CLASS V & VI

3 Feb 2017

Positron Emission Tomography

- generates images depicting the distribution of **positron-emitting nuclides** in patients.

- “PET/CT” systems

- PET scanners use annihilation coincidence detection (ACD) instead of collimation to obtain projections of the activity distribution in the subject.

Flowchart

- Radioactive Decay
  - unstable atomic nuclei due to **too many protons** relative to the number of neutrons
  - decays to stable form by **converting proton to neutron**
  - **ejects a "positron"** to conserve electric charge
  - positron annihilates with an electron, **releasing two anti colinear high-energy photons.**

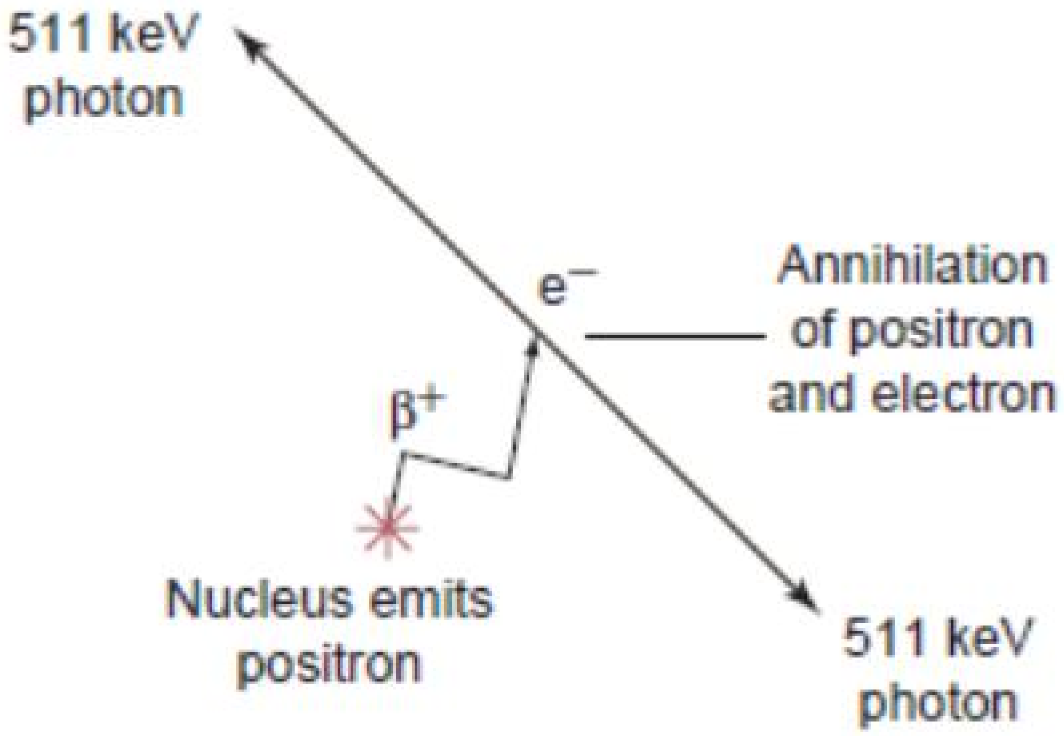
- The clinical importance of PET today is largely due to its ability to
  - image the radiopharmaceutical **fluorine-18 fluorodeoxyglucose (FDG)**, a glucose analog used for differentiating malignant neoplasms from benign lesions,
  - staging patients with malignant neoplasms,
  - monitoring the response to therapy for neoplasms

