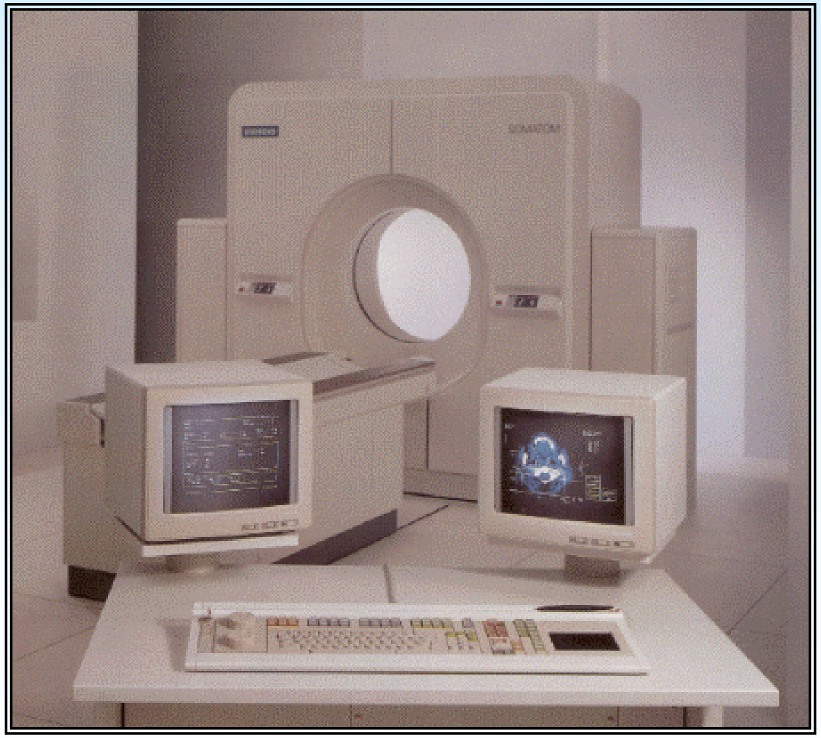
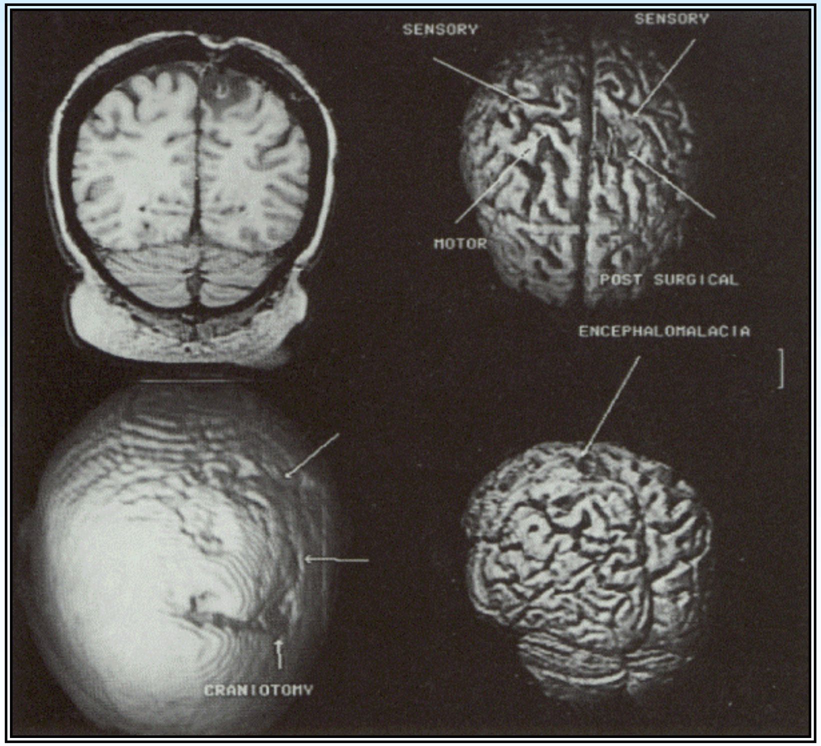
ORGANIZING THE MEDICAL IMAGING DEPARTMENT

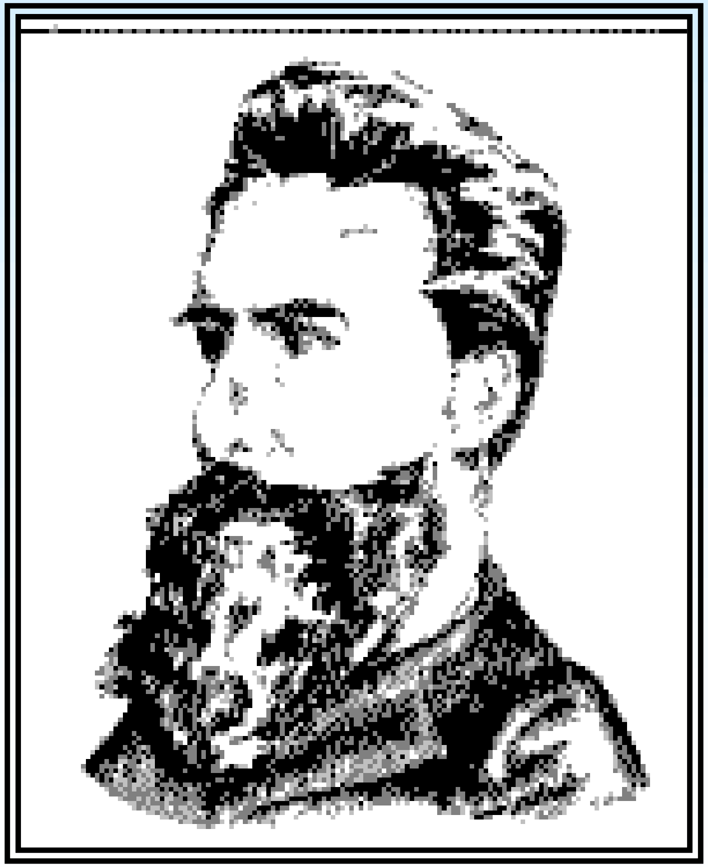


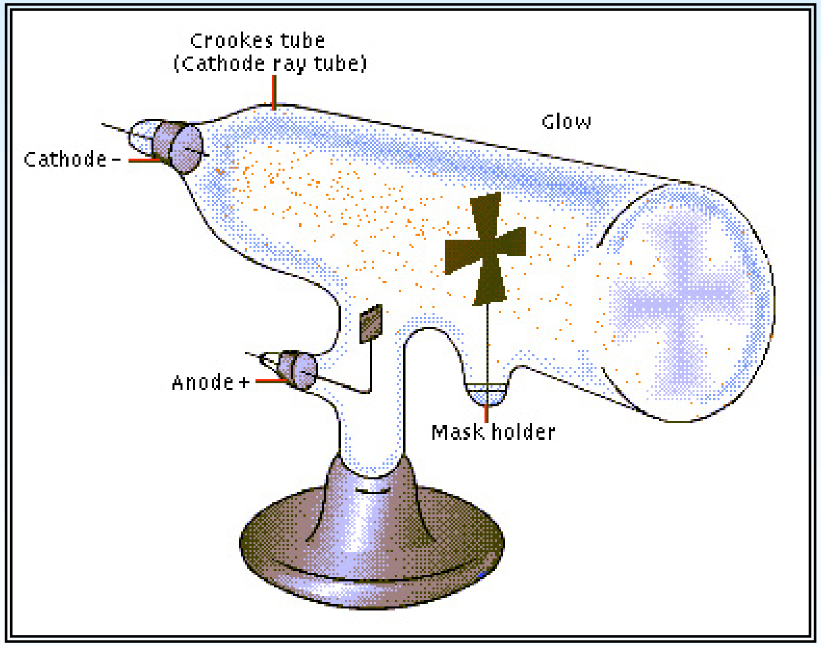


Modern Medical Imaging methods

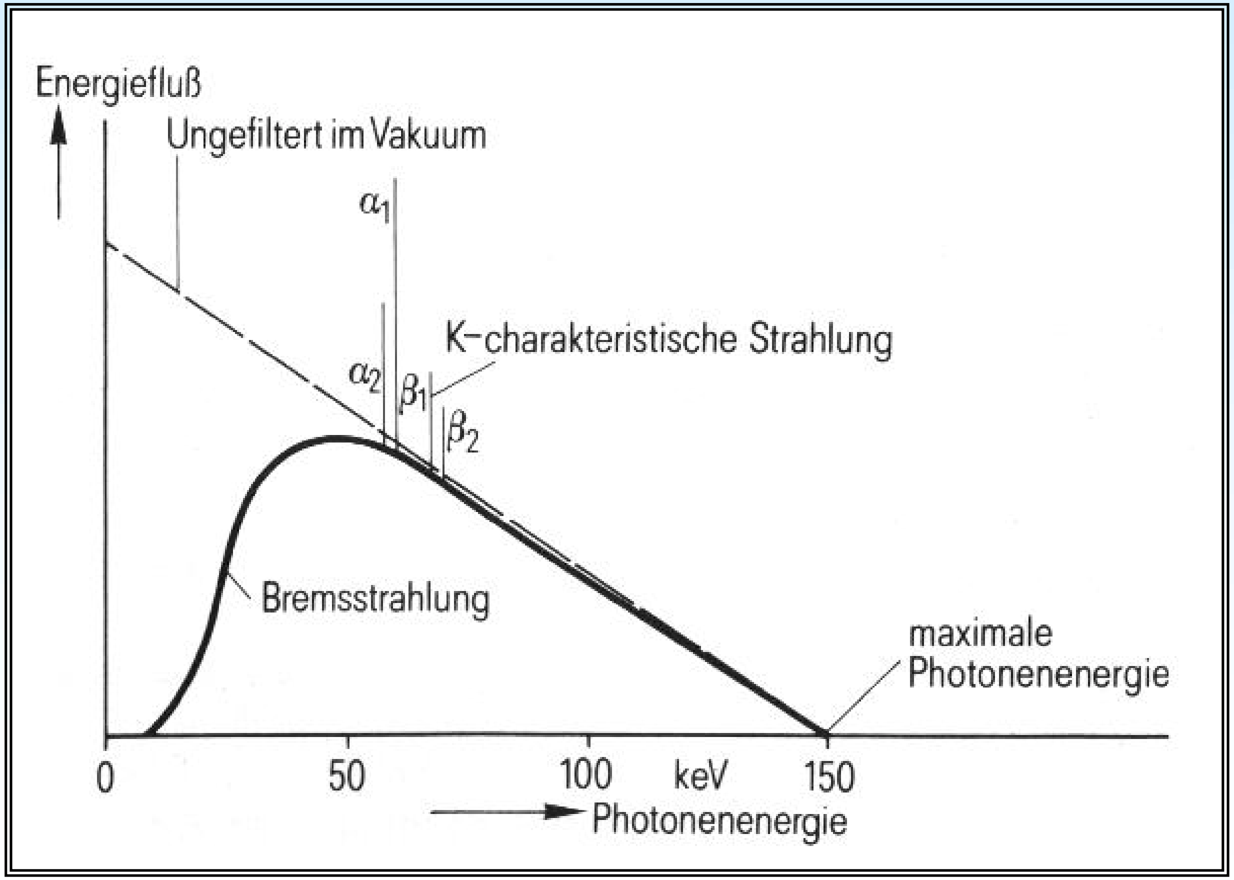
- Modern Medical Imaging includes a lot of methods:
  - *Conventional and Digital Radiology.*
  - *Nuclear Medicine Imaging Methods (SPECT, PET)*
  - *Sonography.*
  - *Magnetic Resonance Imaging.*
- There are also other interesting methods, including *Endoscopic Imaging, Brain Mapping, Biomagnetic Diagnostics, Impedance Imaging, Thermography* etc. that are either closer related to other Departments (Operating Theater, Outpatient Department), or they are not used intensively.

The birth of X-rays (Roentgen 1895) in the Crookes tube

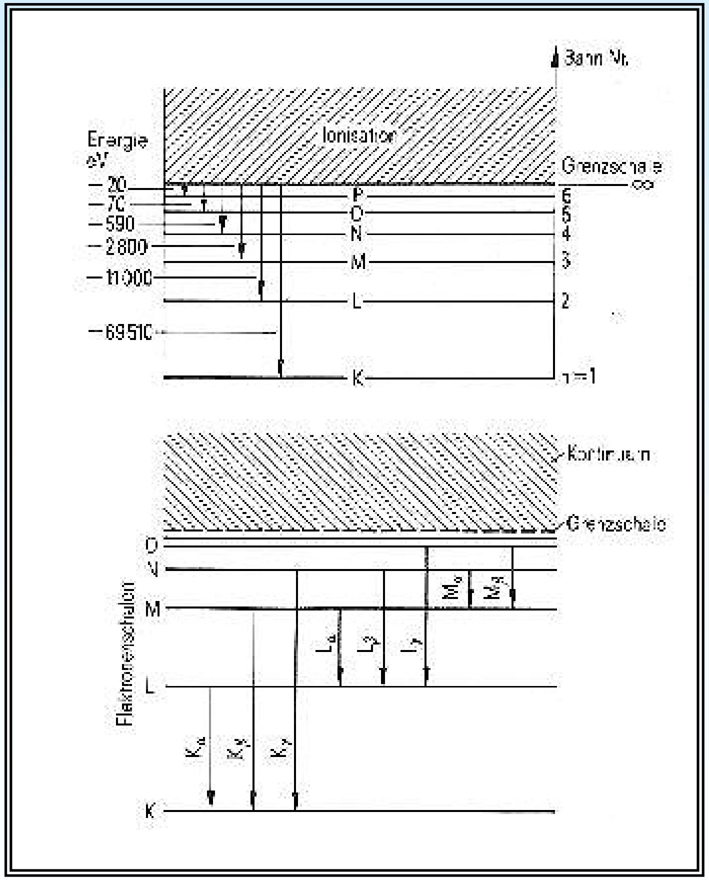




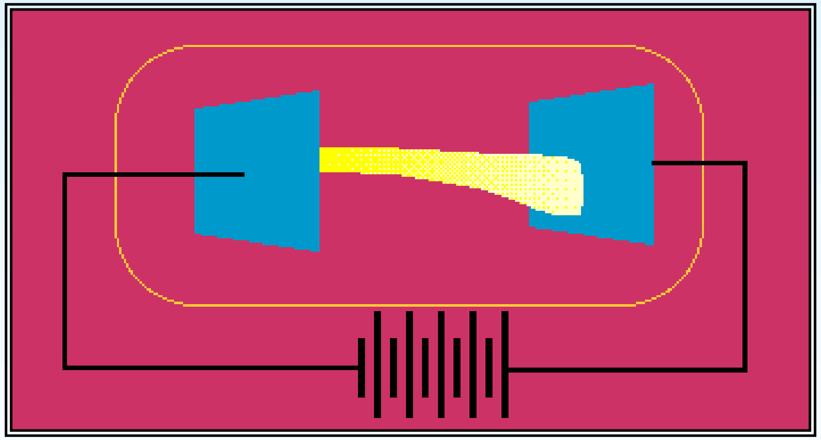
X-ray Bremsstrahlung Spectra



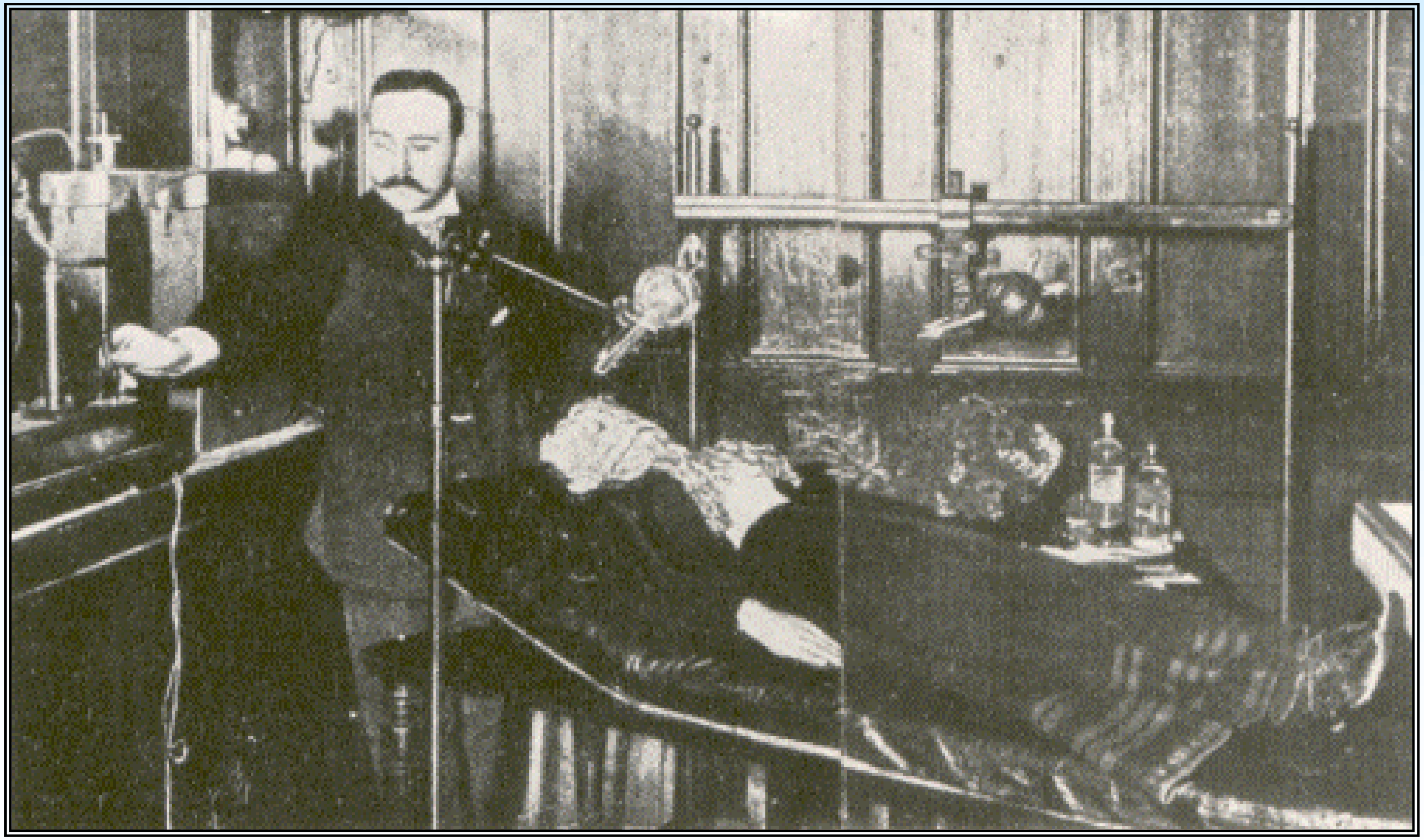
X-ray Anode material characteristic Spectral lines



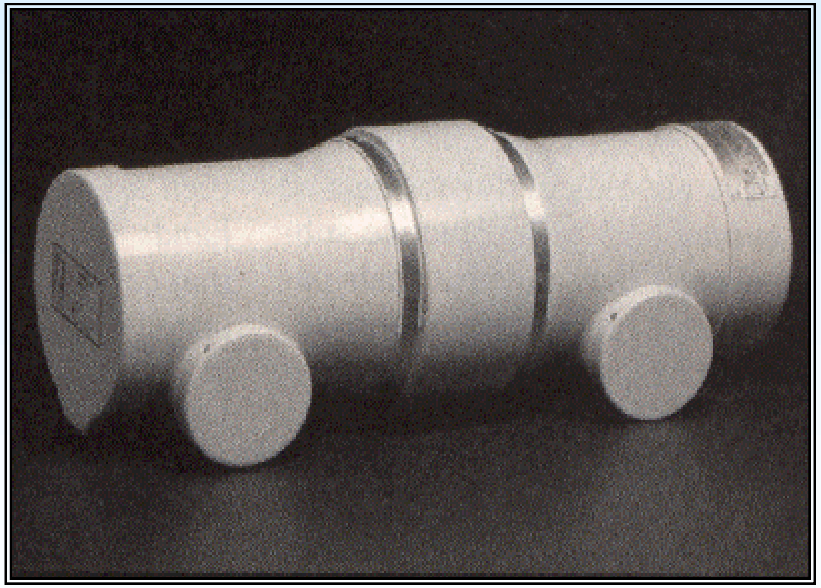
Operation principle of the contemporary (Coolidge) X-ray Tubes (V = 30-300 kV)

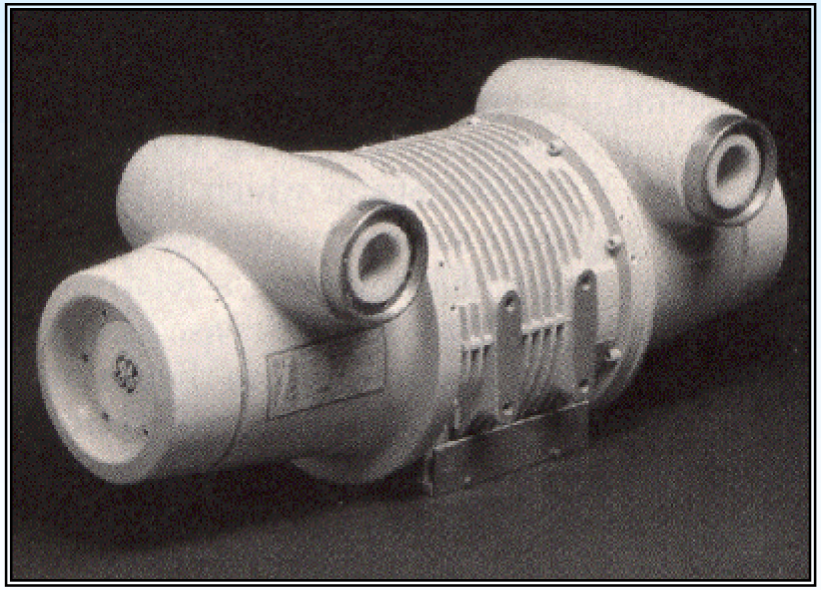


X-ray Tubes in the beginning of the 20th Century

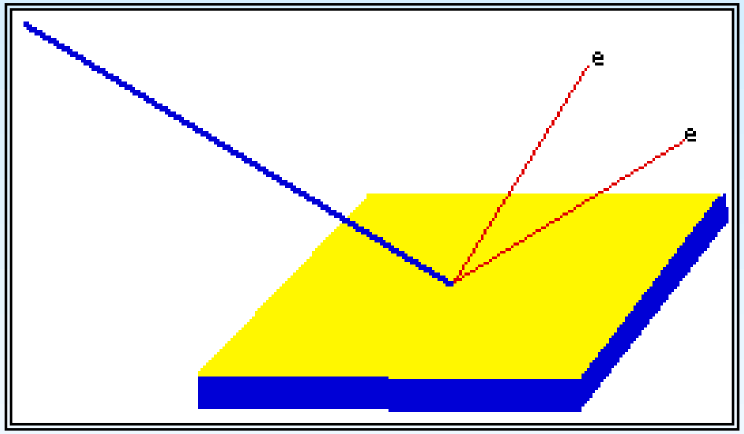


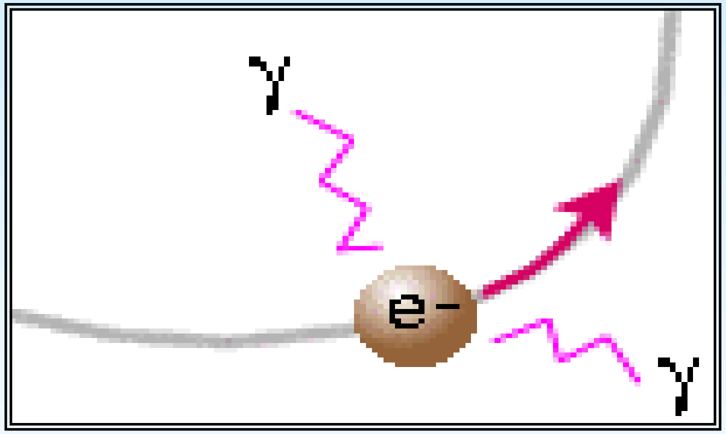
Plomb-shielded & Oil-cooled modern X-ray Tubes

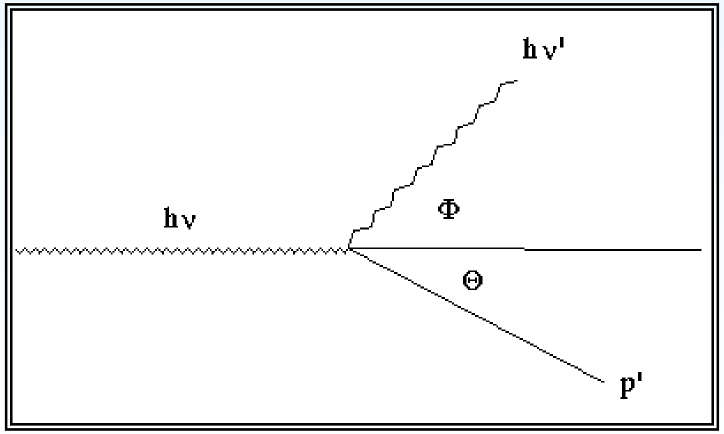


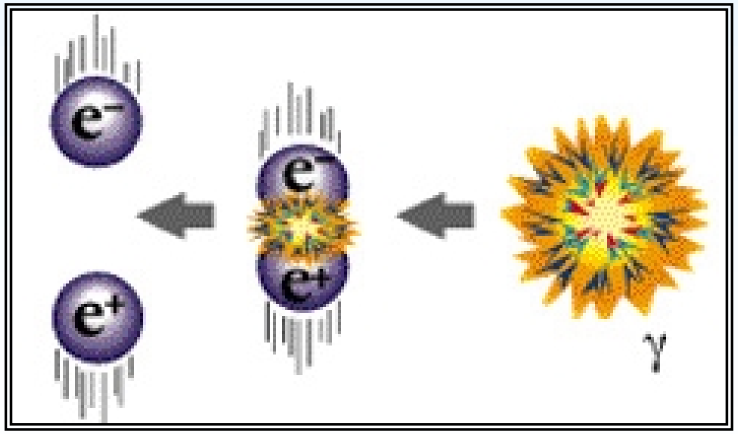


Absorption and Scattering of X-rays

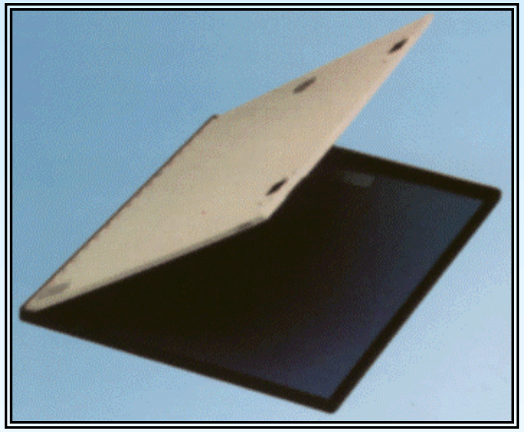


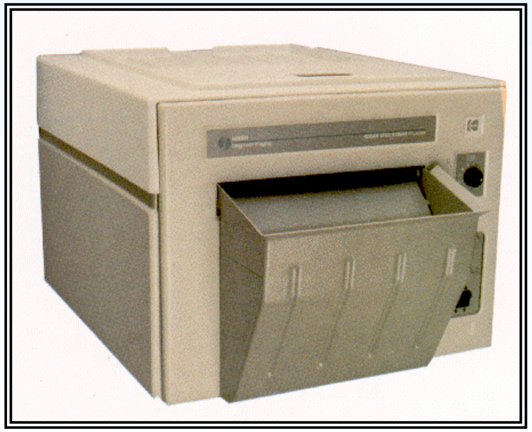




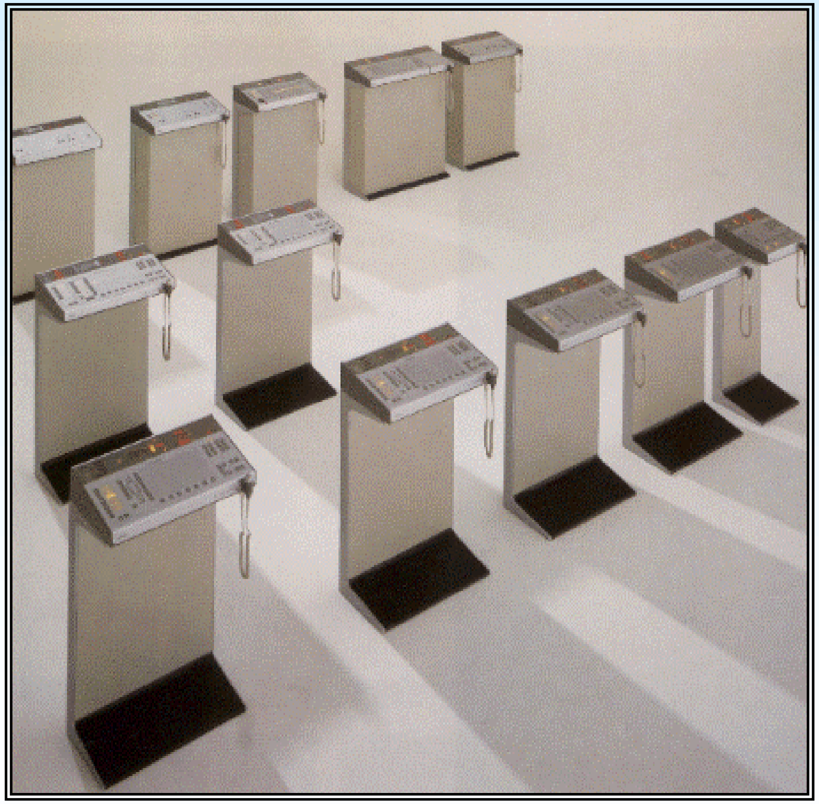


Intensifying Screens and film Processing Unit

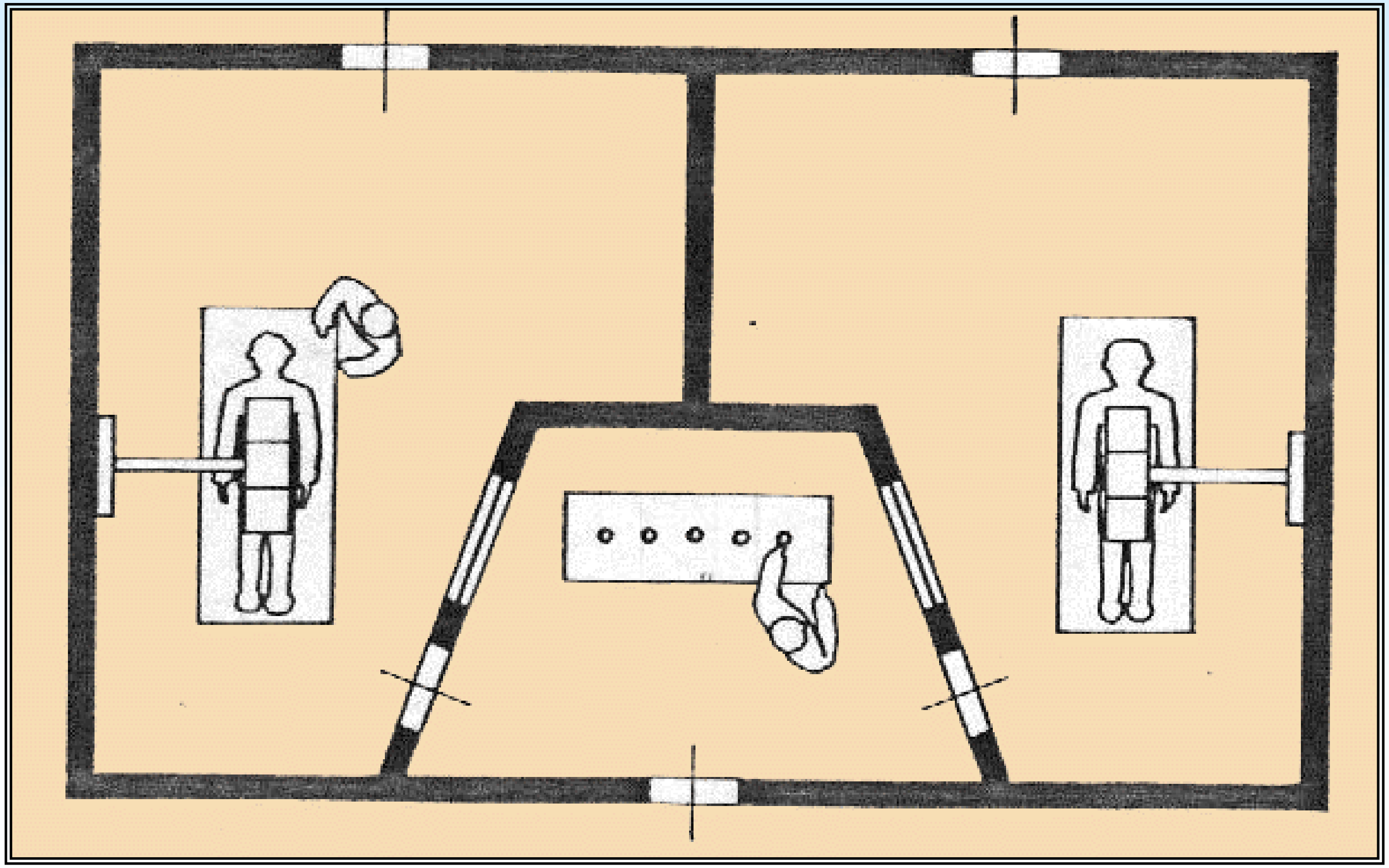




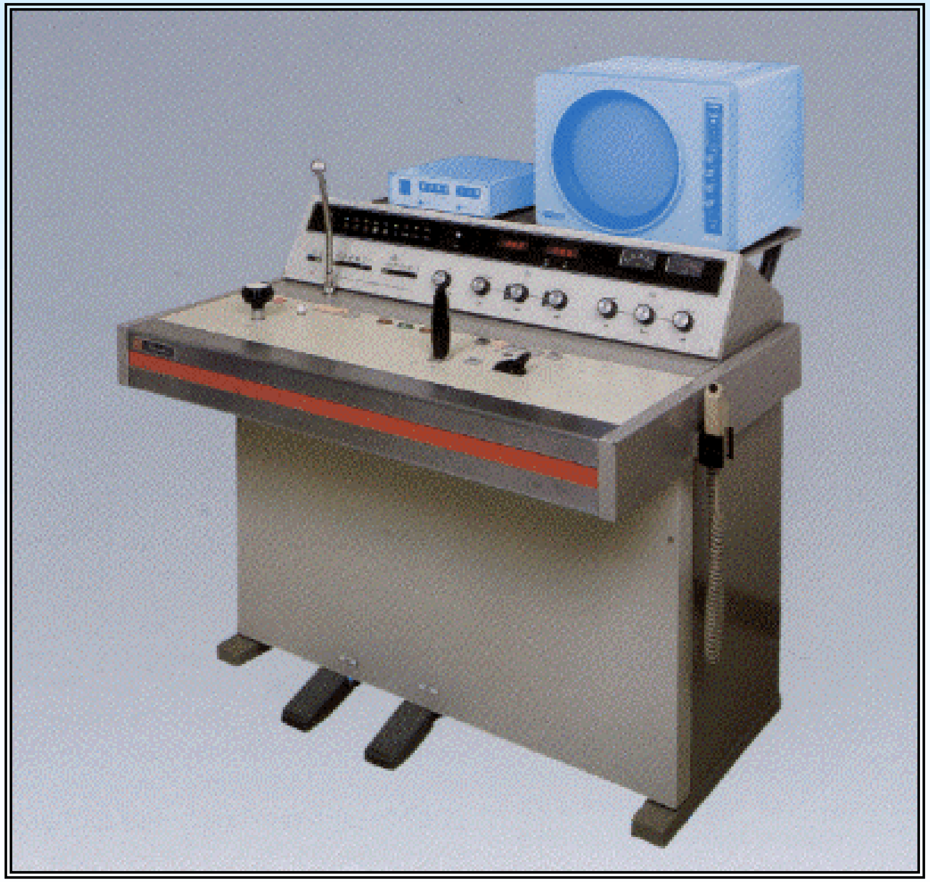
Various Power Supplies



Two examination rooms with common Power Supply



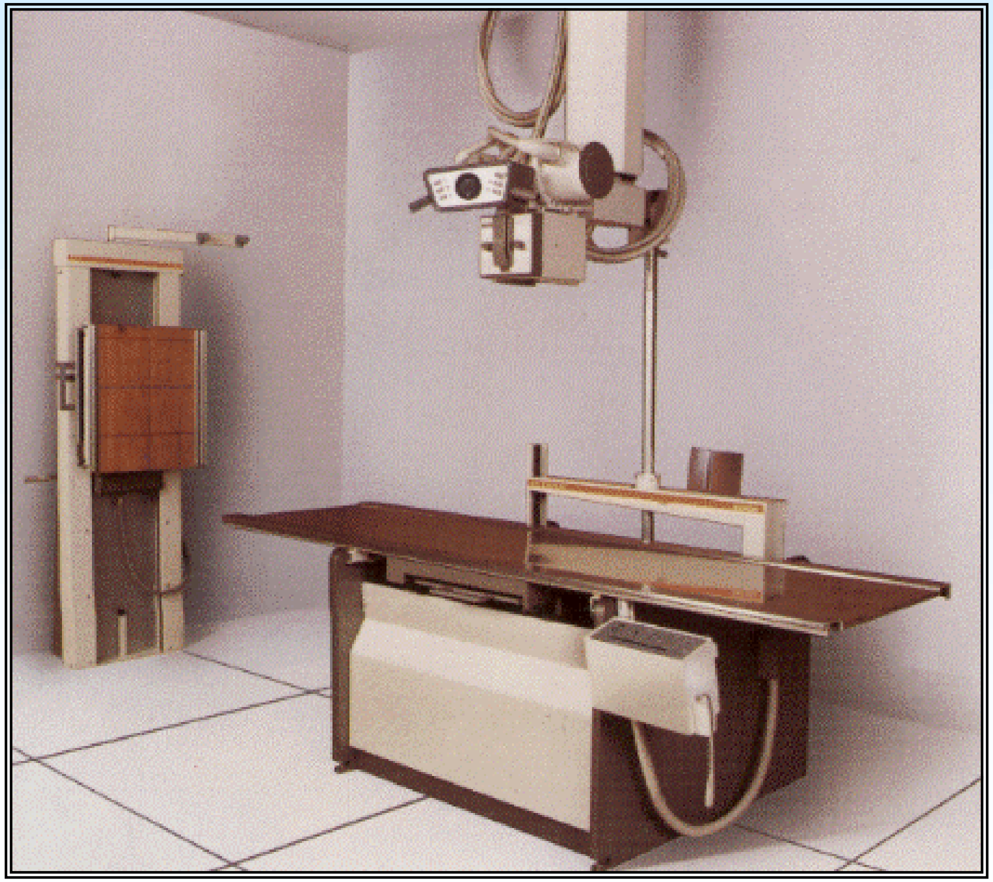
External Power Supply Quality Control (V_p, I_a)



