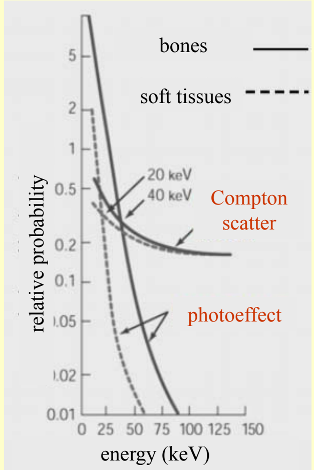
Medical applications of X-rays

X-ray diagnostics and imaging

Diagnostic radiology

Basic principle of X-ray diagnostic is the absorption of radiation



$$\tau_m = C\lambda^3 Z_{eff}^3$$

matter	Z_{eff}
air	7,3
water	7,7
soft tissue	7,4
bone	13,8

Production of X-ray image

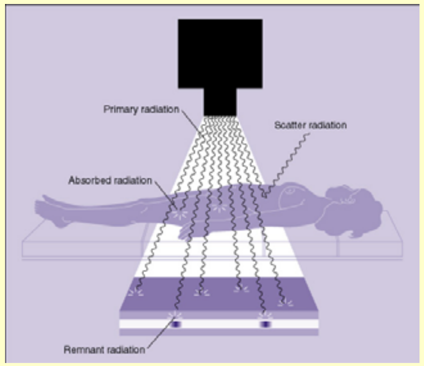
Representation of variations in attenuated intensity

- in radiation sensitive film
- on luminescent screen
- in digitized image

scalp

chest

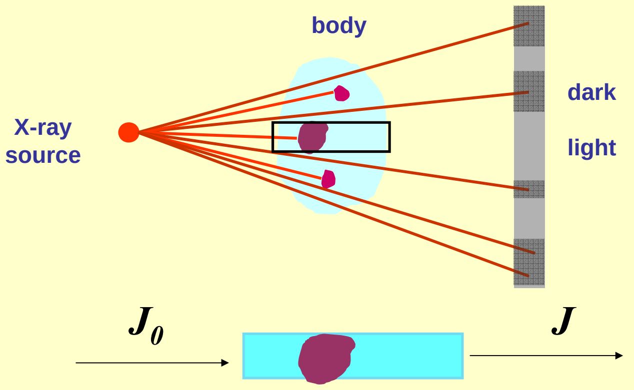
Summation image



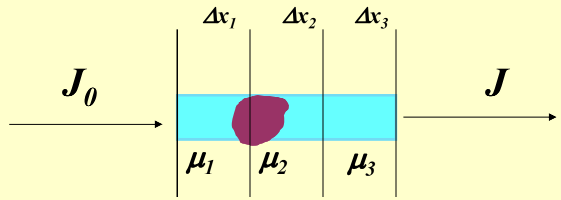
"X-ray image"
or
"radiographic image"

Contrast arises due to relative attenuation

Summation image



$$J = J_0 e^{-\mu x}$$



$$J = J_0 e^{-\mu x}$$

$$J = J_0 e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

no information about details

Density

$$D = \lg \frac{J_0}{J}$$

$$D_1 = \mu_1 x_1 \lg e$$

$$J = J_0 e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

$$J = J_0 e^{-(\mu_1 x_1 + \mu_2 x_2 + \mu_3 x_3)}$$

$$\lg \frac{J_0}{J} = (\mu_1 x_1 + \mu_2 x_2 + \mu_3 x_1) \lg e$$

$$D = D_1 + D_2 + D_3$$

$$D = \sum_i D_i$$

Radiographic contrast

If the differences between

$$\tau_m = C \lambda^3 Z_{eff}^3$$

or

densities

of neighbouring tissues are not sufficient

alteration of Z_{eff} or density

	Z_{eff}	ρ (g/cm^3)
H_2O	7.7	1
soft tissues	7.4	1
bones	13.8	1.7 - 2.0
air	7.3	1.29×10^{-3}

	Z_{eff}	ρ (g/cm^3)
H_2O	7.7	1
soft tissues	7.4	1
bones	13.8	1.7 - 2.0
air	7.3	1.29×10^{-3}

$$\tau_m = C\lambda^3 Z_{eff}^3$$

Positive contrast → *increased attenuation*

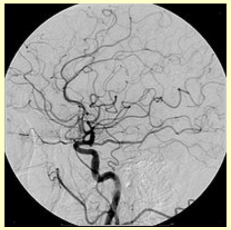
$Z_{eff\ contrast} > Z_{surrounding}$

$\mu_{contrast} > \mu_{surrounding}$

$\mu_{m\ contrast} > \mu_{m surrounding}$

Positive contrast

increased Z_{eff}



E.g., I- or Ba-compounds
$^{56}BaSO4$, ^{53}J

Negative contrast → *smaller attenuation*

$\rho_{contrast} < \rho_{surrounding}$

$\mu_{contrast} < \mu_{surrounding}$

$Z_{eff} \approx Z_{surrounding}$

air, CO_2

Double – positive + negative – contrast

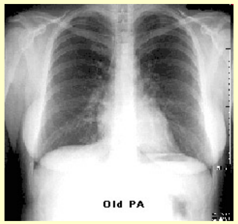
Digital Subtraction Angiography (DSA)

