College of Science and Engineering
School of Physics and Astronomy
PHYS5036 – Detection and Analysis of Ionising Radiation

Welcome to PHYS5036. Detection and Analysis of Ionising Radiation

Neptunium Lifetime: Experiment Notebook

Data collection steps are typically indicated with a blue title.

Computational work is indicated with a red title.

The aim of this experiment is to find the half-life of a particularly long-lived excited state of Neptunium by means of a simple coincidence technique using fast electronics.

Objectives:

1. Describe the physical basis and choice of technique used in the experiment.
2. Explain the method used to establish coincidence and gain knowledge & experience using the fast oscilloscopes.
3. Measure the lifetime of the 60keV level of ^{237}Neptunium.
4. Discuss the limitations of the technique employed both in terms of accuracy and applicability.

Safety in the lab

The experiment makes use of scintillation counters, a radioactive source and unvarnished lead bricks for shielding.

Handling radioactive sources

- Any source removed from the safe **must** be done by one of the demonstators. You are required to sign out any source and **you** are responsible for it until it is returned to the safe.
- Do not "lend" or give your source to a colleague when you are finished with it. Notify a demonstrator who can sign the source back in so it is available for someone else to use.
- Keep exposure to a minimum by handling sources quickly, thinking before handling the source and keeping sources as far away from you and anyone else as much as possible. Hold the sources at arm's length.
  - If the source is not being used for a short time, the source should be put behind lead shielding provided.
  - If the source is not being used for an extended time, it should be returned to the safe. This should be done by a demonstrator who can confirm the source is correctly returned.
- Sources are wrapped, placed inside containers or have a protective shielding around them. **Do not tamper with the containers and shielding**.
- Replace the pen sources into the shielding container when not in use. And keep the shielding container with the sources inside positioned behind a lead brick for shielding when only one of the pen sources is being used at any time.

Operating electronics

Under no circumstances should the HV cables be touched or removed without the lab head present. Make sure you are happy with the setting before turning on the crate and the HV. Ensure you switch the equipment off properly at the end of the day.

Handling Lead Bricks

They are heavy and can cause significant damage if dropped. Do not handle the lead bricks with bare hands. Nitrile (blue rubber) gloves are provided for handling lead bricks. Wash hands thoroughly after contact with lead.

General Rules

Eating and drinking is strictly prohibited in the radiation laboratory. Go into the corridor or stairwell if you need a snack or a drink. Do not have any food or drink on visible display in the lab at any time. Any food or drink must be kept inside your bag.

Further safety guidance can be found in the Radioactive Sources in Teaching Labs located on top of the source safe. Please also adhere to the general and specific lab safety guidelines found elsewhere.

You must fill out a Risk Assessment prior to performing this experiment. The Risk Assessment form is found on Moodle. Once you have completed the assessment, discuss it with a demonstrator and then e-mail it to the Lab Head.

NOTE YOUR SETTINGS!!

Students should note that the PMTs and other electronic apparatus used in this experiment take some time to stabilise after warming up. All electronic equipment should therefore be left on throughout the day and only switched off at the end of the lab session when measurements have been completed for the day. It should not be switched off during any short breaks or at lunchtime. There will always be one demonstrator in the room to keep an eye on equipment switched on.

Students should also note that the same apparatus is used by other students on other courses on Tuesdays and Thursdays. This means that the apparatus may not be left in the same state as you left it when you return on the next lab day. You should therefore carefully note every connection and setting, including cable lengths and the use of 50 \ohm *terminations, so you can quickly reconnect/rebuild the apparatus the way you want it at the start of each new lab day.*

In [1]:
```
# Importing the required modules

import matplotlib.pyplot as plt         # Common python package for plotting
import numpy as np                      # For many numerical operation (e.g. arrays, sine functions, mat
import pandas as pd                     # Common python dataframe package used in industry and academia
from scipy.optimize import curve_fit    # Commonly used fitting package - has some tricky syntax but use
```

Section 1 - Background Theory

Like atoms, nuclei can be excited to discrete energies above their ground state, for example in collisions with other nuclei or particles or, as in this experiment, excited states can be populated following the radioactive decay of other unstable nuclei. Measurements of the energies and lifetimes, or decay rates, of such excited states provide information about the nature of the strong inter-nucleon force responsible for the nucleus as a bound state of neutrons and protons. Excited nuclei can decay, emitting γ-rays (energetic photons), α-particles ($^4\mathrm{He}$ nuclei), β-particles (electrons or positrons, together with an unseen neutrino) or, in some cases, by fission into two daughter nuclei of roughly comparable size.

^{241}Americium decay

This experiment is concerned with the decay of the ground state of ^{241}Am (Americium) by α-particle emission to excited states of ^{237}Np (Neptunium), which then decay by γ-ray emission to the ground state of ^{237}Np.

$$^{241}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np}^* \rightarrow {}^{237}\mathrm{Np}$$

The lifetime of a relatively long-lived excited state of ^{237}Np (~60keV above the ground state) is to be measured. The lifetime of a state typically depends on the energy, angular momentum, and parity differences between the initial and final states. This particular long-lived state has a lifetime between **30ns and 100ns**, which is sufficiently long to make it measurable using fast coincidence electronics.

