

# **Laboratorio di Fisica Medica**

## **Introduzione al Corso**

# Fisica Medica

## Fisica Sanitaria

- Controlli di qualità
  - radiologia, medicina nucleare, radioterapia
- Piani di cura (radioterapia, ecc)

## Radioprotezione

- Dosimetria (pazienti e ambienti di lavoro)

## Applicazione di sviluppi recenti della fisica in medicina (per la diagnosi o la terapia)

- Radiazioni non ionizzanti (MRI, US), segnali elettrici (EEG)



ASSOCIAZIONE ITALIANA  
di FISICA MEDICA e SANITARIA

La Fisica al servizio della salute

## Fisica Medica e Sanitaria si occupa di:

Radiologia, radioterapia, medicina nucleare,  
non ionizzanti&ultrasound, radioprotezione

<https://www.fisicamedica.it>

- <https://www.youtube.com/watch?v=pbGMJZKtKOO>
- <https://www.youtube.com/watch?v=o6jyXHLgGOA> (medicina nucleare)
- [https://www.youtube.com/watch?v=ODCv4\\_nH6c](https://www.youtube.com/watch?v=ODCv4_nH6c) (radioterapia)
- <https://www.youtube.com/watch?v=fAWnctwVQKI> (radiologia)
- <https://www.youtube.com/watch?v=JqcFTHBm4ww> (radioprotezione)

# Fisica Medica

Aree interdisciplinari tra fisica, biologia e medicina:

- **Biofisica**
  - Le cellule: come trasmettono i segnali, come reagiscono alle variazioni ambientali
- **Neuroscienze**
  - Come funziona il cervello e il sistema nervoso centrale
- **Radiobiologia**
  - Come i danni da radiazione ionizzante influenzano lo sviluppo delle cellule e come questi danni vengono “riparati”

# Obiettivi del corso

## **D1. Conoscenza e capacità di comprensione:**

- Competenze di base nell'utilizzo di un tubo radiologico e dei comuni sistemi di dosimetria per la radiologia.
- Competenze nelle tecniche di caratterizzazione dei sistemi radiologici basati su i raggi X e conoscenza dei principi di base dei controlli di qualità dei sistemi stessi.
- Conoscenze di base sulle applicazioni delle simulazioni di MonteCarlo in fisica medica.

## **D.2 Capacità di applicare conoscenza e comprensione**

- Lo studente saprà svolgere ed analizzare misure di caratterizzazione di sistemi radiologici semplici.
- Lo studente saprà adattare alle sue esigenze simulazioni di Montecarlo sviluppate per applicazioni mediche.

# Obiettivi del corso

## **D3 - Autonomia di giudizio**

■ Lo studente saprà valutare i sistemi radiologici e formulare le proprie opinioni sulla base di misure quantitative.

## **D4 - Abilità comunicative**

■ Lo studente alla fine del corso dovrà essere in grado di descrivere gli argomenti del corso con proprietà di linguaggio ad interlocutori esperti e anche in ambito interdisciplinare.

## **D5 - Capacità di apprendimento**

■ Gli studenti alla fine del corso sapranno comprendere articoli scientifici ed utilizzare libri di testo specialistici in modo autonomo.

# Laboratorio di Fisica Medica

## Laboratorio con i raggi X

### Caratterizzazione del tubo (Fulvia Arfelli)

- Camere a ionizzazione (curve di saturazione)
- Misure flusso al variare della corrente del tubo
- Misure di flusso al variare del kV del tubo
- Misure di spettri del tubo al variare dei parametri (con CdTe detector)
- Misure di HVL
- Misure di dose in profondità
- Misura di emissioni raggi X caratteristici con sorgente di  $^{241}\text{Am}$

### Caratterizzazione di un rivelatore digitale (Luigi Rigon)

- Risoluzione spaziale
- Contrasto e SNR delle immagini

### Computed Tomography

- simulazione di acquisizione e ricostruzione
- controlli di qualità della CT clinica

- **Libri di testo**

- Bushberg – The Essential Physics of Medical Imaging, Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt, John M. Boone, Lippincott Williams & Wilkins (disponibile presso la Biblioteca Tecnico Scientifica di Ateneo)
- Handbook of Medical Imaging, Volume 1, J. Beutel, H.L.Kundel, R.L. Van Metter Editors, SPIE press
- Webb\_The Physics of Medical Imaging
- The Physical principles of medical imaging, P. Sprawls  
<http://www.sprawls.org/resources/>

### Simulatore spettro tubo a raggi X

- <https://health.siemens.com/booneweb/index.html>



# Laboratorio di Fisica Medica

## Metodi di MonteCarlo in Fisica Medica

Francesco Longo

(1CFU)

- un toolkit di simulazione per l'interazione radiazione materia (i fondamentali)
- Geometria e Fisica: come costruire una simulazione
- Alcuni esempi di simulazione: hadrontherapy, brachitherapy, medical\_linac, human\_phantom etc

# Laboratorio di Fisica Medica

**Controlli di qualità' in ospedale**  
presso il servizio di Fisica Sanitaria  
Dell'azienda ospedaliero universitaria  
(1CFU)  
aprile – maggio

- Radiologia (CT, Mammografia)
- Medicina Nucleare
- Radioterapia

## Medical Physics

In radiology different form of energy are used to produce the image must be capable of penetrating tissues.

