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DETERMINATION OF DEAD TIME OF A G-M COUNTER USING TWO SOURCE METHOD

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ABSTRACT

This study investigates the dead time of a Geiger–Müller (GM) counter and examines how counting losses arising from detector dead time influence measured count rates. The research question addressed is whether the two-source method can reliably determine the dead time of a GM counter operating under a non paralyzable model. The dead time was determined experimentally using two gamma-emitting radioactive sources, ^{137}Cs and ^{133}Ba. Count rates were measured for each source individually and for the combined sources at a fixed operating voltage of 520 V. Twenty independent measurements were taken for each configuration over a counting interval of 60 seconds. Statistical parameters including average counts, standard deviations, and count rates were evaluated to assess counting losses and the randomness of nuclear decay. The results show that the observed count rate for the combined sources was consistently lower than the sum of the individual count rates, confirming the nonlinear nature of dead time effects in the GM counter. Using the two-source dead time equation for a non paralyzable system, the dead time of the GM counter was calculated to be 31.40 ms. Statistical analysis further revealed inherent fluctuations in the measurements, consistent with the random nature of radioactive disintegration. It is concluded that the two-source method provides a reliable and effective approach for determining the dead time of a GM counter, and that the measured dead time is consistent with values reported in related studies, while remaining dependent on experimental conditions and counting rate.

Keywords: Geiger muller counter, Dead time, Double source, Radiation detection, Nuclear instrumentation

INTRODUCTION

For more than a century, the Geiger–Müller (GM) counter has been used in radiation detection since its development by Hans Geiger and Walter Müller in the 1928 (Vinayak, 2021). It has served mostly as one of the first equipment for introductory exposure of learners, researchers and technologists to radiation detection. It however lacks the reputation of a measuring instrument known for accuracy and precision.

It is a simple to construct device able to detect ionizing radiation such as alpha, beta, neutrons, and gamma radiation with high amplification of up to 10^{10}. It is also quite insensitive to small voltage fluctuations. Thus, since the charge amplification process is significantly enhanced its signal-to-noise ratio, there is often no necessity for subsequent electronic amplification. Its simplicity imply that it serves very suitably as portable instrumentation with high sensitivity and simple counting circuit with and ability to detect low-level radiation.

They are generally more sensitive to low energy and low-intensity radiations than their proportional or ion chamber detectors counterparts. For example, typical GM counter sensitivity ranges between 300-800 millivolt, while the input sensitivity of a typical proportional survey instrument is 2 millivolts. Comparatively, this imply that the GM counter is between 99.33% to 99.75% more sensitive than the proportional survey meters.

Major limitations of the GM Counter system include inability to identify radiation and dead time. The lack of capacity for particle or radiation identification is due to its poor energy resolution such that pulse height is independent of the type and energy of radiation and thus making discrimination impossible. In GM Couter measurement, there is no information on the nature of the ionization that caused the pulse such that the detectors cannot discriminate against different types of radiation such as Alpha (α), Beta (β), Gamma (γ), Neutron (n) or the various associated radiation energies. This is fundamentally because the size of the avalanche in a GM Counter is independent of the primary ionization which created it.

Another very significant drawback is the Dead Time. As a result of the large avalanche induced by any ionization, a GM Counter takes a long time (about 1 ms) to recover between successive pulses. Therefore, Geiger counters cannot measure high radiation rates due to the "dead time" of the tube.

Thus, a minimum time interval between consecutive events is necessary for the device to record two separate radiation events. The system is unresponsive to incoming radiation during this short time, which is referred to as the detector dead time. As a result, any radiation incident on the detector that takes place during this time frame is erased from the count since it is not recorded (Knoll, 2010; Lee and Gardner, 2000). The GM counter therefore requires a specific amount of time to reset and prepare for the subsequent count after a count has been recorded. The detector is not working while this reset is taking place. As a result, the measured activity does not accurately represent the sample's actual activity. When dead time is present, observed signals are frequently significantly reduced, especially when the radiation source intensity is high (Müller, 1973).

To address this challenge, radiation measurement researchers have adopted the approach of quantifying the dead time and compensating or making adjustment for it. Moon developed the two-source method to measure a detector system's dead time (Moon, 1937). Various scholars have also suggested a number of methods to improve and modify the Geiger-Müller counter's dead time determination (Akyurek et al., 2015; Arkani, and Khalafi, 2013; Yousaf et al., 2015).

