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Half-life measurement of excited states in neutron-rich nuclei

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Abstract. Half-lives ($T_{1/2}$) of several states which decay by delayed γ transitions were determined from time-gated triple γ coincidence method. We determined, for the first time, the half-life of $330.6 + x$ state in ^{108}Tc and the half-life of $19/2^-$ state in ^{133}Te based on the new level schemes. Five half-lives of ^{95,97}Sr, ^{99}Zr, ^{134}Te and ^{137}Xe are consistent with the previously reported ones. These results indicate that this new method is useful for measuring the half-lives.

PACS. 21.10.Tg Lifetimes – 25.85.Ca Spontaneous fission – 27.60.+j $90 \leq A \leq 149$

Since the classification of delayed γ-rays by Goldhaber and Sunyar [1], half-life ($T_{1/2}$) measurements of nuclear states have been a major source of information on nuclear deformations, shell structures, and validity of nuclear models. Previously, half-lives of several states in neutron-rich nuclei have been determined by single-γ or γ-γ coincidence relations for the delayed γ transitions emitted from the isotopes produced in the fission of ^{235}U, ^{239}Pu, ^{248}Cm, and ^{252}Cf [1,2]. Most of the previous results were obtained from the coincidence measurement between the γ transition and the fission fragment after fission. And some of them were obtained from the delayed time measurement of the γ transition following the β-decay after fission.

Usually, more than 100 isotopes are produced in the fission of these heavy nuclei, with each isotope emitting many γ-rays. Because several new nuclei and many new levels in the known nuclei have been identified in the spontaneous fission (SF) of ^{252}Cf, the present time-gated triple γ coincidence method is very useful for the half-life measurements of nuclear states in neutron-rich nuclei.

The γ-γ-γ coincidence measurements were done by using the Gammasphere facility with 72 Ge detectors and a ^{252}Cf SF source of strength $\sim$28 μCi at LBNL. Several γ-γ-γ coincidence cubes with different time windows, t_{w}, [1,2] were built for the three- and higher-fold data by using the Radware format. That is, a time-gated cube will contain all triple-coincidence events for which all these time differences are less than the specified time value.

Let us consider a downward cascade consisting of γ_3-γ_2-γ_1-γ_0 transitions where γ_0 is the outgoing transition from a state with long half-life and γ_1 is the incoming transition into the same state. Other higher states in this cascade are assumed to have very short lifetimes. We set a double gate on E_{γ_3} and E_{γ_1} and compare the intensities of transitions, γ_0 and γ_2, $N(\gamma_0)$ and $N(\gamma_2)$ in the spectra. In the present work, γ_1, γ_2, and γ_3, are in prompt coincidence. Therefore, the delay-time between γ_1 and γ_3 will be negligible. Since γ_0 is the ending transition in this cascade, the coincidence time window (t_{w}) limits the TDC time difference, t_{10}, between the γ_1 and γ_0 transitions, and the intensity $N(\gamma_0)$ observed from the state with the long lifetime. The $N(\gamma_0)$ intensity determines the fraction of $N(\gamma_2)$ intensity observed from the state with the long half-life with decay constant, λ. Therefore, $N(\gamma_0)/N(\gamma_2) = C(1 - \mathrm{e}^{-\lambda t_{\mathrm{w}}})$ can be applied in this case, where C is a constant.

We applied this method, for the first time, to extract the half-lives of two states in ^{95,97}Sr [2]. Later, five other cases namely ^{99}Zr, ^{133,134}Te, ^{137}Xe and ^{108}Tc are investigated as shown in table 1 [1]. Recently, the new level schemes of ^{133}Te and ^{108}Tc have been reported from the SF work of ^{252}Cf. Based on these new level schemes, the half-lives of 1610.4 keV state in ^{133}Te and $330.6 + x$ keV

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Table 1. Half-lives ($T_{1/2}$ ns) of several states ($E_{\rm IS}$, keV) [1,2]. $E(\gamma_1)/E(\gamma_3)$ are the double-gated transition energies. For ^{97}Sr, $E(\gamma_2)/E(\gamma_3)$ and $E(\gamma_1)$ are used instead. Half-lives of delayed γ-rays without the mass identification were reported to be 110 ns for 154.0 keV γ-ray and 115 ns and 81.6(114) ns for 125.5 keV γ-ray [1]. The half-life of the 1610.4 keV state in ^{133}Te is the average value extracted from 125.5 and 1150.6 delayed transitions.

