

12. X-ray diagnostics

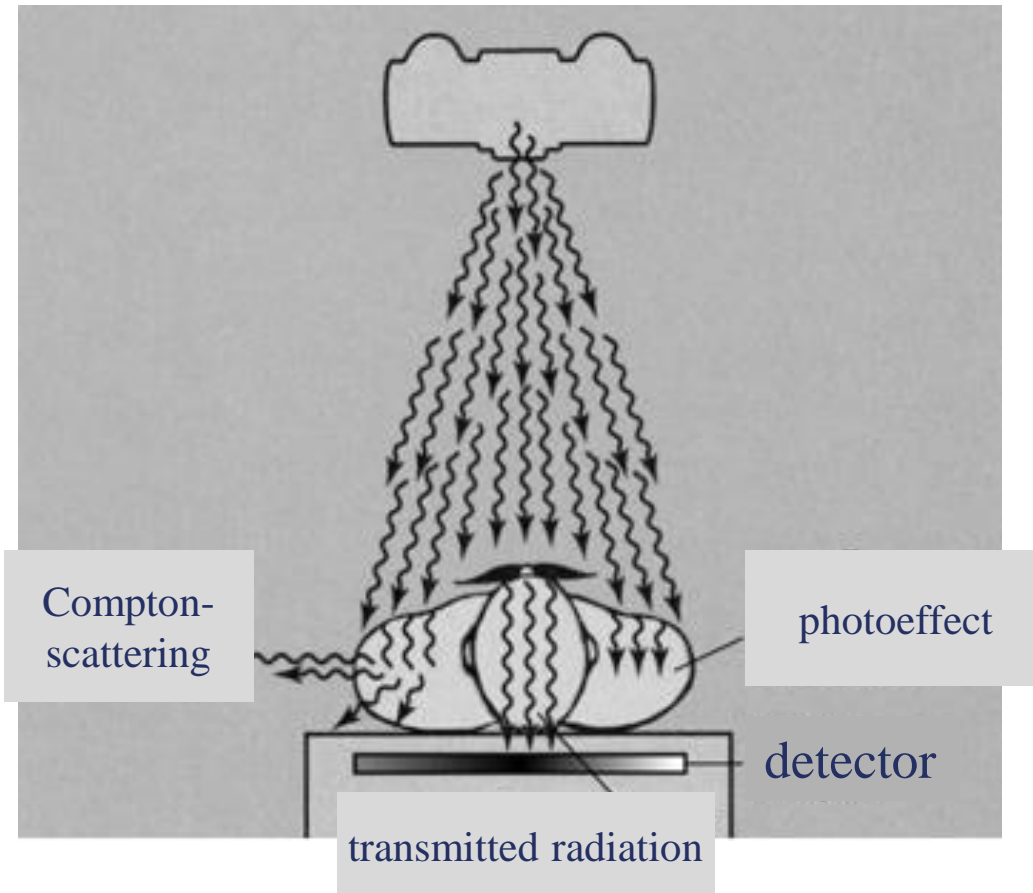
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2025.11.28

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The basis of X ray diagnostics: absorption



Interactions of X-ray
photon:

elastic scattering

photoeffect

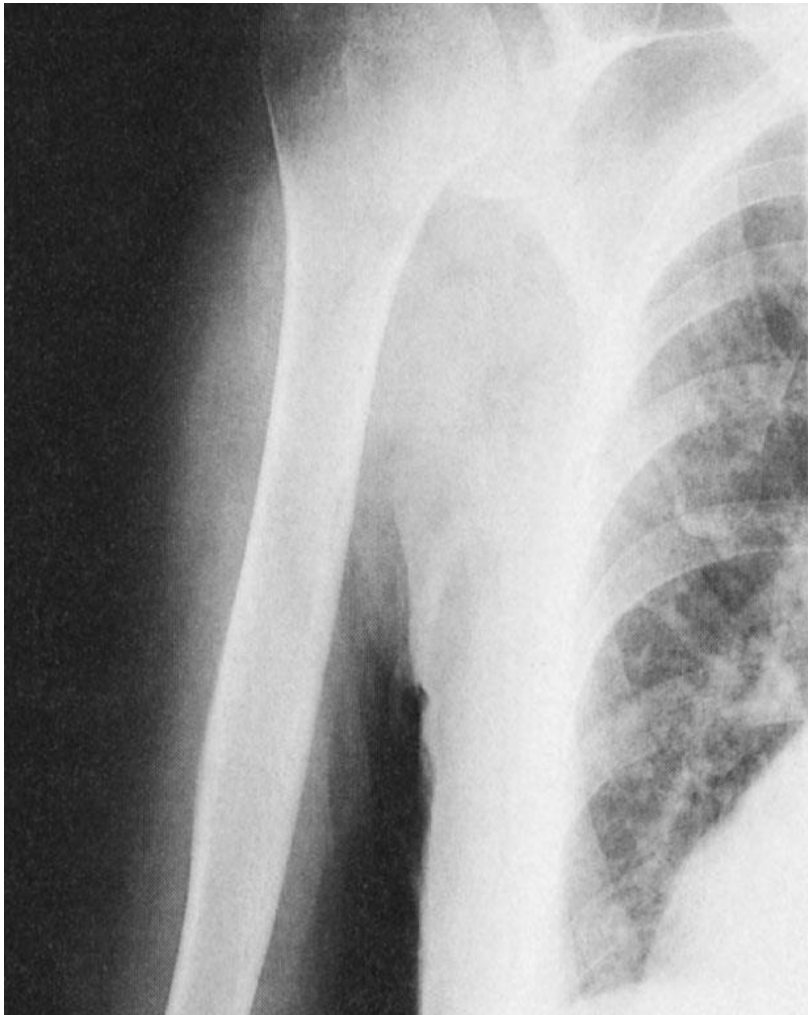
Compton scattering

pair production

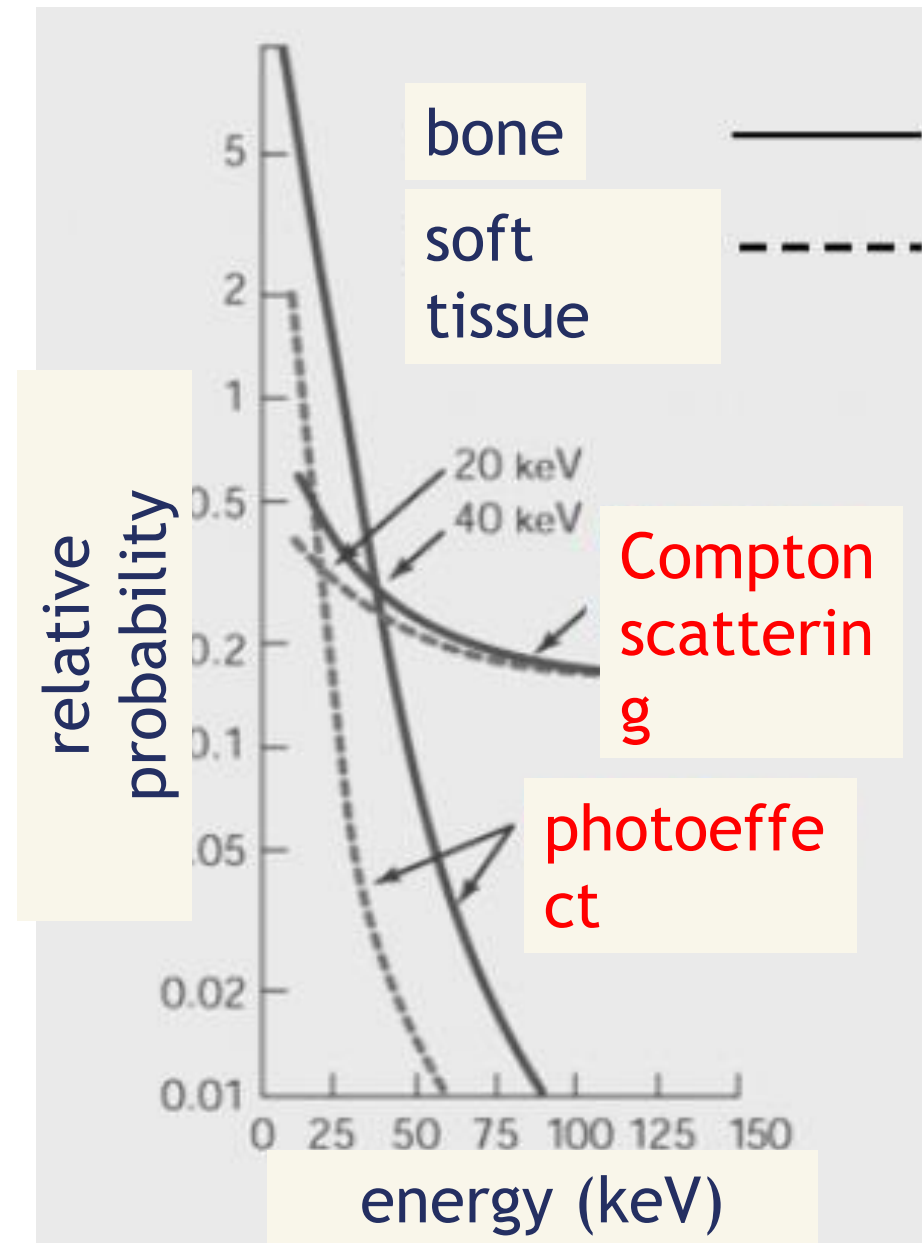
(no interaction)

contribution of absorption processes depends on the photon energy and the atomic number

	Dependence on E	Dependence on Z	Energy range in soft tissue
τ_m	$\sim 1/E^3$	$\sim Z^3$	10 – 100 keV
σ_m	Slowly decreases with increasing E	$\sim Z/M$	0.5 – 5 MeV
κ_m	Slowly increases with increasing E	$\sim Z^2$	> 5 MeV
Elastic scattering	$\sim 1/E^2$	$\sim Z^2$	< 10 keV



Photoeffect and Compton scattering are the main contributors to image formation.