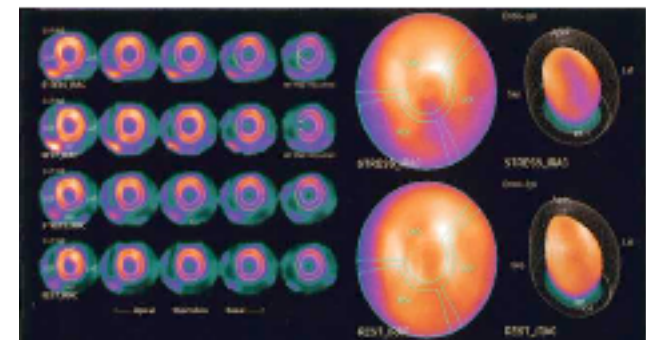
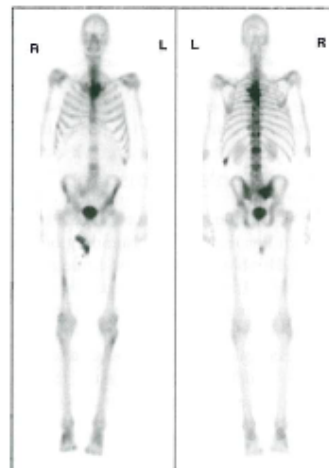
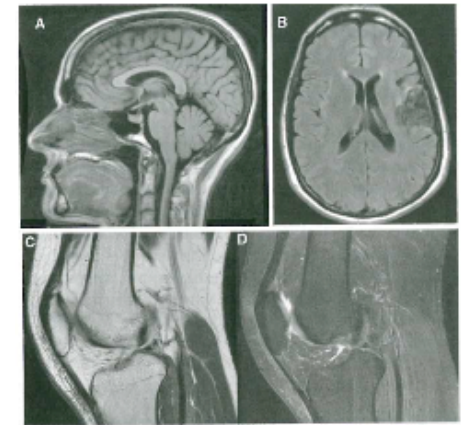
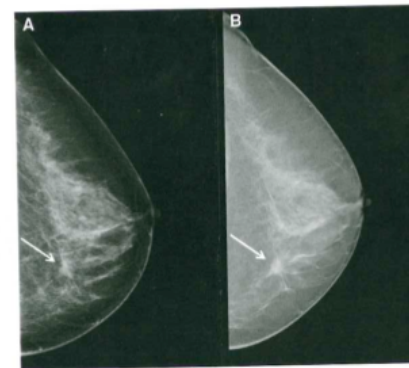
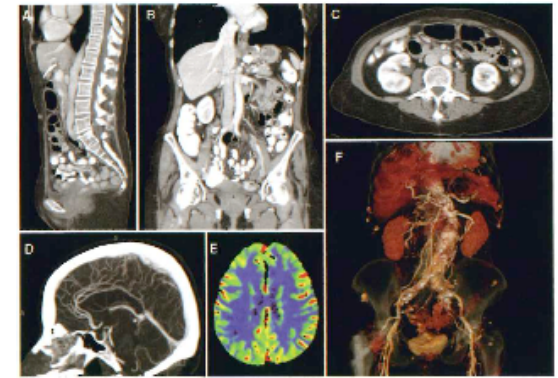
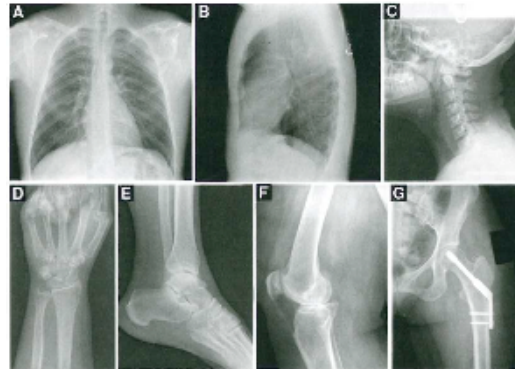
Visible light has limited ability to penetrate tissues at depth and is used mostly outside of the radiology department for medical imaging.

Visible light images are used in dermatology (skin photography), gastroenterology and obstetrics (endoscopy) and pathology (light microscopy).

