Excited states of ^{96}Ru

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The nuclear excited states of ^{96}Ru were studied by means of the decays of 9.25-min and 1.55-min ^{96}Rh isomers, and the ^{93}Nb(^{6}Li, $3n\gamma$) reaction. Approximately 140 γ rays measured in these experiments were incorporated into a level scheme consisting of approximately 50 excited states. The experimental level scheme is compared with a level scheme calculated on the basis of the shell model.

RADIOACTIVITY ^{96}Rh [from ^{96}Ru(p,n)]; measured E_γ, I_γ, $\gamma\gamma$-coin. ^{96}Ru deduced levels, log*ft*. Enriched target, Ge(Li) detector.
NUCLEAR REACTIONS ^{93}Nb(^{6}Li,$3n\gamma$), $E=24$ MeV; measured E_γ, I_γ, $\gamma\gamma$-coin. ^{96}Ru deduced levels. Ge(Li) detector.
NUCLEAR STRUCTURE ^{96}Ru, ^{96}Rh, calculated levels. Shell model. Comparison with experiment.

I. INTRODUCTION

Previous investigations[1,2] have reliably established the existence of two $^{96}_{45}$Rh$_{51}$ isomers (with half-lives[3] of 9.25 $\pm$ 0.10 and 1.55 $\pm$ 0.15 min) excited in the ^{96}Rh (p,n) reaction with a threshold energy of 7.30 $\pm$ 0.01 MeV for both isomers. Ashkenazi *et al.*[2] suggested a 3^+ assignment for the 1.55-min activity and a spin value "not larger than 3" for the 9.25-min activity on the basis of a Hauser-Feshbach analysis of the (p,n) excitation function. Even though Doron and Blann[4] observed a total of 30 γ rays from both isomer decays, they were able to place only 7 γ rays on the level scheme for $^{96}_{44}$Ru$_{52}$. Their inability to place the remainder was due to the absence of coincidence studies and to the fact that pairs of γ rays simply did not add up in energies to that of a crossover γ ray. Doron and Blann[4] also suggested that a 2^+ assignment for the 1.55-min ^{96}Rh and a 6^+ or 7^+ assignment for the 9.25-min ^{96}Rh would be consistent with the β decay and γ decay patterns.

We made some preliminary measurements of ^{96}Rh isomer decays at the Oak Ridge EN tandem Van de Graaff accelerator and initially produced a level scheme no different from that of Doron and Blann.[4] Detailed coincidence data were gathered subsequently and led to a satisfactory decay scheme. These isomer decays were studied independently by Gujrathi, Weiffenbach, and Lee[5] at the McGill Synchrocyclotron. Their scheme and ours are in substantial agreement except that ours contains greater detail. It was clear from both sets of experiments that the 9.25-min activity arose from the decay of a high spin isomer and the 1.55-min activity from a low spin isomer. Unfortunately, with the exception of the yrast 6^+ level, those levels that were fed strongly by direct ($\beta^+ + \epsilon$) decay from the 9.25-min isomer did not possess definite spin and parity assignments. Therefore, we were not able to deduce a definite spin and parity value for the parent state. The situation was the same for the 1.55-min isomer. Gujrathi, Weiffenbach, and Lee[5] did carry out an additional $\beta\gamma$ coincidence measurement which, together with the log *ft* values to selected levels, led them to suggest a 5^+ assignment for the 9.25-min isomer and a 2^+ assignment for the 1.55-min isomer. As discussed later, we were not fully convinced about the validity of these assignments.

The few definite spin assignments that were available for the high-spin ($J>4$) states of ^{96}Ru came from the ^{94}Mo($\alpha,2n\gamma$) angular distribution measurements.[6] In order to improve the situation, we carried out a different (heavy ion,$xn\gamma$) measurement, this time with a ^{6}Li beam. However, the ^{96}Ru levels that were fed strongly in the ^{93}Nb(^{6}Li,3$n\gamma$) reaction were substantially no different from those in the ^{94}Mo(α,2$n\gamma$) reaction and were both substantially different from the levels fed strongly by direct ($\beta^{+}+\epsilon$) decay. Thus thwarted in our attempts, we undertook extensive shell model calculations of levels in both ^{96}Ru and ^{96}Rh for intrinsic reasons and for helping us understand the overall decay pattern. It is our conclusion that further consideration of the nuclear structure aspects raised in the present paper should probably await direct measurements of the spins of the parent states. Such measurements are beyond our present scope.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The ^{96}Rh isomers were produced by the ^{96}Ru(p,n) reaction. A 2 mg/cm^2 thick, 98.7% enriched ^{96}Ru metal foil was bombarded with a 10-MeV, 1-μA proton beam from the Oak Ridge EN tandem Van de Graaff accelerator. A mechanical device permitted irradiation for 3 min, a waiting period of 100 sec, and counting *in situ* for 800 sec. This cycle was repeated for a total period of 10 h. The Ge(Li) spectra were routed sequentially to eight 2048 channel segments of a 16384 channel analyzer for a duration of 100 sec per segment. The early segments contained both the 1.55-min and 9.25-min activities while the last segment contained virtually no 1.55-min activity. The summed spectrum from the first two segments is shown in Fig. 1. A 40-cm^3 Ge(Li) detector of moderate resolution (2.8 keV at 1333 keV) was employed for this part of the study.

In order to study the 9.25-min activity, the ^{96}Ru foil was irradiated for 15 min and taken out of the target chamber for counting in a low background location. The spectra were routed sequentially as before (10 min per segment) in order to follow the half-lives of the γ rays and to make appropriate identifications and corrections for contaminant activities. This procedure was repeated for a total counting period of $\approx$ 20 h. A typical spectrum, obtained with a 55-cm^3 Ge(Li) detector of good resolution (2.0 keV at 1333 keV), is shown in Fig. 2. Ge(Li)-Ge(Li) coincidence ($2\tau \approx$ 15 nsec) data involving 11x10^6 coincidence events were collected in a two-parameter 512 x 2048 channel mode. Typical coincidence spectra are shown in Fig. 3.

The ^{93}Nb(^{6}Li,3$n\gamma$) measurements were carried out with a 24-MeV, 60-nA beam of ^{6}Li from