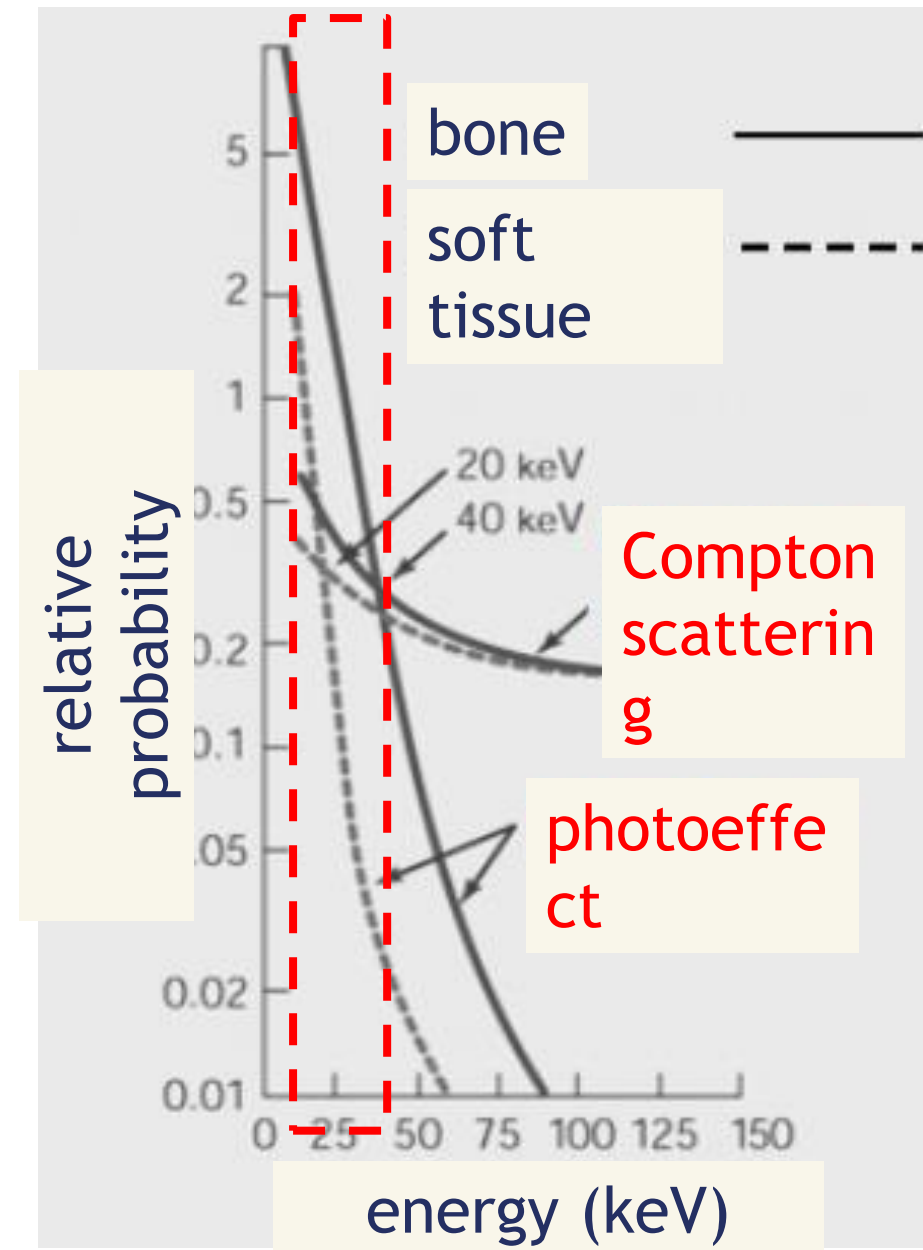


Increasing photon energy decreases attenuation by decreasing the photoeffect. In the low energy regime τ_m is dominating the attenuation process.

τ_m depends strongly on the atomic number:

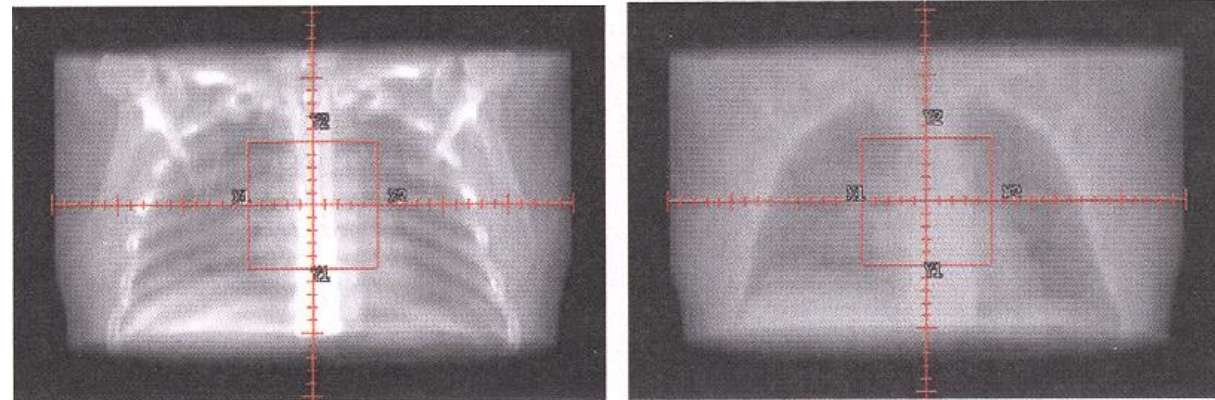
$$\tau_m \approx \lambda^3 Z^3$$

Change in photon energy can have a profound effect on the absorption process.



Photonenergy - picture quality

$U_1 < U_2$
(30 keV) (2 MeV)



Photoeffect*	36%	0%
Compton scattering*	51%	99%
Pair production*	0%	1%

Photonenergy - picture quality

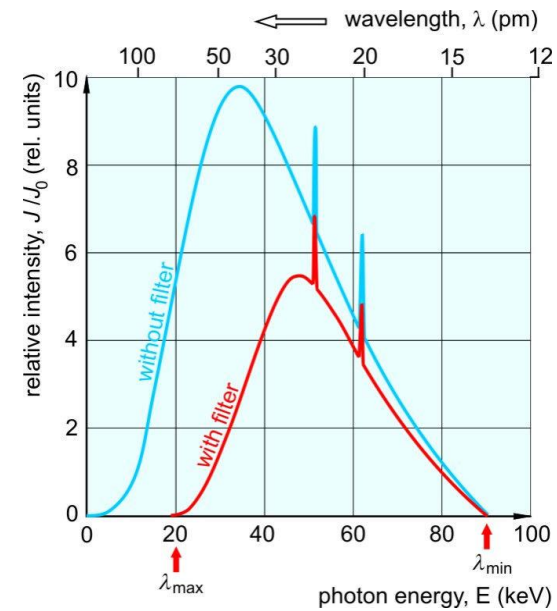
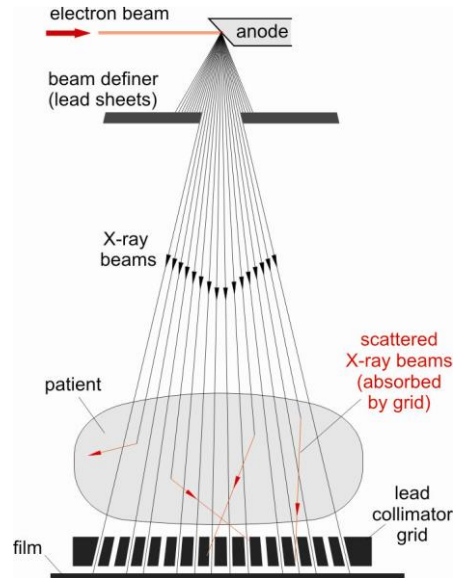


photonenergy: 60 keV
contrast ratio: 200:1
exposition: 141 mAs
dose: 7,6 mGy



120 keV
60:1
6 mAs
1,4 mGy

Improving picture quality



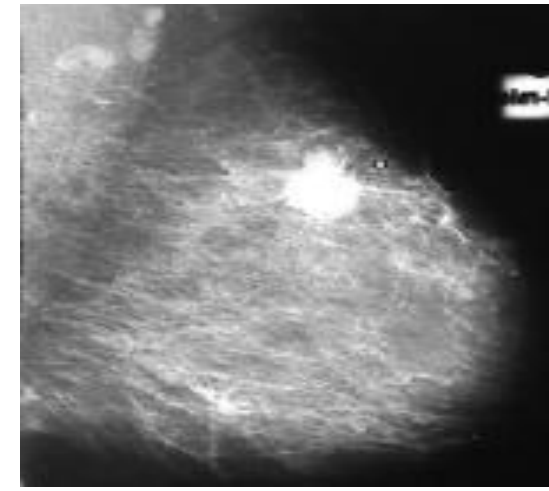
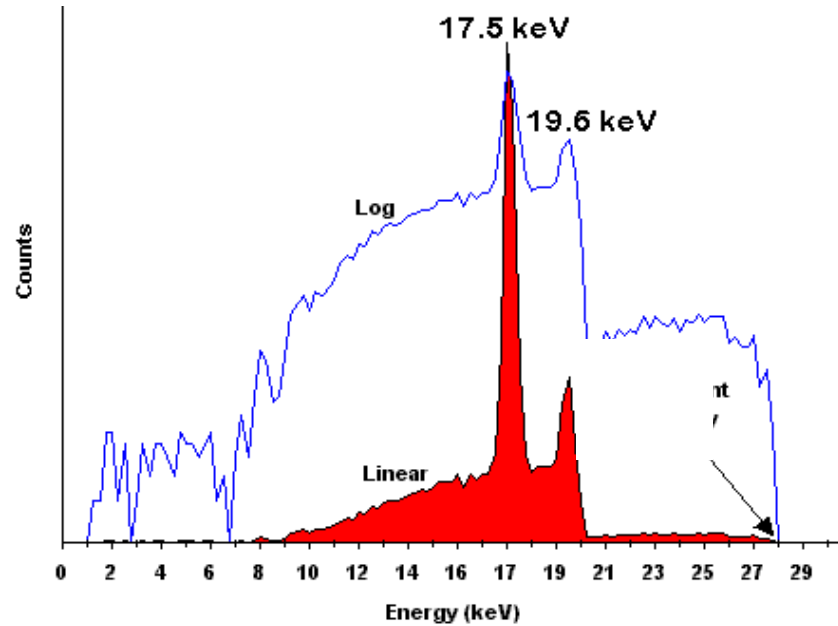
with collimators

with filtering out soft X ray

to reduce scattered radiation

- short exposure time to reduce unsharpness due to patient move

Spectrum of X ray used in mammography

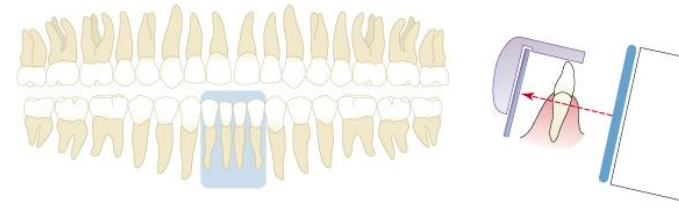


Mammogram showing malignant tissue

Characteristic lines of Molybdenum (Mo)

