Medical Imaging

Presented by

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Second-year students

Radiography (X-Rays)

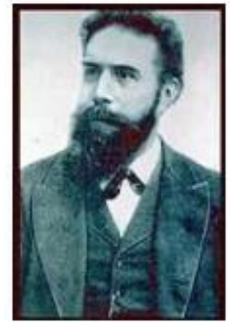
- What are X-rays and when are they useful for medical imaging?
- How are X-rays generated?
- How do X-rays interact with matter (tissue)?
- How do we detect X-rays
- How do we mathematically model X-ray projection radiography

Radiography (X-Rays)

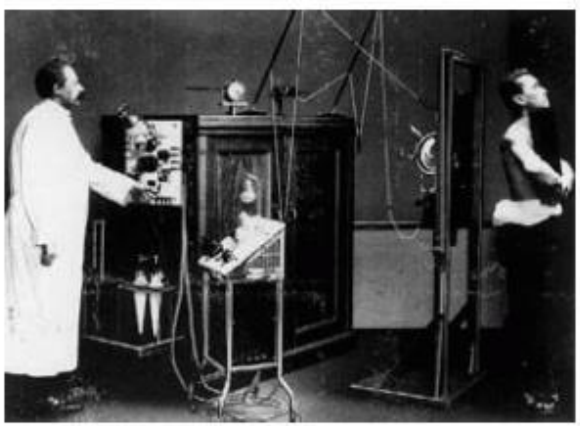
History: X-Rays

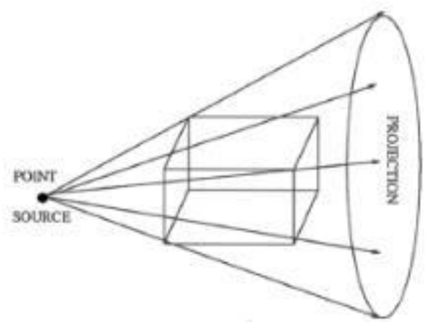
Wilhelm Conrad Röntgen

- 8 November 1895: discovers X-rays.
- 22 November 1895: X-rays Mrs. Röntgen's hand.
- 1901: receives first Nobel Prize in physics



An early X-ray imaging system:





Note: so far all we can see is a projection across the patient:

What are X-Rays?

- X-Rays is an electromagnetic radiation which can ionize the matter through which it passes as it has high energy content.
- The ionization can cause damage to DNA and cells in human tissues. However it can penetrate the body to allow noninvasive visualization of the internal anatomy of the human body.

In order to reduce the ill effect of ionization due to X-Rays while taking radiography, new X-Rays techniques are being developed to minimize the radiation dose.

- If the electron beam is **accelerated with enough energy** by applying **suitable voltage**, the radiation produced is X-Ray portion of the electromagnetic spectrum.

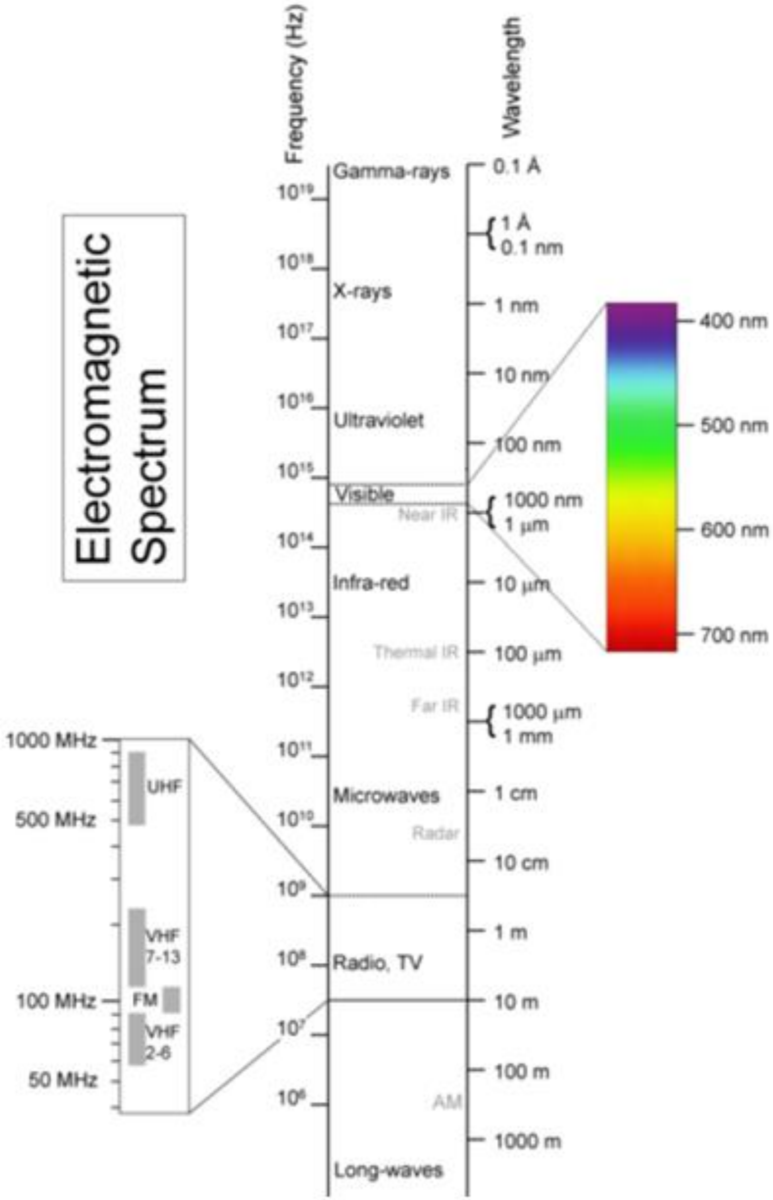
X-Ray Spectra

- In general, there are three ways to measure the "quality" of electromagnetic waves
  - Wavelength
  - Frequency
  - Photon energy

$$\lambda = c / f$$
$$E = hf$$

- f - frequency, Hertz (Hz)
- λ - wavelength, meters (m)
- E - photon energy, electron volts (Ev)
- c - speed of light, 3×10^{10} m/sec
- h - Planck's constant, 4.1×10^{-15} Ev/Hz

Radiography (X-Rays Properties)



Wavelength: 0.01-10 nm

Frequency: 30 petahertz to 30 exahertz ($3x10^{16}$ to $3x10^{19}$)

