Beta Decay of 102Y Produced in Projectile Fission of 238U

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Abstract. The population of ^{102}Zr following the β decay of ^{102}Y produced in the projectile fission of ^{238}U at the GSI facility in Darmstadt, Germany has been studied. ^{102}Y is known to β decay into ^{102}Zr via two states, one of high spin and the other low spin. These states preferentially populate different levels in the ^{102}Zr daughter. In this paper the intensities of transitions in ^{102}Zr observed are compared with those from the decay of the low-spin level studied at the TRISTAN facility at Brookhaven National Laboratory and of the high-spin level studied at the JOSEF separator at the Kernforschungsanlage Jülich.

1. Introduction

The shape-changing region of the nuclear chart around neutron-rich A∼100 remains one of much experimental and theoretical interest. Laser spectroscopy measurements of the mean-square charge radii of the zirconium chain of nuclei [1] show a shape change from spherical to deformed at N=59, ^{99}Zr. For heavier zirconium nuclei, the energy of the first excited $J^{\pi}=2^{+}$ level and the energy ratio between the first excited $J^{\pi}=4^{+}$ and 2^{+} levels indicate increasing prolate deformation. Excited levels in ^{102}Zr have been studied following the beta decay of ^{102}Y [2, 3] and also in induced fission of uranium [4, 5] and spontaneous fission of californium [6, 7]. A partial level scheme is shown in figure 1. The β-decay studies have been complicated by the fact that there are thought to be two β-decaying states in ^{102}Y, one low spin, which has a half-life of 0.30(1) s [2] and another of high spin which has a half-life of 0.36(3) s [3]. The existence of two decay routes is based on the evidence of vastly differing ratios of the $(4_1^+ \rightarrow 2_1^+)/(2_1^+ \rightarrow 0^+)$ transition intensities in studies using two different facilities:

- the TRISTAN facility at Brookhaven National Laboratory [2], where the parent ^{102}Y isotope was produced from the beta decay of ^{102}Sr. The ratio of the $(4_1^+ \rightarrow 2_1^+)/(2_1^+ \rightarrow 0^+)$ transition intensities was 0.09(1) and therefore the ^{102}Y parent was thought to be in a low-spin state;
- the JOSEF recoil separator at the research reactor DIDO of the Kernforschungsanlage Jülich [3], where the parent ^{102}Y isotope was produced directly from thermal fission of ^{235}U. In this case, the ratio of the $(4_1^+ \rightarrow 2_1^+)/(2_1^+ \rightarrow 0^+)$ transition intensities was 0.44(3) and therefore the ^{102}Y parent was thought to be primarily in a high-spin state.

In the current work, ^{102}Y was populated in the projectile fission of ^{238}U. Data on the γ-rays observed will be presented and the intensities will be discussed in the context of the values quoted in the two studies listed above.

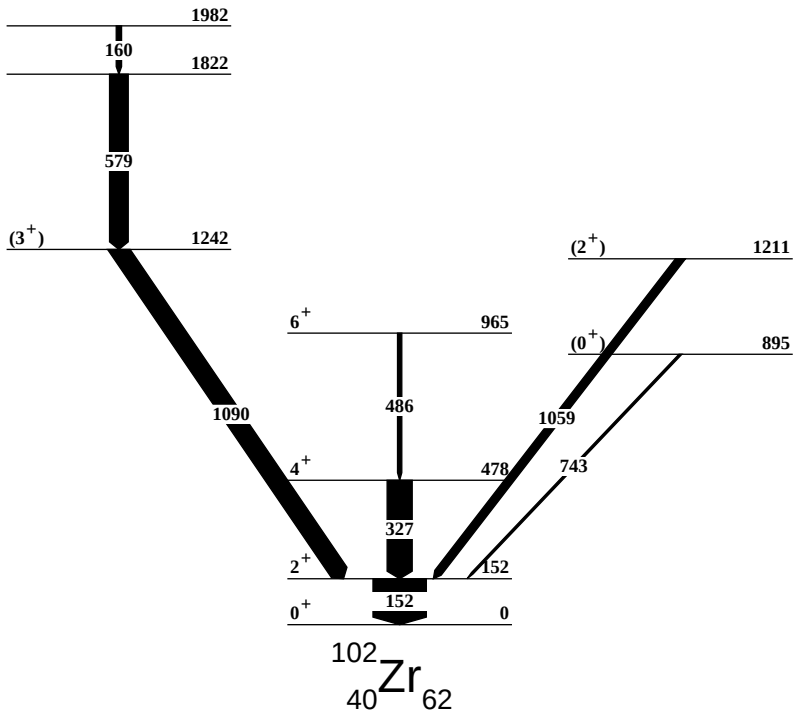

Figure 1. A partial level scheme [6, 3, 2] for ^{102}Zr showing the transitions observed in this work. The widths of the arrows are proportional to the observed γ-ray intensities.

