Medical Imaging

Presented by

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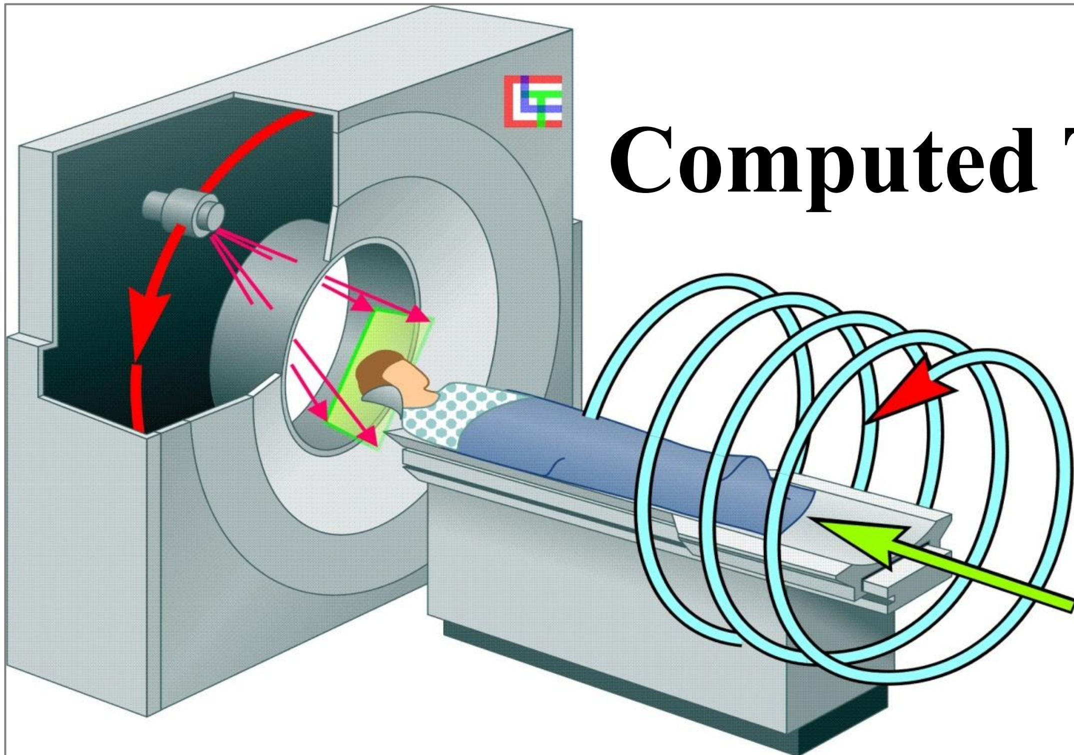
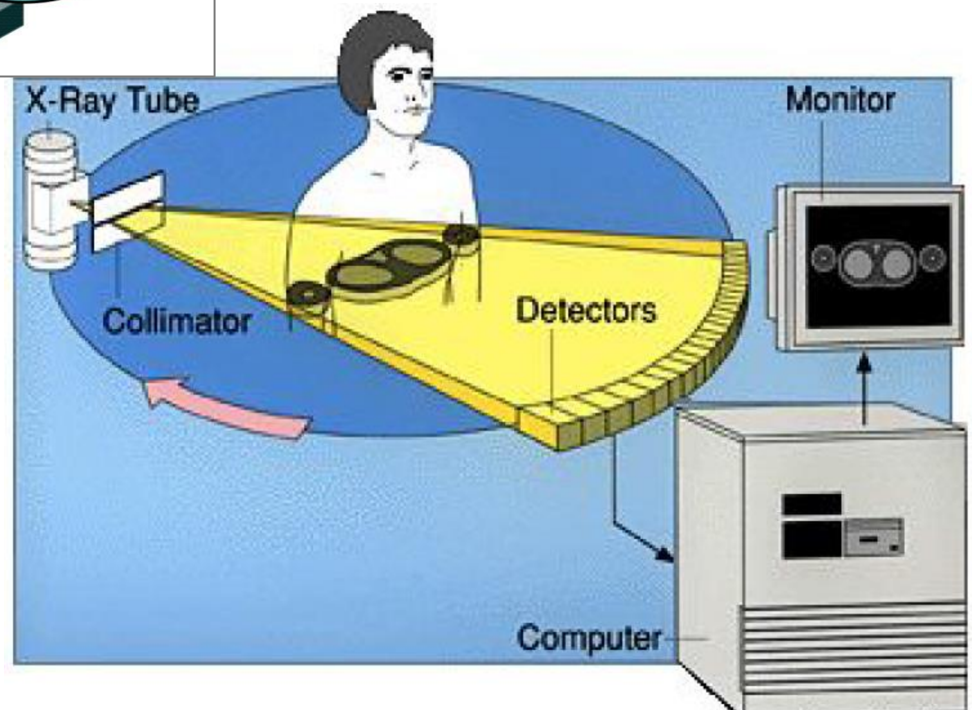
Second-year students

Computed Tomography (CT)



Instead of a single projection X-Ray, computed tomography (CT) provides many projections at different angles looking through the object.

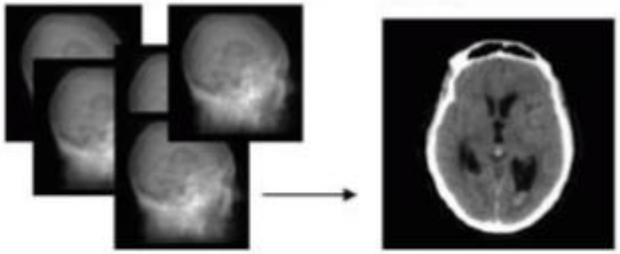
These projections enables the reconstruction of the 3D object (or a cross-sectional 2D slice) and they can be recorded by the computer.



History: Computed Tomography

CT reconstruction pioneers:

- 1917: Johann Radon establishes the mathematical framework for tomography, now called the Radon transform.
- 1963: Allan Cormack publishes mathematical analysis of tomographic image reconstruction, unaware of Radon's work.
- 1972: Godfrey Hounsfield develops first CT system, unaware of either Radon or Cormack's work, develops his own reconstruction method.
- 1979 Hounsfield and Cormack receive the Nobel Prize in Physiology or Medicine.



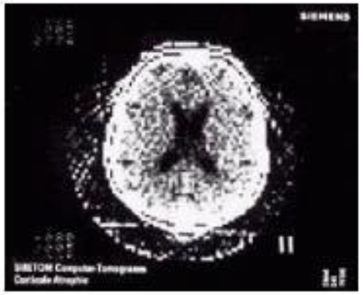
- The first clinical CT scanners were installed between 1974 and 1976. The original systems were dedicated to head imaging only, but "whole body" systems with larger patient openings became available in 1976. CT became widely available by about 1980.

Computed Tomography: Past and Present

Image from the Siemens Siretom CT scanner, ca. 1975

- 128x128 matrix.

Original CT image (128x128) from the CT scanner circa 1975. In 1975 physicians were fascinated by the ability to see the soft tissue structures of the brain.



Modern CT image acquired with a Siemens scanner

- 512x512 matrix

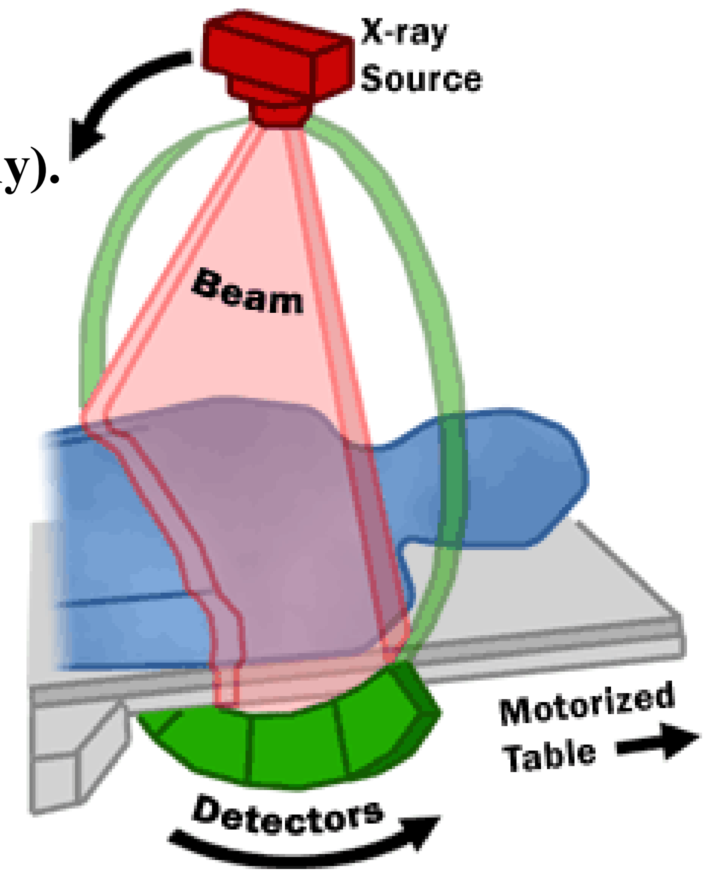
CT image (512 x 512) using a state-of-the-art CT system. Note the two black "pea-shaped" ventricles and the subtle delineation of gray and white matter.

Questions

- What is it?
- How does it work?
- What good is it?

Computer Tomography: What is it?

- Computed tomography (CT) is an imaging procedure that uses (X-Ray source and detector) **system** to create detailed pictures, or scans, of areas inside the body.
- CT provides an examination that uses X-Ray and computer to obtain a cross-sectional image of the human body.
- Computed tomography is also known as **"CAT scanning" (Computed Axial Tomography).**
- **Tomography** is from the Greek word **"tomos" meaning "slice" or "section"** and **"graphia" meaning "describing".**



Computed Tomography (CT)

- Tomography:
  - image of slice /section
  - removes “overlaying structure"
  - improves contrast within slice /section
- Computed:
  - requires computer
  - reconstruction algorithm

Computer Tomography (CT): What is it?

