MANUS

Laboratory Practical Course:

Scintillation Detectors

2009

Scintillation Detectors

A gamma ray or a charged particle interacting with a scintillator produces a pulse of light, which is converted to an electric pulse by a photomultiplier tube. The photomultiplier consists of a photocathode, a focusing electrode and 10 or more dynodes that multiply by each electron striking the dynode knocking out more than one electron from every dynode in the chain. The anode and dynodes are biased by a chain of resistors typically located in a plug-on tube base assembly. Complete assemblies including scintillator and photomultiplier tube are commercially available from Canberra.

The properties of scintillation material required for good detectors are transparency, availability in large size, and large light output proportional to gamma ray energy. Relatively few materials have good properties for detectors. Thallium activated NaI and CsI crystals are commonly used, as well as a wide variety of plastics. NaI is the dominant material for gamma detection because it provides good gamma ray resolution and is economical. However, plastics have much faster pulse light decay and find use in timing applications, even though they often offer little or no energy resolution.

Plastic Scintillators

Many types of plastic scintillators are commercially available and find applications in fast timing, charged particle or neutron detection, as well as in cases where the rugged nature of the plastic (compared to NaI), or very large detector sizes, is appropriate. Sub nanosecond rise times are achieved with plastic detectors coupled to fast photomultiplier tubes, and these assemblies are ideal for fast timing work.

Separate outputs are usually used for timing, with the positive dynode output to a preamplifier and amplifier for energy analysis, and the larger negative anode output to a fast discriminator, as shown in Figure 1.

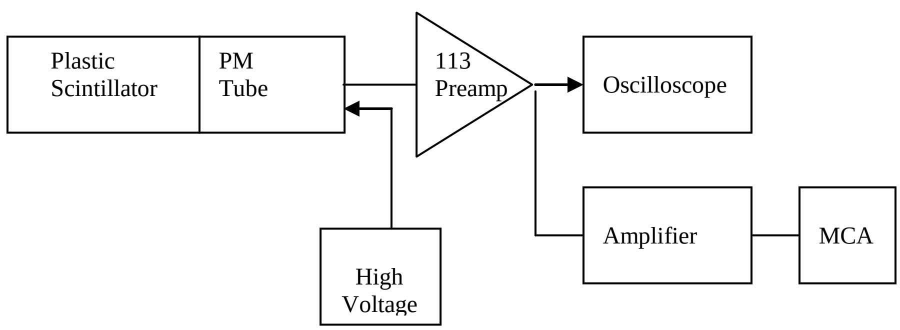
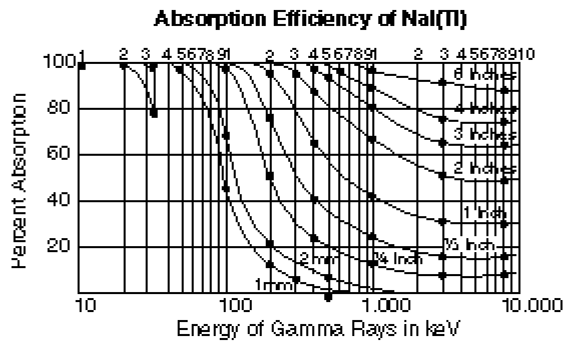


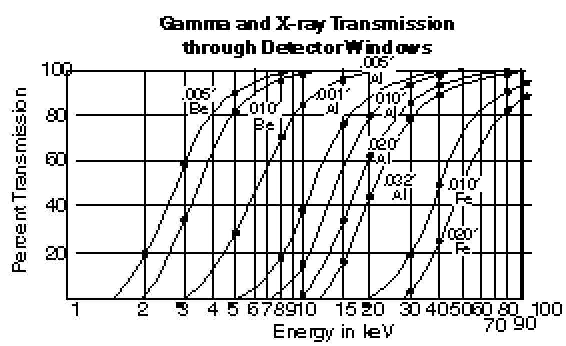
Figure 1: Plastic Scintillation Detector Electronics.

