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PRELIMINARY STUDY OF RADIONUCLIDE STANDARDIZATION BY TDCR METHOD APPLYING A TIME-TO-AMPLITUDE CONVERTER

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ABSTRACT

This paper proposes an alternative to the use of counters for the standardization of radionuclides in a 3-photodetectors liquid scintillation counter by the triple to double coincidence ratio (TDCR) method using an electronic system for processing pulses that allows the subtraction of the accidental coincidences. The electronic system consists of amplifiers, discriminators, logic gates and delay modules feeding a time-to-amplitude converter (TAC) with output to a multichannel analyzer (MCA). This system does not require individual counters for each photodetector and coincident counts contribute to the noise reduction. The method compares 3 different TAC spectra registered in MCA with 4, 3 or 2 peaks obtained from different configurations of the electronic system. For testing the system, a series of measurements with a ^{90}Sr standard solution was performed.

1. INTRODUCTION

Photodetectors can present a significant amount of noise due to thermal noise produced in photocathodes, so the use of a coincidence method is indicated to solve this problem. The triple-to-double coincidence ratio (TDCR) method is one of the techniques widely used in metrology laboratories to radionuclide standardization mainly for β-pure and EC-emitters. With this method it is possible to obtain three different types of double coincidence and one triple coincidence that from physical and statistical models for the photons distribution in a liquid scintillator it is possible to calculate the detection efficiency. [1] [2]

TDCR is an approximation for the efficiency of the sum of double coincidence counts and defined as,

$$TDCR = \frac{T_{exp}}{D_{exp}} \tag{1}$$

where, T_{exp} is the sum of triple coincidences and D_{exp} is the sum of all double coincidences (including triple coincidences). [3] The time-to-amplitude converter (TAC) calculates the time variation between two pulses and assigns a corresponding amplitude to it. From the proper choice of delays, it is possible to choose the amplitude that this coincidence will be counted in the MCA generating a spectrum with 4, 3 or 2 peaks, depending on the choice of electronics configuration.

2. EXPERIMENTAL

Three different configurations of the electronic system for radionuclide standardization by the TDCR method were implemented and, for testing the systems, a series of measurements with a ^{90}Sr standard solution was performed. In all configurations, 10 μs for the full scale of the TAC, corresponding to 8,192 channels in the MCA, was used.

2.1. First Setup: Four-Peak Spectrum

In this first configuration, the electronic system was organized so that four coincidence peaks were presented in the MCA: the first one corresponds to the triple double coincidence peak and the following three peaks to double coincidences. Fig. 1 shows a simplified block-diagram for this configuration.