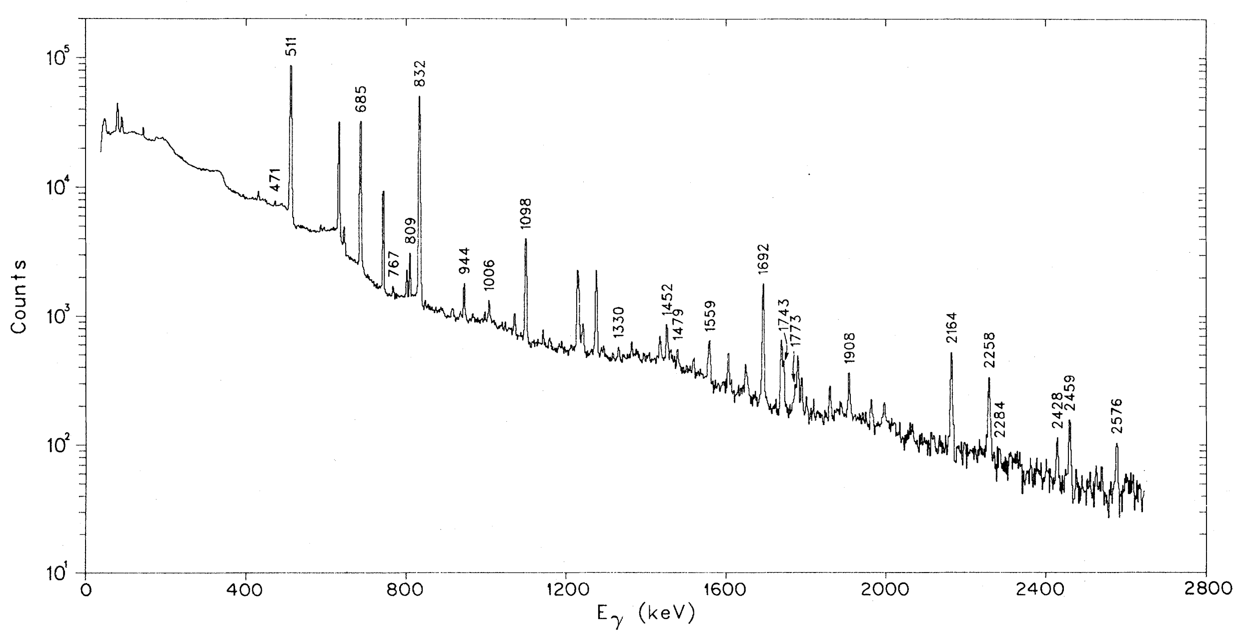

FIG. 1. γ-ray spectrum obtained in $\approx$ 2 h with a 40-cm^3 Ge(Li) detector from a metal foil containing both 1.55-min and 9.25-min ^{96}Rh activities. All energies are in keV. All γ rays definitely ascribed to the 1.55-min ^{96}Rh isomer are labeled in the figure.

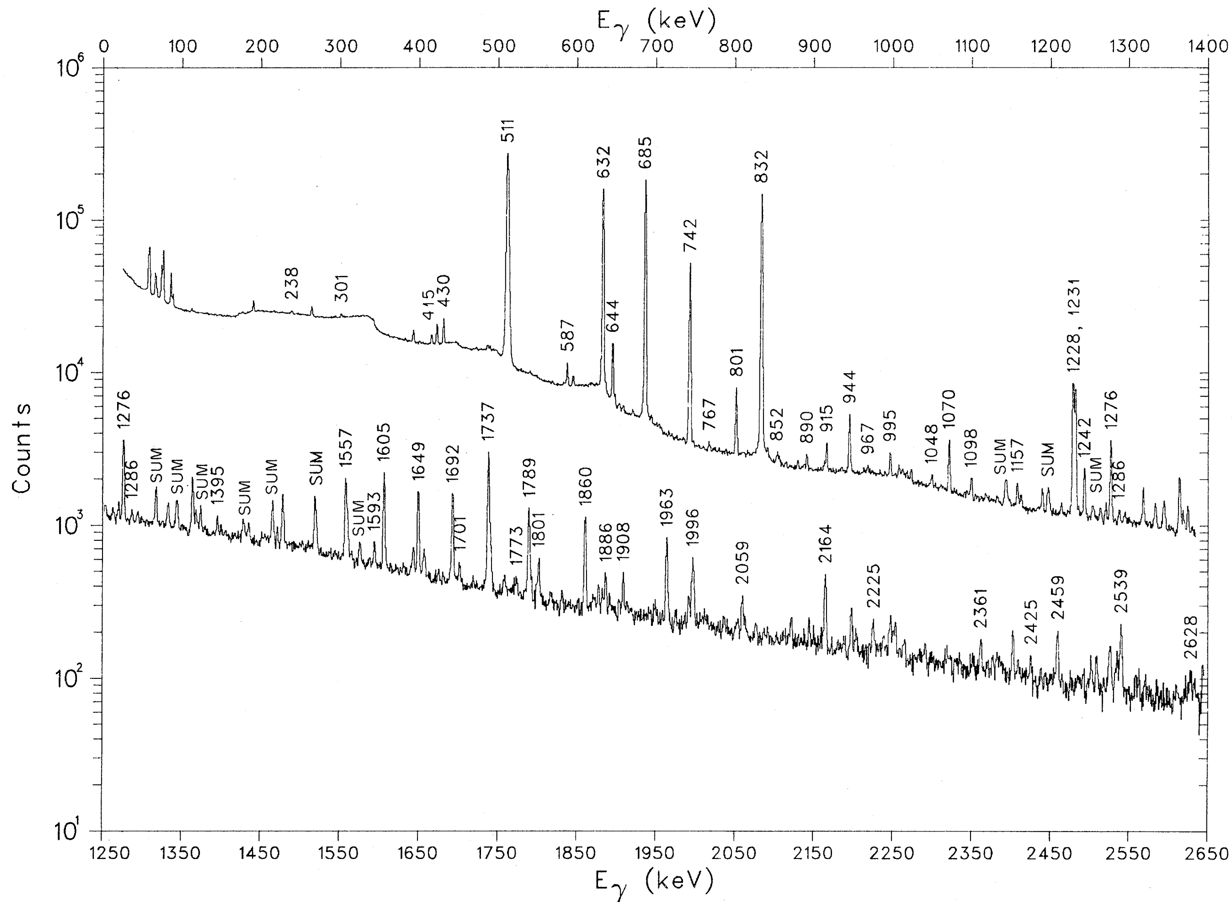

FIG. 2. γ ray spectrum obtained in $\approx$ 5 h with a 55-cm^3 Ge(Li) detector from samples containing essentially only the 9.25-min ^{96}Rh activity. All energies are in keV. Only selected peaks are labeled in the figure.

the same accelerator. Ge(Li)-Ge(Li) coincidence ($2\tau \approx 15$ nsec) data at 0° and 90° involving 9 x 10^6 coincidence events were collected in a two-parameter 1024 x 1024 channel mode. Typical coincidence spectra are shown in Fig. 4.

The measured energies and intensities for approximately 140 γ rays in ^{96}Ru from the above experiments are summarized in Table I. The overall agreement is good between our data and those obtained by Gujrathi, Weiffenbach, and Lee[5] from decay studies and by Lederer, Jaklevic, and Hollander[6] from the (α,$2n\gamma$) reaction studies.

III. DECAY SCHEMES FOR ^{96}Rh ISOMERS

The decay schemes are shown in Fig. 5. In the case of the 9.25-min ^{96}Rh decay, the scheme involving 37 excited states is mostly well-established through detailed coincidence measurements. The 3291.6 and 4949.54 keV levels are not based on coincidence data, but are fairly certain because they accommodate 4 γ rays each in the level scheme. The β-decay energy ($Q^+ \approx 6450$ keV) is from (p,n) threshold measurements.[2] The ($\beta^+ + \epsilon$) intensities were deduced from the measured relative photon intensities, the requirement that the intensity feeding the ^{96}Ru ground state is 100, and the intensity balance at each level. The deduced ($\beta^+ + \epsilon$) intensities were separated into β^+ and ϵ intensities with the aid of the tables presented by Gove and Martin.[7] These tables also enabled the calculations of the log ft values. A complete set of these log ft values has been presented in Fig. 5, but it must be understood that, since the decay scheme is complex, many weak β branches indicated there may not actually exist, especially those deduced from intensity balance requirements.