contrast ***native*** ***contrast - native***

images

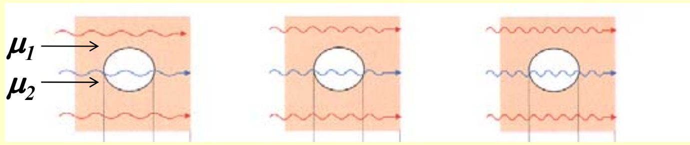
Improving spatial resolution

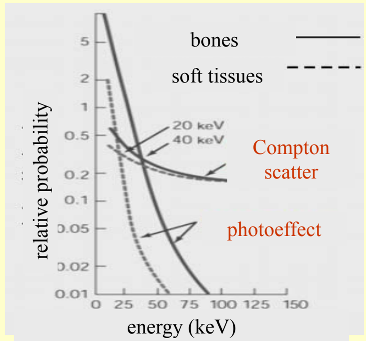
Bi-directional imaging



Photon energy and image quality

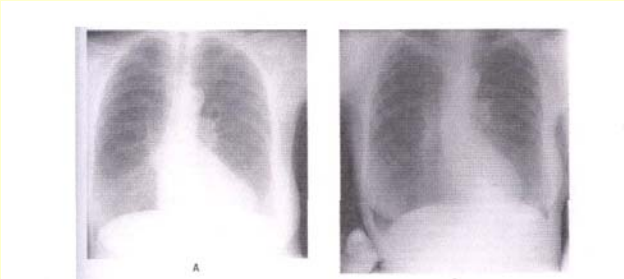
$U_1 < U_2 < U_3$





Photon energy and image quality

U_1 < U_2



Photon energy and image quality

U_1 < U_2

(30 keV) *(2 MeV)*

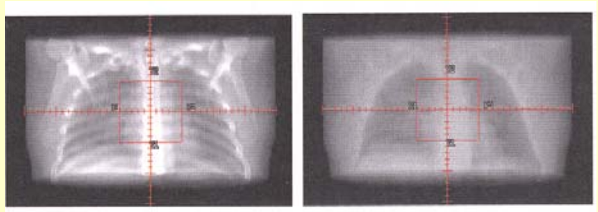


Photo effect	*36%*	*0%*
Compton scatter	*51%*	*99%*
Pair production	*0%*	*1%*

Average values

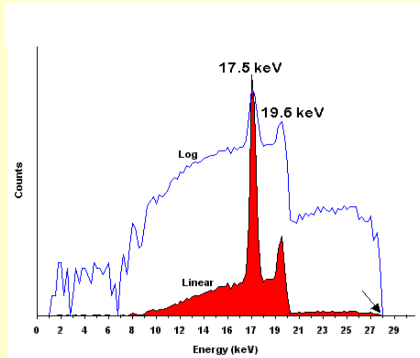
The noise in the image may limit the contrast.

The noise in the receptor image arises from several sources:

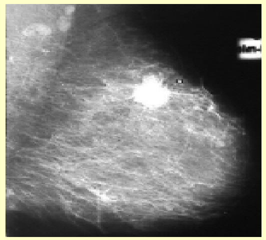
- fluctuations in the number of absorbed X-ray photons per unit area
- fluctuations in the absorbed photon energy
- fluctuations in the number of silver halide per unit area of emulsion

The first and the last are the main sources for noise (quantum mottle and random darkening).

