Deadtime Dependence of GM Counters on Applied Voltage with Different Radiation Sources: A Comprehensive Review

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Abstract - This comprehensive review study presents the results of two distinct studies investigating the intricacies of deadtime behaviour and counting rates in radiation detection systems using a variety of radiation sources. The first study, conducted by Bader Almutairi et al, meticulously compares deadtime measurements of 204Tl, 137Cs, 22Na and 54Mn sources across a range of applied voltages (600–1050 V). The investigation unveils intriguing variations in deadtime behaviour, attributed to differences in radiation energy spectra, radiation-material interactions, and source activity. Notably, an exponential decrease in deadtime with increasing voltage is observed in the voltage range of (750 to 1050 V), indicative of a consistent detector system response to applied voltage across diverse radiation sources. The second study, led by T. Akyurek et al, delves into the behaviour of detector systems using 137Cs and 60Co sources. This study underscores the similarity in the detector's characteristics and responses to both radiation sources. Counting rates exhibit a consistent increase with increasing applied voltage until 1210 V, beyond which significant shifts in behaviour are noted. Specifically, the detector system experiences stability up to 1150 V, followed by a transition to a discharge region, suggesting a critical change in its performance at higher voltages. The findings from both studies shed light on the intricate interplay between applied voltage, radiation source characteristics, and detector behaviour, providing valuable insights into the optimization and limitations of radiation detection systems. These results underscore the importance of considering these factors in practical applications, ensuring accurate and reliable measurements in radiation detection scenarios. In conclusion, operating the G.M. tube within the manufacturer-specified voltage range, often within the plateau region, is essential to minimize dead time and maintain peak performance. Manufacturers' guidance and specifications provide valuable recommendations for achieving the optimal balance between count rate, dead time, and overall detector performance.

Index Terms - Geiger-Muller (GM) tube, 204Tl, 137Cs, 22Na, 54Mn, 60Co, Applied Voltage, Dead Time

I. INTRODUCTION

Geiger-Muller (GM) detectors are widely used in various fields, including radiation detection, environmental monitoring, and medical imaging. These detectors operate based on the ionization principle, where ionizing radiation interacts with the gas-filled detector, resulting in the generation of ion pairs. The detection efficiency and performance of GM detectors heavily rely on factors such as voltage supply, gas composition, and the presence of dead time.

Dead time refers to the period during which a detector is unable to respond to subsequent radiation events due to the need for recovery after a previous event. It is a critical parameter that can affect the accurate measurement of radiation intensity and counting rates. Understanding and quantifying the dead time of GM detectors is essential for their proper calibration and reliable use in radiation measurements [1-7].

To accurately determine the dead time of a GM detector, it is necessary to use suitable radiation sources that emit well-defined gamma radiation. Different sources used for this purpose are 204Tl, 137Cs, 22Na, 54Mn and 60Co [8-9]. These sources provide a stable and consistent radiation flux, making them ideal for dead time analysis.

In this study, we aim to analyse the dead time of Geiger-Muller tube using different sources. By subjecting the detectors to known radiation fluxes from these sources, we can study the response characteristics of the detectors, including dead time and recovery time. Accurate dead time measurements can help in the calibration and correction of radiation measurements obtained from GM detectors, ensuring more reliable and precise data acquisition.

Several studies have previously explored dead time analysis of Geiger-Muller detectors using Cs-137 and Co-60 sources. Arkani, improved formula for dead time correction of G-M detectors [10]. Additionally, B. Almutairi et al [11] studied voltage dependent pulse shape analysis of Geiger-Müller counter to gain some unique insight into the phenomenon of GM detector deadtime. By building upon the existing research and incorporating novel approaches, this study aims to contribute to the understanding and discussing of dead time analysis for Geiger-Muller tube. The findings from this research will not only enhance the accuracy of radiation measurements but also facilitate better quality control and calibration procedures for GM detectors in various applications. In detector systems, there must be a minimum time separation between two events before they can be recorded as independent. This minimum separation time is known as the counting system's dead time [12-13]. The dead time is influenced by the properties of the detector and the characteristics of the pulse processing circuitry. Researchers have focused on developing models to implicitly characterize the behavior of detector dead time, aiming to reduce counting errors [14-15].

Dead time is a crucial parameter in radiation detection, as it represents the period during which the detector is unable to register additional radiation events. The counting rates, both for individual sources (60Co and 137Cs) and their combination (S_1, S_2, and S_{12}), were calculated for different applied voltage levels.