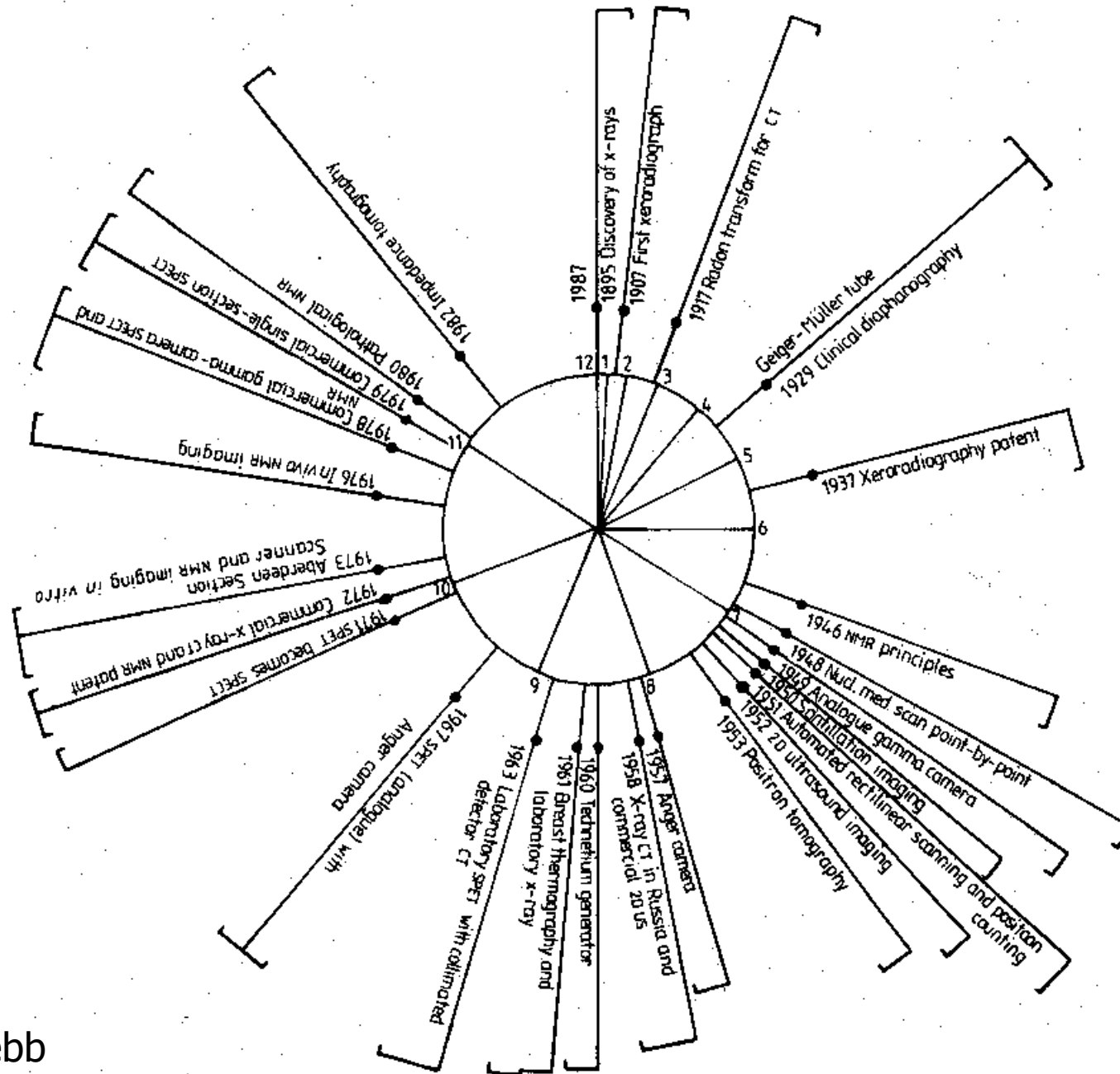
In diagnostic radiology, the electromagnetic spectrum outside the visible light region is used for medical imaging, including x-ray mammography and computed tomography (CT), radiofrequency (RF) in magnetic resonance imaging (MRI) and gamma rays in nuclear medicine.

Energy, in form of high-frequency sound waves, is used in ultrasound imaging.

- Radiography
- Fluoroscopy
- Mammography
- Computed Tomography
- Magnetic Resonance Imaging
- Ultrasound Imaging
- Nuclear medicine Imaging
  - Nuclear medicine planar Imaging
  - Single Photon Emission Computed
  - Position Emission Tomography
- Combined Imaging Modalities