NaI(Tl) Scintillation Detectors

The high Z of iodine in NaI gives good efficiency for gamma ray detection. A small amount of Tl is added in order to activate the crystal, so that the designation is usually NaI(Tl) for the crystal. The best resolution achievable ranges from 7.5%-8.5% for the 662 keV gamma ray from ^{137}Cs for 3 in. diameter by 3 in. long crystal, and is slightly worse for smaller and larger sizes. Figure 1.6 shows, respectively, the absorption efficiencies of various thicknesses of NaI crystals, and the transmission coefficient through the most commonly used entrance windows.



The family of curves is derived from NBS circular 583 (1956), Table 37, mass attenuation coefficients for NaI(Tl). Each curve represents the percent absorption (l-attenuation) of a parallel beam of gamma rays normally incident on that thickness NaI(Tl) crystal.



Compiled from NBS Circular 583 and supplement to NBS Circular 583. (Estimated Max. Error ±2%)

Many configurations of NaI detectors are commercially available, ranging from crystals for x-ray measurements in which the detector is relatively thin (to optimize resolution at the expense of efficiency at higher energies), to large crystals with multiple phototubes. Crystals built with a well to allow nearly spherical 4p geometry counting of weak samples is also a widely used configuration. A typical preamplifier and amplifier combination is shown in Figure 1.

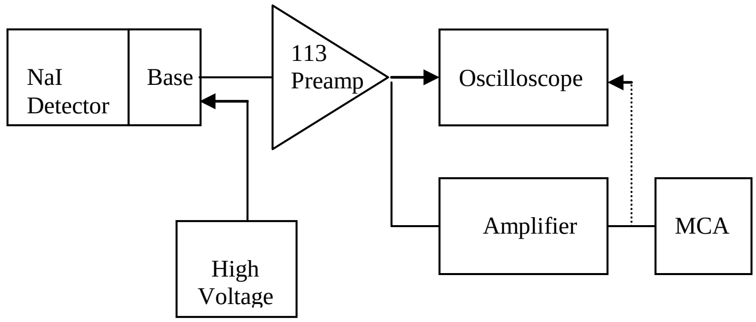


Figure 2: NaI(Tl) Detector Electronics

The light decay time constant in NaI is about 0.25 microseconds, and typical charge sensitive preamplifiers translate this into an output pulse rise time of about 0.5 microseconds. For this reason, NaI detectors are not as well suited as plastic detectors for fast coincidence measurements, where very short resolving times are required.

Apparatus

Scintillator
NE102A is a plastic scintillator, which is coupled to a Perspex light guide.

Photomultiplier tube (PM)
Is equipped with a magnetic shield and a base. The PM tube has a 19mm diameter and operates at a bias of + 800 V.

NaI detector and transistorized base
The 76 mm x 127 mm NaI crystal cylinder has a 7μm thick HAVAR protective window and is viewed by a 76mm diameter photomultiplier tube. The photomultiplier tube is connected to a transistorized base, which provides an output signal from the fifth dynode. The NaI detector takes bias of + 800 V.

High Voltage power supply
Model ORTEC 456 provides positive high voltage.

Cables
Yellow BNC 93Ω(signals), blue BNC 50Ω(signals), thin blue LEMO 50Ω(signals) and orange SHV(high voltage) cables.

Optical grease
Is made of silicone

Black paper, tape, scissors, soft and clean tissues or cloth

Clamp
Use it to secure light guide to PM tube.

Radioactive sources
^{137}Cs and ^{22}Na are γ emitters. These sources will be provided during the practical.

Oscilloscope
Digital oscilloscope allows the recorded signal to be stored onto diskette.

Preamplifier and power supply
Model ORTEC 113 requires 24 V power. Use any NIM bin with e.g. amplifier (CANBERRA 2020) as the preamplifier power supply.

Amplifier
CANBERRA 2020 or ORTEC 572

PC with Multi Channel Analyzer (MCA)
MCA is set for 1024 channels full scale.

Torch lamp

Procedure

Important: Make sure that your High Voltage Power Supply is set to a Positive polarity.
In order not to damage the photomultiplier tubes do not expose the tube to light while the tube is biased.
Avoid the radioactive sources being closer than 50 cm from the body at all times.
One member of the group must wear the electronic dosimeter for the entire practical. Do not forget to switch off the dosimeter at the end of each practical.
Remove the γ source once the measurements are completed or after each practical session. Store the γ source in the radiation source cupboard.
Use the optical grease sparingly.