To do this we can measure the γ-ray transition rate as a function of the time interval between the α-particle emission and the γ-ray emission. If we then plot the number of decays against the time interval, we find the usual exponential function characteristic of radioactive decay. From such a time spectrum the lifetime can be determined.

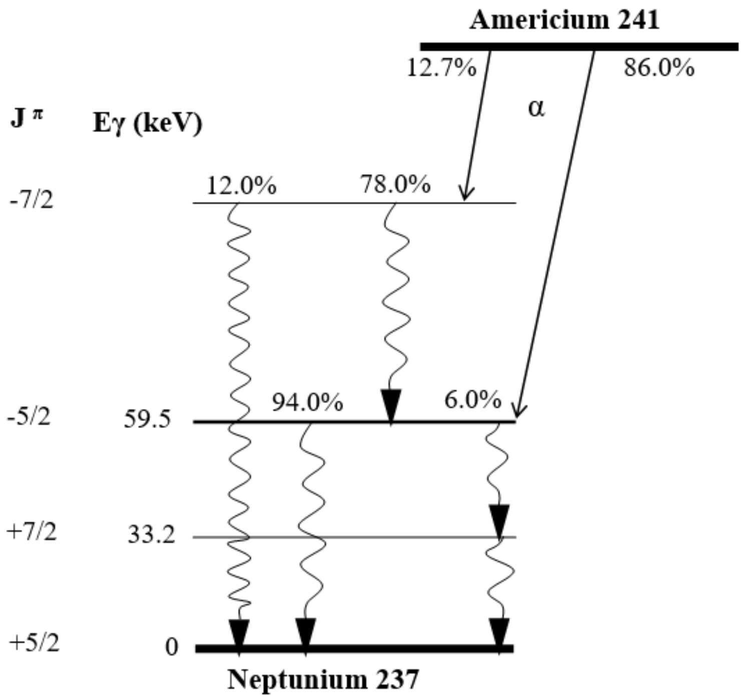

Figure 1: The decay schemes of the α-particle decay of ^{241}Am via excited states of ^{237}Np to the ground state of ^{237}Np with associated γ-emissions.

The decay scheme is shown in Figure 1, which also gives the proportions decaying by each of the available branches. As an experimental "trigger" we will use the emission of an α-particle followed by a γ-ray.

> Using the diagram, calculate the proportion of experimental triggers which go through the required 60keV level

The decay rate of the 60keV level is considerably slower than other similar γ-decays and in particular, the 33keV and 103keV levels of ^{237}Np. This results in a lifetime of the order of tens of nanoseconds, which is easily measurable using the electronics provided.

The detector setup

The ^{241}Am source is deposited on a thin piece of plastic scintillator with a similar piece (around 44mm in diameter and 5mm thick) placed on top to make an ^{241}Am "sandwich". This "sandwich" forms part of a scintillation counter (the one with the label indicating the activity of the source). Both detector arms are shown below (figure 2).

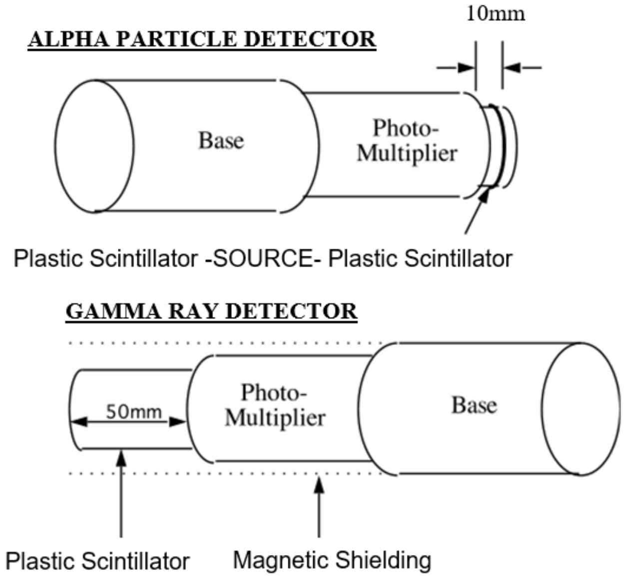

Figure 2: Schematic diagram of the α and γ scintillator-photomultiplier detectors.

The organic material of the plastic scintillator sandwich is too thin to have an appreciable efficiency for the detection of low energy γ-rays, (by contrast with the efficient stopping power of NaI scintillator of comparable thickness), but it acts as a very efficient α-particle detector. A second thicker plastic scintillation detector, 44mm in diameter and 50mm thick, is provided for the detection of "keV" γ-rays.

Scintillation Counter Theory

Despite their low light output, plastic scintillators are used because their very fast response time allows us to make timing measurements of fast transitions, such as the 60 keV transition studied in this experiment.

