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Half-life determination for short-lived radioisotopes ^{52}V, ^{66}Cu and ^{28}Al

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HIGHLIGHTS

- The half-lives of ^{52}V, ^{66}Cu and ^{28}Al were measured with high precision.
- The dead time influence was assessed by two methods, with compatible results.
- The final values were compatible with most results found in the literature.
- Results suggest that compilation values for ^{66}Cu and ^{28}Al should be revised.

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ABSTRACT

In this work, the half lives of ^{52}V, ^{66}Cu and ^{28}Al were measured using a non-paralyzable dead-time correction to the regular exponential decay. For ^{28}Al, a physical dead-time correction was also employed to allow a verification of the mathematical correction used. The resulting values were 3.734(3) min for ^{52}V and 5.061(6) min for ^{66}Cu; as for ^{28}Al, the results were 2.233(9) min using the non-paralyzable correction and 2.228(5) min using the secondary correction, thus validating the mathematical approach.

1. Introduction

Nuclear applications often require a good degree of knowledge on several parameters of the nuclei involved, both regarding the safety of the experiment and the reliability of the results. For instance, in Nuclear Activation Analysis (NAA), many nuclear parameters, such as cross section and decay half-life, have to be well known in order to compute the results, and the uncertainties in these parameters frequently undermine the results obtained in the analyzes (Lindstrom et al., 2007). In the instrumental variation of NAA, which relies on the use of a well known comparator irradiated together with the samples in order to eliminate most of the nuclear parameters from the equations, the value of the decay half-life is still an important parameter and it appears inside an exponential function, so its uncertainty must be carefully assessed because it may distort the results of the whole analysis.

2. Experimental procedure

In the present experiment, samples were produced by pipetting standard solutions of each desired chemical element on pieces of Whatman 40 filter paper; the samples were left to dry naturally and then folded and packed into sealed polyethylene bags. These samples were then irradiated in the IEA-R1 nuclear reactor pneumatic station under a thermal neutron flux of $\sim 5 \times 10^{12}$ n cm^{-2} s^{-1} and analyzed by a 25% HPGe detector coupled to a 8192-channel MCA with a source-detector distance of 9 cm. 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; for ^{52}V and ^{66}Cu, each spectrum was acquired for 120 s and this procedure was repeated 20 times for each irradiation, so that each sample was counted for a little more than 2400 s (the extra time comes from the time consumed by the computer to save the spectra and then reset and start the MCA); for ^{28}Al, due to its considerably shorter half-life, the optimal counting was 90 s per spectrum, 15 spectra per irradiation, adding up to a little more than 1350 s of acquisition time per sample.

3. Data analysis

For the determination of the half-lives, the gamma-ray spectrum for each individual acquisition was analyzed using the

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Genie-2000 computer software (Canberra, 1999), which delivers reliable and accurate peak areas for standard gamma spectra (Zahn et al., 2009). The counts per second associated with the most intense gamma peak of each decay (1434 keV for ^{52}V, 1039 keV for ^{66}Cu and 1779 keV for ^{28}Al) were fitted against the initial time of each acquisition using the non-paralyzable dead-time correction model shown in Eq. (1) (Knoll, 1999), where A_0 (the initial count rate), $\lambda(=\ln(2)/T_{1/2}$, where $T_{1/2}$ is the nuclide half-life) 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 43 measurements were made for the ^{52}V decay, 30 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 Al samples. For them, a 30 kBq ^{60}Co source, with a much longer half-life (1925.28(14) day Tuli, 2003), was counted together with the samples and used is a "live-time chronometer", so the counts obtained for the ^{28}Al peak 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.

