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Standardization of Ca-45 Radioactive Solution by Tracing Method

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The procedure followed by the Laboratório de Metrologia Nuclear (LMN) at the IPEN, in São Paulo, for the standardization of the $^{45}$Ca is described. The activity measurement was carried out in a $4\pi$-$\beta$-$\gamma$ coincidence system, by the tracing method. The radionuclide chosen as the $\beta$-$\gamma$ emitting tracer nuclide was $^{60}$Co because of its end-point beta-ray energy which is close to $^{45}$Ca. Six sources were prepared using a 1:1 ratio ($^{45}$Ca-pure and $^{60}$Co) dropped directly on the Collodion film, and other two solutions of $^{45}$Ca + $^{60}$Co were mixed previously using a 1:1 and 1:2 ratio before making the radioactive sources. The activity of the solution was determined by the extrapolation technique. The events were registered using a Time to Amplitude Converter (TAC) associated with a Multi-channel Analyzer.

1 Introduction

This paper describes the procedure followed by the Laboratório de Metrologia Nuclear (LMN) at the IPEN-CNEN/SP, in São Paulo, for the standardization of $^{45}$Ca radioactive solution by tracing method.

This method consists of using $4\pi$-$\beta$-$\gamma$ coincidence method [1,2] for the standardization of a pure $\beta$-emitter mixed with another radionuclide which decays by simultaneous emission of two radiations such as $\beta$-$\gamma$, $\alpha$-$\gamma$ to be used as tracer. The tracer is standardized separately by means of conventional $4\pi$-$\beta$-$\gamma$ coincidence method.

In the tracing method [3,4] a series of sources containing aliquots of the pure $\beta$-emitter and a suitable $\beta$-$\gamma$ emitter are prepared. The observed disintegration rate of $\beta$-emitter and the tracer $\beta$-efficiency $\epsilon_{\beta_t}$ are measured within a range of $\epsilon_{\beta_t}$ by using external absorbers.

The results are plotted against (1-$\epsilon_{\beta_t}$) and the intercept corresponds to the disintegration rate of the pure $\beta$-emitter.

Radionuclide $^{45}$Ca decays with half-life of (163 ± 1) days [8] by beta transition, 0.0017% populating the excited state of $^{45}$Sc and 99.9983% to the ground state with maximum beta energy of 256 keV. Due to the low gamma ray emission probability per decay it may be considered a pure beta emitter radionuclide. $^{45}$Ca decay is presented in Fig. 1.

Radionuclide $^{60}$Co was chosen as tracer because of its end-point $\beta$-ray energy (317.89 keV) which is close to $^{45}$Ca. It decays with half-life of (5.271 ± 0.002) years, by $\beta^-$ emission populating the excited levels of $^{60}$Ni and proceeds to ground state by emission of two main gamma rays (1173.24 and 1332.51 keV)[8].

2 Experimental Method

2.1 Source Preparation

$^{45}$Ca solution was obtained by means of $^{44}$Ca (n,$\gamma$) $^{45}$Ca reaction in a thermal neutron fluux at the IPEN 2 MW research reactor. The sources were prepared by dropping known aliquots of the solutions on a 20 $\mu$g/cm$^2$ thick Collodion film. Six sources were prepared using a 1:1 ratio ($^{45}$Ca-pure and $^{60}$Co) dropped directly on the Collodion film and other two solutions of $^{45}$Ca + $^{60}$Co were mixed previously using a 1:1 and 1:2 ratio before making the radioactive sources.

The Collodion film was previously coated with a 10 $\mu$g/cm$^2$ gold layer in order to turn the film conductive. A seeding agent (Cystat SM) was used to improve the deposit uniformity and the sources were dried in a warm (45 degrees Celsius) nitrogen jet. The accurate source mass determination was performed using the picnometer technique.[5] The $\beta$-$\gamma$ tracer was standardized previously by measuring several sources prepared by the same procedure.

2.2 $4\pi$-$\beta$-$\gamma$ coincidence measurement

A conventional $4\pi$-$\beta$-$\gamma$ coincidence system was used, consisting of a $4\pi$ proportional counter filled with 0.1 MPa P-10 gas mixture, coupled to a pair of 3” x 3” NaI(Tl) crystals. The events were registered by a method developed at LMN which makes use of a Time to Amplitude Converter (TAC) associated with a Multi-channel Analyzer.[7] The gamma
window was set by gating the gamma-rays of tracer (1173 keV + 1332 keV).

The number of detected events in the proportional counter is given by:

$$N_{\beta(Ca+Co)} = N_{0(Ca+Co)} \epsilon_{\beta Co} + N_{0Ca} \epsilon_{\beta Ca}$$

(1)

where:

$$\epsilon_{\beta Co}$$ is the tracer efficiency in the mixed source;

$$N_{0(Ca+Co)}$$ is the counting rate of proportional counter due to the mixed source;

$$N_{0Co}$$ is the activity of $^{60}$Co tracer of the mixed source;

$$N_{0Ca}$$ is the $^{45}$Ca beta-branch disintegration rate;

$$\epsilon_{\beta Ca}$$ is the $^{45}$Ca beta efficiency.

When the $\beta$-emitter and the $\beta$-$\gamma$ tracer are combined in a single source, a functional relationship exists between the detection efficiencies. This relation can be defined by a polynomial function $G$ where:

$$(1 - \epsilon_{\beta Ca})/\epsilon_{\beta Ca} = G((1 - \epsilon_{\beta Co})/\epsilon_{\beta Co})$$

(2)

Since the tracer efficiency, $\epsilon_{\beta Co}$ may not always be accurately obtainable from coincidence counting data, is convenient to use the expression involving only observed $\beta$-$\gamma$ and coincidence counting rates.

The expression can be rewritten as:

$$\frac{N_{\beta(Ca+Co)} N_{\gamma Co}}{N_{c Co}} - N_{0Co}$$

$$= N_{0Ca} \left[ 1 + G'((1 - \frac{N_{c Co}}{N_{\gamma Co}})/\frac{N_{c Co}}{N_{\gamma Co}}) \right]$$

(3)

The function $G'$ was fitted by weighted least squares using code LINFIT [9] and the extrapolation $(1 - N_{c}/N_{\gamma})/N_{c}/N_{\gamma} = 0$ gave the expected $N_{0Ca}$ value. Suitable corrections for background, decay, dead time and accidental coincidences were included in calculation.

3 Results and Discussion

Figure 2 shows the extrapolation curves obtained for the three different methods of preparing sources: mixing solutions with ratios 1:1 and 1:2 and by drops with 1:1 ratio. The $\beta$ efficiency was varied using external absorbers.

The extrapolated value for the two mixing solutions were in agreement with each other, namely $(154.3 \pm 1.9)$ kBq/g and $(154.3 \pm 2.5)$ kBq/g, respectively. However, for the other preparation method (drops 1:1), the extrapolated value was $(150.3 \pm 1.3)$ kBq/g, 3% lower. The possible causes for this difference are being investigated.

References