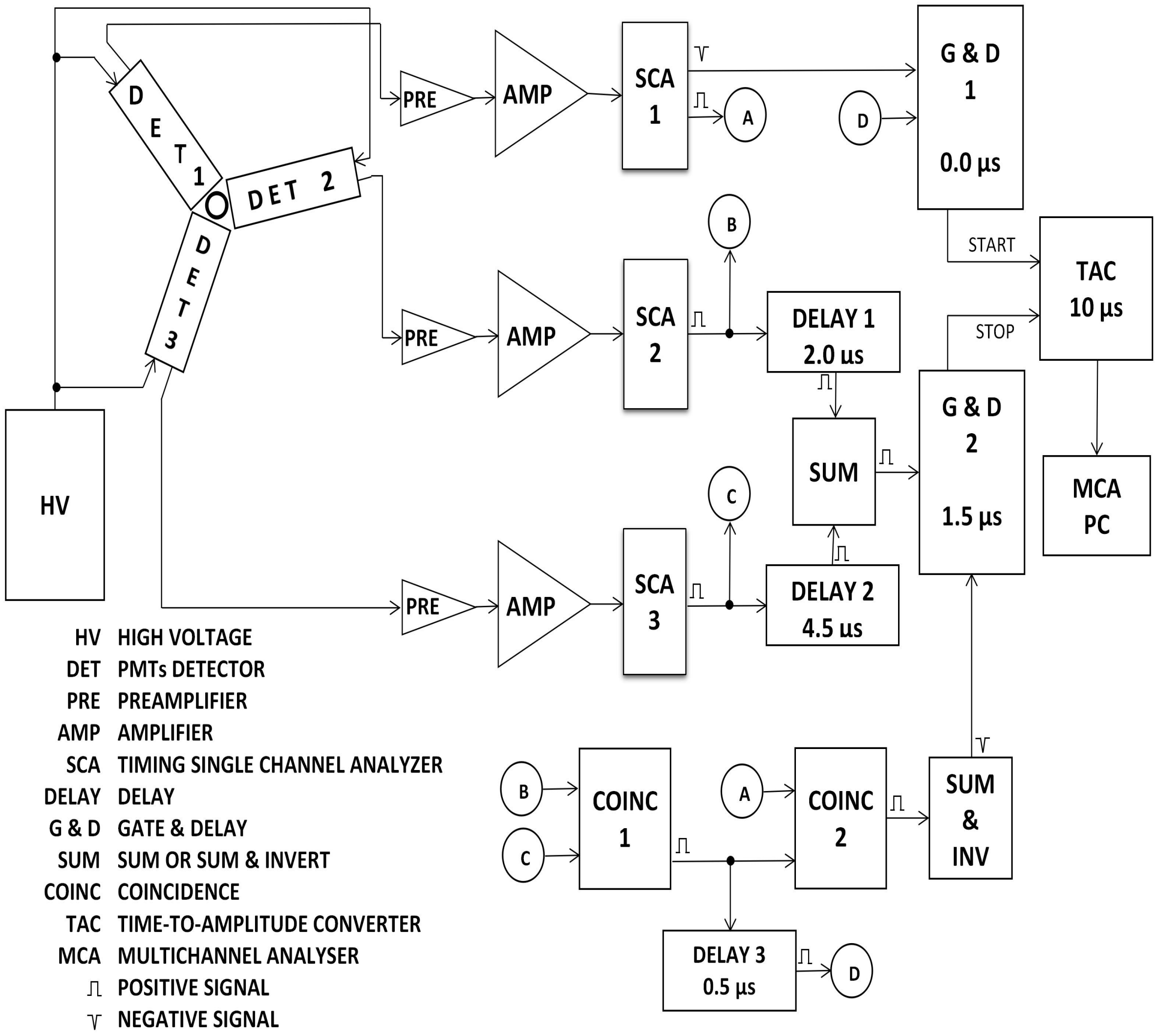

Figure 1: A simplified block-diagram of the TDCR system with three-PMT detector producing four separate coincident peaks.

Table 1 presents the summary of connections among the detectors and the TAC status

Table 1: Summary of connections among detectors and TAC input after delay time in the first setup.

DET	Sum of Delays (μs)	TAC Input
1	0.0	START
2 and 3	0.5	START
1, 2 and 3	1.5	STOP
2	3.5	STOP
3	6.0	STOP

after their respective delay times for the configuration shown in Fig. 1. With this setting it is expected that when an event is detected by the three photomultipliers it will be counted in the channel referring to 1.5 μs in the MCA. The double coincidence between detectors 2 and 3 are counted on the 3.0 μs channel. The coincidence between detectors 1 and 2 are counted on the 3.5 μs channel and the coincidence between detectors 1 and 3 are counted on the 6.0 μs channel. Thus the peak of double coincidences only counts the event when there is no three double coincidences. Therefore in order to apply the TDCR method it is necessary to sum the counts of the four peaks of the spectrum to obtain D_{exp}.

2.2. Second Setup: Three-Peak Spectrum

In the TDCR method it is not necessary to know how many counts there are in each specific double coincidence, but the sum of all of them, so the delays were configured so that the double coincidences were at the same peak. And for this purpose, the first step was to configure the electronic system so that the double coincidences between detectors 1-2 and 1-3 were summed at the same peak (see Fig. 2).