- A single 1-D projection is not informative

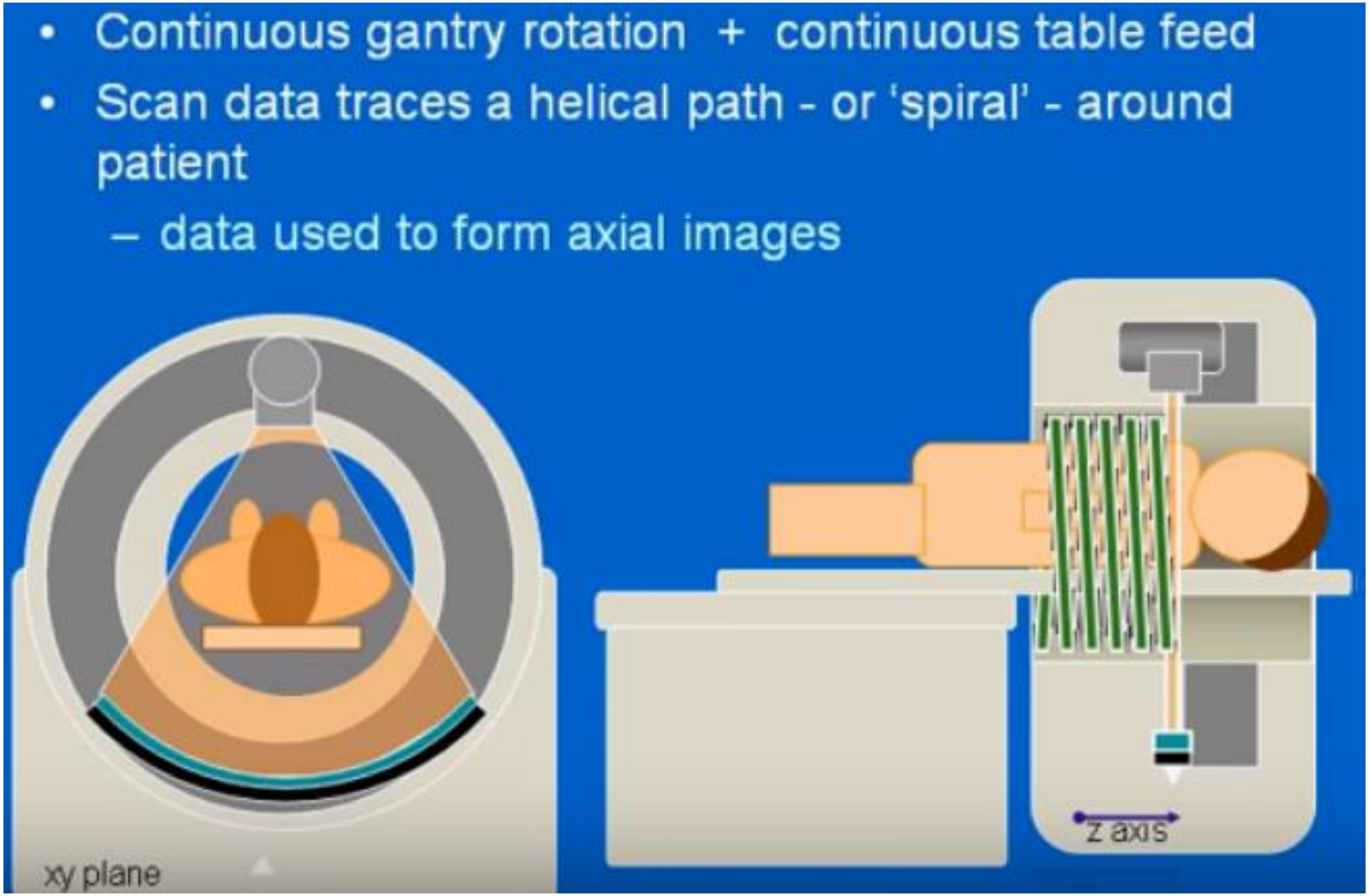
Therefore, CT resolved a single slice of an object using many X-Ray projections.

- Many 1-D projections
  - permit slice reconstruction
  - many angular views is the key

As the gantry rotates, the scanner collects a 1D X-Ray at each angle.

- Two major advantages of CT over radiographs:
  1. The rotating x-ray source allows one to see ***behind*** structures.
  2. The use of digital detectors produces a digital signal which is significantly more sensitive than film to differences in ***contrast***.

Computer Tomography (CT): What is it?



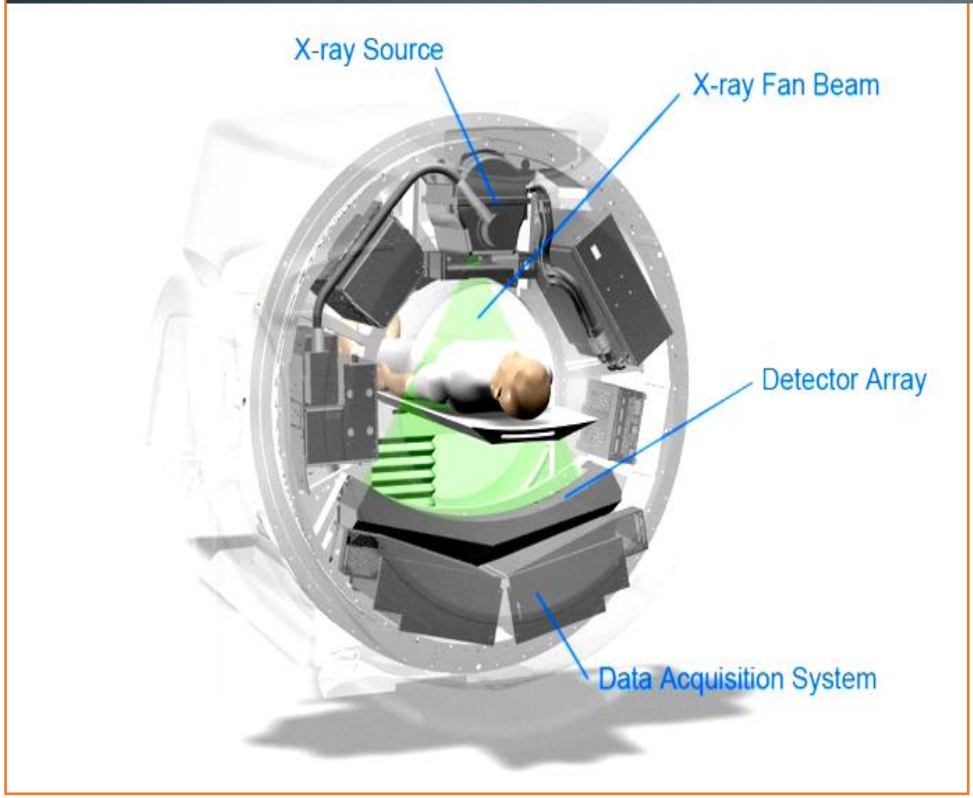
Working Principle

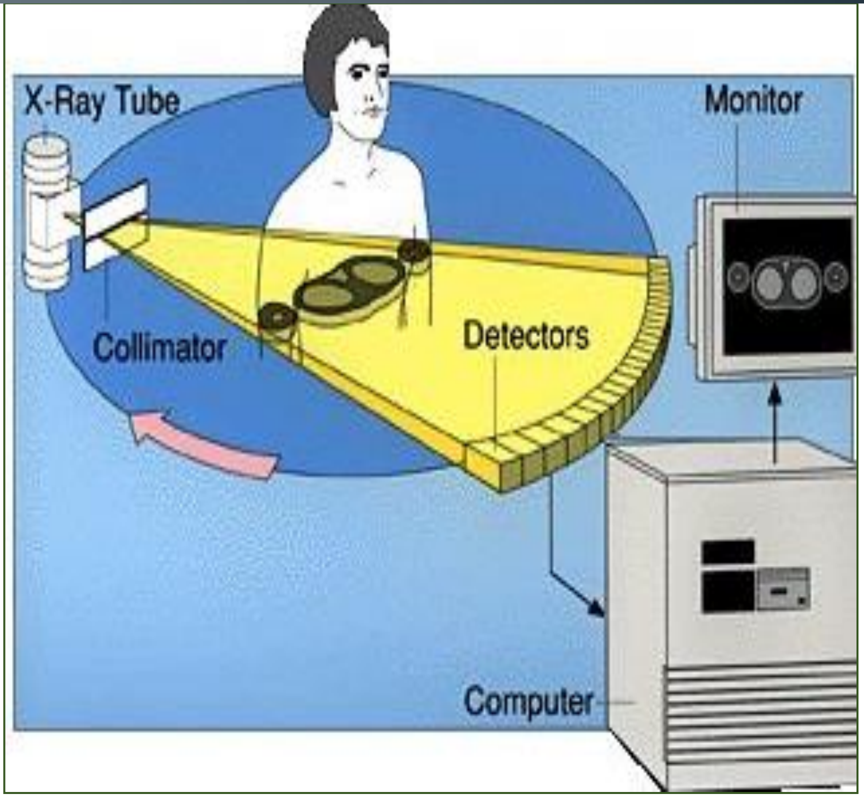
- Beams from one or several small X-ray sources are passed through the body and intercepted by one or more radiation detectors.
- These radiation detectors produce electrical impulses that are proportional to the intensity of the X-ray beam emerging from the body.
- The intensity of the X-ray beam exiting the body is determined by:

1. The energy of the X-ray source.
2. The distance between the source of X-rays and the detector.
3. The attenuation of the beam by materials in the object being scanned.

- The efficiency of the scanning system can be increased multiple folds by using multiple X-ray beams and equivalent number of detectors.
- Each scan produces a penetration or absorption profile. However, construction of the image requires profiles obtained at different angles through the patient under study. The X-ray source and detector assembly are rotated around the patient (360^o) to produce multiple profiles of the particular site of interest.

Components of CT Scan





Gantry

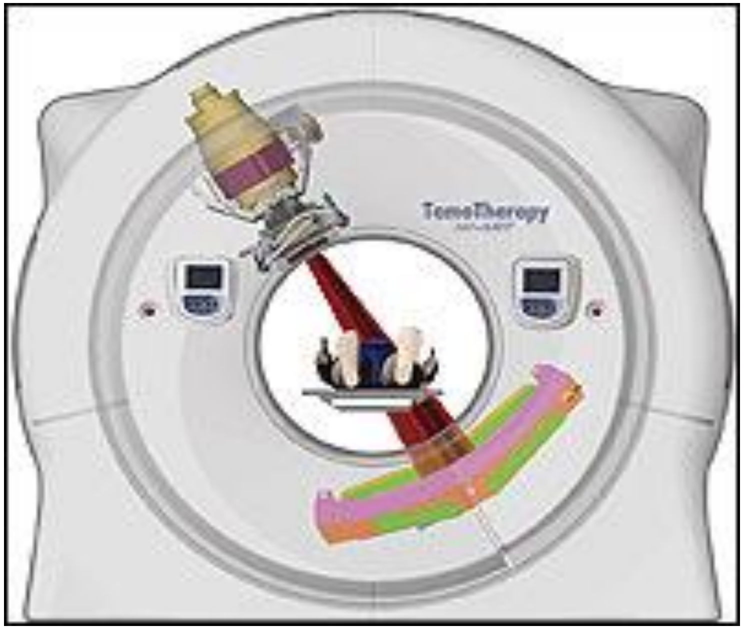
- The gantry assembly is **the largest** of these systems.
- Can be **tilted upto 300 degree**.
- It is made up of all the equipment related to the patient, including:

  -the patient **Support,**

  -the **Positioning couch**,

  -the **Scanner housing**.

