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Short Note

First decay scheme of ^{113}Tc and identification of ^{113}Ru^m

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Abstract. Very neutron–rich fission products of the mass chain A=113 obtained from the IGISOL on–line mass separator have been investigated by $\gamma\gamma$ coincidence techniques and γ-spectra multiscaling. Gamma–rays following β–decay of ^{113}Tc have been observed for the first time and a new 0.5 s isomeric state has been found in ^{113}Ru.

PACS. 27.60.+j $90 \leq A \leq 149$ – 23.20.Lv Gamma transitions and level energies

Neutron–rich Ru isotopes have been subjects of recent investigations by prompt–fission which lead to the observation of various band structures [1–3]. Low-spin non–yrast levels were first reported from β-decay of on-line mass separated products of proton-induced fission of ^{238}U, [4–6]. Here we present a study of the decay of ^{113}Tc to ^{113}Ru, thus providing an extension of the Ru low–spin level systematics past the neutron midshell. The nuclide ^{113}Tc was discovered by Äystö et al. [5]. Recently, Wang et al. observed its β-delayed neutron emission [7].

A ^{238}U target was bombarded with 25 MeV protons from the K-130 cyclotron in Jyväskylä. Neutron-rich fission products were on-line mass separated at the IGISOL facility [8]. The beam of A=113 isobars was implanted onto a plastic collection tape for a 0.7 s "beam–on" period and then was blocked for another 0.7 s. Then the tape was moved away from the collection point to reduce the background of long-lived activities and a new cycle was restarted.

Gamma-ray spectra were measured with a LEGe detector for the low–energy range and a coaxial Ge detector in anticoincidence with a BGO shield. To avoid summing of β particles with γ–rays, the Ge detectors were gated by thin plastic counters placed on the opposite sides with respect to the source. Cycle time, γ-energies and $t(\beta-\gamma)$ were recorded as event parameters.

The decay curve of the β–gated 99 keV transition, Fig. 1, shows a 0.11 ± 0.03 s half-life for ^{113}Tc confirmed by Ru X-rays and the γ-rays of 65 and 165 keV. These lines were observed in coincidence relationships with other lines (Table 1) and with Ru X-rays. The non–β–gated decay curve of the 99 keV line shows another component with a half-life of 0.51 ± 0.03 s. Moreover, the decay half-life of the 211 keV ($9/2^+ \rightarrow 7/2^+$) transition in ^{113}Rh, 0.64 ± 0.03 s, is obviously shorter than the value of 0.9 s for the ground

Table 1. Energies, relative intensities and coincidence relations for γ–rays observed in the decay of ^{113}Tc. Energy in parantheses means a line not placed in the decay scheme, energies marked ^{Rh}are in decay of ^{113}Rh also, a ^{w}means weak coincidence and ^{K}is for Ru K$_\alpha$ X-ray

E_γ [keV]	I_γ^{rel} [%]	Coincident γ-lines
65.8	8	99, (121, 124), 131
98.5	100	19.4^K, 66, 97, (113, 121), 165, (286), (296), 335, (478), 590, (612), (1522)^w, (1827)^w
(113.2)	12	99, (147)
131.1	16	66, 98, (113), 164, 336, 669
147.1	≈ 0	113, 116^{Rh}, 152^{Rh}, 190^{Rh}
164.3	54	19.5^K, (100), 131, (183, 348)
197.1^{Rh}	12	98, (117)
(274.7)^{Rh}	≈ 5	99, 164
294.3	24	
335.5	33	99, 161
433.4	30	
589.5	19	99, 161^w, (190)
668.1^{Rh}		14.9, 21.3, 197
688.5^{Rh}		137^{Rh}
1520.1	25	19.4^{Kw}, 98^w

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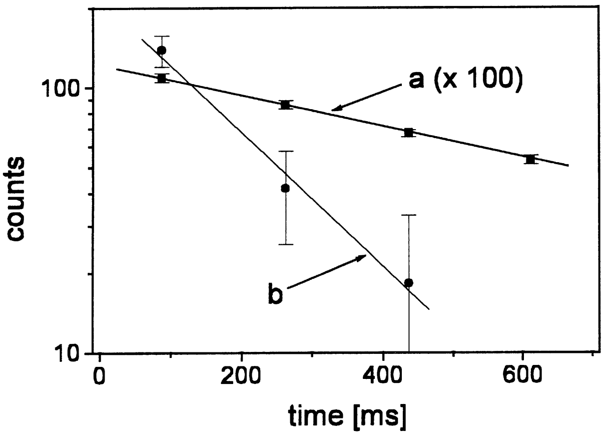

Fig. 1. Decay of 99 keV line; a) in single spectrum (counts must be multiplied by factor 100 to get true experimental peak areas) b) in coincidence with β radiation

