X-rays in medical diagnostics

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History

- **W.C.Röntgen** (1845-1923)
- discovered a new type of radiation

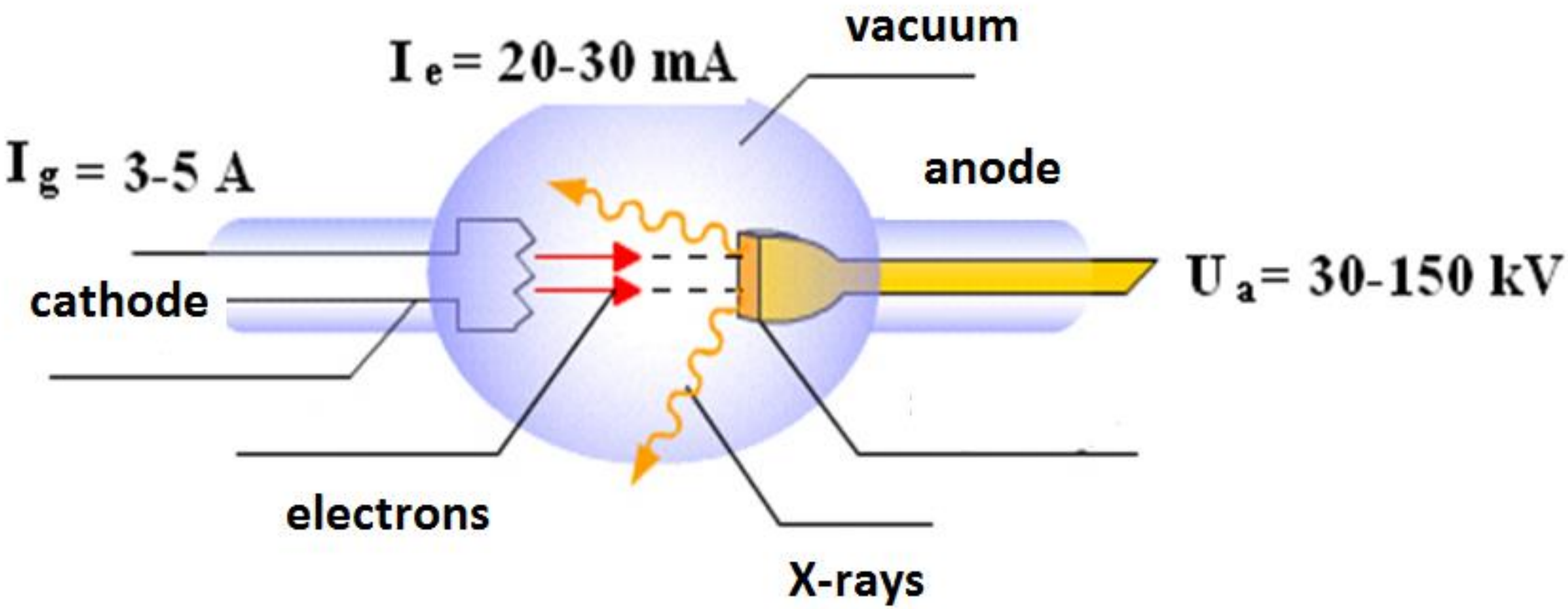
- Nature, Jan. 23. 1896.; Science, Feb.14. 1896.

X- rays:

- Induced the ionization of the air
- penetrates through the matter
- does not deflect in an electric and magnetic field
- induced the burns on skin

Figure 3: Shadowgraph of a human foot in a shoe. Tesla obtained the image in 1896 with x-rays generated by his own vacuum tube, similar to Lenard's tube, at a distance of 8 feet.

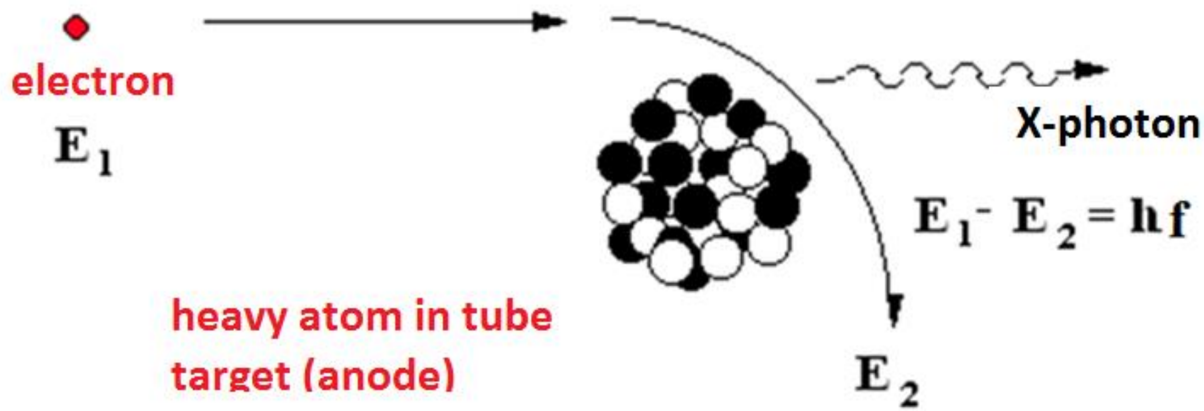
Source of X-rays: X-ray tube



- Heated filament emits electrons by thermionic emission.
- Electrons are accelerated by a high voltage.
- X-rays are produced when high speed electrons hit the metal target.

Braking (Brehmsstrahlung) radiation → continuous spectrum

$$eU = \frac{mv^2}{2}$$



- **X-rays beam consists of photons of different energies - policromatic spectrum**

