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ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

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THE DECAY OF ^{159}Tm (9.0 min) TO ^{159}Er

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Summary

The decay of ^{159}Tm ($T_{1/2}$= 9.0±0.4 min) has been investigated with Ge(Li) and Si(Li) detectors, β-spectrographs and a toroidal β-spectrometer using isotopically separated samples produced by the YASNAPP facility at Dubna. The singles γ-ray spectrum, the conversion electron spectrum, the positron spectrum, prompt and delayed γ-γ coincidences were measured. Using strong thulium activities conversion electrons were also measured with high resolution β-spectrographs. In the ^{159}Tm decay 81 new γ-ray transitions were observed. A decay scheme of ^{159}Tm is proposed involving 12 excited states in ^{159}Er. First members of the rotational bands $3/2^-[521]$, $5/2^-[523]$, $3/2^+\{[402]+[651]\}$, $11/2^-[505]$ and $7/2^-[514]$ and the 5/2, 7/2 and 9/2 states of a strongly perturbed positive parity band were identified. The Q-value of ^{159}Tm was determined to be 3.4 ± 0.3 MeV.

1. Introduction

The existence of an 11 ± 3 min ^{159}Tm activity was reported by Gromov et al. /1/ Recently de Boer et al. /2/ have found for ^{159}Tm a half-life of 12 ±1 min and identified six γ-ray transition in this decay. Balanda et al. /3/ observed in the ^{159}Tm decay nine γ-ray transitions which they placed in a ^{159}Er level scheme involving seven excited states. However, no information about their nature was given.

The most complete information on the level scheme in ^{159}Er has arisen from in-beam experiments in the reactions ^{150}Sm(^{12}C,3nγ), ^{152}Sm(^{12}C,3nγ) and ^{122}Sn(^{40}Ar,3nγ) (refs. /4,5/). These authors identified in ^{159}Er the members of the $3/2^-[521]$ ground-state band up to the $9/2^-$ state, a $11/2^-[505]$ isomeric state with a half-life of 600 ± 60 ns and the $I + 1/2 =$ odd members from 9/2 to 45/2 of a strongly perturbed positive parity band. The half-life of the $9/2^+$ state of this band was determined to be 325 ± 30 ns.

Spins $I = 5/2$ and $I = 3/2$ for the ground-states of ^{159}Tm and ^{159}Er, respectively, have been measured using the atomic beam technique /6/.

The present investigations were undertaken to get more complete information about the low spin states in ^{159}Er by studying the decay of ^{159}Tm. For this purpose Ge(Li) and Si(Li) detectors, magnetic β-spectrographs and a toroidal β-spectrometer have been applied. The singles γ-ray spectrum, the conversion electron spectrum, the positron spectrum, prompt and delayed γ-γ coincidences were measured.

Preliminary results of the present investigations of the ^{159}Tm decay have been published previously /7–9/.

2. Experimental Details and Results

2.1. Source production

The activity of ^{159}Tm was produced by the spallation reaction induced by high energy protons on a tantalum target. Suspensions of about 3 g Ta_2O_5 in 3 ml 0.1M HNO_3 were irradiated for 20 min on the external 660 MeV proton beam (current 0.1 μA) of the synchrocyclotron at Dubna. Because of the high recoil energy of the spallation products about 40% of those are stabilized in the liquid phase and can easily be separated from the target material by filtration /10/ . During one minute the rare earth spallation products were absorbed from the filtrat at a small amount of cation exchange resin (10 mg) with a yield better than 80%. After washing the resin with 0.1 M NH_4Cl solution and water the rare earth spallation products were separated by cation exchange chromatography at a 2 ⌀ x 60 mm column filled with Aminex A5. By elution with 0.08 M α-oxy-isobutyric acid (α-HIB) of the value pH = 4.8 the Tm fraction appeared after elution of the Lu and Yb fractions in a volume of 1-2 drops about 10 min after the end of irradiation. The Tm fraction was heated until dryness at a platinum foil. After adding of 0.02 ml of 2.10^{-3} M α-HIB the Tm activity was deposited as hydroxide by electrolysis on a 5 mm^2 tungsten foil. Using 30 seconds for electrolysis the yield was better than 80%. By heating the foil up to 500°C the Tm hydroxide was transformed to the Tm oxide.

After the end of this chemical process the separation of the Tm isotope was performed by using an electromagnetic isotope separator /11/ with a pipe-type surface ionization source /12/. The separation efficiency has been measured to be about 30% for a 5 min separation time. About 20 min after the end of irradiation the measurements of samples were started.

On the other hand samples were prepared using the method of fast extraction of isobares of rare-earth elements by direct electromagnetic mass-separation from the proton irradiated targets without chemical processing /13/. In these cases about 5 min after the end of irradiation the measurements of samples, obtained from the irradiated during the 5 minute period tantalum target with the thickness 0.05 mm, weight 0.5 g were started.

2.2. Gamma ray singles measurements

High resolution singles γ-ray measurements up to about 600 keV were carried out using Ge(Li) detectors of volumes 1.0, 2.4 and 3.0 cm^3 with system resolutions for ^{57}Co of 0.6, 0.6 and 0.9 keV, respectively. The high energy range of the singles γ-ray spectrum was measured up to about 3.5 MeV with a 38 cm^3 Ge(Li) detector at a system resolution for ^{60}Co of 3.5 keV. The spectra were stored in 4096 channel analysers, recorded on magnetic tape and analysed by means of computers including light pen systems (for further details see refs. /14,15/).