In this second setup the Delay 1 module from Fig. 1 was removed and the signal from the SCA 1 and 2 were summed before entering Delay 2. As a result, it expected that there will be only three peaks in the spectrum for this configuration. Also, in the second setup the Delay 3 module was increased to 2.0 μs when compared to the first setup.

The summary of this setting is presented in Table 2.

Table 2: Summary of connections among detectors and TAC input after delay time in the second setup.

DET	Sum of Delays (μs)	TAC Input
1	0.0	START
2 and 3	2.0	START
1, 2 and 3	1.5	STOP
2 or 3	6.0	STOP

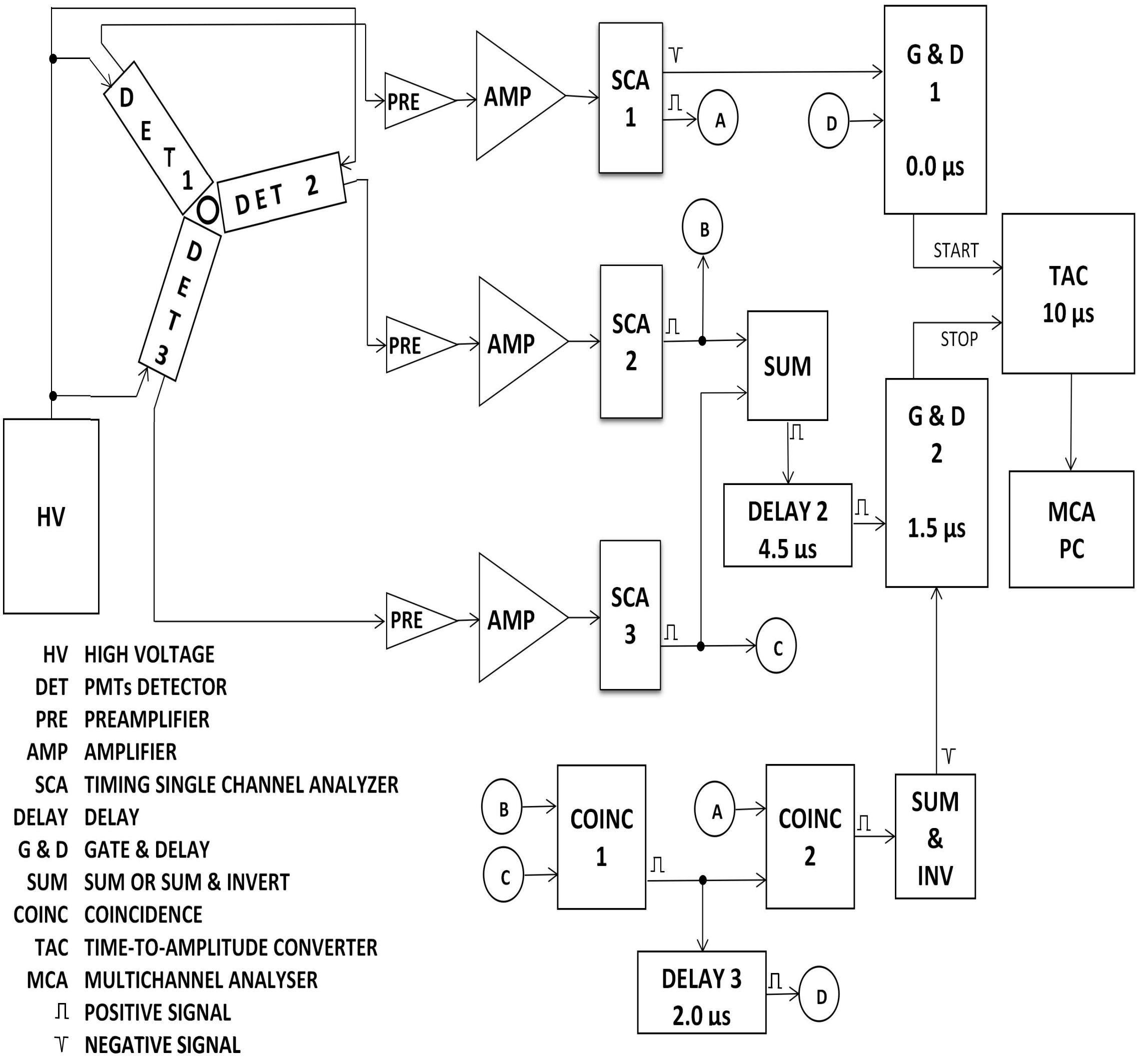

Figure 2: A simplified block-diagram of the TDCR system with three-PMT detector producing three separate coincident peaks.

2.3. Third Setup: Two-Peak Spectrum

In this third setup, the peak formed by the coincidences between photomultipliers 2-3 was added to the peak of the other double coincidences resulting in a two-peak spectrum that will be presented in the results of this work. Compared to the setup shown in Fig. 2, the Delay module 3 was removed, resulting in the scheme shown in Fig. 3. This is the simplest setting for calculating the TDCR value, because all double coincidences are joined at the same peak and the other peak is formed by the triple coincidences. Therefore, a peak represents the value of T_{exp} (which in this setup is represented in the first peak) and the sum of the two peaks results in the value of D_{exp}.

The summary of this setting is presented in Table 3.

