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S u m m a r y

The decay of ^{163}Yb ($T_{1/2}$= 11.4 min) has been investigated with Ge(Li), Si(Li) and NaI(Tl) detectors, a toroidal beta-spectrometer and magnetic beta-spectrographs by using isobarically separated samples produced by the YASNAPP facility at Dubna. The single γ-ray spectrum, the conversion electron spectrum, prompt and delayed γ-γ coincidences and β^+-γ coincidences have been measured. 110 new γ-ray transitions have been observed. A decay scheme of ^{163}Yb is proposed involving 30 excited states in ^{163}Tm. The first members of the rotational bands $1/2^+[411]$, $7/2^-[404]$, $1/2^-[541]$, $3/2^+[411]$ and $7/2^-[523]$ have been identified. Possibilities of interpretation of the high-lying levels are discussed. The Q-value of ^{163}Yb has been determined to be 3370 $\pm$100 keV.

1. Introduction

The first data on the ^{163}Yb half-life have been published by P.Paris [1] ($T_{1/2}$ = 10.9 $\pm$ 0.5 *min*) by K.Gromov et al. [2] ($T_{1/2}$= 13$\pm$3 *min*) and by Y.Chu [3] ($T_{1/2}$ = 10.96$\pm$0.35 *min*).

F. de Boer et al. [4] have discovered 58 γ-rays accompanying the ^{163}Yb decay ($T_{1/2}$ = 11.4$\pm$0.5 *min*). However, no information about the decay scheme of ^{163}Yb has been given.

The present investigations were undertaken to get information about the low spin states in ^{163}Tm by studying the decay of ^{163}Yb. For this purpose Ge(Li), Si(Li) and NaI(Tl) detectors, a toroidal beta-spectrometer and magnetic beta-spectrographs have been applied. The spectra of single γ-rays, conversion electrons, prompt and delayed γ-γ coincidences and β^+-γ coincidences were measured.

The preliminary results of the present investigations have been published previously [5,6].

2. EXPERIMENTAL CONDITIONS AND RESULTS

2.1. Preparation of Sources

The ^{163}Yb activity was produced by the spallation reaction induced by high energy protons at a tantalum target. Ta targets of metallic foil 0.05 *mm* thick and weighting 0.5*g* were exposed for 15 minutes to the external 660 *MeV* proton beam (current of 0.1 μA) of the Dubna synchrocyclotron. The irradiated targets transferred pneumatically was loaded to the pipe-type surface ionization source /7/ of an electromagnetic isotope separator /8/. The products of spallation reaction in the tantalum target diffusing from the target were separated isobarically by the method described in ref. /9/.

About 5 minutes after the end of irradiation the measurements of samples were started.

2.2. Gamma Ray Singles Measurements

The spectra of γ -rays were investigated by using Ge(Li) detectors of sensitive volumes of 2.4 cm^3 at a system resolution for ^{57}Co of 0.6 *keV* and of 41 cm^3 at a system resolution for ^{60}Co of 2.4 *keV*. The spectra were stored in 4096 channel analyzers and were analysed by means of computers. This system of storage and processing of information has been described in more detail in refs. /10,11/.

Figure 1 shows the spectrum of γ -rays in the low energy region. When studying the high energy range of the γ -ray spectrum by means of a large volume detector a (1 *mm* Cd + 1 *mm* Cu) filter was used. The γ -ray spectrum at high energies is plotted in Fig. 2.

As many as 110 new γ -rays are observed in the ^{163}Yb decay. The energies and relative intensities of γ -rays accompanying the ^{163}Yb decay are presented in Table 1.

Gamma-ray energies were calibrated by measuring the isobar A=163 activity with ^{133}Ba , ^{182}Ta and ^{241}Am calibration sources /12/ in the low energy range and ^{56}Co , ^{110m}Ag and ^{152}Eu calibration sources /12/ in the high energy range simultaneously. This allowed to determine sufficiently accurately the energies of γ -rays accompanying the ^{163}Yb decay.

The accuracy of the efficiency calibration of the Ge(Li) detectors with respects to γ -ray intensities from the standard sources ^{22}Na , ^{54}Mn , ^{56}Co , ^{57}Co , ^{60}Co , ^{65}Zn , ^{88}Y , ^{110m}Ag , ^{133}Ba , ^{137}Cs , ^{139}Ce, ^{152}Eu, ^{182}Ta , ^{203}Hg , ^{226}Ra and ^{241}Am (ref. /12/) has been obtained to be 2-5%. The efficiency curves were described

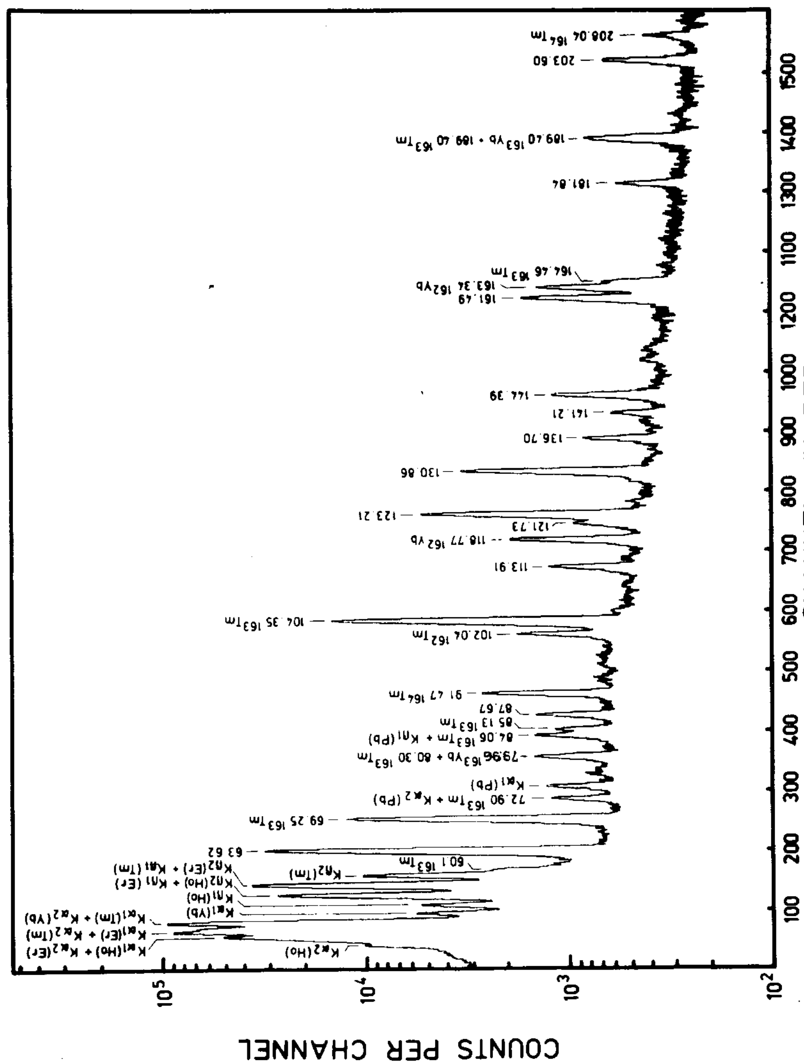

Fig. 1. Low energy part of the ^{163}Yb γ -ray spectrum measured with a 2.4 cm^3 Ge(Li) detector.