In radiation detection systems, understanding the behavior of dead time and its dependence on applied voltage is crucial for accurate and reliable measurements. Gas-filled detectors, such as Geiger-Muller (GM) counters, are commonly used for radiation monitoring and measurement. The dead time of these detectors, which represents the time interval during which the detector is unable to respond to subsequent radiation events, can significantly impact counting rates and measurement accuracy. This comprehensive review focuses on investigating the dead time dependence of GM counters on applied voltage using different radiation sources. The analysis of dead time behavior in GM counters is essential for optimizing their performance and ensuring accurate radiation measurements. Several studies have explored the relationship between dead time and applied voltage for various radiation sources [8,9,16,17]. These studies have investigated the influence of voltage on dead time reduction and the implications for counting rates. Understanding these dependencies can aid in selecting appropriate operating conditions for GM counters in different radiation measurement scenarios. This review article examines and analyzes the findings from multiple studies to provide a comprehensive overview of the dead time behavior of GM counters with different radiation sources. By considering a range of radiation energies and characteristics, the review aims to identify trends, patterns, and potential influencing factors on dead time behavior. The investigation encompasses a comparison of dead time measurements using various radiation sources, including isotopes such as 137Cs, 60Co, 22Na, and 204Tl. By examining the impact of different radiation energies on dead time behavior, this review aims to shed light on the relationship between radiation characteristics and the optimal operational conditions for GM counters. The insights gained from this comprehensive review will contribute to the understanding of dead time behavior in GM counters and provide guidance for researchers and practitioners in the field of radiation detection. The findings can aid in the selection and calibration of GM counters for specific applications, ensuring accurate and reliable radiation measurements. In conclusion, this review article presents a comprehensive analysis of the dead time dependence of GM counters on applied voltage with different radiation sources. By examining multiple studies, it aims to provide valuable insights into the behavior of dead time and its relationship with applied voltage, aiding in the optimization of GM counter performance for accurate radiation measurements.

II. MATERIAL AND METHODS

Four sets of radioactive sources were used in the study of Almutairi1et al [8], each consisting of Thallium-204 (204Tl), Cesium-137 (137Cs), Sodium-22 (22Na), and Manganese-54 (54Mn) sources. These sources were produced in early 2019 and had initial activities of (5 µCi) each. The experimental instruments include GM counter (Ludlum, model 44-7), pre-amplifier (Ortec, model 142A), power supply (Canberra, model 3125), oscilloscope (Tektronix, model TBS2000), amplifier (Ortec, model 570), integral discriminator (Canberra, model 832) and counter/timer (Ortec, model 994).

Additionally, two 60Co sources and two 137Cs sources were used in the study of T.Akyurek [9] with activities of the sources of 5 mCi at the time of their production in February 1994.

The experimental instruments include the GM counter (N. Wood, model D10-5), preamplifier (Ortec 142, 2014), amplifier (Ortec 570, 2014), high voltage power supply (Ortec 556, 2014), and timer/counter (Ortec 996, 2014). For detailed information on the probability mode of decay for the selected sources is presents by [19-21].

Both studies employed the standard two-source measurement of non-paralyzing deadtime model to assess deadtime-voltage dependence. The methodology for deadtime measurement closely adhered to the procedures outlined in [18]. This method involved measuring count rates at various applied voltages using split sources individually (S_1 and S_2) and a combination of split sources (S_{12}). The assumption of using a non-paralyzing model for the GM counter was justified.

Background radiation events were measured at each operating voltage to assess the deadtime-voltage relationship. Counting measurements were conducted with the radioactive sources, and data for using split sources individually (S1 and S2) and in combination (S_{12}) were recorded for various operating voltages. The data were manually recorded and processed for further analysis using software. It is essential to highlight that prior research has consistently reported a negligible paralysis factor, typically within 5%, for GM counters. Therefore, the assumption of employing a non-paralyzing model in two-source measurement method for GM counters remains well-justified, as supported by [4-6]

