EXTENSION OF SYSTEMATICS FOR EVEN-EVEN Zr ISOTOPES TO A = 102

John C. Hill

Kernforschungsanlage Jülich, Germany and Ames Laboratory USDOE, Iowa State University, Ames, Iowa 50011 USA

K. Shizuma+, H. Lawin, M. Shaanan++, H.A. Selič and K. Sistemich

Kernforschungsanlage Jülich, Germany

Abstract

The β^- decay of ^{102}Y to levels in ^{102}Zr was investigated using the gas-filled recoil separator JOSEF. The singles γ spectrum, γ-γ and X-γ coincidences, and half-life were measured. Preliminary results from these measurements are reported. Only one isomer was observed with a $T_{1/2}$ = 0.27 ±0.07 s. The β^- decay populated excited states in ^{102}Zr at 151.9(2^+), 478.4(4^+), 730.7 and 1242.1 keV. No evidence was found for the population of a low-lying 0^+ state of the type seen in ^{100}Zr. The results are compared with earlier fission fragment studies, and implications for the systematics of even-even Zr nuclides are discussed.

1. Introduction

The neutron-rich Zr isotopes are of special interest as they appear to exhibit a very rapid transition from a spherical to a deformed shape. The level structure for ^{96}Zr shows magic properties in accordance with the spherical shell model[1]), while ^{100}Zr appears to be deformed[2]). The nucleus ^{98}Zr appears to be of a transitional character[3]) but more vibrational than rotational in nature. The energy of the 2_1^+ state decreases by a factor of 6 in going from ^{98}Zr to ^{100}Zr indicating a sudden change to rotational behaviour similar to that occuring in the Sr isotopes but more drastic than the change observed in the Sm isotopes between ^{150}Sm and ^{152}Sm. The energy ratio E_{4^+}/E_{2^+} is 1.6 for ^{98}Zr but rises to 2.65 for ^{100}Zr and at ^{102}Zr where the ratio is 3.14 approaches the rigid rotor value.

In order to gain a more detailed picture of the structure of ^{102}Zr and the change from a spherical to a deformed structure in the Zr isotopes, an investigation of levels in ^{102}Zr populated in the β^- decay of ^{102}Y was undertaken. This nucleus cannot be reached by conventional reaction experiments and is most readily accessible through fission.

The only information presently available on the structure of ^{102}Zr was obtained through observation of the prompt electromagnetic decay of ^{102}Zr fission fragments[4]). The YRAST band up to 8^+ was observed. The only information available[5]) on ^{102}Y is a half-life of 0.9 sec. The JOSEF separator was well suited for a study of short-lived ^{102}Y due to the very short separation time inherent in the system, but the low fission yield of ^{102}Y is a limiting factor.

2. Experimental Techniques

2.1 The JOSEF separator

The gasfilled separator JOSEF provides a beam of fission products from the ^{235}U(n,f) reaction. The separation occurs according to the mass of the product and its average ionic charge along the path in the gas-filled magnet and is essentially independent of the primary ionic charges and kinetic energies of identical fission products. The JOSEF separator is described in detail elsewhere[6]). The fission product beam impinged on a 3 cm wide tape of a tape transport device and measurements were carried out at the beam collection position. The tape was periodically moved to reduce interference from long-lived products. The data were accumulated in the megachannel computer analyzer system MECCA[7]).

2.2 Identification of ^{102}Y

Early experiments on γ rays from fission fragments[4]) established that the 2_1^+ state in ^{102}Zr occurred at 152 keV. In initial experiments at JOSEF a search was made for this γ ray using a He-jet system without success. Subsequent measurements at the in-beam position revealed the presence of the 152 keV γ ray with a very short half-life. In all subsequent measurements the fission product beam was collected and counted simultaneously. The tape was moved every 2 seconds to minimize buildup of long-lived products with a tape transfer time of 0.4 seconds.

The identification of the nuclide from which the 152 keV line emanated was carried out by measuring the intensity distribution of the γ ray as a function of the magnetic rigidity $B\rho$ of the gas filled magnet. The position of the $B\rho$ maximum was that expected for ^{102}Y. In this measurement a 30 cc intrinsic Ge-detector with a resolution FWHM of about 0.8 keV at 160 keV was used. Other lines observed in the decay of ^{102}Y were too weak and complex to give unambigious $B\rho$ maxima in a singles γ ray measurement. $B\rho$ coincidence measurements are in progress to establish more firmly the origin of these γ rays.

