Decays of ^{110}Rh and ^{112}Rh to the near neutron midshell isotopes ^{110}Pd and ^{112}Pd

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The decays ^{110}Rh and ^{112}Rh have been investigated using on-line mass separation with the ion-guide technique. Extended decay schemes have been constructed for both the low- and high-spin states in ^{112}Rh. Mixing ratios for the collective transitions from the 2_2^+ and 3_1^+ states in ^{112}Pd have been measured by γ-γ angular correlation. The presence of two sets of 0^+ and 2^+ states in the 1.1–1.4 MeV range suggests the existence of an intruder band, the energy of which is the lowest in ^{110}Pd with two neutrons fewer than the midshell. The quasiparticle levels at 2195 and 2755 keV are assigned $I=4$ and $I=5$, respectively. The corresponding levels in ^{110}Pd are a new level at 2261 keV and the 2805 keV level. Systematics of logft values and excitation energies of these quasiparticle levels is remarkably smooth. The strong β feeding to the $I=5$ quasiparticle state can be regarded as similar to the main branch in the decay of odd Rh isotopes, while a neutron is a spectator. [S0556-2813(99)05707-6]

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I. INTRODUCTION

Neutron-rich Pd isotopes are situated midway between the closed proton shell Sn isotopes and the very strongly deformed region with $\beta=0.35-0.40$ for $Z\simeq 40$. The transition proceeds over Cd, Pd, and Ru isotopes. Even-even Cd isotopes retain a vibrational character while Ru isotopes show sizable triaxial deformations of about $\beta=0.2-0.3$ and $\gamma\simeq 21°$ [1–9]. Thus, Pd isotopes are expected to exhibit transitional features which can be accounted for using appropriate mixing of the properties of their neighbors. Recently, Pan and Draayer described Ru and Pd isotopes as a test case for the transition from the SO(6) to U(5) symmetries of the interacting-boson model [10]. Kim *et al.* also performed systematic calculations for even-even Pd isotopes [11]. They used the proton-neutron interacting-boson model (IBM-II) to describe the systematics from ^{102}Pd up to the presently last known ^{116}Pd and they even presented predictions for the heavier ones. They observed a transition from the vibrational U(5) limit to the γ-soft O(6) limit with increasing neutron number. Thus, ground-state and γ bands for neutron-rich even-even Pd nuclei [12–15] are rather well reproduced.

However, these successful calculations do not account for all observed low-lying states. Coulomb excitation has been performed for $^{106-110}$Pd and revealed the existence of some other band structures [16,17]. As a matter of fact, low-lying intruder configurations have been known in even-even Cd and Sn isotopes [18–21]. Similarily in the odd-proton neighbors of Cd, $K=1/2$ bands have been found with the minima of excitation energy at the midshell for Ag but at $N=64$, i.e., a pair fewer than the midshell, for Rh [22,23]. Thus, it is necessary to clarify the nature of the experimental levels in even-even Pd isotopes near the neutron midshell.

The present work mainly deals with levels in ^{112}Pd at the midshell where intruder configurations might be low lying and easier to identify than in its neighbors. So far, levels in the neutron-rich ^{112}Pd have been observed in β decay of on-line mass-separated rhodium by Äystö *et al.* [13] and $(t,p\gamma)$ studies [24–26]. Since ^{112}Rh has two β-decaying states, one with $I^\pi=1^+$ and the other with $I\geqslant 4$, its decay is very well suited for the observation of nonyrast levels, the ones belonging to the presumed intruder structures in ^{112}Pd. Thus, this work is motivated by the new experimental possibilities offered by increased production yields higher than in Ref. [13] by two orders of magnitude and by the avaibility of larger-volume detectors. These improvements allow information about spins to be obtained for the first time at the IGISOL facility using the angular correlation method. A preliminary report of this work has been given in Ref. [27].

In addition, it became necessary for reasons of irregularities in the quasiparticle level systematics to make a new investigation of β decay of the high-spin state of ^{110}Rh. The relevant γ-γ coincidence data have been obtained from an experiment dedicated to the study of short-lived $A=110$ activities which will be reported elsewhere [28]. We will present here the information about the new transitions in ^{110}Pd.

II. EXPERIMENTAL SETUP AND ANALYSIS

The neutron-rich nucleus ^{112}Rh was produced by 25 MeV proton-induced fission of natural uranium and subsequently on-line mass separated from the other fission products, using the ion-guide technique. The IGISOL facility at Jyväskylä has been described in Refs. [29,30] and more specifically for fission experiments in Ref. [31]. The detection setup and measurements methods were similar to those used in a series of previously reported experiments; see, for instance, Refs. [32,33]. In this particular case, the mass-separated beam was not pulsed. A collection cycle was defined by an implantation period of 30 s onto a tape, after which the tape was moved and a new cycle begun. Two 0.9 mm thick plastic scintillator detectors, one on each side of the source, were used for the detection of β particles. For the detection of γ rays four Ge detectors of the EUROGAM phase-1 type were positioned in a plane around the collection spot at a distance of 10 cm and at angles of 80°, 110°, and 155° with respect to each other. The data included γ singles versus time with respect to the beginning of the cycle, and β-γ-t and γ-γ

coincidences. The events were recorded with the VENLA data-acquisition multiparameter system [34].

A γ-γ energy matrix was formed from the energy pairs regardless of the detectors which fired using a gain-matching algorithm from the EUROGAM software [35]. Moreover, for each of the six Ge-detector pairs, a separate energy-energy matrix was formed, thus allowing the measurement of angular correlations. Coincidence counts for a given γ-γ pair were corrected for their two-dimensional background with the procedure of Ref. [36]. For the energy and relative efficiency calibrations, data from the decay of ^{96}Y to ^{96}Zr [37] were used. This decay was observable in the $A=112$ mass-separated data due to the formation of yttrium oxide as a singly charged ion. In spite of the large source-to-detector distance, coincidence summing effects played a role for these transitions which depopulate a level in competition with a much stronger one. A first-order correction to transition intensities was performed whenever statistically significant. Detector efficiencies needed for this purpose, and for the calculation of fission yields, were calculated using the probability for coincidence summing of transitions belonging to high-multiplicity cascades depopulating the 4390 keV 8^+ state in ^{96}Zr and the 2755 keV level in ^{112}Pd. For the analysis of angular correlations, very accurate efficiencies of three detectors relative to the fourth one were needed. They were obtained from a fit such as to reproduce the well-known anisotropies of coincidence pairs belonging to cascades in ^{96}Zr and to the $6^+\rightarrow4^+\rightarrow2^+\rightarrow0^+$ cascade in ^{112}Pd. Subsequently, data for the six angles were fitted by the Legendre polynomials, the A_{kk} coefficients were corrected for solid angle attenuation factors [38], and a standard analysis was performed to extract spins and mixing ratios [39].

The intensities of γ rays versus cycle time were used for the determination of the parentage of the transitions, since two states are known for ^{112}Rh [13]. In this way, the feedings to levels in ^{112}Pd in the respective decays can be calculated. It is, however, not known which of the 3.8 s ($I^\pi=1^+$) or 6.8 s ($I\geqslant4$) levels is the ground state.

In another run, β-γ delayed coincidences were recorded using one of the plastic scintillators and a single coaxial Ge detector in close geometry. The resolution was 25 ns for the time peak of the β-γ (349 keV) coincidences. Level lifetimes were analyzed by the centroid-shift method. The energy dependence of the prompt curve was determined from time spectra of transitions in the $A=100$ mass chain which is rich in suitable references [40]. These spectra were recorded before and after the $A=112$ measurement in order to correct for electronics instabilities.

III. RESULTS

A. Production yields

Yields of mass-separated $A=112$ isobars are shown in Table I. They have been determined using the last part of the acquisition cycle during which the activities can be regarded as constant. In case of the decay of the 1^+ state of ^{112}Rh, the ground-state β feeding is known with rather poor accuracy [13]. This renders the determination of this yield uncertain.

TABLE I. Independent yields for $A=112$ isobars in units of 10^3 ions/s. The total yield for rhodium is extrapolated from the Tc and Ru independent yields, using a Gaussian Z dependence with maximum at $Z_{max}=45.2$ and width parameter $\sigma_Z=0.65$. The yield for the Rh 1^+ level is the difference of the calculated total yield and the yield measured for the high-spin level.

Isotope	Yield (10^3/s)
^{112}Tc	0.18 (2) [a]
^{112}Ru	3.3 (3) [a]
^{112}Rh (total)	17.3 (7) [b]
^{112}Rh (high j)	9.6 (9) [a]
^{112}Rh (1^+)	7.7 (11) [b]
^{96}YO [c]	2.0 (3) [a]

[a]Experimental value.

[b]Calculated value not including uncertainties on the model parameters Z_{max} and σ_Z which are regarded to influence the deduced total possibly by 20%.

[c]The intensity of the yttrium-oxide beam varies depending on the level of impurities in the He gas used to stop the fission products.

However, a measurement of the ground-state branch by the filiation method was not possible due to the 21 h half-life of ^{112}Pd. Thus, the total Rh yield was estimated using the Gaussian dependence of yields versus Z [41,42] and the yield of the 1^+ Rh state was obtained by subtracting the experimental yield for the high-spin state from the estimated total one. In this calculation, the position of maximum isobaric yield Z_{max} and the width parameter of the Gaussian σ_Z were interpolated from local systematics and kept fixed while a scale parameter was adjusted to reproduce the experimental ^{112}Tc and ^{112}Ru independent yields.

B. Half-lives of ^{112}Rh

The analysis of the growth of activity during collection yields information about the decay half-lives of the ^{112}Rh states. Transitions with intensities higher than 5% of $I_\gamma(560)$ were used to determine the shape of the growth of the activity from the high-spin state decay. However, only the rather weak 686, 777, 1054, and 1074 keV transitions could be regarded as pure for the analysis of the 1^+ Rh decay. For each group we have added the growth curves and subsequently normalized them to unity at the end of the collection cycle where the activity comes to saturation. These representations help to visualize the difference of the half-lives of the ^{112}Rh activities; see Fig. 1. The curves have been fitted with a single lifetime. An extra parameter was added to account for the fraction of the $A=112$ beam not deposited on the collection tape. It was determined to be about 5% from the fit of the high-spin decay. For the analysis of the 1^+ Rh decay of weak statistics, the number of parameters need to be restricted. The first two points in Fig. 1 were excluded from the fit to allow the Tc ($t_{1/2}=0.3$ s) and Ru ($t_{1/2}=1.8$ s) precursor activities to saturate and the fraction of activity not deposited on tape was kept constant. These fits gave $t_{1/2}=6.73(15)$ s for the decay of the high-spin ^{112}Rh state and $t_{1/2}=3.45(37)$ s for the decay of the 1^+ state. These values

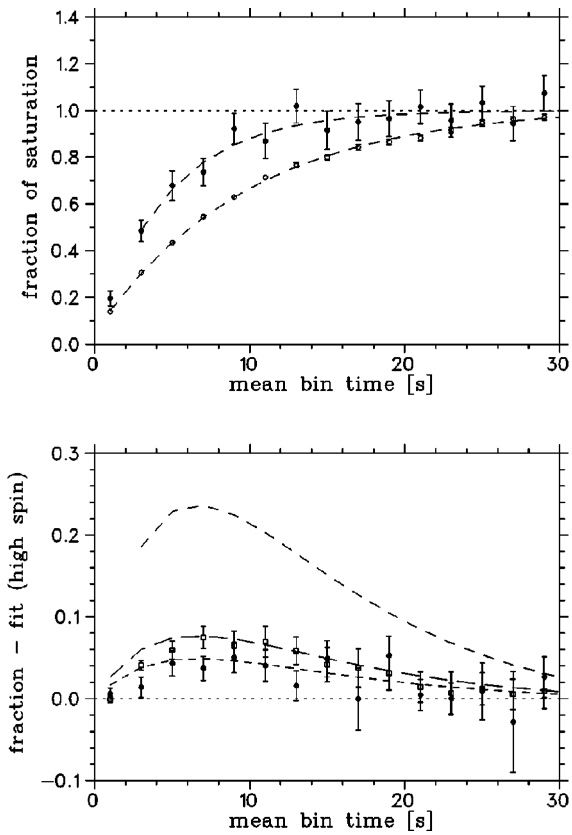

FIG. 1. Growth of the activities for both ^{112}Rh decays. The mass-separated beam is switched off only during the moving of the collection tape. The integration bins are of 2 s and the curves are scaled to unity at saturation. Upper part: the points are sums over γ rays associated with a single ^{112}Rh activity. The decays of the high-spin and 1^+ states are represented by open and solid circles, respectively. Their fits (dashed lines) lead to half-lives in agreement with former results [13]. Lower part: points and fits are deviations with respect to the growth curve for the high-spin state. Analysis of transitions from the 2_1^+ and 2_2^+ states (open and solid circles, respectively) yields the magnitude of the respective feedings of these states in the decay of each Rh state and, after assuming a value for the ground-state branch, of their β feedings in the decay of the 1^+ Rh state. The highest dashed line represents the fitted growth curve for the 1^+ state, taken from the upper part of the figure.

are in good agreement with those reported in Ref. [13] of 6.8(2) s and 3.8(6) s, respectively.

