Gamma Counters in Nuclear Medicine

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1. Count Gamma Ray Emissions from Radioactive Sources

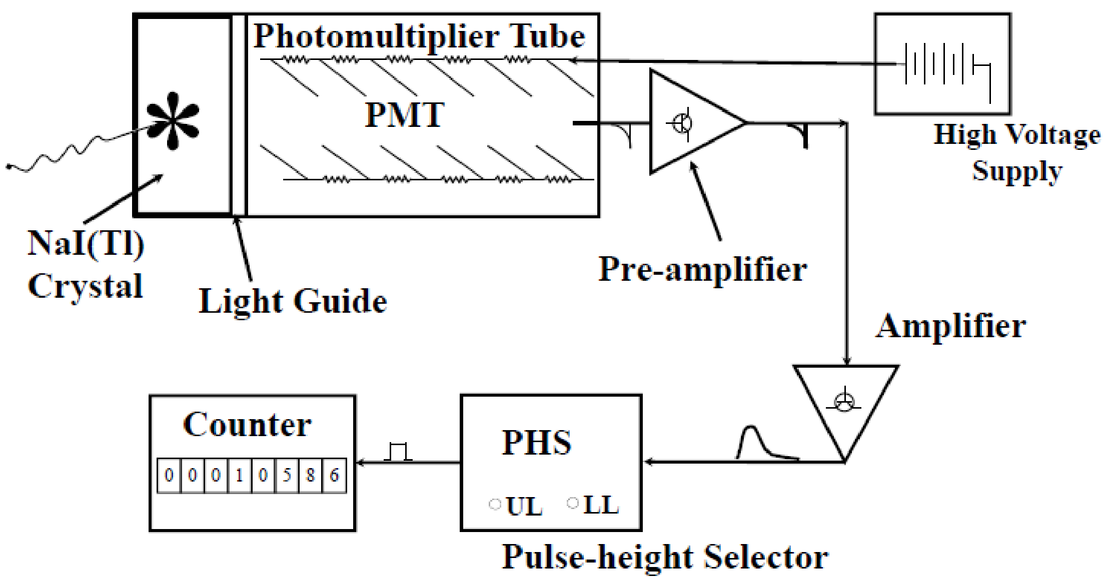
a) The most sensitive method for measuring small amounts of radioactivity.

b) Can measure the energy of a single photon; count only gamma rays, not scatter.

c) The count rate is directly proportional to the activity of a radioactive source.

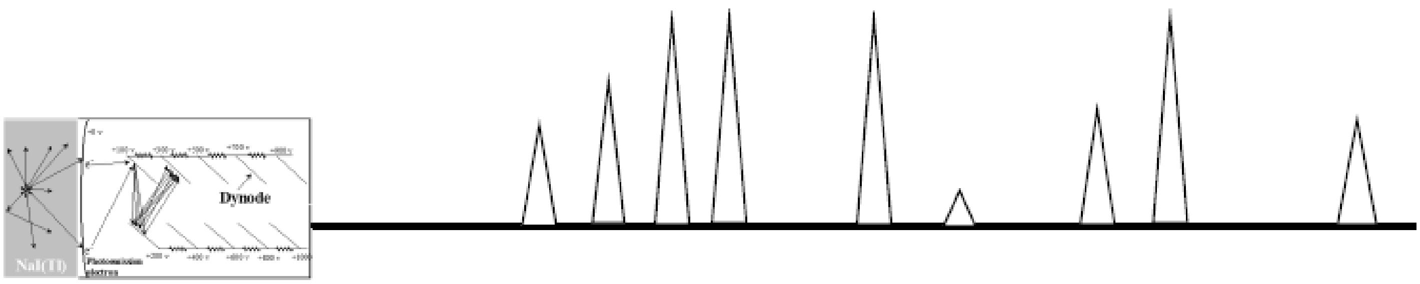
d) Response must be fast enough to generate a complete signal before the next hit. Dead time < 4 μsec.

