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High-spin states of ^{97}Rh

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High-spin states of ^{97}Rh up to $J=(\frac{31}{2})$ and an excitation energy of 7.1 MeV were established by means of the ^{60}Ni(^{40}Ca,3pγ)^{97}Rh reaction. The states are found to decay through two separate γ-ray cascades with the assignments for the lower-spin states being in agreement with previous work. No strong evidence has been found for the existence of collectivity induced by intruder states. The empirical excitation energies are compared to those found recently for the nearby even-A isotones ^{96}Ru and ^{98}Pd, and the systematics of the $N=52$ nuclides are discussed.

INTRODUCTION

The present study of high-spin states of ^{97}Rh is a continuation of an effort[1] to study the level schemes of the $N=52$ nuclides; the earlier study had populated and identified high-spin states of both ^{96}Ru (up to $J^{\pi}=18^{+}$) and ^{98}Pd (up to 16^{+}). One goal is to compare the excitation energies of the levels of the odd-A nuclide ^{97}Rh to those of the neighboring even-even nuclides in order to gain insight as to what nuclear structures become yrast in the $N=52$ system. Additional insight may be obtained from a comparison of the level scheme of ^{97}Rh with that of the odd-A isotone ^{95}Tc, discussed in more detail below.

A second goal is to search in ^{97}Rh for collective five-particle—two-hole (5p-2h) states involving the excitation of a pair of $g_{9/2}$ neutrons across the $N=50$ shell closure. These states would be analogous to collective proton excitation states recently found[2-6] for several even-Sn(2p-2h), odd-Sb(2p-1h), even-Te(4p-2h), odd-I(4p-1h), and odd-Cs(6p-1h) nuclides. Specifically, it is expected that there might exist states of ^{97}Rh which are members of a $\Delta J=1$ positive parity band built upon a $J^{\pi}=\frac{9}{2}^{+}$ excited state; this collective state would consist of a $g_{9/2}$ proton coupled to a 4p-2h $J^{\pi}=0^{+}$ configuration of neutrons. Whether or not transitions between members of this band can actually be observed depends, however, on whether the states occur at a low enough excitation energy to be populated significantly by the fusion-evaporation process. In this regard, the present situation ($N=52$) is not as favorable as is the $Z=52$ system for reasons which have been put forward.[1] In the discussion section below, it is pointed out how this expectation has been modified by the empirical results.

Previous studies of the excited states of ^{97}Rh have emphasized the β^{+}-EC decay[7] of the $J^{\pi}=(\frac{5}{2}^{+})$ ground state of ^{97}Pd; the ^{96}Ru(^{3}He,pnγ)^{97}Rh and ^{96}Ru(d,nγ)^{97}Rh reactions;[8] the ^{96}Ru(α,p2nγ)^{97}Rh reaction;[9] and the ^{94}Mo(^{6}Li,3nγ)^{97}Rh reaction.[10] As will be seen below, the present study extends the previous results to higher spin states while the lower spin states deduced are in agreement with the previous studies. A preliminary report of the present work has also appeared.[11]

EXPERIMENTS

The reaction ^{60}Ni(^{40}Ca,3pγ)^{97}Rh with $E_{\rm lab}=140$ MeV was utilized to populate states of ^{97}Rh using ^{40}Ca ions produced by the Brookhaven tandem Van de Graaff facility. The data recorded during these experiments have already been utilized to report[12] new states of ^{96}Pd, produced by the ^{60}Ni(^{40}Ca,2p2nγ)^{96}Pd reaction. The ^{60}Ni targets of 1 mg/cm^2 were enriched to 99% and backed by 20 mg/cm^2 of lead to stop the beam. The data reported here include γ-ray excitation functions, angular distributions, and γ-γ coincidences. The coincidence data were event mode recorded onto magnetic tape for subsequent analysis. The γ-ray angular distribution spectra were recorded by positioning a Ge(Li) detector successively at each of three angles with respect to the beam direction: 0°, 90°, and 126°. In addition, the angular distributions produced both by the ^{66}Zn(^{35}Cl,2p2nγ)^{97}Rh reaction with $E_{\rm lab}=165$ MeV and by the ^{70}Ge(^{32}S,3p2nγ)^{97}Rh reaction with $E_{\rm lab}=130$ MeV were recorded. For each of these latter experiments, a Ge(Li) detector was positioned successively at each of eight angles ranging from 60° to 162° with respect to the beam direction. The thickness of the ^{66}Zn target (enriched to 98%) was 1.4 mg/cm^2 while that of the ^{70}Ge target (enriched to 85%) was 500 μg/cm^2. Both targets were evaporated onto thick tantalum backings. Large Ge(Li) detectors of about 85 cm^3 volume with energy resolutions of 2.2 keV for 1.33 MeV γ rays were used.

