X-RAYS IN MEDICAL DIAGNOSIS

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PROBLEMS:

- Generation and properties of X Rays

- Parameters of X Ray machines:
  - focal spot size
  - miliamperage
  - peak voltage
  - filtration, beam hardening, aluminum equivalent

- Emission Spectrum of X Rays: continuous and characteristics spectrum, the short wavelength limit

- Attenuation of X Rays:
  - types of X-ray interactions with matter:
    the Compton effect, photoelectric effect, electro-positron pair production
  - Lambert law: half-value layer (penetration depth), linear and mass attenuation coefficient,
  - contrast agents, K-edge of absorption
  - absorption vs. x-ray photons‘ energy.

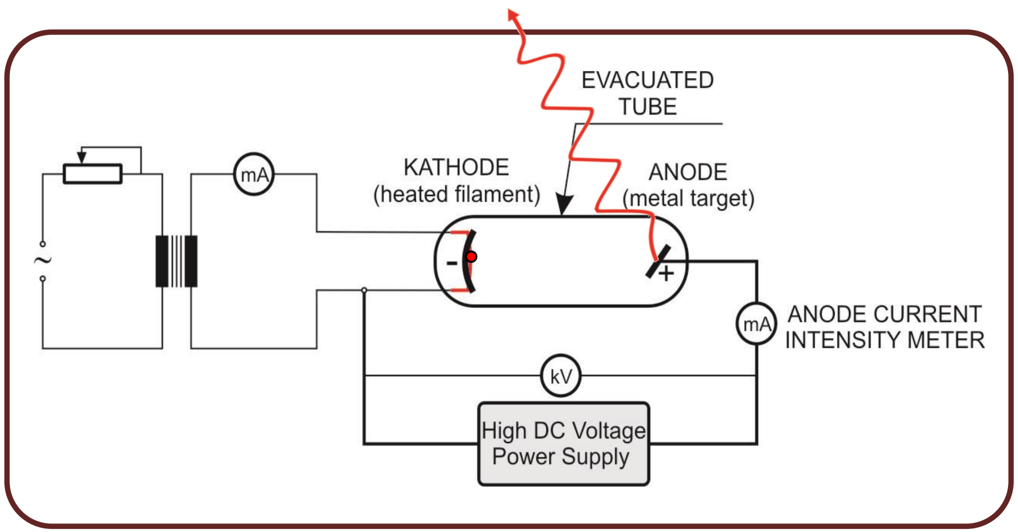
- X-ray based computed tomography (CT):

  Idea and development of the CT technique,
  Image reconstruction - numerical representation, computed tomography numbers, windowing technique

Generation of X-rays

The first mechanism:

✓**bremsstrahlung** (breaking radiation): when rapidly moving electrons strike a solid target and their kinetic energy is converted into energy of electromagnetic radiation.



$$E_k = W_{el} = qU$$

$$qU = h\nu$$

THE CONTINUOUS X-RAY SPECTRUM

$$E_k = qU$$

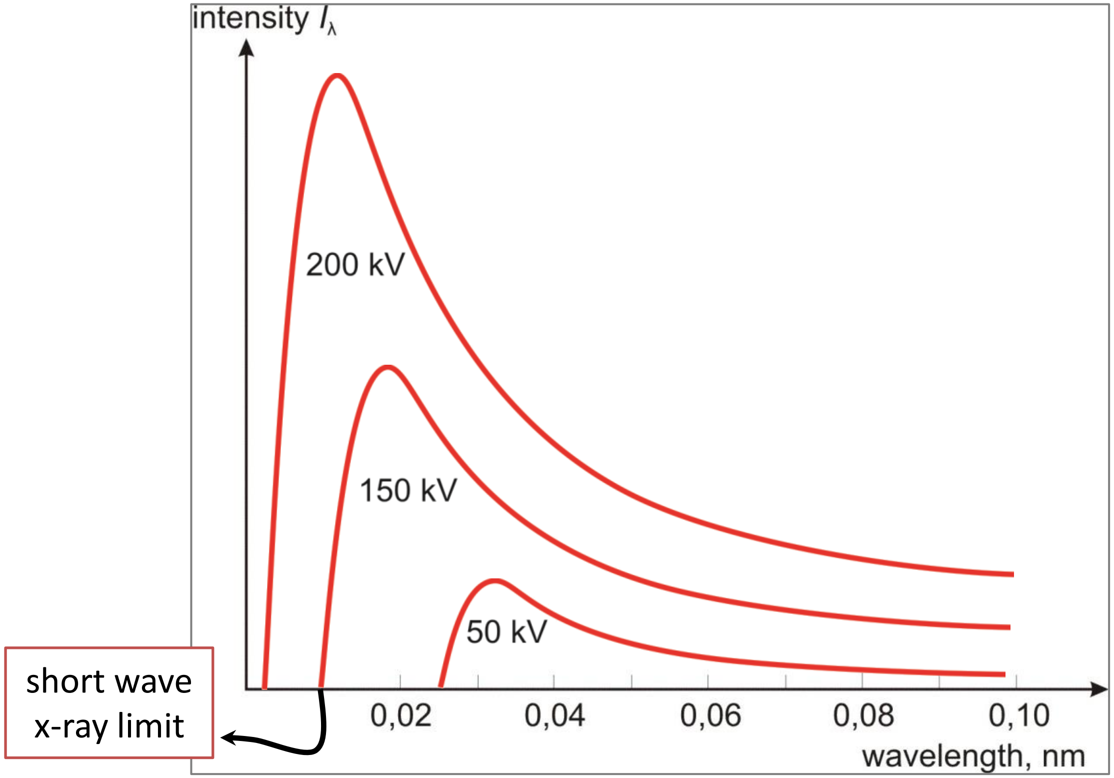
$$E_k = h\nu = h\frac{c}{\lambda}$$

$$qU = h\frac{c}{\lambda}$$

$$\lambda_{min} = \frac{hc}{qU}$$

$$\lambda_{min} = \frac{hc}{eU}$$

Distribution of energy in the ***continuous*** x-ray spectrum



Beam intensity: $I = CZU^2 i_A$

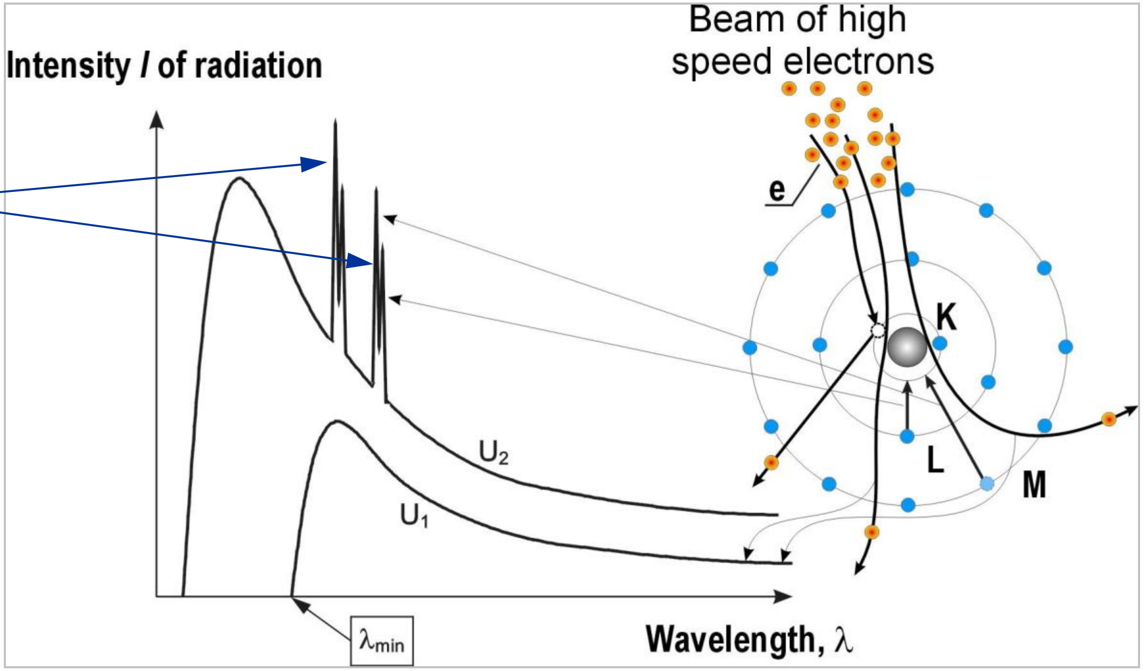
C - tube constant,
Z - atomic number of anode material,
U - supplying voltage (the peak kiloVoltage - **kVp**),
i_A - anode (electron) current. **(MILLIAMPERAGE)**

THE CHARACTERISTIC SPECTRUM

THE SECOND MECHANISM

THE CONTINUOUS SPECTRUM WITH THE CHARACTERISTIC RADIATION SPECTRUM SUPERIMPOSED

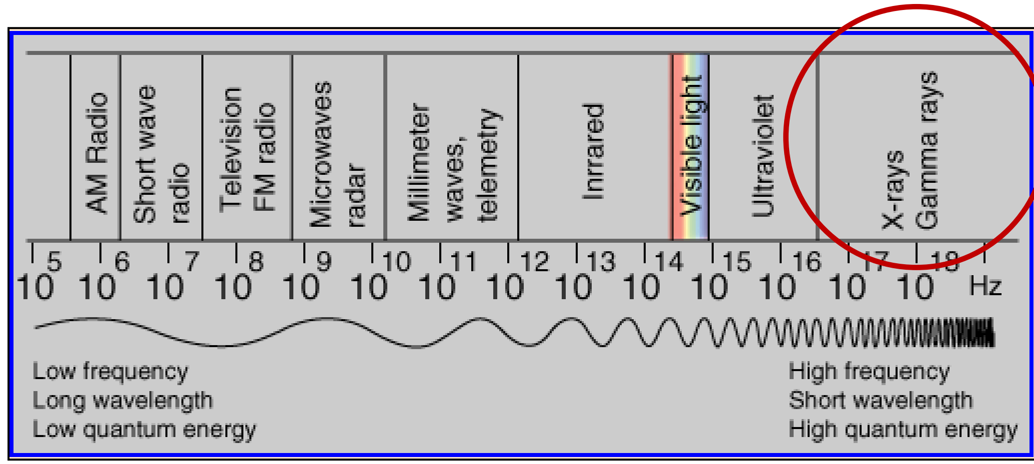
✓THE CHARACTERISTIC RADIATION



In the produced spectrum of x-rays very sharp spikes appear above the smooth background. These spikes are called *characteristic lines* and the x-radiation is termed *characteristic radiation*.

