^{234}U levels fed in the ^{234}Np electron capture decay

C. Ardisson-Marsol and G. Ardisson
Laboratoire de Chimie Physique et Radiochimie, Faculté des Sciences et Techniques, Université de Nice, F-06034 Nice Cedex, France
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The decay of ^{234}Np has been investigated using a coaxial Ge(Li) detector. The source prepared by the ^{235}U(d,3n) reaction was purified from fission products by radiochemical separation. The analysis of the γ ray spectra revealed the presence of 59 photon lines, 29 of which were found for the first time. The absolute values of γ, EC, and β^+ intensities were deduced from Ux-*K* ray intensity. A ^{234}U decay scheme is suggested on the basis of the good sum relationships. Accurate values of 17 low-spin-energy levels are given, 6 of which were previously unreported in the ^{234}Np decay: 849.36(03$^-$), 926.33(22$^+$), 989.41(22$^-$), 1457.1(12$^-$), 1500.88(1), and 1510.22(1) keV.

[RADIOACTIVITY ^{234}Np from ^{235}U(d,3n); radiochemistry, Ge(Li) detector. Measured E_γ, I_γ, $I_{k\text{-x}}$; deduced absolute I_γ, $I_{\rm EC}$, I_{β^+}, log*ft*; ^{234}U level assignment, decay scheme.]

I. INTRODUCTION

The structure of the strongly deformed ^{234}U nucleus has been investigated in the past years in different ways. An extensive study of stripping and pick-up reactions on ^{233}U and ^{235}U nuclei, performed by Bjørnholm *et al.*,[1] allowed the identification of many rotational levels built on two quasiparticle configurations of ^{234}U. Boyno *et al.*[2] used the ^{234}U(d,d′) reaction to characterize the collective states, and reported eleven additional levels. At the same time, Maher *et al.*[3] showed that $K^\pi=0_2^+$ bands were strongly excited in (p,t) reactions, with differential cross sections of about one-fifth of that corresponding to the 0_1^+ ground state (g.s.) value; new types of collectivity were suggested for this 0_2^+ excitation, and several theories were developed to account for their properties.[4-8]

The ^{234}U levels can also be fed in the radioactive decay of ^{234}Pa which was extensively studied by Bjørnholm *et al.*,[9] Godart *et al.*,[10] and then by Ardisson and Ardisson.[11,12] The low-spin levels of ^{234}U fed in the decay of short-lived ^{234}Pa^m, were studied by Wapstra,[13] then by Ardisson and Marsol,[14,15] using a Ge(Li) detector and the γ-γ coincidence method. This last study revealed the existence of several new $I^\pi=1^\pm$ levels above the energy gap. Concerning the ^{234}Np electron capture (EC) decay, the previous measurements of Hansen *et al.*[16] and Wapstra[13] led to a relatively simple ^{234}U level scheme in which about 30 γ rays were placed among seven excited levels.

It seemed useful to reinvestigate the ^{234}Np decay in order to search what kind of low-spin levels fed in ^{234}Pa^m decay were also fed in ^{234}Np decay; for this measurement, we used a Ge(Li) detector with a greater active volume than used in Refs. 13 and 16.

II. CHEMICAL SEPARATION AND INSTRUMENTATION

The ^{234}Np isotope was produced by ^{235}U(d,3n) ^{234}Np reaction. A target of U_3O_8 (enriched to 97.6% in ^{235}U) was bombarded for 2 h in the 23-MeV deuteron beam of the Orleans isochronous cyclotron. At this energy, corresponding to the estimated maximum of the (d,3n) excitation function,[17] the (d,f) cross section reaches the value 1300±300 mb. Other inconvenient reactions were mainly the (d,2n) and (d,n) reactions on ^{235}U which, respectively, produce ^{235}Np (a pure EC emitter) and ^{236}Np ($T_{1/2}=22.5$ h) which emits only two γ lines. The same nuclear reactions on the ^{238}U isotope lead to ^{238}Np and ^{239}Np which have several known γ lines. After a cooling time of 6 h the target was dissolved in 1*M* HNO_3. First, the neptunium isotopes were carrier-free separated from fission products: Np and U were oxydized to the +6 state with a 0.25*M* $KMnO_4$ solution and quantitatively extracted into hexone from an aluminum nitrate salting solution.[18] The separation of the NpO_2^{2+} and UO_2^{2+} ions was then achieved: Np was stripped from the hexone phase by reduction to the 4^+ valence state with an $FeCl_2$,NH_2OH solution, then extracted with 0.5*M* thenoyltrifluoroacetone in xylene and back-extracted by an 8*M* HNO_3 solution. This procedure was repeated twice. A total decontamination of Zr^{4+} was observed, but traces of ^{125}Sn and ^{124}Sb were found at the 10 ppm level. The former could be eliminated by percolating the 8*M* HNO_3 solution on a Dowex 1X8 anion exchange column, and eluting the Np^{4+} with a 0.5*M* HNO_3 solution.

