# Chapter 10: Non-imaging detectors and counters

**Slide set of 87 slides based on the chapter authored by**
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**of the IAEA publication (ISBN 78–92–0–143810–2):**
***Nuclear Medicine Physics:***
***A Handbook for Teachers and Students***

**Objective:** To familiarize the student with the fundamental concepts of electronics related to nuclear medicine imaging devices

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**Slide set prepared in 2015 by J. Schwartz (New York, NY, USA)**

# CHAPTER 10 TABLE OF CONTENTS



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# 10.1. INTRODUCTION

- Historically, nuclear medicine has been largely an imaging based specialty, employing such diverse and increasingly sophisticated modalities as:
    - Rectilinear scanning
    - (Planar) gamma camera imaging
    - Single photon emission computed tomography (SPECT)
    - Positron emission tomography (PET)

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# 10.1. INTRODUCTION

- Non-imaging radiation detection, however, remains an essential component of nuclear medicine, including:
  - Survey meters
  - Dose calibrators
  - Well counters
  - Intra-operative probes
  - Organ uptake probes

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# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

- Radiation detectors encountered in nuclear medicine may generally be characterized as either
  - scintillation
    - Visible light is produced as radiation excites atoms of a crystal
    - Light is converted to an electronic signal/pulse
    - Pulse is amplified by a PMT
    - High voltage (500–1500 V)
  - ionization detectors
    - Free electrons are produced as radiation ionizes a stopping material
    - Happens within a sensitive volume
    - Electrons electrostatically collected by a bias voltage (10–500 V) produce an electron signal

# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

- For both detector types, the ‘unprocessed’ signal is then shaped and amplified

- For some types of detector, the resulting pulses are sorted by their amplitude (or pulse height), which is related to the X-ray or $\gamma$-ray energy absorbed in the detector

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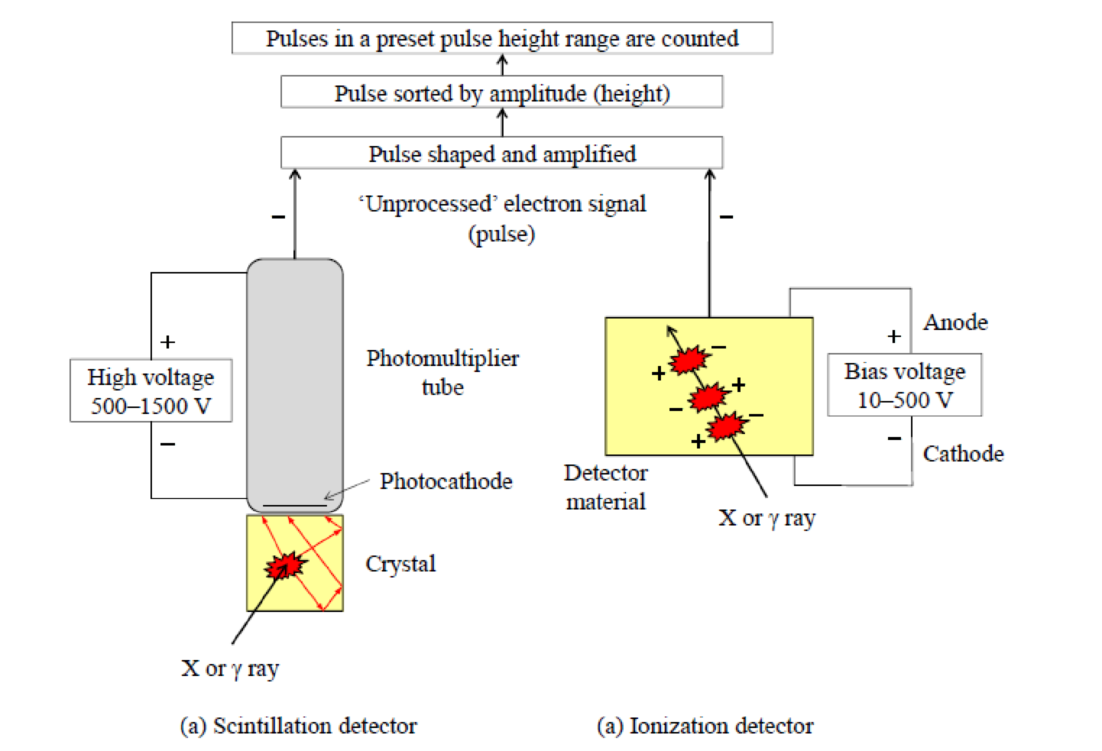
# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

- Basic design and operating principles of
  - a) Scintillation
  - b) Ionization detectors



# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS
## 10.2.1. Ionization detectors

### Detector materials

- Most commonly gaseous
- Known as gas filled detectors
  - Most widely encountered ones in nuclear medicine are
    - Dose calibrators
    - Geiger counters

      (Difference is the bias voltage magnitude between anode & cathode)
- Solid state ionization detectors also exist

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- V < 300 V, Recombination region
  - Created ion pairs may recombine
    - Prevents some electrons from reaching the anode
    - Yields an artefactually low signal

- At V = 300 V
  - All primary electrons are collected at the anode
  - Detector signal is maximized

# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

## 10.2.1. Ionization detectors

- V = 300 – 600 V, Ionization chamber region
    - Signal does not increase
    - There are no additional primary electrons to collect
    - Overall signal is equivalent to the number of primary electrons
    - Proportional to the energy of the incident radiation

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- V = 600 – 900 V, Proportional counter region
  - Large electrostatic force of attraction of the anode
    - Free electrons accelerate towards the anode
  - Gain speeds high enough to eject additional (secondary) orbital electrons
    - Contribute to an increasing overall signal
  - Higher the voltage means:
    - More energetic the electrons
    - More secondary electrons added to the overall signal
  - Number of electrons in the overall signal is proportional to energy of the incident radiation