2. Gamma Counter Components

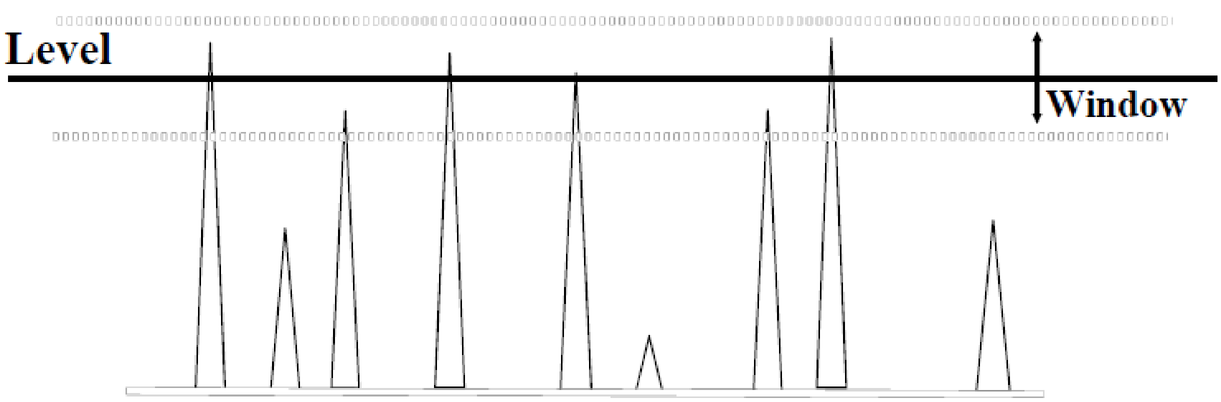


3. **Gamma Detector Pulses**

   a) An electric pulse is generated for every photon hit
   b) Height is proportional to the absorbed energy
   c) Tallest pulses from photoelectric absorption of gamma rays in the NaI(Tl) crystal
   d) Shorter pulses from absorption of scatter emitted from the patient, or from scattering within the crystal.



4. **Pulse-Height Selector**

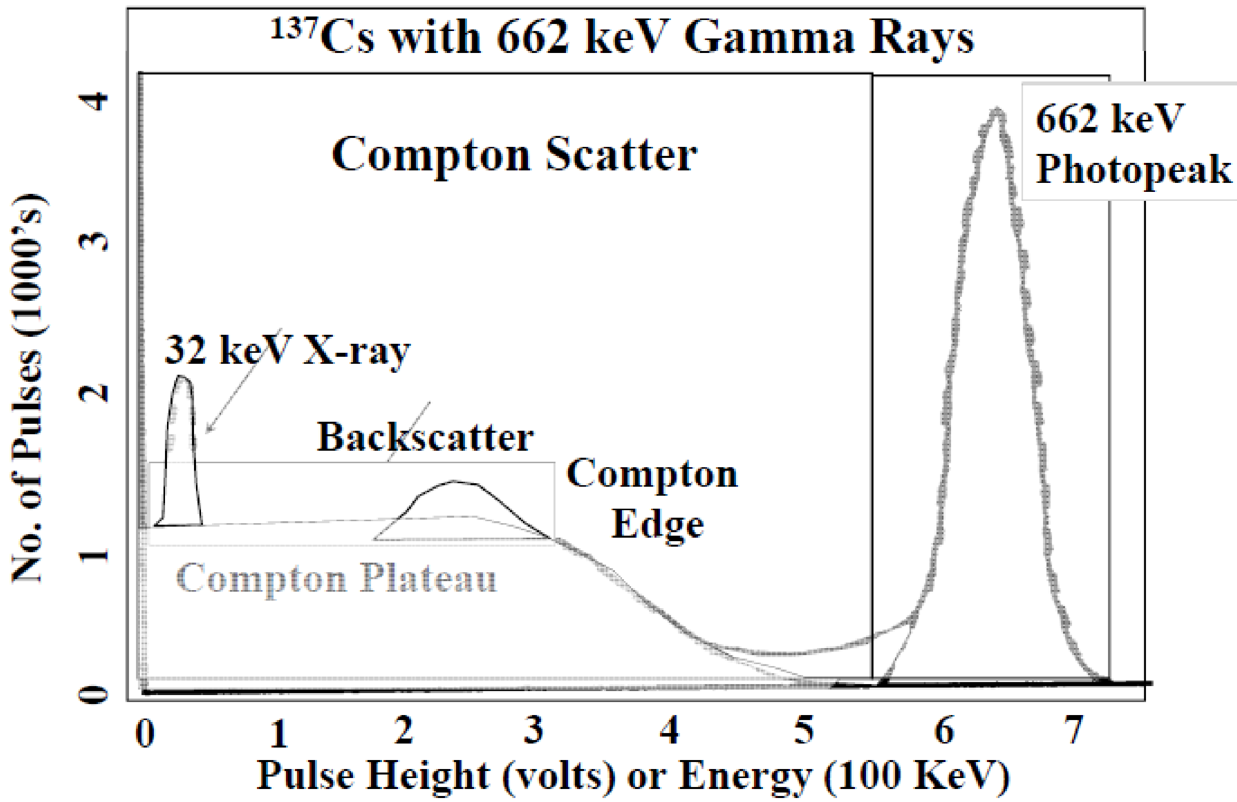


UL - Upper Pulse-height Level

LL - Lower Pulse-height Level

W - Window = UL - LL

5. **Pulse Height Histogram / Energy Spectrum**



6. Energy Spectral Features

a) **Photopeak** – narrow peak associated with photoelectric absorption of γ- rays.

