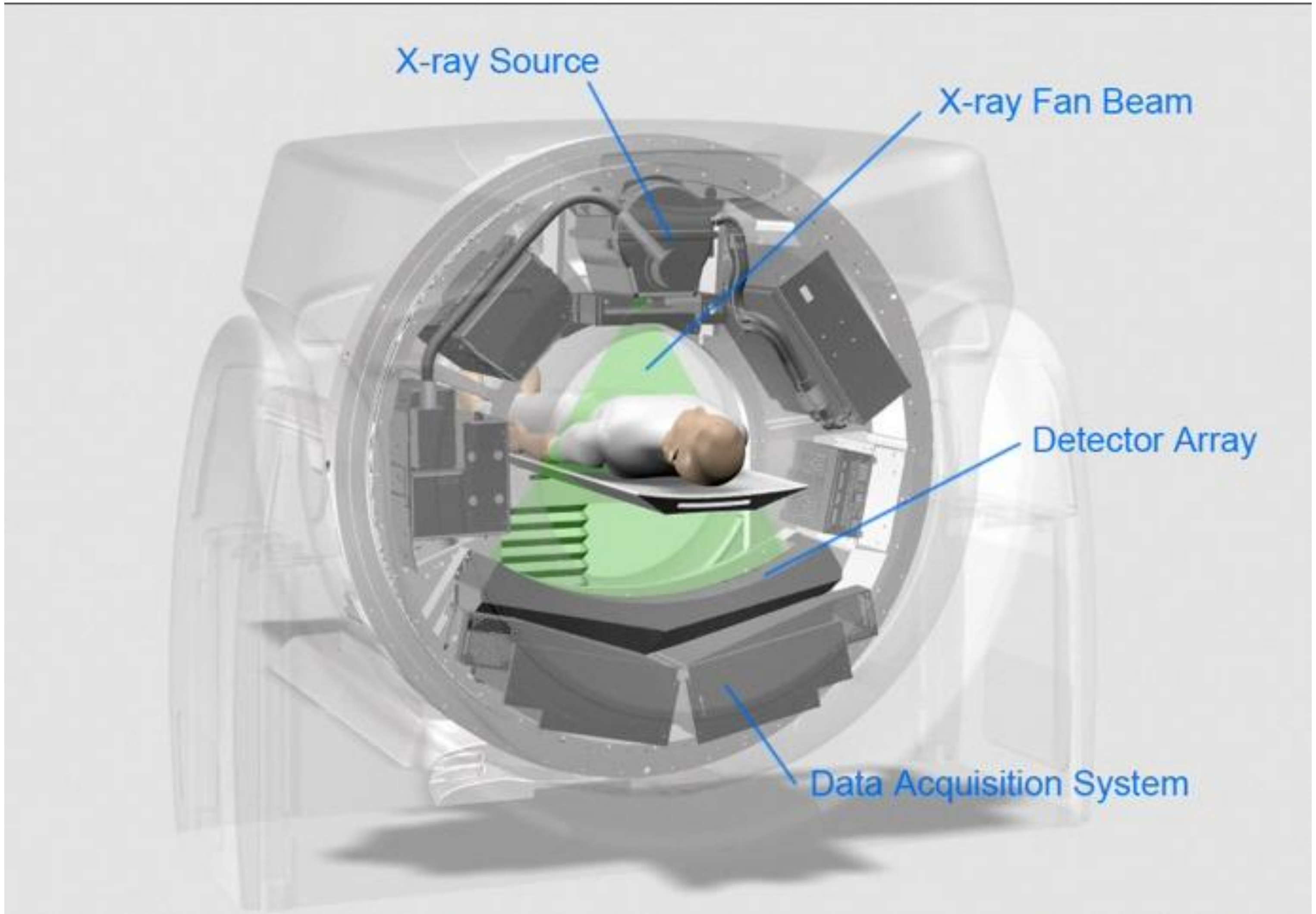
CT Instrumentation and Operation



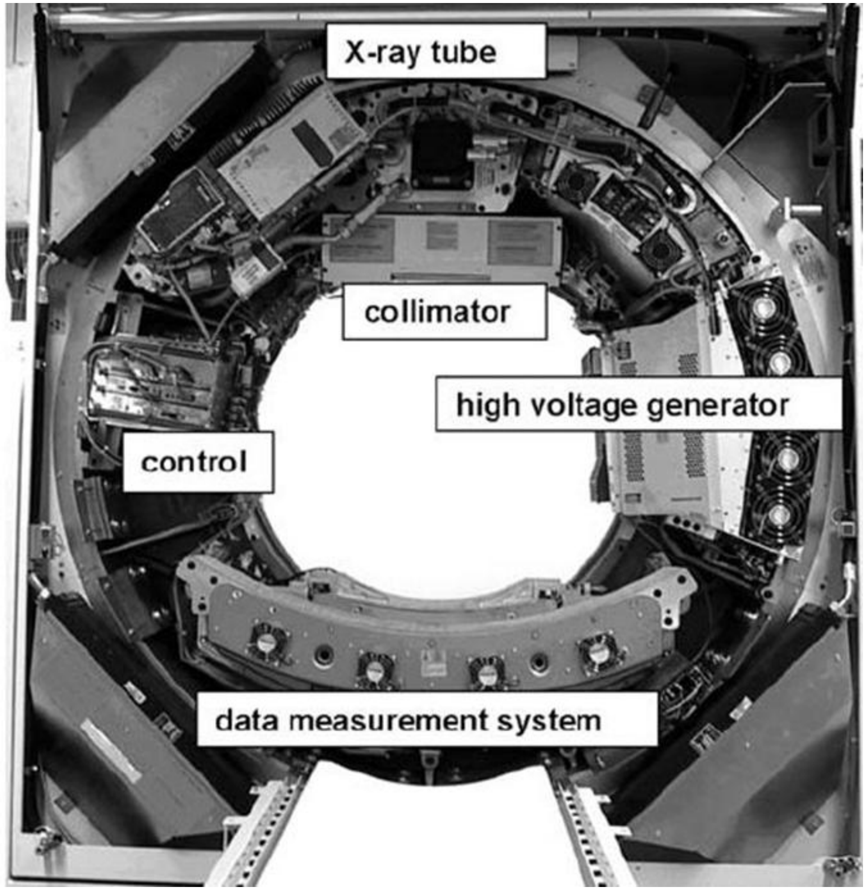
Gantry Overview

•Rotating structure that houses:

- X-ray tube & HV generator.
- Collimators & filters.
- Detectors.
- Cooling systems & slip rings.

•Rotation speed: 0.25–0.35 s/rotation.

•Tilt: ±30° for angled scans.



CT Gantry Bore (Aperture)

Definitions:

•**Bore (aperture):** The circular opening of the CT gantry through which the patient passes.

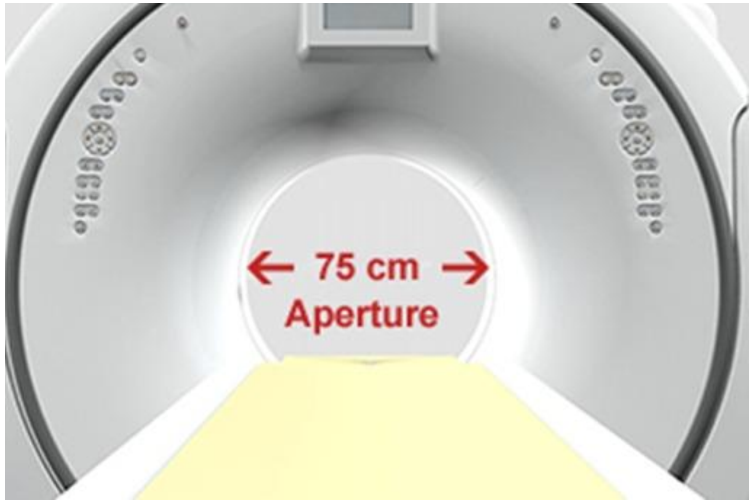
•**Field of View (FOV):** The maximum reconstruction area used in image generation; **smaller than bore diameter** because it depends on detector geometry and data sampling.

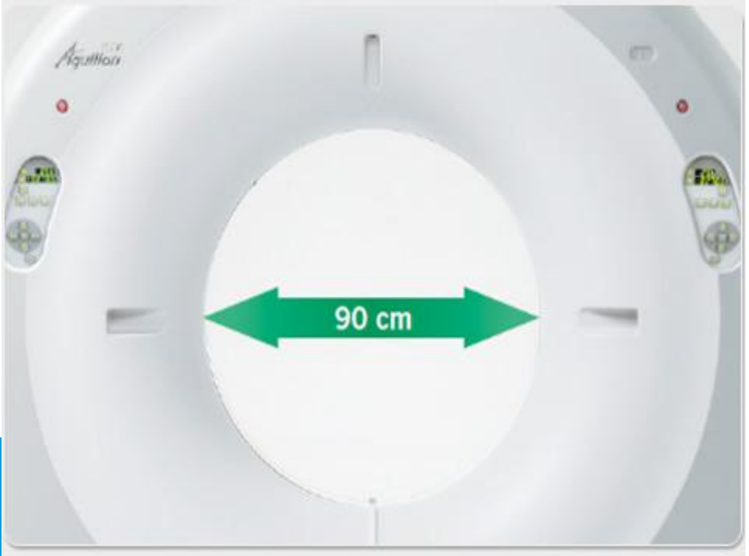
•**Scan Field of View (SFOV):** The maximum area of anatomy that can be imaged without distortion.