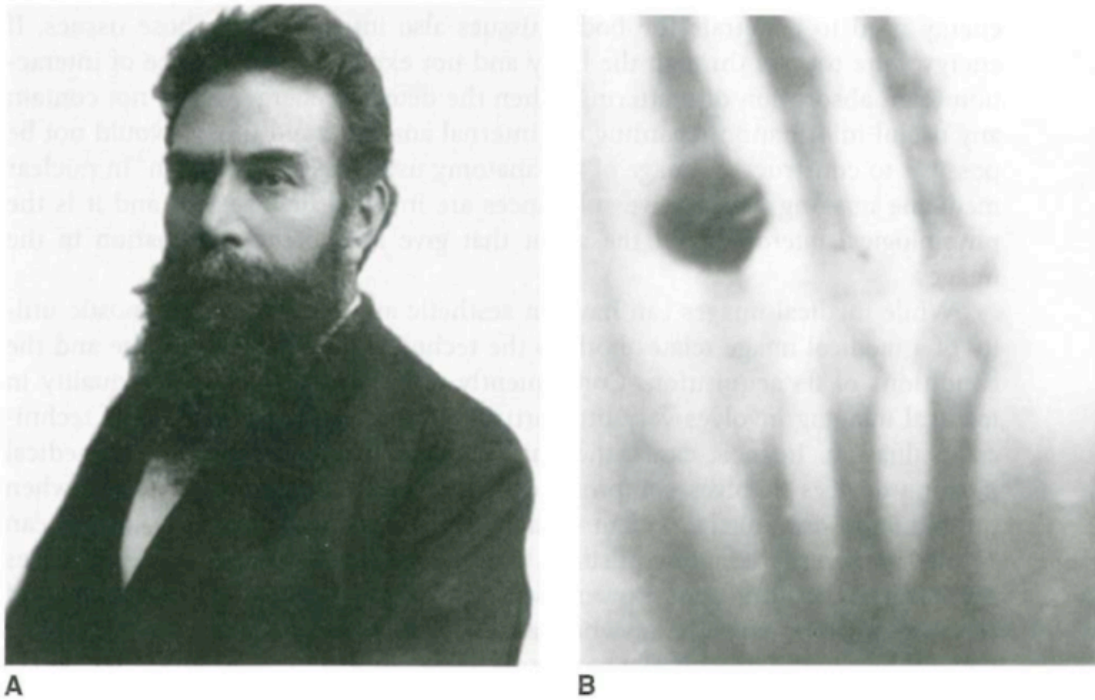
# Medical imaging development



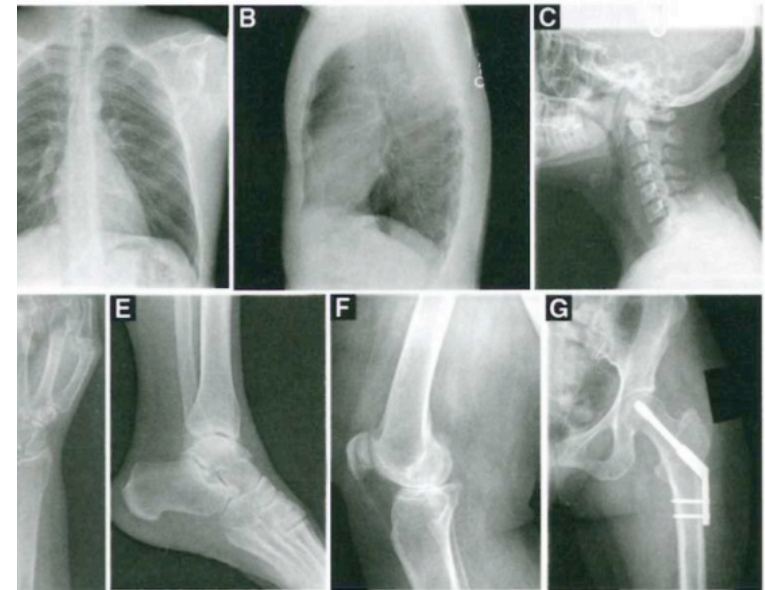
Source: Webb



# Radiography



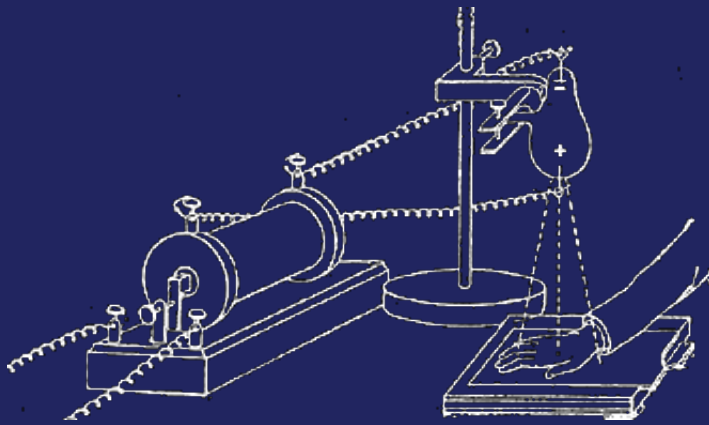
■ **FIGURE 1-1** Wilhelm Conrad Roentgen (1845–1923) in 1896 (A). Roentgen received the first Nobel Prize in Physics in 1901 for his discovery of x-rays on November 8, 1895. The beginning of diagnostic radiology is represented by this famous radiographic image, made by Roentgen on December 22, 1895 of his wife's hand (B). The bones of her hand as well as two rings on her finger are clearly visible. Within a few months, Roentgen had determined the basic physical properties of x-rays. Roentgen published his findings in a preliminary report entitled "On a New Kind of Rays" on December 28, 1895 in the Proceedings of the Physico-Medical Society of Wurzburg. An English translation was published in the journal *Nature* on January 23, 1896. Almost simultaneously, as word of the discovery spread around the world, medical applications of this "new kind of ray" rapidly made radiological imaging an essential component of medical care. In keeping with mathematical conventions, Roentgen assigned the letter "x" to represent the unknown nature of the ray and thus the term "x-rays" was born.



■ **FIGURE 1-2** Chest radiography is the most common imaging procedure in diagnostic radiology, often acquired as orthogonal posterior-anterior (A) and lateral (B) projections to provide information regarding depth and position of the anatomy. High-energy x-rays are used to reduce the conspicuity of the ribs and other bones to permit better visualization of air spaces and soft tissue structures in the thorax. The image is a map of the attenuation of the x-rays: dark areas (high film optical density) correspond to low attenuation, and bright areas (low film optical density) correspond to high attenuation. C. Lateral cervical spine radiographs are commonly performed to assess suspected neck injury after trauma, and extremity images of the (D) wrist, (E) ankle, and (F) knee provide low-dose, cost-effective diagnostic information. G. Metal objects, such as this orthopedic implant designed for fixation of certain types of femoral fractures, are well seen on radiographs.

# Discovery of X-rays

Roentgen 1895



A New kind of rays

First radiograph  
Mrs. Roentgen's  
hand Autumn 1895

First medical device  
commercially  
available Spring 1896

Improvements in

- source
- detector



Fuji 1995  
flat panel system



## Contrast and Spatial resolution

Medical imaging makes use of a variety of physical parameters as the source of image information. The mechanism for generating contrast and the spatial resolution properties differs amongst the modalities, providing a wide range of diagnostic tools for physicians.