A γ-ray singles spectrum produced by 140 MeV ^{40}Ca+^{60}Ni appears in Fig. 4 of Ref. 12. The simultaneous production of several fusion-evaporation products was found to occur. Background-subtracted γ-ray gated spec-

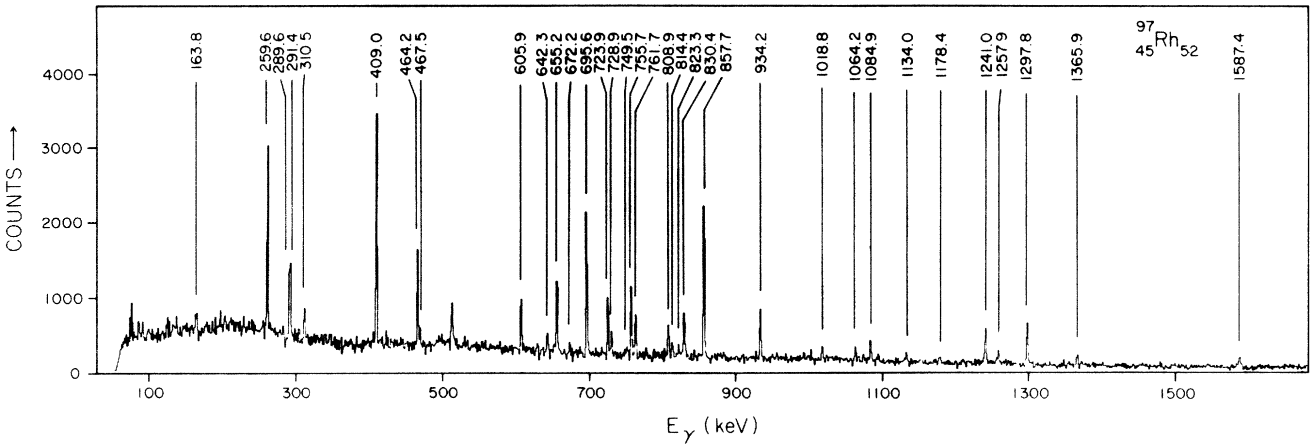

FIG. 1. Summed Ge(Li) spectra of 18 background-subtracted γ-γ gates set on ^{97}Rh transitions produced by the ^{60}Ni(^{40}Ca,3pγ)^{97}Rh reaction at 140 MeV. The transition energies are labeled in keV.

tra were formed from the γ-γ coincidence data by scanning the magnetic tapes with the gates initially set on known ^{97}Rh transitions. Additional ^{97}Rh transitions could then be identified and gated on; this process continued in an iterative manner until no additional ^{97}Rh transitions could be found in the spectra. Figure 1 shows the sum of those 18 ^{97}Rh background-subtracted gates which are largely free of contaminating transitions in other nuclides. The level scheme of ^{97}Rh which has been deduced from the individual γ-ray gates is presented in Fig. 2 and will be discussed below.

RESULTS

In order to obtain information about the multipolarity of each transition of ^{97}Rh, the formula

$$W(\theta)=A_0+A_2P_2(\theta)+A_4P_4(\theta) \qquad (1)$$

was fit to the observed γ-ray intensity function $W(\theta)$, where θ is the angle of the detector measured with respect to the beam direction, A_0, A_2, and A_4 are adjustable parameters, while P_2 and P_4 are Legendre polynomials. The empirical intensity $W(\theta)$ is obtained for each transition by subtracting the Compton background from the intensity under the photopeak. The results of the fitting procedure are listed in Table I. A slight correction was made to each A_2/A_0 and A_4/A_0 value for the finite solid angle subtended by the Ge(Li) detector. The A_0 values were corrected for the efficiency of the Ge(Li) detector used and normalized to the $\frac{13}{2}^+\rightarrow\frac{9}{2}^+$ transition to obtain the relative γ-ray intensities listed in Table I.