Typical spectrum used in mammography

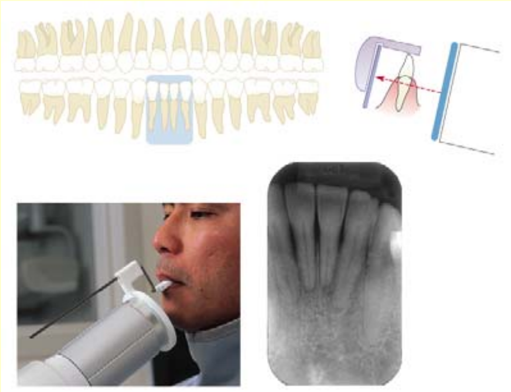


Characteristic lines of Molybdenum

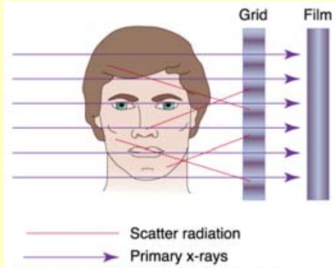


Malignant tissue in a mammogram

Intra-oral radiography

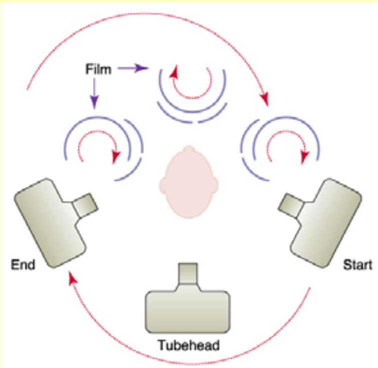


Extra-oral radiography



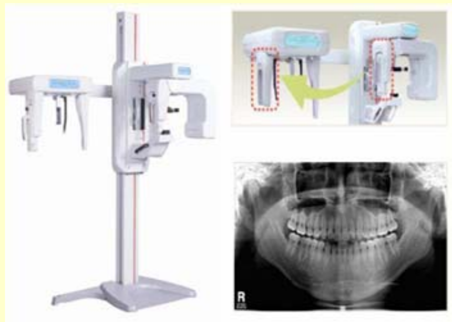
Dental panoramic radiography

The equipment consists of a horizontal rotating arm which holds an X-ray source and a moving film mechanism (carrying a film) arranged at opposed extremities.



Dental panoramic radiography

overlapping individual images projected on the film



a composite picture of the maxillo-facial block is created

Dental panoramic radiography

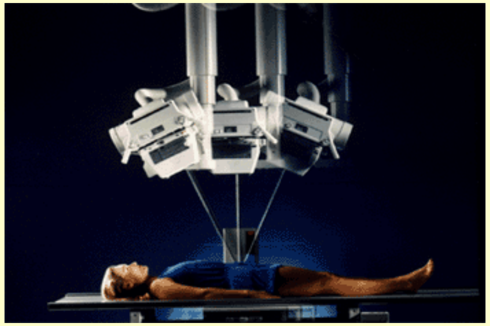
The person bites on a plastic spatula so that all the teeth, especially the crowns, can be viewed individually.

Limitations of conventional radiography

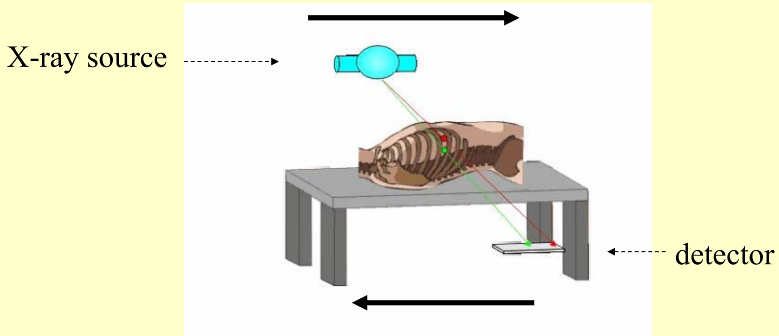
- **Superimposition** – inability to resolve spatially structures along the X-ray propagation axis resulting in loss of depth information (flat picture), because the three-dimensional body is projected on to a two-dimensional receptor.
- Difficulty in **distinguishing** between homogenous objects of **non-uniform thickness**.
- Inability to distinguish soft body tissue because of **limited contrast.**

Conventional Tomography

Tomos ---- section



Tomography

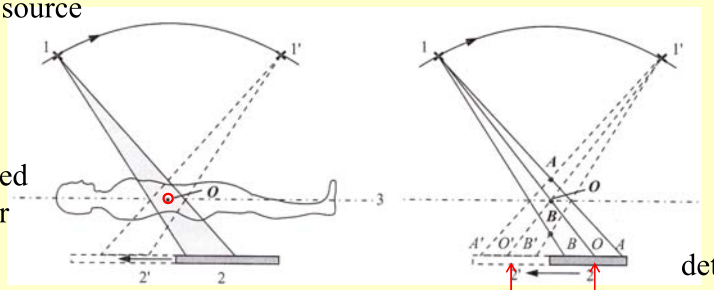


Elmozdulás a jelzett irányban

Tomographic blurring principle

X-ray source

selected layer



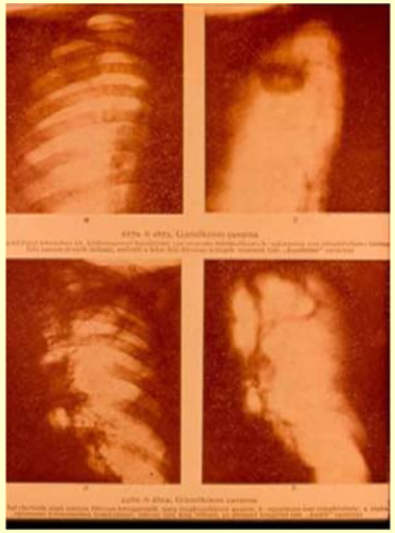
detector

Projectio pont ‘O’

Only ‘O’ remains in same position on the detector

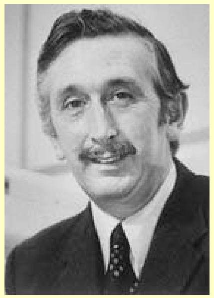
Only the selected layer looks sharply.