The counting equipment consisted of a Ge(Li) coaxial detector (Ortec) with an active volume of 65 cm^3, coupled to a cooled field effect preamplifier. The system resolution [full width at half maximum (FWHM)] measured in 4-μs pulses was 1.80 keV at the 1.33-MeV ^{60}Co photopeak. The analysis system consisted of a 4096 channels Scorpio Canberra ADC with a disk based PDP 11/34 computer system.

III. MEASUREMENTS

Several γ ray spectra of the ^{234}Np sources were measured with this spectrometer and their decays were fol-

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lowed for 5 d to identify all neptunium activities. Because of the weakness of the separated sources, a very close geometry was chosen and the sources were sandwiched between two 2-mm-thick aluminium sheets to annihilate the positrons produced in the ^{234}Np decay. The main peaks of the γ ray spectra were calibrated in energy by simultaneous counting runs with sources of ^{152}Eu, ^{137}Cs, and ^{207}Bi. The photopeak centroid positions were determined by a computer code assuming a Gaussian shape; the energy-channel relation was taken as a quadratic function using the least square method as it has been described elsewhere.[19] Efficiency calibration was determined over the entire energy range of interest using sources of ^{152}Eu, as well as several standard radioactive sources emitting two or more well-studied γ transitions, such as ^{207}Bi, ^{60}Co, or ^{133}Ba.

Figures 1 and 2 show typical parts of the ^{234}Np spectrum measured with a 0.49-keV per channel energy dispersion. In Table I we reported the energy and intensity values of the γ rays associated with the ^{234}Np decay, as well as the data published by Wapstra[13]; the values found in these two measurements are in good agreement and a total of 59 photon lines were observed in our work, 29 of which were found for the first time. The only discrepancy we could note concerns the intensity value of the 557-keV photon for which we measured half the intensity value given by Wapstra[13]; the photon lines given[13] at 706.5 and 807.0 keV happen to be a doublet of lines.

IV. DISCUSSION

As a basis for the construction of the ^{234}Np decay scheme shown in Fig. 3, we adopted the published level scheme of ^{234}U (Ref. 20) and used the summing relationship. Assuming a spin and parity assignment $KI^{\pi}=00^{+}$ for the ^{234}Np ground state, only low-spin levels of ^{234}U will be fed, as in ^{234}Pa^{m} decay.[15] Seven new levels, six of which were previously observed in ^{238}Pu or ^{234}Pa^{m} decays, were found to be fed in the ^{234}Np decay, and over 99.9% of the total γ-ray intensity measured is interpreted.

For most of the transitions, the electron conversion intensities were deduced from the theoretical α_T computed by Rösel *et al.*;[21] concerning the strong E0 transitions of 809.8 and 234.6 keV, we adopted the electron intensities measured by Hansen *et al.*[16] For the $M1+(E2)$ transitions at 140.1, 450.93, 719.01, and 1527.21 keV, we used the compiled values of Ref. 20 for the total conversion coefficient. Furthermore, we deduced the 43.48-keV ($E2$) and 99.850-keV ($E2$) transition intensities from the relative intensities given by Hansen *et al.*[16]

