DETERMINATION OF ^{14}C EFFICIENCY BY LIQUID SCINTILLATION COUNTER USING TWO METHODS: TRIPLE TO DOUBLE COINCIDENCE RATIO AND QUENCH PARAMETER EXTERNAL

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Abstract. *The aim of this study is to determine the ^{14}C efficiency by liquid scintillation counting using two methodologies, Quench Parameter External (QPE) and Triple to Double Coincidence Ratio (TDCR), and to compare the results. The equipment used was the HIDEX model 300-SL Liquid Scintillation Counter, composed of three photomultipliers coupled with coincidence pulses, discrimination level and MikroWin 2000 software. For the determination of the quench curve and efficiency for the two methods, 15 quench cocktail standards with different quenching agents were used. The indication of quenching of cocktail standard varied from 410 to 813. The efficiency varied from 0.493 to 0.964 cps dps^{-1} for QPE and from 0.408 to 0.968 cps dps^{-1} for TDCR. Different efficiencies, above 10%, were obtained using the two methods in the range of 410 to 513 quenching, above this range the efficiencies were similar. The verification of the efficiencies was performed by measuring standard solutions.*

Key words: *TDCR, QPE, liquid scintillation counting, ^{14}C*

Introduction: The liquid scintillation counting (LSC) is a technique in which the sample is mixed to the liquid scintillation, forming a scintillation solution, capable of converting the kinetic energy of nuclear emissions into light photons [1]. The interaction of the emissions occurs in the liquid solution, producing excitement with emission of photons of ultraviolet radiation. Quench is a reduction in system efficiency, as a result of energy loss in the liquid scintillation solution. Because of quench, the energy spectrum detected from the radionuclide appears to shift toward a lower energy. The three major types of quench are photon, chemical and optical [2]. The counting efficiency is determined by the relative quenching of the sample, by using an external source for the determination of quench indicating parameter [3]. Quench Parameter External (QPE) is the most common method for determination of efficiency in LSC, used with external standard generating the parameter of indication of quench. Triple to Double Coincidence Ratio (TDCR) is a primary measurement method based on calculation of the efficiency from the measured ratio of double and triple coincidence counting rates [4]. TDCR does not require radioactive source and quenching curve, therefore it is an absolute measurement [5]. The quenching factor is critical for the determination of ^{14}C. The ^{14}C is a pure beta emitter, with 49.5 keV average energy and half-life of 5.730 years [6], produced naturally in the atmosphere and during atmospheric nuclear tests [7,8]. The ^{14}C is also used as an important tool in research, in the field of pharmaceutical, biology, agriculture, pollution control and archeology [9]; different matrices can generate different quenches. This paper describes the determination of the efficiency for ^{14}C using two methodologies, QPE and TDCR.

Materials and Methods: The efficiency for ^{14}C was measured with a LSC, HIDEX model 300-SL, composed by three photomultipliers coupled with coincidence pulses, discrimination level and MikroWin 2000 software. The counts were determined using two different Quenched Standards Sets, ^{14}C UG Quenched Standard Set (UG) and ^{14}C XR Quenched Standard Set (XR), and two reference standards without quench (Unquenched), provided by PerkinElmer. For QPE methodology, an external source of ^{152}Eu was used for producing a parameter of indication of quench. The counting efficiency was obtained by the equation (1).

$$Ef\_{QPE} = \left(\frac{counts - Bg}{Activity} \right) \qquad (1)$$

where: Ef_{QPE}: counting efficiency (cps dps^{-1}),
Activity: source activity (Bq),
counts: source counts (cps),
Bg: background radiation (cps).

For the TDCR methodology, the calculation took into account the differences between the counting ratios on the photomultipliers, based on the efficiency from the measured ratio of double and triple coincidence counting rates, by the expression (2) [10].

$$TDCR = \frac{\int_0^{E_{max}} S(E)(1-e^{-n})^3\, dE}{\int_0^{E_{max}} S(E)(3(1-e^{-n})^2 - 2(1-e^{-n})^3)\, dE} \quad (2)$$

where: $(1 - e^{-n})^3$: triple coincidences,
$(3(1 - e^{-n})^2 - 2(1 - e^{-n})^3)$: all coincidences.

The counting time was 20 minutes for each Quenched Standard Set. The Quenched Standards Sets were analyzed in triplicate. The background radiation was determined by using the same scintillating vial with deionized water.