PROPERTIES OF X-RAYS

- Short-wave, high energy electromagnetic radiation
- Ionising
- Penetrating



$h = 6.6\times10^{-34}$Js (Planck's constant)

$e = 1.6\times10^{-19}$ C (elementary charge)

$c = 3.0\times10^{8}$ m/s (speed of light in vacum)

Dental bitewing procedure is performed using U_1 = 70 kV = 7×10^4 V

U_2 = 200 kV = 2×10^5 V

$$\lambda_{min} = \frac{hc}{eU} \qquad \nu_{max} = \frac{eU}{h}$$

$\lambda_{min} = 1.8\times10^{-11} = 0.018$ nm, $\nu_{max} = 1.7\times10^{19}$Hz

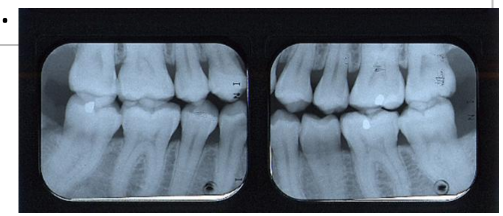
$\lambda_{min} = 0.006$ nm, $\nu_{max} = 5\times10^{19}$Hz

$\lambda_{x\text{-rays}}$ = from 0.001 (or shorter) nm to 10 nm

DENTAL X-RAY UNIT

Periapical x-ray: - at or around the apex of a root of a tooth.

Bitewing - an X-ray film with a projecting edge that is clamped by the teeth to hold the film in place for an exposure.



Filtration shall be inserted in the useful x-ray beam to remove the "softer" or lower energy components which otherwise contribute to:

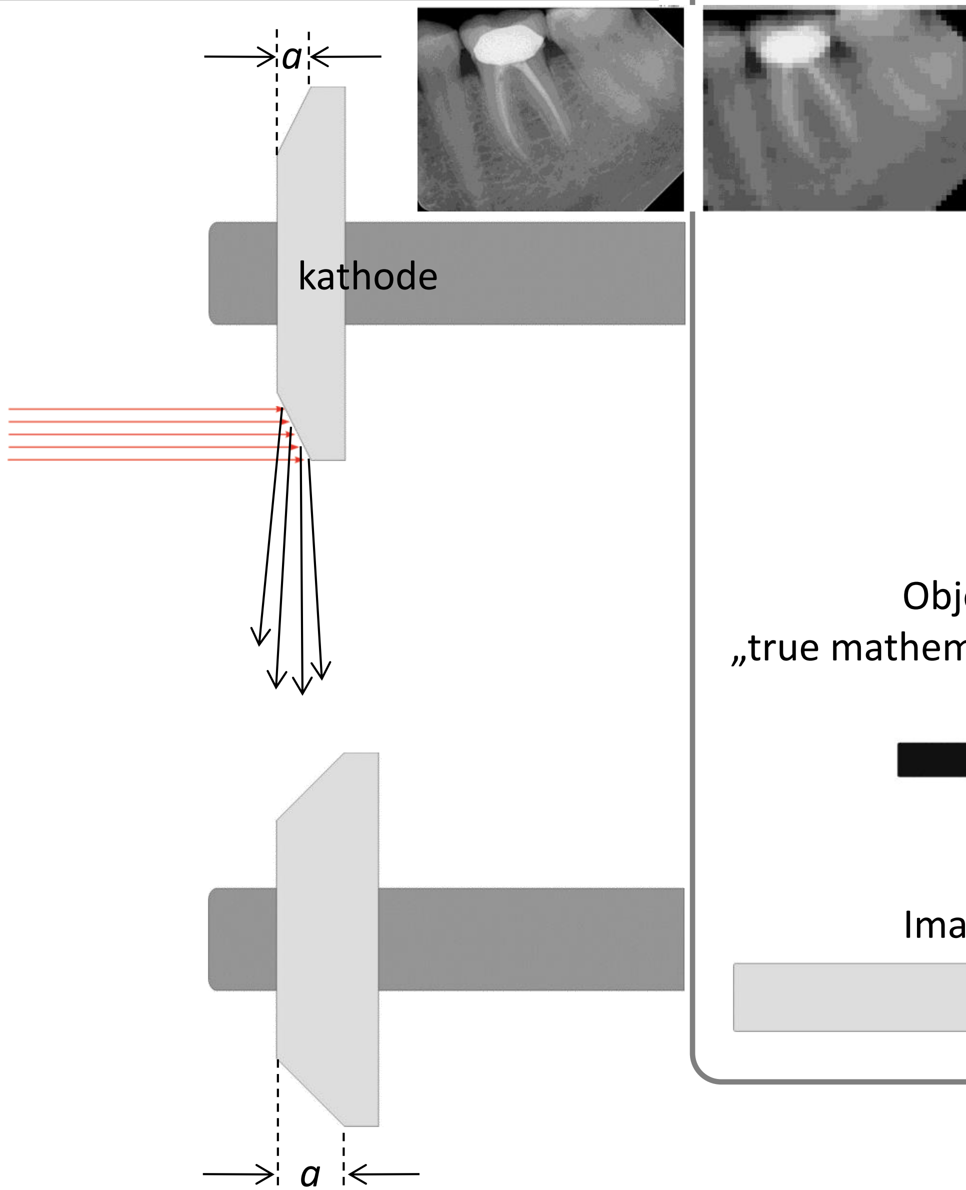
a) patient dosage

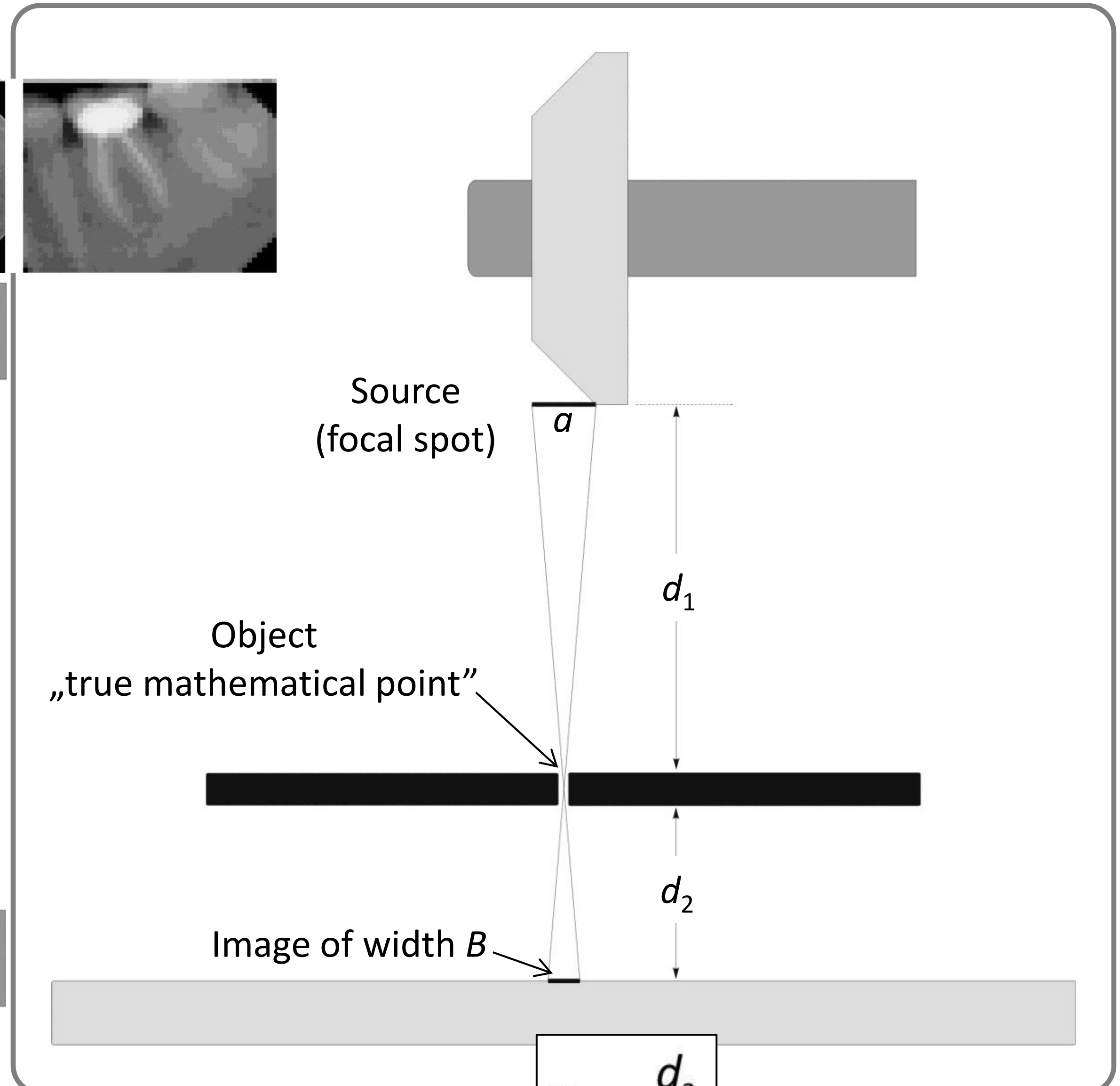
and

b) to scattered radiation levels, without usefully affecting the diagnostic image.