Summation image

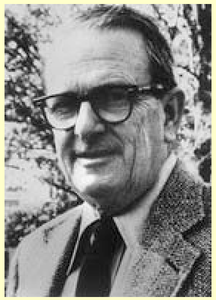


Tomography

X-Ray Transmission Computed Tomography



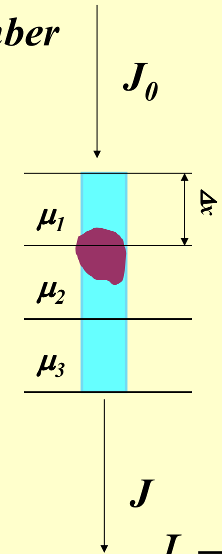
Godfrey Hounsfield

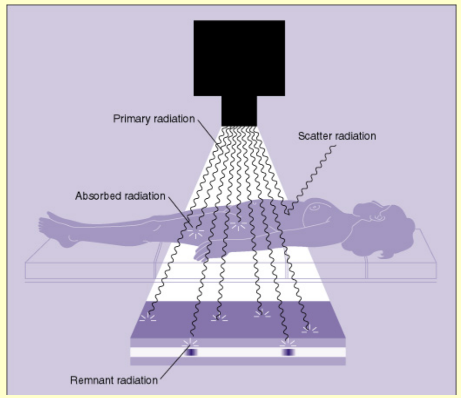


Allan Cormack

1979 Nobel-prize in Medicine

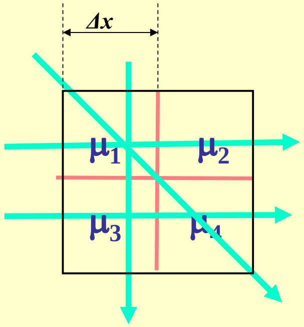
remember





$$J = J_0 e^{-(\mu_1 + \mu_2 + \mu_3)\Delta x}$$

Mathemetical interpretation with a simple example



$$J = J_0 e^{-(\mu_1 + \mu_2)\Delta x}$$

$$J = J_0 e^{-(\mu_3 + \mu_4)\Delta x}$$

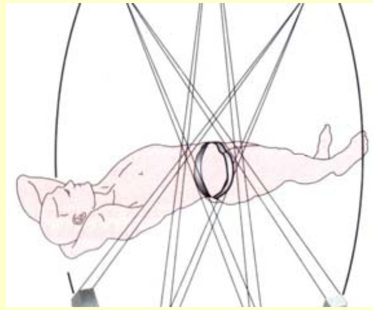
$$J = J_0 e^{-(\mu_1 + \mu_4)\Delta x}$$

$$J = J_0 e^{-(\mu_1 + \mu_3)\Delta x}$$

4 independent equations, 4 unknowns

New – axial – arrangement

The 2D CT image corresponds to a 3D section of the patient



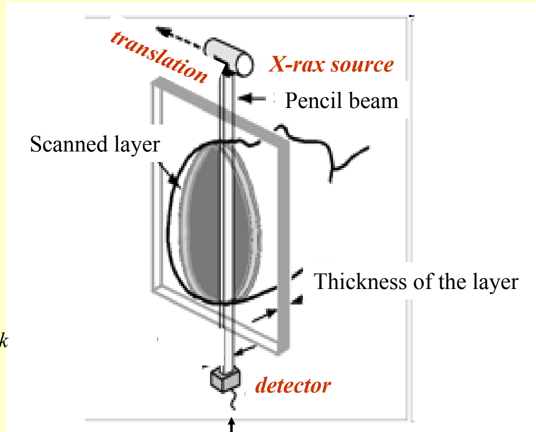
Computed tomography (CT) techniques allows sectional imaging .