The yrast spin-parity assignments for ^{97}Rh shown in

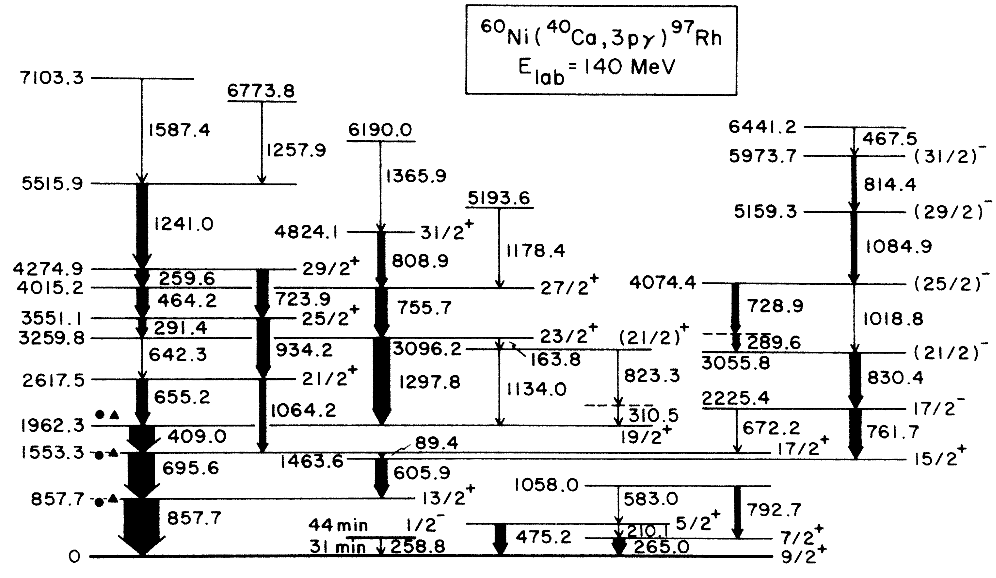

FIG. 2. Proposed ^{97}Rh level scheme deduced from the present work. The relative intensities shown by the width of the arrows are empirical γ-ray intensities corrected for detector efficiency except for γ89.4 for which the total transition intensity is shown. The energies of the 2$^+$, 4$^+$, and 6$^+$ states in ^{96}Ru and ^{98}Pd are indicated by black circles and triangles, respectively.

TABLE I. Transitions in ^{97}Rh produced by 140 MeV ^{40}Ca+^{60}Ni. The relative γ-ray transition intensities at 135° have been corrected for the efficiency of the Ge(Li) detector. The angular distribution results obtained from two other reactions are also listed. The A_2/A_0 and A_4/A_0 values have undergone the slight corrections necessary to take the finite solid angle of the detector into account.

