Detectors

szerző: PGY

Live time correction

Example.

A sample is so active that 50% of the assigned count time (1 minute) is spent processing pulses. You know that the isotope you are interested in has a half life of 60 minutes.

You decide to turn on automatic half-life correction. The count time would be automatically doubled to two minutes.

Detection and Measurement of Radiation

Detection methods for radiation are some of the most sensitive since decay of individual atoms can often be observed.

A number of methods are available.

What approach you take is dependent on

Type of radiation

Type of sample

Sensitivity required

Gas filled detectors

Cloud chamber

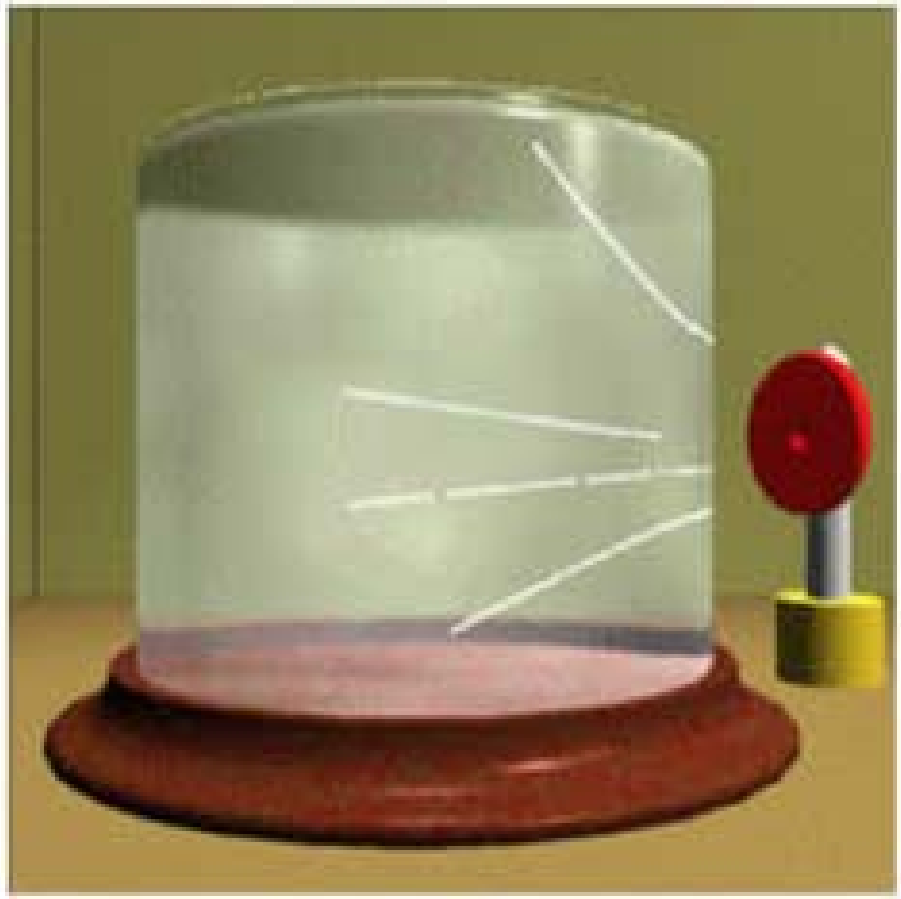
First devised by C.T.R. Wilson - 1911

A particle track through a gas is made visible by condensation of liquid droplets on any ions that are produced.

Common vapors used are CO_2, H_2O and methanol.

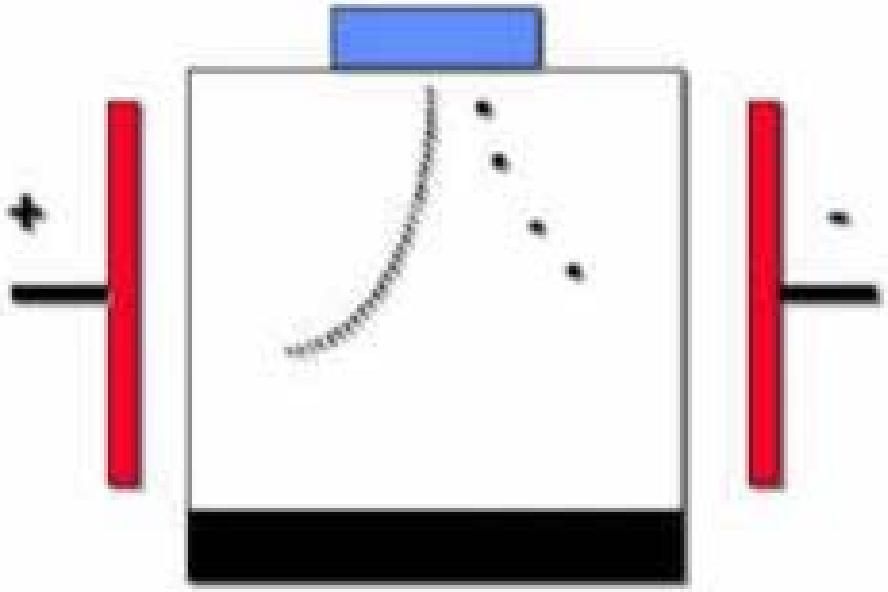
Cloud chamber

- α appear as straight lines of dense fog droplets (>1000/cm)
- β less dense with only a few droplets/cm
- γ not detected

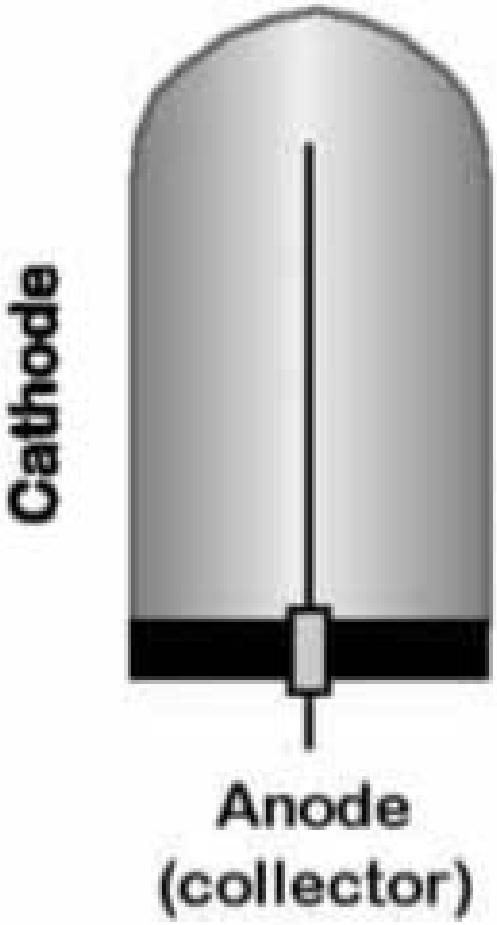


Cloud chamber

The chamber is often put in a magnetic or electrical field to deduce momentum of particles by tracking curvature.



Gas filled detectors
using an applied voltage



This class of detector relies on an argon filled tube. The anode is in the center and the body is commonly used as the cathode.

The actual type of detector is based on the type of voltage that is applied.

Gas filled detectors
using an applied voltage

Argon is the gas commonly used.

It is able to handle a large voltage difference without ionization.

It will simply become excited.

$$Ar \xrightarrow{\text{applied voltage}} Ar^*$$

Ion chamber

Low applied voltage: **~100 - 300 V**

At this voltage, you only collect ions that are directly caused by radiation.

$$Ar^* + \text{ionizing radiation} \downarrow Ar^+ \longrightarrow \text{count}$$

Proportional counter

Voltage: ~300 - 3000V (varies)