Among these methods, the two-source method and the fading source method are two popular techniques for calculating a radiation detection system's total dead time. Source intensity has a significant impact on the two-source method's accuracy; higher intensities typically result in more accurate dead-time estimation. Detector statistics, however, depart from the Poisson distribution due to higher counting losses at unreasonably high counting rates (Lee, and Wang 2015).

According to the detector's paralyzable and nonparalyzable response, there are two popular dead time models (Knoll, 2010). The true count rate n predicted by the two models can be written as follows if the system's dead time is τ and the measured count rate is m.

Nonparalyzable $n = \frac{m}{1-mr}$ (1)

Paralyzable model $m = ne^{-n\tau}$ (2)

As a very popular dead time measurement strategy, the two-source technique is based on counting rates from two sources, both separately and together. The observed rate owing to the combined sources will be lower than the sum of the rates due to the two sources counted separately since the counting losses are nonlinear. Thus, the dead time can be computed from the difference.

Several workers have attempted different approaches in quantifying dead time of GM counters. Pham and Trinh (2024) used a ST360 GM tube to measure count rates from Sr-90 and Cs-137 sources in order to determine the dead time of a Geiger–Müller counter using the two-source approach (Pham, and Trinh, 2024). They reported a dead time of τ=141.5±11.8 µs based on counting intervals of 300 s. Instead of using alternate gamma-only source pairs, the study used a combination of beta (Sr-90) and gamma (Cs-137) emitters. It also did not evaluate the suitability of paralyzable versus non-paralyzable models or investigate the method's validity in other counting-rate regimes. Almutairi and coworkers calculated a wide range of operating voltages using a GM counter and found an odd correlation between the operating voltage and the deadtime of the detector (Almutairi et al., 2020).

In the study, there was a noticeable decrease in deadtime in the low voltage range, with values as low as a few microseconds (22 µs for ^{204}Tl, 26 µs for ^{137}Cs, and 9 µs for ^{22}Na). Reduced recombination with rising voltage may be the cause of this abrupt decrease in deadtime. Deadtime typically grow quickly after the lowest point, reaching a maximum of 292 µs for ^{204}Tl, 277 µs for ^{137}Cs, and 258 µs for ^{22}Na. The on-set of charge multiplication is mostly to blame for the sharp rise in deadtime. Following the maximum deadtime values, the deadtime decreased exponentially, reaching an asymptotic low where the operating voltage advised by the manufacturer is found. All examined sources, with the exception of ^{54}Mn, exhibited this deadtime voltage dependence pattern. The data supplied here is not used for any conclusion, and low count rates resulting in a negative deadtime revealed that the data obtained for ^{54}Mn had poor statistical quality.

In order to ascertain the Dead Time and Randomness of Nuclear Disintegration Using Two Radioactive Sources ^{60}Co and ^{90}Sr, Abbas et al. (2020) also employed a GM counter. Their findings indicate that the dead time of the GM counter was 22 ms. For the radiation activity of the ^{60}Co source, the value of the Standard Deviation residual (σ residual), which represents the experimental mean square deviation, was found to be 15. This value was then compared with the theoretically expected standard deviation (σ expected) of 15.71 in order to comprehend randomness of nuclear disintegration. With a 5% Relative Standard Deviation (RSD) error, these numbers show a correlation between the two values. A comparison was made between the estimated value of the standard error residual (δ residual) of 3.35 and the expected standard error value (δ expected), which was 3.51. Because nuclear decay is unpredictable, the values were consistent with a 5% relative standard deviation error.

In his nuclear experiment, Lovine (Lovine, 2019) also measured the dead time of a Geiger Muller counter. Using the two-source approach with two 10 µCi ^{137}Cs sources. It was found that the detector's dead time was 165µsec.