		130 MeV ^{32}S+^{70}Ge		165 MeV ^{35}Cl+^{66}Zn		
E_γ (keV)	I_γ^{rel} (135°)	A_2/A_0	A_4/A_0	A_2/A_0	A_4/A_0	Assignment
89.4 ±0.4	11.4±2.2^{f}	a	a	a	a	$\frac{17}{2}^+ \to \frac{15}{2}^+$
163.78±0.35	1.9±1.5^{c}	b	b	a	a	$\frac{23}{2}^+ \to (\frac{21}{2})^+$
210.13±0.45	1.7±1.1	a	a	a	a	$\frac{5}{2}^+ \to \frac{7}{2}^+$
258.8						$\frac{1}{2}^- \to \frac{9}{2}^+$
259.62±0.15	28.8±2.2^{c}	−0.31 ±0.05^{d}	0.26 ±0.07^{d}	a	a	$\frac{29}{2}^+ \to \frac{27}{2}^+$
264.98±0.25	33.6±0.6	0.035±0.016	0.009±0.023	−0.09 ±0.07	−0.08 ±0.10	$\frac{7}{2}^+ \to \frac{9}{2}^+$
289.58±0.25	13.7±0.4	a	a	0.02 ±0.24	0.19 ±0.39	$(\to \frac{21}{2}^-)$
291.45±0.35	16.1±3.1^{c}	a	a	−0.15 ±0.10	−0.10 ±0.16	$\frac{25}{2}^+ \to \frac{23}{2}^+$
						$\delta=0.05\pm0.08$
310.53±0.20	5.9±2.8^{c}	a	a	a	a	$(\to \frac{19}{2}^+)$
408.96±0.20	72.1±0.7	−0.264±0.024	0.005±0.036	−0.235 ±0.049	0.072±0.078	$\frac{19}{2}^+ \to \frac{17}{2}^+$
						$\delta=-0.04\pm0.04$
464.18±0.20	33.8±0.7	a	a	0.05 ±0.10	0.11 ±0.15	$\frac{27}{2}^+ \to \frac{25}{2}^+$
						$\delta>0.09$
467.47±0.20	7.0±0.5	a	a	b	b	$\to (\frac{31}{2})^-$
475.2	24.2±0.8	−0.01 ±0.08	0.16 ±0.12	−0.002±0.041	0.031±0.066	$\frac{5}{2}^+ \to \frac{9}{2}^+$
583.05±0.45	≈1	a	a	a	a	$\to \frac{5}{2}^+$
605.89±0.25	34.4±0.9	0.147±0.035	−0.045±0.052	−0.05 ±0.10$^{a e}$	a	$\frac{15}{2}^+ \to \frac{13}{2}^+$
						$\delta=0.27\pm0.05$
642.29±0.25	6.7±2.5^{c}	a	a	a	a	$\frac{23}{2}^+ \to \frac{21}{2}^+$
655.25±0.15	32.6±1.1	a	a	a	a	$\frac{21}{2}^+ \to \frac{19}{2}^+$
672.17±0.25	6.3±0.9	a	a	a	a	$\frac{17}{2}^- \to \frac{17}{2}^+$
695.61±0.20	77.3±0.9	0.333±0.024	−0.146±0.035	a	a	$\frac{17}{2}^+ \to \frac{13}{2}^+$
723.91±0.15	26.9±2.7^{c}	a	a	a	a	$\frac{29}{2}^+ \to \frac{25}{2}^+$

TABLE I. (*Continued*).