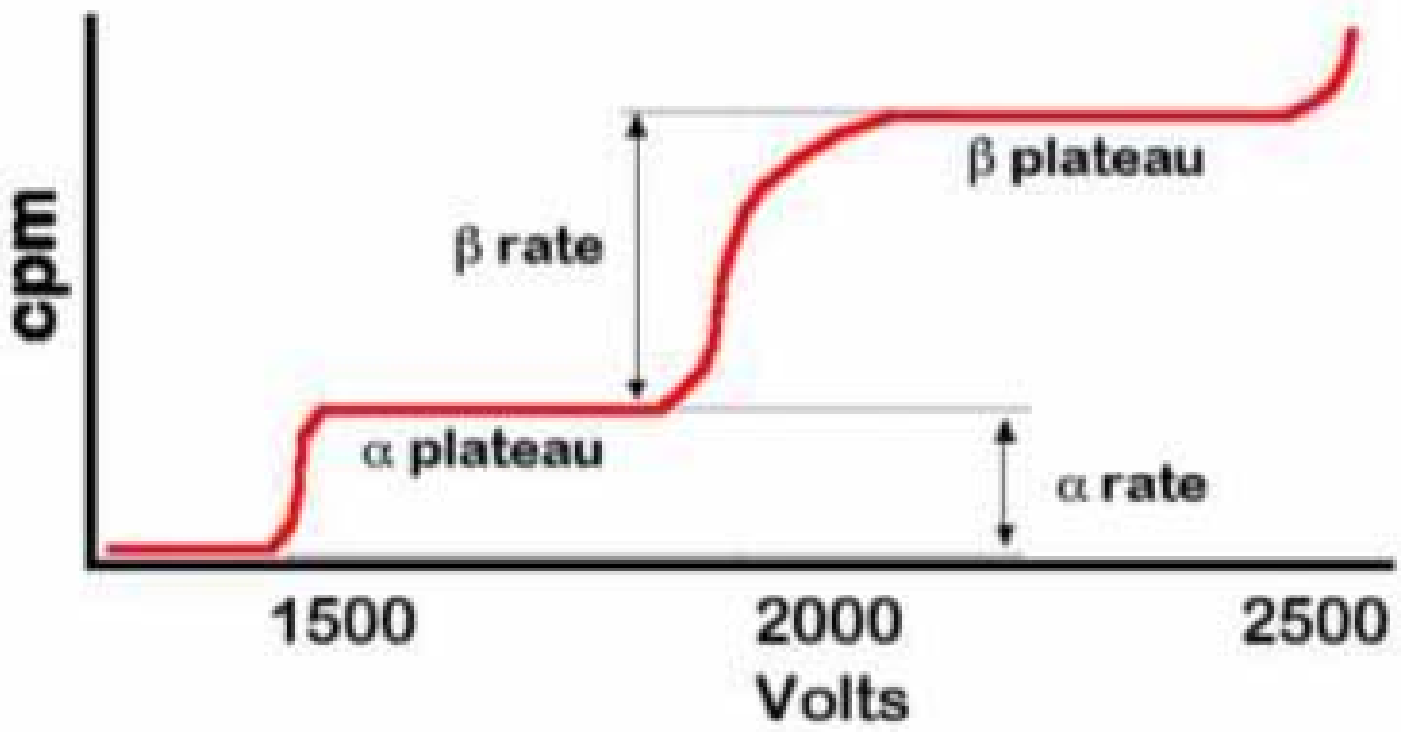
At this voltage, the primary ions will accelerate as they travel to the collector.

This results in the formation of secondary ions - gas multiplication of 10-1000.

$$Ar^* + \text{radiation} \longrightarrow Ar^+ \longrightarrow x\ Ar^+$$

Proportional counter

α, β & γ will each result in a different response and can be distinguished to some extent.



Geiger-Muller counter - GM tube

Voltage: 1000 and up

At this voltage, you get the maximum number of ionizations per radiation event.

Each event causes a total avalanche of ions resulting in a single, large pules.

It is the most sensitive of the but there is no discrimination and it is slow to recover (50-500μs). This can result in tube saturation.

Tube design

Several types of tube designs have been described. Each is an attempt to obtain the maximum possible response.

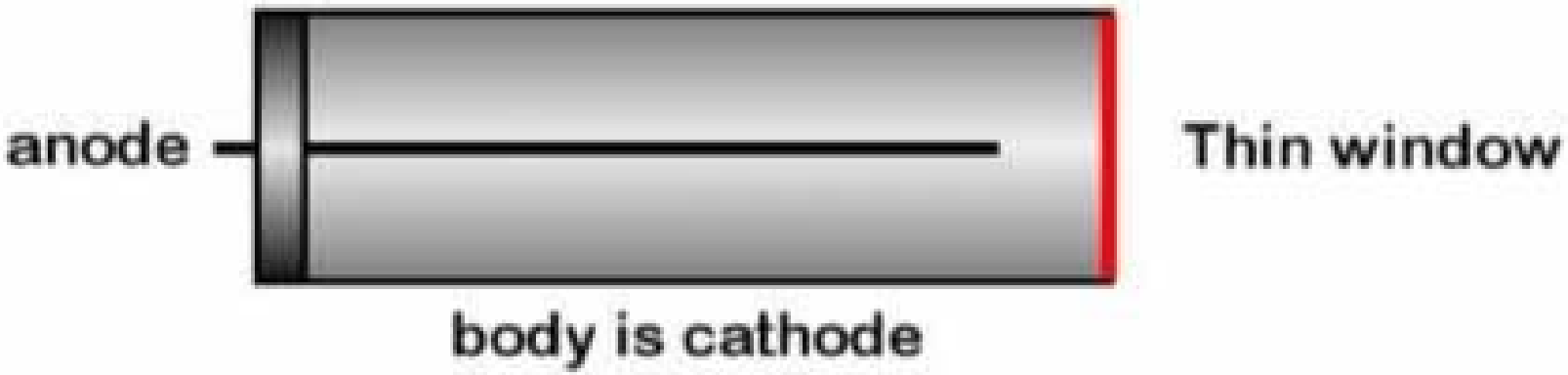
For γ, the most common type is one where the body acts as the cathode.

This is not suitable for detection of α or β emission.

Tube design

Thin window

A thin wall of mylar or mica can be put on one end of a tube to allow β to pass through and be detected.



Tube design

Alpha radiation

The majority of all α particles would be blocked by any type of window.

We must put the sample inside of the detector for any significant detection.

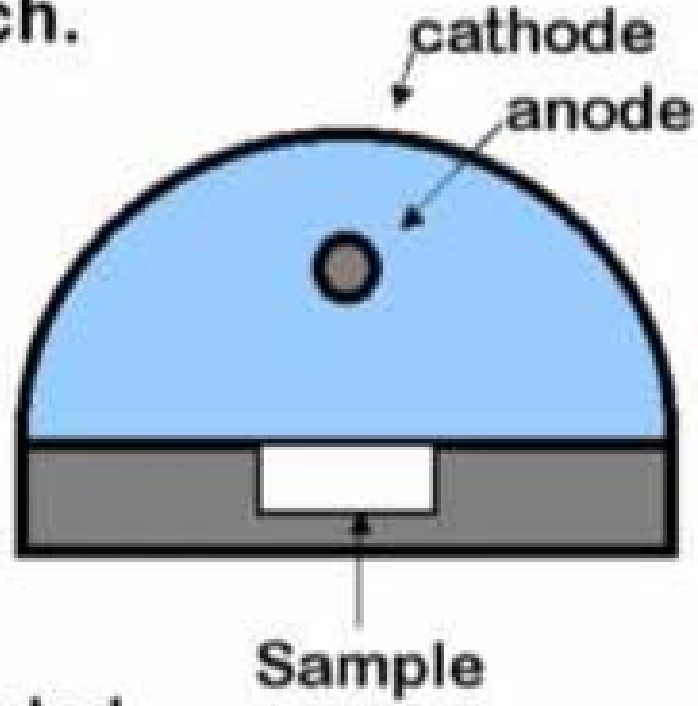
For gas samples, we can mix the sample with argon and use a variant of the γ type detector - 4π symmetry detector.

Tube design

Alpha radiation

For liquids and solids, we must take a different approach.

2π symmetry detector.



With this design, the tube can be opened and a sample placed inside.

The detector is then closed, Ar added and the sample counted.

Scintillation Detectors

Detectors based on the interaction of radiation with a material, resulting in the emission of light.

Inorganic materials

ZnS(Ag)

Silver doping enhances sensitivity.

Visible light is produced when bombarded by α or β.

Scintillation Detectors

NaI(Tl)

Very common material used for γ detection.

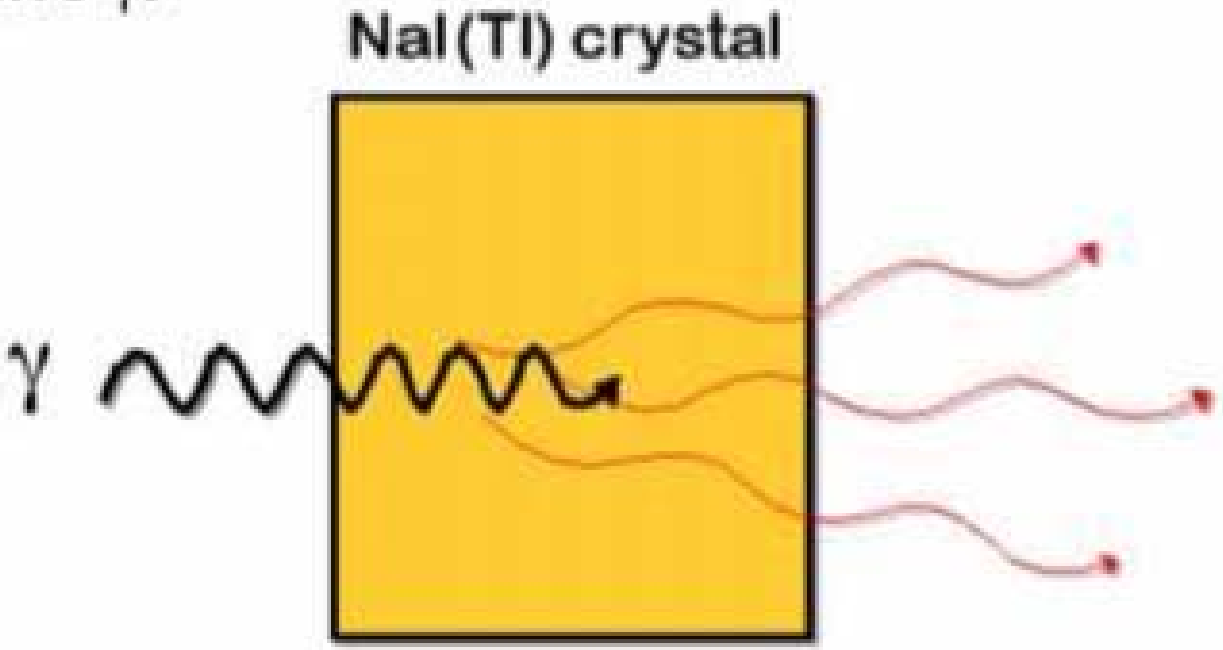
When a γ interacts with a NaI(Tl) crystal, light is produced.