C. Decay schemes

Transitions assigned to β decay of the 1^+ state of ^{112}Rh are listed in Table II. The ^{112}Pd levels fed in this decay are listed in Table III and the decay scheme is shown in Fig. 2. For the decay of the high-spin state of ^{112}Rh transitions are listed in Table IV and ^{112}Pd levels in Table V. The decay scheme is shown in two parts as Figs. 3 and 4. We will present the most important updates of the decay schemes, then the results of angular correlations.

1. Assignment of parent activity

Since ^{112}Rh has two β-decaying states with half-lives close to each other, assignment to the one or other activity by observing the difference in half-life is only possible for the strongest lines. Fortunately, the difference of spins of the ^{112}Rh states is large. It can be assumed that the 1^+ decay directly populates only states with $I \leqslant 2$. This is supported by the intensity balance for the 1096 keV $I^\pi = 3^+$ state obtained without any direct β feeding. In that way, a clear separation is possible for most levels. Among the intensively populated levels only the 2_1^+ and 2_2^+ levels are fed in both β decays. Two methods have been used to deduce their respective feedings. The first one was to calculate the contribution from the high-spin decay by balancing the flow of γ-ray intensity across the 2^+ levels and obtain the contribution of the 1^+ decay by difference from the total intensity. The second method was to decompose the experimental growth curves of the 349 and 388 keV lines, using the normalized shapes obtained in the previous section as corresponding to each half-life component; see Fig. 1.

The 1888 keV level is fed in the high-spin decay and it has a small decay branch to the 2^+ level at 1423 keV. This represents another link between both decays schemes.

2. Levels in ^{112}Pd

The decay schemes for both ^{112}Rh states are based on the γ-γ coincidences and γ-singles data. Assignments of levels which can be made on the basis of decay branchings and in some cases of angular correlation data confirm the previously established ground-state band and the $K=2$ [14,15] band. Both bands are observed here up to their 6^+ members. In addition, the 2195 and 2755 keV levels are, respectively, assigned $I=4$ and $I=5$ on the basis of the angular correlation data. The decay schemes are considerably improved with respect to the previous decay study [13], owing to high statistics, about 15 times larger than in that measurement. The general features of the decay schemes are confirmed. It might be interesting to note that the branching ratio of the 737 keV crossover transition from the second 2^+ state becomes somewhat lower than in Refs. [13,26]. Moreover, there is no convincing evidence for a 890 (0^+)–1126 (2^+)–1715 keV (4^+) band as assumed by Meyer *et al.* [26]. Two closely lying sets of 0^+, 2^+ states are observed instead.

The 890 keV level tentatively proposed by Äystö *et al.* [13] and interpreted by Meyer *et al.* [26] as a 0^+ bandhead is not confirmed. In agreement with their reports a weak line at 541.8 keV is seen in the singles spectra. However, the line in the 349 keV gate is at 539.7 keV and it is also seen in the 534 keV gate, which places it between the 1423 and 883 keV levels. The 541.8 keV line could not be identified. Spectra gated by the 349 and 534 keV transitions have been shown in Ref. [27]. For reasons of systematics a 0^+ level was expected in this energy region. A last possibility is that the 0^+ and 4^+ levels are degenerate at 883 keV. Then the 2^+ state built on such a 0^+ level would be very difficult to identify due to numerous transitions and intense background in the projection gated by the 534 keV $(4^+ \rightarrow 2^+)$ transition. Nevertheless, we favor a new interpretation of level systematics that does not imply a level at this energy [27].

The 1140 keV level is directly fed in the β decay of the 1^+ state of ^{112}Rh. The ground-state (g.s.) transition reported

TABLE II. List of γ rays from 1^+ Rh decay. One hundred γ-intensity units correspond to a β feeding of 30^{+25}_{-10}%. The large errors are due to the uncertainty on the value of the ground-state feeding; see text. The confidence of a coincidence relationship for transitions between brackets is less than or equal to two standard deviations (σ). The intensities of the 360, 534, and 748 keV γ rays have been scaled such as no β feeding to the 883 keV 4^+ and 1096 keV 3^+ levels is needed.

Energy [keV]		γ intensity		From	To	Coincident lines
297.1	(4)	0.5	(1)	1423	1126	349, 777
326.6	(3)	1.0	(2)	1423	1096	349, 360, 388, (748)
348.7	(2)	100	(15)	349	0	(297), 327, (539), 686, 777, 791, 1054, 1074, 1266, (2083), 2340, (2399), 2665 [a]
359.6	(2)	0.6	(2)	1096	737	327 [a]
388.0	(2)	23.3	(78)	737	349	686, 1760, 1804, 1867, 1951 [a]
402.8	(4)	1.3	(3)	1140	737	(388), (1607)
519.8	(5)	0.4	(1)	1403	883	(534)
534.3	(2)	1.3	(2)	883	349	520, 539 [a]
539.7	(3)	0.9	(2)	1423	883	349, 534
665.8	(5)	1.3	(5)	1403	737	(1094), (1285) [b]
686.0	(2)	3.6	(4)	1423	737	349, 388, (465), [c] 737, 1074, 1266
736.7	(2)	7.3	(25)	737	0	686, 1760, (1804), 1867 [a]
747.6	(2)	0.5	(2)	1096	349	(327), 349 [a]
776.9	(2)	9.9	(10)	1126	349	297, 349
791.1	(2)	4.2	(6)	1140	349	349, 1607
1054.0	(2)	4.3	(6)	1403	349	349, 1094, (1285), 1345, (1611), (1823)
1074.0	(2)	2.0	(4)	1423	349	349, (465), [c] (1074), (1266)
1074.3	(3)	1.3	(3)	2497	1423	349, 388, 686, (1074), (1423)
1094.2	(4)	1.2	(4)	2497	1403	1054, (1403)
1265.5	(4)	1.0	(3)	2688	1423	(349), (388), 686, (1074), (1423)
1285.2	(5)	0.9	(3)	2688	1403	349, (1054), (1403)
1344.8	(3)	1.8	(4)	2747	1403	349, 1054, 1403
1398.8	(4)	1.6	(4)	1747	349 [d]	(349)
1402.6	(3)	2.9	(4)	1403	0	(1094), (1285), (1345), (1611), (1823)
1413.5	(5)	1.1	(3)	2836	1423	349, (1423)
1422.6	(3)	2.9	(6)	1423	0	(465), [c] (1074), (1266), (1414)
1425.7	(4)	1.9	(5)	1775	349 [d]	(349)
1607.3	(4)	1.4	(3)	2747	1140	349, 791
1611.2	(5)	1.3	(3)	3014	1403	349, (1054), (1403)
1758.7	(3)	4.2	(9)	2107	349	349
1760.1	(4)	2.4	(4)	2497	737	349, 388, (737)
1803.8	(4)	0.9	(2)	2541	737	349, 388, (737)
1823.1	(8)	0.9	(5)	3226	1403	(1054), (1403)
1867.2	(4)	3.9	(6)	2604	737	349, 388, 737
1951.3	(4)	1.3	(3)	2688	737	349, 388, (737)
2008.1	(6)	0.7	(3)	2357	349 [d]	(349) [e]
2083.4	(7)	0.9	(3)	2433	349	(349)
2106.6	(5)	0.8	(2)	2107	0	[f]
2117.4	(5)	0.7	(3)	2466	349 [d]	(349)
2147.7	(7)	0.6	(3)	2497	349	(349)
2161.1	(5)	1.2	(4)	2510	349	(349)
2316.8	(4)	1.6	(4)	2665	349	349
2339.7	(4)	3.2	(5)	2688	349	349

TABLE II. (*Continued*).

Energy [keV]		γ intensity		From	To	Coincident lines
2398.7	(5)	7.2	(9)	2747	349	349
2421.3	(6)	1.3	(4)	2770	349	349
2432.7	(6)	0.9	(3)	2433	0	f
2447.1	(6)	0.9	(4)	2796	349 [d]	(349) [g]
2488.2	(7)	0.7	(3)	2836	349	(349)
2511.2	(7)	0.3	(1)	2510	0	f
2628.6	(5)	1.4	(4)	2977	349 [d]	(349)
2664.7	(4)	1.1	(8)	2665	0	e,h
2665.0	(7)	2.7	(5)	3014	349	349
2746.6	(5)	1.5	(3)	2747	0	f
2876.6	(7)	1.6	(5)	3226	349	349
2989.2	(9)	0.5	(2)	3338	349 [d]	(349)

[a]Coincidences due to the decay of high-spin ^{112}Rh are not listed here.

[b]Coincidences with 349 and 388 keV lines are masked by the 663 and 668 keV transitions from high-spin decay. A tentative coincidence 665.8–954.5 keV could give further support to the 2357 keV level.

[c]The 465 keV γ ray depopulates the 1888 keV level fed in the decay of high-spin ^{112}Rh.

[d]Level based on a single weak coincidence. Level and transition are not shown in Fig. 2 but have been taken into account in the calculation of β feedings.

[e]A tentative coincidence with the 400 keV γ ray could place this transition or another of close energy in the high-spin decay scheme.

[f]This weak transition seen only in singles cannot be assigned to a particular nucleus but it is assumed as a ground-state transition owing to energy fitting.

[g]Tentative coincidences with 534 and 668 keV γ rays could indicate another 2447 keV transition in high-spin decay.

[h]Tentative transition since the coincidence intensity may not account for all the intensity deduced from the singles.

by Meyer *et al.* [26] with $I_\gamma(1140)/I_\gamma(791)=0.08(4)$ is not confirmed. It could have been due to coincidence summing; see Fig. 5. In fact, this state is a good candidate for the expected low-lying 0^+ state. First, although the $A_{44}(791-349)$ coefficient is not accurate enough to draw any conclusion, the A_{22} coefficient of 0.34(9) does agree with the theoretical value of 0.357 for a 0-2-0 cascade. Second, the new transition to the 2_2^+ level creates a branching pattern in analogy with the one of another low-lying 0^+ state in ^{110}Pd.

The former 1369 keV level [13] is replaced by a level at 2269 keV due to intensity balance forcing the reversal of the order of the 485.4 and 1386.4 keV transitions, in agreement with Ref. [26].

The 1403 keV new level is based on various coincidences. The ground-state transition is supported by coincidence relationships. This strongly suggests $I^\pi=2^+$ for this level.

The 1423 keV level is similar to the 1403 keV level, with additional transitions to the 1126 keV 0^+ state and to the 883 keV 4^+ state, which firmly determine $I^\pi=2^+$.

The 1715 keV level was observed in β-decay and reaction studies [13,26], but not in prompt fission [15]. Population from the $I=5$ level at 2755 keV and decay to 2^+, 3^+, and 4^+ levels only allows $I=3$ or 4.

The new level at 1888 keV has been discussed as a tentative 4^+ state, member of the band on the 1126 keV level [27]. This interpretation is based on its decay by the 465 keV transition to the 2^+ state at 1423 keV, but not to the lowest-lying 2^+ levels.

The new 1952 keV level is supported by the 1215 keV transition to the 2^+ state at 737 keV, weaker branchings to 3^+ and 4^+ states, and feeding from the $I=5$ level at 2755 keV, resulting in $I=3$ or 4.

The 2195 keV level has $I=4$ from the angular correlation data. This is in agreement with its decay branches to 2^+, 3^+, 4^+ states and feeding from the $I=5$ state at 2755 keV. We note that the transitions to the 2^+ states are weak and their intensities are very sensitive to corrections for coincidence summing.

The 2355 keV level can have $I=4$ or 5 according to angular correlation data. A tentative coincidence in the 400 keV gate could indicate a transition to the first 2^+ state and would definitely assign $I=4$. Unfortunately, the postulated line is masked in the 349 keV gate by the 2008 keV transition.

The new 2395 keV level is introduced by the 360–1299 keV cascade fitting between the 2755 and 1096 keV levels and the 1512 keV transition to the 4^+ state. The existence of an extra 360 keV transition is supported by the 748-360 and 360-360 coincidence counts which are above the random level and by the double intensity of the 360 peak in the gates on the other members of this cascade.

The 2755 keV level is assigned $I=5$ by the angular correlation. It is remarkable by the numerous branchings to lev-

TABLE III. Levels in ^{112}Pd fed in the decay of 1^+ ^{112}Rh. Errors in β feedings include contributions from γ-intensity balances only. The estimated limits of 36% and 76% for the ground-state β feeding (see text) have not been propagated on the values listed in the table. log*ft* values are calculated with Q_β=7.0 MeV [43] and $T_{1/2}$=3.6 s.