  -heart of the CT scanner, **the X-ray Tube**, as well as **Detectors** that generate and detect x rays

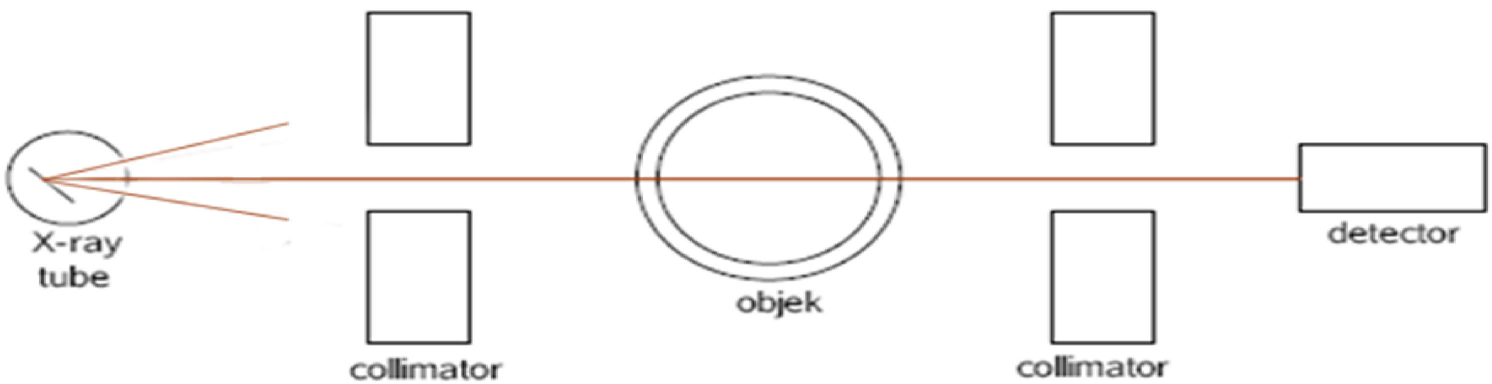


The CT X-ray Tube

- Tubes operates with three phase or high frequency generators and rotating anode.
- Operates at 120 kVp and 200-800 mA.
- High X-Ray output reduces the exposure time and improves image quality as well as decrease bone absorption.
- Focal spot size ranges from 0.5 to 2mm
- **Low slice thickness** result in **higher spatial resolution and contrast, less partial volume artifact** and higher patient dose.

Collimator

- Thin fan shaped Collimator is used to reduce exposure.
- Post patient collimator are also used to remove the scattered photons as well as control slice thickness that ranges from 1 to 3 mm.
- The x-ray beam is collimated at two points ,one close to the x-ray tube and the other at the detector. **The collimator at the detector is the sole means of controlling scatter radiation**. The collimators also regulate the thickness of the tomographic section.



Detectors

- Made up of multiple discrete cells or detectors .
- Capture energy that has not been attenuated by the patient
- Two types of detectors are used

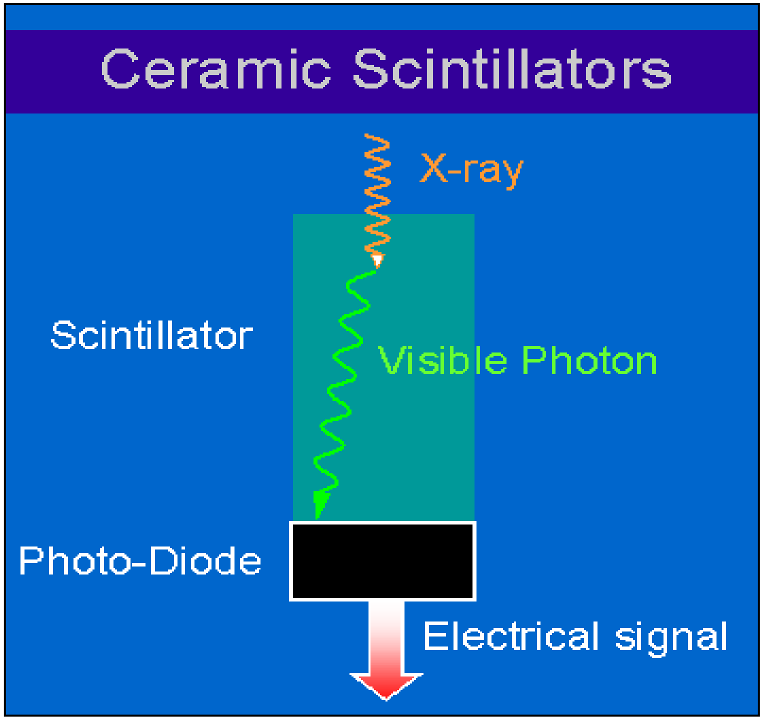
1. Crystal Scintillation Detectors
2. Gas Filled Detectors

FYI: Scintillation Detectors

Coupled optically to photodiode

Materials Used

I. Sodium Iodide
II. Bismuth Germanium Oxide
III. Cesium Iodide
IV. Cadmium Tungstate



Data Acquisition System (DAS)

The DAS consists of the following parts:

- X-ray photons come on the detector.
- The detector detects the intensity in form of current.
- The current is converted into voltage.
- The analog integrator removes spikes.
- The analog signal is converted into digital form.
- This signal can now be processed and reconstructed in the computer.

Image Reconstruction

- After enough transmission measurements (detector)
- Sent to the computer for processing
- A software called **Fourier Slice Transform** is used.
- Many reconstruction algorithms could be used (example: algebraic reconstruction technique) to compute the image.

Operating Console

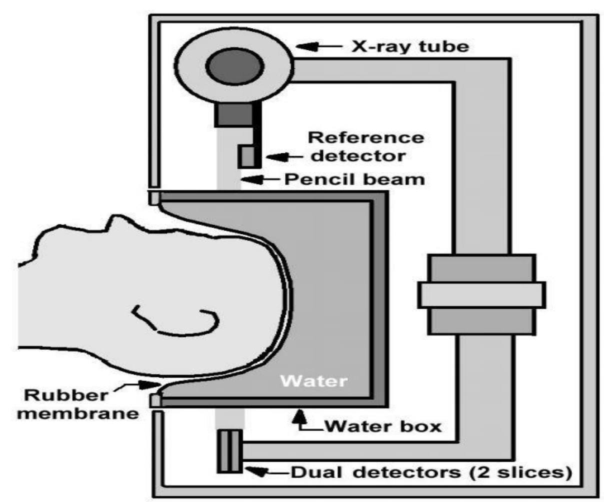
- It is master control center of the CT scanner.
- It is used to input all of the factors related to taking a scan.
- Typically, this console is made up of a **computer, a keyboard, and multiple monitors.**
- Often there are **two different control consoles**, one used by **the CT scanner operator**, and the other used by **the physician**.

Operational modes (Generations of CT)

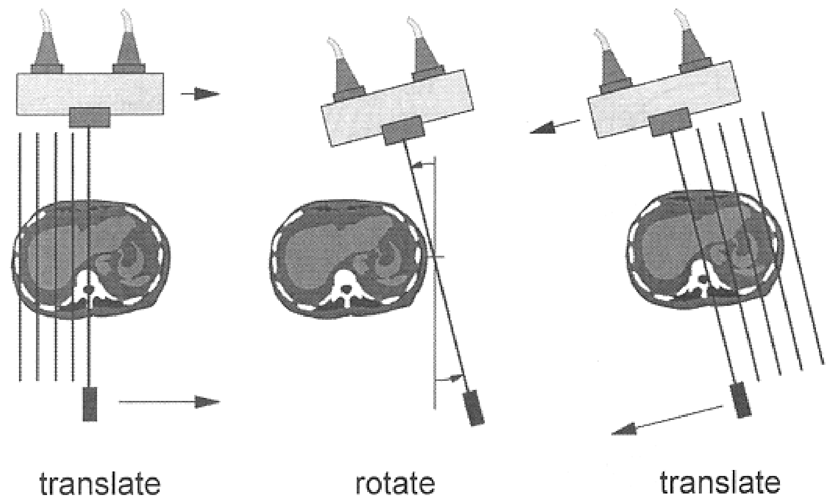
- **First-generation scanners of CT**
- **Second-generation scanners of CT** : Reducing Scan time
- **Third-generation scanners of CT** : Rotate/rotate, wide fan beam
- **Fourth-eneration scanners of CT**
- **Fifth-generation scanners of CT** : ELECTRON-BEAM CT (EBCT)
- **Sixth-generation scanners of CT** : Slip ring Scanners/Helical/Spiral CT
- **Seventh-generation scanners of CT** : Multiple detector array

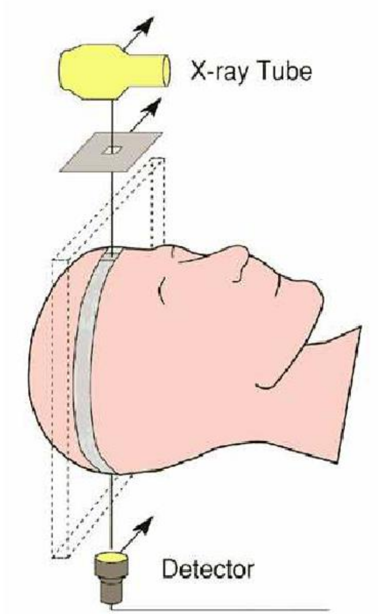
Operational modes
1. First-Generation scanners

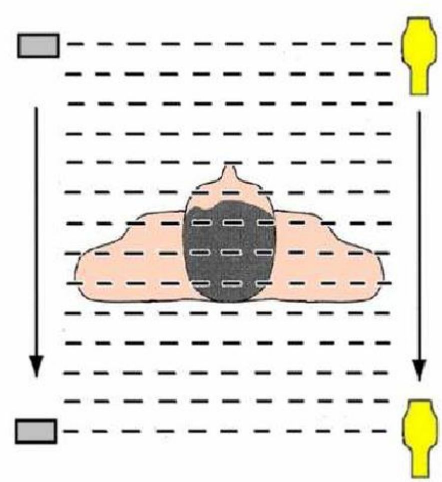
- It was a dedicated head scanner in which the patient's head was recessed via a rubber membrane into a water-filled box.
- X-ray beam (Pencil beam geometry) allowed very efficient scatter reduction, use single detector.
- Only 1 x-ray detectors used
- Scan time almost 5 min (about 4.5 minutes/scan with 1.5 minutes to reconstruct slice).
- The system (X-ray tube-detector) translating across the patient and rotating between successive translations.
- It required 180-translations.
- Each translations separated by a 1 degree rotation.