You get one photon for each 200eV.

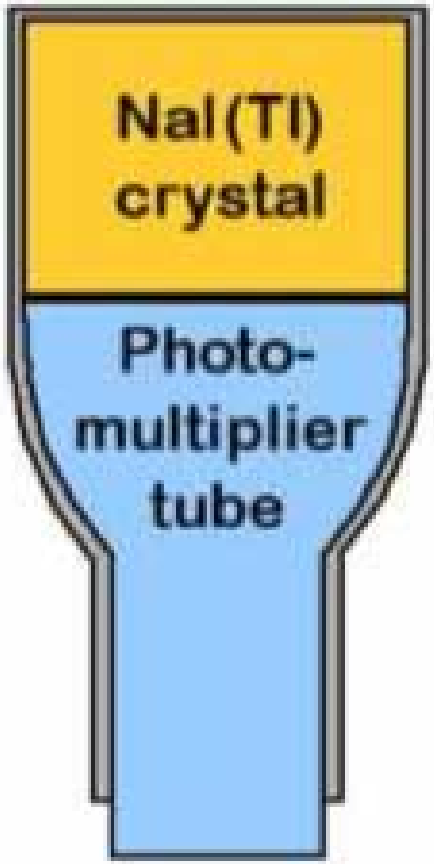
The number of photons is proportional to the energy of the γ.

Scintillation Detectors

When exposed to gamma radiation, the crystal will produce a burst of photons. The intensity of the light is proportional to the energy of the γ.



NaI(Tl) detector



An aluminum 'shield' covers the crystal to prevent contamination and keep water out - can destroy the crystal.

The inner surface is reflective to direct light towards the photomultiplier tube.

NaI(Tl) detector

Detectors are rated based on the size of the NaI(Tl) crystal - thickness x diameter.

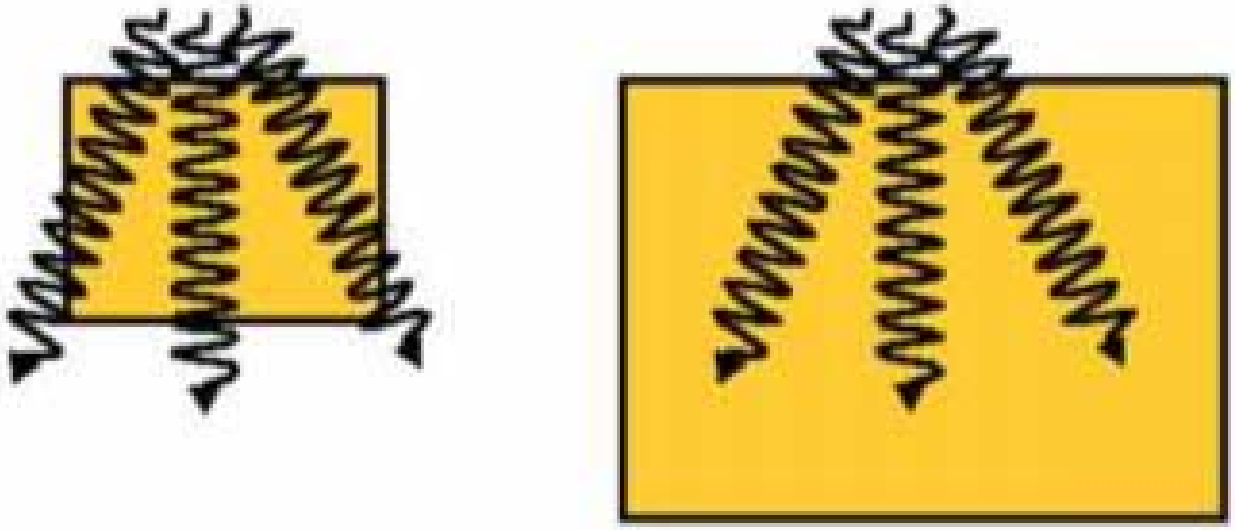
Crystals from 2 x 2 to 5 x 5 are readily available.

Cost increases with increasing size.

Why bother with a larger crystal?

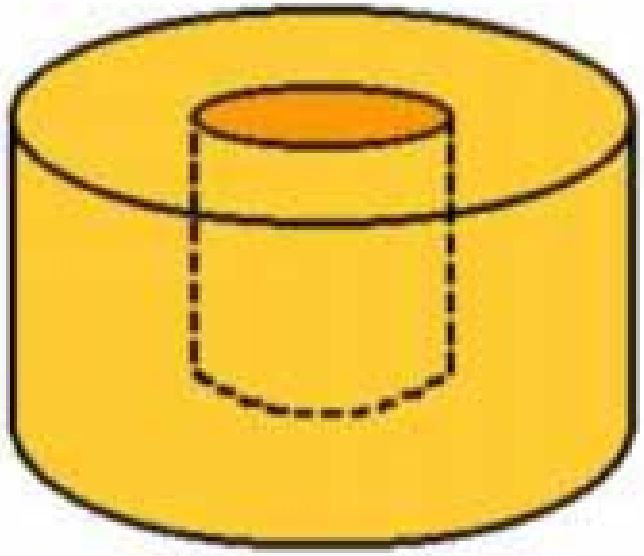
NaI(Tl) detector

Larger crystals give increased sensitivity since more γ are converted. In addition, more of each γ is converted.

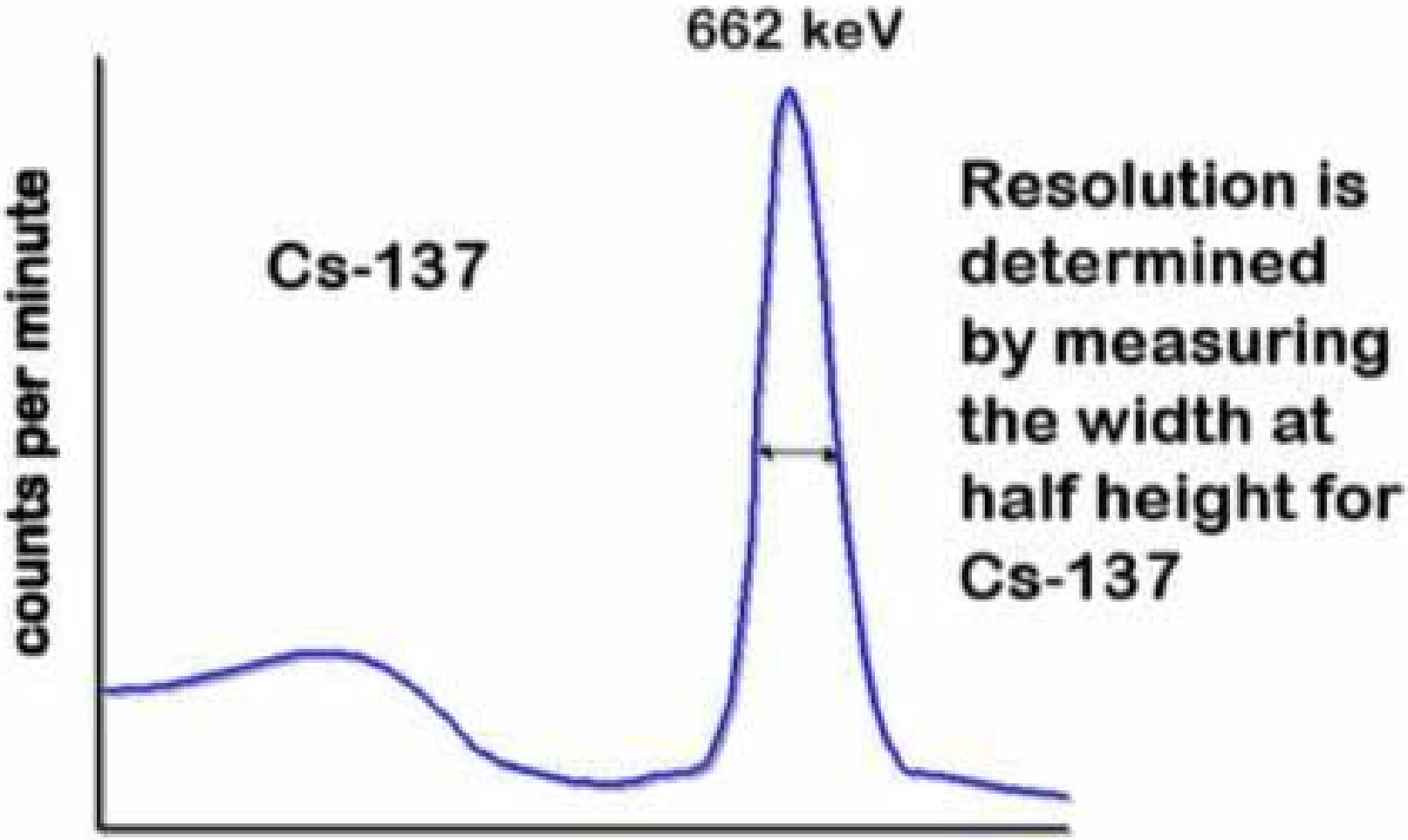


NaI(Tl) detector

A 'well' type detector can be used to increase sensitivity but at a lower resolution.