A thorough examination of the Geiger Mueller counter deadtime dependency on operating voltage for four pairs of radiation sources using the two-source approach over a broad range of operating voltages was published by Almutairi (2020). The investigation found an unusual correlation between the detector deadtime and the operating voltage. In the low voltage range, there was a noticeable decrease in deadtime of as little as 9 µs, followed by an increase of up to 292 µs in the various sources. The quick spike most likely signifies the beginning of charge multiplication, whereas the sharp drop signals decreased recombination with rising voltage. After the peak deadtime values, according to this unusual but repeating general deadtime behaviour, the deadtime decreased exponentially, reaching an asymptotic low when the suggested operation voltage dropped. After a range of nearly constant values, the deadtime decreased to a low at (650–680) V before rising back to a maximum value in the (700–750) V range.

Given the general behaviour of the regions of gaseous ionization and charge multiplication in gas-filled detectors, the observed decline, quick rise, and final exponential fall of deadtime may be explained. Following initial ionizations, free electrons and positive ions float and disperse at extremely low voltage before being gathered. At these low voltages, the count rate is low, and not all the events are recorded mainly due to the recombination of positive ions and electrons as can be illustrated with the different types of interactions of charged species in Gas Filled Detector presented in Figure 1.

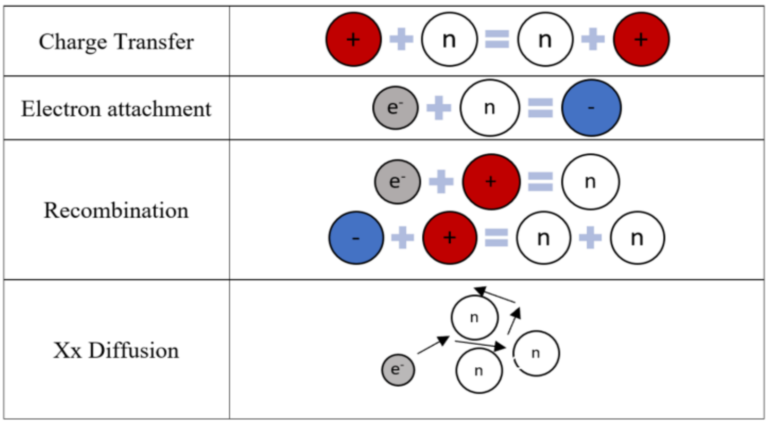

Figure 1: Different Types of Interactions of Charged Species in a Gas Filled Detector (Knoll, 2010)

Positive ions are represented by + circles, negative ions by – circles, neutral atoms or molecules by n circles, and electrons by e-circles. Left Hand Side (LHS) of the equations are interacting components; Right Hand Side (RHS) are the product of interactions. Count rates are observed to increase and deadtime to decrease when the voltage rises from these minimal values.

Deadtime reduction is caused by a shorter collection time as voltage increases. When the collecting time is at its lowest without any appreciable charge multiplication, a minimal deadtime is obtained. Because of the high drift velocity, raising the voltage further causes charge multiplication, which in turn affects electron energy. Deadtime grows as a result of the collecting time increasing because each generated pulse is the aggregate of more charge carriers. The lack of proportionality is the reason for the observed increased association between deadtime and operating voltage. Deadtime cannot be increased further since proportionality has been lost. It begins to diminish exponentially with increased applied voltages after the maximum is reached. No appreciable extra charge multiplication occurs when the voltage is increased further. Conversely, raising the voltage shortens the collection period, which lowers deadtime. This range exhibits the well-known exponential behaviour. In the study by Almutairi (2020), a low asymptotic value of deadtime is noted at 900 V, the detector's recommended operating voltage.

In this study, efforts have been made to determine the Dead Time of a laboratory Geiger Muller Counter with brand LIC-GM-2 using the Non paralyzable method.

MATERIALS AND METHODS

In the current study, the ^{137}Cs and ^{133}Ba are the two sources utilized for the non-paralyzable approach, and they are positioned a specific distance away from the GM tube, Recep, power supply, and digital multimeter. The GM Counter is the system that was used to record the intensity entrance into the Geiger Muller tube. The dead time is calculated using the two-source approach, which combines the counting rates of two separate sources. This method is achieved using the formula for the non paralyzable method.

$$\tau = \frac{CPS_{137Cs} + CPS_{133Ba} - CPS_{137Cs+133Ba}}{2 \times CPS_{137CS} \times CPS_{133Ba}} \quad (3)$$