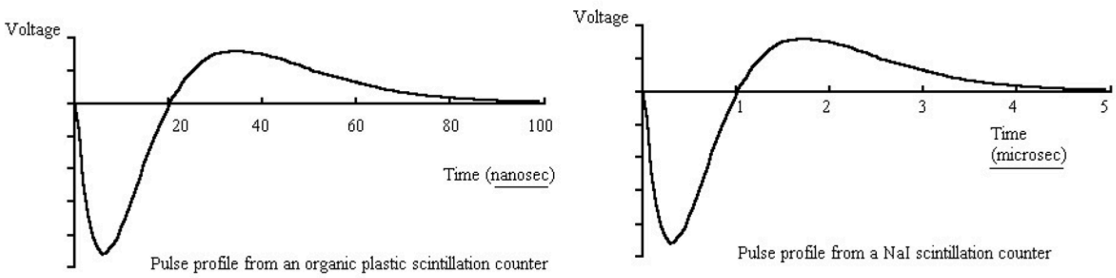

Figure 3: The time and voltage response profile of plastic and NaI scintillation counters

Unlike many of the other scintillation detectors in the laboratory, the plastic scintillation detectors you will be using have a higher operating voltage because their photomultiplier tubes contain more dynodes in order to provide higher gain. This higher gain is needed to compensate for the small light output provided by the plastic scintillator. As a result the operating voltage of these counters is in the range 1.5-2.3kV.

You should discuss the optimum operating voltage with your demonstrator and **UNDER NO CIRCUMSTANCES SHOULD YOU EXCEED 2.5kV.**

> What differences would you expect to see in the pulse height spectrum of a typical gamma ray source, using this plastic scintillator, as compared to NaI (which has a much higher photoelectric absorption coefficient)?

Radioactive Decay Theory

The decay equation is given by:

$$N(t) = N_0 e^{-\lambda t}$$

Where N is the number of excited nuclei remaining, N_0 is the initial number of excited nuclei, and t is the time since excitation.

The decay constant, λ is given by:

$$\lambda = \frac{ln(2)}{T_{1/2}}$$

Where, $T_{1/2}$ is the half-life of the excited state.

Section 2: Electronics Units

This section introduces the main electronic modules used in the experiment. Each unit plays a distinct role in detecting signals, shaping them into standard logic pulses, applying precise timing delays, and finally identifying coincident events. Together, these modules form the core of the data-acquisition chain:

- Two-sided scintillator detector setup.
- A Crate containing:
  - a Dual High Voltage Power Supply – provides the operating voltage for the 2 scintillation detectors.
  - a Dual Discriminator unit - converts analogue detector signals into clean logic pulses above a set threshold
  - Two uncalibrated variable time delay units (multipulser) – introduces controlled electronic delays without the distortions caused by long cables.
  - Coincidence Unit and Counter: – identifies overlapping pulses and records the number of coincidences.
- Fast digital oscilloscope - used to visualise and measure the timing and shape of pulses.
- Pulse Generator – supplies test signals for calibrations.
- Cables

Understanding the purpose and correct use of each unit is essential for setting up the apparatus, performing reliable calibrations, and collecting meaningful experimental data.

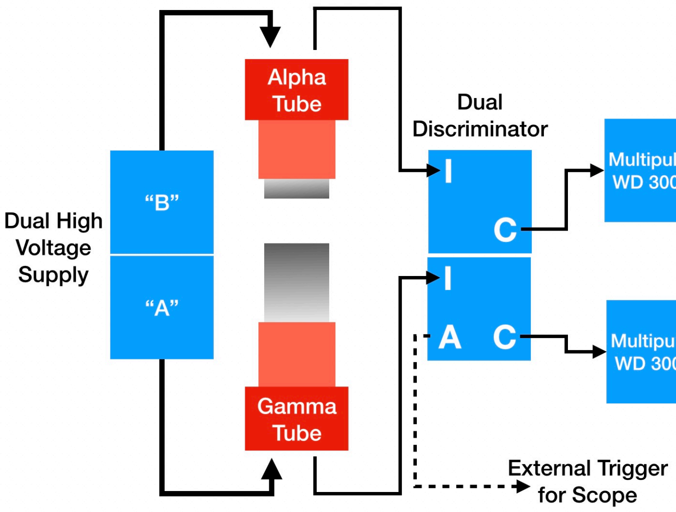

Figure 2: Experiment setup. Blue items are located in the NIM crate. HV cables are already in place.

The following subsections describe each of the crate components in more detail, including their key features and how they are used in this experiment. Before you begin, make sure you have read and understand these components - *ask demonstators if you have any questions.*

2.1 Dual High Voltage Power Supply

The dual high Voltage power supply (red-fronted CAEN supply module N471) is connected to the E.H.T. (Extra High Tension) terminals of the scintillation counters by two long red cables.

- Output A is connected to the γ-detector.
- Output B is connected to the α-detector. These cables should already be in place.

The voltage supplied to each detector is adjusted using the potentiometers on the front panel. However, the dial positions are not precise indicators of the actual output. Instead, the digital display on the power supply should always be used to read the true supplied voltage. The switches at the top of the power supply should be set to `V` and `MON`, meaning the display shows the current voltage supplied to either `A` or `B`, depending on the A/B switch position below.

Instructions for using the HV unit and checking HV settings are given in Section 3.2.

Warning: High voltage can be dangerous. Do not adjust cables or connections while the supply is on.

2.2 Dual Discriminator (T105/N)

The Ortec (EG&G) T105/N Dual Discriminator is a fast NIM (Nuclear Instrument Module) unit with two independent discriminator channels.