NaI(Tl) detector



Resolution is determined by measuring the width at half height for Cs-137

NaI(Tl) detector

NaI(Tl) detectors suffer from a number of artifacts such as:

Compton effect

Pair production

Various X-rays

Escape peaks

Backscatter

We'll cover these when we discuss γ ray spectroscopy.

Liquid scintillation

- Polycyclic species can emit light when they interact with α, β or neutrons.
- A sample can be dissolved in a scintillation liquid (cocktail) resulting in 4π symmetry.
- Several fluids are commercially available for both polar and non-polar samples.
- This is the most commonly used approach for detection of β^- emitters (^{14}C and ^{3}H).

Liquid scintillation

Once the mixture is made, the entire sample is put on a PM tube and counted.

Counting efficiencies: 90-100%

This permits use of low activity samples

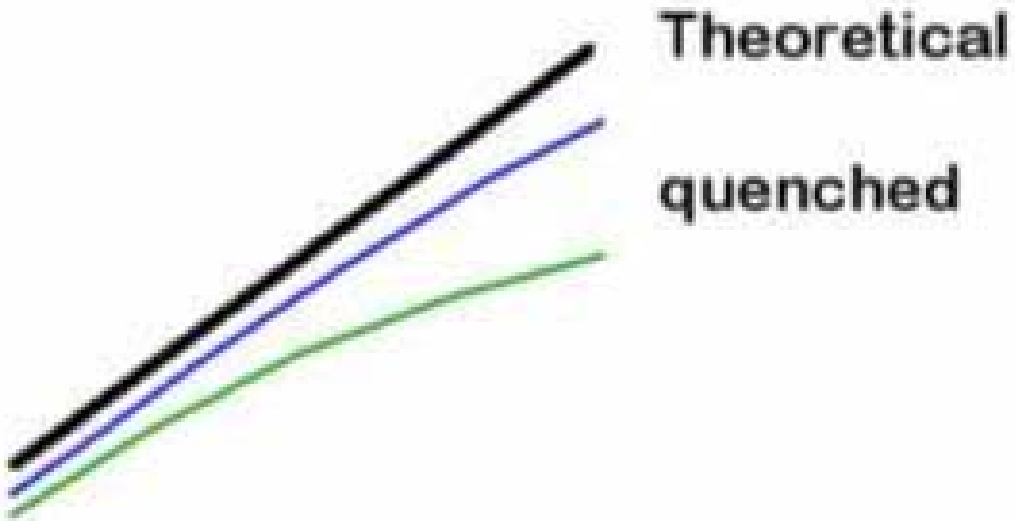
Common approach for tracer studies of biochemical systems.

^{14}C and ^{3}H cause different energy photons so some differentiation is possible.

Liquid scintillation

The most common problem with liquid scintillation is quenching.

Highly colored samples can absorb emitted photons resulting in reduced response.



Semiconductor detectors

Si(Li)

Used for X-rays

Ge(Li) and intrinsic Ge

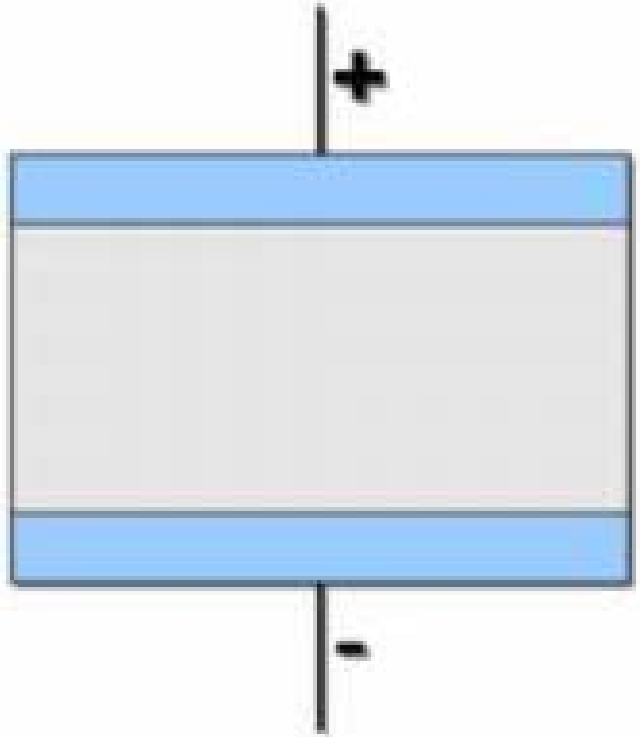
Used for γ rays.

If lithium is added, it is drifted in to balance impurities and increase charge carrier mobility.

Semiconductor detectors

The working principle is basically the same as that of an ionization or cloud chamber.

A solid medium is substituted for a saturated gas and a charge is applied.



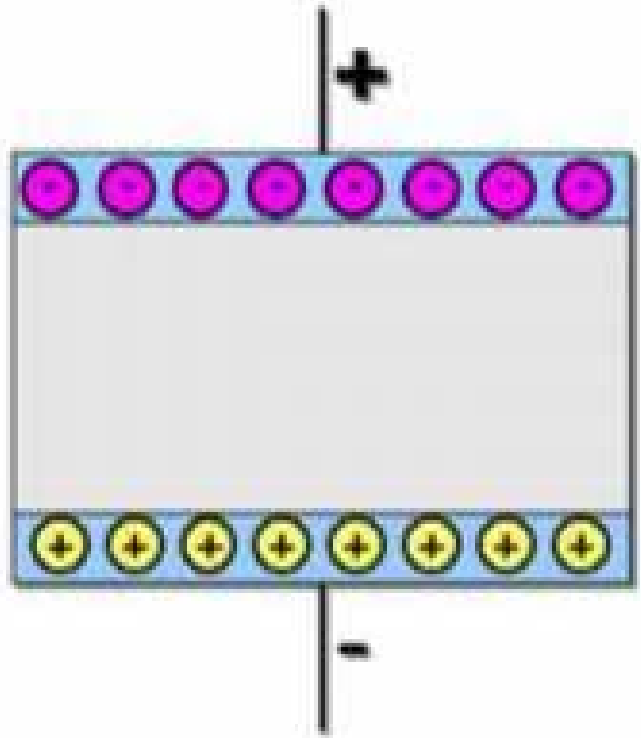
Semiconductor detectors

When a small voltage difference is applied to the crystal, you create a positive, negative and a depleted zone.

This is similar to a transistor (np type).

negative - electrons

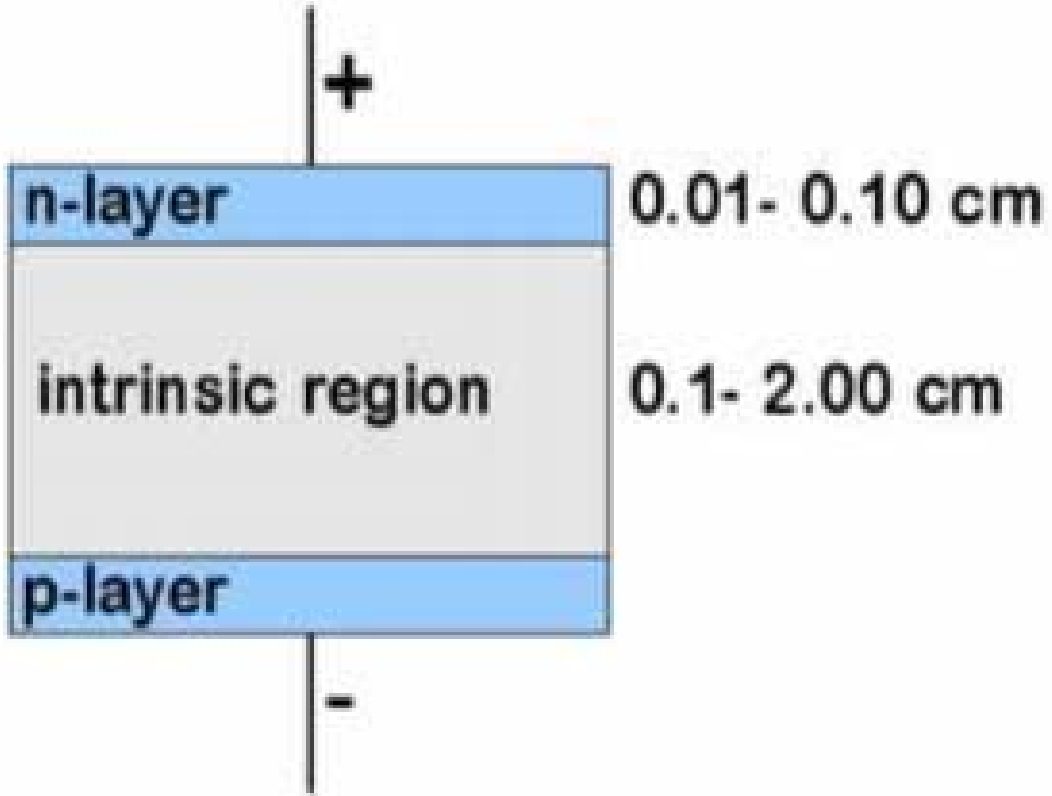
positive - + holes



Semiconductor detectors

These regions are relatively small.