**Contrast manifests as difference in the grayscale values in the image.**

A uniformly gray image has no contrast, while high contrast arises from high transition from dark gray and light gray.

The various imaging modalities generate contrast using a number of different forms of energy which interact within the patient's tissues based on different physical properties.

Each imaging modality has also different abilities to resolve fine details in the patient. **Spatial resolution refers to the ability to see small details** and an imaging system has higher spatial resolution if it can demonstrate the presence of smaller object in the image. The limiting spatial resolution is the size of the smallest object that an imaging system can resolve.



## Contrast

The contrast in x-ray transmission imaging (radiography, fluoroscopy, mammography, and CT) is produced by differences in tissue composition, which determine the local x-ray absorption coefficient, which in turn is dependent upon the density ( $\text{g/cm}^3$ ) and the effective atomic number. The energies of the x-ray photons in the beam (adjusted by the operator) also affect contrast in x-ray images.

CT's contrast is enhanced over other x-ray imaging modalities due to its tomographic nature. The absence of out-of-slice structures in the CT image greatly improves its image contrast.

Nuclear medicine images (planar images, SPECT, and PET) are maps of the spatial distribution of radioisotopes in the patient. Thus, contrast in nuclear images depends upon the tissue's ability to concentrate the radioactive material.

Contrast in MR imaging is related primarily to the proton density and to relaxation phenomena (i.e., how fast a group of protons gives up its absorbed energy).

Contrast in ultrasound imaging is largely determined by the acoustic properties of the tissues being imaged. The difference between the acoustic impedances (tissue density  $\times$  speed of sound in tissue) of two adjacent tissues or other substances affects the amplitude of the returning ultrasound signal. Hence, contrast is quite apparent at tissue interfaces where the differences in acoustic impedance are large.



## Spatial resolution

Table 1-1 lists the limiting spatial resolution of each of the imaging modalities used in medical imaging. The wavelength of the energy used to probe the object is a fundamental limitation of the spatial resolution of an imaging modality. For example, optical microscopes cannot resolve objects smaller than the wavelengths of visible light, about 400 to 700 nm. The wavelength of x-rays depends on the x-ray energy, but even the longest x-ray wavelengths are tiny—about 1 nm. This is far from the actual resolution in x-ray imaging, but it does represent the theoretical limit on the spatial resolution using x-rays. In ultrasound imaging, the wavelength of sound is the fundamental limit of spatial resolution. At 3.5 MHz, the wavelength of sound in soft tissue is about 500  $\mu\text{m}$ . At 10 MHz, the wavelength is 150  $\mu\text{m}$ .

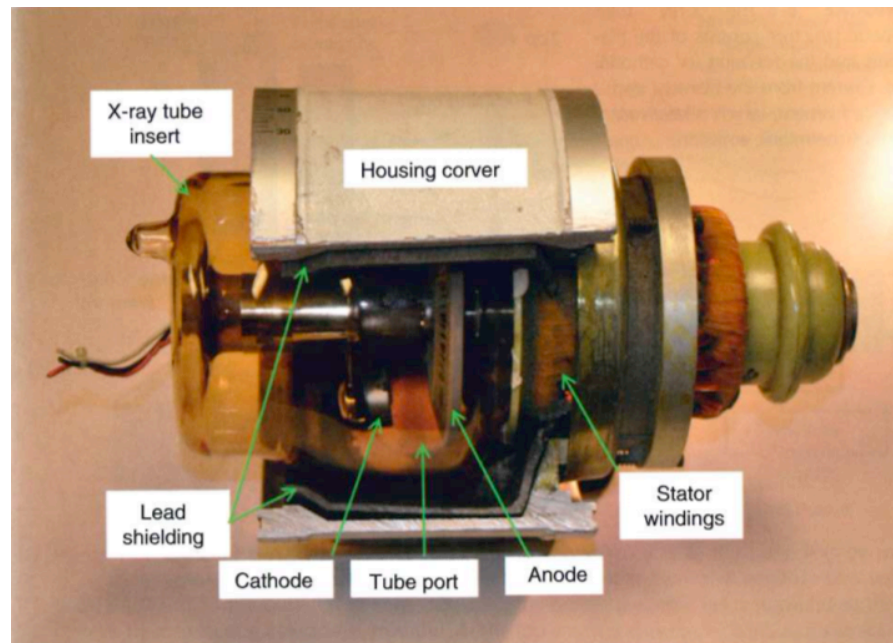


**TABLE 1-1 THE LIMITING SPATIAL RESOLUTIONS OF VARIOUS MEDICAL IMAGING MODALITIES. THE RESOLUTION LEVELS ACHIEVED IN TYPICAL CLINICAL USAGE OF THE MODALITY ARE LISTED**

MODALITY	SPATIAL RESOLUTION (mm)	COMMENTS
Screen film radiography	0.08	Limited by focal spot size and detector resolution
Digital radiography	0.17	Limited by size of detector elements and focal spot size
Fluoroscopy	0.125	Limited by detector resolution and focal spot size
Screen film mammography	0.03	Highest resolution modality in radiology, limited by same factors as in screen film radiography
Digital mammography	0.05–0.10	Limited by same factors as digital radiography
Computed tomography	0.3	About ½ mm pixels
Nuclear medicine planar imaging	2.5 (detector face), 5 (10 cm from detector)	Spatial resolution degrades substantially with distance from detector
Single photon emission computed tomography	7	Spatial resolution worst towards the center of cross-sectional image slice
Positron emission tomography	5	Better spatial resolution than the other nuclear imaging modalities
Magnetic resonance imaging	1.0	Resolution can improve at higher magnetic fields
Ultrasound imaging (5 MHz)	0.3	Limited by wavelength of sound

# Produzione dei raggi X

La produzione dei raggi X avviene solitamente ....