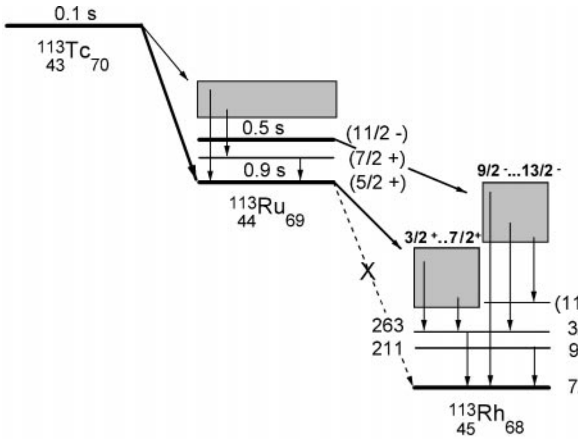

Fig. 3. Schematic decay of the investigated exotic part of A=113 isobaric chain

state of ^{113}Ru (determined from the decay of the 263 keV transition). These observations indicate the existence of an isomer in ^{113}Ru, directly fed in fisssion, which has an isomeric transition to the 99 keV level and a β–decay to ^{113}Rh, Fig. 2. The IT/β–decay ratio is about 0.08. Neither the IT, nor the X–rays resulting from K–conversion, could be detected. From peak-detection limits we estimate the isomeric state to be below 160 keV. The K–shell internal conversion coefficient found by fluorescence method, $\alpha_K(99) = 0.24 \pm 0.12$, is consistent with dipole character. Spin and parity $7/2^+$ of the 99 keV level is tentatively proposed by analogy with ^{111}Ru [6].

Systematics of levels for odd A = 107 - 111 Ru isotopes indicate sequences of $5/2^+$, $5/2^-$, $7/2^-$, $9/2^-$ and $11/2^-$ levels which are observed in β–decay [4] and are heads of band structures populated in spontaneous fission [1,3].

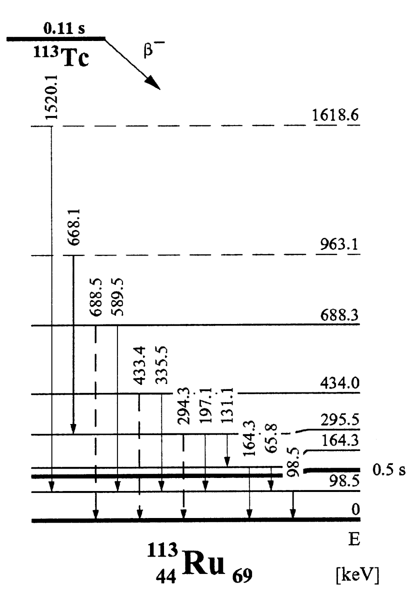

Fig. 2. Decay scheme of ^{113}Tc

For ^{113}Ru, however, levels from β–decay and from spontaneous fission create two separate structures. It looks that the $11/2^-$ level goes down slightly close to the 99 keV level creating an isomeric state. Such a situation is known for odd Pd isotopes (two protons more than Ru) with A = 109 - 115 where a $11/2^-$ state is observed as the second excited state with an energy of 190 – 80 keV. A band structure known from fission experiments [3] is probably built on this isomer.

The β–decay of ^{113}Ru$^{\rm m}$ mainly populates highly excited levels of ^{113}Rh, which subsequently deexcite to the $(7/2^+, 9/2^+, 11/2^+)$ levels of the ground state band, Fig. 3. We tentatively interprete the isomeric state to be the spherical $\nu h_{11/2}$ or perhaps the slightly oblate deformed [505]11/2 Nilsson state. In this case, β-decay can proceed as $(\nu g_{7/2})^2_{0^+} \otimes \nu h_{11/2} \rightarrow (\pi g_{9/2} \nu g_{7/2})_{0,1^+} \otimes \nu h_{11/2}$. This interpretation is based on the low $\log(ft)$ values of ≈ 4.2 for the decays to the 2368 and 2417 keV levels in ^{113}Rh.

The ground state β–decay populates completely different set of high-energy levels connected with structures built on the 263 keV $(3/2^+)$ ^{113}Rh level, from which we propose $I^\pi(^{113}\mathrm{Ru})=5/2^+$. A discussion of Ru to Rh β–decay up to mass A = 111 was presented in [9], where an admixture of $(\pi g_{9/2})^2_{2^+} \otimes \nu g_{7/2}$ amplitude in the Ru ground state and $(\pi g_{9/2})^3$ component in the Rh ground state was invoked for the allowed gs $\rightarrow$ gs transition. This, however, does not fit well to the very weak g.s. β–decay of ^{113}Ru [4] and to other feedings to low-energy and low-spin levels in ^{113}Rh.

The complete decay scheme of ^{113}Ru^m and an extended one for ^{113}Ru^g will be presented in a forthcoming paper.

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