2. Experimental details

^{102}Y was produced in the relativistic fission of a ^{238}U beam impinging on a ^{9}Be target of thickness 1033 mg/cm^2. The 750 A.MeV pulsed beam was provided by the SIS-18 synchrotron accelerator at GSI and typical intensities were up to 2 x 10^9 ions per spill. The fully stripped ions, obtained in the relativistic fission, were separated in the GSI FRagment Separator (FRS) [8] and identified by means of time-of-flight and energy loss techniques. At the exit of the separator, the fragments were slowed by an Al degrader to such an extent that they then implanted in an active stopper [9] consisting of nine, 5 cm x 5 cm x 1 mm DSSSDs. The nine detectors were arranged in 3 rows of 3, with each row being orthogonal to the beam direction. The detector array thus presented an implantation area of 15 cm by 5 cm at the focal plane of the separator. Each DSSSD had 16 strips, of width 3 mm, on each of the front and back faces. The strips on the front and back faces were orthogonal and thus each detector was divided into 16 x 16 =256 pixels which could record the position of the implantation. Fragments which did not implant, triggered a scintillation detector behind the active stopper which provided a veto.

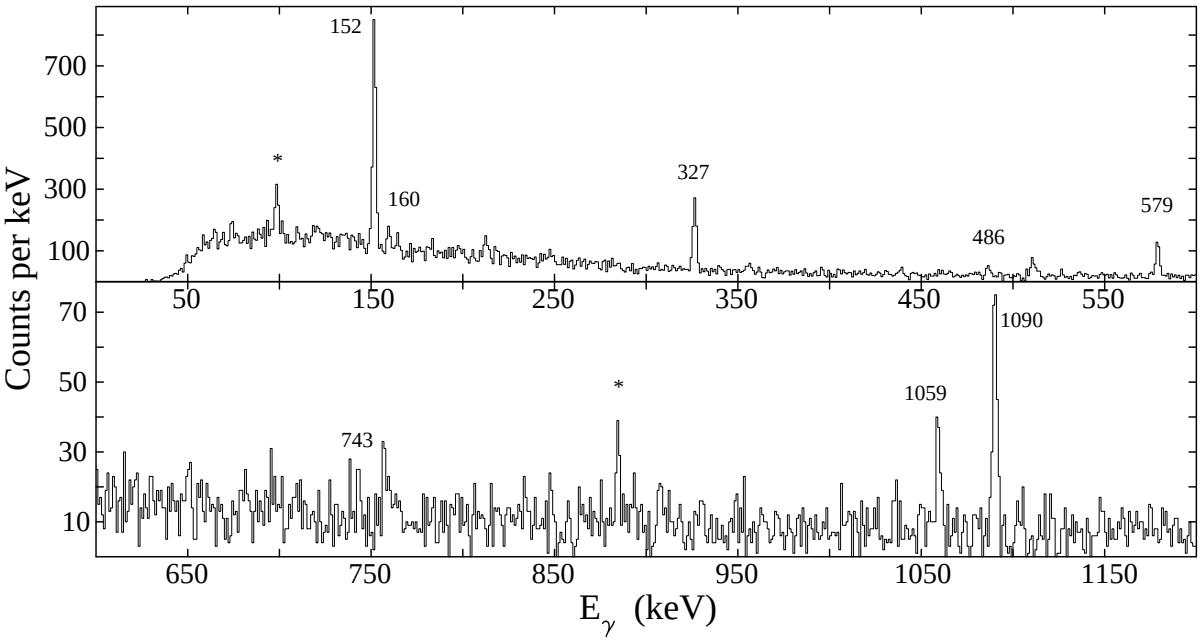

Figure 2. A background-subtracted spectrum of gamma rays observed within a time of 1 second following the beta decay of ^{102}Y. Peaks labelled with an energy belong to ^{102}Zr, those with * are contaminants.

