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Half-life Measurements of Excited Levels in Fission Products around Mass Number 150

Y. Kojima,[1,*] Y. Shima,[2] H. Hayashi,[3] A. Taniguchi,[4] and M. Shibata[1]

[1] *Radioisotope Research Center, Nagoya University, Nagoya 464-8602, Japan*
[2] *Graduate School of Engineering, Nagoya University, Nagoya 464-8603, Japan*
[3] *Institute of Health Biosciences, the University of Tokushima, Tokushima 770-8509, Japan*
[4] *Research Reactor Institute, Kyoto University, Kumatori 590-0494, Japan*

A spectrometer to measure nuclear level half-lives has been installed at the on-line isotope separator of the Kyoto University Reactor. This spectrometer consists of a $LaBr_3$ scintillator, a thin plastic scintillator and an HPGe detector. Half-lives are deduced using the β-γ-γ delayed coincidence method. The prompt-time distribution curves measured with the spectrometer give a time resolution (FWHM) of 600 ps for 100-keV γ rays. This resolution means that half-lives down to the subnanosecond range or shorter can be measured. We reported recent measurements of the half-life of ^{149}Pr and ^{149}Nd. Some of the more interesting results include the first determination of the half-lives of ^{149}Pr levels at 86.5 and 125.6 keV, which are 4.2(5) ns and 1.0(2) ns, respectively. In addition, the data indicate that the half-life of the 270.8-keV level in ^{149}Nd is not 5.1(3) ns as reported previously, but 0.42(3) ns.

I. INTRODUCTION

Half-lives of excited nuclear levels are one of the most fundamental properties of nuclides. Because the half-life is related to the natural width of the level, their precise determination is necessary for nuclear applications such as materials science, in which nuclides are used as research probes. Nuclear level half-lives are also required for the determination of γ-ray reduced transition probabilities or nuclear matrix elements, which are useful for investigating nuclear structure. Although half-life data provide valuable information to nuclear physics, the half-lives of only a limited number of levels in β-unstable nuclides have been measured because these nuclides are difficult to produce and most levels are short-lived.

We have recently installed a spectrometer at the on-line isotope separator of the Kyoto University Reactor (KUR-ISOL) [1], to measure nuclear level half-lives in the range of 0.1 to 10 ns by means of the β-γ delayed coincidence technique. This apparatus has been used to measure nuclear level half-lives of neutron-rich rare-earth nuclides with mass number $\sim$ 150. To date, the nuclear level half-lives for ^{148}Ce, ^{148,149}Pr and ^{149}Nd have been measured, the results are partly reported in Ref. [2]. In this paper, we report new results of measurements of the nuclear level half-lives of ^{149}Nd and ^{149}Pr. Unexpected local changes of nuclear structure are suggested in this region from Q_β measurements [3, 4], and the data acquired in this work provide useful information for modifying the nuclear models.

II. MEASURING SYSTEM

A. Detectors

A spectrometer which consists of a $LaBr_3$ scintillation detector and a plastic scintillation detector was used to measure nuclear level half-lives. Only an outline description of the instrument is provided because the details have already been published elsewhere [2].

A $LaBr_3$ scintillation detector was used for γ-ray detection. The crystal was 1.5 inches in diameter by 1.5 inches in thickness and was coupled with a Hamamatsu 14-pin photomultiplier tube (PMT) model R6231. The $LaBr_3$ scintillator was enclosed in a 0.7-mm-thick Teflon reflector and placed in 0.5-mm-thick aluminum housing. This scintillator material possesses an energy resolution (FWHM of $\leq$ 2.8% for 662-keV γ-rays) superior to other scintillator materials. Furthermore, the decay time of the scintillation light is as good as 16 ns [5]. The $LaBr_3$ scintillator is, therefore, suitable for use as a fast γ-ray detector and some experimental groups already use $LaBr_3$ detectors for half-life measurements (see, for example, Refs. [6–9]).

For the β detector, we used a 1-mm-thick plastic scin-

* Corresponding author:
kojima.yasuaki@f.mbox.nagoya-u.ac.jp

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tillator (pilot-U, 35 mm × 35 mm). The pilot-U was light shielded by a 0.025-mm-thick aluminum foil and was coupled to a fast PMT (Hamamatsu H2431-51).

The β-γ delayed coincidence technique was used to measure the half-lives of excited levels. In this method, the time difference between β and γ detection is measured using a time-to-amplitude converter (TAC, Ortec 567). The β signal, processed by a constant-fraction discriminator (CFD, Canberra 2126), starts the TAC unit. The time measuring system was calibrated using an Ortec 462 time calibrator. From the linearity of the time-calibration curve, we calculate the uncertainty of the calibration to be less than 20 ps.