Classification of Radiography Equipment

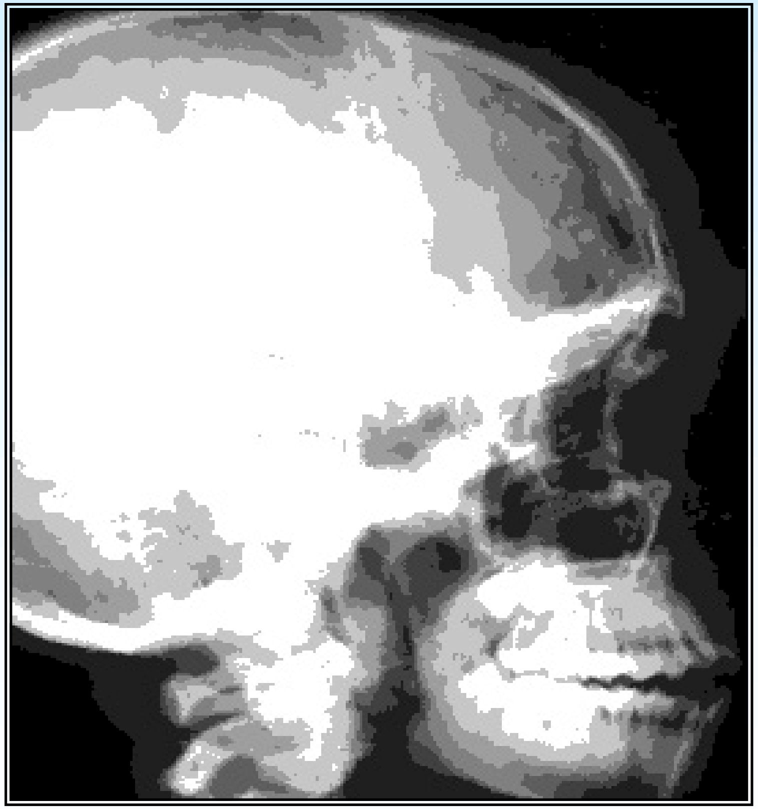
- General radiography equipment (bucky systems) for skeletal, chest and head examination.
- Mammography systems.
- Dental X-ray equipment (simple and panoramic imaging).
- Mobile Radiographic Equipment.

Bucky Systems

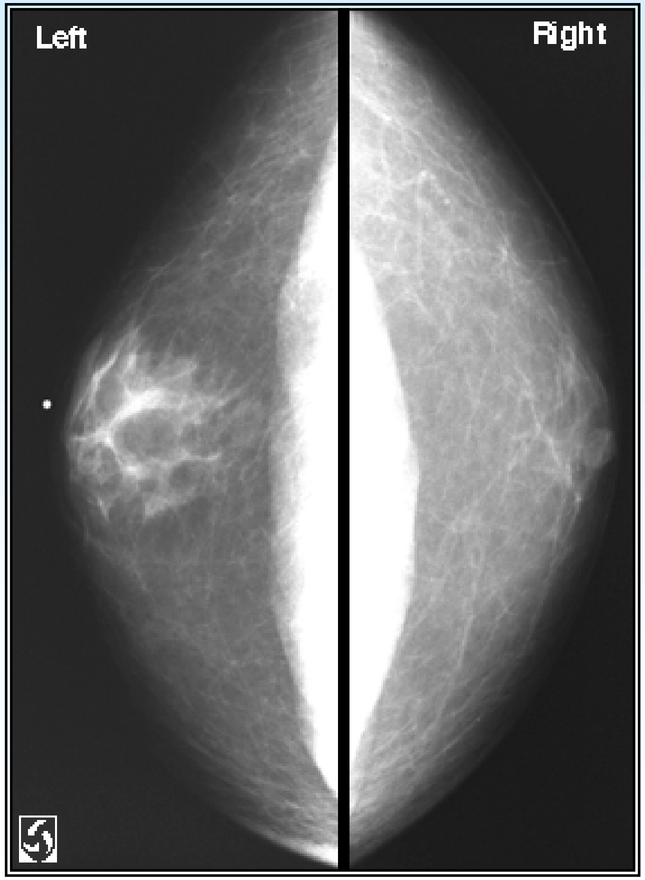


Ceiling suspended X-ray tube

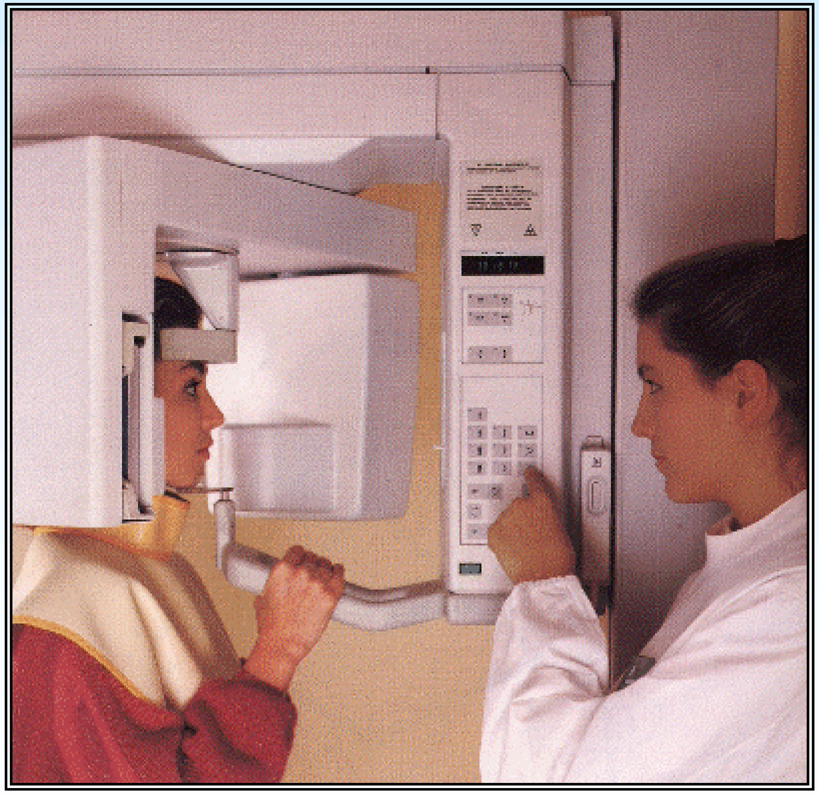
Typical Bucky System and a usual Cranial Radiography

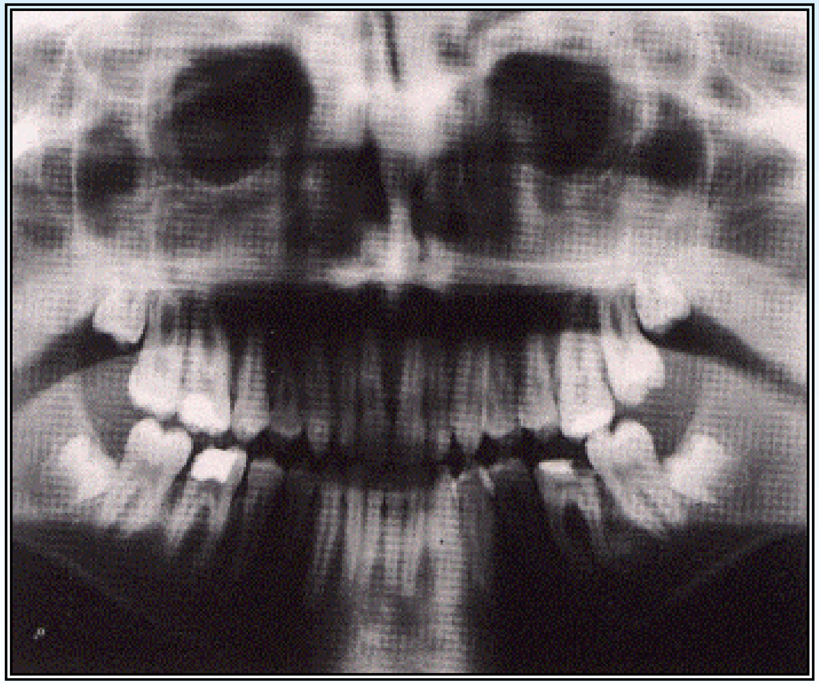


Typical Mammography System and corresponding images

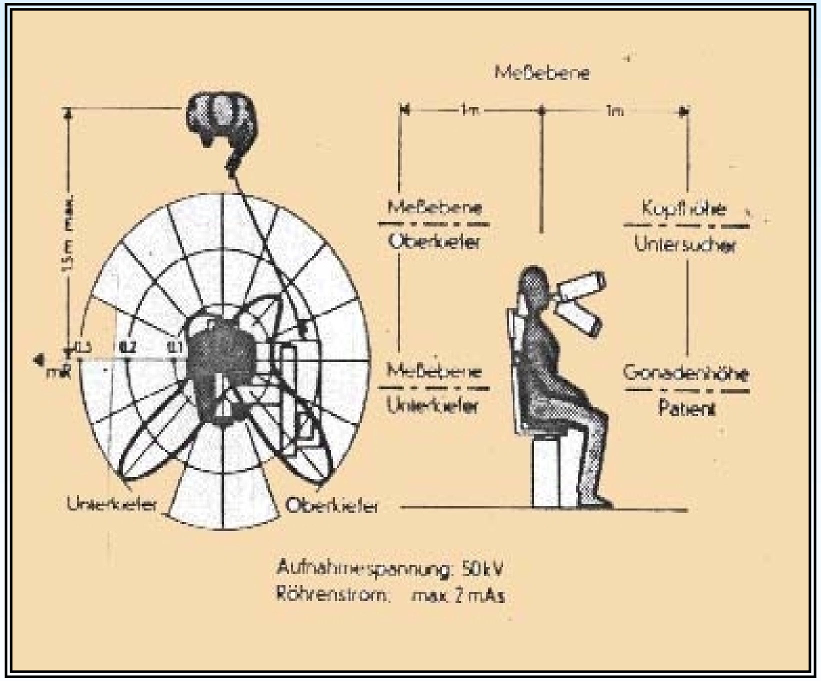


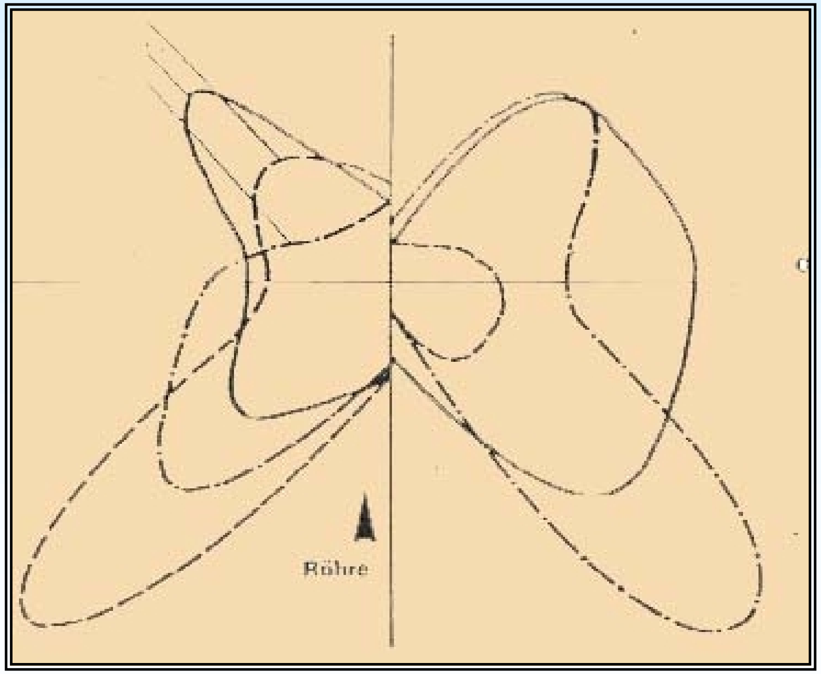
Dental Orthopantograph System (Panoramic Image)



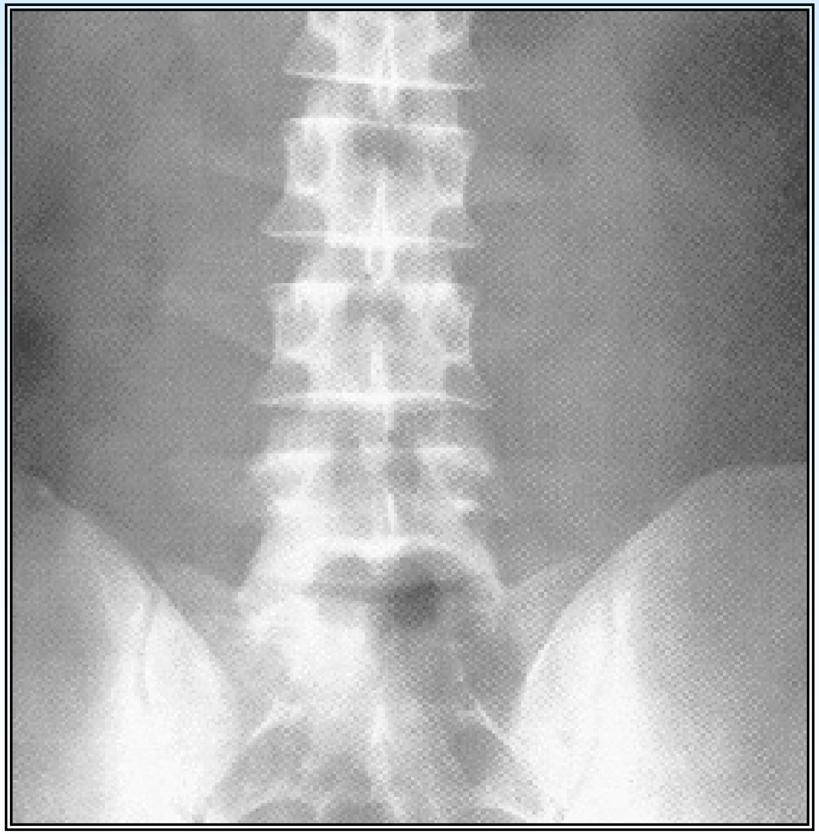


Dose distribution around a Dental System





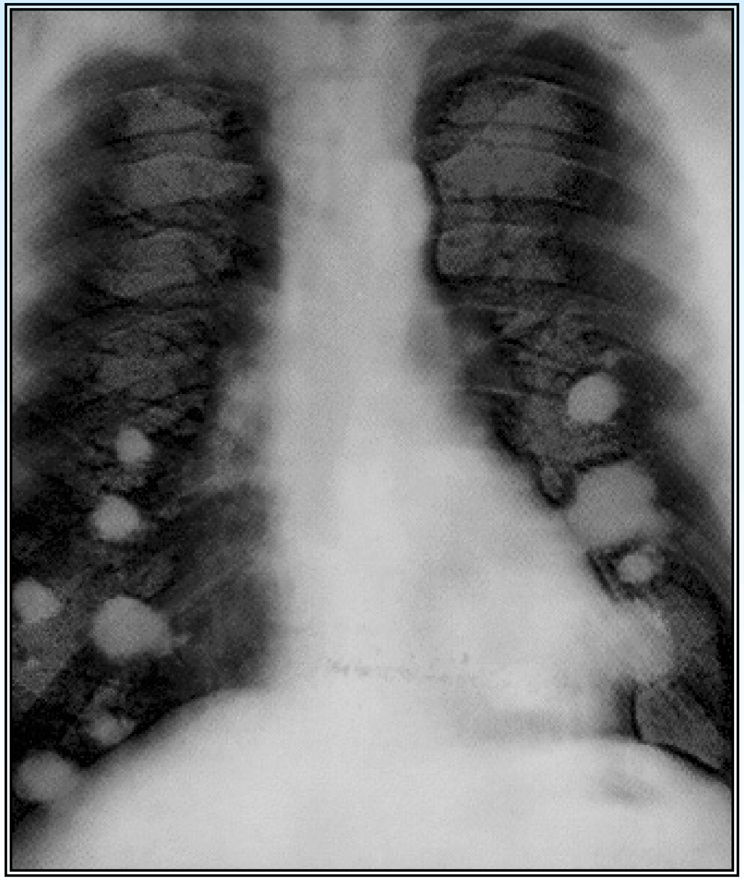
Mobile X-ray System and corresponding image



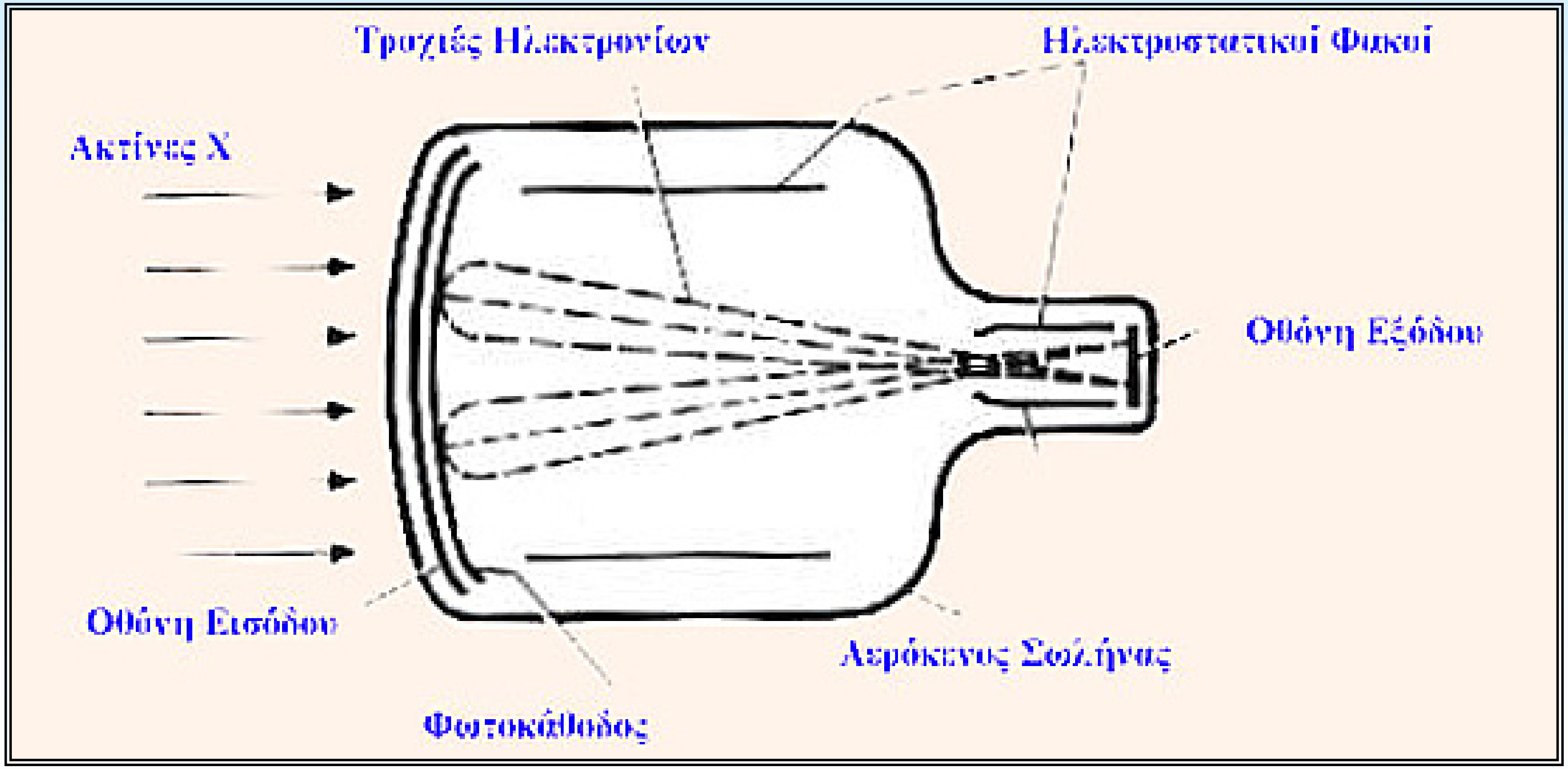
Systems equipped with Image Intensifier

- Remote controlled *(mainly over-table X-ray tube)* fluoroscopy systems.
- Mobile C-arm Operating Theater X-ray Equipment.
- Conventional *(mainly under-table X-ray tube)* mono or biplane Angiography systems.

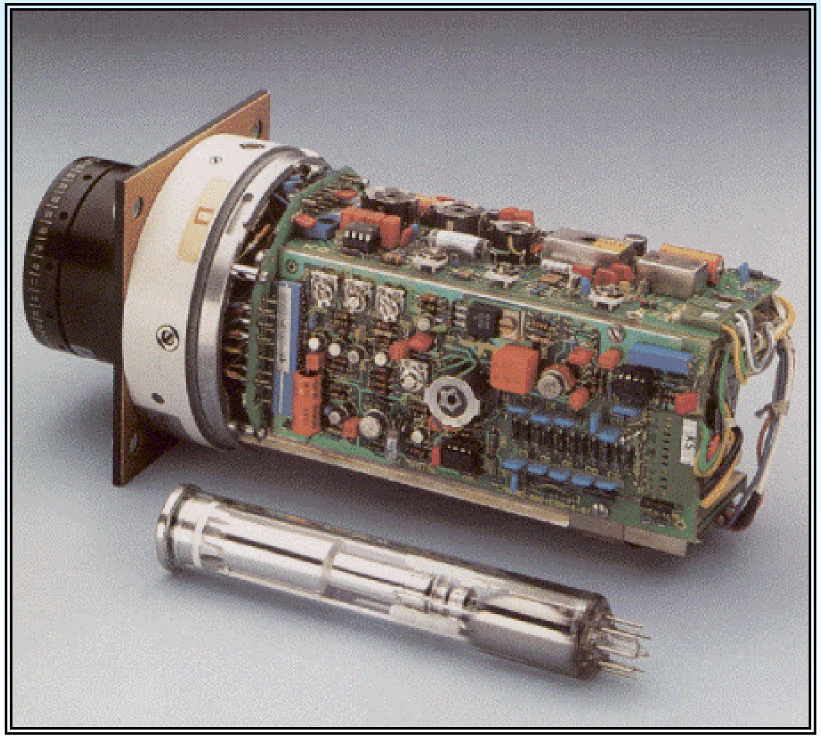
Thorax Fluoroscopic image on Fluorescent Screen and on Image Intensifier

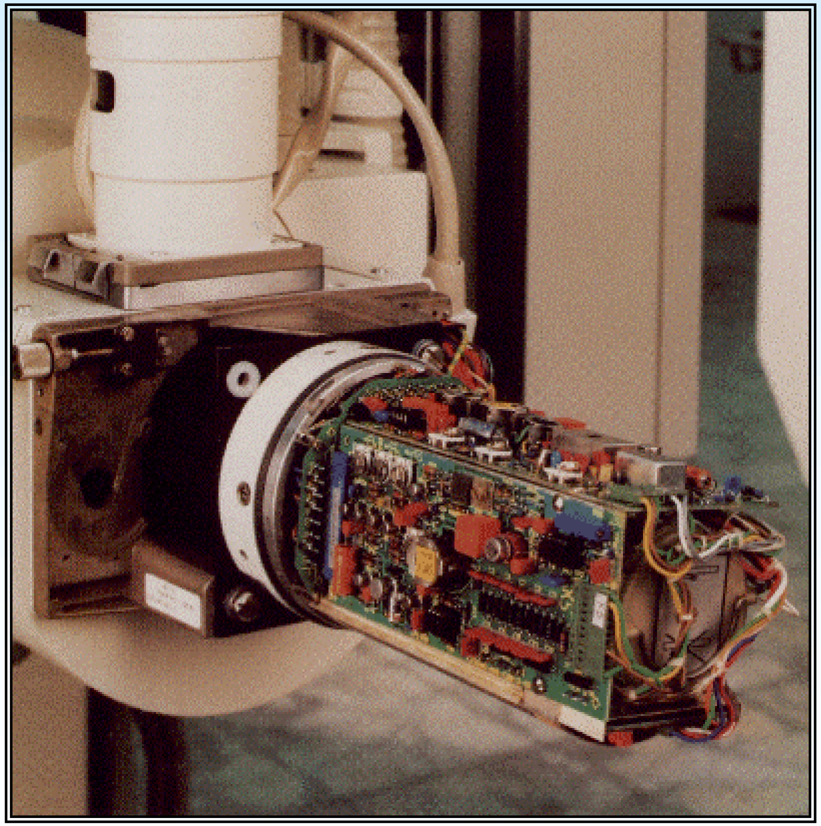


Operation principle of an Image Intensifier (ZnS:CdS:Ag or CsI)

