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NaI(Tl) and CsI Scintillator Detector Operating Voltage Determination

EDITHA P. JACOSALEM
JINGLE B. MAGALLANES
ANGELINA M. BACALA, Ph.D.

Abstract

Sodium iodide activated with Thallium [NaI(Tl)] and the pure Cesium iodide [CsI] crystals are the two types of inorganic crystal scintillators that are mounted to separate photomultiplier tubes (PMT) to form scintillator detector. The operating voltage of these detectors were determined to have minimal influence on the measured counts due to drifts in the photomultiplier gain or voltage supply.

Keywords: inorganic crystal scintillator, photomultiplier tube, NIM

Introduction

Scintillator detectors are instruments designed for indirectly observing atomic and sub-atomic particles and are one of the most versatile and widely used particle detection devices in radiation monitoring. In this experiment, thallium-doped sodium iodide [NaI(Tl)] and pure cesium iodide [CsI] crystals were coupled to a separate photomultiplier tube to form a scintillation detector. This detector can observe radiation if supplied with high voltage.

EDITHA P. JACOSALEM finished her MS Physics degree in 1999 at MSU-IIT. Her masteral thesis on gamma spectroscopy was written under the advisorship of Dr. ANGELINA M. BACALA. JINGLE B. MAGALLANES and Dr. ANGELINA M. BACALA are faculty members of the Physics Department, College of Science and Mathematics, MSU-IIT

However, only for a certain range of voltages this detector can function efficiently. It is thus necessary to determine this range of voltages for proper operation, and any value within this range can be the detector's "operating voltage".

The working or operating voltage for each detector is determined using the plateau measurement which involves measuring of the total count rate from the scaler and discriminator as a function of the applied voltage. Counter plateau represents areas of operation in which the detector has minimum sensitivity to drifts in the discriminator.

Brief Literature

A. Scintillator Detector

Scintillators are materials, which have the ability to convert the incident radiation to pulses of light. They produce sparks when hit by incident radiation. When these materials are coupled to a photomultiplier tube, it forms a scintillation detector wherein the scintillations or sparks are amplified and converted into electrical pulses.

Most of the available inorganic crystal scintillators are alkali iodides in nature. They are doped with an impurity or activator, which is responsible for the luminescence of the crystal; this property of the crystal is associated with the absorption of radiation, conversion and reemission of this energy in the form of visible light.

The basic scintillation detector assembly is composed of scintillating crystal, a photomultiplier tube (PMT), and a light guide. They are all properly encased in a light tight container to prevent ambient light from entering the system. See figure 1. A small light leak can make the radiation detector useless or inefficient.

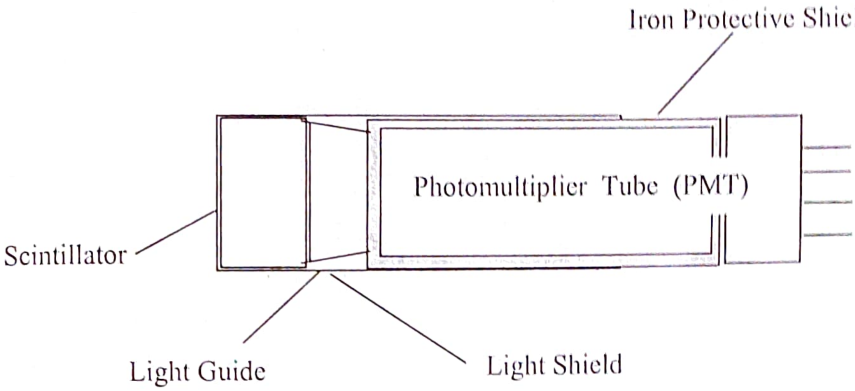

Figure 1. *Basic elements of a Scintillator Detector*

The photomultiplier tube or simply PMT is the one responsible in the amplification and conversion of scintillations into electrical pulses. These pulses are counted and analyzed to give some information on the incident radiation. Figure 2 shows the schematic diagram of the interior of a PMT.

