Half-lives and $Q_\beta$ measurements for new nuclei of $^{89}$Tc and $^{89m}$Tc

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Neutron deficient isotopes of $^{89}$Tc and $^{89m}$Tc have been produced through the $^{60}$Ni($^{32}$S, $p$ $2n$)$^{89}$Tc at 95 MeV and the $^{58}$Ni($^{35}$Cl, $2p$ $2n$)$^{89}$Tc reaction at 135 MeV. A rotating catcher foil system was used to collect the activities and transfer them to a measuring position for $\beta-\gamma$ spectroscopy. The half-lives of $^{89}$Tc and $^{89m}$Tc were measured to be $12.8 \pm 0.9$ s and $12.9 \pm 0.8$ s, respectively. The total decay energy, $Q_{EC}$, for $^{89}$Tc was determined to be $7.51 \pm 0.21$ MeV.

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1. Introduction

Up to now, no detailed investigation of the decay properties of $^{89}$Tc has been reported. Although Gallagher et al. [1] searched for the decay of $^{89}$Tc, they could not observe it because of very small cross section in the $^{92}$Mo($p$, $4n$) reaction. A few low-lying excited levels of $^{89}$Mo which is the daughter nucleus of $^{89}$Tc were investigated by several authors. Pardo et al. [2] measured the mass of $^{89}$Mo using the $^{92}$Mo($^{3}$He, $^{6}$He)$^{89}$Mo reaction, and tentatively assigned the spins and parities of three low-lying levels of $^{89}$Mo. The assignments are $9/2^+$, $7/2^+$ and $1/2^-$ to the ground state, $124 \pm 10$ and $400 \pm 40$ keV level, respectively. Gallagher et al. [3] observed $118.8$ and $268.5$ keV $\gamma$-rays emitted from an isomeric state produced by the $^{92}$Mo($p$, $3n$)$^{89m}$Mo reaction. The half-life of this isomeric state was measured to be $190 \pm 15$ ms (hereafter, the half-life will be simply written as $T_{1/2}$). The energies of both $\gamma$-rays are in agreement with the excitation energies deduced by Pardo et al. [2] with the experimental uncertainty. The value of $T_{1/2}$ is consistent with $E3$ assignment for $268.5$ keV transition. From the singles $\gamma$-ray intensity, $T_{1/2}$, systematical trends in this mass region and the data in [2], Gallagher et al. reported the decay scheme of $^{89m}$Mo as shown in the left part of Fig. 5.

In this article, we describe our recent measurements on the decay of $^{89m}$Mo by $\gamma$-ray spectroscopy, and of its population from the previously unknown isotopes $^{89}$Tc and $^{89m}$Tc by $\beta-\gamma$ coincidence techniques. The $Q_{EC}$ for the decay of $^{89}$Tc has been deduced from the end point measurements and compared to results from several neighboring nuclei and recent theoretical mass predictions [8].

2. Experimental procedure

A preliminary experiment was performed at the Tandem Accelerator Laboratory in the Kyushu University. The $^{60}$Ni($^{32}$S, $p$ $2n$)$^{89}$Tc reaction at a bombarding energy of 95 MeV was employed to measure $\beta-\gamma$ coincidence spectra.

Further experiments including $\gamma-\gamma$ and $X-\gamma$ coincidence measurements were carried out by using the tandem-postaccelerator system at the University of Tsukuba [4]. The residual activity of $^{89}$Tc was produced through the $^{58}$Ni($^{35}$Cl, $2p$ $2n$)$^{89}$Tc reaction at 135 MeV. The target was an enriched (99.89%) $^{58}$Ni foil of 1.0 mg/cm² thickness. The residual nuclei recoiled from the target were captured on Ta foils placed at about 5 mm behind the target. Thirty nine catcher foils were mounted on a rotatable disk 50 cm in diameter. The thickness of each foil was 11.7 mg/cm². After irradiation, the activities were transported to the counting position by 180° rotation of the disk. The time sequence of the measurements was controlled by a microcomputer. A typical irradiation and measurement time were 22 and 36 s, respectively.

Measurements of singles $\gamma$-rays, $\beta-\gamma$, $X-\gamma$ and $\gamma-\gamma$ coincidences were made with two high-purity Ge detectors. Both detectors have a thin entrance window (Be) for transmission of X-rays, and sufficient relative efficiencies (18.6% and 26.7%) in order to observe $\gamma$-rays and high-energy positrons simultaneously. Two amplifier systems were prepared. One was adjusted at high gain
for X-ray detection, whereas the other system was operated at low gain for detection of high-energy positrons with energies between 2 and 10 MeV. To obtain the decay curve of radiations, multispectrum analyses were performed. After the rotation of the disk, energy signals from the detectors were analyzed in a total counting time of 36 s which was divided into 12 intervals of 3 s. The energy scale of the spectrometers was calibrated by $^{57}$Co, $^{60}$Co and $^{152}$Eu sources for X- and γ-rays. For positrons, the full-energy and escape peaks of 4.4 MeV γ-rays from an $^{241}$Am–Be source were used as well as the 1.1 and 1.3 MeV γ-rays from $^{60}$Co source.

3. Experimental results

Figure 1 shows a typical singles spectrum of γ-rays. The γ-rays of 118.8 and 268.5 keV which have been assigned to the decay of $^{89m}$Mo with $T_{1/2} = 190 \pm 15$ ms by Gallagher et al. [3] are clearly observed. Unlabeled peaks in Fig. 1 are unassigned peaks with longer half-lives. From the decay curve obtained from singles spectra, the lifetimes were determined to be $T_{1/2} = 13.16 \pm 0.33$ s for 118.8 keV γ-ray and $T_{1/2} = 15.7 \pm 1.4$ s for 268.5 keV γ-ray, respectively. A half-life of $T_{1/2} = 13.3 \pm 4.6$ s was also obtained for the 118.8 keV γ-ray in the $^{60}$Ni($^{35}$S, p 2n)$^{89}$Tc reaction. However, these values of $T_{1/2}$, especially for the 268.5 keV γ-ray, would be somewhat uncertain because of the poor S/N ratio due to the large Compton continuum in singles spectra and a contribution to the decay curve from activities with longer lifetimes. As discussed below, the values of $T_{1/2}$ obtained from γ–γ and β–γ coincidence are more certain.

In Fig. 2, the square root of counts ($\sqrt{N}$) is displayed for the high-energy part of the positron spectrum measured in coincidence with the 118.8 keV γ-ray. In the present analysis of the positron spectrum, the $\sqrt{N}$ plot was more straight than the Fermi-Kurie plot. An endpoint energy was determined to be $6.37 \pm 0.21$ MeV. Only the statistical error was included, since it was rather difficult to determine a precise response function of the detector. The peak of 268.5 keV γ-ray did not appear in a spectrum measured in coincidence with positrons having energies above 2 MeV.

Typical γ–γ coincidence spectra observed with a resolving time of 20 ns are shown in Fig. 3. The 268.5 keV γ-ray is not in coincidence with annihilation radiation, but with the 118.8 keV γ-ray. In the lower spectrum in Fig. 3, a weak peak is seen around 511 keV. This peak was caused in the subtraction process of data analysis. Also, it should be noted that activities with longer half-lives contribute to the 268.5 keV peak. No other γ-ray in coincidence with the 118.8 and 268.5 keV γ-rays was observed. These facts imply that the 268.5 keV γ-ray follows only the decay of $^{89m}$Mo, while the 118.8 keV γ-ray follows both the β- and the isomeric decay.

![Fig. 2](image-url)