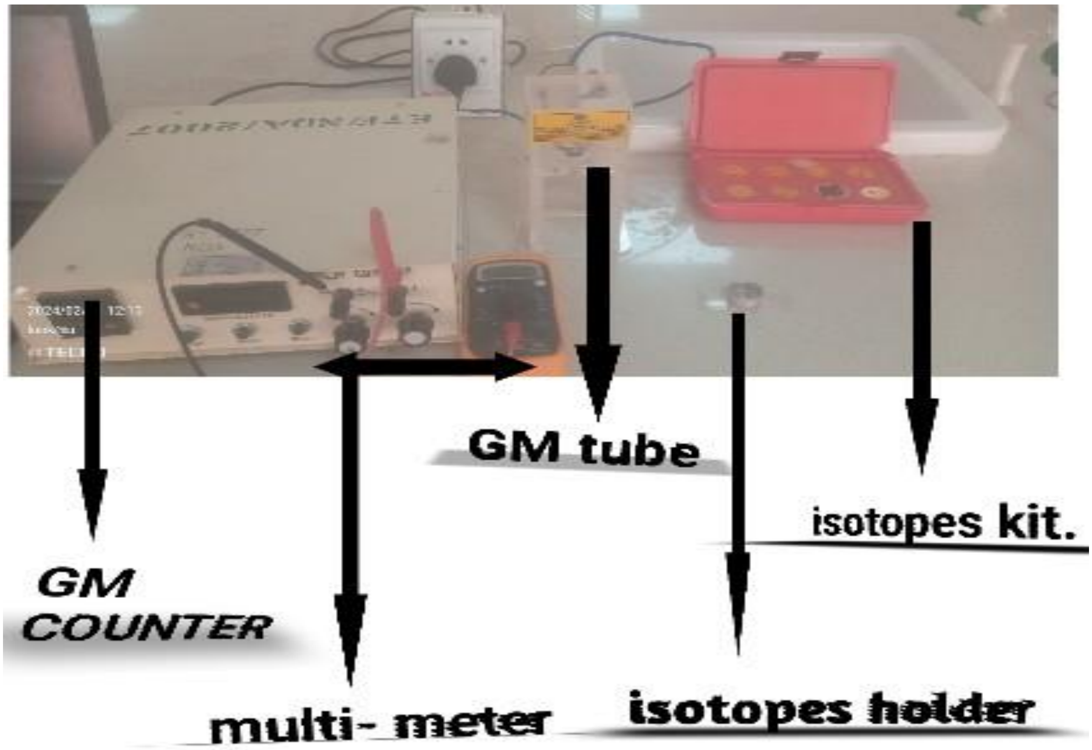

Figure 2: Experimental Setup for Dead Time Measurement

The Geiger Muller counter was set up as shown in Figure 2 above. It operating voltage was determined as 550V After taking readings for a predetermined 60 seconds, source S1 is placed in one of the pits in the source holder, removed, and replaced with source S2, for which measurement is then repeated for an additional 60 seconds. For the combined source S1 and S2, a preset time of 60 seconds I also used. Twenty (20) separate counts for each of these methods were taken with each reading taken in 60 second.

RESULTS AND DISCUSSION

Table 1 presents Counts (N) from using the Two Source Dead Time Determination method with the GM counter at Operational Voltage V_o = 520 V and Count Time T_N = 60 Seconds.

Table 1: Measured Counts from Two Source Method for Dead Time Measurement

Observation	^{137}CS	^{133}Ba	^{137}CS+^{133}Ba
1	254.00	126.00	347.00
2	258.00	125.00	350.00
3	241.00	120.00	328.00
4	252.00	123.00	342.00
5	259.00	125.00	351.00
6	255.00	126.00	348.00
7	256.00	122.00	345.00
8	258.00	122.00	347.00
9	255.00	124.00	346.00
10	260.00	125.00	352.00
11	251.00	123.00	341.00
12	262.00	125.00	354.00
13	250.00	126.00	343.00
14	255.00	125.00	347.00
15	255.00	123.00	345.00
16	268.00	123.00	358.00
17	231.00	123.00	321.00
18	262.00	126.00	355.00
19	250.00	125.00	342.00
20	255.00	122.00	344.00
Average Count (N_{AV})	254.35	123.95	345.30
Standard Deviation (N_{SD})	7.64	1.66	8.32