In order to improve the statistical accuracy the spectra from up to ten sources were added. In fig. 1 the low energy part of the ^{159}Tm γ-ray spectrum is shown. The high energy part of the ^{159}Tm γ-ray spectrum is plotted in fig. 2. Most of the observed γ-ray lines were assigned to the ^{159}Tm decay on the basis of their relative intensities in successive spectra. The lines of the daughter activities ^{159}Er ref. /16/) and ^{159}Ho (ref. /17/) are indicated in figs. 1 and 2. The γ-ray energy and intensity values deduced from the present singles γ-ray measurements of the ^{159}Tm decay are given in column 1 and 2 of table 1. In the decay of ^{159}Tm 81 new γ-rays were observed. The half-life of ^{159}Tm was determined to be 9.0 ± 0.4 min by following the intensity decrease of the dominant γ-rays over approximately 40 minutes.

2.3. Conversion electron and positron measurements

Conversion electrons of the ^{159}Tm decay were measured using two different experimental arrangements. Firstly,

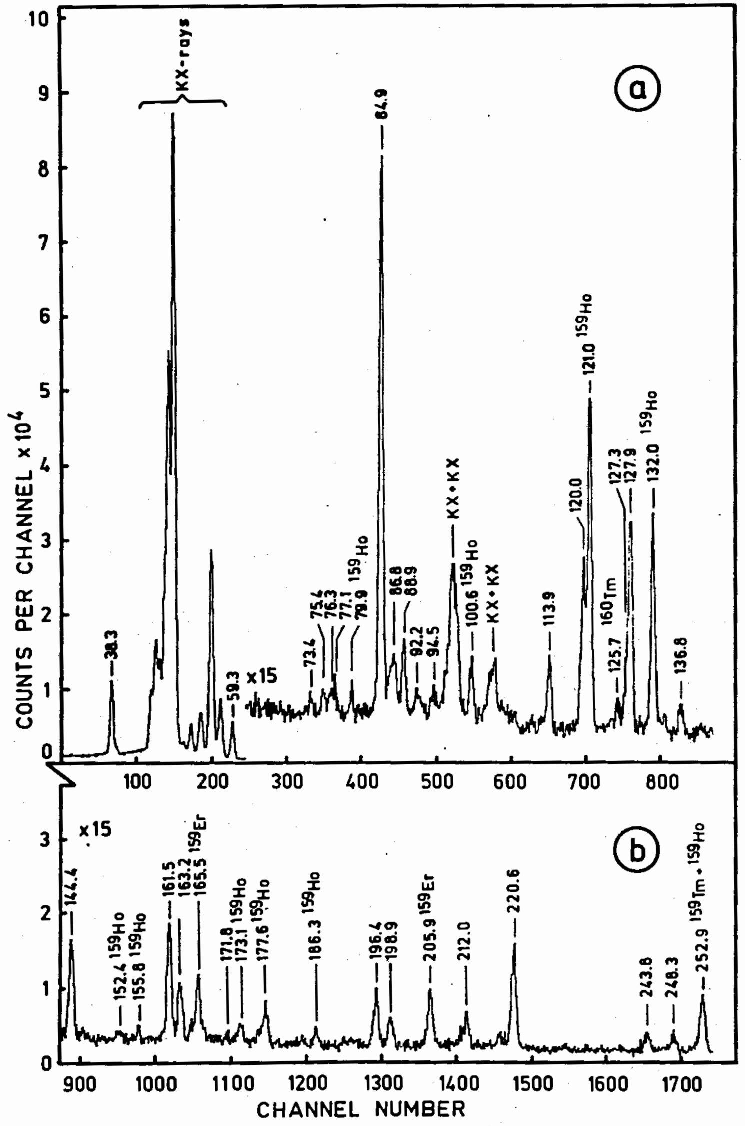

Fig. 1. Low energy part of the ^{159}Tm γ-ray spectrum measured with a 2.4 cm^3 Ge(Li) detector. The ^{159}Tm lines are indicated by vertical strokes and by their energy values given in keV. Other lines are marked by the symbol of their mother nuclei. (a) Energy range of 30 to 140 keV. (b) Energy range of 140 to 255 keV.

