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Absolute disintegration rate and 320 keV γ-ray emission probability of ^{51}Cr

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Abstract

This work describes the procedures for determining absolutely the ^{51}Cr disintegration rate by using the 4πβ−γ coincidence and anti-coincidence counting and the sum-peak methods. A 4″ × 4″−NaI(Tl) scintillation detector was used in the γ- channel of the 4πβ−γ coincidence system for γ-ray counting. In the β-channel, a 4π gas flow proportional counter was used for counting of characteristic X-rays and Auger electrons originating from the electron capture events of the ^{51}Cr decay scheme. Gamma spectrometry measurements by high-pure planar and coaxial germanium detectors were performed in the sum-peak method and in the determination of the 320 keV γ-emission probability of ^{51}Cr. This latter determined value agrees with the recent values found in the literature, confirming the reliability of the three methods used in this work for the disintegration rate measurements.

Keywords: ^{51}Cr; Activity standardization; γ emission probability; Radiation detection; Photon spectrometry

1. Introduction

In nuclear medicine, sodium chromate ($Na_2^{51}CrO_4$) solution may be used in diagnostic practice in the determination of red blood cell volume or mass, study of red blood cell survival time, and evaluation of blood loss. Because ^{51}Cr is a monoenergetic γ emitter ($E_\gamma = 320.08$ keV), it has important applications in nuclear science in the calibration of different gamma spectrometric systems. In both cases, correct activity determination is essential in order to get better clinical information and also reliable radioactivity detection systems. In this work, the activity concentration of a ^{51}Cr solution has been absolutely determined using three different measurement methods: the 4πβ−γ coincidence and anti-coincidence and sum-peak methods. The activity value determined with lower uncertainty has been used for determining the 320.08 keV γ-ray emission probability of ^{51}Cr.

2. Methodology

The decay scheme and relevant nuclear parameters of ^{51}Cr may be found in the literature [1].

2.1. Sum-peak method

The sum-peak method was originally developed by Brinkman [2–4]. The fundamental equation is expressed by the following expression:

$$N_0 = N_T + \left(\frac{N_1 N_2}{N_{12}}\right) \quad (1)$$

where N_0 is the source activity, N_T is the number of total rate interactions on the spectrum, N_1 and N_2 are photo-peak count rates and N_{12} is the sum-peak count rate, results from the simultaneous interaction of the two radiations on detector.

2.2. Coincidence counting method

The 4πβ−γ coincidence method has been described by various authors [5,6] and consists in a linear extrapolation

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of a coincidence absorption function $N_\beta N_\gamma/N_c$ vs. $(1-N_c/N_\gamma)$ to zero, to obtain the disintegration rate or activity N_0 of the measured source. The $4\pi\beta-\gamma$ coincidence system consisted of a 4π proportional counter operating with a gas mixture of $Ar(90\%)+CH_4(10\%)$ at 0.1 MPa pressure, and coupled to a $4'' \times 4''$NaI(Tl) scintillation detector. The proportional counter and the scintillation detector together with its associated electronic chains form the β and γ channels, respectively. A coincidence circuitry to count β–γ coincidence pulses forms the third channel. Events from the electron-capture process are monitored by means of the proportional counter, and γ-rays are detected in the NaI(Tl) crystal. The observed count rates (N_β and N_γ) were corrected for background, dead time and decay, and N_c for dead time and accidental coincidences [7].

2.3. Anti-coincidence counting method

The anti-coincidence method, developed by Bryant [8], has been used in this work, but is modified to take into account the live time in the dead time correction and a circuitry based on extendable dead times [9,10]. Indeed, measurements obtained using the anti-coincidence system are not different from those given by the classical coincidence counting. In the anti-coincidence method, uncorrelated γ-events are registered instead of those correlated with β-events. In this method there is no need for a resolving time; consequently, corrections due to resolving time effects which are known as the Gandy effect [11] and accidental coincidences [6] are none, thus decreasing the uncertainty on the final result of activity. The system uses the same two detectors of the coincidence system and has three channels: the two classical β and γ channels, and a common channel. A delay is added in the γ-channel in order to have all the correlated γ's after the associated βparticles. The common channel is used to count the uncorrelated γ's in order to calculate the true coincidence rate. As in the coincidence method, the activity is determined by a linear extrapolation of an absorption curve using the β, γ and uncorrelated γ count rates.

