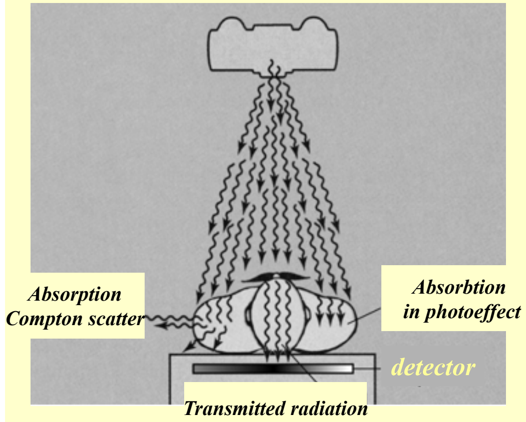
Medical applications of X-rays

X-ray diagnostics and imaging

Diagnostic radiology

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

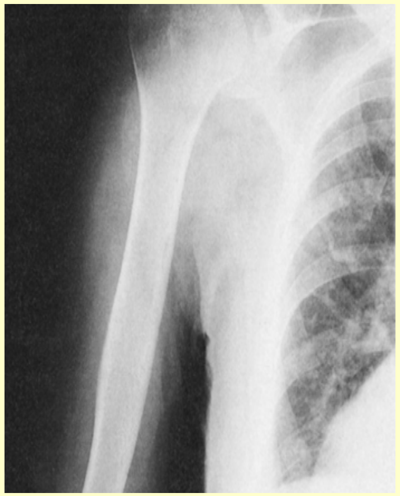


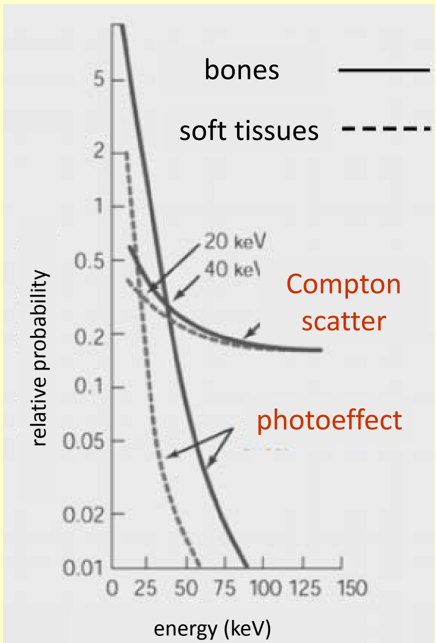
Possible interactions:

Compton scatter

photoeffect

no interaction





Attenuation decreases with increasing photon energy.

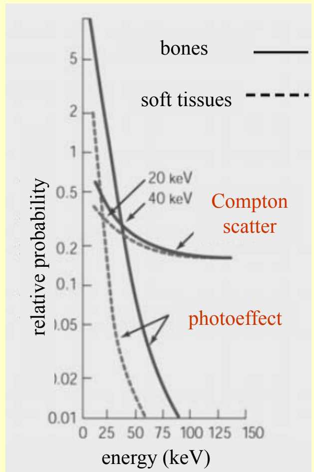
The decrease is more pronounced in the case of photoeffect.

At lower photon energies τ_m is dominant.

τ_m strongly depends on the atomic number.

$$\tau_m \approx \lambda^3 Z^3$$

Spectral changes of radiation drastically modify the attenuation processes.

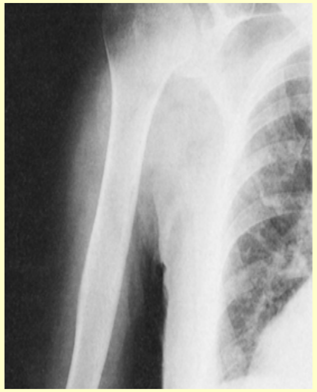


Effective atomic number

$$Z_{eff} = \sqrt[3]{\sum_{i=1}^{n} w_i Z_i^3}$$

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

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



Summary of attenuation mechanisms

	Variation with E	Variation with Z	Energy range in tissues
τ_m	~ $1/E^3$	~ Z^3	10 – 100 keV
σ_m	Slightly falls with E	linear	0.5 – 5 MeV
κ_m	Rises slowly with E	~ Z^2	>5 MeV

