Nuclear medicine

Dr Manik Mahajan
Assistant Professor
Department of Radiology

Nuclear medicine

Can be broadly divide into:

1. Diagnostic
2. Interventional

NUCLEAR MEDICINE

- **IMAGING SPECIALITY THAT FOCUSES ON THE USE OF RADIOACTIVE MATERIALS CALL "RADIOPHARMACEUTICALS" FOR DIAGNOSIS, THERAPY, AND MEDICAL RESEARCH**

NUCLEAR MEDICINE

- **DETERMINE THE CAUSE OF A MEDICAL PROBLEM BASED ON ORGAN OR TISSUE FUNCTION.**
- **PHYSIOLOGY**

NM TEST

- RADIOACTIVE MATERIAL, OR "TRACER", IS INTRODUCED INTO THE BODY BY INJECTION (i.v. or direct injection), SWALLOWING, OR INHALATION.

- DIFFERENT TRACERS ARE USED TO STUDY DIFFERENT PARTS OF THE BODY

RADIO-PHARMACEUTICALS

RADIONUCLIDE	PHARMACEUTICAL
IS TAGGED TO A PHARMACEUTICAL	CHOOSEN BASED ON PARTICIPATION IN THE PHYSIOLOGIC FUNCTION OF A GIVEN ORGAN

RADIOPHARMACEUTICALS

- ARE ADMINISTERED TO PATIENTS
- THEY MUST MEET RECOMENDED STANDARDS FOR SAFETY AND APPROPRIATE PERFORMANCE FOR THE APPROVED CLINICAL USE
- THEY NEED TO BE STERILE

TRACERS

- **ARE SELECTED THAT LOCALIZE IN SPECIFIC ORGANS OR TISSUES**
  - **Ex: GLUCOSE**
- **THE AMOUNT OF RADIOACTIVE TRACER MATERIAL IS SELECTED CAREFULLY TO PROVIDE THE LOWEST AMOUNT OF RADIATION EXPOSURE**

- TRACERS ACT PREDICTABLY IN NON-DISEASED BODY

- **IN CASE OF A PATHOLOGY, THE TRACER WILL BE PROCESSED DIFFERENTLY**

- **ANY CHANGE IN PHYSIOLOGICAL FUNCTION WILL MEAN ALTERED CONC. OF TRACER**

- THIS RESULTS IN ‘HOT–SPOT’ i.e. A FOCAL INCREASE IN RADIO ACCUMULATION

- **SOME DISEASES RESULT IN EXCLUSION OF TRACERS LEADING TO ‘COLD SPOT’**

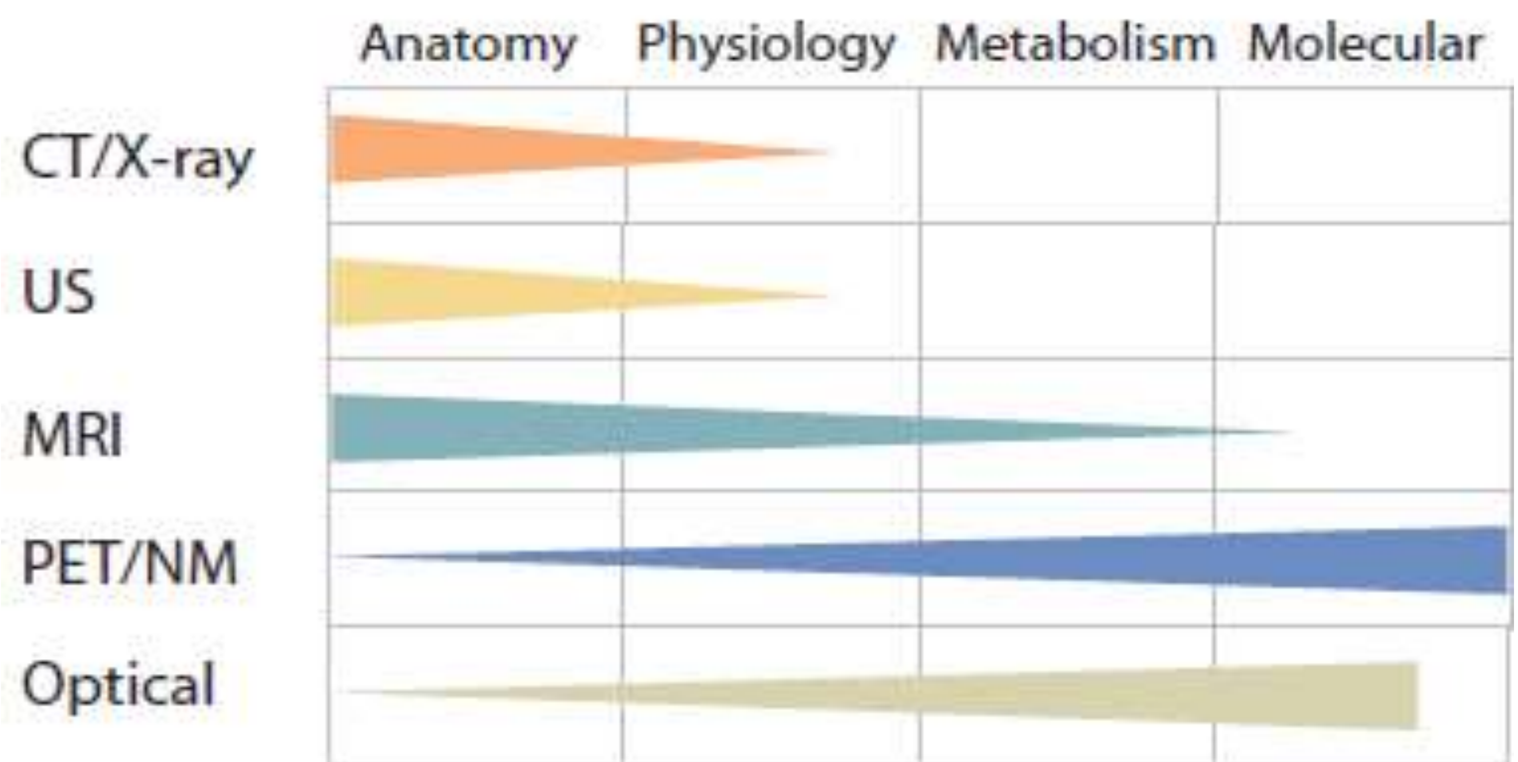
RADIOACTIVE TRACERS

- PRODUCE ALPHA,GAMMA or BETA EMISSION FROM WITHIN THE ORGAN BEING STUDIED
- EMISSIONS ARE TRANSFORMED INTO IMAGE THAT PROVIDE INFORMATION ABOUT THE FUNCTION OF THE ORGAN OR SYSTEM BEING STUDIED.

FUNCTION VS ANATOMY

- THE EMPHASIS OF NUCLEAR MEDICINE STUDIES IS MORE ON PHYSIOLOGIC FUNCTION AND CHEMISTRY THAN ANATOMICAL STRUCTURE

Medical Imaging Modalitites and Their Range of Detection



Diagnostic nuclear medicine

2 D	3 D
SCINTIGRAPHY	PET SPECT

PET

Positron emission tomography

Measures photons

Majorly used in cancer and metastasis detection, alongwith Alzheimer's disease.

SPECT

Single photon emission computed tomography

Measures gamma rays

Heart, bone, gall bladder, intestinal disease, Parkinson's disease.

HISTORY

- A FEW MONTHS AFTER “WHILLHEM CONRAD ROENTGEN” DISCOVERED X-RAYS, HENRI BECQUEREL DISCOVERED NATURALLY OCCURRING RADIOACTIVE SUBSTANCES in 1896.

