YRAST STRUCTURE OF ^{97}Zr*

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The yrast structure of the neutron-rich nucleus ^{97}Zr has been studied using fission of target-like products in the reaction of a ^{48}Ca beam on a thick ^{238}U target. The level scheme known from the previous studies up to an energy and spin of approx. 4619 keV and $23/2^-$, respectively, has been extended by about 3 MeV and a few units of angular momentum. The located structure can be discussed in terms of shell model configurations.

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1. Introduction

The mass region $A \approx 100$ has attracted a lot of attention because neutron-rich nuclei above ^{96}Zr demonstrate a clear shape transition with increasing neutron number. Whereas in both ^{96}Zr and ^{98}Zr the lowest excitations can be described in terms of simple shell model configurations [1,2], ^{102}Zr already exhibits features of a strongly deformed nucleus [3]. In the $^{97-100}$Zr isotopes, coexistence of spherical and deformed structures is expected. Indeed, such features have been observed in ^{98,99,100}Zr, but not in ^{97}Zr. In this nucleus information on higher-lying yrast states is largely missing.

In earlier works performed by some members of the present collaboration, deep-inelastic processes occurring during collisions of a ^{48}Ca beam with a thick ^{238}U target, at an energy roughly 20% above the Coulomb barrier, were successfully used to study the yrast structure of hard-to-reach, neutron-rich nuclei from the neighborhood of ^{48}Ca. In the ^{48}Ca+^{238}U reaction, neutron-rich nuclei may also be produced in fission of the target-like

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fragments resulting from multi-nucleon transfer processes. Indeed, inspection of the data revealed a sizeable population of nuclei with masses between 80 and 140. In particular, Zr isotopes, with $A = 90$–104, were present with cross sections sufficient to examine in detail the coincidence relationships between gamma rays emitted from states with relatively high spins.

2. Experimental setup

The experiment was performed at the Argonne National Laboratory, USA, using the ATLAS accelerator. Gamma rays emitted during reactions induced by a ^{48}Ca beam (330 MeV) on a thick ^{238}U target (50 mg/cm^2), were measured with GAMMASPHERE which consisted of 101 Compton suppressed HPGe detectors [4]. Gamma-ray coincidence data were collected with a trigger requiring three gamma rays to be present in prompt coincidence. Energy and timing information of all Ge detectors firing within 800 ns was stored. The beam was pulsed with a 412 ns repetition rate which allowed for a clean separation between prompt and isomeric decays. In the analysis, various versions of prompt and delayed gamma coincidence matrices and cubes were sorted. The data showed that the process of fission of target-like nuclei populates relatively high-spin states in nuclei near ^{96}Zr. The nucleus of interest, ^{97}Zr, was one of the intense products.

3. Experimental results

Prior to this work, the low-lying yrast excitations in ^{97}Zr were known mostly from the β^--decay study of the $9/2^+$ state in ^{97}Y [5, 6] and from (d, p) and $(\alpha,{}^3\mathrm{He})$ reaction investigations [7]. These were: the $3/2^+$ state at 1103 keV, an isomeric state at 1264 keV with $7/2^+$ spin-parity assignment and half-life of 103 ns, an excitation at 2264 keV with the proposed quantum numbers $11/2^-$ and a state at 2625 keV for which spin-parity $13/2^-$ was suggested. Also, the location of higher yrast states at 3081, 3780 and 4620 keV with spin-parity assignments of $15/2^-$, $19/2^-$ and $23/2^-$, respectively, was tentatively proposed following the beta-decay study of the $27/2^-$ high-spin isomer in ^{97}Y [8].

As a first step in the analysis, we inspected the spectra of gamma rays that were coincident with the beam pulse, but also associated with subsequent (in the range of 1 microsecond) detection of transitions at 161 and 1103 keV deexciting the $7/2^+$ isomer — the spectrum for the 1103 keV gate is shown in Fig. 1(a). We confronted them also with the spectra doubly gated on 457, 407, 1400 keV γ rays depopulating the $11/2^-$ state at 2264 keV (the example is shown in Fig. 1(b)). In this way, we displayed the 361, 457, 698, 818 and 840 keV gamma rays that were reported in Ref. [8] as deexciting higher yrast states. In addition, at the energies of 729, 882, 949 and 986 keV