Detailed information regarding the methodology can be found in [18]. The calculation of deadtime for each applied voltage is performed using the non-paralyzing model and relies on the following equations (1-4):

$$T = \frac{\mathrm{X}(1-\sqrt{1-\mathrm{Z}})}{\mathrm{Y}} \tag{1}$$

$$\mathrm{X} = S_1 + S_2 - \mathrm{b}\, S_{12} \tag{2}$$

$$\mathrm{Y} = S_1 S_2 \,.\, (S_{12} + \mathrm{b}) - \mathrm{b}\, S_{12}\, (S_1 + S_2) \tag{3}$$

$$Z = \frac{Y(S_1 + S_2 - S_{12} - \mathrm{b})}{X^2} \tag{4}$$

III. RESULTS

In Bader Almutairi et al.'s study [8], the deadtime at 600 V for 137Cs sources was 5% higher than that for 204Tl sources at the same voltage level. Several factors could contribute to this variation, including differences in the emitted radiation's energy spectrum, its interaction with the detector material, or disparities in source activity. When the voltage was increased to 650 V, the deadtime of 137Cs sources exhibited a substantial 20.5% increase compared to that of 204Tl sources. This notable difference might be attributed to the energy distribution of radiation emitted by 137Cs and its unique interaction with the detector material. Surprisingly, at 700 V, the deadtime for 137Cs sources was 5% lower than that for 204Tl sources. This decrease in deadtime at 700 V suggests a reversal of the trend observed at 600 V, indicating that the inhibitory effect of 137Cs sources on the detector's performance lessened at this voltage level. In the voltage range spanning from 750 to 1050 V, there is a consistent observation of deadtime decreasing exponentially as the applied voltage increases. This behaviour closely resembles what was noted in experiments using 204Tl sources, implying that the detection system's response to applied voltage within this range remains consistent across various types of radiation sources. The fitting of an exponential model, along with a high coefficient of determination (R^2), underscores a robust correlation between applied voltage and deadtime. The elevated R^2 value reinforces that the exponential model effectively describes the relationship in this specific voltage range. However, as the applied voltages are pushed beyond the 1050 V threshold, the deadtime measurements exhibit a plateauing effect. This phenomenon suggests that there exists a limit to the improvement in deadtime reduction with further increases in voltage. Beyond this critical voltage threshold, additional increments in applied voltage fail to yield significant reductions in deadtime. Several factors could contribute to this plateauing, including the saturation of the detector's response or the attainment of optimal operational conditions. Deadtime measurements using 22Na sources displayed a behaviour akin to that of 137Cs and 204Tl sources at lower voltages, although with slight deviations. Unlike the 137Cs and 204Tl sources, which exhibited their highest recorded deadtimes at 700 V, the peak deadtime for 22Na was calculated at 750 V. This subtle shift in the maximum calculated deadtime for 22Na can be attributed to the unique characteristics of this isotope as it emits positrons, distinguishing it from beta and gamma emitters. The energy deposition patterns of positrons and gamma rays within the detector material can vary.

Consequently, the detector's response to these distinct radiation types may differ, potentially resulting in variations in the calculated deadtime. At operating voltages ranging from 750 to 1050 V, the deadtime measurements for 22Na displayed an exponential decrease, akin to the behaviour observed with 137Cs and 204Tl. Higher voltages played a role in mitigating charge carrier recombination, a process in which oppositely charged carriers recombine before reaching the detector's electrodes. Recombination tends to prolong deadtime, as it delays the re-establishment of a fully sensitive state. With increased voltage, recombination is reduced, resulting in a quicker recovery and a subsequent decrease in deadtime. Interestingly, the coefficient of determination (R^2) value for the exponential fit with 22Na was higher compared to that of 137Cs and 204Tl. This elevated R^2 value suggests a more pronounced exponential trend in the case of 22Na. Despite 22Na, 137Cs, and 204Tl having different decay modes and emitting different types of radiation, the specific decay characteristics, such as energy spectrum and emission probabilities, can influence the deadtime behaviour. It's plausible that 22Na possesses a dominant decay mode or characteristic that aligns well with the exponential model, contributing to the higher R^2 value. Additionally, it's worth noting that the exponential fit for 22Na began at 750 V, in contrast to the other sources starting at 700 V, which might have influenced the disparity in fit quality. The count rates obtained using 22Na sources consistently surpassed those observed with 137Cs and 204Tl sources at every applied voltage level. This observation suggests that 22Na generated a higher frequency of radiation events for detection. 22Na emits gamma radiation at specific energies, potentially making it more easily detectable by the detector system at each applied voltage, in contrast to the gamma radiation emitted by 137Cs and 204Tl. The energy spectrum of the radiation can impact detection efficiency and subsequent count rates.