•**Display Field of View (DFOV):** The area selected by the operator for image display (a subset of SFOV).

Dimensions (by system type):

•**Standard CT bore:** ~70 cm diameter (most common in routine diagnostic CT). complexity and potential limitations in gantry speed.





- **Wide-bore CT:** 78–85 cm diameter, designed for bariatric patients and radiotherapy planning (RT simulation).
- **Ultra-wide bore/research systems:** >90 cm (less common, used in interventional or radiation oncology environments).

- **Clinical Significance:**
- Larger bore diameters improve:
  - Patient comfort (claustrophobic or obese patients).
  - Positioning flexibility (arms up vs down, trauma immobilization).
  - Access for **interventional CT** and **radiotherapy simulation**.

- **Trade-off:** Wider bores require more powerful generators and larger slip ring systems → more engineering

Patient Couch / Table

- Precise translation through gantry.
- Weight limits:
  - Standard: ~450 lb (204 kg).
  - High-capacity: up to 650 lb (295–300 kg).
- Accuracy: ±0.25 mm.
- Longitudinal, vertical, lateral movement.
- Built-in collision sensors.

Maximum Scannable Range

Definition:

•The **maximum scannable range** is the total length of patient anatomy that can be imaged in one continuous exam.

•Determined by:

- **Couch travel distance** (Z-axis translation).
- **Detector coverage per rotation** (number of rows × detector width).

Typical Values:

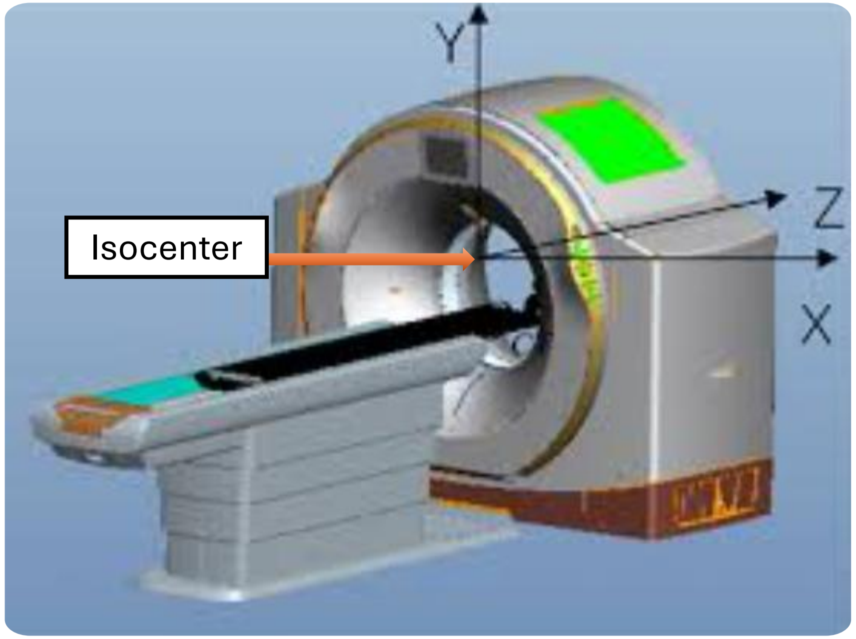
•Standard CT: **160–200 cm** coverage (enough for head-to-thigh exams).
•Wide-detector CT (320-row): **16 cm per rotation**, allowing whole organ coverage (entire brain, heart, liver in one pass).

Clinical Applications:

•**Whole-body trauma protocols** (head-to-toe in emergencies).

•**Oncology staging** (chest–abdomen–pelvis).

•**Vascular run-off studies** (aorta to lower extremities).



Coordinate System & Isocenter

- **X-axis:** left–right.
- **Y-axis:** anterior–posterior.
- **Z-axis:** head–feet.
- **Isocenter:** intersection point.
- Miscentering ↑ dose, ↓ quality.
- **ARRT:** Miscentering → automatic exposure modulation error and out of field artifact

OUT OF FIELD ARTIFACT

Slip Rings

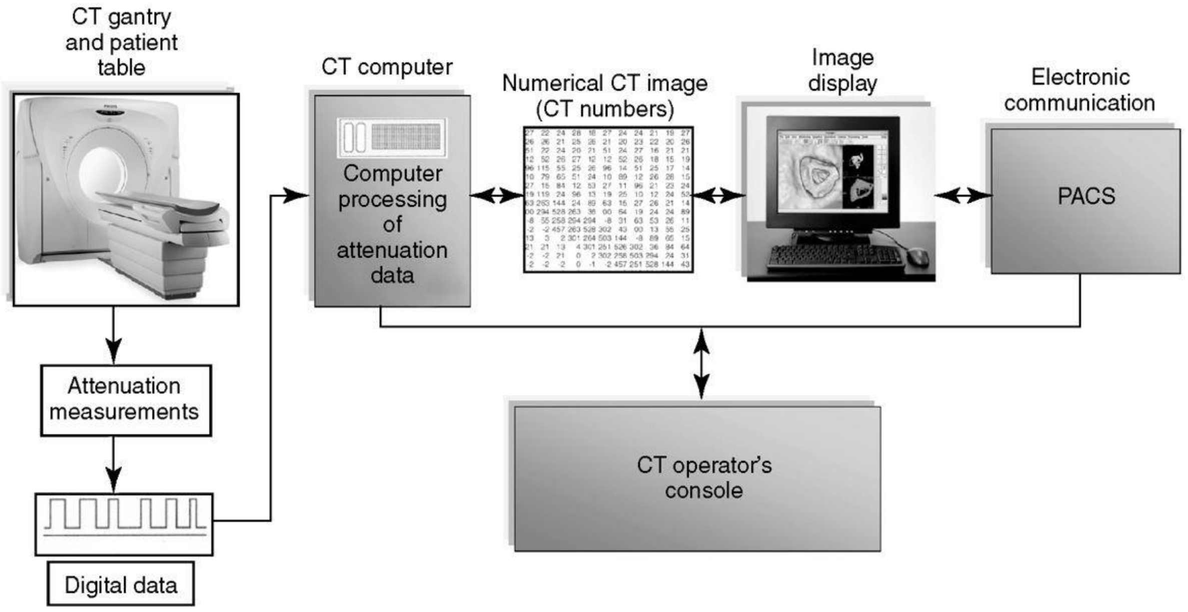
- Provide continuous rotation (replace cables).
- Transfer:
  - High-voltage power.
  - Data signals.

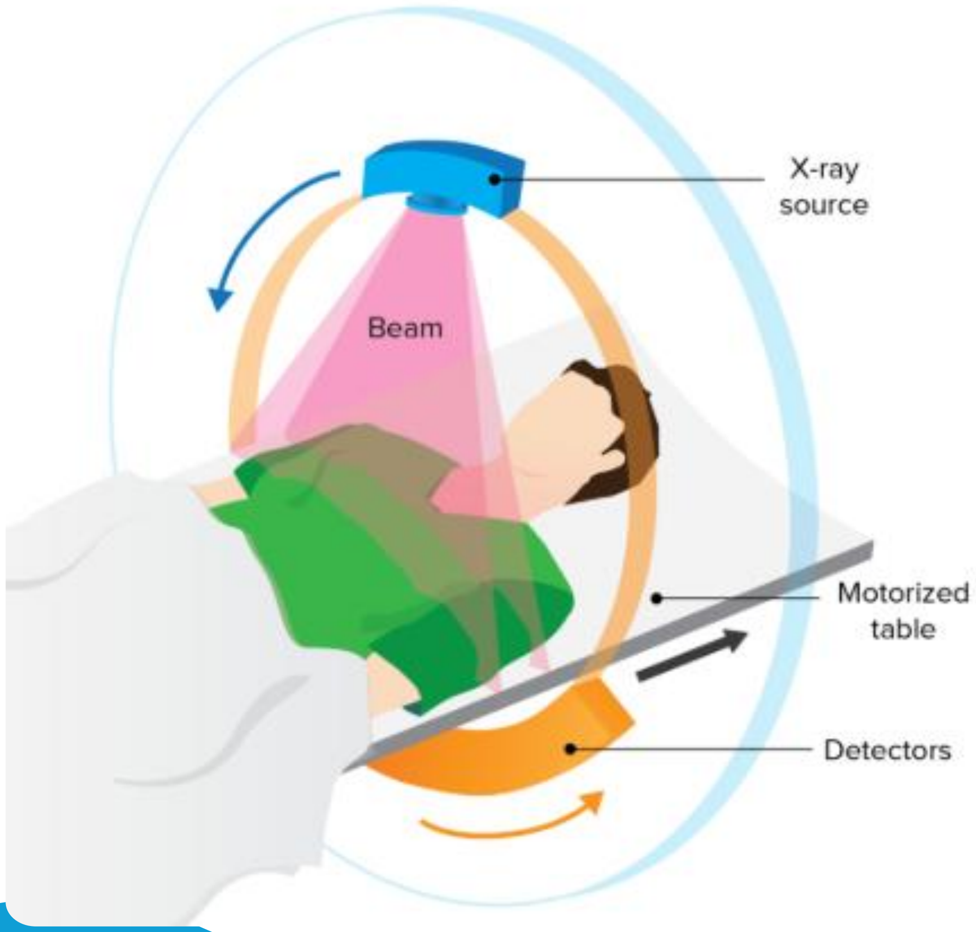
- Enable **helical scanning**.