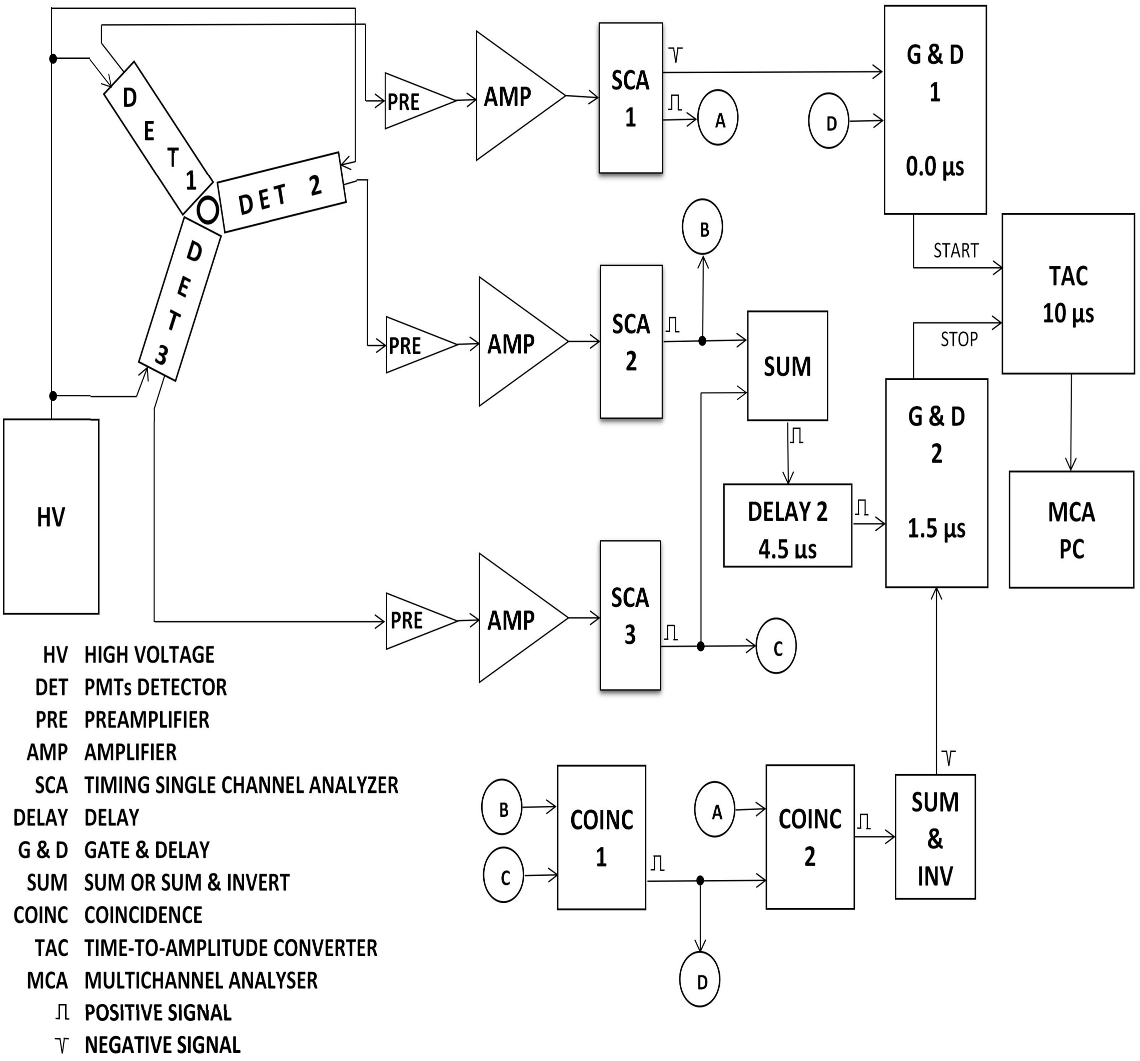

Figure 3: A simplified block-diagram of the TDCR system with three-PMT detector producing two separate coincident peaks.

Table 3: Summary of connections among detectors and TAC input after delay time in the third setup.

DET	Sum of Delays (μs)	TAC Input
1	0.0	START
2 and 3	0.0	START
1, 2 and 3	1.5	STOP
2 or 3	6.0	STOP

3. RESULTS AND DISCUSSION

Fig. 4 shows the three different spectrum types that can be obtained from the electronic configurations presented in the previous section.