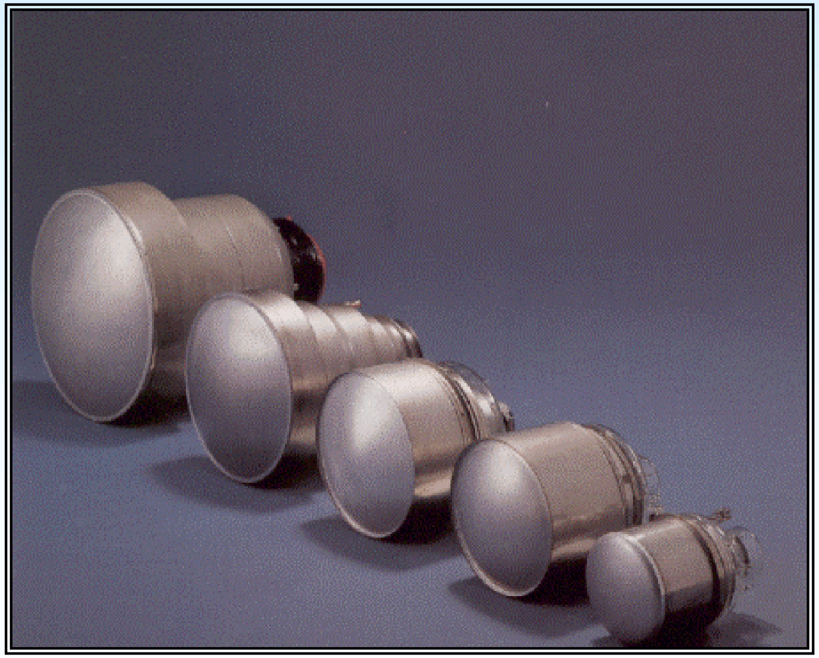


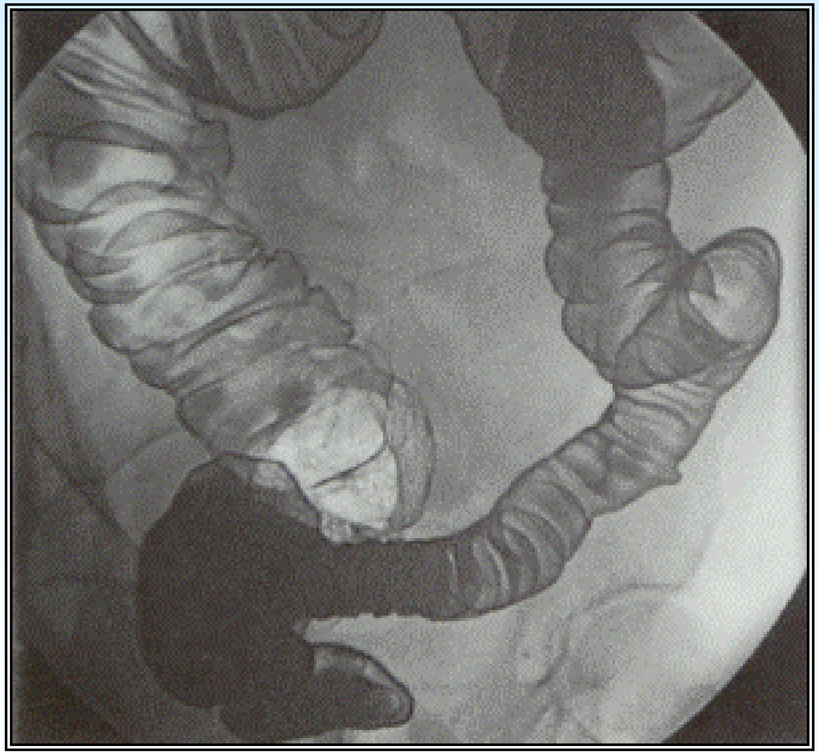
Video Camera of an Image Intensifier



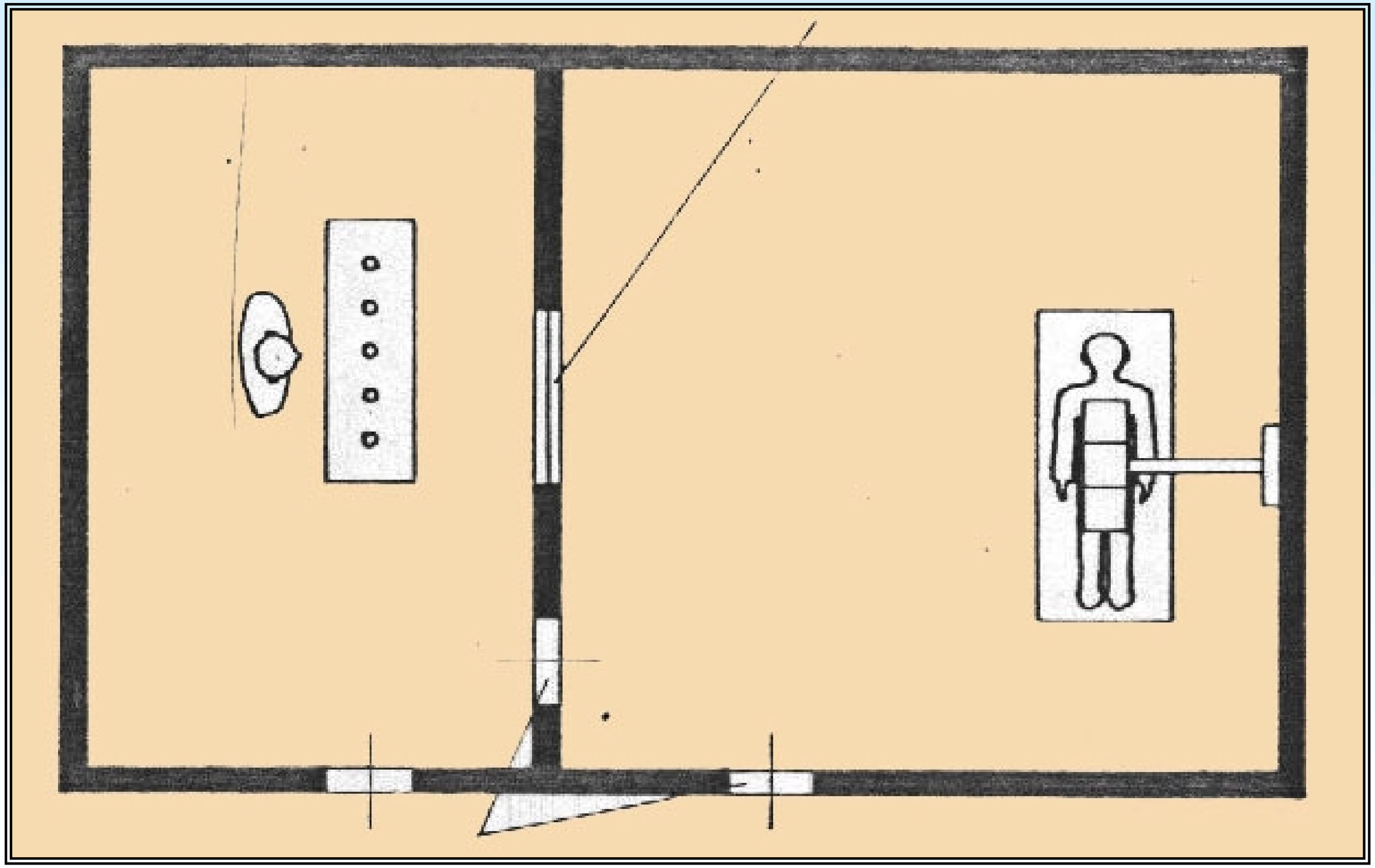


Various size Image Intensifiers and a corresponding Image

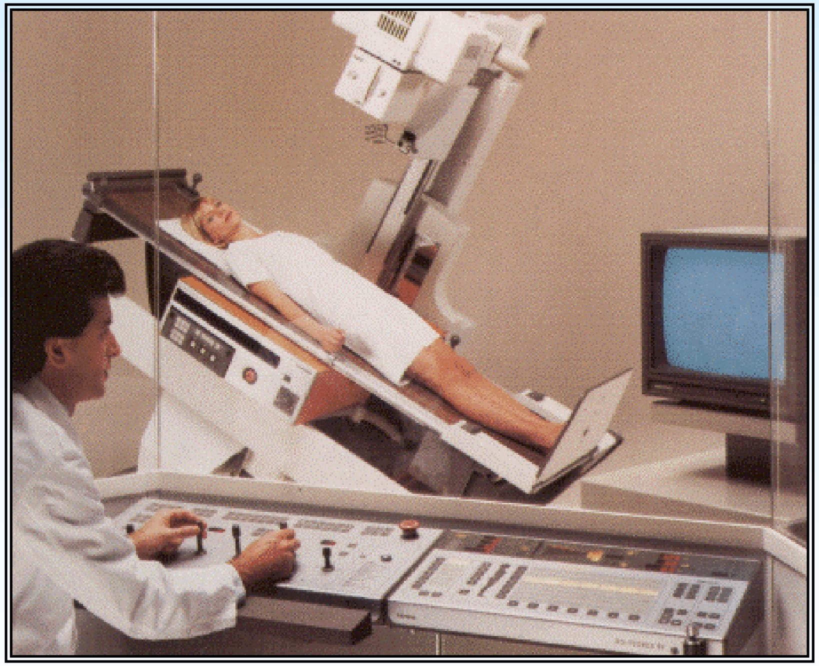


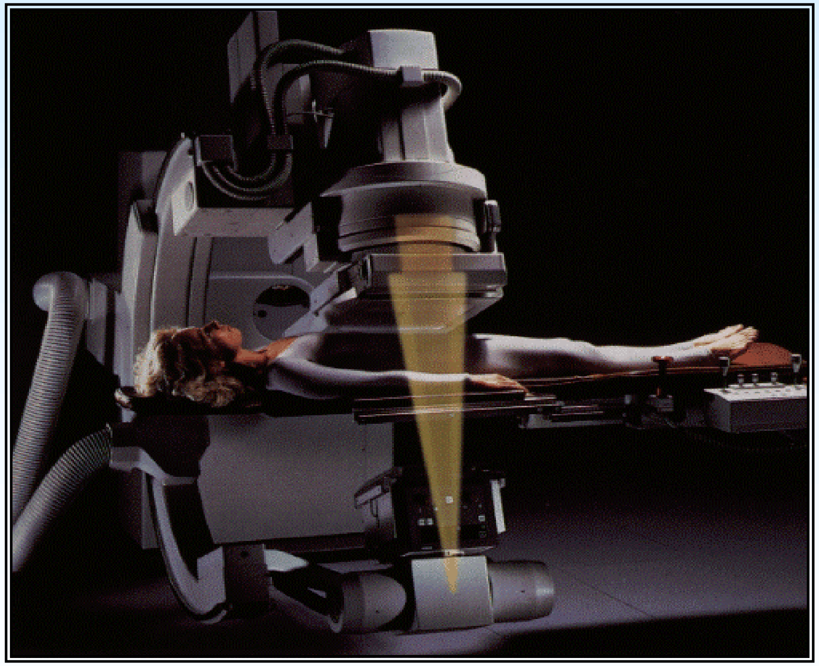


Typical Examination Room

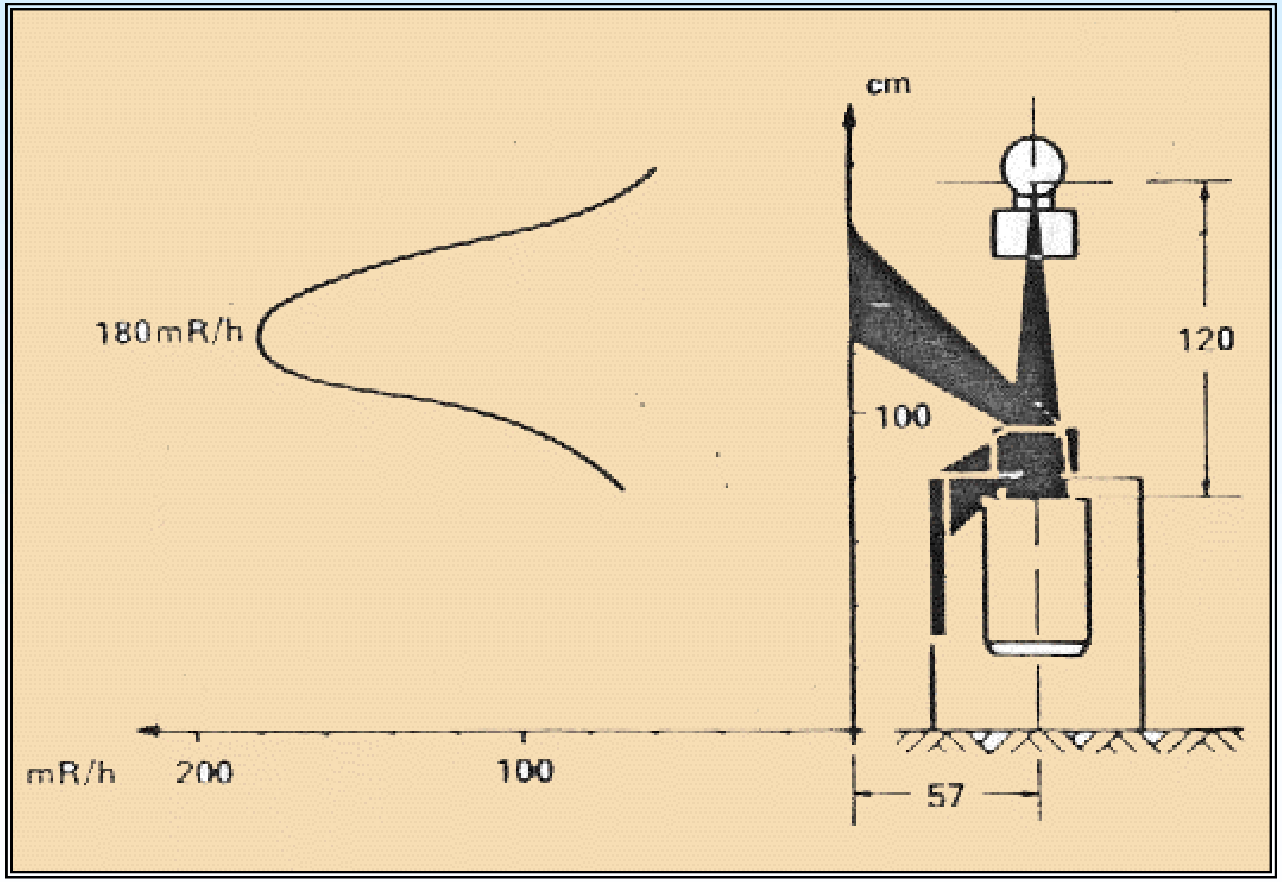


Over-table and Under-table systems

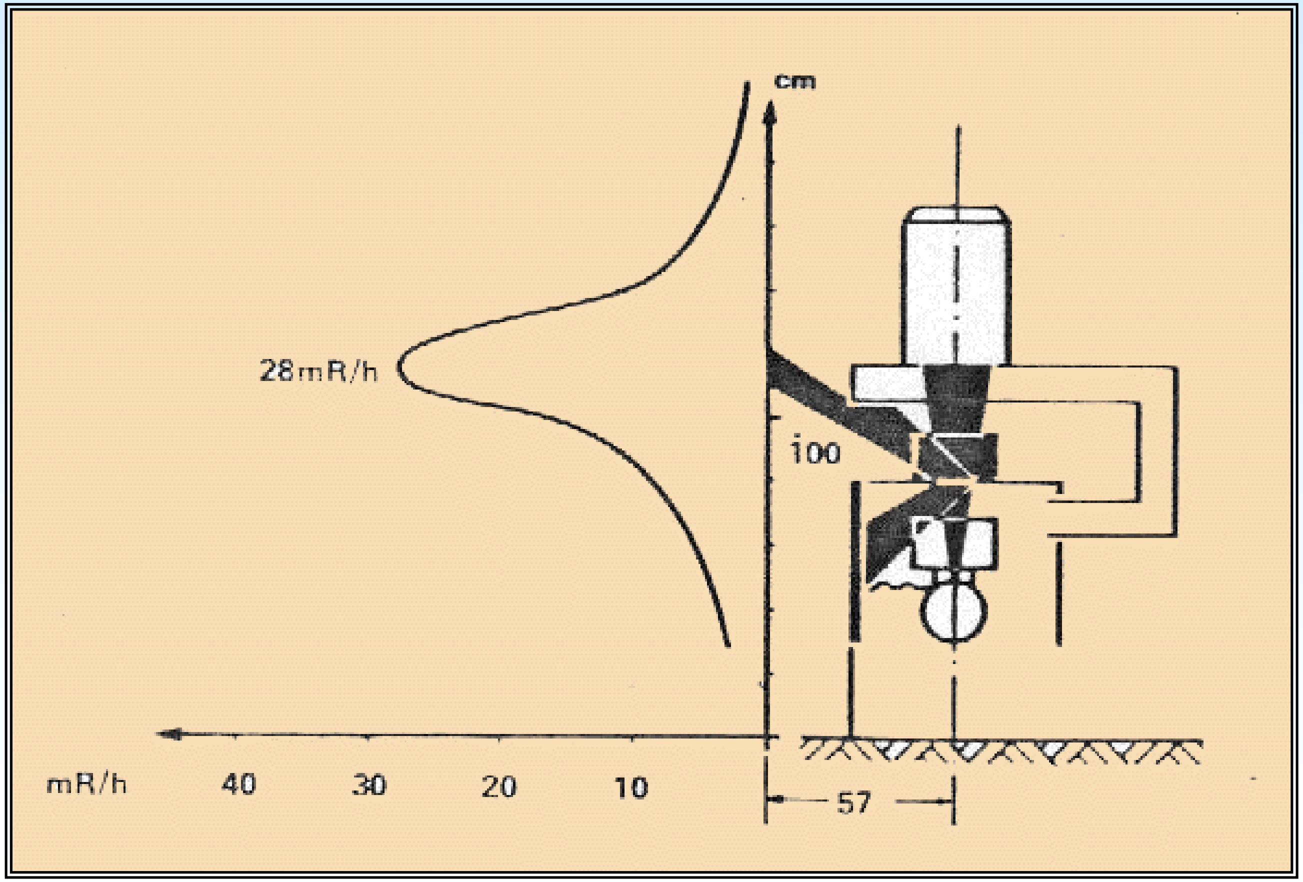




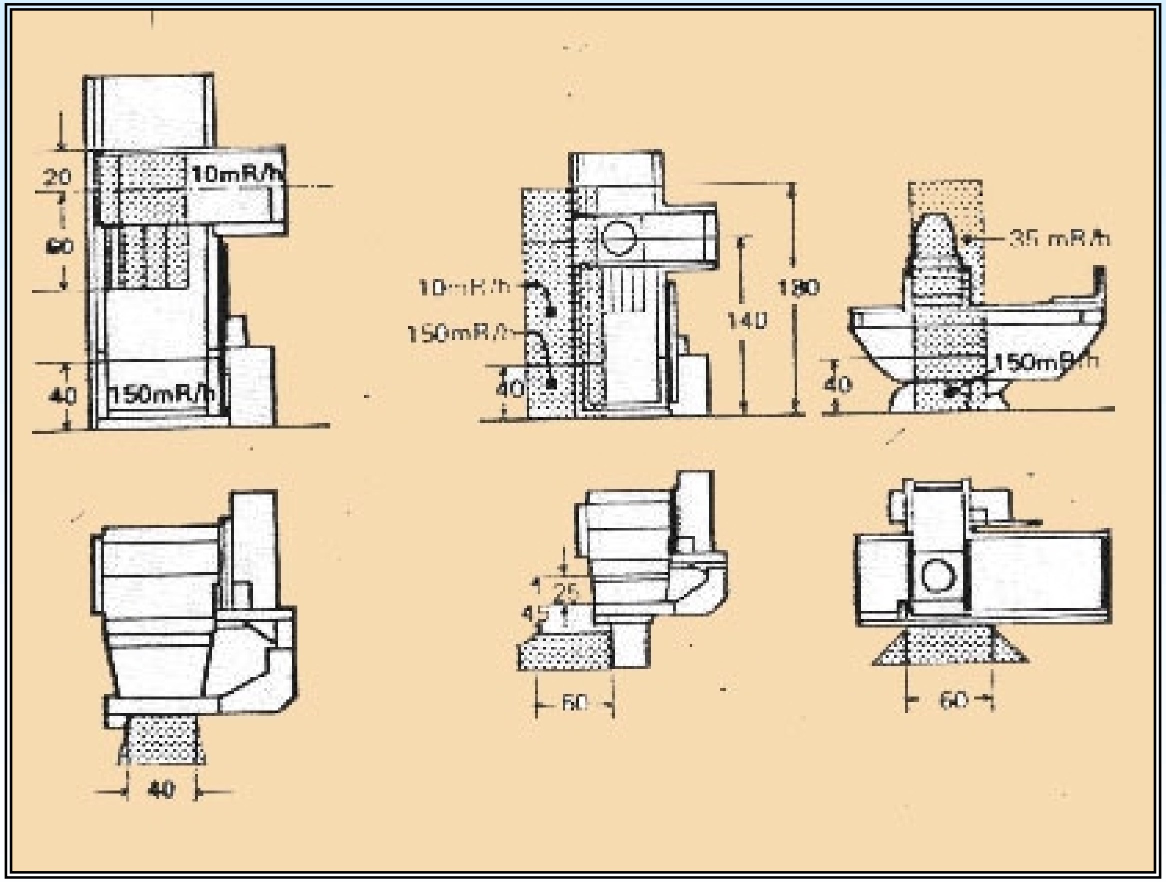
Scattered Dose Distribution around an Over-table System



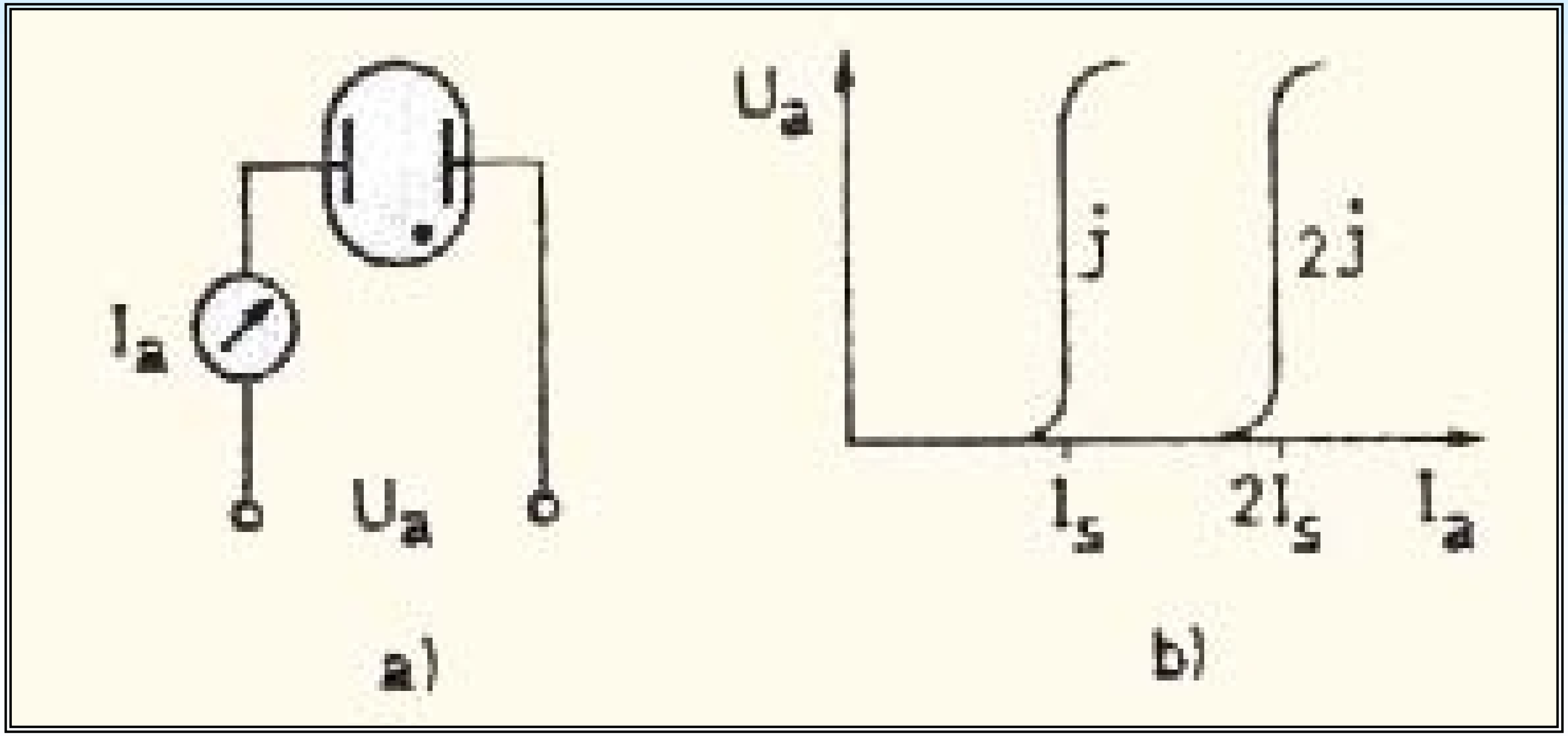
Scattered Dose Distribution around an Under-table System