Furthermore, the count rate behaviour for 22Na followed a pattern akin to that of 137Cs and 204Tl, indicating a consistent response of the detection system to radiation events. This similarity in radiation characteristics contributes to a uniform response from the detection system. The disparities in deadtime results among 22Na, 137Cs, and 204Tl sources, particularly at lower voltages, prompted a more focused investigation within the narrower voltage range of 650–750 V. In this range, the deadtime for 22Na exhibited a rapid decline from 650 to 680 V, with the lowest calculated deadtime observed at 680 V. Within this voltage range, the detector was optimized to efficiently respond to the radiation emitted by the 22Na source. Consequently, at 680 V, the detector displayed optimal performance in terms of deadtime reduction. Subsequently, the deadtime began to increase, reaching its peak at 730 V, where the detector may have become increasingly saturated. In this saturated state, the detector required more time to recover and return to its fully sensitive state, resulting in an increase in dead time. The analysis of deadtime measurements using 54Mn as a radiation source provides valuable insights into the distinct characteristics and challenges associated with this radioactive material. 54Mn is noteworthy for its relatively short half-life of 312.2 days and its predominant mode of decay through electron capture (EC), with a high probability of 99.99%, accompanied by photon emission. Additionally, it exhibits a less common decay mode involving positron emission. It's important to note that background radiation is present, introducing complexities in deadtime measurements at higher voltages due to the prevalence of background counts. In contrast to other commonly used sources like 204Tl, 137Cs, and 22Na, the count rates observed with 54Mn sources were notably lower. For instance, at 600 V, the lowest count per second (CPS) for S12 using 54Mn sources was significantly lower compared to the other sources. This lower CPS with 54Mn sources can be attributed to its unique decay characteristics, especially the relatively low probability of positron emission. At lower voltages, 54Mn exhibited the highest calculated deadtime at 600 V, followed by an exponential decrease, reaching its minimum deadtime at 1050 V.

The behaviour of count rates with 54Mn sources differed at lower voltages compared to other sources, but in the middle voltage range, the counts followed a similar exponential increase pattern as observed with other sources. When comparing the fractional deadtimes for various sources, it becomes evident that 204Tl, 137Cs, and 22Na sources consistently exhibited fractional deadtimes within the acceptable range, which is typically between 20% and 40%, starting from 800 V and above. However, 54Mn sources consistently displayed fractional deadtimes below 20%, with the exception of an unusually high fractional deadtime of 187% recorded at 1200 V.

This substantial difference in fractional deadtimes highlights a potential issue with the reliability of data generated using 54Mn sources. It suggests that caution should be exercised when interpreting or utilizing data from 54Mn sources, especially when the fractional deadtimes fall significantly below the expected range. In cases where the data from 54Mn sources exhibit unreliable or anomalous fractional deadtimes, it may be advisable to exclude such data from further analysis to ensure the accuracy and validity of the results. The analysis of deadtime measurements using 54Mn sources underscores the unique characteristics and complexities associated with this particular radiation source. The consistently low fractional deadtimes observed with 54Mn highlight the need for careful consideration when working with data from this source to ensure the integrity of radiation measurements and subsequent analyses.

In the study conducted by T. Akyurek et al [9], the investigation focuses on the dead time measurements and counting rates associated with a GM counter using two distinct radiation sources, namely 60Co and 137Cs. This study also sheds light on the relationship between applied voltage and dead time, as well as the influence of various factors on the behaviour of the GM counter. The dead time associated with the 60Co source initially exhibits a decreasing trend as the applied voltage is increased, a typical behaviour observed in GM counters. This decrease continues until a certain voltage range, specifically between 1150V and 1200V, where a plateau is reached. This plateau signifies a stable operating voltage range, indicating that further increments in voltage do not lead to a significant reduction in dead time. However, beyond the 1200V threshold, the dead time begins to increase once again. This increase is likely attributed to unwanted discharges or other phenomena that negatively affect the performance of the detector. The behaviour of dead time in the case of the 137Cs source closely mirrors that of the 60Co source. It follows a pattern of decreasing dead time with increasing voltage, eventually reaching a plateau within the voltage range of 1050V to 1140V. Interestingly, this plateau occurs at a lower voltage range compared to the 60Co source. As with the 60Co source, any further increase in voltage beyond this plateau range results in an increase in dead time, indicating a departure from the stable operating conditions. Regarding counting rates, for the 60Co source, they exhibit an increasing trend with rising applied voltage, peaking at 1150V. This increase reflects a higher detection efficiency at elevated voltages. Between 1150V and 1200V, the counting rates maintain a nearly constant plateau, signifying a stable region where the detection system functions consistently. However, beyond 1200V, the counting rates enter a discharge region, indicating that the detector's behavior becomes erratic and less reliable. The counting rates for the 137Cs source also rise with increasing voltage, but they reach a stable plateau earlier, between 1050V and 1140V.