RADIOACTIVITY

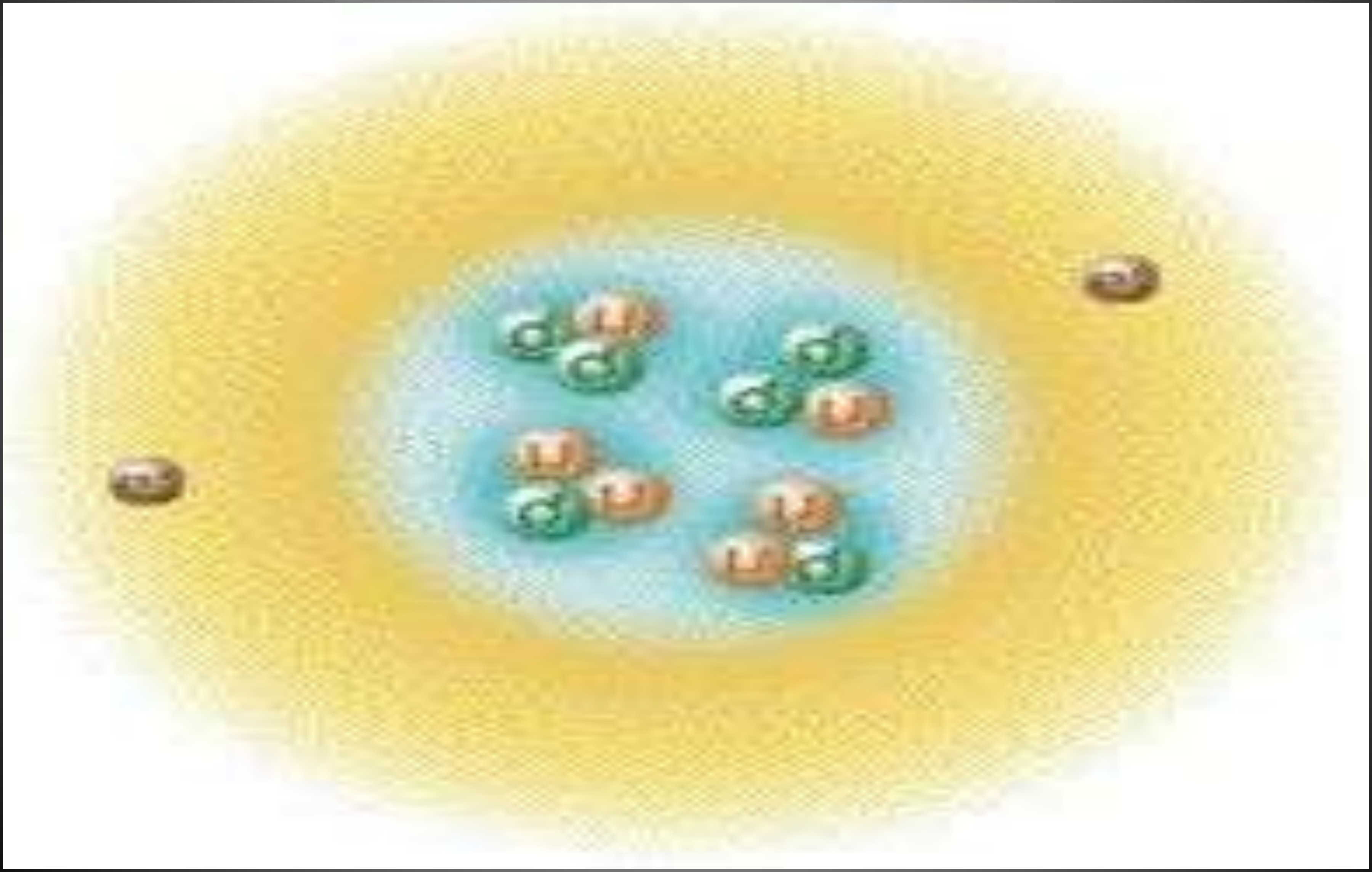
- IS USED TO DESCRIBE THE RADIATION OF ENERGY IN THE FORM OF HIGH-SPEED ALPHA, GAMMA OR BETA PARTICLES OR WAVES (GAMMA RAYS), FROM THE NUCLEUS OF AN ATOM

THYROID

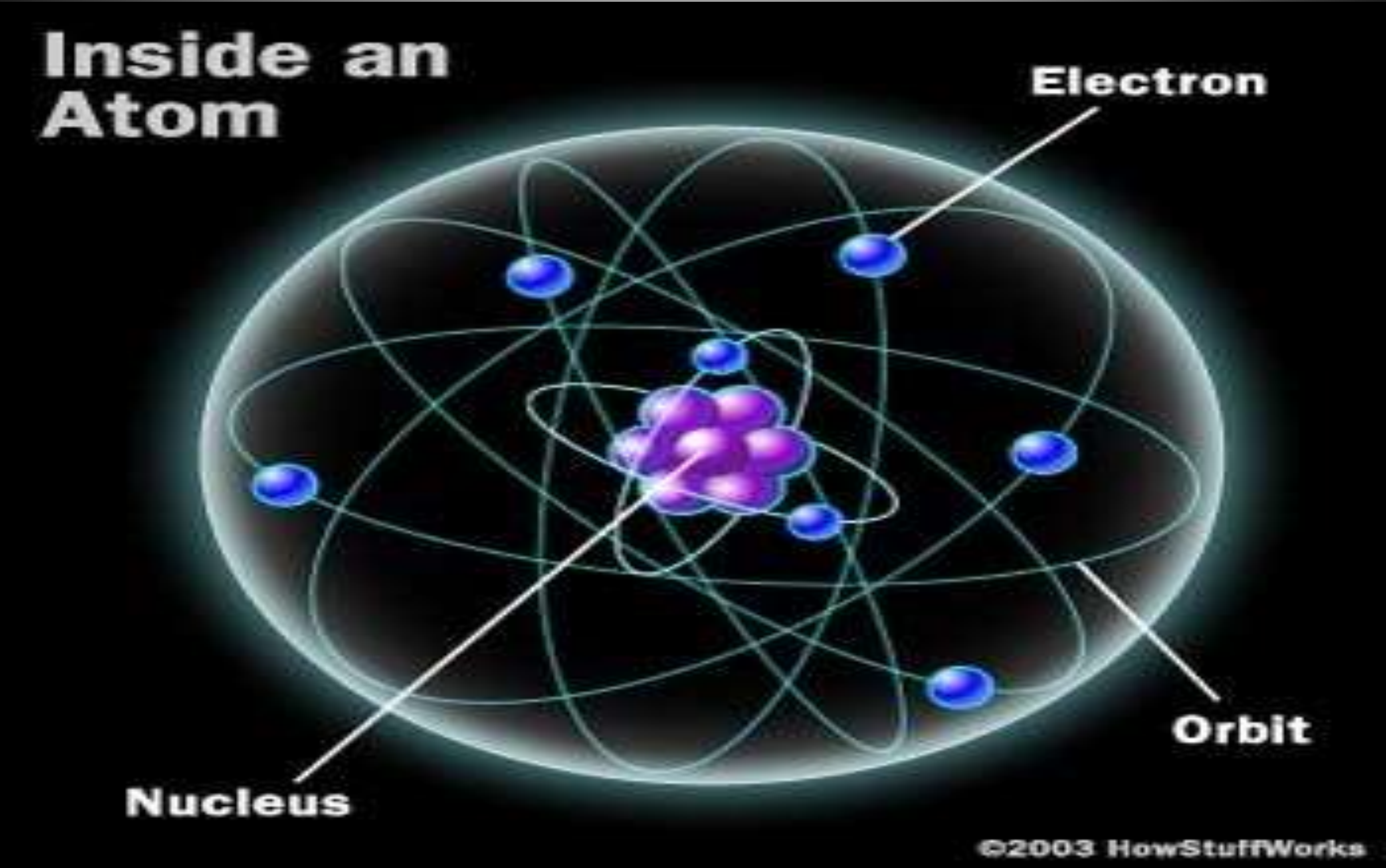
- **Was one of the first organs to be examined by Nuclear Medicine studies in the 1940s-1950s**

- **Endocrine emphasis-initially using I-131 to diagnose and then treat thyroid disease.**

BASIC NUCLEAR PHYSICS



ATOM



ISOTOPES

- **ELEMENTS WITH THE SAME NUMBER OF PROTONS BUT A DIFFERENT NUMBER OF NEUTRONS ARE REFERED TO AS ISOTOPES**

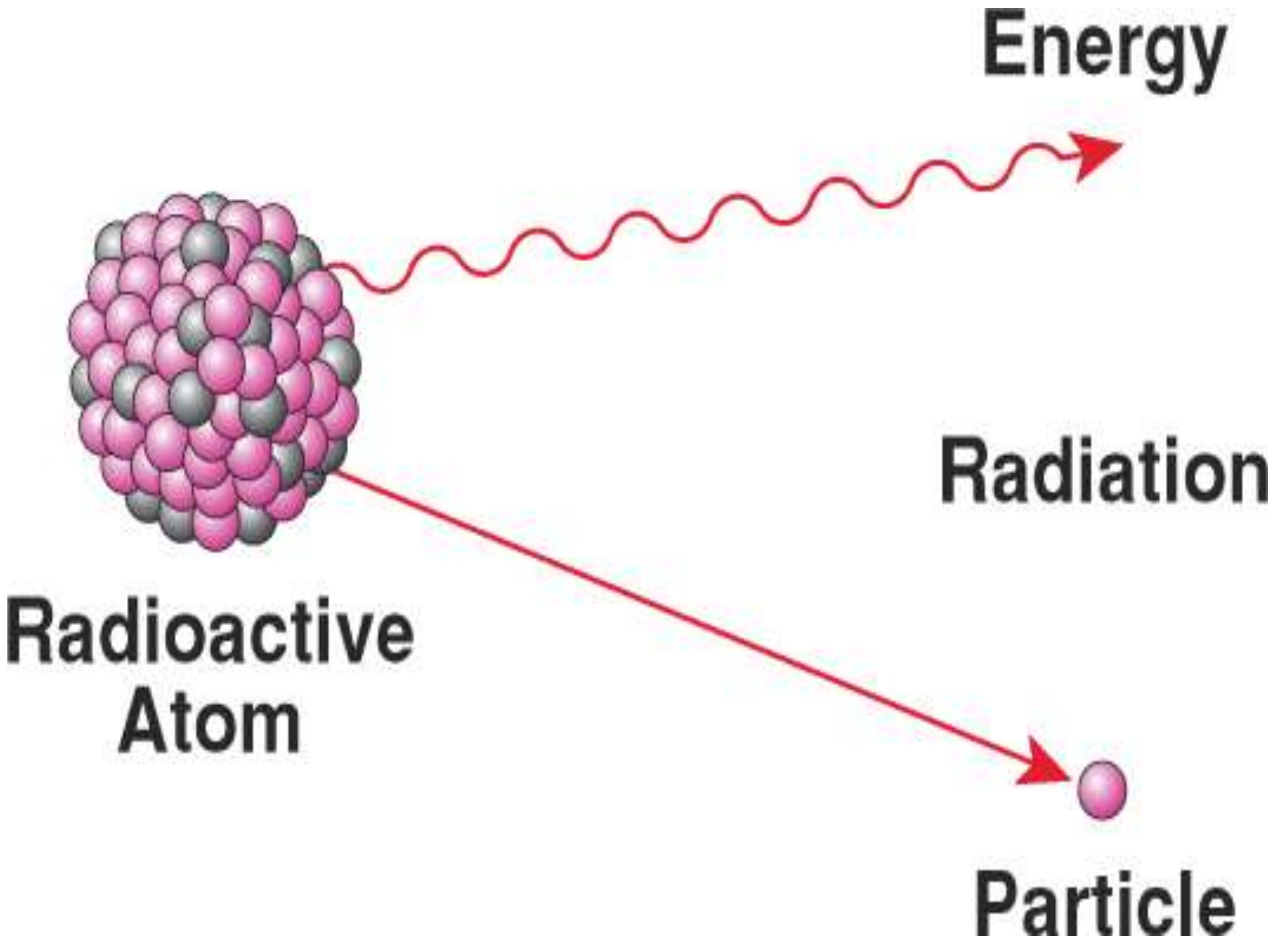
- **THE NEUTRON-TO-PROTON RATIO IN THE NUCLEUS DETERMINES THE STABILITY OF THE ATOM**