Innovation of CT

$$J_k = J_0 e^{-(\Sigma \mu_{ik})\Delta x}$$

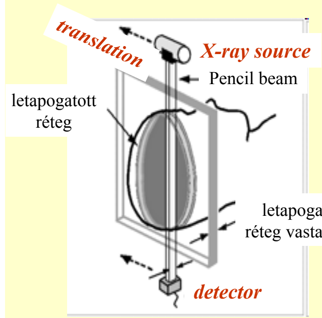
μ_i**:** attenuation coefficient of volume element along the beam

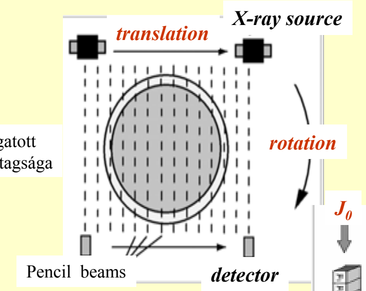
$$\lg \frac{J_0}{J} = \lg e \Delta x \sum_{i=1}^{n} \mu_{ik}$$

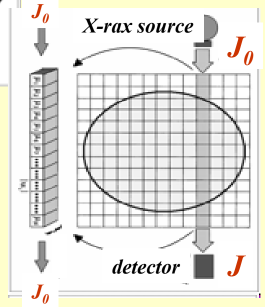


k-th position

First generation CT

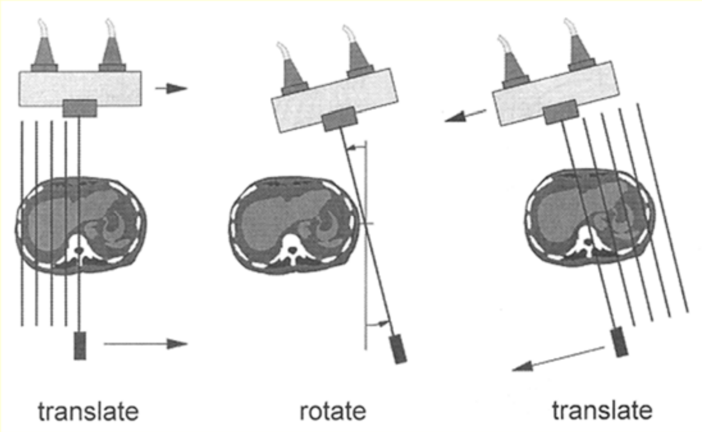






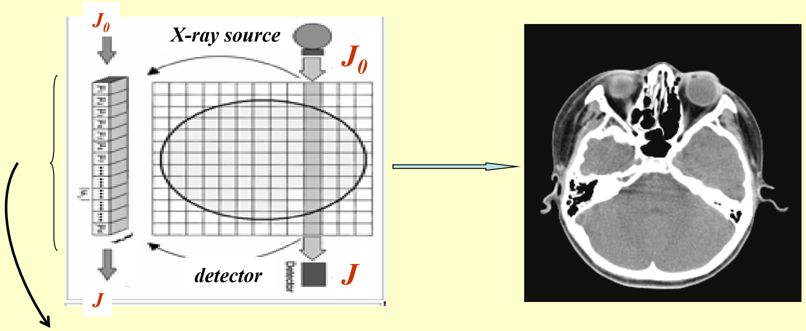
To store the multitude of images and process the data requires computer.

First generation CT



To store the multitude of images and process the data requires computer.

objekt *digital image*



Voxel : volume element

Pixel : picture element

Each ***pixel*** on the CT image displays the average x-ray attenuation properties of the tissue in the corrsponding ***voxel.***