## V = 900 – 1200 V, Geiger–Müller region

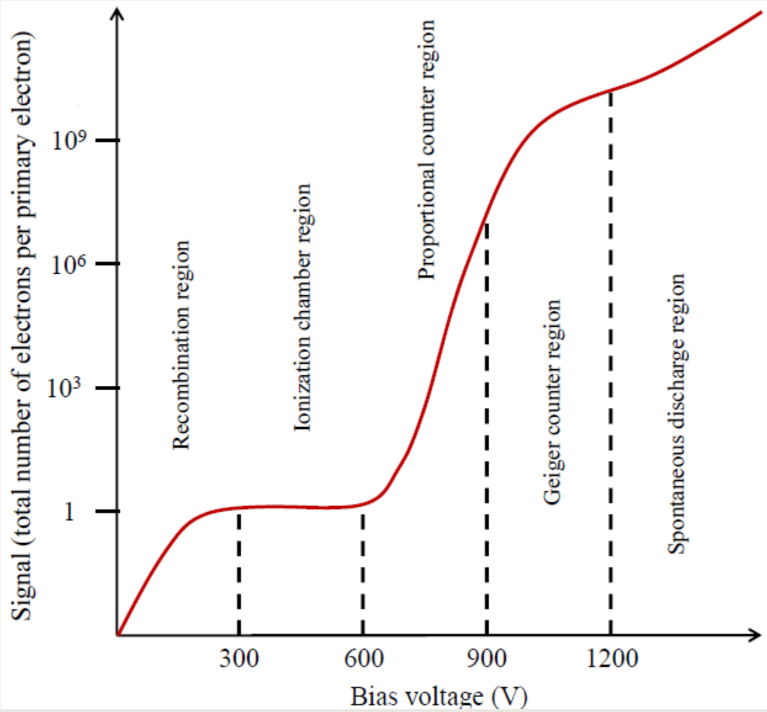
- Free electrons (primary and secondary) are accelerated
- Speeds are very high
- Tertiary electrons are ejected from the anode surface
  - They are accelerated back to the anode surface
  - Eject even more electrons
  - Electron 'cloud' over the anode is formed
    - Charge amount of the electron cloud is independent of the number of electrons initiating its formation
  - Yields a constant overall signal even with more bias increase
- Signals are independent of the incident radiation energy

- V > 1200 V, Spontaneous discharge region
  - Atoms ionized spontaneously without incident radiation
  - Artefactual signal produced

# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

## 10.2.1. Ionization detectors

- The signal (expressed as the amplification factor, that is, the total number of electrons per primary electron produced in the detector material) as a function of the bias voltage for gas filled ionization detectors

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## 10.2.1. Ionization detectors

- Other differences among different types of gas ionization detectors
  - Sealed *vs* unsealed sensitive volumes
    - Unsealed volumes contain only air at atmospheric pressure
      - Signal must be corrected for the difference between the temperature and pressure at which the detector was calibrated and the ambient conditions at the time of an actual measurement
        - Usually STP: 27°C and 760 mm Hg

# 10.2. OPERATING PRINCIPLES OF RADIATION DETECTORS

## 10.2.1. Ionization detectors

- Sealed volumes
  - Use gases other than air (e.g. argon)
  - Gas may be pressurized
    - Provides higher stopping power
    - Provides higher sensitivity

- Different anode and cathode geometries
  - Parallel plates (in some ionization chambers)
  - Wire along the axis of a cylinder (used in Geiger counters)

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- Ionization chambers are widely used in radiation therapy
  - Used to calibrate the output of therapy units
  - Used in nuclear medicine as dose calibrators
    - To assay radiopharmaceutical activities
  - Relatively low sensitivity
    - Not a disadvantage because radiation intensities are typically rather large
  - Response stability is an advantage as it allows the use of unconditioned AC electrical power

### Proportional counters

- Need a stable bias voltage
  - specialized power supplies
- Restricted to research applications (e.g. in radiobiology)
  - Need higher sensitivity
  - Need capability of energy discrimination
- Often employ an unsealed, gas flow-through sensitive volume

### Geiger counters

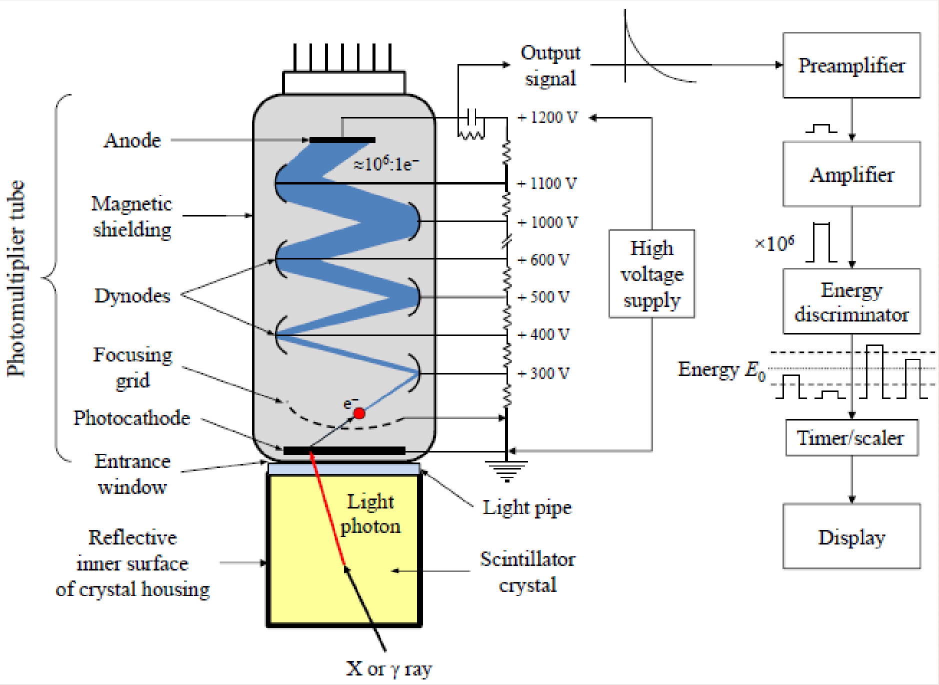
- High sensitivity and stability with respect to voltage
  - Can use a portable power supply such as an ordinary battery
- Widely used as survey meters (sensitivity is critical)
  - To measure ambient radiation levels
  - To detect radioactive contamination
- Sealed sensitive volumes
  - Don’t need temperature–pressure corrections