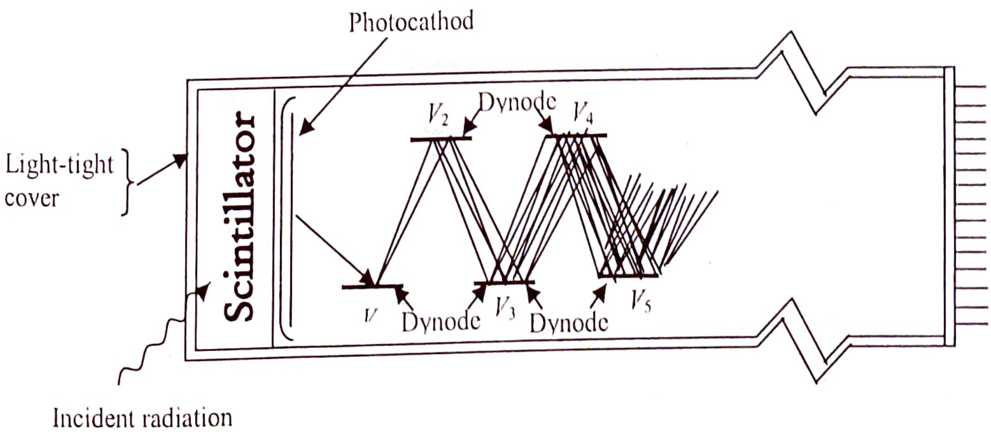

Figure2. *Schematic Diagram of the Interior of a Photomultiplier tube. [From Tsoulfinidis, 6.13]*

The PMT consists of a photocathode, which emits electrons when hit by light; several dynodes, where electrons are multiplied; and an anode, where the final signal is taken. When a nuclear particle or incident radiation enters the scintillating crystal, it interacts and produces electrons, which in turn generate photons in the visible range. When these photons reached the photocathode through a light-coupling system, the photocathode emits electrons. These electrons are guided towards the first dynode, which emits several electrons upon impact on the dynode. These secondary electrons from the first dynode are accelerated towards the second dynode, where more electrons are released and further accelerated towards the next dynode and so on. The output signals are taken at the anode.

Light guide or light pipe is used to avoid loss of emitted photons from the scintillating crystal. The light collection affects the energy resolution of a scintillator. An efficient detector must collect as many of the emitted photons as possible and transport them to the PMT photocathode. Because the scintillation light is emitted in all directions, light may be lost through the sides and front face of the scintillator or by being reflected back to the scintillator when it hits the window of the phototube, hence only a limited fraction can travel directly to the PMT. See figure 3.

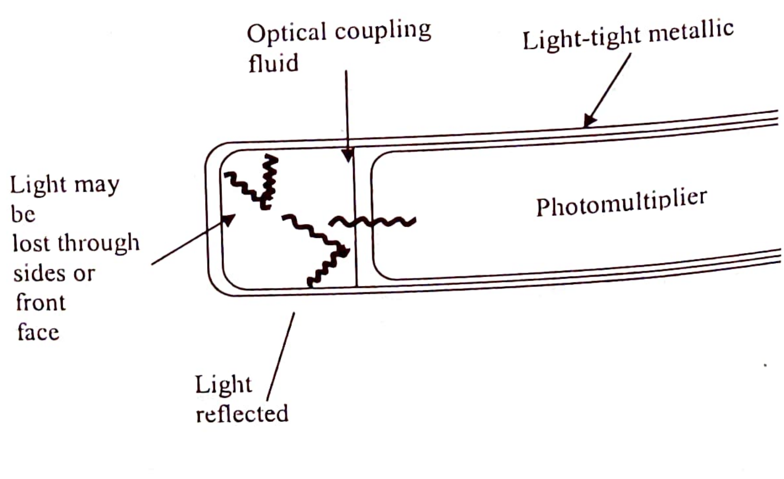

***Figure 3.** Light emitted by the scintillating crystal.*

To maximize the light collection, scintillating light must be reflected one or more times at the scintillator surfaces. The scintillating crystal must be wrapped with a reflector except the surface at which the PMT is to be mounted. Light guide or light pipe is used to physically couple the scintillator to the PMT and to act as a guide for the scintillation light.