E_γ (keV)	I_γ^{rel} (135°)	130 MeV ^{32}S+^{70}Ge A_2/A_0	 A_4/A_0	165 MeV ^{35}Cl+^{66}Zn A_2/A_0	 A_4/A_0	Assignment
728.93±0.20	13.0±1.0	a	a	a	a	$(\frac{25}{2}^- \rightarrow)$
749.53±0.35	3.9±2.1[c]	a	a	a	a	^{97}Rh
755.71±0.15	34.0±3.3[c]	a	a	a	a	$\frac{27}{2}^+ \rightarrow \frac{23}{2}^+$
761.68±0.20	32.2±2.8[c]	a	a	−0.19 ±0.08	−0.07 ±0.13	$\frac{17}{2}^- \rightarrow \frac{15}{2}^+$
792.68±0.30	9.0±3.2[c]	0.344±0.038	−0.065±0.056	−0.30 ±0.19	−0.32 ±0.30	$\rightarrow \frac{7}{2}^+$
808.89±0.20	18.6±0.7	0.248±0.048	−0.017±0.071	a	a	$\frac{31}{2}^+ \frac{27}{2}^+$
814.41±0.20	9.7±0.8	−0.21 ±0.09[d]	0.17 ±0.13[d]	a	a	$(\frac{31}{2})^- \rightarrow (\frac{29}{2})^-$
823.32±0.40	4.7±0.5	a	a	a	a	$(\frac{21}{2}^+ \rightarrow)$
830.36±0.25	33.4±4.2[c]	a	a	a	a	$(\frac{21}{2})^- \rightarrow \frac{17}{2}^-$
857.71±0.15	≡100.0±1.0	0.274±0.017	−0.059±0.024	0.279±0.044	−0.108±0.069	$\frac{13}{2}^+ \rightarrow \frac{9}{2}^+$
934.25±0.20	30.9±0.8	0.13 ±0.09	−0.09 ±0.13	0.27 ±0.13	−0.26 ±0.20	$\frac{25}{2}^+ \rightarrow \frac{21}{2}^+$
1018.78±0.20	5.6±0.8	0.38 ±0.15	−0.20 ±0.22	a	a	$(\frac{25}{2})^- \rightarrow (\frac{21}{2})^-$
1064.16±0.22	14.1±1.2	0.69 ±0.28	−0.18 ±0.40	b	b	$\frac{21}{2}^+ \rightarrow \frac{17}{2}^+$
1084.92±0.22	15.4±1.0	0.51 ±0.18	0.00 ±0.26	0.42 ±0.21[d]	0.02 ±0.31[d]	$(\frac{29}{2})^- \rightarrow (\frac{25}{2})^-$
1134.00±0.27	7.3±1.0	0.21 ±0.13	0.05 ±0.19	a	a	$(\frac{21}{2})_2^+ \rightarrow \frac{19}{2}^+$
1178.43±0.32	7.9±1.0	0.11 ±0.31	−0.24 ±0.45	a	a	$\rightarrow \frac{27}{2}^+$
1241.04±0.25	28.5±1.0	a	a	a	a	$\rightarrow \frac{29}{2}^+$
1257.91±0.45	6.1±0.9	a	a	b	b	→5515.9 keV
1297.78±0.27	44.1±1.2	0.25 ±0.06	−0.15 ±0.09	0.27 ±0.10	−0.08 ±0.17	$\frac{23}{2}^+ \rightarrow \frac{19}{2}^+$
1365.86±0.35	5.0±0.6	−0.13 ±0.25	0.06 ±0.37	a	a	$\rightarrow \frac{31}{2}^+$
1587.39±0.30	12.4±0.9	−0.32 ±0.25	−0.43 ±0.37	−0.21 ±0.22	0.30 ±0.36	→5515.9 keV

[a] Unresolved from another transition.

[b] Transition not observed with sufficient intensity.

[c] Singles intensity is larger than the coincident intensity. The coincident intensity is listed.

[d] This value may be perturbed by an unresolved transition.

[e] Value listed is obtained from ^{40}Ca+^{60}Ni data with $A_4/A_0 \equiv 0$.

[f] Total intensity $I = (1+\alpha)I_\gamma$ obtained from coincident intensities of preceding and following transitions.

Fig. 2 seem straightforward up through the $J^{\pi}=\frac{19}{2}^{+}$ level for those levels proposed to have positive parity. The $\frac{13}{2}^{+}\rightarrow\frac{9}{2}^{+}$ and $\frac{17}{2}^{+}\rightarrow\frac{13}{2}^{+}$ transition energies are found to be similar to the $4^{+}\rightarrow2^{+}$ and $2^{+}\rightarrow0^{+}$ transition energies, respectively, in both ^{98}Pd and ^{96}Ru as indicated in Fig. 2. This suggests a spectator role for the $g_{9/2}$ proton (hole) when coupled with the 2^{+} or 4^{+} (predominantly two-neutron) configurations of either even-even $N=52$ neighbor to the maximum possible spin. It is noteworthy that no $\frac{21}{2}^{+}$ level of ^{97}Rh is found at an excitation energy near those of the 6^{+} levels of the even-even neighbors as indicated in Fig. 2. As pointed out in Ref. 1, the $6^{+}\rightarrow4^{+}$ energy spacings in both ^{96}Ru and ^{98}Pd are larger than expected in the context of the shell model for the $\nu g_{7/2}^{2}$ (or $\nu d_{5/2}g_{7/2}$) configuration. The failure to observe a candidate spectator-proton state with $J^{\pi}=\frac{21}{2}^{+}$ in ^{97}Rh at about 2.13 MeV suggests that the 6^{+} states in both of the even-even neighbors include an important contribution from configurations of $\pi g_{9/2}^{n}(\nu=2)$ coupled to the two valence neutrons.