The correlation between the high-energy implantation events and the subsequent low-energy beta decay was facilitated by the use of Mesytec semi-logarithmic preamplifiers [10] which allow a linear amplification for low energy (decay) signals and a logarithmic amplification for high energy (implantation) signals. The gamma-rays emitted following the beta decay were measured in the RISING γ-ray array, comprising 15 Cluster detectors, which has an efficiency of $\sim$ 15% for the 662-keV line in ^{137}Cs [11]. The signals from each Ge detector were processed via XIA Digital Gamma Finder modules for energy and time analysis. The time stamp of the modules was 25 ns. The observed gamma-rays were timed relative to an electron measured in a specific pixel of the DSSSD array. In subsequent off-line analysis, the data was searched backwards in time to identify the most recent implanation in the same pixel. Thus it is possible to correlate an observed γ-ray with the β-decaying parent nucleus. A more detailed description of the technique is available in [12].

3. Data analysis

Figure 2 shows a background-subtracted spectrum of gamma rays observed within a time of 1 second following the beta decay of ^{102}Y. This time was chosen as it corresponds to approximately three half-lives for the ^{102}Y decay but is significantly smaller than the half-life of the ^{102}Zr ground state ($t_{1/2}$=2.9 s) [13]. The spectrum clearly shows the transitions from the yrast 2^+,4^+, and 6^+ levels but also high-energy transitions from side bands. Figure 3 shows spectra obtained in coincidence with the a) 152, b) 1059 and c) 1090 keV transitions and confirms the partial level scheme shown in figure 1. The intensities of the transitions observed in this work are listed in the second last column of table 1 where they have been normalised to the 152 keV $2_1^+ \rightarrow 0^+$ transition. The two previous columns show the relative intensities observed at the TRISTAN facility where ^{102}Y was producued in the β-decay of ^{102}Sr [2] and at the JOSEF facility where the ^{102}Y fission fragments were separated directly [3]. The last column follows the procedure in [2] and indicates intensities calculated for the decay of only the high-spin state. These values are obtained by subtracting nominal "low-spin" intensities from the intensities observed in the current work. This is done by assuming that all of the intensity of the 743 keV transition arises from the decay of the low-spin state and by normalising to the intensities in column 6 [2].

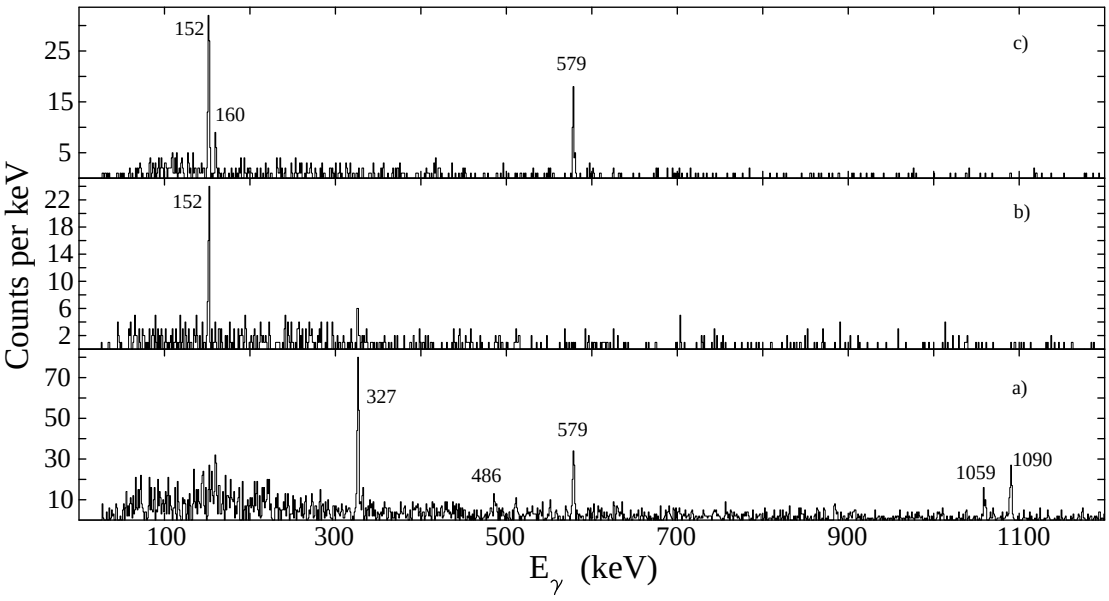

Figure 3. Gamma-ray spectra obtained in coincidence with the a) 152, b) 1059 and c) 1090 keV transitions in ^{102}Zr.

Figure 4 shows the time distribution for the $2_1^+ \rightarrow 0^+$ transition in ^{102}Zr. The data has been fitted to the sum of two exponential decays of $t_{1/2}$ = 360 and 300 ms. The best fit occurs when the intensities of the two components are in the ratio 76% to 24% respectively.

