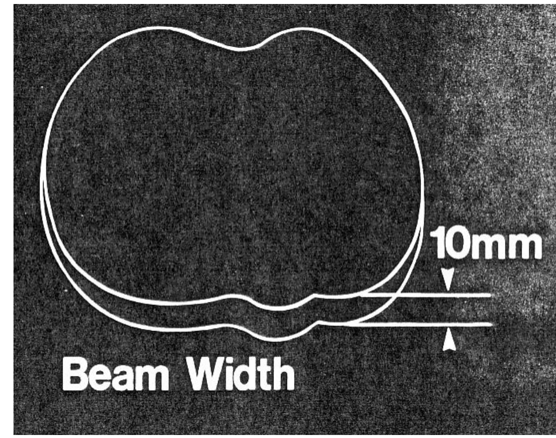


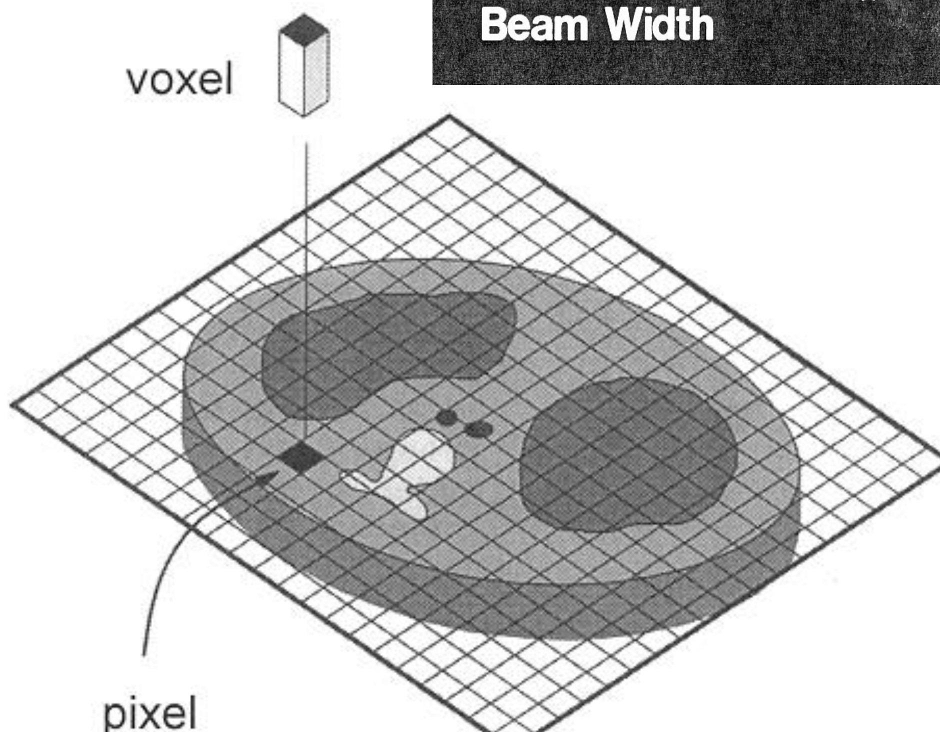
two images at an angle of 90 degrees

Tomographic images

- The tomographic image is a picture of a **slab** (厚片) of the patient’s anatomy
- The 2D CT image corresponds to a **3D section** of the patient
- CT slice thickness is very **thin (1 10 mm)** and is approximately **uniform**
- The **2D array of pixels** in the CT image corresponds to an equal number of **3D voxels** (volume elements) in the patient
- Each pixel on the CT image displ the **average x-ray attenuation properties** of the tissue in the corrsponding voxel