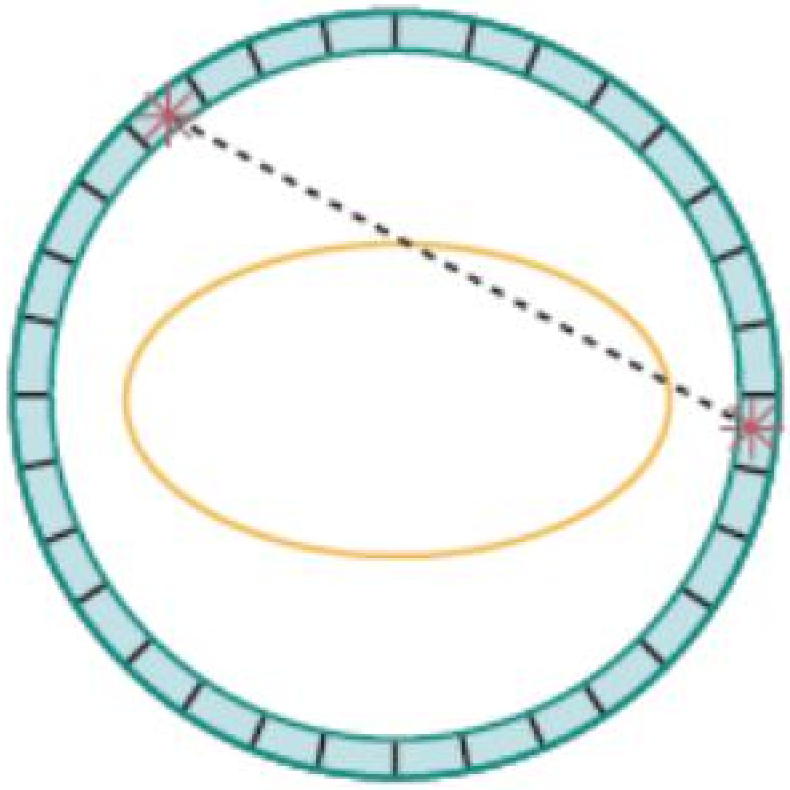
- Positrons emitted in matter lose most of their kinetic energy by causing **ionization and excitation**

FLOWCHART

- When a positron has lost most of its kinetic energy, it interacts with an electron by ***annihilation***
- *The entire mass of the electron-positron pair is converted into two 511-keV photons, which are emitted in nearly opposite directions.*

Q. What is the principle of PET ?





- If both photons from an annihilation interact with detectors and neither photon is scattered in the patient, the annihilation occurred near the line connecting the two interactions

- Circuitry within the scanner identifies pairs of interactions occurring at nearly the same time, a process called annihilation coincidence detection (ACD).

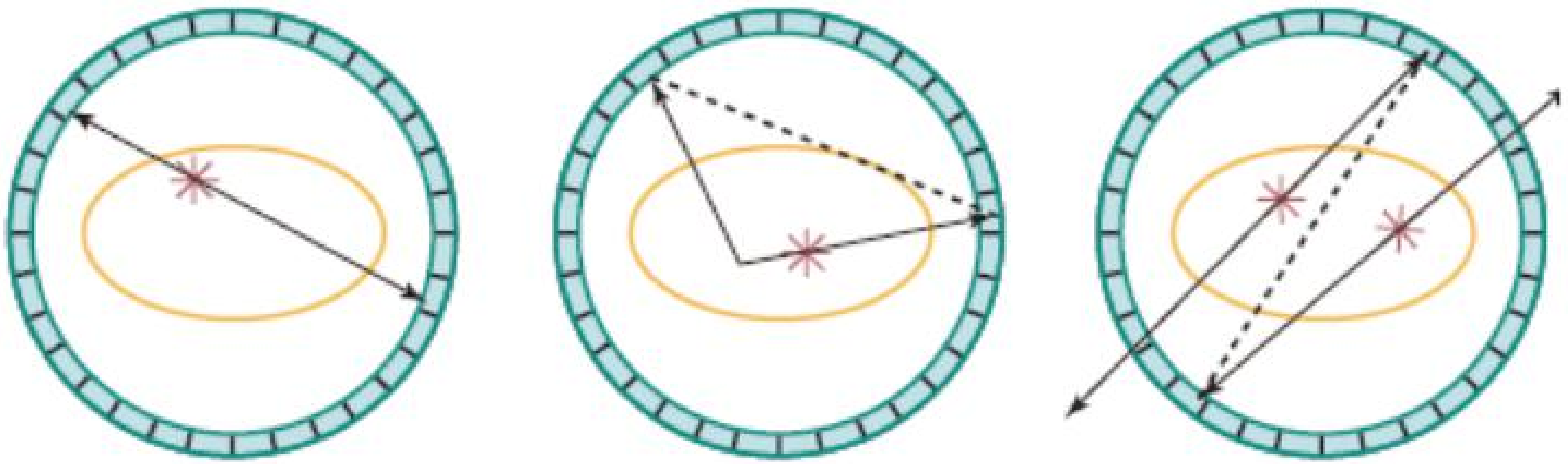
- The circuitry of the scanner then determines the line in space connecting the locations of the two interactions.