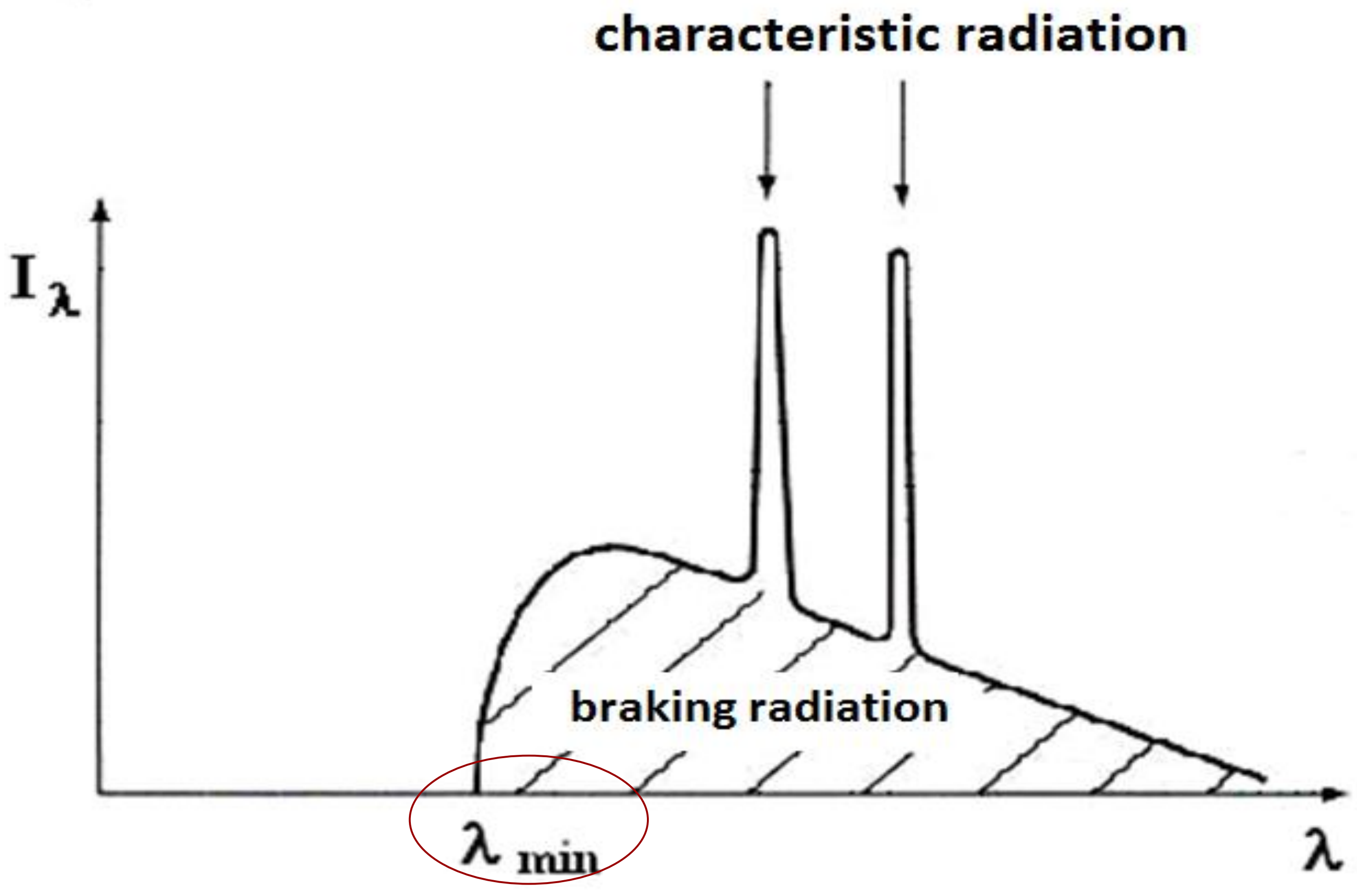
- **The photon with highest energy:**

$$h\,f_{max} = h\frac{c}{\lambda_{min}} = eU_a$$

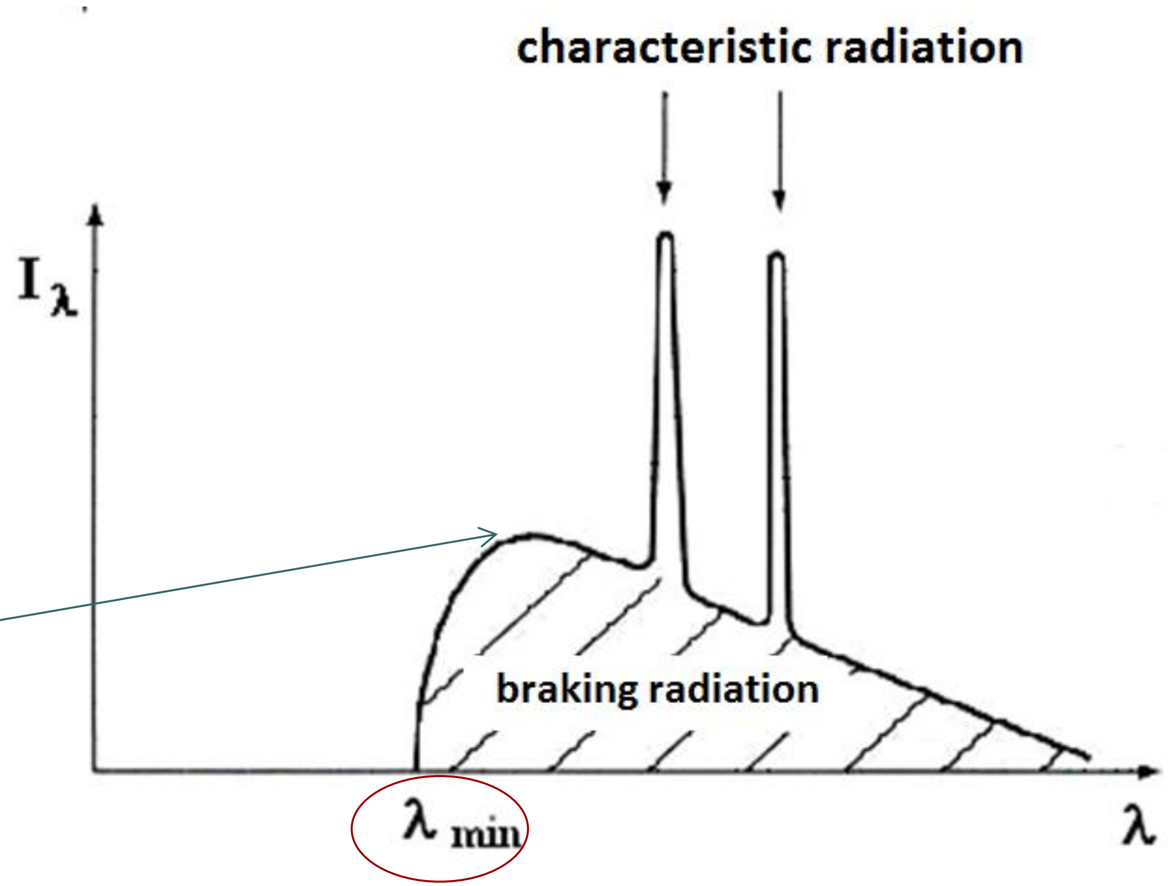
Collisions of incident electrons with electrons in target material → characteristic (linear) X-rays spectrum

- Incident electron ejects one of electrons from inner shell of target atom.
- The empty state is filled by an electron from higher shell, the energy difference is emitted as X-photon.
- Only the photons with energies equal to differences of particular atomic levels are emitted – line spectrum.
- The probability of such events is low – the intensity of line spectrum is low.