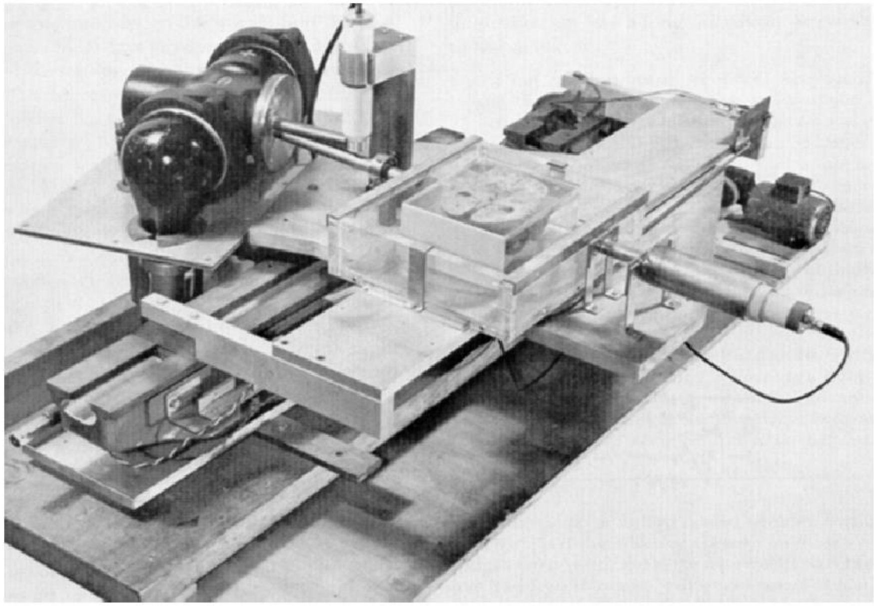
1st Generation CT : Parallel Projections





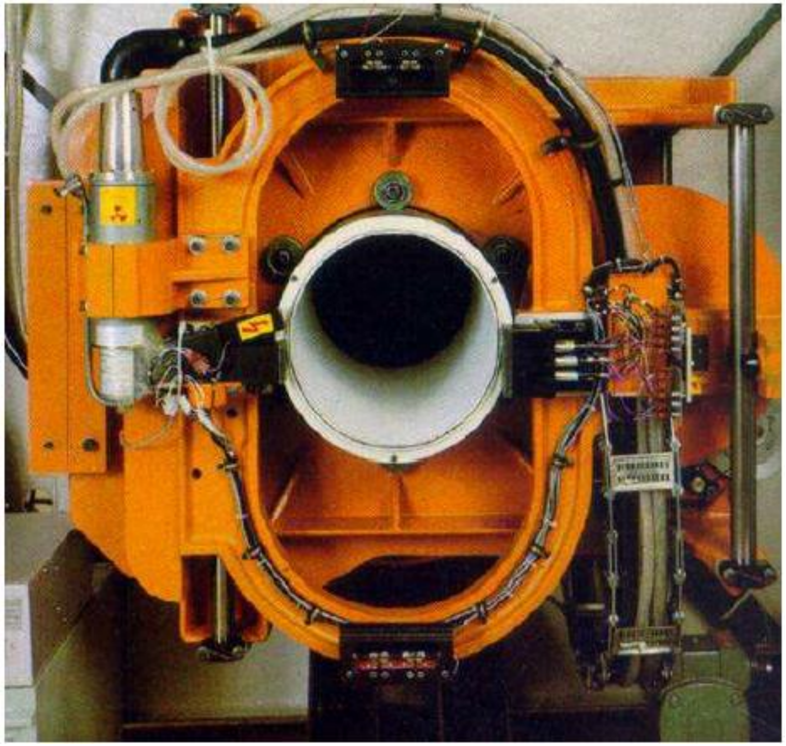


1st Generation CT: Parallel Projections



Operational modes
2. Second-Generation scanners

- The first waterless full-body CT scanner.
- Fan shaped X-ray beam, translate rotate mode (each translations separated by a 1 degree rotation or more).
- Narrow fan beam allows more scattered radiation to be detected.



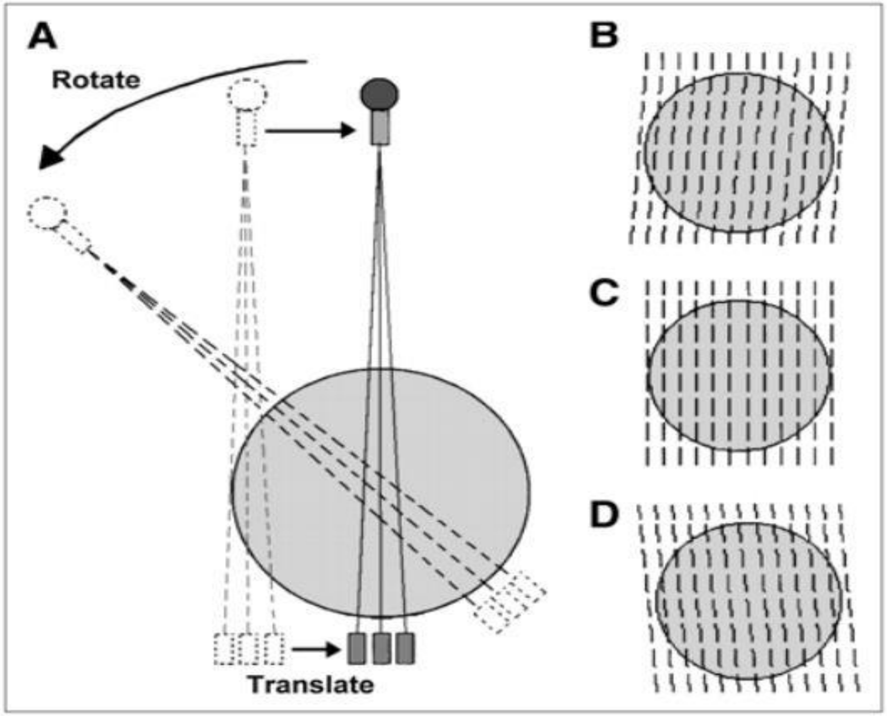


FIGURE 7.

Second-generation data collection. (A) Transmissions of multiple narrow beams (3, in this case) were simultaneously acquired by multiple detectors during each translation. (B–D) Small angle between narrow beams allowed each detector to acquire complete separate view at different angle. Number of required translations was correspondingly reduced by factor of 1/(number of detectors).

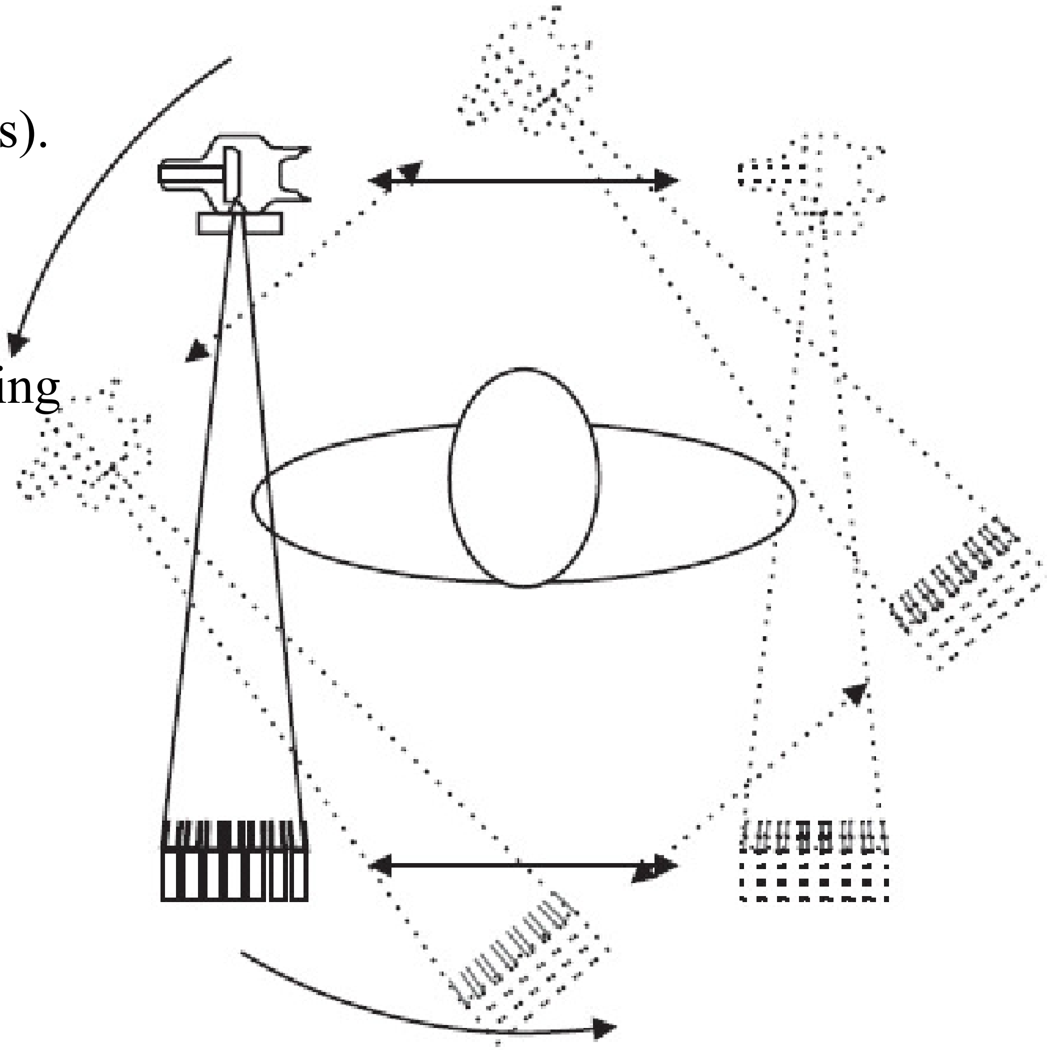
2^{nd} Generation OF CT

- o Incorporated linear array, use **multiple detectors** (30 detectors).
- o Sill translate-rotate:

\- One view acquired per detector (~1° apart).