The fission products ^{105}Mo, ^{104}Nb, and ^{103}Zr have $B\rho$ maxima very close to that for ^{102}Y. In order to eliminate these nuclides as sources of the 152 keV γ ray a X-γ coincidence measurement, which is described in detail below, was carried out. Definite coincidences were observed between the Zr $K\alpha$ X ray and γ lines from ^{102}Y decay at 152 and 326 keV.

2.3 γ ray singles measurements

γ ray singles measurements were carried out both with the 30 cc intrinsic Ge detector and a large volume 150 cc Ge(Li) detector with a resolution of 2.0 keV for the 1332 keV γ ray in ^{60}Co. Also $B\rho$ measurements were made for both detectors. The fission yield for ^{102}Y is quite low for experiments at JOSEF and the resulting γ spectra are complex. γ ray intensities for ^{102}Y are being determined by comparing results from several $B\rho$ measurements. γ ray energies were determined in coincidence measurements and are discussed below.

2.4 The half-life of ^{102}Y

A crude half-life for ^{102}Y was determined using the 150 cc Ge(Li) detector. Because of the very short half-life for ^{102}Y it was necessary to install a "chopper" to interrupt the fission product beam at appropriate intervals. The fission product beam is concentrated at the entrance to the separator magnet by a guide consisting of a wire at a negative potential of from 5 to 20 kV. A second guide concentrates the beam coming out from the magnet at the tape

+ Visitor from Hiroshima University, Hiroshima, Japan
++Visitor from Soreq Nuclear Research Center, Yavne, Israel

collector. The "chopper" alternatively applied a negative and a positive potential to the second guide in order to interrupt the fission product beam.

For the half-life measurement the analyzer was operated in the multiscale mode. The activity was collected for 0.6 seconds and the decay followed for 1.0 seconds. After movement of the tape the cycle was repeated. Analysis of the time structure for the 152 keV γ ray resulted in a preliminary half-life for ^{102}Y of 0.27 ± 0.07 seconds. No evidence was seen for two different half-lives, thus it appears that unlike ^{98}Y and ^{100}Y only one isomer of ^{102}Y undergos β^- decay (the case of two isomers with very similar half-lives cannot absolutely be ruled out). Measurements will be carried out with the high resolution 30 cc intrinsic Ge detector to obtain a more accurate half-life for ^{102}Y.

2.5 γ-γ coincidence measurements

Two sets of coincidence measurements were carried out both using the 150 cc Ge(Li) detector. For the X-γ coincidences the 30 cc intrinsic Ge detector was used and for the γ-γ coincidences a 60 cc Ge(Li). The detectors were at about 90^0 to each other. Two energy and one time descriptor were recorded in buffer tape mode.

In the γ-γ coincidence experiment events were accumulated over a period of about 170 hours. The results of this measurement are given in Table 1.

Table 1: γ-γ coincidences observed in ^{102}Y decay

Gating transition (keV)	Definitely coincident γ rays (keV)
152	326, 579, 1090
326	152
579	152
1090	152

No coincidences were observed with a γ ray at 486 keV that would be the $6^+ \rightarrow 4^+$ transition in ^{102}Zr.

In the X-γ coincidence experiment events were accumulated over a period of about 230 hours. The range of the 30 cc detector was set from 0 to 220 keV to take advantage of its excellent resolution. γ rays at 152 and 326 keV were observed in coincidence with the Kα X ray from Zr. A gate on the 152 keV line in the 30 cc detector spectrum revealed coincidences with γ rays at 326, 579, and 1090 keV but the background was lower due to the smaller Compton distribution under the 152 keV peak. This spectrum is shown in Fig. 1