Protium	^{1}H		1 Proton, keine Neutronen Z = 1 A = 1	99,985 %
Deuterium	^{2}H bzw. **D**		1 Proton, 1 Neutron Z = 1 A = 2	0,0145 %
Tritium	^{3}H bzw. **T**		1 Proton, 2 Neutronen Z = 1 A = 3	10^{-16} % 

ISOTOPES

- **ENERGY IS RELEASED IN VARIOUS WAYS DURING THIS DECAY, OR RETURN TO GROUND STATE**

- **RADIONUCLIDES DECAY BY THE EMISSION OF ALPHA, BETA, AND GAMMA RADIATION**

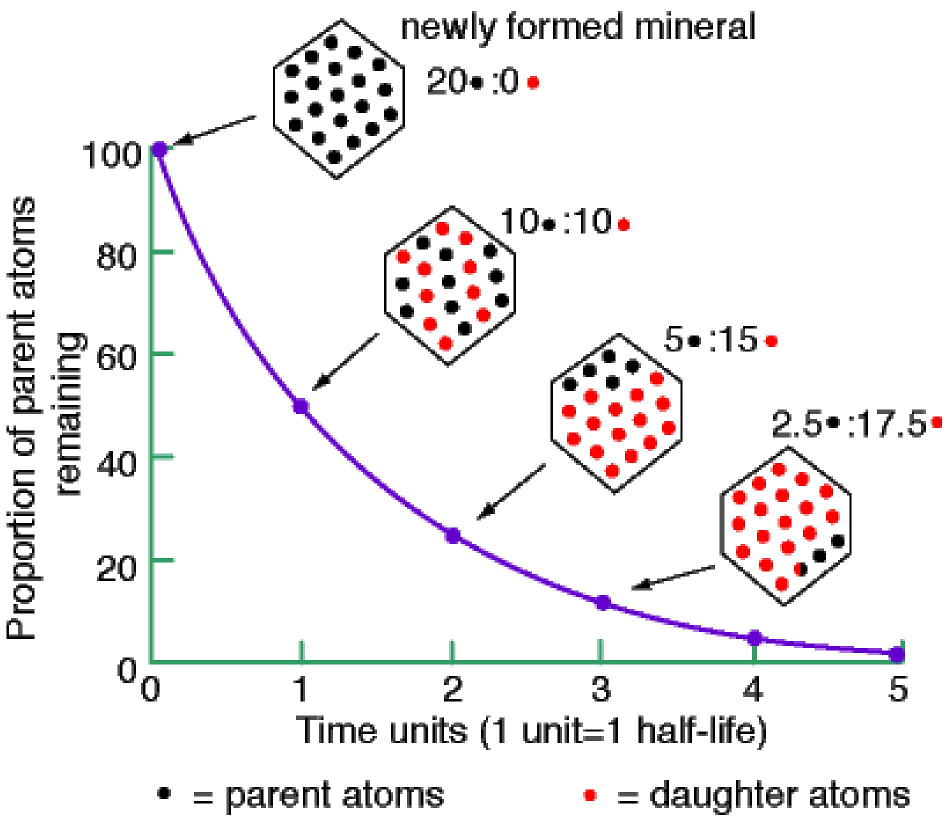

Energy
Radiation
Radioactive
Atom
Particle

Half Life

Physical time it takes for a quantity of radionuclide to decrease to ½ its original activity

Radionuclides half life can range from milliseconds to years

NM radionucldies range from hours to days



NUCLEAR PHARMACY

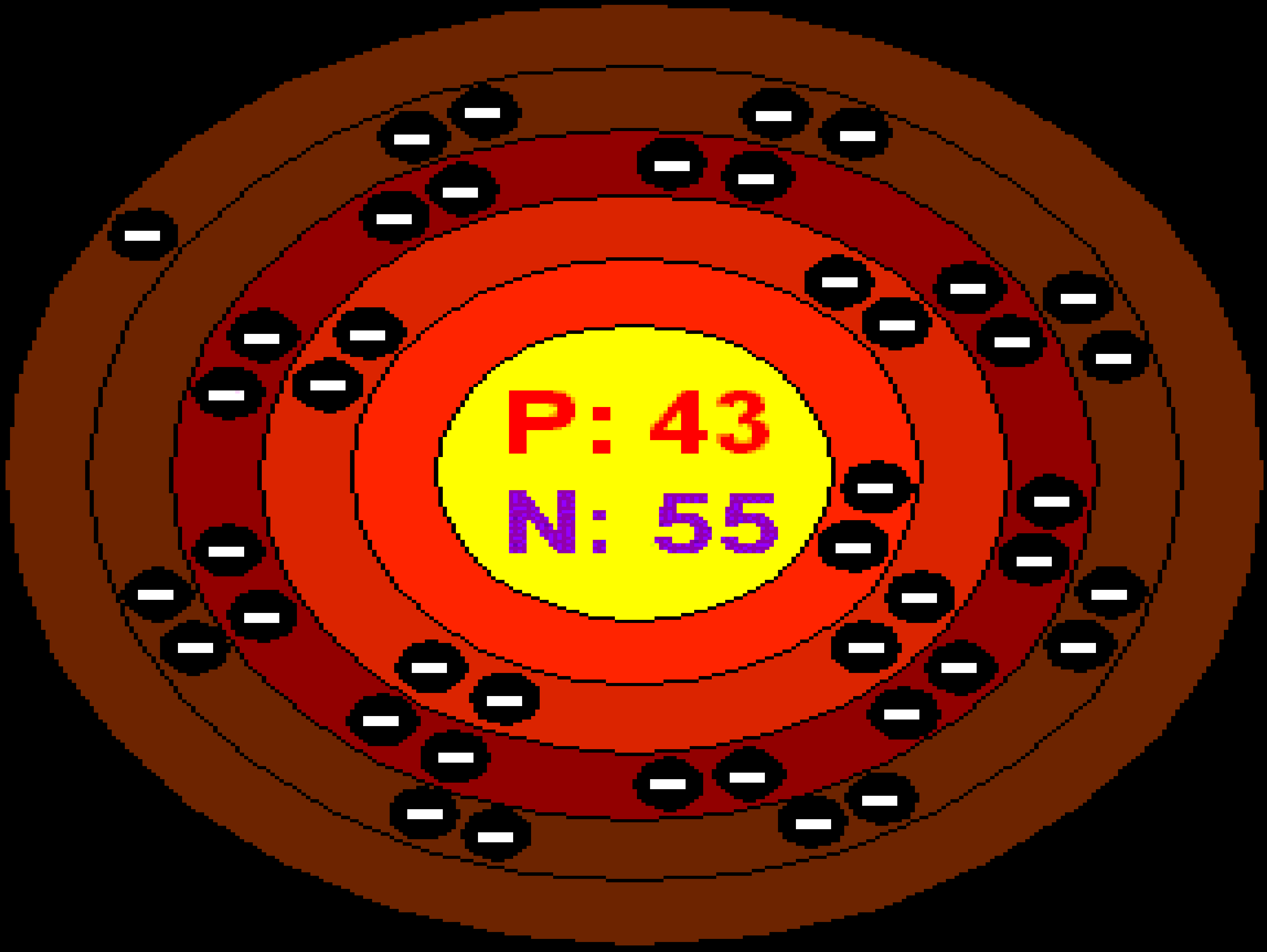
- **NATURALLY OCCURRING RADIONUCLIDES HAVE VERY LONG HALF-LIVES AND DELIVER HIGH ABSORBED DOSE TO THE PATIENTS**

- **NM RADIONUCLIDES ARE MAN MADE**

TECHNETIUM

- **IS THE MOST COMMONLY USED RADIONUCLIDE IN NM TODAY**

^{99}Tc	:	E_{β}	=	300 keV


P: 43
N: 55

^{99M}Tc

- EXHIBITS NEARLY IDEAL CHARACTERSTICS FOR USE IN NM
  - SHORT PHYSICAL HALF-LIFE OF 6.04 HOURS
  - PRODUCES LOW ENERGY, GAMMA PHOTONS

Radionuclides

- Artificial radionuclides are generally produced in a cyclotron or some other particle accelerator, in which we bombard a stable nucleus with specific particles (neutrons, protons, electrons or some combination of these). .