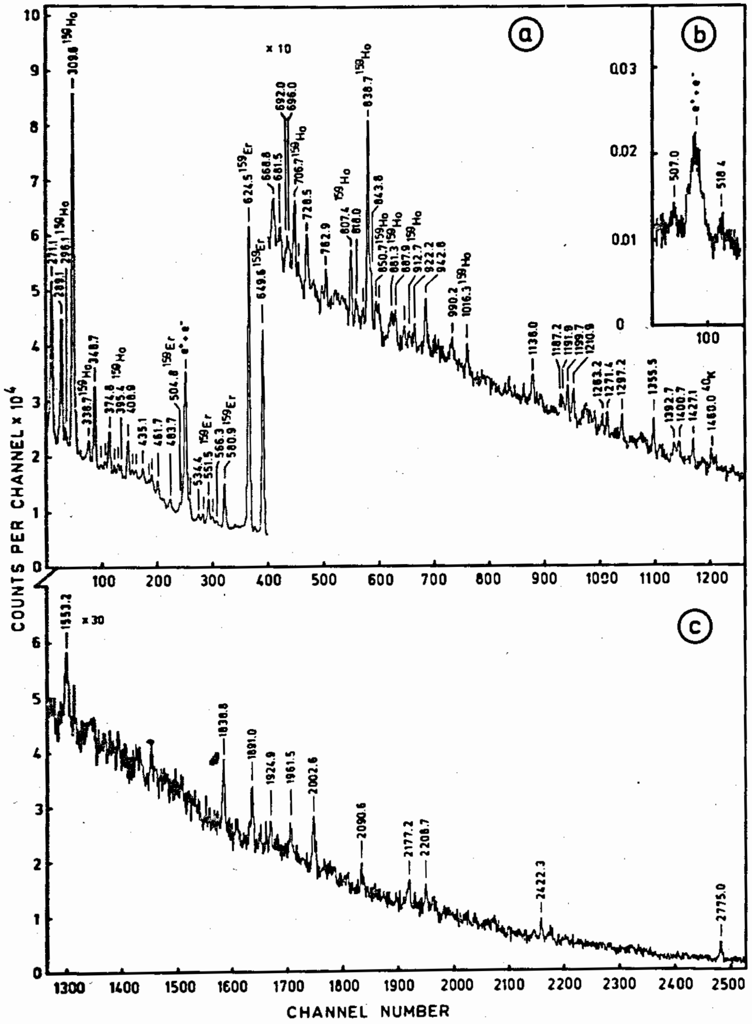

Fig. 2. High energy part of the ^{159}Tm γ-ray spectrum measured with a 38 cm^3 Ge(Li) detector. The ^{159}Tm lines are indicated by vertical strokes and by their energy values given in keV. Other lines are marked by the symbol of their mother nuclei. (a) Energy range of 260 to 1500 keV. (b) Energy range in the neighbourhood of the annihilation peak. (c) Energy range of 1500 to 2800 keV.

a toroidal β-spectrometer [18] with a transmission of 7% and a resolution of 0.5% was used for the conversion electron measurements with mass-separated ^{159}Tm sources. The ^{159}Tm decay was followed over three half-lives in order to subtract contributions of transitions belonging to the daughter activities of ^{159}Er (ref. [16]) and ^{159}Ho (ref. [17]). Secondly, the conversion electrons were measured by the aid of magnetic β-spectrographs with high resolution of 0.05% (ref. [19]) using Tm activities separated chemically from the other spallation products of a metallic tantalum target [20] irradiated on the internal 680 MeV proton beam (current $2.3 \mu A$) of the Dubna synchrocyclotron.

From all these electron measurements the conversion electron intensities are compiled in column 3 of table 1 and normalized to the theoretical values of the K-conversion coefficient for the 144.4 keV E2 transition. The multipolarities of the γ-ray transitions are given in column 4 of table 1. They were deduced from a comparison of the K-conversion coefficients and L-subshell ratios with theoretical values [21].

The positron spectrum of ^{159}Tm was measured with a Si(Li) detector of 5 mm diameter and 2.4 mm thickness having a system resolution for ^{57}Co of 2.5 keV at a temperature of 110 °K. The positrons were selected from the electrons and γ-rays by means of a homogeneous magnetic field [22]. The endpoint energy of the β^+-spectrum of the ^{159}Tm decay was determined to be 2050 ± 100 keV.

2.4. Prompt and delayed coincidence measurements

In order to place the observed γ-ray transitions in the level scheme prompt γ–γ coincidence measurements were performed with two Ge(Li) detectors of volumes of 27 and 41 cm^3 at system resolutions for ^{57}Co of 2.2 and 1.7 keV, respectively. The resolving time of the coincidence system was 50 ns. Sixteen digital windows were placed on the photopeaks and on the continuous background near these

Table 1 Energies and intensities of the γ-ray transitions in the decay of ^{159}Tm

E_γ, keV	I_γ	I_K	Multipolarity	I_{tot} / 100 decays
$38.30 \pm 0.06^{a)}$	160 ± 20	d)	E1	18.5
$59.30 \pm 0.07^{a)}$	72 ± 8	d)	M1+(< 10% E2)	71.4
73.4 ± 0.7	7.7 ± 3.1			
75.4 ± 0.5	7.7 ± 3.1			
$76.3 \pm 0.5^{a)}$	12.3 ± 4.6	114 ± 31	(M1)	5.6
$77.1 \pm 0.5^{a)}$	15.4 ± 5.2	86 ± 23	M1	7.4
$84.90 \pm 0.10^{a,b)}$	$100^{c)}$	409 ± 77	M1+(< 12% E2)	37.0
$86.8 \pm 0.6^{a)}$	9.2 ± 3.1	34 ± 12	M1	3.4
$88.9 \pm 0.5^{a)}$	18.5 ± 4.6	23 ± 8	E2	6.5
92.2 ± 0.6	4.6 ± 1.5			
94.5 ± 0.6	4.6 ± 1.5			
$113.9 \pm 0.4^{a)}$	18.5 ± 2.4	38 ± 15	M1	3.5
120.0 ± 0.3	48 ± 8	71 ± 8	M1	8.5
$127.3 \pm 0.5^{a)}$	15.4 ± 4.6	≤ 2.3	E1	1.2
$127.9 \pm 0.2^{a,b)}$	63 ± 8	18 ± 6	E1	4.8
$136.8 \pm 0.5^{a)}$	15.4 ± 4.6	8 ± 3	E2	1.9
$144.4 \pm 0.2^{a,b)}$	42 ± 4	17 ± 3	E2	4.8
$161.5 \pm 0.2^{a)}$	66 ± 5	29 ± 6	M1	7.5
$163.2 \pm 0.4^{a)}$	29 ± 3	21 ± 6	M1	3.3
$171.8 \pm 0.6^{a)}$	9[illegible] ± 3	≤ 6	M1	1.1
$196.4 \pm 0.4^{a,b)}$	48 ± 3	11 ± 3	M1,(E2)	4.5
$198.9 \pm 0.5^{a)}$	29 ± 3	3.9 ± 1.5	E2	2.4
$212.0 \pm 0.5^{a)}$	35 ± 7	1.5 ± 0.8	E1	2.4
$220.6 \pm 0.2^{a,b)}$	106 ± 8	17 ± 3	M1	9.1
$243.8 \pm 0.3^{a)}$	20.0 ± 4.6	1.5 ± 0.5	(E1)	1.4
$248.1 \pm 0.3^{a)}$	23.1 ± 4.6	3.1 ± 1.2	M1	1.9
252.7 ± 0.7	48 ± 12	≤ 1.5	E1	3.2
$271.1 \pm 0.3^{a,b)}$	128 ± 8	1.5 ± 0.8	E1	8.5
$284.2 \pm 0.8^{a)}$	10.8 ± 4.6	≤ 0.8	E2,(E1)	0.8
$289.1 \pm 0.3^{a,b)}$	100 ± 12	≤ 0.8	E1	6.6
$348.7 \pm 0.5^{a,b)}$	88 ± 8	0.8 ± 0.3	E1	5.8
360.6 ± 0.7	7.7 ± 3.1			0.5
367.7 ± 0.6	9.2 ± 3.1			0.6
374.8 ± 0.5	50.8 ± 5.0			3.3
384.0 ± 0.6	13.9 ± 3.1			0.9
390.8 ± 0.6	18.5 ± 3.1			1.2
$408.9 \pm 0.5^{a)}$	51 ± 5	0.5 ± 0.2	E1	3.3