X-ray spectrum



X-ray spectrum

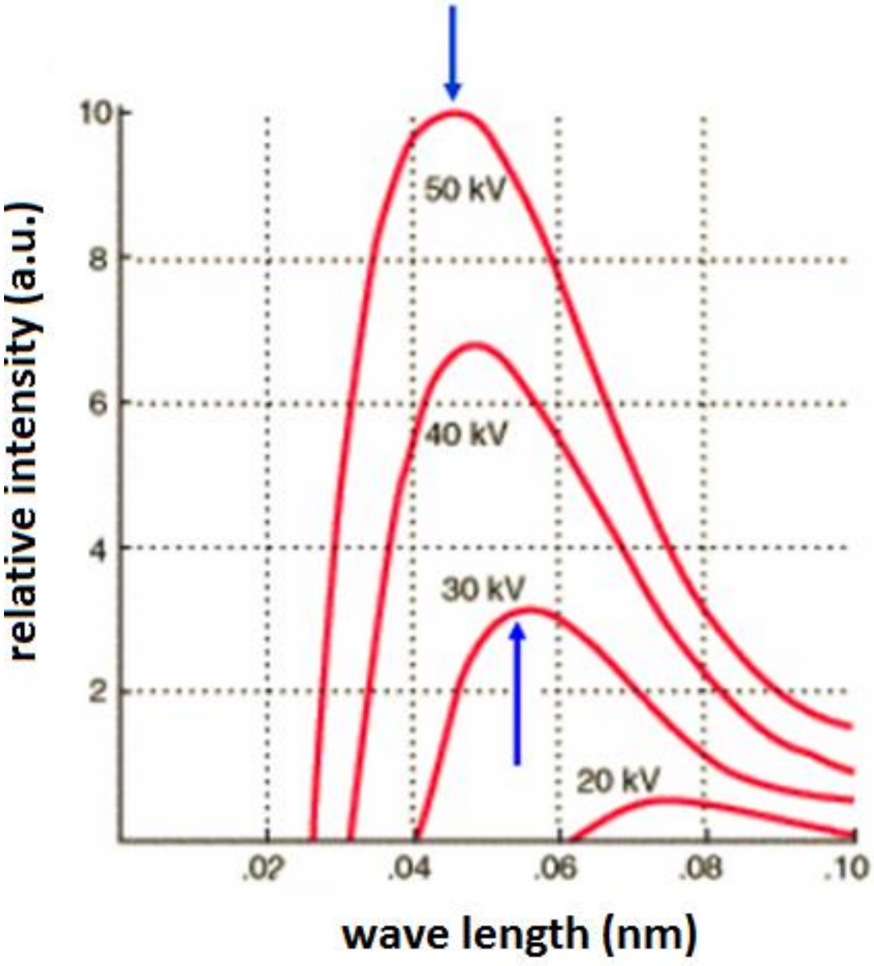


- The highest intensity is for radiation at : $\lambda \approx \frac{4}{3}\lambda_{min}$

$$U_a = 60kV \longrightarrow h\,f_{\max} = h\frac{c}{\lambda_{\min}} = eU_a = 60keV$$

Intensity of X-ray beam is proportional to current of electrons, squared anode voltage and type of target (atomic number).

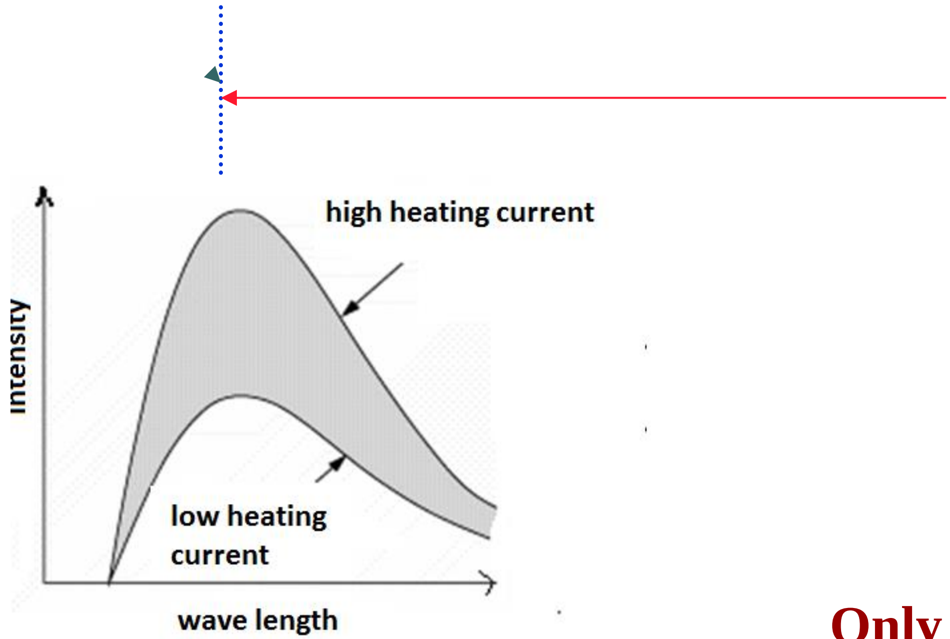
Influence of tube voltage on X-ray spectrum



- Increase of voltage enhances the beam intensity.

- **The spectrum is shifted to shorter wavelenths – the hardness of the beam is higher.**

Influence of heating current on X-ray spectrum



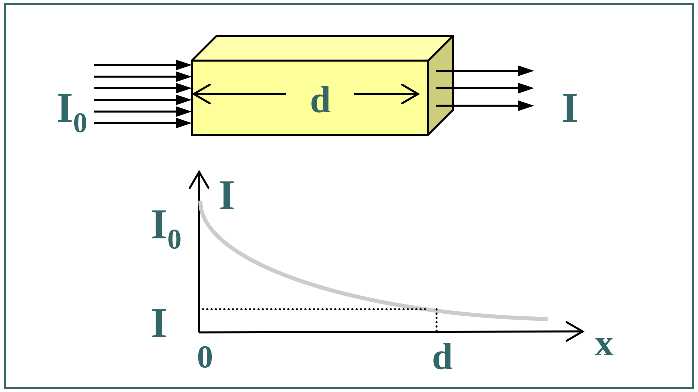
Minimal wave length and wave length of maximum are not changed by changing heating current.

Only the intensity of beam depends on the current.