Given the fact that the individual results for each measurement are obtained from a least-squares fit of the count rate as a function of time, any uncertainty related only to the initial value of the source activity will only influence the value of A_0, thus their influence in the half-life result can be safely neglected; also, uncertainties related to the detection efficiency and geometry can be safely neglected, as the sample holder is very solid and the system can be considered completely stable for the duration of these experiments, as each decay is followed for no more than 50 min. Another possible source of uncertainty would be the variation (*jitter*) of the internal computer clock which is of 0.003% in the worst case scenario (Henderson et al., 2000) and can safely be neglected in this analysis. Therefore, the only relevant source of experimental uncertainty in these measurements comes from the analysis of the gamma-ray spectra; as the system has a low contribution from background radiation and the peaks of interest are very well-defined, the Genie2000 peak-fitting routine is able to deliver very accurate and precise results with reliable uncertainties (Zahn et al., 2009); moreover, the dead-time was never allowed to be above 10–20% so that counting statistics should not be practically affected and either of the dead-time correction algorithms employed should be reliable (Knoll, 1999). In the case of the ^{28}Al source when the ^{60}Co source was used as chronometer, the uncertainty in the peak fits for the ^{60}Co peaks was also taken into consideration. The uncertainties, then, were obtained together with the values from an instrumentally weighted least-squares fit and, as they come from separate measurement sets, they are safely assumed to be uncorrelated.

The results obtained were then analyzed using the regular σ^{-2}-weighted mean as well as two techniques designed specifically for the analysis of discrepant data, the *normalized residuals* and the *Rajeval technique* (Rajput and MacMahon, 1992), in order to obtain a more robust final value which would not be too influenced by outlier results.

4. Results

The results obtained for the three nuclides after applying the statistical tools are shown in Table 1, together with the values from the last ENSDF compilations (Junde et al., 2007; Browne and Tuli, 2010; Endt, 1998) and with the regular unweighted mean of the results. The results for ^{52}V were in rather good agreement with the tabulated data, with a lower uncertainty. For ^{66}Cu, the results were all below the tabulated result, but in good agreement with the two most recent and precise measurements used in that compilation (5.063(20) min Kawade et al., 1990 and 5.080(12) min Kawade et al., 1992), showing that the compiled value is probably overestimated. In the case of ^{28}Al, the results were significantly lower than the tabulated value, but compatible with 5 of the 6 measurements used in the compilation (2.238(6) min Weiss and Hillman, 1963, 2.240(7) min Wyttenbach and Dulakas, 1969, 2.247(18) min Ryves and Perkins, 1970, 2.243(5) min Emery et al., 1972 and 2.2405(8) min Schandevijl et al., 1971), being incompatible with only one, 2.2488(2) min (Becker et al., 1978). On the other hand, the results obtained using the ^{60} Co source as a livetime chronometer delivered lower uncertainties, but the results were compatible with the ones obtained using the mathematical non-paralyzable dead-time correction, thus validating the results obtained by this method. As for the different statistical tools used, the Rajeval technique delivered the lowest uncertainties and is supposed to be more robust than the other techniques, so the results obtained using this procedure were adopted.

Table 1
Results obtained for each of the nuclides studied; *AM* is the (unweighted) arithmetic mean, *WM* is the $1/\sigma^2$ weighted mean, *NR* is the normalized residuals mean and *RT* is the Rajeval technique mean; the uncertainties presented are for a 66% confidence interval; the reference values were taken from Junde et al. (2007) (^{52}V), Browne and Tuli (2010) (^{66}Cu) and Endt (1998) (^{28}Al).

Nuclide	AM (min)	WM (min)	NR (min)	RT (min)	Ref. (min)
^{52}V	3.739 (6)	3.736 (3)	3.734 (3)	3.734 (3)	3.743 (5)
^{66}Cu	5.065 (10)	5.066 (6)	5.064 (9)	5.061 (6)	5.120 (14)
^{28}Al	2.233 (13)	2.236 (8)	2.234 (11)	2.223 (9)	2.2414 (12)
^{28}Al[a]	2.218 (7)	2.229 (5)	2.229 (5)	2.228 (5)	2.2414 (12)

[a] Measurement made using the ^{60}Co source as chronometer.