Table 1 (continued)

E_γ,keV	I_γ	I_{tot}/ 100 decays	E_γ,keV	I_γ	I_{tot}/ 100 decays
$416.3\pm0.6^{b)}$	12.3 ± 3.1	0.8	922.2 ± 0.7	7.7 ± 3.1	0.5
$422.5\pm0.6^{a)}$	12.3 ± 3.1	0.8	942.8 ± 0.6	$20\ \pm5$	1.3
435.1 ± 0.6	15.4 ± 3.1	1.0	990.2 ± 0.7	7.7 ± 3.1	0.5
445.7 ± 0.7	6.2 ± 3.1	0.4	1136.0 ± 0.7	13.9 ± 3.1	0.9
450.0 ± 0.6	18.5 ± 6.2	1.2	1187.2 ± 0.9	9.2 ± 1.5	0.6
461.7 ± 0.6	$22\ \pm5$	1.4	1191.9 ± 0.9	9.2 ± 1.5	0.6
483.7 ± 0.6	15.4 ± 3.1	1.0	1199.7 ± 0.6	18.5 ± 4.6	1,2
500.5 ± 0.8	$25\ \pm8$	1.6	1210.9 ± 0.7	18.5 ± 4.6	1.2
$507.0\pm1.5^{a)}$	$20\ \pm8$	1.3	1263.2 ± 0.9	12.3 ± 3.1	0.8
518.4 ± 0.8	$35\ \pm9$	2.3	1271.4 ± 0.8	15.4 ± 3.1	1.0
534.4 ± 0.6	12.3 ± 3.1	0.8	1297.2 ± 0.7	13.9 ± 3.1	0.9
541.8 ± 0.5	15.4 ± 3.1	1.0	1355.5 ± 0.7	13.9 ± 3.1	0.9
559.3 ± 0.7	15.4 ± 3.1	1.0	1392.7 ± 0.8	7.7 ± 1.5	0.5
$566.3\pm0.6^{a)}$	6.2 ± 3.1	0.4	1400.7 ± 0.8	9.2 ± 1.5	0.6
668.8 ± 0.6	12.0 ± 3.1	0.8	1427.1 ± 0.8	13.9 ± 3.1	0.9
681.5 ± 0.8	6.2 ± 3.1	0.4	1553.2 ± 0.8	13.9 ± 3.1	0.9
692.0 ± 0.8	7.7 ± 3.1	0.5	1838.8 ± 0.6	$20\ \pm5$	1.4
696.0 ± 0.8	9.2 ± 3.1	0.6	1891.0 ± 0.7	18.5 ± 4.6	1.2
714.1 ± 0.8	4.6 ± 1.5	0.3	1924.9 ± 1.2	7.7 ± 3.1	0.5
728.5 ± 0.8	16.9 ± 3.1	1.1	1961.5 ± 0.9	9.2 ± 3.1	0.6
762.9 ± 0.7	7.7 ± 1.5	0.5	2002.6 ± 0.7	18.5 ± 4.6	1.2
818.0 ± 1.0	9.2 ± 3.1	0.6	2090.6 ± 0.8	7.7 ± 3.1	0.5
829.5 ± 0.8	9.2 ± 3.1	0.6	2177.2 ± 1.2	7.7 ± 3.1	0.5
843.8 ± 0.7	18.5 ± 4.6	1.2	2208.7 ± 1.0	7.7 ± 3.1	0.5
858.6 ± 0.6	9.2 ± 3.1	0.6	2422.3 ± 0.8	7.7 ± 3.1	0.5
887.9 ± 0.6	9.2 ± 4.6	0.6	2775.0 ± 0.8	9.2 ± 3.1	0.6
903.5 ± 0.7	6.2 ± 3.1	0.4			

a) Placed in the decay scheme .

b) γ-ray transitions observed in refs 2,3).

c) Normalization value.

d) The experimental L-subshell ratios of the 38.30, 59.30, 84.90 and 144.4 keV transitions were determined to be $L_I/L_{II}/L_{III} = 46/26/34$, $L_I/L_{II} = 69/(\sim 12)$, $L_I/L_{II} = 51/(\sim 9)$ and $L_{II}/L_{III} = 7/7$, respectively.

peaks in order to correct the contributions of coincidences with the continuous distribution under the photopeaks. The coincidence spectra were simultaneously stored in a memory of 16 x 4096 channels (for further details see refs. /23,24/). Measurements of ten sources were added. The $\gamma-\gamma$ coincidence pairs attributed to the decay of ^{159}Tm are summarized in table 2.

