KTH-STH

Detectors, nuclear electronics

[Theory and Lab-instructions]

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Ionising radiation, detectors and nuclear electronics

Introduction

The most common types of ionising radiation are the so called alpha, beta and gamma rays. This nomenclature is a reminiscence of the early days of nuclear physics and denotes the charged helium core, the charged electron (or positron) and the neutral electromagnetic radiation, respectively. All these types of radiation are present in our environment (in the so called background radiation). In this laboratory work some of the most common naturally occurring sources of radiation will be studied.

Ionising radiation lays outside the visible spectrum, therefore dedicated instruments (detectors) have to be used to detect its presence. With these instruments it is possible to determine the type of radiation, measure its energy and register other parameters.

There are many different types of ionising radiation detectors, all of them convert the energy deposited by the impinging ionising radiation to directly observable signals. These are sometimes detectable by the human eye (like X-ray photographic plates) or can be electric signals.

There are dedicated detectors for different type of radiation but they all rely on the same fundamental radiation-matter interaction processes. In this laboratory work some basic type of detectors for registering radiation are presented and the necessary signal handling technique is described.

There are different quantities that measure the effect of the interaction of ionising radiation with matter.

Absorbed dose is defined as the energy deposited by ionising radiation per unit mass

$$1 \text{ Gray} = 1 \text{ J/kg}.$$

The absorbed dose is a *clear cut* physical definition that lacks the capability of describing how harmful the delivered dose is. To modify the dose to reflect the relative *effectiveness* of radiation in producing biological damage, a radiation weighting factor w_R is used. The unit for **equivalent dose** is

$$1 \text{ Sievert} = w_R \bullet 1 \text{ Gray}$$

The value of w_R is 1 for electromagnetic radiation (X-ray or gamma radiation) and as much as 20 for α-particles. The weighting factors reflect the fact that α-particles have a higher Linear Energy Transfer (LET), that is transfer energy in a more concentrated region, than photons or electrons.

Sources of ionising radiation

Our world is radioactive and has been since it was created and all living species are exposed to naturally occurring ionising radiation. Over 60 radionuclides (radioactive elements) can be found in nature, and they can be placed in three general categories depending on their origin:

1. *Primordial* – originating from before the creation of the Earth (i.e. ^{40}K or uranium and thorium activities and their daughters, like ^{222}Rn, , …)
2. *Cosmogenic* - formed as a result of cosmic ray interactions with the atmosphere (i.e. ^{14}C, …)
3. *Human produced* - enhanced or formed due to human actions (minor amounts compared to natural) , (i.e.^{131}I, ^{137}Cs,, ^{99}Tc, ^{241}Am, …)

The largest dose contribution to the public comes from isotopes ^{222}Rn, ^{40}K and ^{14}C .

Radon-222 and its decay products are the most significant exposure from inhalation of radionuclides. ^{222}Rn is produced by the decay of ^{228}Ra which is present wherever uranium is found. Since radon is a gas, it seeps out of uranium-containing soils found across most of the world and may concentrate in well-sealed homes. It is often the single largest contributor to an individual's background radiation dose and is certainly the most variable from location to location. The uranium-238 chain, which contains the ^{228}Ra → ^{222}Rn alpha decay and its daughters are presented in figure 1.

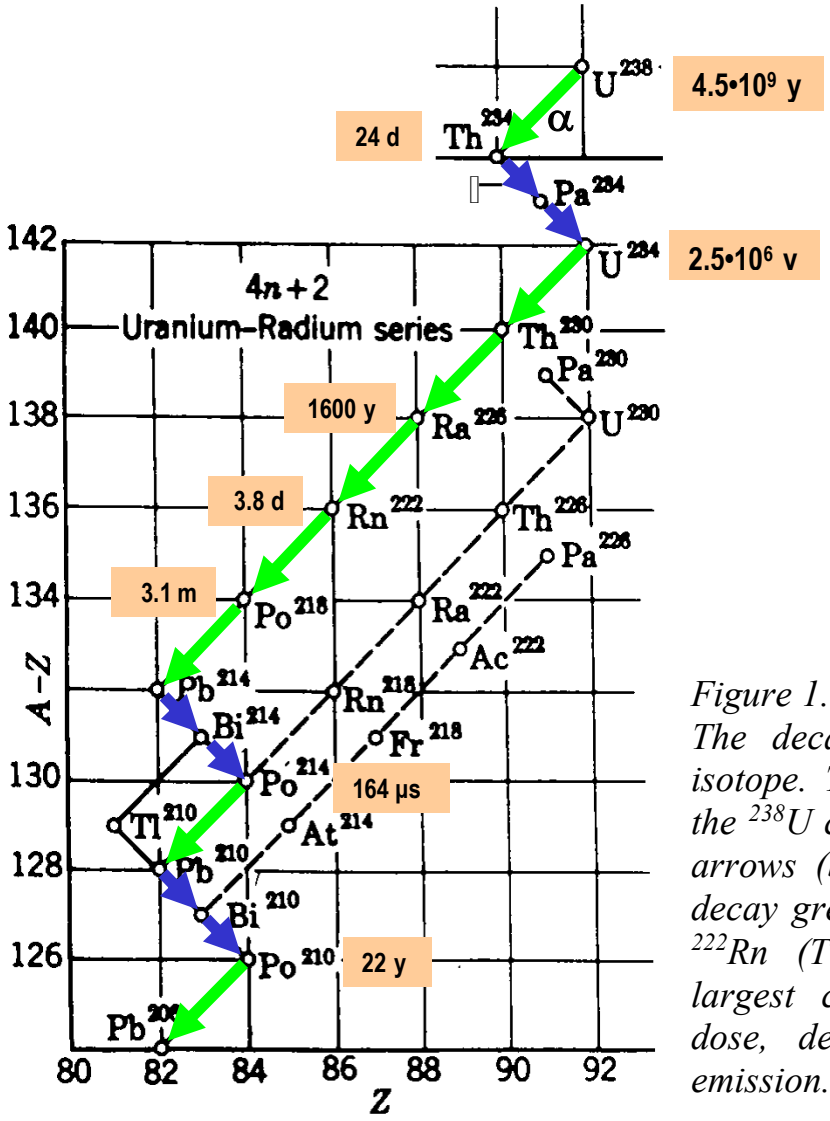


Figure 1.
The decay chain of a primordial isotope. The "main" decay route of the ^{238}U chain is shown with colored arrows (beta decay blue and alpha decay green). The noble gas isotope ^{222}Rn ($T_{½}$ = 3.8 d), which gives the largest contribution to the public dose, decays with alpha particle emission.

The second largest source of natural background radiation comes from ingestion of food and water containing primordial radionuclides (and their decay products), of which ^{40}K is the most significant. Potassium-40 is a naturally occurring isotope of potassium (abundance ~0.01 %). The measurement of the half-life of the radioactive ^{40}K is one of the tasks of this laboratory work.

Dose

To the dose from sources accumulated during a human's life time one has to add dose contribution originating from medical examinations and treatments. This is because a large number of diagnostic or therapy techniques are based on ionizing radiation (i.e. X-ray). In Figure 2 the contribution from different sources of the average annual dose for persons living in Sweden is displayed.

