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HIGH-SPIN STATES IN ^{94}Tc

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Abstract: High-spin states in ^{94}Tc have been populated through the ^{93}Nb(α, 3n) reaction. Excitation functions, γ-ray angular distributions, $\gamma\gamma$ coincidences and half-lives were measured. New levels, with the following energies (in keV), spins and parities are proposed: 1373.5, 9^+; 1447.3, (8^+); 2064.0, (11^+); 2066.2, (9^-); 2234.9, (10^-); 2346.7, (13^+); 2420.7, (11^-); 3454.1, (13^-); and 4059.3, (15^-). The existence of an isomer with $50\text{ ns} < T_{1/2} < 10\ \mu\text{s}$ was established at an energy equal to or greater than 2420.7 keV.

1. Introduction

The low-lying levels of ^{94}Tc have been reasonably well identified. Previous experimental works [1-3]) have established the existence of seven positive-parity states, six of them well described [4,5]) as members of the $[\pi(1g_{9/2})^3, \nu(2d_{5/2})]_{J^\pi=2^+\ldots7^+}$ multiplet and two negative-parity states which have $[\pi(1g_{9/2})^4(2p_{1/2})^{-1}, \nu(2d_{5/2})]_{I^\pi=2^-,3^-}$ as their main configurations [5]).

High-spin states which arise from configurations like $[\pi(1g_{9/2})^3, \nu(2d_{5/2})]$ with seniority three, involving positive-parity states up to 13^+, and those of seniority five $[\pi(1g_{9/2})^4(2p_{1/2})^{-1}, \nu(2d_{5/2})]$ which will lead to spin up to 15^- have not been previously observed. In nuclei in the same region $N \approx 50$ and $Z \approx 43$, levels of the above characteristics have been populated. In particular for $^{93}_{43}$Tc, a number of positive-parity states up to $\frac{21}{2}^+$, described as the coupling of the three $g_{9/2}$ protons, and, at the same time, negative-parity states up to $\frac{25}{2}^-$, have been observed [6,7]).

A similar situation occurs for the ^{91}Nb and ^{92}Nb isotopes and, strikingly enough, the stretched configurations $^{91}\text{Nb} \times \nu d_{5/2}$ give rise to almost all the observed level configurations in ^{92}Nb with remarkable energy parallelism to the corresponding ones observed in ^{91}Nb.

Therefore it is of interest to investigate the ^{94}Tc isotope and compare its level scheme with that of ^{93}Tc in order to see if the above mentioned correspondence between ^{91}Nb–^{92}Nb holds in the present case.