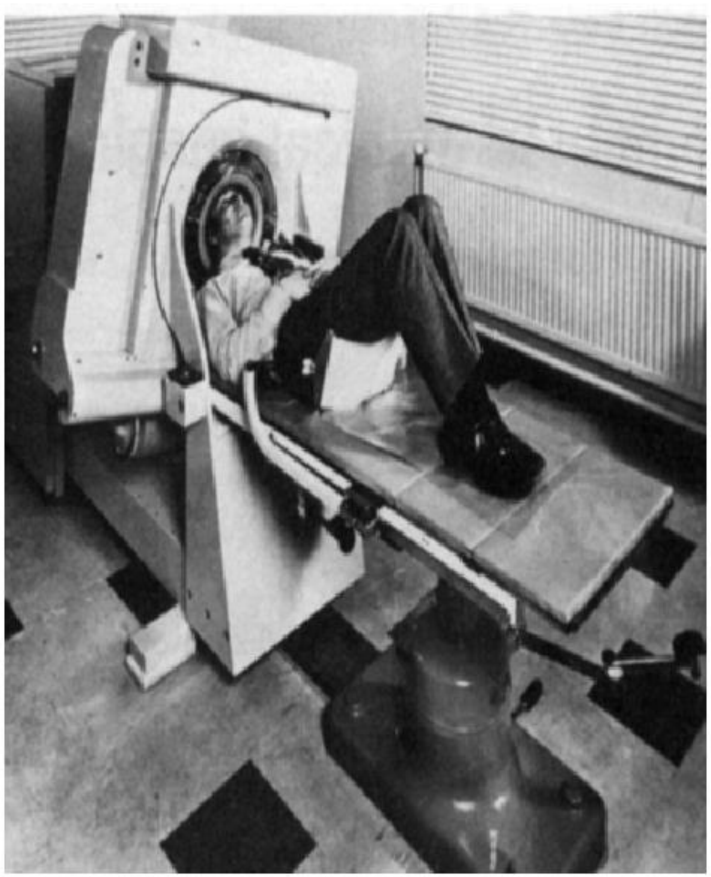
\- Angular increment increased by using more detectors.

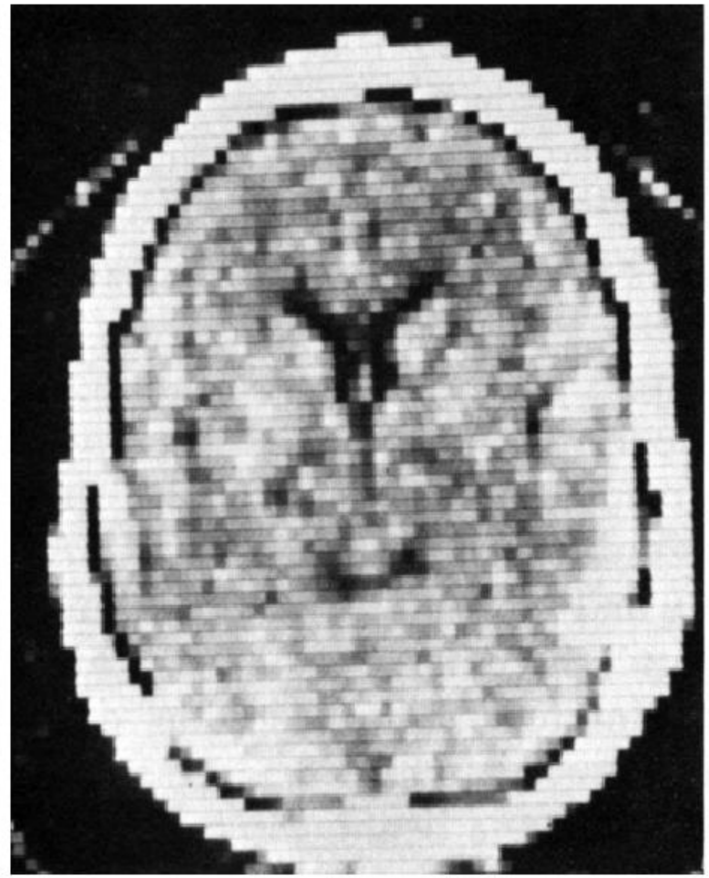
- o More data acquired to improve image quality (600 rays x 540 views)
- o Shortest scan time was 18 seconds/slice
- o Scan time: 10-90 sec.



2^{nd} Generation

EMI Mark 1 - 1971





Operational modes
3. Third-Generation scanners

- Number of detectors increased substantially (to more than 800 detectors)
- Angle of fan beam increased to cover entire patient
- The system is rotated concentrically around the patient.
- Mechanically joined x-ray tube and detector array rotate together
- Newer systems have scan times of ½ second
- Much faster than 2nd Generation.

3rd Generation of CT

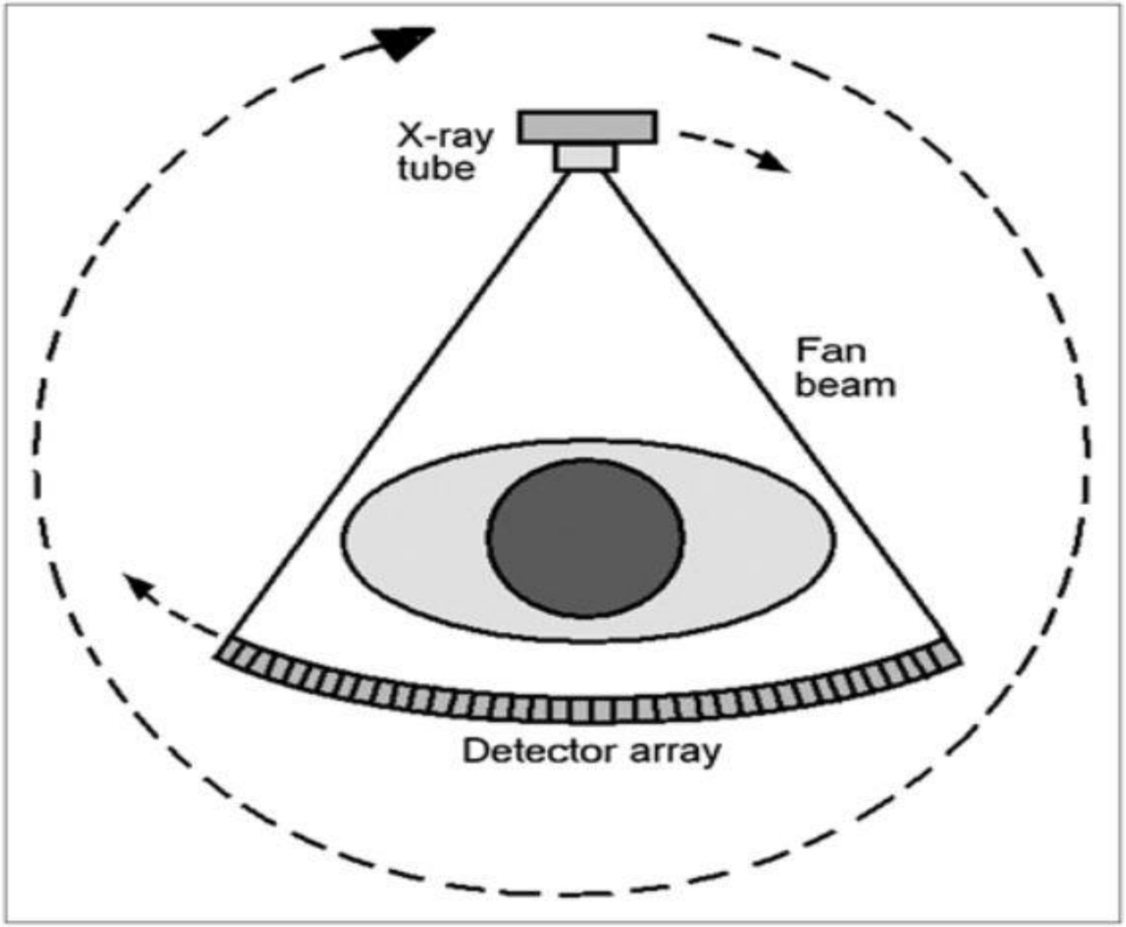


FIGURE 8.

Third-generation geometry. Time-consuming and mechanically complex translation motion was eliminated by opening x-rays into fanbeam. Large array of detectors measured data across width of fan. Tube and detectors were rigidly linked and underwent single rotational motion.