Half-lives of excited levels in ^{159}Er were measured by delayed $\gamma-\gamma$ coincidence technique using a fast-slow coincidence system. This coincidence arrangement consists of a (ϕ 4 x 4) cm^3 NaJ(Tl) scintillation counter as a gate detector with a system resolution of 9% for ^{137}Cs and a 3 cm^3 Ge(Li) detector with a system resolution at ^{57}Co of 0.9 keV for recording the coincidence spectra. The resolving time of the system was 5 ns (ref. /24/). Sixteen time windows, each of 100 ns width, were set on the time distribution curve. The coincidence spectra were stored in a memory of 16 x 4096 channels /24/. The time-to-pulse-height converter stopped by delayed pulses from the NaJ(Tl) detector. In the slow channel of the starting branch all γ-ray transitions above 10 keV were selected. The spectra of γ-ray transitions populating (de-populating) the isomeric states were measured with the Ge(Li) detector in coincidence with the selected pulses from the start detector and by additionally gating this stop channel with pulses within the windows set on the left (right) hand side of the prompt peak of the time distribution curve. In this way it was possible to determine the half-lives of the isomeric states from the change of relative intensities of the populating (windows on the left-hand side) and the de-populating (windows of the right-hand side) γ-ray transitions in the spectra recorded with the Ge(Li) detector (fig. 3). The four selected spectra of the populating and de-populating γ-ray transitions in fig. 4 suggest that the 88.9 and 120.0 keV transitions populate and the 38.30 keV transition de-populate the 310 ± 30 ns isomeric state observed for the first time by Leigh et al. /4/ and the 136.8 keV transition populates an isomeric level with a half-life of 550 ± 150 ns (see also fig. 3).

Table 2 Gamma-gamma coincidences measured in the decay of ^{159}Tm (EC) ^{159}Er

gated lines E γ_1, keV	lines in coincidence with the gate transitions E γ_2, keV
59.30	84.90, 127.9, 161.5, 198.9, 212.0, 243.8, 248.1, 289.1
84.90	59.30, 113.9, 127.3, 163.2
127.3 + 127.9	84.90, 144.4, 161.5, 196.4, 220.6
144.4	127.3, 163.2
212.0	196.4
220.6	127.9
271.1	196.4
289.1	59.30

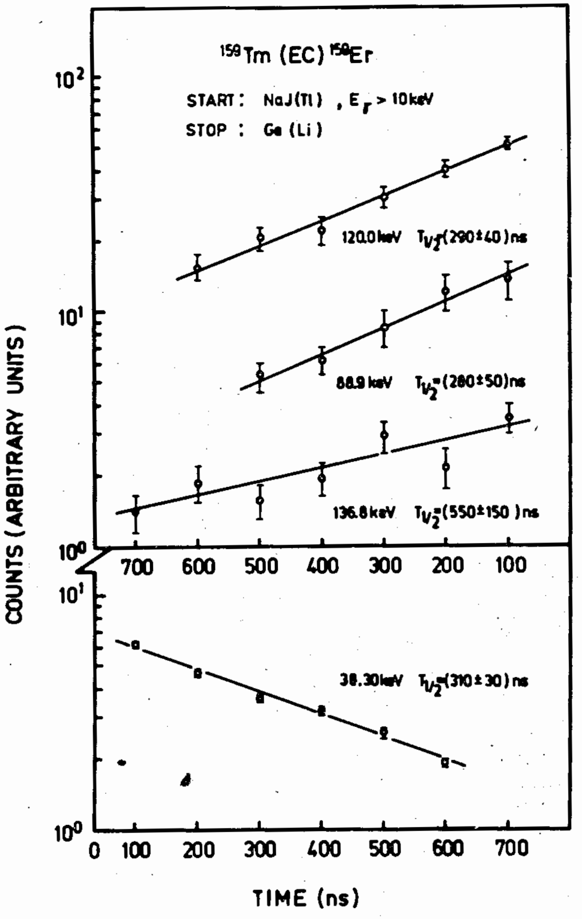

Fig. 3. The half-lives of the isomeric states in ^{159}Er. They were evaluted from the change of relative intensities of the populating (a) and de-populating (b) γ-ray transitions in the spectra recorded with the Ge(Li) detector.