Energy [keV]		β feeding [%]		logft	I^π
0.0		65.0		5.7	0^+ [a]
348.7	(2)	6.3	(42)	6.6	2^+ [a]
736.7	(2)	4.4	(22)	6.6	2^+ [b]
883.0	(3)	[c]			4^+ [a]
1096.3	(2)	[c]			3^+ [b]
1125.6	(3)	2.8	(5)	6.7	0^+ [d]
1139.7	(3)	1.2	(3)	7.1	(0^+) [e]
1402.7	(2)	0.8	(4)	7.2	2^+ [e]
1422.7	(2)	2.1	(4)	6.8	2^+ [d]
1747.5	(5)	0.5	(1)	7.3	[f]
1774.4	(5)	0.6	(2)	7.2	[f]
2107.1	(4)	1.5	(4)	6.7	(1, 2) [g]
2356.8	(6)	0.2	(1)	7.4	[f]
2432.5	(5)	0.5	(1)	7.0	(1, 2) [g]
2466.1	(6)	0.2	(1)	7.4	[f]
2496.9	(2)	1.6	(3)	6.4	
2510.3	(7)	0.5	(1)	7.0	(1, 2) [g]
2540.5	(5)	0.3	(1)	7.2	
2603.9	(5)	1.2	(3)	6.6	
2665.1	(4)	0.8	(3)	6.7	(1, 2) [g]
2688.1	(3)	1.9	(4)	6.3	(0^+) [h]
2747.2	(3)	3.5	(6)	6.0	(1, 2) [g]
2770.0	(7)	0.4	(1)	7.0	
2795.8	(7)	0.3	(1)	7.1	[f]
2836.4	(5)	0.5	(1)	6.8	
2977.3	(6)	0.4	(1)	6.8	[f]
3013.8	(5)	1.2	(3)	6.3	
3225.5	(6)	0.7	(2)	6.4	
3337.9	(9)	0.2	(1)	7.1	[f]

[a]Member of the ground-state band [13–15].
[b]Member of the γ band [13,14].
[c]Direct β feeding is assumed neglectible since $\Delta I \leqslant 2$.
[d]Member of the band on the 1126 keV 0^+ level.
[e]Member of the band on the 1140 keV level, reassigned as 0^+.
[f]Level supported by a single weak coincidence relationship is not shown in Fig. 2.
[g]Assignment based on a possible ground-state transition.
[h]Branchings only to the four identified 2^+ states suggest a possible 0^+ state.

els with spins in the range 3–6 and even parity and by the intensity of its direct β feeding.

3. Ground-state β feedings

The spin of the high-spin ^{112}Rh state is definitely $I = (4,5,6)$ due to allowed feeding of the 2755 keV $I=5$ state. Ground-state β feeding can be neglected in this case. In contrast, it is important in the decay of the 1^+ state of ^{112}Rh. Comparing the β intensity gated by the 349 keV transition with the total intensity Äystö *et al.* [13] deduced a value for the β ground-state feeding of 65% with a relative error estimated to 50%. In this work, the yield for the 1^+ state of ^{112}Rh has been estimated using a model, as discussed above. Subsequently, branchings per decay for the 686, 777, 1054, and 1074 keV transitions were determined and the ground-state feeding deduced. The result is $I_\beta(\text{g.s}) = 65(4)\%$, where the error includes all experimental factors but not the contribution due to the uncertainties of the parameters $Z_{\max}$ and σ_Z. The agreement with Ref. [13] is excellent, but it would be misleading to adopt a weighted average since the present value is not purely experimental. We note that a variation of $\pm 20\%$ on the extrapolated total ^{112}Rh yield, we regard as certainly not overestimated, translates into $I_\beta(\text{g.s.}) = 65^{+11}_{-29}\%$.

D. Angular correlations

Anisotropy coefficients are shown in Table VI. Because of limited statistics, A_{44} coefficients have large errors and little relevance except the one for the 777–349 keV correlation, $A_{44}=0.91(21)$, which confirms $I=0$ for the 1126 keV level [24]. For this reason, the table includes only A_{22} coefficients. Mixing ratios of numerous transitions are measured by different functions, depending whether these transitions are located at the bottom or at the top of cascades or are intermediate nonobserved transitions. The fitted coefficients in Table VI take into account these correlations. They have been obtained by a χ^2 fit, varying δ mixing ratios, A_k and B_k parameters, such as to reproduce the set of experimental A_{22} and A_{44} coefficients. Experimental A_{44} coefficients and $B_4(\delta)$ parameters for the upper-lying transitions of 400, 560, and 1204 keV, which have little impact on the final results, were not included in the fit in order to restrict the size of the parameter space. Quantities deduced from this optimization are listed in Table VII.

The statistics is sufficient to determine the spins of the members of the ground-state band up to the 6^+ level at 1551 keV and of the 3^+ level at 1096 keV, thus confirming the previous reports from β decay [13] and prompt fission [14], using as only assumption $I^\pi = 2^+$ for the 349 and 737 keV levels.

For the $2_2^+ \rightarrow 2_1^+$ transition of 388 keV a $E2/M1$ mixing ratio of $\delta(388) = -4.7^{+17}_{-35}$ is derived. It indicates a very dominant $E2$ character of 96% in this transition. An almost pure $E2$ multipolarity is deduced for the 360 keV $3^+ \rightarrow 2_2^+$ transition while there remains a wide range of values, but with large $E2$ components too, for the 748 keV $3^+ \rightarrow 2_1^+$ transition.

The next members of the strongly fed cascade are the 1098 and 560 keV transitions from the 2195 and 2755 keV levels, respectively. The 2755 keV level decays to the 3^+ and 6^+ states by the rather weak 1659 and 1204 keV transitions. Thus, the spin is limited to $I=4$ or 5 and either the 1204 or the 1659 keV transition must be of $\Delta I = 2$ character. The uncertainties in the A_{22} of the 1659-360 keV and 1659-748 keV cascades are too large to draw definite conclusions. Nevertheless, cascades with the 1204 keV transition at the

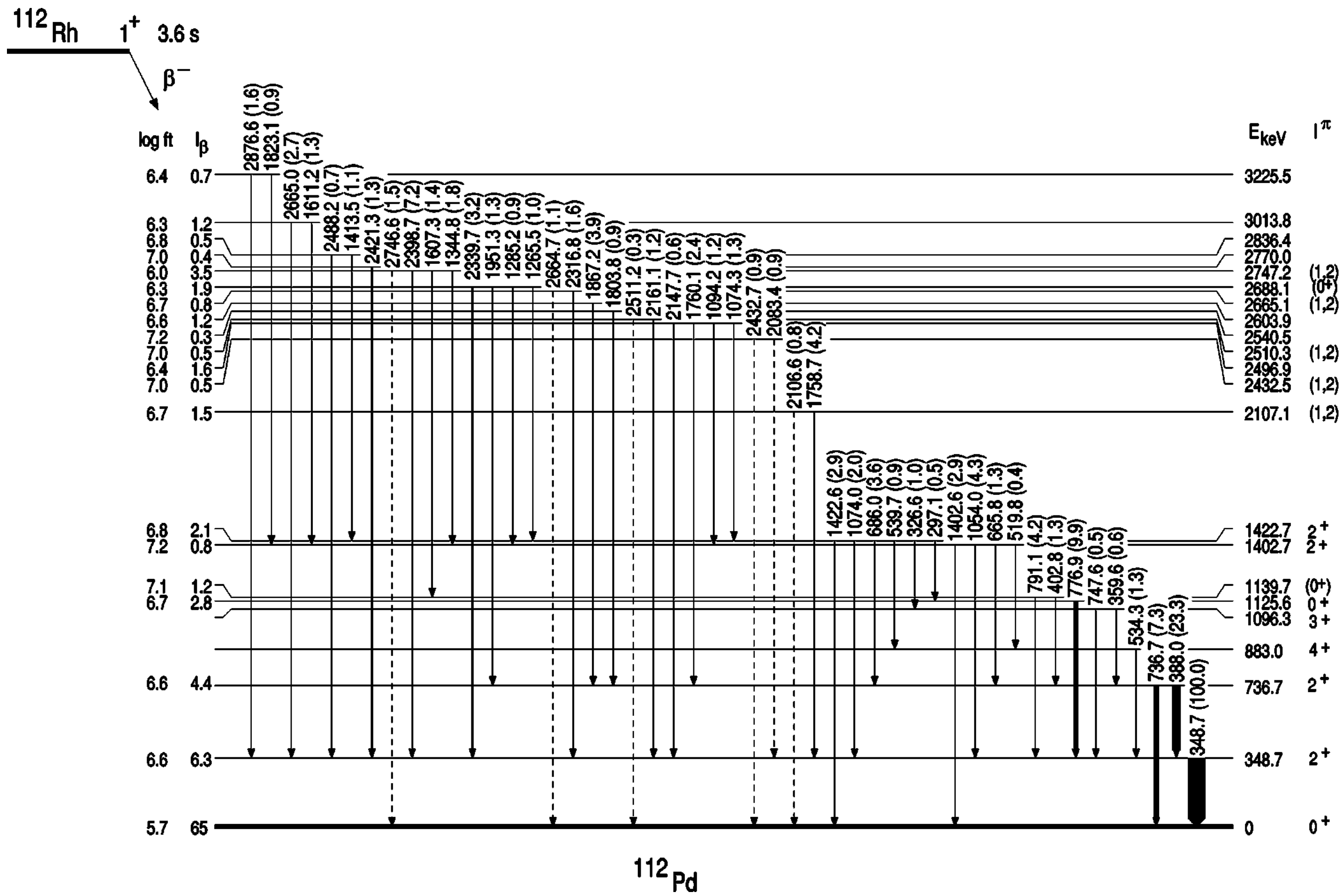

FIG. 2. Decay scheme of the 1^+ state of ^{112}Rh. Dashed transitions are regarded as tentative since they are too weak to be assigned to a particular nucleus. Note also that the ground-state β branching has a large uncertainty. Nevertheless, the levels below 1.5 MeV are well established.

top followed by stretched E2's yield $B_2(1204)=-0.22(10)$ which is near two standard deviations from the value of -0.403 for a $4\rightarrow6$ transition. Thus, it looks most probable that the 2755 keV level is a $I=5$ level. No contradiction is found in the subsequently determined coefficients and the γ-ray branching ratios. In particular, no transition to any established 2^+ state has been found.

The 2195 keV level is fed by the 560 keV transition from the $I=5$ level at 2755 keV and has strong decay branches to the 3^+ and 4^+ states by the 1098 and 1312 keV transitions, respectively. The experimental $A_{22}(1098-748)$ value implies a positive $B_2(1098)$ value of either 0.14(4) or 0.23(10), both inconsistent with a $5\rightarrow3$ transition. Thus, $I(2195)$ is not more than 4. Finally, the $A_{22}(560-534)$ value shows that $B_2(560)$ is not consistent with a $5\rightarrow3$ transition and therefore $I=4$ is assigned to the 2195 keV level.

The 400-1472-534-349 keV transitions form the last cascade with enough intensity to allow some evaluation of anisotropies. First, $A_{22}(400-534)=-0.14(5)$ implies a positive value for $B_2(400)$ which excludes a $5\rightarrow3$ transition. The $B_2(1472)$ value of $-0.45(11)$ is at two standard deviations from the $6\rightarrow4$ value. For the remaining alternatives $I(2355)=4$ and 5 there are sets of $\delta(1472)$ and $B_2(400)$ consistent with the experimental A_{22} coefficients. For $I=5$ all solutions for $\delta(400)$ have large values. Therefore, we favor $I=4$ since the 400 keV transition is not expected to be collective.

E. Level lifetimes

Centroids of the time distributions for β-γ coincidences are shown in Fig. 6. We observe that there is no significant centroid shift between the 349 and 360 keV transitions. The feeding of the former is mainly by decay of the 1^+ state of ^{112}Rh while the feeding of the latter is strongly dominated by a cascade originating from the 2755 keV level. This shows that there is no lifetime in the ns range for the 2755 keV level. However, as a result of the uncertainty in the prompt curve, we can only give an upper half-life limit of 0.5 ns for all transitions. For the 2755 keV level this limit results in a partial half-life of 6.5 ns for the quadrupole transition of 1659 keV to the 3_1^+ state. This value corresponds to a 60 times hindrance with respect to the Weisskopf estimate for a $M2$ transition. Decay-rate systematics for $M2$ transitions [44] in fact show that, far from closed shells, $M2$ transitions are even more hindered than that. This favors the alternative $E2$ multipolarity, which implies even parity for the 2755 keV level. Improving the accuracy of the half-life measurement so as to get close to the single particle is clearly beyond the capability of the simple technique used in this work.

TABLE IV. List of γ rays from decay of the ^{112}Rh high-spin state. One hundred γ-intensity units correspond to a β feeding of 90.4%. The confidence of a coincidence relationship for transitions between brackets is less than or equal to 2σ. The intensities of the 349, 388, and 737 keV γ rays have been scaled such as to balance the population of the 2^+ states at 349 and 737 keV without direct β feeding. Coincidences due to the decay of 1^+ ^{112}Rh in these gates are not listed here.