Operational modes
3. Third-Generation scanners

RING ARTIFACT

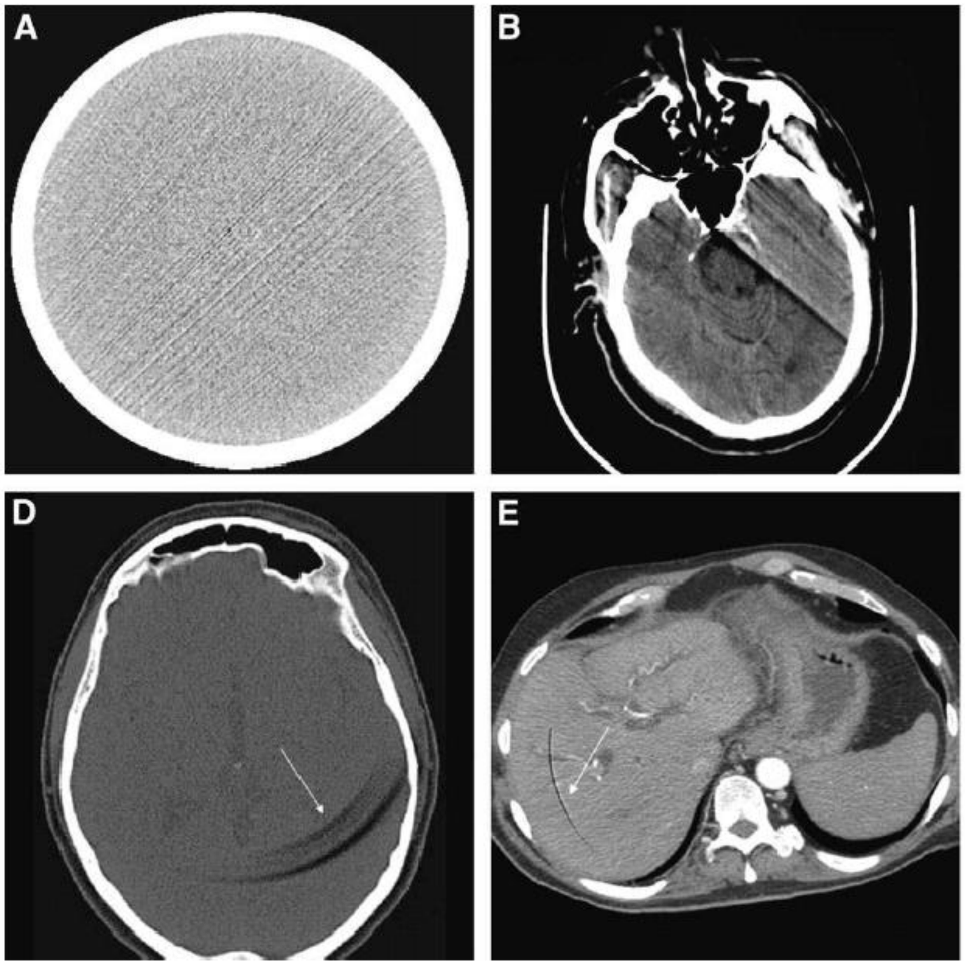
If one of the detectors is out of calibration on a third-generation (rotating x-ray tube and detector assembly) scanner, the detector will give a consistently erroneous reading at each angular position, resulting in a circular artifact called as RING ARTIFACT.

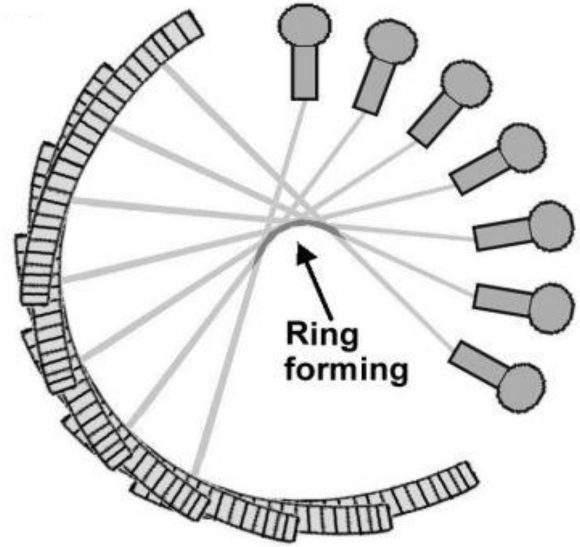
Xenon Detector Array:

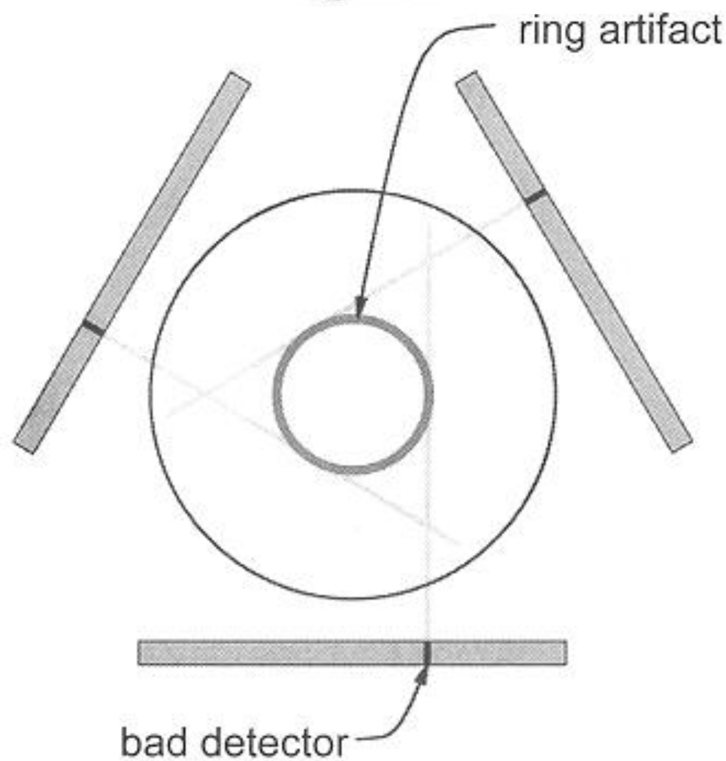
Ring artifacts were minimized by using an inherently stable xenon array. Each small chamber acted as an ionization chamber.