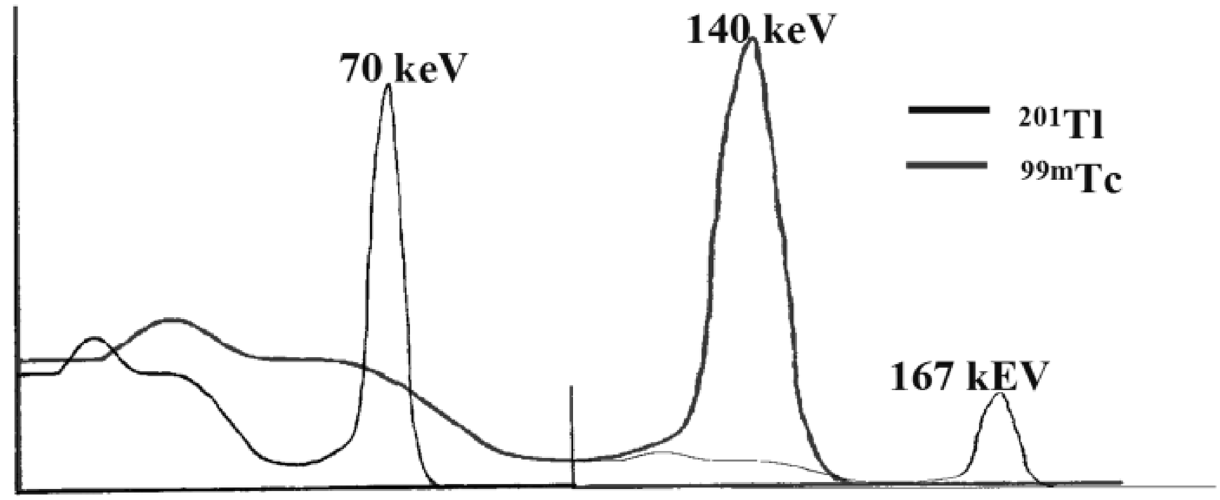
b) **Compton Plateau** – broad region associated with scattering of γ rays in the patient, surroundings, and crystal.

c) **Compton Edge** – right most limit of the Compton plateau at which the γ ray backscatters in the crystal.

d) **Backscatter Peak -** associated with backscattered γ rays from the patient or surroundings.

e) **X-ray Peak -** photopeak-like structure associated with photoelectric absorption of a characteristic X-ray energy.

7. Identifying Radioisotopes by Locating the Photopeaks

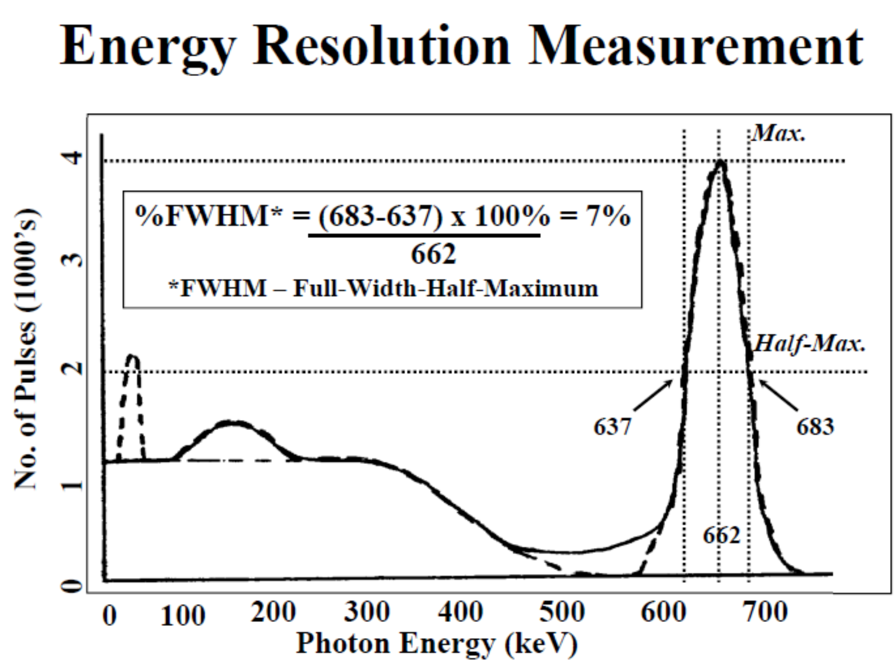


8. Energy Resolution

a) Ability to measure the energy of a gamma ray.

b) Measured from the width of the photopeak at half its height (FWHM).

c) Pulse-height variations result from variations in the fluorescent emissions from a single photon hit.