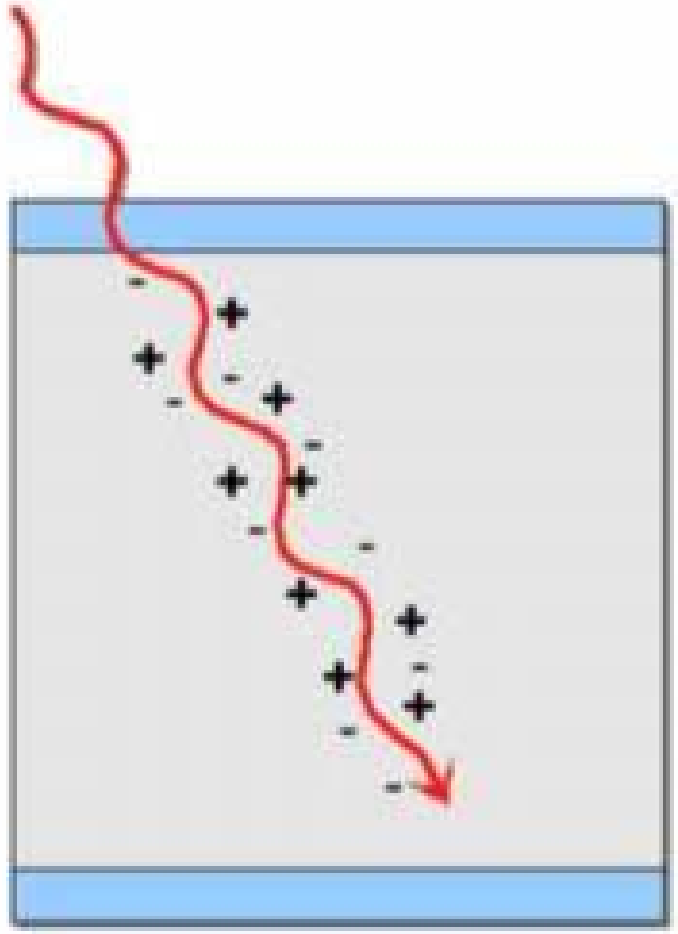
Once created, there is no net movement of charge.



Semiconductor detectors

When ionizing radiation passes through the detector, it leaves behind a trail of + and - charges in the depletion zone.

Detection is based on the current required to re-establish the depletion zone.



Semiconductor detectors

For Ge detectors, only ~2 eV is required per charge carrier.

You get a much higher resolution.

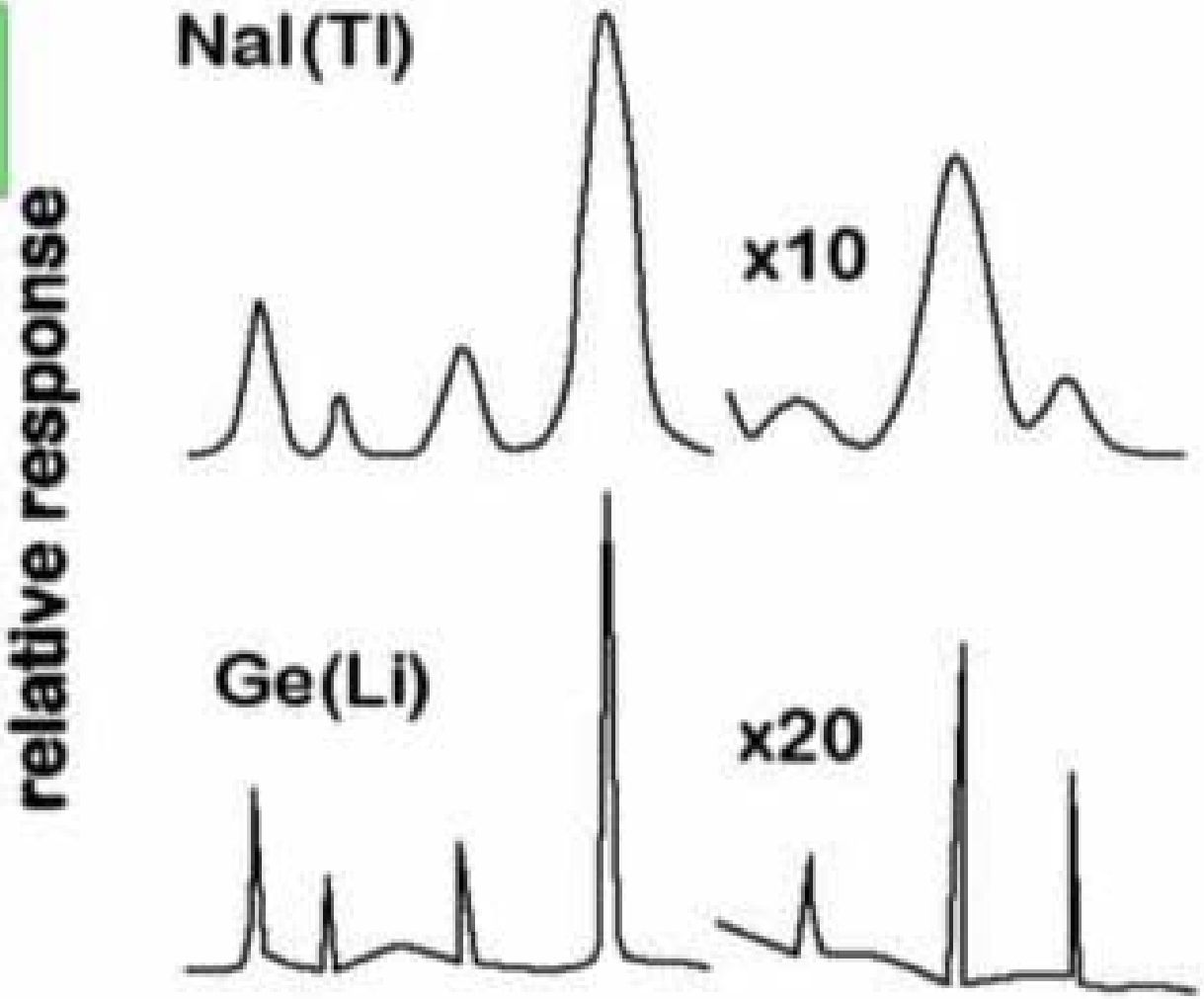
They are very expensive.

> $5000 for a 1 cm^3 detector.

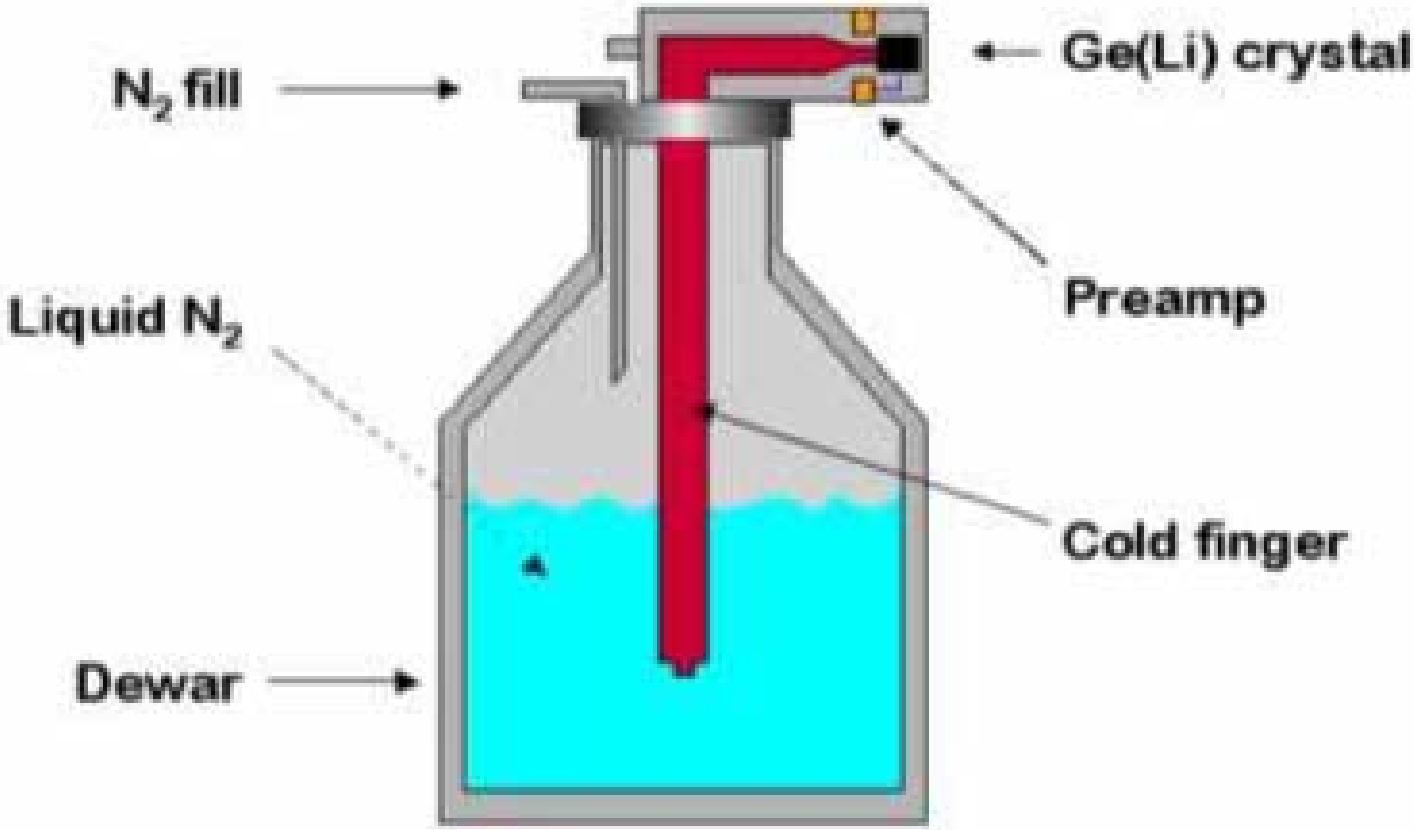
Since they are so small, you end up with relatively poor sensitivity.