A discriminator converts analogue pulses into standard logic pulses. When an input pulse exceeds a set threshold voltage, the unit outputs a fixed height, adjustable width logic pulse.

In the NIM standard:

- Logic “1” ≈ –0.7V (negative-going pulse)
- Logic “0” = 0V.

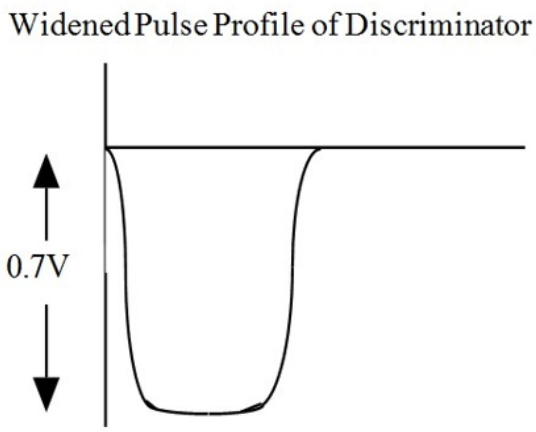

Figure 3: The time and voltage response profile of plastic and NaI scintillation counters. The pulse can be made wider by using a longer cable on the discriminator.

The threshold is set with a 10-turn knob and typically ranges from ~50mV to ~1V. Proper calibration of this threshold is essential for obtaining a clean spectrum in the experiment (see Section 3.1.1 for instructions).

The output pulse width is determined by the cable delay between the two sockets marked `WIDTH`, located just below each input. The output remains active until the delayed signal returns, meaning the pulse width is directly proportional to cable length.

- A longer coaxial cable (≈ 5ns/m for 50Ω cable) produces a wider pulse.
- Alternatively, a switched delay box with preset loops at fixed time intervals (`J`) or manual patch cables (`T`) can be used for convenient adjustments.

Question:

> What pulse width would you get with a 3m cable? How long a cable would be required for a 25ns pulse? What are the advantages and disadvantages of widening the discriminator pulse? (Hint: Consider how this affects coincidence timing and accidental background triggers.)

2.3 Multipulser Unit (Model WD300/N).

The multipulser unit introduces a variable electronic time delay to the logic pulses from the discriminators. It can provide larger delays than the switched cable-delay boxes. Unlike long coaxial cables, which can attenuate or distort signals, the multipulser ensures a clean, reproducible pulse shape. Note that the output pulse from this unit has a fixed width.

The multipulser unit requires calibration. Instructions for the calibration process, along with more information about the multipulser, can be found in Section 3.1.2.

2.4 Coincidence Unit and Counter (Dual Twofold And Model C102A/N).

The coincidence unit has an input selection switch. With the switch pointing towards input `A` or `B`, that input is fed directly through to the output. However, in the central position an output logic pulse is only produced when there is a logic input signal on both inputs with some overlap in time. The counter is used to count the number of coincident pulses.

NOTE: These units expect a standard NIM signal, meaning they use a fixed threshold. If there is too much attenuation in the signal, the pulse amplitude may drop below threshold and not register counts.

2.5 Pulse Generator

As the ^{241}Am source used in this experiment is very weak, we make use of a fast pulse generator to provide a steady train of pulses of controllable amplitude. These pulses simulate the signal pulses from the scintillator detector and are used to:

- calibrate the thresholds scale of the discriminators
- calibrate the time response of the multipulser units.

3.0. Setup & Calibration

The experimental work is divided into two sections:

- ⅔ - Calibrations & Setup.
- ⅓ - Detailed Measurements & Analysis.

The first section will start by getting to know the important features of the apparatus, learning how to use the fast oscilloscope and pulse generator and planning the necessary calibrations and measurements for the next sections.

An example of how to use curve_fit is shown in "plottingHelp.ipynb"

3.1. Calibrations and setup.

In this section we will be performing the following calibration and experiment setup steps.

Calibrations with multipulser:

- Calibrating the threshold values of each of the two discriminators using the pulse generator and the fast oscilloscope.
- Calbrating the time delays of each of the two multipulser units using the pulse generator and fast oscilloscope.

Further setup:

- Deciding on the High Voltage values to use for each photomultiplier tube.
- Obtaining pulse height spectra from the α and γ detectors, using these spectra to decide on the threshold values to set in each channel.
- Doing a trial run of the experiment to plan the counting times and number of measurements to take in the final measurement.
- Deciding an optimal "time-zero" of the experiment where there is enough delay either side of maximum to observe the expected features.

Important Notes: It is necessary to work through the set-up procedure below before taking any measurements in order to set suitable values for the discriminator thresholds such that they eliminate background noise.

This can be a complicated experiment so if you are unsure of anything seek assistance from a demonstrator.

3.1.1 Calibration of the T105/N Dual Discriminator

General Information

- The T105/N Dual Discriminator Module contains two independent discriminators.
- Each discriminator has a threshold adjustable from about –50mV to –1.0V (via multi-turn potentiometer).
- Each provides two equivalent output pairs: (A–B) and (C–D). These must be terminated in 50Ω for correct operation.
- An additional inverse dual output is also provided.
- The discriminator is designed for negative-going input signals. If the signal exceeds the set threshold, a negative standard NIM logic pulse is produced:
  - Logic '1' ≈ –0.8V
  - Logic '0' = 0V
- The pulse width can be adjusted: connect a cable between the `WIDTH` ports and set the switch to `CABLE`. The cable length sets the pulse width.

