

# BMED-4962/ECSE-4962 Introduction to Subsurface Sensing and Imaging Systems

Lecture 20: Nuclear Medicine/PET  
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Center for Sub-Surface Imaging & Sensing



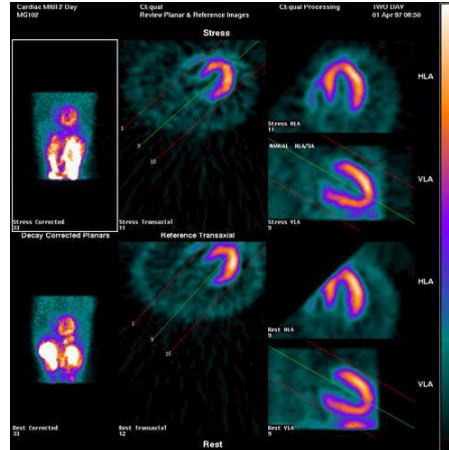
*GE Global Research*

## Recap

- Finished up on MRI scanners:
  - The way gradients generate the spatial info to form an image
  - Frequency and phased encoding
  - K-space
  - fMRI and magnetic resonance spectroscopy
  - Associated clinical applications.
- Let's talk about Projects!!

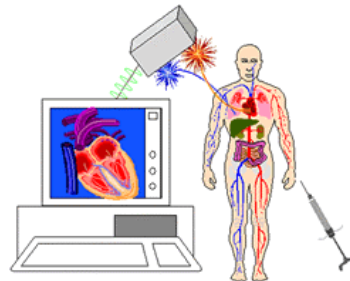
## Nuclear Medicine/PET

- For most part of this course, our focus has been on imaging physical objects.
  - We have looked for features which interact with our probes
    - Attenuation with X-ray
    - Impedance mismatches in pulse-echo methods
    - Variations in proton density in MRI via magnetization vectors
- Nuclear medicine & PET are quite different
  - As with fluorescence-based methods, they image concentrations of exogenous chemicals injected into the patient
  - The observability of these chemicals is based on radioactivity.



## Nuclear Medicine

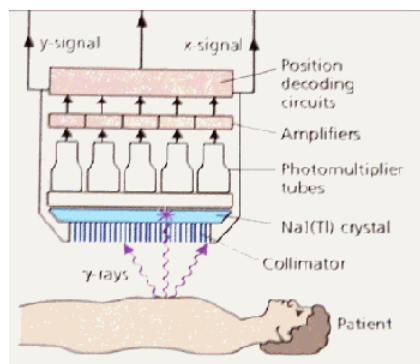
- Imaging is done by tracing the distribution of **radiopharmaceuticals** within the body.
- **Radionuclides** or **radioisotopes** are atoms that undergo radioactive decay and emit radiation.
- In nuclear medicine, we are interested in radionuclides that emit x-rays or **gamma rays**.
- **A radiopharmaceutical is a radionuclide bound to a biological agent.**