B. Data Acquisition Apparatus

After the NaI(Tl) and CsI crystals are coupled to separate photomultiplier tubes they are tested individually using the standard nuclear physics instrumentation called **Nuclear Instrument Module (NIM)**.

Nuclear Instrument Module or **NIM** is a modular system, which was established in 1964 for nuclear and high-energy physics. This is used to extract information about the signal derived from the incident radiation. The basic electronics apparatus such as discriminator, and scaler that were used in this study were constructed in the form of modules in accordance to the standard mechanical and electrical specifications. **NIM**'s basic function is dependent upon the combination of modules used. Researchers use these modules to assemble a system, which meets the requirement of their study.

Discriminator is a NIM module that is use to block low amplitude input signals. This device responds only to input signals with pulse height equal or greater than its threshold voltage. The threshold voltage is a specific voltage value set in the discriminator to eliminate electronic noise and to reject unwanted signals. Only pulses with height equal or greater than the threshold voltage will pass through the discriminator. It will provide a rectangular pulse on its output that can trigger the scaler.

The scaler is also a NIM module that records and displays the number of pulses coming from the discriminator. The scaler adds one count to the previous total counts as the incoming signal enters it. The total number of pulses recorded is displayed at the end of the counting period.

Research Design and Methodology

A. Scintillator Detector Assembly

1. The NaI(Tl) and CsI crystals were coupled separately to the photomultiplier tubes using OKEN 6262A optical grease with index of refraction of 1.12 at 25°C. The NaI(Tl) crystal was coupled to RA 7880-type PMT while CsI crystal to RB 6431-type PMT. The scintillator was wrapped loosely in aluminum foil to maximize internal reflection. The detector, which is the combination of the crystal scintillator and the photomultiplier was then wrapped properly in black electrical tape. The wrapping was in such a way to insure that there is no light leak in the detector.

2. We can see that the detector is working if the detected radiation produces a signal viewed through a 100 MHz oscilloscope. The set-up is shown in Fig. 4, below. When the output signal from detectors does not look like as in Fig. 5, check for possible light leaks and wrap again.

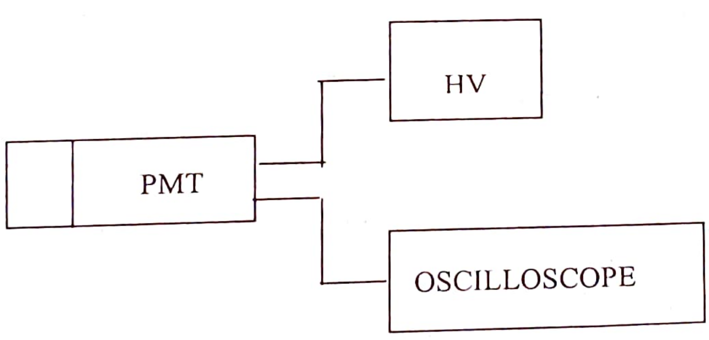

Figure 4. Viewing the detector signal with an oscilloscope.

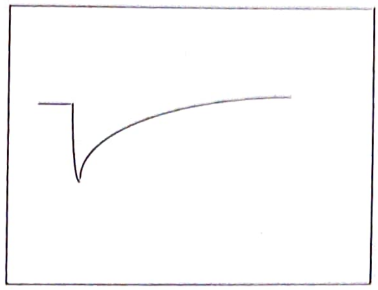

Figure 5. Anode signal viewed from oscilloscope.