The EC feeding of each ^{234}U excited state was computed from the ($e^{-}+\gamma$) intensity balance. Using these experimental values and the theoretical $P_K/P_{L+M+\cdots}$ values from Martin and Blichert Toft,[22] we could deduce the number of K-shell vacancies due to the electronic capture at each excited level. The sum of these K vacancies added to those induced by the K internal conversion process gave the number of uranium x rays produced by means of the fluorescent yield value $\varpi_K=0.976$ (Ref. 23). The experimental U ($K\alpha+K\beta$) ray intensity was first corrected from the known ^{236}Np contribution by using the relative 642.41-keV γ ray intensity, and the $I_{X_K}/I_\gamma=2.98\times10^{-2}$ value from Lederer *et al.*[24] The difference between this experimental x ray intensity and the above calculated value, converted in K vacancies, is equal to the EC_K branch to the ^{234}U ground state. We finally corrected this intensity for capture in higher shells[22] to obtain the total ground state EC feeding. The EC intensities obtained by normalizing the total EC population to ^{234}U states at 100% are reported in Table II. This table also contains the logft values for each ^{234}U level, calculated with the reported $T_{1/2}=4.4$ d for ^{234}Np (Ref. 23). The g.s. population found in our work, i.e., 24.6%, is in good agreement with the value 25% found in the Ellis compilation,[20] but disagrees with the value published by Hansen *et al.*,[16] i.e., (33 ± 8)%. Assuming the theoretical ratio $EC/\beta^{+}=513$ (Ref. 25), we deduced for the β^{+} g.s. branch the value $I_{\beta^+}=0.048\%$ which agrees well with the experimental value $I_{\beta^+}=0.046\%$ (Ref. 26), but which diverges from the later value of Hansen *et al.*[16]: $I_{\beta^+}=0.084\%$.

In Table II we can note that all EC branches have logft values ranging from 6.2 to 10.5, i.e., characteristic of allowed or first forbidden transitions.[27] Special attention was paid to EC transitions to known $KI^{\pi}=00^{+}$ levels. Because of the suggested configuration $\{\frac{5}{2}+(633)_n-\frac{5}{2}+(642)_p\}$ for the ^{234}Np ground state, the spin and parity can only be 0^{+}; this assignment implies that EC transitions to 0^{+} levels should be isospin forbidden. The logft values of Table II were used to calculate the analogous state mixing amplitudes c^2 (Table III) which are related to the ft values by the relation[28]

$$2T_{\max}c^2=6260/ft\ ,$$

where $T_{\max}=25$ is the isospin value.

We turn now to the ^{234}U levels and their properties.

(a) Collective octupole levels. Experimental evidence from previous studies[2] points to a collective interpretation for $K^{\pi}=0^{-}$ and 2^{-} bands.

$K^{\pi}=0^{-}$ band at 786.28 keV. The two lower states $I^{\pi}=1^{-}$ and 3^{-} of this band are found to be fed in ^{234}Np decay. The $I^{\pi}=1^{-}$ state, previously known in this decay,[13,16] is directly fed by EC by a first forbidden transition (logft=8.6). This is expected from quasiparticle forbiddenness if the dominant configurations are those suggested by Ivanova *et al.*[29] in their collective interpretation of this band ($\{\frac{5}{2}+(633)_n;\ \frac{5}{2}-(752)_n\}$ 39%; $\{\frac{7}{2}+(624)_n;\ \frac{7}{2}-(743)_n\}$ 12%, and $\{\frac{3}{2}+(651)_p;\ \frac{3}{2}-(521)_p\}$ 7%); thus, according to the ^{234}Np proton configuration $\frac{5}{2}+(642)_p$ (Ref. 16), the major component gives a first forbidden unhindered transition and the two minor components require a simultaneous change of two quasiparticles. The $I^{\pi}=3^{-}$ state at 849.36 keV, fed by electromagnetic transitions from higher energy levels at 1085.33 keV ($KI^{\pi}=02^{+}$) and at 1237.24 keV (01^{-}), is observed for the first time in ^{234}Np decay; the branching ratio of the γ transitions to the 2^{+} and 4^{+} members of the ground-state band is very close to the value observed in ^{238}Pu decay,[20] and the corresponding E1 reduced intensity ratio is in good agreement with the Alaga intensity rule (Table IV); however, assuming this band may be mixed with the $K^{\pi}=1^{-}$ band at 1435.38 keV, the Coriolis coupling could be evaluated according to the following representation:

$$|\tilde{K}=1,I\rangle=|K=1,I\rangle+af(I)\,|K=0,I\rangle\ ,$$

$$|\tilde{K}=0,I\rangle=|K=0,I\rangle-af(I)\,|K=1,I\rangle\ ,$$

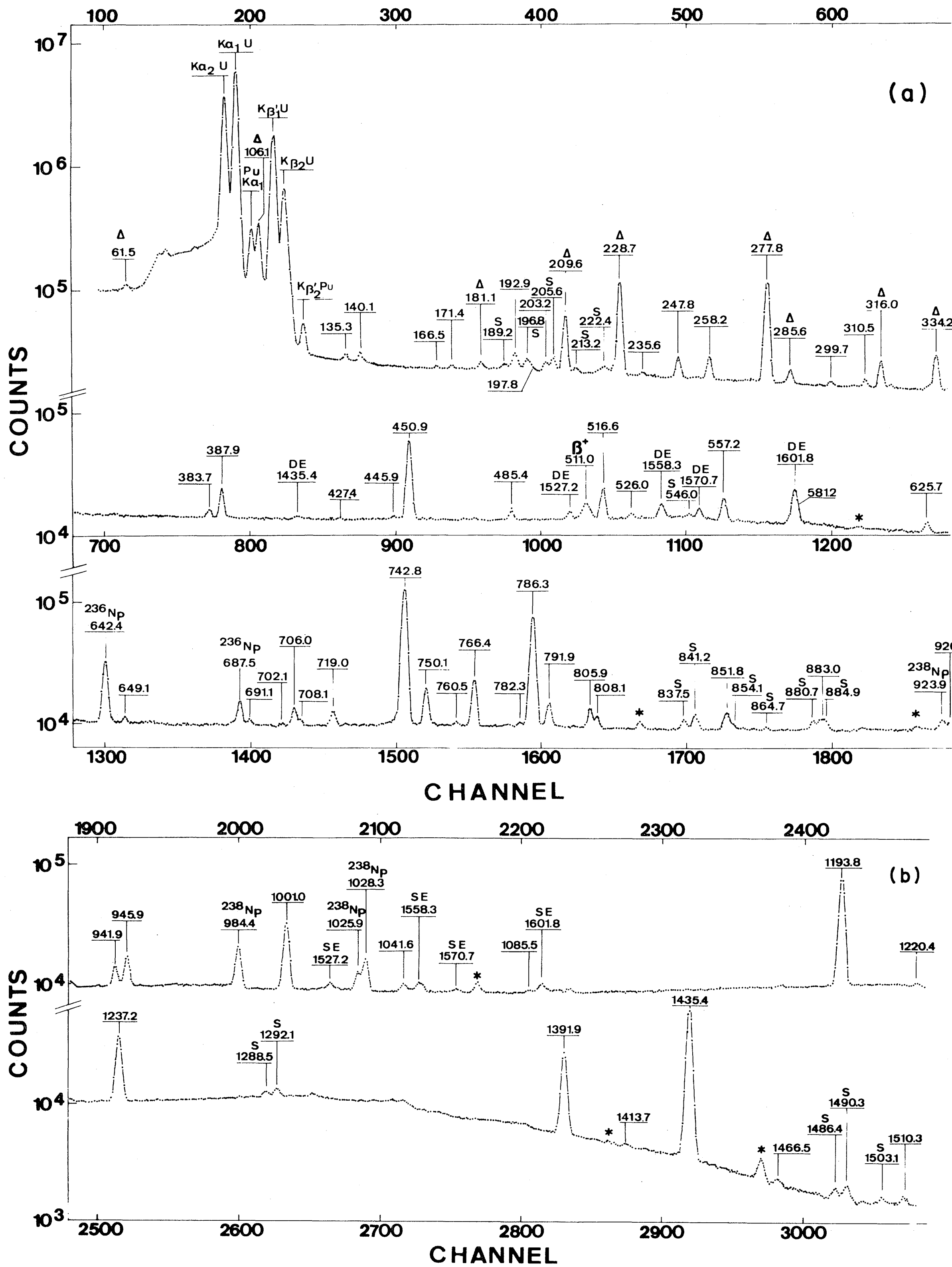

FIG. 1. Low energy spectrum of the γ rays from ^{234}Np decay recorded with a 65-cm^3 Ge(Li) detector. Energies in keV are rounded values. The symbol Δ is used for ^{239}Np γ lines, other Np isotopes are indicated. The symbol S stands for summing lines due to $K\alpha$ or $K\beta$ UX lines. $*$: natural background lines (^{40}K,^{226}Ra).

