Measurement of γ-ray Emission Probabilities of ^{100}Tc

Kazuyoshi FURUTAKA, Shoji NAKAMURA, Hideo HARADA and Toshio KATOH

Japan Nuclear Cycle Development Institute, Tokai works,
Tokai–mura, Naka–gun, Ibaraki–ken 319–1194
email : furutaka@tokai.jnc.go.jp

Toshiyuki FUJII and Hajimu YAMANA

Research Reactor Institute, Kyoto University,
Kumatori–cho, Sennan–gun, Osaka 590–0494

Abstract

In order to precisely determine thermal neutron capture cross section of ^{99}Tc nuclide, γ-ray emission probabilities of ^{100}Tc were measured using a newly developed β-γ coincidence system, which utilizes a plastic scintillator as a β-ray detector.

About 5 kBq of ^{99}Tc samples were irradiated for 15 seconds, and then β and γ rays were measured for three minutes. The measurements were repeated 99 times.

From the obtained data, ratios of coincidence counting rates to β singles counting rates, n_c/n_β, was determined for 540 keV γ ray. To determine γ-ray emission probabilities, a method has been developed which uses a Monte Carlo simulation and takes into account β feedings to excited levels and detection threshold of β rays.

1 Introduction

The ^{99}Tc is a long-lived ($T_{1/2} = 2.1 \times 10^5$ y) fission product nuclide with a large fission yield. Therefore, it is suggested as a candidate for neutron transmutation, and many experimental works have been done in order to determine the thermal neutron capture cross sections of ^{99}Tc, in particular by using an activation method[1].

In order to precisely determine the cross section in the activation method, precise values of γ-ray emission probabilities of the reaction product, ^{100}Tc, are required. These values are, however, determined with large errors (7.0 ± 1.2 % for 540 keV γ ray [2]) mainly because of its short half-life ($T_{1/2} = 15.5$ s).

To determine γ-ray emission probabilities of the ^{100}Tc nuclide, a β-γ coincidence measurement has been done by using a newly developed β-γ coincidence system which utilizes a plastic scintillator as a β-ray detector[3].

2 The experiment and data analysis

The experiment has been carried out at the Research Reactor Institute of Kyoto University. About 10 μl of ammonium hydroxide solution which contained 5 kBq of ^{99}Tc as ammonium pertechnetate, was dried on an acrylic plate and irradiated by neutrons for 15 seconds using a pneumatic tube Pn-3 at the institute, and then β- and γ-rays emitted from the sample were measured.

Beta rays were measured using a plastic scintillation detector placed at 10 cm distance from the sample, whose thickness was 4 mm and which has a trapezoidal shape with an area of 33 cm^2. For γ-ray detection, a HPGe detector was used, whose relative efficiency is 90 % of that of 3"×3" NaI detector. The distance between the irradiated sample and the Ge detector was 3 cm. To follow the decay of the ^{100}Tc nuclei, the obtained data were partitioned every 5 seconds. The irradiations and the measurements were repeated 99 times to improve the statistical accuracy. A total of 2×10^6 counts were obtained for a peak area of the 540 keV γ-ray, which is emitted after β decay of the ^{100}Tc nuclei.

In **figure 1**, an energy spectrum of γ rays observed by the Ge detector is shown, which is obtained by summing singles (projection) spectra over all runs. From the spectrum, γ rays emitted following the decay of ^{100}Tc, namely 540, 591 and 1512 keV, are clearly identified. The figure also shows a