Energy [keV]		γ intensity		From	To	Coincident lines
158.1	(2)	0.09	(3)	2195	2036	160, 349, 400, 560, (1688)
159.9	(3)	0.25	(6)	2355	2195	158, 349, 360, 388, (400), (1098)
213.3	(2)	1.3	(2)	1096	883	349, 400, 534, 560, 1098
348.7	(2)	100.0	(0)	349	0	[a]
359.6	(2)	36.5	(28)	1096	737	160, 349, 360, 388, 400 436, 480, 486, 554, 560, 619, 663, (727), 737, 791, (842), 996, 1040, 1062, 1098, 1258, 1299, (1447), 1659
359.6	(2) [b]	0.3	(1)	2755	2395	(213), 349, 360, 388, 534, 748, 1299, (1512)
388.0	(2)	33.7	(23)	737	349	349, 360, 400, 436, 480, 486, 554, 560, 619, 626, 640, 663, (727), 791, 838, 964, 979, 996, 1040, 1098, 1215, 1258, 1299, 1392, (1447), (1458), 1604, 1659, (2080), [c] 2398, 2410
396.6	(4)	0.3	(1)	1759	1362	(626)
400.3	(2)	4.1	(5)	2755	2355	158, (160), 349, 360, 388, 534, 737, 748, (993), 1258, 1472, 1688 [d]
435.6	(2)	0.4	(1)	2195	1759	349, 360, 388, 560, 663, (748)
441.3	(4)	0.2	(1)	2201	1759	(663)
464.7	(4)	0.3	(1)	1888	1423 [e]	(686), (1423)
479.4	(2)	1.4	(2)	1362	883	349, 534, (554), 640, 838, (964), (1392)
479.7	(2) [b]	1.7	(2)	2195	1715	349, 360, 388, 534, 560, 619, 737, 748, 832, 978
485.4	(2)	1.2	(2)	2755	2269 [f]	349, 534, 1386
485.7	(2) [b]	0.8	(1)	2201	1715	349, 360, 388, 534, 554, (737), 748, 832, 978
534.3	(2)	37.0	(33)	883	349	213, (291), [g] 349, 360, 400, 479, 485, 554, 560, 640, 650, 663, 668, 832, 891, (964), (996), 1040, 1079, 1098, 1204, 1312, 1318, 1386, 1416, 1451, 1472, 1493, 1512, 1548, (1660), 1872, 2209, 3057, (3114) [h]
554.2	(2)	1.0	(1)	2755	2201	349, 360, 388, (479), 486, 534, 626, 650, 668, 737, 748, 838, 979, 1318
560.2	(2)	62.3	(63)	2755	2195	158, 213, 349, 360, 388, 436, 480, 534, 619, (626), 663, 737, 748, (832), 978, 1098, 1312, 1458, 1846
618.6	(2) [i]	3.8	(4)	1715	1096	349, 360, 388, 480, 486 554, 560, 727, 737, 748, 1040

TABLE IV. (*Continued*).

Energy [keV]		γ intensity		From	To	Coincident lines
625.7	(2)	5.7	(5)	1362	737	349, 388, 554, (560), 640, 737, (832), 838, (842), 964, (1101) [j], 1392, 1604, (2398), 2410
640.3	(2)	1.8	(2)	2003	1362	349, 388, 479, 534, 626, 737, 964
650.1	(2)	0.4	(1)	2201	1551	349, 534, 554, 668
662.7	(2)	5.8	(6)	1759	1096	349, 360, 388, 436, 534 560, 737, 748, (842), 996, (2163) [k]
667.5	(2)	9.2	(10)	1551	883	349, 534, 554, 650, 891, (1079), 1204, 1416, 1493, 2209
726.5	(3)	0.4	(1)	2441	1715	(349), (360), (388), 619, (748), (832), (978)
736.7	(2)	10.6	(12)	737	0	[l]
747.6	(2)	28.5	(29)	1096	349	[m]
791.1	(3) [b]	0.6	(2)	1888	1096	349, 360, 388, (737), (748)
802.9	(4)	0.2	(1)	2755	1952	(1215)
831.9	(2)	1.0	(2)	1715	883	349, 480, 486, 534, (554), 560, (727), (1040)
832.2	(2)	0.14	(3)	2195	1362	(349), (388), (626)
838.2	(2)	0.8	(2)	2201	1362	349, 388, 479, (534), 554, 626, (737)
842.4	(5)	0.3	(1)	3043	2201	(626), (838)
855.1	(5)	0.4	(1)	1952	1096	(349), (388), (360), (748)
876.0	(4)	0.2	(1)	1759	883	(349), (534), (996)
890.9	(3)	0.23	(5)	2441	1551	(349), (534), 668
963.9	(2)	0.6	(1)	2967	2003	349, 388, (479), (534), 626, 640, (737)
978.2	(2)	2.0	(2)	1715	737	349, 388, 480, 486, (554), 560, (727), 737, 1040
993.3	(6)	0.07	(3)	2355	1362	(400)
995.8	(2)	2.3	(3)	2755	1759	349, 360, 388, (534), 663, 737, 748, (876)
1004.7	(5)	0.14	(6)	1888	883	(534)
1013.9	(4) [n]	0.27	(14)	1362	349	(349)
1028.3	(4)	0.12	(4)	2579	1551	(349), (534), (668) [o]
1039.9	(2)	1.2	(2)	2755	1715	349, 360, 388, (534), 619, 737, 748, 832, 978
1061.7	(3)	0.4	(1)	2158	1096	(349), (360), (388) [o]
1069.2	(6)	0.21	(5)	1952	883	(349), (534)
1079.2	(2)	0.27	(7)	2630	1551	(349), (534), 668 [o]
1098.3	(2)	49.9	(50)	2195	1096	(160), 213, 349, 360, 388, (400), 534, 560, 737, 748
1204.3	(2)	2.5	(4)	2755	1551	349, 534, 668
1214.8	(5)	0.5	(2)	1952	737	(349), 388, (737)
1258.2	(2)	1.0	(2)	2355	1096	349, 360, 388, 400, (737), 748
1298.9	(3)	0.6	(1)	2395	1096	(349), 360, (388), 748
1311.6	(2)	8.6	(11)	2195	883	349, 534, 560
1317.6	(3)	0.5	(2)	2201	883	(349), (534), (554)
1366.2	(4)	0.4	(2)	1715	349	(349)
1386.4	(2)	2.0	(3)	2269	883 [f]	349, 485, 534
1392.4	(3)	0.5	(1)	2755	1362	349, 388, (479), 626, (737)

TABLE IV. (*Continued*).

Energy [keV]		γ intensity		From	To	Coincident lines
1416.1	(2)	0.7	(1)	2967	1551	349, 534, 668
1446.9	(3)	1.3	(2)	2543	1096	(349), 360, 388, 748
1451.1	(3)	0.5	(1)	(2334	883)	349, 534 [o, p]
1457.9	(2)	0.2	(2) [q]	2195	737	349, 388, 560
1471.5	(2)	3.4	(5)	2355	883	349, 400, 534
1493.1	(4)	0.3	(1)	3043	1551	349, 534, 668
1512.1	(5)	0.5	(1)	2395	883	349, 534, (360)
1547.8	(4)	0.7	(2)	2431	883	349, 534 [o]
1604.2	(5)	0.3	(1)	2967	1362	349, 388, 626
1658.5	(3)	3.4	(5)	2755	1096	349, 360, 388, 737, 748
1660.3	(5)	0.5	(1)	2543	883	534 [r]
1687.8	(5)	0.3	(1)	2037	349	(158), (349)
1845.9	(5)	0.5	(2)	2195	349	349, 560
1871.8	(4)	2.3	(4)	2755	883	349, 534
2208.9	(5)	0.6	(2)	3760	1551	349, 534, 668
2397.6	(8)	0.3	(1)	3760	1362	349, 388, (626)
2409.6	(7)	0.5	(1)	3772	1362	349, 388, 626 [o]
2911.3	(8)	0.5	(2)	3794	883	349, 534 [o]
3057.3	(8)	0.6	(2)	3940	883	349, 534 [o]

[a]Coincidences are not listed in order to save space. See other transitions.

[b]This weak transition was not resolved from the doublet in previous works.

[c]Unplaced γ ray of 2080.6(6) keV with $I_\gamma = 0.4(2)$ if from a level 2817 keV fed in this decay.

[d]A tentative coincidence with a γ ray of 2007(1) keV, with $I_\gamma = 0.10(6)$ could determine $I(2355) = 4$.

[e]Weak link between decay schemes of 1^+ and high-spin ^{112}Rh. Not shown in Fig. 3. See Fig. 2 for decay of 1423 keV level.

[f]Reverse order of 485.4 and 1386.4 keV transitions with respect to [13] was also suggested by [26] in order to satisfy intensity balance.

[g]Unplaced γ ray of 291.3(5) keV with $I_\gamma = 0.3(1)$ if from level 1174 keV to 883 keV.

[h]Possible γ ray of 3114.2(8) keV with $I_\gamma = 0.3(1)$ if placed from level 3997 keV to 883 keV. Level 3997 keV could be supported by a tentative peak at 2447 keV in the 534 and 668 keV gates; see Table II.

[i]Transition not reported before in spite of its large branching ratio. It was presumably interpreted as the $2^+ \rightarrow 0^+$ transition of 617.6 keV in ^{112}Cd.

[j]Unplaced transition of 1101.3(4) keV with $I_\gamma = 0.2(1)$ if placed from level 2463 keV to level 1362 keV.

[k]Unplaced transition of 2163.5(8) keV with $I_\gamma = 0.2(1)$ if placed from level 3923 keV to level 1759 keV.

[l]Coincidences are the same as listed with the 388 keV transition, but without 349 keV.

[m]Coincidences are the same as listed with the 360 keV transition from the 1096 keV level, but without 388 keV.

[n]Transition reported in Ref. [26] but not in Ref. [13,14] while all reported the 1362 keV level.

[o]This transition is the only one to support a new level. It is accepted in the level scheme owing to at least two weak but consistent coincidences.

[p]A tentative coincidence with the 668 keV line could suggest a level at 3002 keV in addition or instead of the 2334 keV one. Level and transition are not shown in Fig. 4.

[q]Residual intensity after correction for coincidence summing of the 360 and 1098 keV transitions might vanish.

[r]Transition masked by the 1658.5 keV line in the gate on the 349 keV transition.

IV. DECAY OF THE HIGH-SPIN STATE OF ^{110}Rh

The short cycles for the above mentioned experiment [28] are unfavorable for the observation of this decay with $t_{1/2} = 28.5$ s. Nevertheless, a few new transitions have been identified and placed in the level scheme of ^{110}Pd. These γ rays are shown in Table VIII.

The data confirm the previous results of Ref. [13] and give some new information on the levels of ^{110}Pd. Transitions of 1096.0 and 1515.8 keV from the 2^+ states at 1470 keV and 1890 keV [45] are now observed in the decay of the low-spin Rh state. The former belongs to the band on the 0_3^+ level at 1171 keV. The latter level is a bandhead [16]. Thus, the $(0^+,2^+)$ members of the excited bands, with levels at (947, 1212 keV), and (1171, 1470 keV), are populated in β

TABLE V. Levels in ^{112}Pd fed by the decay of the ^{112}Rh high-spin level. log*ft* values are calculated with $Q_{\beta}=7.0$ MeV [43] and $T_{1/2}=6.8$ s. Nonlisted β feedings are consistent with zero within 1σ.