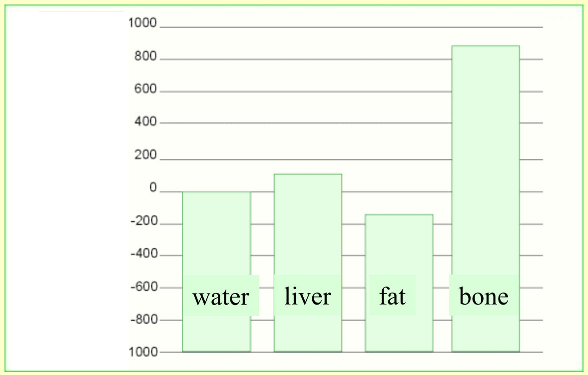
Reconstruction of the image

Density matrix

Hounsfield units

$$H_{CT} = 1000 \frac{\mu - \mu_{water}}{\mu_{water}}$$

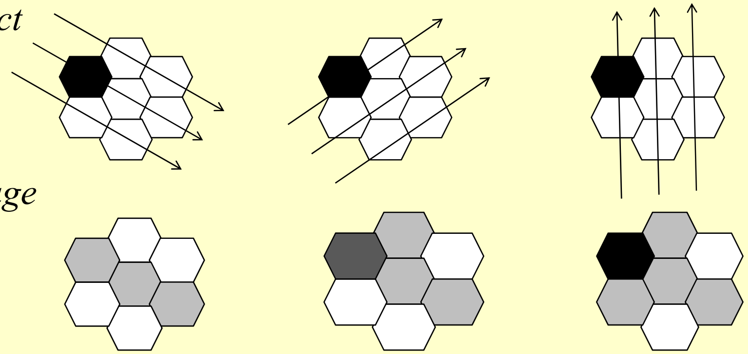
Hounsfield scale



Tomographic reconstruction

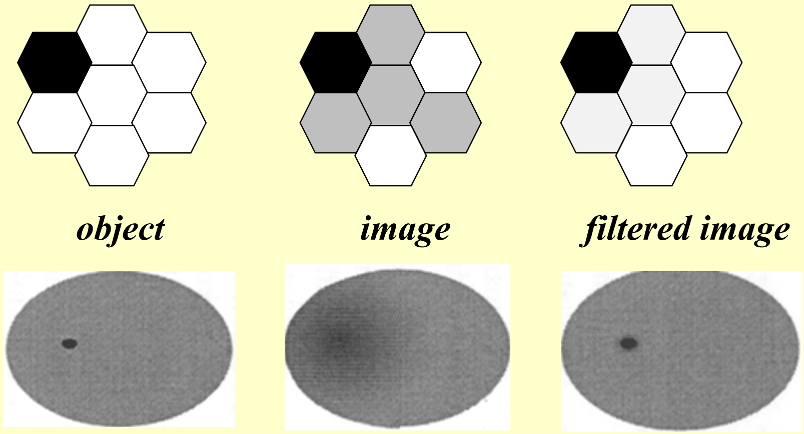
object

image



As data from a large number of rays are backprojected onto the image matrix, areas of high attenutation tend to reinforce one another, as do areas of low attenuation, building up the image.

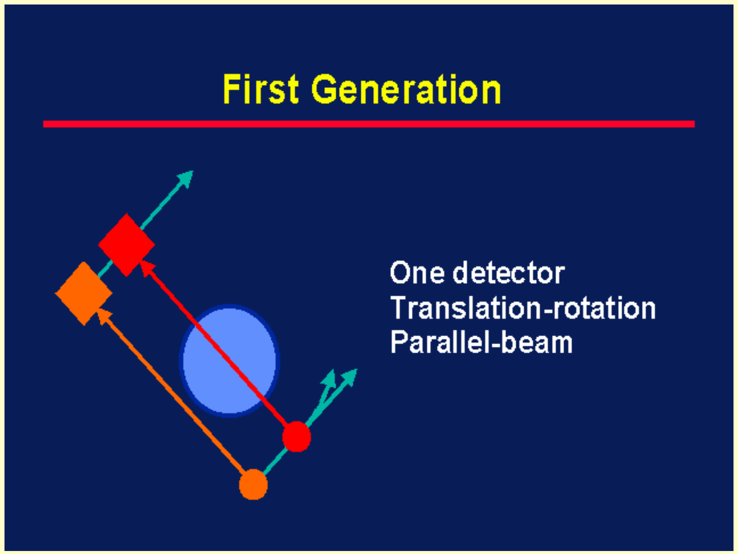
Tomographic reconstruction



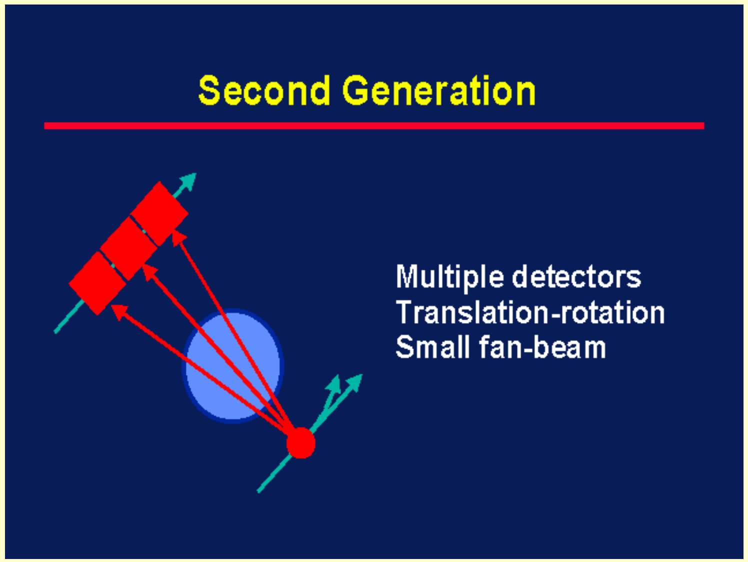
GOALS OF CT

- Minimal superimposition
- Image contrast improvement
- Small tissue difference recording

180 DEG ROTATION

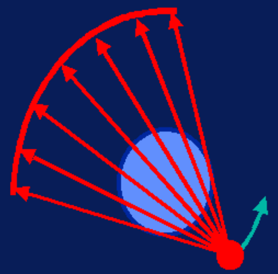


180 DEG ROTATION



360 DEG ROTATION

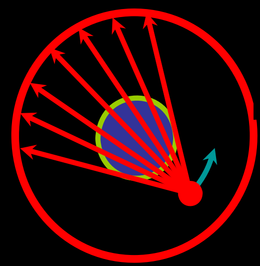
Third Generation



Multiple detectors
Rotation
Large fan-beam

360 DEG ROTATION

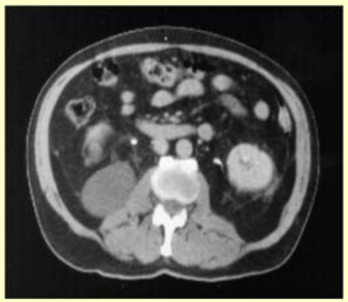
Fourth Generation



Rotatable X-ray source.
Stationary ring of detectors
Fanned X-ray beam.