- By doing so, we make the nucleus of starting material unstable, and this nucleus will then try to become stable by emitting radioactivity

RADIOPHARMACEUTICALS

- **Radioactive material is obtained from a manufacturer, or from an in house generator system.**

- **"Milking" the generator - sodium chloride is passed over the molybdenum-99 column, which removes the radioactive material.**


STERILE
COLLECTING
VIAL


TECHNETOPE
STERILE GENERATOR

RADIATION SAFETY IN NM

- **RADIATION PROTECTION PRACTICES DIFFER SOMEWHAT FROM THE GENERAL SAFETY RULES**
- **RADIONUCLIDES ARE LIQUID, SOLID, OR GASEOUS FORM.**
- **BECAUSE OF THE NATURE OF DECAY, RADIATION IS EMITTED AFTER INJECTION**

ALARA

- FILM BADGES
- RING BADGES
- SPILLED CHEMICALS MUST BE CLEANED UP IMMEDIATELY

Exposure vs Effective dose- the mean effective dose:

NM diagnostic procedure	4.6 mSv
CXR	0.008 mSv
UGI series	4.5 mSv
Lower GI series	6 mSv
CT Head	1.5 mSv
CT Chest	5.4 mSv
CT Abdomen	3.9 mSV – 6.1 mSv

SCINTILLATION DETECTORS Image Production

- Used for NM image production
- GIVE OFF LIGHT IN THE PRESENCE OF IONIZING RADIATION (GAMMA RAYS)
- Scintillation detectors were used in the development of the first-generation NM scanner – the rectilinear scanner, 1950

Modern-day Gamma Camera

- Rectilinear scanners have evolved in complex imaging systems – gamma cameras
- Still use scintillation detectors: use thallium activated sodium iodide crystal to detect and transform radioactive emissions into light photons. Light photons are amplified and an image is recorded


VERTEX

Gamma Cameras

- Can be stationary or mobile

- Mobile cameras can move throughout the hospital
  - Mobile cameras have limitations of smaller field of view and quality of images

Portable Gamma Camera

Gamma Camera

- Collimator: used to separate gamma rays and keep scattered rays from entering the scintillation crystal
  - Resolution and sensitivity are terms used to describe the physical characteristics of collimators
  - Made of material with a high atomic number, lead, to absorb scattered gamma rays

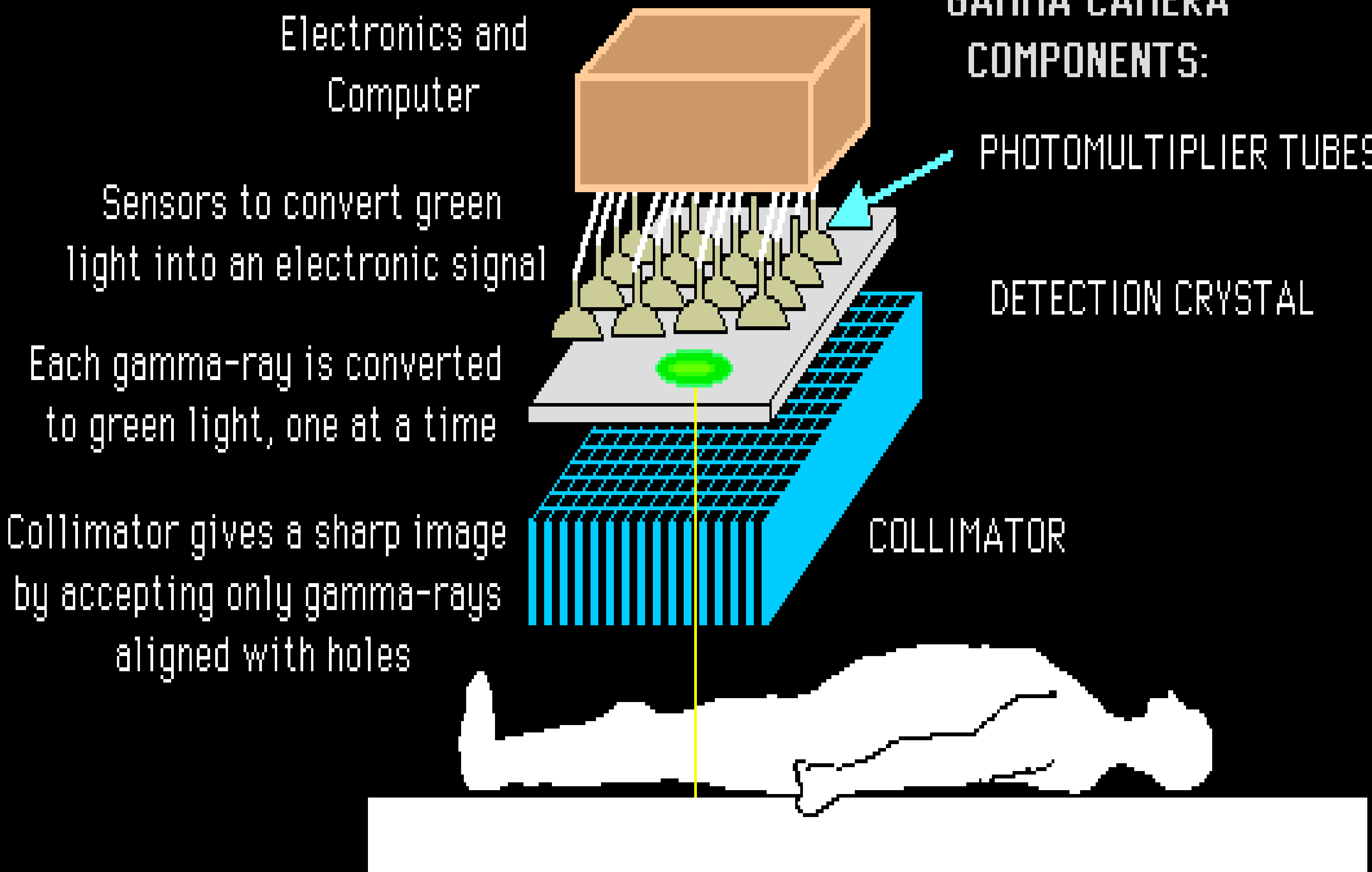
Crystals

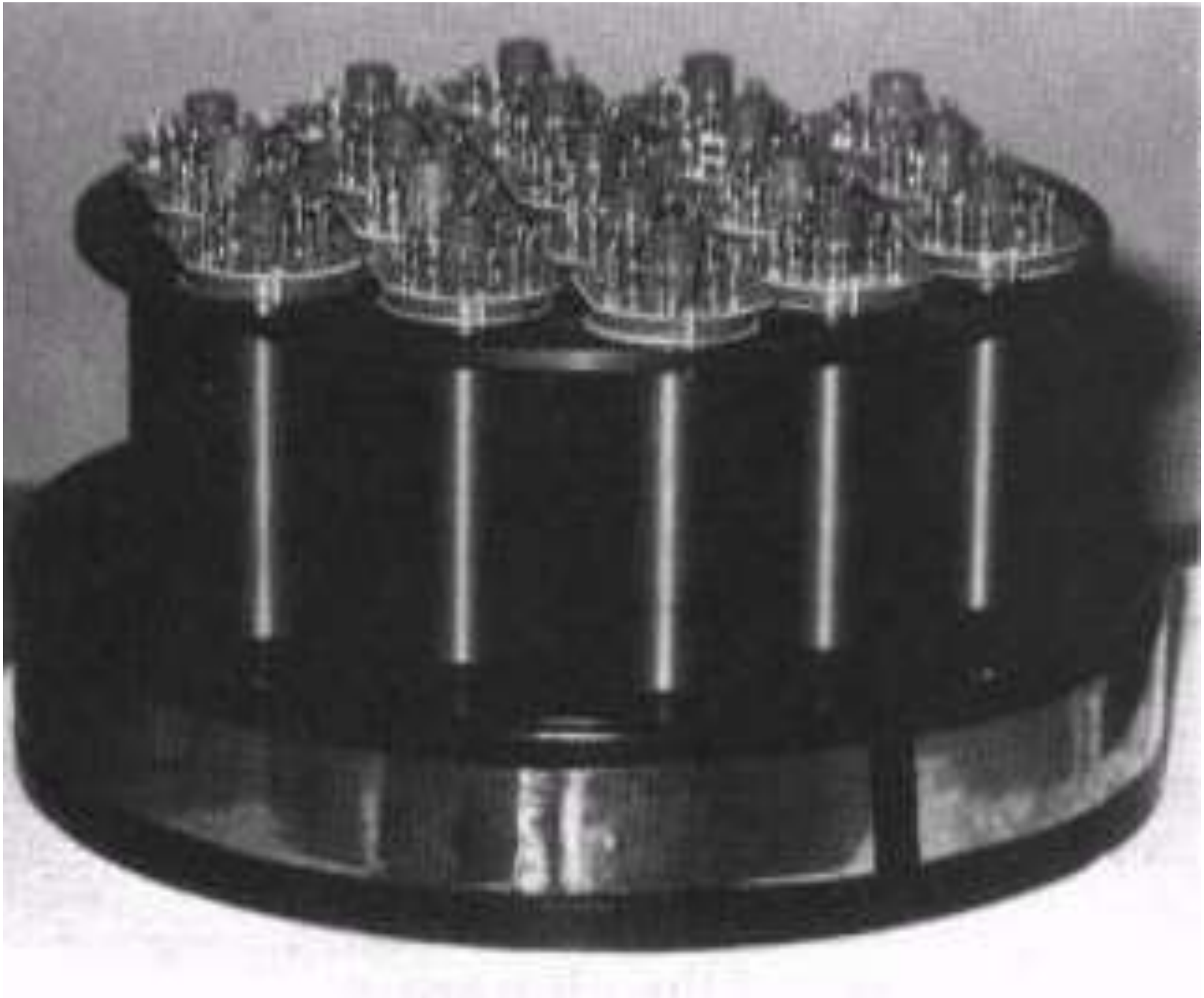
- Scintillation crystals commonly used are sodium iodide with trace amounts of thallium to increase light production
  - Thicker crystals are better for imaging radiopharmaceuticals with higher energies, but have decreased resolution
  - Thinner crystals provide improved resolution but not efficient with higher Kv