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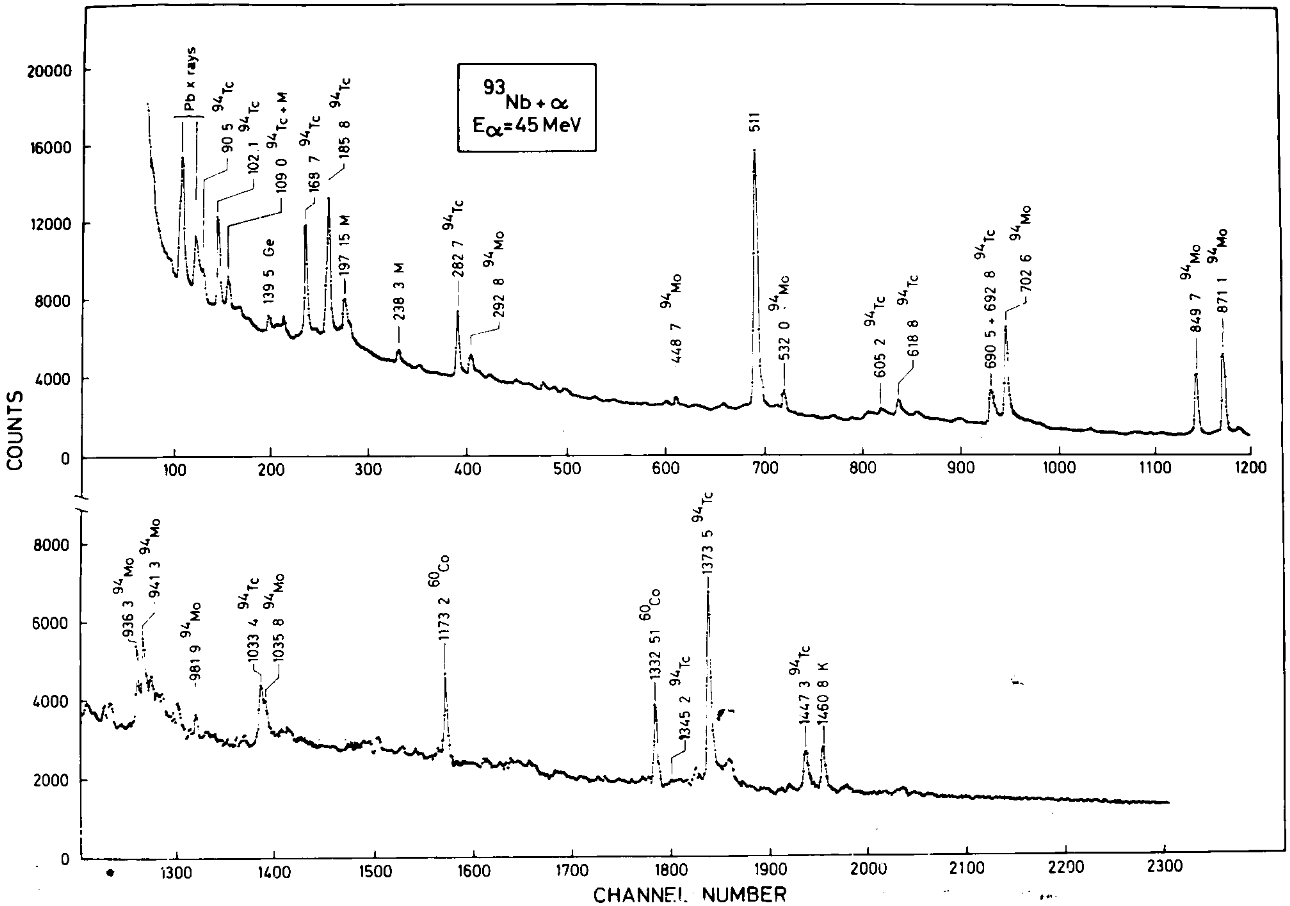

Fig. 1. Singles γ-ray spectrum obtained following the ^{93}Nb+45 MeV alpha reaction. M-labelled lines originated in the mylar target holder, basically γ-rays which belong to ^{18}F and ^{19}F.

2. Experimental procedure and results

A 55 MeV α-particle beam was obtained from the Buenos Aires Synchrocylotron and was subsequently degraded to energies between 30 MeV and 50 MeV. The target was a foil of natural Nb. Its area was about 2 cm^2 and the thickness was 10 μm.

The γ-radiation was detected with two coaxial Ge(Li) detectors of 10% and 7% efficiencies and 2.3 and 3 keV of resolution, respectively. Also a small X-ray detector with 700 eV of resolution at 122 keV was used.

The analysis of the γ-spectra was performed with help of the usual computer techniques. Sources of ^{152}Eu and ^{133}Ba were used for energy and efficiency calibration of the Ge(Li) detectors in the experimental geometry.

The ^{94}Tc was investigated through the ^{93}Nb(α, 3n)^{94}Tc reaction. A singles γ–ray spectrum taken at E_α=45 MeV is shown in fig. 1. There are several lines which belong to the (α, 2np)^{94}Mo reaction. The 102.1 keV γ–ray is known to belong to ^{94}Tc. Similarity of excitation functions and coincidences with this transition allow us to identify the lines which belong to the decay scheme of ^{94}Tc.

On this basis the lines at 90.5, 102.1, 109.0, 168.7, 185.8, 282.7, 605.2, 618.8, 690.5, 692.8, 1033.4, 1345.2, 1373.5 and 1447.3 keV were assigned as transitions in ^{94}Tc. The energies and intensities are given in table 1.