A sequence of states with $J^{\pi}=\frac{19}{2}^{+}, \frac{21}{2}^{+}, \ldots, \frac{29}{2}^{+}$ is shown in Fig. 2, ranging from 1962.3- to 4274.9 keV. These states are connected by $M1/E2$ transitions and strong $E2$ crossover transitions. The angular distribution data for these five latter transitions are seen to be consistent with the $E2$ assignments except for $\gamma755.7$ and $\gamma723.9$ which were unresolved from other transitions. Three of the $M1/E2$ mixing ratios for the $\Delta J=1$ transitions in this cascade are listed in Table I. Moreover, the energies of the $E2$ crossover transitions in this cascade decrease as J increases. This suggests shell-model couplings rather than collectivity for which an increase in energy should have been found. These states may involve $\pi g_{9/2}^{-5}\,(\nu=1)\otimes\nu h_{11/2}^{2}$ configurations which can achieve a maximum spin parity of $J^{\pi}=\frac{29}{2}^{+}$. However, the irregular sequence of the $M1$ transition energies may be an indication of strong admixtures of competing configurations. Candidate structures are the $\nu=3$ configuration of $\pi g_{9/2}^{n}$ with $J^{\pi}=\frac{21}{2}^{+}$ and the $\nu=5$ one with $J^{\pi}=\frac{25}{2}^{+}$. Several additional empirical states, probably of positive parity, are shown on the left-hand side of Fig. 2. The ordering of the 823.3- and 310.5-keV transitions could not be determined. Therefore, the level between them is dashed in Fig. 2.

On the right-hand side of Fig. 2 are shown two transitions: $\gamma672.2$ and $\gamma761.7$. The level at 1463.6 keV can only have a spin of $\frac{15}{2}$ since if the spin were instead $\frac{13}{2}$, a transition to the $\frac{9}{2}^{+}$ ground state would have been expected—in contrast to the empirical upper limit of $3.3[I(\gamma857.7)\equiv100]$. Moreover, a spin of $\frac{17}{2}$ would require $\gamma605.9$ to be a stretched quadrupole transition. However, the A_2/A_0 values listed in Table I for $\gamma605.9$ are not the expected value of $\sim+0.31$ for a stretched quadrupole assignment. Then J^{π} must be $\frac{15}{2}^{+}$ for the 1463.6 keV level, since if instead a $\frac{15}{2}^{-}$ assignment were made, the A_2/A_0 value listed in Table I for $\gamma605.9$ would require an $E1/M2$ admixture—which seems unlikely. We remark that the angular distribution results listed in Table I for $\gamma605.9$ are somewhat different from those obtained by Kajrys *et al.*[10] who were using the (^{7}Li,3nγ) reaction. Their result would allow $\gamma605.9$ to be a stretched $E1$ transition and not rule out the $J^{\pi}=\frac{15}{2}^{-}$ assignment for the 1463.6 keV level. Nevertheless, $J^{\pi}=\frac{15}{2}^{+}$ is more likely the correct assignment; the systematics of this level is discussed below. The 2225.4 keV level can only have a spin of $\frac{17}{2}$, since if instead the spin would be $\frac{15}{2}$, then a 1367.6 keV transition to the $\frac{13}{2}^{+}$ level would be expected in contrast to the experimental upper limit of 4.9 for the intensity. Moreover, the assignment of a spin of $\frac{19}{2}$ is ruled out by the empirical A_2/A_0 value for $\gamma761.7$. However, the data at first glance allow an assignment of either positive or negative parity for the 2225.4 keV level, i.e., $J^{\pi}=\frac{17}{2}^{+}$ or $\frac{17}{2}^{-}$. We return to this point below. The 3055.8 keV level probably does not have $J^{\pi}=\frac{17}{2}^{+}, \frac{19}{2}^{+}$, or $\frac{21}{2}^{+}$ since a transition to the 1553.3 keV level would have been found—in contrast to the empirical upper limit of 1.0 for this intensity. However, the possibility that $J^{\pi}=\frac{17}{2}^{-}$ or $\frac{19}{2}^{-}$ cannot be ruled out. Therefore, the proposed $(\frac{21}{2})^{-}$ assignment is shown tentatively in Fig. 2. At this point, the 2225.4 keV level discussed above can be assigned negative parity since, otherwise, a transition from the 3055.8 keV level to the 1553.3 keV level should have been able to compete successfully with the 830.4 keV transition—in contrast to experiment. Similar arguments can be given that the remaining higher-lying states shown in the right-hand side of Fig. 2 are of negative parity although the proposed spin assignments are only tentatively shown in parentheses. The order of the coincident transitions $\gamma728.9$ and $\gamma289.6$ could not be determined; therefore, the level between them is dashed in Fig. 2. We mention that the 749.5 keV transition listed in Table I (but not shown in Fig. 2) is observed to be in coincidence with the upper transitions in the negative parity cascade but is probably not in coincidence with the 857.7 keV transition. Therefore, this transition may be part of a weak nonyrast cascade that terminates in the $\frac{1}{2}^{-}$ isomer.