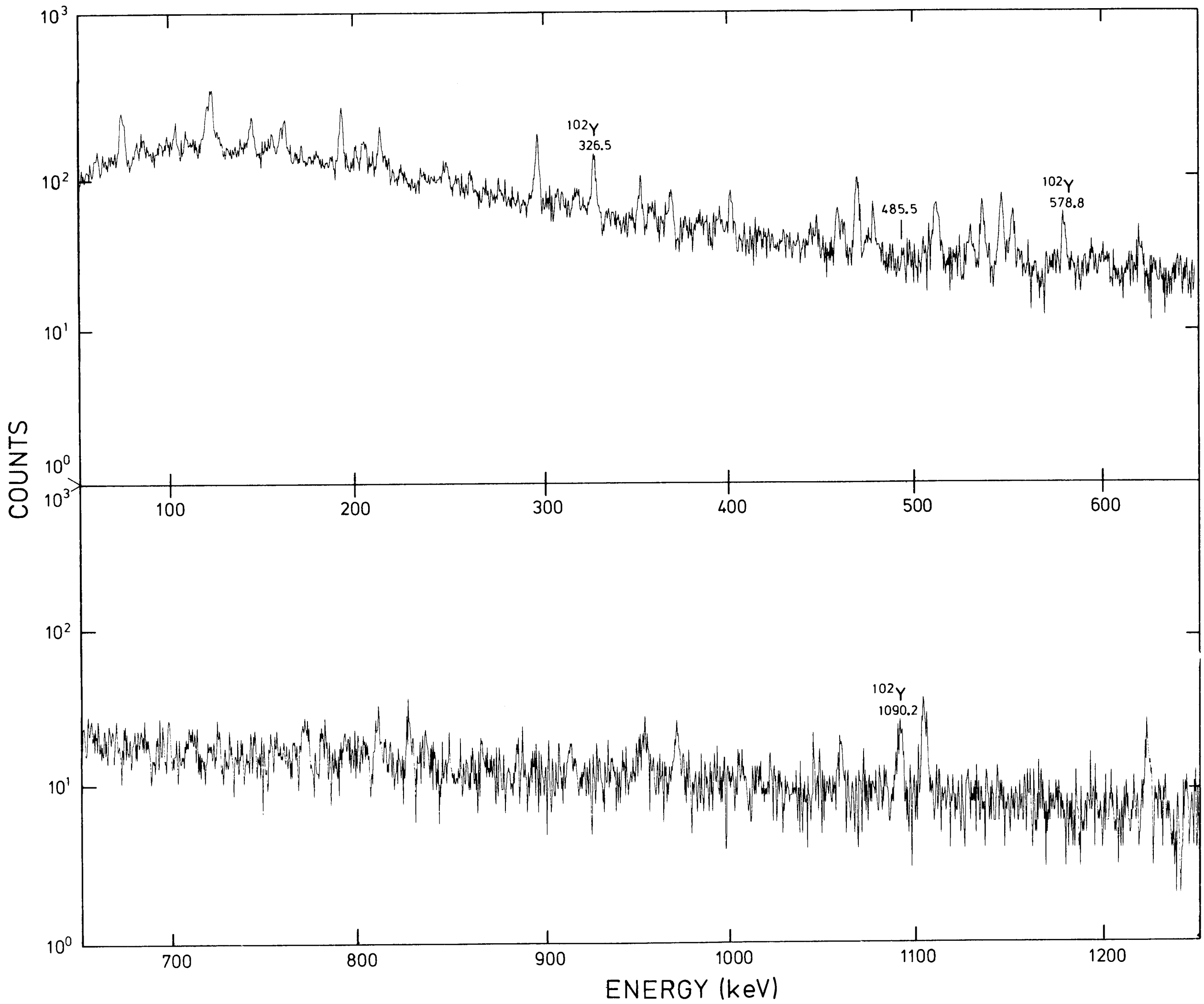

Fig. 1: Spectrum of γ rays in coincidence with the 152 keV γ ray from ^{102}Y decay.