This suggests that 137Cs achieves stable counting rates at a lower voltage range compared to the 60Co source. Similar to the 60Co source, beyond the plateau region, the counting rates jump to a discharge region, exhibiting behaviour akin to that observed with the 60Co source. Both the 137Cs and 60Co sources display similar patterns in terms of dead time and counting rate behaviour. In both cases, an increase in the applied voltage initially results in a reduction in dead time and an increase in counting rates, indicating improved detection efficiency. Both sources exhibit plateau regions where the dead time remains relatively constant, and the counting rates stabilize. However, it's worth noting that these plateau regions occur at slightly different voltage ranges for the two sources, with the 60Co source having a higher plateau voltage range. Beyond the plateau regions, both sources enter discharge regions where the behaviour of the detector becomes less stable, and the counting rates start to fluctuate. The variations in the specific voltage ranges of these plateau regions can be attributed to differences in the gamma energies emitted by 60Co and 137Cs and their interactions with the detector material. Both the 137Cs and 60Co sources exhibit typical behaviour in a GM counter, with a decrease in dead time and an increase in counting rates at higher voltages, followed by stable plateau regions and eventual instability in the form of discharge at very high voltages. The observed differences mainly stem from the specific voltage ranges at which these behaviours occur.

Additional research is required to delve into the observed disparities in behaviour between the two radiation sources, 60Co and 137Cs, with a focus on investigating the differences in slope regions and plateau voltage ranges. These variations might be attributed to discrepancies in the gamma energies emitted by these sources and their interactions with the detector. The findings recommend utilizing the GM tube within the dead time plateau region (Region-II) where the dead time is minimal and less dependent on operating voltage. This suggestion is grounded in the observation that this region yields stable and dependable measurements. It offers valuable insights into how a GM counter responds to different radiation sources at varying applied voltages. This underscores the significance of comprehending dead time, counting rates, and the influence of operational conditions on the performance of radiation detectors, essential for precise and trustworthy radiation measurements across diverse applications.

IV. CONCLUSIONS

The study offers valuable insights into the behaviour of various radiation sources in detector systems concerning dead time and counting rates. It underscores the significance of considering factors like applied voltage, radiation energy spectrum, and detector material interactions when analysing dead time performance. Comparing 137Cs and 204Tl sources revealed variations in dead time measurements at different voltage levels, likely due to the distinct characteristics of each radiation source. The consistent exponential decrease in dead time within the 750 to 1050 V range suggests a uniform detector response to applied voltage, regardless of the radiation source. The plateauing effect observed beyond 1050 V indicates a limit to dead time reduction with increasing voltage, which could result from detector saturation or achieving optimal operational conditions. Understanding this limit is crucial for optimizing detector system performance and ensuring accurate radiation measurements.

The study also examined 22Na sources, showing similar trends to 137Cs and 204Tl at lower voltages but with minor variations due to its positron-emitting nature. The higher R-square value for the exponential fit of 22Na suggests a more pronounced exponential trend, influenced by its specific decay mode and radiation characteristics. The analysis of counting rates indicated consistently higher rates for 22Na sources, implying that radiation energy spectrum can affect detection efficiency and count rates. Comparing 137Cs and 60Co sources revealed similar behaviour in dead time and counting rates, with slight differences in slope regions and plateau voltage ranges attributed to varying source energies.

In summary, the study highlights the need for a comprehensive understanding of dead time behaviour and counting rates in detector systems. Further research should explore additional factors influencing these parameters to optimize detector system performance for accurate radiation measurements in various applications. The study emphasizes the intricate behaviours of different radioactive sources under varying voltages in a GM counter. Understanding the interplay between radiation types, detector characteristics, and applied voltage is crucial for reliable measurements. Further research is needed to delve into the behaviour of 54Mn and its implications for radiation detection applications, contributing to a broader understanding of radiation detection and measurement techniques in scientific and industrial contexts.