- The functional properties & applications of the various types of ionization are largely dictated by their respective bias voltage dependent signal

| | Ionization detector | Proportional counter | Geiger counter |
|---|---|---|---|
| **Bias voltage operating range** | 300–600 V | 600–900 V | 900–1200 V |
| **Response stable with respect to voltage?[a]** | Yes | No | Yes |
| **Sensitivity[b]** | Low | Intermediate | High |
| **Capable of energy discrimination?[c]** | Yes | Yes | No |
| **Applications** | Dose calibrator | Research | Survey meter |

### Scintillation detectors

- Most commonly a crystalline solid such as
  - Thallium-doped sodium iodide (NaI(Tl))
- Radiation interacts with and deposits energy in a scintillator
- Deposited radiation energy is converted to visible light
  - Emitted isotopically

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## Scintillation detector structure

- Light-tight crystal housing
  - Inner surface coated with reflective material
    - Light emitted towards crystal's sides and front of the of the crystal are reflected back towards a PMT
  - Maximizes the amount of light collected
  - Maximizes overall sensitivity
- Photocathode
  - Coated on the inner surface of the PMT
  - Emits electrons

## 10.2.2. Scintillation detectors

- Scintillation detector structure
  - Focusing grid
    - Immediately beyond the photocathode
    - At relatively low +voltage , ~10 V
  - Light pipe
    - Between crystal back and PMT entrance window
    - Thin layer of transparent optical gel
    - Optically couples crystal to PMT
    - Maximizes transmission (>90%) of the light signal from the crystal into the PMT
    - At ground: 0 V

- Scintillation detector structure
  - Dynodes
    - 1st dynode: attracts electrons passing through the focusing grid
      - Relatively large +voltage, ~300 V
      - Average of 3 electrons are ejected
    - 2nd dynode:
      - Even larger +voltage, ~400 V
      - Average of 3 $e^-$'s ejected per incident one

### Scintillation detector structure

- Dynodes
  - PMT has 10–12 such dynodes (or stages)
    - Each ~100 V more + than the preceding
    - Entire PMT $e^-$ amplification = $3^{10}$–$3^{12}$
    - Output signal generated at last anode
      - Irregularly shaped
      - Shaped by a preamplifier
      - Further amplified into a logic pulse
        - can be further processed electronically

- Pulse amplitudes (or ‘heights’) are proportional to:
  - Number of electrons produced at photocathode
  - Energy of the incident radiation

→ Energy discriminator

- Known as a pulse height analyser
- Sorts pulses by heights
- Pulses with height (i.e. energy) within the preset energy window are counted by a timer/scaler

- Advantageous features of scintillation detectors include:
  - High electron density, determined by:
    - $\rho$
    - $Z_{eff}$
      - More photoelectric than Compton interactions
      - Facilitates energy discrimination of photons
      - Maximizes
        - Stopping power (i.e. linear attenuation coefficient $\mu$)
        - Sensitivity

- Advantageous features of scintillation detectors include:
  - High light output
    - Reduces statistical uncertainty (noise)
    - Improves energy resolution & scatter rejection
  - Speed of light emission
    - Example: Important for PET

- Other detector considerations include:
  - Transparency of the crystal to its own scintillations (i.e. minimal self-absorption)
  - Matching of the index of refraction $\eta$ of the crystal to that of the photodetector
  - Matching of the scintillation wavelength to the light response of the photodetector
  - Minimal hygroscopic behaviour

- Most widely used scintillators in nuclear medicine include
  - NaI(Tl)
    - $\gamma$-cameras / SPECT systems
    - Well counters
    - Organ uptake probes
  - BGO
    - PET (higher stopping power for 511 keV)
  - LSO(Ce) or LSO
  - GSO(Ce) or GSO
  - CsI(Tl), CsI(Na), NaI(Tl), BGO and LSO have also been used in intra-operative probes

# 10.3. RADIATION DETECTOR PERFORMANCE

- Radiation detectors may be quantitatively characterized by many different performance parameters
  - Particularly for those detectors such as γ-cameras which localize (image) as well as count radiation

- For non-imaging radiation detectors and counters, the most important performance parameters are:
  - Sensitivity (or efficiency)
  - Energy resolution
  - Count rate performance (or ‘speed’)

- Sensitivity (or efficiency)
  - Detected count rate per unit activity (e.g. cpm/MBq)
    - Highly dependent on:
      - Source–detector geometry
      - Intervening media

# 10.3. RADIATION DETECTOR PERFORMANCE

## 10.3.1. Sensitivity

- Geometric sensitivity
  - Fraction of emitted radiations which strike the detector
  - Directly proportional to the detector area
  - Inversely proportional to the square of source–detector distance (for point source)

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# 10.3. RADIATION DETECTOR PERFORMANCE

## 10.3.1. Sensitivity

- Intrinsic sensitivity
  - Fraction of radiation striking the detector & stopped within the detector
  - Intrinsic sensitivity ↗ with:
    - Detector thickness
    - $Z_{eff}$
    - $\rho$
  - Intrinsic sensitivity ↘ with:
    - photon energy

      (Higher energy photons are more penetrating & are more likely to pass detector without interacting)

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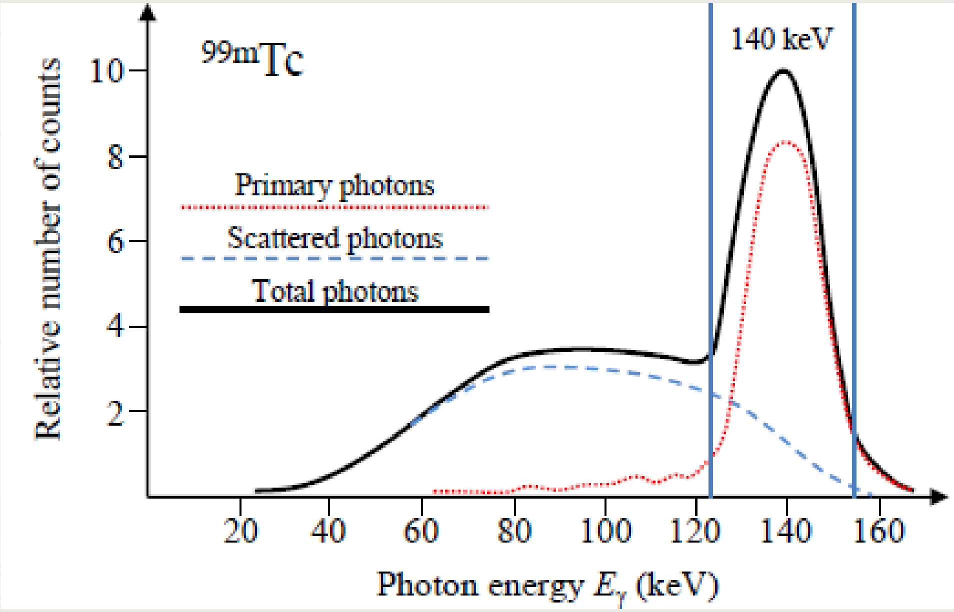
# 10.3. RADIATION DETECTOR PERFORMANCE
## 10.3.1. Sensitivity

