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# Primary standardization of $^{72}$Ga

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**Abstract**

The activity of $^{72}$Ga sources produced by irradiation at the IEA-R1 reactor have been performed in a $4\pi\beta-\gamma$ coincidence system by using the extrapolation technique. The measurements were undertaken selecting two windows in the $\gamma$-channel, in order to check the consistency of the results. A Monte Carlo calculation was performed in order to predict the behavior of the observed activity as a function of the $4\pi\beta$ detector efficiency and the results were compared to experimental values.


*Keywords:* Activity; $^{72}$Ga; Coincidence system; Disintegration rate; Monte Carlo simulation

## 1. Introduction

The $^{72}$Ga standardization in a $4\pi\beta-\gamma$ coincidence system was undertaken due to the interest of its gamma-rays in the region of high energy (around 2000 keV) where there are not many standards. For calibrating gamma spectrometers, in this region of energy, in general, $^{24}$Na is used, which has a short half-life (15 h) and has two main gamma lines of 1369 and 2754 keV. The $^{72}$Ga decays with a half-life of 14.10 h (Firestone, 1996) by $\beta^-$ emission populating the excited levels of $^{72}$Ge (Fig. 1). Hence its half-life is similar to $^{24}$Na and it emits intense gamma-rays of 630, 834, 2202, 2491 and 2508 keV that help to fill the range between 1369 and 2754 keV. This feature makes $^{72}$Ga a quite interesting radionuclide to be used as standard source in spite of its short half-life.

In this paper the method developed by the Laboratório de Metrologia Nuclear of IPEN for the standardization of $^{72}$Ga in a $4\pi\beta-\gamma$ coincidence system is presented. The methodology recently developed by our laboratory for simulating all detection processes in a $4\pi(\beta, X)-\gamma$ coincidence system by means of the Monte Carlo technique (Takeda et al., 2004) was applied to this measurement and the predicted extrapolation curve was compared to experimental data. The results obtained were in good agreement within the experimental uncertainty.

## 2. Experimental method

### 2.1. Source preparation

The $^{72}$Ga sample has been obtained by means of the $^{71}$Ga(n,γ) $^{72}$Ga reaction, irradiating 500 μg $Ga_2O_3$ powder sealed in a quartz tube in a thermal neutron flux of $1\times10^{13}\,cm^{-2}\,s^{-1}$, obtained near the core of the IPEN research reactor operating at 3 MW. The irradiation time was 45 min and the samples were left to decay for about 24 h in order to reduce the activity of $^{70}$Ga (half-life of 21 min). After irradiation, the $Ga_2O_3$ powder was mixed with distilled water and aliquots of this mixture were dropped on $60\,\mu g\,cm^{-2}$ thick Collodion film. The sources were dried under a hot red lamp, and sealed afterwards by a $60\,\mu g\,cm^{-2}$ thick Collodion cover film. The films had been previously coated with a $10\,\mu g\,cm^{-2}$ gold layer in order to make them conductive. Two irradiations have been performed and two sources were prepared from each.

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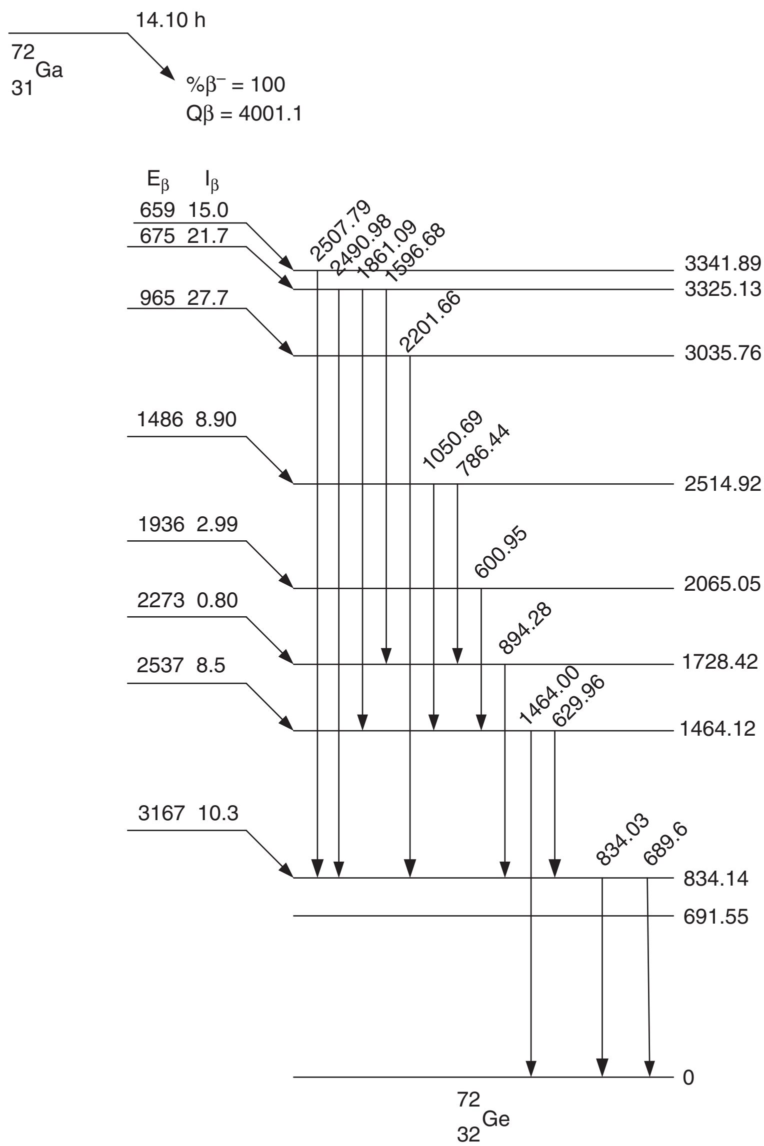