- Eliminated stop–reverse motion of early CTs.

Major CT Subsystems:

- **Imaging system**: x-ray tube, generator, collimators, detectors
- **Data Acquisition System (DAS):** converts analog signals → digital data
- **Computer system:** reconstruction, image processing, scanner control
- **Display, recording, storage:** workstations, PACS, archives





Imaging Chain

- **Signal pathway:**
  - Tube produces X-rays.
  - Beam shaped by collimators & filters.
  - Passes through patient → attenuated.
  - Detectors capture remnant beam.
  - DAS digitizes → computer reconstructs.
  - Image displayed & stored.

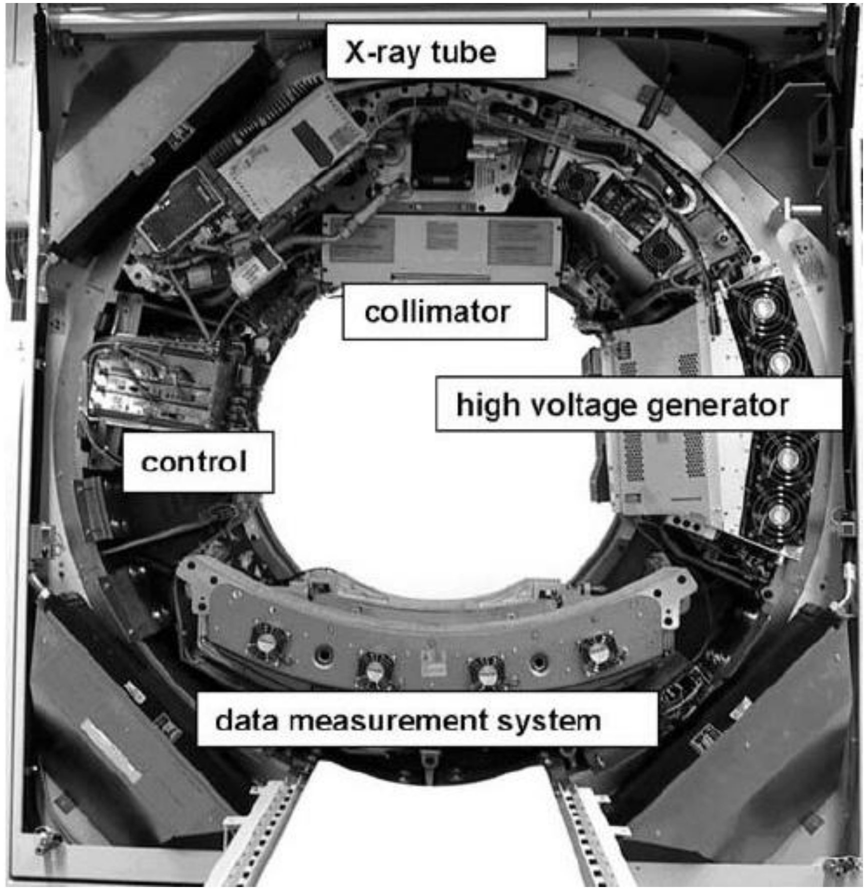
- Each stage affects **quality, dose, and artifact level**

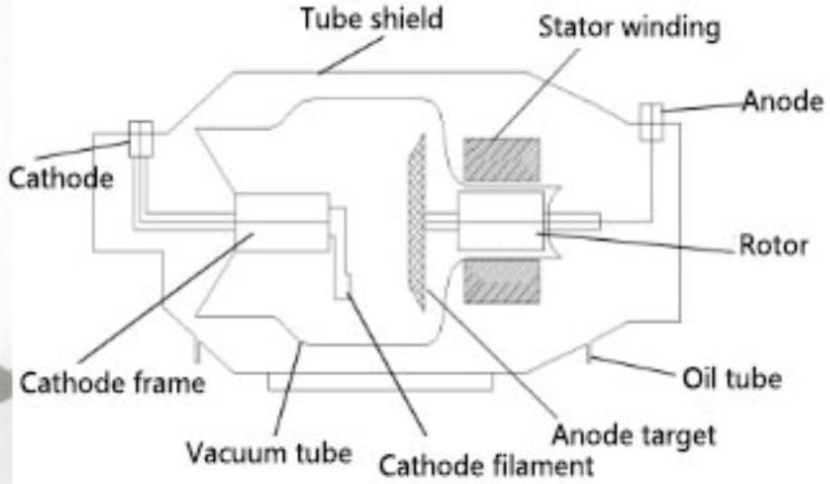
Imaging System Overview

•Produces and shapes the x-ray beam, captures transmitted photons.
•Major components:

- X-ray tube
- High-voltage generator (HVG)
- Collimators & filters
- Detector array

•Determines **photon quantity (mA), quality (kVp), shape, and detection efficiency**.





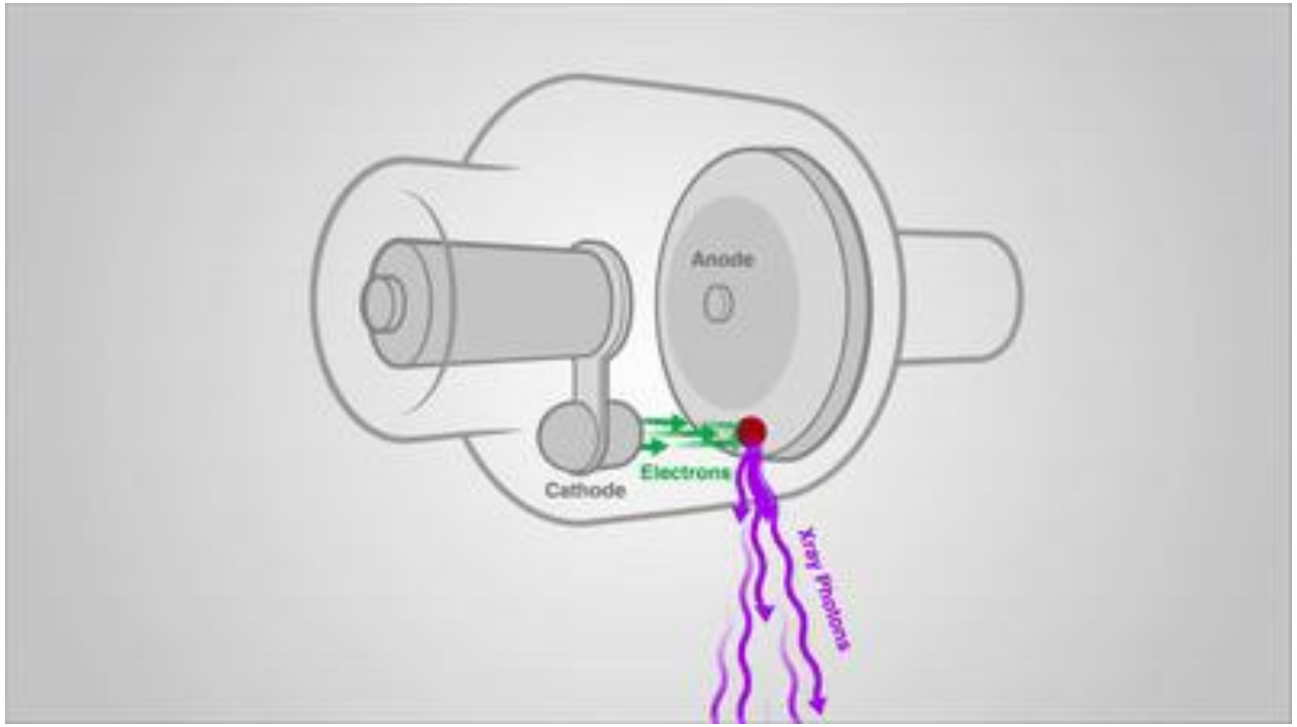
CT X-ray Tube (Design)

- Modified diagnostic tube designed for:
  - **High heat capacity:** 5–8 million heat units (MHU).
  - **Rapid rotation:** withstands centrifugal forces at 0.3 s/rotation.
  - **Long duty cycles:** continuous scanning.
- Components:
  - **Cathode:** dual filaments (small & large focal spot).
  - **Anode:** large rotating tungsten-rhenium disk (molybdenum substrate).
  - **Housing:** oil-cooled, heat-dissipation fins.