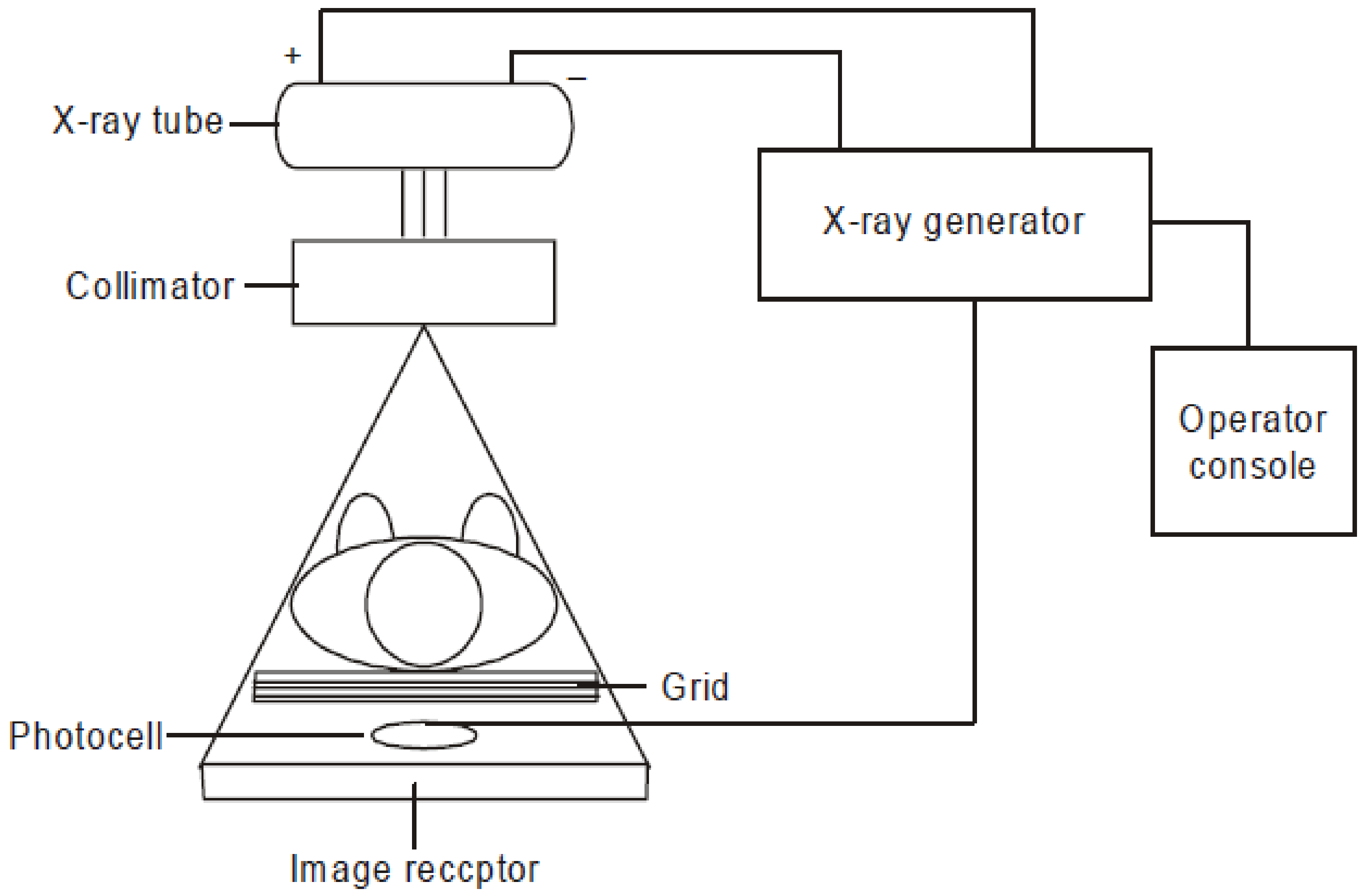
Energies: 120 ev to 120 keV

Soft X-rays: 0.12 keV to 30 keV

Hard X-rays: 30 keV to 120 keV

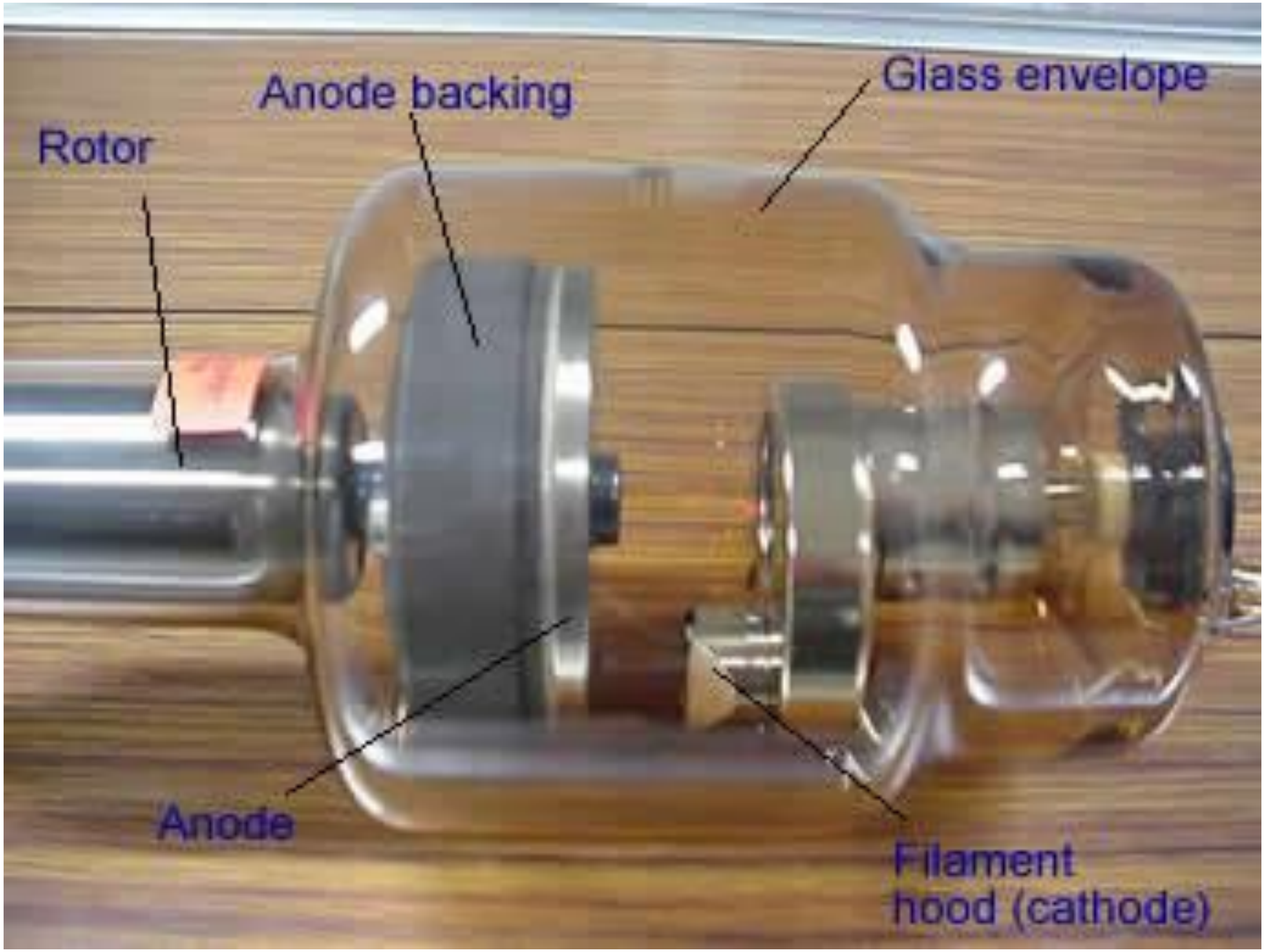
Soft X-rays do not penetrate matter where hard X-rays do

X-Ray Imaging: How does it work.