PMTs

- Photomultiplier tubes are attached to the back of the crystals
- PMTs are used to detect and convert light photons emitted from the crystal into electronic signal that amplifies the original photon signal
- The electronic signal is displayed on a cathode ray tube for filming or reading

GAMMA CAMERA COMPONENTS:





Gamma Camera Systems

- Standard camera: Single detector that is moved in various positions around the Patient
- Dual-head camera: Allows simultaneous anterior and posterior imaging and may be used for whole-body bone or tumor imaging.
- Triple-head systems may be used for brain and heart studies

Imaging Methods

- Examination can be described on the basis of imaging method used:
  - Static
  - Whole body
  - Dynamic
  - Single photon emission computed tomography, SPECT
  - Positron emission tomography, PET

STATIC

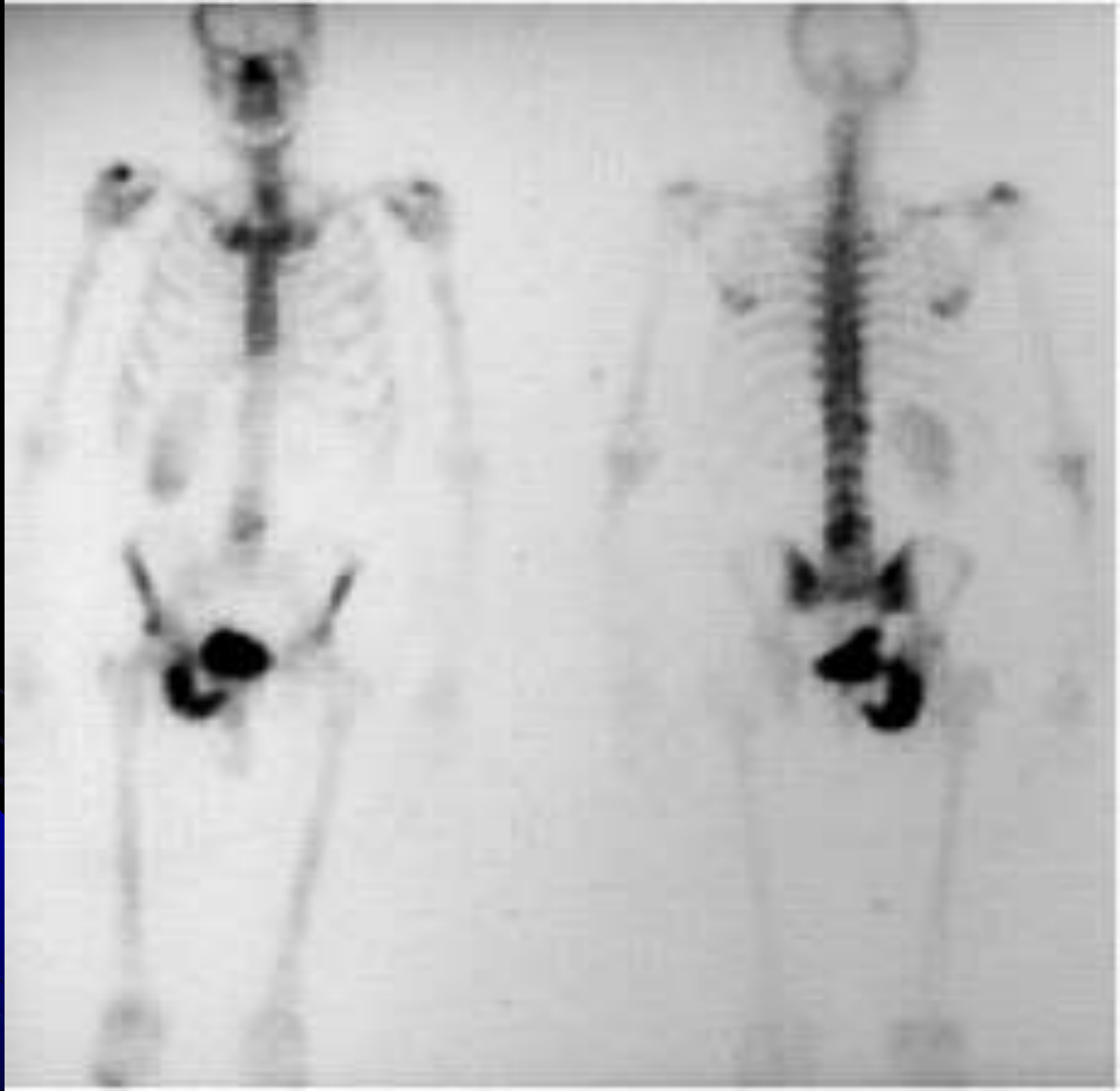
- A “snapshot” of the radiopharmaceutical distribution within a part of the body.
- Ex: lung scans, spot bone scans images, thyroid images
- Static images of the organ or structure are usually obtained in various orientations, anterior, posterior, and oblique

Normal Thyroid Scan

Nodular Thyroid

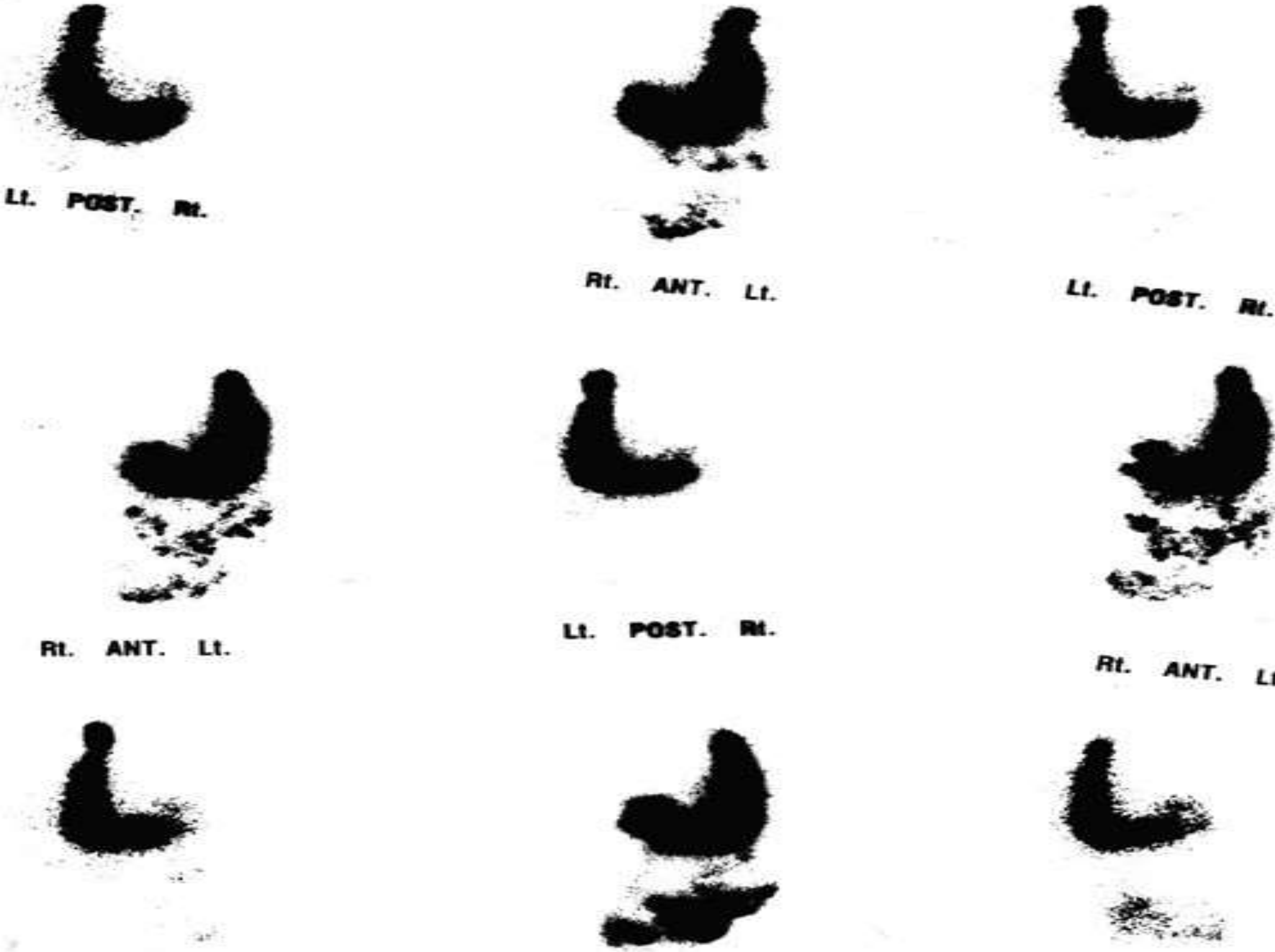
Whole-Body Imaging

- Uses a specially designed moving detector system to produce and image of the entire body or a large body section. The gamma camera collect data as it passes over the body
- Ex: whole-body bone scans, tumor or abscess imaging.