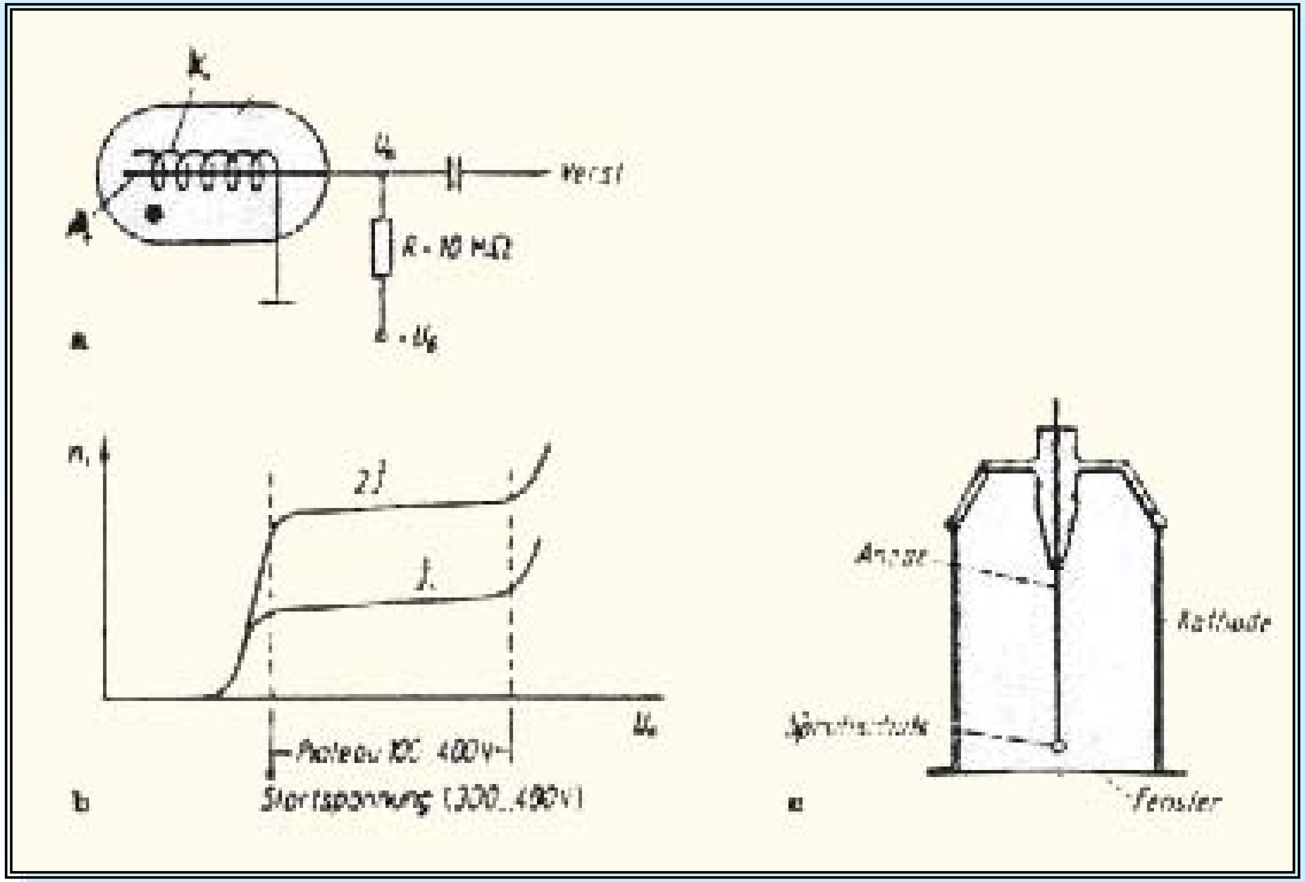
Protection zones according to DIN 6811



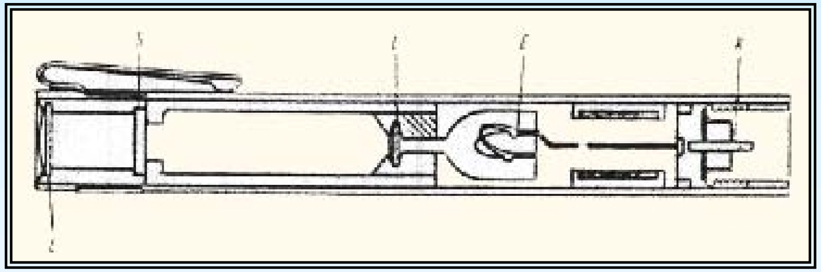
Ionization chamber

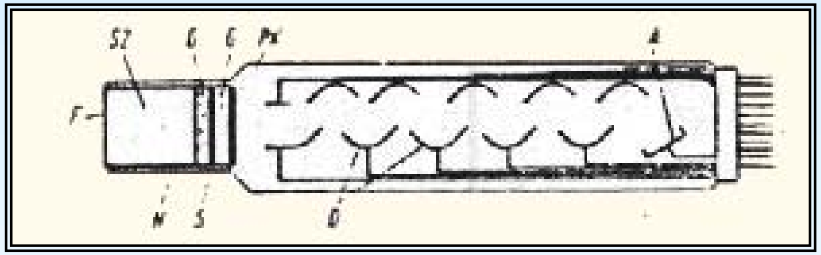


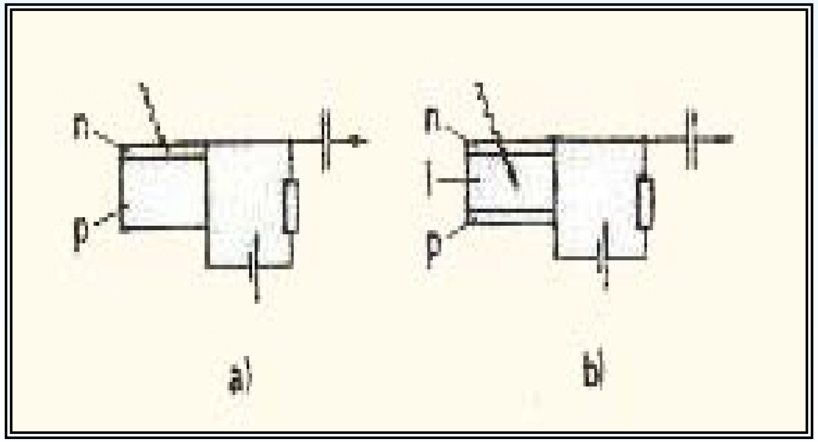
Geiger-Mueller detector

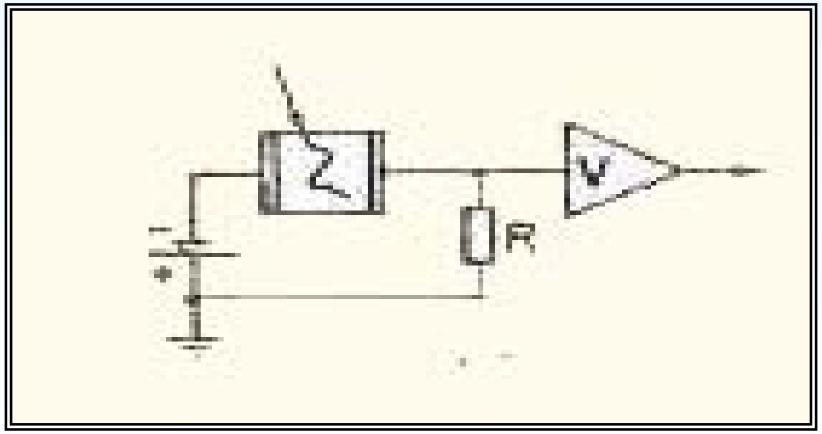


Other Detectors

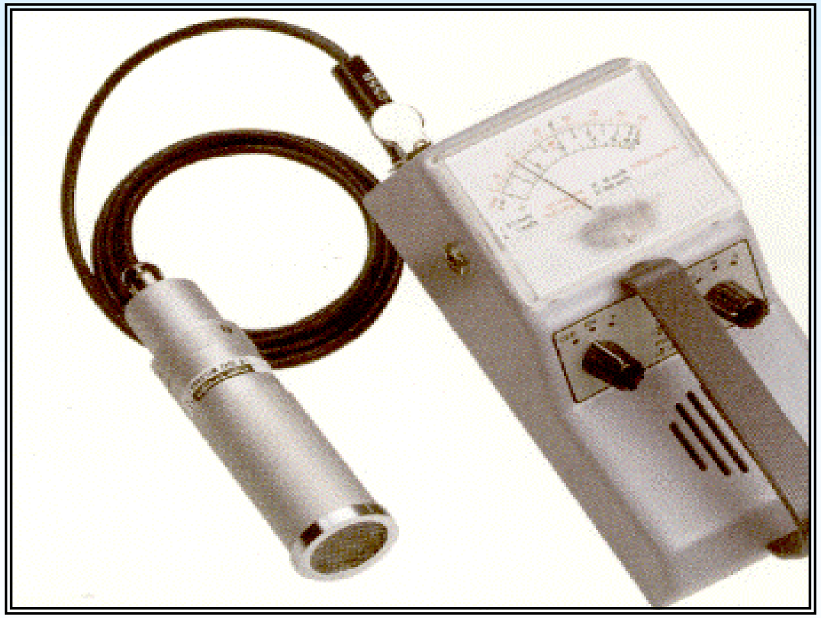


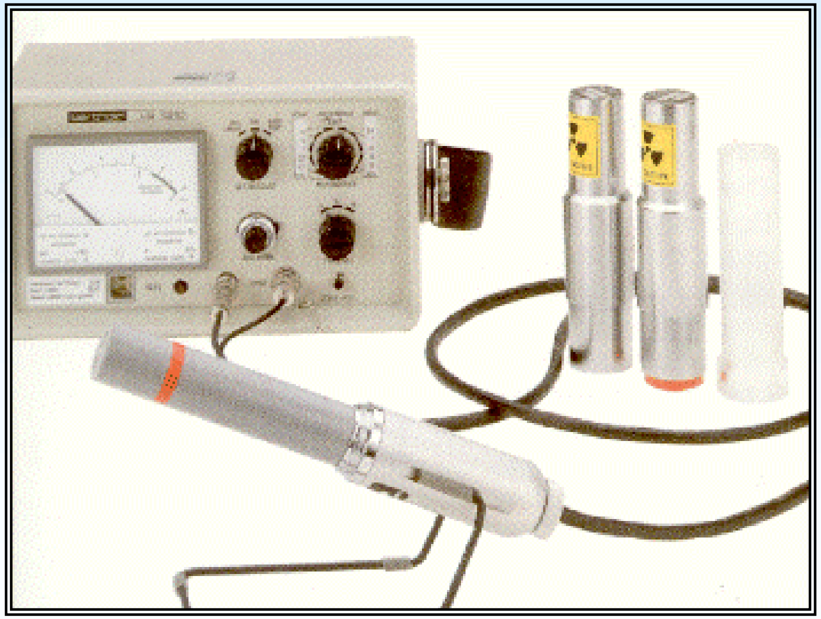




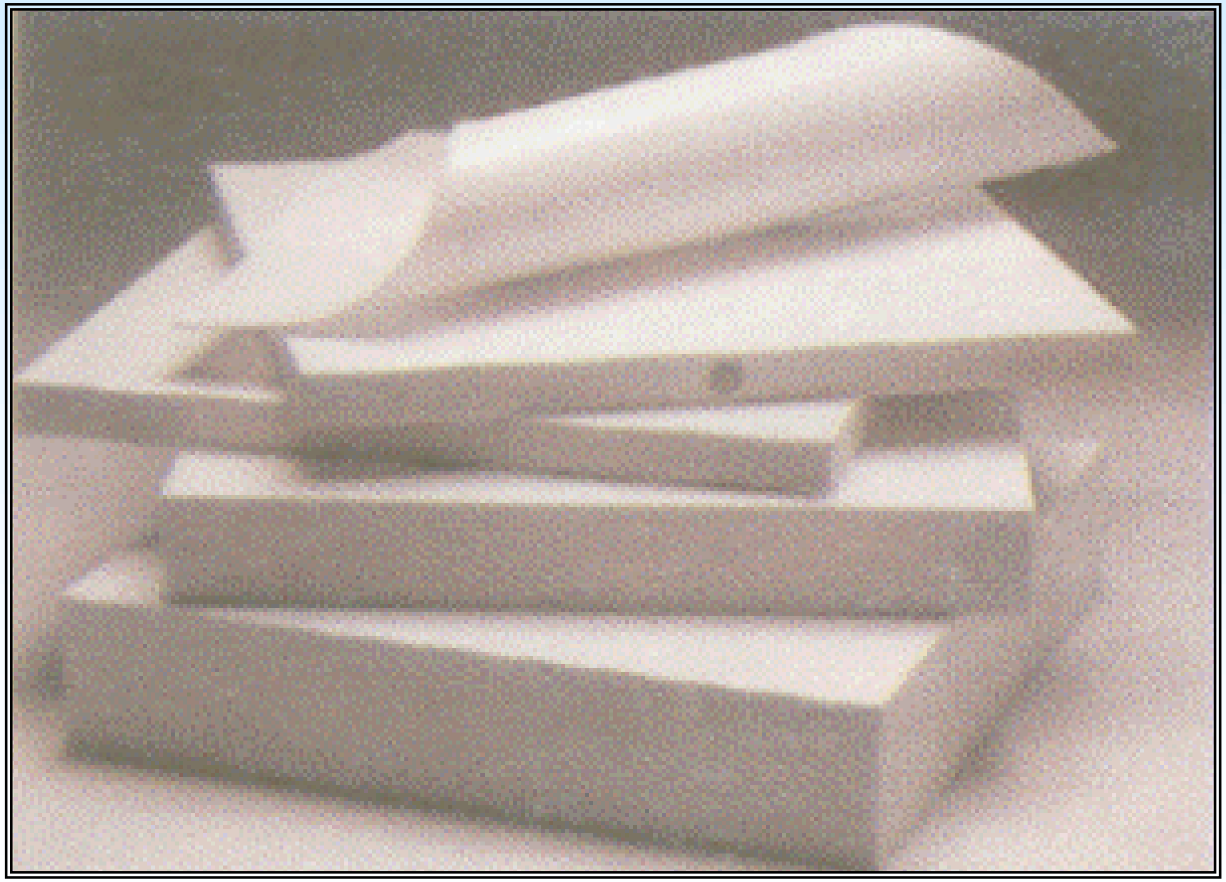


Radiation Protection Counters

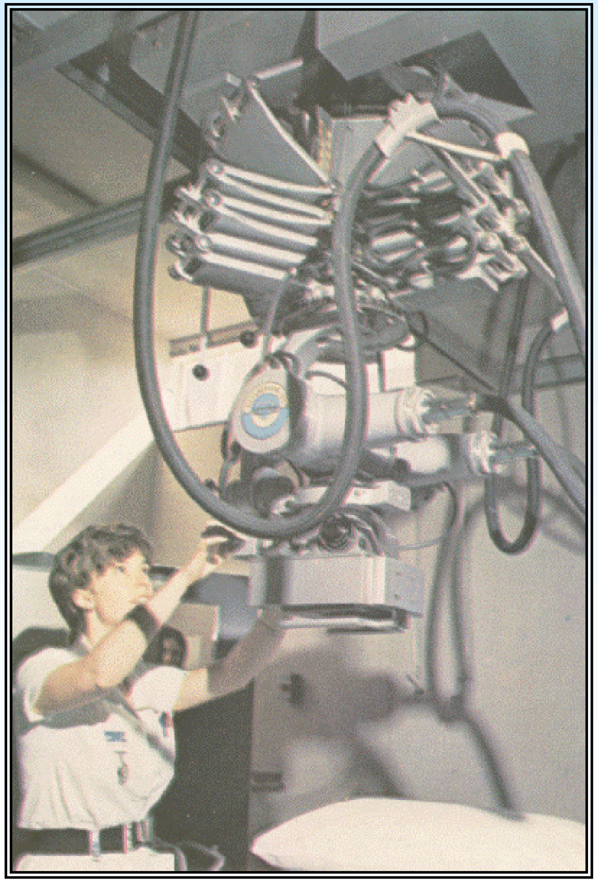


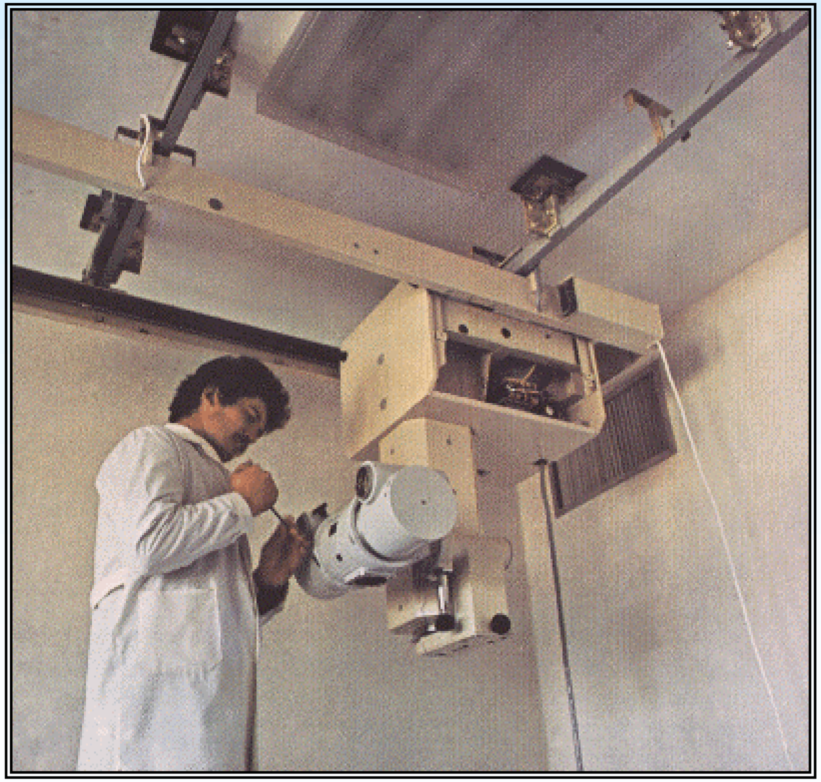


Dosimetry Phantoms

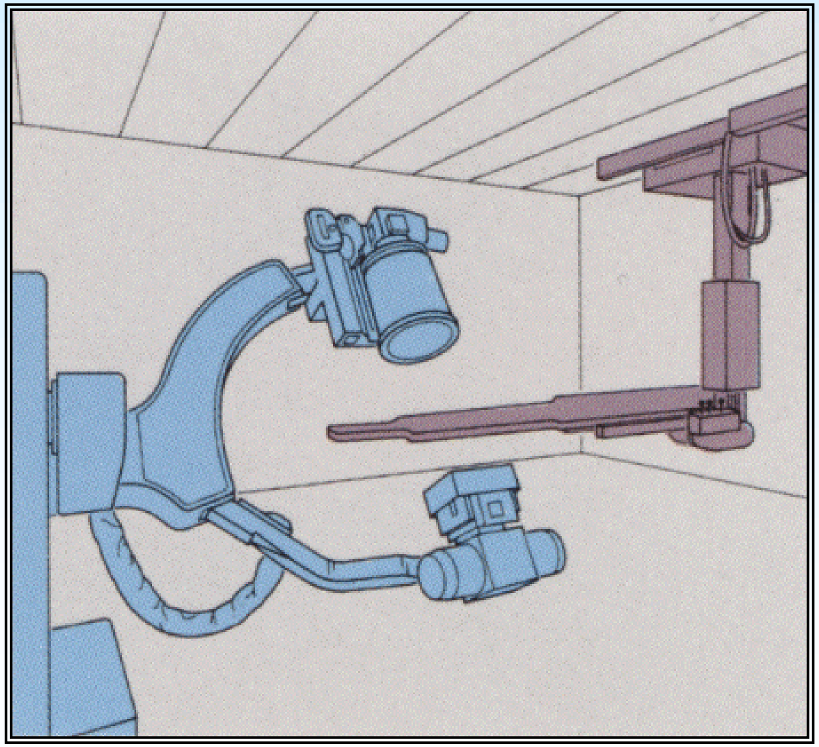


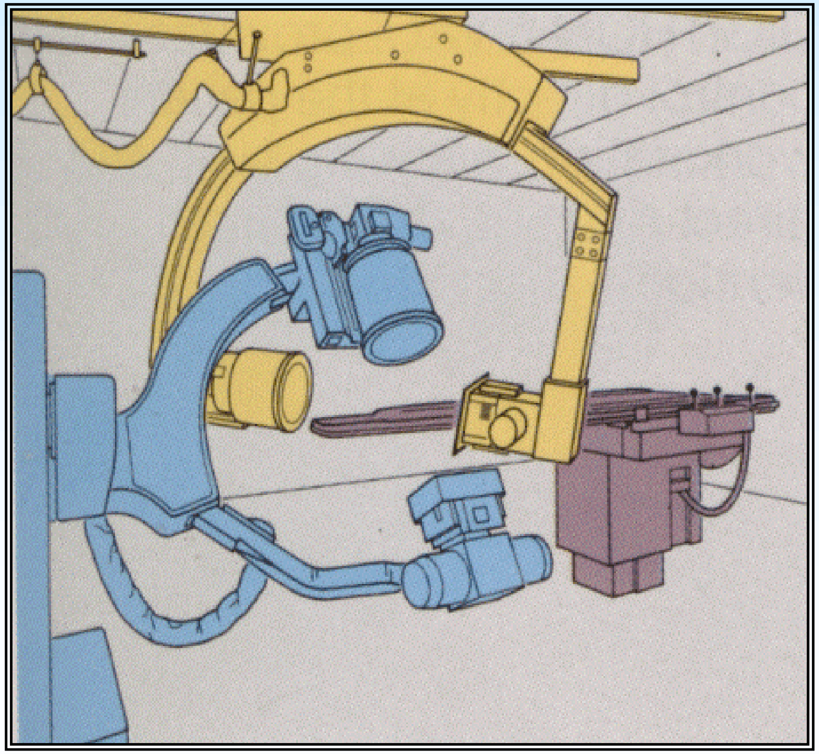
Radiological System Maintenance



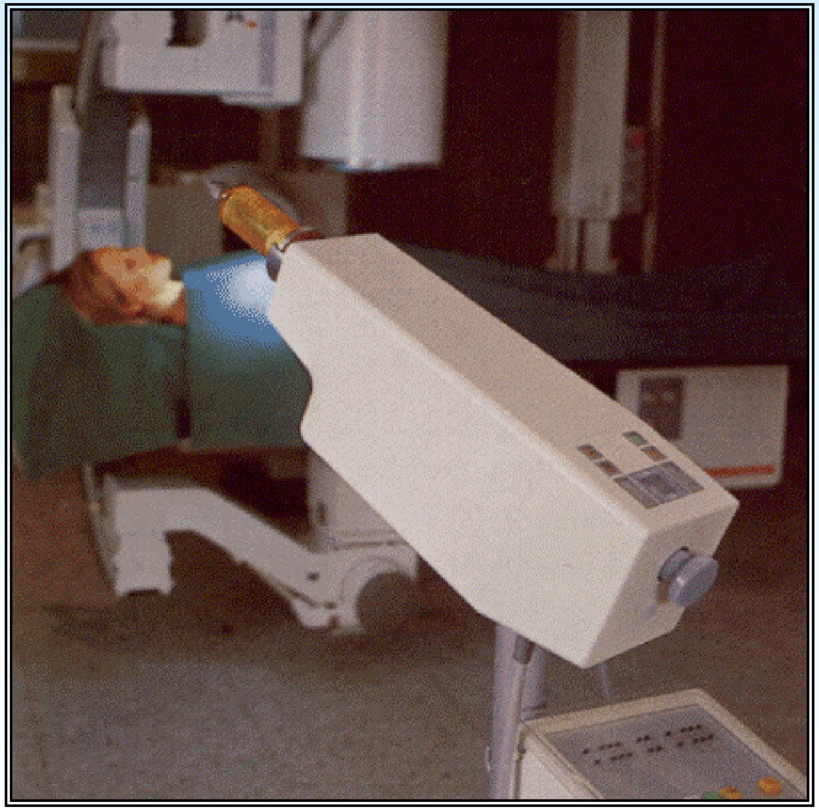


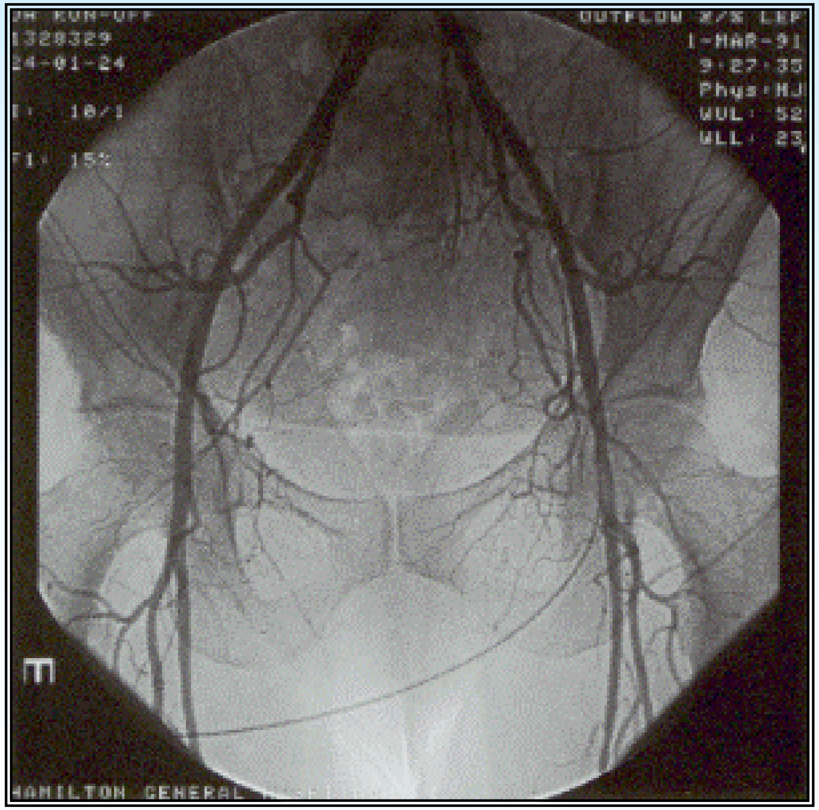
One and two level Angiography Systems





Angiography Systems equipped with synchronized contrast media distributor



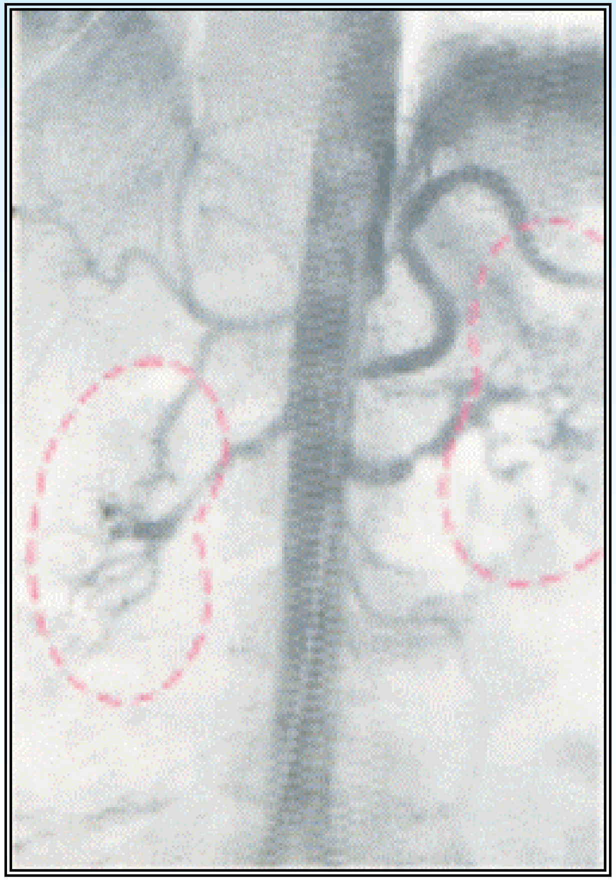


Digital X-ray equipment

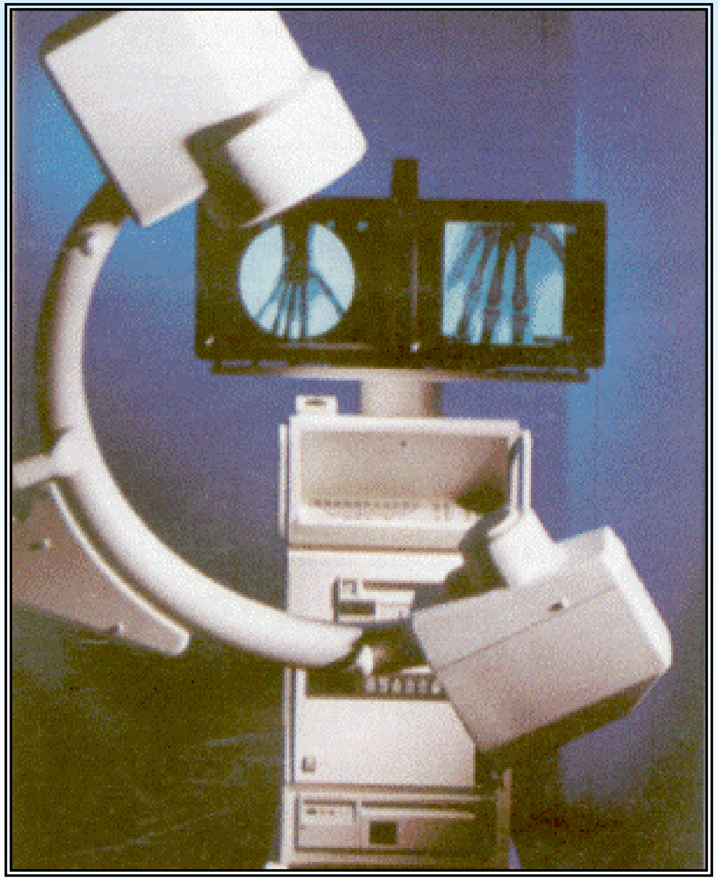
- Computer assisted tomography (CT-scanner).
- Digital Subtraction Angiography.
- Digital Fluoroscopy Systems (including remote controlled systems, C-arms etc).

Digital Angiography Systems

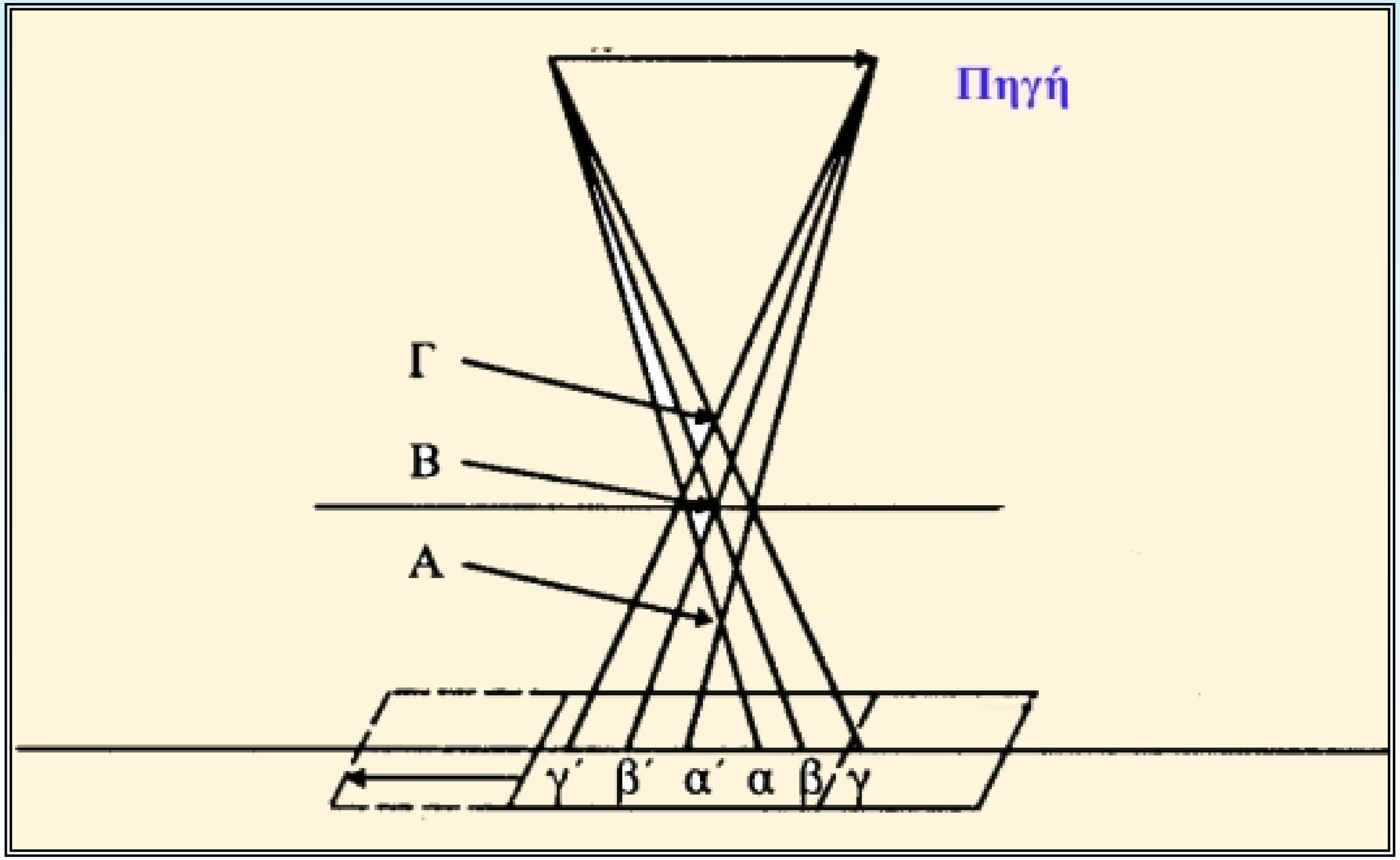
Two differently processed Digital Subtraction Angiography Images



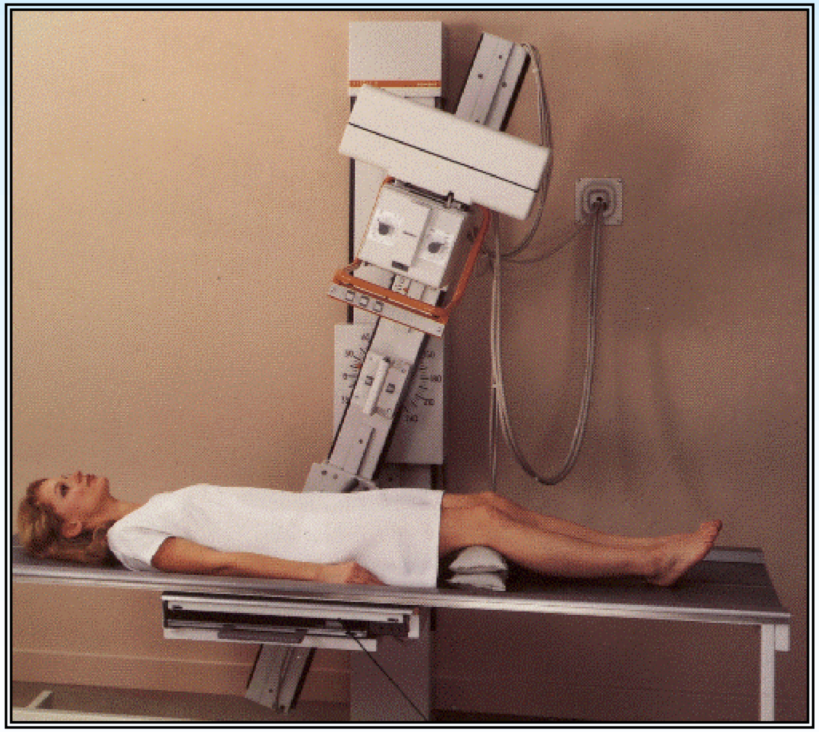
Digital Radiology Systems and Digital C-arm System for the Operation Room

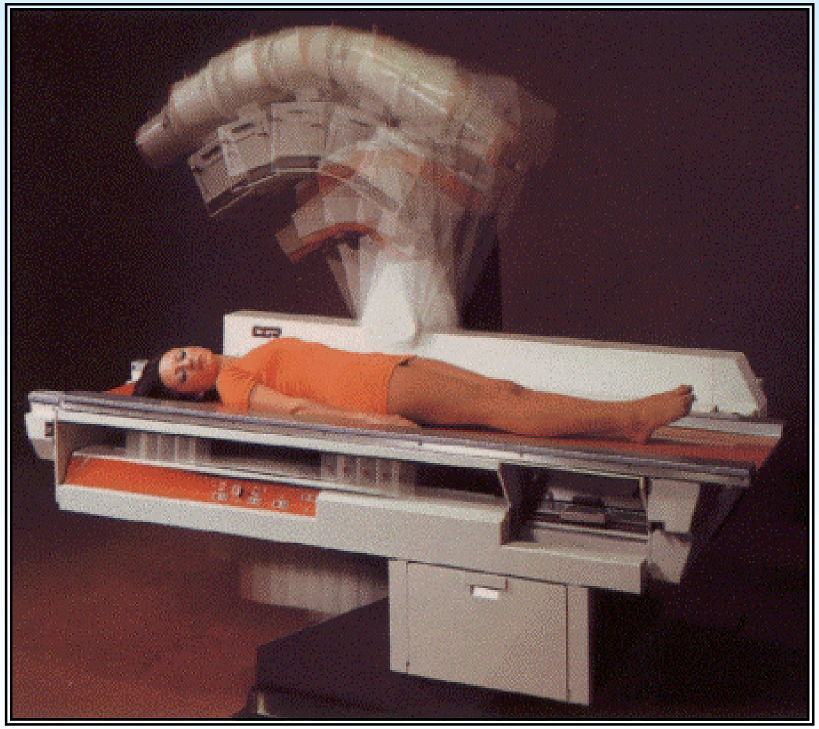


Conventional Tomography: Principle

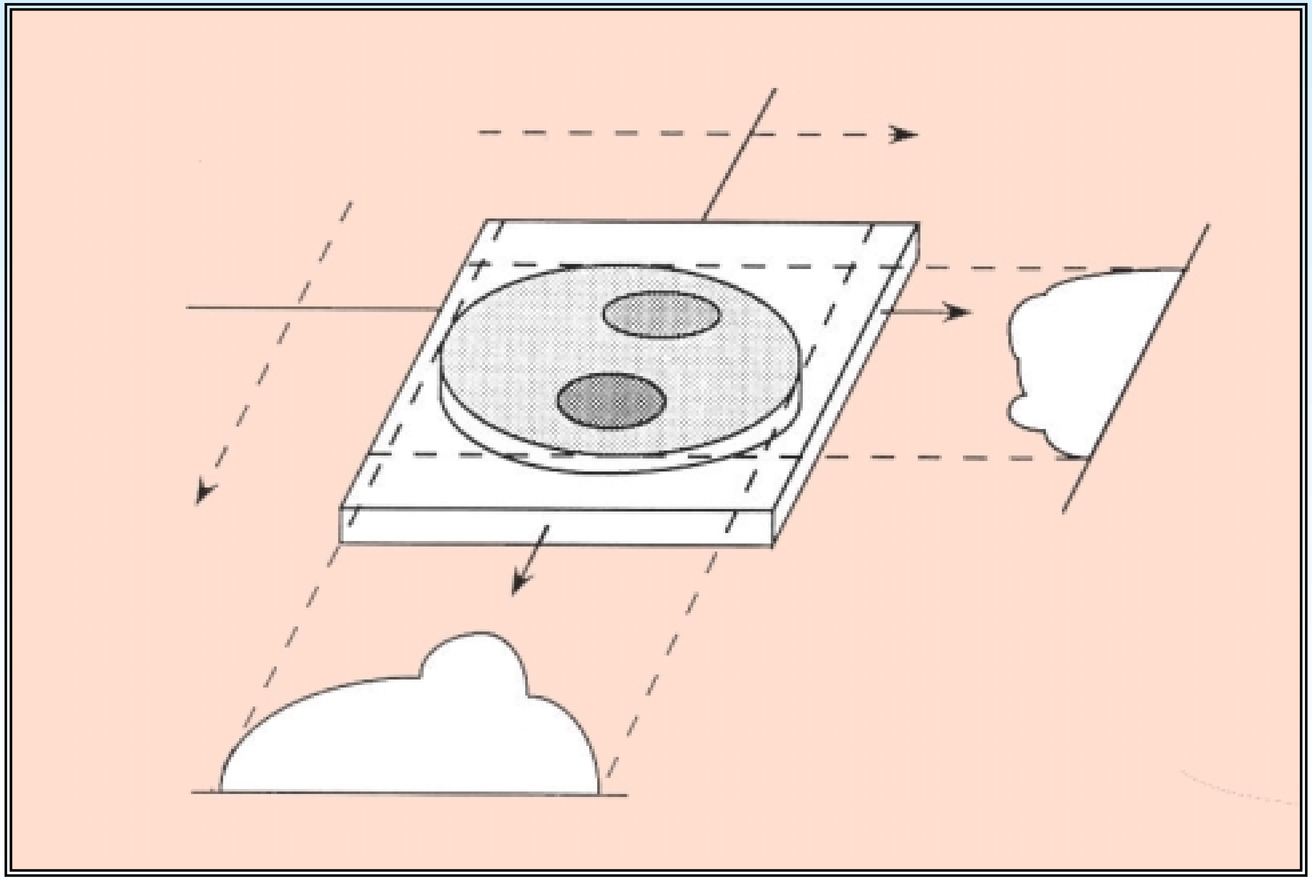


Conventional Tomography: Implementation

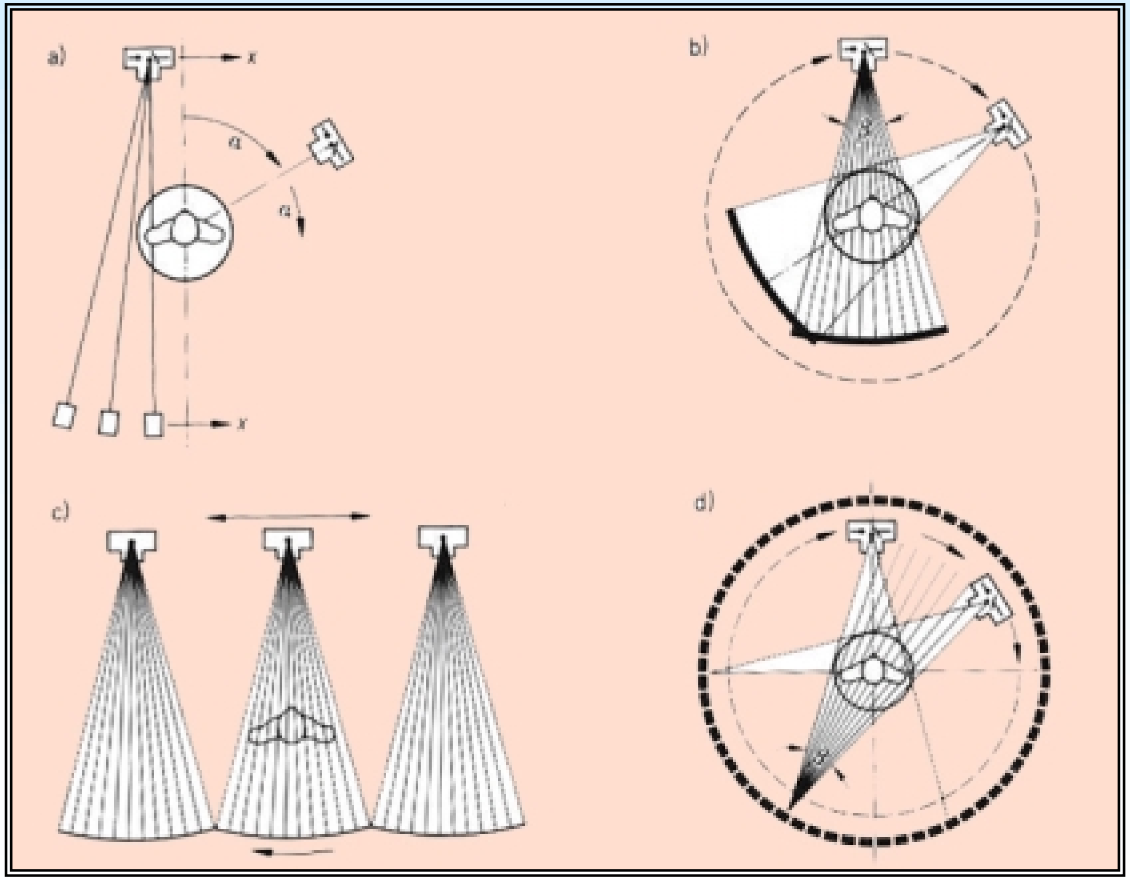




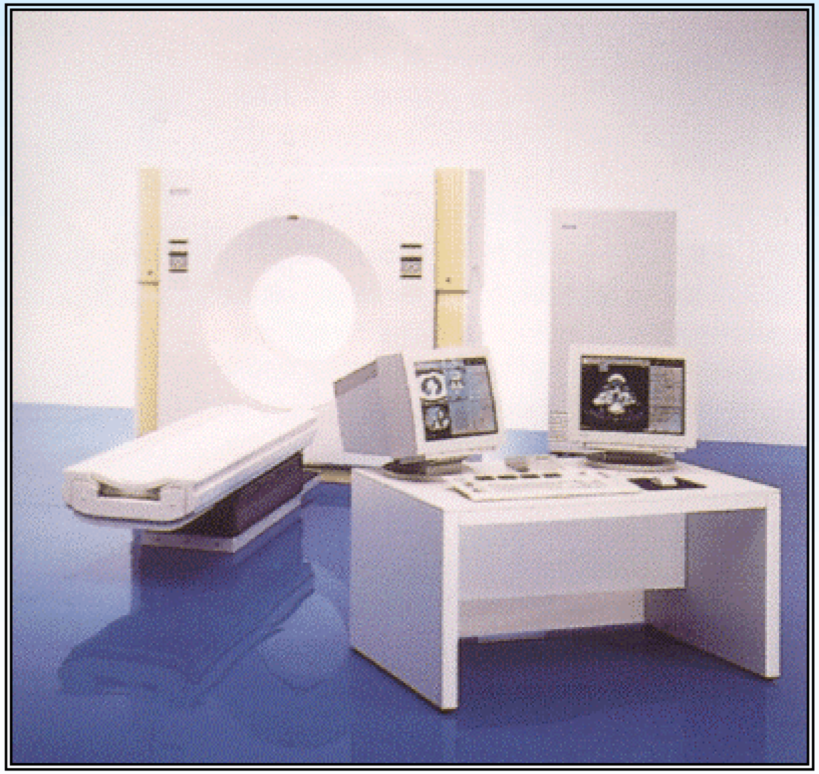
2 - D Object Reconstruction based on its multiple projections (Algorithm: J. Radon, Austria, 1917)

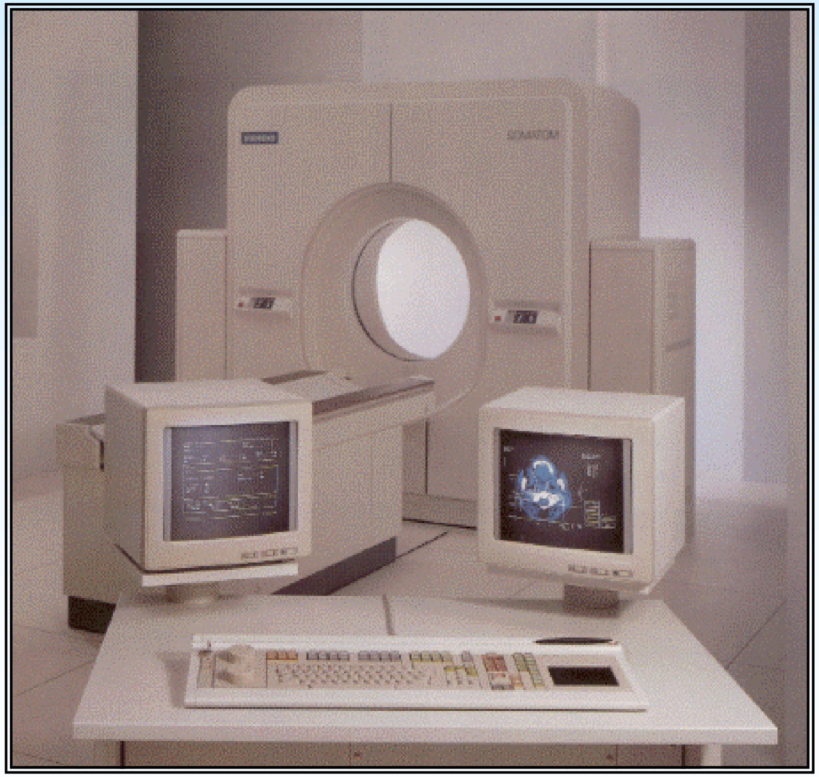


The Invention (Sir Godfrey Hounsfield, EMI, London, and Alan Cormack, Tufts University, Medford, MA) and the Evolution of CT

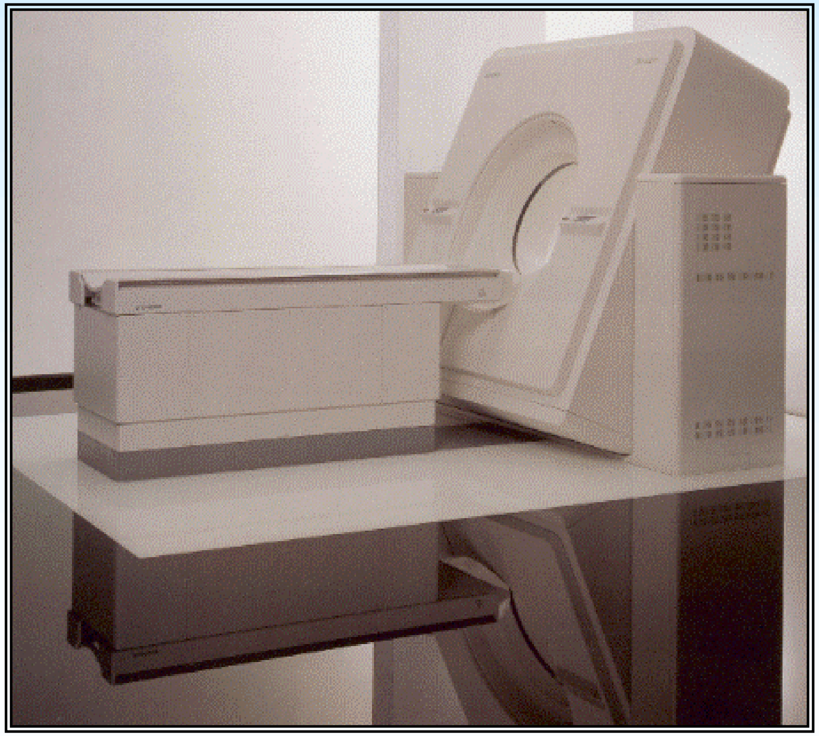


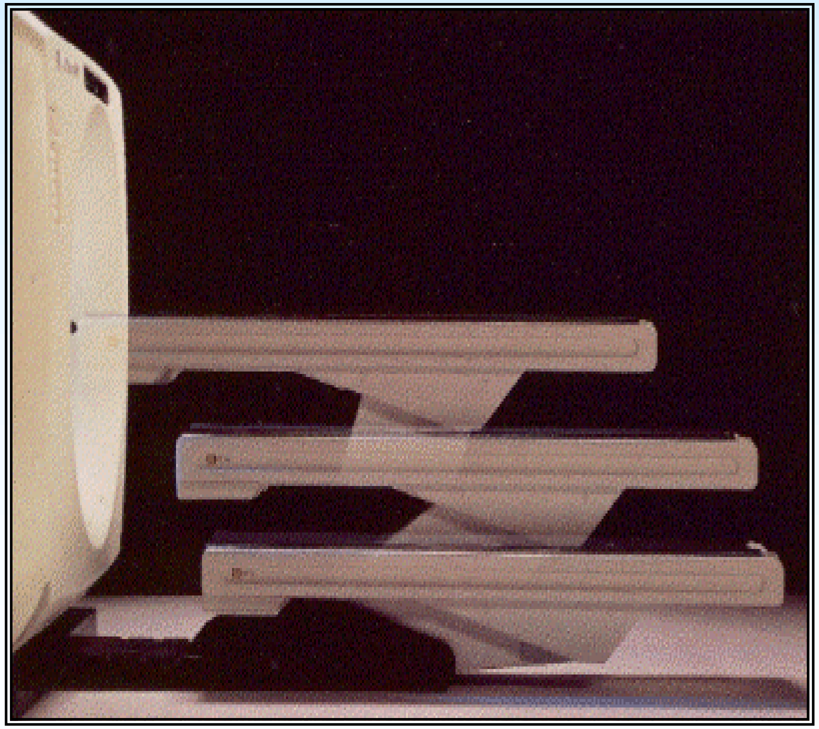
Modern CT





CT Gantry and Patient Table Movements

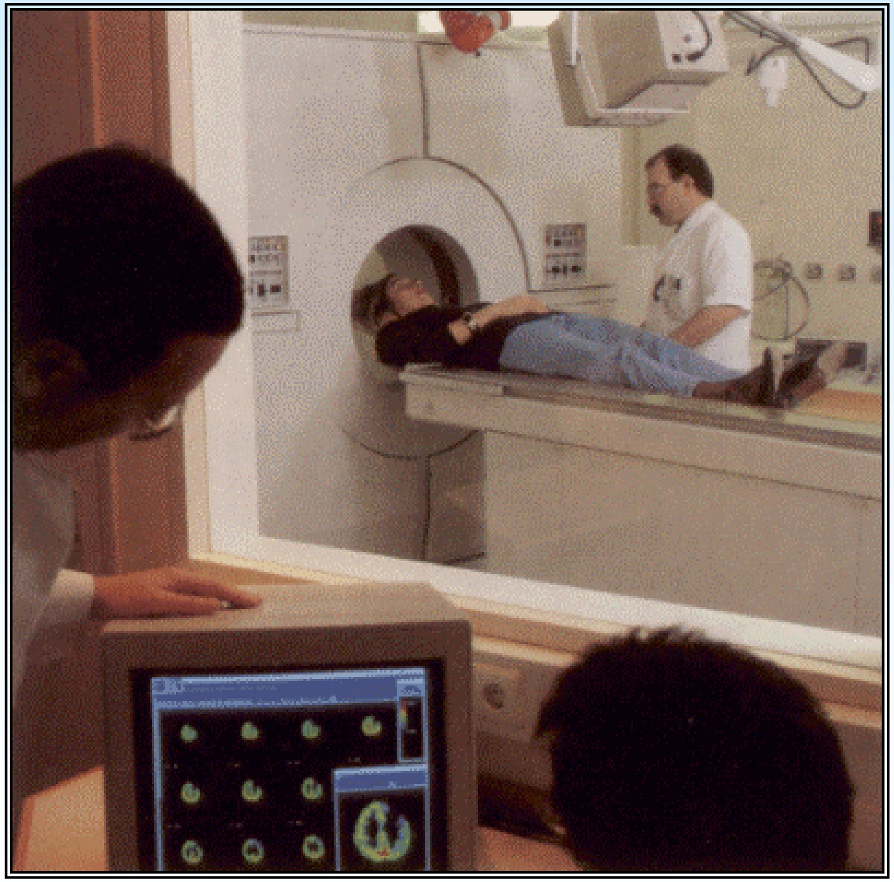




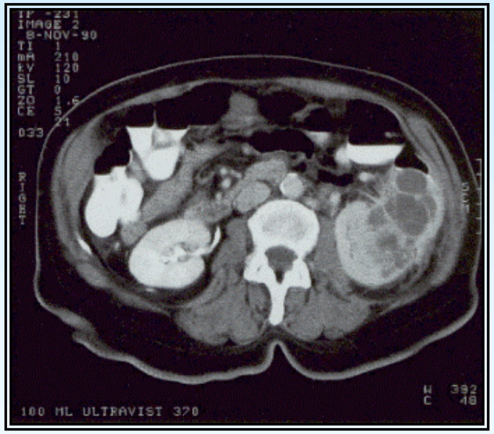
CT Detectors

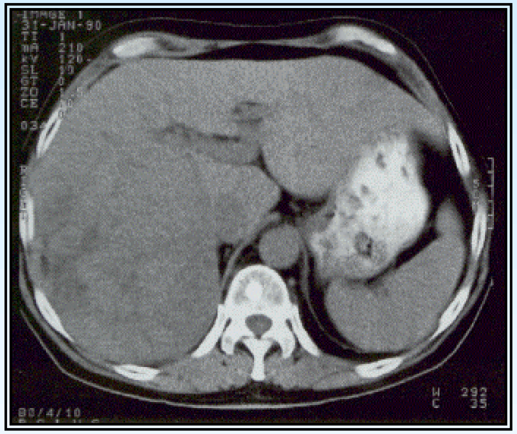
- Scintillators (NaI, CaF_2, $CdWO_4$, CsI) connected to Photomultiplier or Photodiodes.
- High Pressure Ionization Chambers (Xe or Xe-Kr).