- Characteristic X- & γ-rays are emitted with well-defined discrete energies
  - Output pulses from absorption will appear to originate over a range of energies (due to the relatively coarse energy resolution of the detector)

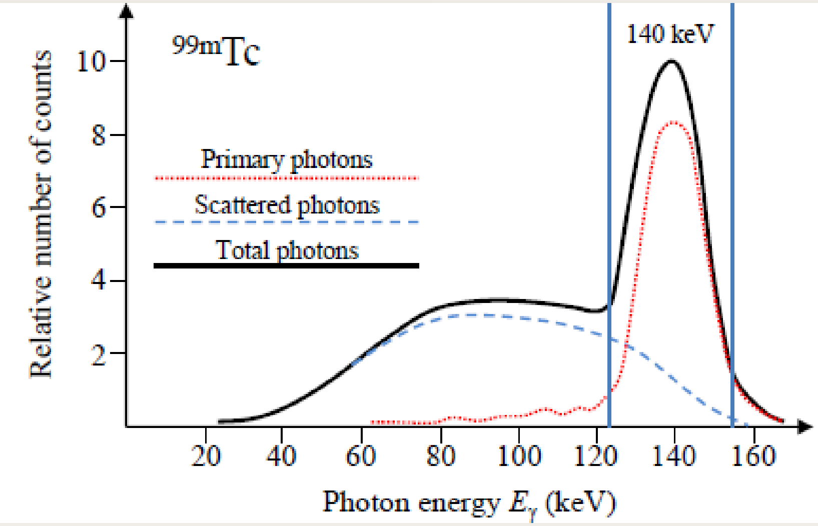


# 10.3. RADIATION DETECTOR PERFORMANCE

## 10.3.1. Sensitivity

- Many radiation detectors employ energy-selective counting
  - Using energy range (windows)
    - Scintillation detectors use a 20% window ($E_\gamma$ ± 10%)

      e.g. 126–154 keV for 140 keV $^{99m}Tc$ $\gamma$-ray
    - Overall sensitivity appears to increase as $E_\gamma$ window is widened
    - This results in acceptance of more scattered as well as primary (i.e. unscattered) radiations



# 10.3. RADIATION DETECTOR PERFORMANCE

## 10.3.1. Sensitivity

- Detector should be calibrated for each radionuclide & energy window used

  - Sensitivity S must be determined at installation & periodically after:

$$S = \frac{R_g - R_b}{\mathcal{A}_0 e^{-\lambda \Delta t}}$$

$R_g$ is the gross (i.e. total) count rate (cpm) of the radionuclide source (RS);

$R_b$ is the background (BG), or blank, count rate (cpm);

$\mathcal{A}_0$ is the activity (MBq) of the radionuclide source at calibration;

$\lambda$ is the physical decay constant

$\Delta t$ is the time interval (in months or years depending on the half-life) between the calibration of the radionuclide and the current measurement

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- S is highly dependent on the source–detector counting geometry
  - Size of the source
  - Shape of the source
  - Source–detector distance
- Measured value applies exactly only for the geometry used for the measurement

# 10.3. RADIATION DETECTOR PERFORMANCE

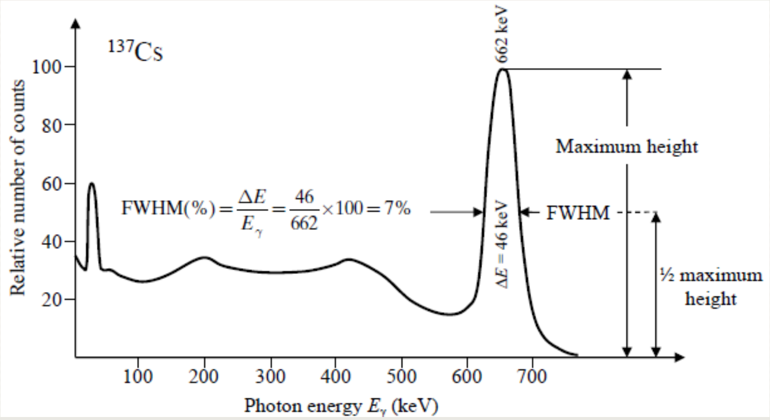
## 10.3.2. Energy resolution

### ❑ Energy resolution

- Ability to separate/discriminate different energies
- Given by the width of photopeak

$$\mathrm{FWHM}(\%) = \frac{\Delta E}{E_\lambda} \times 100\%$$

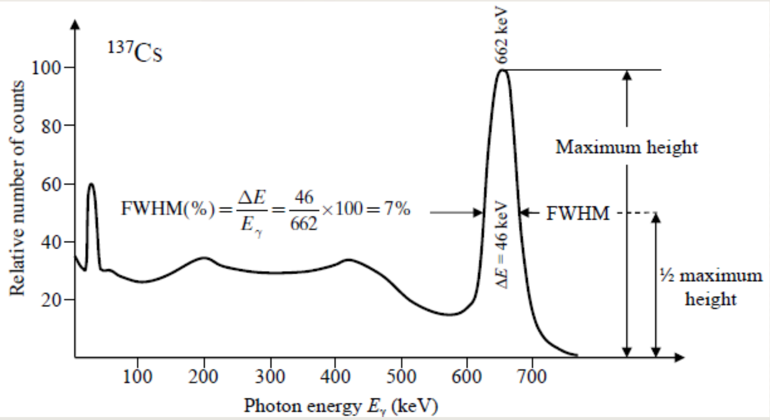
- Related to Poisson 'noise'
  - Statistical uncertainty inherent in the detection process
- Important for scatter rejection with imaging detectors
  - Compton scattered radiation within source loses energy
  - Discrimination between scattered from primary radiations