Dynamic Imaging

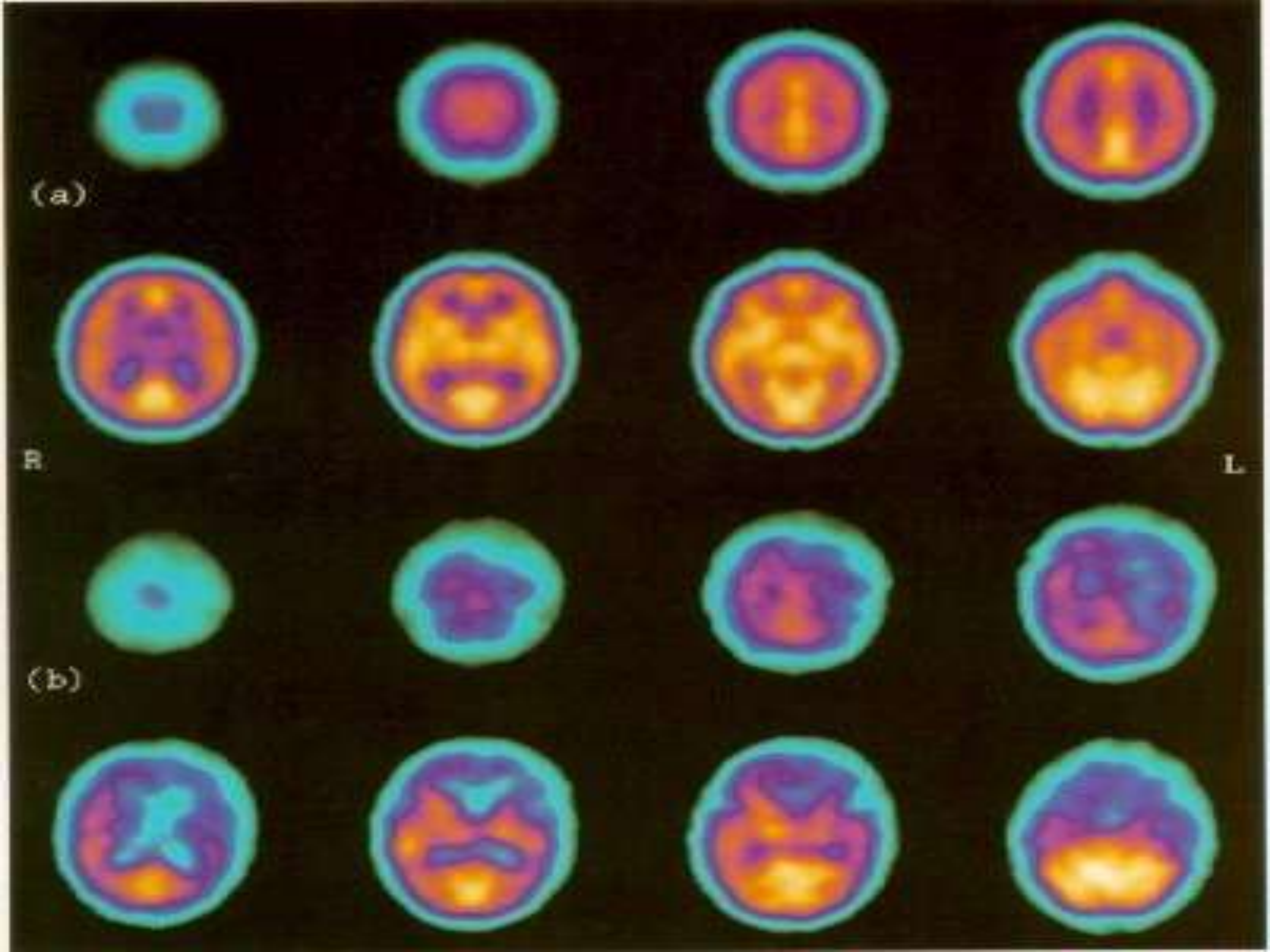
- Display the distribution of a particular radiopharmaceutical over a specific period.
- “Flow” study of a particular structure is generally used to evaluate blood perfusion to the tissue
- Time-lapse images
- Ex: cardiac, hepatibiliary, gastric emptying studies


Lt. POST. Rt.
Rt. ANT. Lt.
Lt. POST. Rt.
Rt. ANT. Lt.
Lt. POST. Rt.
Rt. ANT. Lt.

SPECT

- SPECT: produces image similar to CT & MRI in that a computer creates thin slices through a particular organ.

- Ex: cardiac perfusion, brain, liver and bone studies


(a)
R
L
(b)

PET

- Uses positron emission from particular radionuclides to produce detailed functional images within the body. PET is unique in that its images are of blood flow or metabolic processes at the cellular level rather than the more conventional anatomic image produced by x-ray, CT, MRI, or even SPECT

- A tumor grows and divides and ultimately goes to distant sites (metastasizes)
- This process needs energy and hence needs GLUCOSE
- Glucose analog FDG is labelled with Fluorine-18 and this is used as a tracer in PET (F-18 FDG)

- Since the cancer cells have increased glycolytic activity, the FDG is trapped into these cancer cells and can be detected.
- Renal system helps in the excretion of this FDG as the reabsorption of the tracer is not possible

- Some clinical applications of 18F-FDG PET in head and neck cancer:

1. Diagnosis of distant metastases
2. Identification of synchronous 2nd primaries
3. Detection of carcinoma of unknown primary
4. Detection of residual or recurrent disease.

- Provides precise delineation of the tumor volume for radiation treatment planning and monitoring of treatment.

SALIVARY GLAND SCINTIGRAPHY

- Intoduced by Boner et al. for functional assessment of Xerostomia
- Utilizes **99mTc.PERTECHNETATE and** visual evaluation is done using a gamma camera
- The rate and density of [99mTc]pertechnetate uptake and its time of appearance in the mouth over a 60-min period after intravenous injection is observed

- This allows for glandular functions and excretions to be assessed.
- Non-invasively assesses the site, the severity, and the nature of salivary derangement, a unique capability
- The parenchymal and excretory function of salivary glands can be simultaneously quantified

- Gland aplasia/agenesis, obstruction, trauma, as well as fistulas in the glands can be detected
- Acute inflammation usually shows increase in uptake while decreased intake is seen chronic inflammatory stages

LYMPHOSCINTIGRAPHY
OR
SENTINEL NODE MAPPING

- Uses the property of carcinomas to spread via lymphatics.
- If sentinel node is diagnosed to be involved then chances of lymphatic spread to other nodes is present.

- It prevents unnecessary surgical intervention if sentinel node is found to be negative for metastases.
- Technetium 99m sulfur colloid is injected in four to six subcutaneous sites around the neoplastic lesion
- Gamma camera is used to detect the sentinel node which if found is then resected surgically

Skeletal Scintigraphy (Bone Scan)

- Follows the principle of SPECT,utilizing a gamma camera, aka scintillation camera
- Uses the bone seeking property of technetium **99M LABELLED DISPHOSPHANATES** which gets incorporated in mineral matrix of bones (hydroxyapatite and calcium phosphate)

- Diphosphonate gets incorporated in areas with increase osteoblastic activity and vascularity
- A three-phase bone scan is often performed sp. when the clinician is trying to distinguish osteomyelitis from cellulitis

- The first phase: <u>Dynamic vascular flow phase</u> in which difference in vascularity is determined by imaging every 2-3 sec for the first 30 sec

- **Second phase:D**ifference in regional blood low and vascularity can be appreciated by imaging 5 min after first scan.