- Thus, ACD establishes the trajectories of detected photons, a function performed by collimation in SPECT systems

- ACD method is much less wasteful of photons than collimation.

- ACD avoids the degradation of spatial resolution with distance from the detector

True, Random, and Scatter Coincidences



■ **FIGURE 19-16** True coincidence (**left**), scatter coincidence (**center**), and random (accidental) coincidence (**right**). A scatter coincidence is a true coincidence, because it is caused by a single nuclear transformation, but results in a count attributed to the wrong LOR (*dashed line*). The random coincidence is also attributed to the wrong LOR.

- true coincidence
  - is the nearly simultaneous interaction with the detectors of emissions resulting from a single nuclear transformation
- random coincidence (also called an accidental or chance coincidence)
  - which mimics a true coincidence, occurs when emissions from different nuclear transformations interact nearly simultaneously with the detectors
- scatter coincidence
  - occurs when one or both of the photons from a single annihilation are scattered, and both are detected

- A scatter coincidence is a true coincidence, because both interactions result from a single positron annihilation

- Random coincidences and scatter coincidences result in misplaced coincidences, because they are assigned to lines of response (LORs) that do not intersect the actual locations of the annihilations. They are therefore sources of noise, whose main effects are to reduce image contrast and increase statistical noise.

TABLE 19-2 PROPERTIES OF SEVERAL INORGANIC SCINTILLATORS OF INTEREST IN PET

SCINTILLATOR	DECAY CONSTANT (ns)	PEAK WAVELENGTH (nm)	ATOMIC NUMBERS	DENSITY (g/cm^3)	ATTENUATION COEFFICIENT 511 keV (cm^{-1})	CONVERSION EFFICIENCY RELATIVE TO NaI
NaI(Tl)	250	415	11,53	3.67	0.343	100%
BGO	300	460	83,32,8	7.17	0.964	12%–14%
GSO(Ce)	56	430	64,14,8	6.71	0.704	41%
LSO(Ce)	40	420	71,14,8	7.4	0.870	75%

- most PET systems used crystals of bismuth germanate ($Bi_4Ge_3O_{12}$, abbreviated BGO). The light output of BGO is only 12% to 14% of that of NaI(Tl), but its **greater density and average atomic number** give it a much higher efficiency in detecting 511-keV annihilation photons

- Light is emitted rather slowly from BGO (decay constant of 300 ns), which contributes to **dead-time count losses** and **random coincidences at high interaction rates. (Problem)**

- Several inorganic scintillators that emit light more quickly are replacing BGO. These include **lutetium oxyorthosilicate** (Lu_2SiO_4O, abbreviated LSO), **lutetium yttrium oxyorthosilicate** ($Lu_xY_{2-x}SiO_4O$, abbreviated LYSO), and **gadolinium oxyorthosilicate** (Gd_2SiO_4O, abbreviated GSO), all activated with **cerium**.

- Their **attenuation properties** are nearly as favorable as those of BGO and their much faster light emission produces better performance at high interaction rates, especially in **reducing dead-time effects** and **in discriminating between true and random coincidences.**