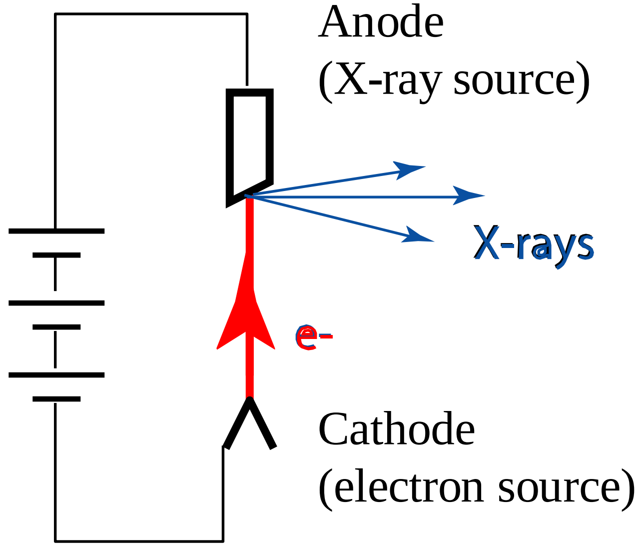


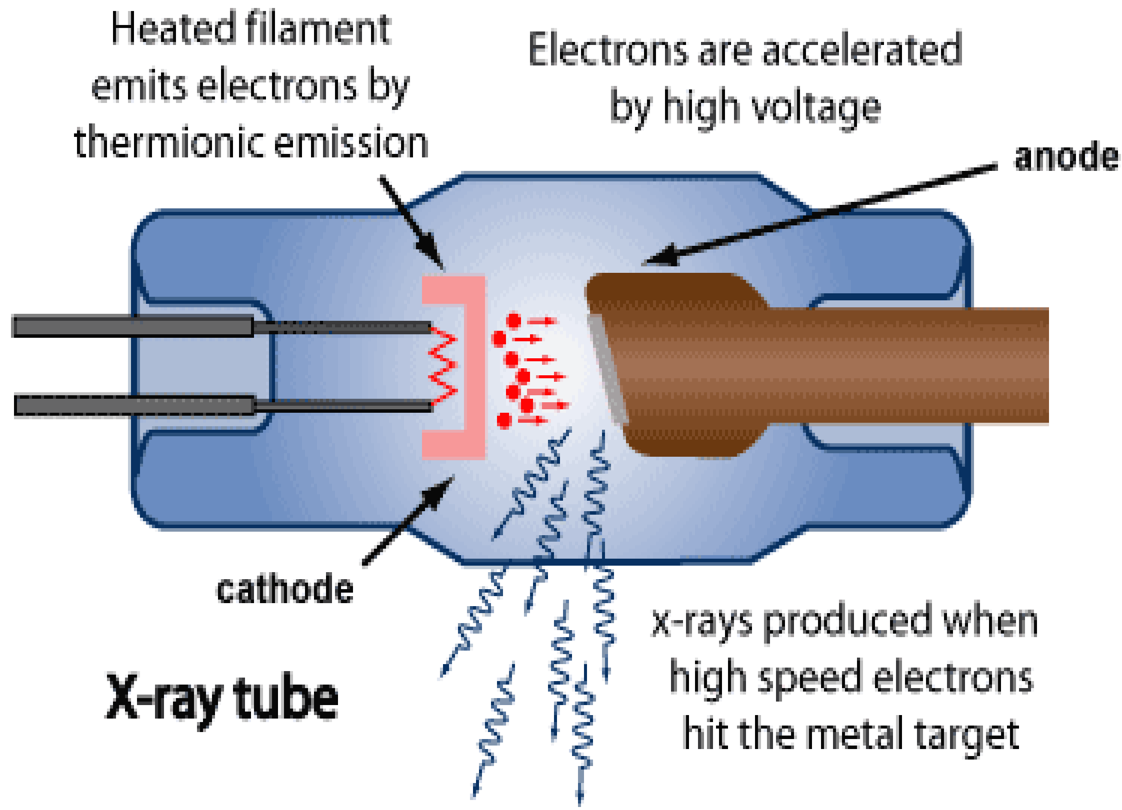
X-Ray Imaging System

X-Ray tube


Glass envelope
Anode backing
Rotor
Anode
Filament
hood (cathode)

Generation of X-Rays





- X-Rays emanate from a small point source and <u>pass through a portion of the body</u> and onto a detector that records the X-Rays that reach the detector as an image which is called radiograph

How does it work (Operating Principles)

- X-Rays are absorbed by the body in relation to specific density and atomic number of various tissues.
- In irradiating a volume of interest, these absorption differences are recorded on an image receptor.
- A high voltage generator, supplies the essential power to X-Ray tube.

How does it work (Operating Principles)

- A collimator is used at the exit port of the X-Ray tube to adjust the size and the shape of the X-Ray field.

- The X-Ray exposure is kept for precise and finite duration by an electronic time switch.

- The exposure is also automatically terminated after a certain amount of radiation has been received by the image receptor with the help of phototiming circuit.

- The operator selects all operating parameters like exposure and dose of radiation from the operator's console

Filtration

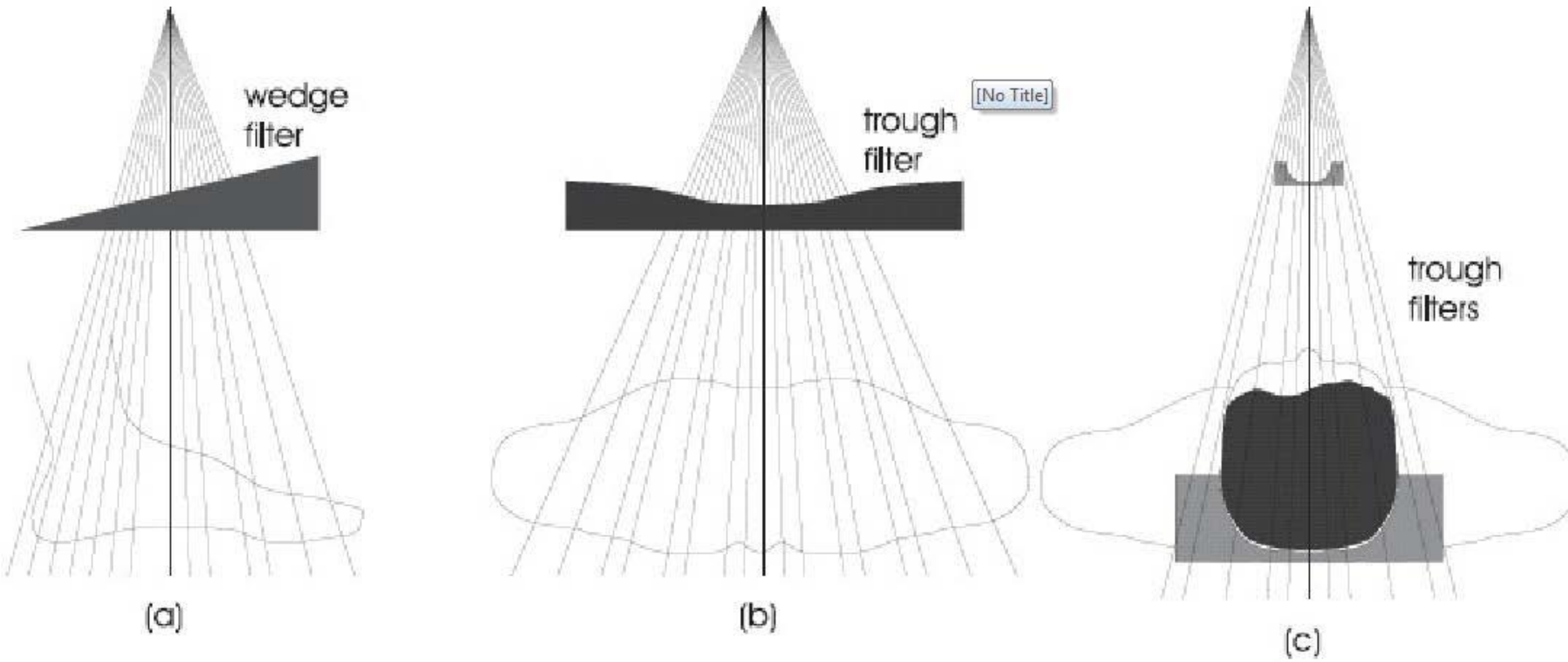
- Low energy x-ray will be absorbed by the body, without providing diagnostic information
- Filtration: Process of absorbing low-energy x-ray photons before they enter the patient
  - Inherent filtration
    - Within anode
    - Glass housing
  - Added filtration
    - Aluminum
    - Copper/Aluminum

Restriction (Collimator)

- Goal: To direct beam toward desired anatomy

Compensation Filters

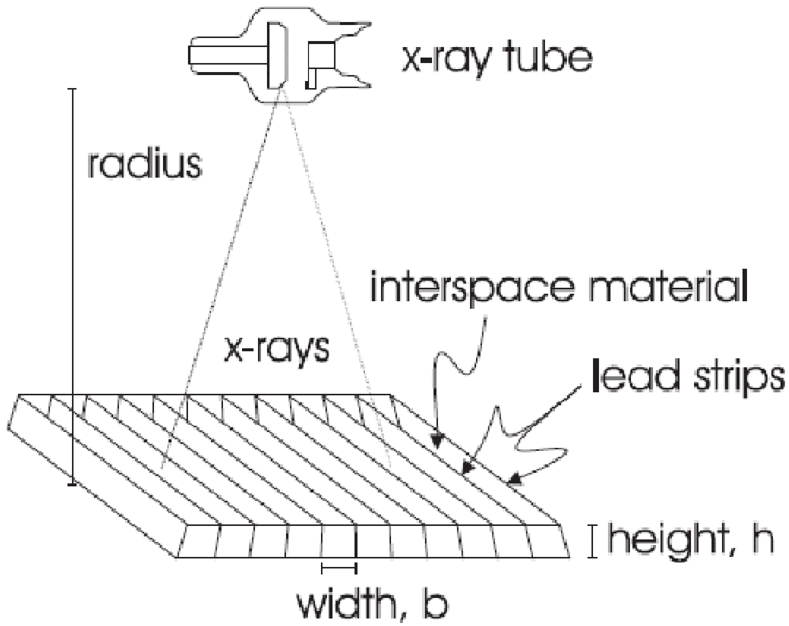
- Goal: to even out film exposure



Scatter Control

- Ideal x-ray path: a line!
- Compton scattering causes blurring
- How to reduce scatter?
  - airgap
  - scanning slit
  - grid

Grids



- Effectiveness in scatter reduction?

$$\text{grid ratio} = \frac{h}{b}$$

- 6:1 to 16:1 (radiography) or 2:1 (mammo)

X-Ray Attenuation

- For medical imaging, we can assume that X-Rays travel along straight lines (rays).
- In the presence of matter, X-Rays are removed from a beam. This process is called attenuation.