3. Experimental procedures

3.1. Coincidence measurements

Ten sources were prepared by drop deposition of ^{51}Cr onto a 15 μg cm^{-2} thick VYNS film coated on both sides with a 10 μg cm^{-2} thick gold layer. The discrimination window in the γ-channel was set around the 320 keV photopeak, and the equation that describes the coincidence absorption function may be expressed as follows.

$$\frac{N_\beta N_\gamma}{N_c} = N_0\left[1+\varepsilon_{\beta\gamma}\frac{(1-\varepsilon_\beta)}{\varepsilon_\beta}\right] \quad (2)$$

where $\varepsilon_\beta = N_c/N_\gamma$ is the counting efficiency for X-rays + Auger electrons and $\varepsilon_{\beta\gamma}$ is the sensitivity of proportional counter for 320 keV γ-ray. The coincidence absorption function was obtained by varying ε_β by electronic discrimination of the single β-channel analyzer.

3.2. Anti-coincidence measurements

The anti-coincidence measurements may be expressed as

$$N_0 = \frac{C_\beta C_\gamma}{C_\gamma - C_\gamma^c} \quad (3)$$

where N_0 is the activity of the source and C_β, C_γ and C_γ^C are β, γ and uncorrelated count rates, respectively. As in the coincidence measurements, an extrapolation curve is obtained and N_0 is determined. Fig. 1 shows the extrapolation curve obtained from the anti-coincidence measurements.

3.3. Sum-peak measurements

Six sources were prepared from the ^{51}Cr solution by drop deposition on 0.05-mm-thick polystyrene foils and masses determined as in Section 3.1. The sources were placed on top of the planar germanium detector and the count time for each source was about 10^4 s.

The photon spectrum of ^{51}Cr obtained by a planar germanium detector is shown in Fig. 2. It exhibits three photo-peaks, which are used for the activity determination.

3.4. 320 keV γ-emission probability measurements

A coaxial germanium detector with 260 cm^3 volume and 1.9 keV energy resolution at 1332.5 keV was used for the determination of the 320 keV γ-emission probability of ^{51}Cr. Standard point sources of ^{152}Eu, ^{133}Ba and ^{57}Co, with combined standard uncertainty from 0.2% to 1.0%, have been used to calibrate the germanium detector in terms of efficiency vs energy [12]. The distance source detector adopted was 10 cm in order to minimize pile-up losses and source geometry effects [13].

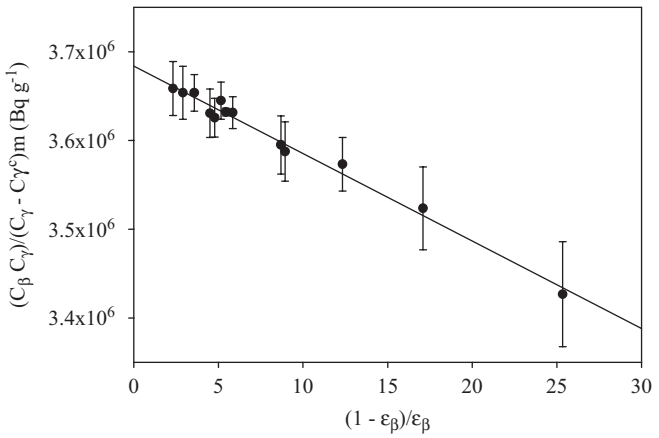

Fig. 1. Typical extrapolation curve using anti-coincidence measurements of a ^{51}Cr source.