TABLE 1

Energies, intensities and angular distribution coefficients for γ-ray transitions from the ^{93}Nb(α, 3n) ^{94}Tc reaction at E_α=45 MeV

E_γ (keV)	I_γ	A_2	A_4
90.5	6±1		
102.1	29±3	−0.16±0.02	
109.0	10±1		
168.7	43±4	−0.26±0.02	
185.8	41±4	−0.42±0.02	
282.7	44±4	0.29±0.03	−0.07±0.03
605.2	27±3	0.19±0.07	
618.8	21±3	−0.43±0.07	
690.5	57±8	0.24±0.12	
692.8	30±6	0.36±0.15	
1033.4	32±3	0.36±0.06	−0.08±0.04
1345.2	5±1		
1373.5	100±10	0.34±0.03	−0.10±0.04
1447.3	30±3	−0.26±0.05	

Measurements of $\gamma\gamma$ coincidences were carried out using two large Ge(Li) detectors. Two runs were made, the first one over a 1.2 MeV energy range, and 2 MeV for the second. A conventional coincidence circuit of time resolution $2\tau = 60$ ns was used, and coincidences were stored in the event-by-event mode.

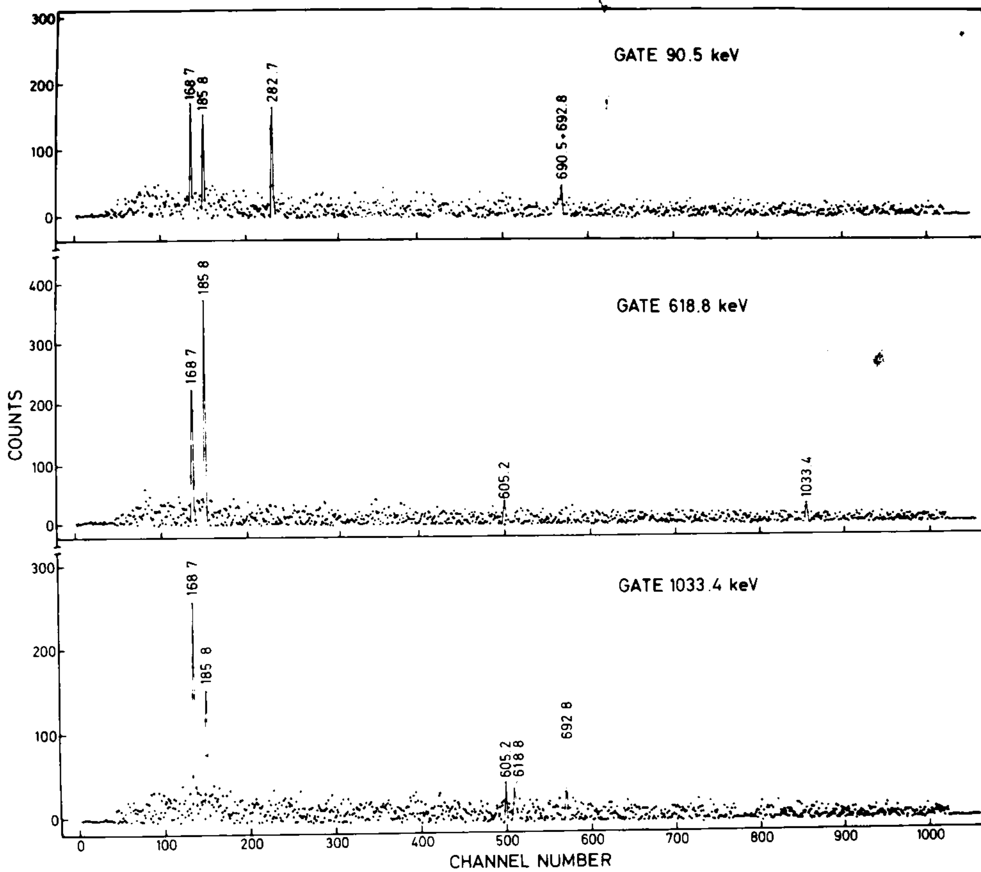

Fig. 2a. Gamma-gamma coincidence spectra in the range 0 to 1.2 MeV at $E_\alpha = 45$ MeV.

The results of both coincidence experiments are summarized in table 2. The numbers represent the peak areas corrected for the efficiency of both detectors, and some coincidence spectra are shown in fig. 2.

Three runs of γ-ray angular distribution measurements were performed by recording spectra at four different angles (90, 110, 120 and 145°) with respect to the beam direction. The movable detector was placed at 12 cm from the target. To normalize the spectra taken at different angles, the output of a pulser triggered by the pulses from a monitor detector was fed into the preamplifier of the moving detector. The normalized peak areas were fitted to the usual angular correlation function $W(\theta) = A_0[1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta)]$. In those cases where the resulting A_4 coefficients were consistent with zero a second fit was carried out with only two free parameters, A_0 and A_2. The obtained angular distribution coefficients are given in table 1.