The results given was taken from utilizing ^{137}Cs, ^{133}Ba, and ^{137}Cs+^{133}Ba for the determination of 20 different counts obtained in 60 seconds each. The Two Source Method employed for this experiment is based on observing the counting rate from two sources separately and in combination. Next, the Standard Deviation (NSD) and Average Counts (NAV) for ^{137}Cs, ^{133}Ba, and ^{137}Cs+^{133}Ba are calculated.
From Table 1, the nonlinear nature of counting losses whereby the observed rate due to the combined sources is less than the sum of the rates due to the two sources counted individually as can be accommodated using the two-source approach can be noted. In this way, the dead time can be calculated from the discrepancy of these data. Furthermore, the random nature of radioactive decay can be noted in the measurement which shows statistical fluctuations down the table and reflects in the difference in the computed Standard Deviations (N_{SD}) where N_{SD} - ^{137}Cs = 7.64; N_{SD} – ^{133}Ba = 1.66; and N_{SD} – [^{137}Cs+^{133}Ba] = 8.32. This is made clearer in Table 4.3 when the Percentage Difference of the Standard Deviation (ΔSD%) as defined by Equation 4 is determined for the Arithmetic Sum of the Standard Deviation for the two sources given as N_{SD} -^{137}Cs + N_{SD} - ^{133}Ba and the observed Standard Deviation for the two sources combined, N_{SD} – [^{137}Cs+^{133}Ba].

$$\Delta SD\% = \frac{[N_{SD} - {}^{137}Cs + N_{SD} - {}^{133}Ba] 〚 - [N〛_{SD} - [{}^{137}Cs + {}^{133}Ba]]}{〚\boldsymbol{Mean}\ \{[N〛_{SD} - {}^{137}\boldsymbol{Cs} + \boldsymbol{N_{SD}} - {}^{133}\boldsymbol{Ba}] | 〚(N〛_{SD} - [{}^{137}Cs + {}^{133}Ba])\}} \quad (4)$$

Table 2: Determination of Percentage Difference of Observed Standard Deviation in the Two Source Method

	N_{SD}
N_{SD} - ^{137}Cs + N_{SD} – ^{133}Ba	9.30
N_{SD} – [^{137}Cs+^{133}Ba]	8.32
Percentage Difference ΔSD% (%)	11.12

The NSD's 11.12% Percentage Difference amply demonstrates how inevitable the inherent fluctuations in nuclear measurements are. The value aids in processing nuclear counting experiment findings and forecasting the anticipated accuracy of measurement-derived values. For a large number of individual measurements, the deviation of the individual count rates from the average count rate behaves in a predictable way such that small deviations from the average are much more likely than large deviations, even though each measurement representing the number of decays in a given interval for a radioactive sample is independent of all previous measurements due to the randomness of the process.
In Table 3, the Count Per Second (CPS) has been calculated and reported for the three components in the measurements of the two-source method.

Table 3: Count Rate Calculated for the Components of the Two Source Method

Sources	N_{AV}	CPS
^{137}Cs	254.35	4.2392
^{133}Ba	123.95	2.0658
^{137}Cs+^{133}Ba	345.30	5.7550

$$\tau = \frac{CPS_{137Cs} + CPS_{133Ba} - CPS_{137Cs+133Ba}}{2 \times CPS_{137Cs} \times CPS_{133Ba}} \quad (5)$$

$$= \frac{4.2392 + 2.0658 - 5.7550}{2 \times 4.2392 \times 2.0658} = \frac{0.5500}{17.5147} = 0.0314s = 31.40ms$$

The Dead Time of this particular GM counter obtained as 31.40 ms compare well with Abbas (2020) and Almutairi et al. (2020)

CONCLUSION

Th calculated dead times of τ = 31.40 ms for the GM Counter has been determined based on the measured count rates. This finding supports the idea that a GM counter's true dead time depends on the counting rate. When compared to other published values, such as the 22 ms (Almutairi et al., 2020) the value shows good agreement. It should be noted however that proposals of the dependence of the deadtime on other fixed parameters, including the operational voltages (Abbas et al., (2020) will provide further insight into the quaitification of dead time for enhanced use of the Geiger Muller Counter.

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