Interaction of Photons with Matter: Attenuation (Homogeneous Slab)

Homogeneous slab: the attenuation rate is the same over the entire slab

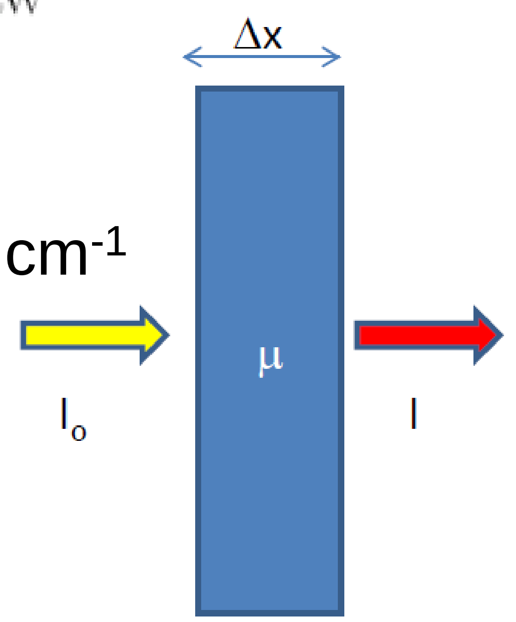
- Homogeneous slab thickness Δx
- Fundamental photon attenuation law

$$N = N_0 e^{-\mu \Delta x}$$

- μ is linear attenuation coefficient in cm^{-1}
- In terms of intensity:

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

This is known as Beer's Law



Interaction of Photons with Matter: Attenuation

X-rays image radiodensity = amount of absorption in material

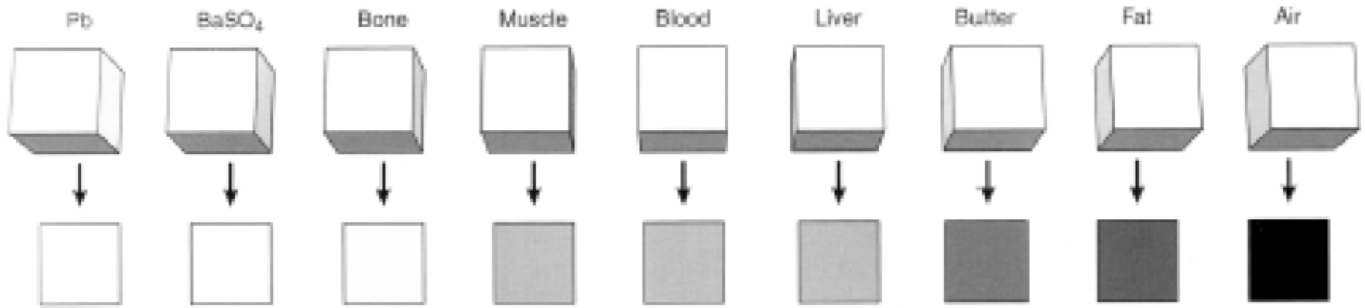
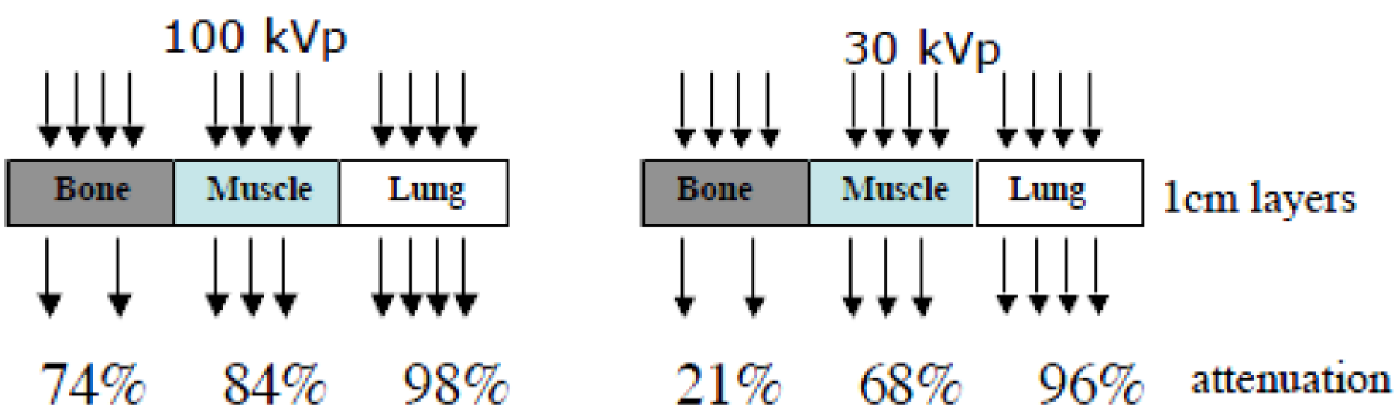


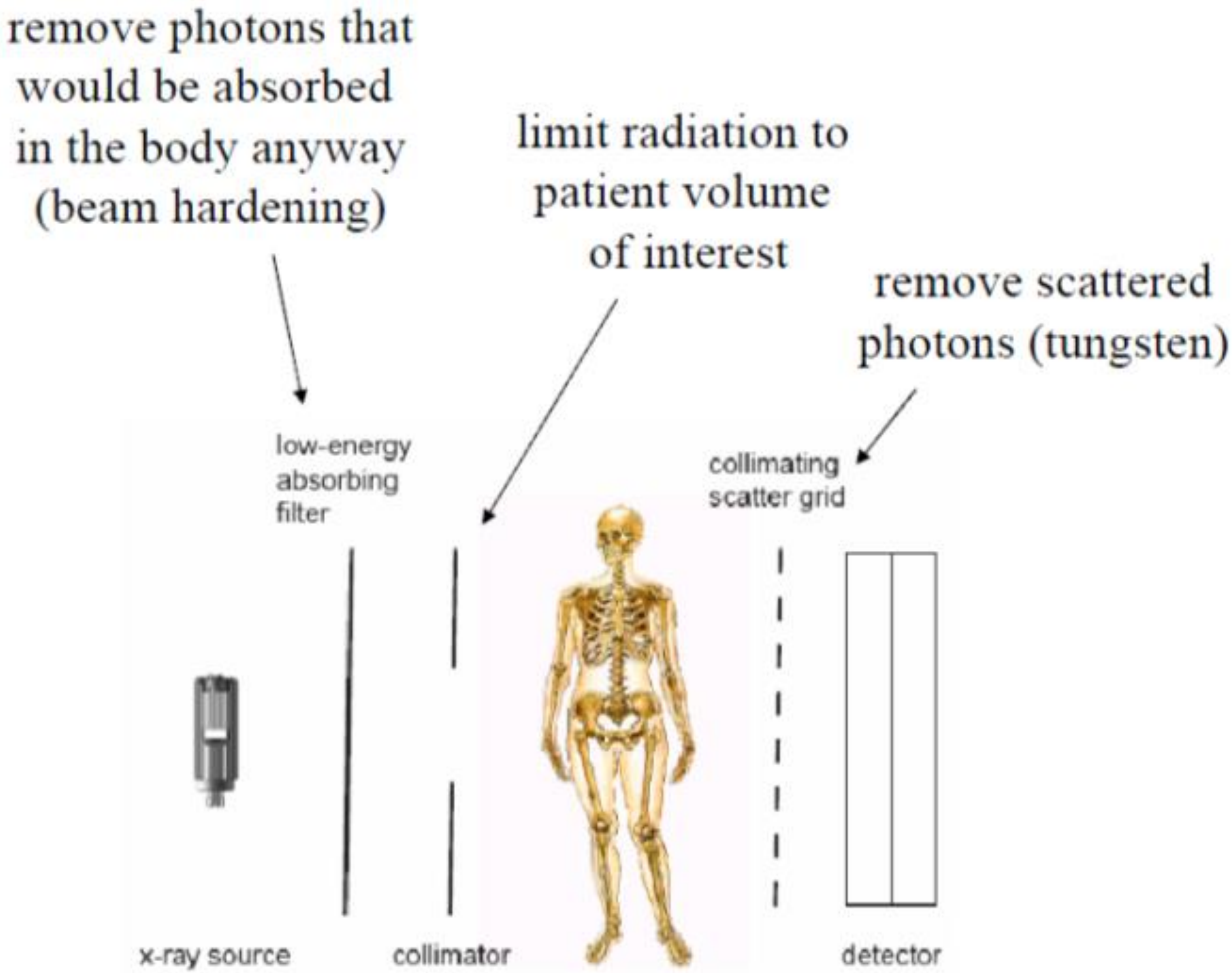
Figure 1.12. Radiodensity as a function of composition, with thickness kept constant.