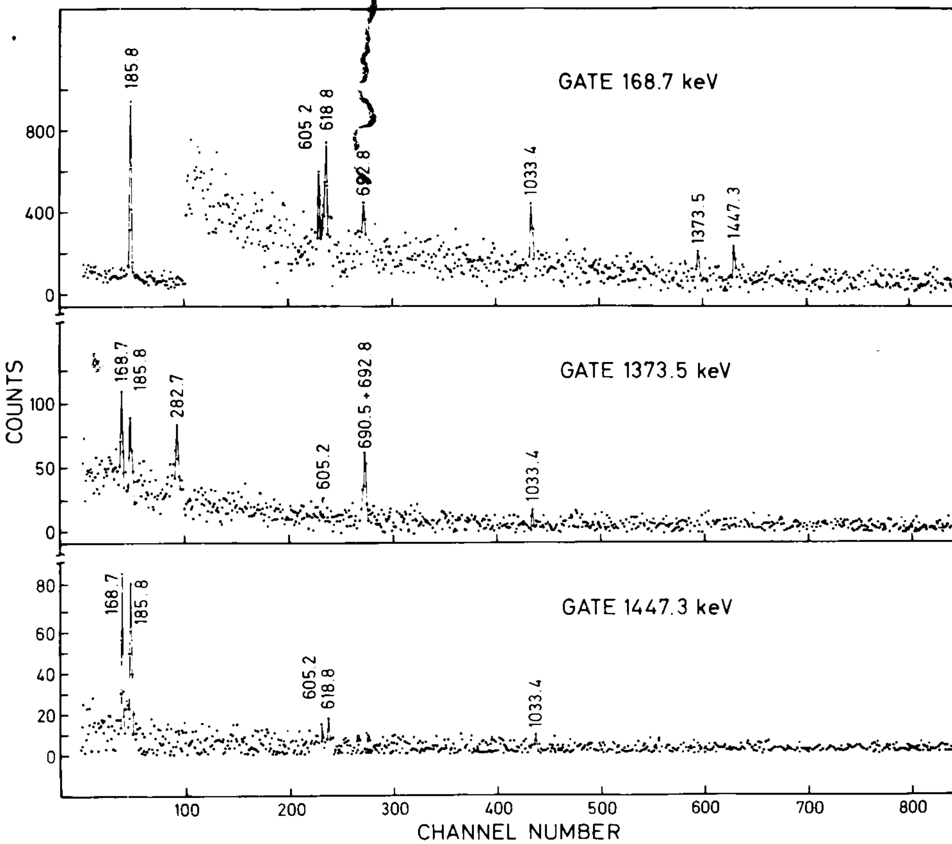

Fig. 2b. Gamma-gamma coincidence spectra in the range 0 to 2 MeV at $E_{\alpha} = 45$ MeV.

A search for isomeric states with lifetimes longer than a few ns was performed. The natural 100 ns pulsing of the synchrocyclotron beam was used to stop a TAC which was triggered by the γ-ray signals from the γ-ray detector. The 102.1 and the 109.0 keV γ-rays do not exhibit any measurable lifetime and a limit $T_{1/2} \leq 5$ ns has been determined. The same limit applies for the 90.5, 168.7 and 185.8 keV γ-rays, although they show, in addition to the prompt distribution, a long-lived component (our experimental set up only allows for a limit of $t > 50$ ns for a flat background in the ns time spectrum). In the first case this component carries about 30% of the total intensity, while it is only 10% of the total for the 168.7 and 185.8 keV lines. In view of this we have used the μs time structure of the synchrocyclotron modulated beam (30 μs beam bursts every 500 μs) to search for lifetimes in this time range. None of these three lines shows a time distribution wider than that corresponding to the prompt radiation. Thus the observed isomerism must have $50\ \text{ns} \leq T_{1/2} < 10\ \mu\text{s}$.