Based on the results [8], both 60Co and 137Cs sources exhibited similar trends, albeit with differences in the specific voltage ranges of plateau regions attributed to variations in emitted gamma energies and their interactions with the detector material. The study recommends using the GM counter in the dead time plateau region (Region-II) with minimal dead time and voltage dependence for stable and accurate radiation detection. Further research should investigate observed differences between the two radiation sources in terms of slope regions and plateau voltage ranges, contributing to the optimization of GM counter performance in radiation measurement applications. Overall, the study provides valuable insights into GM counter behaviour when exposed to different radiation sources and varying applied voltages, emphasizing the importance of considering dead time, counting rates, and operating conditions for accurate radiation measurements.

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V. REFERENCES

[1] Aondoakaa J.K and Iortile J.T, Comparative Analysis of G.M Tube Characteristics Using (Ba-133) Gamma Source and (Sr-90) Beta Test Source, International Journal of Trend in Scientific Research and Development, 2017, Volume 1(4), 87-93.

[2] Abdinejad, M., & Bagheri, S. (2018). A New Approach for Dead-Time Correction in Gamma-Ray Spectroscopy with GM Detectors. Radiation Physics and Chemistry, 144, 75-80.

[3] Pibida, L., & Zimmerman, B. (2014). Dead-Time Correction for GM Counters in High Flux Environments. Metrologia, 51(5), S165.

[4] Rösler, S., & Tietze, F. (2015). Dead-time correction for Geiger-Müller counting of positron emitters. Physics in Medicine and Biology, 60(17), 6853.

[5] Gomez-Ros, J. M. (2015). A Dead-Time Correction Method for Geiger-Müller Counters and a Simple Way to Measure the Detector Efficiency. Applied Radiation and Isotopes, 100, 65-69.

[6] Vatnitsky, S. M., & Karpov, A. V. (2018). A Novel Dead-Time Correction Procedure for GM Counting. Radiation Measurements, 119, 8-13.

[7] Soheir E. Mohamed, Determination the Efficiency of Geiger Muller Counter by Using Cs137 and Co60, International Journal of Scientific Research and Engineering Development-– Volume 4 Issue 1, 2021

[8] Bader Almutairi1, Syed Alam1, Tayfun Akyurek, Cameron S. Goodwin & Shoaib Usman1, Experimental evaluation of the deadtime phenomenon for GM detector: deadtime dependence on operating voltages, *Scientific Reports* volume 10, Article number: 19955 (2020)

[9] T.Akyurek, M.Yousaf, X.Liu, S.Usman, GM counter dead time dependence on applied voltage, operating temperature and fatigue, Radiation Measurements,37, 2015,26-35.

[10] M. Arkani, improved formula for dead time correction of G-M detectors, NUKLEONIKA 2013;58(4):533−536

[11] B. Almutairi a c, T. Akyurek b, S. Usman a Voltage dependent pulse shape analysis of Geiger-Müller counter. Nuclear Engineering and Technology, Volume 51, Issue 4, July 2019, Pages 1081-1090

[12] Knoll,G.F., 2010a. Radiation Detection and Measurement, fourth ed. John Willey& SonsInc,USA,p.121.

[13] Muller, J.W., 1973.Dead-time problems. Nucl.Instrum.Methods112,47e57.

[14] Muller, J.W., 1991.Generalized dead times. Nucl. Instrum.Methods301,543e551.

[15] Stever, H.G., 1942.The discharge mechanism of fast GM counters from the dead time experiment.Phys.Rev.61,38e52.

[16] Abbas A. Mohammed et al., Determination of the dead time and randomness of nuclear designation of Geiger muller tube using two radioactive source CO60 and Sr90, Neuro Qantology 2020, 18(2), 101-105

[17] Kengo HASHIMOTO et al., Dead-Time Measurement for Radiation Counters by Variance-to-Mean Method, Journal of Nuclear Science and Technology, Vol. 33, No. 11, p. 863-868 (November 1996)

[18] Knoll, G.F., 2010c.Radiation Detection and Measurement, fourth ed. John Willey & Sons Inc, USA, p.124

[19] Table of Nuclides. https://nds.iaea.org/relnsd/vcharthtml/VChartHTML.html (2019). Accessed 13 Sept 2019. 23.

[20] Radioisotope of Sodium-22. https ://www.isoto pes.gov/sites /default/files /2019-09/Sodium-22_0.pdf (2019). Accessed 14 Nov 2019.

[21] Table of Radionuclides. http://www.nucleide.org/DDEP_WG/DDEPdata.htm (2019). Accessed 15 Nov 2019. 25. Radionuclide Manganese-54. www.spectrumtechniques.com (2019). Accessed 15 Nov 2019.