Attenuation is Energy dependent:



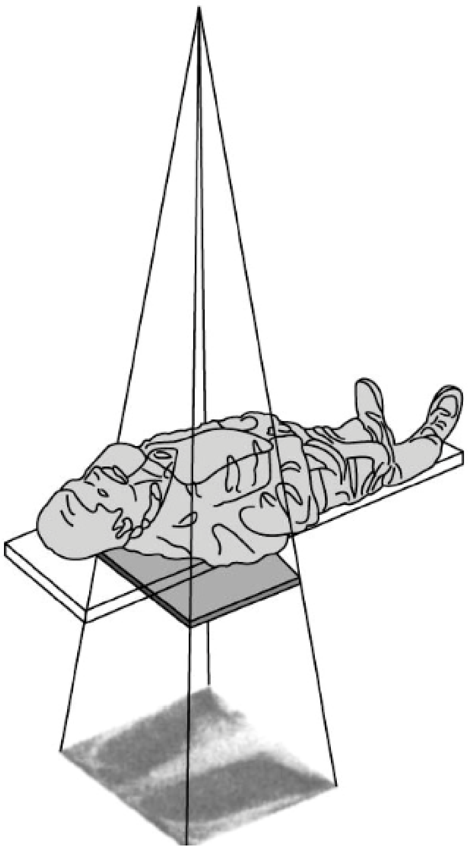
Low energies can distinguish different material better than higher energies

Projection Radiography Generic System Description



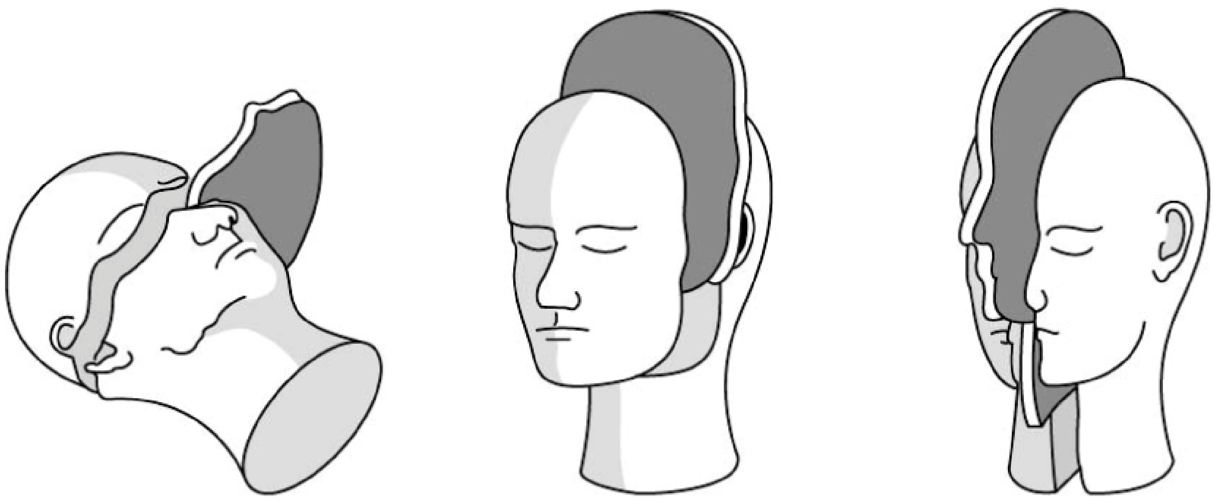
Projection vs. Tomography

- Projection:
  - A single image is created for a 3D body, which is a “shadow” of the body in a particular direction (integration through the body)



Projection vs. Tomography

- Tomography
  - A series of images are generated, one from each slice of a 3D object in a particular direction (axial, coronal, sagital)
  - To form image of each slice, projections along different directions are first obtained, images are then reconstructed from projections (back-projection, Radon transform)

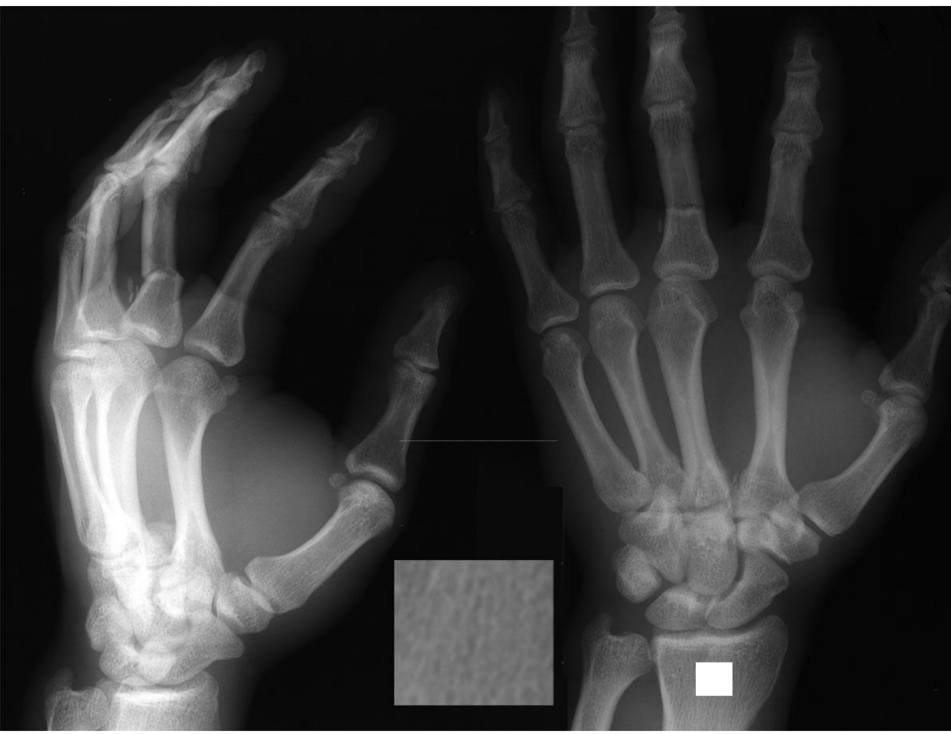


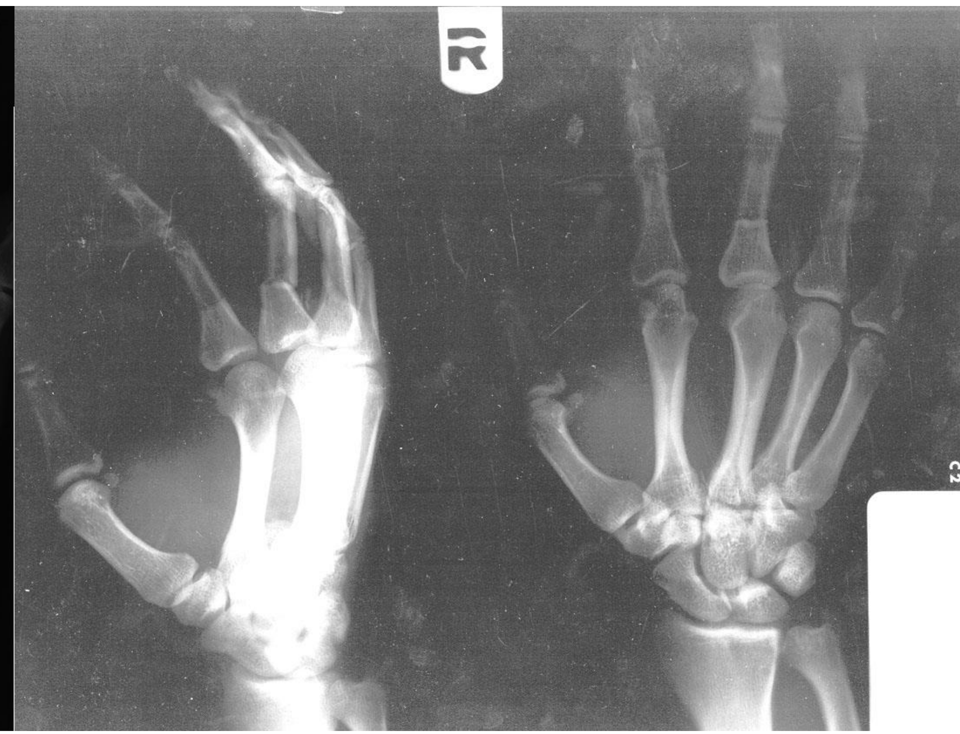
(a) (b) (c)

Radiography (X-Ray Imaging)

What does the image show?