TABLE 2

Summary of the $\gamma\gamma$ coincidence experiments performed in the present work

Gate \ Display	90.5	102.1	109.0	168.7	185.8	282.7	605.2
90.5 [a]				90 ± 30	80 ± 25	115 ± 35	
102.1 [a]			270 ± 30	115 ± 30	170 ± 46		80 ± 35
109.0		250 ± 30 [a]					
168.7	50 ± 25 [a]	80 ± 30 [a]			1400 ± 100		440 ± 90
185.8	45 ± 25 [a]	90 ± 30 [a]		1400 ± 100			400 ± 95
282.7	75 ± 25 [a]						
605.2		W		390 ± 85	345 ± 80		
618.8		70 ± 20 [a]		720 ± 130	1090 ± 190		240 ± 110
690.1						1500 ± 200	
692.8	150 ± 30 [a]			310 ± 75	340 ± 75		200 ± 70
1033.4				720 ± 160	660 ± 160		330 ± 100
1373.5				420 ± 80	400 ± 80	840 ± 150	W
1447.3				400 ± 100	420 ± 100		W

Gate \ Display	618.8	690.5	692.8	1033.4	1373.5	1447.3
90.5 [a]			130 ± 40			
120.1 [a]	160 ± 40			W		
109.0						
168.7	600 ± 100		400 ± 100	660 ± 150	300 ± 50	330 ± 50
185.8	550 ± 100		360 ± 80	670 ± 170	310 ± 70	350 ± 50
282.7		1500 ± 200			1100 ± 200	
605.2	210 ± 100		220 ± 70	340 ± 135	W	W
618.8				380 ± 135		W
690.1					1700 ± 300	
692.8				150 ± 100		
1033.4	300 ± 100		300 ± 100		W	W
1373.5			1400 ± 200	W		
1447.3	200 ± 70			150 ± 75		

In this table are summarized both coincidence experiments (see text); some of the quoted numbers (due to used energy range) correspond only to one experiment.

W means weak intensities.

The quoted errors include the statistical errors and those due to the efficiency of the detectors.

[a]) Coincidences observed only in the 1.2 MeV range experiment (see text).

3. Energy levels and decay scheme

The ^{94}Tc level scheme shown in fig. 3 was constructed on the basis of the γ-ray intensity balance, $\gamma\gamma$ coincidences, energy relationships and γ-ray angular distributions.

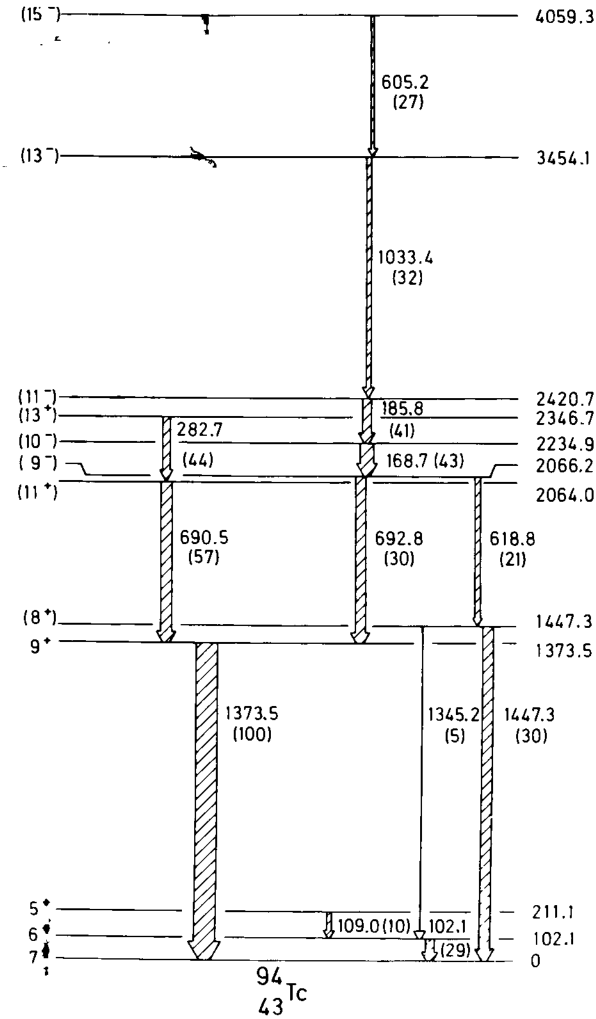

Fig. 3. Level scheme of ^{94}Tc.