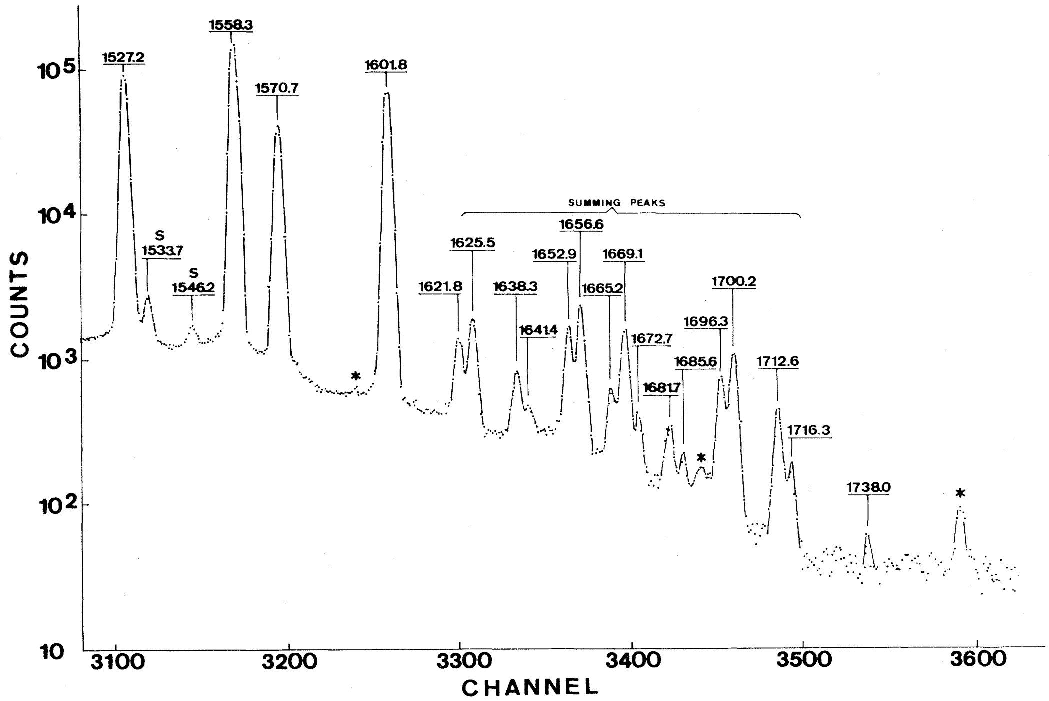

FIG. 2. High energy γ ray spectrum from ^{234}Np decay (see Fig. 1).

where $f(I)=|I(I+1)|^{1/2}$ and a is the amplitude mixing; the reduced transition probability ratio is given by

$$\frac{B(E1;I_i\to I_{f_1})}{B(E1;I_i\to I_{f_2})}=\frac{\langle I_i010\,|\,I_{f_1}0\rangle+z_0f(I)\langle I_i11-1\,|\,I_{f_1}0\rangle}{\langle I_i010\,|\,I_{f_2}0\rangle+z_0f(I)\langle I_i11-1\,|\,I_{f_2}0\rangle}\,,$$

where z_0 is related to the ratio of the reduced E1 matrix elements by

$$z_0=a\frac{\langle 11^-||E1||00^+\rangle}{\langle 01^-||E1||00^+\rangle}\,.$$

The z_0 values deduced for the two members $I^\pi=1^-$ and 3^- are $z_0=-0.005^{+0.011}_{-0.012}$ and $z_0=-0.0065^{+0.0050}_{-0.0093}$, respectively, with the mean value $z_0=-0.008\pm0.006$, showing a very weak coupling with the $K^\pi=1^-$ band; the mixing amplitude a, defined by $a=(-z_0z_1)^{1/2}$, was found to be $a=1.25\times10^{-2}$, using the z_1 value calculated below (see 1435.38-keV level).

Octupole band $K^\pi=2^-$ at 989.41 keV. This band is well known from the decay of neighboring nuclei[9–15] and from pick-up reaction studies on ^{235}U (Ref. 1). The $I^\pi=2^-$ band-head level is identified for the first time in ^{234}Np decay on the basis of energy relationships between deexciting γ rays to the 2^+ member of the g.s. band and to the 1^- and 3^- members of the $K^\pi=0^-$ octupole band; intensity ratios of the corresponding γ rays, i.e., 1/0.095/0.067, are in good agreement with analogous ratios measured in ^{234}Pa decay,[9] 1/0.071/0.054. The EC branch to this level is classified as a second forbidden transition and hence strongly hindered ($\log ft=10.5$).