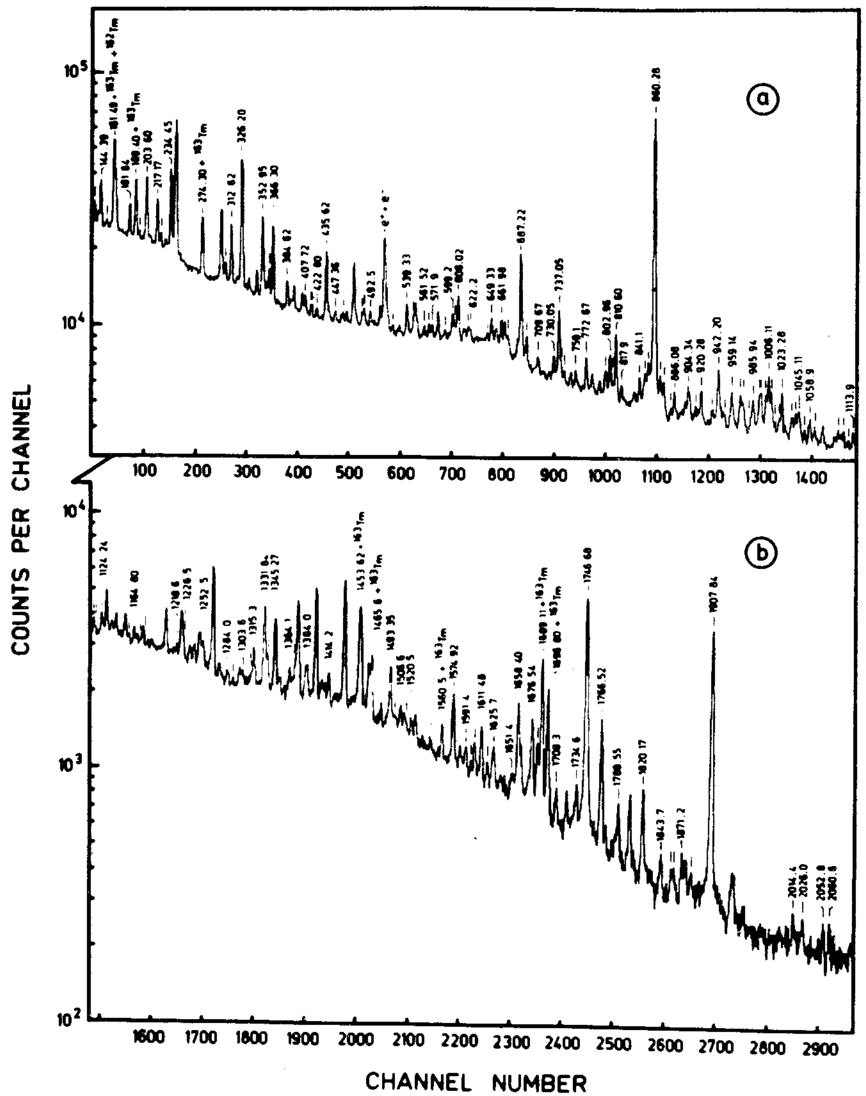

Fig. 2. High energy part of the ^{163}Yb γ-ray spectrum measured with a 41 cm^3 Ge(Li) detector using a (1 mm Cd + 1 mm Cu) filter. The ^{163}Yb lines are indicated by vertical strokes and by their energy values given in keV. a) Energy range of 135-1115 keV. b) Energy range of 1110-2080 keV.

by the modified analytical function including six parameters [13]. According to γ-ray intensity reductions found in some sets of measurements of the isobar A = 163 activity γ-rays following the decays of ^{163}Yb and ^{163}Tm

Table 1 Energies and intensities of γ-rays in the ^{163}Yb decay

E_γ	ΔE_γ	I_γ	ΔI_γ	E_γ	ΔE_γ	I_γ	ΔI_γ
7.68[a])	0.03	15[b])	5	415.0	0.3	0.48	0.07
9.74[c])	0.05	156[b])	7	416.8	0.3	0.60	0.08
13.53[c])	0.03	585[b])	160	422.80	0.20	0.30	0.10
63.62	0.03	64	3	435.62	0.07	6.0	0.4
79.96[c])	0.05	1.0	0.2	447.36	0.20	0.70	0.04
87.67	0.03	2.0	0.2	(457.4)	0.5	0.30	0.10
113.91	0.03	2.7	0.2	481.97	0.20	0.86	0.10
121.73	0.05	2.0	0.2	484.6	0.3	0.9	0.2
123.21	0.02	19.6	0.7	492.5	0.3	0.6	0.2
130.86	0.02	13.1	0.4	520.7	0.7	0.64	0.15
136.70	0.03	2.24	0.10	539.33	0.14	3.3	0.3
141.21	0.06	1.10	0.10	547.32	0.7	1.2	0.3
144.39	0.03	4.9	0.2	561.52	0.3	0.78	0.11
152.2	0.5	0.40	0.15	567.71	0.20	1.00	0.11
161.49	0.03	10.6	0.4	571.9	0.5	0.70	0.11
181.84	0.05	2.40	0.15	(588.8)	1.0	0.64	0.17
189.40	0.10	2.6	0.5	599.2	0.3	2.6	0.3
194.1	0.5	0.45	0.15	601.0	3.0	0.20	0.06
203.60	0.04	5.4	0.3	606.02	0.15	5.5	0.3
217.17	0.05	4.3	0.4	619.3	0.3	1.2	0.2
221.74	0.20	0.93	0.15	622.2	0.4	1.0	0.2
234.45	0.05	7.7	0.4	643.8	0.3	0.70	0.10
274.30	0.15	2.2	0.3	649.33	0.15	2.2	0.2
304.67	0.20	1.3	0.2	661.98	0.15	1.86	0.19
312.52[d])	0.06	3.2	0.5	670.0	0.5	1.0	0.3
312.71[d])	0.04	1.9	0.5	687.22	0.10	16.0	0.8
326.20	0.07	15.5	0.6	688.94[a])	0.08	2.0	0.5
352.95	0.10	7.2	0.4	694.64	0.3	2.4	0.3
353.8[a])	0.3	2.0	0.5	709.67	0.20	1.1	0.3
361.55	0.20	2.4	0.2	730.05	0.20	1.6	0.2
366.30	0.10	7.1	0.3	737.05	0.10	7.4	0.4
384.62	0.10	2.23	0.15	(739.9)	0.7	0.9	0.2
407.72	0.10	1.42	0.10	743.7	0.5	0.78	0.15

Table 1 (continued)

