

Part I-A: radio-isotopes for medical diagnosis

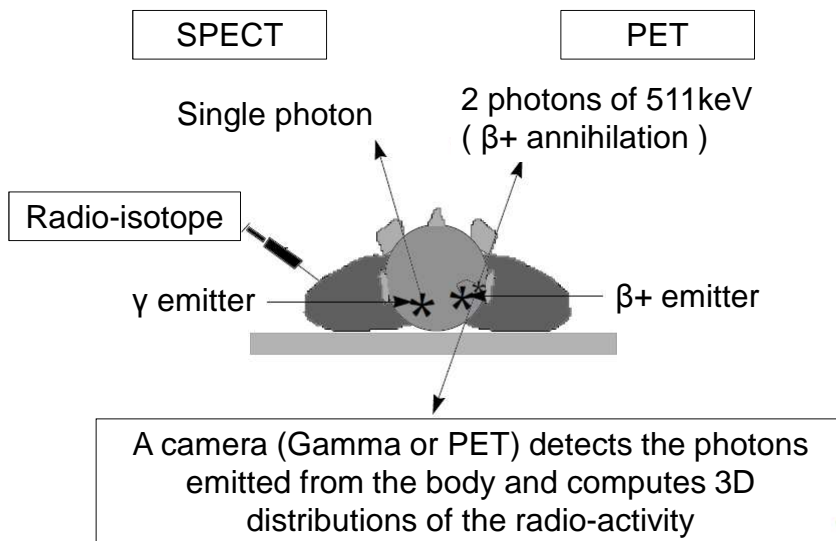
SPECT: Single Photon Emission Computed Tomography

PET: Positron Emission Tomography



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How is imaging done with radio-tracers ?



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The use of Radio Isotopes for medical imaging

- Radio tracers can be used to label a specific bio-chemical molecule.
- They allow to see metabolism
 - X-ray (CT-) scan or MRI are better to see the anatomy (structure)
- Nuclear medicine (imaging of metabolism using molecules labeled with an appropriate radioisotope) is therefore not in competition, but in complement of imaging techniques such as X-ray, X-ray CT-scan or MRI.

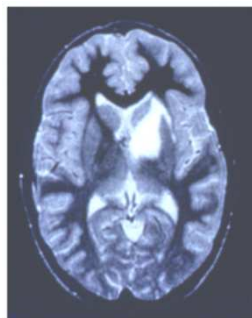
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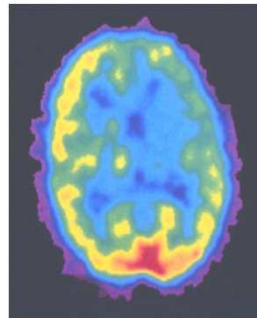
Metabolic versus anatomic imaging

MRI



Anatomic View
(Tissue-structure)

PET



Metabolic imaging
(Biological-function)

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How is imaging done with radio-tracers ?

Single photon isotopes (SPECT)

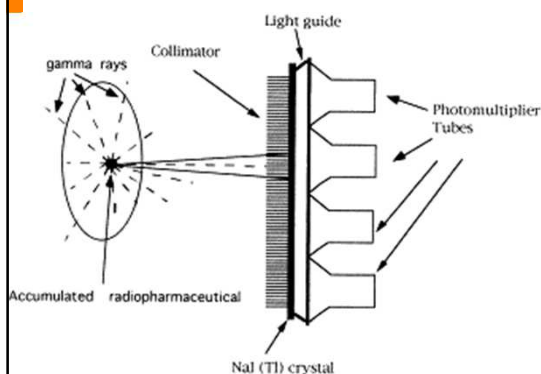
- The imaging of single photons emitters requires:
 - a collimator (causes a loss of efficiency !).
 - a position-sensitive detector (with good detection efficiency): the Gamma (or Anger) camera.
- The image obtained is a projection.
- Multiple (perpendicular) projections can be mathematically correlated to produce a 3D representation.
- SPECT (Single Photon Emission Computed Tomography).

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The SPECT gamma camera (Anger camera)

Anger camera The collimator prevents photons that are not approximately perpendicular to the collimator holes from interacting with the detector.



The field of view for the detector element behind each hole of the collimator is divergent, so that in a gamma camera, spatial resolution degrades as the distance to the object is increased. Collimators are usually made of lead.

Typical dimensions: holes 3mm, walls 1mm, depth 40mm.

