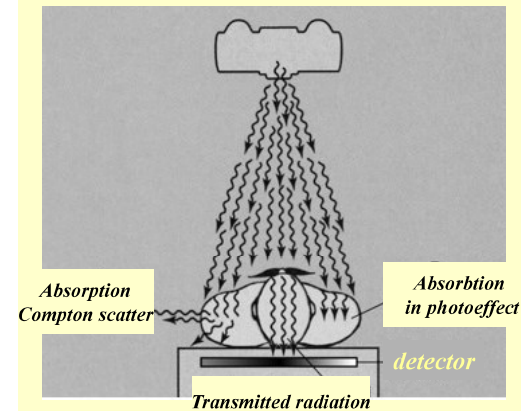


Medical applications of X-rays

X-ray diagnostics and imaging

Diagnostic radiology

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

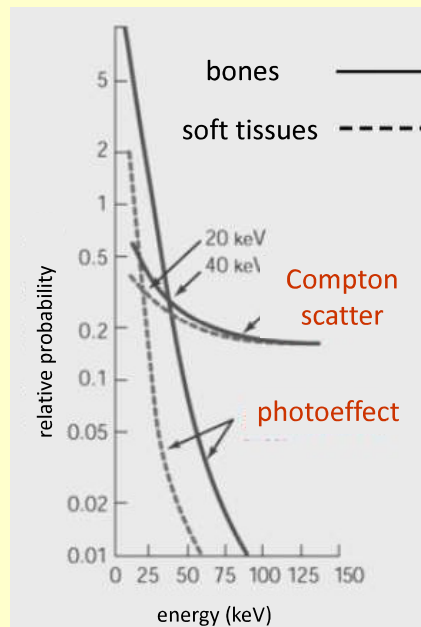
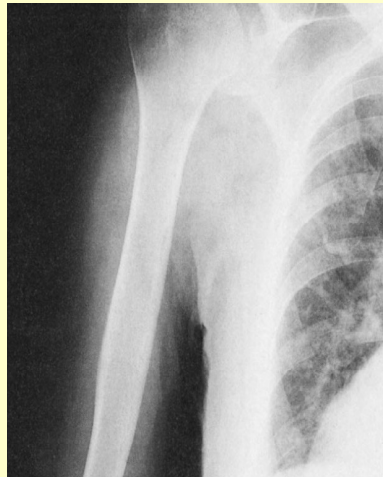


Possible interactions:

Compton scatter

photoeffect

no interaction



Attenuation decreases with
increasing photon energy.

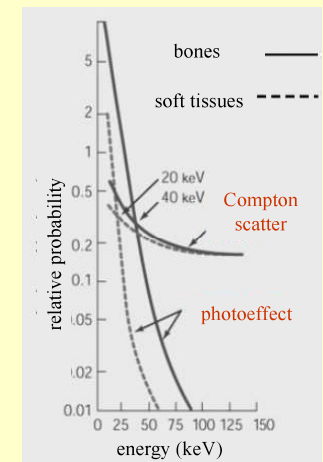
The decrease is more pronounced
in the case of photoeffect.

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	$\sim 1/E^3$	$\sim Z^3$	10 – 100 keV
σ_m	Slightly falls with E	linear	0.5 – 5 MeV
κ_m	Rises slowly with E	$\sim Z^2$	>5 MeV

Main contrast mechanism in diagnostic X-ray:
photoeffect ($\sim Z^3$)