1237.24-keV level, $KI^\pi=01^-$. This level, known from ^{234}Pa^m and ^{238}Pu decays,[20] feeds out to 0^+ and 2^+ members of the g.s. band, to 1^- and 3^- states of the $K^\pi=0^-$ octupole band, to the $I=0$ members of the two $K^\pi=0^+$ bands, and to the $KI^\pi=22^+$ vibrational band-head level. The reduced probability ratio of $E1$ transitions to the g.s. band (Table IV) confirms the $K=0$ assignment previously suggested.[13,16] We tentatively evaluated the Coriolis coupling with the $K^\pi=1^-$ band at 1435.38 keV; the value $z_0=0.085\pm0.012$ shows a stronger coupling over that with the first octupole band at 786.28 keV. The strongly collective character of this band was deduced from inelastic scattering of deuterons[2] although no theoretical model predicts such a $K=0$ band in this energy region.

(b) Collective $K^\pi=0^+$ bands. The three $I=0$ band-head levels at 0.0, 809.86, and 1044.52 keV are directly fed in ^{234}Np decay with high $\log ft$ values, as noted above; the 2^+ members of these bands are excited indirectly by γ feeding.

As concerns the β-vibrational band $K^\pi=0_2^+$, the reduced probability ratios of the assumed $E2$ transitions from the 2^+ state at 851.71 keV to $I^\pi=0^+$, 2^+, and 4^+ members of the g.s. band are 1.27/1/1.0 (Table IV) in moderate agreement with corresponding ^{238}Pu values (1.3/1/0.65); these ratios deviate from the theoretical

TABLE I. Energies and absolute intensities of γ rays following ^{234}Np decay. The brackets denote the uncertainties in the last digits of the energies and intensities; a, b, c, and d are, respectively, $K\alpha_1$, $K\alpha_2$, $K\beta_1'$, and $K\beta_2$ uranium X lines.

Present work		Wapstra (Ref. 10)	
E_γ (keV)	I_γ (% decays)	E_γ (keV)	I_γ (% decays)
94.645(50)[a]	18.5(9)		
98.428(50)[b]	31.0(15)		
111.24(6)[c]	10.7(6)		
114.48(6)[d]	3.77(23)		
135.32(8)	0.020(2)		
140.1(2)	0.029(3)		
166.5(1)	0.006(1)		
171.41(10)	0.011(2)		
192.91(7)	0.066(7)	192.9(5)	0.04(2)
197.91(15)	0.018(4)		
203.16(7)	0.041(4)		
235.62(10)	0.012(2)		<0.04
247.79(7)	0.109(7)	247.5(4)	0.12(4)
258.19(7)	0.119(8)	258.3(4)	0.12(4)
299.70(10)	0.021(2)	299(1)	0.02(1)
310.52(10)	0.039(4)	311.4(10)	0.04(2)
383.75(10)	0.042(5)		
387.94(6)	0.208(12)	388.3(5)	0.20(4)
427.4(2)	0.009(2)		
445.91(10)	0.020(4)		
450.93(4)	1.15(5)	451.0(4)	1.4(2)
485.44(7)	0.089(7)	484.4(8)	0.10(4)
516.60(6)	0.313(19)	517.2(6)	0.40(6)
526.02(10)	0.043(5)		<0.2
557.24(6)	0.214(13)	556.0(10)	0.50(6)
581.19(10)	0.38(4)		
625.66(7)	0.076(7)	625.0(15)	0.08(5)
649.12(10)	0.032(4)		
691.08(10)	0.038(4)		
702.11(20)	0.020(4)		
706.04(10)	0.153(9)	706.5(10)	0.24(12)
708.11(20)	0.052(6)		
719.01(7)	0.122(7)	720.5(10)	0.18(8)

$K=0$ values 0.7/1/1.8. For the 2^+ member of the second excited $K^\pi=0_3^+$ band, the $E1$ reduced probability ratio of the transitions to the octupole band is 0.82/1, the theoretical ratio being 0.67/1 for $K=0$.