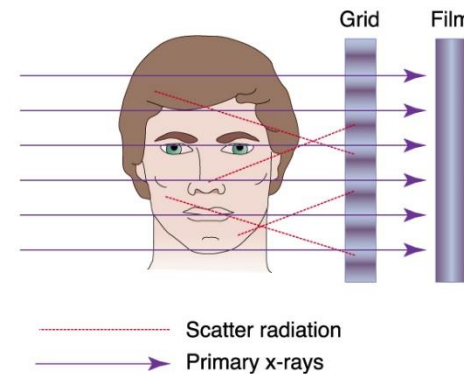


Intraoral radiography

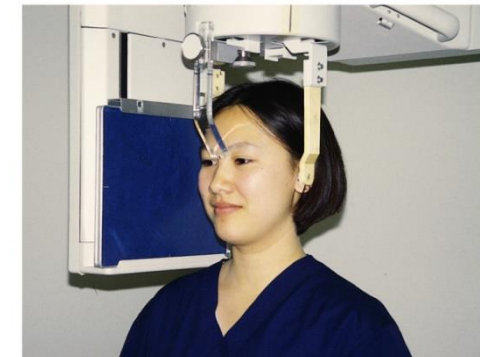


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Extraoral radiography



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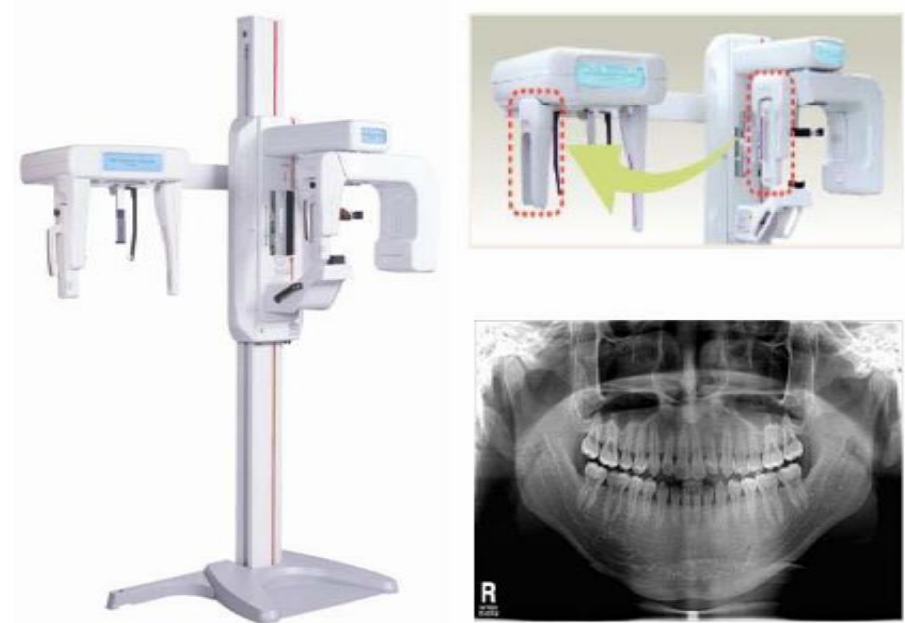


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Panoramic dentistry imaging

In panoramic imaging, the film and the source are rotated around the patient's head, taking several individual images in a series.

Combining these overlapping images results in a panoramic image of the maxilla and the mandible.

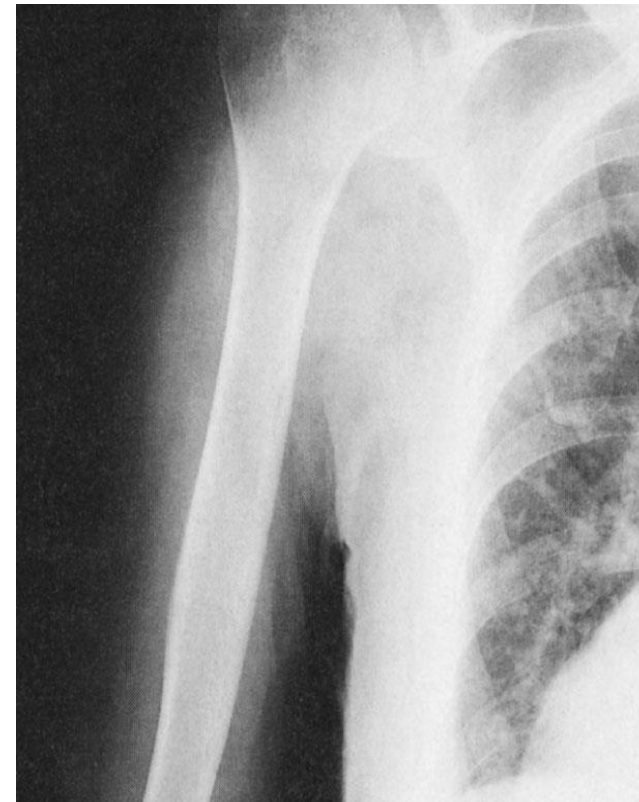


Effective atomic number

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

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

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



Applying contrast materials

	Z_{eff}	ρ (g/cm ³)
H ₂ O	7.7	1
Soft tissue	7.4	1
Bone	13.8	1.7 - 2.0
Air	7.3	$1.29 \cdot 10^{-3}$

Positive contrast → higher attenuation to surroundings

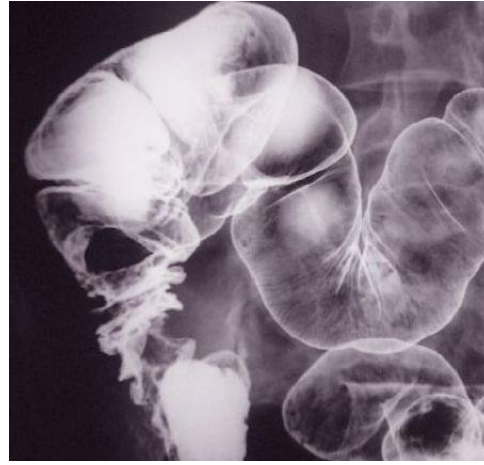
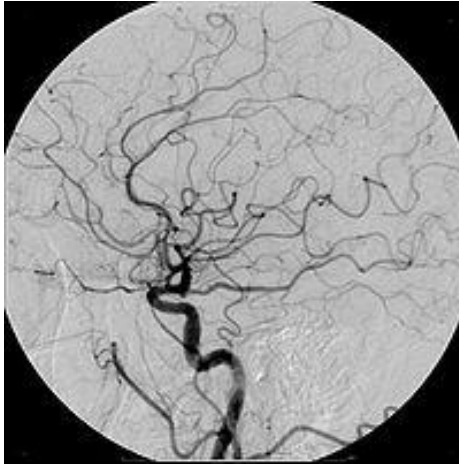
$$Z_{\text{eff}} > Z_{\text{environment}} \rightarrow \mu > \mu_{\text{environment}}$$

Negative contrast → lower attenuation to surroundings

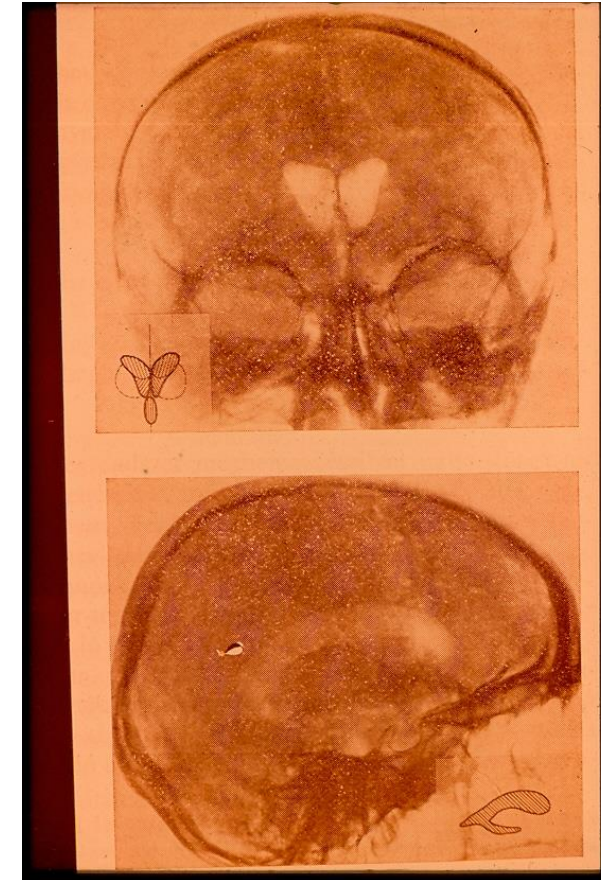
$$Z_{\text{eff}} < Z_{\text{environment}} \rightarrow \mu < \mu_{\text{environment}}$$

Applying contrast materials

higher Z_{eff}



lower density

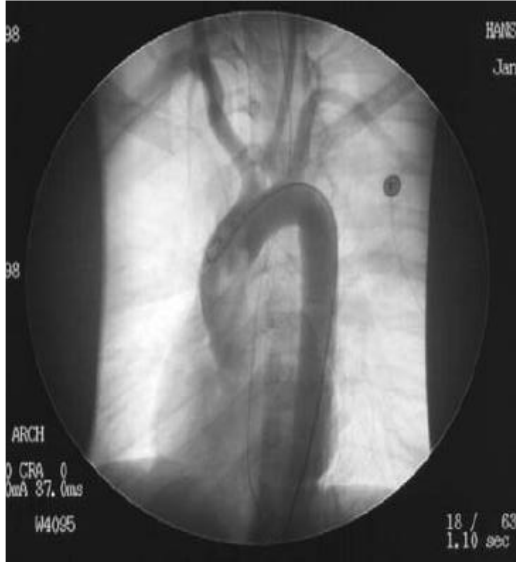


Iodine or barium compounds

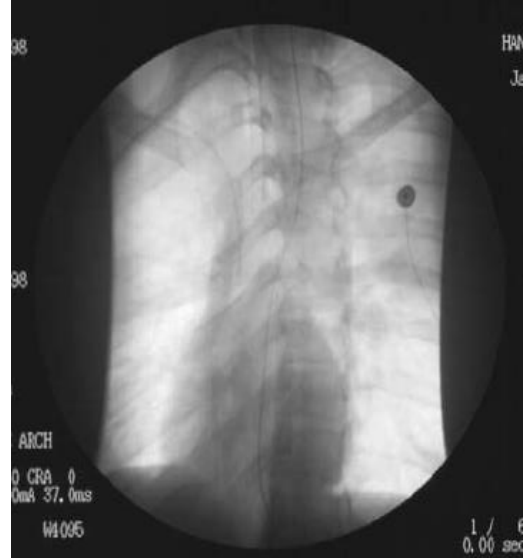


air, CO_2

Digital Subtraction Angiography (DSA)