B. Time Resolution

Time resolution is the most important property of a spectrometer designed to measure nuclear level half-lives. After careful adjustment of the CFD time walks, we evaluated the time resolution from the prompt-time distribution curves. The prompt spectra were measured using standard radioactive sources, ^{60}Co and ^{134}Cs, and short-lived nuclides, ^{93}Rb and ^{148}Ce. A mass-separator was used to obtain ^{93}Rb and ^{148}Ce; details of the separator are given in Section III.

An example of a time spectrum obtained using the 1333-keV γ ray from ^{60}Co is shown in the inset of Fig. 1. The half-life of the 1333-keV level is 0.7 ps [10], which is far shorter than the expected time resolution of a few hundred picoseconds. Therefore, the time-distribution curve is a prompt-time peak. By least-squares fitting to a gaussian curve, we find a time resolution (FWHM) of 375(6) ps.

Figure 1 shows the energy dependence of the time resolution. We find a time resolution for 100-keV γ rays of 600 ps, which is several times worse than that reported for spectrometers which use BaF_2 scintillators [11], but much better than that of other γ detectors such as NaI and planar Ge detectors [12].

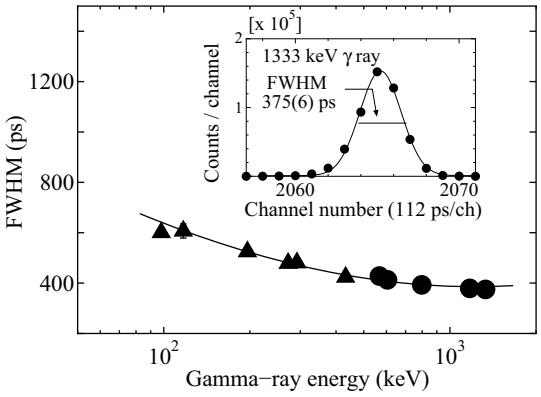

FIG. 1. Energy dependence of time resolution (FWHM) for the spectrometer. Closed circles are data obtained using γ rays from standard radioactive sources, and closed triangles show data obtained using mass-separated short-lived nuclides. The solid curve is to guide the eyes. The inset shows a prompt-time distribution curve obtained using a 1333-keV γ ray.

III. NUCLEAR LEVEL HALF-LIFE MEASUREMENTS

Nuclear level half-lives were measured for ^{149}Nd and ^{149}Pr. The parent nuclides (i.e. ^{149}Pr and ^{149}Ce) were prepared at KUR-ISOL [1], following the thermal-neutron-induced fission of ^{235}U. A 93%-enriched $^{235}UF_4$ target (50 mg) was irradiated with thermal neutrons from the KUR. The neutron flux was 3×10^{12} n/cm^{2}s at a thermal power of 5 MW or 6×10^{11} n/cm^{2}s at 1 MW. The fission products were thermalized in the target chamber and were transported to a surface-ionization-type ion source by a He-N_2 mixed-gas jet stream. After ionization, the nuclides were extracted, accelerated to 30 keV, and mass-separated with a resolution of $M/\Delta M \sim 600$. The mass-separated beams were implanted into an aluminum-coated Mylar tape in a computer-controlled tape-transport system. Radioactive ions were periodically moved to a lead-shielded detector station at a time interval of 240 s for ^{149}Pr and 8.5 s for ^{149}Ce.

We installed the $LaBr_3$ and plastic scintillators in the detection port, both at 20 mm from the source. In addition to these detectors, we also used a short coaxial Ge detector (Ortec LO-AX, 51 mm in diameter, 20 mm thick) to measure γ-ray spectra at a source-to-detector distance of 10 mm to determine if contamination occurred due to neighboring isobars and to select a desired decay branch through off-line sorting. The β-γ-γ coincidence data and TAC signals were recorded in list mode. Measuring times were 42 h for ^{149}Pr and 6 h for ^{149}Ce.

IV. RESULTS AND DISCUSSION

A. ^{149}Nd

The decay curve obtained for the 220.7-keV level in ^{149}Nd is shown in Fig. 2(a). These data were obtained by gating on the 112.1- and 108.5-keV γ rays measured with the $LaBr_3$ and the HPGe detectors, respectively. A long slope is clearly observed. Only the 109-keV γ ray is observed in the γ-ray spectrum gated on the 112-keV γ ray, which means that the slope is due to the decay of the 221-keV level. By least-squares fitting to an exponential function, we find a half-life $T_{1/2} = 1.60(4)$ ns. The uncertainty of 40 ps includes statistical (30 ps) and time calibration (20 ps) components. Our result agrees with the previous value of 2.1(5) ns [10, 13], and the precision is much improved because the time resolution of our spectrometer is superior to that of the planar Ge detector used in the previous work.

We also analyzed the decay curves using the centroid-