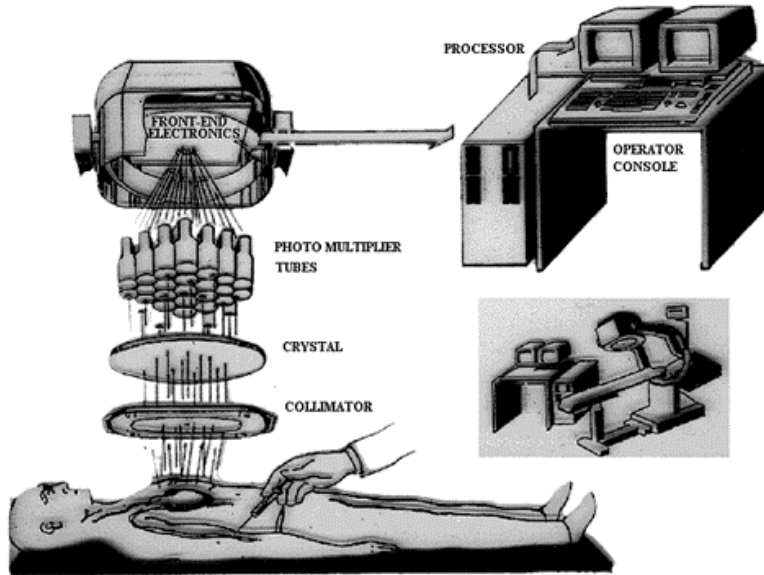
## The Gamma Camera



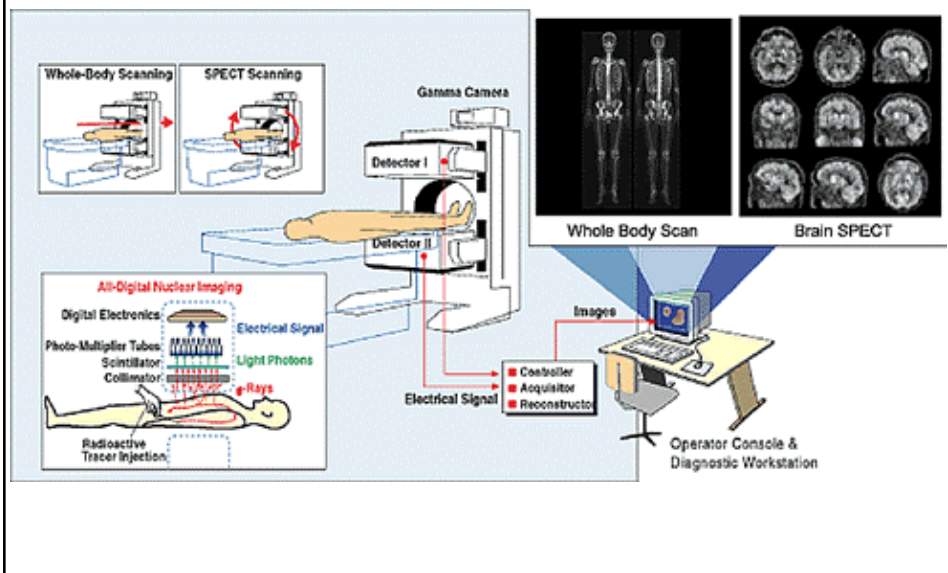
## Basics of Gamma Camera Imaging



# Nuclear Imaging - Instruments

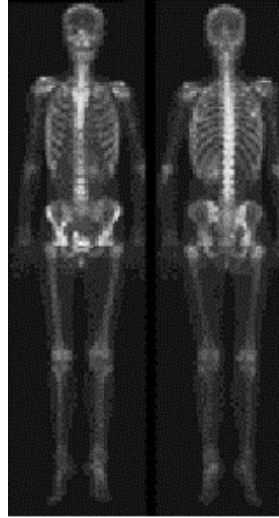


# Nuclear Medicine Imagers

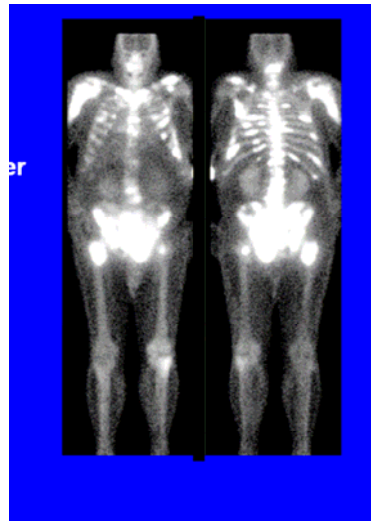
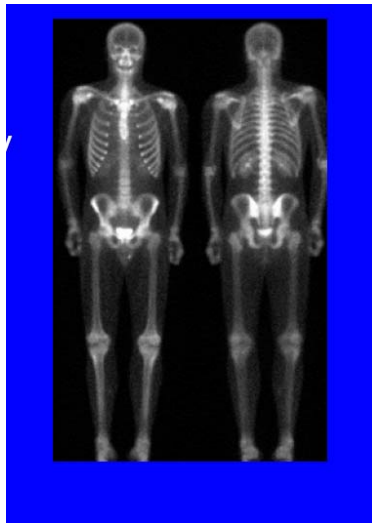


## How does this work?

- Radioisotopes are injected into the body
- A radioisotope can be:
  - a pure element (e.g. I-131 which connects to Thyroid)
  - a biological agent labeled with radioisotopes like MIBI-Tc99m
- All isotopes have a half life.
- All isotopes are expelled from the body with an associated half life.
- Nuclear Medicine provides physiological images, i.e. the metabolic activity of the organs process the radiopharmaceutical and concentrate it in the target organs for imaging.