Energy [keV]		β feeding [%]		logft	I^{π}
0.0		[a]			0^+ [b]
348.7	(2)	[a]			2^+ [b]
736.7	(2)	[a]			2^+ [c]
883.0	(3)				4^+ [b]
1096.3	(2)				3^+ [c]
1362.4	(2)	2.2	(6)	7.0	4^+ [c]
1550.5	(4)	3.7	(11)	6.7	6^+ [b]
1714.9	(2)	2.8	(6)	6.8	(3, 4) [d]
1759.0	(2)	3.1	(7)	6.7	5^+ [c]
1887.5	(3)	0.7	(2)	7.3	(4^+) [e]
1951.6	(4)	0.8	(2)	7.2	(3, 4) [d]
2002.7	(3)	1.1	(2)	7.1	6^+ [c]
2036.5	(6)	0.2	(1)	7.8	
2158.0	(4)	0.4	(1)	7.5	
2194.6	(2)				4 [f]
2200.6	(2)	1.3	(4)	6.9	
2269.4	(4)	0.7	(3)	7.2	
2334.1	(4)	0.4	(1)	7.3	[g]
2354.5	(2)	0.5	(7)	7.3	(4,5) [f, h]
2395.2	(3)	0.7	(2)	7.1	
2430.8	(5)	0.6	(2)	7.1	
2441.4	(3)	0.6	(1)	7.2	
2543.2	(3)	1.6	(3)	6.7	
2578.8	(6)	0.11	(4)	7.8	
2629.7	(4)	0.24	(6)	7.5	
2754.8	(2)	73.5	(87)	4.9	5 [f]
2966.6	(3)	1.5	(2)	6.5	
3043.3	(4)	0.5	(1)	6.9	
3759.6	(5)	0.8	(2)	6.4	
3772.0	(8)	0.5	(1)	6.6	
3794.3	(9)	0.5	(2)	6.6	
3940.3	(9)	0.5	(2)	6.4	

[a] Direct β feeding assumed to be neglectible due to $\Delta I \geqslant 2$.
[b] Member of the ground-state band [13,15,14].
[c] Member of the γ band [13,14].
[d] Spin limited by feeding from the $I=5$ level at 2755 keV and deexcitation to a 2^+ state.
[e] Proposed as member of the band built on the 1126 keV 0^+ state.
[f] New result from angular correlation.
[g] This level could be replaced by another at 3002 keV; see footnotes in Table IV.
[h] $I=4$ favored for structural reasons and a tentative transition to the 349 keV first excited 2^+ state.

decay of ^{110}Rh. However, the 4^+ states, the next band members reported at 1718 and 1936 keV in Coulomb excitation, are not observed. In the decay of ^{112}Rh the postulated 4^+ states are also weakly populated.

The decay branches from the 1900 keV level as quoted in [45] include a 730 keV transition to the 1171 keV level, and another of 1527 keV to the 2_1^+ state which both cannot be detected in our experiment, suggesting that there could be two different close-lying levels, one of low spin and another one with $I=3$ or $I=4$, observed in β decay. A possibly similar situation occurs for the 2448 keV which could be distinct from the 3^- level observed in several scattering experiments, since we fail to detect some of the reported branches and only see a single transition to the 4_2^+ level.

The most important result for the present discussion is a new level at 2261 keV fed by a transition of 544 keV from the 2805 keV level. The decay branches to the 3_1^+ and 4_1^+ states imply a clear similarity with the $I=4$ level at 2195 keV in ^{112}Pd. This suggests that the 2805 keV level corresponds to the $I=5$ level at 2755 keV in ^{112}Pd. Evidence for the placement of the new 544 keV transition is displayed in Fig. 7. The other strongly β-decay fed level at 2791 keV is a $I=(4,5)$ level. Finally, a new level at 1987 keV is introduced on the basis of its population from both 2791 and 2805 keV levels and a single decay branch to the 4^+ state of the γ-band.

The only states with a clear β feeding are the levels at 1900 keV (log$ft=5.9$), 2791 keV (log$ft=5.1$), and 2805 keV (log$ft=4.8$). Since $I(1900)\leqslant 5$, the spin of the high-spin ^{110}Rh state is definitely lower than 6. The absence of feeding to the 3^+ state of the γ band favors $I=5$ over the other alternative $I=4$. As a matter of fact, a spin lower than the one of ^{112}Rh provides an explanation for the feedings of the levels at 1900 and 2791 keV, while the corresponding levels are not observed in ^{112}Rh decay, if these have $I\leqslant 4$. In this case, the strong γ branch of the 2791 keV level to the 6^+ state is unlikely to be a $M2$ transition. Thus, even parity is favored for ^{110}Rh and the strongly fed levels in ^{110}Pd.

V. DISCUSSION

Pd isotopes are situated in a transition region between the triaxially deformed Ru isotopes [3–8] and the more vibrator-like Cd isotopes [2]. For neighboring isotones of ^{112}Pd, deformations deduced from the available $B(E2,2^+\rightarrow 0^+)$ values are $\beta=0.29(1)$ for ^{110}Ru [46] and $\beta=0.18(1)$ for ^{114}Cd [1]. A recent unpublished measurement of $t_{1/2}(2_1^+)=68(4)$ ps for ^{112}Pd by Mach [47], corresponding to $\beta=0.24(1)$, confirms this trend. In addition, Cd isotopes exhibit intruder states which are low-lying at the neutron mid-shell [19]. Thus, it is expected that Pd isotopes have a complex structure.

A. Band structure

The systematics of neutron-rich palladium isotopes shows a smooth variation of the energies of the levels in the ground-state and in the $K=2$ bands. Palladium levels have been recently studied in the framework of the interacting boson model by Kim *et al.* [11] and succesfully reproduced by increasing the amount of $O(6)$ symmetry with increasing neutron number. We note that for ^{112}Pd their experimental data set only includes an excited 0^+ state which look to be the 890 keV level we have not observed. Nevertheless, they calculate the 0_2^+ level close to 1 MeV, in reasonable agreement with the location of experimental 0^+ states at 1126 and

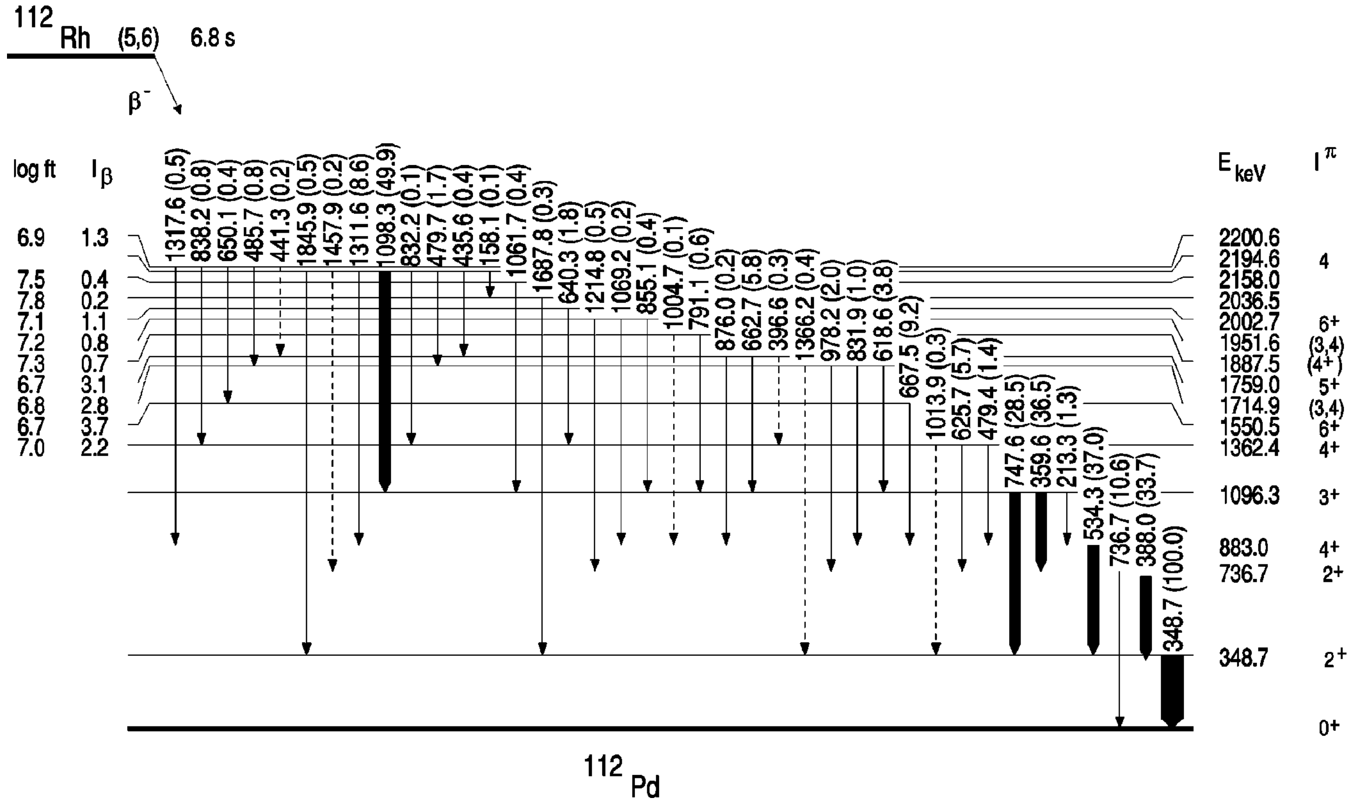

FIG. 3. Decay scheme of the high-spin state of [112]Rh (lower part). Dashed transitions are regarded as tentative since only part of the required coincidences can be detected.

1140 keV. In contrast, for Pd isotopes with $A<112$ they calculate two 0^+ states in this energy region in agreement with the experiments. For the heavier isotopes the experimental assignments are not so firm. In [114]Pd the lowest-lying 0^+ state is tentatively reported at 872 keV [13]. The calculation in fact produces two closely-lying 0^+ states near 1.1 MeV, resembling the experimental situation in [112]Pd.

The experimental A_{22} coefficients obtained in this work for [112]Pd imply large $E2$ components in the 388 keV ($2_2^+ \rightarrow 2_1^+$) and 360 keV ($3^+ \rightarrow 2_2^+$) transitions and give solutions with large δ values for the 748 keV ($3^+ \rightarrow 2_1^+$) transition; see Table VII. Such large mixing ratios are found in the immediate neighborhood of [112]Pd. Tables IX and X show ratios of $B(E2)$ values for transitions from the 2_2^+ and 3^+ states, respectively. In the vibrational limit the $2_2^+ \rightarrow 0_1^+$ and $3_1^+ \rightarrow 2_1^+$ transitions are forbidden as they correspond to a change of two phonons. As expected, anharmonicities are smaller in Pd isotopes than in their Ru isotones due to the dominant $O(6)$ character of the latter. Nevertheless, the $2_2^+ \rightarrow 0_1^+$ crossover transitions in Pd are surprisingly weak with respect to those in the Cd isotopes.

B. New low-spin levels and intruder band

Important information from this work consists of low-spin levels which are nonyrast and have not been observed by prompt fission, while some of them have been identified in former decay or reaction studies. Following the smooth trend of level energies in Pd isotopes, assumed to decrease with increasing N until neutron midshell, a 890 keV $I^\pi=0^+$ level and a 1140 keV $I^\pi=2^+$ level were proposed [13,26]. However, our new data do not confirm the former level and suggest 0^+ for the 1140 keV level. Thus, there are a definite 0^+ state at 1126 keV, a probable other 0^+ state at 1140 keV, and further two definitely $I^\pi=2^+$ states at 1403 keV (a new level) and 1423 keV. We note that below 2 MeV, there are a few possible $I=4$ levels and it is tempting to look whether any band structures could be built extending the sets of 0^+ and 2^+ states.

In Coulomb excitation measurements on [106]Pd, [108]Pd, and [110]Pd [16,17], Svensson *et al.* identified two extra bands (i.e., in addition to the g.s. and γ bands) based on 0^+ states. These bands become increasingly clear with increasing N, especially in [110]Pd where they are the lowest lying. Connecting levels of same spin while choosing levels with similar decay pattern creates a new systematics which is shown in our first report [27]. There is a fairly good similarity between the γ-ray branching ratios of selected levels in [110]Pd and [112]Pd; see Fig. 8. The $B(E2,0^+ \rightarrow 2_2^+)/B(E2,0^+ \rightarrow 2_1^+)$ ratio is 0 if the initial states are the 947 keV ([110]Pd) and 1126 keV ([112]Pd) levels, while it becomes 27 and 9 if they are the 1171 keV ([110]Pd) and 1140 keV ([112]Pd) levels. We assume that the next member of the band on the 1126 keV level is the 1423 keV 2^+ level owing to the linking transition of 297 keV with $B(E2,2^+ \rightarrow 0_3^+)/B(E2,2^+ \rightarrow 0_1^+)=466$. The 1888 keV level could be the next 4^+ member of the band. This fits