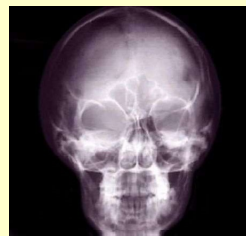
Production of X-ray image

Representation of variations in
attenuated intensity

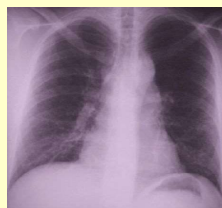
in radiation sensitive film

on luminescent screen

in digitized image

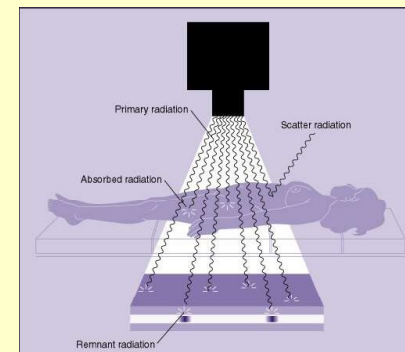


scalp



chest

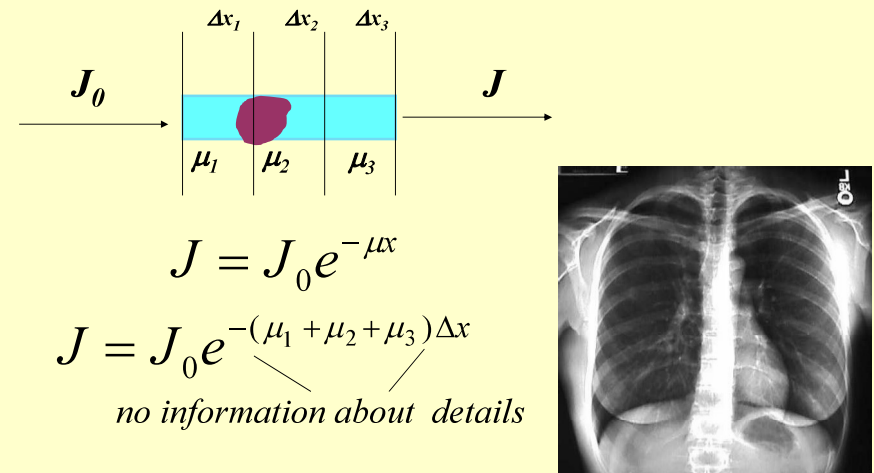
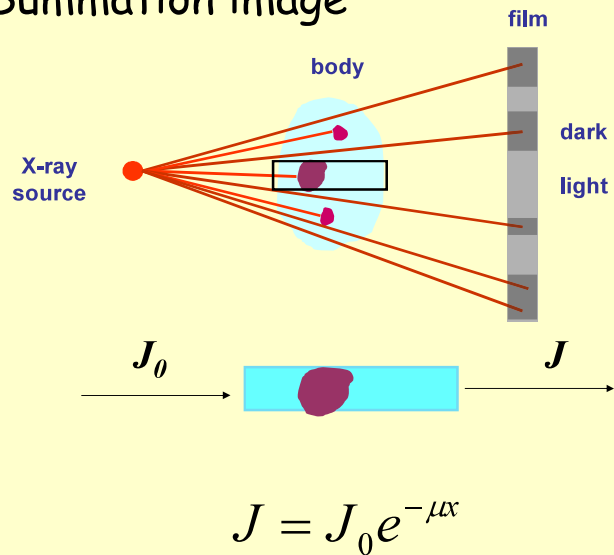
Summation image



*“X-ray image”
or
“radiographic image”*

Contrast arises due to relative attenuation

Summation image



Radiographic contrast

If the differences between

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

or
densities

of neighboring tissues are not sufficient

alteration of Z_{eff} or density

	Z_{eff}	ρ (g/cm ³)	$\tau_m = C \lambda^3 Z_{eff}^3$
H ₂ O	7.7	1	
soft tissies	7.4	1	
bones	13.8	1.7 - 2.0	
air	7.3	1.29 x 10 ⁻³	

Positive contrast → *increased attenuation*

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

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

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

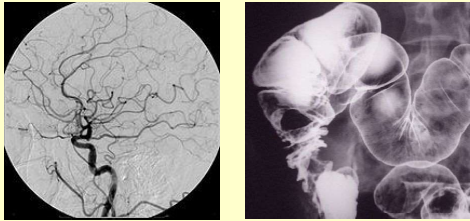
Negative contrast → *decreased attenuation*

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

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

Positive contrast

increased Z_{eff}



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

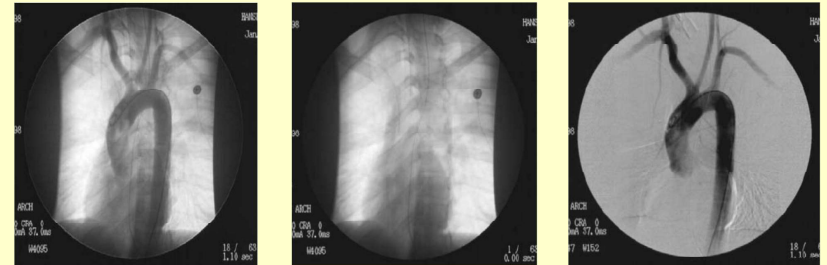
Negative contrast

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



air,
 CO_2

Digital Subtraction Angiography (DSA)