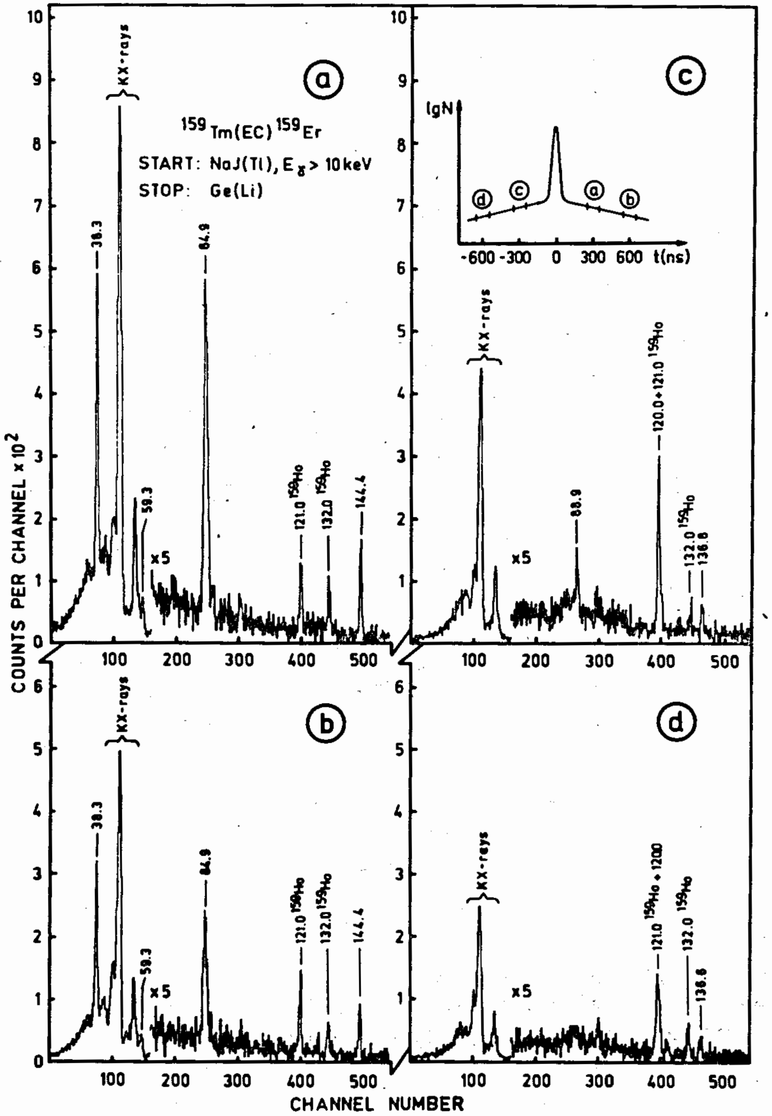

Fig. 4. Selected γ-ray spectra obtained in the delayed γ-γ -coincidence measurement. (a) and (b) spectra of the de-populating transitions with different delay time (time gates are given in the insert). (c) and (d) Spectra of the populating transitions with different delay time (time gates are given in the insert).

3. Discussion

The ^{159}Tm decay scheme based on our experimental results is shown in fig. 5. It contains 12 excited states in ^{159}Er, ten of which are confirmed by coincidence measurements. The levels at 302.8, 307.4, 467.9 and 566.5 keV were observed for the first time. Spin and parity of all the levels are supported by the multipolarities of the γ -ray transitions. In the decay scheme 30 from the 90 observed γ -ray transitions are involved.

From the seven ^{159}Er levels proposed by Balanda et al. /3/ in the ^{159}Tm decay the levels at 84, 289, 415 and 620 keV were not confirmed.

On the basis of spin measurements Ekstrom and Lamm /6/ attributed the 5.2^{+}[402] and $3/2^{-}$ [521] Nilsson orbitals to the ground-states of ^{159}Tm and ^{159}Er, respectively.

The total transition intensities given in column 5 of table 1 were evaluated by assuming no β -feeding to the ^{159}Er ground-state. The sum of the total intensities of the ground-state transitions in ^{159}Er was set to 100. The assumption of no β -feeding to the ^{159}Er ground-state is reasonable since a log ft value of ≈ 8.0 is expected for a hindered first forbidden β-transition (see ref. /25/). Such a log ft value corresponds to a feeding intensity of the ^{159}Er ground-state of 0.2% at Q -value of 3.4± ± 0.3 MeV. This Q -value was deduced from the endpoint energy of the ^{159}Tm positron spectrum and the assumption that most of the positrons feed levels at 300 keV excitation energy (see fig. 5). The log ft values given in fig. 5 have to be considered only as lower limits mainly as a consequence of unplaces γ -rays with a total intensity of about 20%.

The members of the $3/2^{-}$[521] ground-state band were identified in ^{159}Er up to the $9/2^{-}$ state. This result is consistent with the in-beam measurements in the reactions ^{150}Sm(^{12}C,3nγ) and ^{122}Sn(^{40}Ar,3nγ) (ref. /4/).

The levels at 182.6, 271.3 and 302.8 keV are proposed to be the members of a strongly perturbed positive parity