9. FWHM & Energy Resolution

a) For NaI(Tl) scintillators, FWHM:

   i. 7% for 662 KeV (Cs-137)
   ii. 10% for 140 KeV (Tc-99m)
   iii. 15% for 70 KeV (Tl -201)

b) FWHM is a quasi-statistical measure of resolution, (e.g., measures 140 KeV gamma rays to within + 5%)

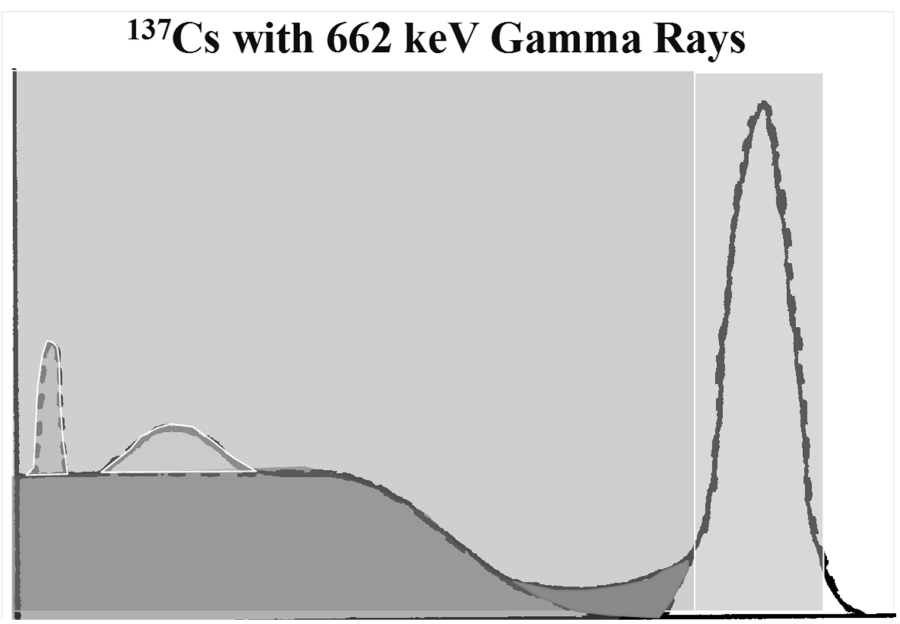
10. Energy Resolution Dependence

a) Energy resolution is best with high intensity fluorescent emissions.

b) Intensity of emissions depends on conversion efficiency of the gamma energy to fluorescence and the energy of the incoming photon

11. Energy Window & Level Selection

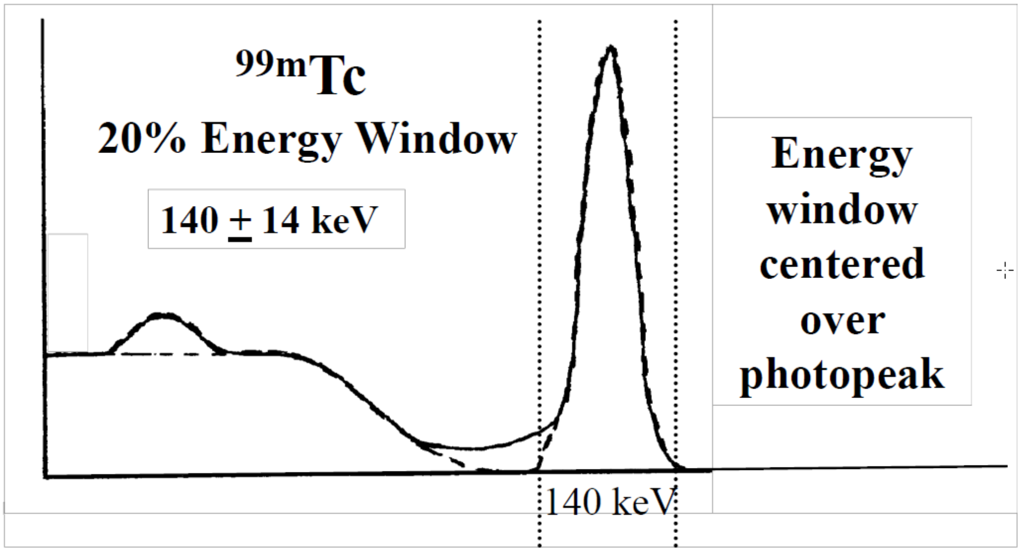
Set to count only events in the photopeak