In addition to the two main cascades discussed above, Fig. 2 also shows for completeness several transitions found previously, as well as in the present data. The first excited state is a $J^{\pi}=\frac{1}{2}^{-}$ β-decaying isomer while the five transitions shown at the lower right-hand side of Fig. 2 have been placed more definitely[7] in a study of the β^{+}-EC decay of the $J^{\pi}=(\frac{5}{2}^{+})$ ground state of ^{97}Pd. In addition, 39 other low-spin levels, not shown in Fig. 2, have been identified[7,8] up to 3.6 MeV in excitation energy. The levels and transitions shown in Fig. 2 are generally in agreement with the (α,p2nγ) and (^{6}Li,3nγ) studies[9,10] and extend the results to higher spins. One exception is that the order of the 655.2- and 934.2-keV transitions has been reversed from the proposed level scheme of Behar *et al.*[9] Vanhorenbeeck *et al.*[8] reported the observation of a medium-spin cascade of stretched $E2$ transitions connecting states up to a spin of $\frac{17}{2}$ proposed to have negative parity. The four transitions are not found with certainty in the present data. The previously proposed $(\frac{17}{2})^{-}$ level is at 2364 keV while Fig. 2 shows instead a $\frac{17}{2}^{-}$ level at 2225 keV. It is somewhat surprising that this previously reported γ-ray cascade is not found to occur more robustly in the present data.

The present γ-ray angular distribution results are also generally in agreement with previous results[9,10] with the exception of those for γ605.9 discussed above. It is worthwhile to point to the two differing A_2/A_0 values listed in Table I for the 792.7 keV transition. The A_2/A_0 value of -0.11 found from the (^{3}He,pnγ) reaction[8] suggests that the positive result listed in Table I from the ^{32}S+^{70}Ge data is strongly perturbed by an unresolved transition. It is interesting to compare the alignment of nuclear spins obtained by the present (^{35}Cl,2p2nγ) and (^{32}S,3p2nγ) reactions with that obtained from the (α,p2nγ) and (^{6}Li,3nγ) reactions.[9,10] Considering only the average results for the $\frac{13}{2}^+ \rightarrow \frac{9}{2}^+$ and $\frac{17}{2}^+ \rightarrow \frac{13}{2}^+$ transitions, we find the alignment coefficient α_2 for each of the present reactions to have the value 0.70, while for (α,p2nγ) and (^{6}Li,3nγ), values of 0.79 and 0.59 are found, respectively. Therefore, the nuclear alignment of the low-lying yrast states obtained with the ^{35}Cl and ^{32}S beams is not significantly larger than the average obtained with the α and ^{6}Li beams.[9,10]