contrast

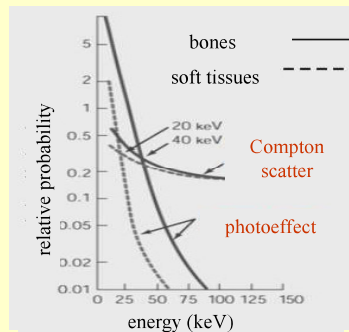
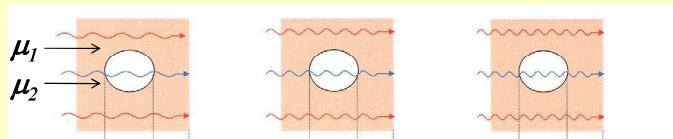
native

contrast - native

images

Photon energy and image quality

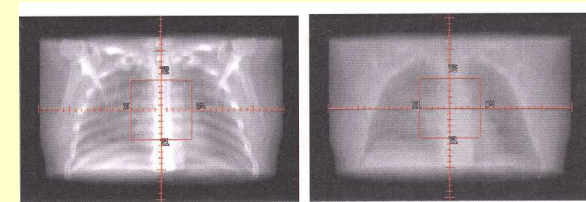
$$U_1 < U_2 < U_3$$



Photon energy and image quality

$$U_1 < U_2$$

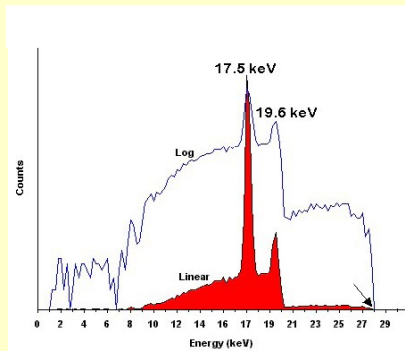
(30 keV) (2 MeV)



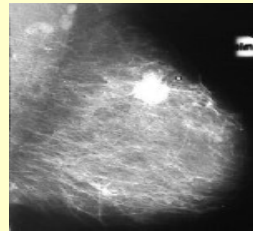
<i>Photo effect</i>	36%	0%
<i>Compton scatter</i>	51%	99%
<i>Pair production</i>	0%	1%

Average values

Typical spectrum used in mammography



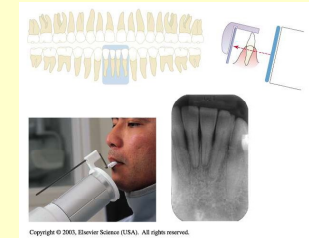
Characteristic lines of Molybdenum



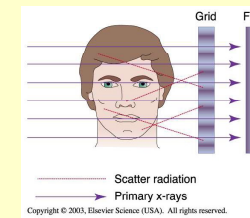
Malignant tissue in a mammogram



Intra-oral radiography

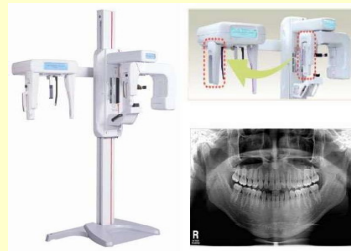


Extra-oral radiography



Dental panoramic radiography

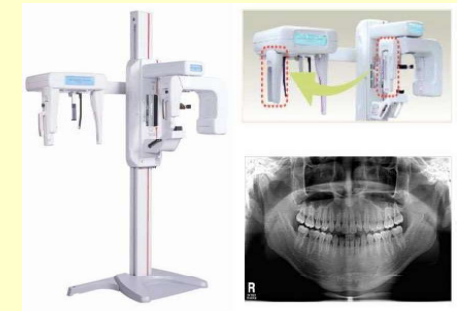
The equipment consists of a horizontal rotating arm which holds an X-ray source and a moving film mechanism (carrying a film) arranged at opposed extremities.



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

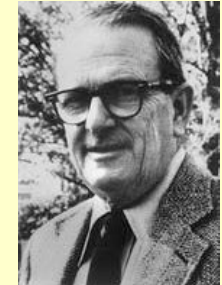
Limitations of conventional radiography

- **Superposition** – 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**.
- In-ability to distinguish soft body tissue because of **limited contrast**.