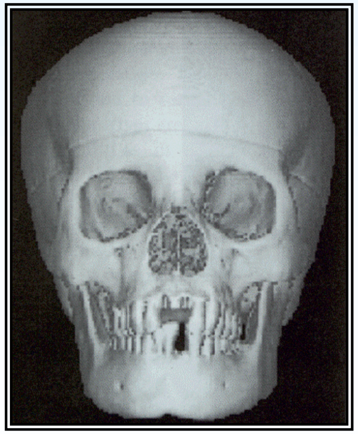
Typical CT Examination Room



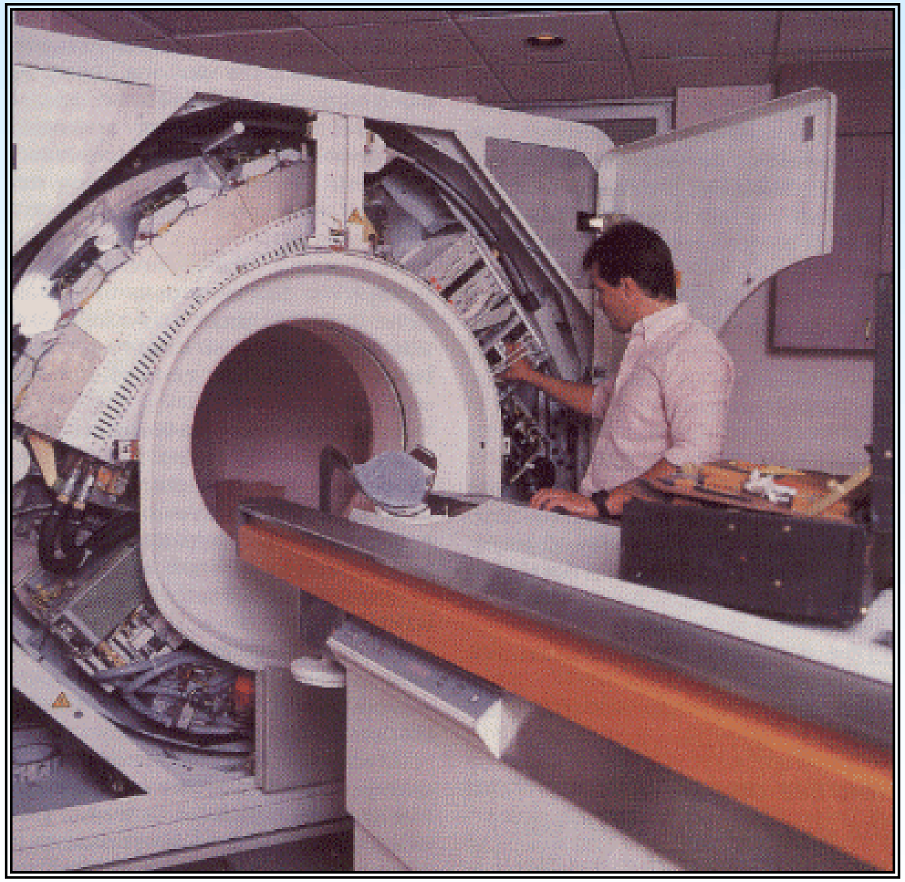
CT Slices and 3-D Image Reconstruction



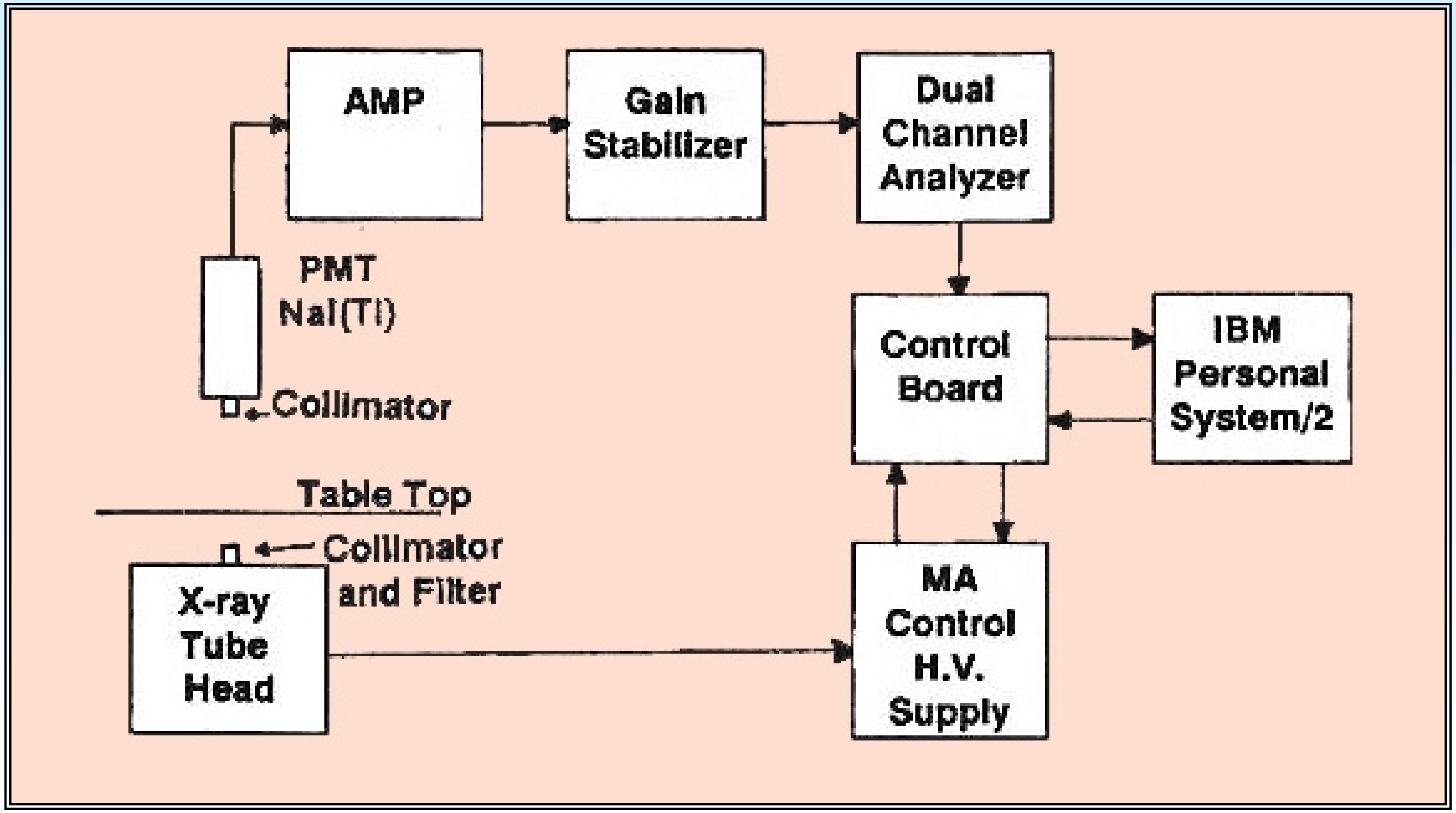




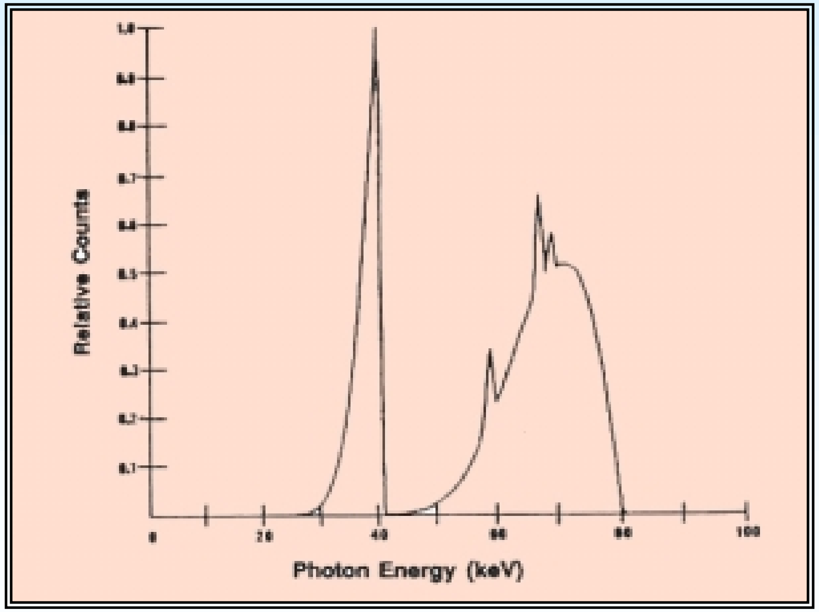
CT Service and Maintenance Contracts

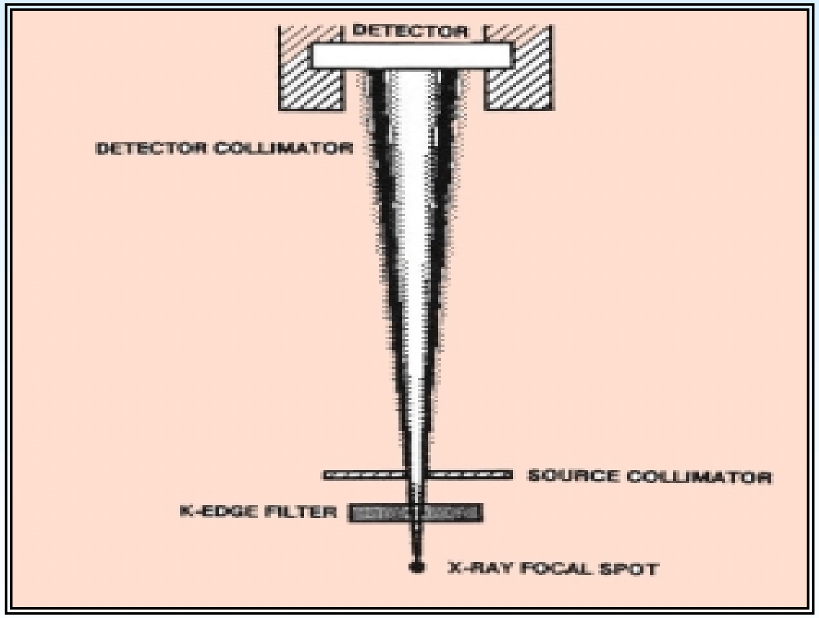


Bone Densitometry Systems

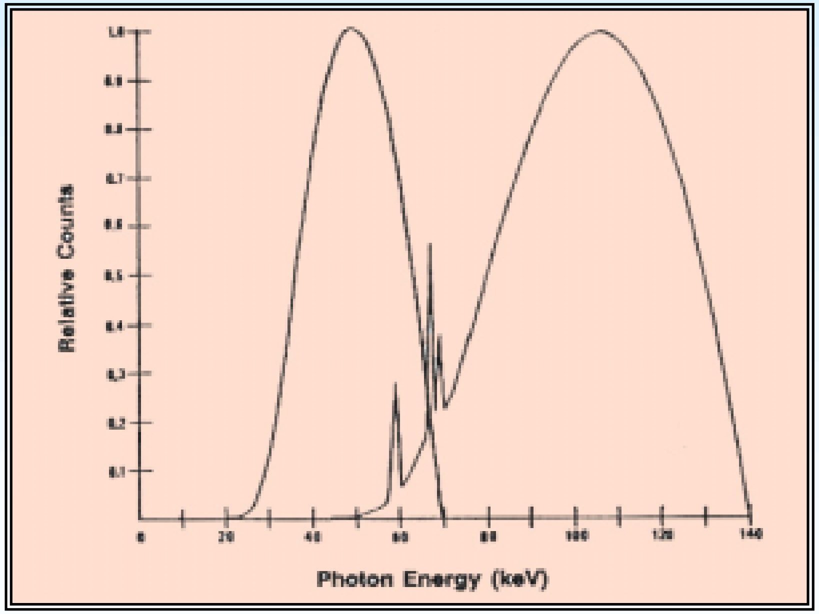


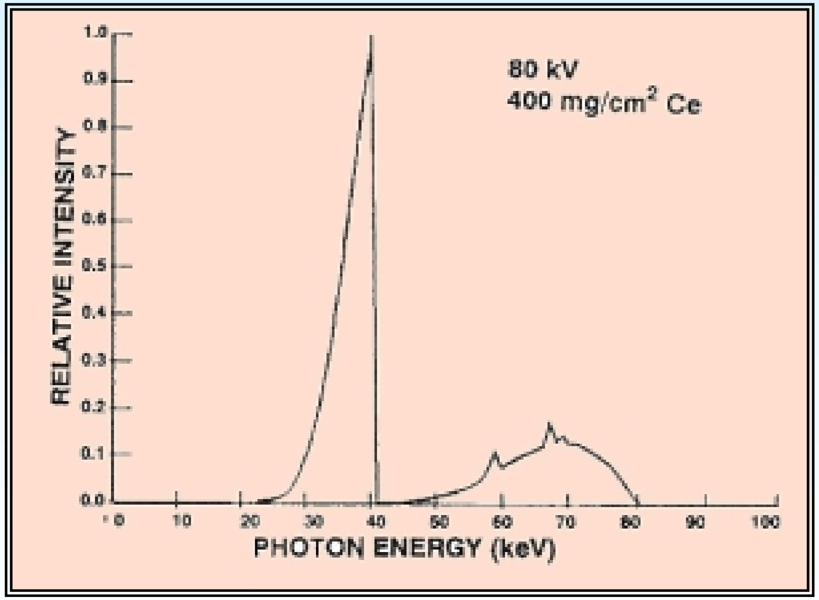
80 kV filtered X-ray spectrum and NaI(Tl) detector



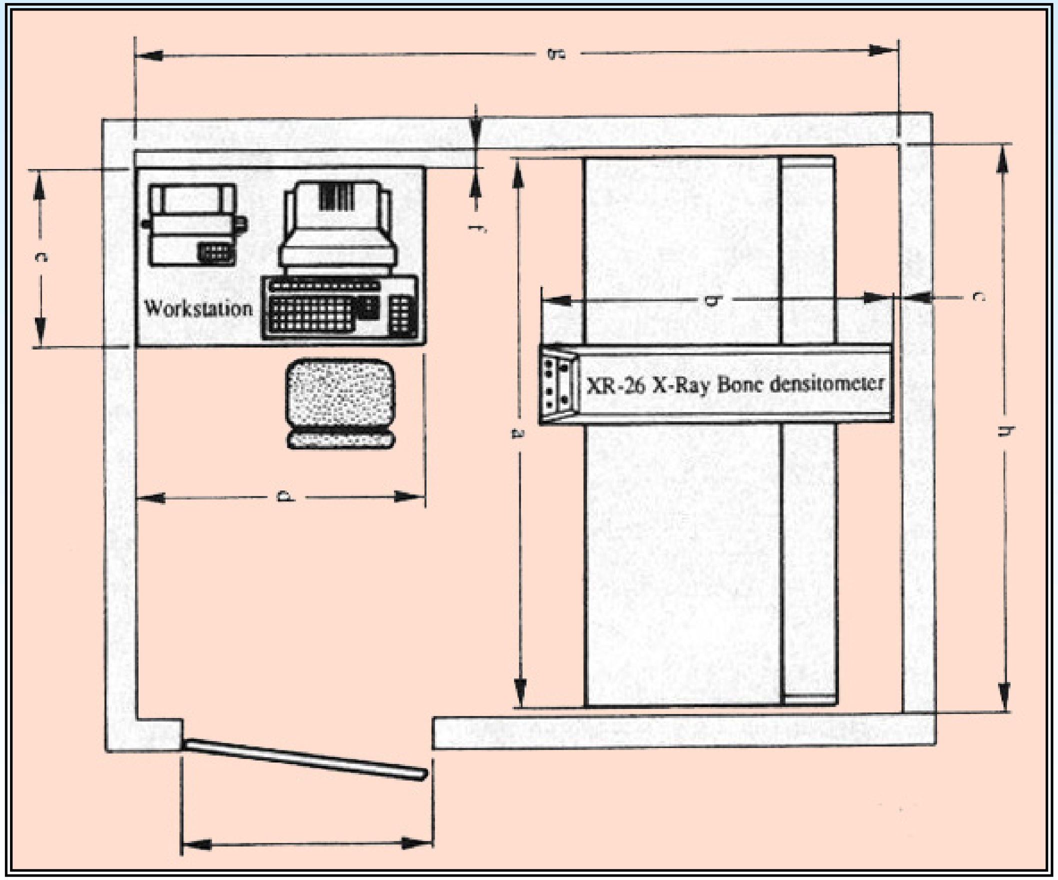


40 kV and 70 kV X-ray spectra and 80 kV 400 mg/cm² Ce filtered X-ray spectrum

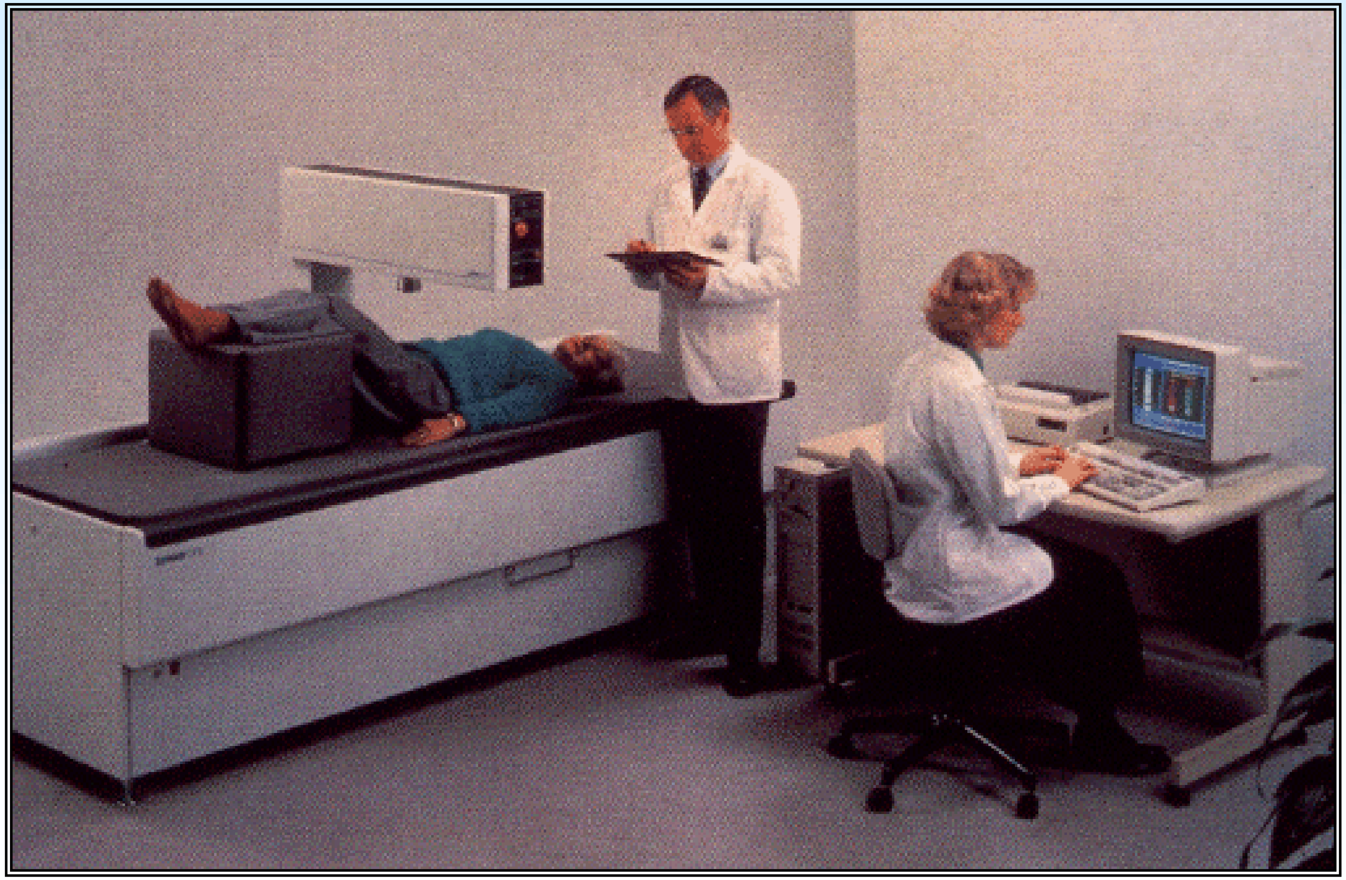




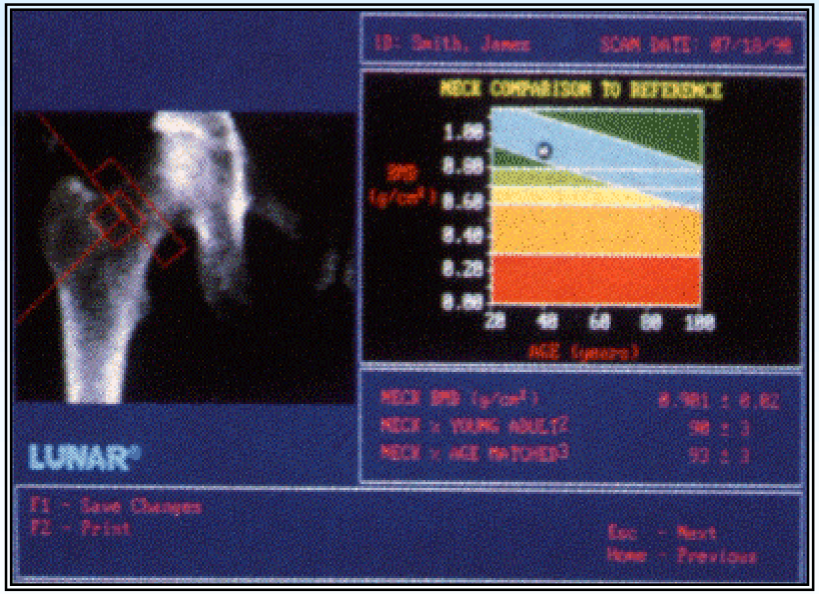
Typical Layout of a Bone Densitometry Examination Room

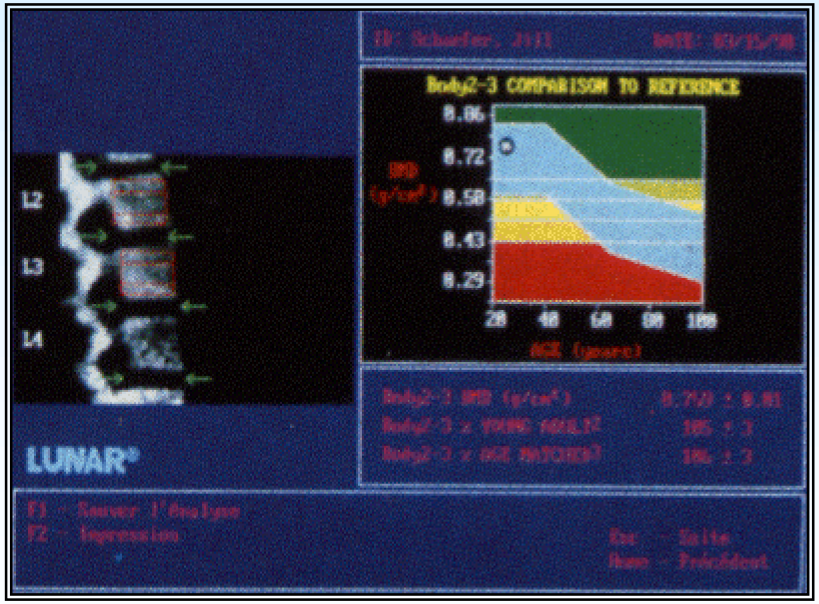


Typical Bone Densitometry Examination Room



Typical Bone Densitometry Examination Print-outs

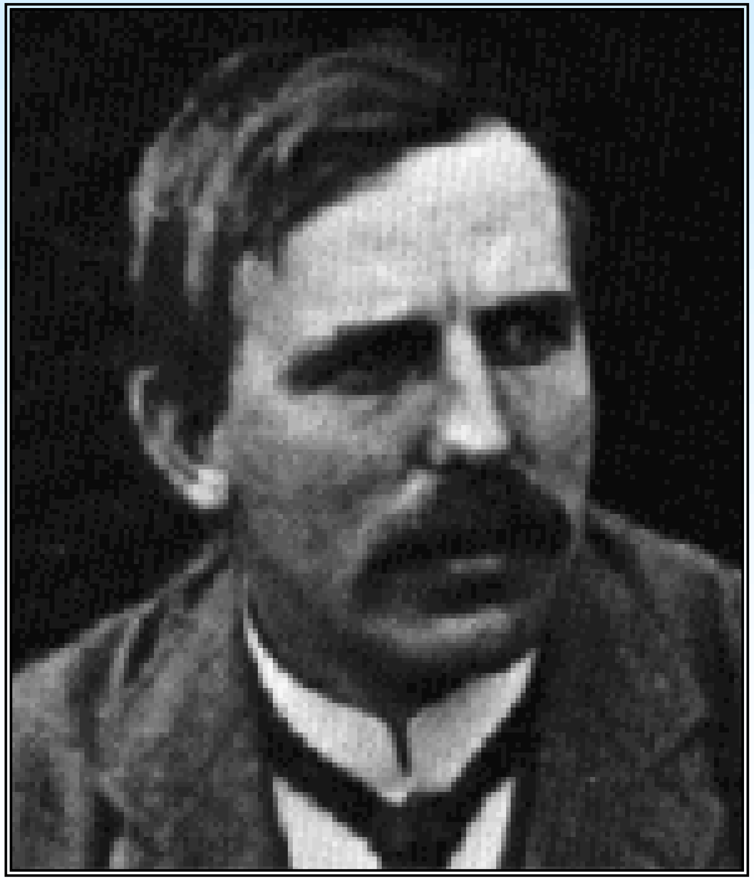


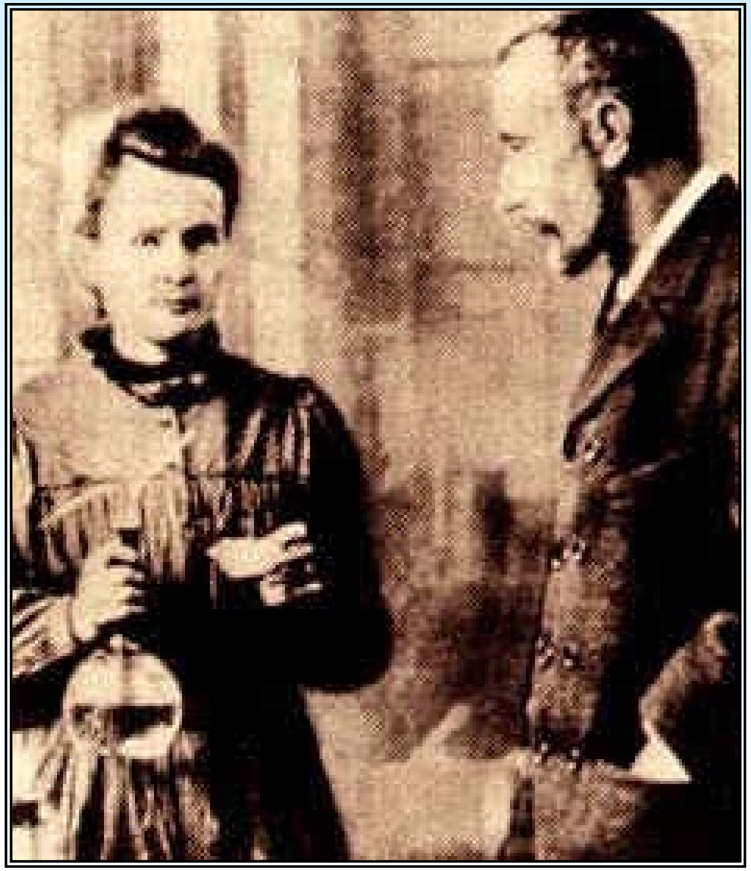


Management of X-ray Diagnostic Equipment

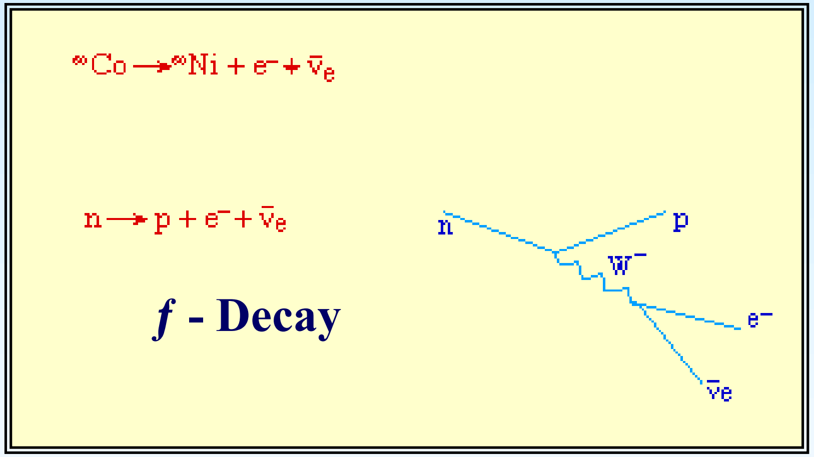
- Workflow planning to optimize existing architectural design.
- Selection of appropriate system, fitting to the Hospital needs.
- Selection and sharing of X-ray equipment power supply (generator).
- Film processing method and associated quality control.
- Conditions of X-ray equipment maintenance contract.
- Conditions of X-ray tube guarantee.
- Archiving and Digital Image handling.
- Radiation Protection.
- Quality Assurance in everyday Operation.