**Alternative possibili:**

- i generatori basati sui laser

- le macchine di luce di sincrotrone.

Radiographics 1997 17:1259-1268

Radiographics 1997 17:1533-1557

# I controlli di qualità' in radiologia

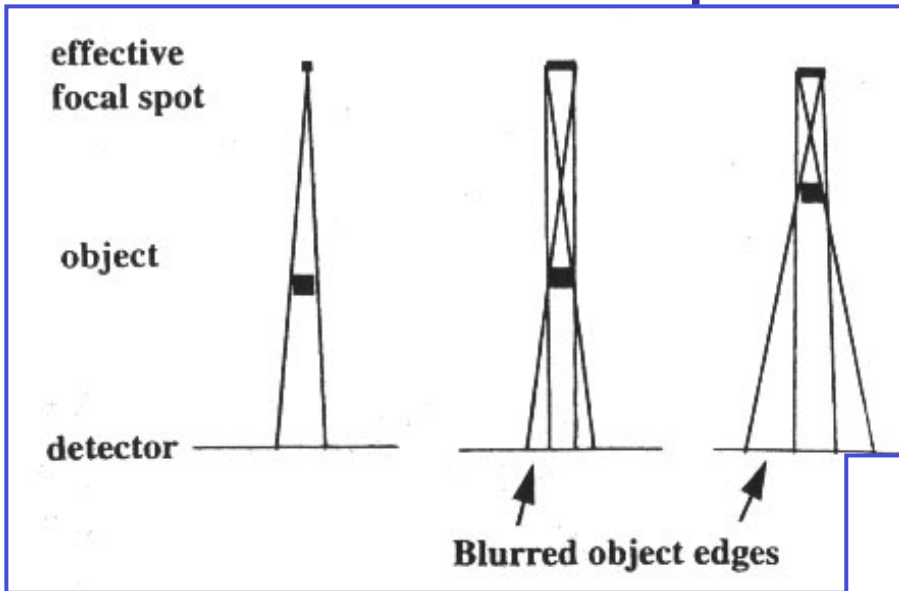
- Sono un mezzo per mantenere alta la qualità' dell'imaging lavorando per minimizzare la dose per i pazienti e per lo staff sanitario.
- Occorre misurare un insieme di parametri fisici che determinano la qualità' delle immagini, verificare la loro stabilità' nel tempo.

S.Webb ed. The physics of Medical Imaging, 1988 IOP(UK)

# I controlli di qualità' in radiologia X

- Tensione applicata
  - Influenza contrasto e dose depositata
- Tempo di esposizione
- Output (mGy)
  - Si misura con IC calibrate
- Spessore di dimezzamento
- Dimensione del focal spot
- Allineamento della luce di posizionamento  
Per i mammografi
- Risoluzione spaziale e in contrasto

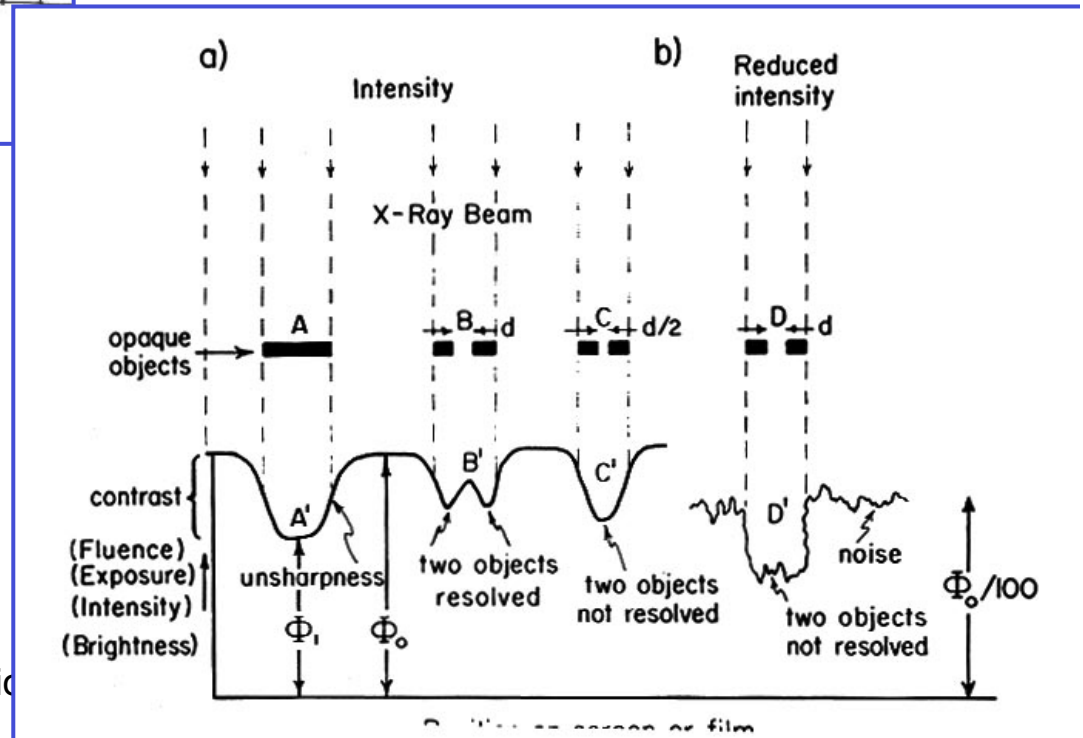
# Definizione delle immagini & risoluzione spaziale