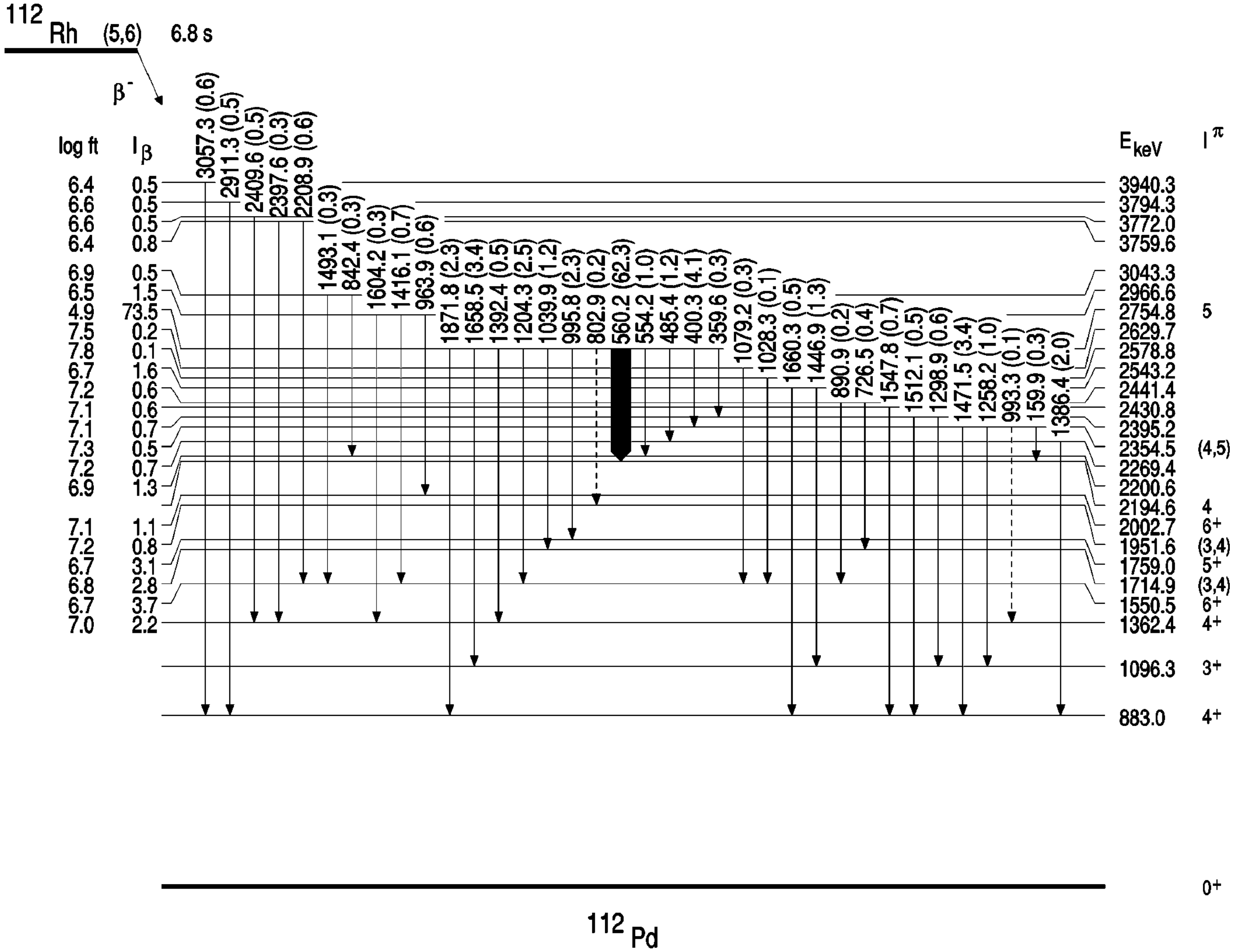

FIG. 4. Decay scheme of the high-spin state of ^{112}Rh (higher part). See also caption for Fig. 3.

energy trends and is consistent with the feeding and decay pattern. The 465 keV transition to the 1423 keV level indicates a strong link between these levels. The $E(4^+)/E(2^+)$ ratio of 2.56 is close to the 2.53 value for the ground-state band. For the 2^+ level of the corresponding band in ^{110}Pd Svensson [16] gives two values of half-lives, the average of which is 15(1) ps. After correction for branching ratios and conversion, the partial γ half-life of the $2^+ \rightarrow 0^+$ transition becomes 284 ps, which corresponds to 44 single-particle units and a deformation of $\beta = 0.22$. This is indeed in the range of ground-state deformations for Pd isotopes near midshell. In the other set of $(0^+,\ 2^+)$ ^{112}Pd levels, no $2^+ \rightarrow 0^+$ transition is observed, contrasting with the level scheme of ^{110}Pd. The weakness of the expected intensity, close to the detection limit, might be invoked for this failure. Evidence for the next $I^\pi = 4^+$ member of this second band is even more uncertain. The remaining candidates, the levels at 1715 keV and 1952 keV, are either too low or too high with respect to a smooth extrapolation from the lighter Pd isotopes and furthermore no connection to the 1403 keV level is found. We have arbitrarily favored the former level in Fig. 8.

A V-shape pattern for excitation energies of selected states versus neutron number has also been observed in the systematics of even-even Cd isotopes [19] and of both odd-proton Pd neighbors, namely, the $_{45}$Rh and $_{47}$Ag isotopes [23]. This suggests that the band which is the lowest in ^{110}Pd and ^{112}Pd is of intruder origin. It is remarkable that the lowest 0^+ state is the one in ^{110}Pd (947 keV), with a neutron pair less than midshell, and not in ^{112}Pd (1126 keV). This represents a further analogy with the systematics of the odd-proton rhodiums in which the [431]1/2 band exhibits its minimum energy for ^{111}Rh also at $N = 64$. Yet the $K = 1/2$ bands in Ag isotopes with one proton pair more than Pd do have their minimum energy at the midshell. The reason is not clear to us but we note that at lower proton number, even larger deformations are reached already for $N = 60$ [48–50].

C. Quasiparticle states

Below 2 MeV only two of the well-established levels have not been included in a band. Above this energy it becomes very difficult to propose assignments. Therefore we

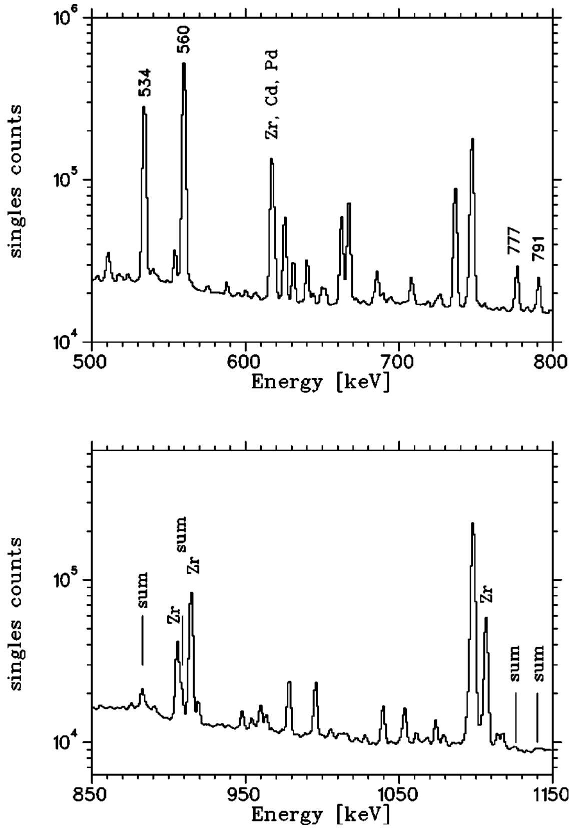

FIG. 5. Part of the singles spectrum for an estimate of coincidence summing with the ($2^+ \rightarrow 0^+$) 349 keV transition. The strong 534 ($4^+ \rightarrow 2^+$) and 560 keV and the weaker ($0^+ \rightarrow 2^+$) 777 keV transitions are indicated in the upper part of the figure, while their sum peaks are shown in the lower part. Coincidence summing of the 349 and 791 keV transitions to a peak at 1140 keV accounts for the whole intensity in contrast to a former report [26] where the 1140 keV level was interpreted as a 2^+ state due to its ground-state transition.

only attempt to interpret the levels fed strongly in β decay of the high-spin ^{112}Rh state. The 2195 keV ($I=4$) and 2755 keV ($I=5$) levels are prominent due to the strong feeding of the latter in β decay with $\log ft = 4.9$ and the strong link between them via the 560 keV transition. The 2195 keV level decays to the 3^+ level of the γ band and 4^+ level of the ground-state band by the strong dipole transitions of 1098 and 1312 keV. The 2755 keV level has numerous branches but clearly the $\Delta I = 1$ transitions of 400 and 560 keV compete favorably with those of much higher energy towards the collective levels. Thus, it looks logical to interpret these levels as due to quasiparticles. Strong β feeding of Pd levels at about 2.5 MeV is a general feature of odd-odd Rh decays. There is a very close similarity between the levels at 2864 keV (^{108}Pd) and 2755 keV (^{112}Pd). Even parity has been suggested for the ^{108}Pd level and $I=5$ is one of the alternatives [1]. Thus, $I^\pi = 5^+$ could be tentatively assigned to the 2755 keV level in ^{112}Pd. In the intermediate ^{110}Pd nucleus two levels at 2790 keV ($\log ft = 5.1$) and 2805 keV ($\log ft = 4.8$) are strongly populated. Both have branches to the $I = 3^+$, 4^+, and 6^+ collective levels obviously stronger

TABLE VI. Table of experimental and fitted A_{22} coefficients. Fitted values are obtained by varying δ mixing ratios and B_2 coefficients to get best agreement with the experimental data set. The 400-1472-534-349 keV cascade has not been included in the fit due to its very poor accuracy.

γ_1 [keV]	γ_2 [keV]	A_{22} expt.		A_{22} fitted
349	360	0.041	(35)	0.042
349	388	0.089	(34)	0.086
349	534	0.105	(34)	0.102
349	668	0.097	(45)	0.102
349	748	-0.485	(47)	-0.487
349	777	0.493	(66)	0.357
349	791	0.339	(77)	
349	1204	0.078	(73)	0.028
349	1312	0.169	(52)	0.224
349	1472	0.188	(65)	
360	388	0.117	(34)	0.137
360	560	0.013	(35)	-0.009
360	737	-0.208	(41)	-0.231
360	1098	0.014	(40)	-0.010
360	1659	-0.105	(89)	0.012
388	560	0.009	(35)	0.012
388	1098	0.002	(45)	0.012
388	1659	-0.122	(93)	-0.015
400	534	-0.131	(54)	-0.107
400	1472	-0.092	(62)	
534	560	-0.059	(39)	-0.068
534	668	0.143	(42)	0.102
534	1204	0.113	(71)	0.028
534	1312	0.279	(45)	0.224
534	1472	0.213	(66)	
560	736	0.038	(41)	-0.020
560	748	0.135	(37)	0.116
560	1098	0.042	(35)	0.062
560	1312	-0.083	(43)	-0.065
668	1204	-0.075	(67)	0.028
737	1098	0.103	(68)	-0.021
737	1659	0.304	(311)	0.026
748	1098	0.148	(42)	0.121
748	1659	0.082	(120)	0.147

than exhibited by the corresponding levels in their neighbors. Nevertheless, some similarities remain. The new data for ^{110}Pd suggest that the 2805 keV level is the one belonging to this systematics; see Fig. 9. In contrast, the strongly fed states in ^{114}Pd look very different since only the 2623 keV level has a transition to one of the collective states mentioned above, namely, to the 6^+. Even more different is ^{116}Pd with a strongly fed level at 2450 keV and two decays to levels of unknown spin. Whether this means a different nature of their parent nuclei or is the mere consequence of poorer statistics in the experiments cannot be said at present.

Another systematic feature is that there is a level populated via a γ transition from the above discussed levels. This level further decays to the 3_1^+ and 4_1^+ levels, the branching to

TABLE VII. Quantities deduced from angular correlation data. They result from a fit of a set of experimental A_{kk} coefficients. Mixing ratios are expressed as arctan(δ) in degrees. Errors are standard deviations.

δ or B_2	I_i	I_f	Deduced value
δ(388)	2	2	-78 (3)
δ(748)	3	2	from -69 (-5) to -36 (+7) [a]
δ(360)	3	2	±90 (3)
δ(1098)	4	3	-2 (3)
δ(1312)	4	4	from -37 (-10) to -6 (11)
δ(1472)	4 [b]	4	-1 (-16,+8)
	5 [b]	4	29 (-7,+34)
B_2(400)	5	(4,5) [b]	0.28 (10)
B_2(560)	5	4	0.18 (5) [c]
B_2(1204)	5	6	-0.22 (10)

[a] This means that there are two solutions for arctan(δ), $-69°$ and $-36°$. One standard deviation covers the interval between these values and it is -5 on the lower side of the first value and $+7$ on the higher side of the second.

[b] $I(2355)=4$ or 5. $I=4$ is favored by the solution $\arctan(\delta_{400}) = -4(4)°$ in agreement with the expected noncollective character of this transition, while $\arctan(\delta_{400})$ extends from 53° to 90° and $-90°$ to $-81°$ for $I=5$.

[c] One solution is $\arctan(\delta_{560}) = -1(3)°$ which allows a $E1$ $(+M2)$ transition with $M2$ component much slower than the single-particle estimate.

the 3^+ level clearly being the strongest one. These are the levels at 2282 keV (^{108}Pd), the new level at 2261 keV (^{110}Pd), the $I=4$ level at 2195 keV (^{112}Pd), and the 2064 keV level (^{114}Pd). This suggests that these levels all are $I=4$ states of similar structure. The transitions to the 2^+ states are very weak and this prevents conclusions based on the decay rate limits obtained for ^{112}Pd. Nevertheless, the ^{106}Pd levels at 2757 keV ($I^\pi=5^+$) and 2306 keV ($I^\pi=4^-$) [1] show some similarity with the $I=5$ and $I=4$ levels mentioned above. This favors odd parity for the $I=4$ levels in the heavier Pd isotopes. In this case, the weakness of the transitions to the 2^+ states is naturally due to their $M2$ character. We note that change of parity for the $5^+ \rightarrow 4^-$ 560 keV transition is possible owing to the existence of a solution with a very small $\delta(560)$ value; see Table VII. In this case, the partial half-life upper limit of 0.80 ns lets plenty of room for a strongly retarded $M2$ component in the 560 keV $E1(+M2)$ transition.