### ❑ Energy resolution

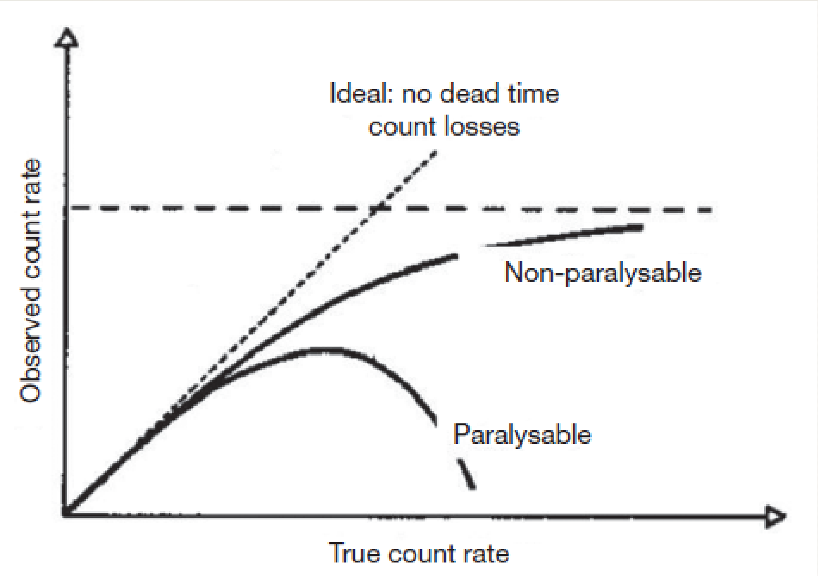
- Scattered and primary radiations overlap (due to finite resolution)
- Better resolution = narrower photopeak
  - Can better separate unscattered & scattered radiations
  - Can eliminate more scattered radiation counts
  - Fewer counts due to unscattered radiation are discarded

$$\mathrm{FWHM}(\%) = \frac{\Delta E}{E_{\lambda}} \times 100\%$$



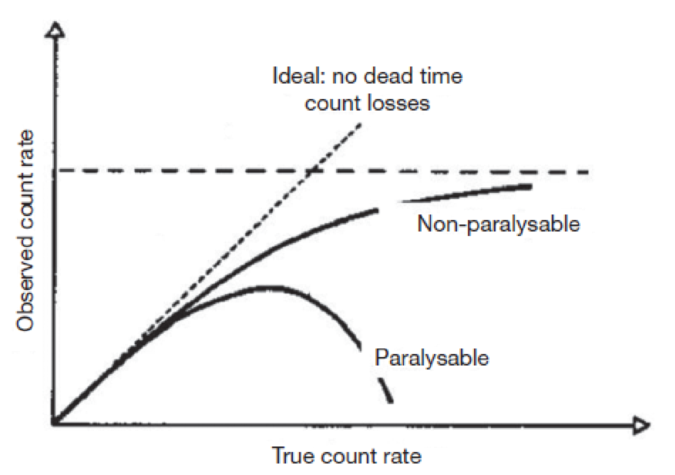
### Dead time for radiation detectors

- Time required for a counting system to record an event
  - Additional events cannot be recorded
- Typically $\tau \sim$ 5–10 μs for modern scintillation detectors
- Associated count losses
  - Measured count rate is lower than actual count rate



- Detectors are characterized as either
  - Non-paralysable
    - Dead-time due only to counted events
    - Example: Geiger counters (with quenching gas)
  - Paralysable
    - Dead-time due counted & not counted events
    - Example: well counters, $\gamma$ cameras, PET scanners
  - Modern scintillators generally incorporate automated algorithms to correct for dead time

Observed *vs* true count rates for paralysable and non-paralysable radiation detectors



- Essential component of any radiation safety program
- Portable
- Battery operated
- Monitor ambient radiation levels

  exposure rates ($C \cdot kg^{-1} \cdot h^{-1}$) / count rates (e.g. in cpm)
- Solid state scintillation detectors
  - Employ non-air-equivalent crystal as the detection medium
  - Cannot measure exposure rates, only count rates

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# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.1. Survey meters

- Gas filled ionization detectors
  - ‘Cutie-pies’
    - Low sensitivity ionization chambers (i.e. low $\Delta V$ between anode & cathode)
    - Used with high fluxes of X-rays and $\gamma$-rays
    - Signal depends on the energy of the detected X-/$\gamma$-rays
    - Directly related to the exposure for all radionuclides

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- Gas filled ionization detectors
  - ‘Geiger counters
    - Operated at high ΔV
    - High $e^-$ amplification
    - High sensitivity
    - Suited for low level surveys (e.g. radioactive contamination)
    - Same amplitude signal for all energies
    - Calibrations apply only to the particular radionuclide(s) used to calibrate the counter

# 10.4. DETECTION AND COUNTING DEVICES
## 10.4.2. Dose calibrator

- Used for assaying radiopharmaceutical activities in:
  - vials
  - syringes
  - other small sources (e.g. brachytherapy sources)

- Pressurized gas filled ionization chamber
  - sealed sensitive volume
  - ‘well’-type geometry
    - High geometric efficiency
    - Overall sensitivity adequate for relatively high radiopharmaceutical activities

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# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.2. Dose calibrator

- Relatively low intrinsic sensitivity
- Adjust energy dependent responses via
  - Isotope-specific push-buttons
  - Potentiometer with isotope-specific settings
  - Accurate activity readouts (i.e. kBq or MBq) for any radioisotope

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- Used for high sensitivity counting of radioactive specimens
  - Blood
  - Urine
  - 'Wipe testing'

- Use isotope specific calibration factor (cpm/MBq)
  - Provides results in terms of activity (e.g. MBq)

- Most commonly NaI(Tl))

- Common design
  - Cylindrical scintillation crystal
  - Circular bore (well) for sample drilled part-way into the crystal backed by a PMT + electronics