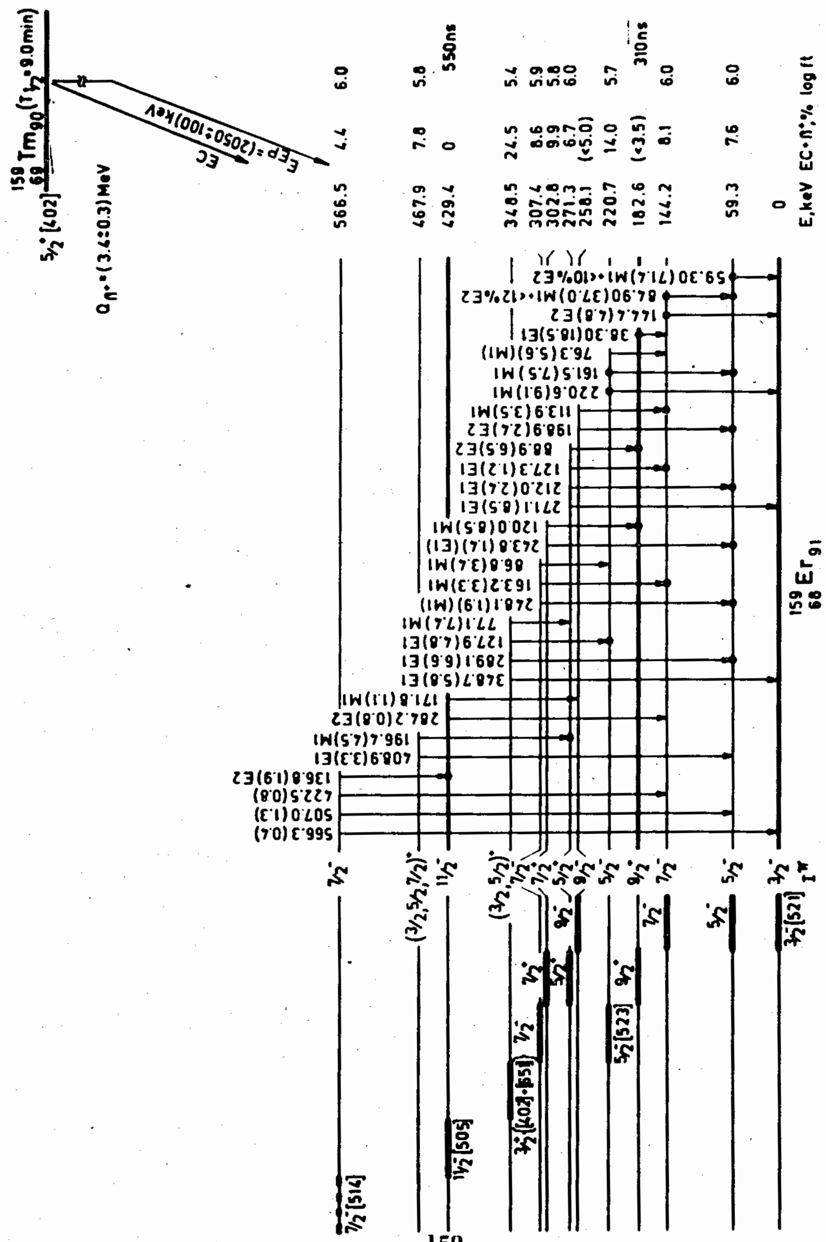

Fig. 5. The decay scheme of ^{159}Tm. Energies are given in keV, total intensities per 100 decays. Transitions the placement of which is supported by coincidences are marked by full dots.

band with the spins 9/2, 5/2 and 7/2, respectively. The I+1/2 = odd members from $9/2^+$ to $45/2^+$ of this band were found for the first time by the Berkeley group /4,5/). The $9/2^+$ state decays by an E1 transition only to the 7/2 $3/2^-$[521] level. Its half-life was determined to be 310 ± 30 ns. This value is in good agreement with that of ref. /4/. Arguments supporting our interpretation are the log ft values of the β-transitions, the spin and parity values of these levels and the de-population of the levels at 271.3 and 302.8 keV by E2 and M1 transitions, respectively, to the $9/2^+$ state at 182.6 keV.

For the energy analysis of the strongly perturbed positive parity band a modified description in the framework of the nonadiabatic model was used by taking into account the residual centrifugal and spin-spin interaction between nucleons /26-29/. In this description for the calculation of the wave function and the level energies only two free parameters, the moment of inertia J and the gap parameter Δ, are adjusted. In table 3 the level energies and wave functions obtained by analysing the rotational energies are given. The wave functions show a remarkable mixing between the configurations $3/2^+$[651] and $5/2^+$[642] and parity the $1/2^+$[660] in all states, while the contributions of the other configurations remain small. The energies of this strongly perturbed band can be described with the parameter values Δ = 1.06 MeV and $h^2/2J$ = 15.6 keV (see table 3).

The levels at 220.7 and 307.4 keV with spin and parity $5/2^-$ and $7/2^-$, respectively, are interpreted as the first two members of the $5/2^-$[523] band. This assignment is supported by the log ft values of β-transitions, the rotational parameter of $h^2/2J$ = 12.4 keV and the multipolarities of the γ-ray transitions de-populating these levels. This interpretation is in very good agreement with the systematics of the Nilsson states in the neighbouring nuclides /30/.

The spin and parity values of the 348.5 keV level are restricted by the multipolarities of the de-populating transitions to be $3/2^+$ or $5/2^+$. This level is very probably the $3/2^+${[402]+[651]} state. Its low log ft value

Table 3 Energies and amplitudes of the wave functions for the strongly perturbed positive parity band built on the $5/2^+$ level at 271.3 keV in ^{159}Er. Calculations including six configurations are carried out with the parameters $\hbar^2/2J = 15.6$ keV, $\Delta = 1.06$ MeV and the deformation parameters $\beta_{20} = 0.32$ and $\beta_{40} = 0$.