Energy Level – center of the photopeak red line)

Energy Window – % width of the Energy Level (pink region)

12. Peaking the Detector - Centering the Energy Level on the Peak of the Photopeak



13. Energy Level & Window Selections for Radioisotopes Commonly used in NM

Radio-nuclide	Energy #1 (keV)	Window (%)	Energy #2 (keV)	Window (%)	Energy #3 (keV)	Window (%)
^{201}Tl	70	30	167	15		
^{133}Xe	81	30				
^{57}Co	122	20				
^{99m}Tc	140	20				
^{123}I	159	15				
^{67}Ga	94	30	184	15	296	15
^{111}In	173	15	247	15		
^{131}I	364	15				
^{18}F	511	15				

14. Dead Time

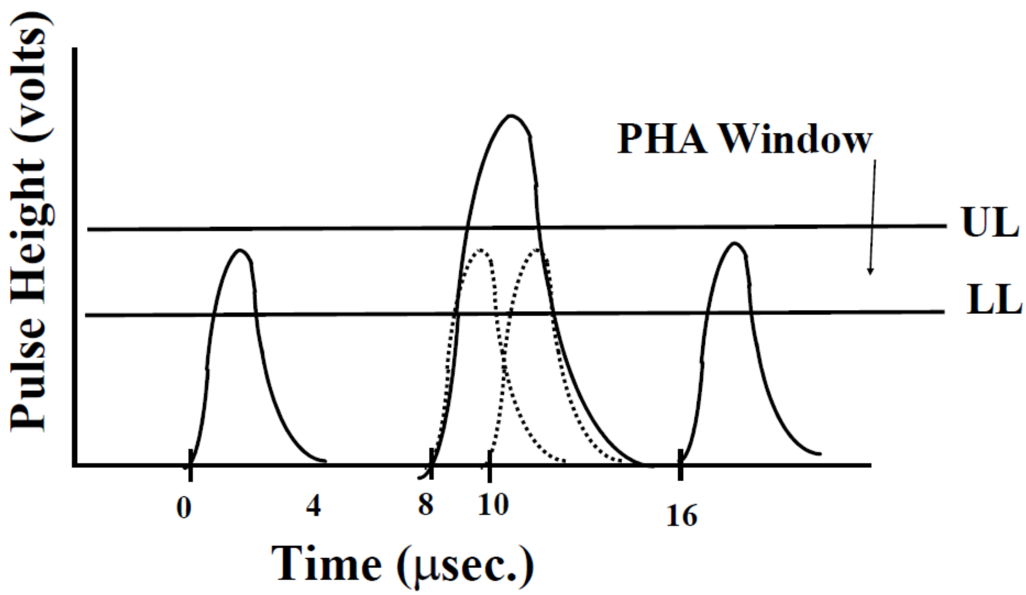
a) Defined as time required to process a single photon hit

b) Depends on:

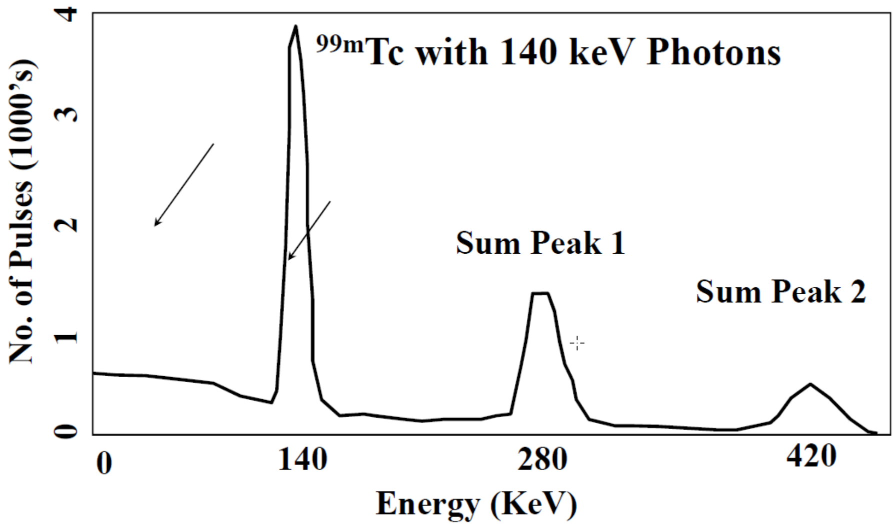
   i. the length of time light is emitted in the scintillation crystal. Crystals with a short light decay time have short dead times.

   ii. release time of the electric pulse by the preamplifier. Can be artificially shortened, but results in lessened energy resolution.