Marie and Pierre Curie / Ernest Rutherford





Nuclear Medicine

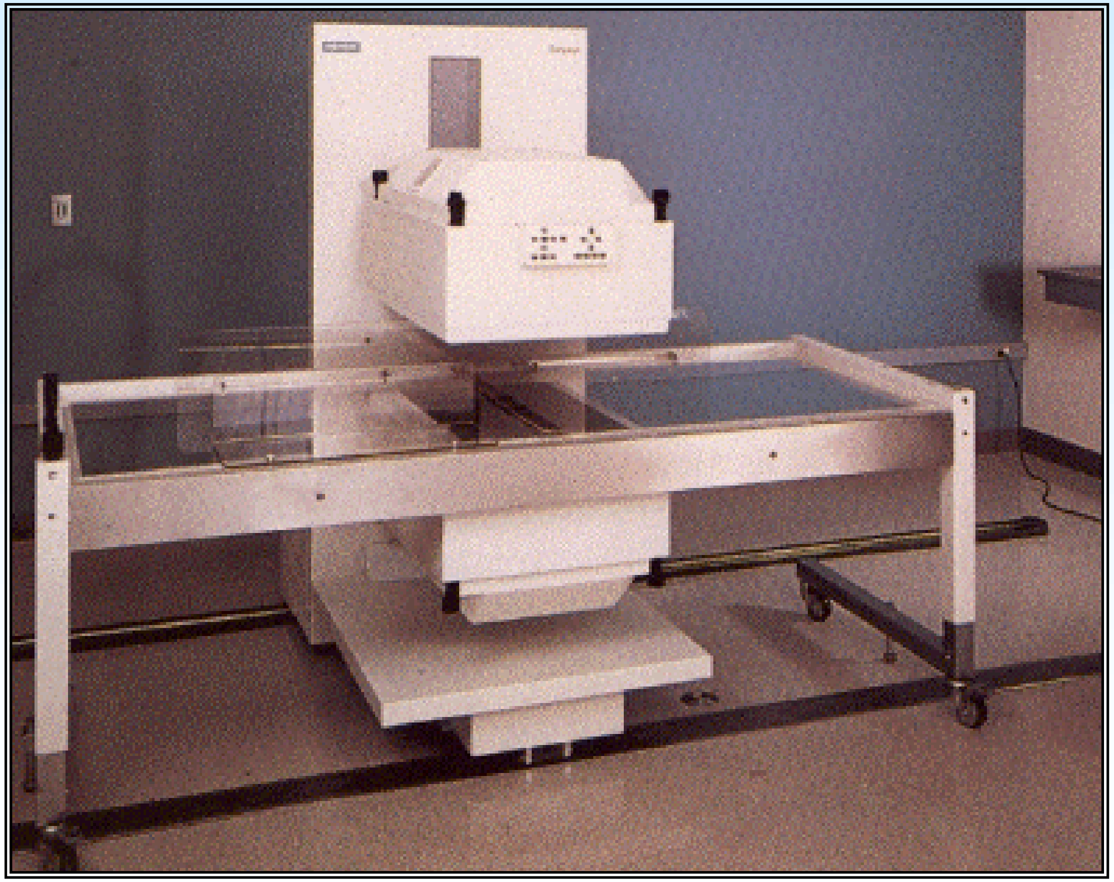


- Nuclear Medicine is the specialty that uses *radioactive tracers* to medical situations, mainly for imaging purposes, but also for therapeutic ones.
- A complete nuclear medical service includes several sections and rooms.

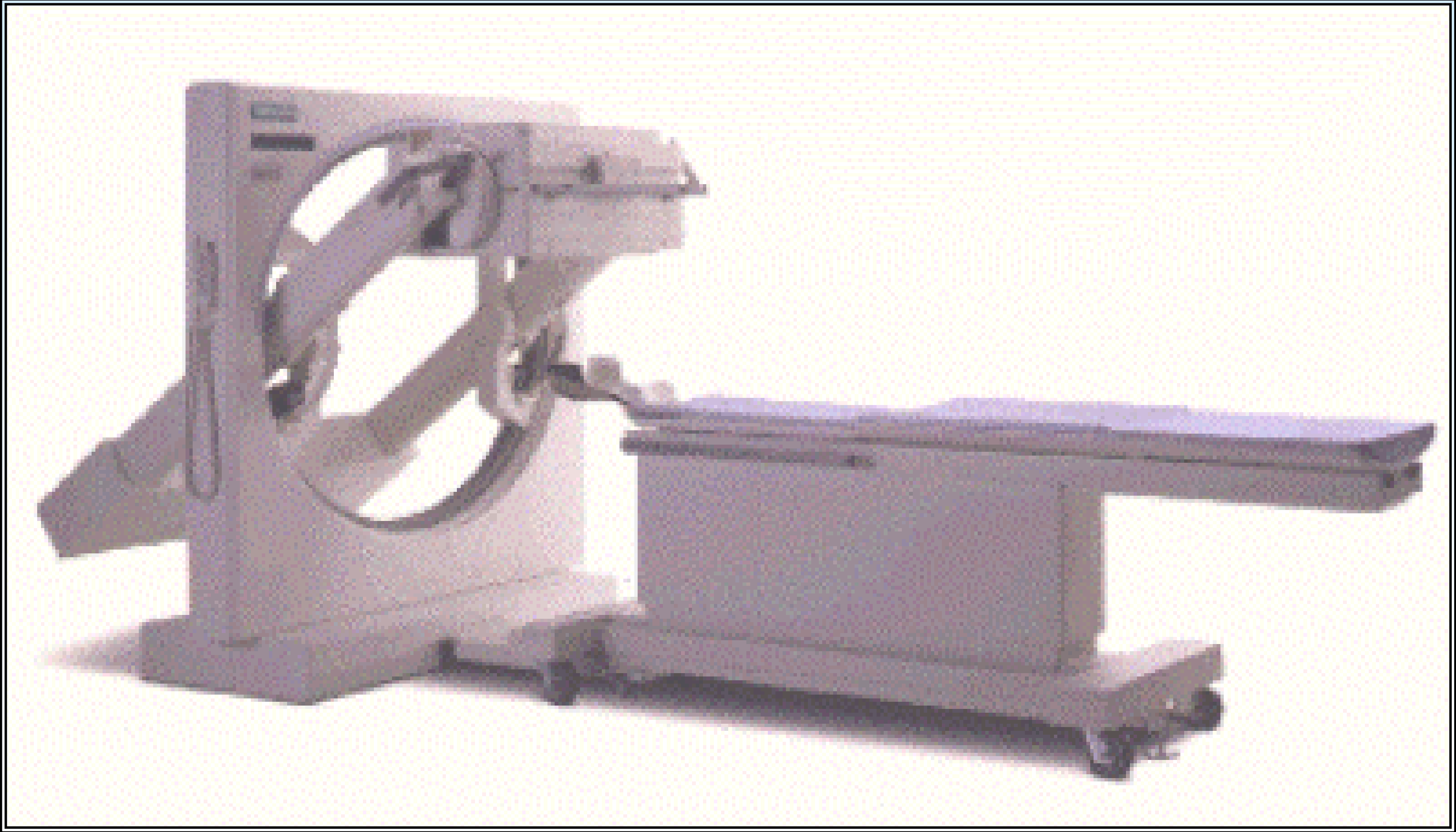
Nuclear Medical Service Sections and Rooms.

- **Radio-pharmaceutical preparation:** hot-lab, application room and in some major University Hospitals also a Cyclotron Facility for the production of positron emitting isotopes for Positron Emmission Tomography (PET).
- **Examination area:** …-Camera examination rooms, also for planar, SPECT, etc., image-processing room, physical examination room, dark room.
- **Physics area:** Radiation shielded store for isotopes, laboratory, electronic shop.
- **Patient area:** Waiting rooms for ambulant and for non-ambulant patients, lavatories.
- **Therapy:** Preparation and treatment rooms, treatment planning room, radiation protected isotope store, nuclear medicine ward.

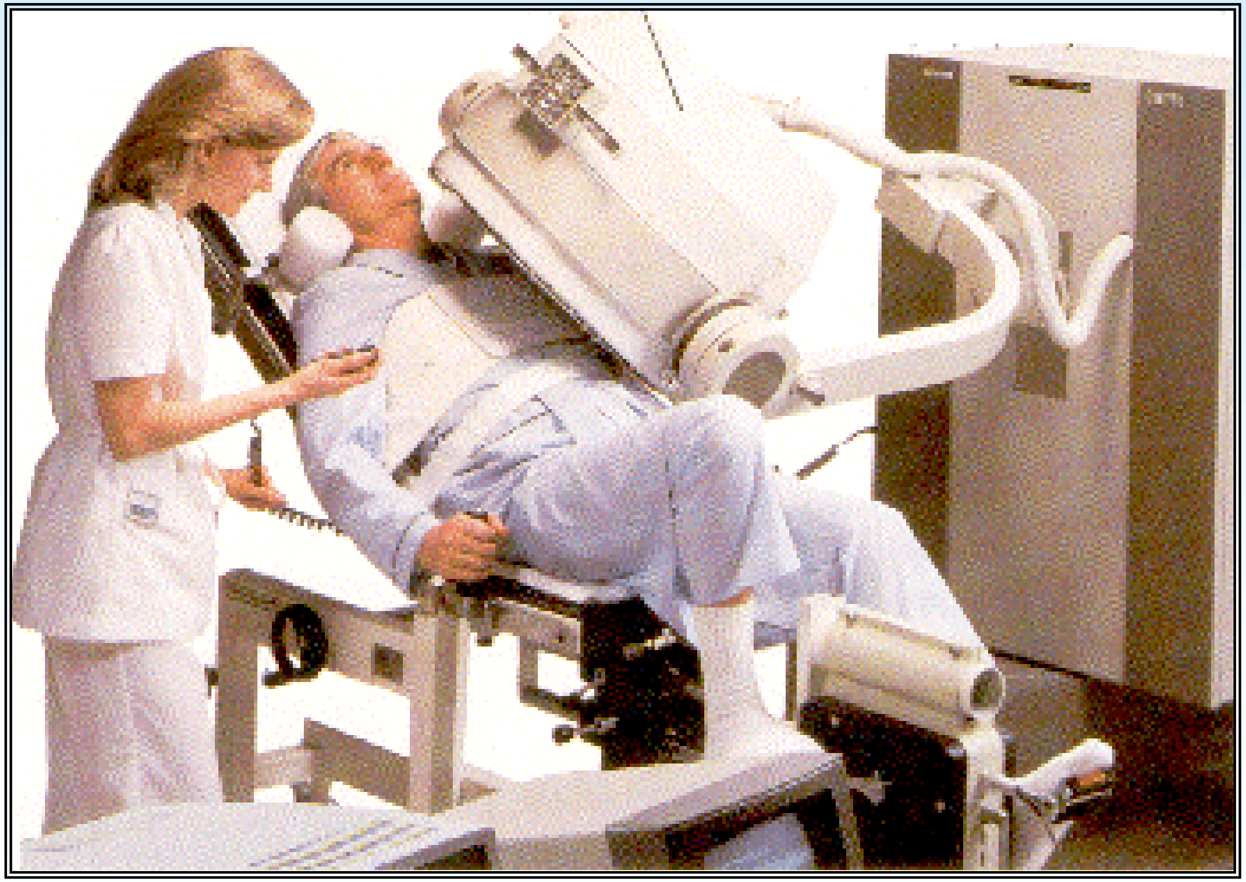
Planar Bone scanning gamma- Camera I



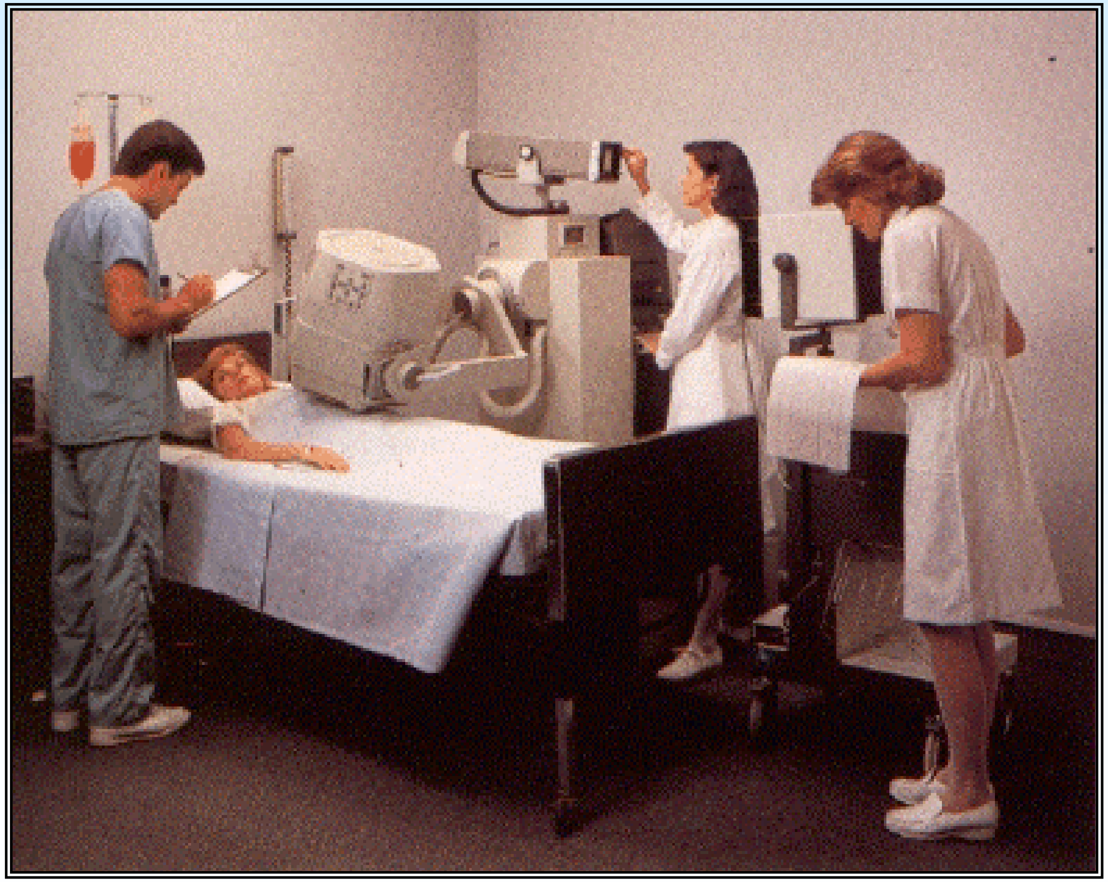
Modern Bone scanning gamma - Camera II



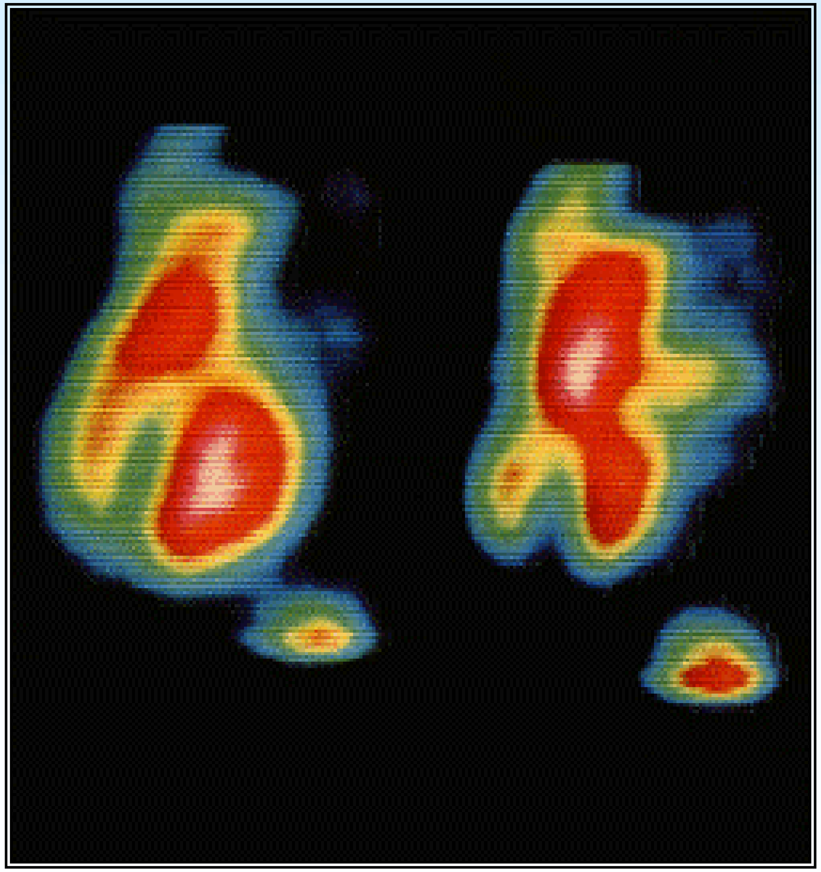
...Camera Tl ^{204} examination combined to stress test



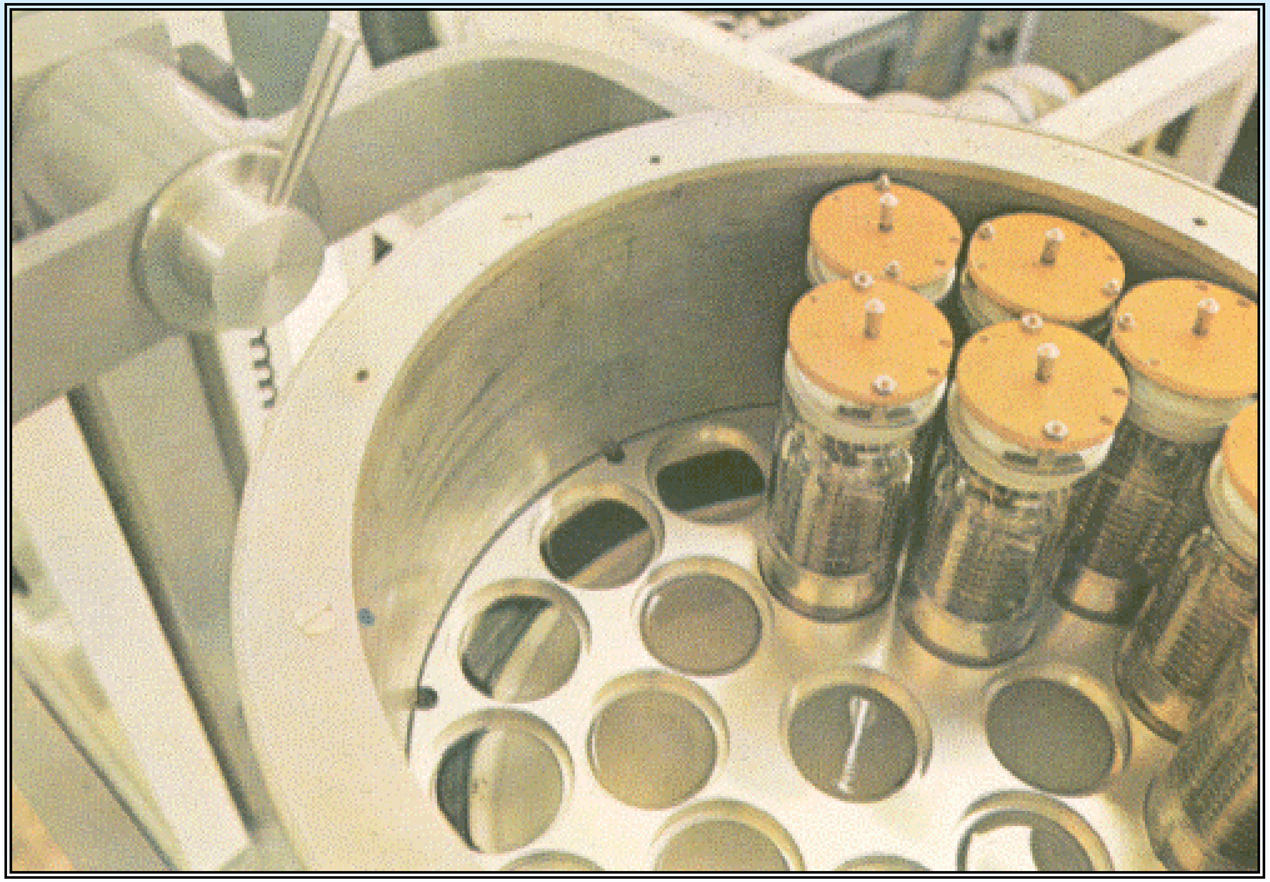
Mobile gamma - Camera



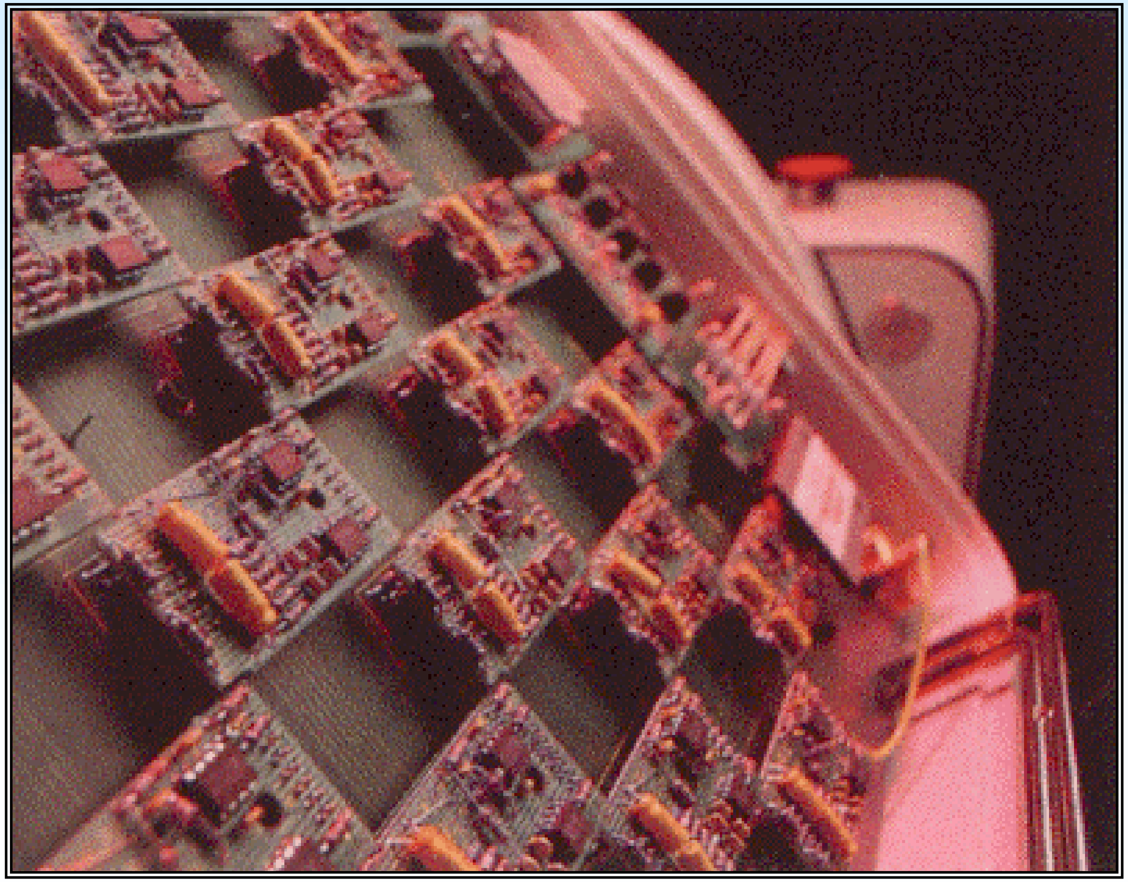
Typical gamma - Camera Images



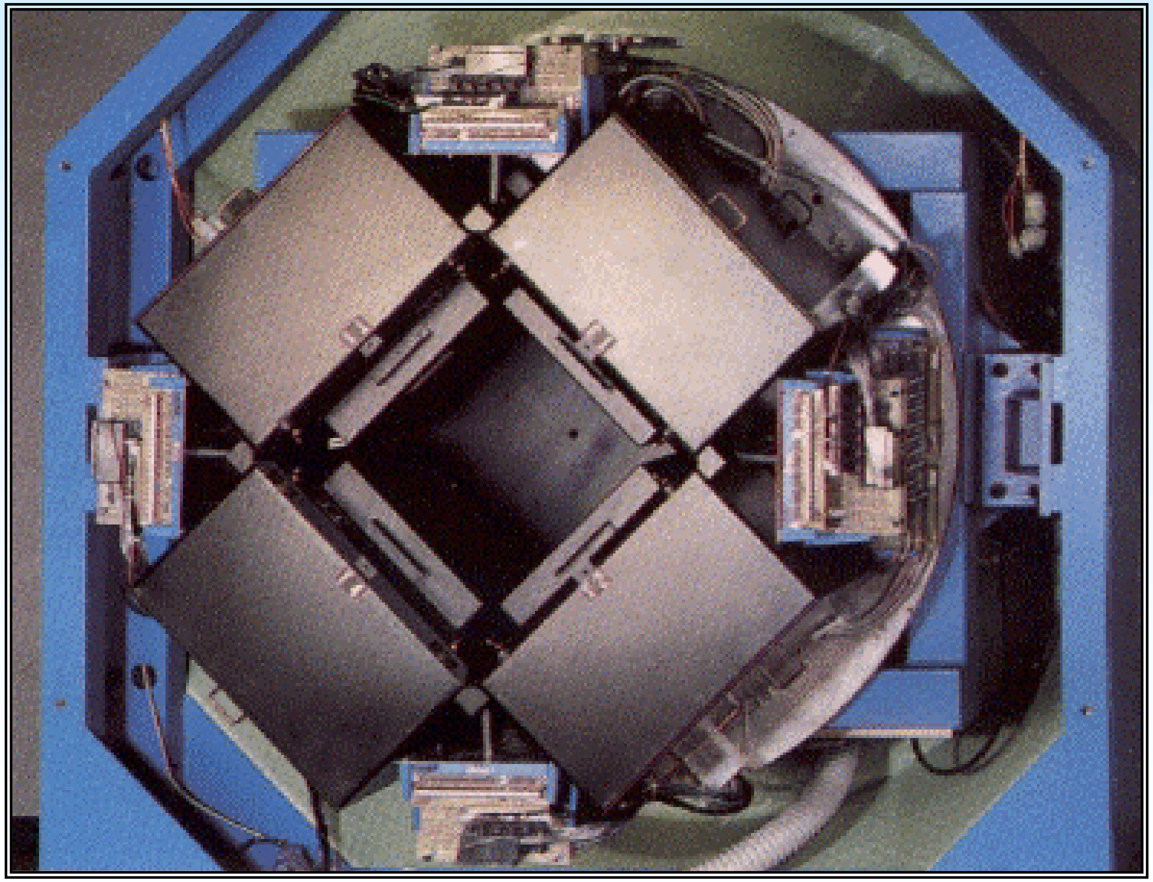
Gamma - Camera round NaI(Tl) crystal and the associated Photomultipliers



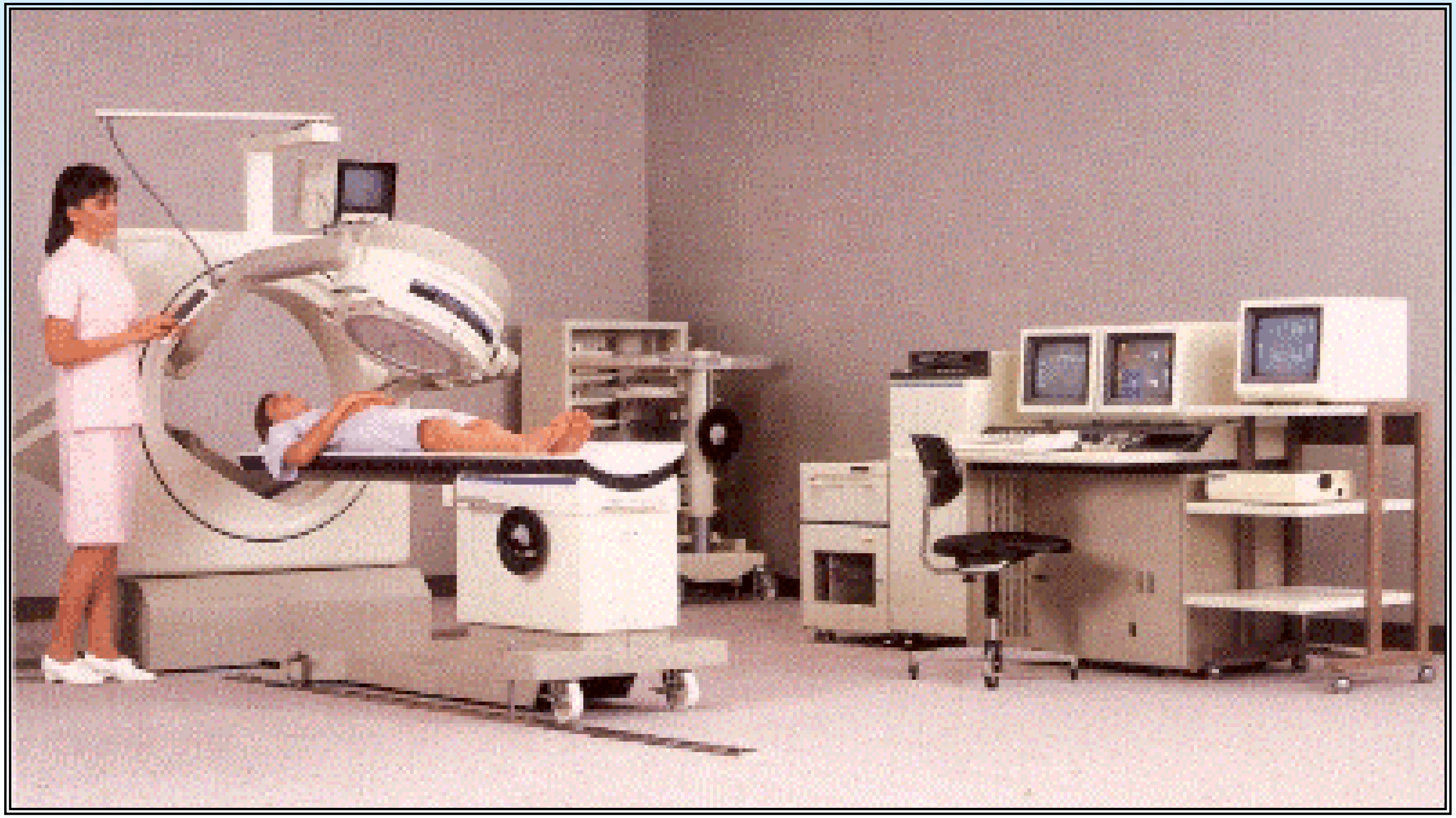
Photomultiplier Amplifier



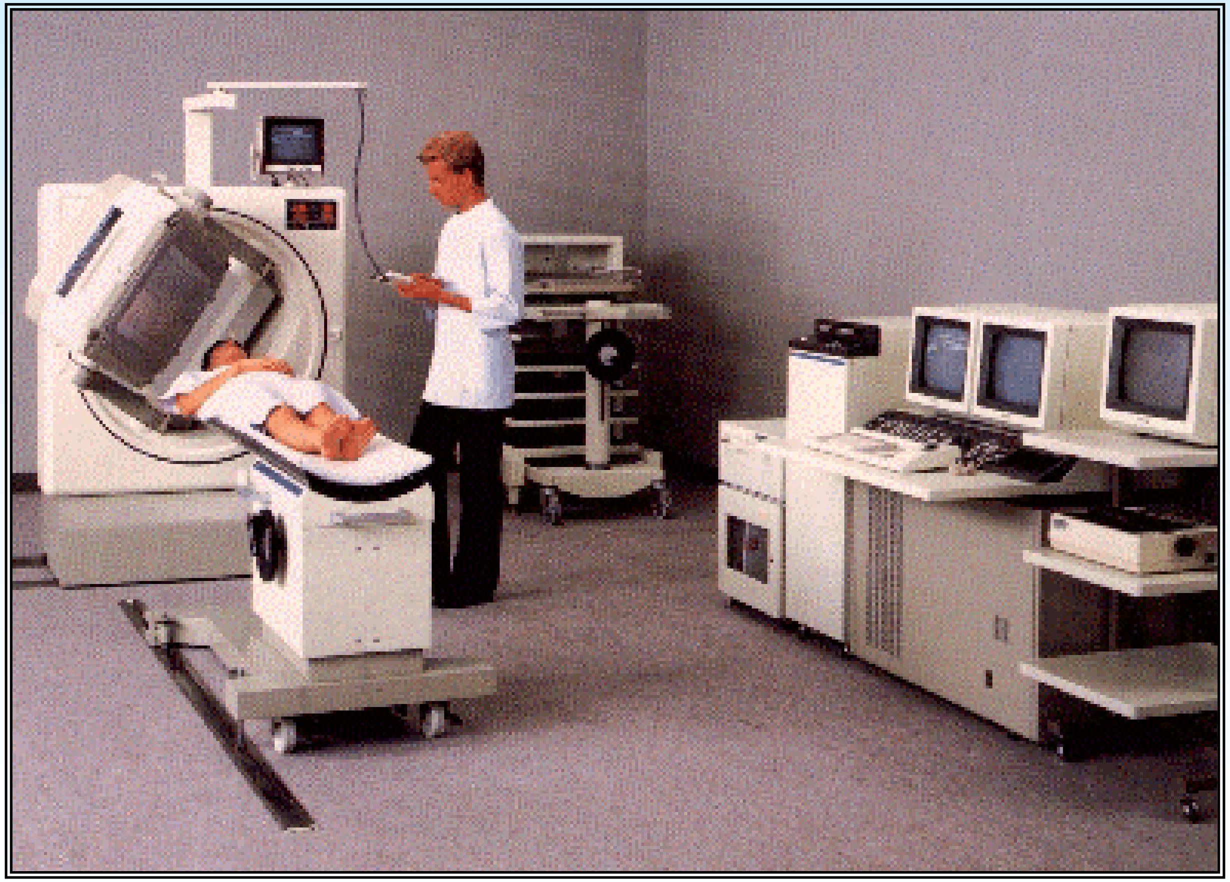
Gamma - Camera Gantry



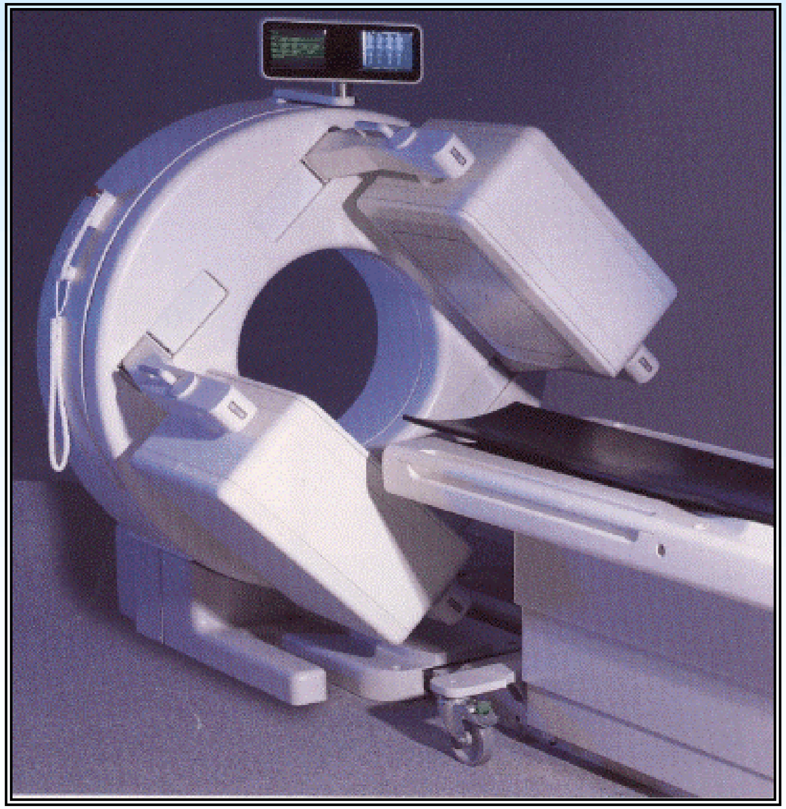
Tomographic gamma - Camera with round crystal



Tomographic gamma - Camera with rectangular crystal



Tomographic gamma - Camera with double round and rectangular crystals



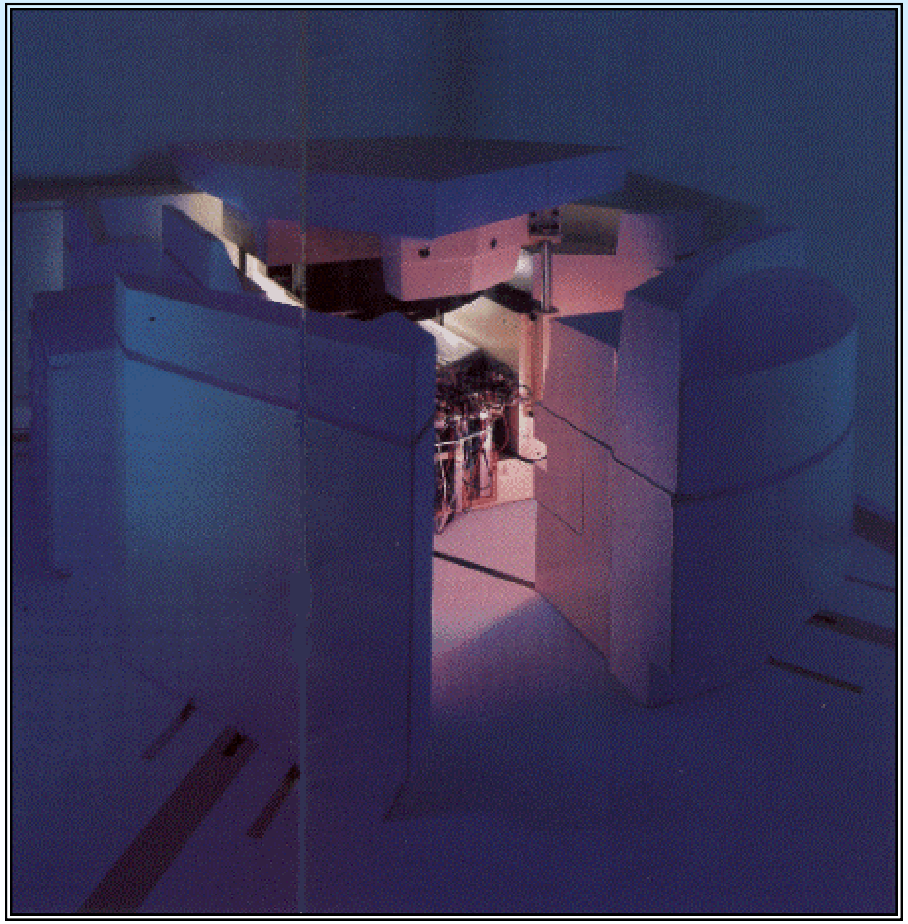
Positron Emission Tomography (PET)

- Positron Emission Tomography (PET) has proven to be a unique tool in analyzing biomedical metabolic function or dysfunction, qualitatively and quantitatively.
- It finds application in cardiology for tissue viability and perfusion studies, in neurology for studying epilepsy, dementia, and other investigative brain studies, and in oncology for early tumor diagnosis, tumor grading, and extent of metastasis.