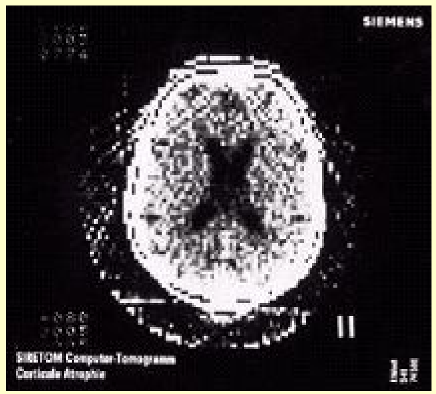
Early days vs Today

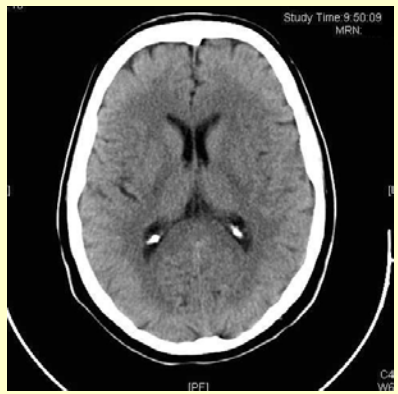
Second generation	Fourth generation



5 minutes — *2 seconds*

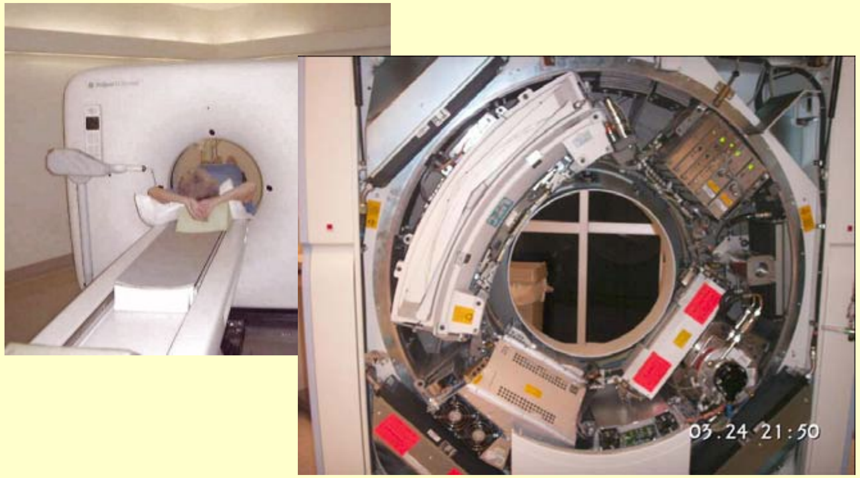
Early days vs Today



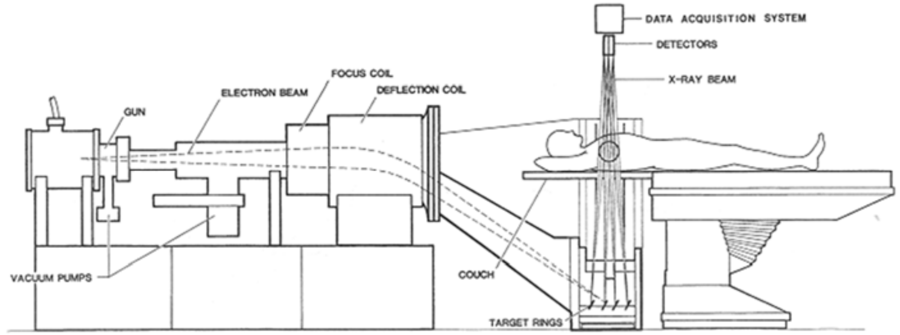


80 x 80 — ***512 x 512***

Scanner



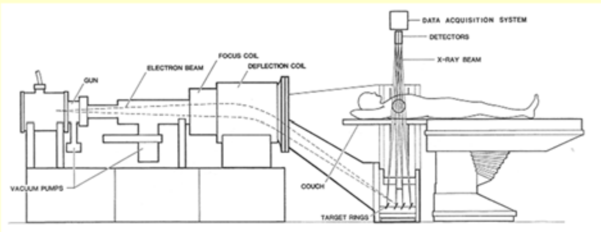
5th generation: stationary/stationary



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.