Attenuation of electromagnetic radiation in matter

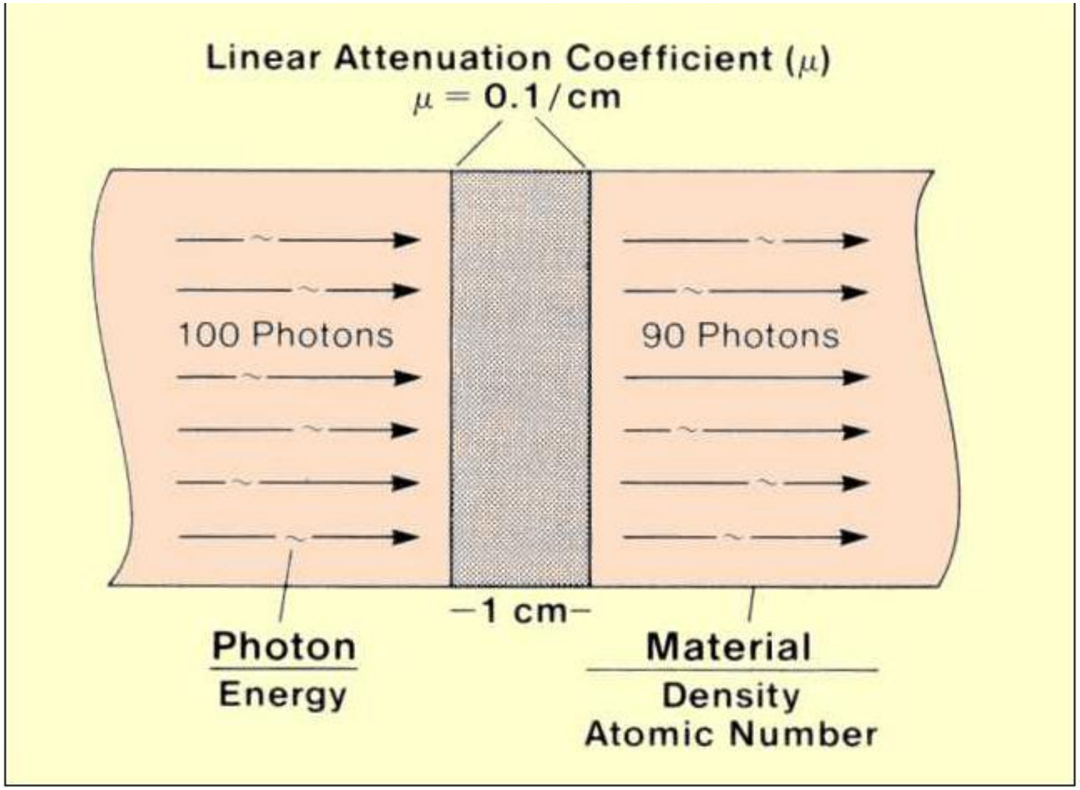
- Due to interaction of photons with molecules the intensity (**I**) of the beam is decreasing along its path through the sample.

$$I(x) = I_0 e^{-\mu x}$$



- $\mu(\lambda)$ is attenuation coefficient which depends on the medium and wavelength of radiation
- monochromatic radiation

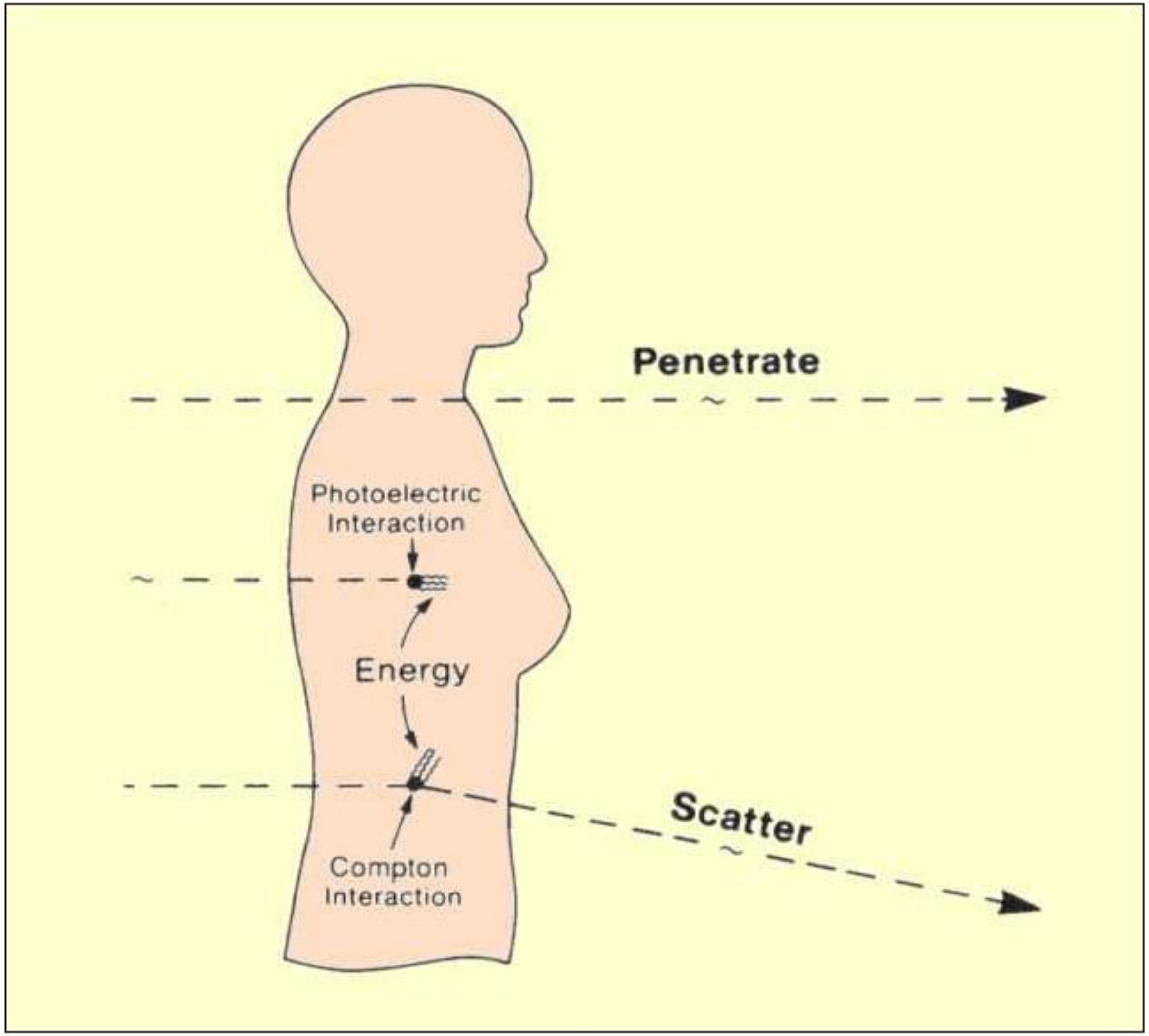
Atenuation of monochromatic radiation



- $\mu(\lambda)$ is attenuation coefficient which depends on the medium and wavelength of radiation