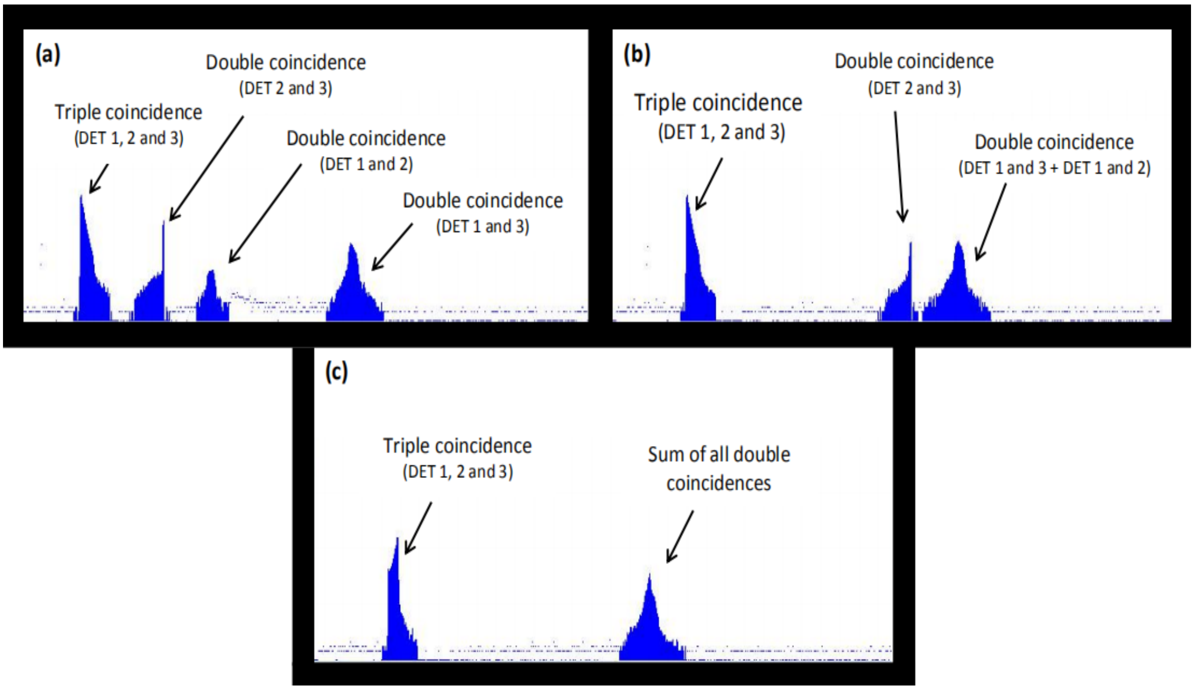

Figure 4: Spectra for three different configurations of the electronic system (in log scale).(a) Four-peak spectrum obtained with the scheme shown in the block-diagram of Fig. 1. (b) Three-peak spectrum obtained with the scheme shown in the block-diagram of Fig. 2. (c) Two-peak spectrum obtained with the scheme shown in the block-diagram of Fig. 3.

As mentioned before, the third setup of the electronic system has advantages for its simplicity, because besides presenting only one peak for all double coincidences, it is also possible to better spacing the two peaks (Fig. 4c) and for this reason, this setting will be used to calculate the activity of the ^{90}Sr. In addition, the third setup requires fewer electronic modules than the first setup, which results in less noise and undesirable delays generated by signal processing on these modules.