X-Ray Transmission Computed Tomography



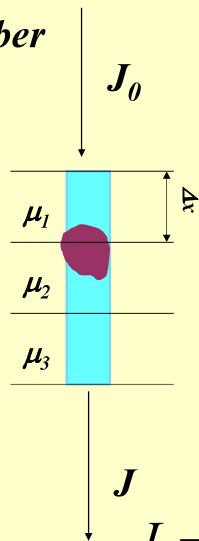
Godfrey Hounsfield



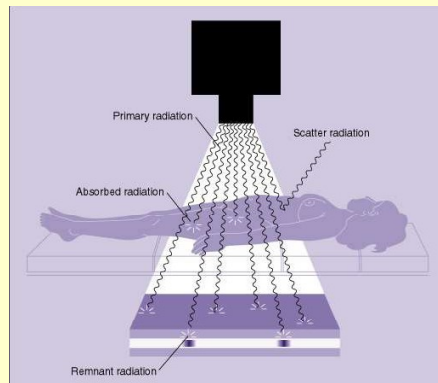
Allan Cormack

1979 Nobel-prize in Medicine

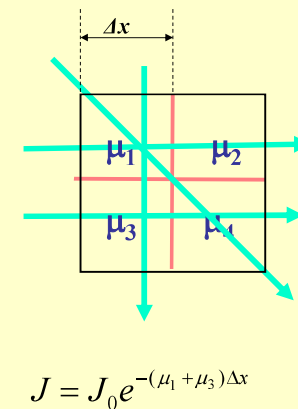
remember



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



Mathematical interpretation with a simple example



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

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

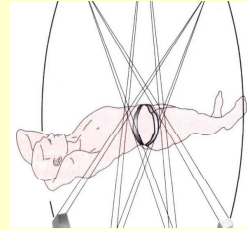
$$J = J_0 e^{-(\mu_1 + \mu_4) \Delta x}$$

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

4 independent equations, 4 unknowns

New – axial – arrangement

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



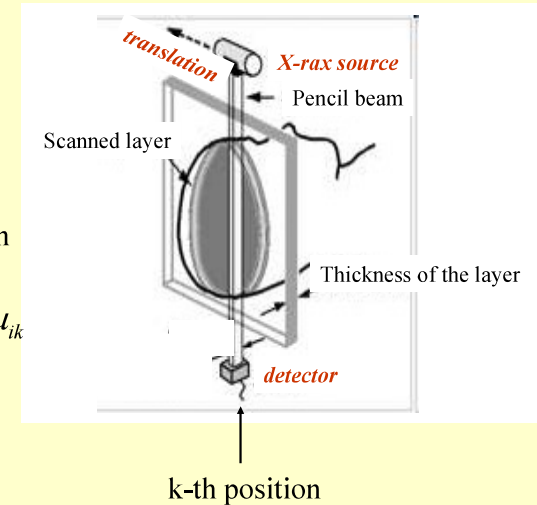
Computed tomography (CT) techniques allows sectional imaging .

Innovation of CT

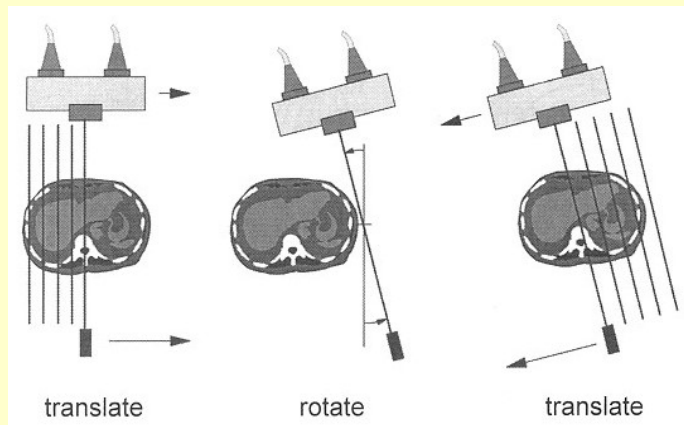
$$J_k = J_0 e^{-(\sum \mu_{ik}) \Delta x}$$