Main contrast mechanism in diagnostic X-ray: photoeffect (~Z^3)

Production of X-ray image

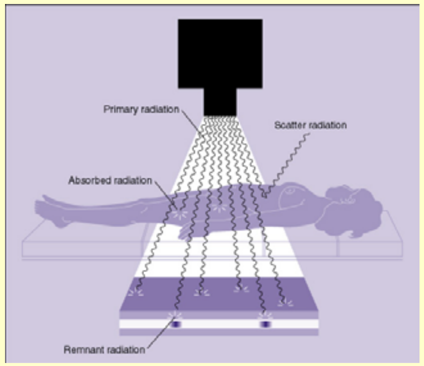
Representation of variations in attenuated intensity

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

scalp

chest

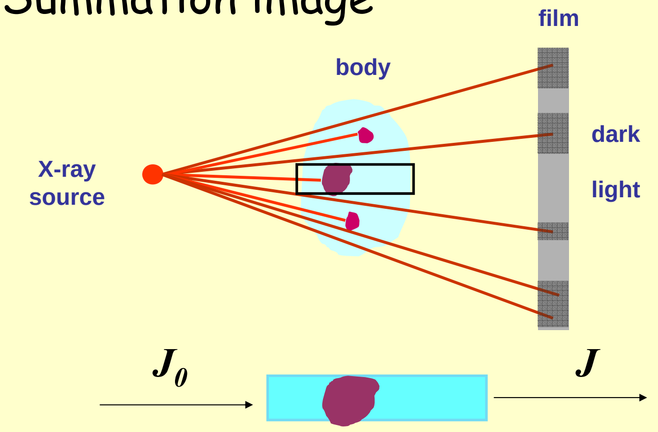
Summation image



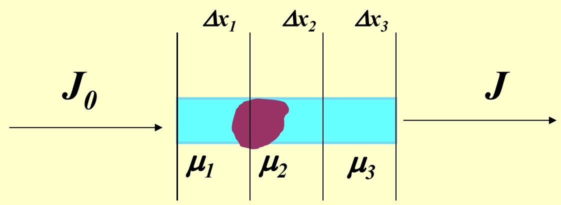
"X-ray image" or "radiographic image"

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

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

$$D = \sum_i D_i$$

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/cm³)
H_2O	7.7	1
soft tissies	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 $\rightarrow$ ***increased attenuation***

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

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

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

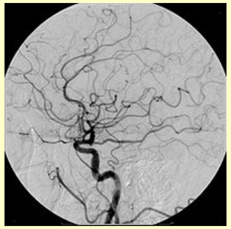
Negative contrast $\rightarrow$ ***decreased attenuation***

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

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

Positive contrast

increased Z_{eff}



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

Negative contrast

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

air, CO_2

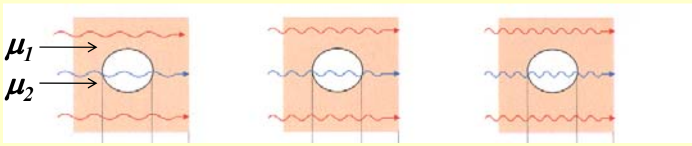
Digital Subtraction Angiography (DSA)