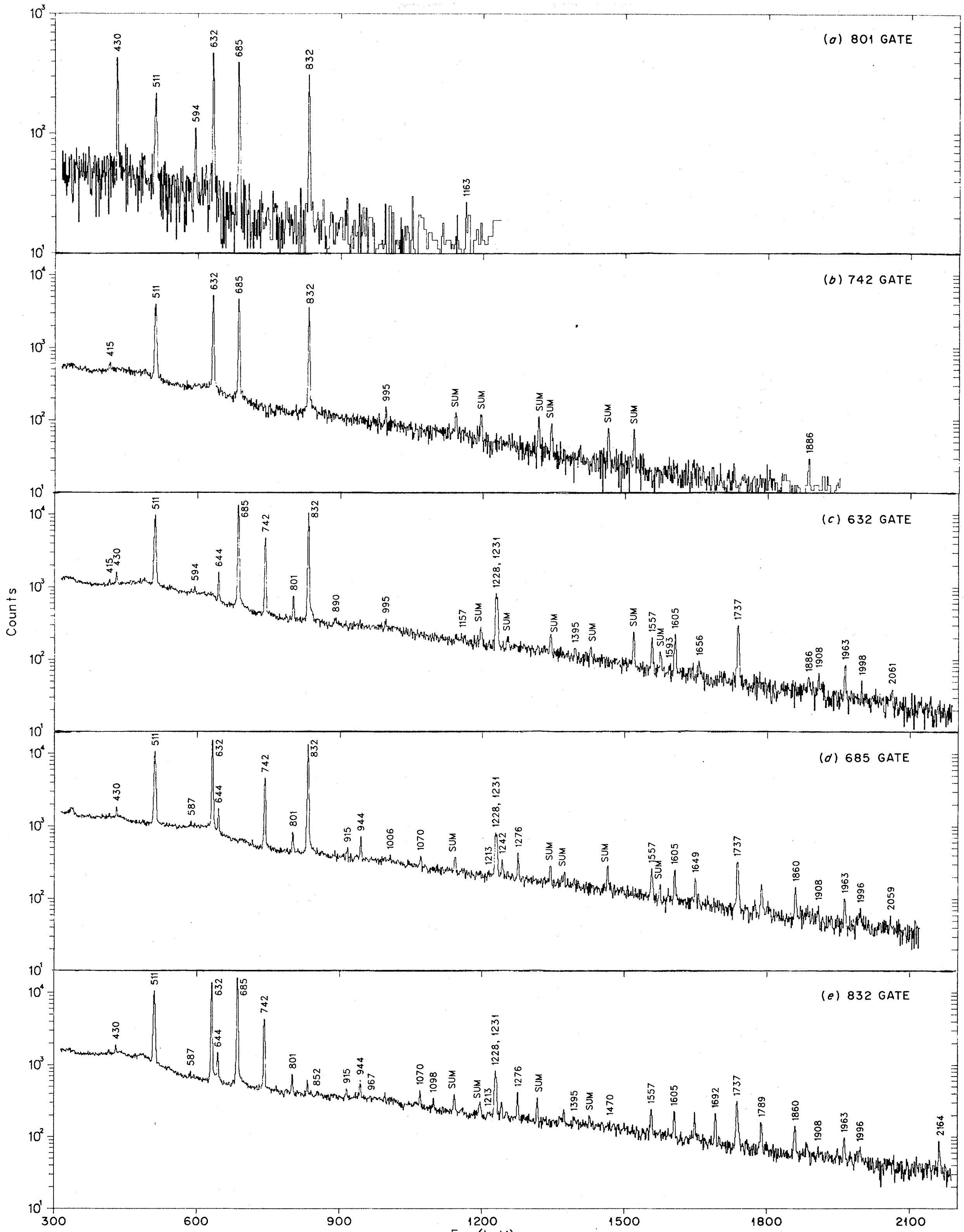

FIG. 3. Typical Ge(Li) γ-ray spectra from ^{96}Rh observed in coincidence with various γ ray gates selected by a second Ge(Li) detector. All energies are in keV. Contributions to the spectra due to Compton events present within the gate have been subtracted.

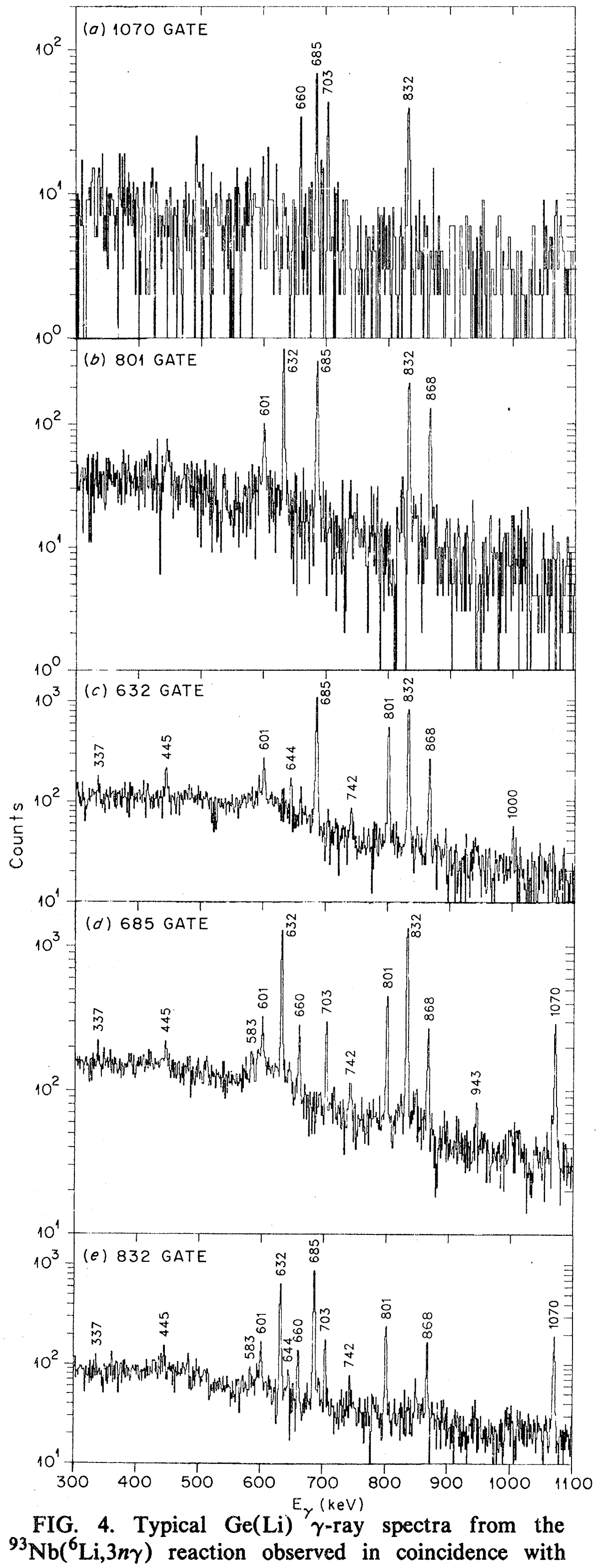

FIG. 4. Typical Ge(Li) γ-ray spectra from the $^{93}Nb(^{6}Li,3n\gamma)$ reaction observed in coincidence with various γ ray gates selected by a second Ge(Li) detector. All energies are in keV. Contributions to the spectra due to Compton events present within the gate have been subtracted.

The scheme presented in Fig. 5 contains significantly more information and details compared to any previously published decay scheme for the 9.25-min ^{96}Rh isomer. This scheme, consisting of 37 excited states, accommodates 80 γ rays; 18 additional weak γ rays observed in this decay (see Table I) remain unplaced.

There are also minor differences between our scheme and that proposed in Ref. 5. We found no evidence for the 3514.0 keV level proposed in the latter work. The 1996 (3514 $\rightarrow$ 1518) keV γ ray which led to this level was placed elsewhere (4521 $\rightarrow$ 2525) in our scheme. A second γ ray of energy 1365 (3514 $\rightarrow$ 2149) keV deexciting this level was ascribed to an impurity. The 2059 keV γ ray placed as a 4950 $\rightarrow$ 2891 keV transition in Ref. 5 was placed differently as a 4521 $\rightarrow$ 2462 keV transition on the basis of our coincidence data. We also did not observe the 2800 and 3431 keV γ rays shown deexciting the 4950 keV level in Ref. 5, since our measurements did not extend that far in energy.