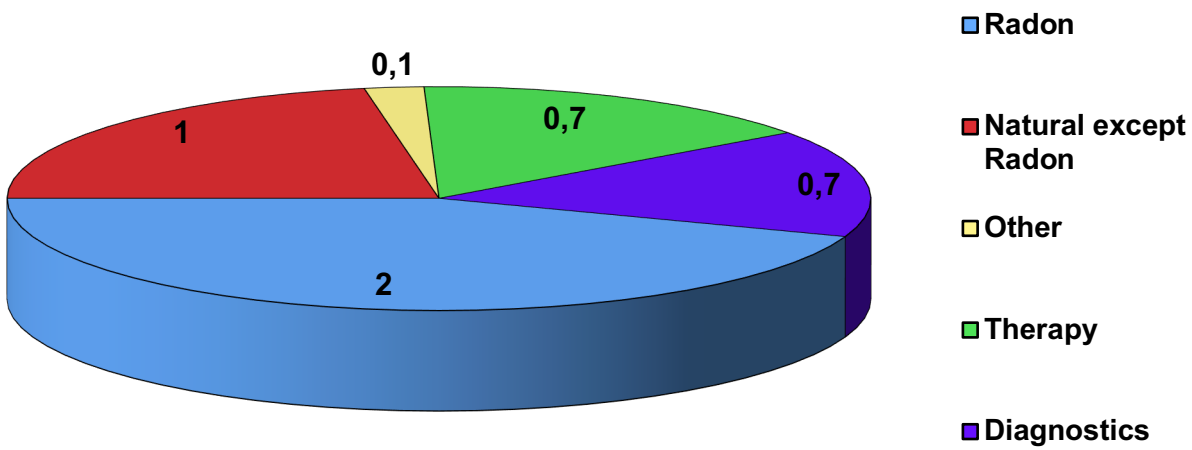


Figure 2. Average human dose in Sweden, mSv/year

Detecting charged particles

To detect radiation one utilizes the interaction process with matter where the interacting medium converts the invisible radiation to detectable signals. If the radiation consists of charged heavy particles such as alphas, or light ones, like electrons or positrons, the electromagnetic interaction create charges which can be collected and detected. It can also initiate further processes, which can give rise to recordable signals in the detector.

Detecting gamma radiation and other neutrals

The neutral gamma radiation interacts with matter via electromagnetic processes and transfer part or all its energy to electrons. The dominating interaction processes for gammas in matter at the energies relevant to medical imaging are Compton scattering and Photoelectic Effect. For photon energies above 1,022 MeV electron-positron pair creation is also possible. Gamma radiation transfers its energy to the charged particles (electrons) present in matter and give rise to recordable signals (charge, current, potential difference …). Similar two-step processes are exploited to register all neutral particles, like neutrons, muons etc.

Detectors

In both transmission and emission medical imaging one uses photons (x-ray and gammas, respectively). The corresponding detector should therefore be able

to 1. produce charged particles from the impinging photons and 2. register the charged secondary products (electrons).

In the following section some of the most common detector types are described. The common requirement for all detectors is good spatial and energy resolution. A formal definition of spatial and energy resolution is not given here, for the moment it is sufficient to understand that spatial resolution is related to the precision with which a the detector assigns a position to an impinging photon, while energy resolution is related to the precision with which the energy of the photon is measured by the detector.

In addition to position and energy some applications (e.g. PET) require precise timing information.

Basic interaction processes of the electromagnetic radiation (like X- and gamma rays) are: *Photoeffect*
Compton scattering
Pair production *(above the energy threshold 1022 keV, the mass of the electron-positron pair)*

In all three processes the secondary charged products are electrons (and positrons). These electrons can induce chemical reactions, such as the blackening of photosensitive film, can create vacancies in atoms (by further ionization) resulting in light emission in scintillators or creating charges (electrons and holes) in semiconductors. The latter two types of detectors are also able to give the often-necessary information about the exact time of the interaction.

The sensitivity of a system for detecting ionizing radiation depends on several parameters. One is the intrinsic detector efficiency determined by the absorption coefficient of the detector material. The linear absorption coefficient, μ, is proportional to the probability of interaction per unit length. It varies with the atomic number and density of the detector and depends on the energy of the photon to be detected.

If radiation of energy (E_0) and of intensity I_0 (that is number of photons per unit area) impinges on a detector of thickness x and with a linear absorption coefficient μ, the intensity I of the radiation with the very same energy coming out of the detector can be calculated according to Beer's law:

$$I(x) = I_0 e^{-\mu x}$$

The photons interacting in the detector (proportional to I_0-I) will deposit their energy in the detector. This will in turn result in a measurable (analog) pulse with amplitude proportional to absorbed photon energy.

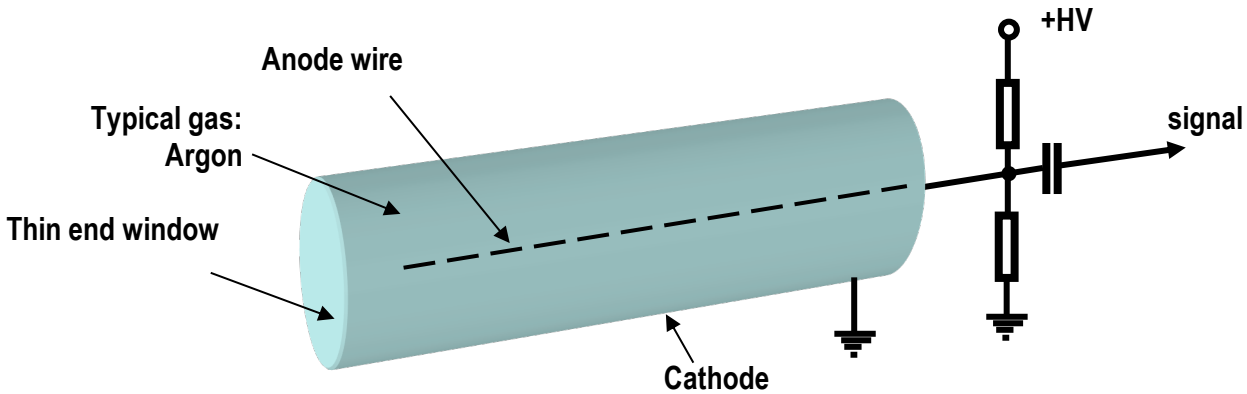
In addition, the size and the geometrical form of the detector and the distance to the source of radiation are important parameters of the total detector efficiency.
In brief one can say that:
The *efficiency* of a detector system depends
on the energy of the photons to be detected (1),
on the size and shape of the part sensitive to radiation (2) and
on the detector distance to the radioactive source (the solid angle) (3)

In the following gaseous, scintillator and solid state detectors will be quickly described.

Gaseous type of ionization detectors

The most widely used type of detectors is based on the effects produced when a charged particle passes through a gas. A charged particle, the electron originally produced in one of the processes mentioned above, will along its track ionize the gas molecules. The energy needed to create an electron ion pair in gases is in the order of 30 eV and depends on the type of the molecule. If an electric field is applied the created charge will be collected on the electrodes resulting in an electric pulse that contains the total collected charge and thus the absorbed energy of the electron.

Depending on the voltage applied across a gas-filled chamber, the free electrons created might give rise to secondary ionization. The counter will work as an electron multiplier resulting in much larger output signals.
One of the advantages of the gas filled counters is the relatively simple and cheap construction. It permits also to manufacture large area detectors with multiple wires having position sensitive readout.



Electric field in the tube:
$E(r) = V_0 / r * \ln (r_2/r_1)$
r_1 wire radius; r_2 inner tube radius