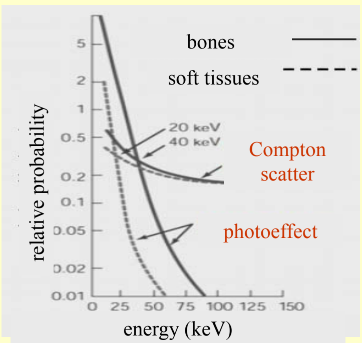
contrast ***native*** ***contrast - native***

images

Photon energy and image quality

$U_1 < U_2 < U_3$

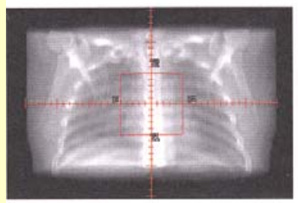




Photon energy and image quality

$U_1 < U_2$

(30 keV) ***(2 MeV)***



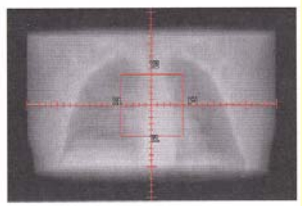
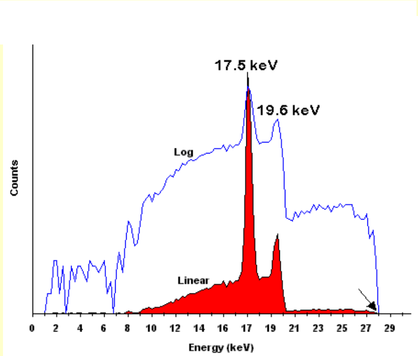


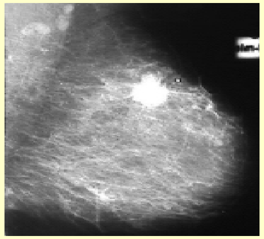
Photo effect	*36%*	*0%*
Compton scatter	*51%*	*99%*
Pair production	*0%*	*1%*

Average values

Typical spectrum used in mammography

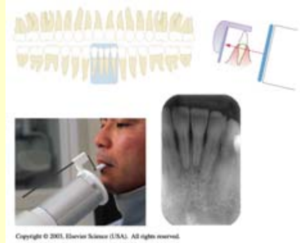


Characteristic lines of Molybdenum

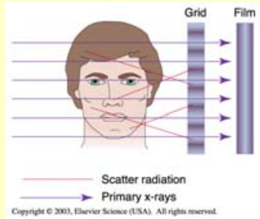


Malignant tissue in a mammogram

Intra-oral radiography



Extra-oral radiography



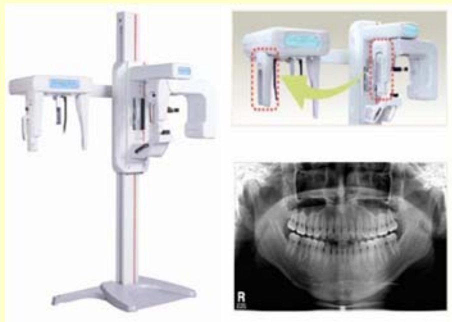
Dental panoramic radiography

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.