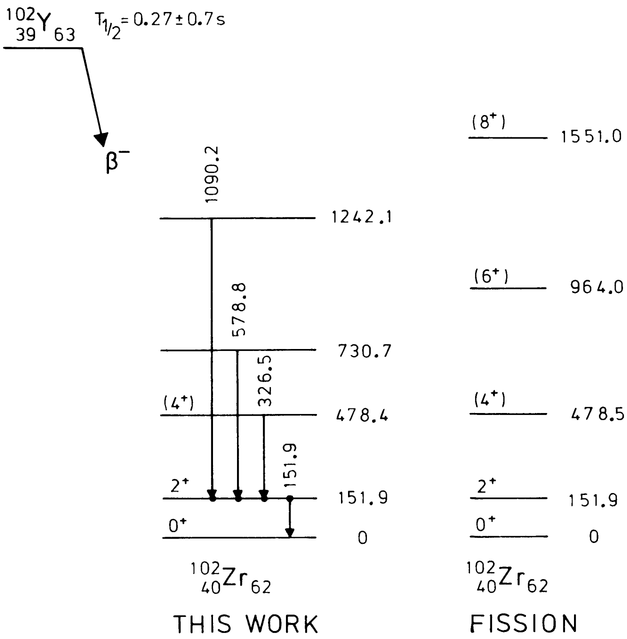

Fig. 2: Decay scheme for ^{102}Y from this work (left), and ^{102}Zr levels from fission fragment studies (right).

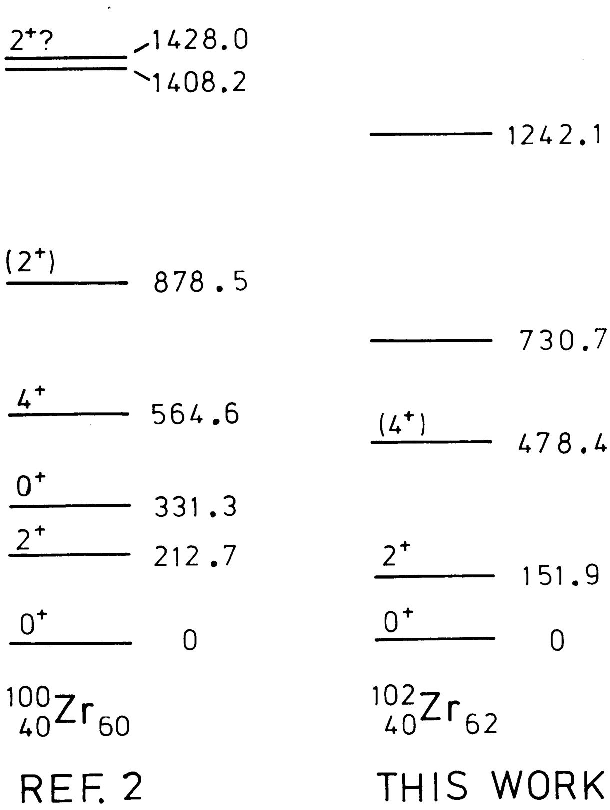

Fig. 3: Comparison of the level structure of ^{102}Zr and ^{100}Zr.

Because of the complexity of the γ ray singles spectra, the energies for the ^{102}Y γ rays were measured in the coincidence mode. A ^{152}Eu source was placed in front of the detectors and the ^{152}Eu and fission product spectra were measured simultaneously. By choosing suitable gates and in some cases developing secondary standards it was possible to determine the ^{102}Y γ ray energies which are given in Table 2. The results are compared with those from earlier fission fragment experiments[4]).

Table 2: γ-ray energies observed in ^{102}Y decay

E_γ (keV) this work	E_γ (keV) Ref.4
151.9 ± 0.1	151.9
326.5 ± 0.2	326.6
	485.5
578.8 ± 0.2	
1090.2 ± 0.2	

3. Decay scheme and discussion

3.1 The decay scheme of ^{102}Y

The measurements described above have been used to construct a preliminary first decay scheme for ^{102}Y. The measured half-life of 0.27 ± 0.07 sec is in poor agreement with a range of values from about 0.9 to 3 sec predicted by the Gross-Theory of β decay[8]). Theoretical predictions were systematically too large for other lower mass odd-odd Y isotopes. The decay scheme is shown in Fig. 2 and the levels in ^{102}Zr are compared with results from fission fragment studies[4]).

The level energies of 151.9 (2^+) and 478.4 (4^+) keV are in good agreement with values of 151.9 and 478.5 keV obtained in fission fragment studies[4]). The 6^+ and 8^+ members of the YRAST band in ^{102}Zr were not observed. This implies that J for ^{102}Y is probably less than 5. In addition to the $4_1^+ \rightarrow 2_1^+ \rightarrow 0_1^+$ cascade new levels in ^{102}Zr at 730.7 and 1242.1 were confirmed by coincidence measurements.