The decay scheme for the 1.55-min ^{96}Rh isomer is less extensive and is essentially the same as that reported by Gujrathi, Weiffenbach, and Lee.[5] According to these authors, an $M3$ isomeric transition of energy 52 keV is present in ^{96}Rh with an intensity of $(60\pm5)\%$. They also found no evidence for a direct β transition from this isomer to the ground state of ^{96}Ru. Accordingly, we have set the sum of the photon intensities feeding the ground state of ^{96}Ru as $(40\pm5)\%$ in order to deduce the $(\beta^{+}+\epsilon)$ intensities in this decay. The deduced β^{+} and ϵ intensities and the corresponding log ft values are also given in Fig. 5.

IV. IN-BEAM SPECTROSCOPY

The γ rays observed in the $^{93}Nb(^{6}Li,3n\gamma)$ reaction were incorporated into the level scheme as shown in Fig. 6. This scheme is well-supported by coincidence data and is also in agreement with the scheme proposed in Ref. 6 from a study of the $^{94}Mo(\alpha,2n\gamma)$ reaction. The spin and parity assignments shown in Fig. 6 are those proposed in Ref. 6 on the basis of γ ray angular distributions, γ ray decay patterns, and energy level systematics in this mass region.

In-beam γ ray spectroscopy of ^{96}Ru with more emphasis on the low spin states has been carried out by Lange *et al.*[8] via the $^{96}Ru(p,p'\gamma)$ reaction. Based mainly on their $p\gamma$ angular correlation data, these authors have proposed 2^{+} assignments for states at 1930, 2286, 2529, 2578, and 2651

TABLE I. Energies and intensities of γ rays observed in ^{96}Ru.

(A) The decay of 9.25-min ^{96}Rh.

Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]	
237.9	2	1.9	3	915.2	2	10.3	6	1525.2	5	0.70	20	2061.2	5	0.67	20
300.7	5	2.4	6	944.07	10	24.3	7	1556.72	20	19.2	10	2075.0[d]	5	1.1	3
380.4	5	1.6	5	966.8	5	2.2	3	1559.0	5	9.6	19	2121.0[d]	5	1.5	3
400.0[c]	5	1.3	3	995.5	2	7.9	4	1593.1	2	3.5	4	2143.1[d]	2	1.4	2
415.2[c]	5	6.2	7	1006.5	5	2.8	4	1605.4	2	26.5	8	2149.6	5	0.65	20
430.18	10	20.7	5	1011.4	5	2.0	4	1642.7	2	3.6	4	2163.9	2	7.6	8
471.7[d]	5	1.6	4	1016.8	5	1.8	5	1648.66	10	20.6	6	2196.9[d]	2	3.0	3
485.9	5	5.0	7	1048.0	5	3.2	4	1656.0	2	3.8	4	2203.0[d]	5	1.3	3
488.9	5	3.9	10	1070.35	10	18.3	5	1692.3	2	21.6	5	2224.8	2	2.3	3
586.62	20	15.3	5	1098.2	2	5.2	5	1701.1	2	2.6	3	2252.7	2	2.5	4
594.1[c]	2	5.7	6	1157.0	2	≈4.0		1737.45	10	44.7	22	2264.9[d]	5	1.2	4
631.73	10	745	19	1162.9	5	3.4	5	1743.1	5	4.4	14	2290.5[d]	5	0.8	2
644.16	10	45.7	12	1188.6	2	5.8	5	1758.2[d]	5	2.1	3	2361.5	5	1.6	3
657.5	5	2.4	10	1212.8	2	1.9	3	1773.4	5	1.6	5	2402.4[d]	2	2.2	3
685.47	10	957	24	1227.85	10	78	5	1788.6	2	19.6	8	2424.9	5	1.2	3
693.1[d]	2	2.6	5	1230.66	10	72	5	1800.7	2	4.7	5	2459.1	5	3.6	5
699.5	5	0.9	3	1242.14	10	12.9	9	1859.7	2	16.1	6	2500.9[d]	5	1.3	3
741.87	10	294	7	1269.1	5	3.1	4	1885.7	2	3.6	4	2508.7[d]	5	1.6	3
766.8	5	2.0	4	1275.76	10	30.7	8	1907.8	2	3.8	4	2525.6[d]	2	2.9	3
800.70	10	33.2	10	1286.4	2	2.5	5	1963.19	10	12.7	6	2534.5[d]	5	2.0	3
832.52	10	1000		1367.8[d]	2	5.0	5	1991.1[d]	5	2.2	9	2539.2	5	4.6	3
852.3	5	4.8	7	1394.7	2	2.7	5	1996.16	2	9.2	5	2628.0	5	1.1	3
863.5[c]	5	1.3	4	1400.5	5	1.1	3	1998.4	5	0.22	9	2698.5[d]	5	1.3	3
890.0	2	3.8	3	1450.5	5	0.7	3	2052.4	5	1.2	5				
912.2	5	2.5	2	1470.2	5	4.3	9	2059.2	5	2.8	2				

(B) The decay of 1.55-min ^{96}Rh.

Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]	
471.4	5	10	3	1098.2	2	227	10	1743.1[c]	5	41	6	2459.1	5	20	3
685.47	10	92	40	1242.14	10	16	3	1773.4	5	15	5	2576.1	2	16	3
766.8	5	10	3	1330.5	10	<5		1907.5	2	23	4	2840.2[d]	5	8	2
808.6	2	75	6	1451.9	5	43	7	2163.8	2	66	7	3090.1	5	1.0	5
832.52	10	1000		1479.0	5	11	4	2257.6	2	47	6	3119.1[d]	5	5	1
944.07	10	20	3	1559.0	5	12	5	2283.9	5	3.7	20	3261.5	5	3.6	10
1006.5	5	22	5	1692.3	2	178	10	2428.3	2	13	3				

(C) The ^{93}Nb(^{6}Li,3nγ) reaction.

Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]		Energy[a] (keV)		Intensity[b]	
336.8	5	13	2	631.92	20	491	16	741.8	5	47	4	1000.1	5	34	6
445.1	5	30	3	643.8	5	23	4	800.69	20	269	7	1070.54	20	210	6
583.5	5	34	3	659.87	20	86	7	832.67	20	1000					
597.9	5	20	6	685.32	20	923	28	867.6	5	172	17				
601.0	5	97	8	702.81	20	123	12	943.2	5	42	8				

[a] In our notation, 237.9 *2* is 237.9 ± 0.2 keV, etc.
[b] Relative photon intensity normalized to 1000 for the 832.5 keV γ ray for each data set.
[c] γ ray placed more than once on the level scheme.
[d] γ ray not placed on the level scheme.

keV. They have also identified a level at 2148 keV and interpreted it as the 0^+ member of a widely split two-phonon triplet.

Seven γ rays observed from the bombardment of ^{90}Zr with 56-MeV ^{12}C ions have been ascribed to ^{96}Ru by Lumpkin, Harwood, Parks, and Fox.[9] The reaction is ^{90}Zr(^{12}C,$\alpha 2n\gamma$). Six of these correspond to cascade $E2$ transitions (see Fig. 6) between the 4419.3 keV, (12^+) state and the ^{96}Ru, 0^+ ground state.