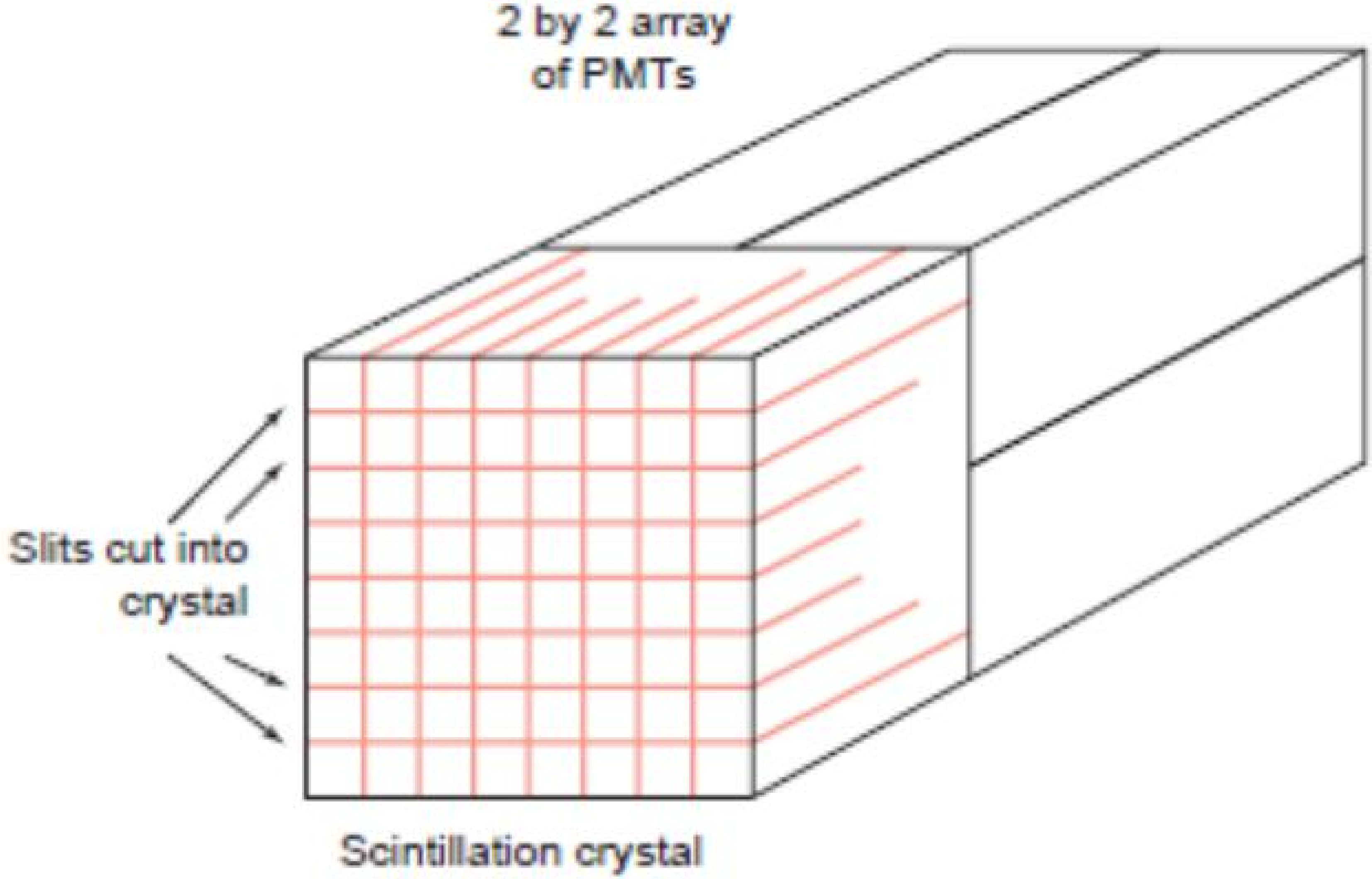
- The energy signals from the detectors are sent to **energy discrimination circuits**, which can reject events in which the deposited energy differs significantly from 511 keV to reduce the effect of photon scattering in the patient.

- FLOWCHART:
  - Positron interaction with electron
  - Annihilation
  - Detection with the help of energy discrimination circuits
  - time signals of interactions not rejected by the energy discrimination circuits are used for coincidence detection