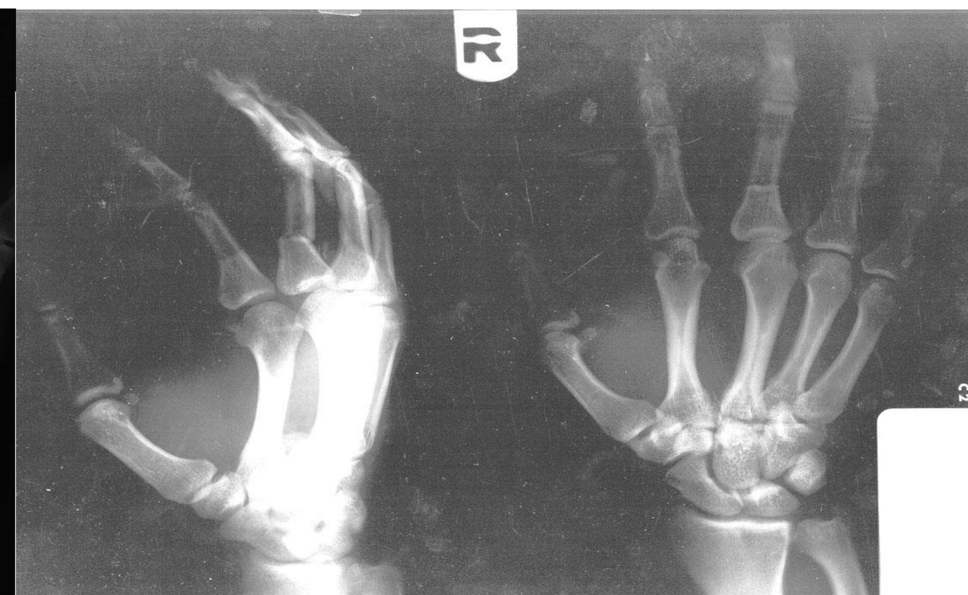
X-Ray Image of Hand





Radiography (X-Ray Imaging)
What is it?

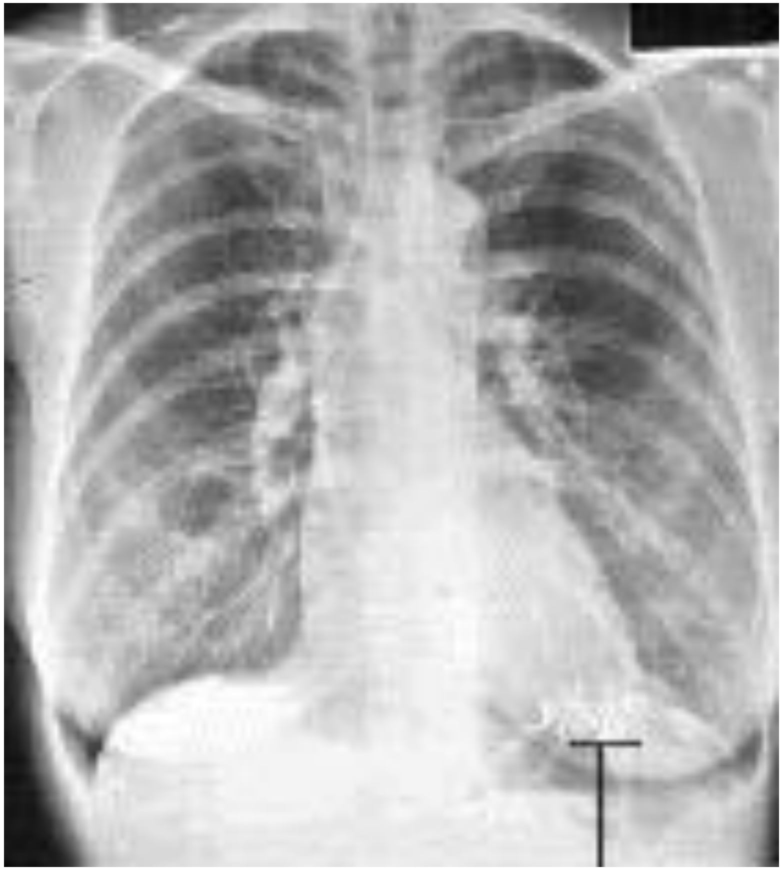
- Two x-Ray views of the Right hand is illustrated in the first image whereas the same hand is illustrated in the second image with high contrast.
- A fracture of the middle finger is seen on both views, though it is clearer on the view on the left. This image can be used for diagnosis - to distinguish between a sprain and a fracture, and to choose a course of treatment.



X-Rays at Present

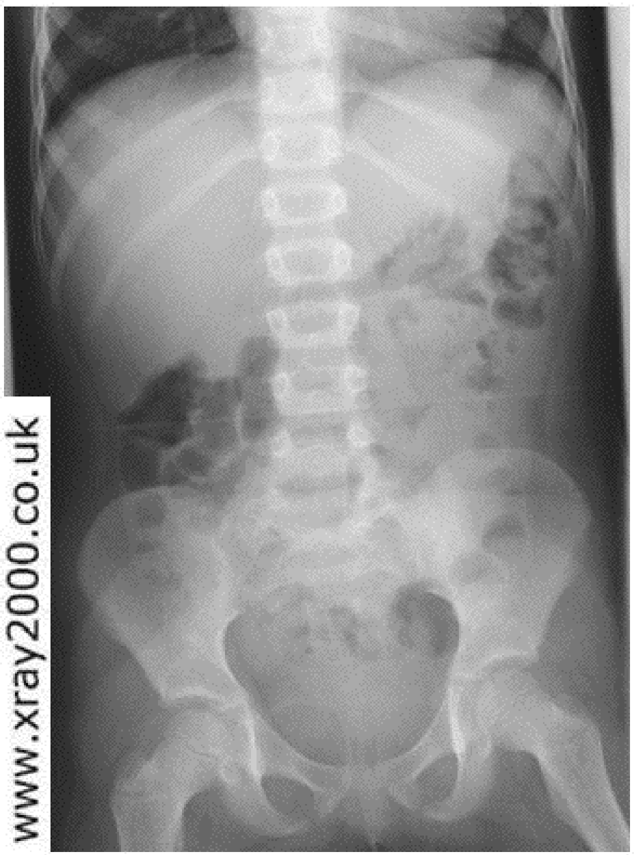
- Clear images of bones
- Some indication of tissue
- No tissue detail (tendon, muscle, skin)
- Negative image: bone is white, air is black

Chest X-Ray



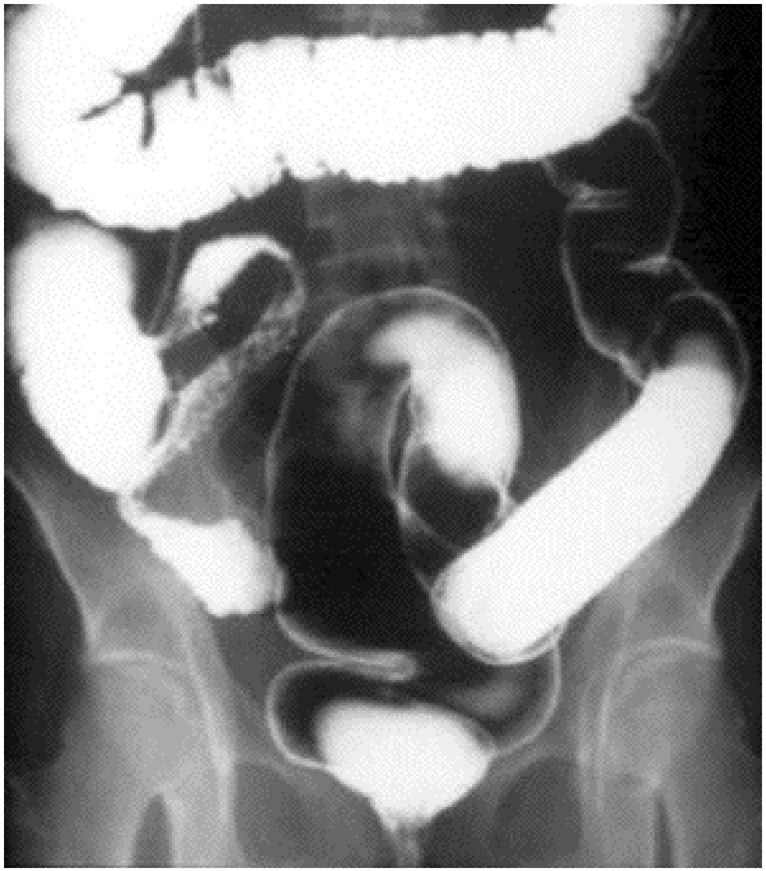
- **Clear images of bone**
  - ribs, vertebra, clavicles
- **Soft tissue**
  - shoulder muscles, heart, abdomen
- **Pattern of passages in lungs**