- Tube Voltage: 60-70 kVp
- Tube Current: 8mA
- Focus Size: 1.5 mm
- Total Filtration: 2.5 mmAL
- Exposure Time: 0.2-4 sec

Focal spot – vs. spatial resolution

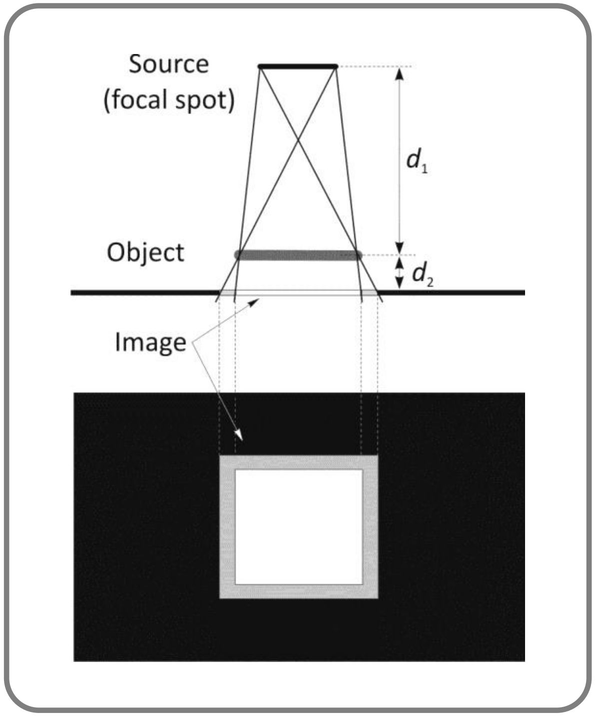




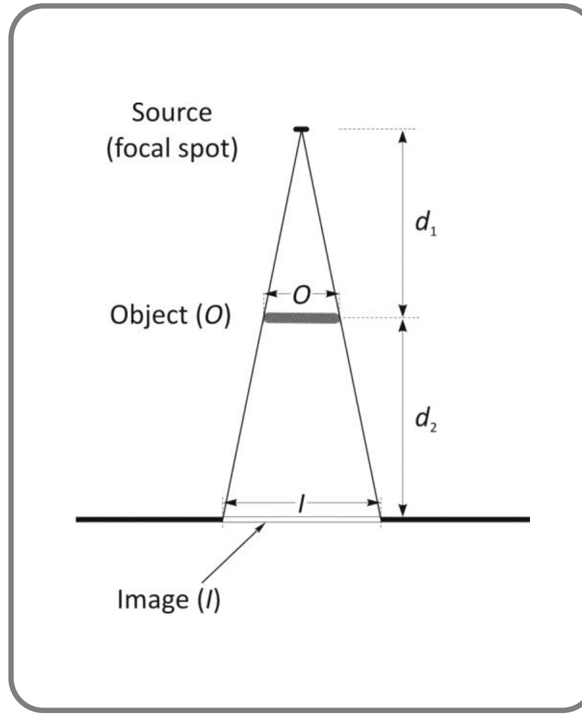
$$B = a\frac{d_2}{d_1}$$

Both, the geometry (d_1, d_2) and the dimension (a) of the focal spot determine spatial resolution.
Under optimal conditions in radiography the spatial resolution reaches 0.1 mm.

CONTRAST
(shadow – blurring which appears at the edges of an image)



MAGNIFICATION



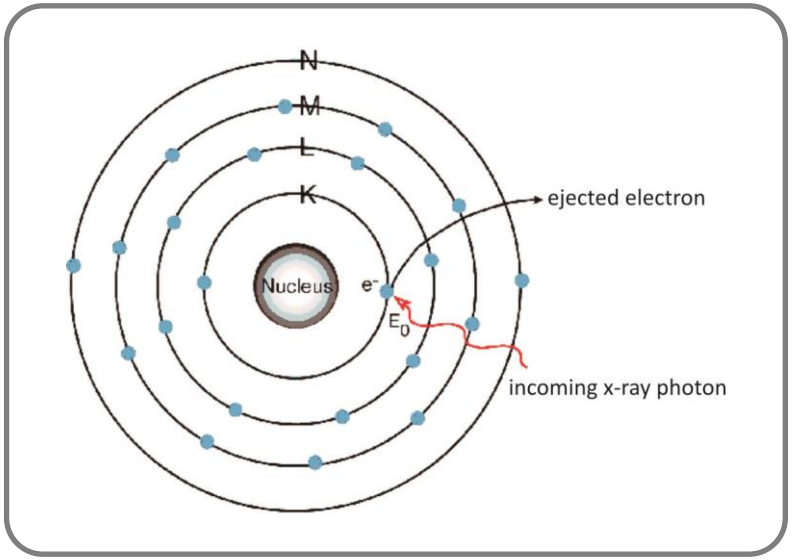
$$M = \frac{I}{O} = \frac{d_1 + d_2}{d_1} = 1 + \frac{d_2}{d_1}$$

Magnification increasies with increasing d_2 but at the cost of reduced spatial resolution.

$$B = a\frac{d_2}{d_1}$$

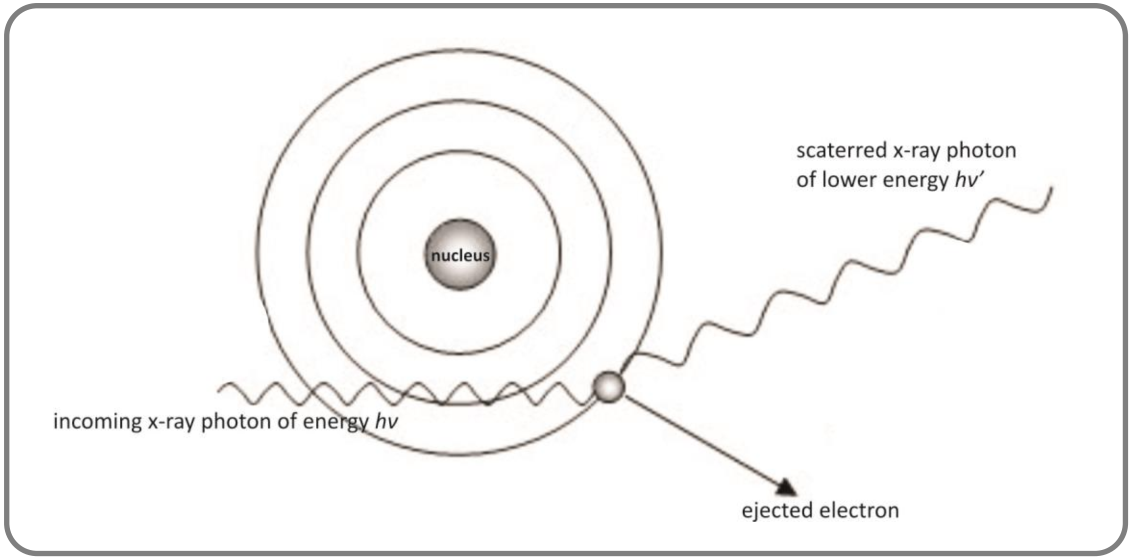
INTERACTION OF X-RAYS WITH MATTER

THE PHOTOELECTRIC EFFECT



Probability of the photoelectric effect occurrence is proportional to Z^3. Average Z for soft tissues: 7.4, for bones: 11.6 – 13.8

THE COMPTON EFFECT

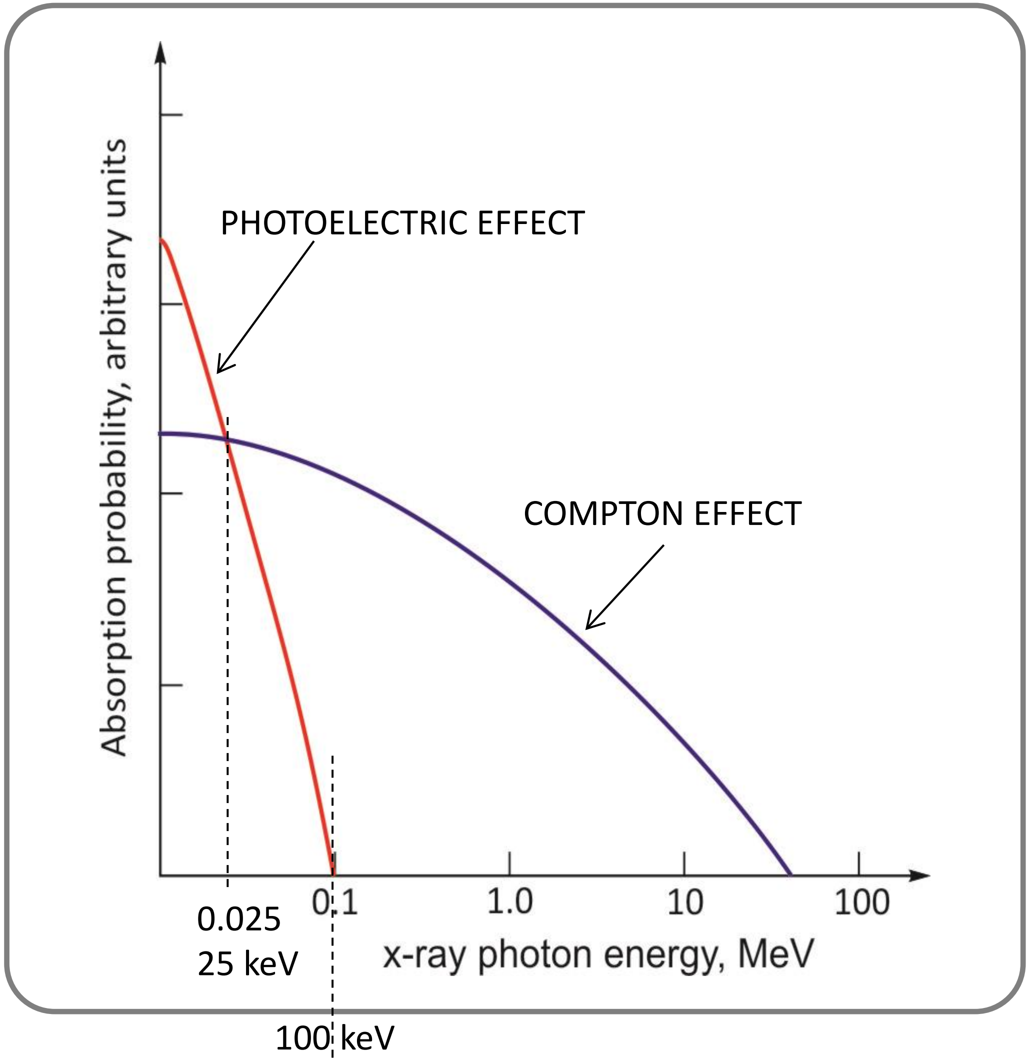


Probability of occurrence depends on the number of electrons in a sample of material (and related density!)

⇩

Because most of soft tissues have very similar densities, the Compton effect, as compared to the photoelectric effect is relatively insensitive to differences in anatomy.

ABSORPTION OF X-RAYS IN WATER



The amount of x-rays absorbed or scattered depends upon how many electrons are encountered along x-ray's path.