Figure 3. Gas filled ionisation detector

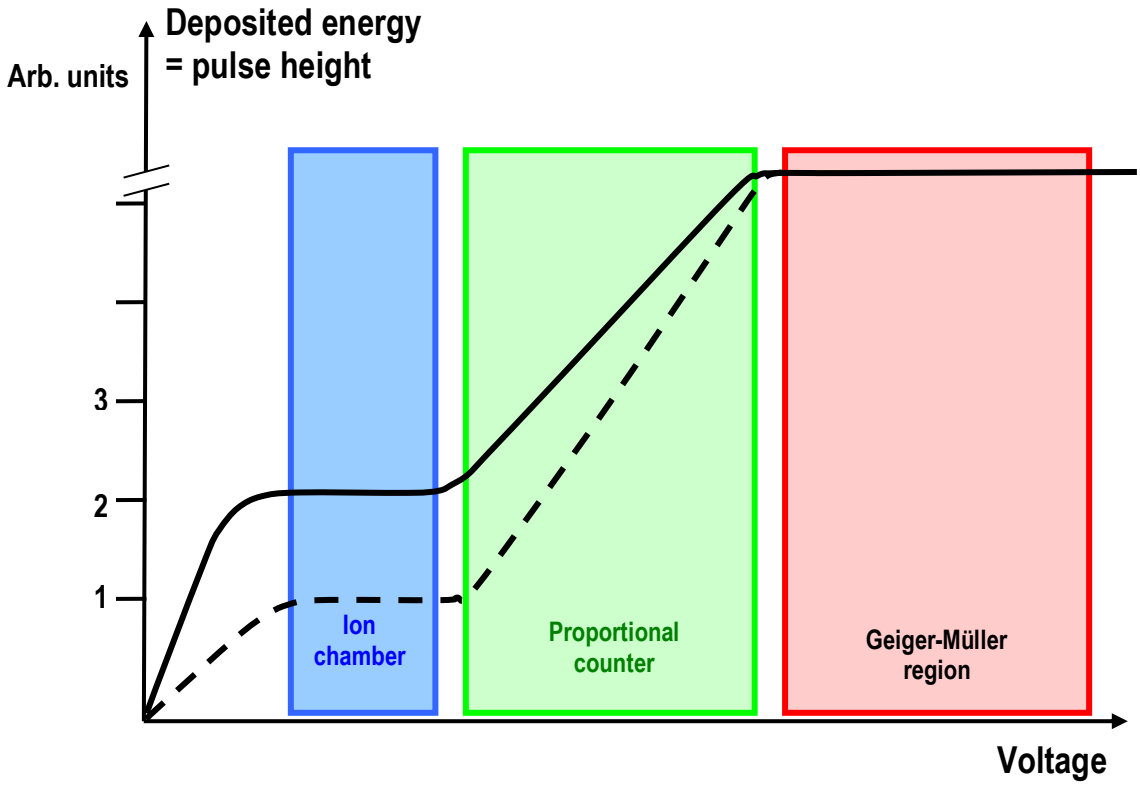


Figure 4. The pulse height produced by different gas-filled counters as a function of the applied voltage, for two different radiations differing in energy by a factor of 2. In the Geiger-Müller region, all radiations give the same output pulse-height. In the other regions, the output pulse height is proportional to the energy deposited by the radiation through primary ionization.

At substantially higher electric fields electron avalanches are created as a result of the original ionization. Under proper conditions one avalanche can trigger another one at a different position in the tube, now working as a Geiger Müller counter. A typical pulse from the Geiger Müller tube represents an unusually large number of ions, (up to 10^{10} charges), giving rise to output pulses of identical amplitude and in the order of some volts. The electronic circuits for pulse treatment and counting are therefore greatly simplified. The GM tube is mostly used as a radiation survey monitor.

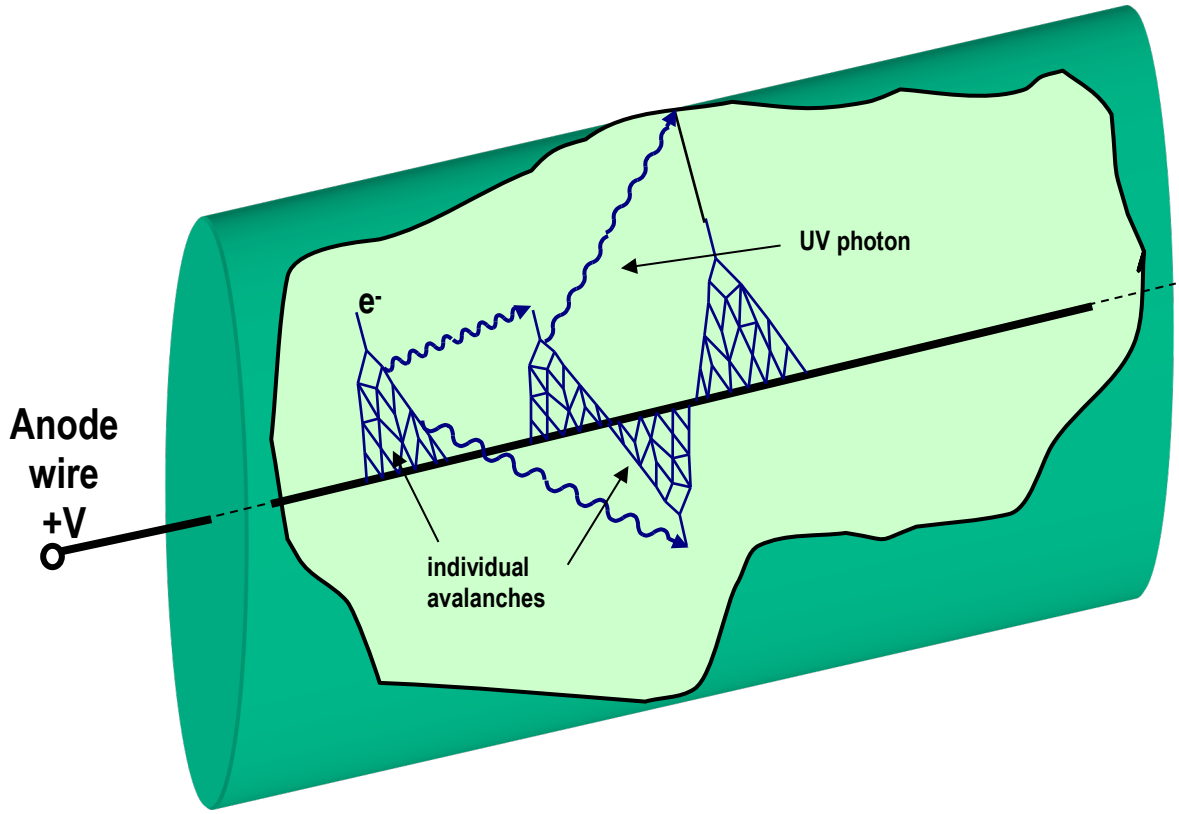


Figure 5. The mechanism by which additional avalanches are triggered in a Geiger-Müller discharge.

Scintillators

A scintillator is a transparent material that converts the energy lost by ionization into pulses of visible light. Scintillators are commonly used when the energy of the ionizing radiation needs to be recorded. The basic mechanism is the following: gamma radiation interacts with the crystal via Photoelectric-Effect, Compton scattering or pair production, creating high energetic charged particles that will in turn excite many atoms around the point of interaction. In this way the kinetic energy of the charged particles is converted into light in the visible wavelength region when the atoms of the scintillator de-excite. The conversion of the gammas to visible photons is linear over a wide energy range. The scintillating medium should also be transparent with a refractive index not too far from the construction material of the light-detecting device (glass or plastic).

There are a large number of scintillator materials, with a variety of properties. Depending on the application one chooses the most suitable material. For

detecting electromagnetic radiation, both organic and inorganic scintillating crystals are used. To obtain a high conversion ratio of the ionizing radiation to light, the scintillating material should have high density (large Z). This is the case for the most commonly used inorganic crystals such as NaI and CsI. Even higher density is found in bismuthgermanat, BGO. Another important property of BGO is its speed to convert the ionizing radiation to light. A drawback of BGO is its high cost. One of the fastest scintillator materials is BaF_2, and because of that BaF_2 is used in Time-of-Flight, TOF-PET, where the time difference of the two positron-electron annihilation quanta is measured.
Properties of some of the inorganic scintillators commonly used are listed below.

Scint.	**Density (g/cm^3)**	**Wavelength λ_{max} (nm)**	**Decay time (ns)**	**Light yield (quanta/MeV)**
NaI(Tl)	3.67	415	230	38000
CsI(Tl)	4.51	540	1000	52000
BGO	7.15	505	300	8200
BaF_2(slow)	4.89	310	620	10000
BaF_2(fast)		220	0.6	1800

The light emitted in the scintillator is converted to detectable electronic signals by a photo-multiplier, a PM tube, or by a photo-diode. In figure 6 the wavelength of the emission spectra of different scintillators and the spectral sensitivity for photocathodes are shown. The conversion is linear and the amplitude of the output signal will therefore be proportional to the energy of the absorbed radiation. In the photo-cathode of the PM tube, the incoming light will stimulate electron emission. The electrons are accelerated by a potential to an electrode, called a dynode, with a properly selected surface to give a multiplying effect, see figure 7. Tubes with 10 – 14 dynodes are available and the number of electrons is multiplied by the dynode chain (see fig. 7).