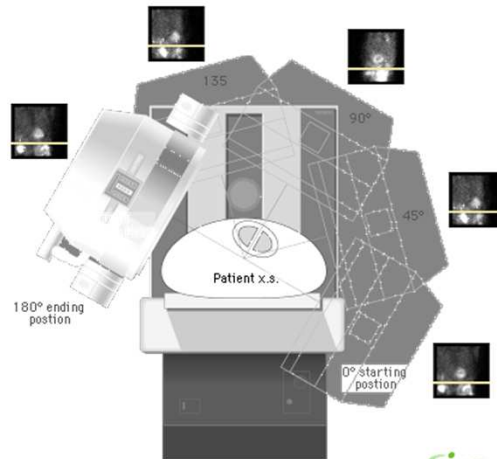
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The SPECT gamma camera



Projections from different angles are taken by rotating the camera around the patient



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“Traditional” nuclear medicine

- Technetium 99m, the most commonly used radio-isotopes in nuclear medicine is produced in reactors.
 - 90% of diagnostic studies in hospitals is done with ^{99m}Tc !
- But a number of other, very important nuclear medicine radio-isotopes are produced with cyclotrons of higher energy.
 - ^{201}Tl (Cardiac studies).
 - ^{123}I (Thyroid, Various examinations).
- For these longer life isotopes, international distribution is possible.
- Large, very powerful cyclotrons are owned by radiopharmaceutical companies.

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How to select a good single-photon radio-tracer?

1. The energy of the emitted photon

- Low enough to keep a good detector efficiency
- Low enough in order to achieve good collimation
- High enough to cross the body tissue
- $100 \text{ keV} \leq E \leq 300 \text{ keV}$ is generally the optimum

2. The half-life:

- Short enough to minimize the patient's exposure
- Long enough to allow distribution to the hospitals
- Practically $10\text{h} \leq T_{1/2} \leq 100\text{h}$ is roughly best
- Generators are great too !

^{99}Mo (66 hours) = $^{99}\text{Tc}_m$ (6 hours)

^{81}Rb (4.6 hours) \Rightarrow ^{81}Kr (13sec)

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How to select a good single-photon radio-tracer

3. The chemistry

- The radio-tracer should bind easily to organic bio-molecules of interest
- Essential bio-chemical behavior of the molecule should remain intact after labeling
 - Halogens (Fluor, Iodine), Technetium \Rightarrow good;
 - Noble metals (Gold) \Rightarrow difficult

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Nuclear reactions for SPECT radio-Isotopes

Radioisotope	Half-life	Reaction	Energy (MeV)
^{201}Tl	73.1 h	$^{203}\text{Tl} (p,3n) \Rightarrow ^{201}\text{Pb} \Rightarrow ^{201}\text{Tl}$	17~28
^{67}Ga	78.3 h	$^{68}\text{Zn} (p,2n) \Rightarrow ^{67}\text{Ga}$	12~28
^{111}In	67.4 h	$^{112}\text{Cd} (p,2n) \Rightarrow ^{111}\text{In}$	12~28
^{123}I	13.2 h	$^{124}\text{Te} (p,2n) \Rightarrow ^{123}\text{I}$	20~25
		$^{124}\text{Xe} (p,2n) \Rightarrow ^{123}\text{Cs} \Rightarrow ^{123}\text{I}$	20~30
		$^{124}\text{Xe} (p,pn) \Rightarrow ^{123}\text{I}$	
		$^{127}\text{I} (p,5n) \Rightarrow ^{123}\text{Xe} \Rightarrow ^{123}\text{I}$	45~68

A 30 MeV cyclotron can often do the job



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Positron emitting radio-isotopes (PET)

- The emitted positron travels a few millimeters, then meets an electron and annihilates, emitting two anti-parallel photons of 511keV.
- These two photons can be detected in **coincidence** by a ring of detectors surrounding the region of interest.
- One knows then that the origin of the photons is on the line connecting the two detectors => no collimator needed
- Several detections allow to locate the source.
- By mathematical reconstruction, a 3D representation of the activity can be obtained.
- PET (Positron Emission Tomography).



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The PET scanner

The diagram illustrates the PET scanner workflow. A patient is positioned inside a large ring-shaped detector. Positrons from the patient annihilate with electrons, producing two gamma rays that travel in opposite directions. These are detected by the ring, and the data is sent to a Coincidence Processing Unit. The unit outputs Sinogram/Listmode Data to a computer for Image Reconstruction. A small inset shows the annihilation process with a positron and electron meeting and producing two gamma rays.

Currently available are

- PET scanners integrated with CT: PET-CT
- PET scanners integrated with MRI: PET-MRI

PET scanner in a hospital

- Coincidents events are grouped into projected images (sinograms) and sorted by the angle of view
- Analogous to the projections obtained with Computed Tomography (CT) scanners
- 3D image re-construction is similar

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Common positron emitting radioisotopes for PET

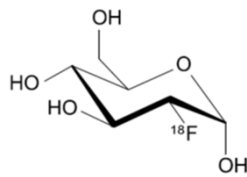
Radioisotope	Half-life (min)	Positron energy (MeV)	Reaction	Energy (MeV)
¹¹ C	20.4	1.0	¹⁴ N (p,α) => ¹¹ C	5=>16
¹³ N	9.96	1.2	¹⁶ O (p,α) => ¹³ N	8=>16
			¹² C (d,n) => ¹³ N	3=>8
¹⁵ O	2.07	1.7	¹⁵ N (p,n) => ¹⁵ O	5=>14
			¹⁴ N (d,n) => ¹⁵ O	3=>8
¹⁸ F	109.8	0.6	¹⁸ O (p,n) => ¹⁸ F	5=>14