μ_i : attenuation coefficient of volume element along the beam

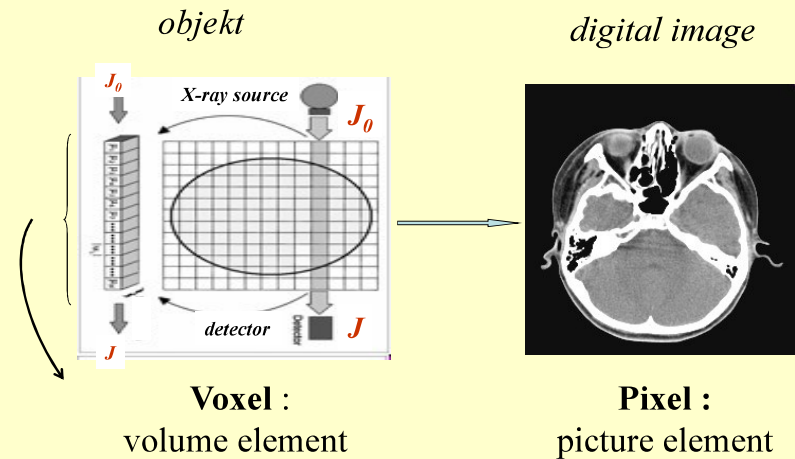
$$\lg \frac{J_0}{J} = \lg e \Delta x \sum_{i=1}^n \mu_{ik}$$