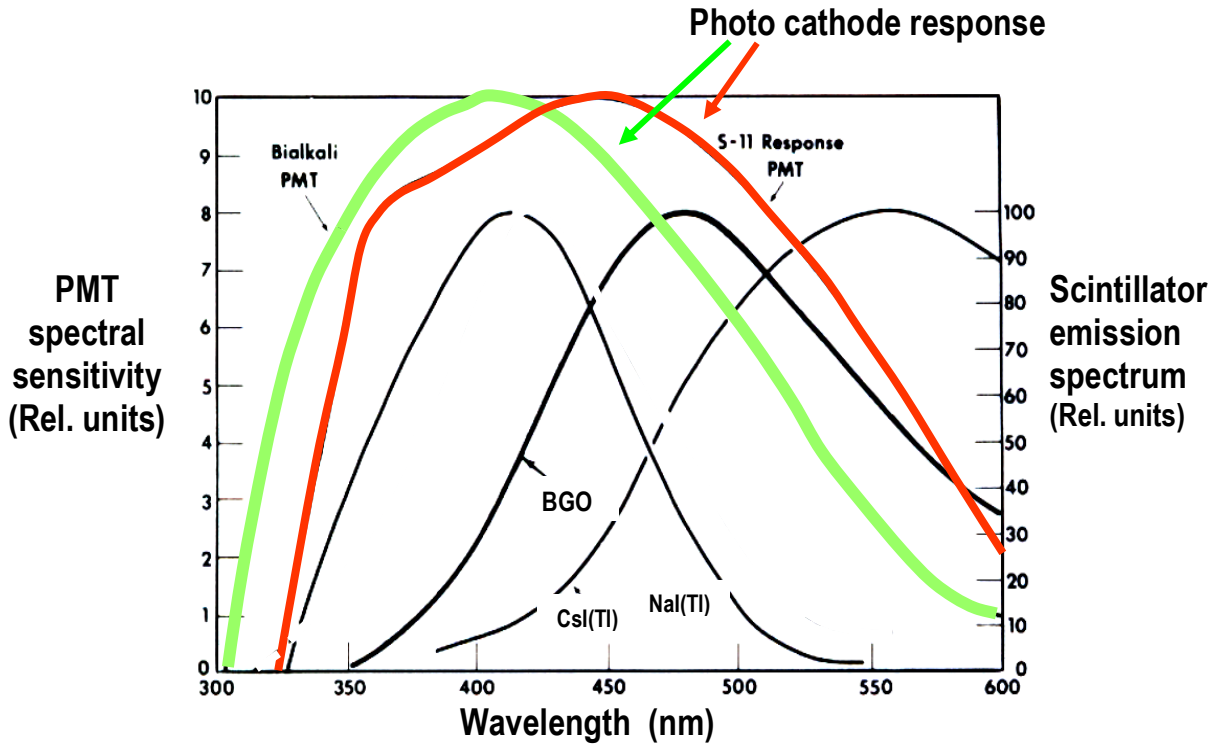


Figure 6. Emission spectra of scintillators and the response curves for two widely used photocathodes.

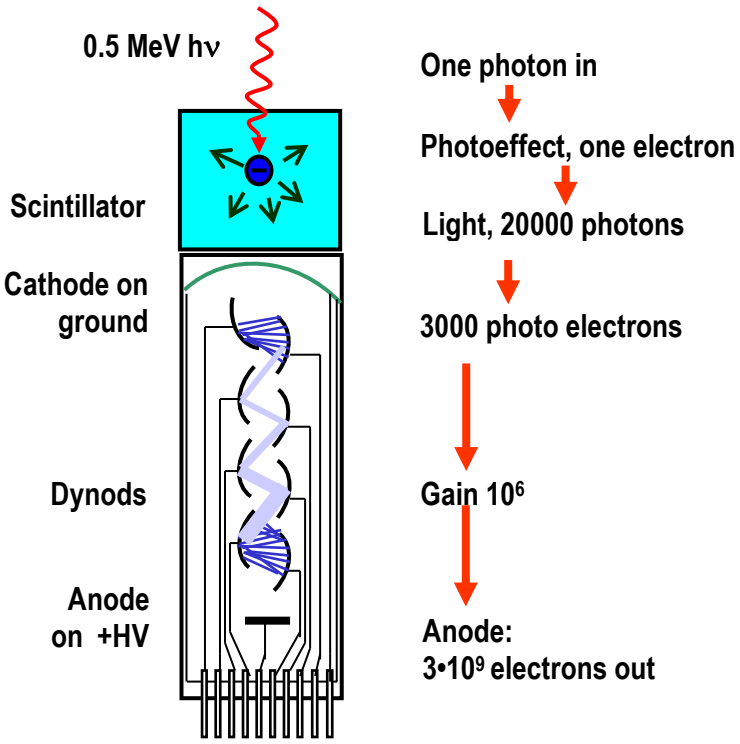


Figure 7.
Example of a scintillator and photomultiplier operation.
A 500 keV photon interacts with the scintillator crystal with photo effect. The scintillation light is absorbed in the photocathode of the PM-tube. Electrons released from the cathode are attracted to the first dynode and multiplied. Each successive dynode is at higher potential than the previous one, a typical tube might have 10 or 14 dynodes. At each stage, the number of electrons is increased by a factor of approx. 3.

An alternative to a PM tube is a semiconductor photo-diode. These devices offer the advantages of higher quantum efficiency (which can potentially result in better

energy resolution), lower power consumption, compact size and ruggedness. However, since the diode has little internal gain, an external amplifier has to be used.
The wavelength of the emitted light from the scintillator and the sensitive region of the photo-detecting devise, PM tube or photodiode, is selected to be as close as possible, c.f. figures 6 and 8.

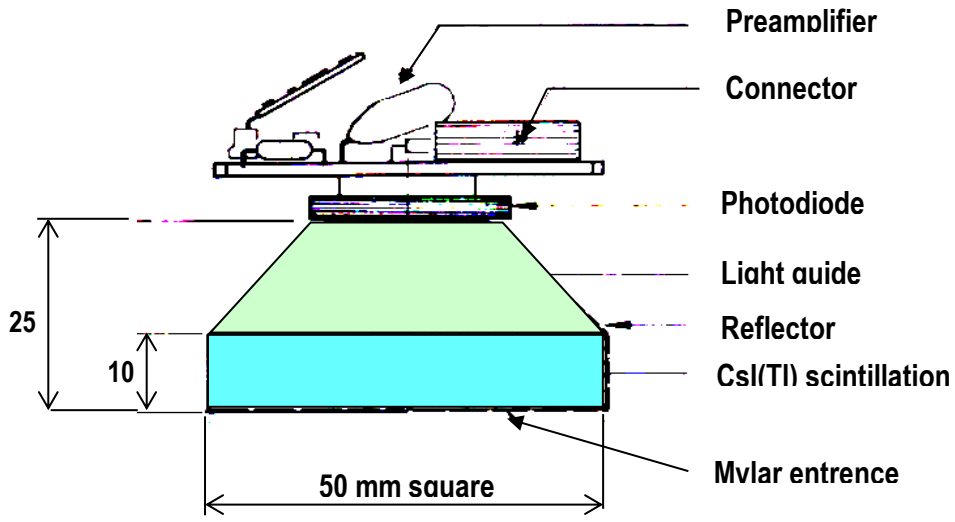


Figure 8. An example of a CsI scintillator with photodiode light readout

CsI(Tl) has the advantage that it is non-hygroscopic, does not cleave and in addition the color of the emitted light suits the spectral response of silicon photodiodes. These detectors are compact and do not require any high voltage, are rugged and can be operated in high magnetic fields. These detectors are frequently used in arrays or matrices.

The energy dependence of the NaI(Tl) scintillator detector follows the linear attenuation behavior of the NaI(Tl) crystal (see figure 9). The size and shape of the detector is important to optimize the detector efficiency; an increasing size of the crystal favors interaction of secondary photons originating from Compton scattering. As a result the photo peak to Compton scatter distribution will increase. Finally, to maximize the solid angle a well type of detector can be used, figure 10.