E_γ	ΔE_γ	I_γ	ΔI_γ	E_γ	ΔE_γ	I_γ	ΔI_γ
759.1	0.3	1.0	0.2	1102.12	0.17	1.0	0.2
772.67	0.10	2.54	0.14	(1108.0)	0.7	0.37	0.10
797.0	0.3	1.7	0.2	1113.9	0.5	0.9	0.2
802.96	0.15	3.5	0.3	(1115.9)	2.0	0.22	0.16
(805.6)	1.6	0.30	0.05	1124.24	0.20	1.22	0.15
810.60	0.10	6.1	0.3	1158.0	0.7	0.43	0.13
817.9	0.5	0.93	0.15	1164.80	0.20	1.3	0.3
841.1	1.2	1.5	0.7	1172.0	1.0	0.2	0.1
848.5	0.7	2.7	0.7	1178.0	1.5	0.6	0.2
853.0	0.5	4.0	0.7	1218.6	0.5	0.60	0.10
860.28	0.06	100.0	3.5	1226.5	0.5	1.5	0.2
867.5	0.8	2.3	0.7	1235.3	0.3	1.25	0.15
871.9	1.0	1.8	0.7	1240.88	0.25	1.30	0.15
(881.4)	0.5	0.56	0.15	1252.5	0.5	1.0	0.2
886.08	0.20	1.5	0.2	1284.0	0.5	0.40	0.15
904.34	0.25	2.8	0.3	1291.0	0.8	0.22	0.10
913.7	0.6	1.0	0.2	1303.6	0.4	0.5	0.2
920.28	0.20	2.8	0.3	1315.3	0.7	0.50	0.10
934.91	0.5	1.5	0.3	1331.84	0.08	6.5	0.3
942.20	0.20	4.8	0.4	1335.77	0.20	1.86	0.13
948.5	0.6	1.4	0.2	1345.27	0.08	5.7	0.2
959.14	0.15	3.4	0.2	1364.1	0.3	1.7	0.2
970.00	0.20	3.0	0.2	1370.0	0.5	1.6	0.2
973.6	0.3	2.0	0.3	1384.0	0.6	1.2	0.2
983.0	1.0	1.2	0.3	1414.2	0.3	1.31	0.17
985.94	0.20	2.5	0.3	1453.62	0.20	6.1	0.5
994.17	0.25	1.9	0.3	(1465.6)	1.0	0.8	0.3
996.50	0.20	2.3	0.3	1493.35	0.12	3.5	0.2
1002.68	0.15	2.5	0.2	(1498.0)	1.0	0.5	0.2
1006.11	0.10	4.1	0.2	1506.6	0.3	1.18	0.13
1009.59	0.15	2.78	0.16	1511.8	0.5	0.8	0.2
1015.3	0.5	0.40	0.15	(1514.0)	1.5	0.30	0.15
1019.8	0.5	0.5	0.2	1520.5	0.4	0.74	0.14
1023.28	0.14	2.82	0.17	1545.3	0.5	0.40	0.08
1035.9	0.3	1.7	0.2	1560.5	0.3	1.0	0.2
1040.8	0.3	2.2	0.2	1574.92	0.10	3.53	0.15
1045.11	0.20	3.0	0.2	1591.4	0.3	0.75	0.10
1052.2	0.7	0.5	0.2	(1598.5)	0.8	0.30	0.12
1058.9	0.3	1.9	0.2	1603.05	0.20	1.24	0.14
1065.3	0.4	1.30	0.17	1611.48	0.15	1.96	0.15
1095.04	0.25	1.1	0.2	1619.2	0.5	0.51	0.10

Table 1 (continued)

E_γ	E_γ	I_γ	I_γ	E_γ	E_γ	I_γ	I_γ
1625.7	0.8	0.7	0.2	1820.17	0.15	2.02	0.15
1651.4	0.8	0.6	0.2	1843.7	0.4	0.68	0.08
1658.40	0.16	3.9	0.3	(1857.1)	0.8	0.40	0.08
1676.54	0.13	3.5	0.2	(1861.0)	0.9	0.4	0.1
1683.87	0.16	2.26	0.14	1871.2	0.4	0.7	0.10
1689.11	0.08	7.5	0.4	(1883.0)	0.3	0.46	0.08
1696.80	0.20	5.0	0.4	1907.84	0.10	15.2	0.6
1708.3	0.3	0.95	0.11	2014.4	0.6	0.31	0.06
1734.6	0.3	0.90	0.13	2026.0	0.6	0.30	0.06
1746.68	0.15	17.0	1.0	2052.8	0.6	0.25	0.06
1766.52	0.15	4.0	0.3	2060.6	0.6	0.24	0.06
1788.55	0.20	1.20	0.15				

[a]) The transition has been discovered on the basis of γ-γ coincidences. Its energy (error) has been determined by the level scheme, its intensity (error) has been obtained from the analysis of γ-γ coincidence spectra.

[b]) The total transition intensity has been presented.

[c]) Transition energy has been determined in the measurement with a toroidal beta-spectrometer.

[d]) Double lines as concluded from the γ-γ coincidence measurements. Their energies (errors) have been determined from the level scheme, their intensities (errors) have been obtained from the analysis of γ-γ coincidence spectra.

($T_{1/2}$ = 108 *min*)/14/ were identified. Some low intensity γ-rays are an exception. They were attributed to the ^{163}Yb decay by comparing their energies and intensities with the known γ-rays of the ^{163}Tm decay /14/ . When measuring the isobar A=163 X-ray radiation from Yb is observed. This indicates possible presence of ^{163}Lu activity in the isobar sources, the half-life of which has been estimated to be smaller than 3 *min*. Gamma-rays accompanying the ^{163}Lu decay, the half-life being ≤ 3 *min*, have not been observed.

2.3. Conversion Electron Measurements

The conversion electrons of the ^{163}Yb decay at 5-300 *keV* were investigated by means of an ironless beta-spectrometer having a toroidal magnetic field /15/ with a resolution of 0.65% and a transmission of about 10% using mass-separated isobar sources.

A Si(Li) detector having a drift thickness of 3 *mm*, a working surface of 150 mm^2 and a system resolution of 2.2 *keV* for the K-electron line of the 121 *keV* transition in ^{152}Sm were applied for measuring the conversion electron spectra of ^{163}Yb at 100-900 *keV*. The ^{163}Yb decay was followed over three half-lives in order to subtract contributions of transitions belonging to the daughter activity of ^{163}Tm /14/. Simultaneous measurements of the consersion electrons and γ-rays and the known multipolarity of the 104 *keV* (M1) transition belonging to the ^{163}Tm decay allowed to determine the multipolarity of some transitions of ^{163}Yb.

On the other hand, conversion electrons were measured by means of magnetic beta-spectrograph with a high resolution of 0.04% /15/ using Yb activities separated chemically from the other spallation products of a metallic tantalum target /16/ irradiated on the internal 680 *MeV* proton beam (current of 2.3 μA) of the Dubna sychrocyclotron.