3. The PMT working voltage for each detector was determined using the plateau measurement which involves measuring of the total count rate from the scaler as a function of the applied voltage. The set-up for the measurement is shown in Fig. 6. High Voltage (HV) source was set first at minimum voltage and the number of counts from the scaler was recorded. This procedure was repeated as the voltage is increased in desired uniform increment.

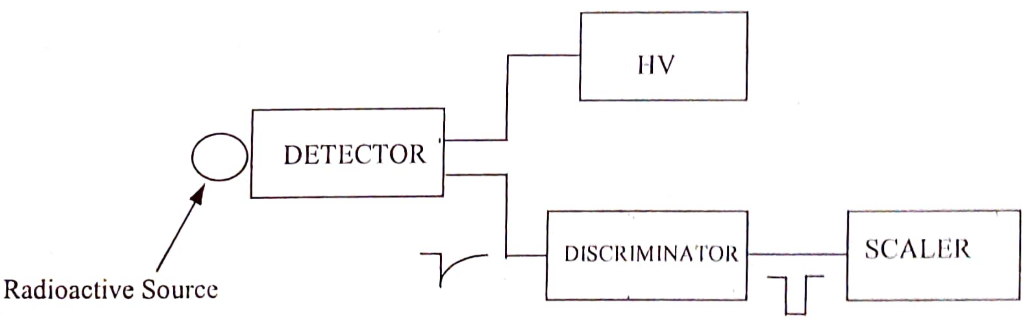

Figure 6. Set-up for plateau measurement.

Data

The working voltage of a scintillator detector should be known first before it can be used. This is determined by doing counter plateau measurements. The results are shown in figures 7-12. From the plots, it can be seen that few counts are registered when the HV source was set at low voltage, then it rises sharply as the voltage increases. However the number of counts becomes almost steady at a higher voltage range; the so-called counter plateau. The PMT working voltage is then set at the middle part of the plateau. The graphs also showed that the operating voltage of each detector depends on the discriminator's threshold voltage and the radioactive source used.

NaI(Tl) and CsI detectors counter plateaus were determined using cobalt 60 (Co60) as source with variable threshold voltage. In figures 7 and 8, the plateaus were observed only at lower threshold voltage (-300mV to -1000mV) because at higher discriminator level (more than 1V), no plateau was formed.

Different counter plateaus were also obtained using different sources at –315mV and at –400mV discriminator's threshold voltage in both detectors (Refer to figures 9-12). In figures 9 and 10, NaI(Tl) detector's operating voltage for gamma source is 1750V at –315mV DTV(discriminator threshold voltage), and 1800V at –400mV DTV. For beta source, working voltage for the same detector was 1600V for both –315mV and –400mV DTV.

The CsI detector's on the other hand has an operating voltage of 2000V for gamma sources at –315mV and at –400mV DTV as shown in figures 11 and 12 . For beta source however, only Sr 90 source formed a plateau and its working voltage is at 2000V for both at –315mV and –400mV DTV.

Figures 7 and 8 show the response of each detector with varying thresholds for the same source. Figures 9 and 10 (corresponding to two thresholds) on the other hand give the counter plateau for various sources using a NaI(Tl) scintillator. Figures 11 and 12 give the corresponding counter plateaus for different sources using a CsI scintillator.