Results and Discussion: For the two methodologies, fifteen ^{14}C quench cocktail standards with different quenching agents, with activity of 2087 Bq for UG, 2167 Bq for XR and Unquenched with activities 2143 Bq and 1651 Bq, were used. The efficiency results of QPE and TDCR are presented in Table 1**.**

Table 1 Calculated counting efficiency (cps dps^{-1}) by QPE and TDCR methods

Quench	QPE Efficiency (cps dps^{-1})	TDCR Efficiency (cps dps^{-1})	QPE/ TDCR
410	0.493 ± 0.003	0.408 ± 0.001	1.21
431	0.587 ± 0.001	0.492 ± 0.002	1.19
470	0.677 ± 0.001	0.587 ± 0.001	1.15
513	0.766 ± 0.001	0. 694 ± 0.001	1.10
580	0.845± 0.001	0.802 ± 0.001	1.05
598	0.876 ± 0.001	0.844 ± 0.001	1.04
662	0.912 ± 0.001	0.898 ± 0.001	1.02
688	0.926 ± 0.001	0.918 ± 0.001	1.01
703	0.939 ± 0.002	0.935 ± 0.001	1.00
710	0.936 ± 0.001	0.932 ± 0.001	1.00
727	0.946 ± 0.001	0.946 ± 0.001	1.00
765	0.956 ± 0.001	0.958 ± 0.001	1.00
796	0.962 ± 0.003	0.965 ± 0.001	1.00
810	0.960 ± 0.001	0.967 ± 0.001	0.99
813	0.964 ± 0.001	0.968 ± 0.001	0.99

Figure 1 presents the efficiency curve with parameter of indication of quench for ^{14}C using QPE method obtained in the present study. The curve was adjusted with polynomial equation and a high correlation of 0.9979 was obtained.

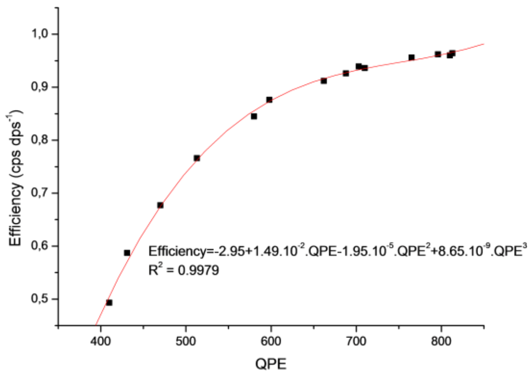

Fig. 1 Quenching curve obtained for ^{14}C

Figure 2 presents the relationship between the TDCR efficiency and the QPE efficiency, for ^{14}C standards with different quenching agents, calculated in the present study.

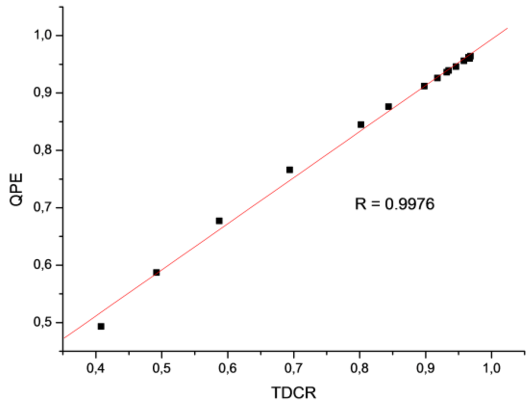

Fig. 2 Relationship between the TDCR efficiency and the QPE efficiency for ^{14}C

The adjustment showed a good correlation, of 0.9976, between the TDCR efficiency and the QPE efficiency.

The verification of the TDCR and QPE efficiencies was performed by measuring two standards solutions provided by PerkinElmer, for quench indication range from 807 to 491. Each standard solution was analyzed in triplicate. The results are presented in table 2.

Table 2 Relative Error and Relative Standard Deviation of ^{14}C determination by using QPE and TDCR efficiencies

Quench	Relative Error % (QPE)	Relative Error % (TDCR)	Relative Standard Deviation (QPE)	Relative Standard Deviation (TDCR)
807	0.15	0.31	2.15	0.07
759	0.29	0.02	2.19	0.06
731	0.22	0.27	2.19	0.09
653	0.27	1.54	2.14	0.03
628	1.05	2.94	2.20	0.12
537	1.90	7.39	2.13	0.06
491	3.31	11.5	2.11	0.07

The QPE and TDCR methods gave results with a good precision and accuracy in the range from 537 to 807 for the quench indication. The QPE and TDCR methods gave worse results with the increment of the quench indication. The QPE method was more appropriate in the quench indication 491.

Conclusions: The TDCR method requires equipment with three photomultipliers, whereas the QPE method requires equipment with only two photomultipliers, but needs different quenching standards of the element to be analyzed.

The TDCR method is in general faster and simpler, and does not require radioactive standard and quench curve, since it is an absolute measurement.

The QPE and TDCR methods gave results with a good precision and accuracy in the range from 537 to 807 for the quench indication.

The relative error obtained for the efficiency using the TDCR method in the quench indication 491was higher than 10%. Above this value, the efficiencies were similar for the two methods. The QPE method in the quench indication 491 was more appropriate.

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