3rd Generation of CT

Ring artifacts

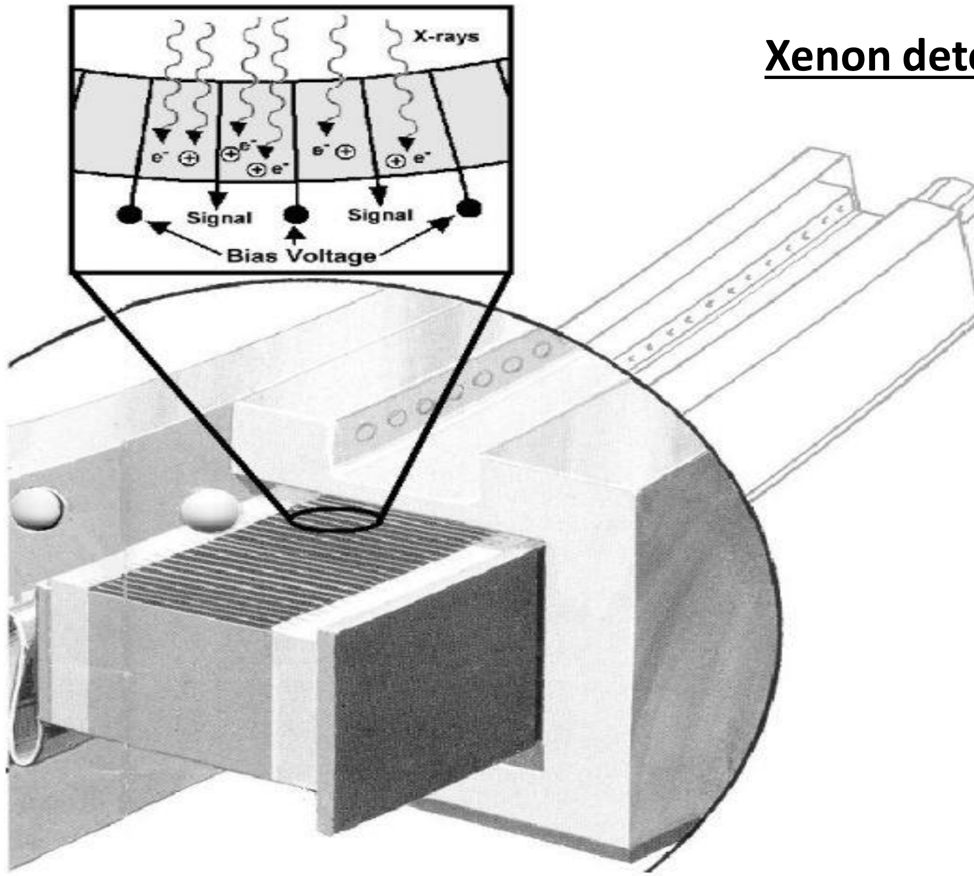






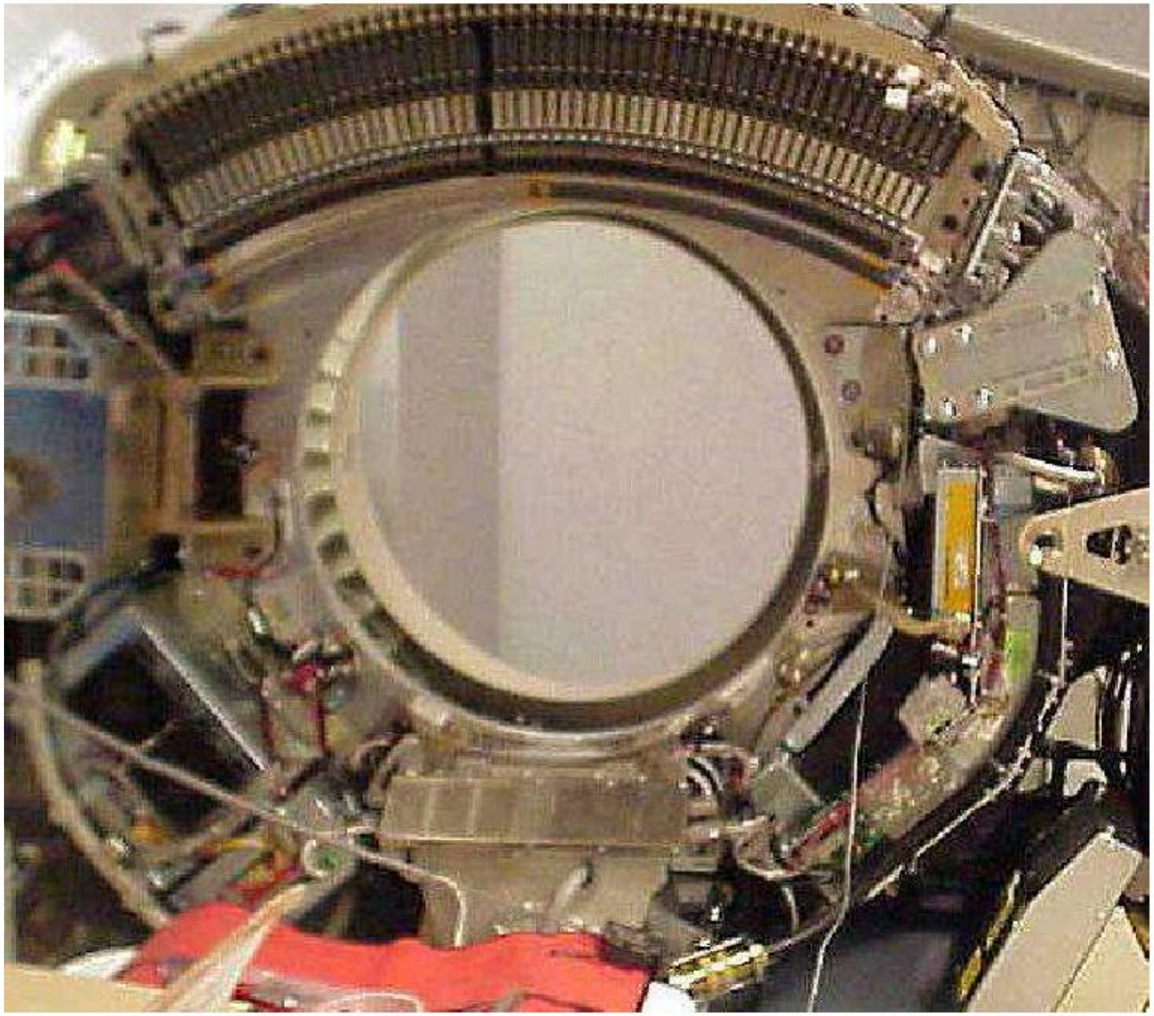
3rd Generation of CT

Ring artifacts



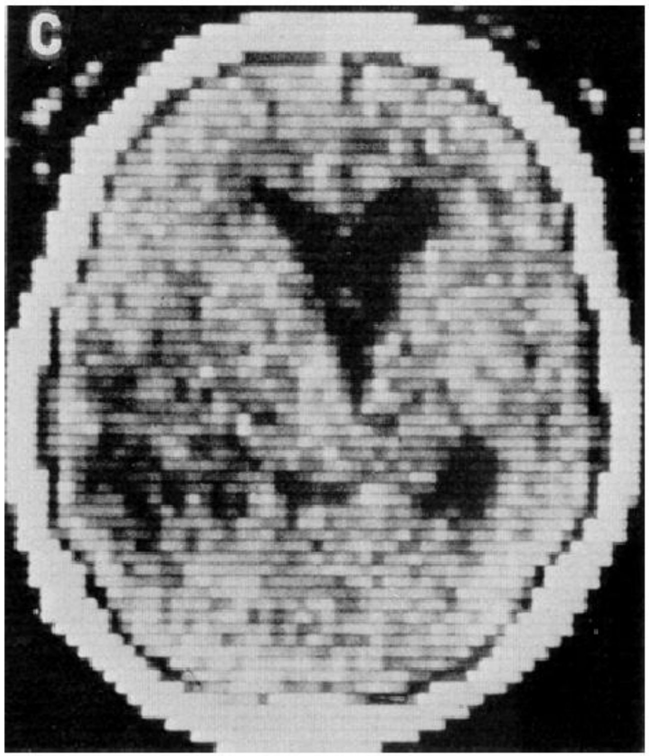
Xenon detector array

3G: Fan Beam



3G: Fan Beam

1972: 5 Minutes



2G

1976: 2 Seconds

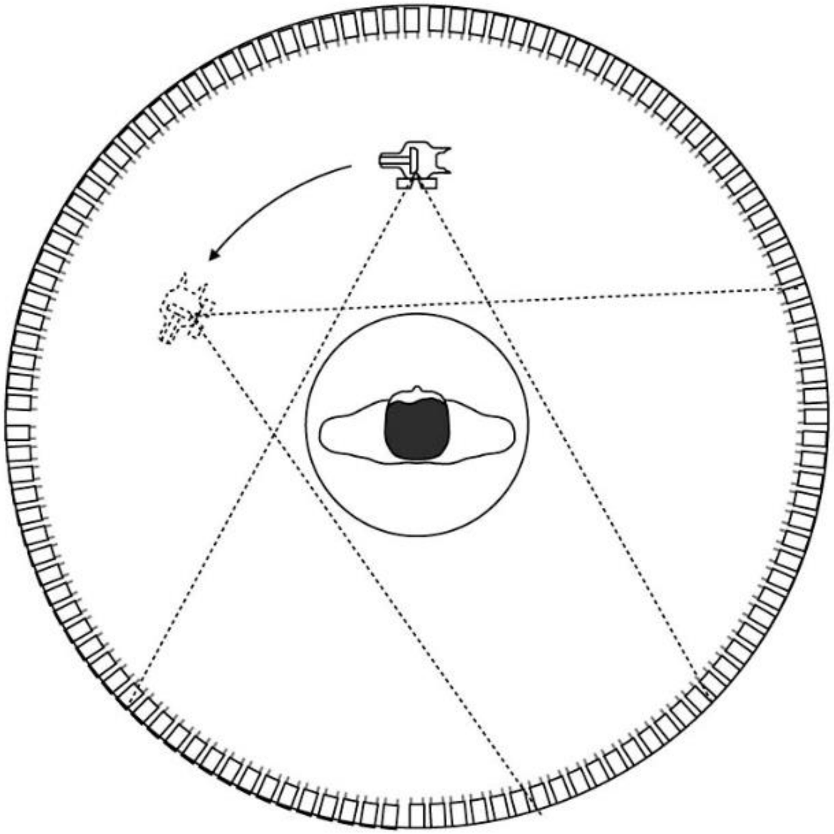
3G

Operational modes
4. Fourth-Generation scanners

- Developed principally to suppress Ring artifacts.
- Several thousands of ring detectors are used.
- Mechanical motion is rotation of X-ray source around a fixed detector array.
- As fan beam passes across each detector, and image projection is acquired.
- Scan time is: ½ - 1 second
- During tube rotation, the part of the ring between the tube and the patient would tilt out of the way of the x-ray beam (the peculiar wobbling motion of the ring was called nutation).
- Another disadvantage of fourth-generation designs was scattering.

4G

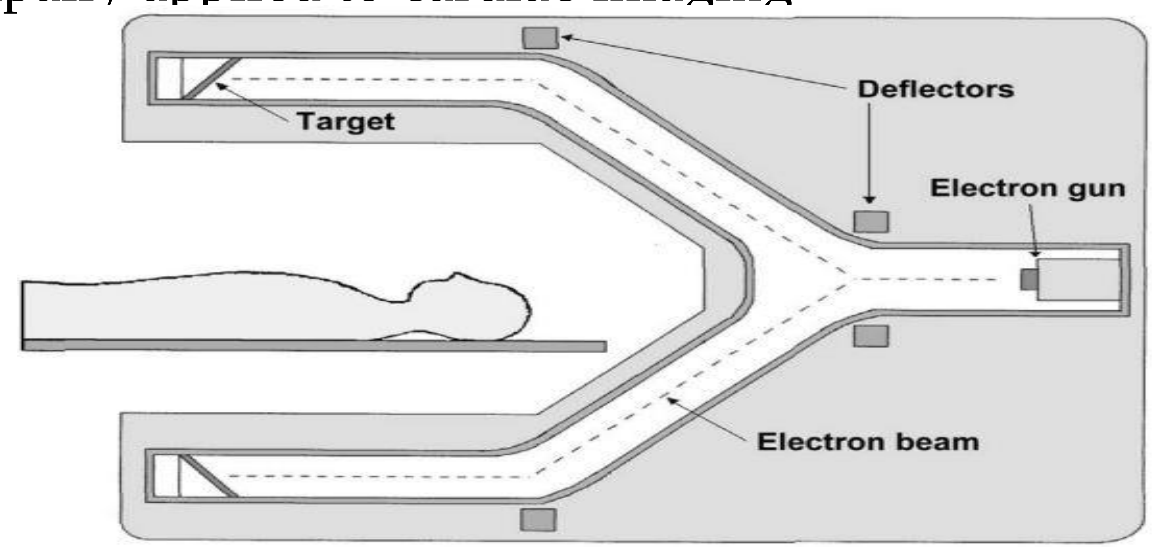
- Designed to overcome the problem of ring artifacts
- Stationary ring of about 4,800 detectors



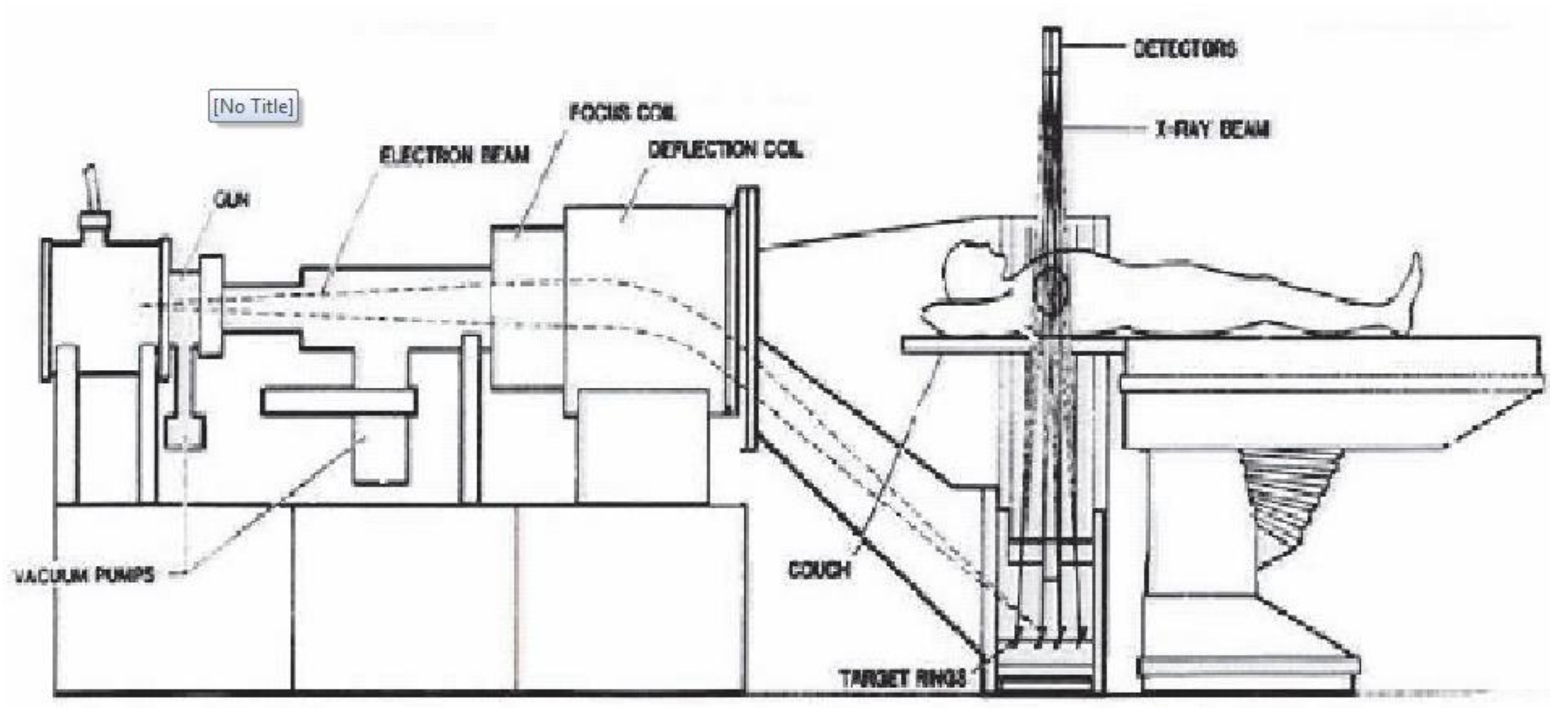
Fast
Cannot use collimator at detector, hence affected by scattering