- Alternative design
  - ‘Through-hole’
  - Hole is drilled through the entire crystal
  - Facilitates sample exchange
  - Samples are centered lengthwise
  - More constant response for different volumes
  - Slightly higher sensitivity than well counters
- Crystal is surrounded by thick lead shielding in both designs
  - Minimizes ambient radiation background

- Scintillation counters often have:
  - Multichannel analyzer for energy (i.e. isotope) selective counting
  - Automatic sample changer for multiple samples automated counting
- High intrinsic & geometric efficiencies
  - Resulting from thick crystal & well-type configuration
  - Extremely sensitive
  - Can reliably count activities ≤ ~100 kBq
  - At higher activities
    - Dead time losses may become prohibitive
    - The measured counts inaccurate

# 10.4. DETECTION AND COUNTING DEVICES
## 10.4.3. Well counter

- Integrated computer
  - To create & manage counting protocols
    - Specify isotope
    - Specify energy window
    - Specify counting interval
    - Manage sample handling
    - Apply background, decay, dead time & other corrections
  - Yield dead time-corrected net count rate decay corrected to the start of the current counting session

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# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.4. Intra-operative probes

- Small hand-held counting devices
- Widely used in cancer management
  - To expeditiously identify & localize sentinel lymph nodes
  - Reduce the need for more extensive surgery
  - Identify & localize visually occult disease

# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.4. Intra-operative probes

- Almost exclusively for X-/γ-rays counting
  - Scintillation
    - Low cost
    - High sensitivity for medium-high energy γ ‘s
    - Disadvantages relative to semiconductor
      - bulkiness
      - poor energy resolution
      - Poor scatter rejection
  - Semiconductor (ionization)

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# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.4. Intra-operative probes

- Plastic scintillator β probes have also been developed
- Small (~10 cm) FOV intra-operative γ-cameras recently available
- Semiconductor based probes
  - Compact
  - More electrons per X/γ-ray stopped
    - ➢ Excellent energy resolution
    - ➢ Excellent scatter rejection
  - Thin (only ~1 mm)
    - Minimize structural imperfections which degrade energy resolution
    - Lower intrinsic sensitivity
  - Disadvantage
    - Limited thickness
    - Lower sensitivity

# 10.4. DETECTION AND COUNTING DEVICES
## 10.4.4. Intra-operative probes

- Typical intra-operative probe

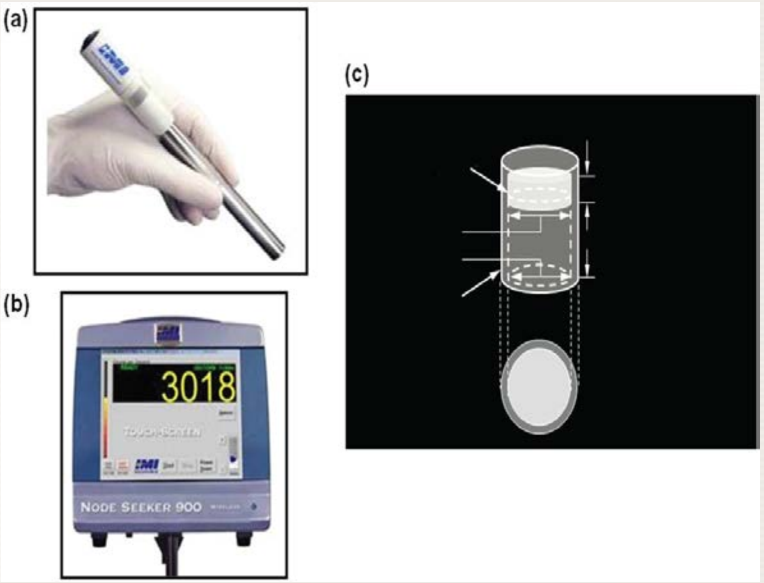
  a) Hand-held detector

  b) Control and display unit

  - Displays current count rate
  - Often emits an audible signal, the tone of which is related to the count rate

  c) Detector & collimator assembly diagram

  - Detector (crystal) recessed from the collimator aperture



## 10.4.5. Organ uptake probe

- Almost exclusively for ‘thyroid’ uptake
  - Decay-corrected % of administered activity in the thyroid
  - May be measured following oral administration of:
    - $^{131}$I-iodide
    - $^{123}$I-iodide
    - $^{99m}$Tc-pertechnetate
- Consists of
  - Wide-aperture, diverging collimator
  - NaI(Tl) crystal (~5 cm thick, ~5 cm diameter)
  - PMT
  - Preamplifier
  - Amplifier
  - Energy discriminator (i.e. energy window)
  - Gantry (stand)

# 10.4. DETECTION AND COUNTING DEVICES

## 10.4.5. Organ uptake probe

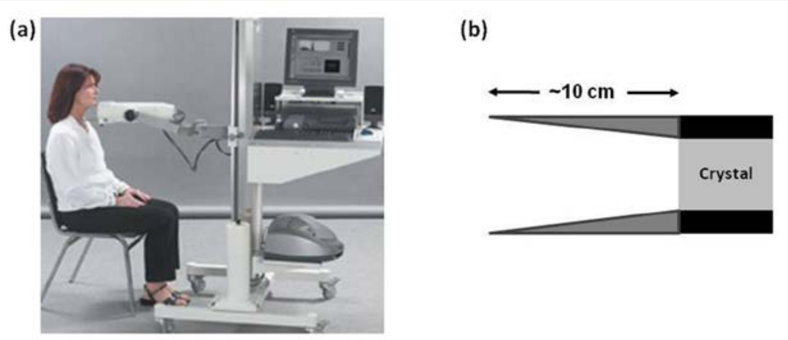
- Generally supplied as
  - Integrated computerized system
  - With automated
    - Data acquisition
    - Processing capabilities
  - Yield results in terms of % uptake

# 10.4. DETECTION AND COUNTING DEVICES
## 10.4.5. Organ uptake probe

a) A typical organ ('thyroid') uptake probe system

- Integrated computer, set-up
- Large neck to collimator aperture distance (~30 cm)
  - Reduces overall sensitivity
  - BUT serves to minimize the effect of
    - the exact size, shape and position of the thyroid
    - distribution of radioisotope within the gland

b) A diagram (side view) of the open, or 'flat-field', diverging collimator



- Determination of thyroid uptake includes:
  - Measurement of the thyroid (i.e. neck) count rate
  - 'Thigh' background count rate
    - Measured over thigh
    - Presumed to approximate the count contribution of extra-thyroidal neck activity
  - Ambient (i.e. 'room') background
  - 1–5 min interval for each measurement