with contrast material

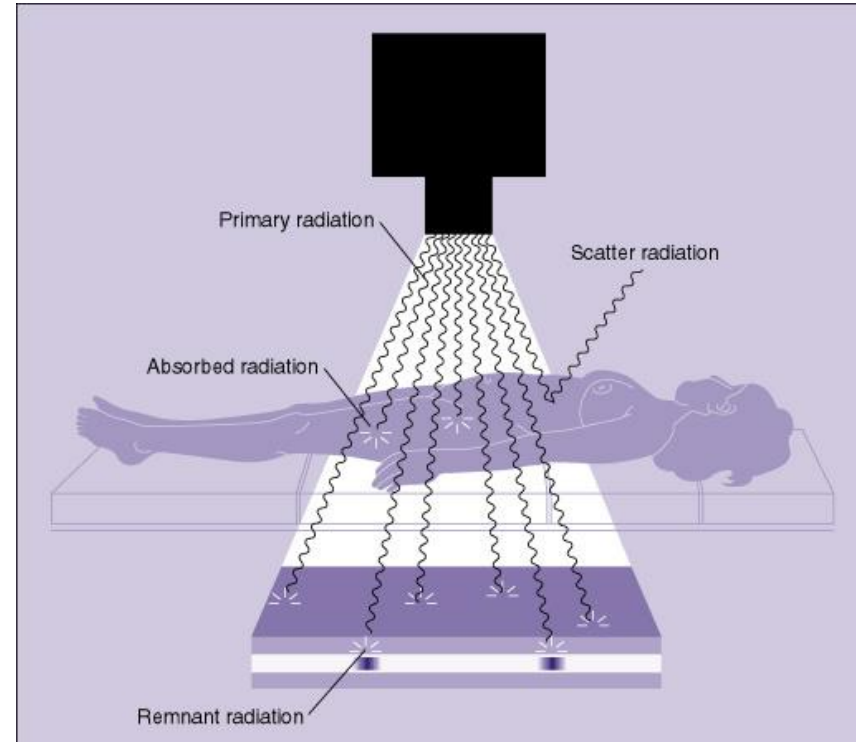
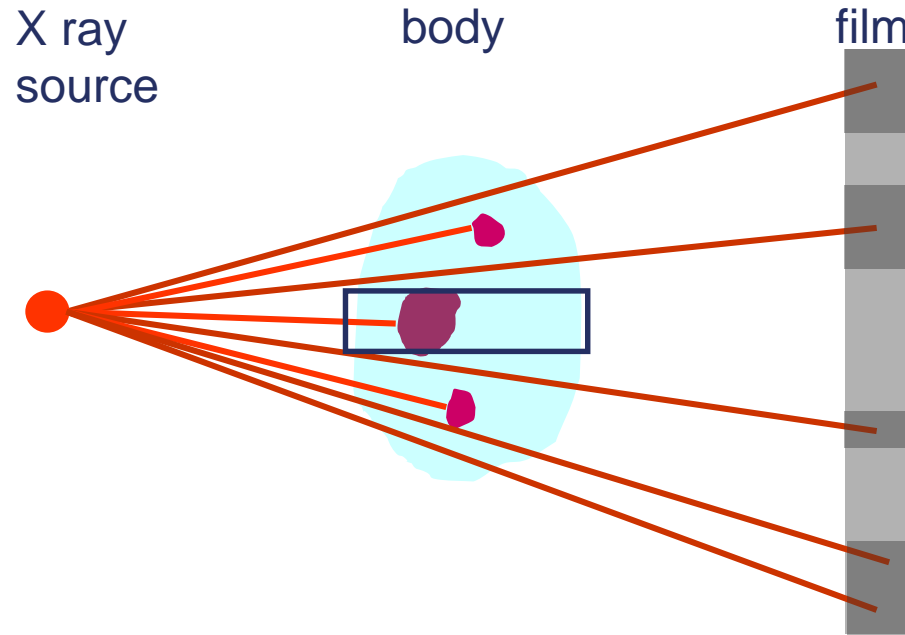


native



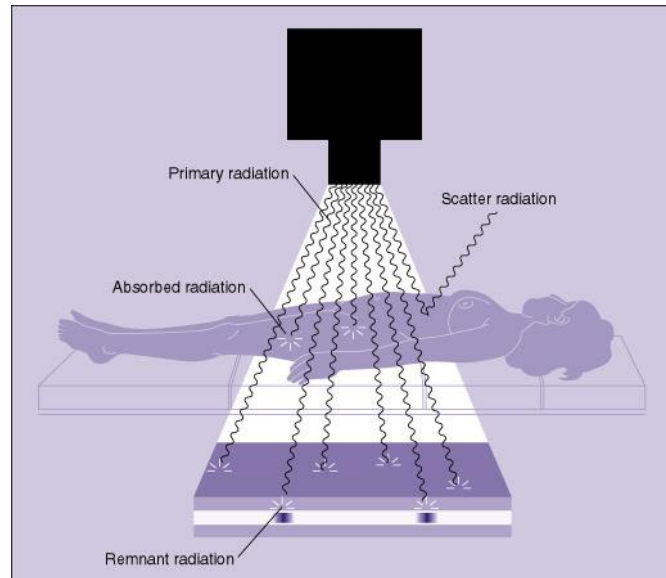
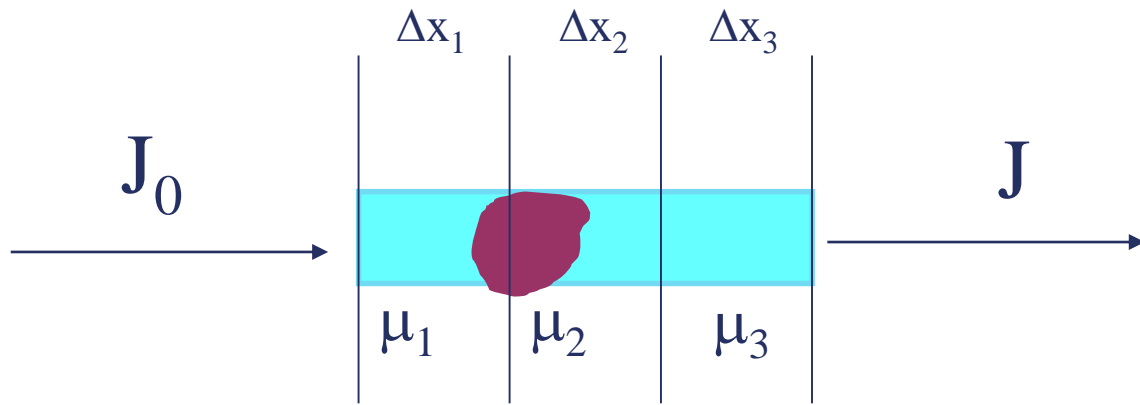
contrast - native

Summation image



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

Intensity changes are proportional with the total attenuation across the body!



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

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

This information is missing!

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

$$D = \sum_i D_i$$

Solution: CT - computed tomography



Godfrey Hounsfield

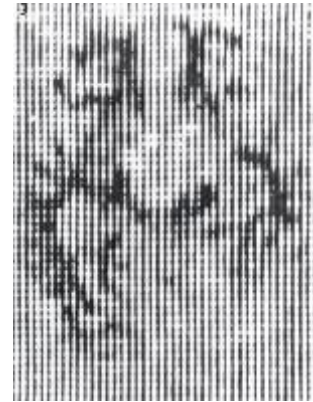


Allan Cormack

1979 - Nobel price in medicine

Brief history:

- 1967: first CT image
- 1972: prototype of CT
- 1974: first clinical CT image
- 1976: whole body CT
- 1979: Nobel price
- 1990: spiral CT
- 1992: multislice CT
- 2006: 64 slices
- multiplex and hybrid CT:
SPECT-CT, PET-CT,
“Dual-source” CT



First lab CT of brain slice



Prototype CT (EMI)



„Siretom” head scanner (1974)

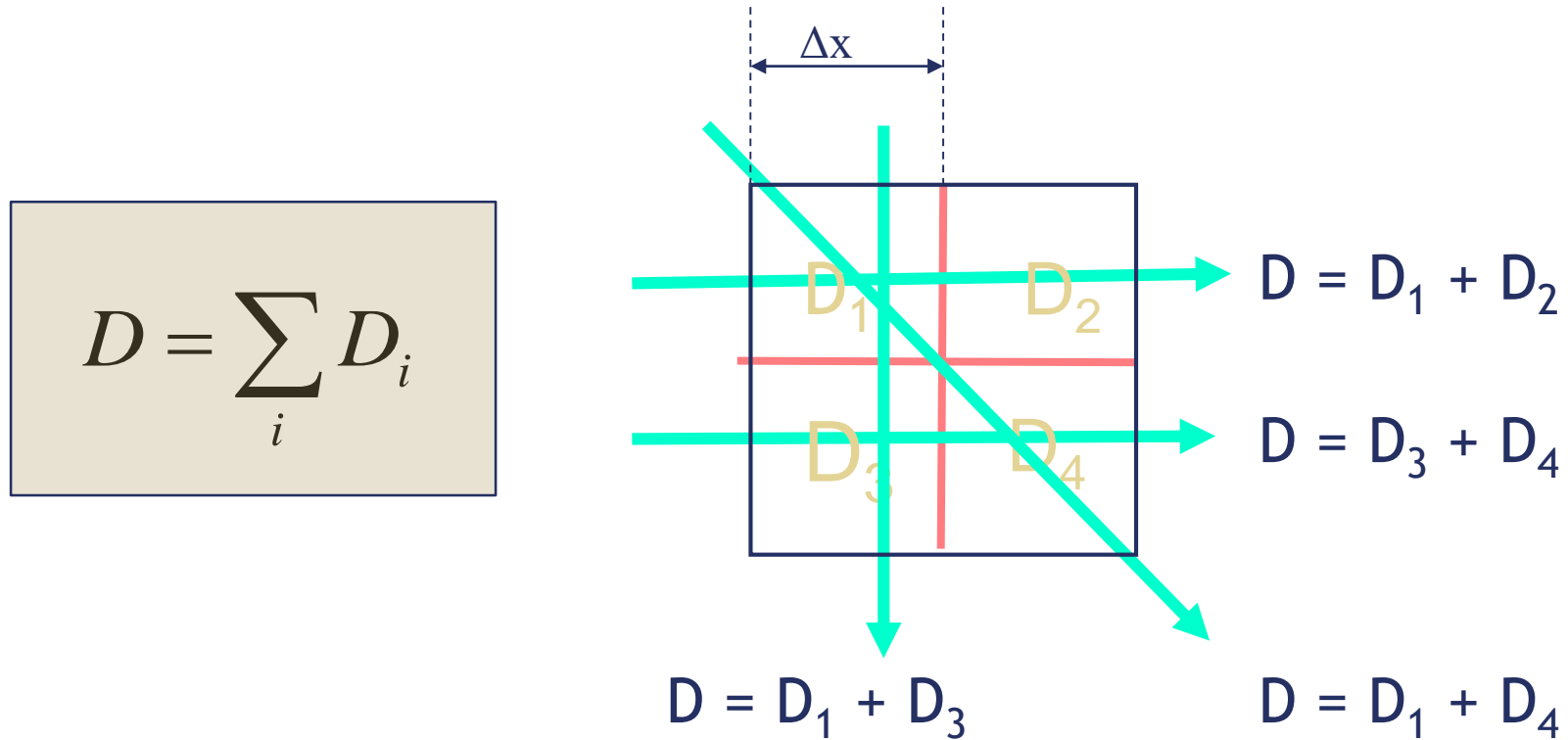


128x128 pixel image (1975)



