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ANALYSIS OF TWO DEAD TIME CORRECTION METHODS FOR PRECISE HALF-LIFE DETERMINATION

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ABSTRACT

In this paper two different dead time correction methods are applied to the determination of the half-life of short-lived radioisotopes ^{28}Al, ^{52}V and ^{66}Cu; in the first, the mathematical non-paralyzable model correction is applied to the decay data, and in the second a ^{60}Co source, counted together with the radioactive samples, was used as a "livetime chronometer". Both methods delivered compatible results for two of the radioisotopes, but not for ^{52}V; also, while the results obtained with the mathematical correction are closer to the tabulated values from ENSDF, the data obtained with the ^{60}Co chronometer are more consistent. These results indicate that the added dead time due to the additional ^{60}Co source may not be negligible.

1. INTRODUCTION

In all nuclear analytical techniques and applications, a good degree of knowledge about the nuclear parameters involved is essential, both regarding the safety of the experiment and the reliability of the results. In the specific case of the decay half-life, as it usually occurs inside an exponential function, its uncertainty can become increasingly important depending on the relation between the duration of the experiment and the value of the half-life. On the other hand, the measurement of short half-lives is usually problematic due to the large variation of the count rate during the experiment, thus incurring in a large variation of the dead time and pile-up effects.

Some short half-life elements are widely used in neutron activation analysis (NAA) measurements. Particularly Al, Cu and V are important in health studies because they are toxic elements and also have applications in environmental studies in which the high levels of Al and Cu arise from their mining and production process and V is associated with vehicular emissions

In this work, the analysis of the decay half-life of three radioisotopes used in NAA ,^{28}Al, ^{66}Cu and ^{52}V was used to study two different methods for the correction of these secondary effects: the fit of the decay data to a function which adds a non-paralizable dead time correction to the regular exponential decay; and the concomitant use of a ^{60}Co radioactive source as a chronometer to precisely determine the live time in each measurement. The two methods were then assessed by comparing the results obtained to the values found in the literature, allowing to determine the usability and reliability of each one.

2. EXPERIMENTAL PROCEDURE

In the present experiment, samples were produced by pippetting standard solutions of each desired chemical element in pieces of Whatman 40 filter paper; the samples were left to dry naturally and then folded and packed into clean heat-sealed polyethilene bags. These samples were then irradiated in the IEA-R1 nuclear reactor pneumatic station under a thermal neutron flux of ~$5x10^{12}$n.cm^{-2}s^{-1} and analyzed by a 25% beryllium window HPGe detector coupled to a 8192-channel MCA with a source-detector distance of 9cm. The optimum irradiation time was experimentally determined for each element so as to provide for dead-times below 15% when the counting was initiated – Table 1 shows the complete data for each isotope. The data collection for each individual sample was made through a batch of short subsequent acquisitions with identical realtime duration; initially both the duration of each acquisition and total number of acquisitions were evaluated, and the optimal condition for all isotopes, judging from the relative standard deviation of the fitted half-life, were obtained. All these characteristics are also shown in Table 1.

Table 1. Concentration of the standard solution, pippetted volume, irradiation time, duration of each data acquisition and number of subsequent acquisitions for each of the samples.

Element	Solution Concentration (mg.L^{-1})	Pippetted Volume (μL)	Irradiation Time (s)	Acquisition Time (s)	Repetitions
V	1000	50	60	120	20
Cu	10000	100	60	120	20
Al	10000	2.0	60	90	15

3. DATA ANALYSIS

For the determination of the half-lives, the gamma-ray spectrum for each individual acquisition was analyzed using the Genie-2000 computer software [1]. The counts per second associated with the most intense gamma peak of each decay (1434keV for ^{52}V, 1039keV for ^{66}Cu and 1779keV for ^{28}Al) were fitted against the initial time of each acquisition using the non-paralyzable dead-time correction model shown in Eq.1 [2], where A_0 (the initial count rate), λ (=ln(2)/$T_{1/2}$) and τ (the dead-time parameter) were the fit parameters. The fit was performed using a covariant Gauss-Marquardt routine implemented in the MatLab® environment. A total of 11 measurements were made for the ^{52}V decay, 13 for the ^{66}Cu decay and 14 for the ^{28}Al decay.

$$A = \frac{A_0 \cdot e^{-\lambda t}}{1 + A_0 \cdot \tau} \quad (1)$$

In order to validate the mathematical dead-time correction, a second dead-time correction was tested in the samples. For them, a 30kBq ^{60}Co source was counted together with the samples and used as a "live-time chronometer", so the counts obtained for the produced isotopes peaks were divided by the sum of the areas of the 1173 and 1332 keV peaks of the ^{60}Co decay, and the result was fitted to a regular exponential decay function.

The results obtained were then analyzed using the regular σ^{-2}-weighted mean as well as a technique designed specifically for the analysis of discrepant data, the *Normalized Residuals* [3], in order to obtain a more robust final value which would not be too influenced by possible outliers.

4. RESULTS AND DISCUSSION

The results obtained for the three nuclides using the two dead time correction methods for each one of the statistical tools are shown in Table 2, together with the values from the last ENSDF compilations [4-6]

Table 2. Results obtained for each of the nuclides studied; WM is the σ^{-2} weighted mean, NR is the Normalized Residuals mean.

Nuclide	WM (min)	NR (min)	ENDSF (min)
^{28}Al	2.236 (8)	2.234 (9)	2.2414 (12)
^{28}Al*	2.229 (5)	2.229 (5)	[6]
^{66}Cu	5.070 (11)	5.054 (11)	5.120 (14)
^{66}Cu*	5.081 (7)	5.081 (7)	[5]
^{52}V	3.751 (3)	3.735 (3)	3.743 (5)
^{52}V*	3.777 (5)	3.777 (5)	[4]

* Using the ^{60}Co source as chronometer

The half life values obtained for the ^{28}Al and ^{66}Cu by the both dead time correction methods are statiscally compatible, thus showing the mathematical method for correction the dead time is reliable. In the case of ^{52}V, though, there is some inconsistence that shall demand further analysis.

Both for ^{28}Al and ^{52}V, in which the gamma transitions used have high emission probability, the correction using the ^{60}Co chronometer delivers a value more discrepant with the literature one, what may indicate that the influence of the increase in dead time caused by the addition of a second radioactive source is not negligible. On the other hand, in all cases the use of the ^{60}Co chronometer led to more consistent results, what is evidenced by the fact that both the Normalized Residuals and the regular weighted mean are identical (thus showing that no outliers were identified in the process).

3. CONCLUSIONS

The comparison between the two studied methods for dead-time correction showed that they delivered compatible results both for the ^{66}Cu and ^{28}Al decays; in the case of the ^{52}V decay, though, the results obtained using the mathematical non-paralyzable model correction were significantly lower than the ones obtained using the ^{60}Co chronometer. The comparison with the ENSDF values shows that both for ^{28}Al and ^{52}V the results obtained with the mathematical correction were closer to the tabulated values, indicating a possible influence of the additional activity and dead-time caused by the use of an extra radioactive source may not be negligible, and that extra caution should be taken in order to add the minimum additional activity in the measurement.

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