Table 2 shows the experimental values of the internal conversion coefficients calculated on the basis of the analysis of relative γ-ray intensities and the relative conversion electron intensities. The γ-ray multipolarities are given in the last column of Table 2. They have been obtained by comparing the internal conversion coefficients with theoretical values /17/. The errors in the determination of the experimental values of conversion coefficients are not worse than 20%, while they are about 50% in the case of the line syperposition of different transitions in the

Table 2 The values of the conversion coefficients and the conclusions on the multipolarity of some transitions in ^{163}Tm

E_γ, keV	α_K	ratios of I_{ce} ; α_L ; α_M	Multipolatity
9.74	-	$I_{M_1} \ll I_{M_2} \simeq I_{M_3}$	E2
13.53	-	$I_{M_1} : I_{M_2} \approx 4$	M1 + ≈ 0.2% E2
63.62	-	$I_{L_1} : I_{L_2} : I_{L_3} = 2.7 : 1 : 1.3$ $\alpha_{\Sigma L} = 0.18$; $\alpha_{\Sigma M} \approx 0.06$	E1 + ≲ 0.2% M2
79.96	4	$I_K : I_{L_1} \approx 6.7$	M1 (+ E2)
87.67	3.5	$I_K : I_{L_1} \approx 7$	M1 + < 16% E2
113.91	1.8	$I_K : I_{L_1} \approx 6.2$	M1 + E2
121.73	1.5	$I_K : I_{L_1} \approx 5$	M1 + E2
123.21	1.4	$I_K : I_{L_1} : I_{L_2} = 6.7 : 1 : \leq 0.15$	M1 + ≲ 5% E2
130.86	11.22	$I_K : I_{L_1} : I_{L_2} = 6.4 : 1 : \leq 0.24$	M1 + ≲ 12% E2
136.70	0.8		M1
144.39	0.5	$I_K : I_{L_2} : I_{L_3} = 3 : \approx 1 : \approx 1$	E2
161.49	0.35	$I_K : I_{L_1} : I_{L_2} : I_{L_3} = 4 : \leq 0.4 : 1 : 0.8$	E2
181.84	<0.1		E1
189.40	<0.1		E1
203.60	0.075		E1
217.17	0.04		E1
221.74	≈ 0.09		M1 + E2
234.45	0.026		E1
304.67	0.1		M1 + E2
312.52	0.06		M1 + E2
326.20	0.011		E1
352.95	0.033		E2 (+ M1)
361.55	≈ 0.015		E1
366.30	0.055		M1 (+ E2)
384.62	0.04		M1 + E2
407.72	≈ 0.02		E2
435.62	0.02		M1 + E2
687.22	0.0037		E1, E2
860.28	≈ 0.006		M1, E2

spectrum of conversion electrons such as L63.62+K113.91 *keV* and K121.73+ M63.62 + K 123.21 *keV*. In addition to α_K values other data were also used to determine the multipolarity. Thus, the multipolarity of the 63.62 *keV* transition was found from the intensity ratios of the L_I, L_{II} and

L_{III} lines and the values of α_L and α_M. The multipolarity of the 113.91, 121.73 and 123.21 *keV* transitions was obtained by means of α_K and K/L_I. The multipolarity of 113.91 *keV* transition is confirmed by the results of the analysis of the intensities of $\gamma-\gamma$ coincidences of this transition with 688.94 and 1574.92 *keV* γ-rays. The 9.74 and 13.53 *keV* transition multipolarities were determined from the intensity ratios of conversion lines of the M and N subshells. The part of the ^{163}Yb conversion electron spectrum within 5-15 *keV* measured with a toroidal beta-spectrometer is shown in Fig. 3.

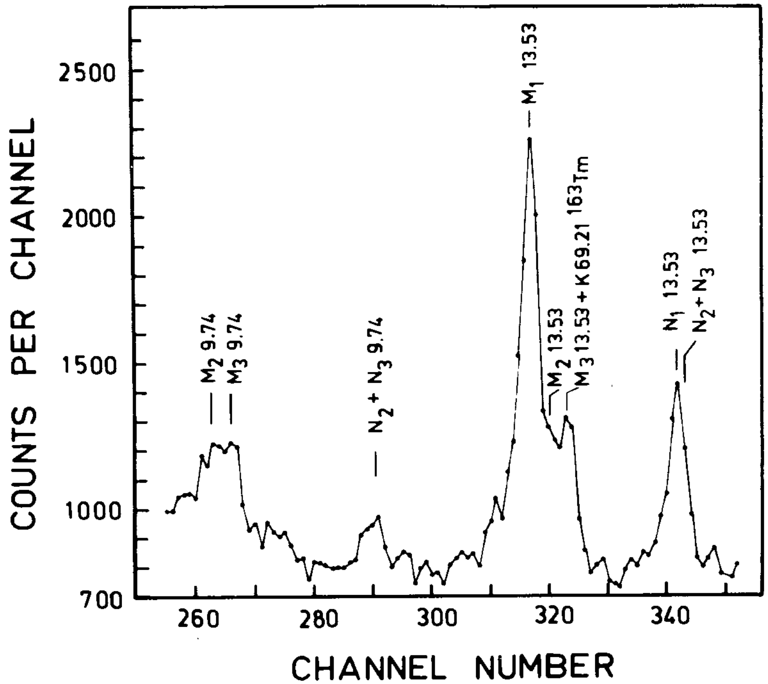

Fig. 3. A part of the conversion electron spectrum measured with a beta-spectrometer having a toroidal magnetic field (E_e = 5-15 keV).

2.4. Prompt and Delayed Gamma-Gamma Coincidence Measurements

Gamma-gamma coincidence spectra were studied by means of two Ge(Li) detectors having sensitive 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 circuits was 50 *nsec*. The two-dimensional coincidence spectrum (4096 x 4096 channels) was tape-recorded and then further treated by the HP 2116 C computer [11].

Table 3 presents the results of the analysis of $\gamma-\gamma$ coincidence spectra, the last column includes also the calculated intensities of $\gamma-\gamma$ coincidences according to the ^{163}Tm level scheme.

Figure 4 shows the representative sorts of $\gamma-\gamma$ coincidence data from gated energies of 121.73 + 123.21 *keV* and 130.86 *keV* in the ^{163}Yb decay.

The sum-peak coincidences of γ-transition pairs [18] were considered in $\gamma-\gamma$ coincidence spectra. This allowed in some cases to identify safely the position of low-intensity γ-transitions in the decay scheme.

The half-life of the ^{163}Tm excited state of 86.95 *keV* was measured by the delayed $\gamma-\gamma$ coincidence technique using a fast-slow coincidence system. This coincidence arrangement consists of a (ϕ 4 x 4) cm^3 NaI(Tl) scintillation counter as a gate detector with a system resolution of 9% for ^{137}Cs and a 41 cm^3 Ge(Li) detector for recording the coincidence spectra. The resolving time of the system was 10 *nsec* [11]. The time-to-pulse-height convertor was triggered with pulses from the NaI(Tl) detector and was stopped by delayed pulses from the Ge(Li) detector. Pulses responsible for γ-rays above 10 *keV* were selected in the channel of the triggering coincidence circuit. A two-dimensional spectrum (4096 x 4096 channels) consisting of the time distribution curve and the γ-ray spectrum from the Ge(Li) detector was tape-recorded by the HP 2116 C computer.