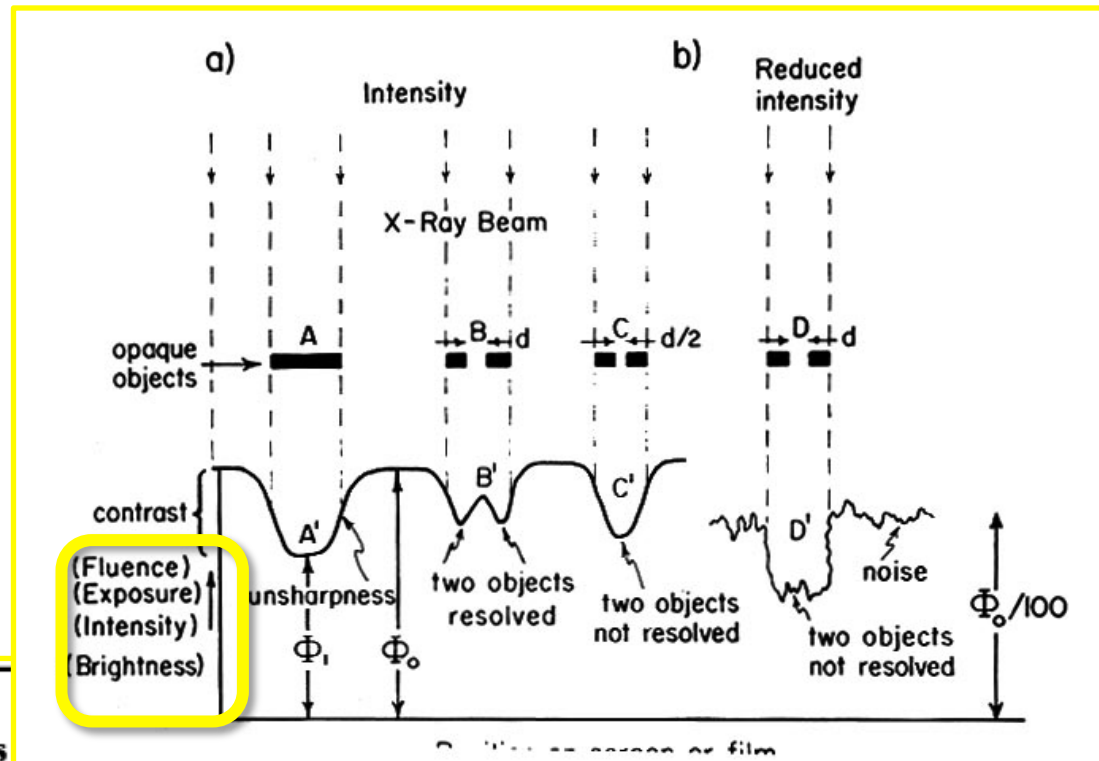
Risolvere i dettagli dipende da:

- Dimensione della sorgente
- Risoluzione spaziale del rivelatore
- Rapporto S/N

Laboratorio







**Table 6  
Radiologic Units**

Quantity	Description	Conventional Unit*
Fluence	Number of photons per unit area	1/centimeter <sup>2</sup> [1/meter <sup>2</sup> ]
Flux (fluence rate)	Fluence per unit time	1/(centimeter <sup>2</sup> · second) [1/(meter <sup>2</sup> · second)]
Intensity (energy fluence)	Number of photons times photon energy per unit area	kiloelectron volt/centimeter <sup>2</sup> [joule/meter <sup>2</sup> ]
Exposure (X)	Charge produced per unit mass of air from x and gamma rays	roentgen [coulomb/kilogram] <sup>†</sup>
Kerma (K)	Kinetic energy released in matter per unit mass	rad [joule/kilogram or gray] <sup>‡</sup>
Dose (D)	Energy absorbed per unit mass	rad [joule/kilogram or gray] <sup>‡</sup>