CT tubes must store/dissipate far more heat than radiography tubes. Tubes rotate 10,000 – 12,000 rpms.

Tube Performance Parameters

- **Tube Current (mA):** 10–800+ mA, proportional to photon flux.
- **Tube Voltage (kVp):** 80–140 kVp typical range.
- **Exposure Time:** 0.25–1.0 s/rotation.
- **mAs:** product of mA × time → controls dose & SNR.
- **Heat Units (HU):** HU = kVp × mA × time × waveform factor.
- **Summary :** mAs ↑ → dose ↑ & noise ↓; kVp ↑ → penetration ↑ & contrast ↓.

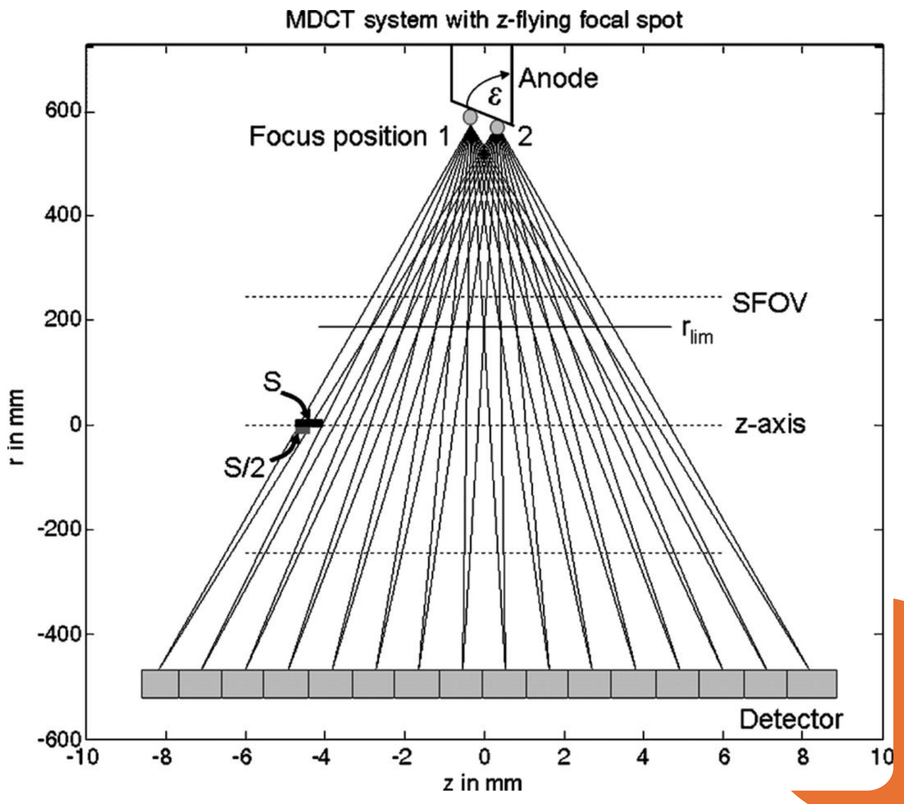

Anode
Cathode
Electrons
Xray photons

Focal Spots

- **Small focal spot (~0.5–1 mm):** sharp resolution, low mA.
- **Large focal spot (~1.2–2 mm):** higher mA, lower resolution.
- **Flying focal spot:** alternates between two points → doubles sampling.

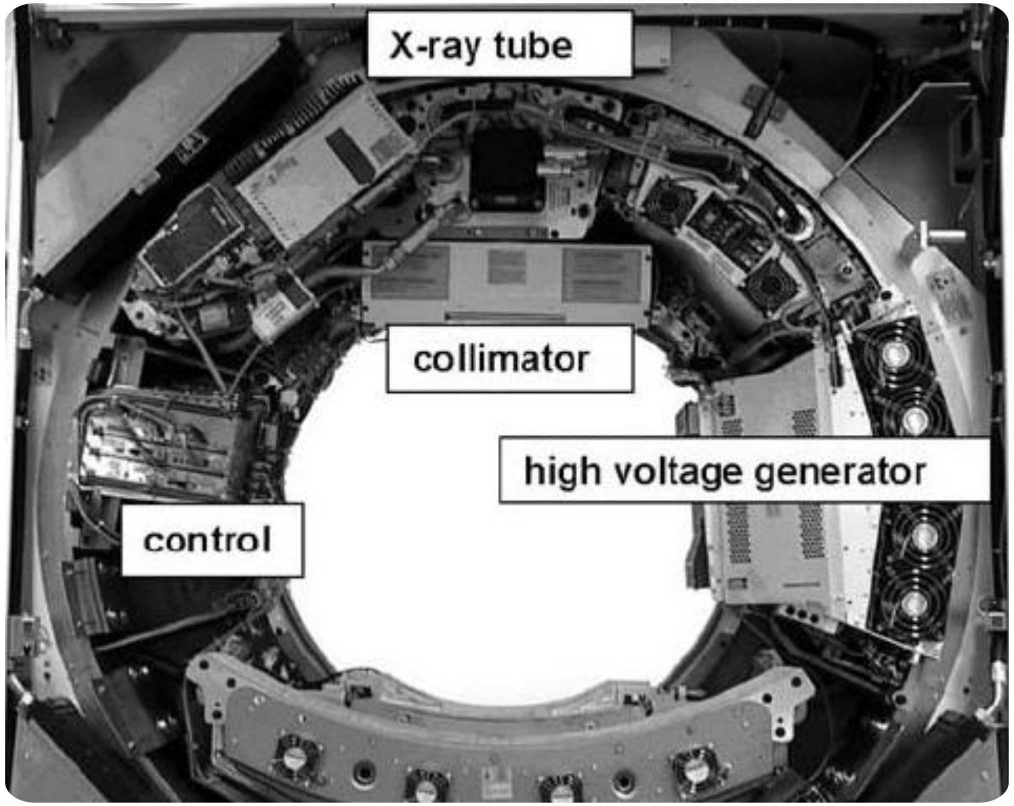
- Flying focal spot technology involves the electromagnetic steering of the electron beam emitted from the cathode. The beam of electrons is directed toward two separate locations on the rotating anode, resulting in two sources of x-radiation.

- As the tube rotates around the patient, the number of data samples is essentially doubled owing to the electronic switching between the two focal spots. This oversampling technology can be used to improve the system's temporal and spatial resolution.



Tube Heat & Cooling

- <1% energy → x-rays, >99% → heat.
- Cooling methods: oil, liquid, air, conduction.
- Larger anodes with graphite backing.
- Overheating → tube shutoff/failure.



High-Voltage Generator (HVG)

- Supplies kVp between cathode & anode.
- Located in gantry for compactness.
- Must deliver stable, ripple-free power.
- Power output: 60–100 kW.

Generator Settings

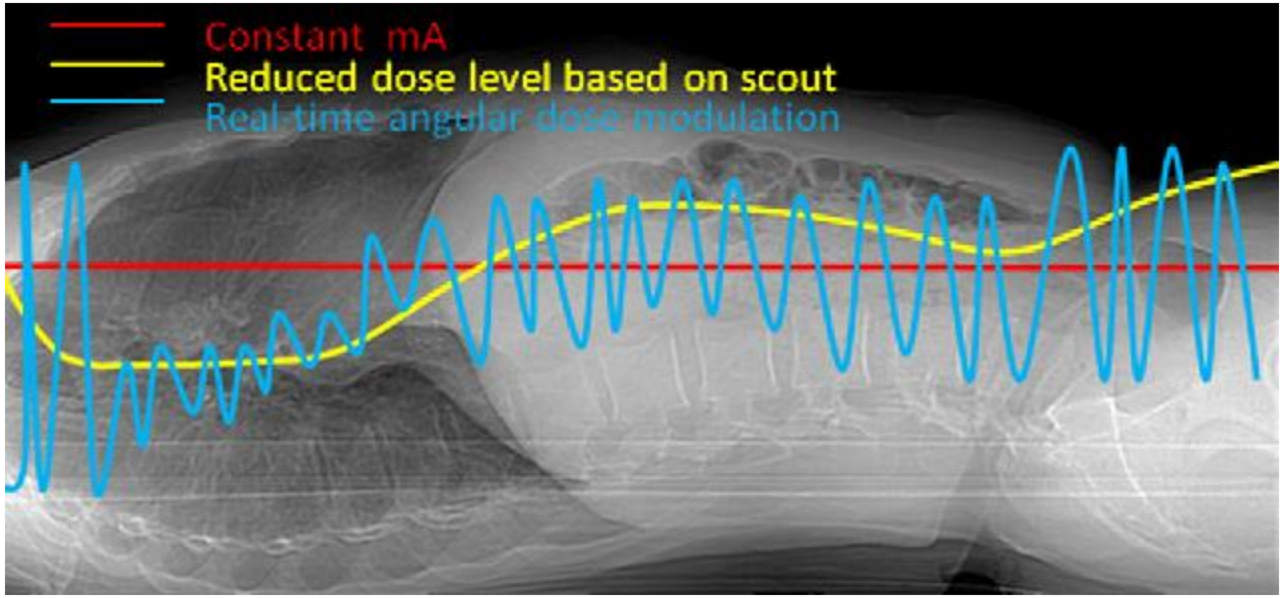
- kVp selections: 80, 100, 120, 140.