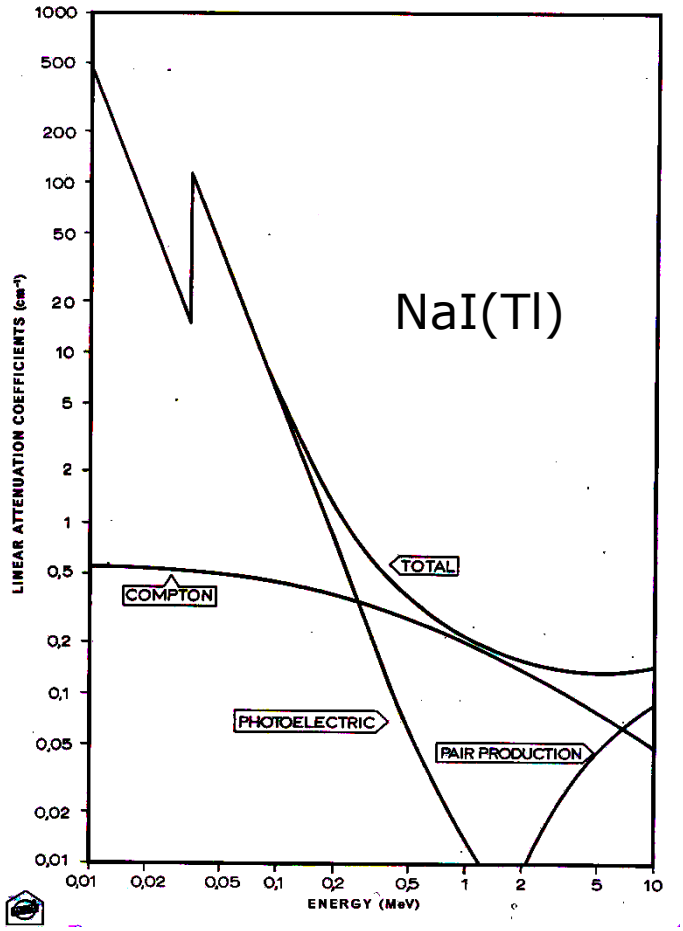
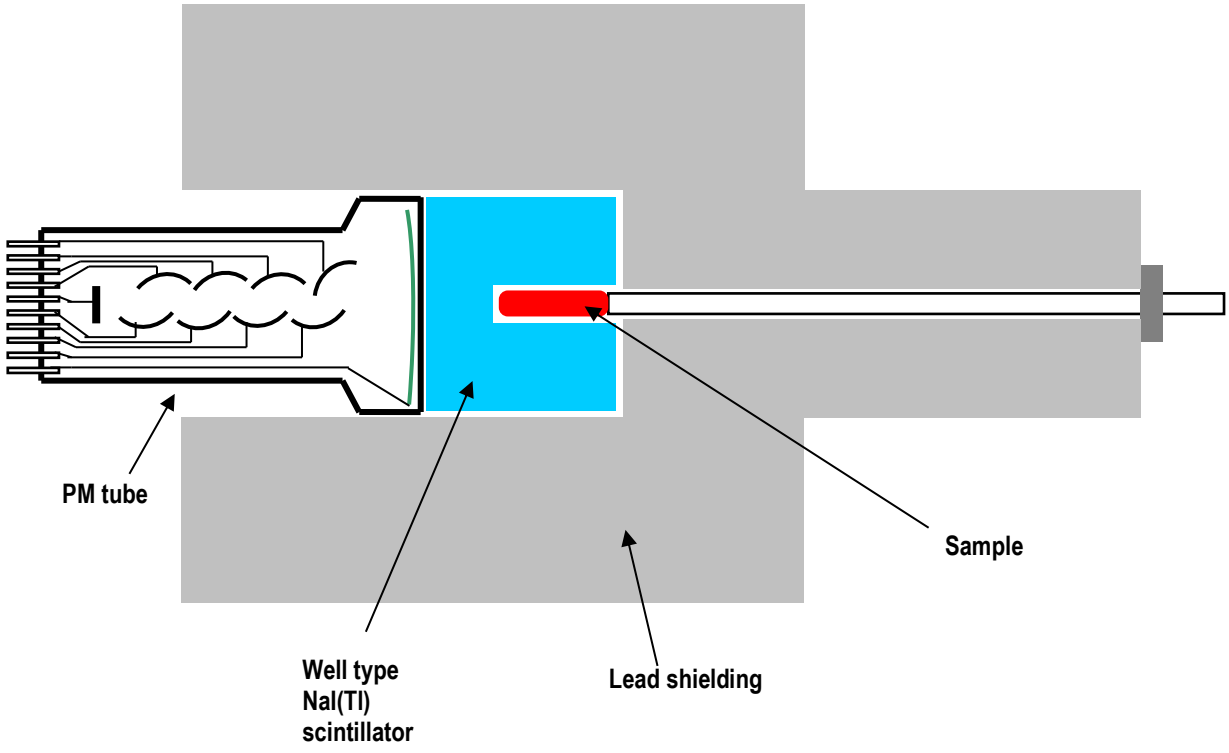


Figure 9.
Linear attenuation coefficients in NaI(Tl) for the different interaction mechanisms as a function of the gamma ray energy.

Figure 10.
In applications where the source is contained within a small volume and where counting efficiency is more important than energy resolution a well type of crystal is used. An almost 100% solid angle can be achieved by placing the source inside the NaI(Tl) crystal. The total detection efficiency however is determined on the energy of the photon to be detected.



Semiconductor detectors

The functionality of semiconductor or solid-state detectors is analogous to gas ionization devices. However, the density of the ionizing medium, the semiconductor material, is some 1000 greater than that for a gas. In addition, the energy needed to create an electron–hole pair is ten times lower; it is 3.7 eV for Si and 2.9 eV for Ge. Since the basic information carriers are the electron-hole pairs created along the path of the ionizing particle, the charge per unit length will be substantially higher than in the gaseous detector chamber.

Due to its ruggedness and compactness, silicon detectors are implemented in many modern medical imaging systems where large arrays or matrices of detector elements are needed, like CT- tomographs and other poisition sensing devices.

Nuclear electronics and counting systems

(This section presents an overview of the most frequently used building-blocks of nuclear electronics their function and operation)

Most detectors can be represented as a capacitor into which a charge is deposited. By applying HV on the anode of the PM tube, or detector bias on a solid state detector, an electric field is created which causes the charges to migrate and be collected. During the charge collection a small current flow and the voltage drop across a resistor is the pulse voltage. The amplitude of this pulse is proportional to the absorbed energy of the radiation and its measurement is the goal of the analysis.

The amplitude of the pulse is proportional to the deposited energy and corresponds to the energy of the photon for photo-effect interaction. If the interaction results in Compton scattering only a fraction of the original photon energy is absorbed. The fraction is depending on the scattering angles. The result is a broad spectrum of pulses corresponding to the total amount of energy gained from the original photon which varies from zero to the Compton edge – the maximum energy transferred to an electron emitted in the forward direction. Figure 11 show a schematic oscilloscope picture of detector pulses from a mono energetic gamma source and the corresponding of a gamma spectrum.

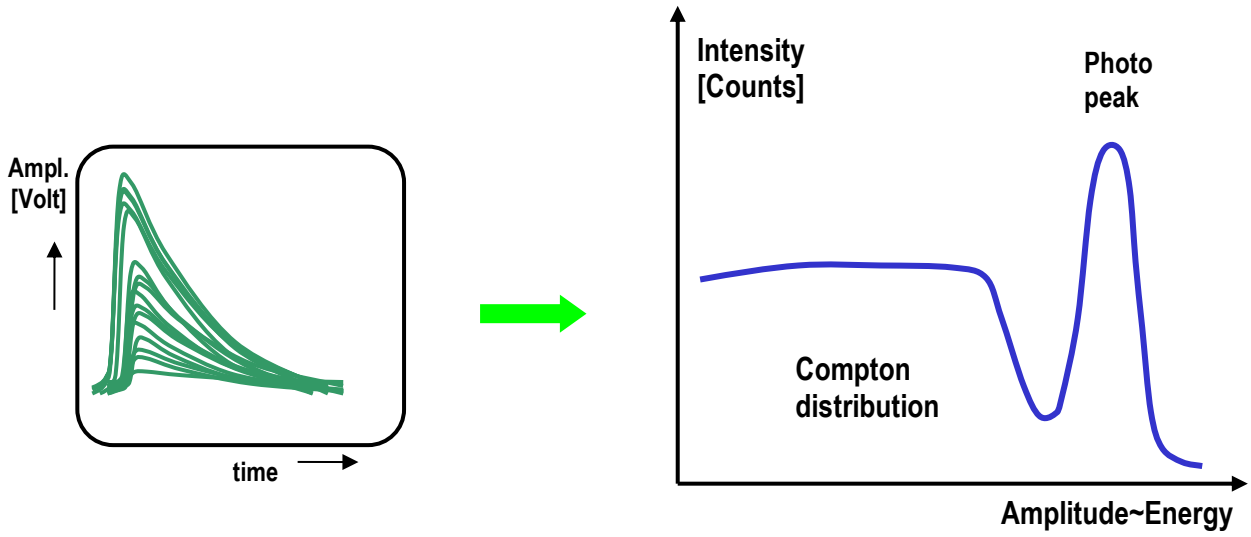


Figure 11. Detector output pulses from a monoenergetic gamma source viewed with an oscilloscope (left) and the corresponding energy spectrum (right).