DISCUSSION

It is worthwhile to compare the present results with what has been found for the isotone ^{95}Tc by three distinct groups.[13–15] In ^{95}Tc, the high-spin states up to $\frac{27}{2}^+$ and $\frac{29}{2}^-$ decay through two separate cascades in a manner similar to the present results for ^{97}Rh. In ^{95}Tc, however, the negative parity cascade has been found to decay also to the $\frac{1}{2}^-$ β-decaying isomer through a series of stretched $E2$ transitions. We have searched the present data, to no avail, for an analogous $\frac{17}{2}^- \rightarrow \frac{13}{2}^-$ transition in ^{97}Rh. However, as mentioned above, the study of Vanhorenbeeck *et al.*[8] has located in ^{97}Rh a sequence of γ rays terminating in the $\frac{1}{2}^-$ isomer, although their $\frac{17}{2}^-$ level (2364 keV) is at a higher energy than the one shown in Fig. 2 at 2225 keV. The structure of the $\frac{17}{2}^-$, $\frac{21}{2}^-$, and $\frac{25}{2}^-$ states possibly involves $\pi p_{1/2} g_{9/2}^{-4}(v=2)$ or $\pi g_{9/2} \otimes \nu d_{5/2} h_{11/2}$, although the irregularity of the energy spacings between the yrast negative states suggests that changes in structure are occurring as the spin changes. A similar statement can be made for ^{95}Tc.

Interestingly, a $J^\pi = \frac{11}{2}^+$ state in ^{95}Tc has been found at a slightly higher excitation energy ($\Delta E = 75$ keV) than a yrast $\frac{13}{2}^+$ level. These two levels are probably the $J_{\max}$ and $J_{\max}-1$ members of the $\pi g_{9/2} \otimes 2^+$ multiplet for the yrast 2^+ state in ^{94}Mo. In addition, ^{95}Tc exhibits a closely spaced pair of yrast levels near 1.5 MeV with $J^\pi = \frac{15}{2}^+$ and $\frac{17}{2}^+$ where the $\frac{15}{2}^+$ level is slightly higher ($\Delta E = 112$ keV) than the $\frac{17}{2}^+$ level. These latter two levels are likely the $J_{\max}$ and $J_{\max}-1$ members of $\pi g_{9/2} \otimes 4^+$. Thus, for both multiplets in ^{95}Tc, the $J_{\max}$ member lies below the $J_{\max}-1$ member. This behavior is characteristic of a particle-particle-type interaction between the valence proton and neutron configurations. By contrast, the yrast $\frac{17}{2}^+$ state of ^{97}Rh shown in Fig. 2 lies just above the $\frac{15}{2}^+$ state, suggesting a hole-particle interaction between the $v=1$ proton configuration and the $v=2$ neutron configuration. Since, in the shell model, ^{97}Rh lies just above the middle of the $Z=38$–50 shell while ^{95}Tc lies just below, this reversal of the excitation energies of the $\frac{15}{2}^+$ and $\frac{17}{2}^+$ states is not surprising. Unfortunately, the location of the yrast $\frac{11}{2}^+$ level of ^{97}Rh could not be determined from the present data (it is expected to lie slightly below the $\frac{13}{2}^+$ level). This would have further documented the interaction. However, in the isotone ^{93}Nb the yrast $\frac{13}{2}^+$ level does lie slightly below ($\Delta E = 29$ keV) the $\frac{11}{2}^+$ level as expected for a particle-particle-type interaction.

As discussed in the Introduction, it seemed possible that a sequence of collective states with $J^\pi = \frac{9}{2}^+, \frac{11}{2}^+, \frac{13}{2}^+, \ldots,$ might become yrast. The positive parity levels shown in Fig. 2 ranging from $\frac{19}{2}^+$ to $\frac{29}{2}^+$ are apparently not members of a collective band. This follows both because the electric quadrupole energy spacings decrease with increasing spin and because the $\Delta J = 1$ spacings evolve in an irregular manner. These empirical states may instead involve quasiparticle states such as $\pi g_{9/2}^5(v=1) \otimes \nu h_{11/2}^2$, which naturally achieve a maximum spin parity of $\frac{29}{2}^+$.

In summary, new high-spin states of ^{97}Rh have been identified by in-beam γ-ray spectroscopy. The lower-spin states are in agreement with the results of previous studies. No collectivity induced by an intruder state in ^{97}Rh has been observed. A comparison of the yrast positive states with those of ^{95}Tc and ^{93}Nb documents an expected change in the effective interaction of the valence protons with the two valence neutrons above $N=50$.

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