Equipment Required

- Digital oscilloscope
- Bipolar pulse generator (pulser)
- Dual Discriminator T105/N module in NIM bin
- Standard BNC coaxial cables (2 × 1m and 1 × 2m)
- Several 50Ω terminators and T-junctions

Recommended Settings

- Pulse generator: period = 1μs (1MHz), width = 20ns, negative output pulse.
  - Pulse setting gives positive pulses, to get a 20ns negative pulse, set the positive width to be 980ns.
  - Set the rise/fall time to minimum (7ns)
- Digital oscilloscope:
  - Channel 1: 50mV/div (adjust as needed)
  - Channel 2: 500mV/div
  - Trigger set to Channel 1, DC coupled, falling slope
  - Time sweep: 25ns/div

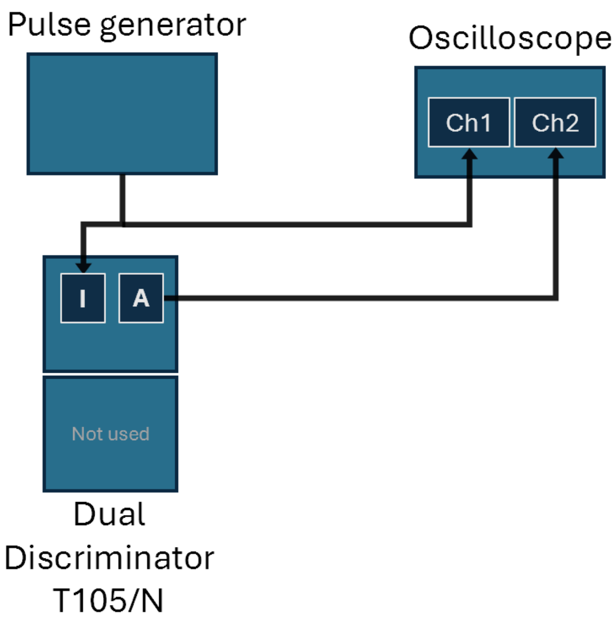

Figure 4: Schematic configuration for calibration of T105/N Dual Discriminator.

Calibration Procedure (Setup & Data Taking)

- Connect the pulse generator to oscilloscope channel 1 via a T-piece, and connect the other side of the T-piece to the discriminator input.
- Connect the discriminator output to oscilloscope channel 2 via a T-piece and 50Ω terminator.
- Terminate all unused discriminator outputs (otherwise you will see doubled amplitudes).
- Connect a 0.5m cable between the `WIDTH` ports, set the switch to `CABLE`.

- Set the discriminator potentiometer to minimum (~0.50).
- Starting from zero, increase the signal from the pulse generator until channel 2 **always** shows a pulse with channel 1.
- Record this amplitude - it is the threshold for the current descriminator value.

> - Is the scope amplitude the same as the signal generator? If not, why?
> - What size should the pulse on channel 2 be?

- Increase the potentiometer by a chosen step size and repeat up to ~9.00 on potentiometer.

Analysis

- Plot pulse amplitude (input) vs. discriminator threshold setting (potentiometer).
- Note there is a plottingHelp.ipynb if you need help getting started with the plot.
- Identify the linear region of this relationship and determine its slope and intercept.
- A typical calibration curve is shown below.

> - What range of pulse heights does each discriminator cover?

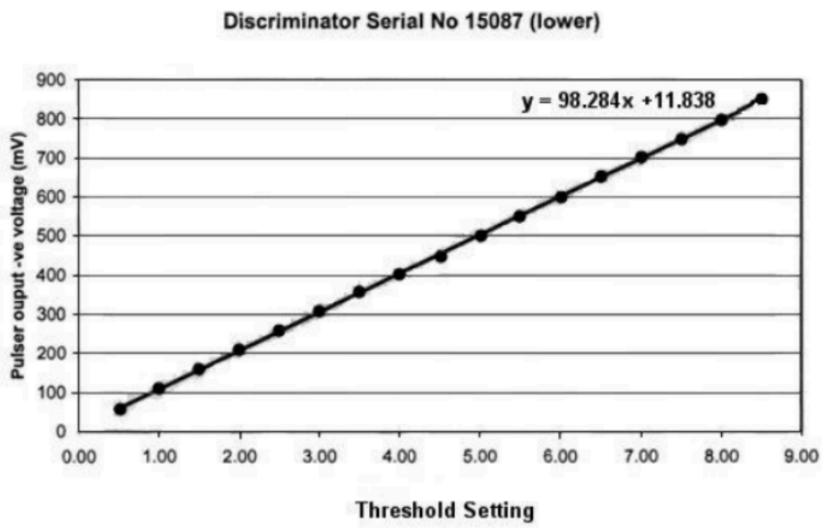

Figure 5: Example calibration plot for the T105/N Dual Discriminator.

In [2]:
```
# Space for working
```

Repeat for the 2nd descriminator.