modern CT

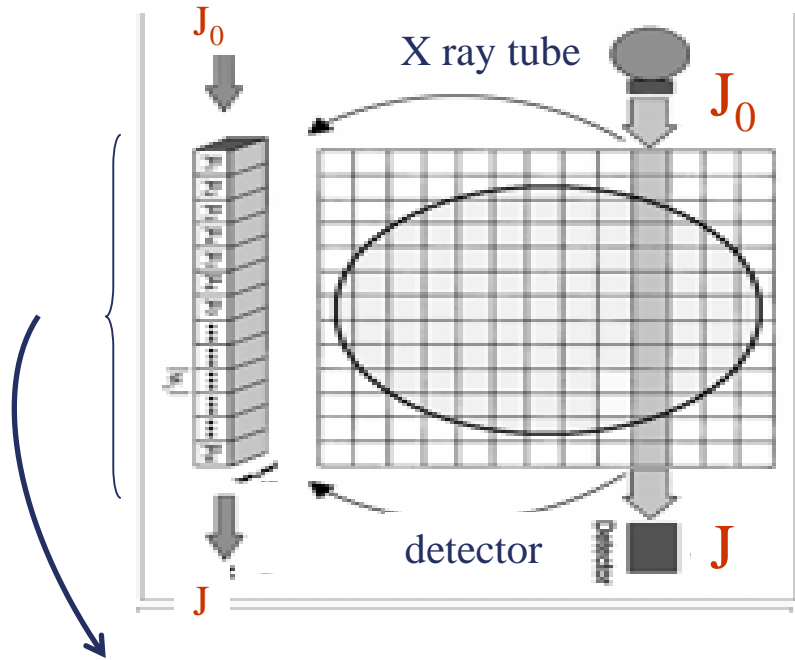
Illustration of math principle



“n” independent equation for „n” unknowns
→ unambiguous solution exists!

object

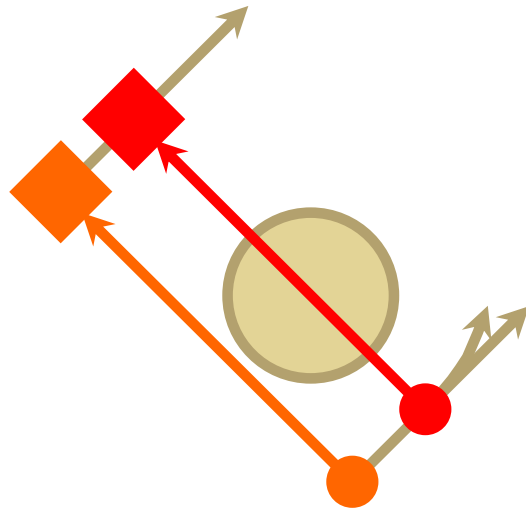
digital image



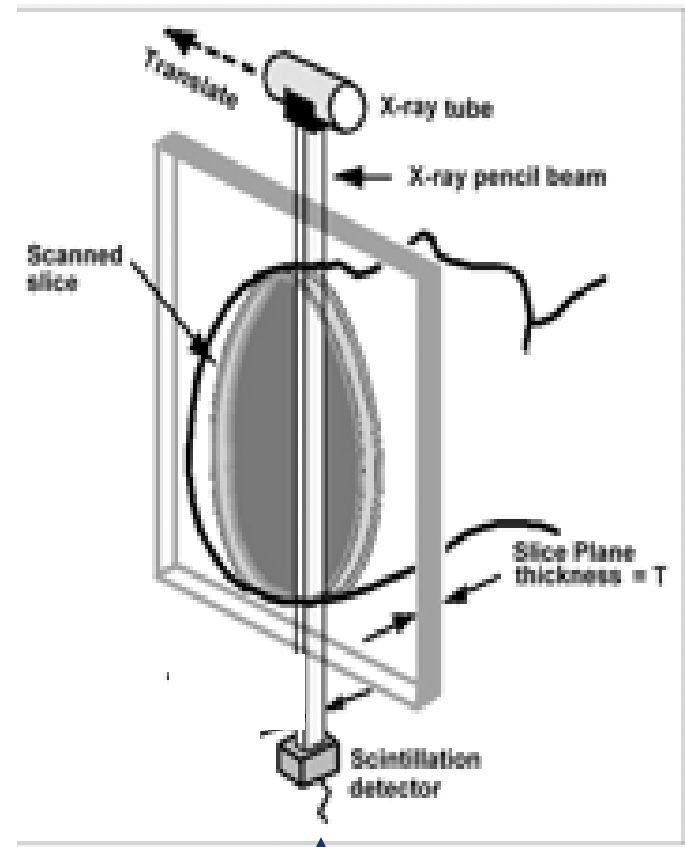
Voxel :
volume element

Pixel :
picture element

First generation CT



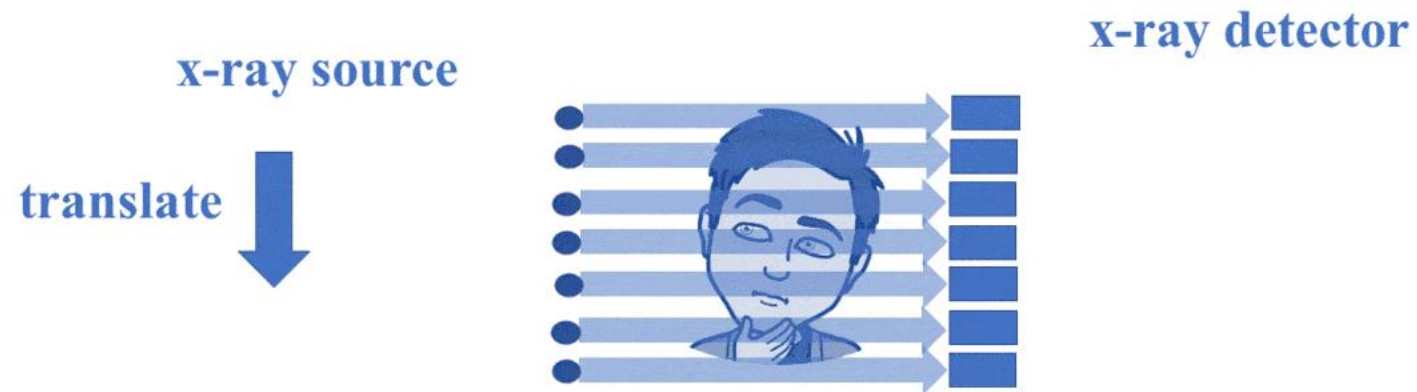
Single detector
Translation and rotation
Parallel beams