15. Pulse Pileup: Summing of pulses from multiple photon interactions

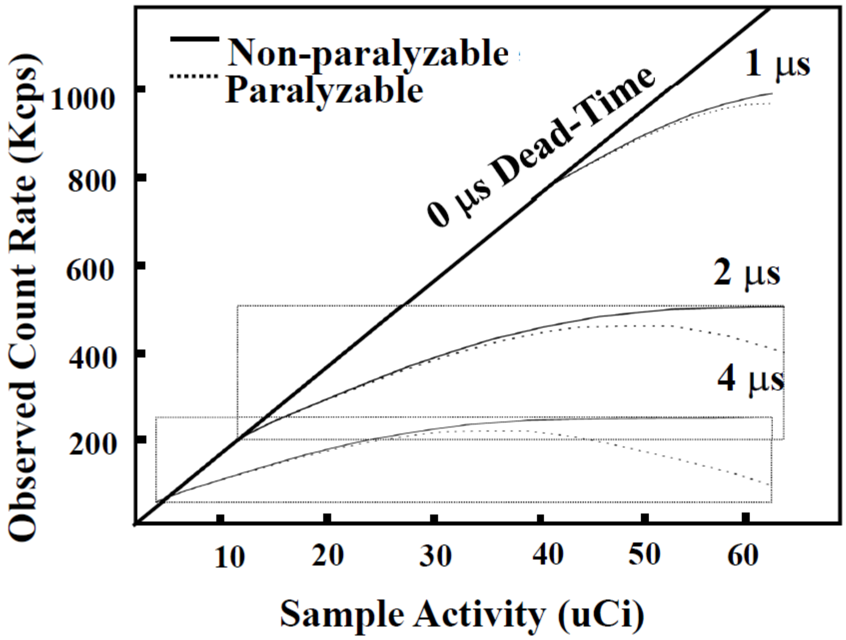


16. Sum Peaks: Simultaneous absorption of two or more γ-rays in the crystal



^{99m}Tc with 140 keV Photons
Sum Peak 1
Sum Peak 2
No. of Pulses (1000's)
0
1
2
3
4
0
140
280
420
Energy (KeV)

17. Count Losses Due to Dead Time



All Scintillation detector systems exhibit paralyzable characteristics.

Well Counter: 1 μsec.