- Determination of thyroid uptake includes:
  - Standard count rate
    - Often counted in neck phantom
    - Used to automatically correct for:
      - Decay
      - Day-to-day system sensitivity variation
    - Typically a dilution of the administered solution
    - Fraction of administered activity is independently determined < 1

- Determination of thyroid uptake includes:
  - Thyroid uptake is calculated as follows:

$$\text{uptake}\,(\%) = \frac{C_{\text{neck}}/t_{\text{neck}} - C_{\text{thigh}}/t_{\text{thigh}}}{C_{\text{standard}}/t_{\text{standard}} - C_{\text{room}}/t_{\text{room}}} \times F \times 100\%$$

    - *C* = total counts
    - *t* = measurement time
    - *F* = fraction of administered activity in the standard

  - Known as 'two-capsule' method
    - One $^{131}$I capsule administered
    - A second, identical one is the standard
      - Counted with each uptake measurement

Alternatively, 'One-capsule' method:

- Patient capsule can be measured immediately before administration
- Each subsequent uptake value can be corrected from time of measurement administration:
  - By multiplying right side of previous equation by $e^{\lambda \Delta t}$

    $\lambda$ = physical decay constant

    $\Delta t$ = administration to measurement time

# 10.4. DETECTION AND COUNTING DEVICES
## 10.4.5. Organ uptake probe

- For both methods, the fraction of administered activity in the standard is 1

- Some centers administer radio-iodine as a solution
  - More cost effective

- Now often done by ROI analysis of planar gamma-camera images of neck & a standard (i.e. phantom) acquired with parallel-hole collimator

- Organ uptake probes have also been used to measure total body activity
  - Example: As part of individualized thyroid cancer dosimetry-based radioiodine treatment
    - Patient may serve as own standard
    - Performed with:
      - Collimator removed from probe
      - Crystal
        - Oriented horizontally
        - Height above the floor = mid-height of patient at ~3 m from crystal
    - Conjugate-view measurements
    - ‘Time 0’ total body count rate S measurement
      - Shortly (30–60 min) after administration
        - Allows some dispersion throughout body
      - Before patient has voided / excreted any activity

- The % administered activity in the body is:

$$\text{Total body activity (\%)} = \frac{\left[\left(\frac{A}{t_{\mathrm{A}}} - \frac{B}{t_{\mathrm{B}}}\right) \times \left(\frac{P}{t_{\mathrm{P}}} - \frac{B}{t_{\mathrm{B}}}\right)\right]^{1/2}}{\left[\left(\frac{A(0)}{t_{\mathrm{A(0)}}} - \frac{B(0)}{t_{\mathrm{B(0)}}}\right) \times \left(\frac{P(0)}{t_{\mathrm{P(0)}}} - \frac{B(0)}{t_{\mathrm{B(0)}}}\right)\right]^{1/2}} \times 100\%$$

*A* & *P* = Anterior / Posterior total counts

*B* = Room (background) counts

$t_A$, $t_P$ & $t_B$ = counting intervals A, P & B

(0) = quantities at time 0

## Quality control (QC)

- Established set of ongoing measurements & analyses
- Designed to ensure procedure / instrument performance is within a predefined acceptable range
- Critical component in routine nuclear medicine practice

# 10.5. QUALITY CONTROL OF DETECTION AND COUNTING DEVICES

- A sound & compliant QC programme requires
  - Documentation
  - Organized, retrievable results records
  - Written description included in the facility's procedure manual:
    - Tolerance of results of each procedure
    - Corrective action for an out of tolerance result
    - Signed and dated by facility director, physicist or other responsible individual

# 10.5. QUALITY CONTROL OF DETECTION AND COUNTING DEVICES

- Each QC test should have a record of:
  - Initials/signature of individual performing test
  - Test date and time
  - Device make, model and serial number
  - Refernce sources make, model, serial number, activity at date of  calibration
  - Result(s)
  - Notation indicating on whether test result was or not acceptable

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# 10.5. QUALITY CONTROL OF DETECTION AND COUNTING DEVICES
## 10.5.1. Reference sources

- QC tests often performed with surrogate radionuclides called reference sources
  - Not radionuclides used clinically
    - Longer lived
    - Must match frequency & energy of X and $\gamma$-ray emissions of clinical radionuclide
  - Commercially available in various activities & geometries, depending on the application

## 10.5.1. Reference sources

- QC tests often performed with surrogate radionuclides called reference sources
  - In the USA, certified activities must be traceable NIST
    - Helps ensure calibrated activity accuracy
    - A single standard may be used for months to years
    - No need to prepare sources on a daily/weekly basis
    - Avoid possible inaccuracies in dispensing activity
    - Avoids possibility of radioactive contamination

## 10.5.1. Reference sources

- QC tests often performed with surrogate radionuclides called reference sources
  - Must be periodically checked for leakage (i.e. ‘wipe-tested’)
  - Up-to-date inventory must be maintained
  - Still radioactive at end of useful lifespan
    - Must be returned to vendor / third party / otherwise disposed of as radioactive waste

- QC tests of survey meters generally include daily battery check

  - Voltage should be within acceptable range
  - Confirm it's not contaminated
    - Reproducibly low exposure in the absence of radioactivity
    - Measure background exposure / count rate daily
      - Use area remote from radioactive sources

# 10.5. QUALITY CONTROL OF DETECTION AND COUNTING DEVICES

## 10.5.2. Survey meter

- Check daily for response constancy
  - Measure exposure / count rate of long-lived reference
  - Reproducible measurement geometry
  - Should agree ± 10%; if not, the meter should be re-calibrated
- Checked for accuracy
  - Use long lived reference sources
  - At installation
  - Annually
  - After any repair