Preamplifiers and amplifiers.

The preamplifier is isolated from the high voltage by a capacitor. The rise time of the preamplifier's output pulse is determined by the collection time of the charge in the detector while the decay time is the characteristic RC time constant of the preamplifier itself. Charge sensitive preamplifiers are used for solid state detectors with output voltage signal that is proportional to the input charge.

To maximize the performance, the preamplifier should be located at the detector to reduce capacitance of the leads, which can degrade the rise time and lower the signal size. Additionally, the preamplifier also serves to provide a match between the high impedance of the detector and the low impedance of the coaxial cables to the amplifier, which may be located at great distances from the preamplifier.

The amplifier serves to shape the pulse as well as further amplify it. The long delay time of the preamplifier pulse, (~50 μs), may not be returned to zero voltage before another pulse occurs, so it is important to shorten it by differentiation and only preserve the detector information in the pulse rise time. In amplifiers an active circuitry is used to form a short uni-polar near-Gaussian shaped output pulse with optimum signal-to-noise characteristics, figure 12.

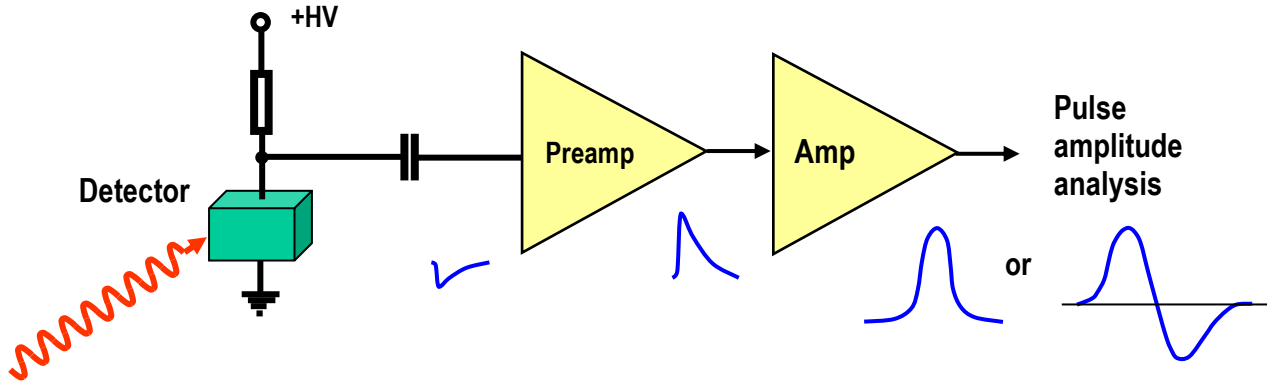


Figure 12. Detector and typical preamplifier and amplifier pulses. A *second differentiation in the main amplifier can produce a bipolar pulse. The bipolar pulse has the advantage over unipolar in that the zero crossing point is nearly independent of time for a wide range of amplitudes. This is very useful in timing applications.*

Pulse height analysis

Pulse height analysis may consist of a simple discriminator that can be set above noise level and which produces a standard logic pulse for counting in a pulse counter. However, most data consists of a range of pulse heights of which only a small portion is of interest. A most simple but time consuming method is to use a Single Channel Analyzer and a Counter.

A Single Channel Analyzer, SCA, has a lower and an upper level discriminator, and produces an output logic pulse whenever an input pulse falls between the discriminator levels, figure 13. With this device, all voltage pulses in a specific range can be selected and counted. If a full voltage (i.e. energy) spectrum is desired, the SCA discriminators can be set to narrow range, window, and then stepped through a range of voltages. If the counts are recorded and plotted for each step, an energy spectrum will result. The method requires some time meaning that the decay of short lived radioactive (life times close to the measuring time) sources can not be studied by this method.

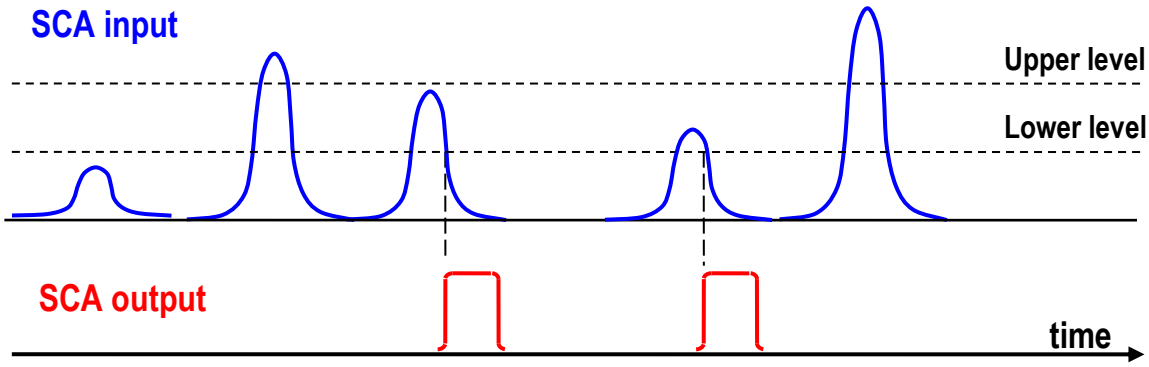


Figure 13. Basic operation of a single channel analyzer, SCA: only those signals whose amplitudes fall within the window defined by the upper and lower level threshold trigger the signal.

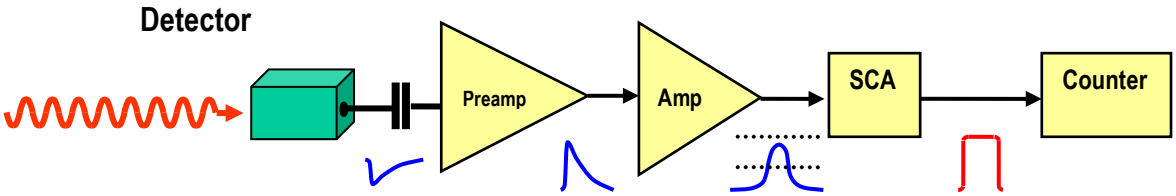


Figure 14. Schematic diagram of pulse electronic units for counting photons in the energy (=amplitude) range defined by the SCA.

Flash ADC.

In principle several parallel-coupled SCA's can be linked together so that the acceptance window for a channel starts at a voltage level where the previous window ends, figure 15. The output of each channel is stored in an individual counter. This type of converter is fast, (Flash ADC), but the total number of channels is limited of practical reasons.