- mA range: 10–800 mA.

- Integrated with ATCM (auto modulation).

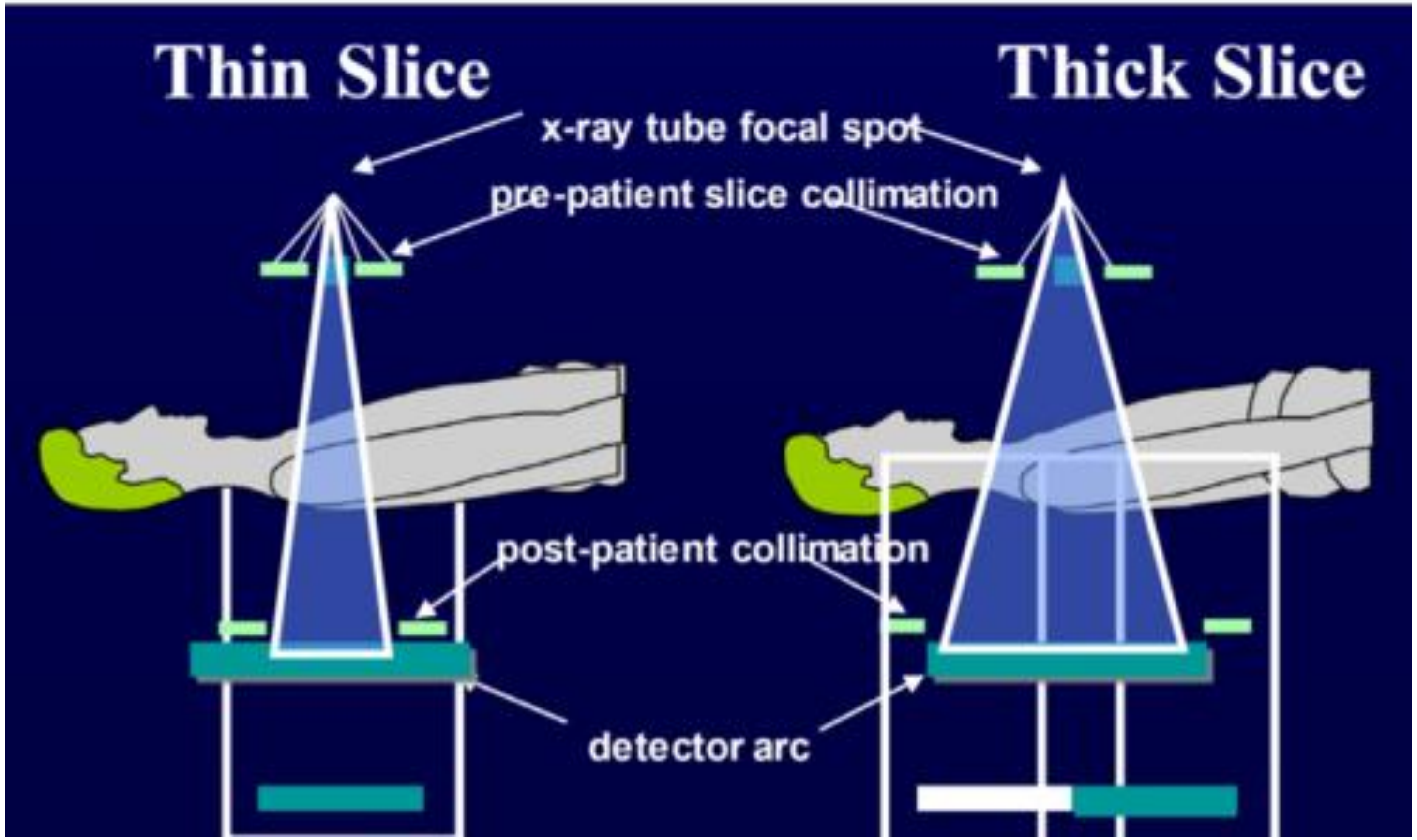
What is ATCM?
ATCM is a technology built into modern CT scanners that **automatically adjusts the tube current (mA)** in real time during the scan.
Its purpose is to maintain **consistent image quality** while **minimizing patient radiation dose**.

How It Works
•**Patient size & attenuation**: Before or during the scan, the system evaluates how much the patient's body attenuates the X-ray beam.
•**Real-time modulation**: The scanner increases mA when penetrating denser areas (e.g., shoulders, pelvis) and decreases mA when scanning less dense areas (e.g., lungs, extremities).
•**Goal**: Maintain a constant noise level (image quality) across the entire study while avoiding unnecessary exposure.



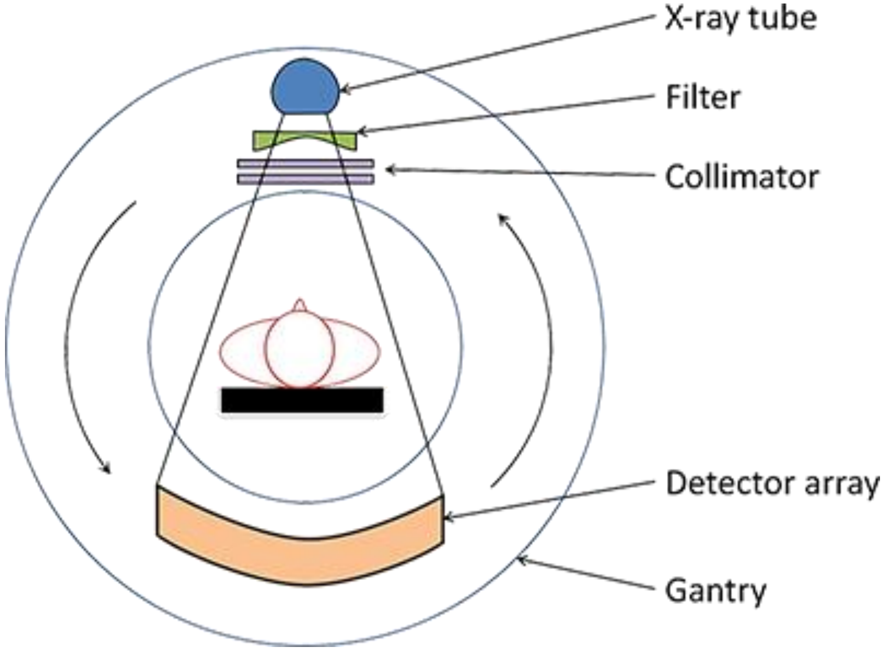
Collimators:

- **Pre-patient:** define beam width, slice thickness.
- **Post-patient:** reduce scatter before detectors.



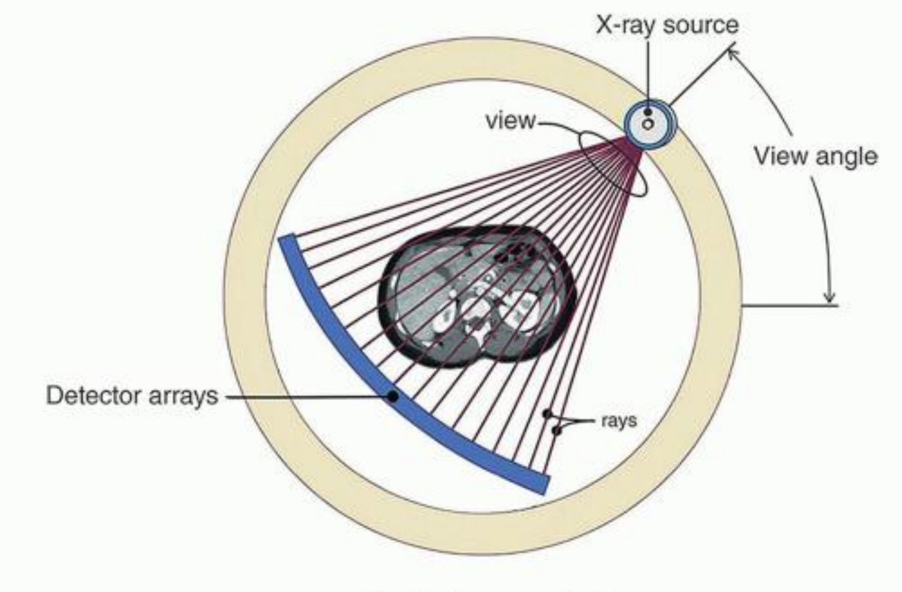
Filtration

- Removes low-energy photons → ↓ dose.
- **Aluminum or copper filters.**
- **Bowtie filters:** thick edges, thin center.
    - Compensates for body shape.
    - Evens detector exposure.
- Dose efficiency ↑, peripheral noise ↓.