First generation CT



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



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

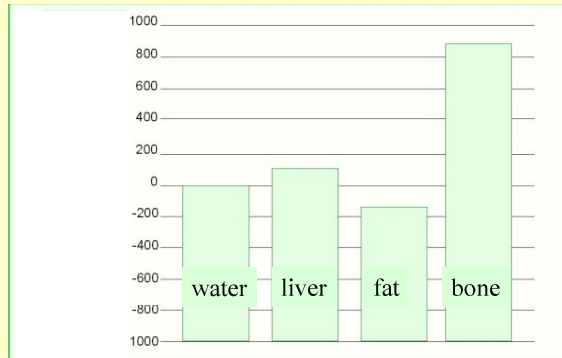
Reconstruction of the image

Density matrix

Hounsfield units

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

Hounsfield scale

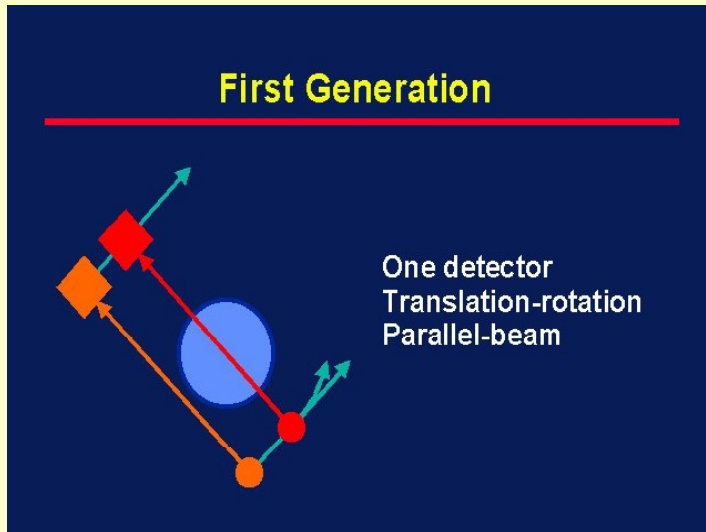


GOALS OF CT

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

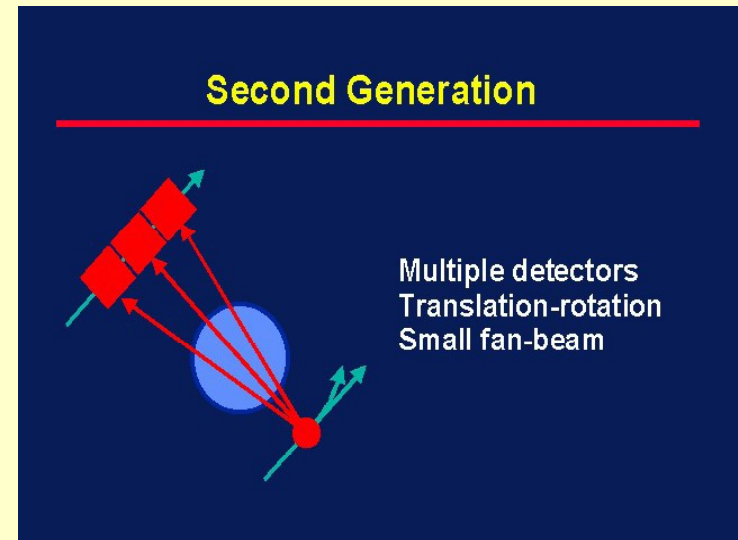
180 DEG ROTATION

First Generation



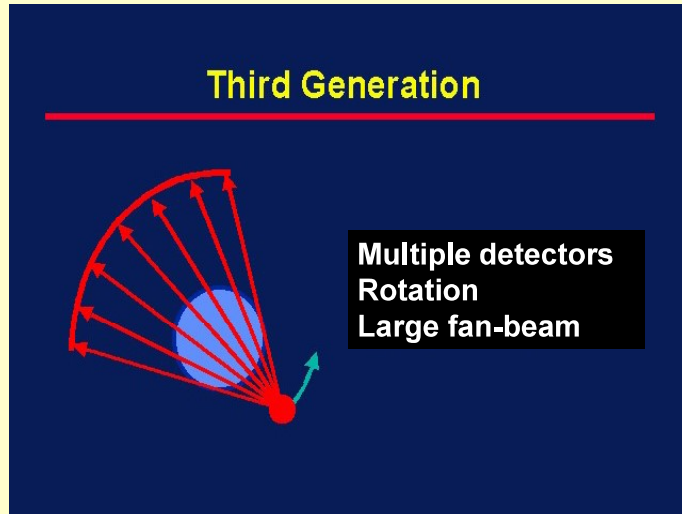
180 DEG ROTATION

Second Generation



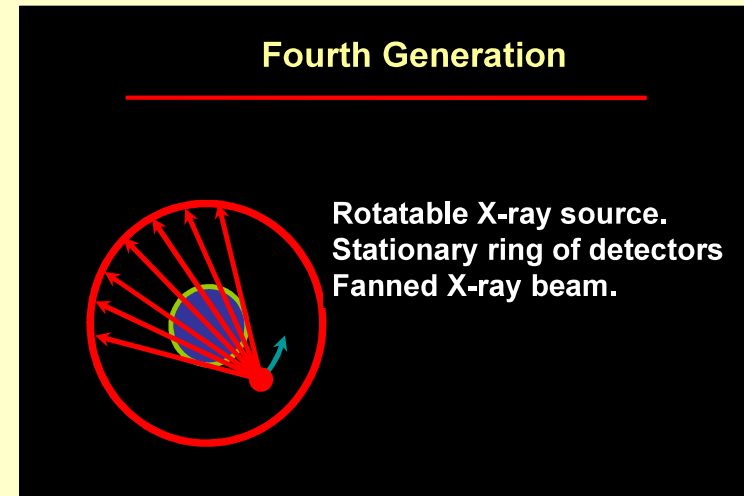
360 DEG ROTATION

Third Generation



360 DEG ROTATION

Fourth Generation



Early days vs Today

Second generation



5 minutes

Fourth generation



2 seconds

AXIAL SCAN

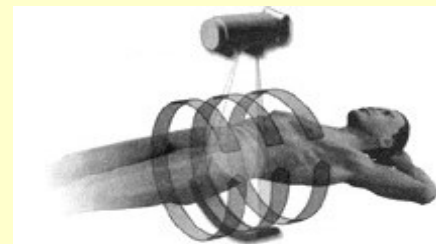
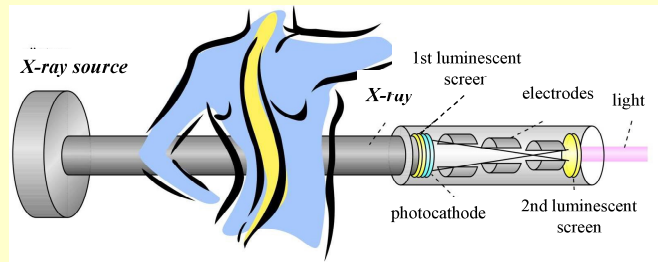


Table stops at the scanning position and the tube rotates around a patient.

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

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 the atomic number of the absorber and the mass attenuation coefficient for photoeffect?

Damjanovich, Fidy, Szöllősi: Medical Biophysics

VIII. 3.1

3.1.1

3.1.2

VIII.4.3