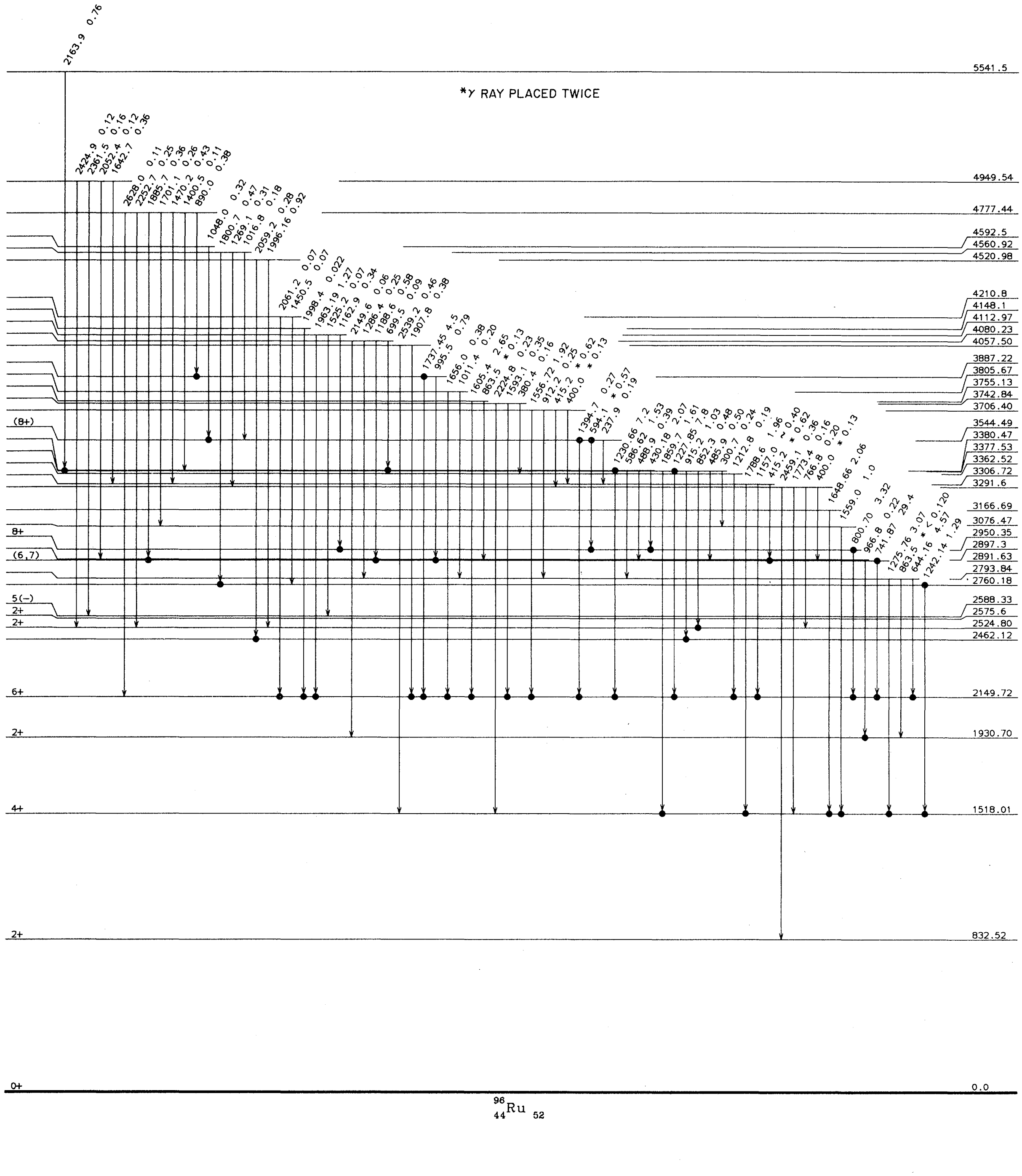

FIG. 5. Proposed decay schemes for ^{96}Rh isomers. All energies are in keV. The heavy dots indicate coincidences. The numbers next to the γ-ray energies denote the absolute transition intensities per 100 disintegrations of the parent. In the case of the low-J ^{96}Rh decay, the intensity of the isomeric transition (not shown) was assumed to be 60% (Ref. 5).

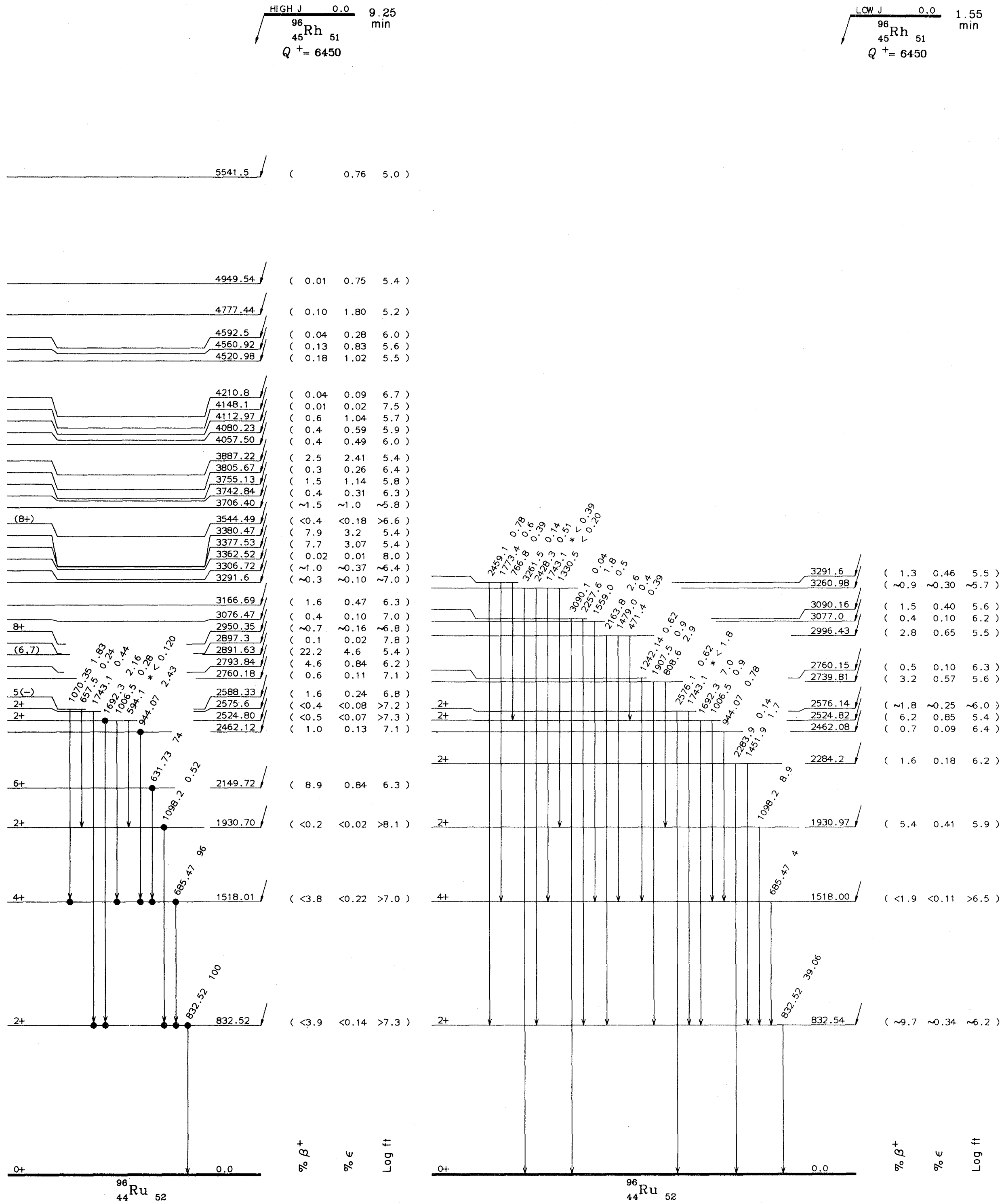

FIG 5. (*continued*). Proposed decay scheme for ^{96}Rh isomers. All energies are in keV. The heavy dots indicate coincidences. The numbers next to the γ-ray energies denote the absolute transition intensities per 100 disintegrations of the parent. In the case of the low-J ^{96}Rh decay, the intensity of the isomeric transition (not shown) was assumed to be 60% (Ref. 5). Since the decay scheme is complex, many weak β branches, especially those based on intensity balance requirements, may not actually exist.