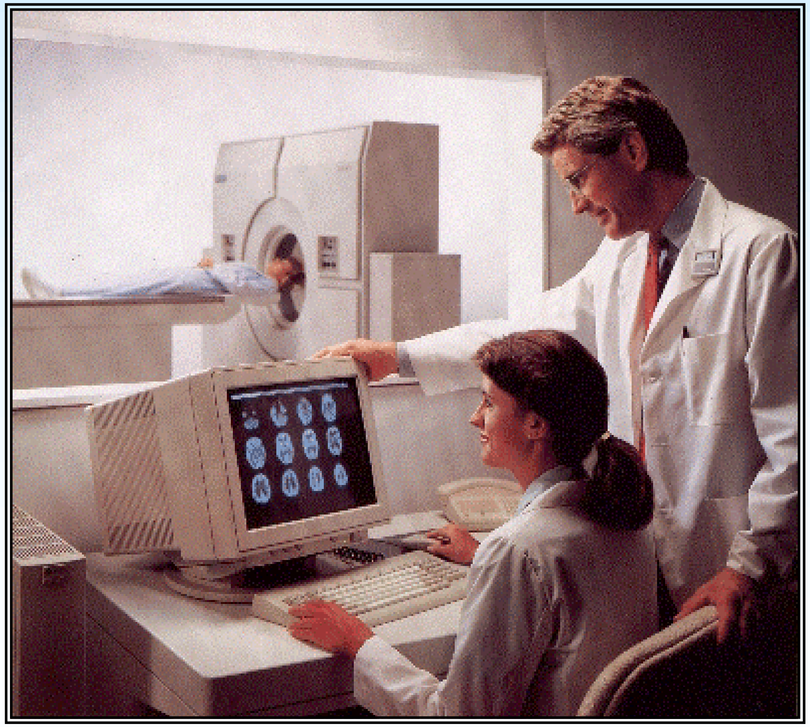
PET Implementation

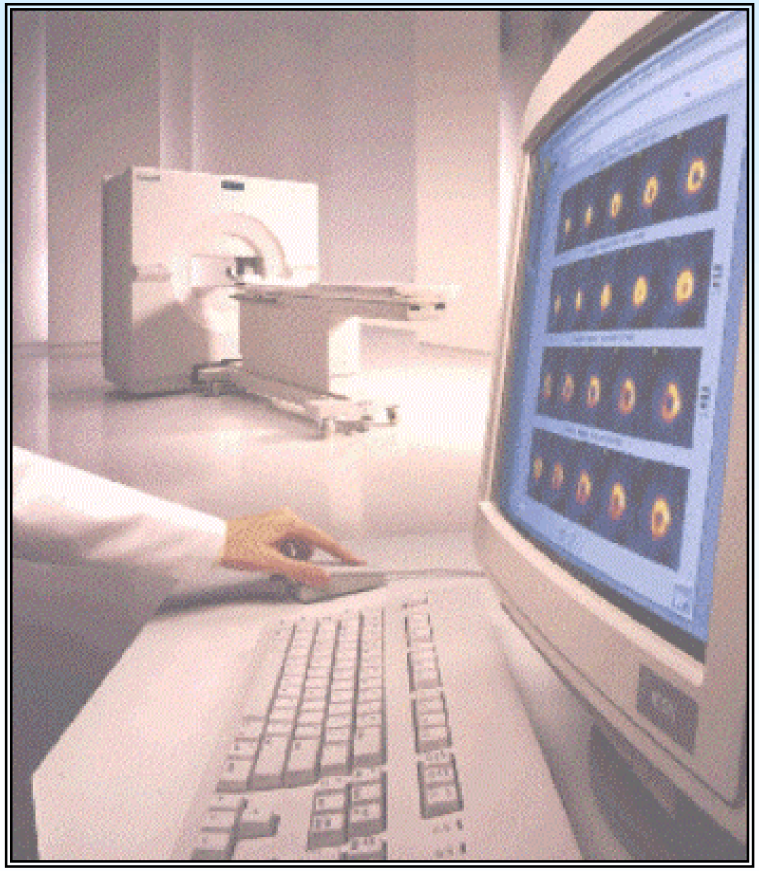
- Positron emission tomography begins with isotopes such as Rubidium 82, Oxygen 15, and Fluorine 18.
- The typical isotopes used in PET scanning have a half-life that ranges from 75 seconds to 110 minutes.
- Cyclotron is a cost effective, easy to operate, shelf-shielded radioisotope delivery system.
- A commercially available modern machine, produces substantial quantities of the major positron emitting isotopes and compounds in a variety of chemical forms under full automation.

A typical commercially available Cyclotron

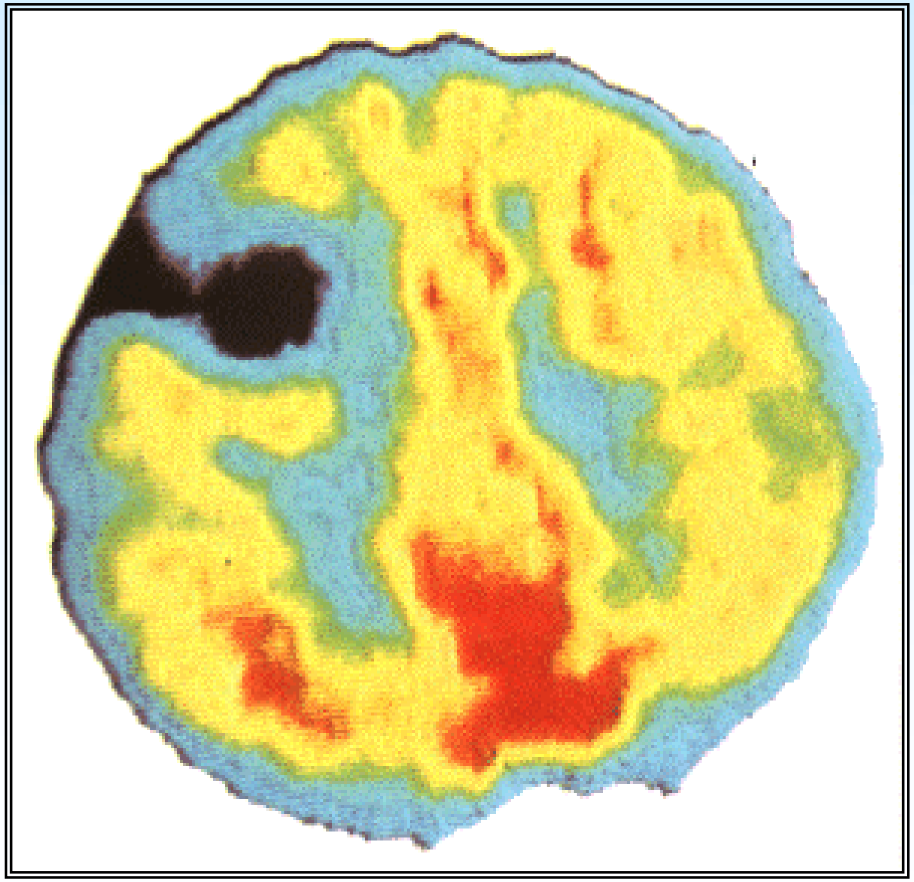


PET System Console



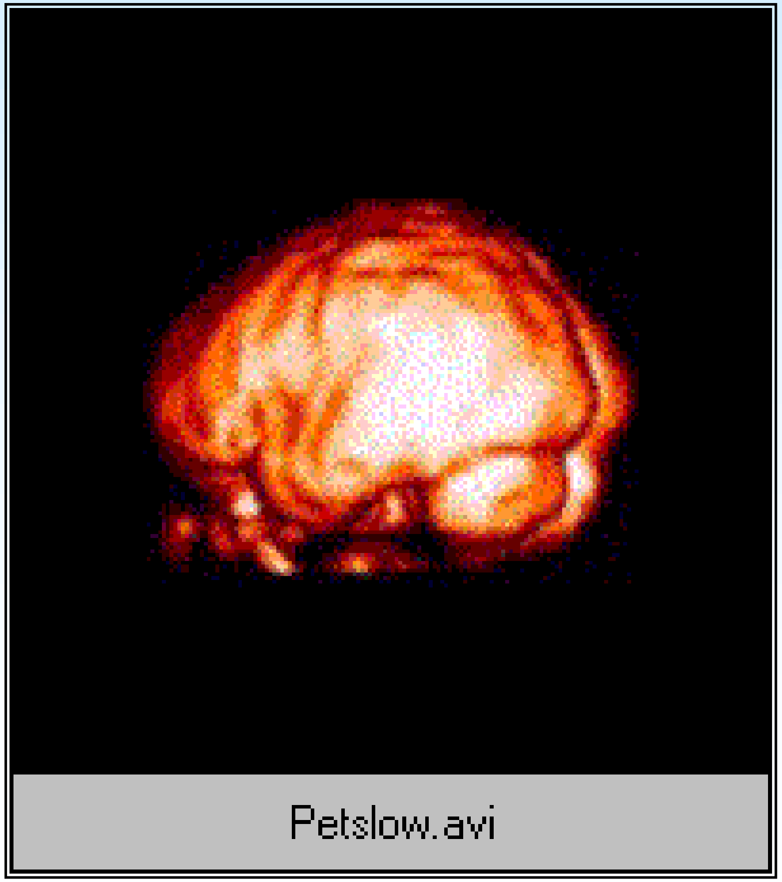


PET scan of a heart following acute myocardial infarction and thrombolytic therapy

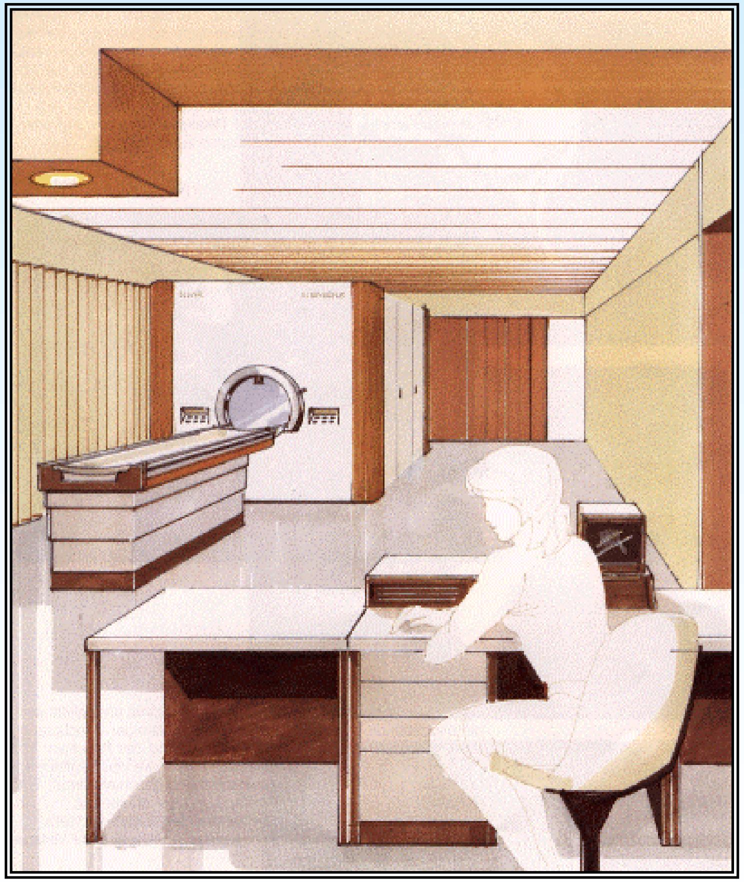


The Rubidium areas show that the tissue, although mechanically abnormal, is metabolically alive.

PET 3-D Brain Image Reconstruction



Magnetic Resonance Imaging (MRI)



Magnetic Resonance Imaging

- In common with all other imaging processes in medical diagnostics, magnetic resonance tomography makes use of the interaction of anatomical structures within the human body with a radiation field.
- With the aid of a radio-frequency field in the Mhz range and a locally variable magnetic field, the sharp resonance absorption of magnetic nuclei in biological tissue is used in order to obtain the spatial distribution of the nuclear magnetization.

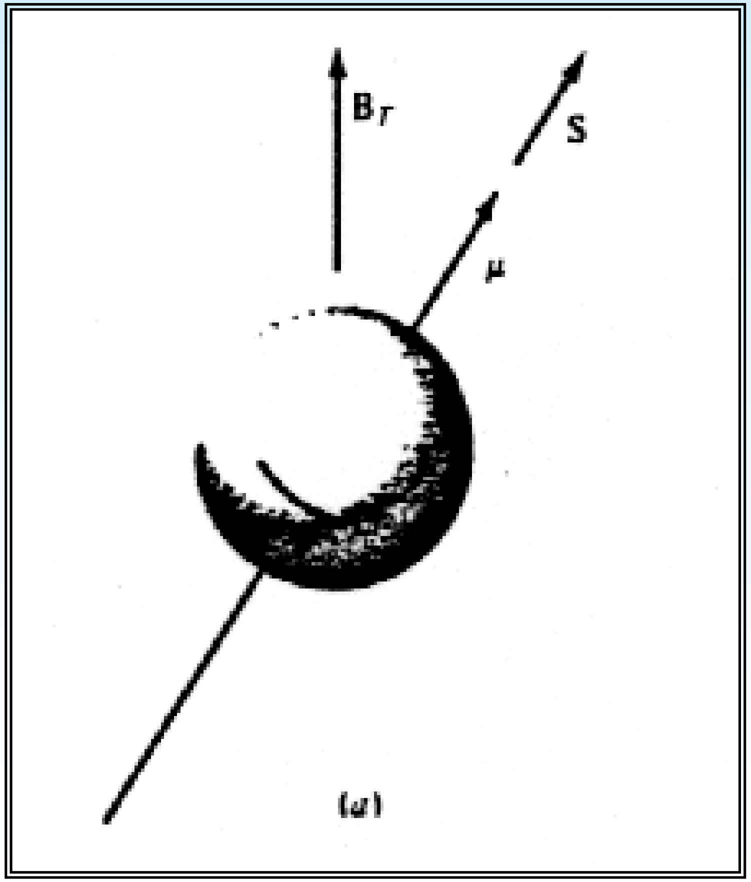
MRI Principle

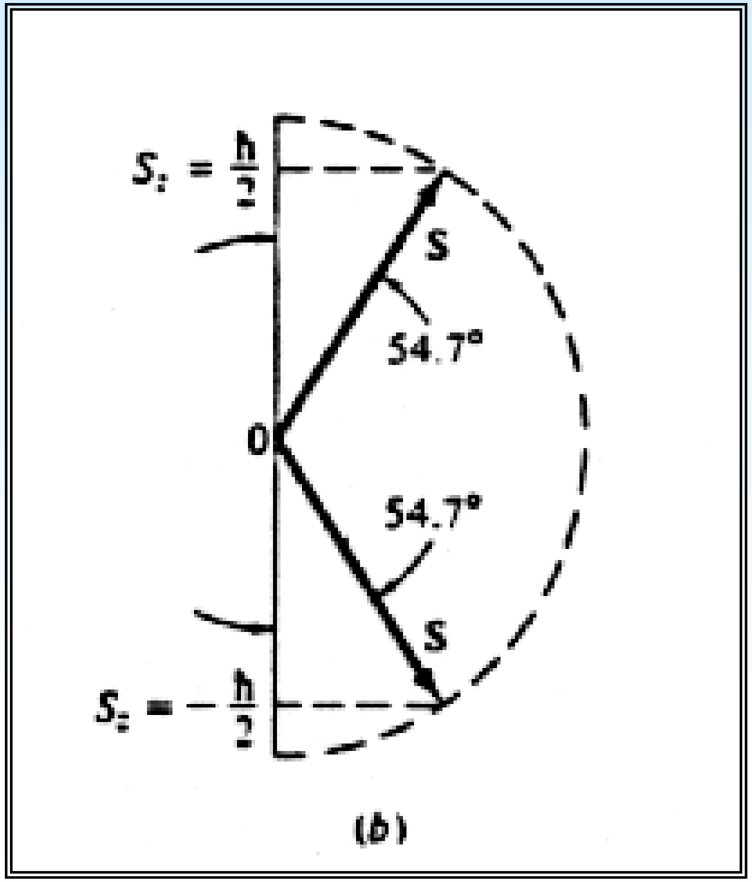
- In particular, Hydrogen atoms, which occur naturally in large numbers, allow medically meaningful images to be formed, with a spatial resolution comparable to that of X-ray computed tomography, and which show previously unseen contrasts between tissues.
- In addition, it is even possible to detect magnetic nuclei, such as ^{13}C, ^{19}F, ^{23}Na, ^{31}P, in spite of their low concentration in biological tissue; nevertheless, the value of the information thus gained does not approach that obtained through proton resonance.

Magnetic Moment alignment of a probe with Nuclear Spins

- In the case of thermal equilibrium, the magnetic moment of a probe with nuclear spins, aligns itself parallel to the external magnetic field.
- If this equilibrium is disturbed, for example by suddenly changing the direction of the external magnetic field, then a torque acts on the magnetic moment of the sample, causing a change in time, of the angular momentum of the probe.

The magnetic moment of a probe with nuclear spins aligns itself parallel to the external magnetic field

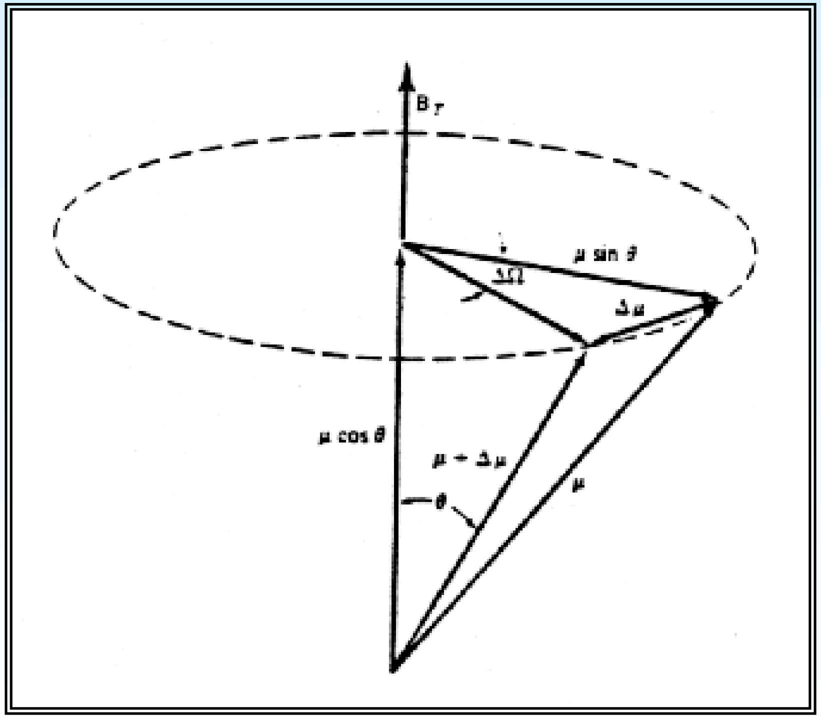


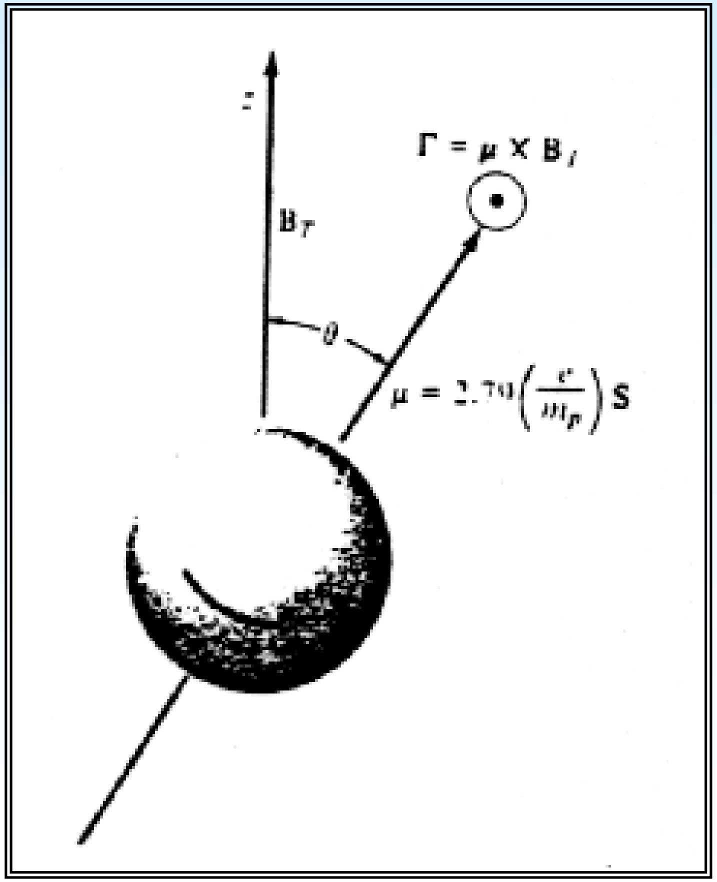


Precession of the nuclear magnetization

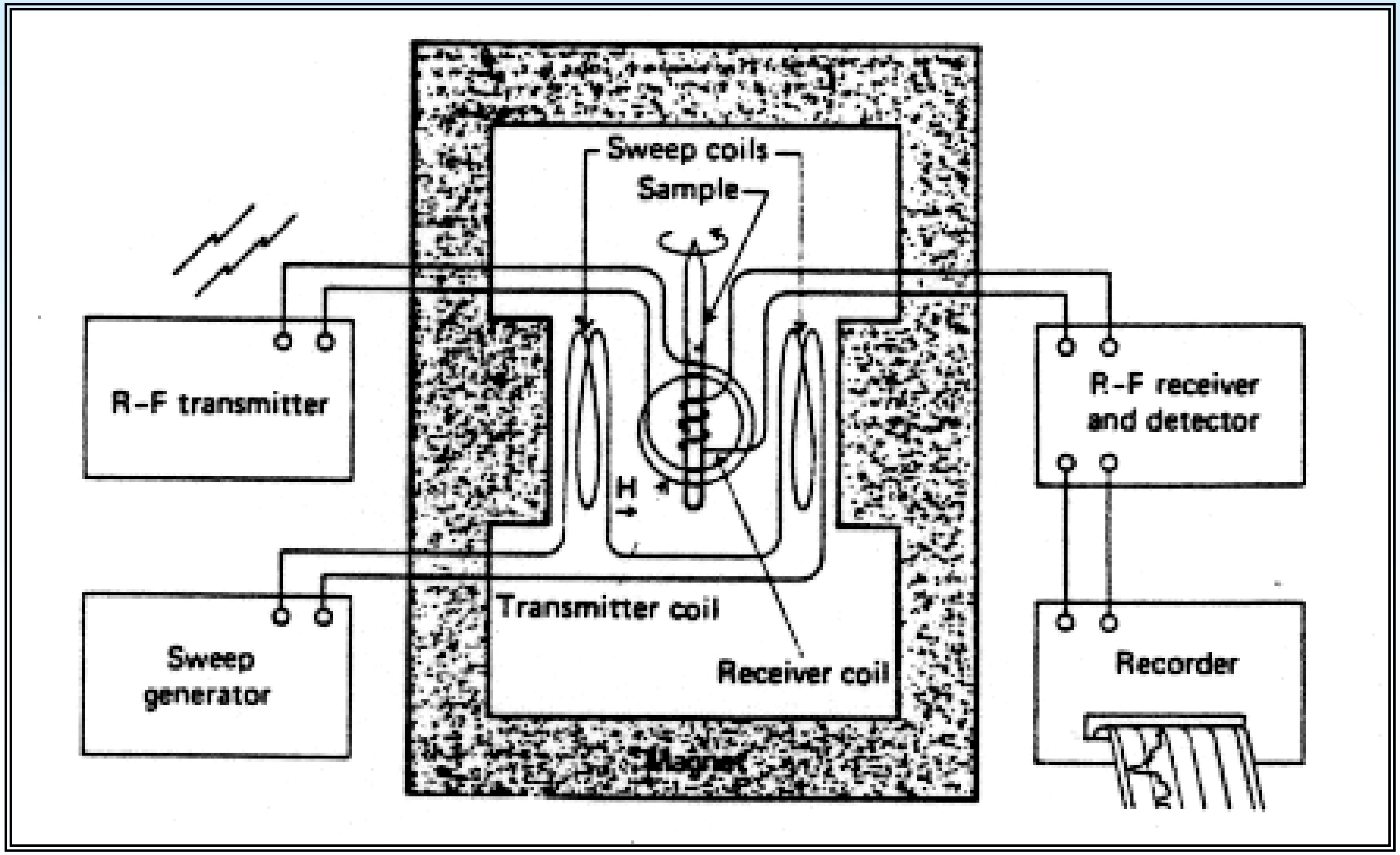
- This results in, the precession of the nuclear magnetization, around the direction of the magnetic field, with the Larmor frequency.
- This precession (Nuclear Magnetic Resonance) can be detected easily, by measuring the induced alternating voltage, in a coil surrounding the sample.
- After a finite period of time the thermal equilibrium which had previously been disturbed is reestablished.

Changing the direction of the magnetic field a torque acts on the magnetic moment of the sample





The precession (NMR) can be measured as induced alternating voltage in a coil surrounding the sample



Relaxation times

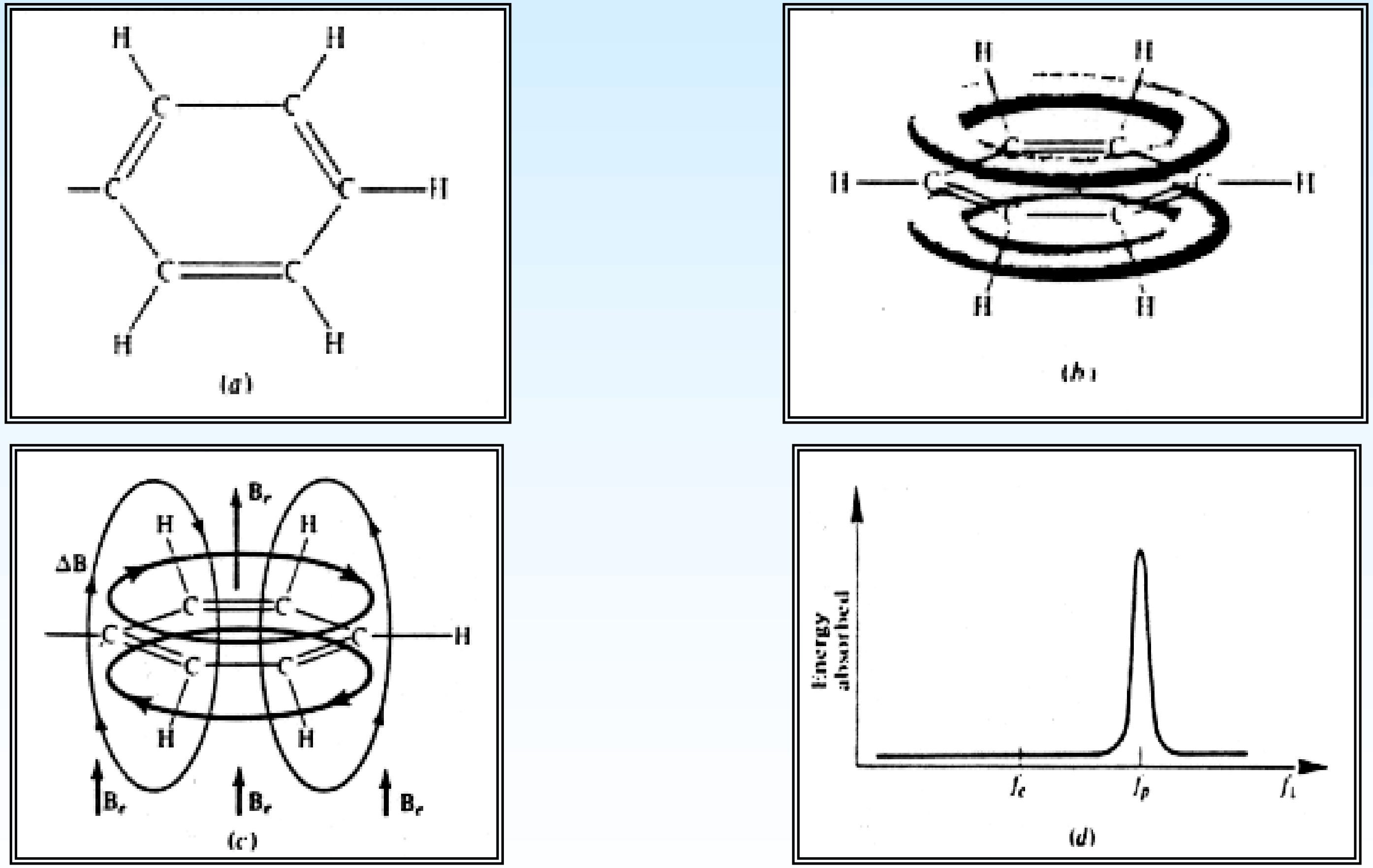
Two time constants are of interest:

- The *longitudinal relaxation time* T_1 is the time constant with which is restored the magnetization along the direction of the basic field, and it is associated with the emission of energy to the crystal lattice in which the atomic nuclei are embedded *(spin-lattice relaxation)*.
- The *transverse relaxation time* T_2 is the time constant with which the transverse component decays, due to the mutual interactions of the nuclear spins *(spin-spin relaxation)*.

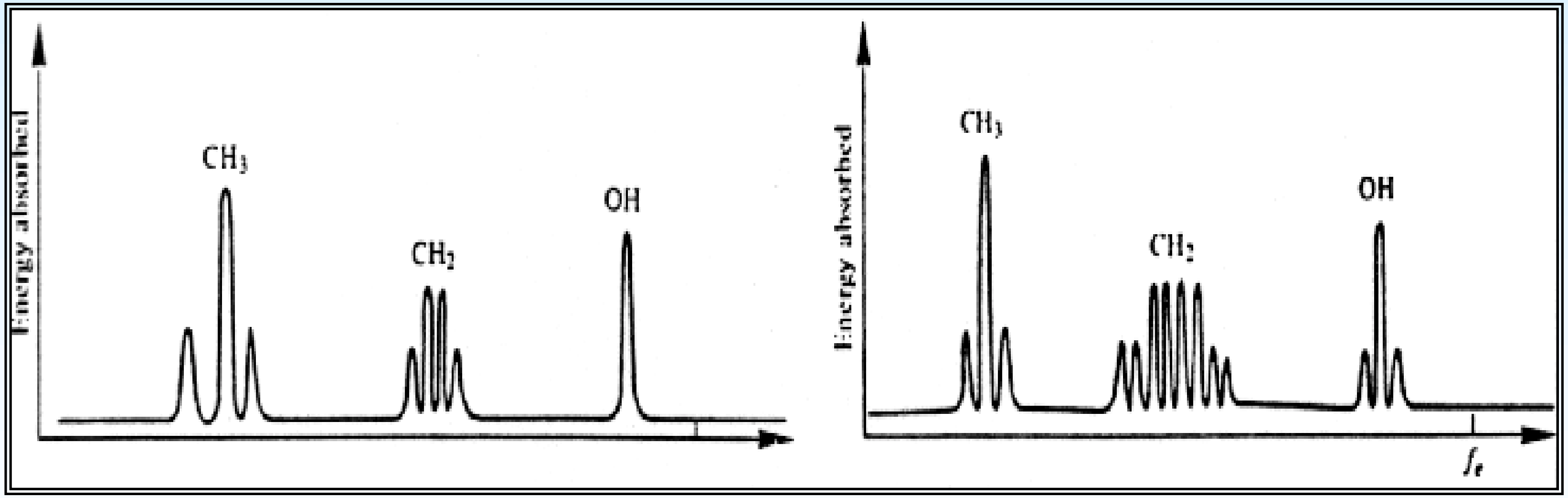
The physical significance of the Relaxation times

- The relaxation times express the mobility of the molecules in which the nuclei under consideration are located.
- Each nucleus is surrounded by other magnetic moments which are in constant *thermal Brownian molecular motion*, and produce a continuously changing magnetic perturbation field.
- Spectral components which correspond to the precession frequency of the nuclear magnetization, induce the *longitudinal relaxation*.
- *Transverse relaxation* is determined by the frequency of collisions between the molecules as a whole.