k-th position

First generation CT

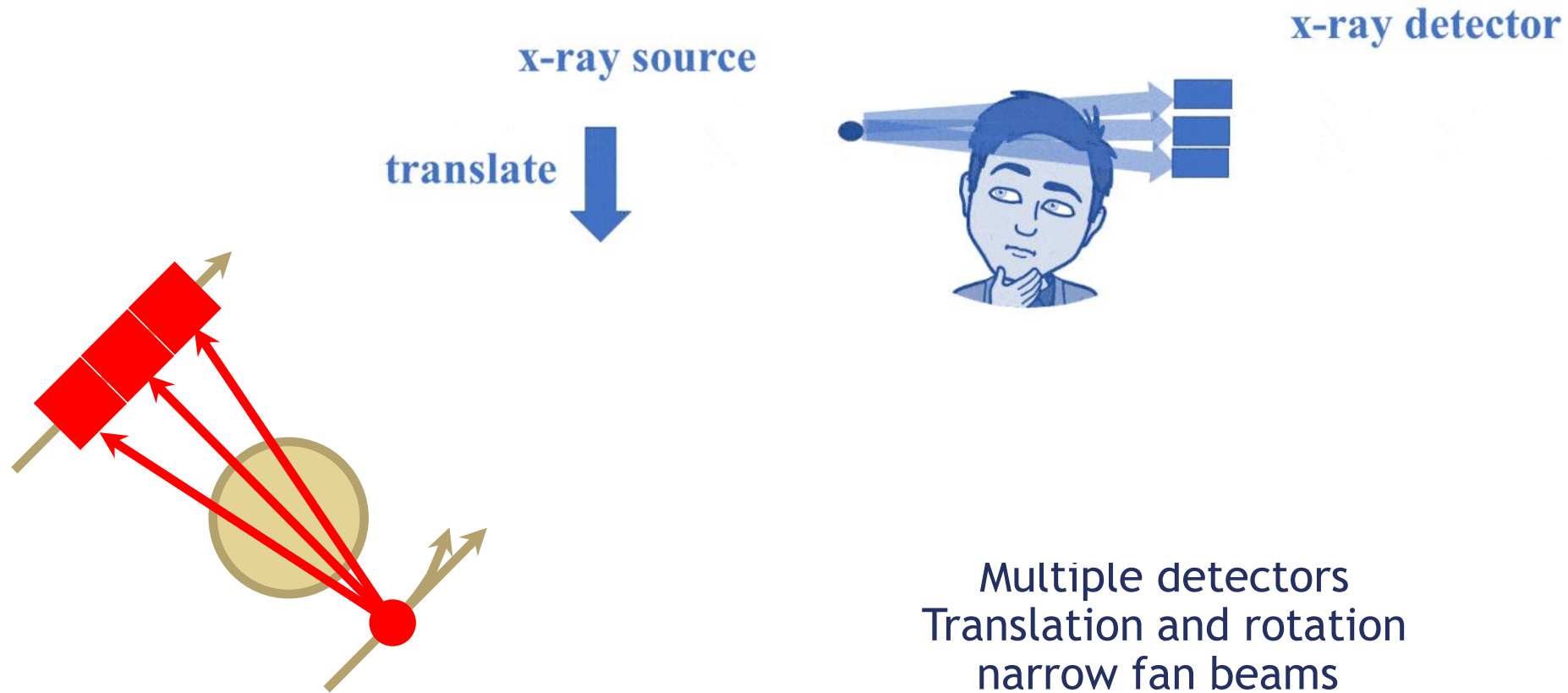
1st Gen Rotating CT



Single detector
Translation and rotation
Parallel beams

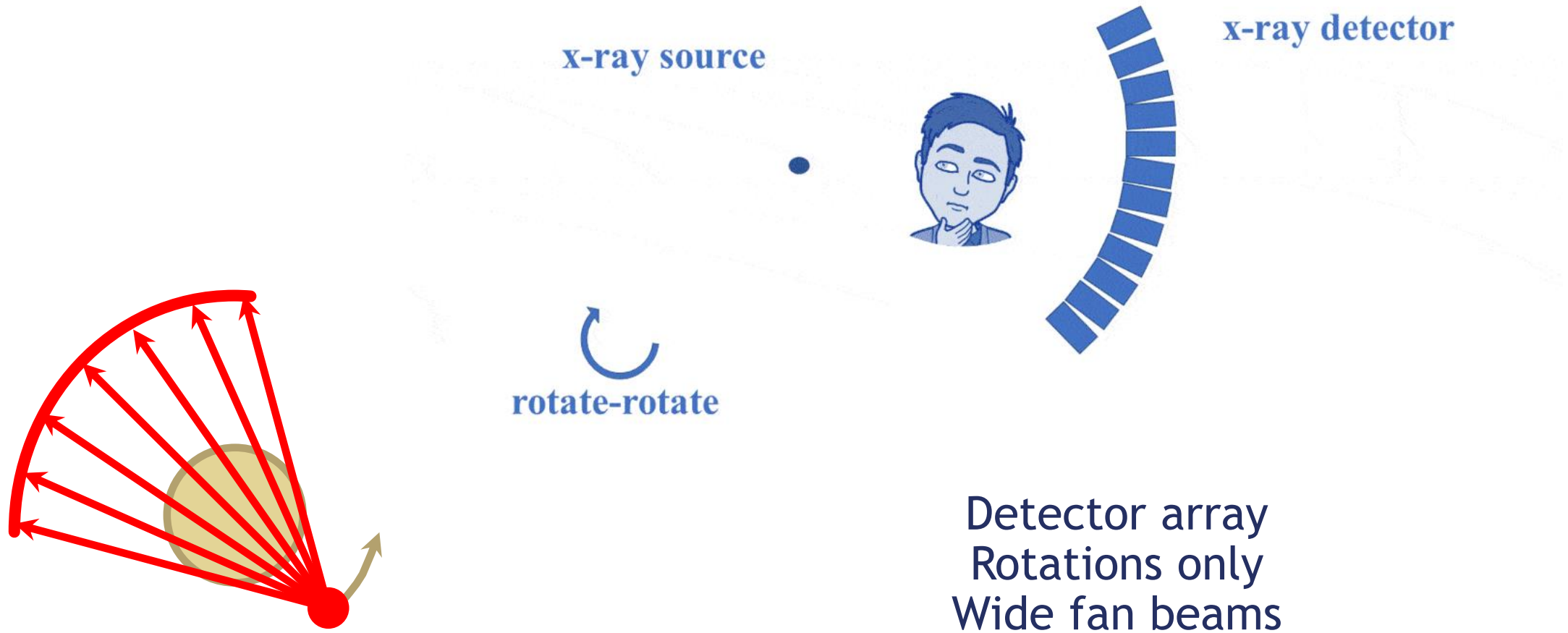
Second generation CT

2nd Gen CT



Third generation CT

3rd Gen CT



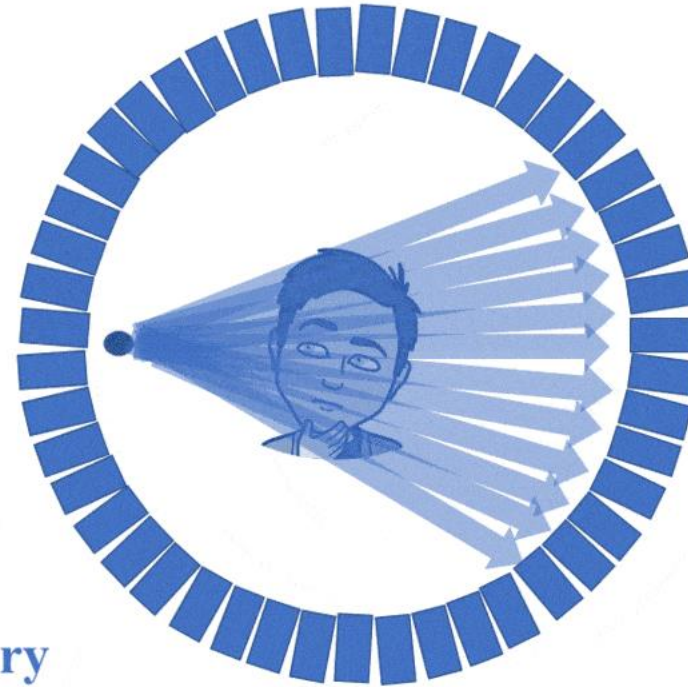
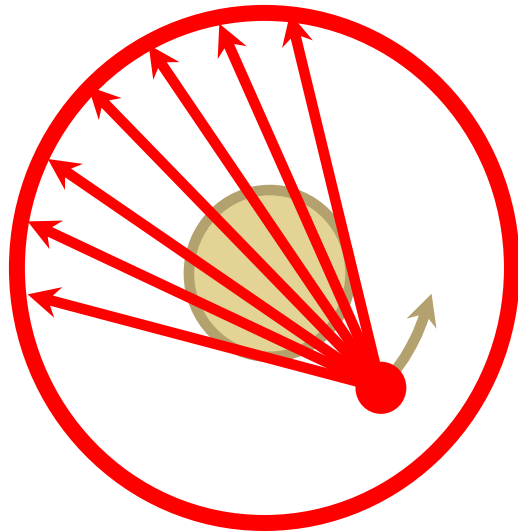
Fourth generation CT