1. Do a literature study: (Chapters 7,8 and 9) in "Techniques for Nuclear and Particle Experiments" by W R Leo. Make extensive use of the section pp 197-200 in Leo to perform this practical.

2. Make sure and check that all the items listed under Apparatus are available.

3. Prepare, assemble and test Scintillation Detector by following Steps 1 to 5 as described in Leo. Remember that the plastic scintillator and light guide are painted with a white reflective paint so that the aluminum foil is not required (Step 3). **Please use the optical grease sparingly.**

4. Instead of wrapping the whole assembly with black tape use black paper and tape to make it light tight.

Questions of tasks 5 to 16 must be answered in writing and presented together with your results in a Report.

5. In order to test the scintillation detector, set up the electronics as shown in Fig. 1. Since the first test involves light tightness, this should be performed in a dark room. Apply +800 V to the PM tube. Which of Einstein's many famous discoveries is applied in the operation of the PM tube?

6. Find the anode signal on the oscilloscope. Shine torchlight across the scintillator. If there is no major change in the intensity of the signal, the detector is most probably light tight. Measure the rise and fall time of the signal. What is the origin of this signal?

7. Compare this signal with the dynode and anode signals from the NaI(Tl) detector. Measure again the rise and fall time of the signals. Which of the two detectors produces the faster signal?

8. In the case of the NaI(Tl) detector explain what the difference is between the dynode and the anode signal. Why does the NaI crystal have a HAVAR window?

9. Record all the signal shapes of both the plastic scintillator and the NaI detector on a diskette as described in the appendix.

10. Place the ^{137}Cs γ source close to the NaI detector. What do you observe on the oscilloscope as you increase the distance between the source and the detector and why?

11. Patch the preamplifier signal through to the amplifier (see Fig. 2). Observe and record the amplitude of the amplified signal on the oscilloscope by dropping the voltage to +700 V and raising it to +1000 V. Change the bias voltage of the NaI detector back to +800 V. Why is there a difference in the amplitudes?

12. Measure the γ energy spectrum and the energy resolution of the NaI detector using the pre-amplifier, amplifier and MCA (see circuit diagram in Fig. 2). Record the settings of the amplifier and then record the spectrum on the diskette.

13. Repeat exercise 12. with a ^{22}Na source. If one of the γ energy lines in the spectrum is 1275 keV, what is the energy of the other peak? What is its origin? Make use of all three energy positions, including the energy line of ^{137}Cs, to measure the energies of the γ's emitted from the "mystery source". What is the "mystery source"? Record its spectrum on the diskette.

14. Repeat this measurement using the Plastic scintillator. How does its energy resolution differ to the one obtained for the NaI detector and why?

15. Which detector would you use to obtain timing information and which one for measuring the energy and why?

16. Explain what the role is of the magnetic shield surrounding the PM tube of any scintillation detector.

17. Disassemble the plastic scintillator set up and clean the surfaces of both the light guide and the PM tube. Make sure that all the apparatus are ready for the next practical.

APPENDIX: How to record a scope trace onto a diskette.

- Set oscilloscope to "Fast Trig" on Acquire
- Insert a diskette.
- Press "Run/Stop" and "Single seq" to obtain a single trace.
- Press the "Save/Recall" button near the top of the scope.
- Press the button for "File Utilities" at bottom of the screen.
- Turn the "Select/Coarse" knob on the top left of the scope to select "tek.csv" on the screen.
- Press the button for "Rename" next to the screen.
- Remove all "?" with the "Back Space" button.
- Changing the name of the save file: Use the "Select/Coarse" knob to select the letter you choose. Use the arrow button to move to the correct position in the word and repeat till you have completed the name then press the "Enter Character" button.
- Once finished press the "Accept" button to enter the changed name.
- Press the button for "Save Waveform to Ch 1".
- Press the button for "To File".
- Turn "Select/Coarse" knob to select file (*.csv).
- Press the button for "Save Ch 1 to selected File".
- The file is then stored on the diskette and can be read by Excel.