NaI(Tl) vs Ge type γ spectra

^{131}I spectrum



Ge(Li) detectors



Ge(Li) detectors

A Ge(Li) detector must be kept cold at all times - in liquid nitrogen.

- It will not work if not chilled.
- It will also destroy the 'balanced'Ge-Li.
- If it is ever allowed to warm up, theLi must be redrifted.

So, a Ge(Li) detector has a higher level of required maintenance.

Intrinsic Ge detectors.

Ultra high purity Ge

Li does not need to be drifted in.

You only need to chill the detector when you plan on using it.

However, they make Ge(Li) detectors look cheap.

Some other detectors

Film Used primarily in dosimetry and autoradiography, which we will cover later.

Bubble chamber

Similar to a cloud chamber but filled with a liquid. Radiation leaves a trail of bubbles.

Spark chamber

A gas filled detector with charged plates. Sparks are produced when an ionization occurs.

Summary of detectors

Type	Detects	% Eff.	Res	bkg (cpm)	relative cost
ion chamber	α, β	30-100	N/A	low	-
proportional	α, β	20-50	poor	0-100	-
GM tube	β	<1-30	N/A	10-100	-
	γ	<1	N/A	10-20	-
NaI(Tl)	γ	10-30	200eV	100-600	+
Ge/Ge(Li)	γ	up to 10	2eV	10-100	++
Liquid Scint.	β	50-100	varies	10-30	+/-

Counting equipment

Now that we have appropriate detectors, we still need a way of measuring their response.

For our discussion, we'll omit power supplies, pre-amps and amps.

We'll assume that you have what is needed.

Scalers

Most detectors will provide information on the quantity of radiation received.

For most application, this information is enough.

You have added a single radioactive species.

If this is true, a simple scaler is all that is required.

Scalers

All a scaler does is to count the number of pulses that is fed into its input.

It typically will allow you to record the information in digital form.

You are also able to either

- count for a fixed period of time
- count for a fixed number of counts and report the time required.

Scalers

The equipment consists of two basic components.

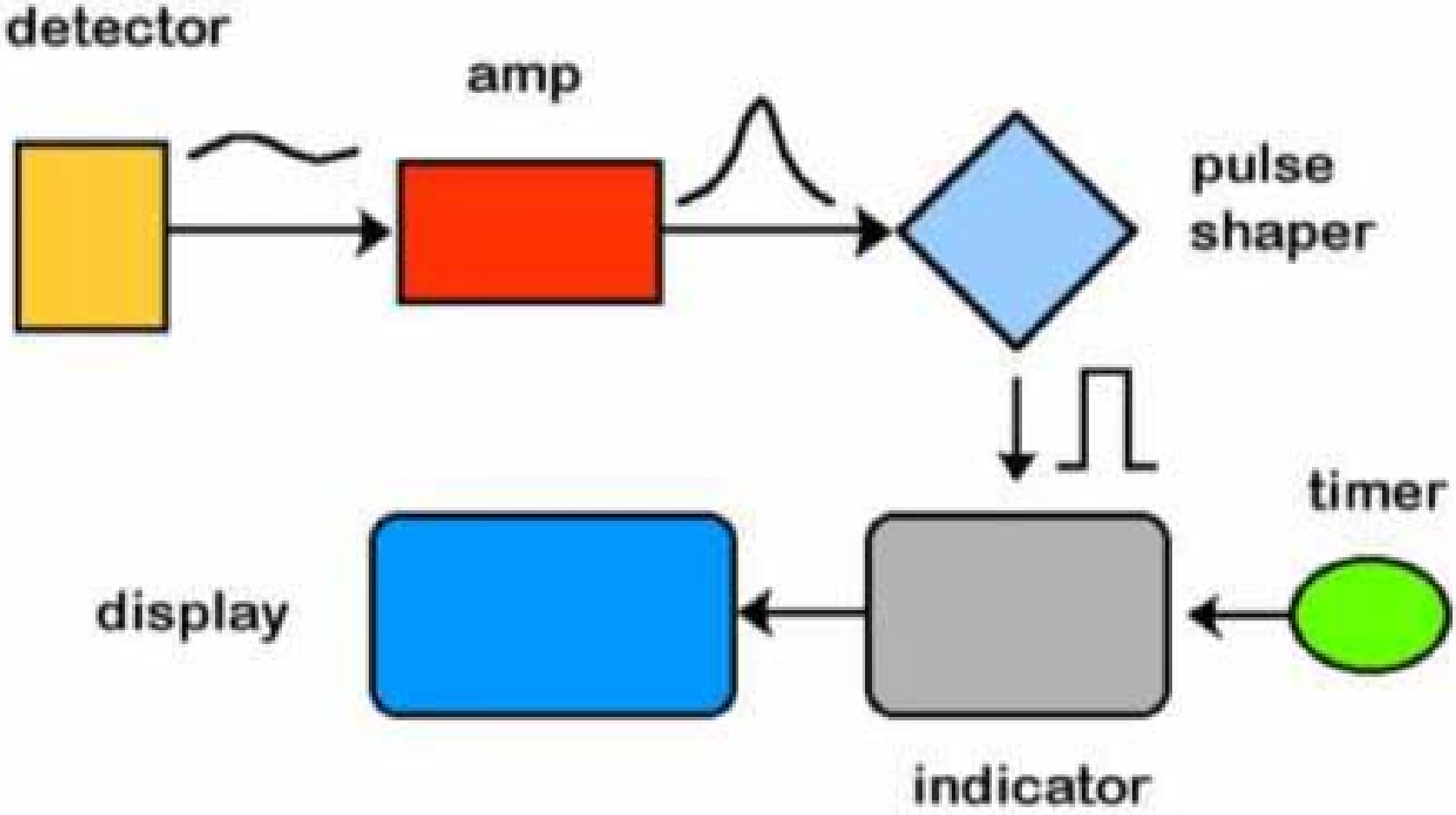
Pulse shaper

Receives the signal from the detector or amp and shapes it to the required form to excite the indicator block. It may also have a discriminator to reject noise.

Indicator

What counts and displays your results.

Scalers



Scalers

Advantages

Sensitivity	usually up to 500cps
Fast	Keeps up with all detectors
Low cost	$500-1000

Disadvantages

Not discriminating

If count rate is too high, you lose data.