Detector Requirements

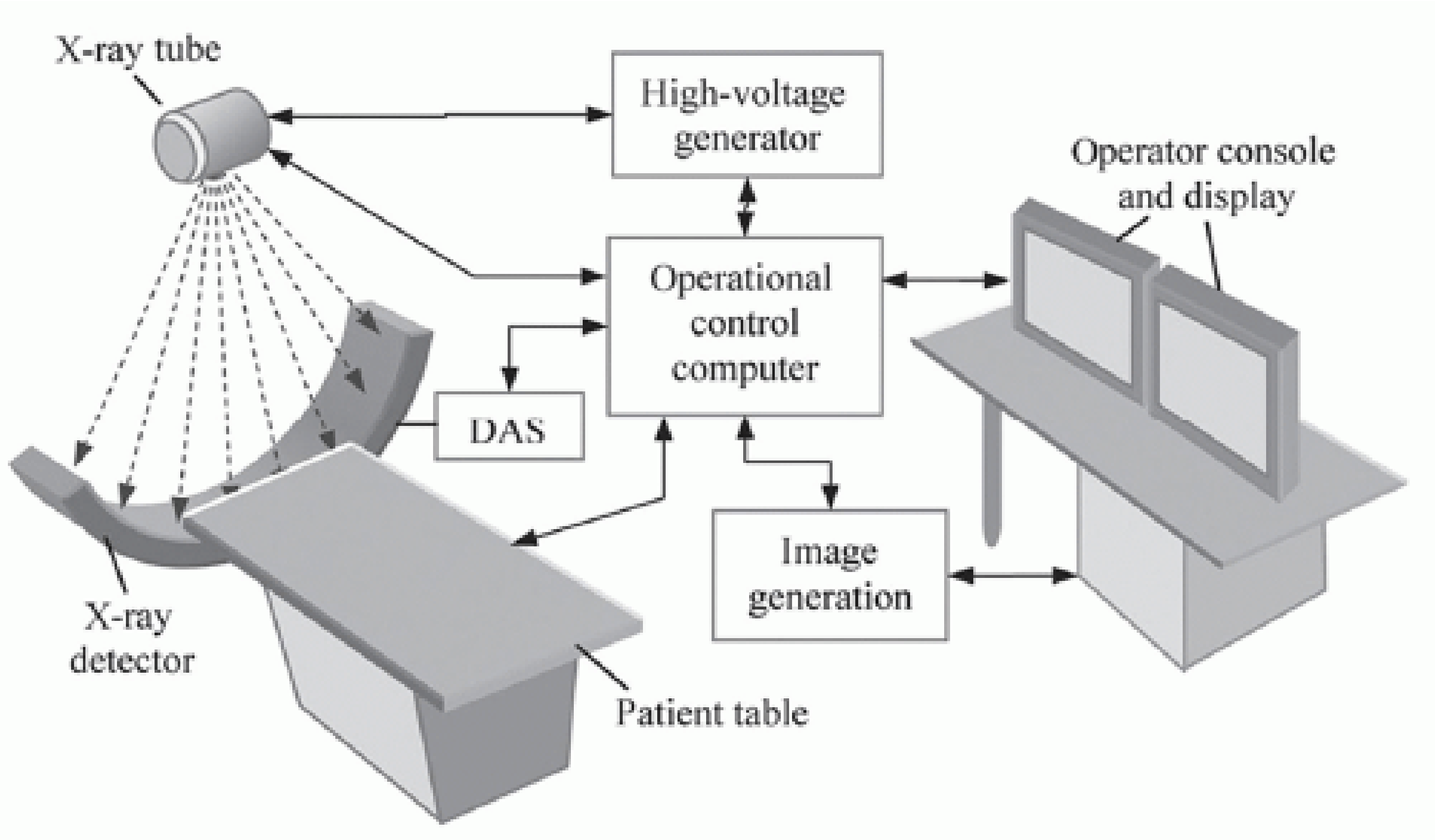
- **Definition:**
- Detectors capture x-ray photons after they pass through the patient and convert them into electrical signals for image reconstruction.
- **What We Use Today:**
- **Scintillation (solid-state) detectors** are the standard in modern CT.
  - Made of rare earth crystals (e.g., gadolinium oxysulfide, ceramic).
  - Convert x-rays → light → electrical current (photodiode).
  - **Quantum Detection Efficiency (QDE):** ~95–100%.
  - Advantages: high efficiency, fast response, minimal afterglow.
- **Requirements:**
- High QDE (efficient photon capture).
- Fast response (handles 0.25–0.35 s rotations).
- Wide dynamic range (detect both weak & strong signals).
- Stability and linearity for consistent Hounsfield Units.



The fan beam projection

DAS (Data Acquisition System) Overview

- Electronics between detectors & computer.
- Functions:
  - Amplification.
  - Sample-and-hold.
  - ADC.
  - Data transfer.
- Must process millions of samples/sec.



Amplifiers

•Boost weak detector signals.
•Improve SNR before digitization.
•Must be linear across full dynamic range.

Sample-and-Hold (S/H) Unit

Definition:

•The **Sample-and-Hold unit (S/H)** captures the analog signal from the detectors at precise time intervals and "holds" it steady for conversion to digital form by the ADC.

Function:

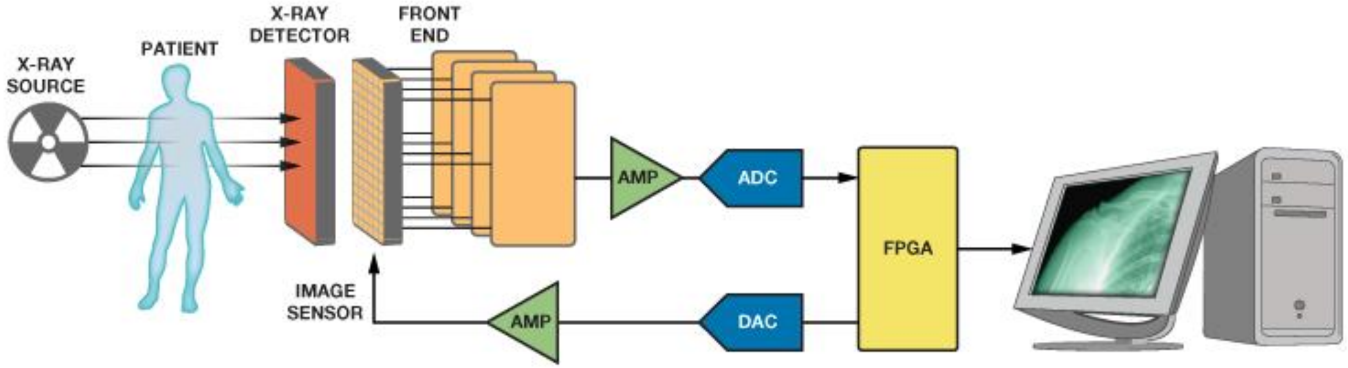
•Ensures **accurate timing** of each measurement during gantry rotation.
•**Assigns shades of gray to pixels** in the digital matrix according to signal intensity.
•Synchronizes with rotation speed and couch motion for consistent data sampling.

Clinical Relevance:

•Precise sampling = accurate HU values.
•Errors in S/H lead to streaks or misregistration artifacts

- **Analog-to-Digital Converter (ADC)**

- Converts analog voltage → digital code.
- CT typically uses 16–20 bit ADC.
- More bits = more gray levels.
- High sampling frequency required.