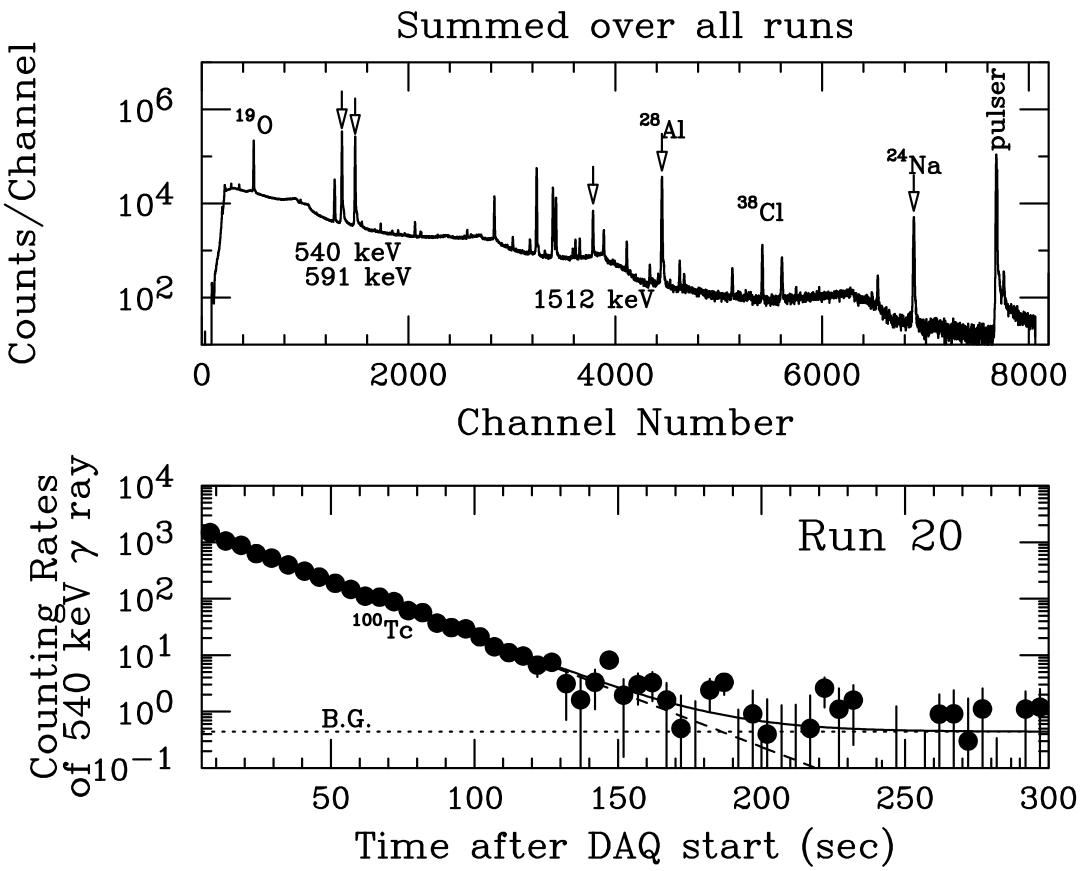

Figure 1: (upper) Singles spectrum of γ rays summed over all runs. (lower) Decay curve of 540 keV peak yields. The dashed line represents contribution from ^{100}Tc, while dotted lines are that from backgrounds.

decay curve of peak-areal counts of the 540 keV γ ray in a typical run. The decay data for each run were fitted by a function with the following form:

$$Y(t) = a \exp\left(-\frac{\ln(2)}{\tau}t\right) + C, \tag{1}$$

where τ, a and C were varied as free parameters. The τ corresponds to the half-life of ^{100}Tc. By averaging the obtained values for τ over all runs, τ for ^{100}Tc was determined to be 15.27 ± 0.02 (s), thus the 540 keV γ rays were confirmed to be emitted following the decay of ^{100}Tc.

Shown in **figure 2** is a β-ray energy spectrum summed over all runs. A bump around 50 channel bin was caused by noises, and therefore counts above 90 channel (inclusive) are summed as a β counts. **Figure 3** shows a decay curve for the β-ray counting rate in a typical run. To extract a contribution from ^{100}Tc to the singles β counts, the decay curves were fitted by a function with the following form:

$$Y'(t) = \sum_{i=1}^{3} a_i \exp\left(-\frac{\ln(2)}{\tau_i}t\right) + C', \tag{2}$$

In the fit, a_is and C' were varied as free parameters while τ_is were fixed to half-lives of ^{100}Tc (15.27 s), ^{19}O (26.91 s [2]) and ^{27}Al (2.248 min. [3]). The solid line in the figure shows a result of a fit, while contribution from the decay of ^{100}Tc was shown by the dashed line. Coincidence counting rates of the β rays were determined in the same manner.