- 5th generation: stationary/stationary

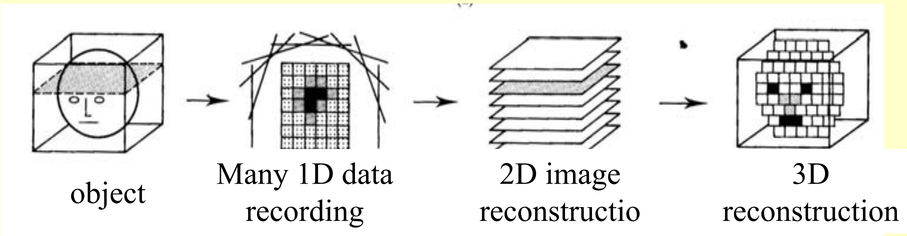


- Developed specifically for cardiac tomographic imaging
- No conventional x-ray tube; large arc of tungsten encircles patient and lies directly opposite to the detector ring
- Electron beam steered around the patient to strike the annular tungsten target
- Capable of 50-msec scan times; can produce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

Increasing CT quality

year	Scan time (s/scan)	Thickness of layer (mm)	Number of layers
1980	10	10	25-30
1985	5	8-10	30-45
1990	1	3-5	100
1995	0,75	3	100
1999	0,5	1-3	220
2003	0,4	0,5-0,75	400-1200
2004	0,33	0,5-0,75	600-2500

CT 3D reconstruction



AXIAL SCAN

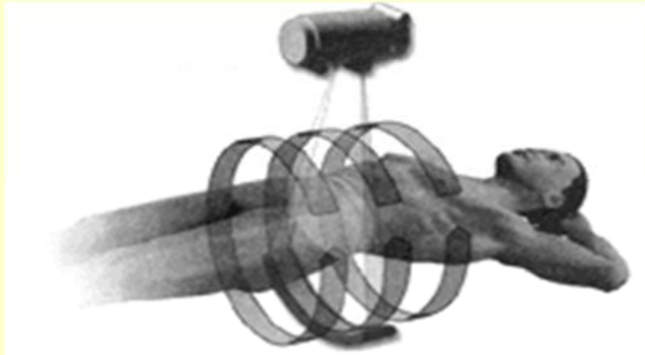
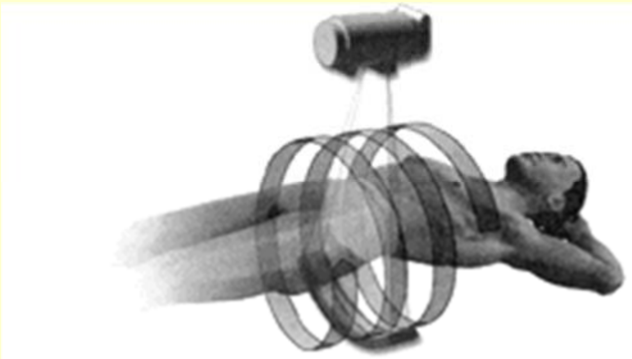


Table stops at the scanning position and the tube rotates around a patient.

SPIRAL CT



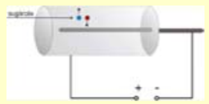
Patient continuously moves in the Z-axis direction while the tube rotates around.

Detectors for X-ray dianostics

radiation sensitive film

scintillators

gas ionisation chamber



semiconductor detectors

Image preparation

Photografic method

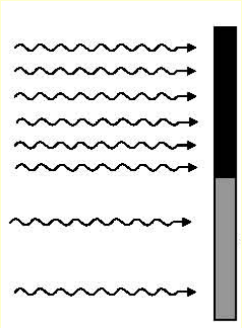
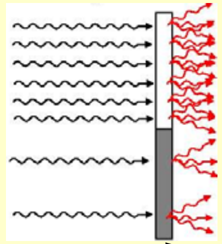


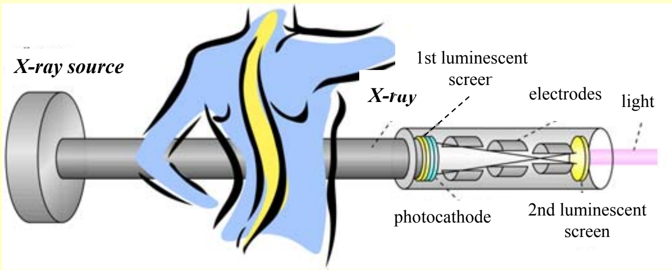
Image preparation

Convencional fluoroscopy



advantage: no film development,
image guided manipulation
disadvantage: high exposure
poor quality

X-ray image intensifier



Possibility of image digitization

Smaller patient exposure

Manipulation under X-ray control

Damjanovich, Fidy, Szöllősi: Medical Biophysics

VIII. 3.1
3.1.1
3.1.2
VIII.4.3