overlapping individual images projected on the film

Dental panoramic radiography

overlapping individual images projected on the film

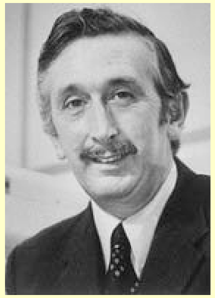


a composite picture of the maxillo-facial block is created

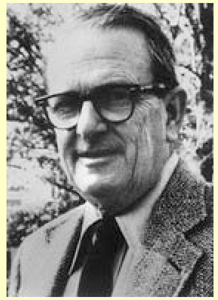
Limitations of conventional radiography

- **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.**

X-Ray Transmission Computed Tomography



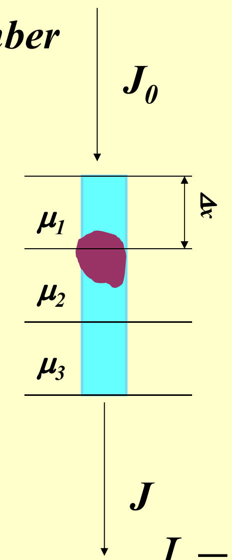
Godfrey Hounsfield

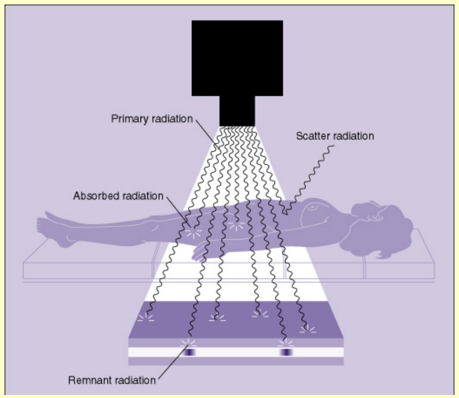


Allan Cormack

1979 Nobel-prize in Medicine

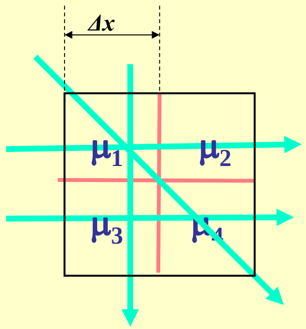
remember





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

Mathematical interpretation with a simple example



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

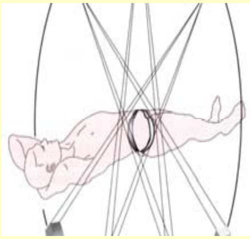
$$J = J_0 e^{-(\mu_3 + \mu_4)\Delta x}$$

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

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

4 independent equations, 4 unknowns

New – axial – arrangement



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

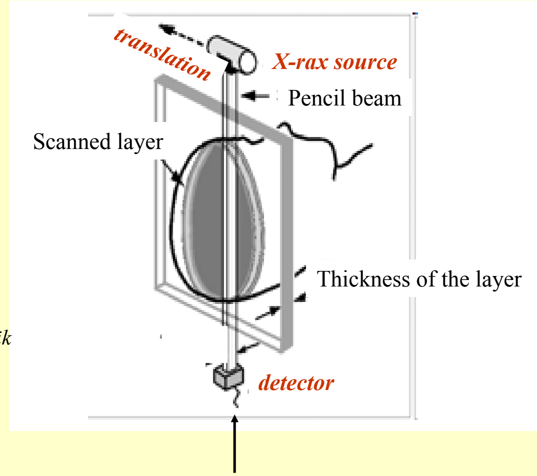
Computed tomography (CT) techniques allows sectional imaging .

Innovation of CT

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

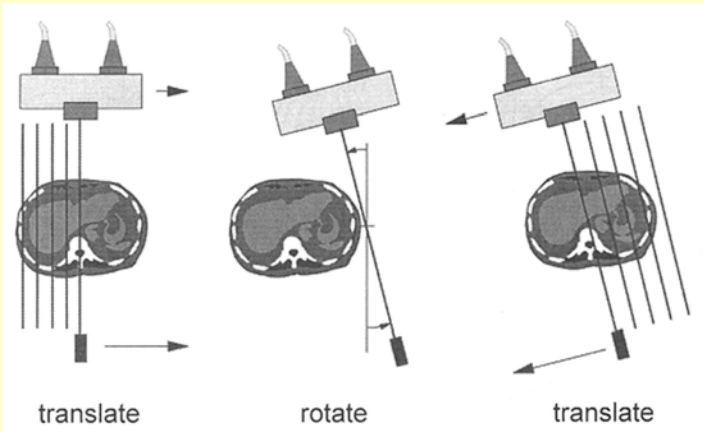
μ_i**:** attenuation coefficient of volume element along the beam