Main determinants of absorption are:

- density (dependent on atomic number Z) of a material
- energy of photons
- thickness of the layer of absorbing material

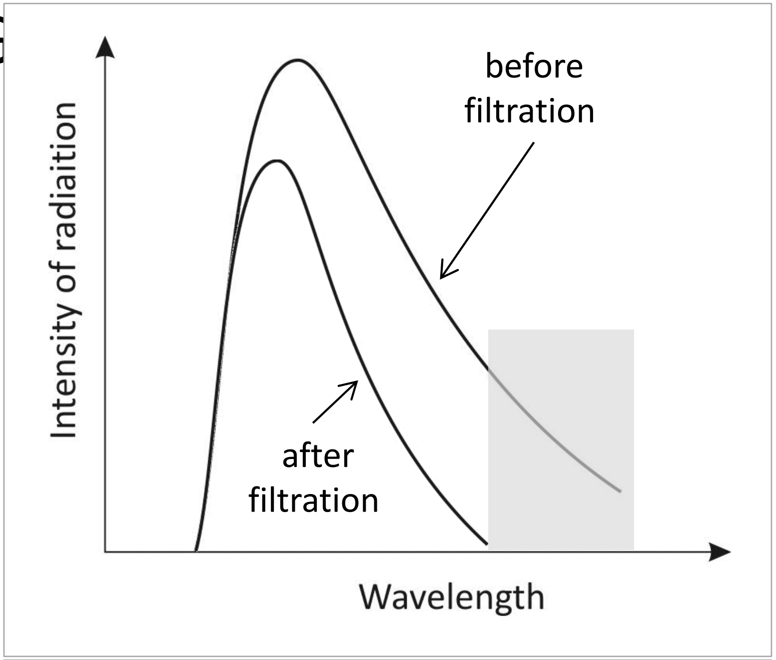
Let us remember that:

- the *photoelectric effect predominates* attenuation of photons of energies below 0.025MeV (25 keV).
- for higher energies of photons the *Compton effect* becomes dominating and
- for energies higher than 2 MeV both, the *electron-positron pair production* (not shown) and the *Compton effect* plays their role in attenuation of electromagnetic ionizing radiation.

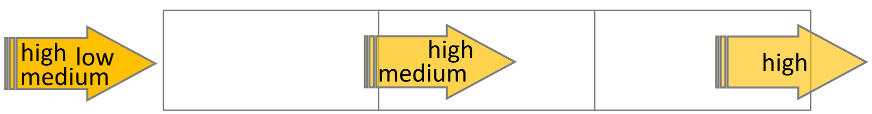
FILTRATION AND BEAM HARDENING

Absorption of x-rays is affected by the energy of photons!

	aluminium	
kV	*HVL* , m	μ, m^{-1}
30	0.003	230
50	0.012	58
70	0.015	46
90	0.025	28
110	0.030	23



ADDING FILTERS REMOVES LOW-ENERGY PHOTONS.



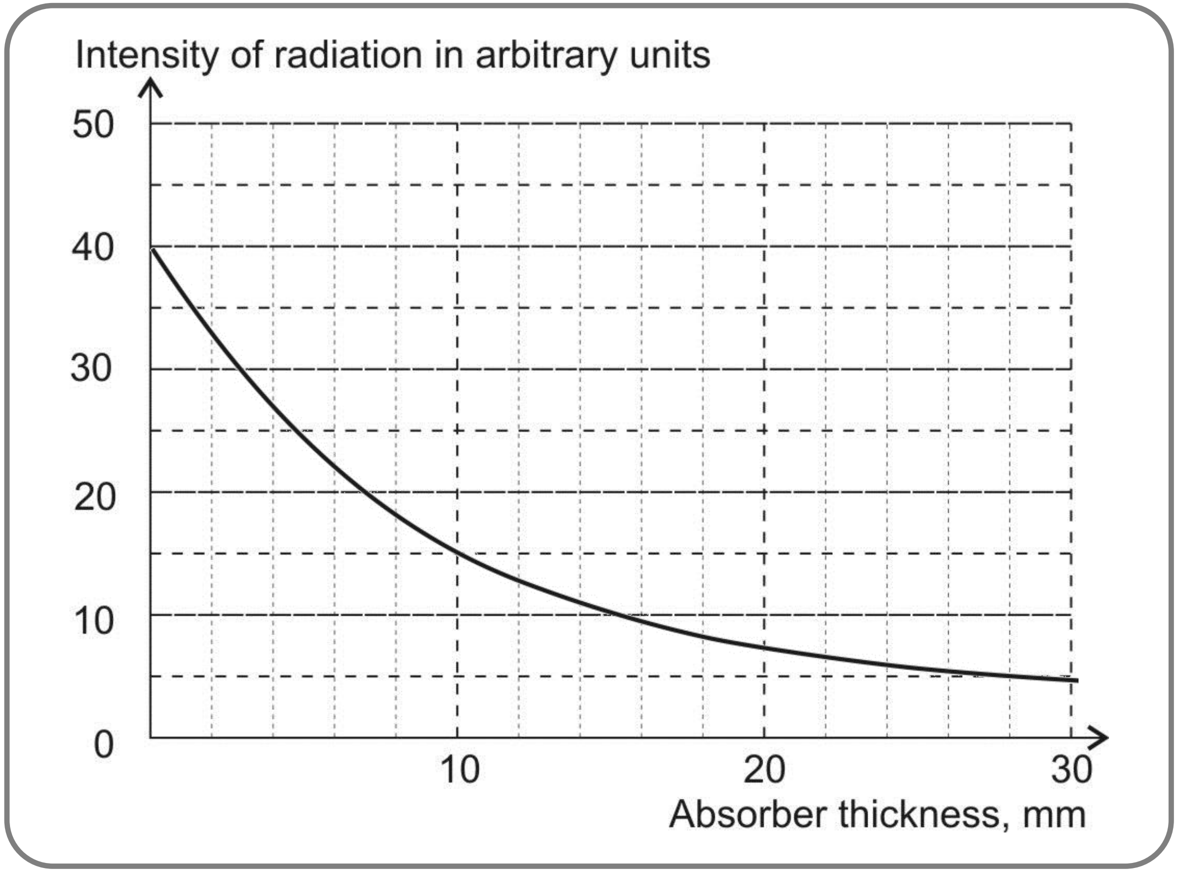
Beam hardening is the process of selective removal of soft x-rays from the x-ray beam. As these x-rays are removed, the beam becomes progressively harder .

"Aluminum equivalent„ is the thickness of any absorbing material that would attenuate the x-ray beam to the same degree as a given thickness of aluminum (1100 aluminum alloy).

The use of filters produce a cleaner image by absorbing the lower energy x-ray photons that tend to scatter more than those of high energy.

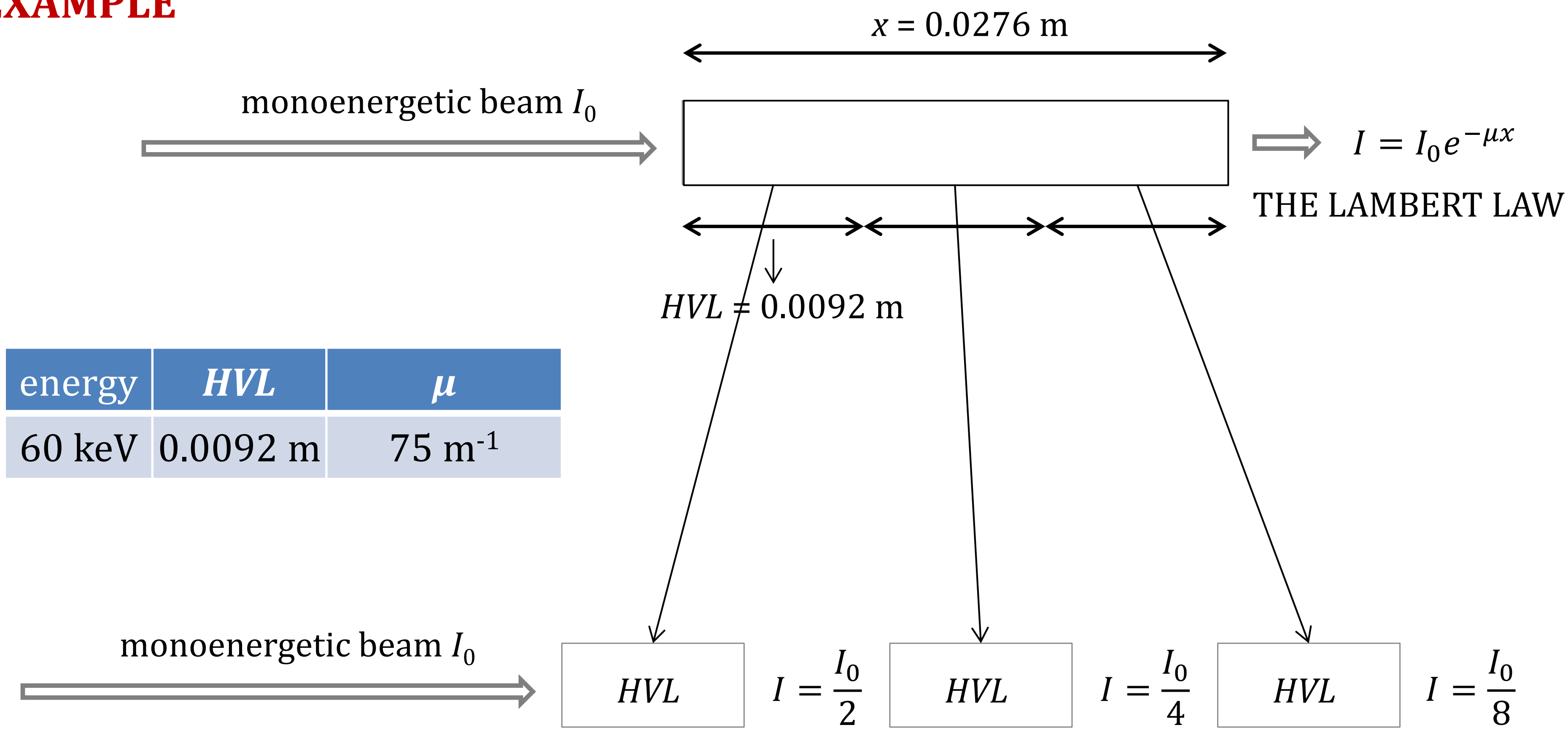
THE LAMBERT LAW

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



μ – LINEAR ATTENUATION COEFFICIENT

EXAMPLE



energy	*HVL*	*μ*
60 keV	0.0092 m	75 m^{-1}

$$I = I_0 e^{-75m^{-1} \cdot 0.0276m} = I_0 e^{-2.07} = I_0 \cdot 0.125 = \frac{I_0}{8}$$

Aluminum equivalent

Aluminum equivalent is the thickness of any absorbing material that would attenuate the x-ray beam to the same degree as a given thickness of aluminum (1100 aluminum alloy).