Abdominal X-Ray



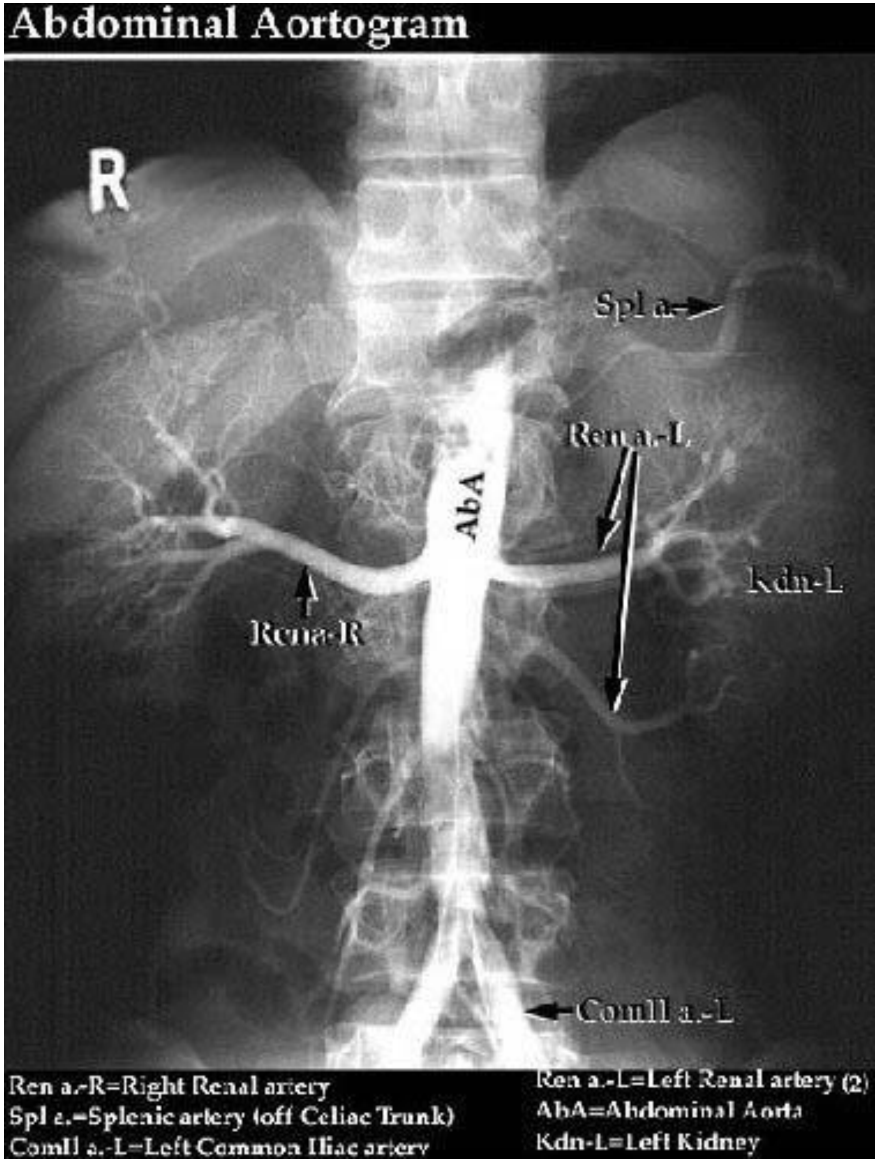
- **Visible: Bony structures**
  - Vertebra, pelvic bones, legs, ribs
- **Soft tissues**
  - liver, stomach, leg muscles
- **Confusing image of intestines**
  - Intestinal gas, walls
- **Cannot see:**
  - Details of liver, back muscles, kidneys

Abdomen - more



- Abdomen after Barium contrast enema (real – time radiography)
- Large intestine easily visible

Another Abdomen

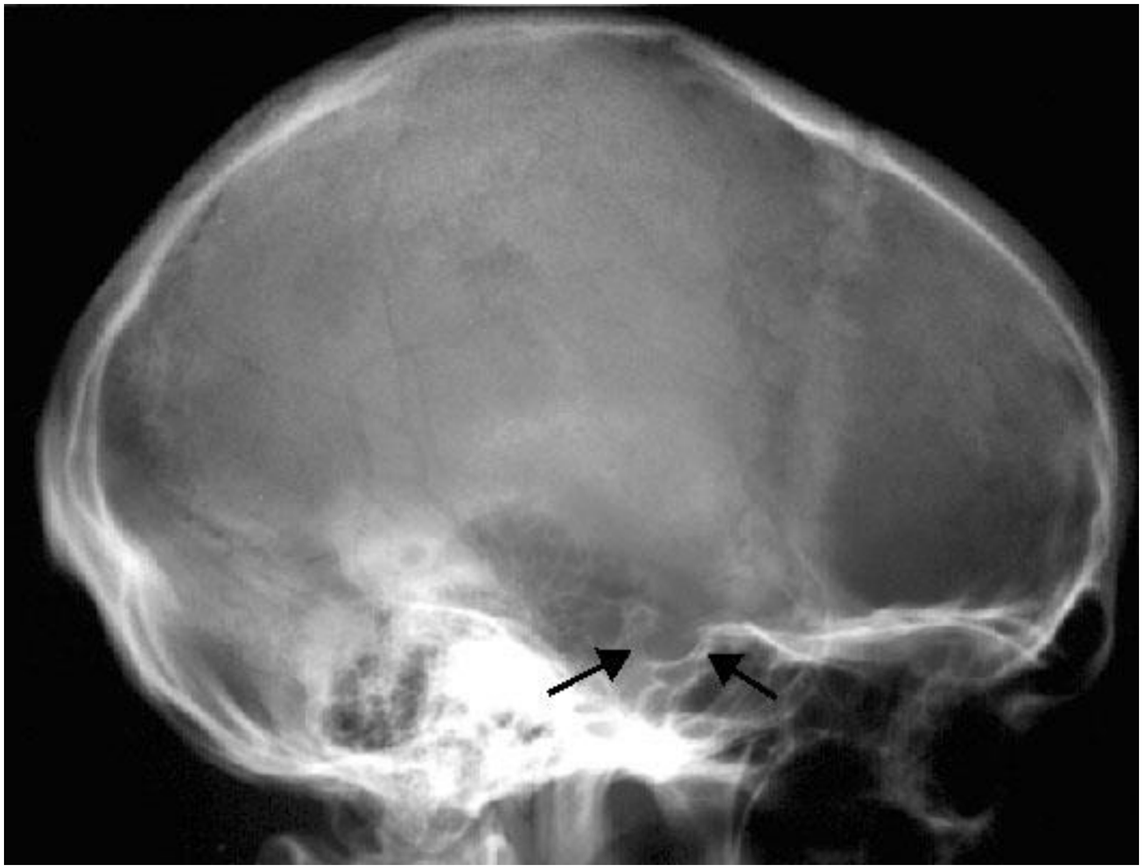


- **Contrast medium in aorta (angiography)**
- **Visible**:
  - descending aorta,
  - renal arteries,
  - iliac arteries

Pelvic X-Ray

- **Can see**
  - Fracture in pelvis
  - Femur
- **Cannot see**
  - Soft tissues

Skull



- **Can see** bones, scalp
- **Cannot see** ventricles, blood vessels

X-Rays

• Year discovered:	1895 (Röntgen, NP 1905)
• Form of radiation: radiation	X-rays = electromagnetic (photons)
• Energy / wavelength of radiation:	0.1 – 100 keV / 10 – 0.01 nm (ionizing)
• Imaging principle:	X-rays penetrate tissue and create "shadowgram" of differences in density.
• Imaging volume:	Whole body
• Resolution:	Very high (sub-mm)
• Applications:	Mammography, lung diseases, orthopedics, dentistry, cardiovascular, GI

Radiography (recap)

- Radiography was the first medical imaging technology, made possible when the physicist Wilhelm Roentgen discovered X-Rays.
- <u>Radiography</u> defined the field of radiology and gave rise to <u>radiologists</u>, physicians who specialize in the interpretation of medical images.
- Radiography is performed with an X-Ray source on one side of the patient and a (typically flat) X-Ray detector on the other side. A short-duration (typically less than ½ second) pulse of X-Rays is emitted by the X-Ray tube, a large fraction of the X-Rays interact in the patient, and some of the X-Rays pass through the patient and reach the detector, where a radiographic image is formed.
- The homogeneous distribution of X-Rays that enters the patient is modified by the degree to which the X-Rays are removed from the beam (i.e., attenuated) by scattering and absorption within the tissues.
- The attenuation properties of tissues such as bone, soft tissue, and air inside the patient are very different, resulting in a heterogeneous distribution of X-Rays that emerges from the patient.
- The radiographic image is a picture of this X-Rays distribution. The detector used in radiography can be photographic film (e.g., screen-film radiography) or an electronic detector system (i.e., digital radiography).