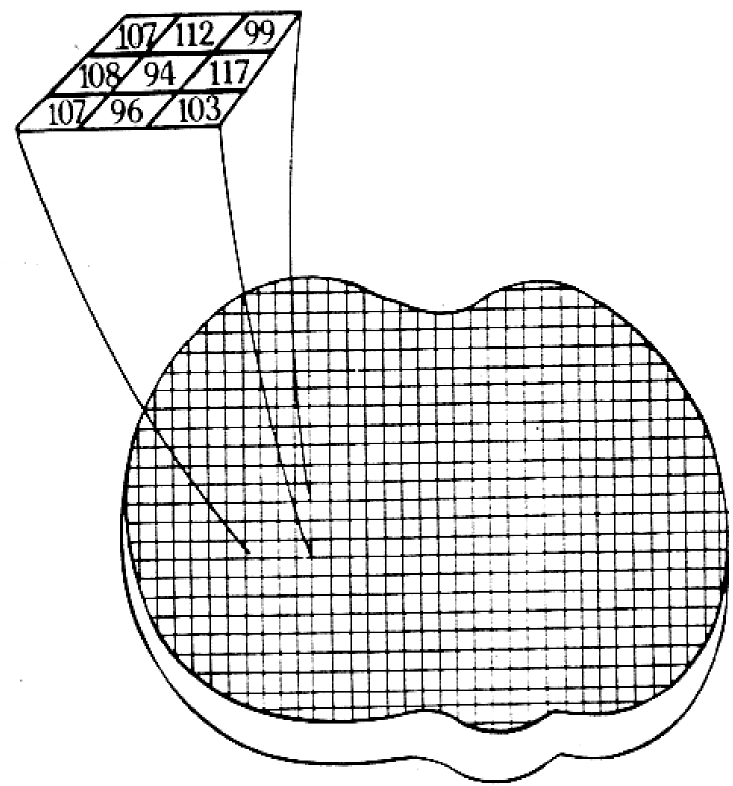




CT numbers

The numbers in the image matrix are called **CT numbe**

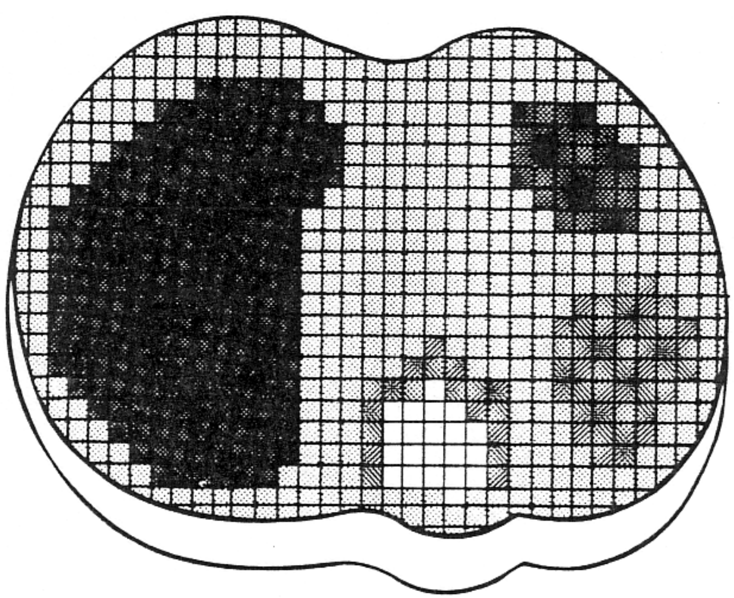
Each **pixel** has a number which represents the **x-ray attenuation** in the corresponding **voxel** of the object