EXAMPLE:

Calculate the aluminum equivalent of iron (μ_{Fe} = 940 m^{-1}) for 0.010 m thick layer of aluminum at 60 keV.

energy	*HVL*	*μ - Aluminum*
60 keV	0.0092 m	75 m^{-1}

$$\frac{I_{ALUMINUM}}{I_0} = \frac{I_{IRON}}{I_0} \qquad \frac{I}{I_0} = e^{-\mu x}$$

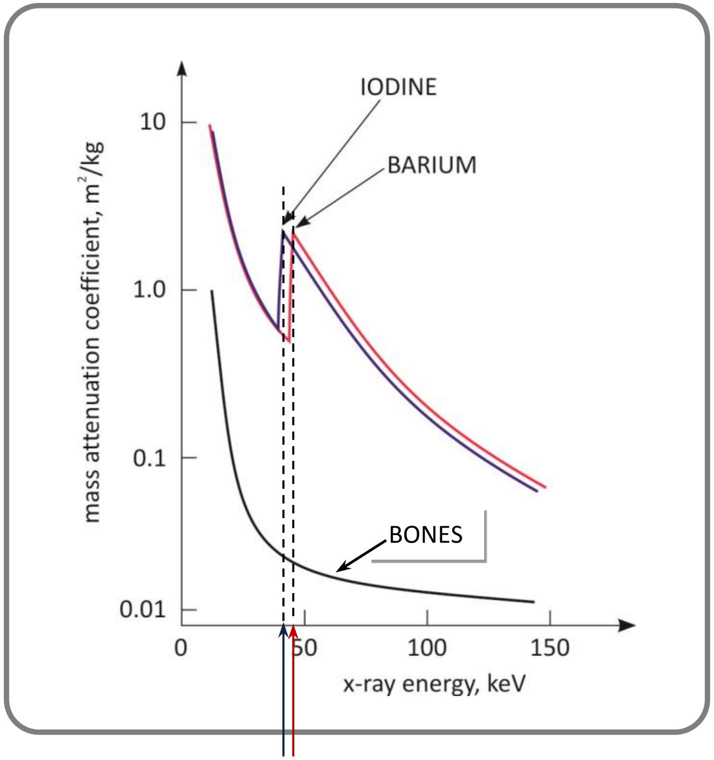
$$e^{-\mu_{Al} \cdot x_{Al}} = e^{-\mu_{Fe} \cdot x_{Fe}}$$

$$\mu_{Al} \cdot x_{Al} = \mu_{Fe} \cdot x_{Fe} \longrightarrow 75m^{-1} \cdot 0.010m = 940m^{-1} \cdot x_{Fe}$$

$$x_{Fe} = \frac{75m^{-1} \cdot 0.010 \text{ m}}{940 \text{ m}^{-1}} = 0.0008 \text{ m}$$

CONTRAST AGENTS

K – EDGE OF ABSORPTION



E_{iodine} = 33.2 keV

E_{Barium} = 37.4 keV

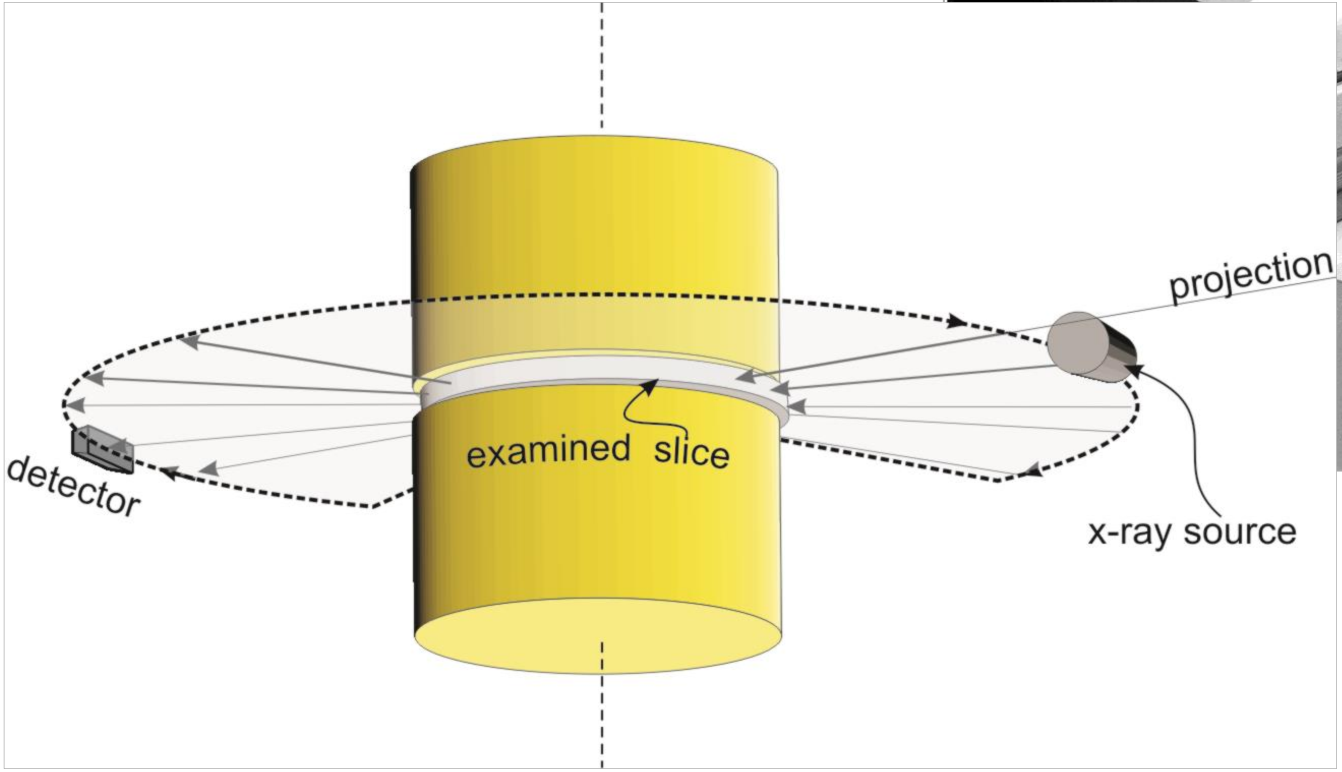
The „EDGE” is a discontinuity in the attenuation coefficient vs. photon energy curve which occurs when a photon impinging on an atom carries an energy just above the binding energy of an electron in a specific shell of the atom.

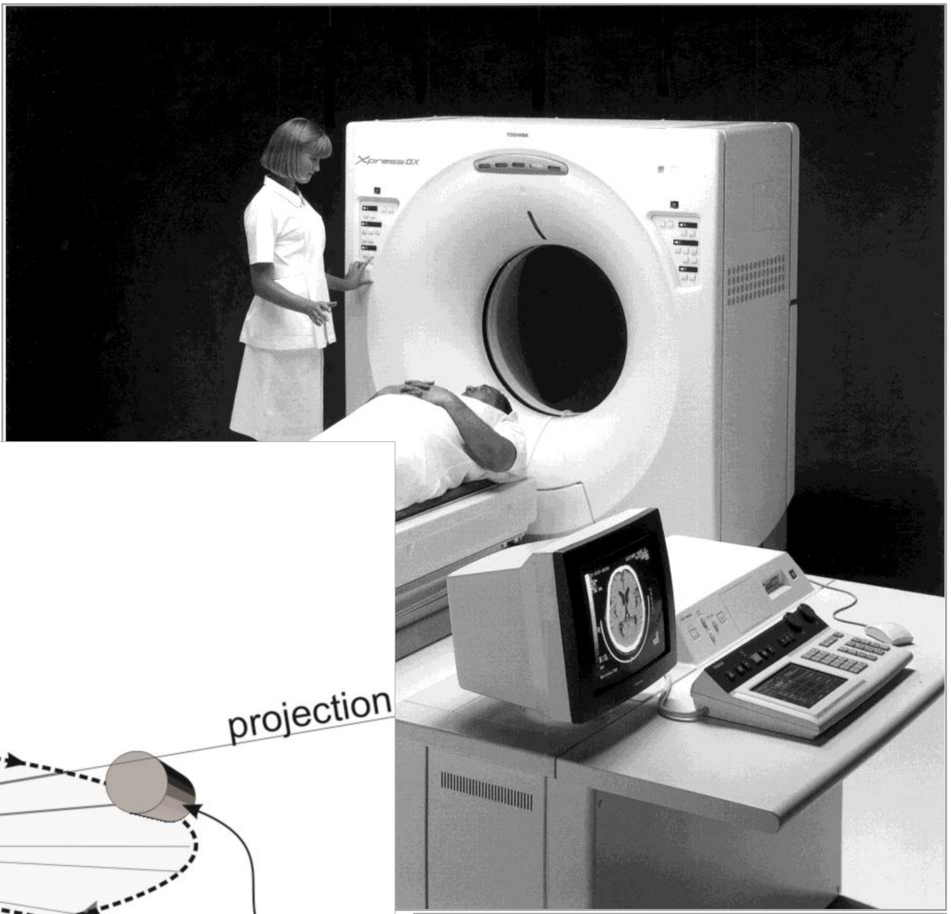
In such situation the attenuation coefficient suddenly increases in magnitude.
The observed phenomenon is due to the photoelectric effect.

Barium sulfate is in a group of drugs called contrast agents. Barium sulfate works by coating the inside of the esophagus, stomach, or intestines which allows them to be seen more clearly on a CT scan or other radiologic (x-ray) examination.

Iodine solutions are primarily used to visualize vessels, and changes in tissues on radiography and CT, but can also be used for tests of the urinary tract and uterus.