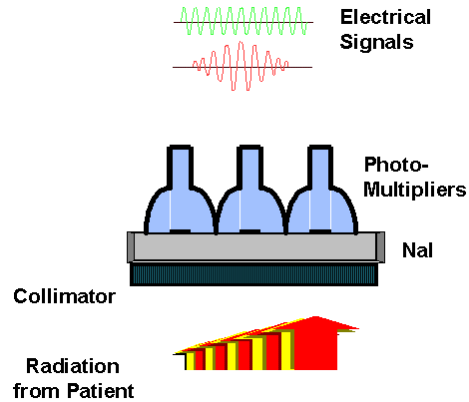


## Normal v. Bone Cancer Scan

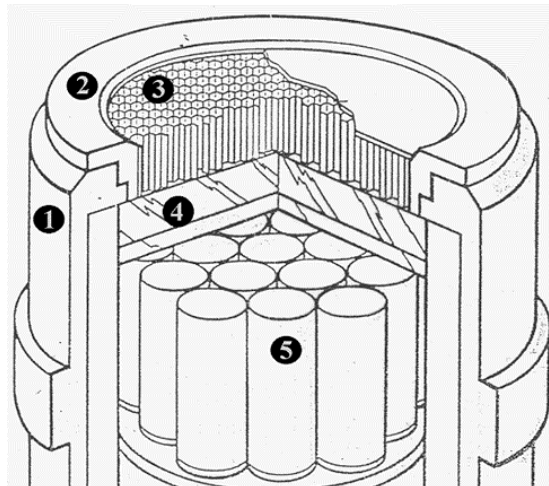


## Detector or Scintillator

- (NaI): Emits light whenever hit by gamma ray. Amount of light is proportional to gamma energy level.
- Photomultiplier Tubes: read the light signals and translate them into electrical signals



## Cross-section of an Anger Camera

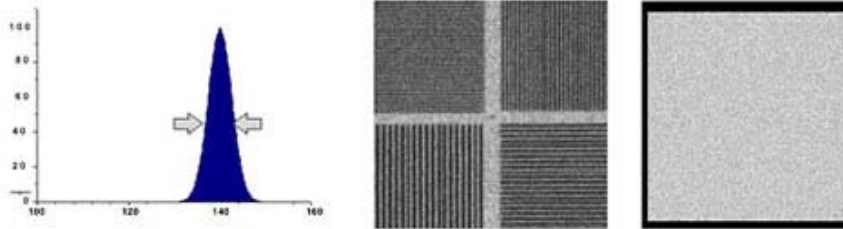


1. Shield Around Head
2. Mounting Ring
3. Collimator Core
4. Sodium Iodide Crystal
5. Photomultiplier Tubes

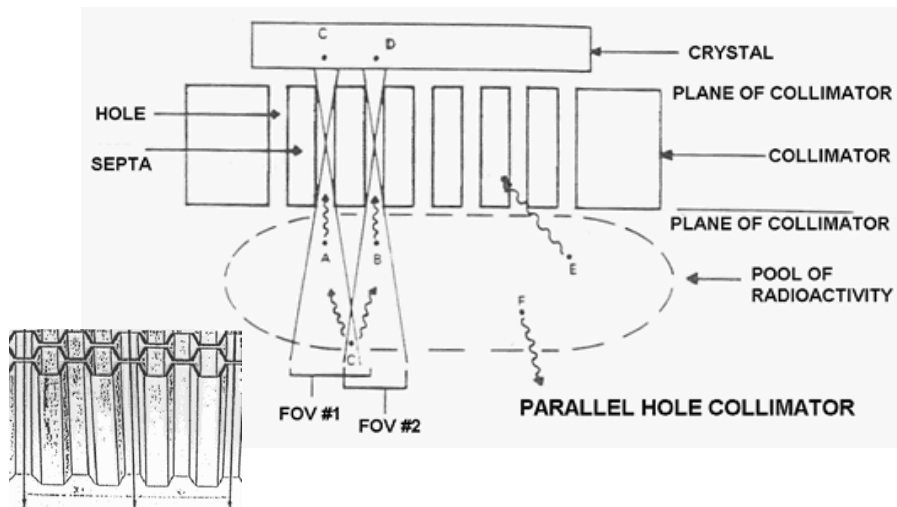
Gamma Camera invented by Harold Anger in early 50s.