- polychromatic – X-ray spectrum

$$I\ (x, wave\ length) = I_0 e^{-\mu(matter, wave\ length)x}$$

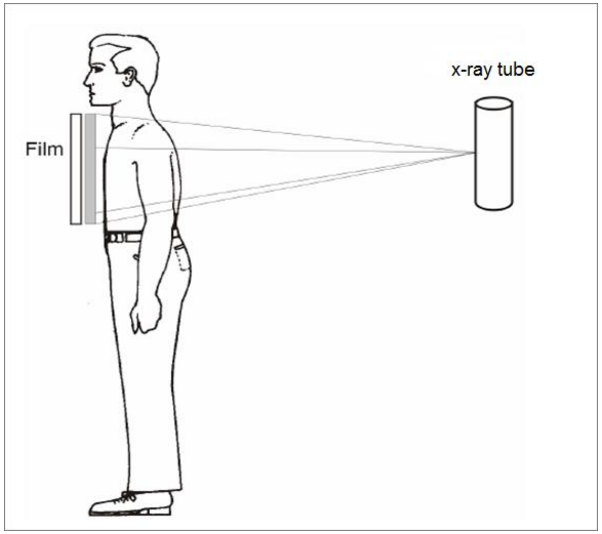


Photons Entering the Human Body Will Either Penetrate, Be Absorbed, or Produce Scattered Radiation

- preuzeto: http://www.sprawls.org

Image formation- clasical roendgenography

- X-rays beam directed to human body
  - fraction passes through without interaction (transmitted rays)
  - bulk will interact (absorbed or scattered)



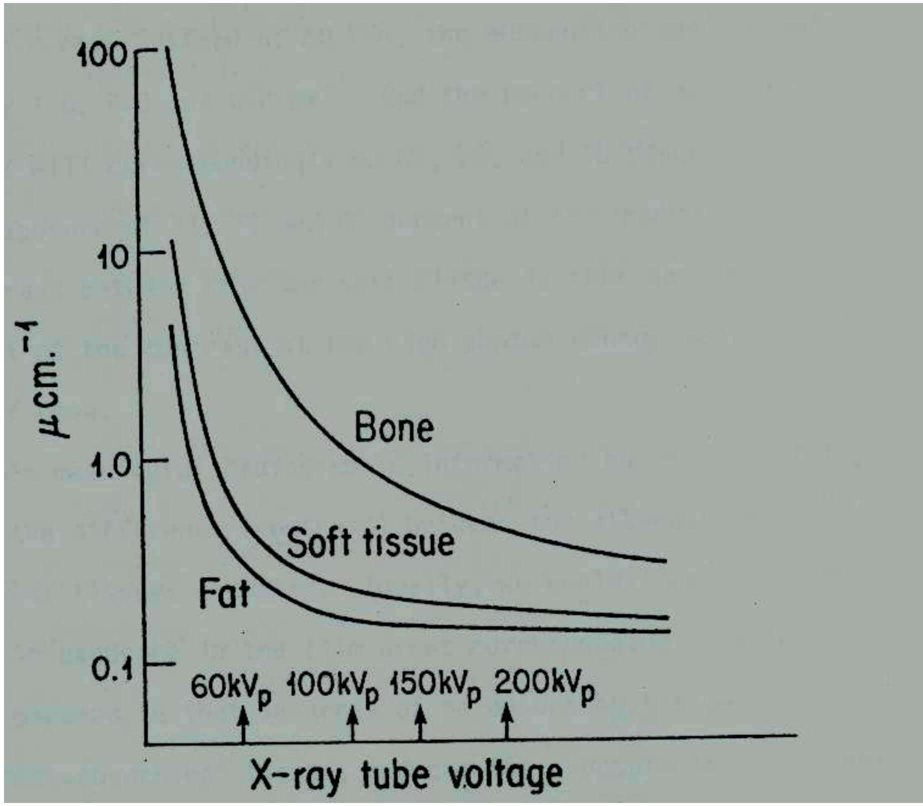
- Relative proportion of transmission, absorption and scatter change depending on amount of bone, blood and soft tissue (less dense tissue composed of lighter atoms – more black in the image)

- Transmission intensity- the sum of transmitted intensities through parts of different transitivity (different absorption coefficients, μ)

- Image is 2D projection of 3D object

Contrast enhancement

- Bones absorb more than soft tissue at all tube voltages
- Right choice of tube voltage can enhance contrast inside the soft tissue
- Tube voltage depends on tissue thickness
  - For 14 cm - U = 80 kV
  - For 20 cm - U = 110 kV



- All soft tissue have similar Z so the probability of Compton interaction is similar - weak contrast
- It can be enhanced by introduction of substance with high density and high Z number (contrast agent) in organ under investigation.
- These agents are absorbing X ray-radiation by photoelectric effect.
- Using the lower voltage, only the soft tissues with contrast agent will have strong absorption.