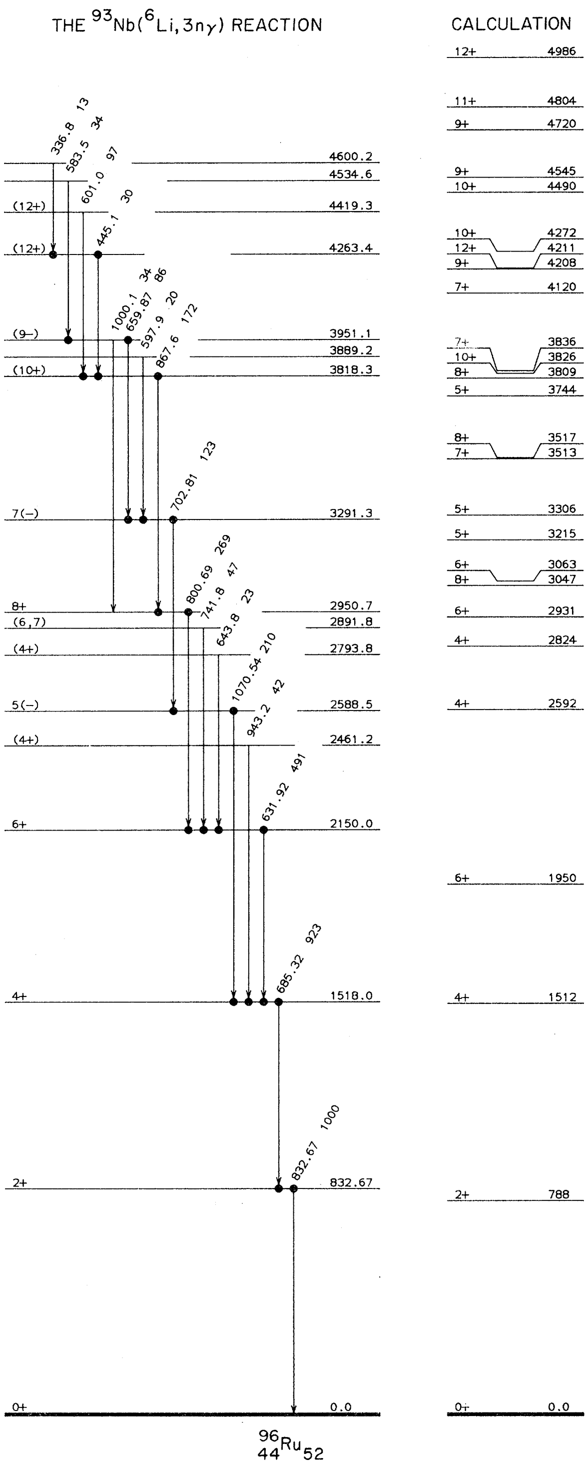

FIG. 6. Level scheme deduced from the ^{93}Nb(^{6}Li,3$n\gamma$) reaction compared to the calculated (positive parity only) levels. The heavy dots indicate coincidences.

For those levels that are common to γ decay and in-beam spectroscopy, the spin and parity assignments from Refs. 6 and 8 are explicitly shown in Fig. 5 (see also Table II).

V. J^{π} ASSIGNMENTS FOR ^{96}Rh ISOMERS

The β decay from the 9.25-min ^{96}Rh isomer (see Fig. 5) is highly fragmented. Between 2 and 5 MeV excitation energy, there are approximately 30 states that are fed by β decay to varying degrees. Since the decay scheme is so complex and necessarily incomplete, only the strongest $(\beta^{+}+\epsilon)$ groups and the corresponding log ft values can be relied upon in attempting J^{π} assignments.[10] There are six β groups with >5% $(\beta^{+}+\epsilon)$ intensities. They lead to states at 2150, 2794, 2892, 3377, 3380, and 3887 keV. Of these, only the 2150 keV level has a definite J^{π} assignment of 6^{+} from previous in-beam studies. The β feedings to the known 4^{+} level at 1518 keV and the known 8^{+} level at 2950 keV are both weak. Therefore, a reliable J^{π} assignment for the 9.25-min ^{96}Rh isomer cannot be made based on the log ft values.

Faced with this problem, we attempted to provide J^{π} assignments for several states in ^{96}Ru that are populated strongly in this β decay. We were going to utilize the DCO (directional correlation from oriented nuclei) method proposed by Krane, Steffen, and Wheeler[11] to accomplish this. We were, however, not successful in these attempts because the states that were sought were not populated strongly enough in the ^{93}Nb(^{6}Li,3$n\gamma$) reaction. Gujrathi, Weiffenbach, and Lee,[5] on the other hand, tried a different approach. They carried out a difficult $\beta\gamma$ coincidence measurement which suggested the possibility of some (≈ 2%) direct β feeding from the 9.25-min ^{96}Rh isomer to the 1518 keV, 4^{+} state in ^{96}Ru. This result, if correct, is sufficient to pin down the J^{π} of the 9.25-min ^{96}Rh as 5^{+}. However, these authors recognized that their evidence was tenuous because, towards the end of their paper, they raised the possibility of this J^{π} value being different from 5^{+}.

According to us, the 5^{+} assignment for the 9.25-min ^{96}Rh isomer is unsatisfactory for a different reason. If it were correct, a significant number of the approximately 30 states between 2 and 5 MeV excitation energy would have J^{π} = 4^{+}, 5^{+}, or 6^{+}, as permitted by allowed β decay. In turn, a large fraction of these states can be expected to decay via γ transitions to the first 4^{+}

state at 1518 keV. Several of the 4^+ states in this group would also decay to the first 2^+ state at 832 keV. Despite a careful search made by us for these transitions, only 12 such states between 2 and 5 MeV had an observable γ branch to the 1518 keV level, and only one state to the 832 keV level. We believe that this is a much smaller fraction than one would normally expect. We, therefore, prefer a 7^+ or 6^+ assignment for the 9.25-min ^{96}Rh isomer, either of which would give a more consistent explanation for the observed β decay and γ decay patterns. We show later that a 7^+ or 6^+ assignment is also preferred by the shell model calculations.

There are similar uncertainties concerning the J^π value for the 1.55-min ^{96}Rh isomer. Gujrathi, Weiffenbach, and Lee[5] suggested a 2^+ assignment on the basis of strong β feeding to the 832 keV, 2^+ level and absence of β feeding to the $0+$ ground state and the 1518 keV, 4^+ state. The 2^+ - 5^+ combination for the 1.55-min - 9.25-min isomers was also consistent with an isomeric transition between them of energy 52 keV whose estimated K-conversion coefficient and γ-ray half-life were suggestive of an $M3$ transition. The absence of β feeding is, of course, a weak argument. Our shell model calculations (see below) indicate a preference for a 3^+ assignment for the 1.55-min ^{96}Rh isomer.

VI. SHELL MODEL CALCULATIONS

We have performed large bases shell model calculations of the positive parity states of ^{96}Ru and ^{96}Rh wherein energy levels, wave functions, and log *ft* values for Gamow-Teller (GT) β decays from the lowest two states in ^{96}Rh are calculated. The shell model space assumes an inert ^{88}Sr core. Active protons occupy the $g_{9/2}$ and $p_{1/2}$ orbits, while neutrons occupy the $d_{5/2}$, $s_{1/2}$, $d_{3/2}$, and $g_{7/2}$ single-particle orbits. Previously,[12] shell model calculations of nuclei in this mass region have been performed where only the $d_{5/2}$ and $s_{1/2}$ neutron orbits were active. We include the extra two neutron orbits to obtain a better estimate of the density of levels at relatively low energies and so as to include the possibility of β decay. (The closed $g_{9/2}$ neutron shell precludes the $\pi g_{9/2} \rightarrow \nu g_{9/2}$ decay.)