## Nuclear Medicine Performance Metrics

- Typical performance:
  - Energy resolution: 9.5 - 10%
    - FWHM response
  - Spatial resolution: 3.2 - 3.8 mm
  - Uniformity: 2 - 4%

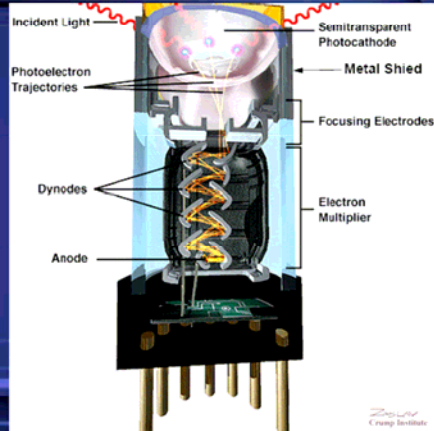


## Collimator Design & Function



Resolution v. Efficiency Trade-off

## Photomultiplier Tube (PMT)

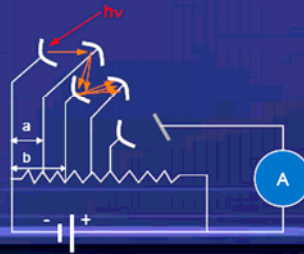


R-I-T

## Photomultiplier Tube (PMT)

- Used to provide several orders of gain ( $10^6$ )
  - Includes “several” intermediate anodes (dynodes)
    - Each is given a voltage higher than the previous one
    - $e^-$  arrives with enough energy to eject **multiple** electrons

a: 100 V  
b: 200 V



R-I-T

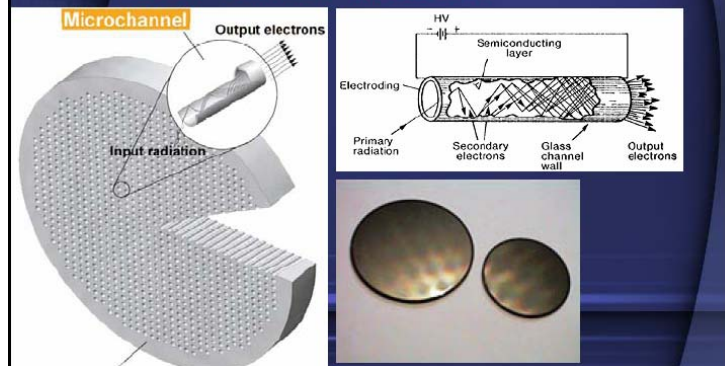
## Photomultiplier Tube (PMT)

- Advantages
  - Standard device
  - Large signals
  - Large active area possible
  - Fast rise time possible
- Disadvantages
  - Large physical dimension
  - High voltage required
  - Gain instability as a function of temperature
  - Sensitive to magnetic fields