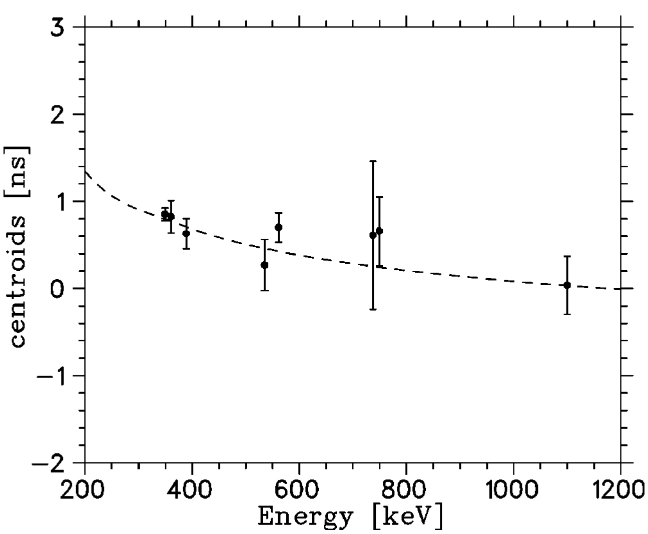

FIG. 6. Centroid-shift plot from β-γ-t delayed coincidences. The prompt curve (dashed line) is deduced from positions of centroids for the time distributions of lines in the schemes of ^{100}Zr and ^{100}Mo known with high accuracy [40], but it may have to be translated due to electronic unstabilities occurring in the time between the $A=112$ and $A=100$ measurements; see text.

In addition to the above-mentioned levels, ^{110}Pd exhibits two other levels having no obvious partner level in ^{112}Pd. They are strongly populated in β decay but were not reported in other studies, a fact that suggests a noncollective character. As discussed previously, we regard $I^\pi=4^+$ as the most probable assignment for the 2791 keV level. The 1900 keV level with $I^\pi=(3,4)^+$ is rather low lying, considering the standard value of the pairing gap. However, ^{108}Ru, a neighboring isotone of ^{110}Pd, has a level at 1826 keV with a strong β feeding in ^{108}Tc decay [51] which could indicate another quasiparticle (broken neutron pair) configuration at a comparable excitation energy, showing that the 1900 keV level is not a singularity.

D. Beta decay of ^{112}Rh

The β decay of the 1^+ Rh state populates a number of levels including the ^{112}Pd ground state, the two low-lying 0^+ states, the four well-established 2^+ states, and other various levels. Most of the β branches are slow with logft values larger than 6.5. This is contrasting with the decay of the high-spin state which strongly favors the 2755 keV level with log$ft=4.9$ while other branches are weak. For this reason, it is not possible to definitely assign a spin to the high-spin state other than $I=4$, 5, or 6. The very small overlap of levels fed in both ^{112}Rh decays seems to favor the largest values of 5 or 6 with respect to $I=4$.

The neighboring odd-proton $_{45}$Rh isotopes [52], have their ground states built on the seniority $v=3$ $(g_{9/2})^3$ configuration leading to the $I=j-1$ anomaly, i.e., $I=7/2$ [53]. In Ag isotopes, this configuration is also below the single $g_{9/2}$ proton one, but the ground state is the $p_{1/2}$ orbital. The low-lying neutron levels in odd-Pd nuclei include $5/2^+$, $1/2^+$, and $11/2^-$ levels which are known experimentally throughout the systematics [1] and can be probably associated with $d_{5/2}$, $s_{1/2}$, and $h_{11/2}$ single particles. However, the strongest β branch populates another $5/2^+$ level at moderate excitation energy with logft values typically of 5.0. This level can be thought of being built on a core + particle coupling where the particle is the $g_{7/2}$ neutron produced by Gamow-Teller decay of one of the $g_{9/2}$ protons in the $v=3$ Rh ground state.

Accordingly, the $\pi(g_{9/2})^3_{7/2^+} \otimes \nu d_{5/2}$ and $\pi g_{9/2} \otimes \nu g_{7/2}$ configurations probably represent the dominant components in the lowest-lying 1^+ states of ^{112}Rh. Experimentally, two 1^+ states separated by 327 keV are known, both being

TABLE VIII. List of γ rays from decay of the ^{110}Rh high-spin state. One hundred γ-intensity units correspond to a β feeding of 90%. The confidence of a coincidence relationship for transitions between brackets is less than or equal to 2σ. The intensities of the 374, 440, and 814 keV γ rays have been scaled such as to balance the population of the 2^+ states at 374 and 814 keV without direct β feeding.

Energy [keV]		γ intensity		From	To	Coincident lines
291.6	(2) [a]	2.0	(4)	1212	921	374, 544, 547, 688, (891), 905, (1049), 1579, 1594
373.8	(2)	100.	(38)	374	0	292, 399, 440, 478, 502, 544, 547, 585, 589, 653, 688, 804, 818, 838, 891, 905, 979, 1049, [b] 1087, 1217, 1231, 1340, 1392, 1407, 1579, 1594, 1870, 1884
398.6	(2)	22.2	(12)	1212	814	374, 440, 544, 688, 814, 891, 905, 1049, (1579), 1594
439.8	(2)	32.9	(21)	814	374	374, 399, 502, 544, 585, 589, 688, 804, 818, 891, 905, 1049, 1087, 1392, 1407, 1594
477.8	(2)	8.1	(6)	1398	921	374, 502, 547, 589, (818), (891), (905), 1392, 1407
501.9	(2)	3.6	(10)	1900	1398	374, 440, 478, 547, 585, (814), 891, 905
544.4	(2) [a]	6.8	(12)	2805	2261	292, 374, 399, 440, 547, 814, 838, 1049, 1340
546.9	(2)	43.1	(27)	921	374	292, 374, 478, (502), 544, 589, 653, 688, (804), 818, 891, 905, 979, (1049 [b]), 1217, 1231, 1340, 1407, (1594), 1870, 1884
584.6	(2)	15.2	(12)	1398	814	374, 440, 502, 589, 804, 814, 818, 891, 905, 1050, 1392, 1407
588.8	(2) [a]	4.1	(4)	1987	1398	374, 440, 478, 547, 585, 804, 814, 818
653.3	(2)	18.3	(16)	1574	921	374, 547, 1217, 1231
687.7	(2)	32.6	(24)	1900	1212	292, 374, 399, 440, 547, 814, 838, 891, 905
803.5	(2) [a]	1.1	(3)	2791	1987	(374), 440, (478), (547), 585, 589, (814)
813.6	(2)	11.5	(14)	814	0	399, (502), 544, 585, 589, 688, (804), 891, 905, 1049, [b] (1087), (1392), 1407, 1594
817.6	(2) [a]	2.0	(6)	2805	1987	374, 440, 478, 547, 585, 589, (814)
838.2	(3)	23.9	(19)	1212	374	374, 544, 688, 891, 905, 1049, 1579, 1594
890.5	(3)	10.0	(12)	2791	1900	374, 399, 440, (478), 502, 547, (585), 688, 814, 838, 979
904.5	(3)	19.5	(20)	2805	1900	292, 374, 399, 440, (478), 502, 547, 585, 688, 814, 838, 979
979.2	(3)	3.2	(6)	1900	921	374, 547, 891, 905
1048.5	(3) [a]	7.8	(16)	2261	1212	(292), 374, 399, 440, 544, (547), (814), 838
1049.5	(3)	1.6	(6)	2448	1398	374, 440, 585, 814
1086.5	(3) [a]	7.0	(24)	1900	814	374, 440, 814, (891), 905
1216.5	(3)	2.2	(6)	2791	1574	374, 547, 653
1230.9	(3)	8.1	(15)	2805	1574	374, 547, 653
1340.0	(3) [a]	2.8	(6)	2261	921	374, 544, 547
1392.1	(3) [a]	9.3	(10)	2791	1398	374, 440, 477, 547, 585, (814)
1406.6	(3)	4.7	(7)	2805	1398	374, 440, 477, 547, 585, (814)
1579.2	(4)	1.1	(5)	2791	1212	(292), 374, 399, 440, 547, (814), 838
1593.6	(3) [a]	4.0	(9)	2805	1212	292, 374, 399, 440, 547, (814), 838
1869.5	(5) [a]	2.0	(4)	2791	921	374, 547
1884.1	(4) [a]	5.1	(9)	2805	921	374, 547

[a]Transition previously not observed in β decay.

[b]Both transitions of 1048.5 and 1049.5 keV are coincident in this gate.

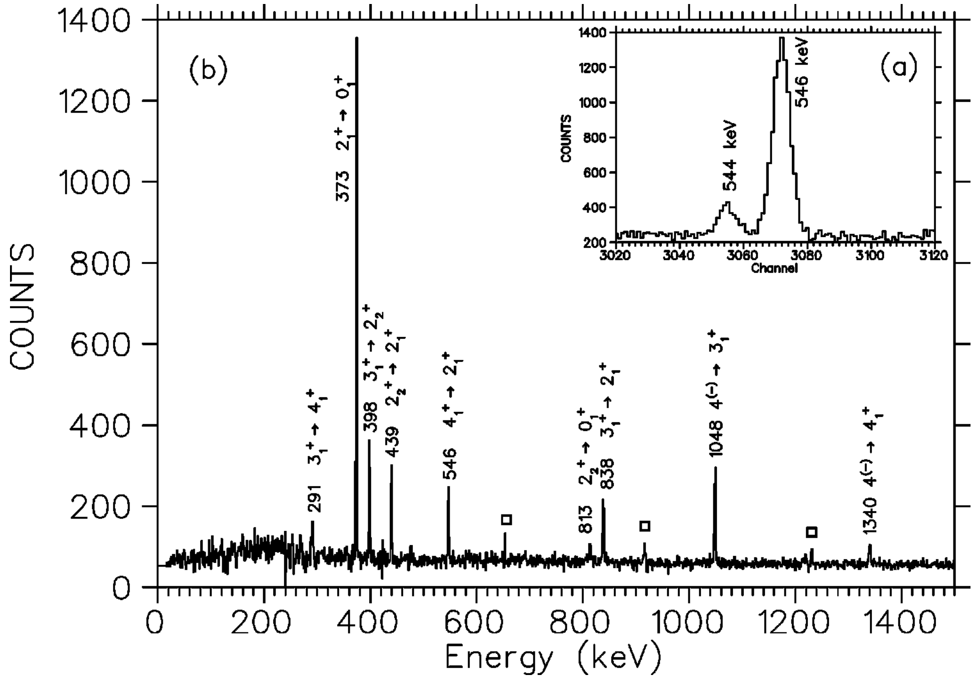

FIG. 7. A new transition of 544 keV in ^{110}Pd. The inset (a) shows the transitions of 544.4 and 546.9 keV resolved by the planar detector. The projection of γ-γ coincidences recorded with coaxial detectors (b) shows the coincident transitions leading to the placement of the 544 keV transition from the 2805 keV level to a new level at 2261 keV. Open squares mark transitions due to contamination by the 547 keV transition in the gate.

strongly fed in the ^{112}Ru decay [54]. Both above-mentioned configurations should be present to some extent in the wave function of the 1^+ Rh state. The $\pi(g_{9/2})^3_{7/2^+} \otimes \nu d_{5/2}$ configuration could decay to high-lying levels where the $d_{5/2}$ neutron spectator is coupled to the residual $g_{7/2}$ neutron. Such a level could be the level at 2747 keV. The other $\pi g_{9/2} \otimes \nu g_{7/2}$ configuration could directly decay to the ^{112}Pd ground state by a Gamow-Teller transition of the unpaired $g_{7/2}$ neutron. In both cases, however, the transitions are not especially fast, which could indicate that this is an oversimplified picture.

We tentatively could invoke a similar mechanism to account for the decay of the high-spin ^{112}Rh state. The logft value of 4.9 for the decay to the 2755 keV level is indeed very close to the logft values of about 5.0 for the odd-Rh decays to the low-lying excited $5/2^+$ state. A simple way to account for the strong decay branch to the 2755 keV $I=5$ level is to add another 5/2 units of angular momentum provided by a neutron spectator to both initial and final states, thus making $I(^{112}\mathrm{Rh})=6$. This could be achieved either by a $d_{5/2}$ or a $h_{11/2}$ neutron. The decay rate of the 1659 keV transition as discussed previously favors even parity and, as such, the odd $d_{5/2}$ neutron. We note that a $g_{7/2}$ neutron would not be a spectator as it could decay. Moreover, the final state would include an even number of $g_{9/2}$ protons and be inconsistent with $I=5$.