The single-particle energies were derived from observed single-particle energies in ^{89}Y and ^{89}Sr, with some modification to fit levels in lighter nuclei in this mass region in the same shell model space. The two-body interaction is based on the interaction derived by Bhatt and Ball[12] for the model where only the $d_{5/2}$ and $s_{1/2}$ neutron orbits were included. The modified surface-delta interaction was used to determine those matrix elements not needed in the original Bhatt-Ball space. Some empirical adjustments of the interaction were made to improve the fits for the nuclei near the ^{88}Sr core; however, no adjustments were made to improve the fit in the $A=96$ nuclei treated here.

The calculated spectra of positive parity states in ^{96}Ru are compared with the observed spectra in Figs. 6, 7, and 8. Many of the observed features of the spectra are reproduced in the calculations. The yrast levels and the known levels with $J \geqslant 5$ are reproduced in the calculations to within $\approx$ 200 keV. There is a preponderance of 2^+ states in both theory and experiment below $\approx$ 2.5 MeV. The observed general trend of the level density up to $\approx$ 3.0 MeV is reproduced by theory. For each observed state to which some spin assignment is made, there is a reasonably placed analog in the calculated spectrum.

The energy levels of ^{96}Rh have been calculated in the same model space with the same one-body and two-body interaction matrix elements. The calculated excitation energies of states in ^{96}Rh are listed in Table III. The calculated spectrum shows a ground state doublet with J^π = 3^+ and J^π = 7^+. This feature was not altered by minor changes in the interaction matrix elements. One cannot rule out the possibility that the 6^+ state could be lowered, but it is very unlikely that a 5^+ state could be forced to be the ground state. There are no features of the experimental β decay data that are seriously inconsistent with the calculation of a 3^+ - 7^+ doublet near the ground state.

The existing experimental information on ^{96}Rh levels is quite limited. Aras, Gallagher, and Walters[13] have proposed that the β decay of ^{96}Pd proceeds strongly to a 1^+ level lying only 125 keV above the 1.55-min isomer. Kurcewicz *et al.*[14] have proposed a more detailed and different decay scheme with 1^+ assignments to two levels located 888 and 1224 keV above the 1.55-min isomer. Our shell model calculations (see Table III) favor the latter scheme because the lowest 1^+ state occurs at 861 keV, and additional 1^+ states are predicted at 989 and 1150 keV.

We have calculated the log *ft* values for the decay of the 7^+ (high-J) and 3^+ (low-J) states in ^{96}Rh to the states in ^{96}Ru. Such calculations are

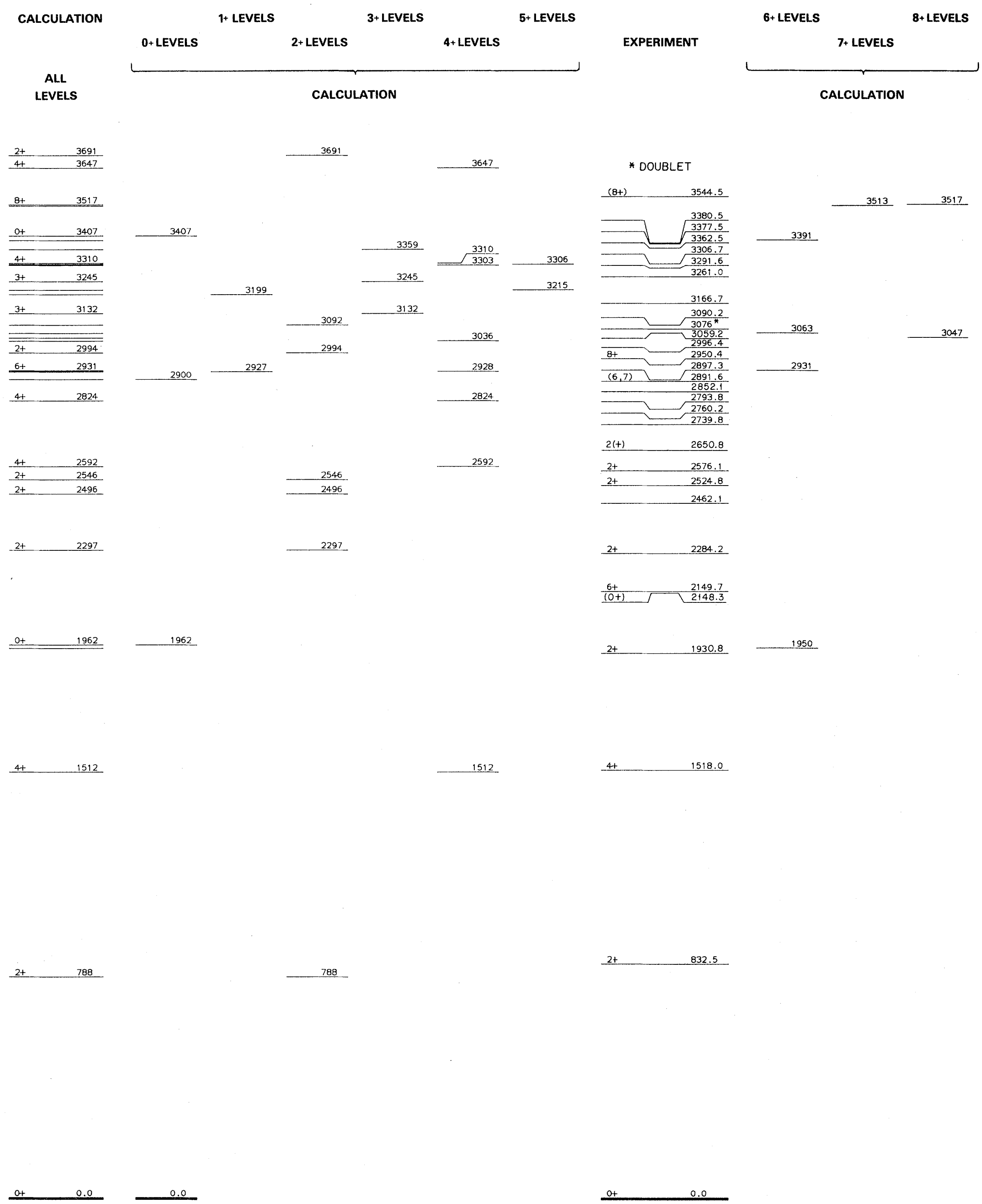

FIG. 7. Comparison between calculated (positive parity only) and experimentally known energy levels in ^{96}Ru below 3700 keV. Known negative parity levels have been excluded.

of very limited value here. In the model space we use, the only possible GT matrix element involves a $\pi g_{9/2} \rightarrow \nu g_{7/2}$ transition. The $\nu g_{7/2}$ orbit is the highest lying single-particle neutron level in the model space, and the structure calculations are not particularly sensitive to this orbit. Thus, the $g_{7/2}$ admixtures are highly uncertain, and any conclusions drawn from results of the log ft