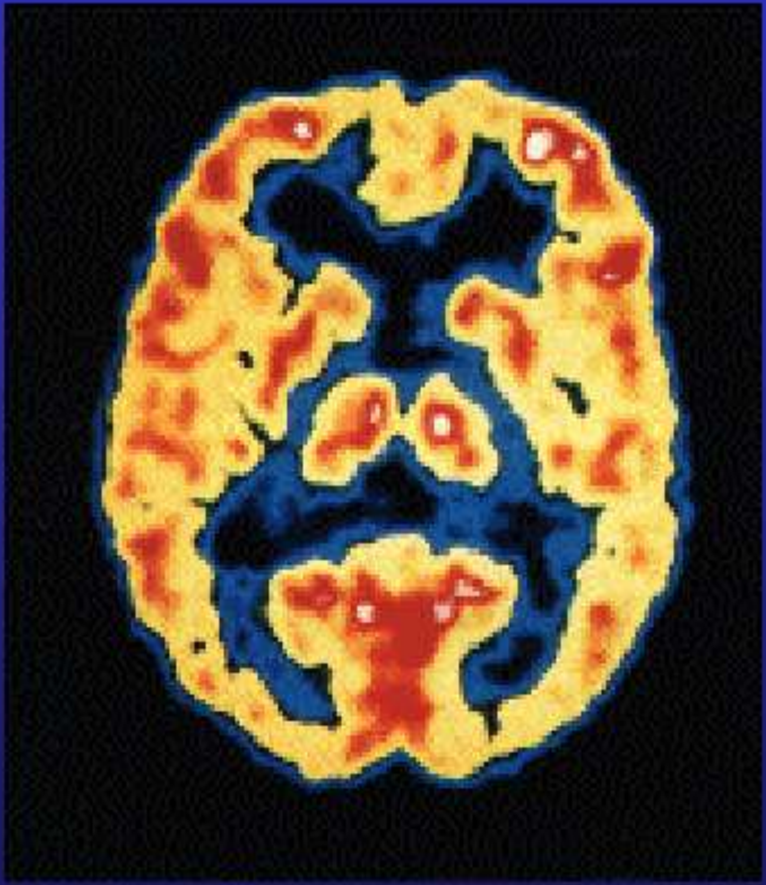
- 2-4 hours later, **A third phase:** <u>Osseous delayed</u> static image is taken for the entire body to determine metabolic activity of bone and hence regional distribution in the skeleton. In non inflammatory conditions is suspected, the third phase is usually the only image obtained.

- In non inflammatory conditions is suspected, the third phase is usually the only image obtained
- Can even detect approximately a 10% increase in the osteoblastic activity of the bone above normal

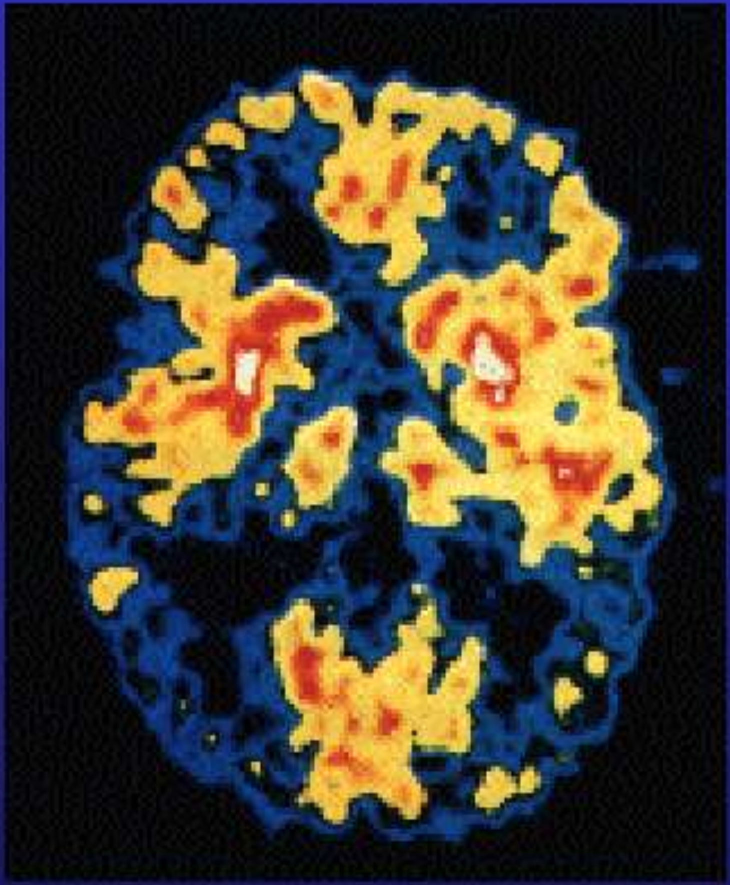
- **Fibrous dysplasia**: Increased tracer uptake on99mTc bone scans.
- **Paget disease**:osteolytic activity with resorption of normal bone followed by a vigorous osteoblastic activity forming woven bone.If mandibleis affected, increased uptake present from condyle to condyle. This is termed as black beard or Lincoln’s Sign

- **Fractures:** Most fractures show increased uptake on bone scintigraphy within hours after trauma
- **Condylar hyperplasia:** bone scan can to detect abnormalities at an earlier stage.

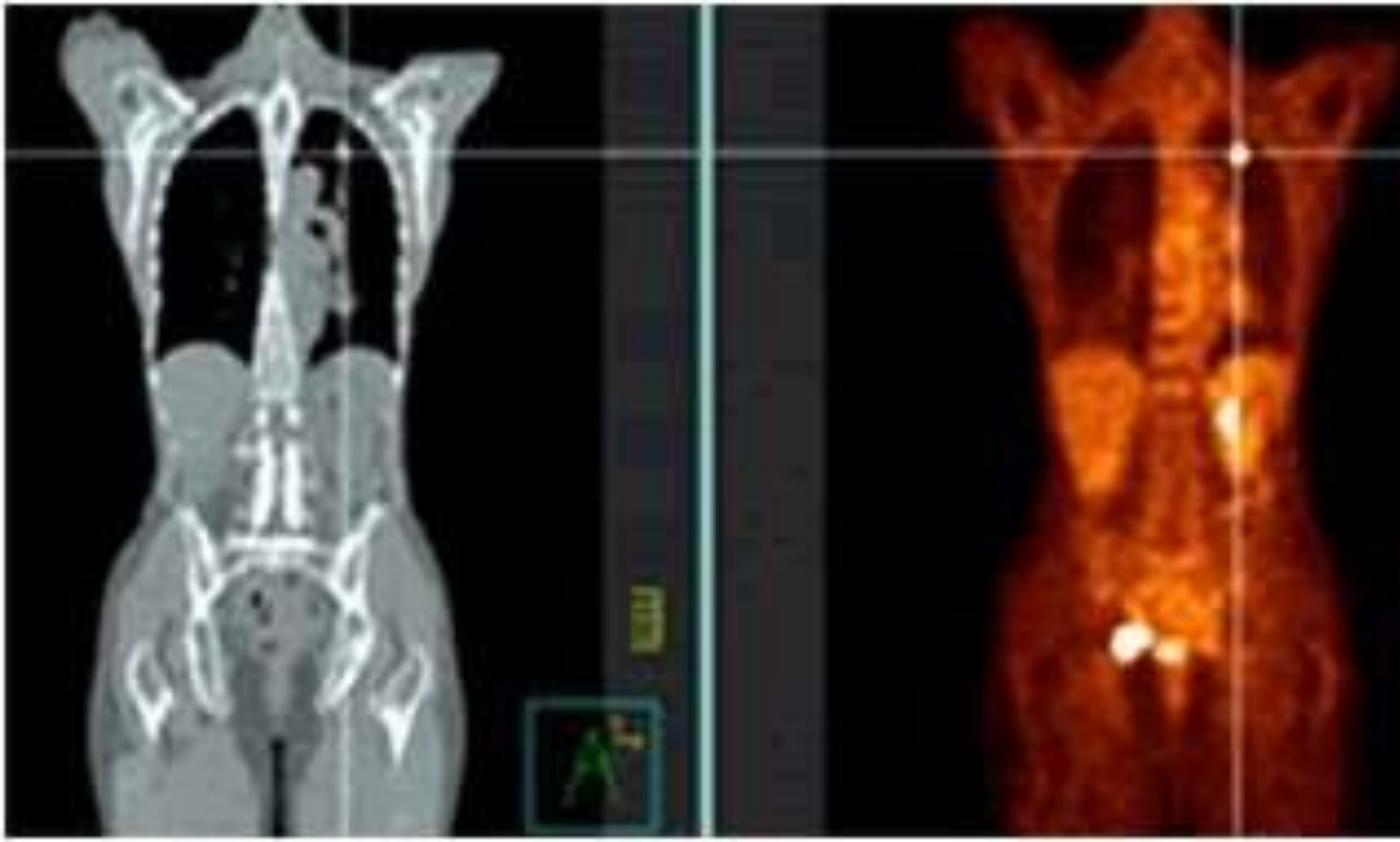
Brain Metabolism in Alzheimer's Disease: PET Scan