EXAMINED SLICE





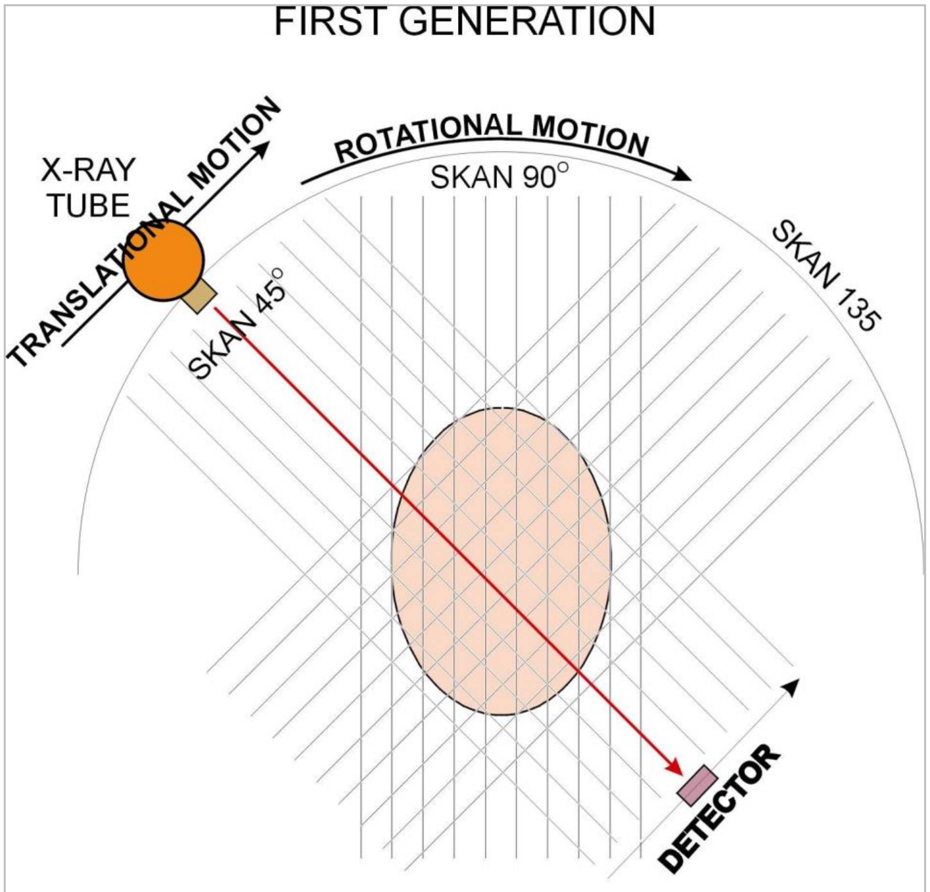
Noble Price in Physiology and Medicine 1976:
Godfrey N. Hounsfield
Allan M. Cormack

THE RAY PROJECTIONS ARE FORMED BY A PASSAGE OF AN X-RAY BEAM THROUGH A THIN CROSS SECTION OF THE BODY AND MEASURING THE TRANSMITTED RADIATION WITH A SENSITIVE RADIATION DETECTOR

DEVELOPMENT OF CT TECHNIQUE; GENERATIONS OF CT SCANNERS

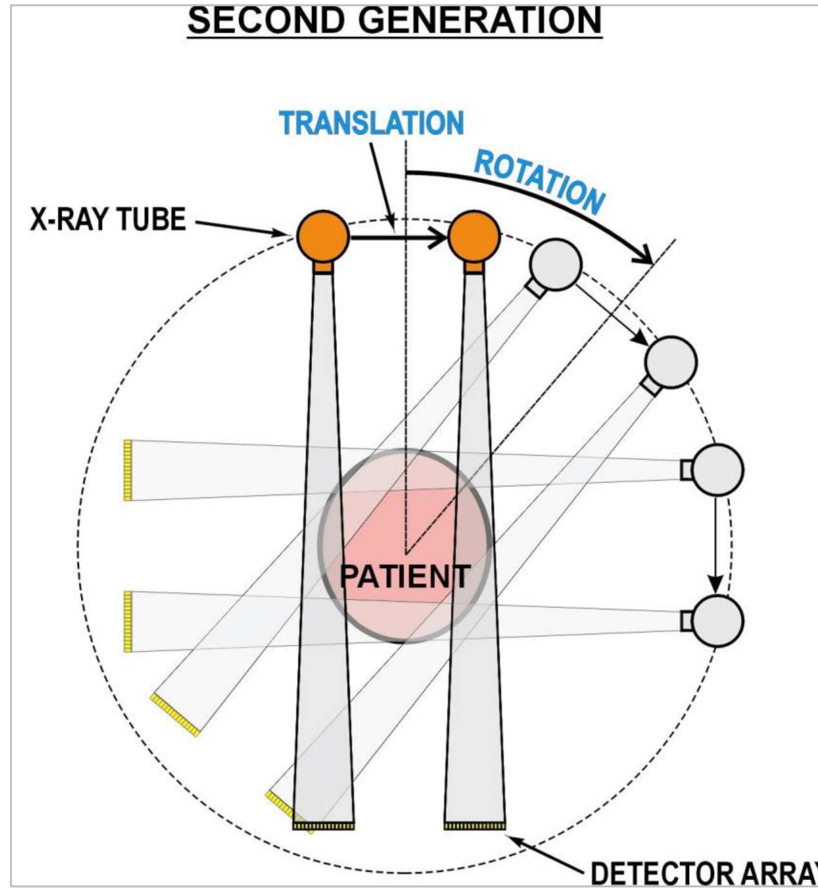
THE FIRST GENERATION

- pencil-like x-ray beam
- single detector

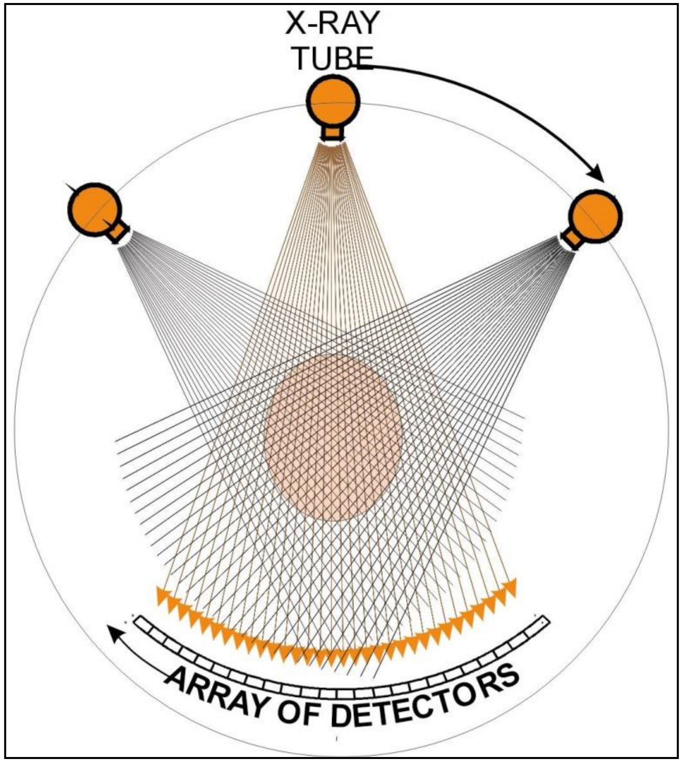


THE SECOND GENERATION

- Fan-shaped x-ray beam, array of detectors.
- Two types of motion: translational and rotational.

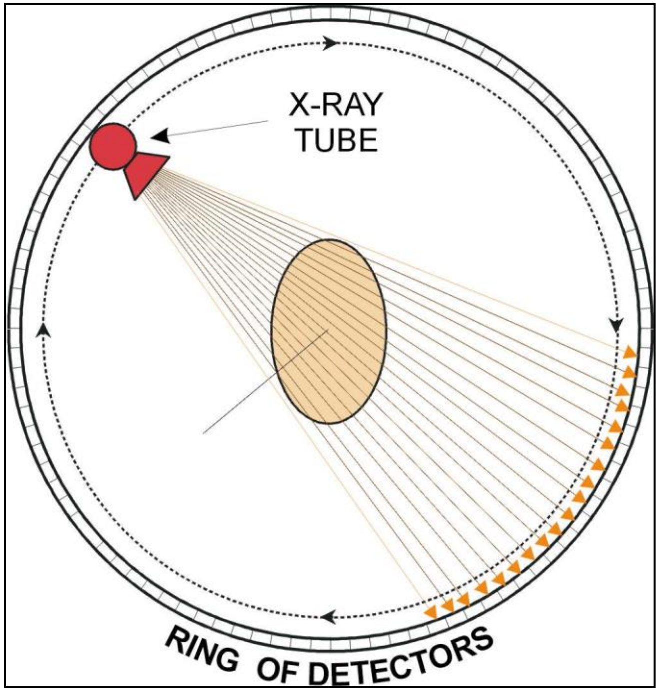


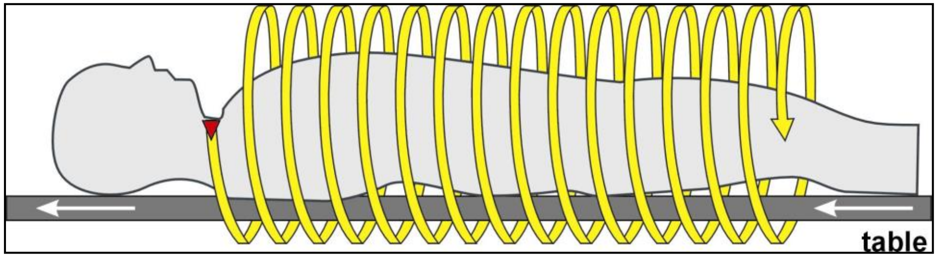
THE THIRD GENERATION



In the "third generation" CT scanner, the rigidly coupled source-detector unit is rotated around the scanned body and yield projection data for different angular positions.