Fig. 1. Simplified decay scheme of $^{72}$Ga. All energies are in keV.

### 2.2. 4π$\beta-\gamma$ Coincidence method

The primary system used to determine the source activity consisted of a 4π proportional counter filled with P-10 gas and operated at 0.1 MPa, coupled to a 76 mm × 76 mm NaI(Tl) scintillator counter. Measurements were done for two different energy windows in the $\gamma$-channel, in order to check the consistency of the results. The windows selected were: 630–834 and 2202–2508 keV, respectively.

The activity is given by the well-known relationship (Baerg, 1973):

$$\frac{N_\beta N_\gamma}{N_c} = N_0\left(1 + \frac{(1-\varepsilon_\beta)}{\varepsilon_\beta}\left(\frac{(\alpha\varepsilon_{ec} + \varepsilon_{\beta\gamma})}{1+\alpha}\right)\right), \quad (1)$$

where $\varepsilon_\beta = N_c/N_\gamma$.

In this equation $N_0$ corresponds to the source activity, $\varepsilon_\beta$ and $\varepsilon_{ce}$ are the detection efficiency of the proportional counter for beta particles, conversion electrons, respectively, and α is the total conversion coefficient of branch i. The values of $N_\beta$, $N_\gamma$ and $N_c$ have been corrected for background, dead time, decay, and accidental coincidences. The Cox–Isham formalism (Cox and Isham, 1977) adapted by Smith has been used (Smith, 1978).

The time amplitude converter (TAC) method developed in our laboratory (Lavras et al., 2001) was used. In this method a TAC module coupled to a Multi-channel Analyzer is used to collect the observed $N_\beta$, $N_\gamma$ and $N_c$ count rates.

The efficiency extrapolation technique was applied for determining the activity. The beta efficiency was changed by using external absorbers at both sides of the sources. The

Table 1
Parameters obtained by linear least square fitting to the data in Figs. 2 and 3

| Source | Window 1 | | Window 2 | | Average (Bq) |
|---|---|---|---|---|---|
| | Intercept | Slope | Intercept | Slope | |
| IR1-1 | 3882±10 | 0 | 3860±31 | 0.26±0.12 | 3871±10 |
| IR1-2 | 3875±9 | 0 | 3889±9 | 0.18±0.01 | 3881±7 |
| IR2-1 | 11 578±60 | 0 | 11 440±61 | 0.25±0.01 | 11 509±41 |
| IR2-2 | 41 536±220 | 0 | 41 391±206 | 0.21±0.02 | 41 463±149 |

Table 2
Fitting parameters obtained for the two selected γ-windows, using Monte Carlo simulation (see text)

| Source | Activity (Bq) | | |
|---|---|---|---|
| | Window 1 | Window 2 | Average |
| IR1-1 | 3878±8 | 3861±8 | 3870±7 |
| IR1-2 | 3877±8 | 3884±18 | 3878±5 |
| IR2-1 | 11 578±23 | 11 440±34 | 11 547±16 |
| IR2-2 | 41 524±203 | 41 272±252 | 41 501±74 |
| Monte Carlo | Slope = 0.0119±0.0005 | Slope = 0.228±0.003 | |

absorbers were made of Collodion films previously coated with a 20 μg cm$^{-2}$ gold layer, and aluminum foils. The efficiency parameter was varied between 95% and 69% for window 1 and between 95% and 76% for window 2.