On the other hand, the third setup suppresses more information than can be obtained in the first. This happens because there is information on the counts of each double coincidence, so if an electronic problem occurs in any module or cables, it is easier to detect where the problem is and it can be solved more quickly.

The behavior of the two peak spectrum was also observed when the value of all discriminator lower levels (SCA) were equally changed. In Fig. 5 some examples of spectra obtained with different discrimination values for low amplitude pulses are shown.

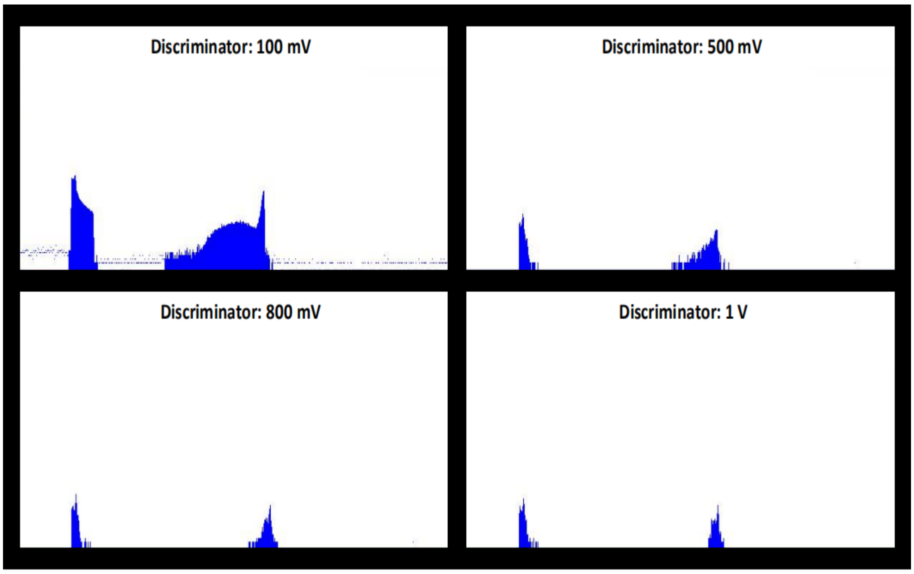

Figure 5: Spectra for different discrimination values adjusted in the Timing Single Channel Analyzer (SCA), in log scale, based on the third setup.