Cyclotrons 10-18 MeV

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FDG = Fluoro-Deoxy-Glucose

- Most commonly made PET scan (90% of cases) is done with ^{18}F -FDG (Fluoro-Deoxy-Glucose)
- Metabolic activity by virtue of glucose uptake in tissue
- This tracer is mainly used to explore the possibility of cancer metastasis and the response to treatment

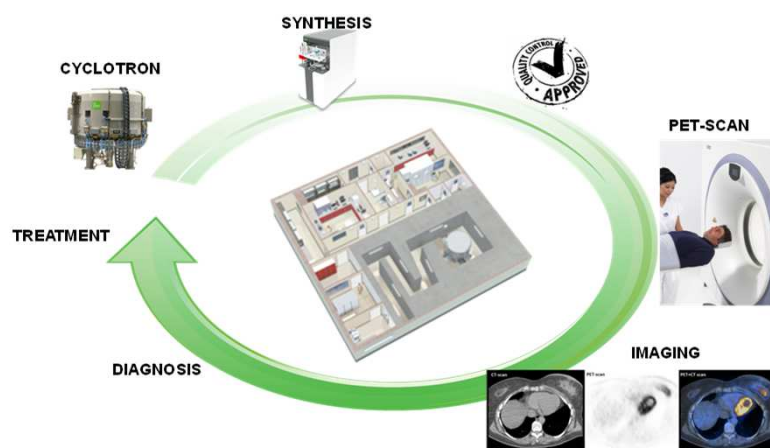


- In glucose one OH-group is replaced by a ^{18}F atom
- Both atoms have about the same size =>
- Bio-chemical behaviour almost not altered

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The full production and application cycle of PET radio-isotopes



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Four different types of radiation therapy

1. External beam radiation therapy (teletherapy)
 - Radiation source is external (like proton therapy)
2. Brachy therapy:
 - Sealed radioactive sources placed precisely in the tumor
 - Can use temporary or permanent placement of radioactive sources
3. Systemic radiation therapy
 - Radioisotopes are given by infusion or by oral ingestion. Example: iodine => thyroid gland
4. BNCT: Boron Neutron Capture Therapy
 - mixture of 1 and 3.



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Part I-B: radio-isotopes for cancer therapy

In a radioisotope, the nucleus decays spontaneously, giving off particles with some kinetic energy.

β^+

γ

diagnosis

α

β^-

therapy

PET - $T_{1/2}$:

- F-18- 2h
- Ga-68- 1h
- Zr-89-3 d
- I-124-4 d
- O-15- 2min

SPECT- $T_{1/2}$:

- I-123-13d
- Tc-99m-6h
- Ga-67
- In-111
- Tl-201

- I-131
- Y-90
- Re-188
- Lu-177
- At-211*



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Brachy therapy

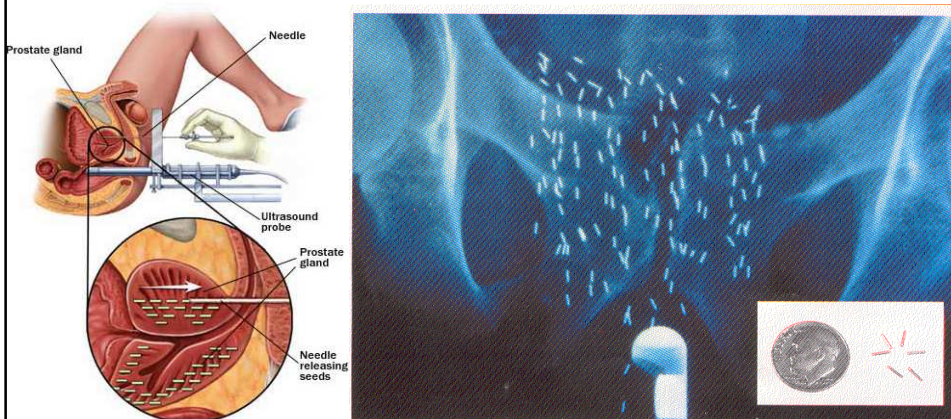
- Dose is delivered by placing the radiation source directly inside the area requiring treatment
- Commonly used for cervical (uterus), prostate, breast and skin cancer
- Irradiation affects only a very localized area => healthy tissues are spared
- Much higher doses can be delivered. For comparison:
 - Proton therapy: about 40 Gray
 - Prostate brachytherapy: about 100 to 150 Gray
- Brachytherapy can often be completed in less time
 - Reduce the possibility of recovery of cancer cells between treatment intervals



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Prostate brachytherapy with Pd-103 or I-125

Seeds placed with 3D precision verified with ultrasound probe
Seeds are not harmful and can stay in place after treatment



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