4th Gen CT

x-ray source

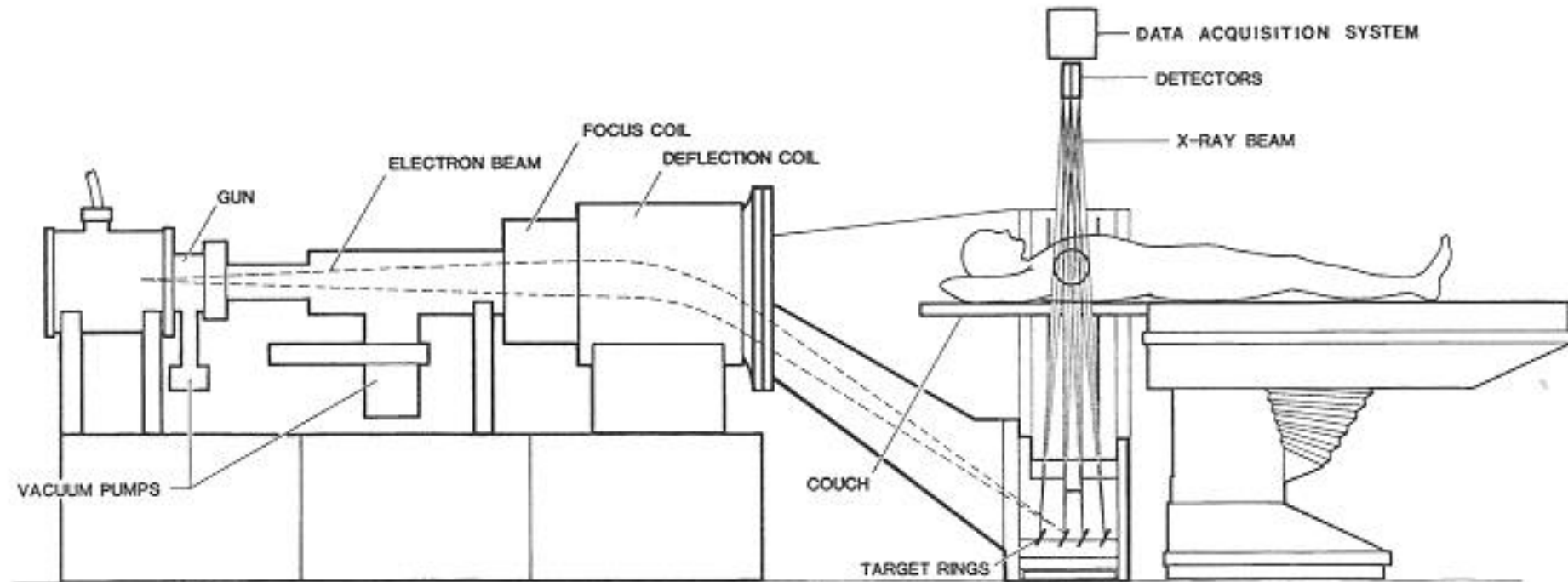
x-ray detector

rotate-stationary



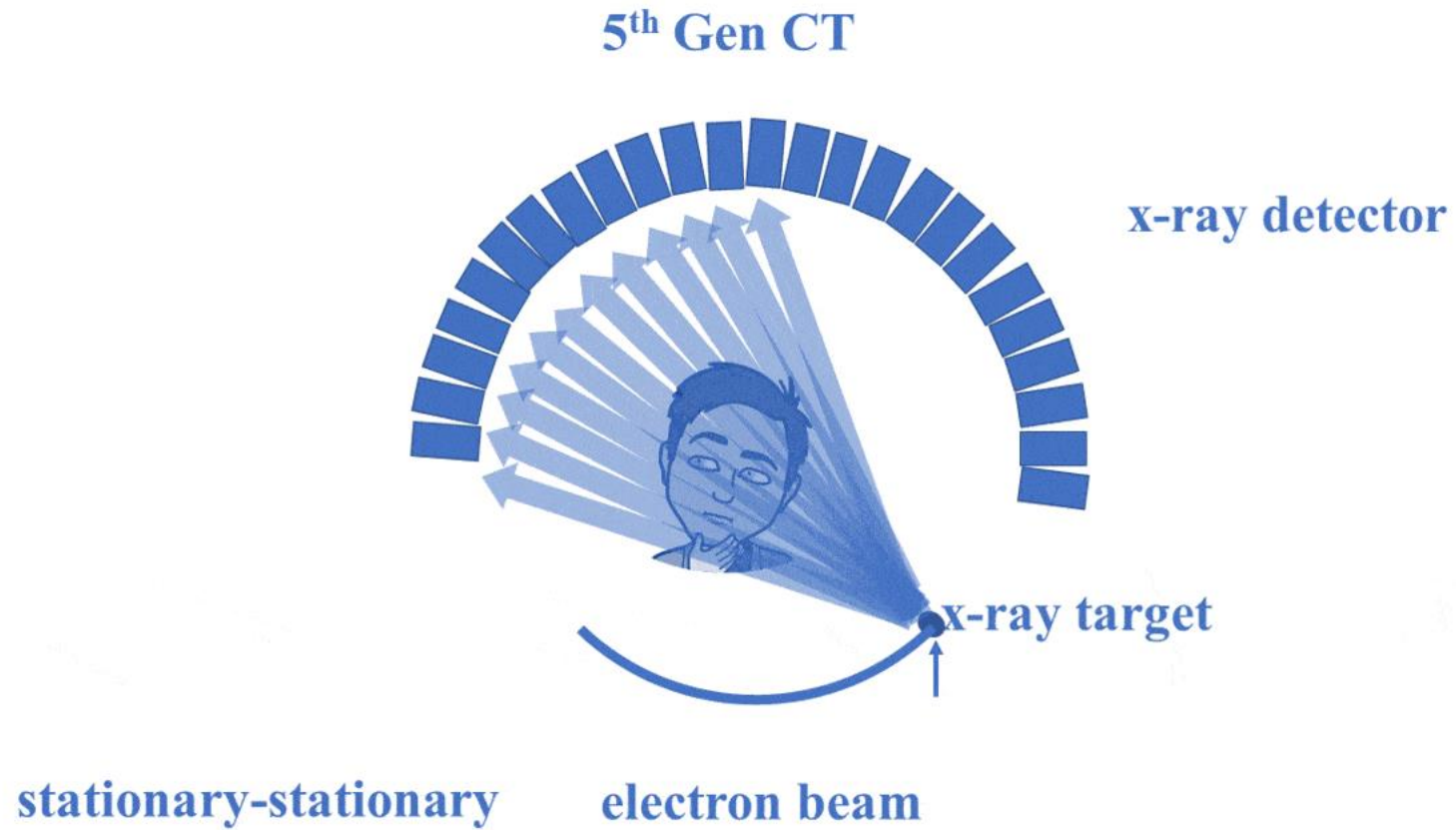
Detector ring fixed
Rotation of X ray source only
Wide fan beams

Fifth generation CT



Electron gun instead of X ray tube. Electron beam directed to fixed W-target.

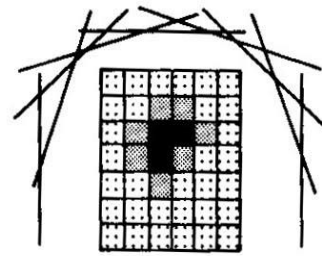
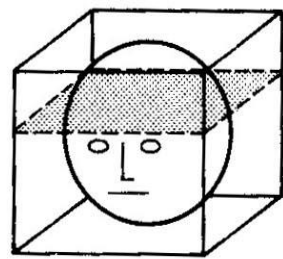
Fifth generation CT



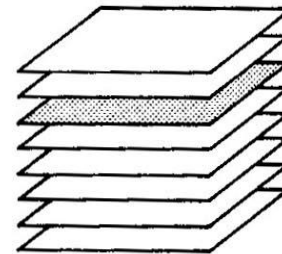
Comparison of CT generations

Generation	Year	Why Developed	Anatomy	Source-Detector Movement	Time to acquire 1 image	Why it died?
1 st Gen	1971	To show CT works	Head Only	Translate-Rotate	~5 min	Slow
2nd Gen	1974	Image Faster	Head Only	Translate-Rotate	20sec-2min	Slow
3rd Gen	1975	Image Faster	All Anatomy	Rotate-Rotate	1 sec	This Geometry won.
4th Gen	1976	Make images without rings	All Anatomy	Rotate-Stationary	1 sec	Expensive, not good for scatter.
5th Gen	1980s	Fast Cardiac CT	Cardiac Only	Stationary-Stationary	50 ms	Cardiac specific, low x-ray flux.

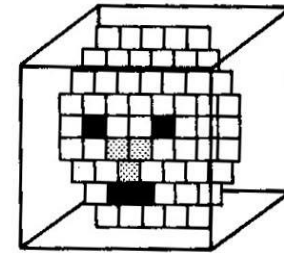
3D reconstructions



Many 1D projections
are used to reconstruct
a single slice of data

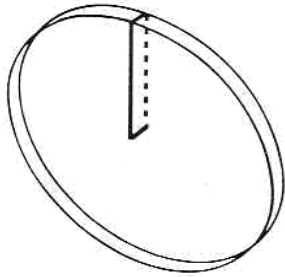


Many 2D slices

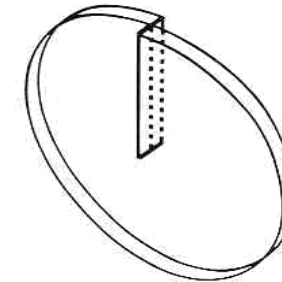
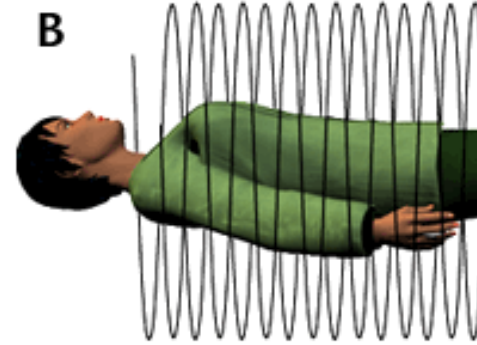
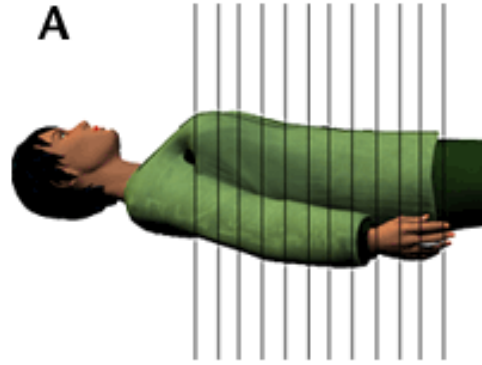


One 3D voxel model

Spiral CT

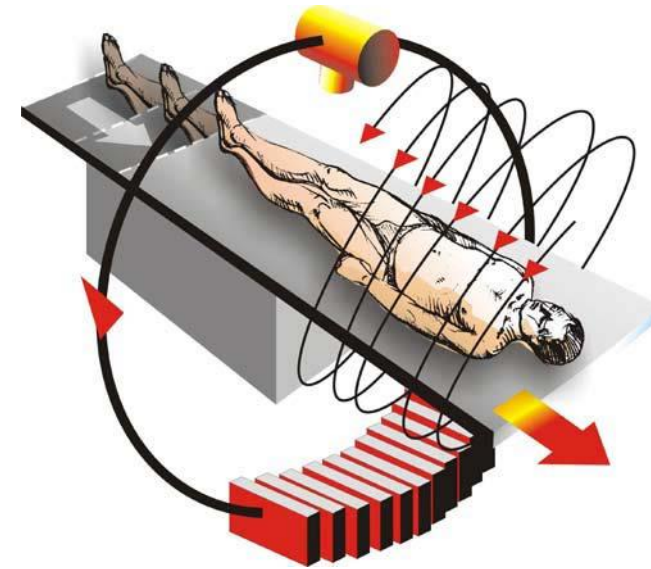
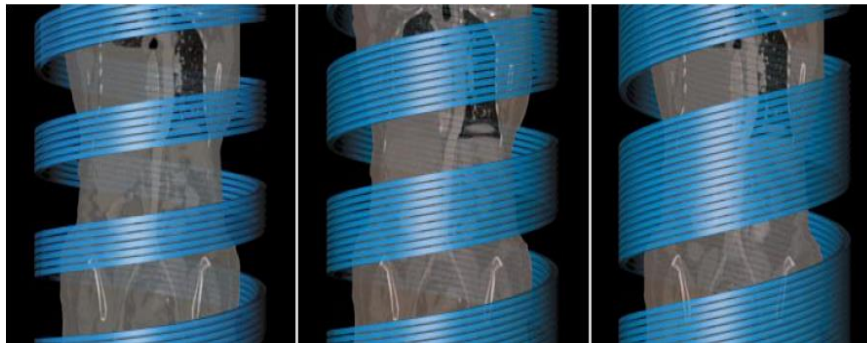


Conventional
CT slice



Spiral CT
slice

Precise 3D reconstruction
faster data acquisition



Dentistry: Cone beam CT

- Cone-beam computed tomography (CBCT), C-arm CT, cone beam volume CT, flat panel CT
- Conical X ray beams
- Volumetric data produced, needs digital image reconstruction
- Dentistry, interventional radiology, radiotherapy