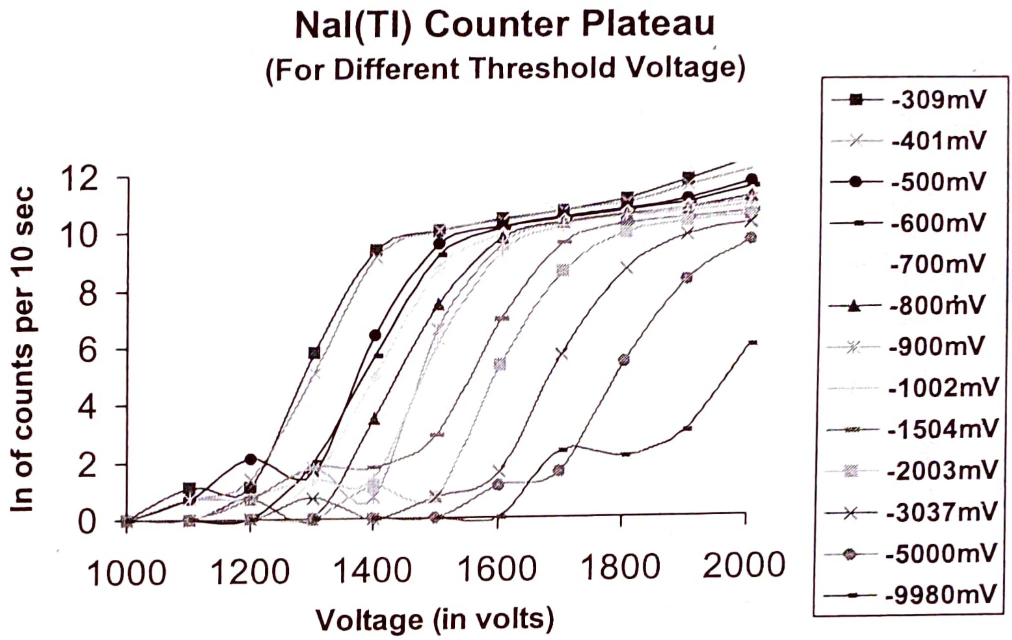

Figure 7

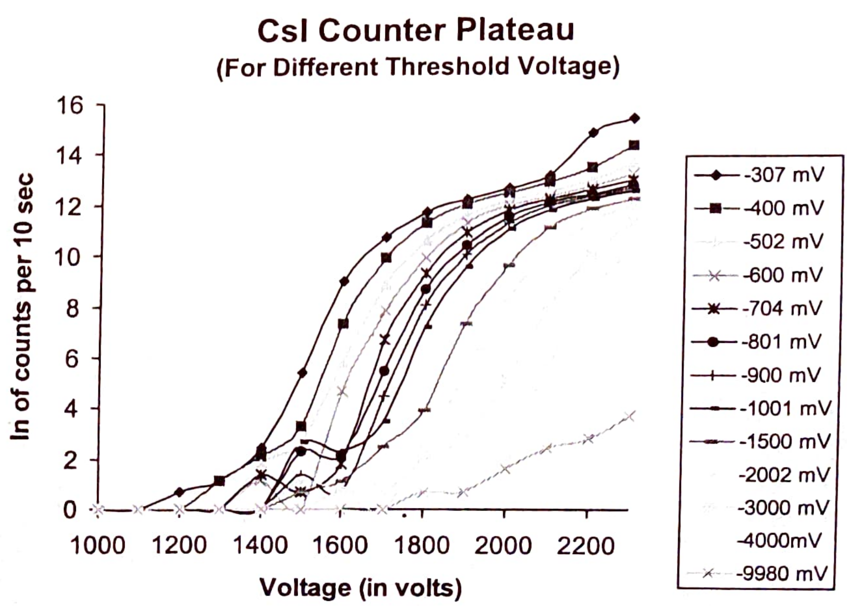

Figure 8

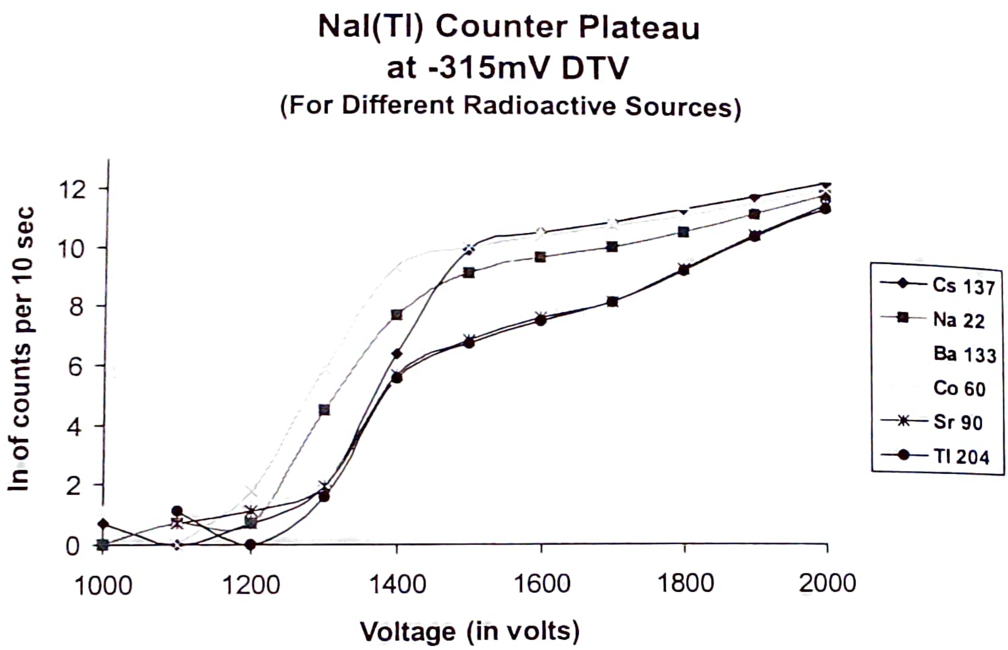

Figure 9

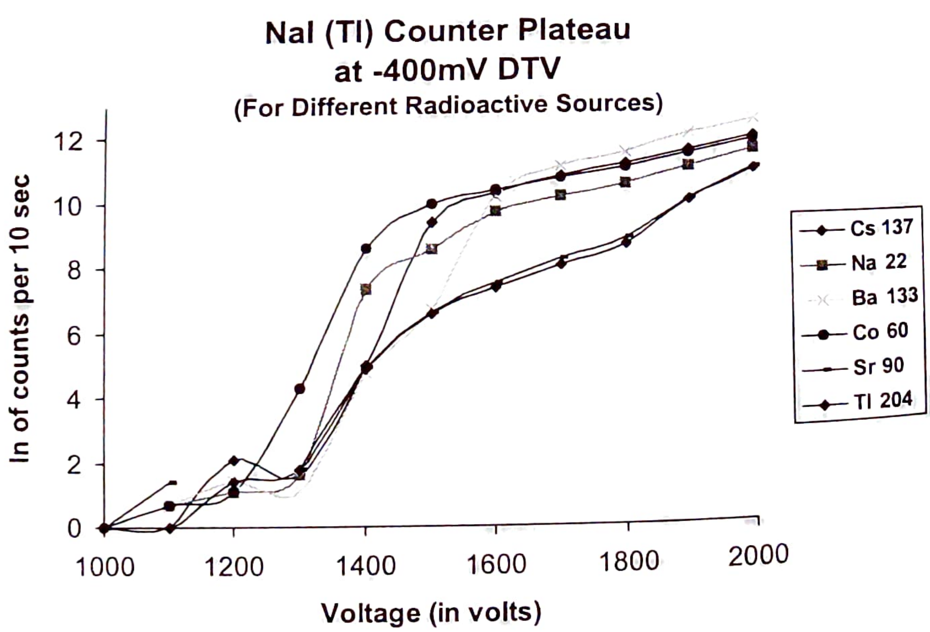

Figure 10

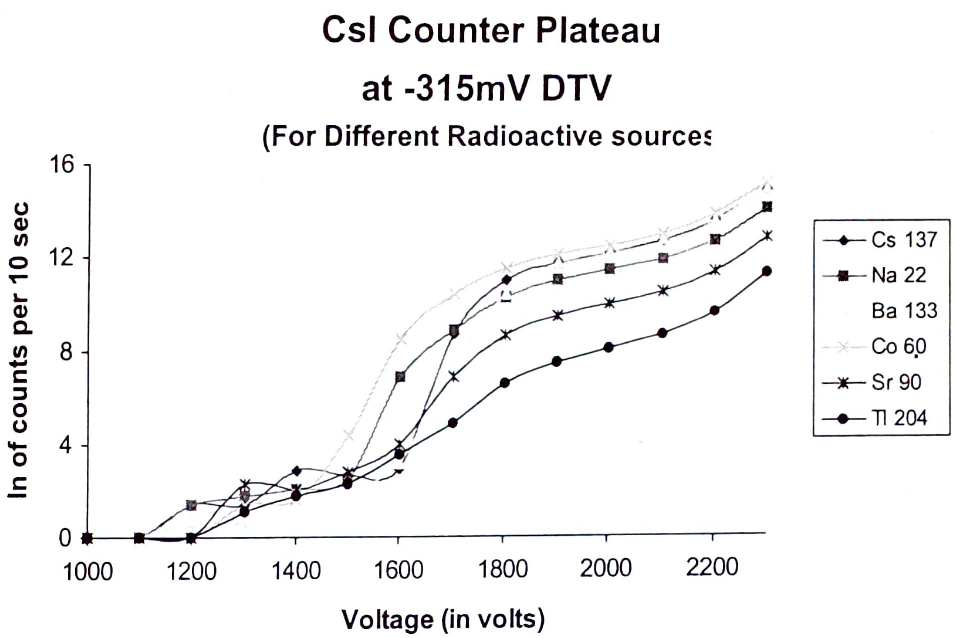

Figure 11