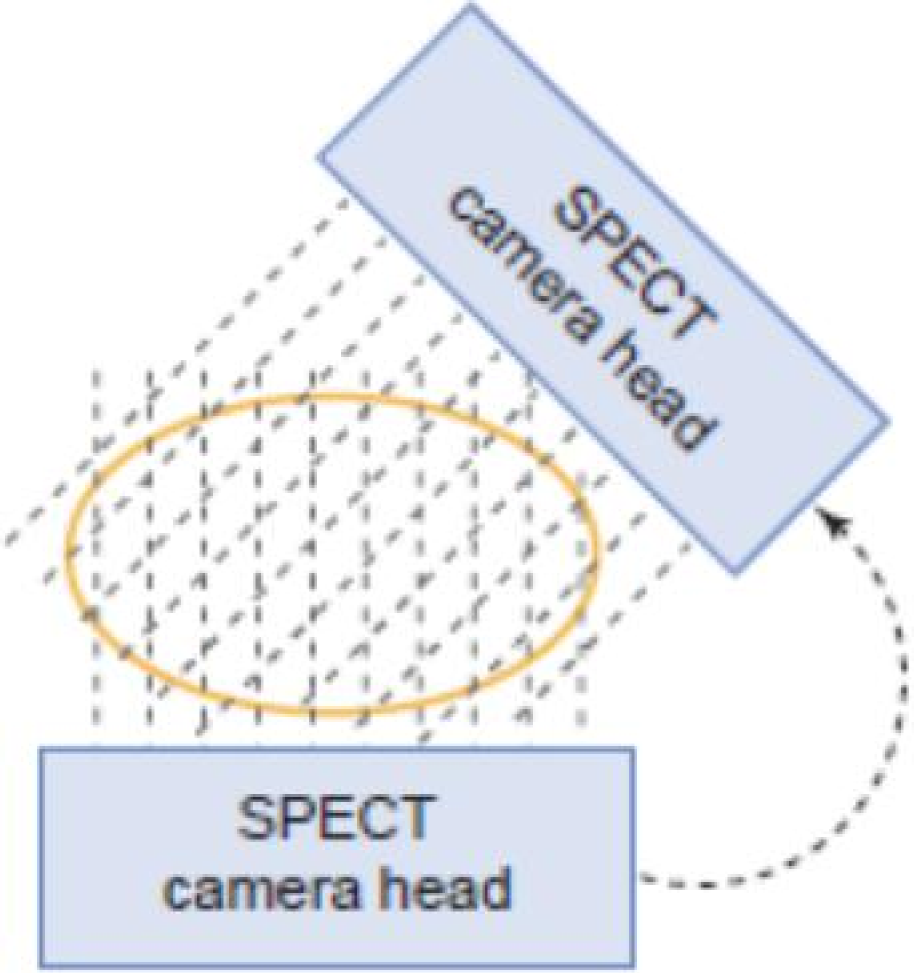
- When a coincidence is detected, the circuitry or a computer in the scanner determines a line in space connecting the two interactions: ***Line of Response***

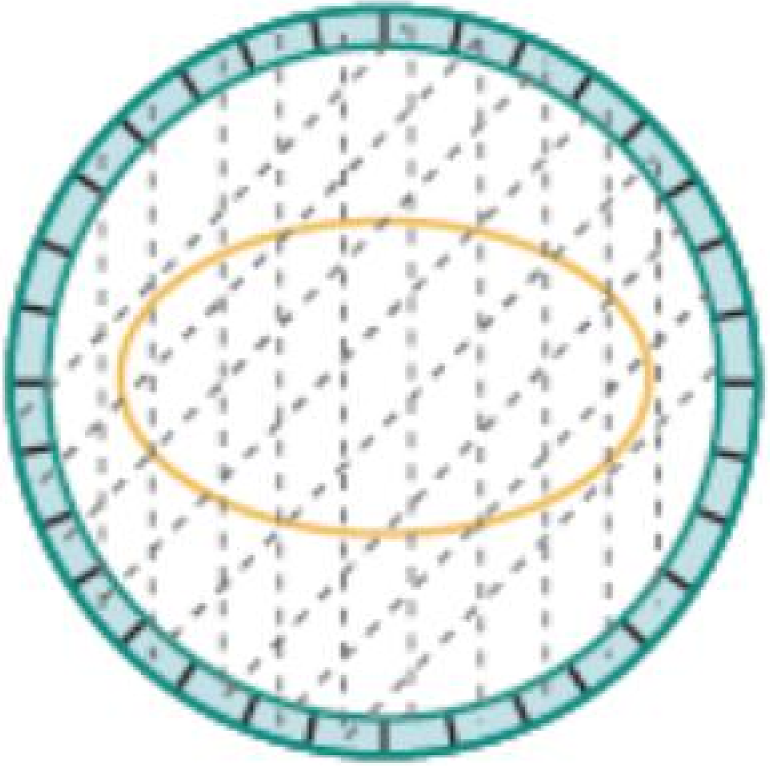
- The number of coincidences detected along each LOR is stored in the memory of the computer.

- the computer uses the projection data to produce transverse images of the radionuclide distribution in the patient, as in x-ray CT or SPECT.


2 by 2 array
of PMTs
Slits cut into
crystal
Scintillation crystal

SPECT vs PET
Why PET has 360 degree detectors ?





Ideas to avoid signal overlap (SPECT)

- The detectors should detect the peak intensity in the dead-time window, to avoid signal overlap (in SPECT)
- 2
- 3
- ...
- When the time signals from two detectors occur within a selected time interval called the time window, a coincidence is recorded. A typical time window for a system with BGO detectors is 12 ns. A typical time window for a system with LSO detectors, which emit light more promptly, is 4.5 ns. (PET)