R-I-T

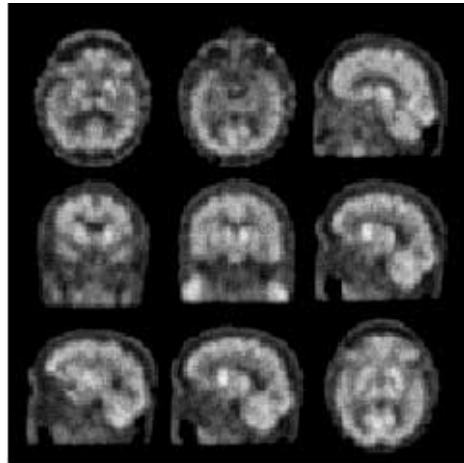
## Microchannel Plate

- A 2d array of photo-multiplier tubes
  - Uses a “continuous” dynode chain

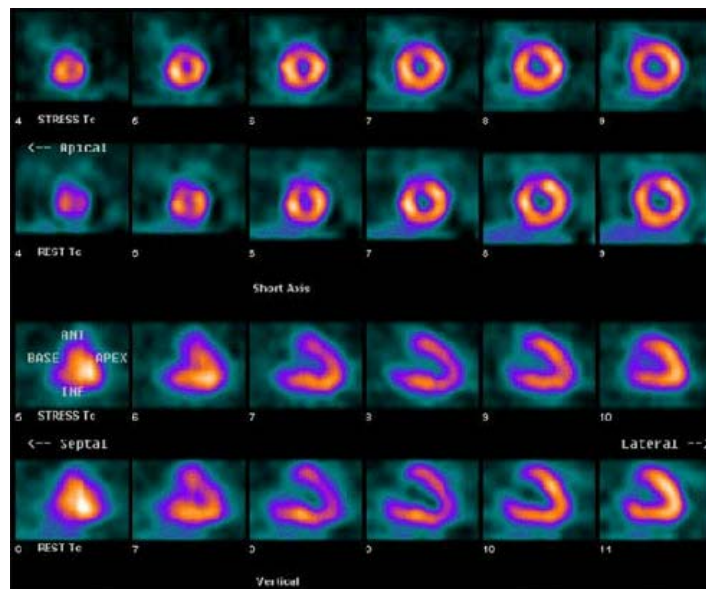


## Nuclear Medicine Images

- Typical image:
  - 64 by 64 pixels
- Intensity gives "counts per pixel"
- Pseudocolor often used.
- Nuclear med imaging modes:
  - Static
  - Dynamic
  - MUGA (multi-gated acquisition)
  - Whole Body
  - SPECT

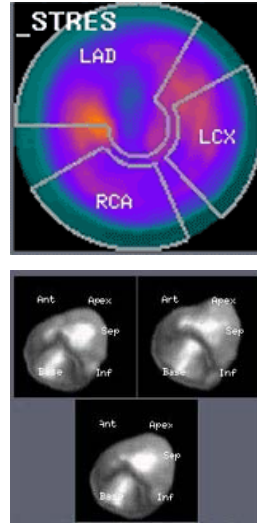


## Cardiac Study



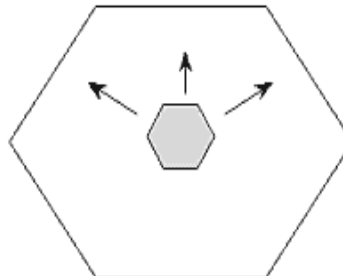
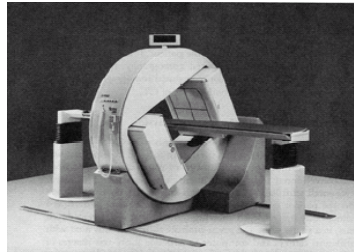
## Cardiac Study

- Evaluation of the coronary artery circulation
  - Myocardial perfusion
- 3D Studies of the radionuclide activity



## SPECT Scanners

- Single Photon Emission Computerized Tomography
  - Store radionuclide emission data from multiple projections
  - Projections taken every 3 or 6 degrees.
  - Use CT type algorithms to determine the location and degree of accumulation of agent.



## **Clinical Applications**

- In the 70's & 80's, SPECT was largely replaced by CT and MRI scans because they provided superior resolution.
- Recently, SPECT has returned to prominent use, especially in diagnosing cardiac and neurological abnormalities.
- While CT and MRI scans only provide images of static brain anatomy, SPECT offers clues to brain function by tracing blood allocation.

## **Pros of SPECT**

- Unlike MRI and X-ray, ECT produces 3-D images that relate an organ's function.
- This allows for better relay of extent of disease and reveals the course of the disease earlier.
- Large amount of data on brain function already comes from SPECT scans.
- Simple process with immediate results.
- Much less expensive than MRI or PET (\$1000 per scan)
- Covered by insurance when brain injury is present.

## Cons of SPECT

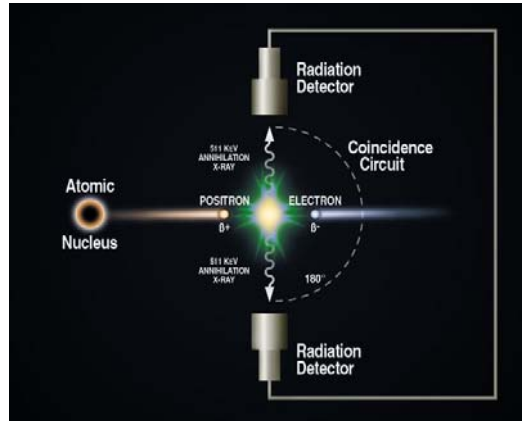
- Unlike MRI and X-ray, there is an injection.
- Claustrophobia is a cause for concern.
- Quality of image can be lessened by patient movement.