4. Discussion

The intensities measured in this work (listed in the second last column of table 1) are consistent with those measured at the JOSEF facility [3] (column 7) rather than those measured at the TRISTAN facility [2] (column 6) and support the conclusion that there are two β-decaying states in ^{102}Y. In particular, the table shows that high-spin levels (at 478-, 965- and (presumably) 1242-1822- and 1982 keV) are populated more strongly in the current work than in the work of Hill

Table 1. The relative intensities of gamma-rays observed in ^{102}Zr (normalised to the 152 keV $2_1^+ \rightarrow 0^+$ transition).

$E_{initial}$ (keV)	$J^\pi_{initial}$	E_{final} (keV)	J^π_{final}	E_γ (keV)	TRISTAN [2] I_γ(%)	JOSEF [3] I_γ(%)	This work I_γ(%)	High spin I_γ(%)
152	2^+	0	0^+	152	100(4)	100(3)	100(4)	76(5)
478	4^+	152	2^+	327	8.6(9)	44(3)	47(3)	45(4)
895	(0^+)	152	2^+	743	17(4)	3.5(14)	4(1)	
965	6^+	478	4^+	486	<1.9	6.7(11)	8(2)	8(2)
1211	(2^+)	152	2^+	1059	29(3)	14.1(17)	15(2)	8(3)
1242	(3^+)	152	2^+	1090	<1.3	33(3)	35(3)	35(3)
1822		1242	(3^+)	579	<1.1	28(3)	35(3)	35(3)
1982		1822		160	<1.1	8.0(8)	10(2)	10(2)

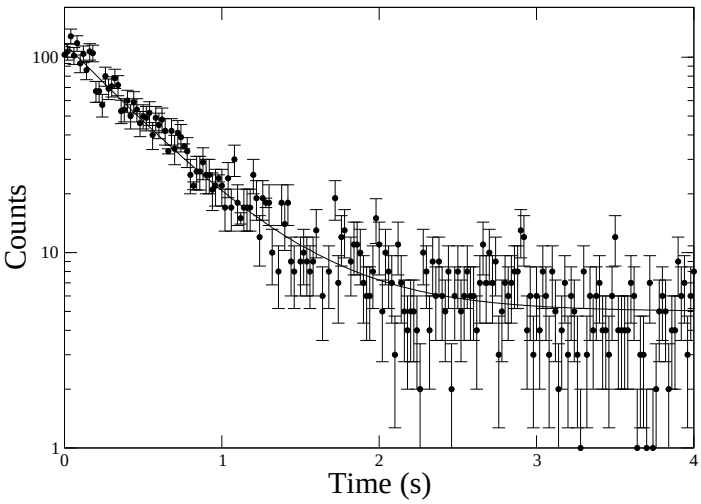

Figure 4. A spectrum showing the time profile of the 152 keV transition in ^{102}Zr. The line shows the best fit using two exponential functions (see text for details).

et al [2]. The opposite is true for the low-spin levels at 895- and 1211 keV. The value of 76(5)% listed in the last column of table 1 for the 'high-spin' intensity of the $2_1^+ \rightarrow 0^+$ transition indicates that, in this work, this transition is fed ∼3 times more strongly by decays from the high-spin state in ^{102}Y than from the low-spin state. This is consistent with the 76% obtained from the fit to the time profile of the 152 keV transition as shown in figure 4. The analogous value in Shizuma's work [3] was 79(10)%. In the current work, the parent ^{102}Y nucleus was produced in projectile fission of a ^{238}U beam whereas in the work of Shizuma et al [3] it was produced in thermal neutron induced fission of ^{235}U. In both cases, it is clear that it is the high-spin state in ^{102}Y which is predominantly β-decaying into excited states in ^{102}Zr.

5. Conclusion

The gamma-ray intensities observed in ^{102}Zr following the β decay of ^{102}Y produced in projectile fission of ^{238}U indicate decay from both the high-spin and low-spin levels in ^{102}Y. The relative strength is observed to be in the ratio of ∼3 to 1. The low-spin level populates $J^\pi=(0^+)$ and (2^+) levels in the daughter, perhaps indicating $J^\pi=1^+$ for the parent. The high-spin level populates $J^\pi=(3^+)$, 4^+ and 6^+ levels in the daughter, perhaps indicating $J^\pi=4^+$ or 5^+ for the parent. It is intriguing that none of these suggestions coincides with the laser spectroscopy measurements of

Cheal et al. [14] who propose J= 2 or 3 for the state they observe in ^{102}Y. Further investigation is therefore required.

6. Acknowledgments

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