Intestines with solution of barium salt

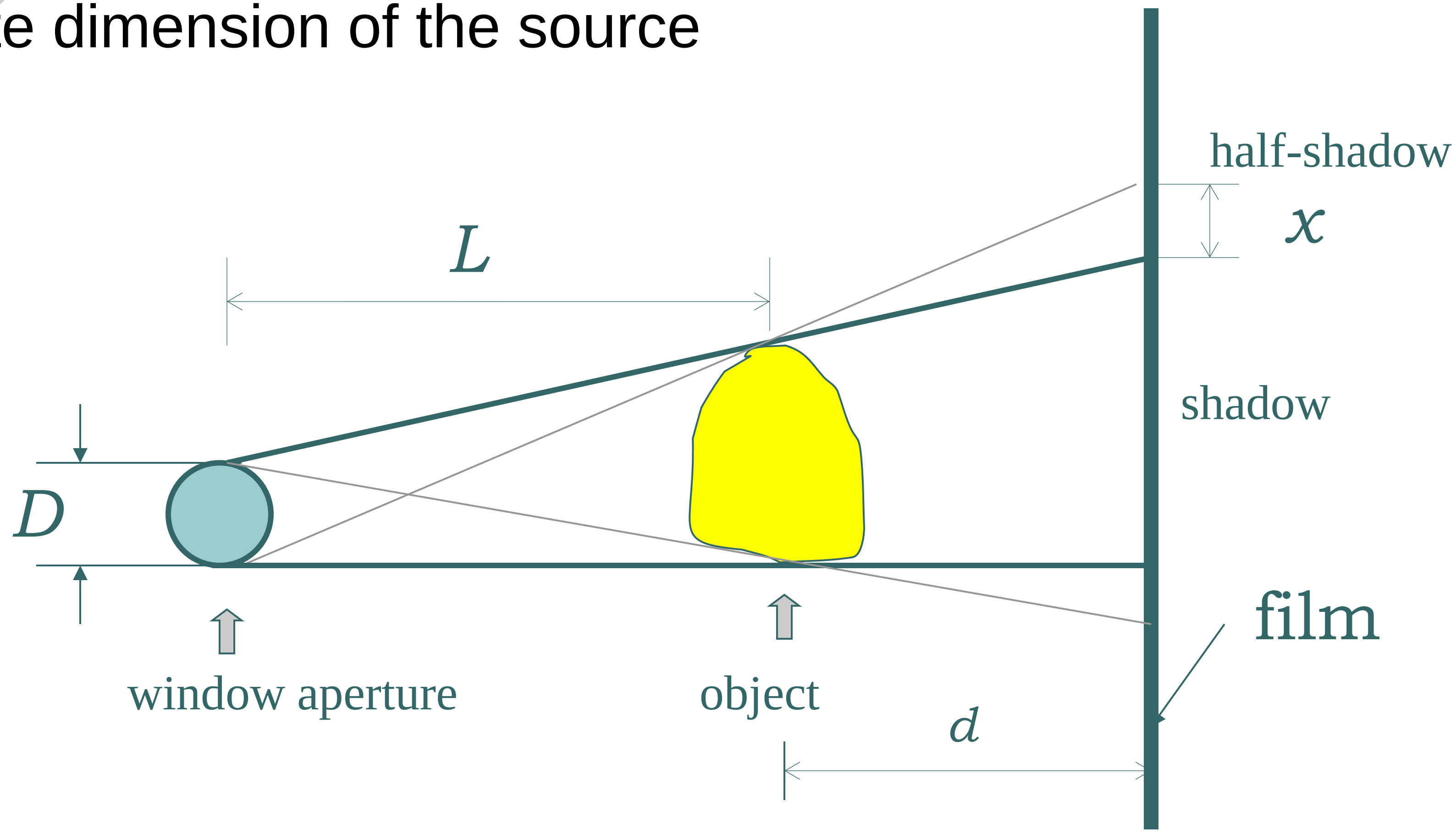
Image sharpness

- The "geometrical" unsharpness is limited by finite dimension of the source, i.e. the window on X-ray tube. Therefore the optical shadow is always surrounded by half-shadow. By adjustment of distance between the tube, object and film we try to minimize the half-shadow.

- Secondary photons, emitted by relaxation of atoms after Compton scattering, leave the body and uniformly increase the exposure of the film reducing the contrast.

- The quality of radiographs can be improved by the use of special filters, X-ray film coated with fluorescence layer and image intensifier.

The half-shadow (penumbra) is the consequence of the finite dimension of the source

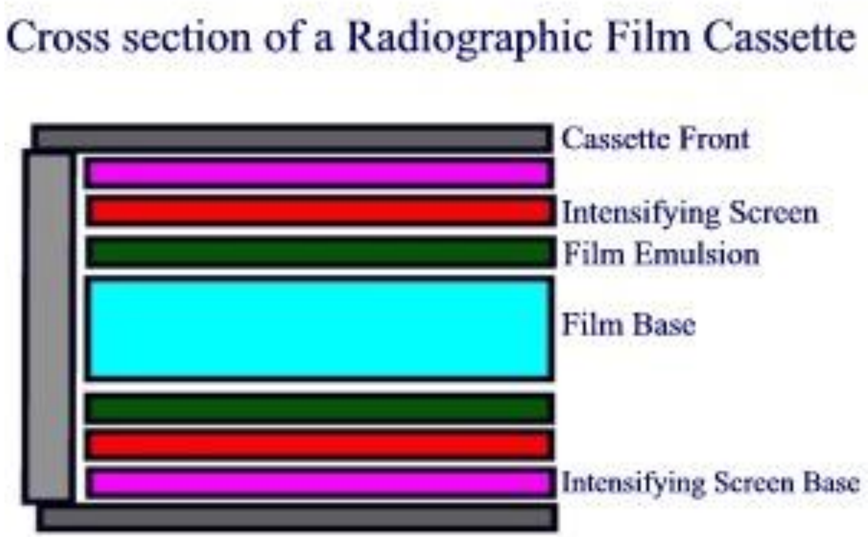


$$x = D\, d/L$$

half-shadow is thinner if the distance from object to film is small in comparison with distance from object to source

Image recording

- Photographic emulsion is not sensitive for X-photons but is for visible light - only 1% of incident X-photons are absorbed in film
- It would require a long irradiation of patient to get a good image
- Intensifying screen (phosphorescence substance) enables the transformation of X-photons into light photons (1 X - 1000 VIS) which can be completely absorbed in film
- The intensity of image can be enhanced about 30 times



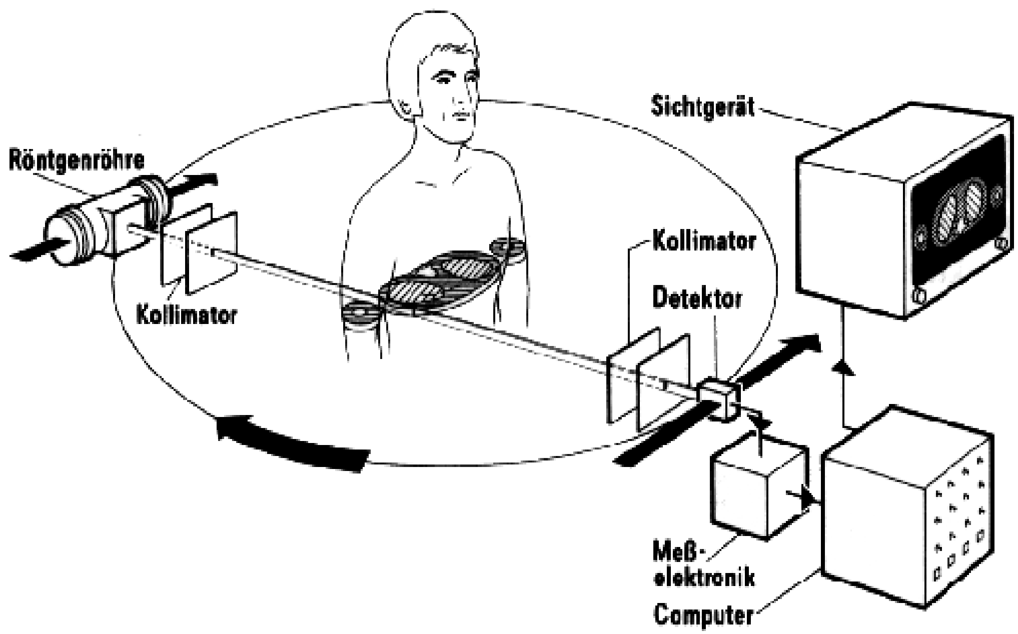
Phosphorescence substances- barium titanate, zinc sulphide, caesium iodine….