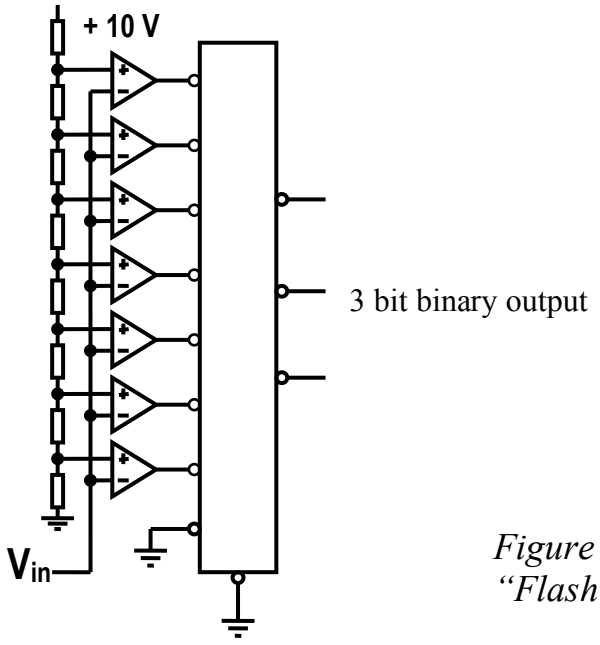


Figure 15. Parallel encoded "Flash" A/D converter (ADC).

Wilkinson ADC

The oldest and still the most common type of ADC are of the Wilkinson type. The input signal used to charge a capacitor. The capacitor is then discharged with *constant current* resulting in a linearly decreasing output voltage, a run-down. At the start of the discharge a scaler counting the pulses from an oscillator is started. When the capacitor has completely discharged, the scaler is stopped. Thus the input pulse amplitude via the discharge time is converted to a number, see fig. 16.

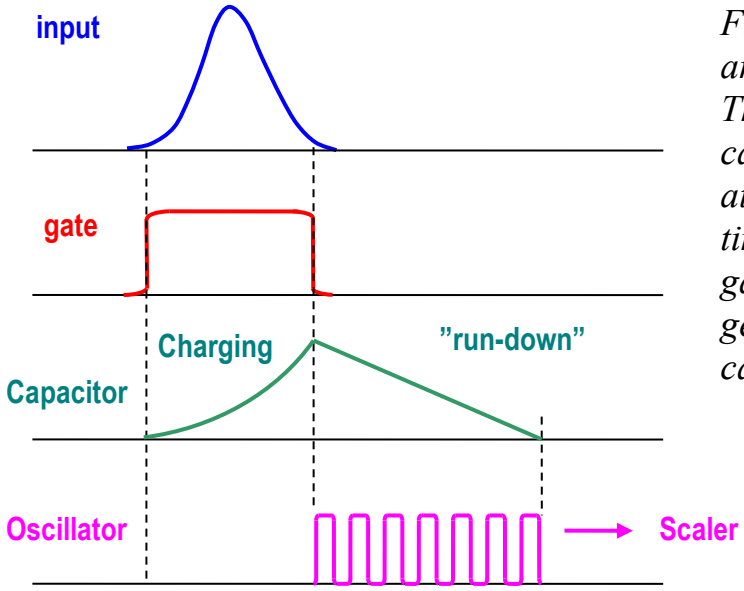


Figure 16. Wilkinson's method of analog-to-digital conversion. The input is used to charge a capacitor which is then "run down" at a constant current. At the same time, a fixed frequency oscillator is gated on and the number of pulses generated during the time it takes the capacitor to discharge counted.

Multi Channel Analyzer, MCA

The multichannel pulse height analyzer or Multi Channel Analyzer, MCA, which can be considered as a series of SCAs with incrementing narrow windows, basically consists of an Analog to Digital Converter, ADC, control logic, memory and display. The MCA collects pulses in all voltage ranges at once and displays this information in real time, providing a major improvement over SCA spectrum analysis.

Today's MCA often uses a PC for data storage and presentation. The ADC and other control circuits are located on an extension card or connected to the PC via a USB input. The total number of ADC- and memory channels is often large to match the resolution of solid state detectors (up to 16 K). The heart of a MCA is its ADC and apart the above mentioned Wilkinson type another type of ADC based on the successive approximation method resulting in a constant conversion time is used. Here, the incoming pulse is compared to a series of reference voltages to determine the height of the pulse.

The basic function of a MCA involves only the ADC and a memory. Once the pulse has been processed by the ADC, the analyzer control circuits seek out the memory location and corresponding to the digitalized amplitude stored in the address register, and the content of that location is incremented by one count, ("add-one"). Because the ADC can be relatively slow, high counting rates will result in situations in which the input gate is closed and a fraction of counts are lost. To measure this dead time MCA's are equipped with an internal clock whose output pulses are routed through the same input gate and stored in a special memory location. Since, the fraction of clock pulses blocked by the input gate is the same as the fraction of signals are blocked by the same gate; the live time can be measured.

Figure 17 illustrates a block diagram of a MCA connected to a detector setup for pulse height analysis. This setup includes also an optional SCA to reject pulses outside the energy range of interest.

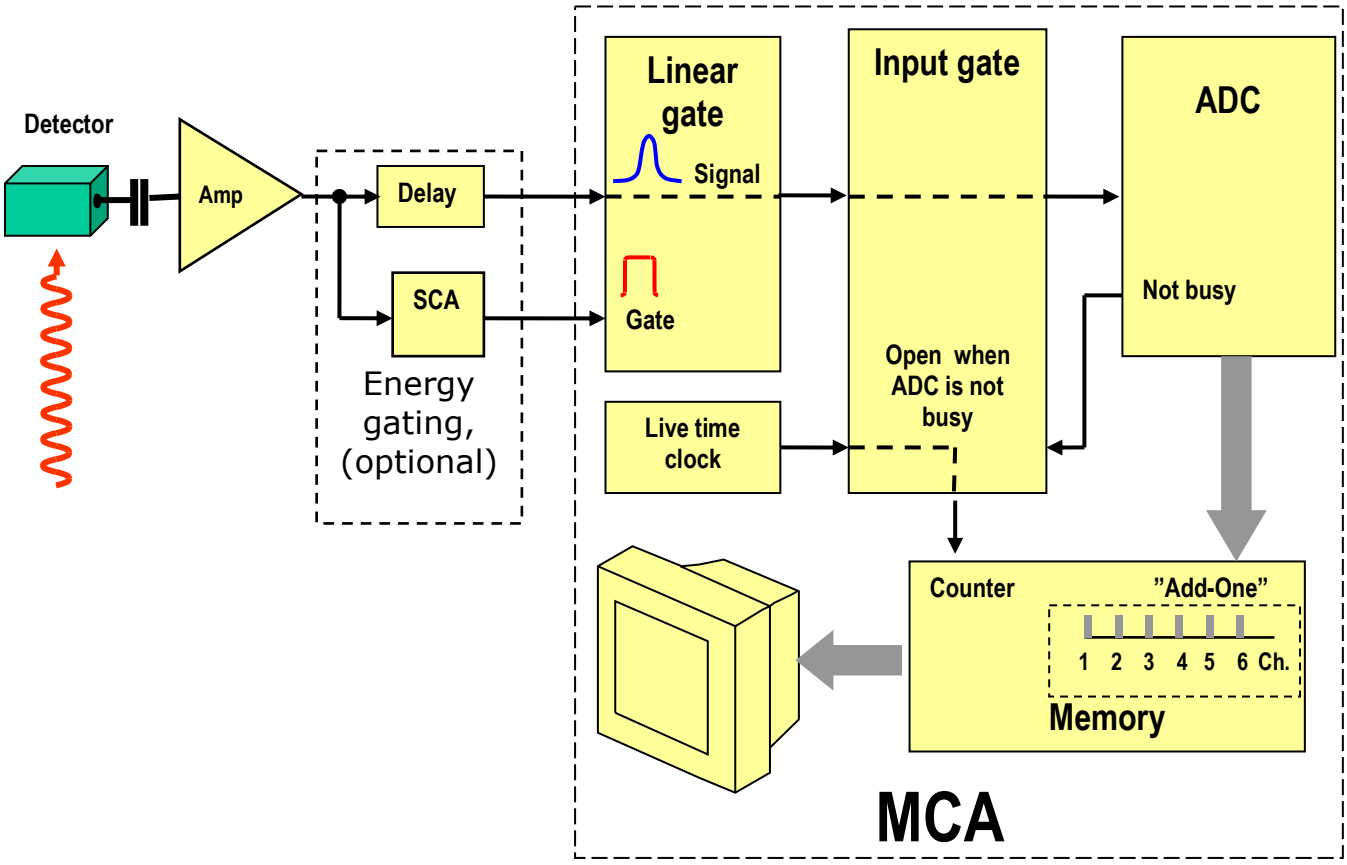


Figure 17. Block diagram of a setup for pulse height analysis. The Multi Channel Analyzer, MCA

Multi Scaling systems, MSC

MSC is a mode of operation of a multichannel pulse height analyzer, MCA, for studying the time dependence of radiation. The analyzer, when operated in the "multiscaling" mode, stores all pulses in a fixed channel until a preset time, the "dwell time", elapses, after which the pulses are stored in the next channel, and so on. Dwell times are typically fraction of seconds or larger. In MSC mode the lifetime of radioactive nuclei can conveniently be measured. Other application, as is used in other laboratory work, is to perform repetitive measurements for studying random error behavior. The Bone Mineral Density measurement in that laboratory work uses also MSC for scanning a bone phantom.