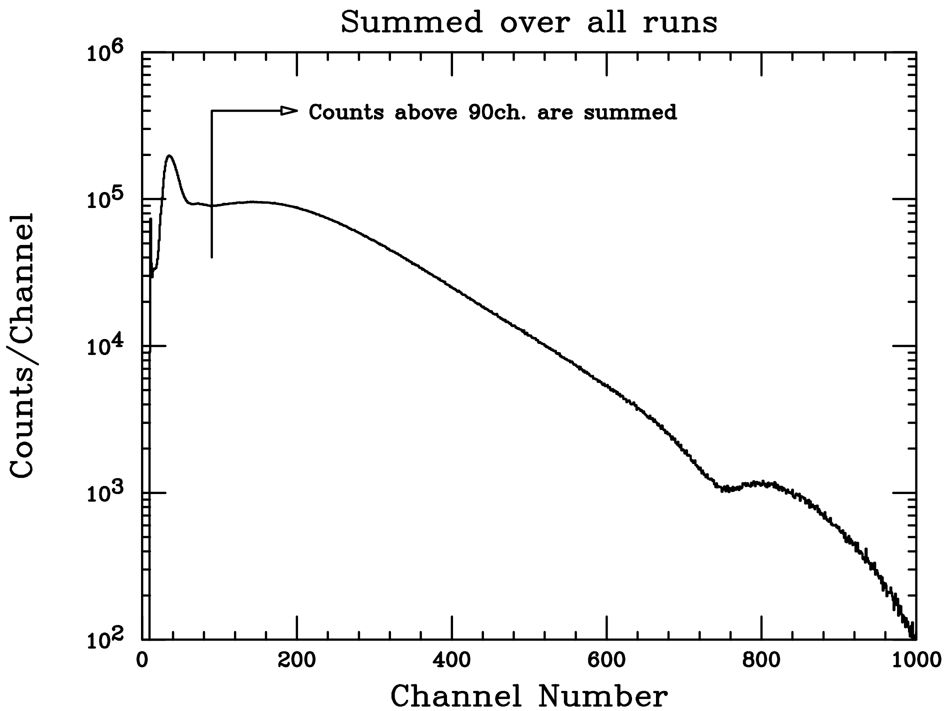

Figure 2: Singles spectrum of β rays summed over all runs.

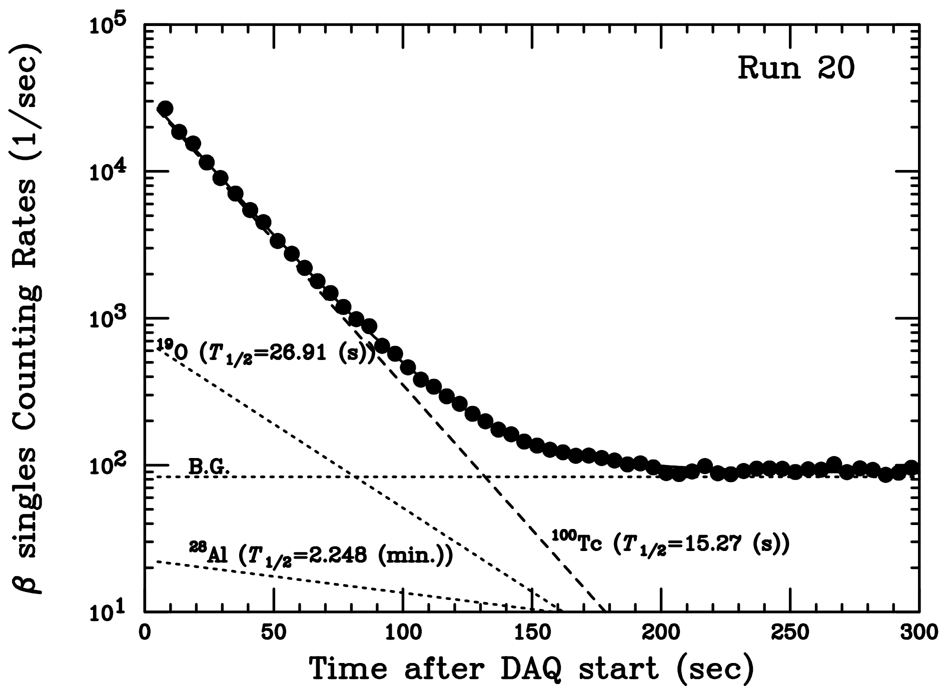

Figure 3: Decay curves of singles β ray counts above 90 ch. The solid line represents the result of the fit and dashed line contribution from ^{100}Tc. The dotted lines express contributions from ^{19}O, ^{28}Al and backgrounds.

From the result of the above mentioned fits, ratios of coincidence counting rates to β singles counting rates, n_c/n_β, were calculated for each time bin in each run. The final values of n_c/n_β were obtained after averaging over all time bins and all runs. For 540 keV γ ray, $n_c(540\ keV)/n_\beta$ was determined to be 0.00168 ± 0.00001.

To deduce γ-ray emission probabilities from the obtained n_c/n_β values, a method has been developed using the Monte Carlo simulation code EGS4[4]. It simulates the decay of the ^{100}Tc nuclei and the interaction between the detectors and the emitted particles (β and γ rays), and calculates n_c/n_β values as a function of β branching ratio to the ground state of ^{100}Ru. Four excited states of ^{100}Ru with large β branching ratios were taken into account in the simulation, namely the ground state, 540, 1131, 1362 and 2052 keV levels. With the five levels, more than 99.8 % of β decay feedings are exhausted[2]. Ratios between the feeding probabilities to the excited states were determined from the obtained singles γ-ray spectrum, after sum-coincidence corrections. By varying the β feeding probability to the ground state and searching for the value which reproduce the observed n_c/n_β values, the γ-ray emission probabilities can be determined. The analysis is now under way.

This work has been carried out in part under the Visiting Researcher's Program of the Research Reactor Institute, Kyoto University.

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