5. Conclusions

The half-life values obtained in these measurements have been 3.734(3) min for ^{52}V, 5.061(6) min for ^{66}Cu and 2.228(5) min for ^{28} Al. These results are in good agreement with most values found in the literature but, in the cases of both ^{66}Cu and ^{28}Al, incompatible with the ENSDF-tabulated evaluations, suggesting that the latter should be re-evaluated as they could be distorted by some dominating individual results.

References

Becker, J.A., Chalmers, R.A., Watson, B.A., Wilkinson, D.H., 1978. Precision measurements of nuclide half-lives. Nucl. Instrum. Methods 155, 211–220.
Browne, E., Tuli, J.K., 2010. Nuclear data sheets for A=66. Nucl. Data Sheets 111, 1093–1209.
Canberra, 1999. Genie-2000 Spectroscopy System—operations manual. Canberra Industries. USA.
Emery, J.F., Reynolds, S.A., Wyatt, E.I., Gleason, G.I., 1972. Half-lives of radionuclides—IV. Nucl. Sci. Eng. 48, 319–323.
Endt, P.M., 1998. Supplement to energy levels of A = 21–44 nuclei (VII). Nucl. Phys. A 633, 1–220.
Henderson, W., Kendall, D., Robson, A., 2000. Accounting for clock frequency variation in the analysis of distributed factory control systems. In: Proceedings of the 3rd IEEE International Workshop on Factory Communication Systems, Porto, Portugal, pp. 51–58.
Junde, H., Su, H., Chunhui, M., 2007. Nuclear data sheets for A=52. Nucl. Data Sheets 108, 773–882.
Kawade, K., Yamamoto, H., Tanaka, A., Hosoya, A., Katoh, T., Iida, T., Takahashi, A.,1992. Measurement of beta-decay half-lives of short-lived nuclei. In: Proceedings of the 1991 Symposium on Nuclear Data—JAERI-M 92-027, Japan Atomic Energy Reserach Institute, Ibaraki-ken, Japan, pp. 364–368.
Kawade, K., Yamamoto, H., Yamada, T., Katoh, T., Iida, T., Takahashi, A.,1990. Measurement of Formation Cross Sections of Short-Lived Nuclei by 14 MeV

Neutrons. Technical Report AERI-M-90-171. Japan Atomic Energy Research Institute.
Knoll, G.F., 1999. Radiation Detection and Measurement, 3rd ed Wiley.
Lindstrom, R.M., Zeisler, R., Greenberg, R.R., 2007. Accuracy and uncertainty in radioactivity measurement for NAA. J. Radioanal. Nucl. Chem 271, 311–315.
Rajput, M.U., MacMahon, T.D., 1992. Techniques for evaluating discrepant data. Nucl. Instrum. Methods A 312, 289–295.
Ryves, T.B., Perkins, D.R., 1970. Thermal neutron capture cross-section measurements for ^{23}Na, ^{27}Al, ^{37}Cl and ^{51}V. J. Nucl. Energy 24, 419–430.
Schandevijl, R.V., Grieken, R.V., Hoste, J., 1971. The half-life of ^{28}Al. J. Radioanal. Chem. 9, 55–60.
Tuli, J.K., 2003. Nuclear data sheets for A=60. Nucl. Data Sheets 100, 347–482.
Weiss, A.J., Hillman, M., 1963. The magnesium-28-aluminum-28 system: an aluminum-28 generator. Int. J. Appl. Radiat. Isot. 14, 628–629.
Wyttenbach, A., Dulakas, H., 1969. The half-life of ^{28}Al. J. Radioanal. Chem. 2, 287–290.
Zahn, G.S., Genezini, F.A., Moralles, M., 2009. Evaluation of peak-fitting software for gamma spectrum analysis. In: Proceedings of the 2009 International Nuclear Atlantic Conference – INAC2009, Associação Brasileira de Energia Nuclear – Aben, Rio de Janeiro, Brazil.