Counting ionising radiation

Radioactive decay is a random process that follows Poisson statistics. Two countings of the decays of exactly the same number of atoms of a radionuclide for a small fraction of its half-life will most likely result in different results. The difference one observes is not due to experimental error but the inherent random nature of radioactive decay. The basic limitation in accuracy of counting ionising radiation is the fact that the emission follows the laws of probability. Radioactive decay is described by the Poisson's distribution, where the accuracy (standard deviation σ) is dependent on the number of events detected, N,

$$\sigma = \sqrt{N}$$

and thus the relative error of a measurement is equal to

$$\frac{\sigma}{N} = \frac{1}{\sqrt{N}}$$

N	σ	Rel. error
100	10	10
1000	32	3.2
10000	100	1
10^6	1000	0.1

Table1
Relative error as function of number of acquired counts

Preparatory Exercises

Note: you should solve/understand all of the following exercises. Should you have troubles don't wait until the day of your lab! Contact Mamo –mct@kth.se- and/or write your questions in Bilda (the last option being highly preferable).
…and do not forget that your textbook and google are great sources of information as well!

1. The three major interaction modes of photons with matter are …

2. The probability of the three interaction processes are depending on the energy of the incoming photons. The three dominating energy regions are …

3. The amplitude of the attenuation coefficient exhibits drastic changes (edges) in the low energy region. These edges depend on the absorbing material. Explain!

4. Lead bricks, with dimensions 5 x 10 x 20 cm^3, are used for shielding against radiation in nuclear physics laboratories. What is the attenuation factor for a 5 cm thick Pb-wall for 100 keV, 500 keV and 1 MeV gamma rays.

5. How is it possible that the GM-tube gives few volt large pulses when the released energy from the ionization gives only a sub-millivolt signal?

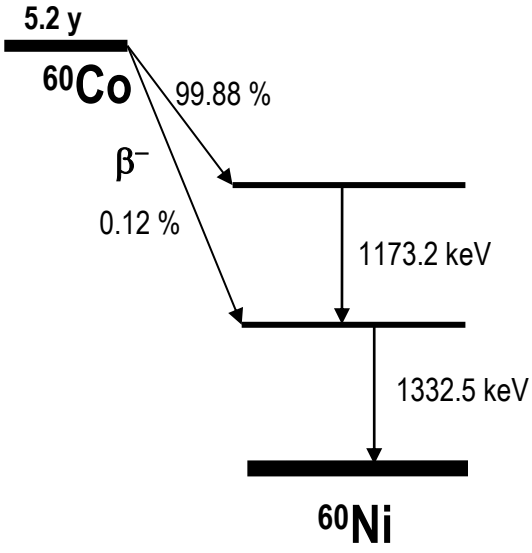
6. What is the activity of the ^{60}Co-source (see page 23) on the day of your laboratory?

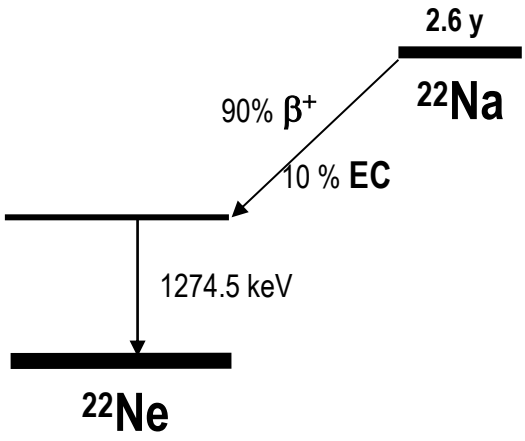
7. Suppose that you collect data for 1 minute from the ^{60}Co-source in point 6. Let us say that your detector registers 1539 counts in a ROI centered around 1,173 MeV and 1359 counts in a ROI centered around 1,333 MeV. Estimate the efficiency of your detector at these two energies. Estimate then, by extrapolation, the efficiency for ^{40}K-decays detection.

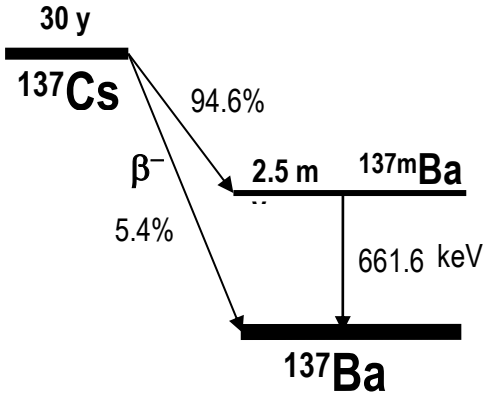
8. The two portraits on the old French 500 francs banknote are of …

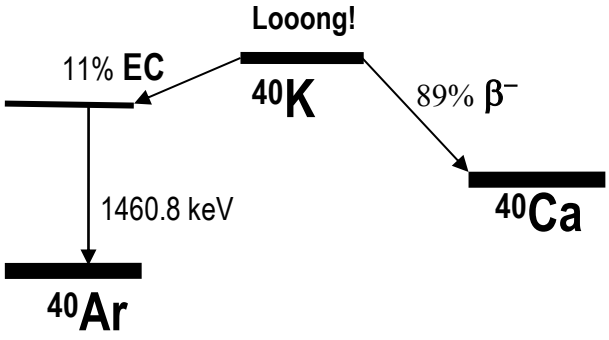
Laboratory work

Decay schemes of the radioactive sources used









Source	Photon energy [keV]	Relative photon intensity [%]	Half life [year]	Activity in kBq on date
^{60}Co	1173.2 1332.5	100 100	5.2	185 1 Oct 1988
^{22}Na	511.0 1274.5	(2x90) 100	2.6	455 1 June 1981
^{137}Cs	661.6	85.1	30	150 17 Dec 2007

^{40}K	1460	11	?	

1. NaI(Tl) scintillator and nuclear electronics

   Study the pulse-height from a NaI(Tl) scintillator with an oscilloscope for different calibration sources.

   Oscilloscope: Study the change of the analog output signals (pulses on the oscilloscope) when the source is placed at different distances from the detector. What happens to the height of the pulse? What happens to the frequency of pulses?

   PC – based MCA. Measure the pulse height spectrum of different calibration sources at constant setting of electronics and at fixed detector source distance.

   a) Measure the energy spectrum of the ^{60}Co calibration source

   b) Calculate the well scintillator efficiencies for the two photopeaks of the ^{60}Co calibration source using the activity calculated in the preparatory exercise 6

   c) Estimate by extrapolation of the efficiencies of the two ^{60}Co peaks the detector efficiency for the expected photon energy from ^{40}K-decay

   d) Put the 250 g Seltin sample in the detector and record the spectrum for a time close to 1h. Under the time for this measurement calculate the activity [Bq] of the K-sample supposing that 218274 photons were registered in 79021 seconds in a ROI centered around 1,461 MeV when 250 g Seltin were used as a sample in the barrel. The abundance of ^{40}K in K is 0,01% and the composition of Seltin is 50% NaCl, 40% KCl and 10% $MgSO_4$.

Calculations to be done **after** the lab, individually:

   e) Calculate the activity [Bq] of the K-sample(Seltin) using the spectrum measured in point d).
   f) Estimate the half-life of ^{40}K

Mail point d) and e) to mct@kth.se 1 week after the date of your lab at the latest.