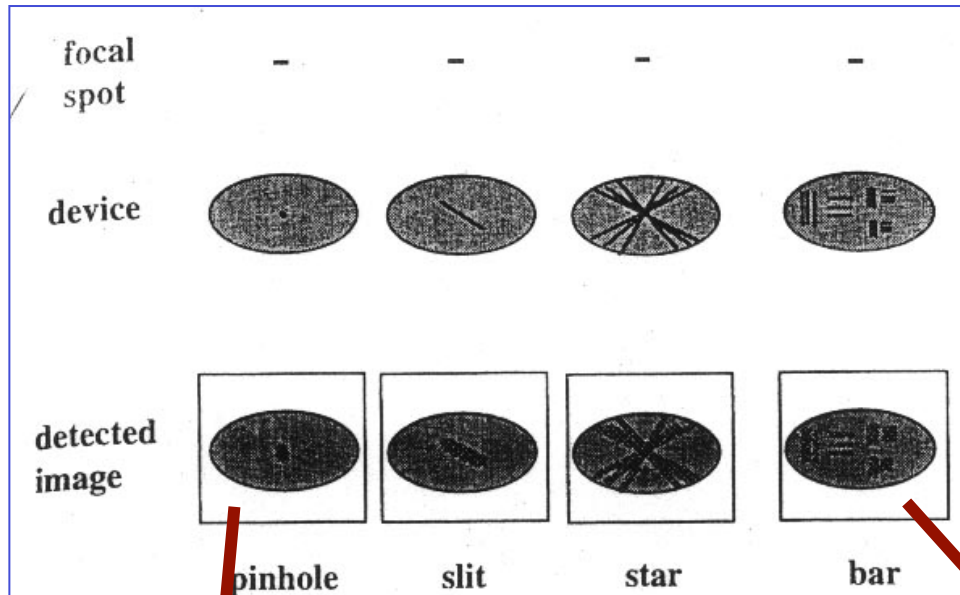
\*SI units are given in brackets.

<sup>†</sup> 1 roentgen =  $2.58 \times 10^{-4}$  coulomb/kilogram.

<sup>‡</sup> 100 rad = 1 gray.



# Misura della macchia focale



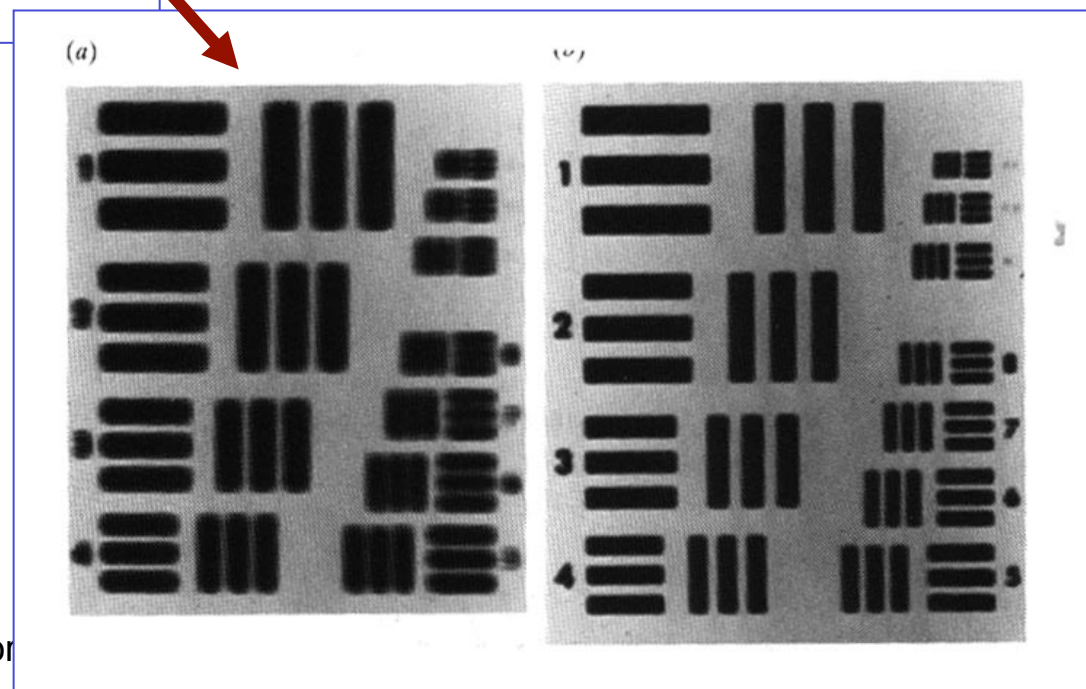
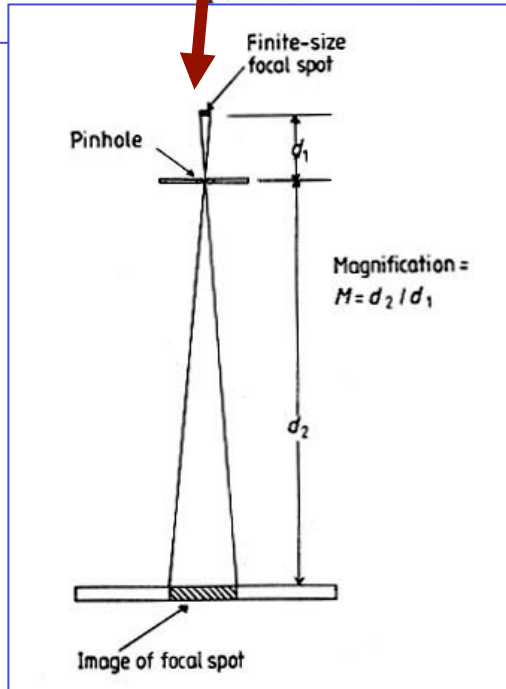
Le dimensioni effettive della macchia focale vanno misurate.

Possono deteriorarsi

**Bar pattern**  
**Macchia focale**

**1.3x1.5 mm<sup>2</sup>**

**0.6x0.6 mm<sup>2</sup>**



Laborator

# Laboratorio di Fisica Medica

## Modalita' di esame

- relazioni di laboratorio scritte
  - Da consegnare entro fine corso
- esercizio Geant4
  - personale
- orale