The ground state is known to be 7^+ [ref. [1])]. The angular distributions corresponding to the 1373.5, 690.5 and 282.7 keV transitions are consistent with stretched quadrupole transitions. Therefore the most likely spin-parity assignments for the 1373.5, 2064.0 and 2346.7 keV levels are $J^\pi = 9^+$, 11^+ and 13^+, respectively.

The level at 1447.3 keV decays to the ground state and to the first excited 6^+ state, through the 1447.3 and the 1345.2 keV lines respectively. The 1447.3 keV line angular distribution shows negative anisotropy which is indicative of a $\Delta J = 1$ transition; therefore we propose $J = 8$ for this level. This is consistent with the branching ratio $I(1447.3)/I(1345.2) = 6$ which indicates that the 1345.2 keV transition is likely to have E2 character. Consequently, positive parity is favored for the 1447.3 keV level.

The 2066.2 keV level decays to the 1447.3 and to the 1373.5 keV levels through the 618.8 and 692.8 keV transitions. The former shows an angular distribution consistent with $\Delta J = 1$, while the angular distribution corresponding to the latter has positive anisotropy, indicating $\Delta J = 0$ or 2. Both results become compatible with each other if we assign spin $J = 9$ to the 2066.2 keV level.

The 185.8 and 168.7 keV transitions show angular distributions which indicate $\Delta J = 1$ character. Therefore we propose spins $J = 10$ and 11 for the 2234.9 and 2420.7 keV levels respectively. Finally the 1033.4 and 605.2 keV γ-ray show positive A_2 coefficients, typical of $\Delta J = 0$ or 2. The absence of sizeable crossover transitions indicates that the most likely assignments are $J(3454.1) = 13$ and $J(4059.3) = 15$.

It is not possible to establish unambiguously the parity of the 2066.2, 2234.9, 2420.7, 3454.1 and 4059.3 keV levels. However the lack of transitions from the 3454.1, 2420.7 and 2234.9 keV levels to the positive-parity levels, like the 2346.7 and 2064.0 levels, may indicate that these are negative-parity states.

The 90.5 keV line has not been placed in the decay scheme. It is in coincidence with the 282.7 keV line and also with the 185.8 keV γ-ray but no other γ-ray which can connect both branches is observed. On the other hand, as was mentioned above the time spectrum of this γ-ray shows a flat background which also appears in the time spectra of the 185.8 and 168.7 γ-rays but not of the 282.7 keV line. All these facts could indicate the presence of an unresolved doublet, as yet unidentified.

4. Discussion and conclusions

In the present experiment we have populated high-spin states in ^{94}Tc. It is interesting to compare the present level scheme with that of ^{93}Tc.

Shell-model calculations of ^{93}Tc have been performed by several authors [4,8]). In all cases the first 38 protons and the 50 neutrons are included in an inert core. Positive- and negative-parity states are due to the $[(2p_{1/2})^2(1g_{9/2})^3]$ and $[(2p_{1/2})^{-1}(1g_{9/2})^4]$ proton configurations, respectively. These calculations reproduce fairly well the known experimental level scheme [6,7]).

By comparing the results of the present experiment with those of ^{93}Tc one can observe that the stretched configurations for $^{93}\mathrm{Tc} \times \nu d_{5/2}$, give rise to all the high-spin levels observed in the present experiment as is shown in fig. 4 with the exception of the (10^-), 2234.9 keV level. In general the energy parallelism between the corresponding positive and negative states is remarkable. It is likely that the 2234.9 keV level arises from the $^{93}\mathrm{Tc} \times \nu h_{11/2}$ configuration. It is interesting to point out that in ^{92}Nb [ref. [9])] a 10^- level appears almost exactly in the same position