Nuclei	$E_{\rm IS}$	$E(\gamma_1)/E(\gamma_3)$	$E(\gamma_2)$	$E(\gamma_0)$	Present $T_{1/2}$	Reference's $T_{1/2}$ [1]	ENSDF [3]
^{95}Sr	556.1	682.4/678.6	427.1	204.0	23.6(24)	24, 21, 21.8(11)	21.7(5)
^{97}Sr	830.8	239.6/272.5	205.9	522.0	265(27)	382(11), 255(10)	255(10)
^{99}Zr	252.0	426.4/415.2	142.5	130.2	316(48)	294(10), 375(11)	293(10)
^{108}Tc	$330.6+x$	123.4/341.6	125.7	154.0	94(10)		
^{133}Te	1610.4	721.1/933.4	738.6	125.5	99(6)		
^{134}Te	1692.0	2322.0/516.0	549.7	115.2	197(20)	161(4), 196(7), 175(6)	164(1)
^{137}Xe	1935.2	311.3/304.1	1046.4	314.1	10.1(9)	8.1(4)	8.1(4)

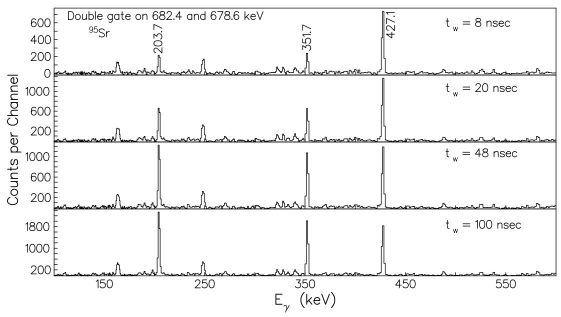

Fig. 1. Coincidence spectra with double gate on 682.4 and 678.6 keV transitions in ^{95}Sr.

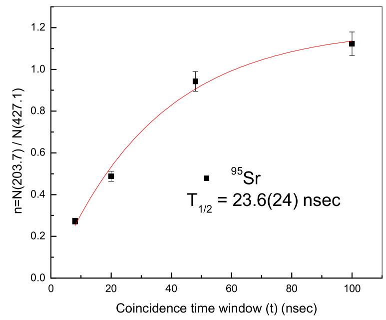

Fig. 2. Count ratio *versus* coincidence time window ($t_{\rm w}$) plot for ^{95}Sr. The curve is the fitted line to $C(1-{\rm e}^{-\lambda t_{\rm w}})$.

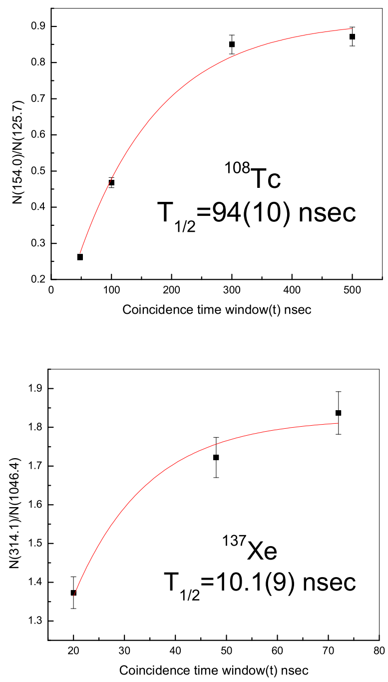

Fig. 3. Count ratio *versus* coincidence time window ($t_{\rm w}$) plots for ^{108}Tc and ^{137}Xe. The curves are the fitted lines to $C(1-{\rm e}^{-\lambda t_{\rm w}})$.

state in ^{108}Tc are reported in the present work. As one example, coincidence spectra with double gate on 682.4 and 678.6 keV transitions in ^{95}Sr [2] is shown in fig. 1. And the plots for the count ratio *versus* coincidence time window are shown in figs. 2 and 3. The more details for this time-gated triple-coincidence method to determine the level half-life can be seen in refs. [1,2].

In summary, we report half-lives of five states in ^{95,97}Sr, ^{99}Zr, ^{108}Tc, ^{133}Te, ^{134}Te, and ^{137}Xe by using the new time-gated triple-coincidence method. We determined, for the first time, half-lives of ^{108}Tc and ^{133}Te based on the new level schemes. The half-lives of states in ^{95,97}Sr, ^{99}Zr, ^{134}Te, and ^{137}Xe are consistent with the previously reported ones. These results indicate that this new method is useful for the half-life measurements.

References

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