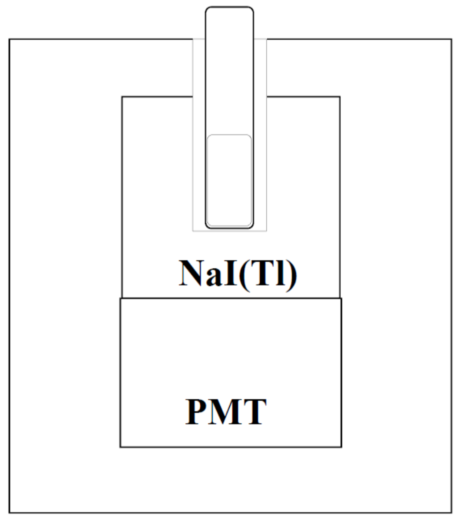
Gamma Camera: 4 μsec

18. Instruments in Nuclear Medicine that Employ Gamma Counting Detectors

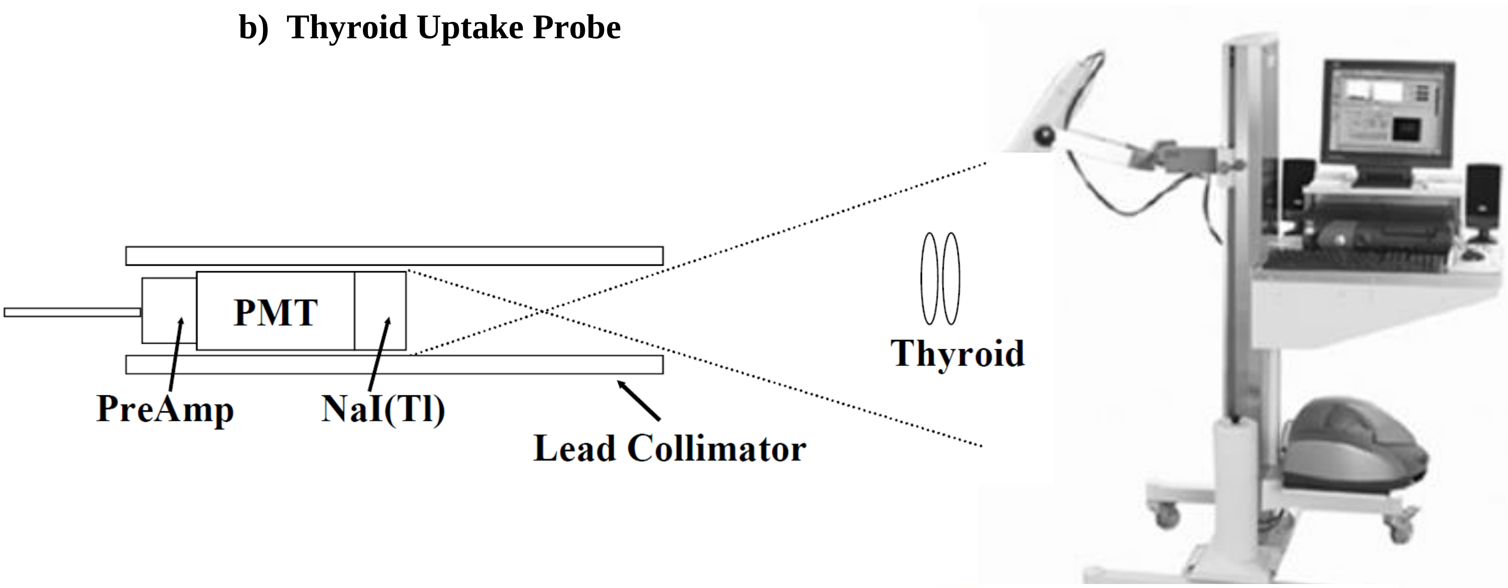
a) **Well Counter**

   i. **Contains NaI(Tl) Crystal 2” or 3” in Diameter**
   ii. **Contains Lead Shield 2-3” Thick**
   iii. **Used for Counting blood samples in in vitro tests or for counting wipe test samples**

iv. **Well Counter Nearly 100%**
v. **Geometric Efficiency**


NaI(Tl)
PMT

b) Thyroid Uptake Probe



c) Gamma Camera

d. PET Scanner

19. Gamma Counter Efficiency & Sensitivity

a) Efficiency: Counts per disintegration

b) Sensitivity: Counts per minute per unit of activity

c) Counting efficiency = cpm/dpm x 100%

d) Sensitivity may be expressed as counts per minute per Becquerel (cpm/Bq) or counts per minute per microCurie (cpm/μCi)

e) 1 Bq = 1 dps = 60 dpm and 1 mCi = 37,000 dps = 2,220,000 dpm

20. Factors That Affect Detector Efficiency

a) **Nuclear Decay Scheme** – number of gamma rays emitted per decay.

b) **Geometric** – fraction of gamma rays emitted from a radioactive source that will intersect with the detector crystal.

c) **Intrinsic** – fraction of gamma rays that intersect with the crystal that interact in the crystal.

21. Nuclear Decay Scheme

a) E_N – Number of gamma rays emitted per disintegration

b) Tc-99m – 0.9 140 Kev gamma rays emitted/disintegration (E_N=0.9)

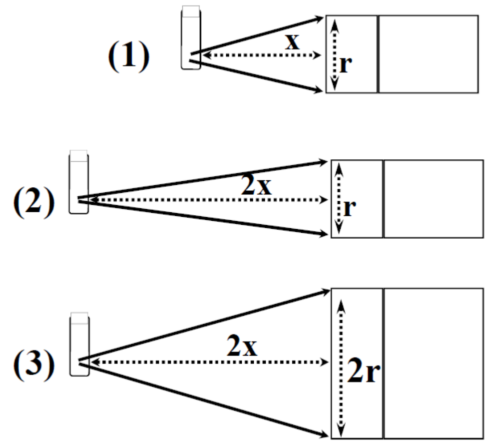
c) F-18 – Two 511 Kev gamma rays emitted per disintegration following positron annihilation (E_N=2.0)

22. Geometric Efficiency: Eγ - Fraction of emitted gamma rays intercepted by the detector

a) NaI(Tl) Crystal almost surrounds the source with a solid angle near 4π steradians

1. Decreases as inverse-square of the distance between the source and detector $(x/2x)^2$

2. ~ linear with detector cross-sectional area.