Figure 5 shows the time distribution curve corresponding to γ-ray coincidences with the 63.62 *keV* γ-transition in ^{163}Tm. The slope of the time distribution curve

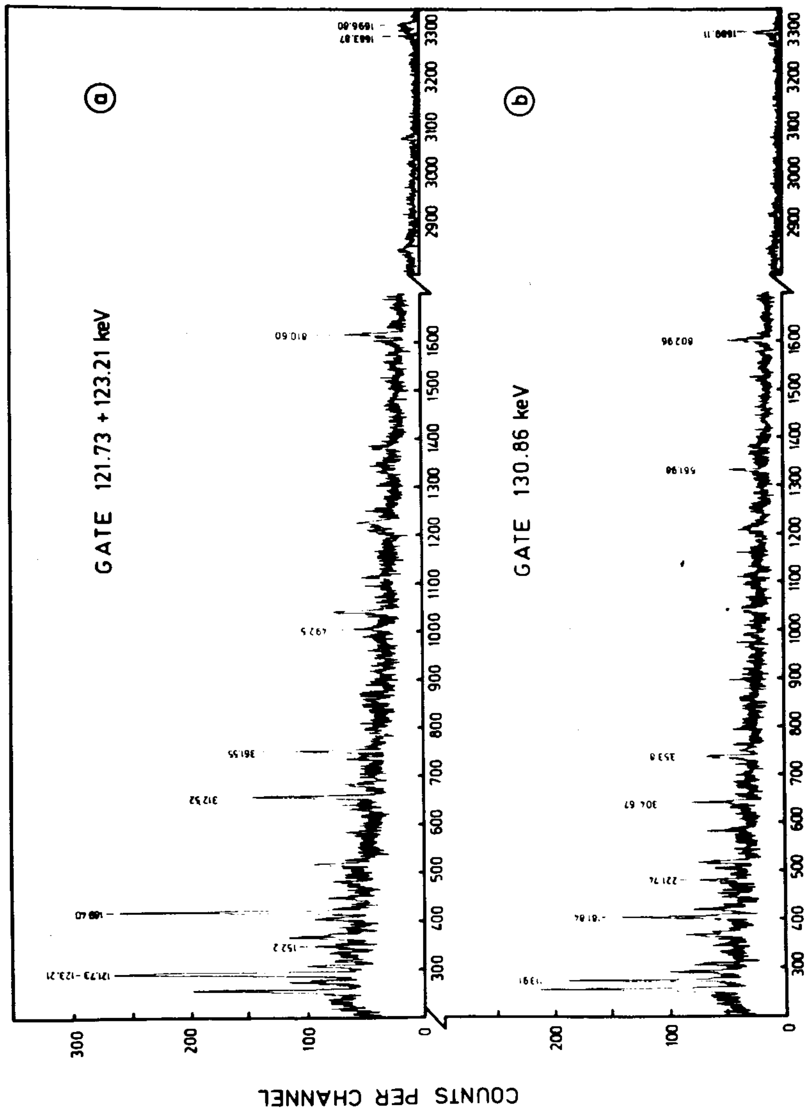

Fig. 4. Gamma-ray spectra obtained in the $\gamma-\gamma$ coincidence measurement from gated 121.73 + 123.21 keV (a) and 130.86 keV (b) γ-rays.

Table 3 The results of prompt $\gamma-\gamma$ coincidence measurements in the decay ^{163}Yb (EC) ^{163}Tm

level E, keV	gated lines $E_{\gamma 1}$, keV	coincident lines $E_{\gamma 2}$, keV	I_γ coinc. a)	I_γ coinc. b)
136.70	123.21	121.73	10	10.2
		152.15	2	2.0
		189.40	15	13.3
		312.52	15	15
		361.55	15	12.2
		492.5	4	3.2
		810.60	30	31.2
		994.17	12	10
		1683.87	10	11.5
		1696.80	30	25.3
	136.70	189.40	2	1.4
144.39	130.86	113.91	10	11.1
		181.84	7	9.9
		221.74	4	3.8
		304.67	6	5.4
		353.8	9	8.3
		415.02	2	2.1
		484.6	8	13.6
		661.98	9	7.7
		802.96	17	14.2
		1676.54	8	14.2
		1688.55	32	31.2
	144.39	113.91	3	4.2
		181.84	3	3.7
		304.67	2	2
		353.8	3	3.1
		802.96	8	5.4
175.00	161.49	194.1	3	4.2
		274.30	15	20.8
		384.62	16	21.1
		1658.40	22	37.0
217.14	203.60	1603.05	10	9.9
	217.17	1603.05	10	8.5
258.35	113.91	688.94	6	5.6
		1574.92	10	10

Table 3 (continued)

level E, keV	gated lines $E_{\gamma 1}$, keV	coincident lines $E_{\gamma 2}$, keV	$I_{\gamma}^{coinc.}$ a)	$I_{\gamma}^{coinc.}$ b)
326.21	181.84	1453.62	10	10
	189.40	1453.62	20	11
		1493.35	15	6.2
	326.20	1453.62	55	66
		1493.35	30	37
366.36	352.95	407.72	9.5	10
		959.14	16	23
		996.50	12	15.7
	366.30	407.72	10	9.4
		959.14	16	22
		996.50	12	15.5

a) Intensities have been obtained from the analysis of γ-γ coincidence spectra.

b) Intensities have been determined from the level scheme.

shows that the 63.62 *keV* transition de-populates the 86.95 *keV* isomeric state with $T_{1/2} = 380 \pm 30$ *nsec*. The spectra of γ-rays populating (de-populating) the isomeric state measured with a Ge(Li) detector in coincidence with pulses of the triggering detector and the sorting out by additional selecting within the windows located on the left (right)-hand side of the time distribution curve are shown in Figure 6.

Table 4 presents the data of the analysis of the delayed $\gamma-\gamma$ coincidences in the ^{163}Yb decay. The last column gives the γ-transition intensities populating the ^{163}Tm 86.95 *keV* level calculated according to the level scheme.

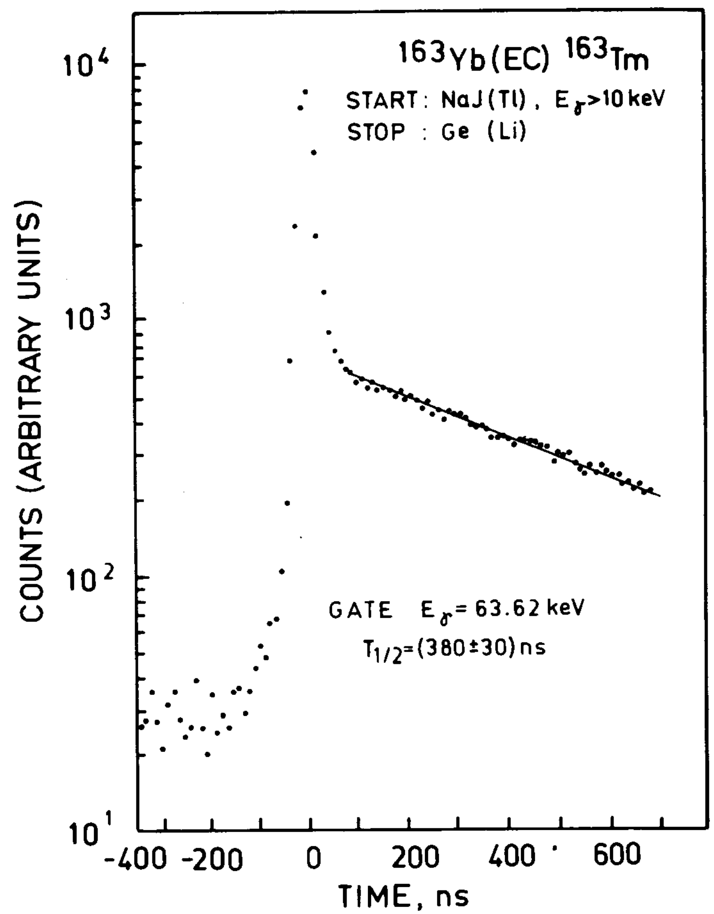

Fig. 5. The time distribution curve of delayed $\gamma-\gamma$ coincidences with 63.62 keV γ-rays.