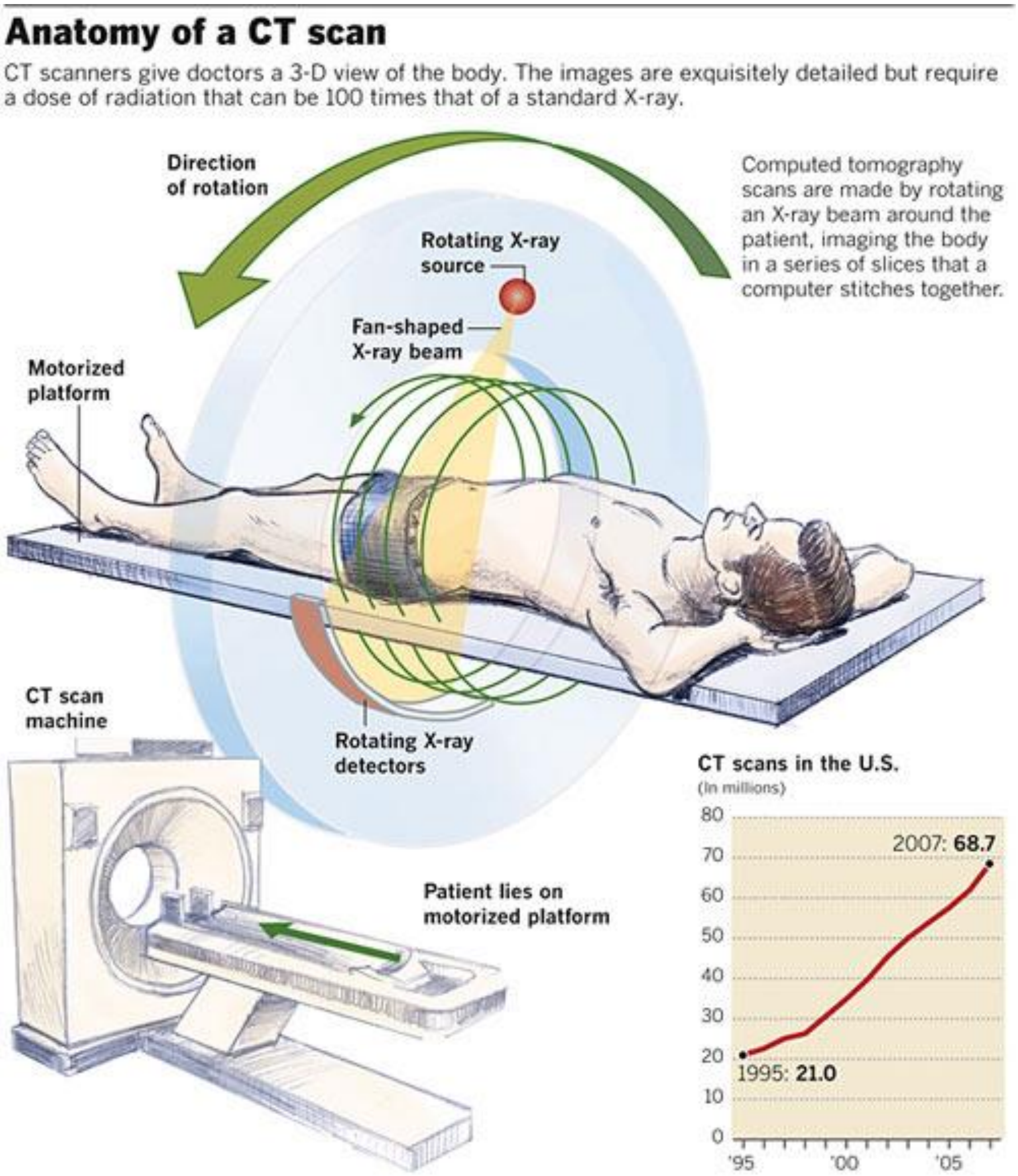
Computed tomography- CT

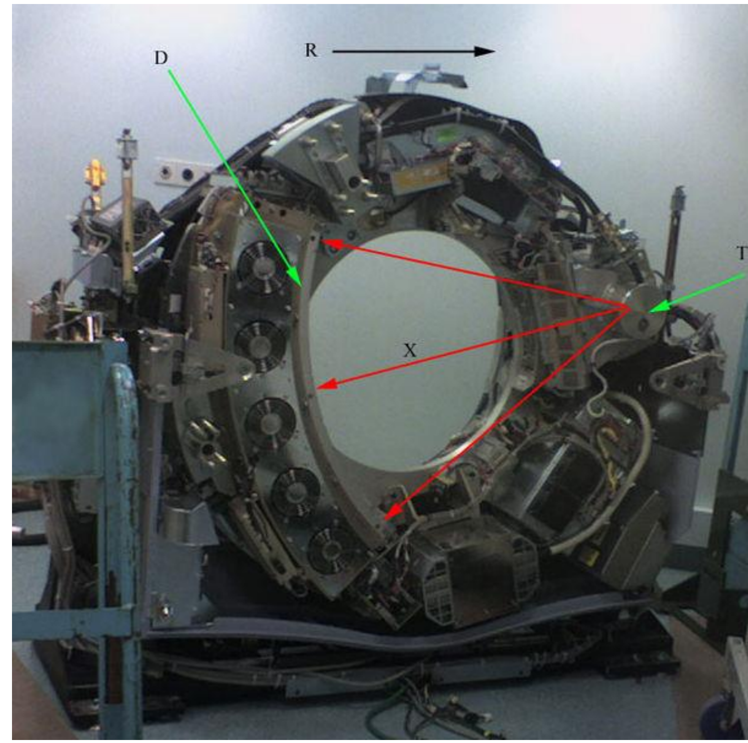
- G. N. Hounsfield i A. M. Cormack (1972.) – Special way of recording transmitted intensities and mathematical processing of recorded data for image reconstruction
- 1979. Nobel price for medicine

- Narrow beam (1 – 10 mm) passes through chosen tissue layer determined by the beam width

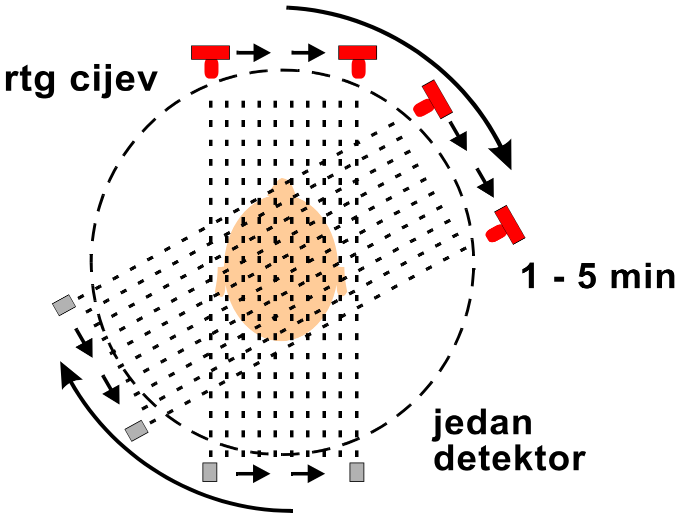
- On the opposite side the detector records the intensities of the transmitted beam