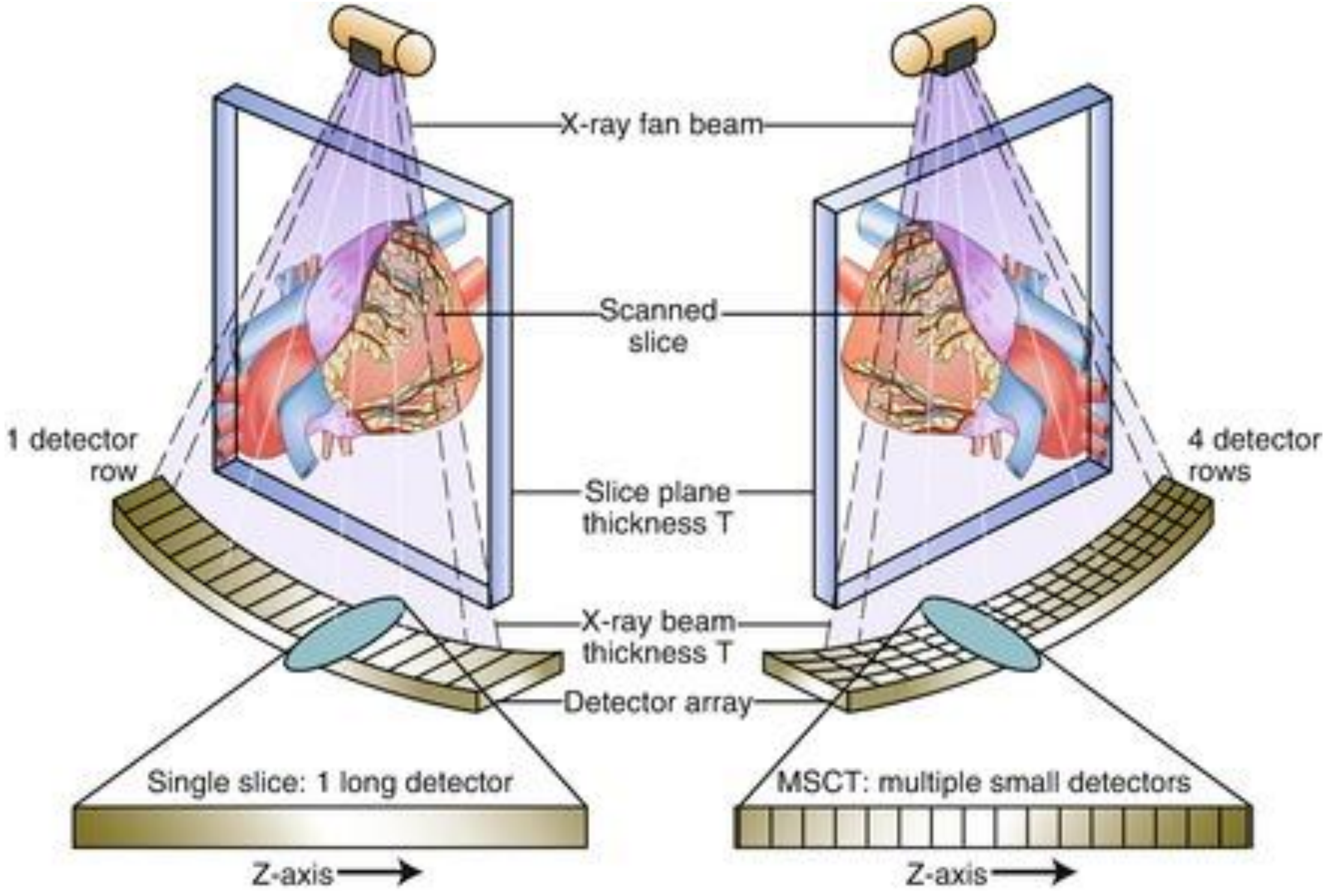


Computer System

- Controls all scanner components.
- Reconstruction & postprocessing.
- Stores & routes data.
- Must handle large datasets (hundreds of MB per scan).

Detector Arrays

- Arranged in rows/channels.
- Multirow systems: 16, 64, 128, 320.
- Wide detectors: 16 cm coverage → whole organs in one rotation.
- More rows = faster scans, less motion artifact.



MAGE DISPLAY, RECORDING, & STORAGE

•Displays reconstructed images from the computer system.

•Allows **image review and manipulation** (window/level, measurements, MPR).

•Stores images in **digital format (DICOM standard)**.

•Facilitates **retrieval and archiving** through PACS or local servers.

•Enables **communication and sharing** across hospital networks and teleradiology systems.

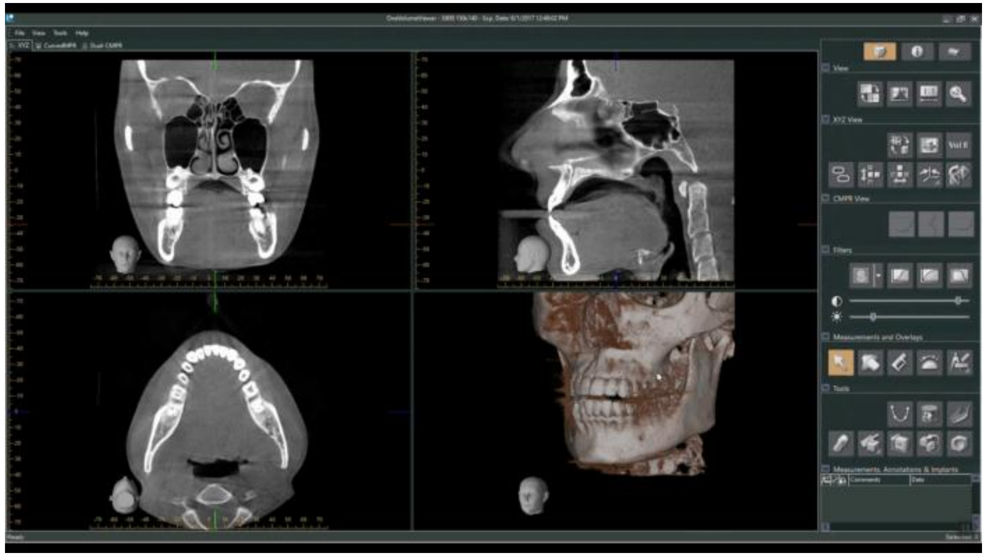
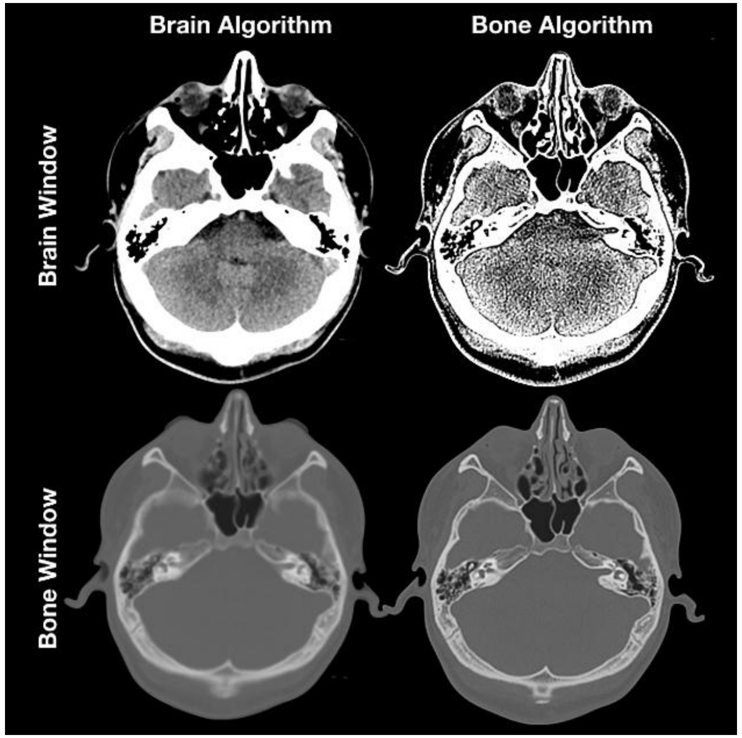
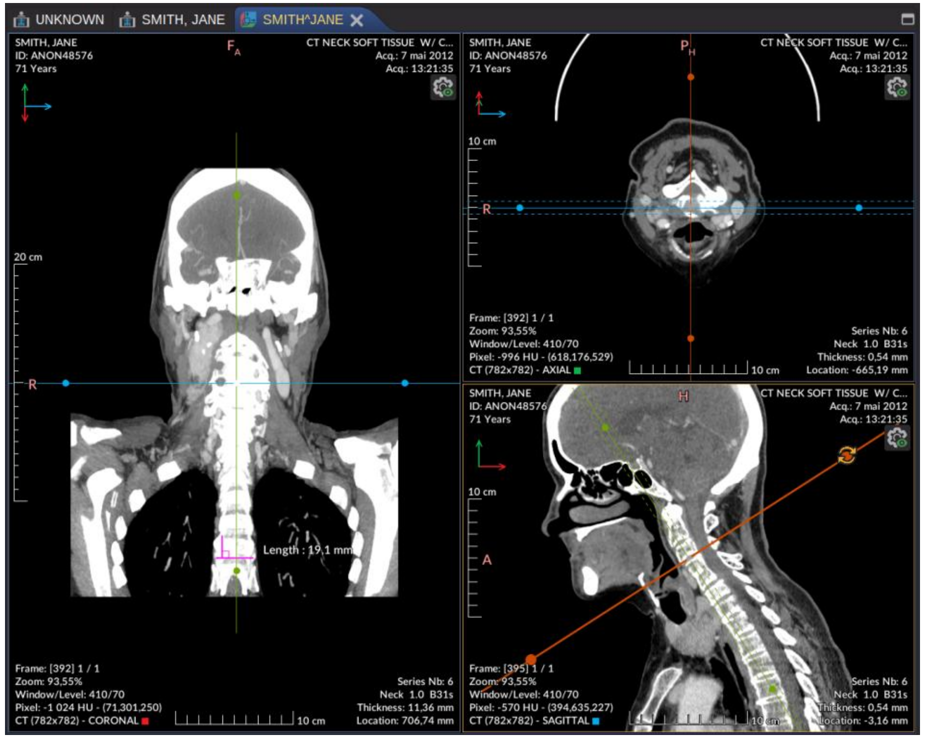


Image Display

- Workstations with:
  - High-res monitors.
  - Window/level controls.
  - Measurement & annotation tools.