## 3. Results and discussion

The parameters obtained by linear least square fitting of experimental data using the code LINFIT (Dias, 1999), which incorporates covariance matrix methodology, for the two gamma windows are shown in Table 1. The best fit for window 1 was a constant and the best fit for window 2 was a straight line. The weighted average of both results is also presented.

Another way of obtaining the activity was performed using a theoretical value $(N_\beta N_\gamma/N_c)_{\mathrm{MC}}$ for unitary activity, as calculated from Monte Carlo simulation of the experimental inefficiency, yielding the ratio $(N_\beta N_\gamma/N_\mathrm{c})_{\mathrm{Exp}}/(N_\beta N_\gamma/N_c)_{\mathrm{MC}}$ for each measurement. The average value of these ratios gives the disintegration rate as predicted by the Monte Carlo method. Table 2 shows these values for the two selected windows. The final activity is the weighted average between the results from the two gamma windows. Figs. 2 and 3 show a comparison between the simulated (solid line) and the experimental values of $(N_\beta N_\gamma/N_c)/N_0$ versus $(1 - N_c/N_\gamma)/N_c/N_\gamma$.

These results show a good agreement. This is an indication that the use of Monte Carlo predictions can be used as additional information in cases where there are only a few experimental points and the extrapolation becomes difficult.

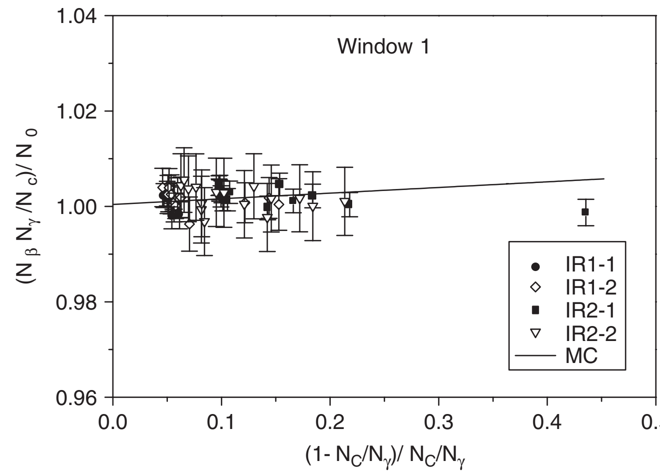


Fig. 2. Normalized extrapolation curves of $(N_\beta N_\gamma/N_\mathrm{c})/N_0$ as a function of $(1-N_\mathrm{c}/N_\gamma)/(N_\mathrm{c}/N_\gamma)$ of window 1, normalized to unity activity. The solid line refers to the Monte Carlo calculation.

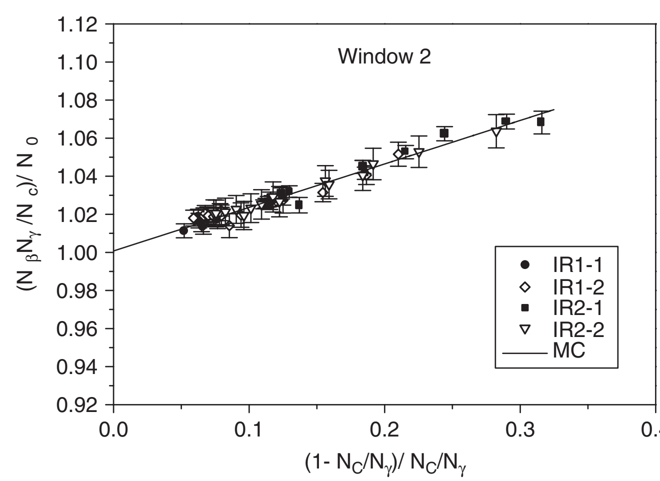


Fig. 3. Normalized extrapolation curves of $(N_\beta N_\gamma/N_\mathrm{c})/N_0$ as a function of $(1-N_\mathrm{c}/N_\gamma)/(N_\mathrm{c}/N_\gamma)$ of window 2, normalized to unity activity. The solid line refers to the Monte Carlo calculation.

## 4. Conclusions

The results obtained by linear least square fitting to the data for the two γ windows have shown consistency and these results agree with the Monte Carlo simulation.

Since the $\gamma$-ray emission probabilities per decay are well known, our methodology complements the requirements for this radionuclide to be used as a standard. This is a strong indication that $^{72}Ga$ can be used as an alternative standard source specially for the high energy range.

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