Ratemeters

A modification of a scalar

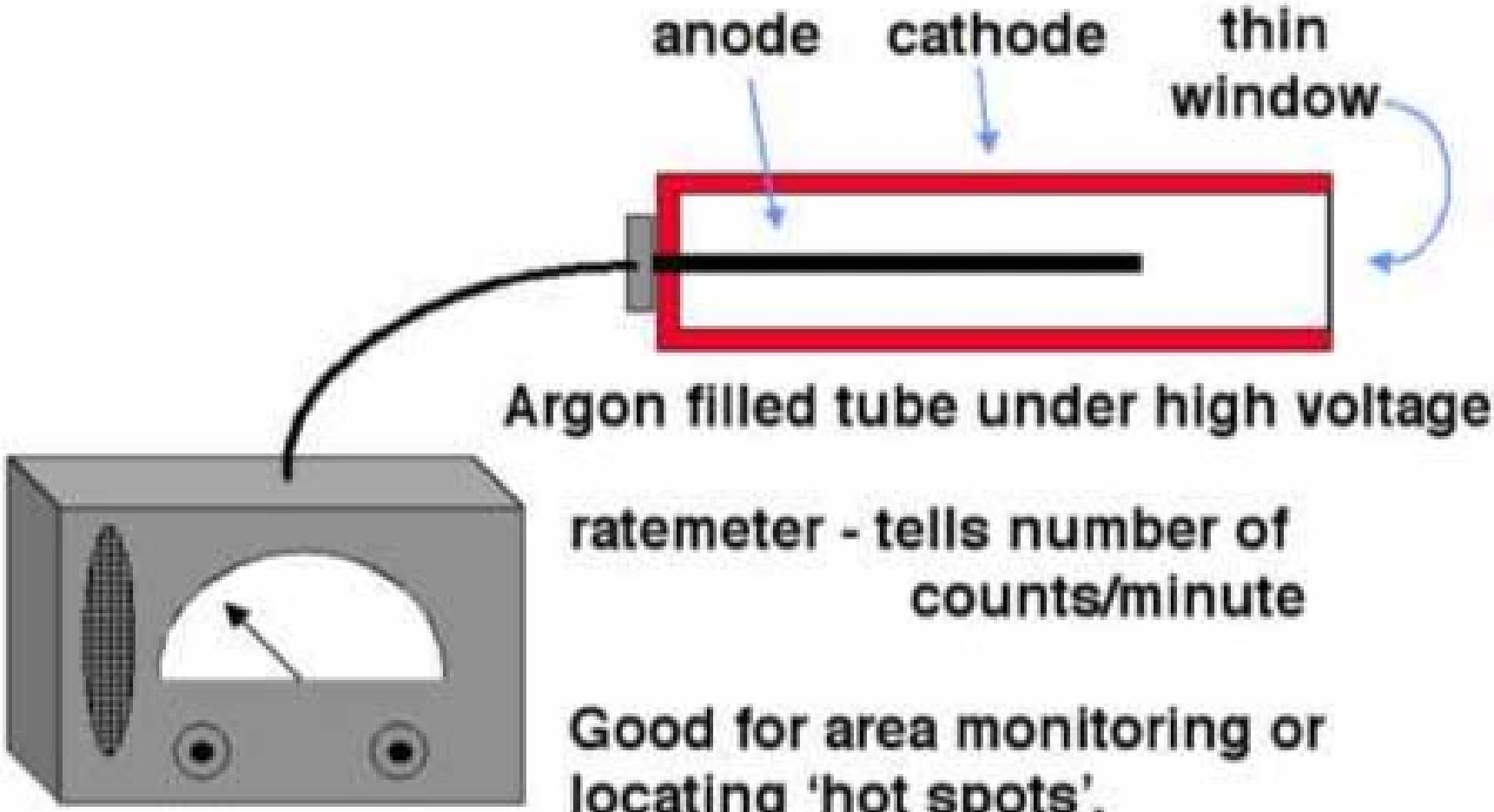
Measures and reports instantaneous average of the number of events occurring per unit time.

Most often used in dosimetry

Can drive either a meter or a recorder

Survey meter - a combination of a GM tube and a ratemeter.

Survey meter



Analyzers

If you are using a detector that is capable of discriminating between different energy values, its pretty stupid to use ascaler.

Analyzers

Counting equipment that is capable of evaluating pulses and assigning energy values.

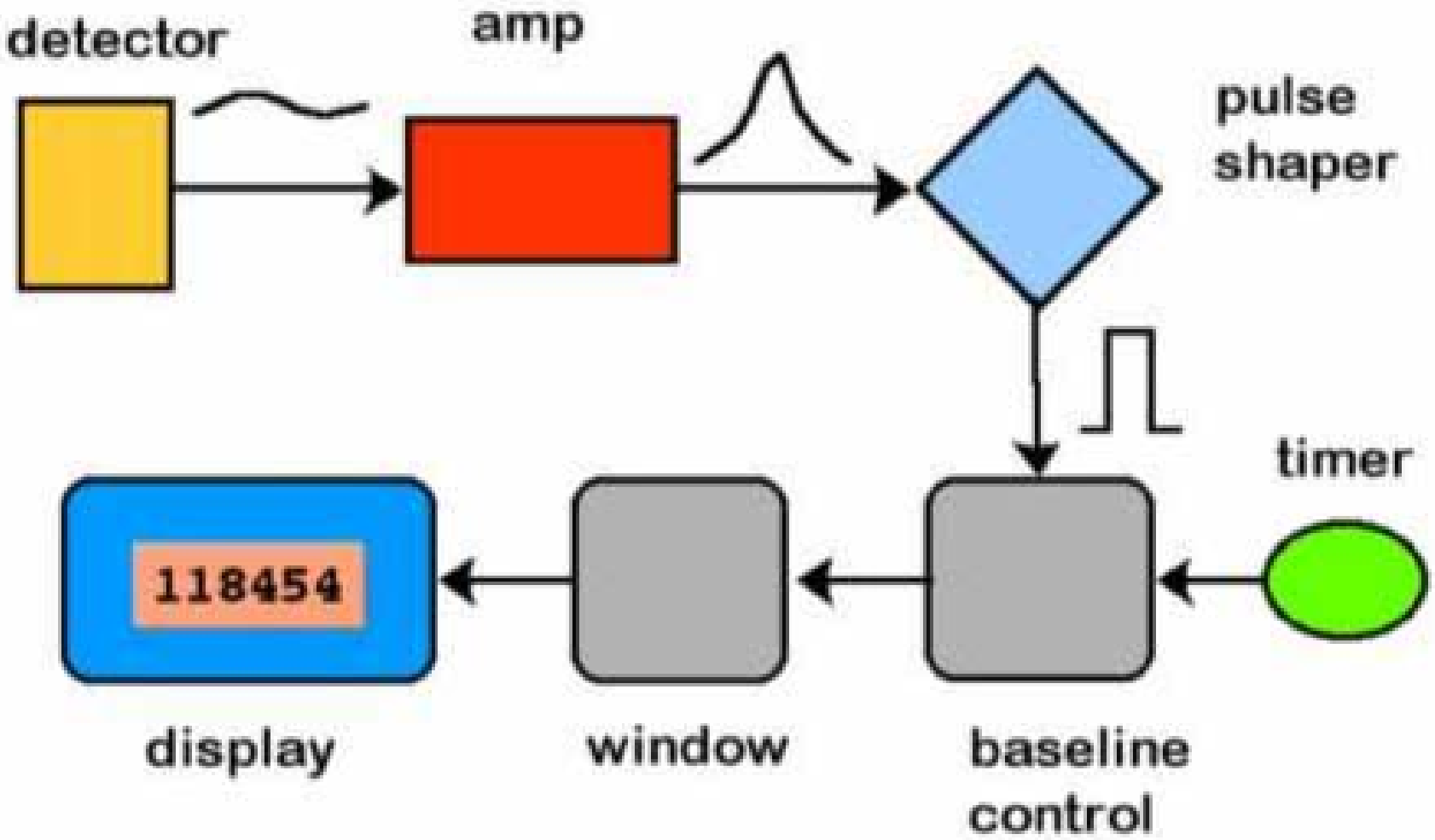
Single channel analyzers (SCA)

This device sorts pulses according to their amplitude so spectroscopy can be performed.

It works by only collecting counts of a specific height or energy range.

It represents another simple modification of a scaler where the discriminator is a bit more advanced.

SCA


detector
amp
pulse
shaper
timer
118454
display
window
baseline
control

SCA

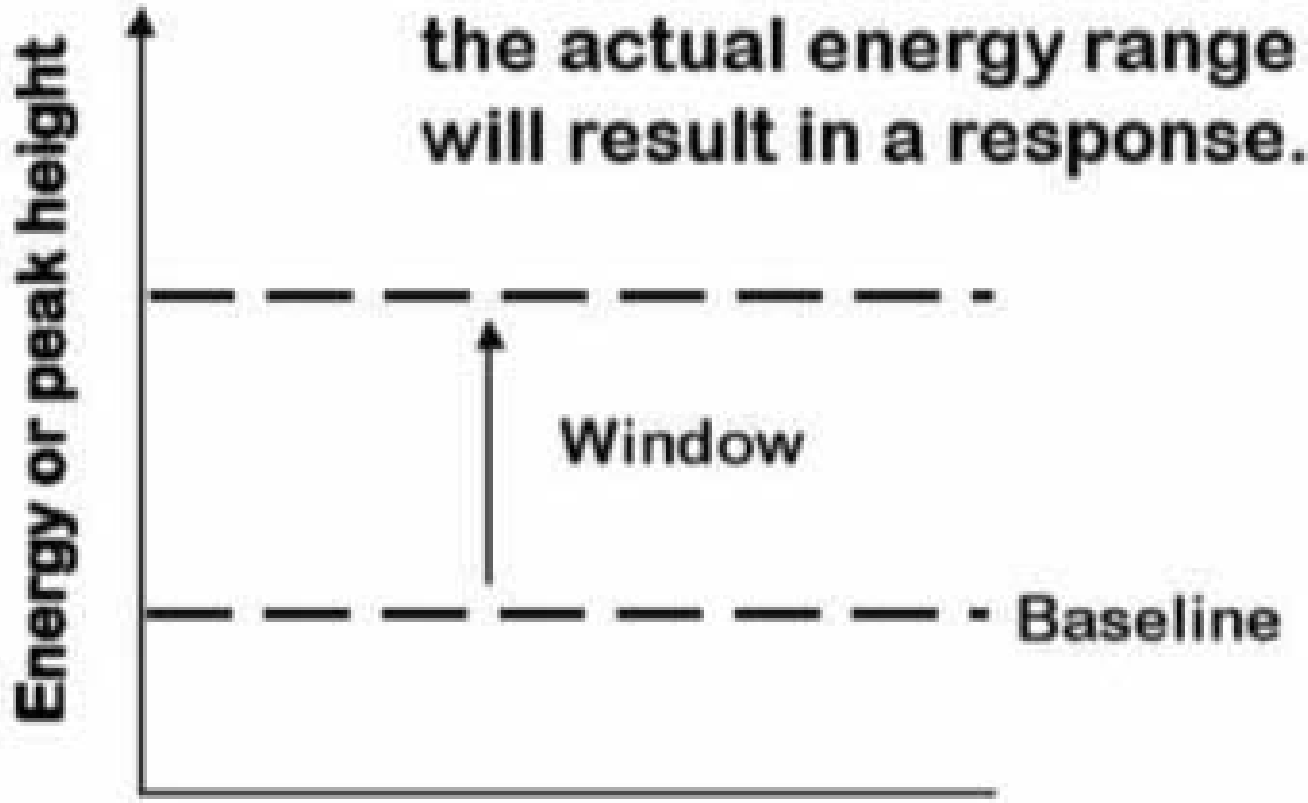
The input signal is fed through an initial discriminator after amplification and pulse shaping.