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



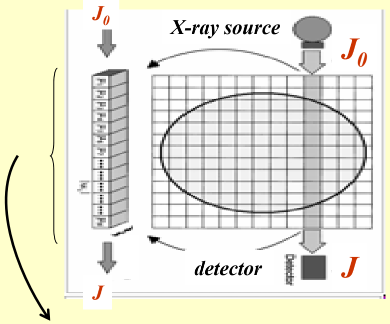
k-th position

First generation CT



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

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.***

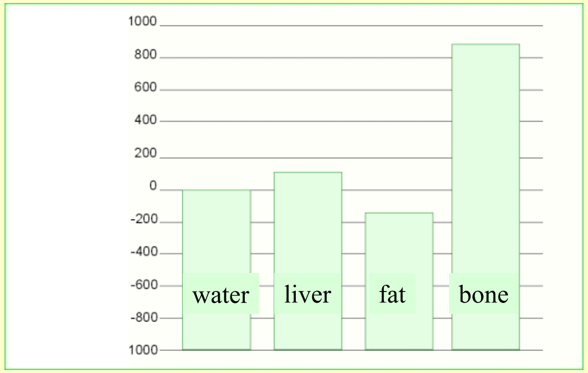
Reconstruction of the image

Density matrix

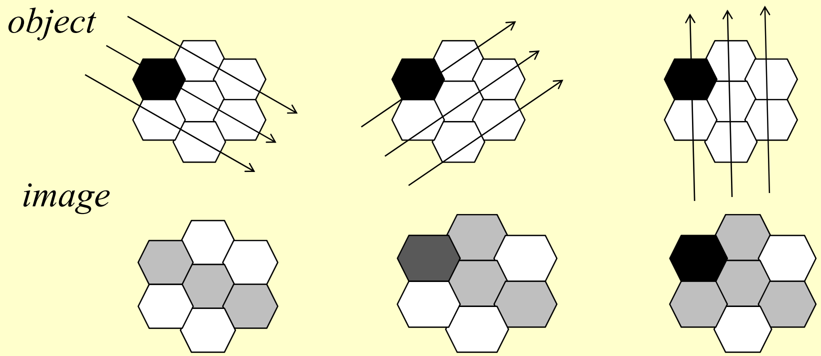
Hounsfield units

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

Hounsfield scale

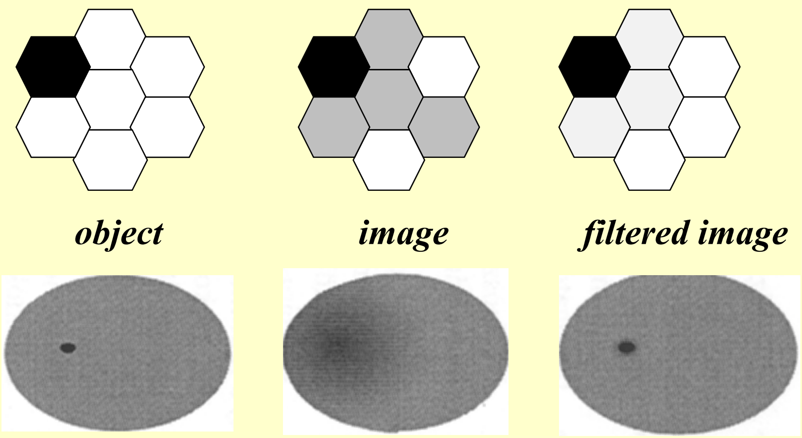


Tomographic reconstruction



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.