The signal depends on the electron density of the chemical groups to which belong the protons

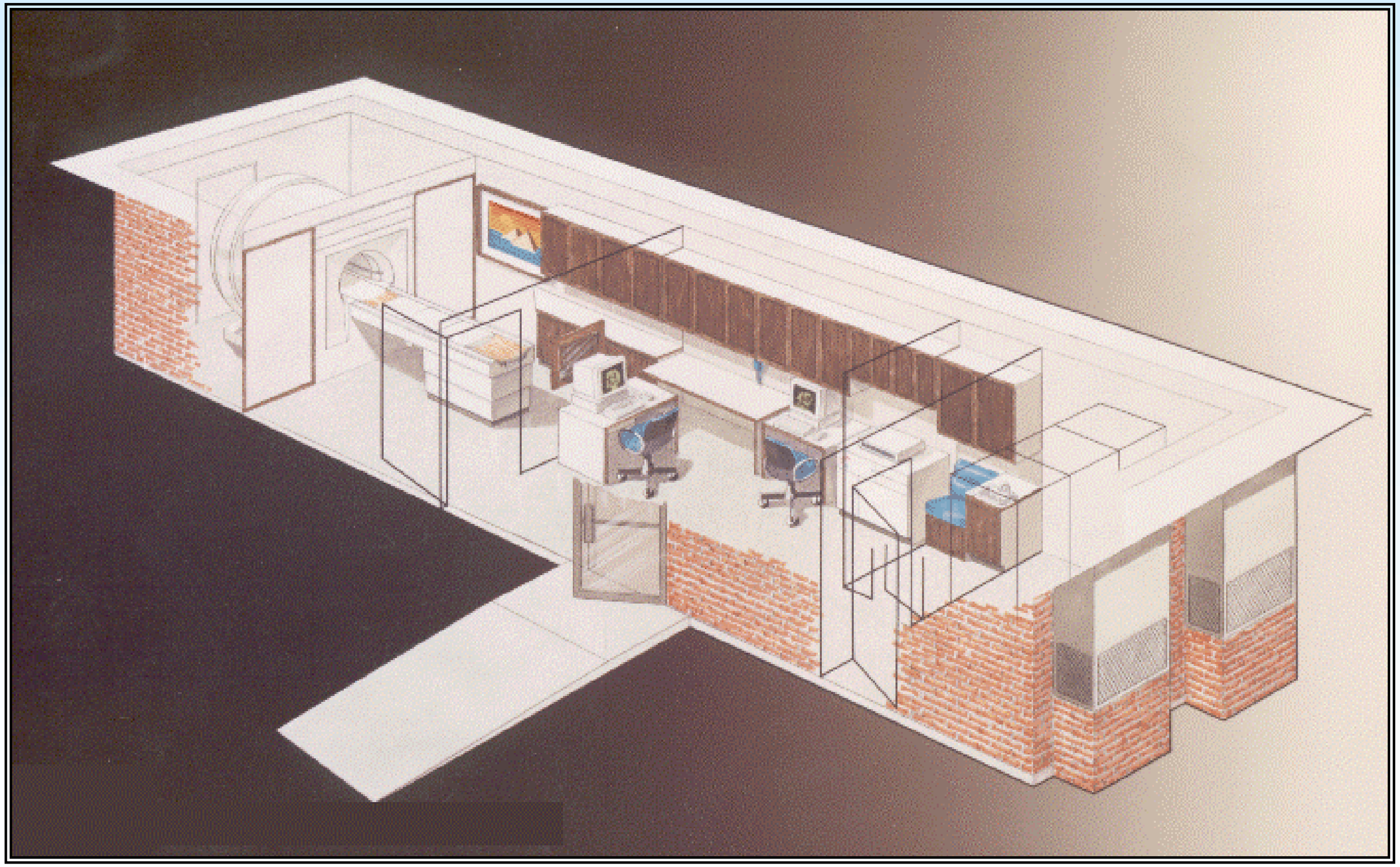


MRI signal of characteristic groups



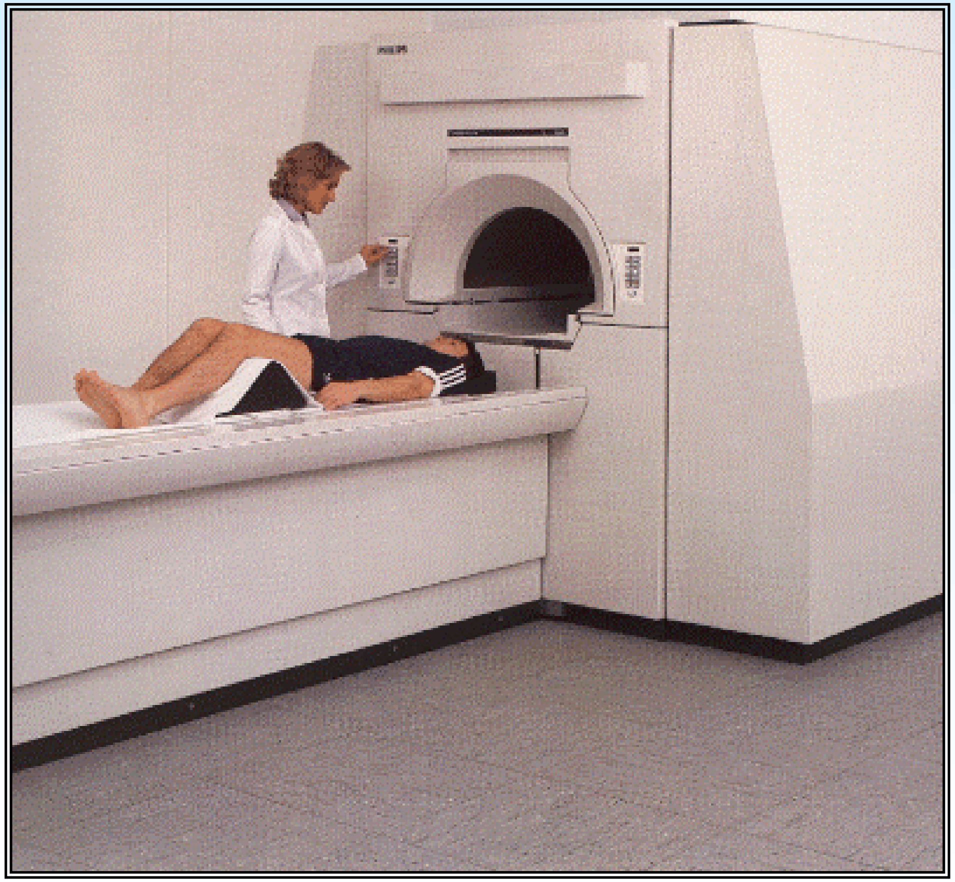
Typical MRI System

Typical MRI Suite in the beginning of the ‘80s



A modern MRI examination unit

Patient positioning

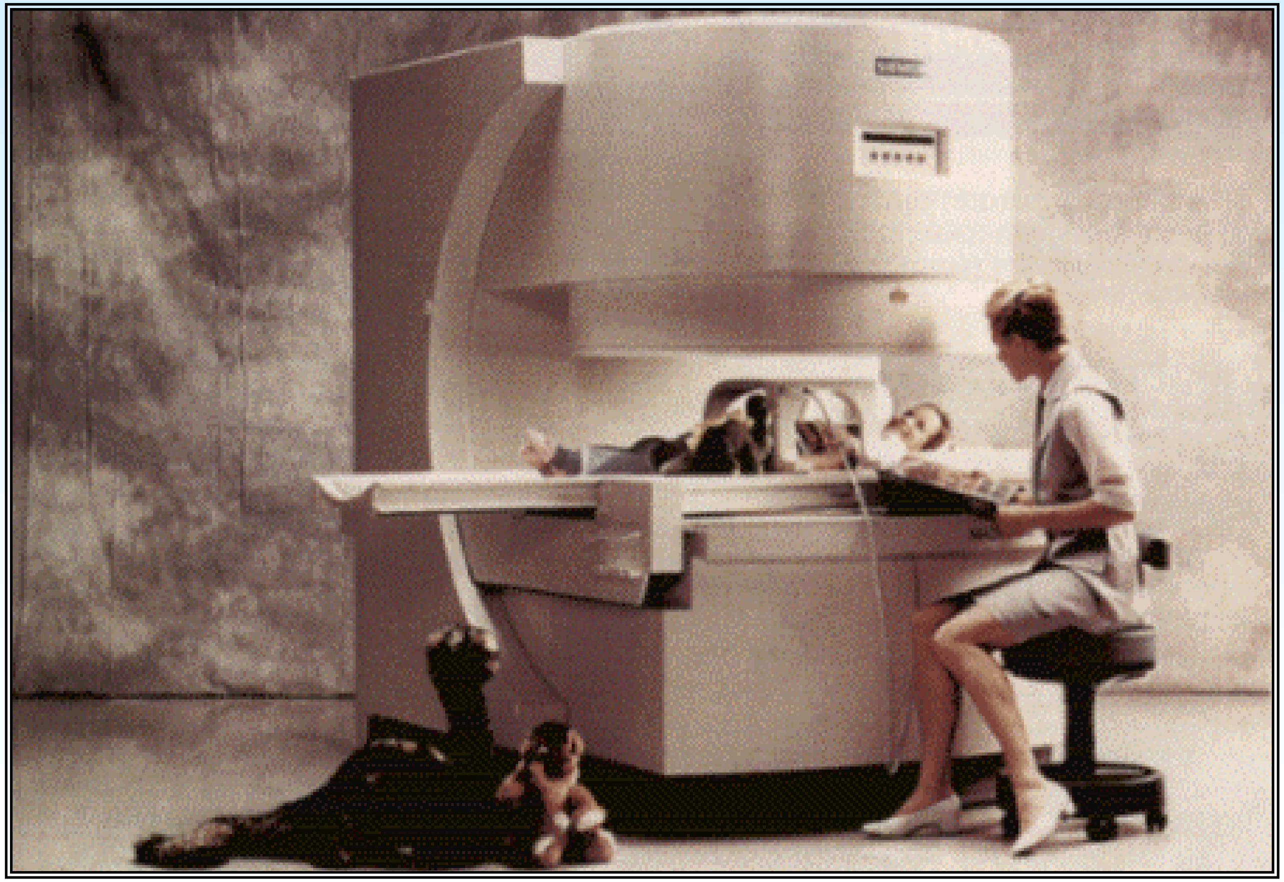


A typical pass-through MRI system

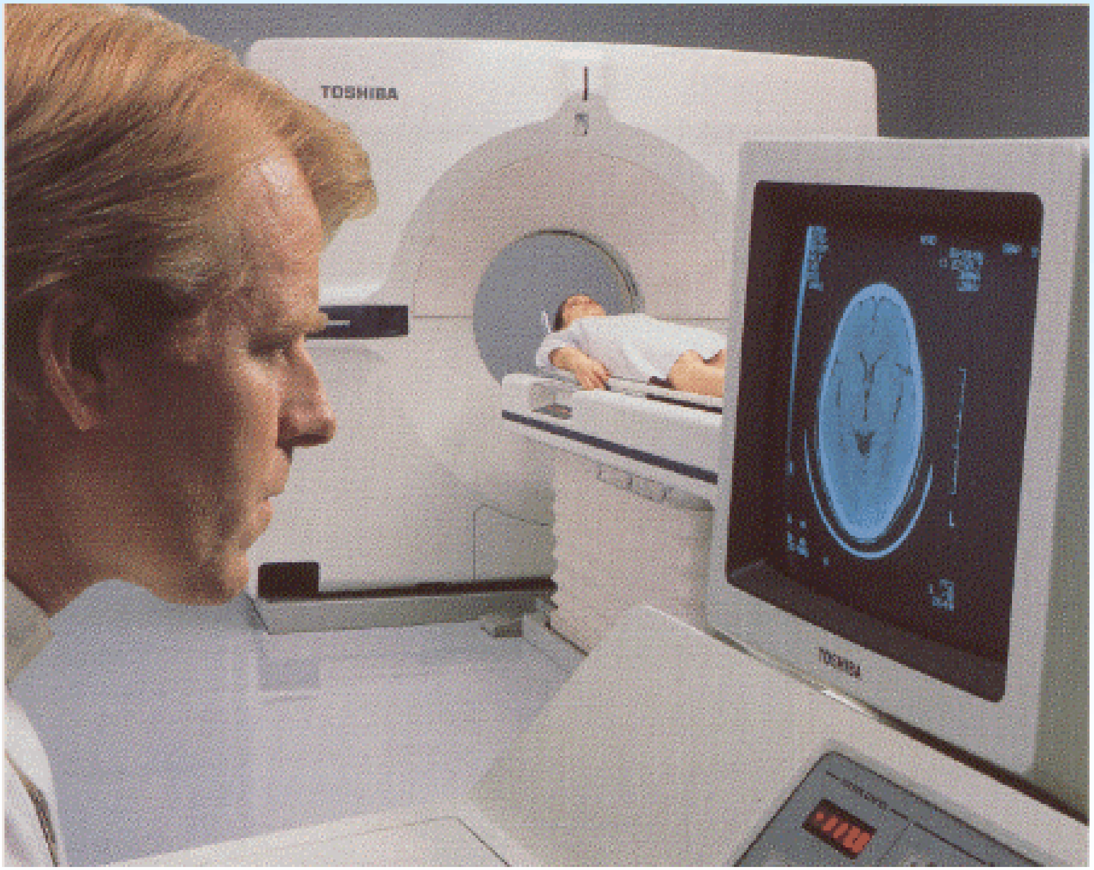
Cranial examination coil

Head fixing accessories and a Cranial examination coil

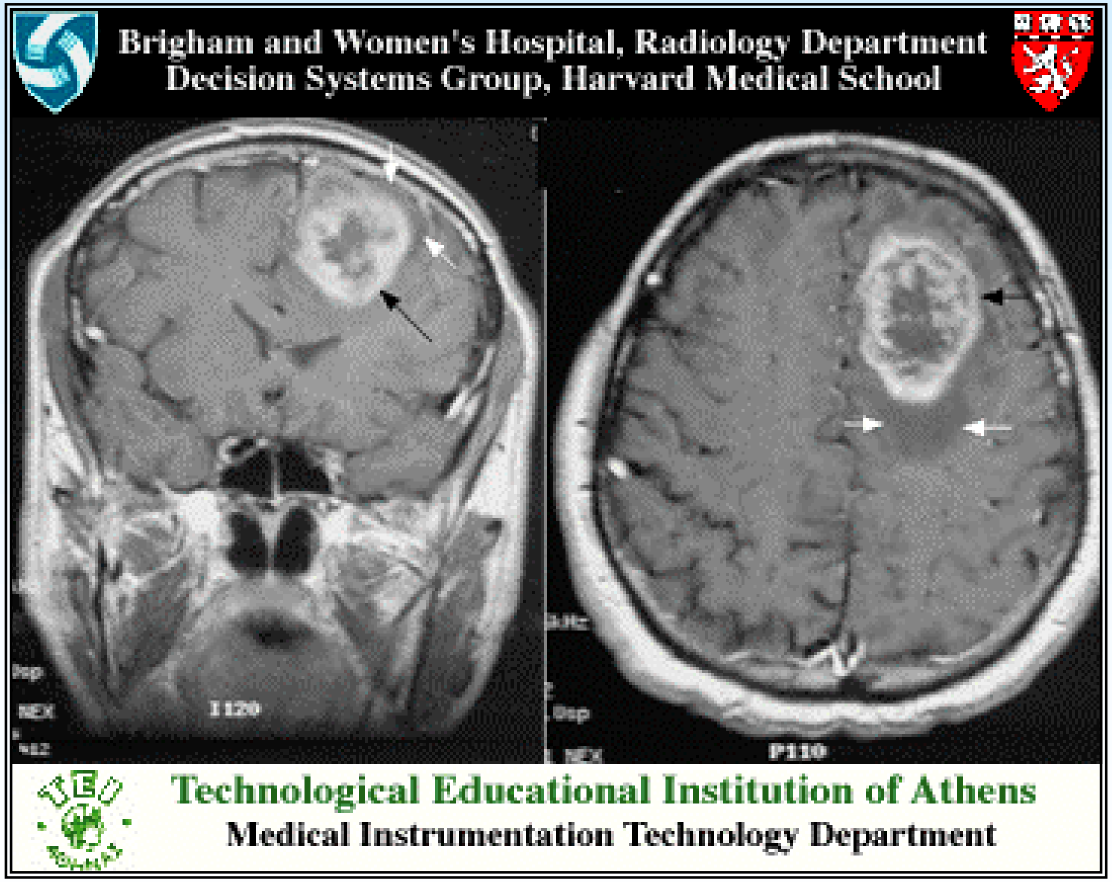
An open MRI system



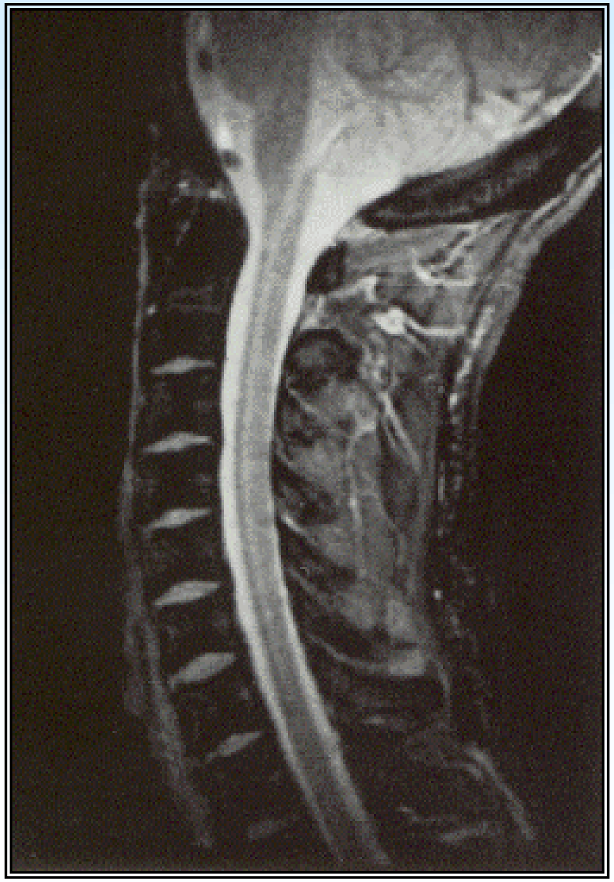
MRI Console

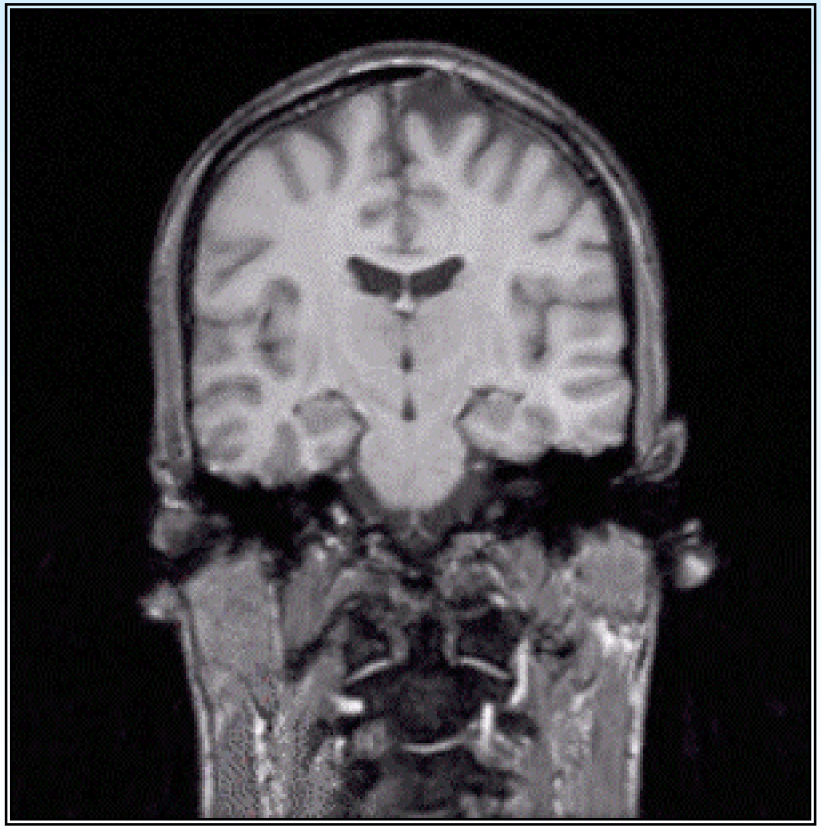


Some typical MRI images (a)



Some typical MRI images (b)





Super-conductive MRI Magnet

MRI advantages

MRI has various attractive attributes:

- *Non-ionizing radiation.*
- *Excellent soft tissue contrast.*
- *Visualization of any desired plane, without special patient positioning.*
- *No bone artifacts.*
- *Non invasive character of the examination.*
- *Potential for flow measurements.*
- *Potential for dynamic studies.*

Sonography

- The development of *Ultra-sound* equipment started in the fifties with equipment for examining the skull and the heart.
- Stimulated by *sonar* and *radar* technology, these developments culminated in two-dimensional ultrasound examination of:
  - *The abdominal organs.*
  - *The thyroid glands.*
  - *Obstetric examinations.*
  - *Sectional displays of the heart.*

Combination units

- Today, combination units using several scanning methods and satisfying all diagnostic requirements are widespread.
- Almost all ultrasound methods used today in medical diagnostics are based on the echo pulse technique.
  - *Amplitude modulation (A mode)*
  - *Time motion mode (M mode)*
  - *Brightness modulation (B mode)*

  have been used, that evaluate the amplitude of the echo signals received by the transducer.

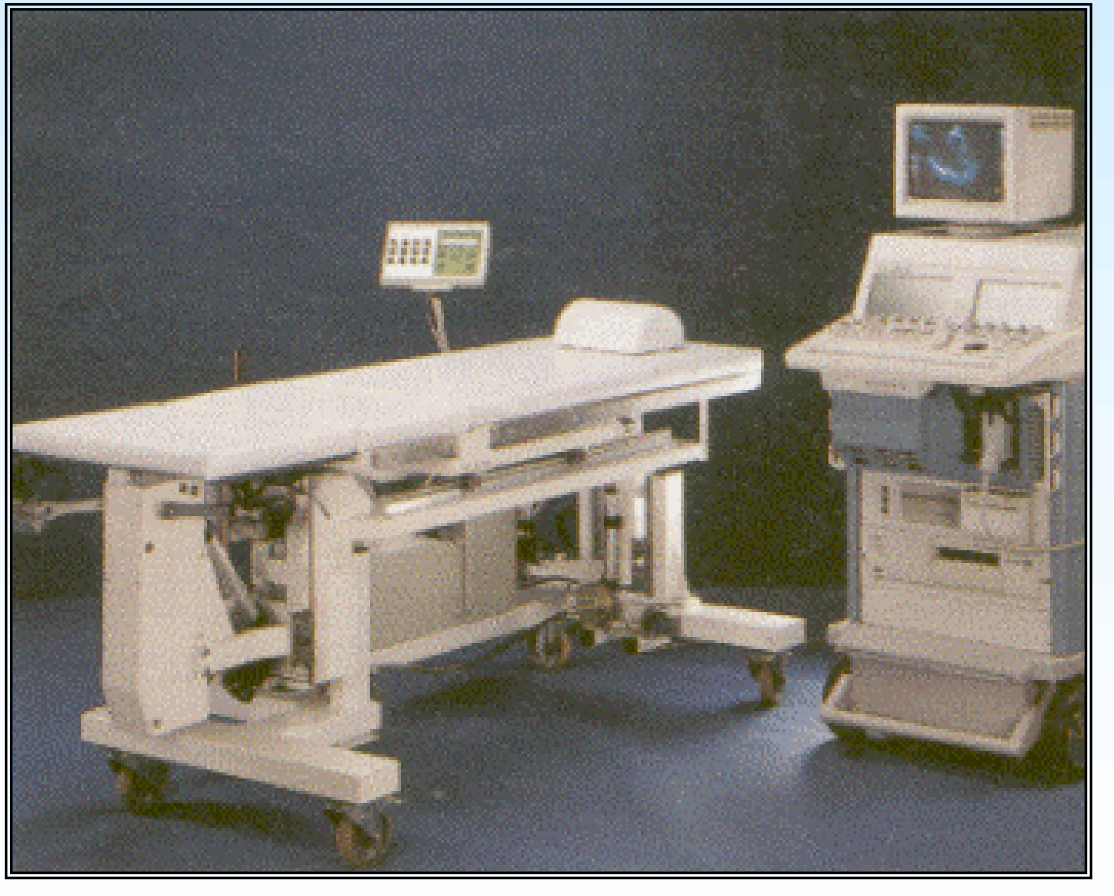
Scanning procedures

- There are two major scanning procedures:
- Mechanical sector scanning with good price-performance ratio, based on the rotor principle or the wobbler principle.
- Electronic scanning, i.e. the required scanning width (image width) is covered by a large number of identical individual transducers, formed as a linear or curved array.
- Scanning may be performed in rectilinear coordinates (linear array) or in polar coordinates (sector, mechanical systems, curved or phased array systems).

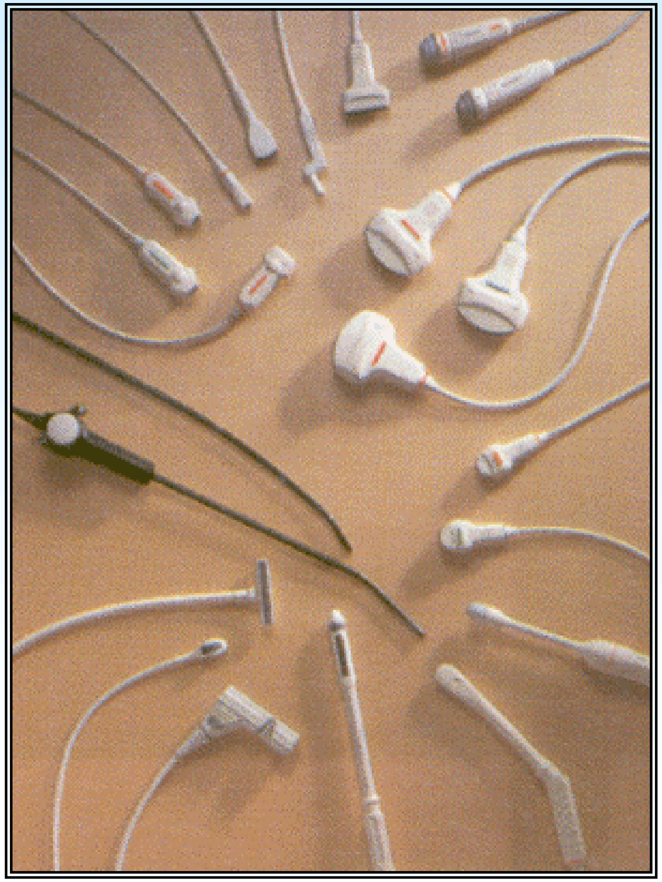
Doppler frequency shift

- A source for extra information is the frequency content of the ultrasound oscillations and especially the *Doppler frequency shift* of the moving signal source (e.g. blood).
- A *continuous wave (CW)* or a *pulse wave (PW)* Doppler method can be applied.
- *Duplex* and *triplex* scanners combine independent transducer arrangements allowing for *Imaging* and *Doppler examination*.

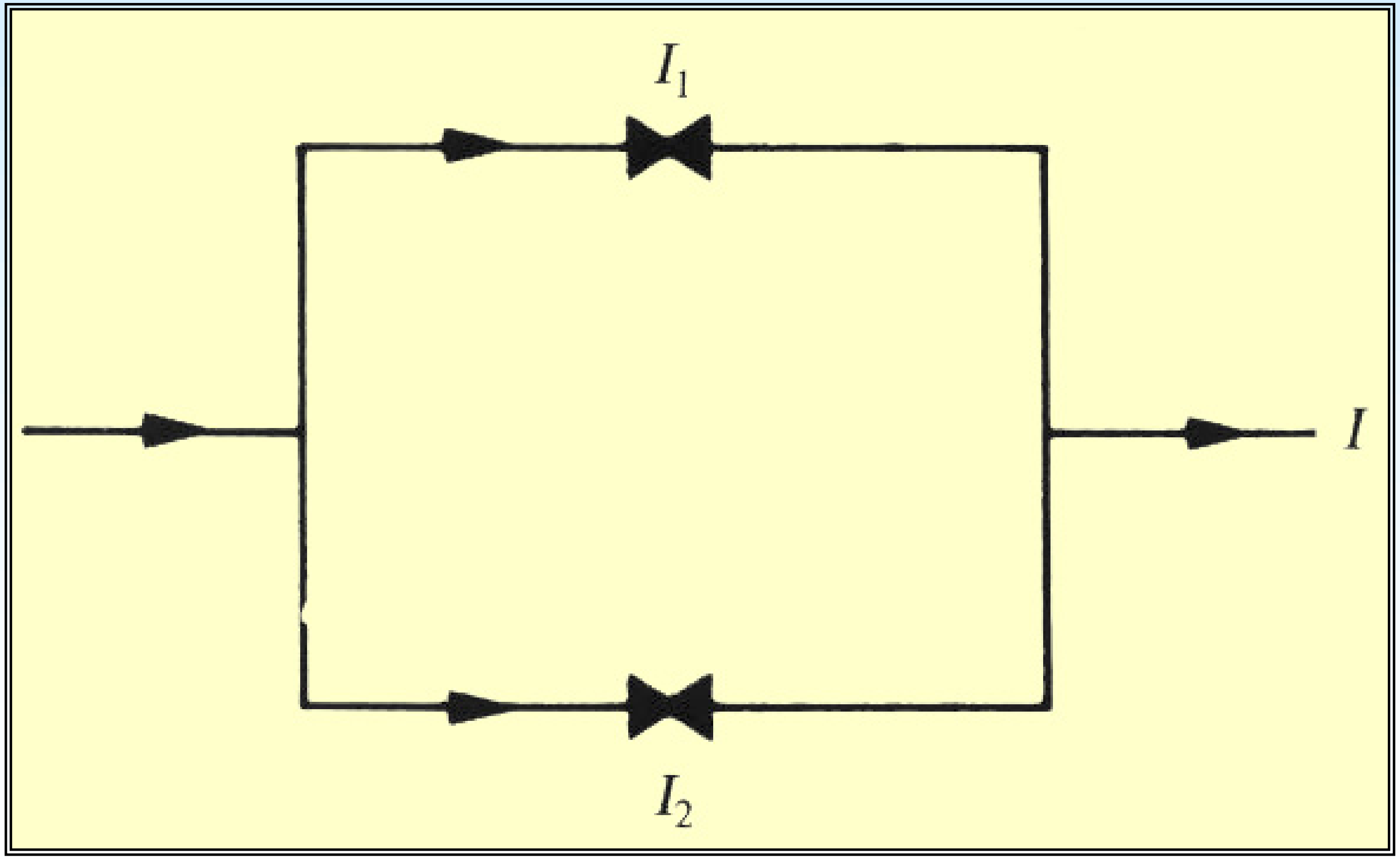
A typical ultrasound system



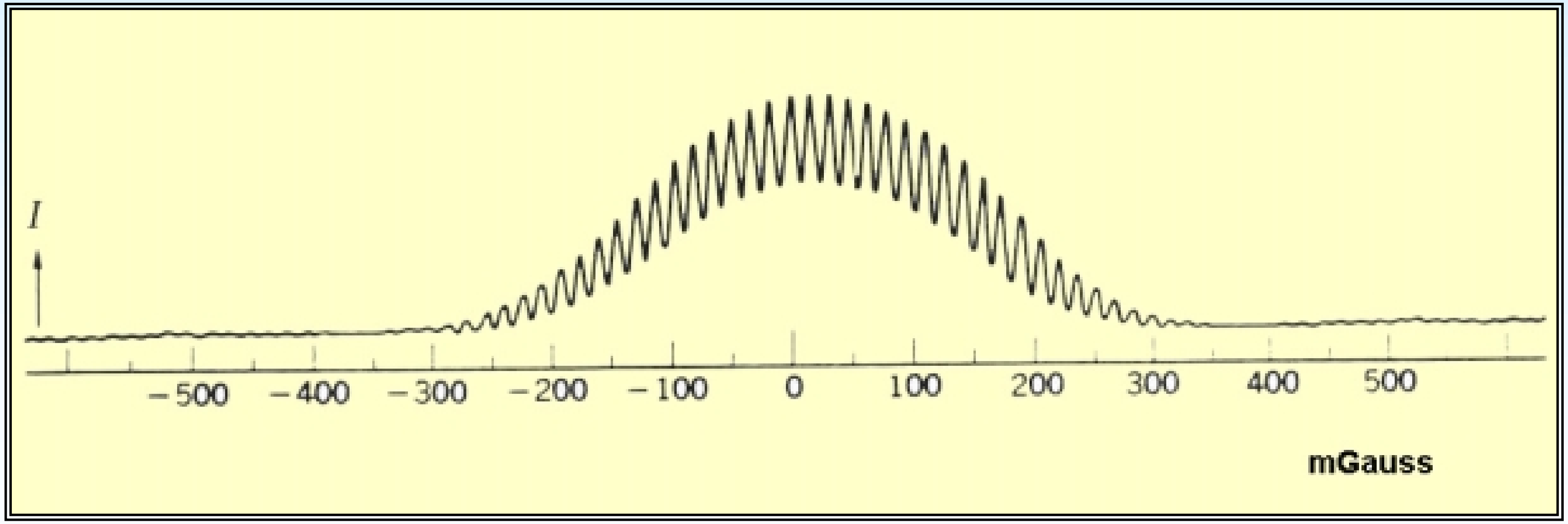
Various Ultra-sound transducers



Josephson Effect and the Super-conducting QUantum Interference Devices (SQUID)

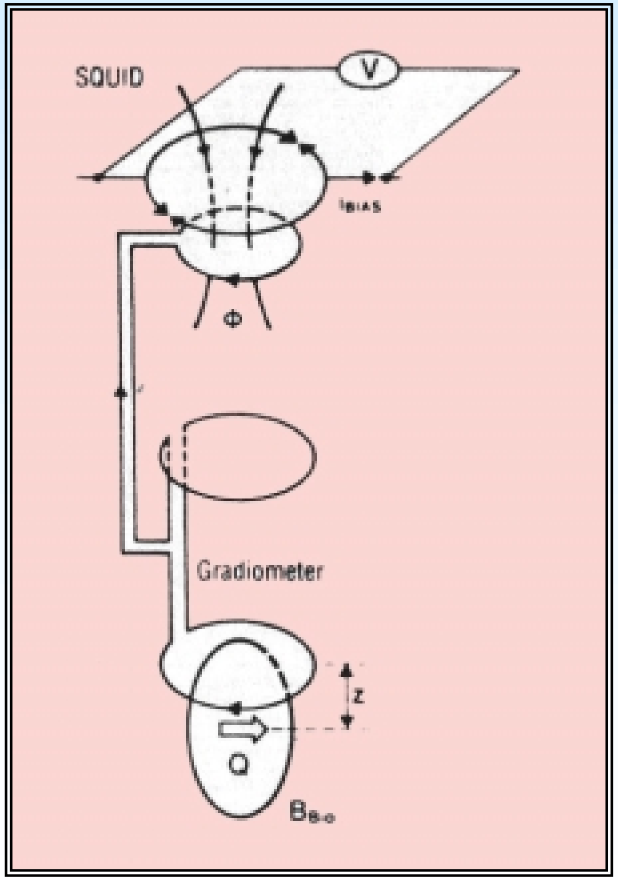


The Current of the Interference Circuit versus Magnetic Field Intensity



V = 0,   û = c . ÷‹ (”° /° 0)

Block Diagram of SQUID applied in Medicine



SQUID based Magneto-cardiogram (MCG)