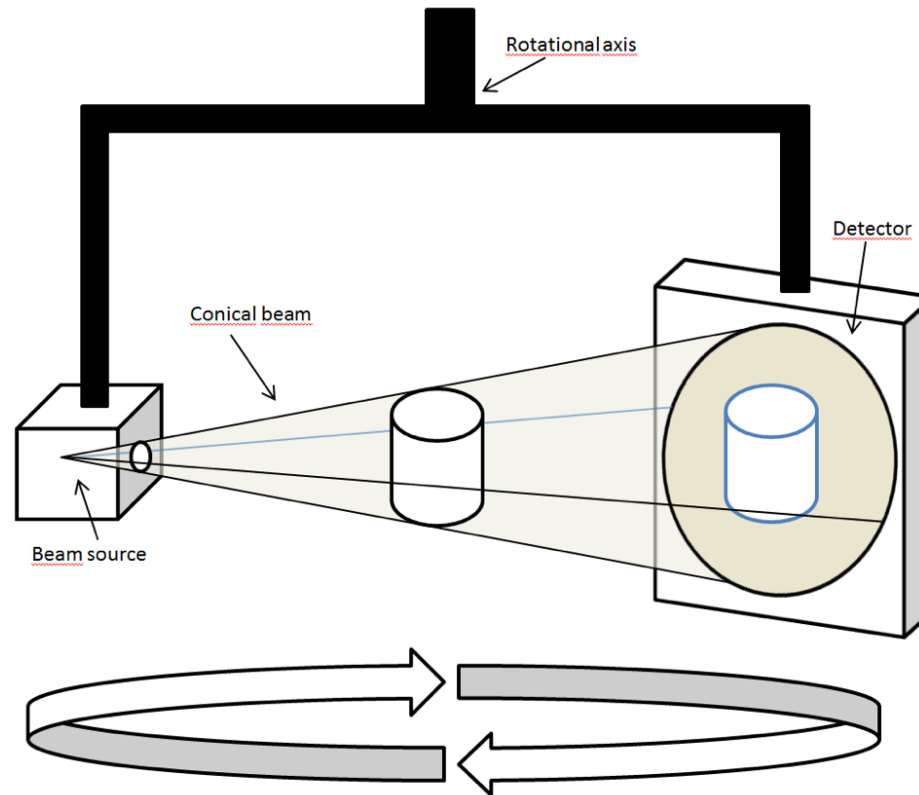
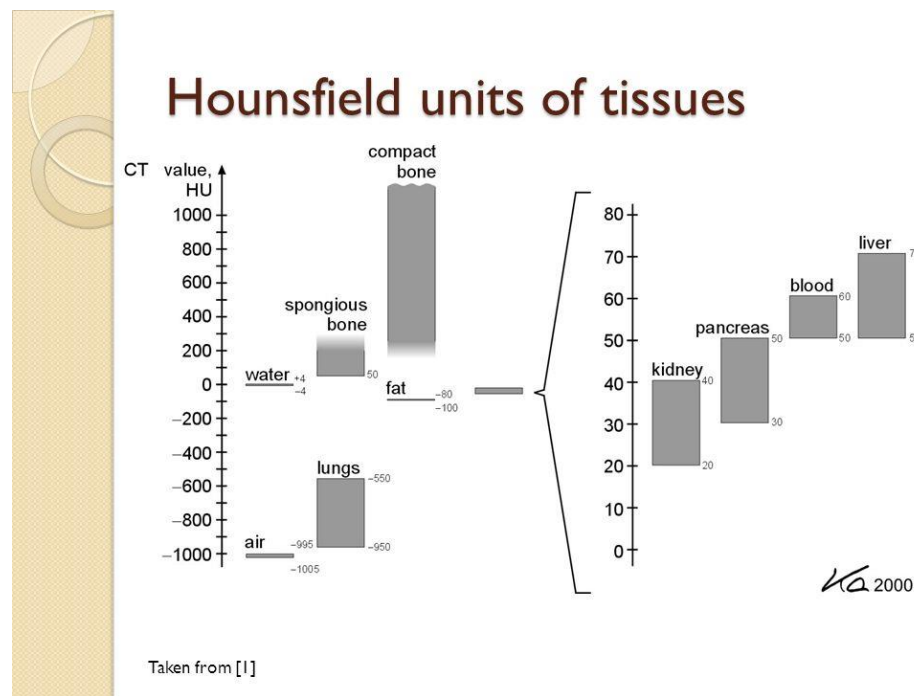


Image reconstruction

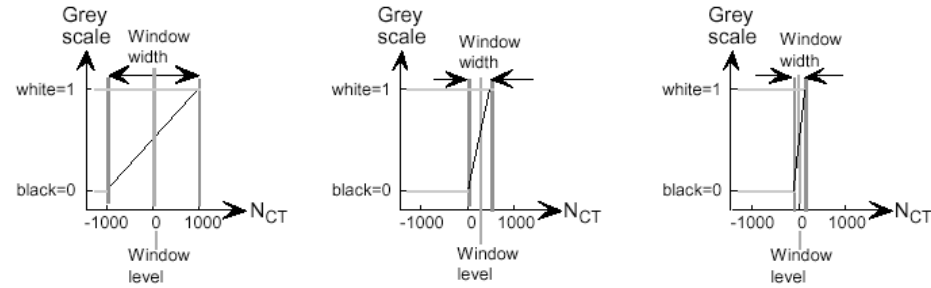
- density matrices (D_i) \rightarrow attenuation coefficients (m_i)

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

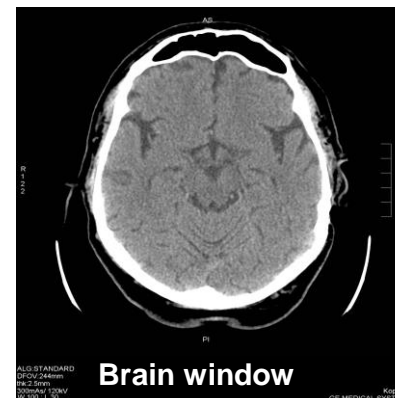
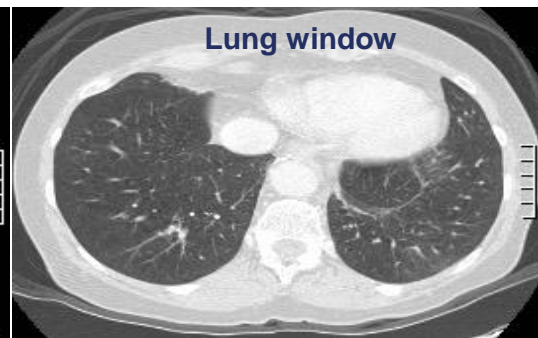
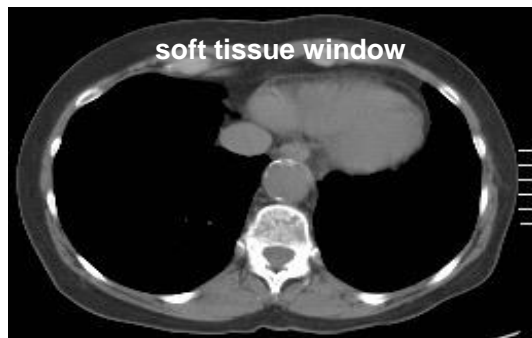
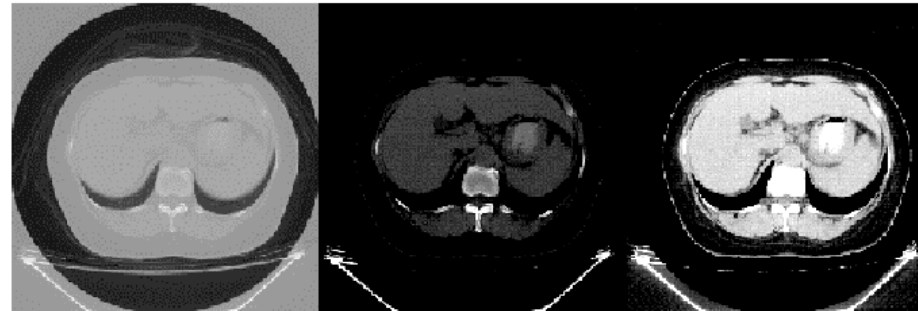
Hounsfield scale



CT contrast enhancement „windowing”



Same thoracic image with different windowing



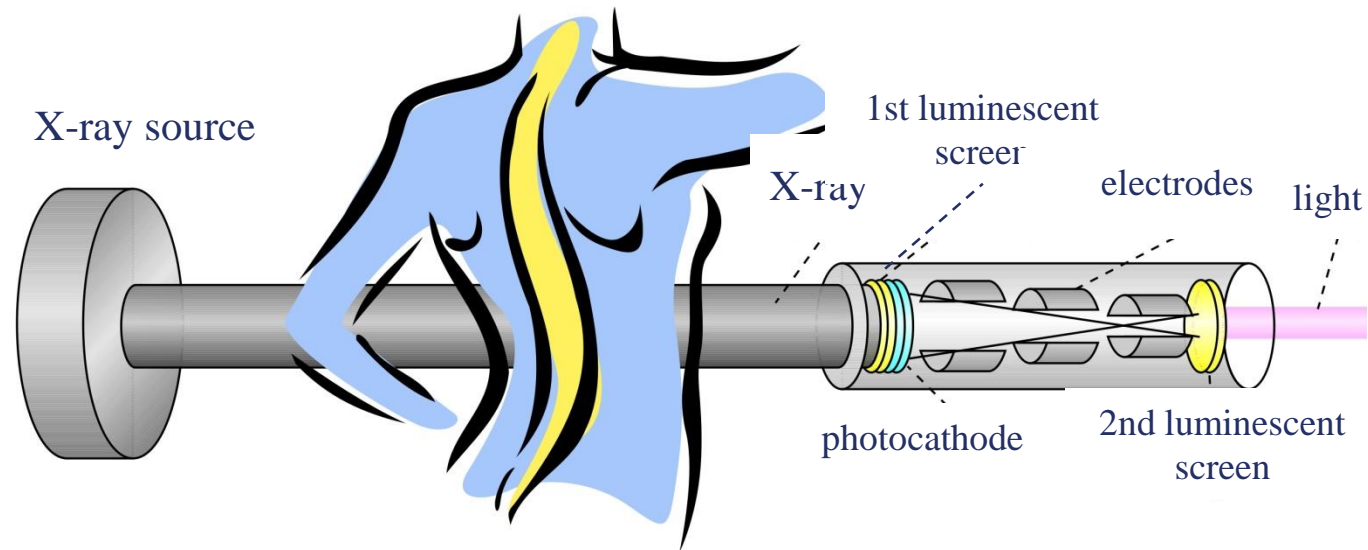
Brief summary of CT

- Imaging is based on the differences in X ray absorption / attenuation
- 3D image that can viewed and manipulated, and combined with other imaging techniques
- Spiral CT: one slice – 1-1.5 s, total time: 30-60 s
- Multislice spiral CT (up to 256 detector): one slice – 0.4-1 s, total: 5-15 s

Limitations of CT

- Ionizing radiation
- Dose can be as high as 50-100-times the conventional X ray!
- Indirect exposition due to scattered radiation

X-ray image intensifier



Manipulation under X-ray control

Smaller patient exposure

Checklist

Absorption of X-ray

Mass-attenuation coefficient

Basic concept of X-ray imaging

Optimal setting of X-ray tube

Summation image - role of the atomic number

Contrast materials

Panoramic X-ray

X-ray image amplifier

Concept of CT

Hounsfield unit

Generations of CT