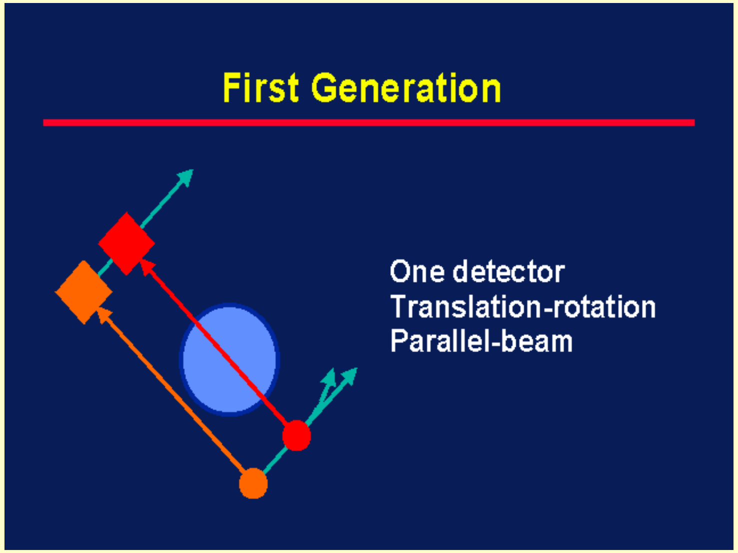
Tomographic reconstruction



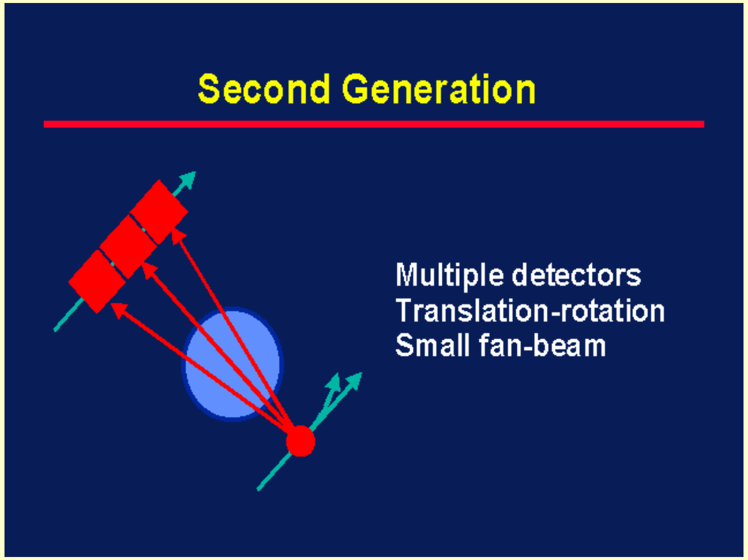
GOALS OF CT

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

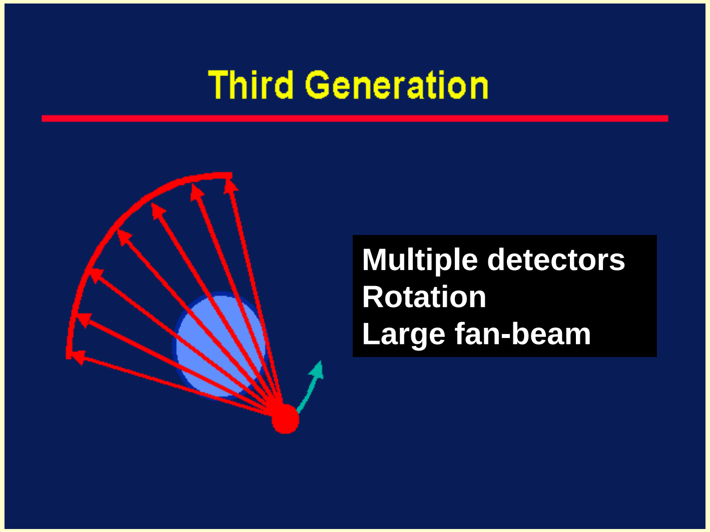
180 DEG ROTATION



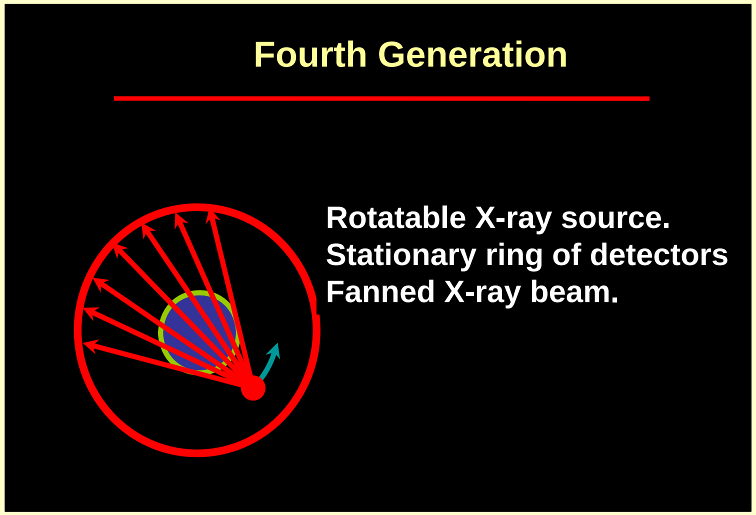
180 DEG ROTATION



360 DEG ROTATION



360 DEG ROTATION

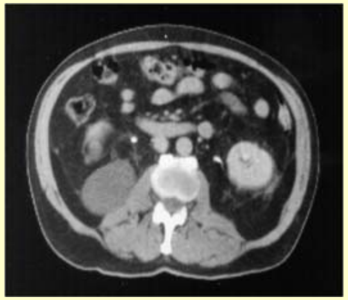


Early days vs Today

Second generation

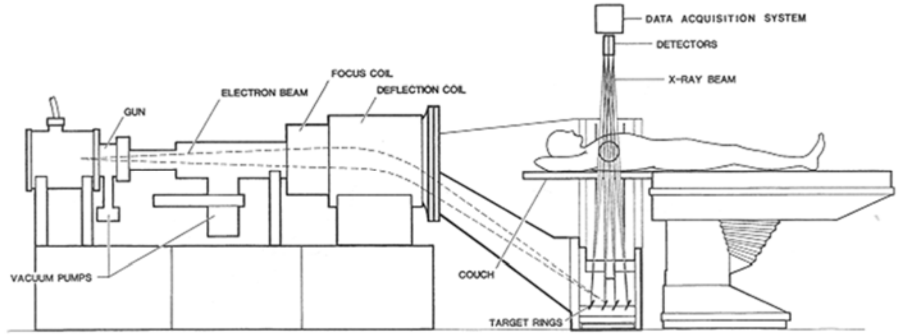
5 minutes

Fourth generation



2 seconds

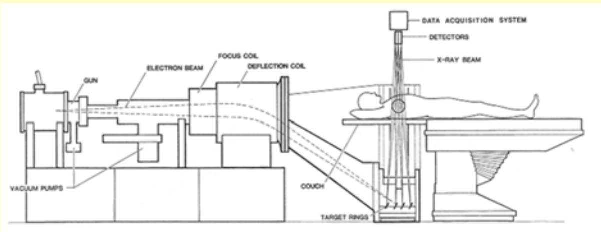
5^{th} generation: stationary/stationary



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.

- 5^{th} 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

AXIAL SCAN

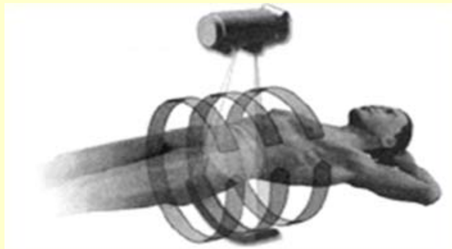


Table stops at the scanning position and the tube rotates around a patient.

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

Detectors for X-ray dianostics

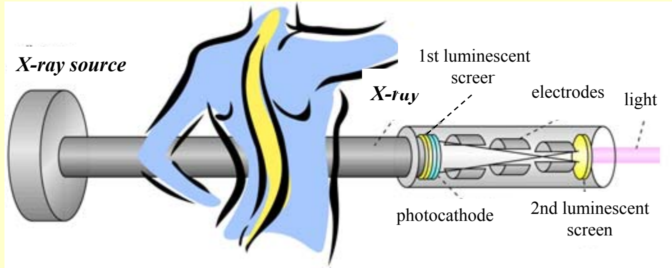
radiation sensitive film

scintillators

gas ionisation chamber

semiconductor detectors

X-ray image intensifier



Possibility of image digitization

Smaller patient exposure

Manipulation under X-ray control

Question of the week

What is the connection between effective atomic number of an absorber and the relative probability of X-ray absorption in various absorption mechanisms (photo-effect, Compton-scattering or pair-production)?

Damjanovich, Fidy, Szöllősi: Medical Biophysics

VIII. 3.1
3.1.1
3.1.2
VIII.4.3