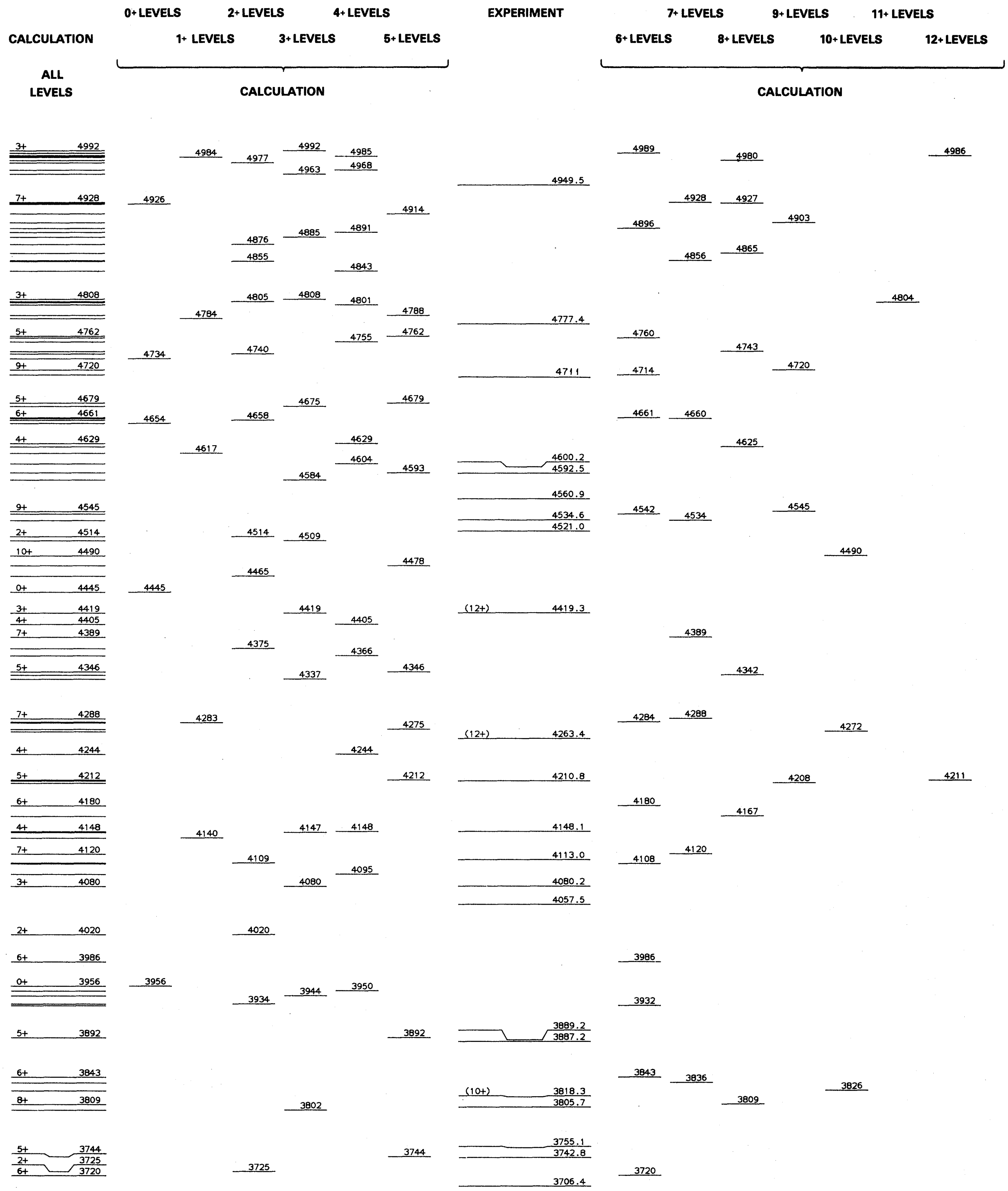

FIG. 8. Comparison between calculated (positive parity only) and experimentally known energy levels in ^{96}Ru above 3700 keV and below 5000 keV. Known negative parity levels have been excluded.

values are tenuous at best. The calculated log *ft* for the $3^+ \rightarrow 2^+$ transition is 7.1, whereas the measured value is 6.2, a rather significant disagreement. The log *ft* value for the $3^+ \rightarrow 4^+$ transition is calculated to be 8.0 and measured to be >6.5. Thus, the calculation is consistent with the

TABLE II. Experimentally known energy levels in ^{96}Ru.

Level energy[a] (keV)	$J^{\pi b}$	Level energy (keV)	$J^{\pi b}$
0.0	0^+	3362.52 *24*	
832.55 *7*	2^+	3377.53 *16*	
1518.00 *9*	4^+	3380.47 *17*	
1930.84 *14*	2^+	3544.49 *21*	(8^+)
2148.3[c] *1*	(0^+)	3706.40 *24*	
2149.75 *14*	6^+	3742.84 *20*	
2284.2 *4*	2^+	3755.13 *25*	
2462.07 *12*		3805.67 *24*	
2524.81 *13*	2^+	3818.3 *7*	(10^+)
2576.07 *19*	2^+	3887.22 *17*	
2588.36 *16*	$5^{(-)}$	3889.2 *7*	
2650.8[c] *3*	$2^{(+)}$	3951.1 *4*	(9^-)
2739.81 *19*		4057.50 *24*	
2760.17 *12*		4080.23 *20*	
2793.84 *15*		4112.97 *18*	
2852.1[c] *5*		4148.1 *6*	
2891.64 *16*	(6,7)	4210.8 *4*	
2897.3 *4*		4263.4 *8*	(12^+)
2950.40 *16*	8^+	4419.3 *8*	(12^+)
2996.43 *20*		4520.98 *18*	
3059.2[c] *4*		4534.6 *7*	
3074.8[c] *3*		4560.92 *24*	
3076.54 *22*		4592.5 *6*	
3090.16 *21*		4600.2 *10*	
3166.69 *17*		4711[d] *1*	
3260.98 *20*		4777.44 *18*	
3291.3 *4*	$7^{(-)}$	4949.54 *23*	
3291.60 *24*		5541.5 *3*	
3306.72 *18*			

[a]All entries are based on the present work except where noted. In our notation 832.55 *7* is 832.55 ± 0.07 keV, etc.
[b]From Refs. 6 and 8.
[c]Reference 8.
[d]Reference 6.

TABLE III . Calculated energy levels in ^{96}Rh.

Level energy (keV)	J^π	Level energy (keV)	J^π
0	3^+	1150	1^+
21	7^+	1169	6^+
79	6^+	1207	2^+
172	4^+	1213	5^+
206	5^+	1234	6^+
242	2^+	1321	4^+
385	7^+	1356	5^+
405	6^+	1374	3^+
450	4^+	1380	2^+
494	3^+	1388	0^+
518	2^+	1412	5^+
553	5^+	1415	3^+
556	4^+	1423	5^+
672	3^+	1462	1^+
685	5^+	1487	8^+
716	8^+	1498	9^+
741	2^+	1505	8^+
790	3^+	1525	1^+
861	1^+	1544	2^+
863	3^+	1551	4^+
880	4^+	1556	2^+
989	1^+	1594	4^+
1034	0^+	1619	5^+
1036	6^+	1640	7^+
1124	4^+	1643	6^+

observation of a relatively weak population of the 4^+ state in ^{96}Ru by β decay of the low-J state. The first five observed 2^+ states in ^{96}Ru are populated by decay of the ^{96}Rh low-J state with log *ft* values of 6.2, 5.9, 6.2, 5.4, and 6.0, respectively. In the calculation, the analogous numbers for the lowest six $J^\pi = 2^+$ states are 7.1, 6.5, 7.1, 10.7, 5.7, and 5.2, respectively. Thus, there is a rather surprising consistency in the relative strengths to the 2^+ states if it is assumed that the calculated 2^+ state with log ft = 10.7 has no experimental analog. A comparison of the decays of the 7^+ (high-J) state is not illuminating.

In summary, the shell model calculations are entirely consistent with experiment insofar as energy levels are concerned for states below ≈ 3.0 MeV. Above this energy, there are many more states calculated than are observed. A comparison of theory and experiment for the possible (12^+) states suggests that the second (12^+) state is probably not correct. Because of the limited shell model space, the calculations of log *ft* values for β decay do not allow any strong conclusions. The shifting of the strong β decay strength to the higher states is consistent with the $g_{7/2}$ orbit being a more important component in the higher levels.

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