Normal Brain



Alzheimer's Disease



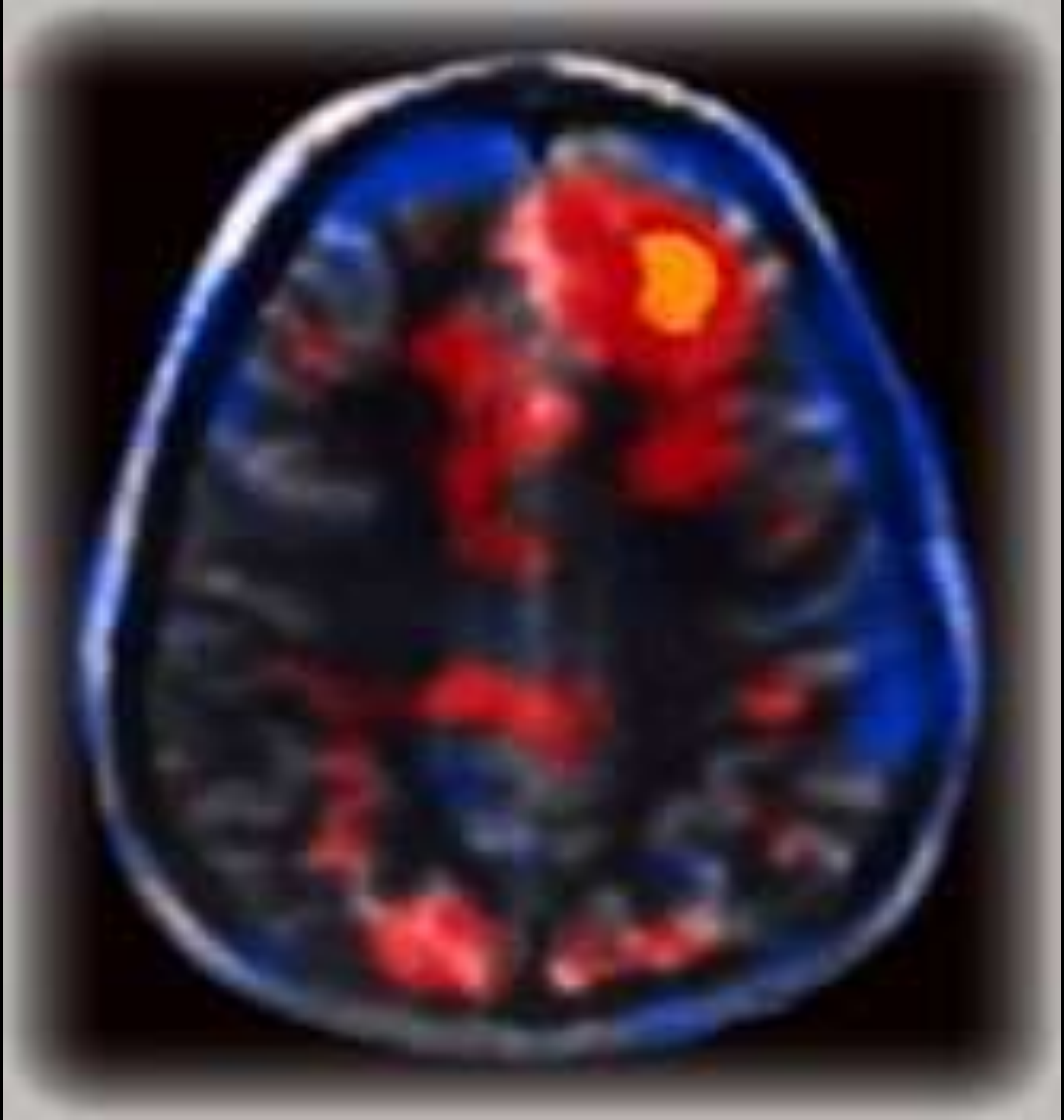
CT scan shows the anatomy.

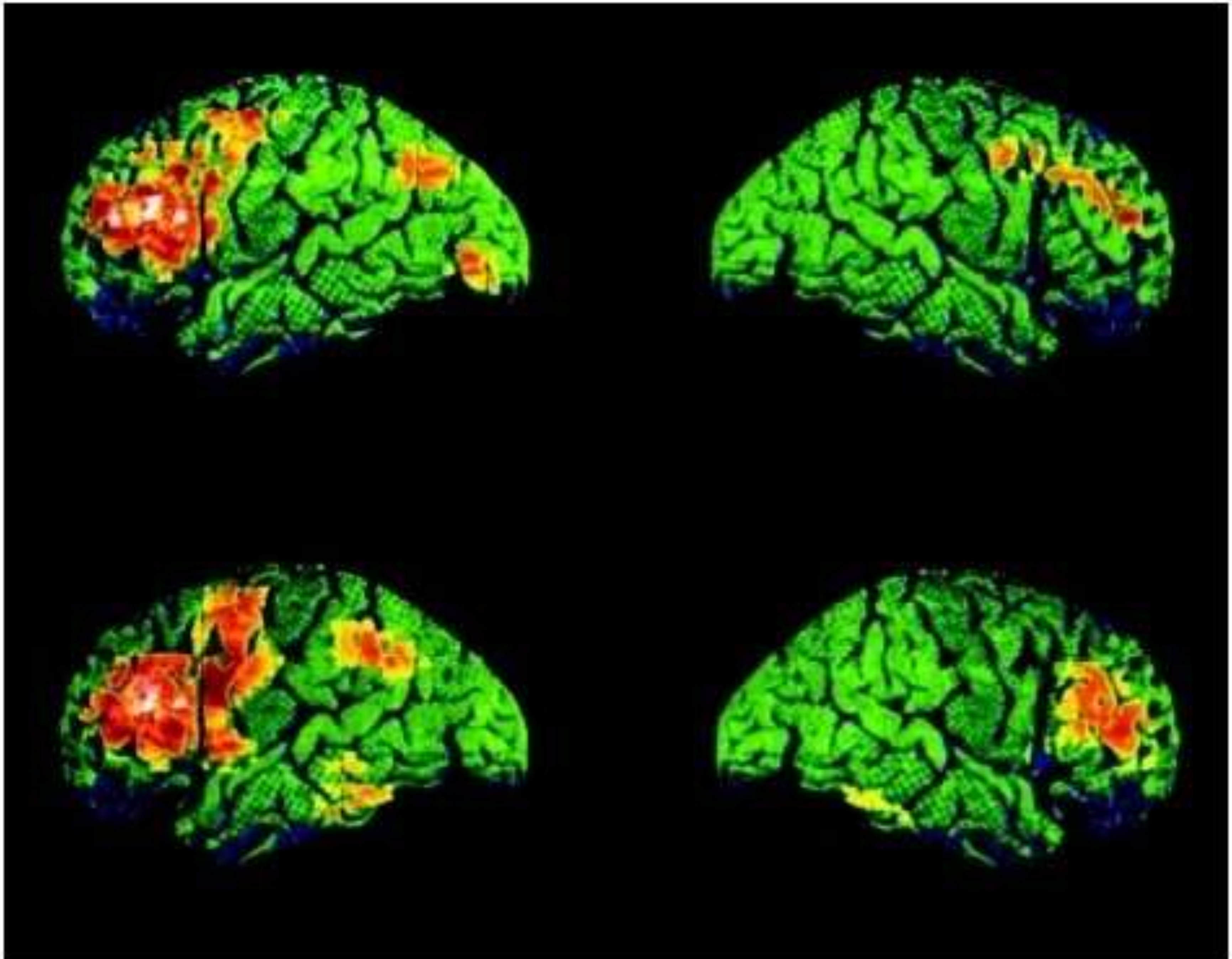
PET scan shows increased cellular activity indicating cancer.

Combined, PET/CT pinpoints cancer anatomically.

PET/CT & SPECT/CT

- Now available is a blending of imaging function and form. By merging the functional imaging of PET and SPECT with the anatomical landmarks of CT
- More powerful diagnostic information is obtainable.





Common Nuclear Medicine Studies

- **NEUROLOGIC**
- diagnose stroke
- diagnose Alzheimer's - demonstrate changes
- disease in AIDS dementia

ONCOLOGIC

tumor localization - tumor staging

identification of bone pain due metastatic cancer

Common Nuclear Medicine Studies

- **RENAL**

•diagnose renovascular obstruction, hypertension

•detect renal transplant Rejection - renal function

CARDIAC

select patients for artery bypass or angioplasty

localize toxicity due to acute myocardial chemotherapy infarction

identify cardiac shunts

Common Nuclear Medicine Studies

- **PULMONARY**
- diagnose & quantify pulmonary function
- emboli perfusion
- detect pulmonary complications of AIDS

ORTHOPEDIC

identify bone trauma

diagnose osteomyelitis

evaluate arthritic changes

Common Nuclear Medicine Studies

- **OTHER COMMON APPLICATIONS**
- diagnose and treat thyroid cancer
- hyperthyroidism or metastatic spread
- detect acute GI & cholecystitis bleeding
- detect testicular torsion & infections

Hybrid scanning techniques

- NM scans superimposed on MRI/CT images, highlight the part of body in which tracer is concentrated
- Commonly referred to as Image Fusion or Co-registration e.g. SPECT/CT, PET/CT
- Provides information about both anatomy and function

Brachytherapy

- It is one of the radio-therapeutic methods where the radioisotopes are directly placed at the site of the malignant tumor.
- These isotopes are placed in a protective capsule which prevents its movement and later the capsule may be left behind or removed.

- These isotopes emit ionizing radiation to the surrounding tissue and kills the cancer cells
- Radioactive iodine (I-131) therapy used to treat hyperthyroidism (for example, Graves' disease) and thyroid cancer

- Radioactive phosphorus (P-32) used to treat certain blood disorders
- I-131 MIBG (radioactive iodine labeled with metaiodobenzylguanidine) used to treat adrenal gland tumors

Radioimmunotherapy

- RIT, a monoclonal antibody is paired with a radioactive material. When injected into the patient's bloodstream, the antibody travels to and binds to the cancer cells, allowing a high dose of radiation to be delivered directly to the tumor.

Patient Prep & Safety

- For NM procedures prep is minimal, most tests requiring no special prep.
  - A few procedures the patient will need to be NPO
- Pt. Usually remain in their own clothing, removing all metal objects. Metal can mimic pathologic conditions.

Patient Prep & Safety

- Pt. first receive the radiopharmaceutical injection and then will return for imaging in a few hours. Waiting time between dose administration and imaging varies with each study
- Some radiopharmaceuticals require the Pt. to remain in isolation after injection, or require special disposal of urine products

THANK YOU