In [3]:
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# Space for working
```

> - Using these calibration results, what voltage range does each discriminator cover linearly?

3.1.2 - WD300/N Multipulser Calibration

General Information:

- The WD300/N MULTIPULSER MODULE (Figure 1) contains a variable delay unit.
- Provides an electronic delay to logic pulses fed into the input.
- Has four switchable delay ranges: 50-200ns, 0.2-2µs, 2-20µs and 20-200µs.
- Each range is variable through a multi-turn potentiometer, but it is necessary to calibrate the setting to obtain the corresponding time delay.
- The multipulser has a 'dual' input.
- The unused input port must be terminated.
- Output is via the `DELAY` port.
- The two other unused output ports must also be terminated.
- The multipulser is capable of providing larger delays than a switched delay box, and also has the advantage that the delayed pulse output by the unit has a standard shape (amplitude -0.8V, and a fixed pulse width 10ns) and is

not degraded by attenuation or dispersion in long cables.

Required equipment:

- Digital oscilloscope
- Bipolar pulse generator
- Multipulser module located in NIM bin
- Standard length (1m) coaxial cables with BNC plug connectors
- A number of 50Ω terminators and T-junctions.

Recommended Settings:

- Pulse generator:
  - Period: 1μs (frequency 1MHz);
  - Width: 20ns;
  - Output: negative pulse 0.8V amplitude.
- Digital oscilloscope:
  - DC coupled;
  - Channel 1 vertical scale 500mV/div;
  - Channel 2 vertical scale 500mV/div;
  - Time sweep 25ns per division initially and adjust as required.
- Multipulser: range 50ns to 200ns.

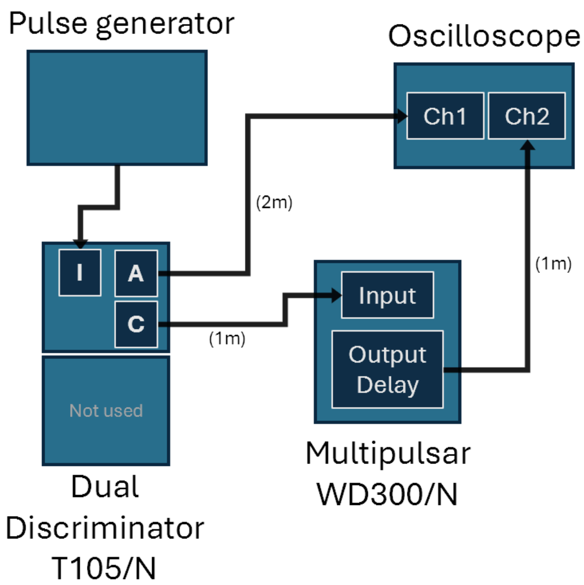

Figure 6: Apparatus configuration for calibration of MULTIPULSER.

Calibration Procedure:

Setup and Data taking.

- Connect the pulse generator to a discriminator and set the amplitude and threshold values so that the discriminator outputs logic pulses.
- Feed one output logic pulse from the descriminator to channel 1 of the oscilloscope, remembering to use a T-piece and a 50Ω terminator.
- Connect another output to the input of the multipulser unit. Connect the output of the multipulser unit to channel 2 of the oscilloscope, again using a T-piece and a 50Ω terminator.
- All unused input and output ports of the multipulser must be terminated with 50Ω terminators.
- You should now see two pulses on the oscilloscope, with the pulse on channel 2 occuring later than the pulse on channel 1.
- The difference in time is due to the difference in cable lengths after the discriminator and the processing time of the multipulser unit.
- Determine each of these delays before proceeding.
- Switch the multipulser range to 50-200ns.

- Set the multipulser to the minimum value 0.0.
- Figure 7 shows the form of the scope display; use the horizontal time sweep display to determine the delay between the input and output pulse.Note this delay and the corresponding potentiometer setting.
- Increase the multipulser potentiometer value by a suitable amount and determine the new delay.
- Repeat this process for potentiometer settings across the entire range.

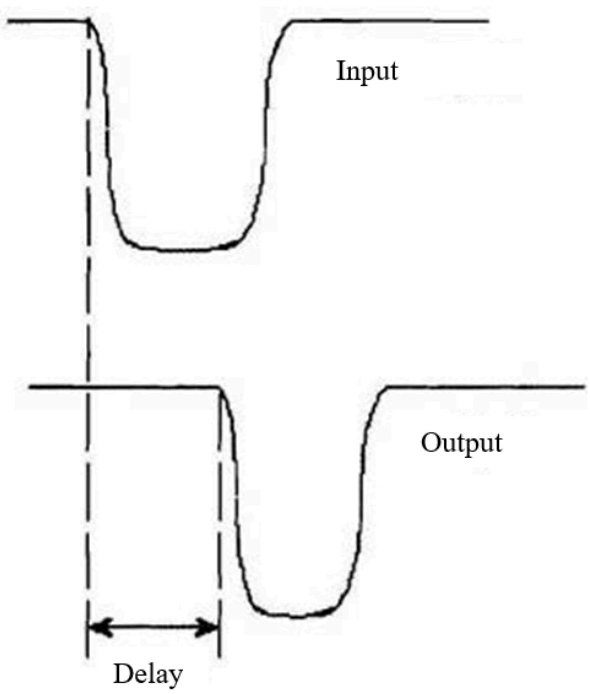

Figure 7: Determination of delay induced by multipulser from scope display.

Analysis.

- Plot delay against multipulser potentiometer.
- Using curve_fit (or otherwise), determine whether this is linear and fit a trend line to the data.
- For the Neptunium lifetime experiment it is only necessary to calibrate the 50-200ns range.
- A typical calibration plot is shown in Figure 8.

NOTE BOTH multipulsers will need seperate calibrations.

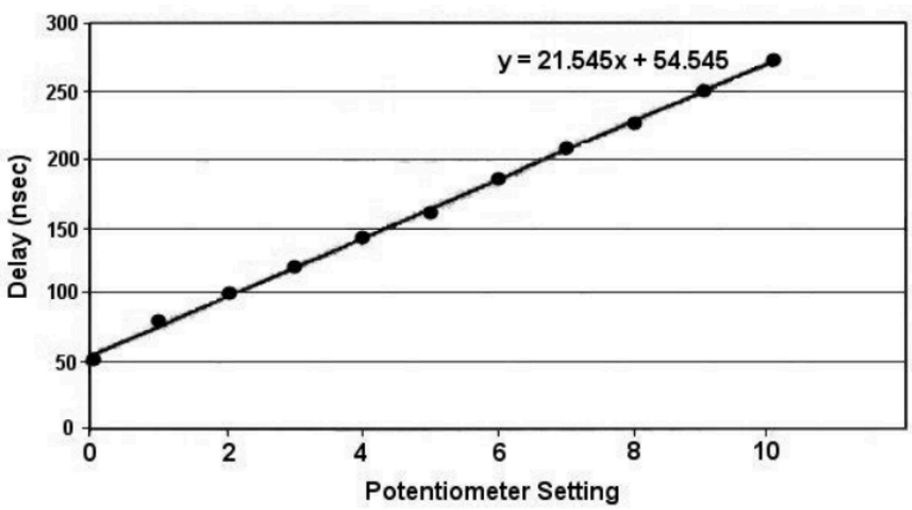

Figure 8: Typical calibration plot for WD300/N MULTIPULSER.

In [4]:
```
# Space for code
```

Now repeat for the second multipulser.

In [5]:
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# Space for code
```