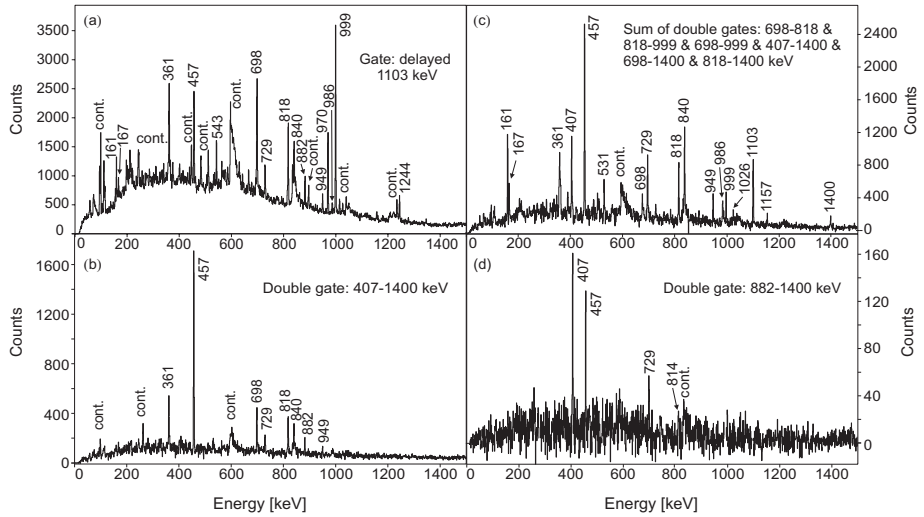

Fig. 1. The γ-ray spectra from the ^{48}Ca+^{238}U reaction obtained by setting: (a) a single gate on the delayed 1103 keV, (b) a double gate on the 407 and 1400 keV lines, (c) sum of double gates on selected ^{97}Zr transitions used to find the highest spin transitions, (d) a double gate on the 882 and 1400 keV γ rays.

other candidates for transitions preceding the $11/2^-$ state appeared. Subsequently, the sum of double coincidence gates placed on the members of the 999–818–698–840 keV cascade in the prompt $\gamma\gamma\gamma$ cube as well as on the pairs of lines belonging to the cascade 457–407–1400 keV that deexcites the $11/2^-$ level at 2264 keV, showed distinct 949 and 986 keV gamma rays and also weaker transitions at 1026, 990, 1157, 531 and 167 keV clearly belonging to ^{97}Zr (Fig. 1(c)). On the basis of these findings and the coincidence relationships between the new lines, the following states were placed in the ^{97}Zr level scheme: a state at 5569 keV decaying by a 949 keV transition, a 5606 keV state connected to the 4620 keV level by a 986 keV transition and states at 6595, 6763, 7127, 7294 keV. The cascade consisting of three gamma rays 729, 814 and 882 keV forms a branch parallel to the main branch feeding the 2264 keV state — this feature is illustrated in Fig. 1(d). The resulting level scheme is presented in Fig. 2.

As mentioned above, the states at 3082, 3780 and 4620 keV were identified in the beta-decay study of the $27/2^-$ high spin isomer in ^{97}Y [8] and tentative spin-parity assignments of $15/2^-$, $19/2^-$ and $23/2^-$, respectively, were proposed. The excitations located in the present work at 5569, 5606, 6595, 6763, 7127, and 7294 keV are very likely higher-lying yrast states. The two levels placed at 5569 and 5606 keV are very good candidates for excitations with $25/2^-$ and $27/2^-$ that were searched for in Ref. [8] as states fed

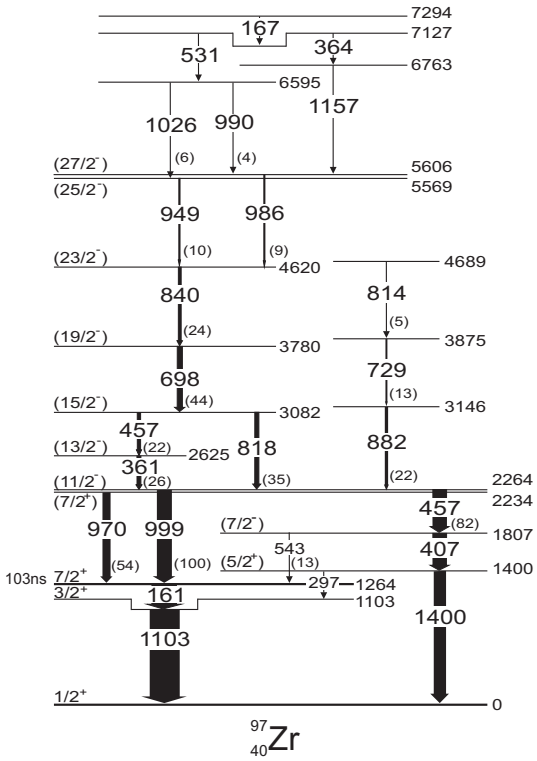

Fig. 2. The level scheme of ^{97}Zr obtained from the ^{48}Ca+^{238}U reaction. Relative transition intensities are shown in parentheses.

in beta decay of the $27/2^-$ isomer in ^{97}Y. The gamma decay pattern of the states located at higher energies indicates that their spin values are in the range of $29/2 - 33/2$.

4. Summary and conclusions

We have studied the yrast structure of the neutron-rich nucleus ^{97}Zr produced in fission of target-like fragments following the ^{48}Ca(330 MeV)+^{238}U reaction. By using prompt and delayed γ–γ coincidence spectroscopy, we have extended the ^{97}Zr level scheme up to an excitation energy of ~ 7.3 MeV and a spin of approximately $33/2$. The new findings point out that ^{97}Zr, with one neutron outside the ^{96}Zr core, retains the character of a spherical nucleus up to quite high excitation energy and spin.

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