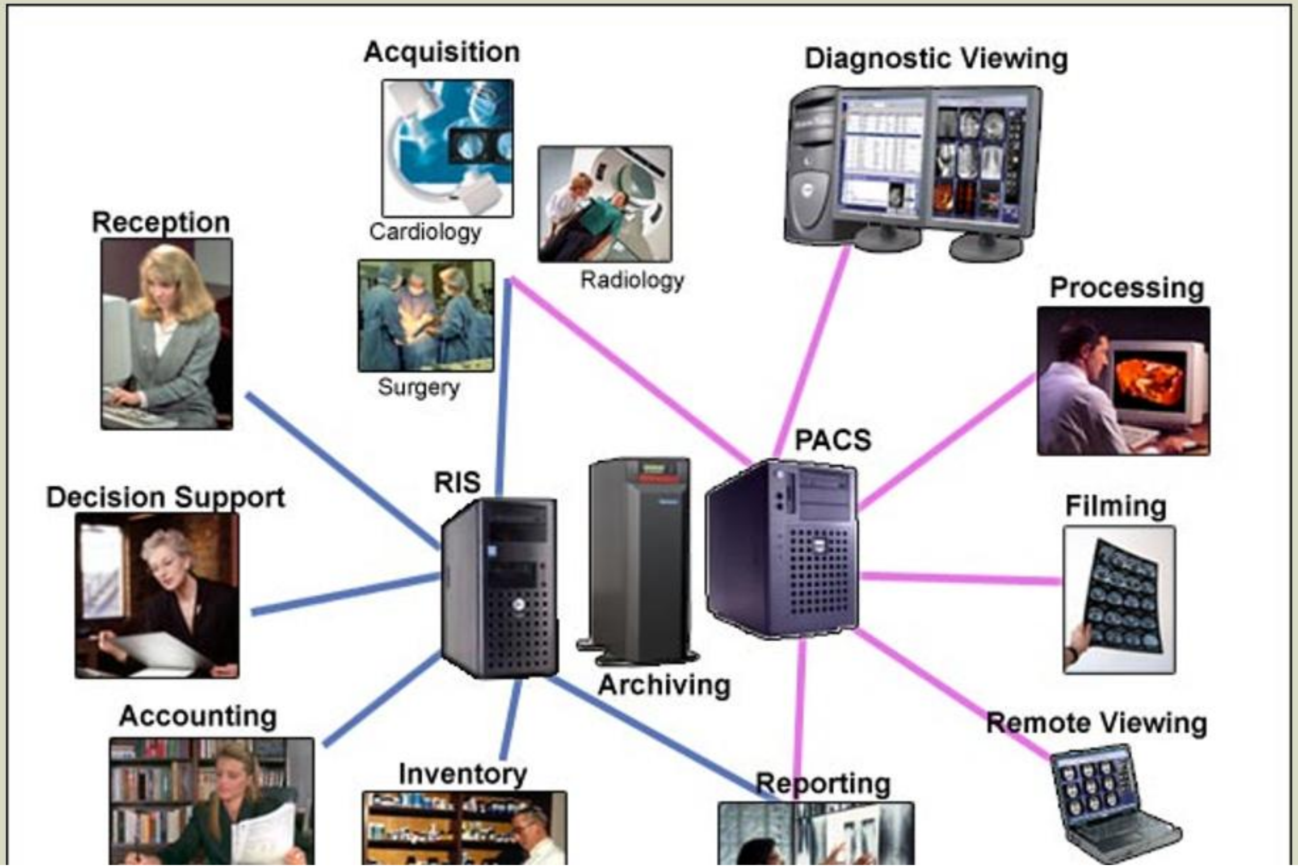
• **Image review and manipulation** (window/level, measurements, MPR



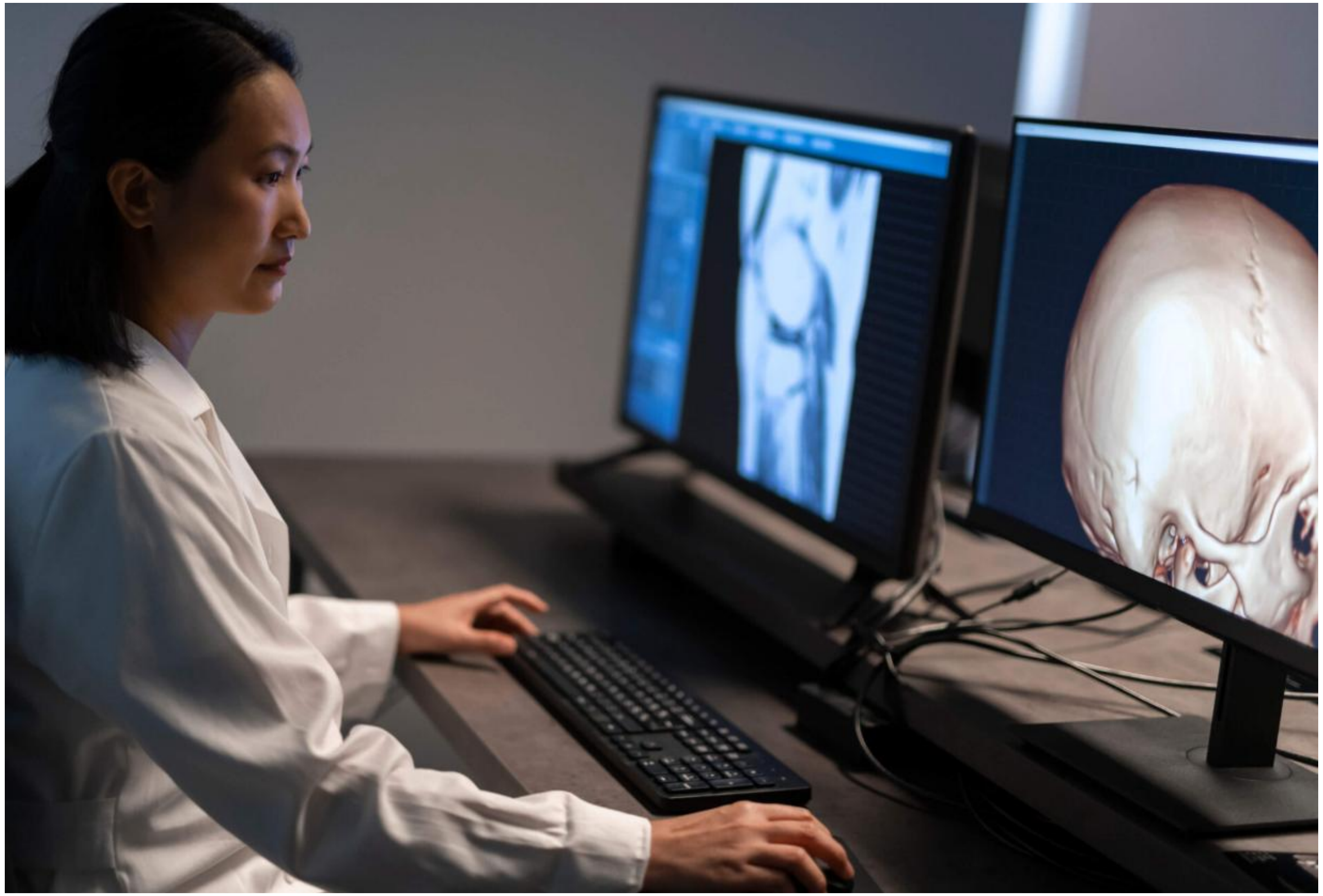


COMMUNICATION

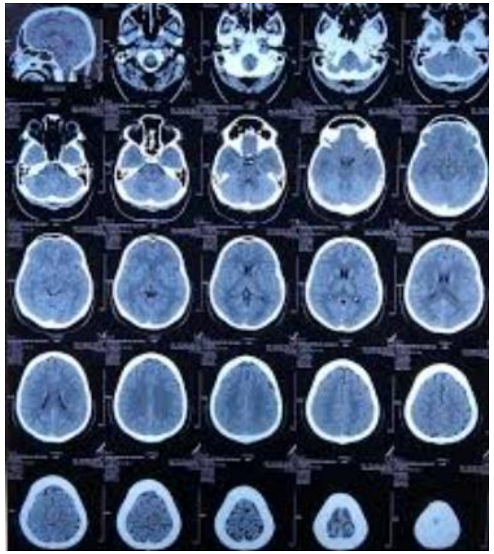
PACS



NightHawk Radiology Services was an early leader in global teleradiology, pioneering the use of international reading centers in Sydney, Australia, and Zurich, Switzerland, to provide 24/7 emergency radiology coverage for U.S. hospitals. By leveraging time zone differences, U.S.-trained, board-certified radiologists could interpret CT, MRI, and x-ray studies during their daytime hours overseas, ensuring rapid turnaround for American physicians working overnight. This model highlighted the internationalization of radiology, where geography and technology combined to deliver real-time, cross-border diagnostic expertise, setting the stage for today's global telemedicine networks



•Provides **hard copies** when needed.



Provides **digital exports** when needed.