Operational modes
5. Fifth-Generation scanners: Electron-Beam CT (EBCT)

- Fast imaging
- X-ray source is not an X-ray tube rather a focused, steered, and micro wave- accelerated electron beam incident on a tungsten target.
- Scan time : <50 ms
- Principally applied to cardiac imaging



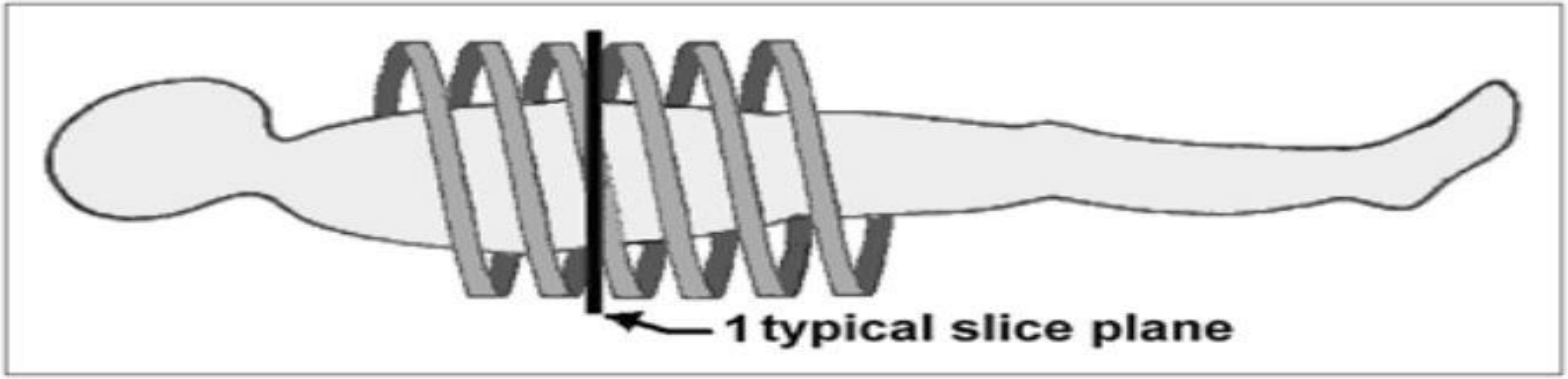
5th -Generation scanners: Electron-Beam CT (EBCT)



- 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

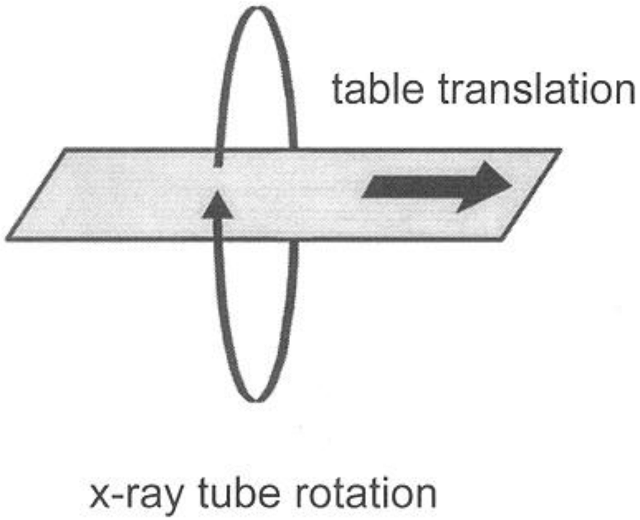
Operational modes
6. Sixth-Generation scanners

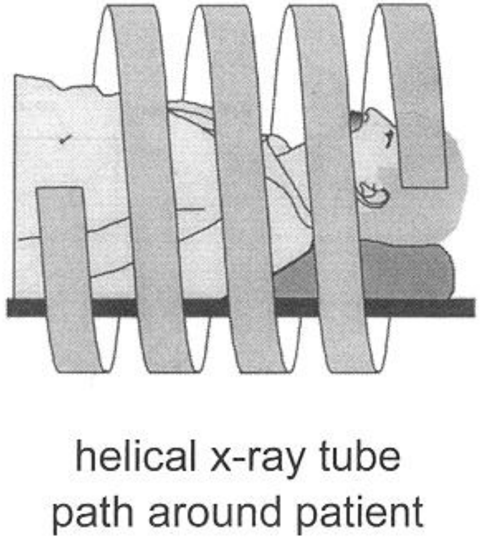
- Helical CT scanners acquire data while the table is moving
- Mostly used nowadays



Helical CT. Improved body CT was made possible with advent of helical CT (or spiral CT). Patient table is moved smoothly through gantry as rotation and data collection continue. Resulting data form spiral (or helical) path relative to patient; slices at arbitrary locations may be reconstructed from these data.

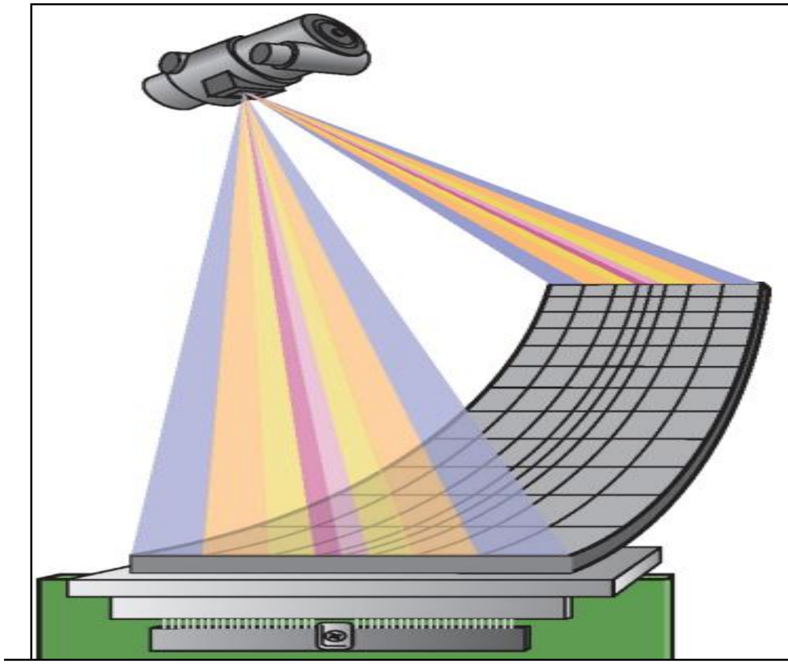
6G: Helical CT



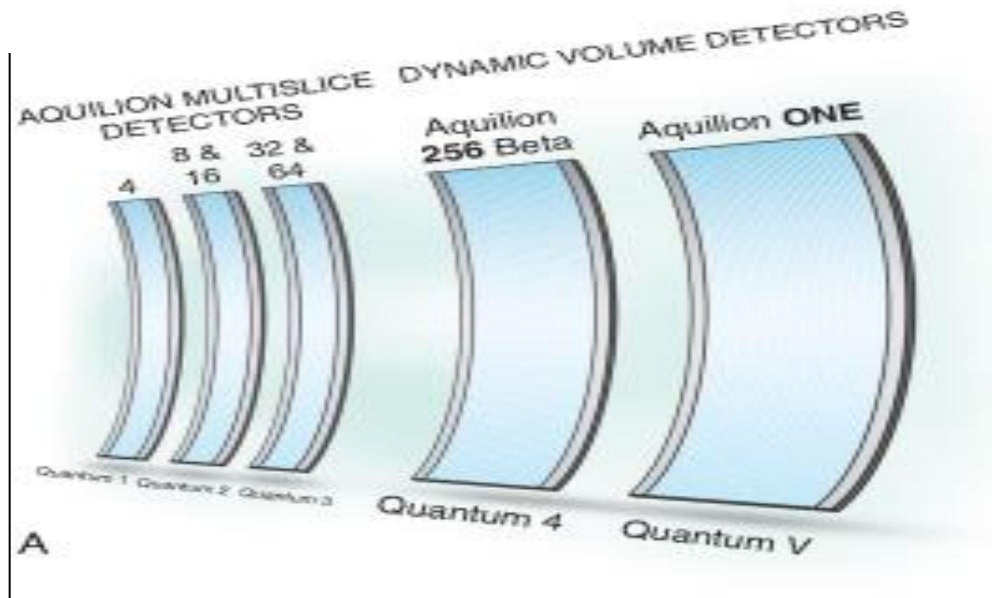


- Helical CT scanners acquire data while the table is moving
- By avoiding the time required to translate the patient table, the total scan time required to image the patient can be much shorter
- Allows the use of less contrast agent and increases patient throughput
- In some instances the entire scan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

Operational modes
7. Seventh-Generation scanners: Multidetector /Multislice /Multirow CT



- Most recent advancement, introduced in 1998.
- This uses usually 64-128 adjacent multiple detector arrays in conjunction with a helical CT scanner , the collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data.
- Scanning time: 0.25 second



7G: Multislice

- Features:
  - 40 parallel detector rows
  - 35,840 detector elements
  - 32mm detector length
  - 16 0.5mm slices with each second gantry revolution
- CT is becoming "cone beam"