Due to the complexity of the singles γ ray spectra analysis of relative γ ray intensities is still in progress, but preliminary results indicate significant β^- feeding to both the 4^+ and 2^+ levels in ^{102}Y. Thus log fts' to both the above levels are probably less than 5.5 thus favouring a J^π assignment of 3^+ for the ^{102}Y ground state.

Although isomerism is well established for ^{96}Y, ^{98}Y, and ^{100}Y we were unable to detect an isomer for ^{102}Y. The reason for this is not clear. Unfortunately if a low-lying 0_2^+ state exists in ^{102}Zr it would be difficult to populate by β^- decay from the 3^+ ^{102}Y ground state. We see no evidence for population of a 0_2^+ state.

3.2 Systematics of even-even Zr isotopes

As was pointed out above the energy ratio E_{4^+}/E_{2^+} is 1.6 for the nucleus ^{98}Zr which is assumed to be spherical in nature but rapidly rises to 2.65 for ^{100}Zr and 3.14 for ^{102}Zr indicating a transition to a nucleus with a significant deformation. In Fig. 3 our level scheme for ^{102}Zr is compared to that for ^{100}Zr obtained in a study[2])of the decay of ^{100}Y. The most obvious feature is the lowering in energy of the YRAST band from A = 100 to 102. The feeding and decay patterns for the 878.5 and 1408.2 keV levels in ^{100}Zr are correspondingly similar to those of the 730.7 and 1242.1 keV levels in ^{102}Zr. If these levels prove to be similar in structure then an appealing pattern emerges in which all the low-lying levels in ^{102}Zr are systematically lowered relative to those in ^{100}Zr. This is also true for the 6^+ and 8^+ members of the YRAST bands not observed in this study.

The 730.7 keV level in ^{102}Zr is especially interesting. It could correspond to the 878.5 keV level in ^{100}Zr which seems to have the characteristics of the bandhead of a γ-vibrational band[2] as far as its decay pattern to the 0_1^+, 2_1^+, and 4_1^+ states is concerned. If the 730.7 keV level in ^{102}Zr is actually a γ-vibrational bandhead, then both ^{100}Zr and ^{102}Zr would be axially asymmetric with softness in the γ direction.

3.3 Conclusion

A first attempt has been made to study the structure of levels in ^{102}Zr populated in the β^- decay of ^{102}Y. No low-lying 0_2^+ state was observed probably due to the J^π for ^{102}Y. Experiments are continuing in an effort to obtain accurate relative γ ray intensities and search for new levels. Although only a few states in ^{102}Zr were observed due to the short half-life and low fission yield of ^{102}Y it is evident that ^{102}Zr is well deformed but probably not axially symmetric.

References

1) E.R. Flynn, J.G. Beery, and A.G. Blair, Nucl. Phys. A218 (1974) 285
2) T.A. Khan, W.D. Lauppe, K. Sistemich, H. Lawin, G. Sadler and H.A. Selic, Z. Physik A283 (1977) 105
3) K. Sistemich, G. Sadler, T.A. Khan, H. Lawin, W.D. Lauppe, H.A. Selic, F. Schussler, J. Blachot, E. Monnand, J.P. Bocquet and B. Pfeiffer, Z. Physik A281 (1977) 169
4) E. Cheifetz, J.B. Wilhelmy, R.C. Jared, and S.G. Thompson, Phys. Rev. C4 (1971) 1913
5) J.W. Grüter, G. Sadler, K. Sistemich, W. Borgs, and H. Lawin, Proc. International Conf. Nucl. Structure and Spectroscopy, Vol. 1, p. 89, Ed. H.P. Blok and A.E.L. Dieperink, Scholais Press, Amsterdam (1974).
6) H. Lawin, J. Eidens, J.W. Borgs, R. Fabbri, J.W. Grüter, G. Joswig, T.A. Khan, W.D. Lauppe, G. Sadler, H.A. Selic, M. Shaanan, K. Sistemich, and P. Armbruster, Nucl. Instr. Meth. 137 (1976) 103
7) W. Tenten, P. Reinhart and K.D. Müller, IEEE Trans. Nucl. Sci. 22 (1975) 529.
8) K. Takahashi, M. Yamada, and T. Kondoh, Atomic Data Nucl. Data Tables 12 (1973) 101.