3.2. Setting-Up Procedure.

By this point you should have calibrated both multipulser units and discriminators units and are ready to start setting up the experiment proper.

1. Make sure all switches on the apparatus are off before turning on the wall socket switches.

2. Switch on the oscilloscope with the following settings:

   - Input coupling to AC,
   - Trigger mode to normal,
   - Trigger on falling/negative slope,
   - Time base to 50ns/cm.

   Use T-junctions and 50Ω terminators on all input connections to the oscilloscope.

3. Using the High Voltage (HV) supply unit. Check:

   - Both polarity settings are negative.
   - The two output settings are visible in the small window of the red CAEN supply module by toggling the switch between positions `A` and `B`.
   - To start, set a voltage of ~2000V (the switch below the voltage indicator will need to be at `SET` to do this), and then switch on the high voltage.
   - There will be small red light at the bottom of the power supply unit labelled `INHIBIT`. This switch will prevent any voltage being supplied unless it is pushed towards `RST` until the light goes out.

   Ensure you are using the digital display to get an accurate reading for both `A` and `B` when setting voltages.

4. Determining the voltages for the experiment:

   - Put the signal cable from each detector directly into the scope inputs.
   - Observe the maximum pulse height from the γ detector.
   - Set the trigger on the oscilliscope to be around 20% of the viable discriminator range.
   - Adjust the high voltage of α until the observed noise height fluctuations are just under the trigger. **Remember never go above 2500V.**
   - Calculate the expected discriminator setting using your discriminator calibration.

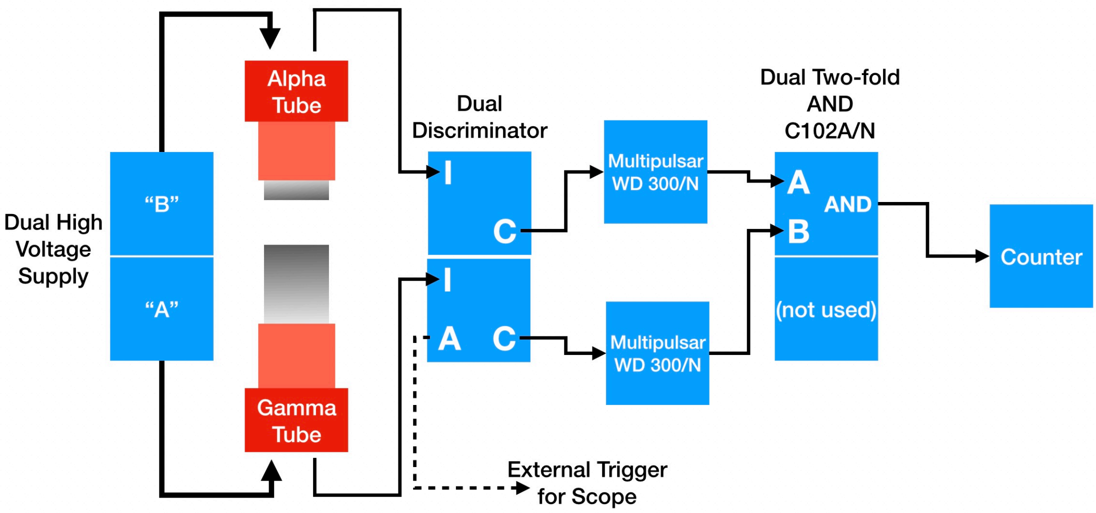

Figure 2 (again): Experiment setup

Obtain a pulse amplitude spectrum from the γ-counter

- Connect up the switches as shown in Figure 2.
- Set the toggle switch on the coincidence unit to let the γ-signal pass straight through to the counter.