23. Intrinsic Efficiency

a) Ei - Fraction of γ-rays intercepted by the crystal that interact in the crystal

b) Factors include:

   i. Photon energy - increases as photon energy decreases.

   ii. Crystal thickness – increases as crystal thickness increases.

   iii. Crystal density - increases as crystal density increases.

24. Total Efficiency

$$E_{Total} = E_N * E_g * E_i$$

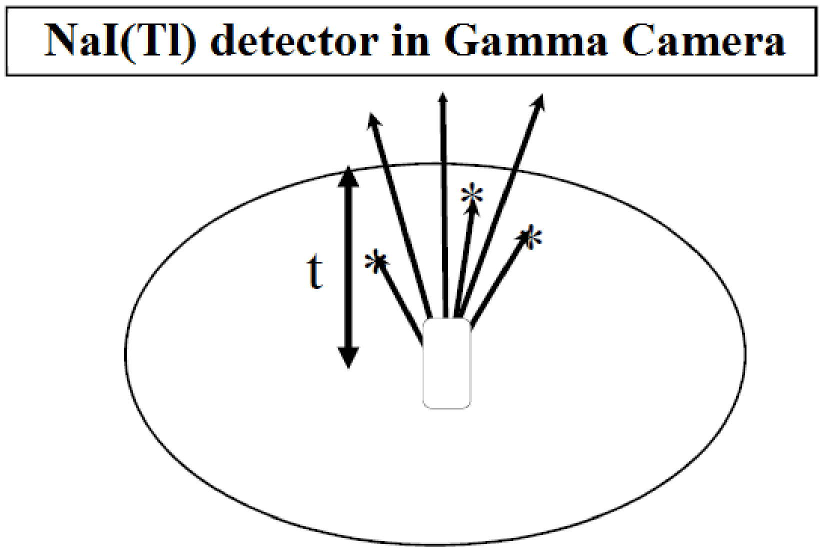
Scintillation Detector	**Total Efficiency (E_N =1)**	**cps/μCi**	**Activites Used for Exams**
Well Detector	99%	36,000	~ 1 μCi
Thyroid Uptake Probe	10%	3,600	~ 400 μCi
PET Scanner	1%	360	~10 mCi
Gamma Camera	**0.01%**	**3-4**	**~ 30 mCi**

25. Attenuation - Absorption Fraction

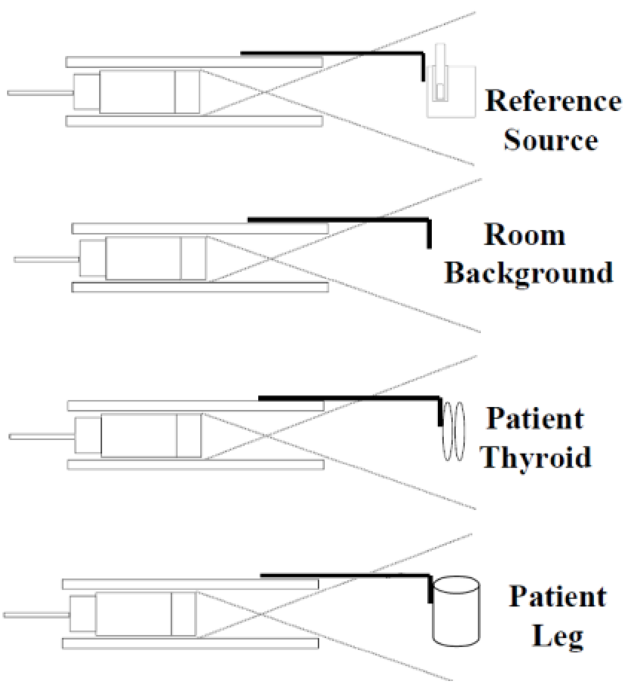
a) E_a - Fraction of emitted γ-rays absorbed by the patient.

b) Attenuation is exponential - $e^{-\mu t}$

c) Depends on Photon energy, Source depth t, and Tissue density



26. Thyroid Uptake Measurement



Day 1:

- Count 400 μCi ^{123}I patient dose to be used for Reference
- Count Room Bkg
- Patient ingests 400 μCi ^{123}I

Day 2:

- Count Pt. Thyroid
- Count Pt. Leg

%Uptake in 24 hrs

$$= \frac{(\text{Thyroid} - \text{Pt. Leg}) * 100\%}{(\text{Ref.} - \text{Room Bkg}) * e^{-0.693t/T_{1/2}}}$$