The decay of ^{110}Rh has three main branches. The strongest one populates the 2805 keV level in ^{110}Pd. This level is assumed to correspond to the $I=5$ level at 2755 keV in ^{112}Pd. This analogy leads to $I^\pi=5^+$ and 6^+ for ^{110}Rh and ^{112}Rh, respectively. As stated above, the $I^\pi=7/2^+$ ground state of odd-mass rhodium isotopes is a seniority $v=3$ state built out of $g_{9/2}$ protons and the odd neutron orbital is $d_{5/2}$. According to the parabolic rule [55], $I=5$,6 are energetically favored by the $l+s$ character of both involved odd nucleons. Thus, the proposed Rh spins are in agreement with this simple model. The other low-lying configuration is $\pi g_{9/2}$

TABLE IX. $B(E2,2_2\to0)/B(E2,2_2\to2_1)$ ratios for ^{112}Pd (this work) and for its neighbors [14,1].

Ru isotopes		Pd isotopes		Cd isotopes	
^{106}Ru	0.086 (2)	^{108}Pd	0.011 (2)	^{110}Cd	0.044 (1)
^{108}Ru	0.098 (15)	^{110}Pd	0.017 (1)	^{112}Cd	0.045 (5)
^{110}Ru	0.070 (7)	^{112}Pd	0.019 (1)	^{114}Cd	0.023 (3)
^{112}Ru	0.040 (4)	^{114}Pd	0.025 (3) [a]	^{116}Cd	0.055 (13)

[a] $\delta(2_2\to0)$ was assumed infinite.

TABLE X. $B(E2,3\to2_1)/B(E2,3\to2_2)$ ratios for ^{112}Pd (this work) and for its Pd and Ru neighbors [14,1].

Ru isotopes		Pd isotopes	
^{108}Ru	0.045 (5)	^{110}Pd	0.014 (3) [a]
^{110}Ru	0.043 (4)	^{112}Pd	(0.008, 0.020) [b]
^{112}Ru	0.053 (4)	^{114}Pd	0.025 (2) [a]

[a] Both $\delta(3\to2_1)$ and $\delta(3\to2_2)$ were assumed infinite.
[b] Range of $B(E2)$ ratio is due to the range of δ values for the 748 keV $(3\to2_1)$ transition.

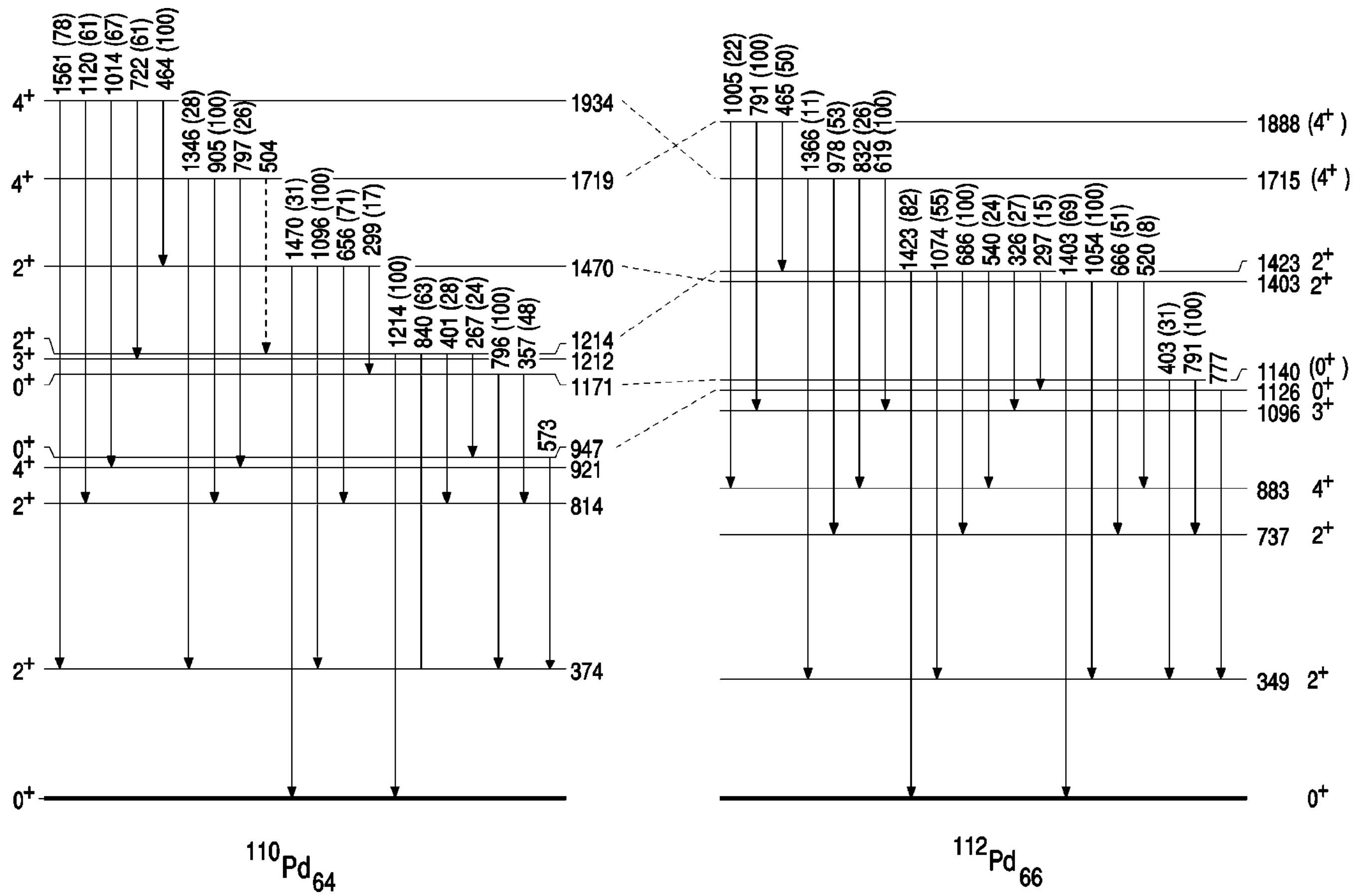

FIG. 8. Comparison of low-spin levels in ^{110}Pd [1,13,14,16] and ^{112}Pd (this work). The lowest 0^+ level is found in ^{110}Pd with two neutron fewer than at midshell. The seemingly two-phonon multiplet is in fact due to closely lying 2^+ head of the γ band, 4^+ member of the ground-state band, and 0^+ intruder state. The tentative assignments to the 1715 and 1888 keV levels in ^{112}Pd are only based on the expectation for the 4^+ states extending the bands on the 0^+ states at 1140 and 1126 keV, respectively.

$\otimes \nu g_{7/2}$ which, however, favors the 1^+ state with respect to the states of large spin. As a consequence of these opposite contributions it is not possible to predict the respective positions of the 1^+ and high-spin states of odd-odd rhodium isotopes by these simple considerations.

VI. CONCLUSION

In this work, detailed decay schemes for both states of ^{112}Rh have been constructed. New information has been gained on the levels of the daughter nucleus ^{112}Pd. The ground-state and γ bands are observed up to their $I^\pi = 6^+$ states. Mixing ratios for the $\Delta I = 1$ transitions from the 2_2^+ and 3_1^+ states have been measured, which should help to refine the calculations of the collective states. In addition, two sets of 0^+ and 2^+ states have been identified and new bands have been proposed. The one with the head at 1126 keV seems to be extended to the 1888 keV level as its 4^+ member. The bandhead energy is lowest for ^{110}Pd and not for the midshell nucleus ^{112}Pd, meaning that a shift to lower neutron numbers starts with $Z \leqslant 46$ in palladium isotopes. The fact that the energy systematics for the $K = 1/2$ band in $_{45}$Rh isotopes exhibits the same shifted pattern might provide a useful hint for an explanation to come.

An $I = 5$ quasiparticle state at 2755 keV is strongly fed ($\log ft = 4.9$) in the decay of the high-spin ^{112}Rh state. The lifetime limit and the close analogy with ^{108}Rh decay favors even parity. We propose that this β decay proceeds by the same mechanism as the odd-Rh $I^\pi = 7/2^+$ decays and that a neutron spectator ($d_{5/2}$ if even parity) is added in the decay of ^{112}Rh to ^{112}Pd. The $I = 4$ level at 2195 keV is another quasiparticle state, tentatively of odd parity. These pairs of quasiparticle states are observed in neutron-rich Pd isotopes up to ^{112}Pd. The irregularity in the systematics being now removed by the new data for ^{110}Pd, they exhibit a very smooth trend of excitation energies, with a very slight decrease with increasing neutron number.

The structure of ^{112}Rh is still an open question. Spin and parity of the high-spin level could not be determined better than $I = (4,5,6)$ from purely experimental data, while the above arguments result in $I^\pi = 6^+$. The new data for ^{110}Pd definitely assign a spin lower than 6 and the most probable assignment is $I^\pi = 5^+$.

Finally, this study demonstrates the improved experimental possibilities for structure studies in this region of refractory elements using the IGISOL technique. It should be possible to perform more detailed measurements for some of the most produced nuclei. Especially appealing are lifetime mea-

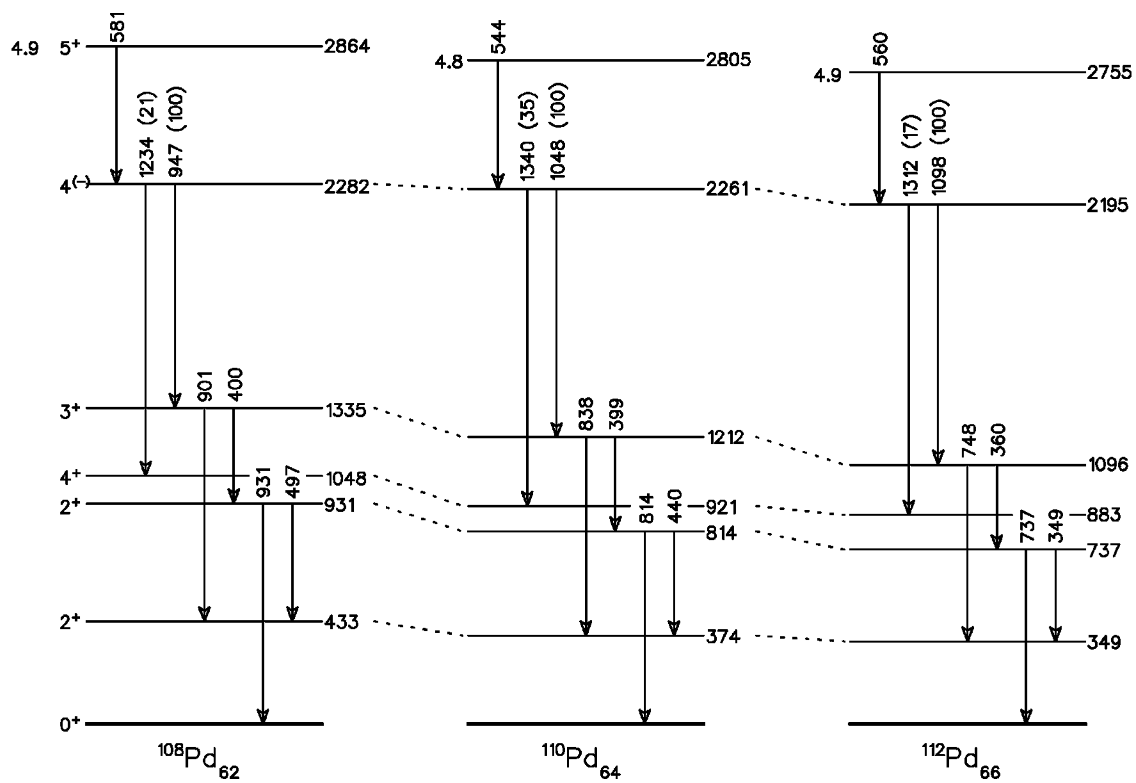

FIG. 9. Systematics of the quasiparticle levels in even-even Pd isotopes strongly fed in β decay of the high-spin state of Rh. Only selected transitions are shown for clarity. Spins for ^{112}Pd are measured by angular correlation. Parities are the most probable according to the decay branchings and some analogy with levels in ^{106}Pd. The 2261 keV level in ^{110}Pd was not reported prior to this work. Another strongly fed level at 2790 keV ($\log ft = 5.1$) in ^{110}Pd exists, which has no obvious partner level in the neighboring nuclei.

surements for the collective levels so that models could be tested in their most sensitive predictions. We also hope to extend detailed experiments to the more neutron-rich Pd isotopes in order to identify extra bands beyond midshell and locate and clarify the nature of the quasiparticle states strongly fed in β decay.

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