As can be seen, as the discrimination value increases, the number of counts of each peak decreases and these become better defined with a smaller resolution time value. This is due to the choice of time by the SCA module to generate the logical pulse to be at the middle pulse position (which for bipolar signal is defined by the position that the pulse crosses the horizontal axis). But this mean position changes with pulse amplitude, as can be seen in Fig. 6 which shows the layout of pulses generated by the photodetector after amplification and observed on the oscilloscope.

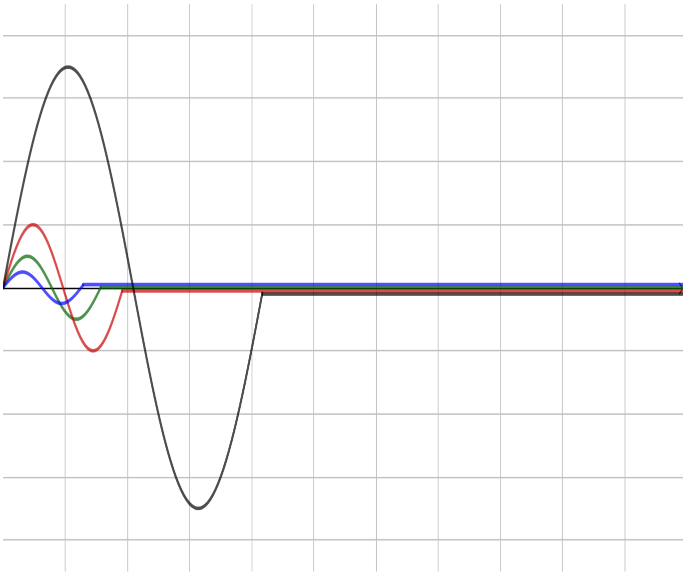

Figure 6: Representation of pulses coming from an amplifier and viewed on the oscilloscope.

This effect could be avoided using constant fraction discriminator (CFD) modules, but the required quantity was not available. Nevertheless, as will be seen below, from the results calculated for the third setup, no significant problems were observed for the activity calculation.

Based on this information, the 300 mV discrimination value was chosen for the determination of the ^{90}Sr source activity, because with this discrimination value the best results were achieved, following the procedure described by R. Broda [3], cutting off as much noise as possible, but preserving the single photoelectron pulse detection.

As a result, the value of 4967 ± 54 Bq for the ^{90}Sr activity was obtained, which is compatible within 95% confidence level, applying the Zeta Score [4], which was equal to 1.9, comparing the present measurement with the reference value (5110 ± 52 Bq). To calculate the efficiency of the sum of the double coincidence counts, the *MICELLE2* program was used, with kB 0.012 [3].

4. CONCLUSIONS

Although the present measurements are preliminary for the implementation of this data acquisition system for the TDCR method, it was possible to obtain results in good agreement with the reference value. The simplicity of the proposed method, applying the third setup for activity calculation, encourages the improvement of the measurement system. However, for this improvement it is suggested that the first setup be used initially, until all possible problems can be detected and solved. In this way, knowing the detailed information of each part of coincidence system, it becomes easier to verify which part is faulty and adjust it until good results are obtained. Moreover, although it is possible to develop the calculations without the use of CFD, its implementation is suggested for the refinement of the results.

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REFERENCES

1. "TDCR Method: Laboratoire National Henri Becquerel", `http://www.nucleide.org/ICRM_LSCWG/icrmtdcr.htm` (2019).
2. B. E. Zimmerman, R. Collé and J. T. Cessna, "Construction and implementation of the NISTtriple-to-double coincidence ratio (TDCR) spectrometer", *Applied Radiation and Isotopes*, **Volume 60**, pp. 433-438, (2004).
3. R. Broda, "A review of the triple-to-double coincidence ratio (TDCR) method for standardizing radionuclides", *Applied Radiation and Isotopes*, **Volume 58**, pp. 585-594, (2003).

4. "ISO 13528 ZETA SCORE: NIST - Statistical Engineering Division", `https`://www.itl.nist.gov/div898/software/dataplot/refman2/auxillar/zetascor.htm (2019).