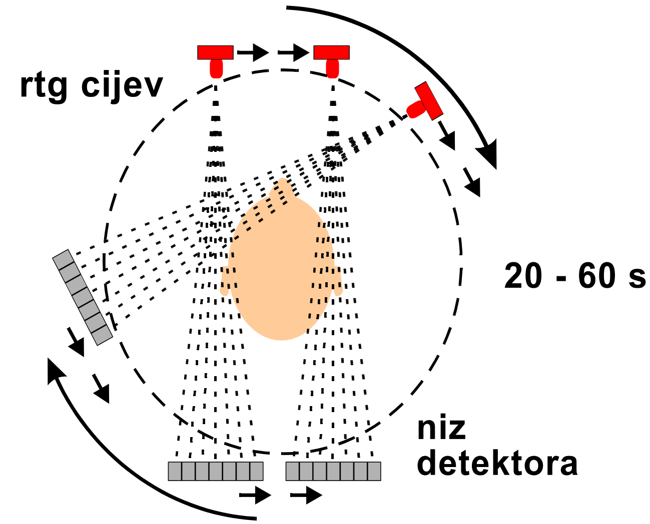



Anatomy of a CT scan
CT scanners give doctors a 3-D view of the body. The images are exquisitely detailed but require a dose of radiation that can be 100 times that of a standard X-ray.
Direction of rotation
Computed tomography scans are made by rotating an X-ray beam around the patient, imaging the body in a series of slices that a computer stitches together.
Rotating X-ray source
Fan-shaped X-ray beam
Motorized platform
CT scan machine
Rotating X-ray detectors
Patient lies on motorized platform
CT scans in the U.S.
(In millions)
80
70
60
50
40
30
20
10
0
2007: 68.7
1995: 21.0
'95
'00
'05


D
R
T
X

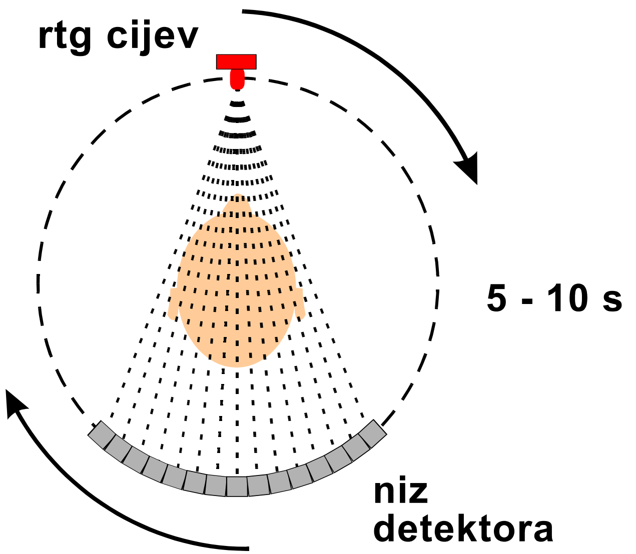
Method development



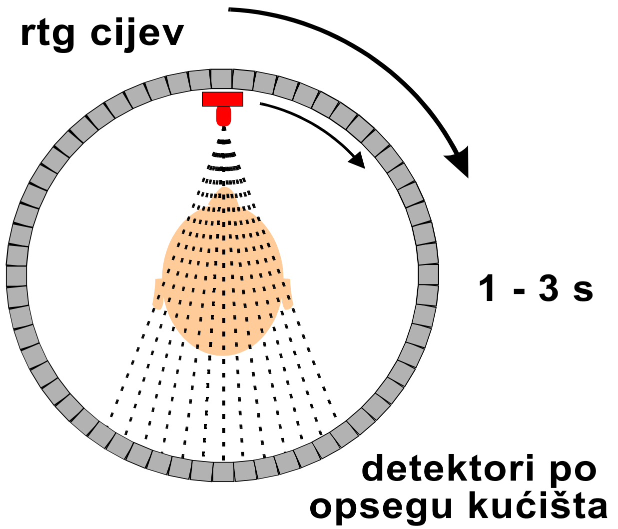


- 1. generation – the detector and source move linearly and record intensity at each step. Than the detector and the source move simultaneously for the certain angle and the process of recording is repeated.
- 2. generation – one wide beam source is added and one detector

- 3. generation – the source produces a wide beam and several detectors record transmitted intensities. Intensive pulse of X-rays is produced every 2 – 4 ms for each projection and detector rotates for 360º.

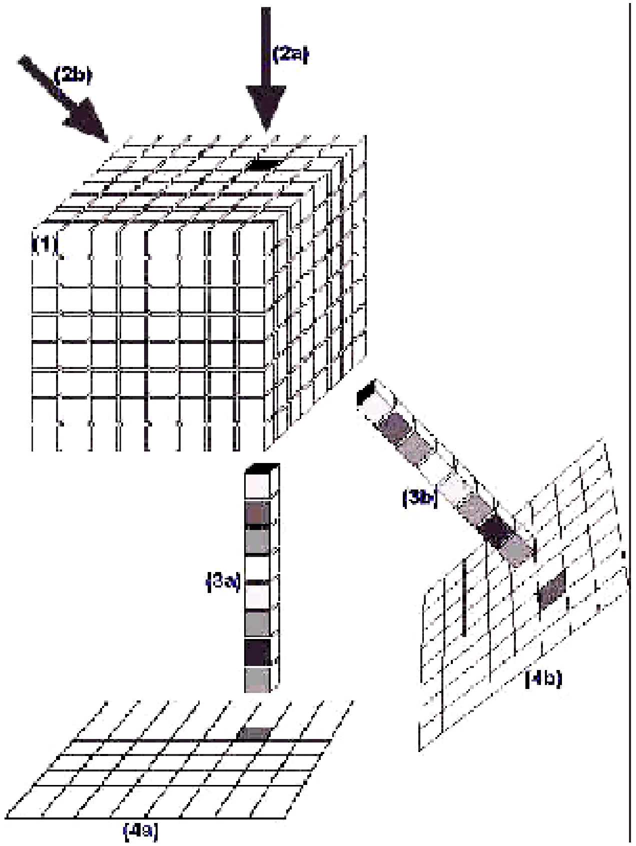


- 4. generation – the whole ring is slab-sided by detectors and wide beam source rotates for 360º



How image is formed

- Image formation goes in parallel with image acquisition
- The layer is divided into volume elements - **voxels** (**10 mm³**).
- Each voxel has his own absorption coefficient.
- Beam passes through series of woxels and the intensity of transmitted beam is:



$$I_t = I_0 \, e^{-(\mu_1+\mu_2+\mu_3+\ldots\mu_n)\Delta x}$$

- The information about the absorption coefficient of the woxels is in image transferred to a pixel which is 2D element of layer image; the number of pixels is determined by the number of woxels; pixel = voxel/layer thickness ~ **1 mm²**

Literatura:

1. J.Brnjas-Kraljević, *Struktura materije i dijagnostičke metode*, Medicinska naklada, Zagreb (2001)

2. Predavanja i seminari na web adresi: http://physics.mef.hr

3. D. Eterović, *Fizikalne osnove slikovne dijagnostike*, Medicinska naklada, Zagreb (2002)

4. Sprawls Educational Foundation na web adresi: http://www.sprawls.org