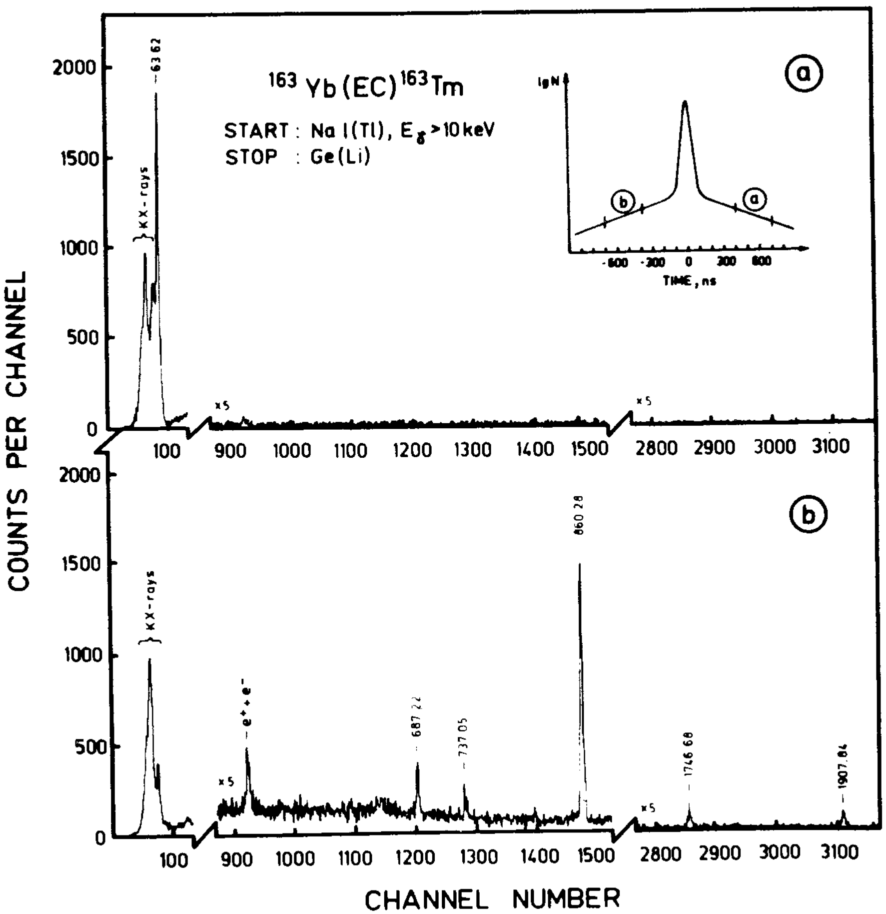

Fig. 6. Selected γ-ray spectra obtained in the delayed γ-γ coincidence measurement. a) Spectrum of de-populating transitions. b) Spectrum of populating transitions.

Table 4 The results of delayed γ-γ coincidence measurements in the decay ^{163}Yb (EC) ^{163}Tm

de-populating γ-ray $E_{\gamma 1}$, keV	populating γ-rays $E_{\gamma 2}$, keV	I_γ coinc. a)	I_γ coinc. b)
63.62	687.22	15.6	16
	737.05	8.0	7.4
	860.28	100	100
	1746.68	18.5	17.0
	1907.84	15.0	15.0

a) Intensities have been obtained from the analysis of delayed γ-γ coincidence spectra.

b) Intensities have been determined from the level scheme.

2.5. Positron-Gamma Coincidence Measurements

In order to determine the decay energy of the ^{163}Yb the coincidences of positrons with 860.28 *keV* γ -rays were measured. The fast-slow coincidence system consisted of a (⌀8 x 8) cm^3 NaI(Tl) crystal with a 10.5% system resolution for ^{137}Cs and a Si(Li) detector (100mm^2 surface, 15 *mm* thickness) with a system resolution of 8 *keV* for the 976 *keV* K-electron line of ^{207}Bi . The resolving time of the coincidence circuit was 50 *nsec*. The two-dimensional spectrum was analysed by 4096 x x 4096 channels and was tape-recorded by the HP 2116 C computer /11/.

The energy calibration of the beta-detector was performed by means of ^{207}Bi conversion electron lines. The corrections of the positron spectrum for the back-

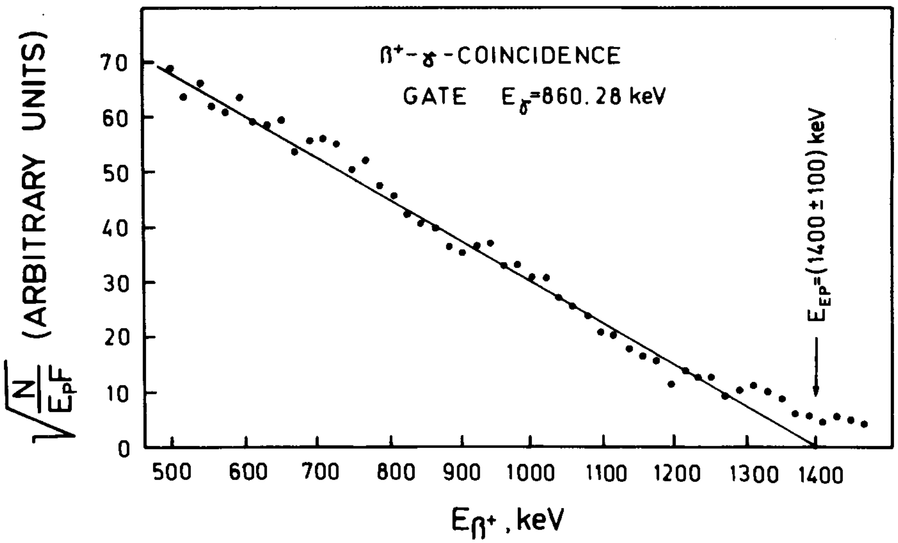

Fig. 7. Fermi-Curie Plot of the spectrum of positrons coinciding with 860.28 keV γ-rays in the ^{163}Yb decay.

ward scattering effect in the Si(Li) detector [20] were obtained by means of the ^{140}Pr positron spectrum. From the analysis of the spectrum of positrons coinciding with 860.28 *keV* γ -rays by the Fermi-Curie Plot contributions from the back-ground events have been subtracted by gatting on a nearby flat position of the γ -ray spectrum, the end point energy of 1400 ±100 *keV* for positrons populating the 947.28 *keV* excited state in ^{163}Tm was determined (Fig. 7).