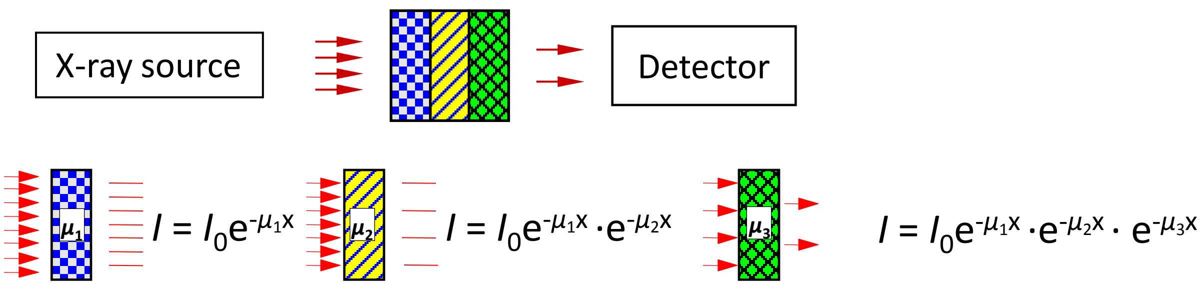
THE FOURTH GENERATION



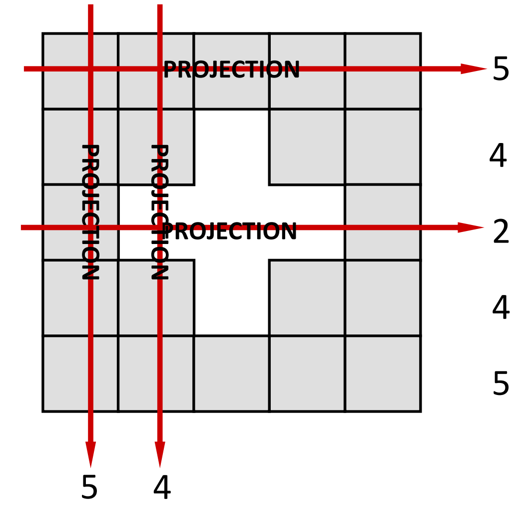


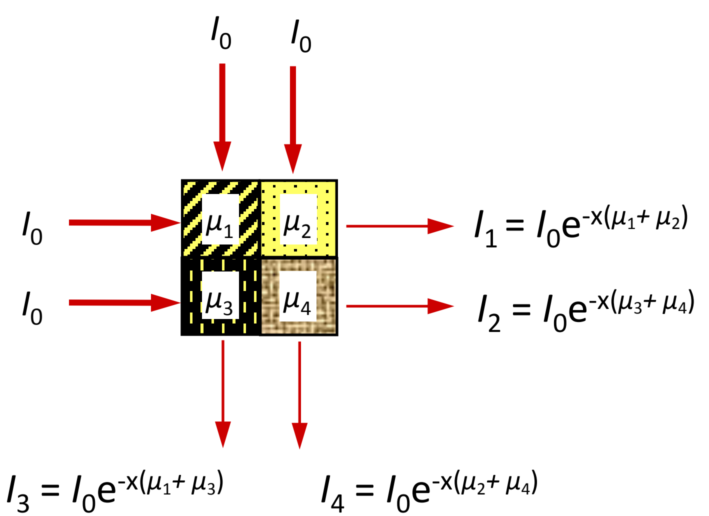
With spiral CT, the patient table advances at a constant rate through the gantry while the X-ray tube rotates continuously around the patient.

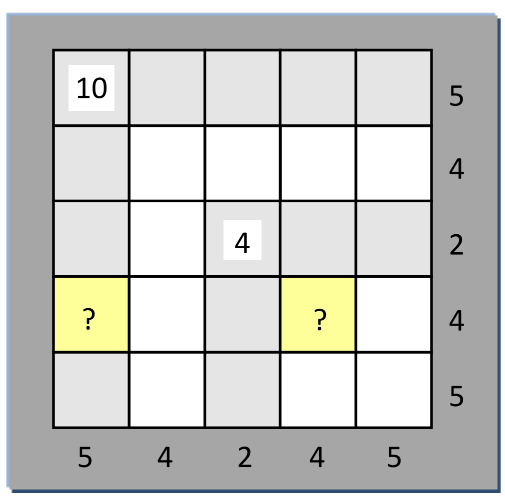
NUMERICAL REPRESENTATION

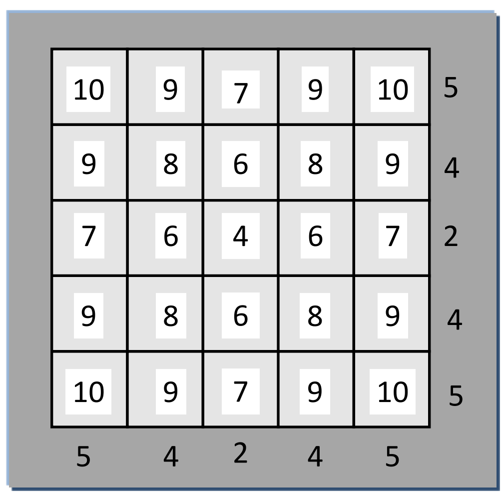


$$\textbf{PROJECTION} = (\mu_1 + \mu_2 + \mu_3) = \frac{1}{x} ln \frac{I_0}{I}$$









Computed Tomography numbers (CTN)

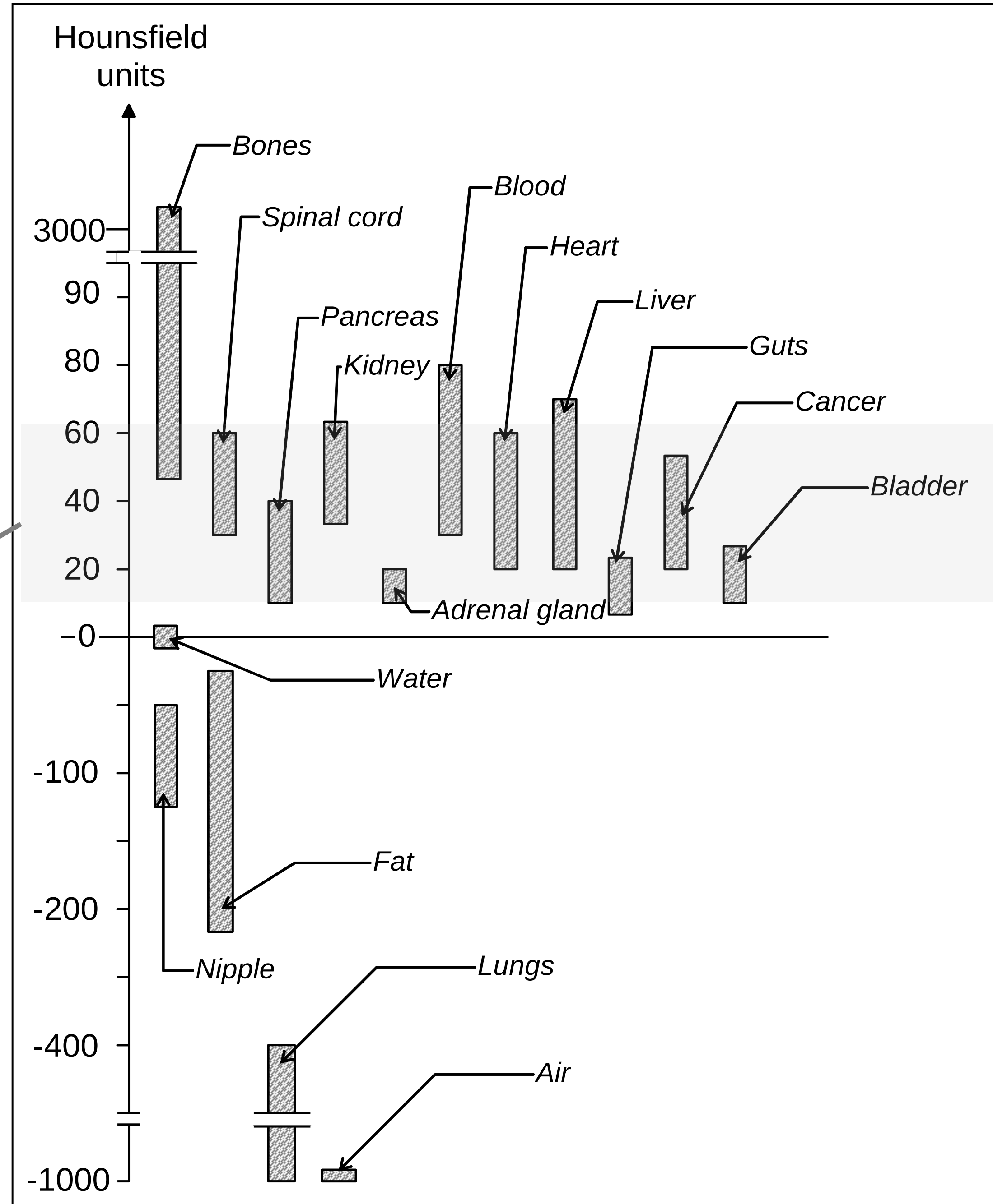
$$CTN = \frac{\mu_{tissue} - \mu_{water}}{\mu_{water}} \times 1000$$