- Set the discriminator level for the γ-detector to its upper limit.
- Take a 1-minute count using the counter.
- Repeat the 1-minute counting after decreasing the discriminator level by suitable steps.

Analysis

- Subtract consecutive readings in order to obtain a spectrum, and plot the results.
- Using this spectrum you can set the discriminator level just above the level of the electronic noise. If this level is not obvious discuss with a demonstrator.

In [6]:
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5. Check the chosen threshold is not allowing any pulses lower than the set threshold to pass.
    - Connect a pulse generator directly into the oscilloscope and to the discriminator with a T-junction. This ensures that the input cable feeds both the oscilloscope and the discriminator and that it is terminated once only.
    - Take a signal from output `A` of the discriminator and connect this to the `external trigger` input of the oscilloscope (terminating with a T-junction and a 50\ohm terminator.)
    - Display channel 1 on the oscilloscope while triggering on the `external input`.
    - The minimum amplitude signals that you see on the oscilloscope corresponds to the actual threshold of the setup. In other words, you shouldn't see any pulses of amplitude less than the value the discriminator is set at.

> - Try adjusting the threshold and note the effects on the minimum pulse height. Can you explain this?
> - Does it match your expected value?

This is just a visual check to make sure the desired threshold is set. When you have finished checking the threshold, return all the connections to their previous configuration (as in figure 2).

6. Now Repeat steps 4 and 5 for descriminator for the γ-detector signal by setting the coincidence unit to only let γ-signal pass straight through.

Once you reach this point you are ready to begin data taking for the experiment proper.

4. Detailed Measurements & Analysis

In this final stage of the experiment, you will collect a comprehensive set of measurements aimed at achieving high statistical accuracy. The goal is to sample coincidence events across a wide range of positive and negative time-differences between α and γ events, allowing you to construct a detailed time spectrum.

Once sufficient data has been gathered, you will analyse the spectrum and perform a fit to determine the lifetime of the 60keV excited state of ^{237}Np. This is the key quantitative result of the experiment, so careful attention to setup and calibration is essential.

Remember: Electronic apparatus takes time to stabilise, and the same apparatus is used by other students on other days. Double-check you have noted every connection and setting.

Setup and Data Taking

1. Confirm that you are satisfied with the following variables before proceeding:

    - γ-detector HV, discriminator threshold, discriminator pulse width.
    - α-detector HV, discriminator threshold, discriminator pulse width.
    - Multipulser settings and time calibration(s).

2. Sketch the expected decay curve.

    > How would the finite width of pulses going into the coincidence unit modify the curve?
    > Would maximum coincidence occur exactly at zero delay?

> **Discuss your sketch with a demonstrator.**

3. Select a fixed delay value for the γ-signal

> Justify your choice to a demonstrator.

4. Vary the α-delay to find the maximum coincidence rate.

> Does this match your initial prediction?
> How far is the maximum from your γ-signal?

5. Take short (1-min) measurements of the coincidence rate with incrementally increasing α-delay. From this decide what step size to use to cover the full range of the multipusler delay range.

> Do you need to adjust your γ delay?
> How long should each measurement be to achieve reasonable statistics?
> Are there regions where more measurements might be needed? Why?

In [7]:
```
# Space for working
```

6. Full measurement run.
   - For your chosen γ-delay, record the coincidence count rate for increasing α-delay values.
   - Ensure good statistical accuracy at each step and the full range is well-sampled.
   - Consult a demonstrator if you are unsure about step sizes, timing, or coverage.

In [8]:
```
# Space for working
```

Analysis and result

5. Estimate the random coincidence rate by setting the α-delay so pulses arrive before the earliest γ-rays.

> Why does this mean that any coincidences measured must be random?

6. Confirm by setting the α-delay to a much larger value (many half-lives beyond "zero")

7. Correct your coincidence spectrum for random coincidences.

8. Fit the corrected data to extract the lifetime of the 60keV state.

In [9]:
```
# Space for working
```

Discussion

8. Consider cosmic-ray background.

> How might this alter the shape of your decay spectrum?

9. Apply the uncertainty principle to estimate the maximum measurable width (in eV) of a nuclear excited state which can be measured with the electronics of this experiment.

10. Discuss whether all ^{241}Am $\rightarrow$ ^{237}Np decays via the 60 keV level are observed. If not, why not?

> How could detection efficiency be improved?

11. How could you measure the branching fractions quoted on the ^{241}Am decay scheme?

12. Estimate the maximum coincidence rate at which this system will function reliably.

Hint: Compare how the random coincidence rate scales with source activity vs. real coincidence rate.