3. DISCUSSION

3.1. The ^{163}Yb $\rightarrow$ ^{163}Tm *Decay Scheme*

By analogy with neighbouring nuclei having the neutron number N = 93 (ref. [21]) the Nilsson orbital 3/2$^-$[521] was attributed to the ground state of $^{163}_{70}$Yb$_{93}$.

Basing on the analysis of experimental data on γ -rays, conversion electrons and spectra of prompt and delayed

coincidences in the ^{163}Yb decay we have proposed a ^{163}Tm level scheme (Fig. 8) including 30 excited states.

The 161.49 *keV* transition is difficult to place in the decay scheme unambiguously. However, resulting from its intensity, we can assume its most probable placing between the 175.00 and the 13.51 *keV* excited states in ^{163}Tm, which agrees well with the 274.30, 384.62 and 1658.40 *keV* transition positions de-populating the excited states of 449.22, 559.56 and 1833.48 *keV*, respectively. These transitions were placed on the basis of the analysis of $\gamma-\gamma$ coincidence spectra. The intensive transition of 63.62 *keV* most likely populates the 23.33 *keV* level in good agreement with the transition positions of 687.22, 860.28 and 1746.68 *keV* de-populating levels of 774.09, 947.29 and 1833.48 *keV*, respectively. The placement of these transitions is supported by delayed $\gamma-\gamma$ coincidences. The 7.68 *keV* transition was introduced as a result of analyzing the coincidence spectrum of gated 123.21 *keV* γ -transition with γ -rays populating the excited 144.39 *keV* state.

The full (open) dots of Fig. 8 mark the transitions the placement of which is strongly (weakly) supported by coincidences. Low intensity γ -rays of the energies of 274.30, 415.02, 492.50, 539.33, 994.17 and 996.50 *keV* were evidently observed in the spectra of sum-peak coincidence of γ -transition pairs and therefore are indicated by full dots. The transitions not marked by dots are placed in the decay scheme from energy sum relations.

The energies of excited levels in ^{163}Tm were determined by the least squares method, by using energies together with their errors of all the γ -transitions included in the decay scheme [22]. It is worth noting that the γ -transition of 1603.05 *keV* due to the error in the energy determination cannot be placed in the decay scheme unambiguously (1820.79 $\rightarrow$ 217.14 *keV* or 1819.54$\rightarrow$217.14 *keV*).

The Q -value of 3.37 ±0.01 *MeV* of ^{163}Yb was deduced from the end point energy of positrons feeding the

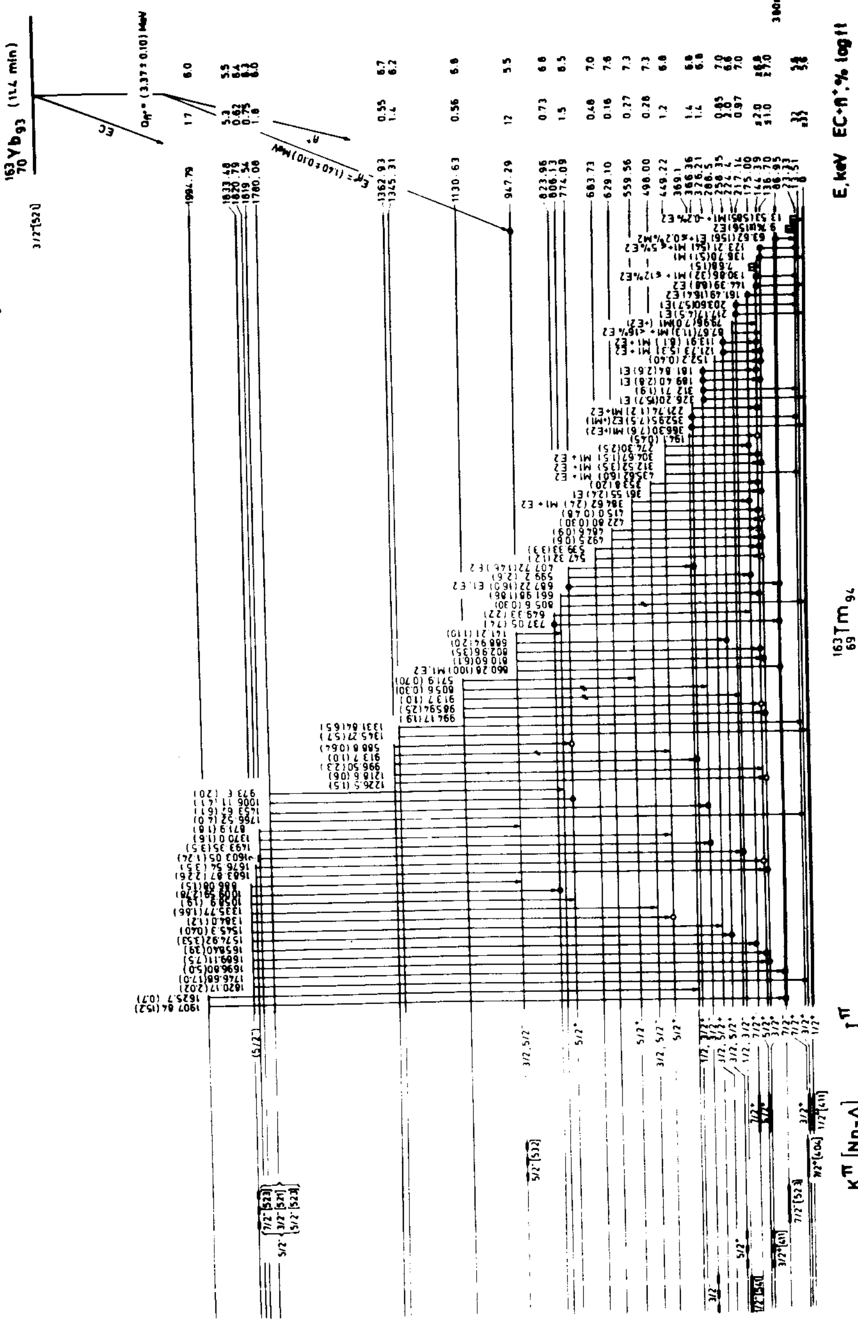

Fig. 8. The ^{163}Yb → ^{163}Tm decay scheme. In brackets data on the total intensity of transitions whose multipolarity has been determined are given.

947.28 *keV* level in ^{163}Tm obtained in $\beta^+ - \gamma$ coincidence measurements.

The calculation of the log ft values is based on the assumption of the same order of beta feeding to the first excited and the ground states of ^{163}Tm in the ^{163}Yb decay and by using the Q-value of 3.37 *MeV*. The intensity of the observed γ-transitions not placed in the decay scheme is about 7%. The value of log ft = 5.5 for the 1833.48 *keV* excited state and the de-population mode shows the probable spin and parity of this state $I^{\pi} = 5/2^-$. Then, with such a conclusion on the spin and parity of the 1833.48 *keV* state a possible value of spin and parity $I^{\pi} = 1/2^+$ for the 136.70 and 258.35 *keV* levels is excluded.