Radiography

- Transmission imaging refers to imaging in which the energy source is outside the body on one side, and the energy passes through the body and is detected on the other side of the body.

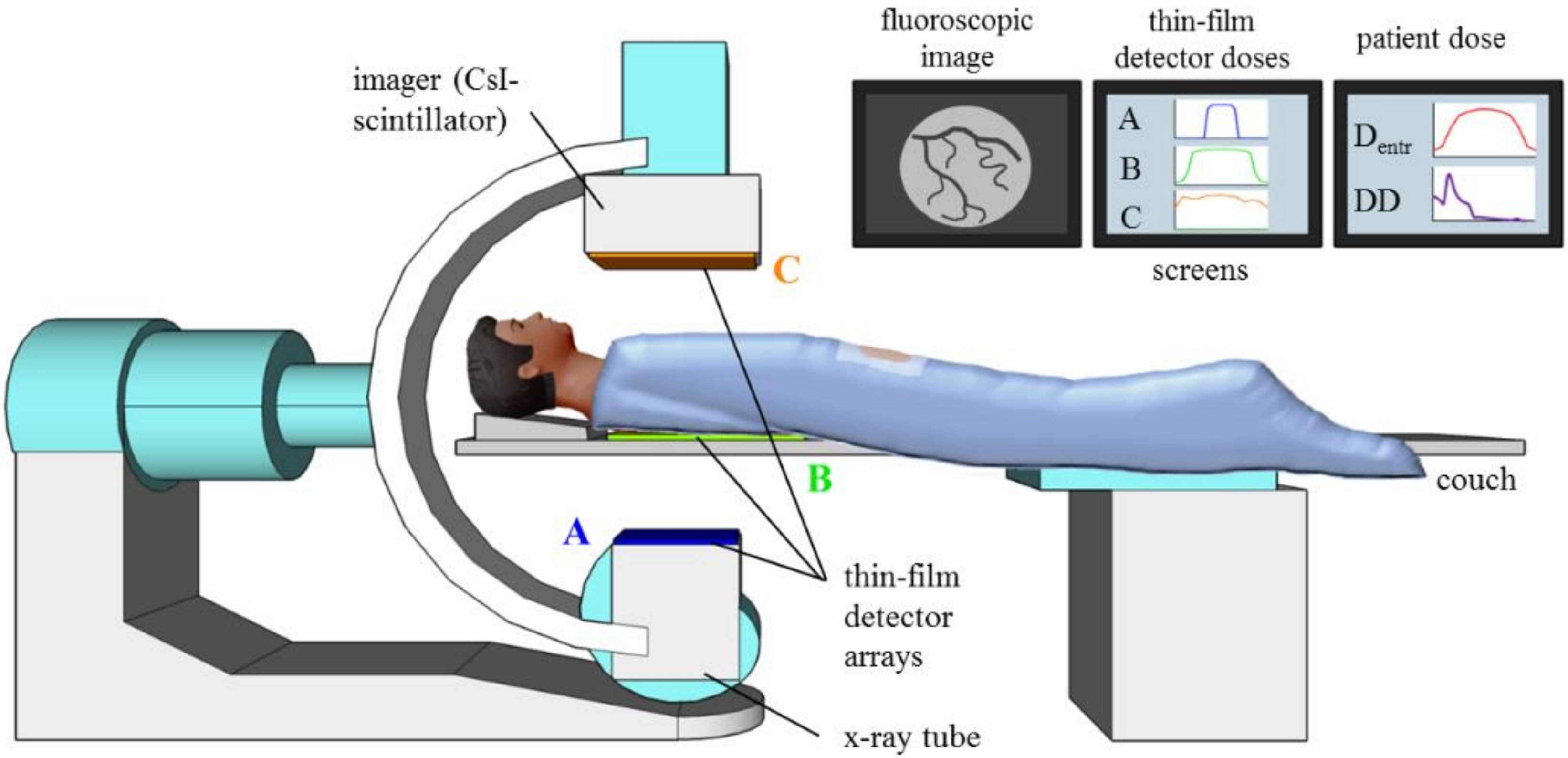
Radiography is a transmission imaging modality.

- Projection imaging refers to the case when each point on the image corresponds to information along a straight line trajectory through the patient.

Radiography is also a projection imaging modality.

- Radiographic images are useful for a very wide range of medical indications, including the diagnosis of broken bones, lung cancer, cardiovascular disorders, etc.

Fluoroscopy



https://youtu.be/-DJiW1YADoE

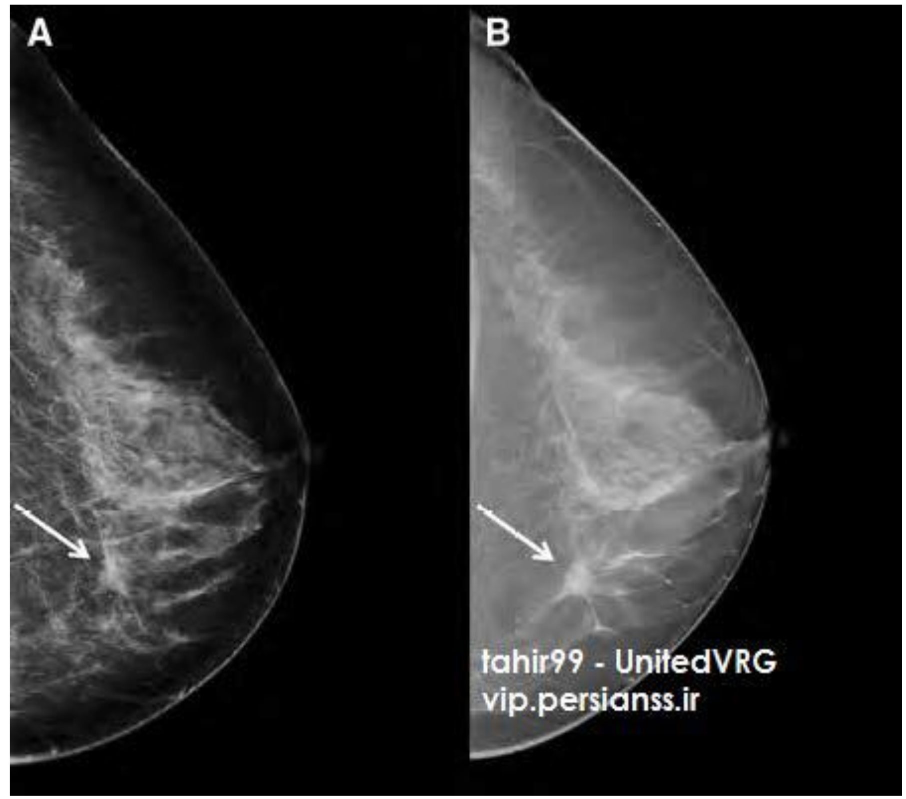
Radiography (Fluoroscopy)

- Fluoroscopy refers to the continuous acquisition of a sequence of X-Ray images over time, essentially a real-time X-Ray movie of the patient. It is a transmission projection imaging modality, and is, in essence, just real-time radiography.
- Fluoroscopic systems use X-Rays detector systems capable of producing images in rapid temporal sequence.
- Fluoroscopy is used for positioning catheters in arteries, visualizing contrast agents in the GI tract, and for other medical applications such as invasive therapeutic procedures where real-time image feedback is necessary. It is also used to make X-Ray movies of anatomic motion, such as of the heart or the esophagus.

Radiography (Mammography)

- Mammography is radiography of the breast, and is thus a transmission projection type of imaging. To accentuate contrast in the breast, mammography makes use of much lower X-Ray energies than general purpose radiography, and consequently the X-Rays and detector systems are designed specifically for breast imaging.
- Mammography is used to screen asymptomatic women for breast cancer (screening mammography) and is also used to aid in the diagnosis of women with breast symptoms such as the presence of a lump (diagnostic mammography).
- Digital mammography has eclipsed the use of screen-film mammography, and the use of computer-aided detection is widespread in digital mammography.

Mammography



3D-Mammography (Tomosynthesis)

- Some digital mammography systems are now capable of tomosynthesis, whereby the X-Ray tube (and in some cases the detector) moves in an arc from approximately 7 to 40 degrees around the breast. This limited angle tomographic method leads to the reconstruction of tomosynthesis images, which are parallel to the plane of the detector, and can reduce the superimposition of anatomy above and below the in-focus plane.

https://youtu.be/KU8Uz1x9xWM