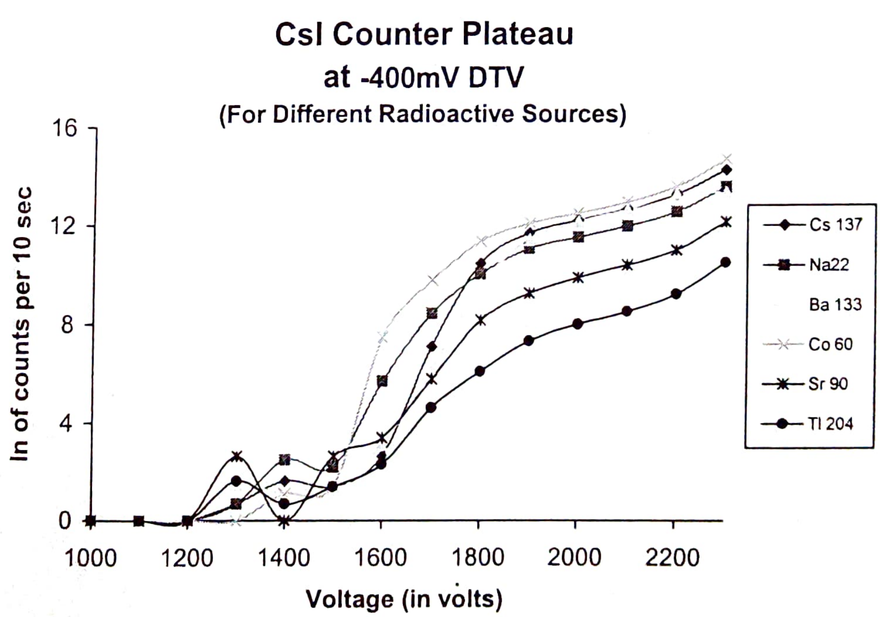

Figure 12

Conclusion / Recommendation

Based on the data gathered, the detector's operating voltage depends on the radioactive source used, the discriminator's threshold voltage and the type of scintillating crystal used. Hence, it is recommended that the discriminator threshold voltage and the radioactive source used should be the same throughout the actual experiment to be able to achieve good results in radiation measurement.

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