3.2. Levels of the $1/2^+$[411] Rotational Band

The spin I = 1/2 for the ground state of ^{163}Tm was measured by means of an atomic beam technique /23,24/. Ekström et al. /24/ have attributed the $1/2^+$[411] Nilsson orbital to the ground state of ^{163}Tm proceedings from the prediction of the Nilsson model for nuclei with 69 protons and strong deformation $\beta \simeq 0.26$. On the other hand, V.G.Soloviev /25/ has predicted the existence of three-quasiparticle state {p $7/2^-$[523] p $1/2^+$[411] n $5/2^-$[523]} of about 1.3 *MeV*.

Hnatovitz et al. /26/ have discovered this state and shown it to be populated with an allowed unhindred beta-transition (log ft = 5.4) in the ^{163}Tm decay. This circumstance is an additional evidence for the $1/2^+$[411] assignment to the ground state of ^{163}Tm.

The conclusions on the multipolarity of transitions allowed to attribute the spin and parity values to excited ^{163}Tm states of 13.51 *keV* - $I^{\pi} = 3/2^+$, 144.39 *keV* - $I^{\pi} = 5/2^+$, 175.00 *keV* - $I^{\pi} = 7/2^+$. The energies of these excited states of ^{163}Tm are well described by the formula for the states of the K = 1/2 rotational band

$$E(I) = A\,[\,I(I+1) + a(-1)^{I+1/2}\,(I+1/2)\,]$$

with $A = 15.36$ *keV* and with the decoupling factor $a = -0.707$.

The value of the admixture parameter $\delta^2 \simeq 0.02$ for the transitions from $3/2^+ 1/2 \rightarrow 1/2^+ 1/2$ level of ^{163}Tm is in agreement with the proper values of δ^2 in ^{169}Tm and ^{171}Tm[27]. The 144.39 *keV* level with $I^\pi = 5/2^+$ is de-populated by the 130.86 *keV* transition ($M1 + \lesssim 12\% E2$), $\delta^2 < 0.14$. From the intensity ratio of 130.86 and 144.39 *keV* γ-transitions de-populating the excited $5/2^+ 1/2$ [411] state one can calculate the ratio

$$S^2 = \frac{(g_K - g_R)^2}{Q_0^2}(1 - b_0)^2 ,$$

it is 4.2×10^{-2}.

Proceeding from the data of refs.[28,29] on the de-population of the $5/2^+ 1/2$ [411] level of ^{165}Tm and ^{167}Tm one obtaines $S^2 \doteq 2.98 \times 10^{-2}$ and 4.58×10^{-2}, respectively. For ^{169}Tm and ^{171}Tm nuclei the values of S^2 according to the data of ref. [27] 6.22×10^{-2} and 4.47×10^{-2}, respectively.

Thus, the value $S^2 = 4.2 \times 10^{-2}$ for ^{163}Tm is close to those of S^2 for neighbouring Tm nuclei.

3.3. Levels of 23.33, 86.95, 136.70, 217.14, 224.4, 326.21, 947.29 and 1833.48 keV

The levels of 23.33 and 86.95 *keV* can be attributed to the Nilsson orbitals $7/2^-[523]$ and $7/2^+[404]$, respectively, by comparing them to the neighbouring Tm odd isotopes [21]. The half-life of the 86.95 *keV* level was measured to be $T_{1/2} = 380 \pm 30$ *nsec*. The calculated value of the hindrance factor $F_{s.p.} = T^{\gamma}_{1/2\,exp.} / T^{\gamma}_{1/2\,s.p.} = 1.1 \times 10^6$ for the E1 transition of 63.62 *keV* in ^{163}Tm is in agreement with the hindrance factor of 4.8×10^7 for the E1 transition of 80.3 *keV* de-populating the identical state $7/2^-$ [523] in the neighbouring ^{165}Tm nucleus.

It is most probable that the observed excited states of 136.70 ($3/2^+$) and 224.4 *keV* ($3/2^+$, $5/2^+$) belong to the

rotational band built on the Nilsson orbital $3/2^+ 3/2$ [411]. This interpretation is supported by the multipolarities of the γ-ray transitions de-populating these levels and agrees with the systematics of the single particle states in ref. [21].

The spin and parity value of the 217.14 *keV* level are restricted by the multipolarities of the de-populating transitions to be $1/2^-$ or $3/2^-$. This level is interpreted as the $1/2^-$[541] state. This assignment is in very good agreement with the systematics of the single particle states in the neighbouring nuclei with $Z = 69$ (ref. [21]). The level at 326.21 *keV* may be the first excited rotational state of the $1/2^-$[541] band. Arguments supporting this interpretation are the log ft value, spin and parity of the 326.21 *keV* level.

One can consider in more detail the most populated 947.29 *keV* (12.9%) and 1833.48 *keV* (5.4%) level in the ^{163}Yb decay. Both the levels have a negative parity and log ft = 5.5. The spin 5/2 of the 1833.48 *keV* level is deduced from the de-population mode. The possible values of the 947.29 *keV* level are 3/2 or 5/2.

The intensive 860.28 *keV* transition from the 947.29 *keV* level with a possible multipolarity E2 to the $7/2^-$[523] state of 86.95 *keV* allow the suggestion that this level has a considerable component of the vibrational state $|523| + Q_{22}(I^\pi = 3/2^-)$. But the representation of such a vibrational phonon in the microscopic model is contradictive, especially when explaining the low log ft = 5.5.

Consider the levels of 947.29 and 1833.48 *keV* taking into account that they both have $I^\pi = 5/2^-$. The above value I^π has a one-quasiparticle state $5/2^-$[532]. This state has been found in the ^{167}Tm nucleus at 1528 *keV* [29]. According to the calculations in the Woods-Saxon potential [30], the energy of this state with respect to the $1/2^+$[411] state is decreased with decreasing deformation. The reduction of nuclear deformation can be expected in the transition from ^{167}Tm(N = 98) to ^{163}Tm(N = 94). The value log ft = 5.5 seems reasonable for the allowed hindered ($\Delta N = 0$) beta-transitions $3/2^-[521] \rightarrow 5/2^-[532]$. This value of log ft can be also observed for beta-transition having a component of the allowed unhindred beta-transition if the final state has a considerable admixture of the three-quasiparticle state of the type $5/2^-\{p\,7/2^-[523]\ n\,3/2^-[521]\ n\,5/2^-[523]\}$.

Thus, we consider that in order to interprete the structure of the levels of 947.29 and 1833.48 *keV* there are two above-said possibilities where the 947.29 *keV* level seems to be related to the one-quasiparticle state $5/2^-[532]$ while the 1833.48 *keV* level contains the above mentioned three-quasiparticle component.

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Возбужденные состояния ^{163}Tm, наблюдаемые при распаде ^{163}Yb ($T_{1/2}$ = 11,4 мин)

Распад ^{163}Yb ($T_{1/2}$ = 11,4 мин) изучен с помощью Ge(Li), Si(Li) и NaI(Tl) -детекторов, а также на тороидальном бета-спектрометре. Измерены: спектр γ-лучей, спектр конверсионных электронов, спектры мгновенных и задержанных γ-γ -совпадений и β^+-γ-совпадений. Предлагается схема распада ^{163}Yb→ ^{163}Tm. Определена энергия распада ^{163}Yb – (3370±100) кэВ.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Levels in ^{163}Tm Excited by the Decay of 11.4 min ^{163}Yb

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

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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