This first stage is the Baseline. It establishes the minimum energy level that will result in a count.

If a signal passes this first stage, a second discriminator (Window) is used to establish the maximum energy that will be cause a count.

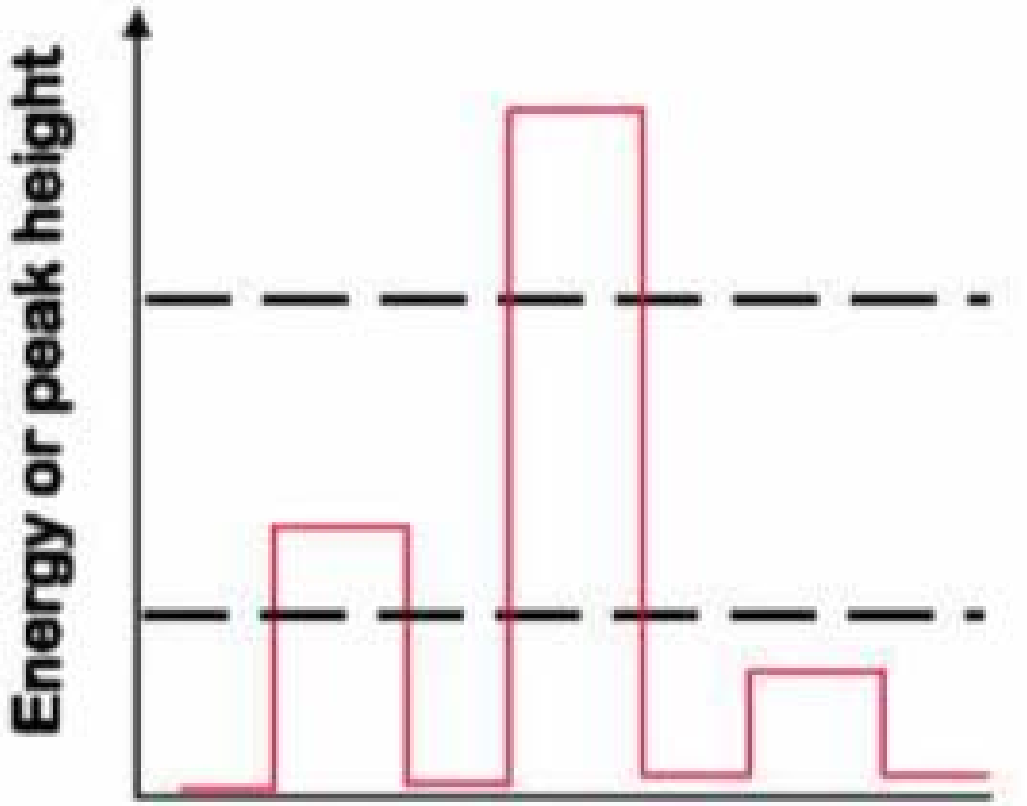
SCA

A combination of the Baseline and the Window value determine the actual energy range that will result in a response.



SCA

In this example only the first pulse would result in a count being recorded.



SCA

If the half life of your sample is long enough, you can collect spectra using a single channel analyzer.

Move the baseline at known intervals with a fixed window size. Count for a known time period.

This is how standard γ spectra were originally collected - explains why they are listed as 'connect the dot' spectra

SCA

By varying the Window size, you control resolution - must be $\geq$ detector resolution.

The Window can be turned off and the SCA operated in Integral mode. You are then using the equipment as ascaler with the ability to eliminate noise below a known energy level.

The Baseline can also be turned off by setting it to zero - you then have a simple scaler.

SCA calibration

You must initially calibrate the SCA using known radioisotopes.

For γ spectroscopy

Co-60	**2.5 MeV**
Cs-137	**0.667 MeV**

The Cs-137 also serves to determine the resolution of your system.

SCAs and detectors.

NaI(Tl) - resolution of 200 eV

A pretty good combination

Can do quant and qual analysis

Slow to do much spectroscopy.

Ge(Li) or Ge - resolution of 2 eV

A waste of money

Detector has much more resolution than a SCA can ever use.

Multichannel analyzers (MCA)

Probably the most important instrument for nuclear chemistry.

Capable of looking at a range of energies at once.

Allows construction of entire γ spectra at one time.

These were originally banks of SCAs with overlapping energy ranges.

MCA

With modern electronics and flash A/D conversion, MCA equipment has become pretty advanced - really just a PC with an A/D and appropriate software.

Typically have 1024, 2048, ... channels.

You may also have:

spectral memory, bkg correction, peak integration, libraries, programming.

MCA

Live time correction

Pulse height analysis and channel assignment takes time.

processing time = 15 + 0.25 nμs

where n = the channel number.

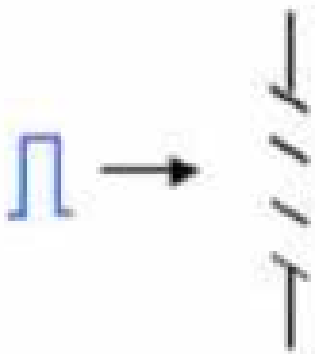
When the system is processing a pulse, any additional pulses will be lost

- dead time.

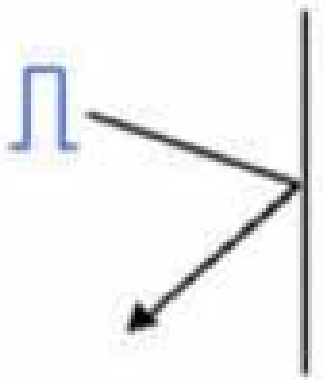
A MCA is capable of tracking how much time is lost as a result of data processing.

Live time correction

Pulse arrives from detector/amp



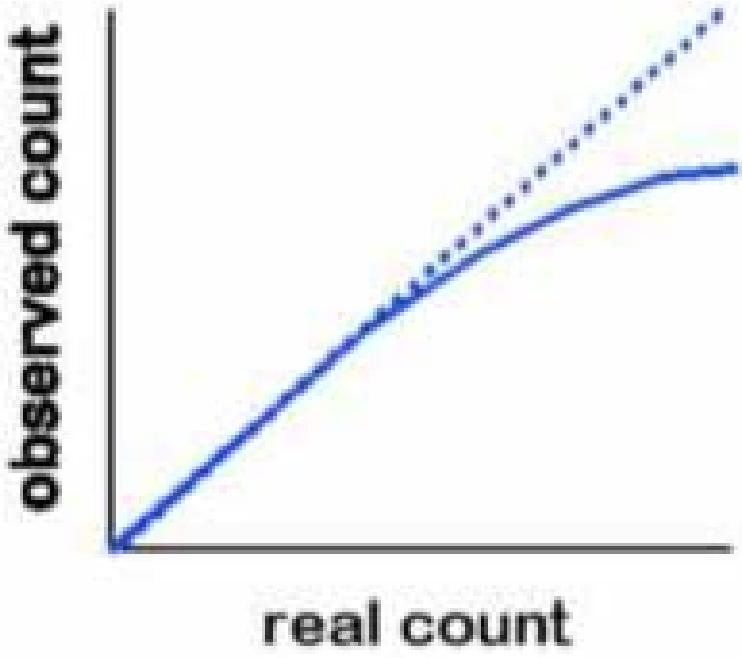
Pulse rejected while earlier peak is being processed



Live time correction is used to help account for any peaks that are lost as a result of time spent processing earlier pulses

Live time correction

With out some method of accounting for the time spent processing data, the linear range for counting is limited.



Live time correction

Live time - represents how long the system must count to represent what would have been sampled if no signal was lost.

Two approaches

Extend count time automatically

Valid if $t_{1/2}$ >> count time

Multiply observed values

Used when half-lives are short or when count times are very long.