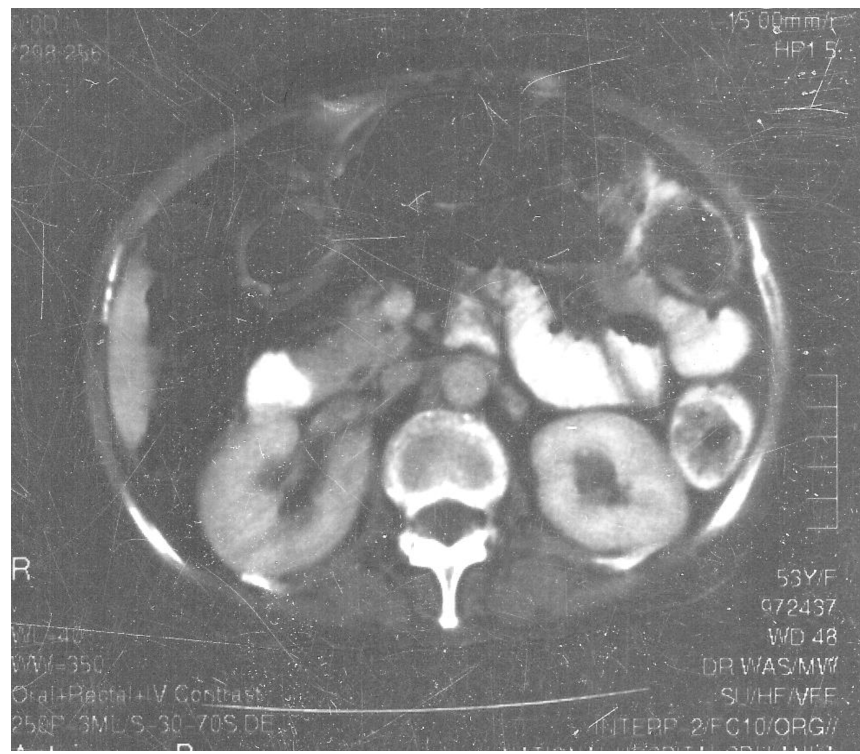
Visual image & Gray Scale

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**

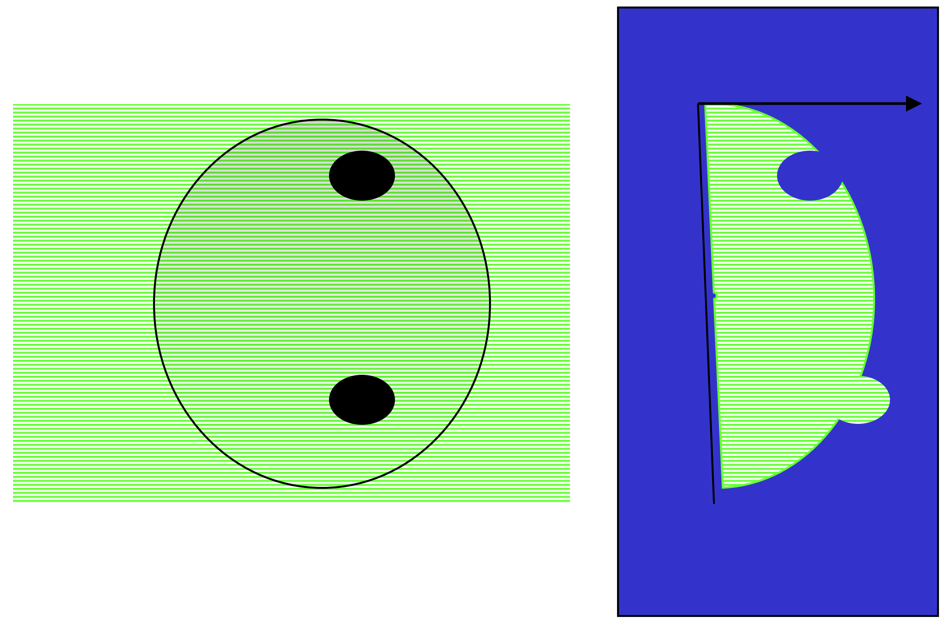


Gray Scale



Attenuation Profile of Different Structures

Attenuation of objects with **different densities** will change the **attenuation profile**

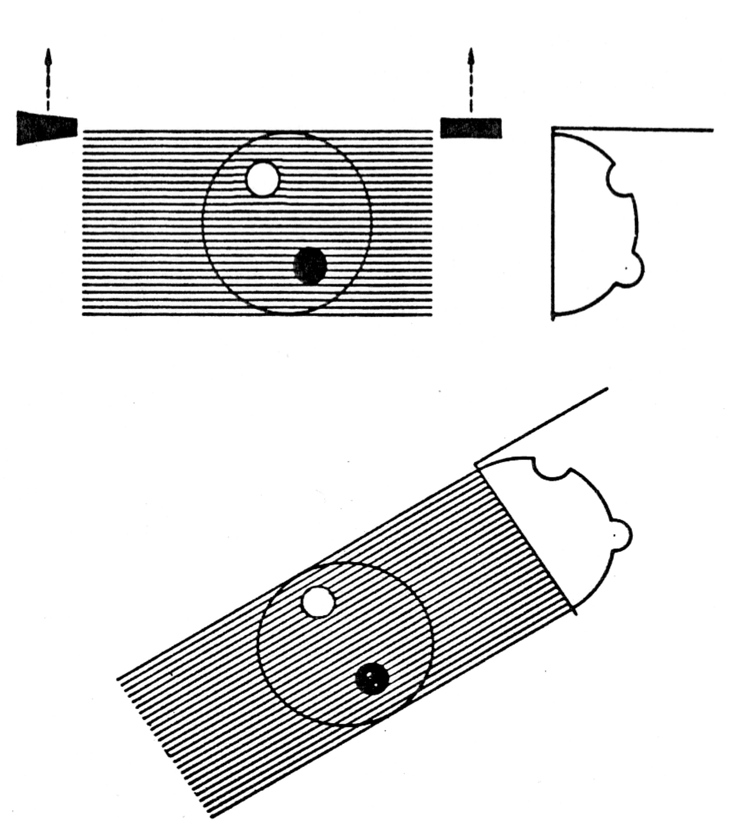


Object with low attenuation

Object with high attenuation

Attenuation Profile of Different Structures

In a translate – rotate CT, after a view is recorded, the **tube and detector rotate a small angle** and the entire process is repeated until many views have been recorded for the same slice



Views & Attenuation Profiles for a Slice