I^π	Amplitudes of the wave functions						E(I), keV theory	E(I), keV experiment
	$1/2^+[400]$	$1/2^+[660]$	$3/2^+[402]$	$3/2^+[651]$	$5/2^+[642]$	$7/2^+[633]$		
$5/2^+$	0.170	0.516	-0.093	0.663	0.507	-	85	88.7
$7/2^+$	0.073	0.213	-0.093	0.658	0.697	0.148	124	120.2
$9/2^+$	0.192	0.559	-0.094	0.631	0.477	0.123	$0^{a)}$	$0^{a)}$
$11/2^+$	0.078	0.220	-0.094	0.641	0.685	0.235	176	-
$13/2^+$	0.204	0.584	-0.094	0.615	0.456	0.150	49	43
$15/2^+$	0.079	0.222	-0.094	0.628	0.677	0.282	288	-
$17/2^+$	0.211	0.598	-0.093	0.605	0.443	0.165	225	252
$19/2^+$	0.080	0.222	-0.093	0.617	0.672	0.315	664	-
$21/2^+$	0.216	0.606	-0.092	0.598	0.434	0.175	527	603
$23/2^+$	0.080	0.220	-0.093	0.607	0.667	0.340	1095	-
$25/2^+$	0.219	0.612	-0.092	0.592	0.428	0.183	953	1068

a) Normalization value

of 5.4 can then be explained by an allowed unhindered β-transition between the proton ground-state $5/2^+$ [402] of ^{159}Tm and the admixture of the neutron state 3.2^+[402] in the 348.5 keV level. This interpretation agrees with the systematics of the Nilsson states in ref. /30/.

For the 467.9 keV state confirmed by the strong coincidence pair 271.1 - 196.4 keV the spins 3/2, 5/2 or 7/2 are possible. Positive parity of this level is suggested by the multipolarities of the de-populating transitions. The nature of this state is not yet clear.

The life-time measurements show that the 136.8 keV transition populates a 550 ± 150 ns isomeric state. This results suggest that the 136.8 keV transition populates the $11/2^-$[505] isomeric state observed in ref. /4/ with a half-life of 600 ± 60 ns. Since the 136.8 keV transition is an E2 transition, spin and parity of the 566.5 keV level are most likely $7/2^-$. The 566.5 keV level is very probably connected with the $7/2^-$[514] Nilsson orbital. The observation of the $11/2^-$[505] isomeric state in the β-decay of the $5/2^+$[402] ground-state of ^{159}Tm is then clear since it is populated by the 136.8 keV transition from the $7/2^-$[514] state.

The transition probabilities of the K-forbidden transitions de-populating the $9/2^+$ and $11/2^-$ isomers in ^{159}Er and ^{161}Er have been calculated and compared with the single particle estimation /33/. The hindrance factors $F_{s.p.} = T_{s.p.}/T_{exp.}$ are listed in table 4. It is seen that the K-forbidden M1 ($11/2^- \to 9/2^-$) and E2 ($11/2^- \to 7/2^-$) transitions in ^{159}Er are more than one order of magnitude faster than those in ^{161}Er.

Many high energy transitions in the ^{159}Tm decay (see fig. 2 and table 1) indicate a significant of high lying states. From the available information, however, their establishment on the level scheme is not unambiguous.

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Table 4 The hindrance factors $F_{s.p.} = T_{s.p.} / T_{exp.}$ for the transitions de-populating the $9/2^+$ and $11/2^-$ isomeric levels in ^{161}Er [refs.^{31,32})] and ^{159}Er

^{159}Er

$I_i K_i^{\pi}$	$I_f K_f^{\pi}$	E_γ, keV	Multi-polarity	$F_{s.p.}$
$9/2\ (5/2)^+$	$7/2\ 3/2^-$	38.30	E1	2.0×10^5
$11/2\ 11/2^-$	$7/2\ 3/2^-$	284.2	E2	5.2×10^2
$11/2\ 11/2^-$	$9/2\ 3/2^-$	171.8	M1	3.3×10^5

^{161}Er

$I_i K_i^{\pi}$	$I_f K_f^{\pi}$	E_γ, keV	Multi-polarity	$F_{s.p.}$
$9/2\ (5/2)^+$	$7/2\ 3/2^-$	45.54	E1	6.5×10^4
$11/2\ 11/2^-$	$7/2\ 3/2^-$	252.50	E2	2.1×10^4
$11/2\ 11/2^-$	$9/2\ 3/2^-$	146.65	M1	4.4×10^6
$11/2\ 11/2^-$	$9/2(5/2)^+$	207.12	E1	4.0×10^9
$11/2\ 11/2^-$	$11/2(5/2)^+$	99.76	E1	4.4×10^8
$11/2\ 11/2^-$	$13/2(5/2)^+$	128.90	E1	7.3×10^8

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Распад ^{159}Tm (9,0 мин) в ^{159}Er

Распад ^{159}Tm ($T_{1/2}$ = 9,0±0,4 мин) изучен с помощью Ge(Li) и Si(Li) -детекторов, бета-спектрографов и тороидального бета-спектрометра. Использованные моноизотопные источники получены на установке ЯСНАПП в Дубне. Измерены: спектр γ-лучей, спектр конверсионных электронов, спектр позитронов, спектры мгновенных и задержанных $\gamma - \gamma$ -совпадений. Обнаружен 81 новый переход.

Предложена схема распада ^{159}Tm, включающая в себя 12 возбужденных состояний ^{159}Er. Идентифицированы первые члены ротационных полос типа: $3/2^-$ /521/; $5/2^-$ /523/; $3/2^+$ {/402/+/651/} ; $11/2^-$ /505/ и $7/2^-$ /514/, а также уровни 5/2; 7/2 и 9/2 сильно возмущенной полосы с положительной четностью. Определена энергия распада ^{159}Tm 3,4 ± 0,3 МэВ.

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The Decay of ^{159}Tm (9.0 min) to ^{159}Er

See the Summary on the reverse side of the title-page.

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