$\mu_{water} = 20\ m^{-1}$

$\mu_{bone} = 40\ m^{-1}$

$\mu_{air} = 0\ m^{-1}$

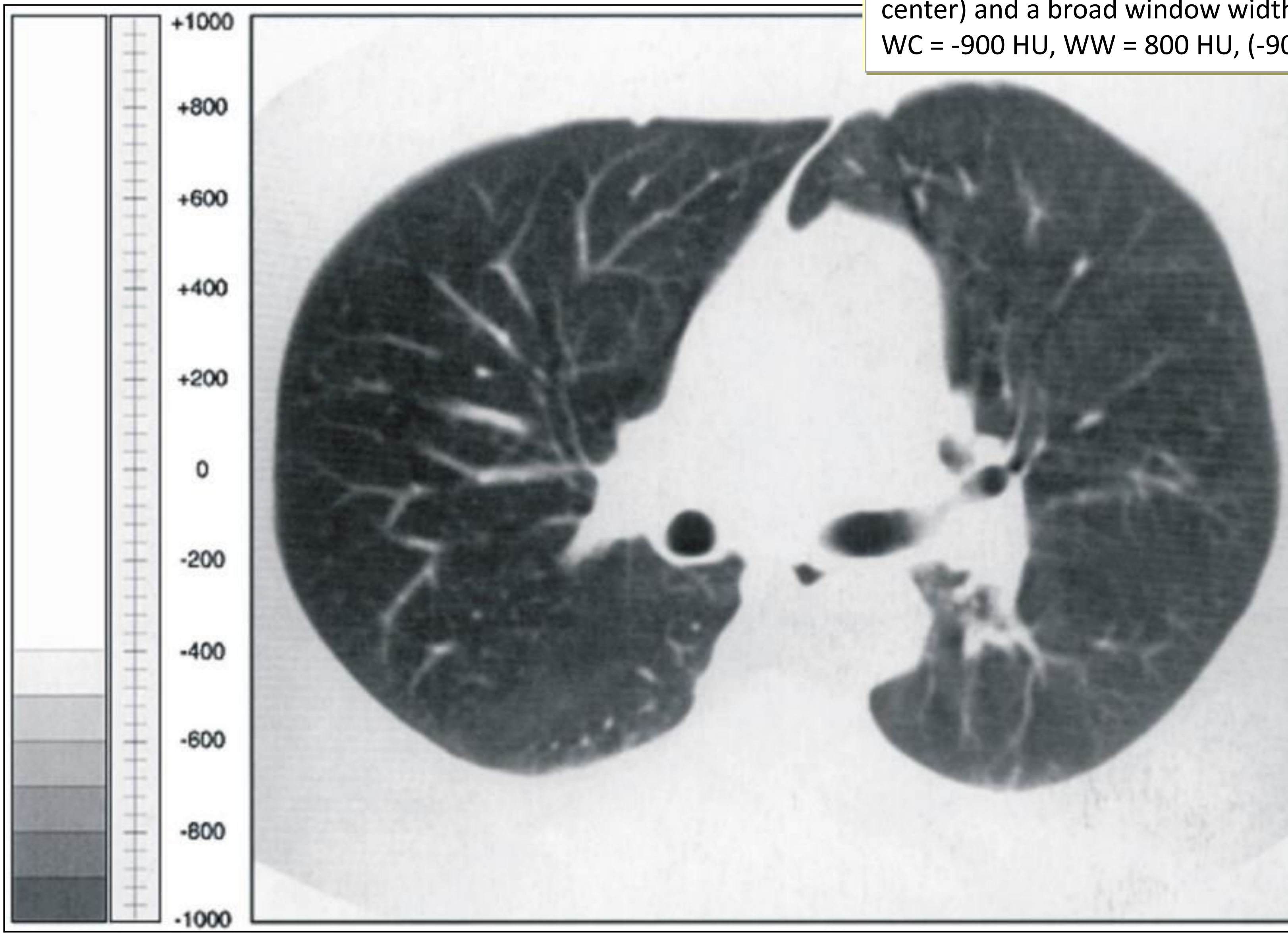
Necessity for contrast media!



WINDOWS FOR TISSUES AND ORGANS: LUNGS

LUNG WINDOW

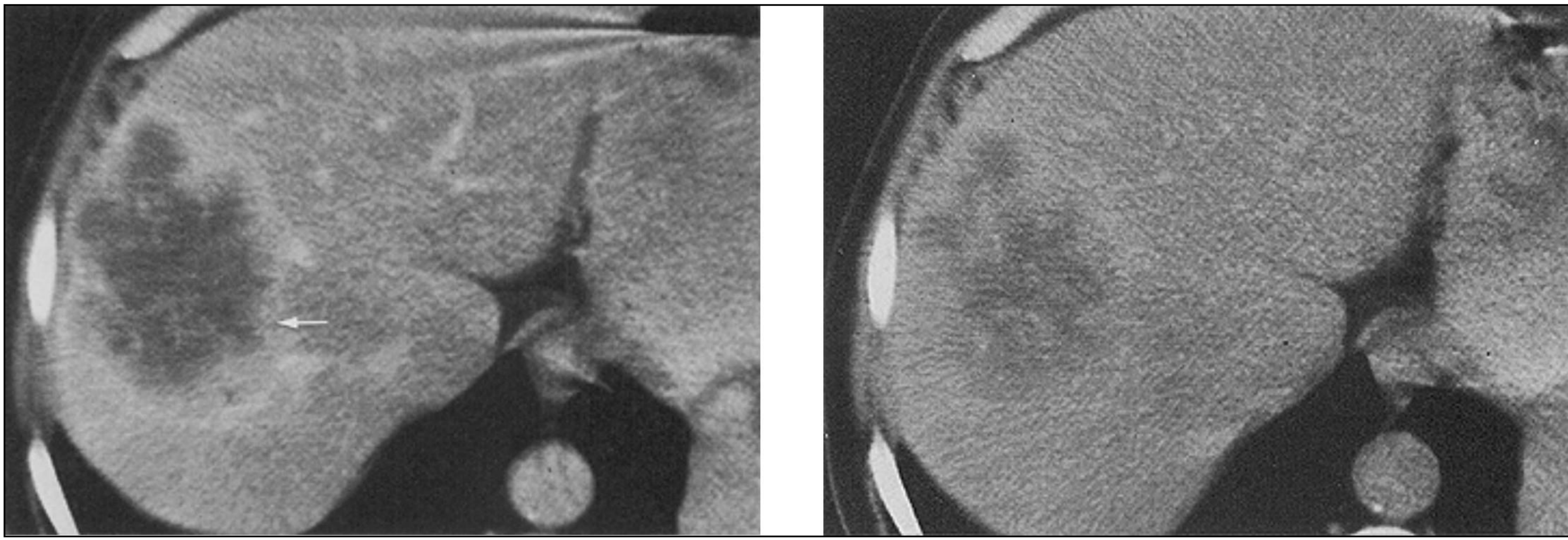
Since it contains air, lung tissue has a wide range of densities. Satisfactory images can be obtained with a negative window level (window center) and a broad window width:
WC = -900 HU, WW = 800 HU, (-900±400) HU.



CONTRAST

Contrast media: agents of higher than water and soft tissues radio-opacity, introduced intravenously or introduced into natural body cavities.

They typically contain Ba (barium Z=56) and I (iodine Z=53) compounds.



Radiation Dose Comparison

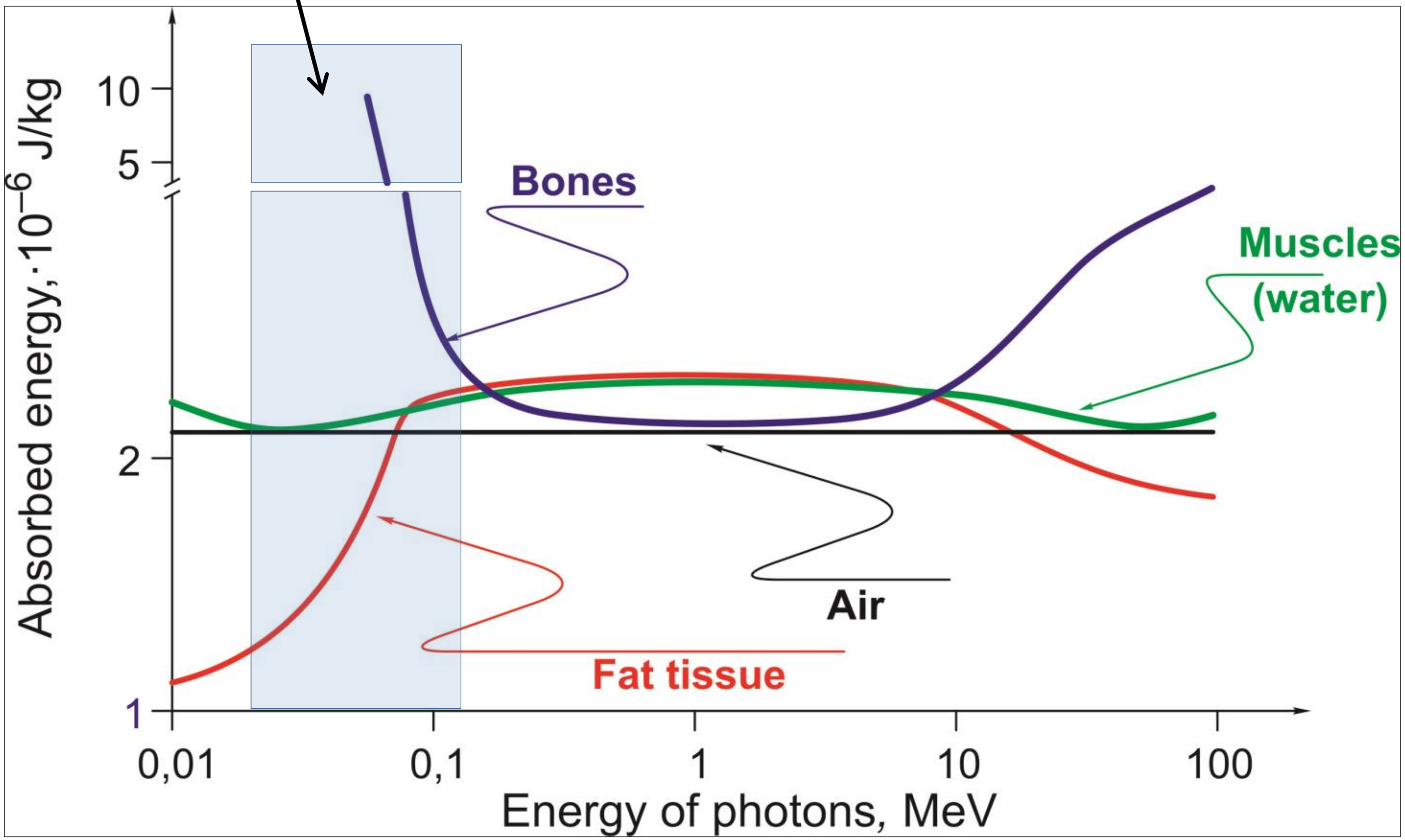
Information on typical radiation effective doses from diagnostic procedures.

European Commission, Radiation Protection Report 118, "Referral guidelines for imaging.„ Directorate-General for the Environment of the European Commission, 2000

Diagnostic Procedure	Typical Effective Dose (mSv)	Number of Chest X rays (PA film) for Equivalent Effective Dose	Time Period for Equivalent Effective Dose from Natural Background Radiation
Chest x ray (PA film)	0.02	1	2.4 days
Skull x ray	0.07	4	8.5 days
Lumbar spine	1.3	65	158 days
I.V. urogram	2.5	125	304 days
Upper G.I. exam	3.0	150	1.0 year
Barium enema	7.0	350	2.3 years
CT head	2.0	100	243 days
CT abdomen	10.0	500	3.3 years
Dental X-ray (the dental panorama)	0.026-0.038		2-4 days

The energy of electromagnetic radiation absorbed in bones, fat tissue, water and muscle tissue vs. energy of photons

Range for diagnostic purposes



Substantial differences in absorbed energy occur for small and for very high energies of photons.