## 10.5.2. Survey meter

- Point-source geometry is approximated when
  - Source is ‘small’
    - When compared to photon mean free path
  - Source - meter distance is ‘large’
    - When compared to source dimensions
  - Expected dose rate in air is given by:

$$\dot{D} = \frac{\mathcal{A}_0 e^{-\lambda \Delta t} \Gamma_\delta}{d^2}$$

$\mathcal{A}_0$ = reference source activity at calibration

$\lambda$ = physical decay constant

$\Delta t$ = calibration - current measurement time interval

$\Gamma_\delta$ = Air kerma rate constant ($\gamma$-energies > 20 keV) of source

$d$ = source-mete distance

## 10.5.2. Survey meter

- Long lived radionuclides used as reference sources for instrumentation quality control

| Radionuclide | Half-life | Physical decay constant $\lambda$ | Photopeak energy $E_\gamma$ and frequency of principal X ray or γ ray | Air kerma rate constant $\Gamma_\delta$ $(mGy \cdot m^2 \cdot h^{-1} \cdot GBq^{-1})$[a] | Geometry and activity | Quality control application |
|---|---|---|---|---|---|---|
| $^{57}Co$ | 272 d | 0.00254/d | 122 keV (86%) | 14.1 | Test tube-size rod, ~37 kBq | Well counter constancy and accuracy |
| | | | | | Vial/small bottle, 185–370 MBq | Dose calibrator accuracy and constancy |
| $^{68}Ge$[b] | 287 d | 0.00241/d | 511 keV (178%) | 129 | Test tube-size rod, 37 kBq | Well counter constancy and accuracy |
| | | | | | Vial/small bottle, 185–370 MBq | Dose calibrator accuracy and constancy |
| $^{137}Cs$ | 30 a | 0.0231/a | 662 keV (86%) | 82.1 | Test tube-size rod, 37 kBq | Well counter constancy and accuracy |
| | | | | | Vial/small bottle, 185–370 MBq | Dose calibrator accuracy and constancy |

[a] The air kerma rate constant $\Gamma_\delta$ is equivalent to the older specific γ ray constant Γ.
[b] Germanium-68 in a sealed source is in secular equilibrium with its short lived, positron emitting daughter $^{68}Ga$ (half-life: 68 min).

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## Routine dose calibrator QC tests

- Constancy must be checked daily
  - Use NIST-traceable reference source, e.g. $^{57}Co$, $^{68}Ge$ or $^{137}Cs$
  - Place in calibrator
  - Record activity reading on each scale
  - Daily readings should agree within 10%

## Routine dose calibrator QC tests

- Accuracy
  - At least quarterly
  - Daily checks recommended
  - At least 2 NIST-sources placed separately in the calibrator
  - Record activity reading on each scale

- Linearity
  - ‘decay method’
  - At least quarterly
  - Daily readings should agree within 10%

- Measurements at installation

  - $^{99m}$Tc geometry dependent response
  - Volume dependent (2–25 mL) correction factors relative to ‘standard’ volume (e.g. 10 mL)
  - Required periodically following installation

## ‘Decay method’ of linearity

- Quarterly
- Use $^{99m}$Tc source
  - High activity (~37 GBq)
  - Independently calibrated
- Activity is assayed at 12 h intervals over 3 consecutive days
  - Time = 12 $^{99m}$Tc half-lives
  - Activity decays to ~10 MBq
- Plot measured activities versus time on a semi-logarithmic graph
- Draw best fit straight line through data
- Difference between each measured activity point and best fit line should be less than 10%

## ‘Shield method’ to checking linearity

- $^{99m}$Tc source
- Place Pb sleeves of increasing ‘decay-equivalent’ thickness in dose calibrator
  - Causes decay-equivalent activity for each sleeve
- Much faster than the decay method
  - Takes minutes instead of days
- Initial decay based calibration of the set of sleeves is recommended

## Set of lead-lined plastic sleeves

- For evaluation of dose calibrator linearity by the shield method
- The set is supplied with a
  - 0.64 cm thick lead base
  - Color coded unlined sleeve
    - Provide activity measurement equivalent to ‘0’ time point measurement of the decay method
  - 6 color coded lead-lined sleeves
    - Provide attenuation factors
    - Nominally equivalent to decay over 6, 12, 20, 30, 40 and 50 h, respectively

## 10.5.4. Well counter

- Routine well counter QC tests
  - Photopeak energy window checks
    - If equipped with a multichannel analyser
    - Check energy spectrum is 'peaked'
      - i.e. photopeak should coincide with preset photopeak energy window
  - Background
    - Check for each energy window used
    - Count rate should be checked daily
    - Electronic noise & ambient radiation
      - May be relatively high and variable in a nuclear medicine facility
      - Will produce a non-zero/potentially fluctuating count rate
      - Trace contamination will produce inaccurately high count rate values

- Routine well counter QC tests
  - Always include ‘blank’ (i.e. an empty counting tube or vial)
    - To determine the current background count
  - Constancy
    - Use at least one NIST-traceable source
    - Should be counted each day
    - Daily net (i.e. gross minus background) count rates should agree within 10%
  - Efficiency (or sensitivity) (in cpm/kBq)
    - Counter should be calibrated
    - Measure for each radionuclide used
    - Measure at installation, annually & after any repair

## 10.5.5. Intra-operative probe

- QC tests of intra-operative probes
  - Daily battery and background checks
  - Daily bias check for primary & any backup battery
    - Verify bias/high voltage is within acceptable range
  - Lower counts/count rates from inappropriate energy window may go unnoticed
    - May not provide energy spectrum display
    - May not be possible to visually check peaking

## 10.5.5. Intra-operative probe

### QC tests of intra-operative probes

- Daily checks count rate constancy
  - Use long lived reference source (e.g. $^{57}Co$, $^{68}Ge$ and/or $^{137}Cs$)
  - A marked change (e.g. >+10%) in the net count rate from one day to the next may indicate an inappropriate energy window setting or some other technical problem.

- Reference sources should each be put into some sort of cap
  - To fit reproducibly over the probe
  - To avoid spurious count-rate differences due to source–detector geometry variations

## 10.5.6. Organ uptake probe

- Aside from differences in counting geometry and sensitivity, uptake probes and well counters actually have very much in common

- The QC procedures — checks of the photopeak energy window, background, constancy and efficiency — are, therefore, analogous

- Importantly, however, efficiency should be measured more frequently — for each patient — than for a well counter, so that the probe net count rates can be reliably converted to thyroid uptakes for individual patients