## PET Imaging

- What is PET Imaging?
  - A technique tracks biochemical and physiological processes *in vivo*
    - Uses tracer compounds labeled with positron-emitting radionuclides
    - As such, it is considered a form of functional imaging
    - Positron Emission Tomography
- Functional v. Anatomical Imaging: Choose:
  - X-Ray
  - MRI
  - US
  - Nuclear Medicine
  - CT
- How is PET different from Nuclear?

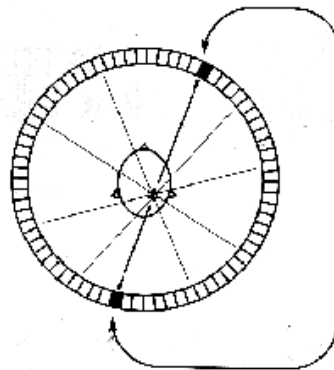
## PET – Positron Emission Tomography

- Certain radionuclides emit positrons.
- When a positron meets an electron, they annihilate each other.
- This annihilation results in a generation of two gamma rays.
  - The gamma rays travel in opposite directions.
  - The energy of these gamma rays is 511 KeV.
- PET Imaging is based on detection of these gamma rays.



## PET Systems Event Detection

- Several **gamma-detector rings** surround the patient.
- When one of these detects a photon, a detector opposite to it, looks for a match.
- **Time window** for the search is few nanosecs.
- If such a **coincidence** is detected, a line is drawn between the detectors.
- When done, there will be areas of overlapping lines indicating regions of radioactivity.



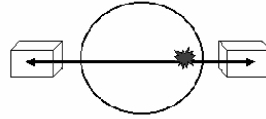
LOR – Line of Response

## Coincidence Events

- Three Types:

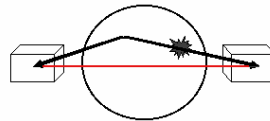
- True

- The event we are after



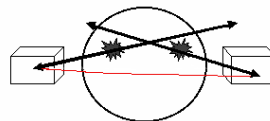
- Scatter

- At least one Compton scatter event
- Wrong LOR



- Random

- Unlucky break



## How Does PET Compare With Other Imaging Modalities?

- PET provides images of molecular-level physiology
  - accumulation of the metabolically active radionuclide
- Extends capabilities of other modalities.
  - Like CT, it uses tomographic algorithms
  - Like Nuclear, images represent distributions of radiotracers.
- That's where the similarity ends. Here are three studies of a patient done with CT, MRI, and PET scanners.

CT Scan



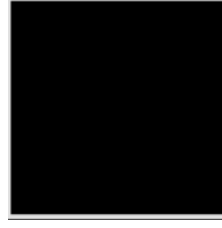
Report: Normal

MRI Scan



Report: Normal

PET Scan



Report: Patient Deceased.

## Source Material

- [http://www.gehealthcare.com/usen/fun\\_img/nmedicine/nmindex\\_new.html](http://www.gehealthcare.com/usen/fun_img/nmedicine/nmindex_new.html)
- Siemens & Philips web sites for nuclear medicine & PET
- <http://www.crump.ucla.edu/software/lpp/lpphome.html>
- [http://thayer.dartmouth.edu/~bpogue/ENG\\_G167/13%20Nuclear%20Medicine.pdf](http://thayer.dartmouth.edu/~bpogue/ENG_G167/13%20Nuclear%20Medicine.pdf)
- [http://zoot.radiology.wisc.edu/~block/bme\\_530lectures/L01Intro.ppt](http://zoot.radiology.wisc.edu/~block/bme_530lectures/L01Intro.ppt)

## Summary

- Introduction to Nuclear Medicine and PET imaging.
  - Additional examples of agents (probes) introduced to reveal subsurface phenomena.
  - Today's focus on radioactive labeling.
- Review of instruments
  - Relatively straightforward devices.
  - Signal-to-noise ratio challenges, need to limit exposure.
- Powerful clinical tools.
- Much of today's research focused on PET and extensions of PET technology.

## Homework: Lecture 20

- Using internet sources,
  - discuss the patient and clinician safety issues from the use of radioactive tracers in nuclear imaging.
  - Avalanche photodiodes (APDs) are sometimes proposed as an alternative to photomultiplier tubes. Discuss the pros and cons of these two types of devices.

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