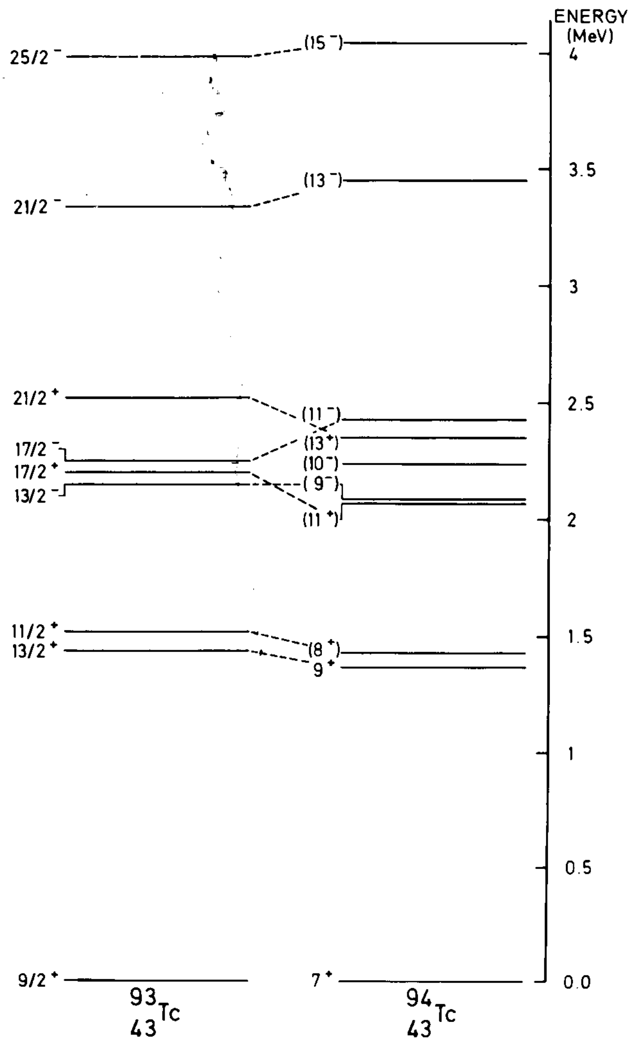

Fig. 4. Comparison of high-spin level energies in ^{93}Tc and ^{94}Tc. With the exception of the 2234.9 keV level, which is interpreted as $h_{11/2}$ neutron coupled to the ^{93}Tc ground state, all other ^{94}Tc levels are likely to correspond to the stretched coupling of a $d_{5/2}$ neutron with the ^{93}Tc excitations.

(^{92}Nb: 2235 keV; ^{94}Tc: 2234.9 keV) and it is described as arising from a neutron $h_{11/2}$ orbital.

In the present case, both the 168.7 and 185.8 keV γ-rays show a similar flat background in the time distribution (around 10%) indicating that they are populated by an isomer with a half-life 50 ns $\leq T_{1/2} \leq 10$ μs. This means that at least the isomer lies at an energy higher than 2420.7 keV. Moreover, since the 90.5 keV transition shows also a flat background in its time distribution it is likely that this transition is in the decay path of such an isomer. In that case the isomer would lie at an energy of 2511.2 keV or higher. It is noteworthy that in the same region of the periodic table, $N \simeq 50$, $Z \simeq 41$, the Mo and Nb isotopes exhibit isomers with $40\ \text{ns} \leq T_{1/2} \leq 40\ \mu\text{s}$ around 2.4 MeV, as in the present case.

Finally, it is interesting to remark that the stretched weak coupling scheme seems to be a common feature in nuclei near the $N = 50$ shell closure. It is observed in the even-even $N = 50$ nuclei and the adjacent $N = 51$ nuclei and also in the ^{91}Nb–^{92}Nb pair [7]. The present results show that this pattern also occurs for the ^{93}Tc–^{94}Tc pair.

References

1) D.C. Kocher, Nucl. Data Sheets **10** (1973) 241
2) M.R. McPherson and F. Galbard, Phys. Rev. **C7** (1973) 1097, and references therein
3) D.E. Miracle and B.D. Kern, Nucl. Phys. **A320** (1979) 353
4) J. Vervier, Nucl. Phys. **75** (1966) 17
5) G.CH. Madueme and K. Arita, Nucl. Phys. **A297** (1978) 347
6) M. Grecescu, A. Nilsson and L. Harms Ringdahl, Nucl. Phys. **A212** (1973) 429
7) B.A. Brown, D.B. Fossan, P.M.S. Lesser and A.R. Poletti, Phys. Rev. **C13** (1976) 1194
8) D.H. Gloeckner and F.J.D. Serduke, Nucl. Phys. **A220** (1974) 477
9) B.A. Brown and D.B. Fossan, Phys. Rev. **C15** (1977) 2044