Allowing for coupling between intrinsic and rotational motion, the perturbed wave function of the g.s., β, and γ bands can be expressed in terms of the unperturbed wave functions[29]

$$|00I\rangle = |00I\rangle_0 - \epsilon_\beta f_\beta(I)\,|10I\rangle_0 - \epsilon_\gamma f_\gamma(I)\,|12I\rangle_0\,,$$

$$|10I\rangle = |10I\rangle_0 + \epsilon_\beta f_\beta(I)\,|00I\rangle_0 - \epsilon_\gamma f_\gamma(I)\,|12I\rangle_0\,,$$

$$|12I\rangle = |12I\rangle_0 + \tfrac{1}{2}\{1+(-)^I\}\epsilon_\gamma f_\gamma(I)\,|00I\rangle_0 - \tfrac{1}{2}\{1+(-)^I\}\epsilon_{\beta\gamma} f_\gamma(I)\,|10I\rangle_0\,.$$

The corresponding expression of the $E2$ reduced probability ratios is given in Table V, with the aid of the coupling parameters[30] Z_β, Z_0, and Z_γ with the g.s. band, $\zeta_{\beta\gamma}$ and $\zeta_{0\gamma}$ with the γ band, and $Z_{\beta\gamma}$ with the β band. The Z_0 and $\zeta_{0\gamma}$ calculated values for the 1085.33-keV level are in agreement (Table V) with analogous values from ^{234}Pa^m decay,[15] $Z_0=(37.5\pm10.5)\times10^{-3}$ and $\zeta_{0\gamma}=(8\pm10)\times10^{-3}$.

(c) Higher energy intrinsic states. We note the following.

1435.38-keV level ($KI^\pi=11^-$). This level was identified earlier in ^{234}Np decay,[13,16] in ^{235}U(d,t) reaction studies and in ^{234}Pa^m decay.[15] Three weak new γ rays deexcite it (Fig. 3) to odd parity levels; although the reduced probability ratio to 0^+ and 2^+ members of the g.s. band confirms the $K=1$ assignment suggested elsewhere,[16] the existence of a 197.96-keV interband transition to the 1237.24-keV level leads us to assume there is Coriolis coupling between these two bands. The mixing parameter z_1 was derived from the reduced branching ratio of the γ rays deexciting it towards 0^+ and 2^+ states of the g.s. band by means of the following relation:

$$W(E1;I_i\to I_f)=\{\langle I_i 1 1 -1\,|\,I_f 0\rangle + z_1 f(I)\langle I_i 0 1 0\,|\,I_f 0\rangle\}^2$$

TABLE I. (*Continued.*)

Present work		Wapstra (Ref. 10)	
E_γ (keV)	I_γ (% decays)	E_γ (keV)	I_γ (% decays)
742.78(4)	5.27(21)	743.1(4)	5.4(6)
750.12(6)	0.440(26)	750.7(10)	0.5(2)
760.53(15)	0.020(4)		
766.37(5)	0.584(29)	766.6(6)	0.6(1)
782.32(15)	0.027(13)		
786.28(4)	3.19(13)	786.4(4)	3.1(4)
791.94(5)	0.254(15)	793.5(15)	0.20(15)
805.86(7)	0.182(19)		
808.13(10)	0.101(10)	807.0(10)	0.40(15)
851.77(6)	0.167(10)	851.7(10)	0.24(12)
883.04(15)	0.105(10)		
926.63(10)	0.068(7)		
941.93(17)	0.248(15)		
945.91(5)	0.432(26)	945.7(10)	0.6(2)
1001.05(5)	1.59(7)	1001.6(6)	1.6(3)
1041.62(10)	0.15(2)		
1085.45(15)	0.019(4)		
1193.78(4)	6.02(24)	1194.1(5)	5.8(6)
1220.38(15)	0.040(5)		
1237.22(4)	2.30(9)	1237.3(6)	2.4(3)
1391.87(4)	2.27(9)	1392.2(7)	2.2(4)
1413.6(3)	0.021(4)		
1435.36(4)	6.38(25)	1435.7(6)	6.6(6)
1466.5(2)	0.032(3)		
1510.35(15)	0.024(3)		
1527.21(4)	11.23(45)	1527.5(6)	12.4(12)
1558.31(4)	18.72(20)	1558.7(6)	20.0
1570.68(4)	5.09(21)	1570.7(6)	5.8(6)
1601.80(4)	9.15(37)	1602.2(6)	10.2(12)
1738.0(5)	0.003(1)		

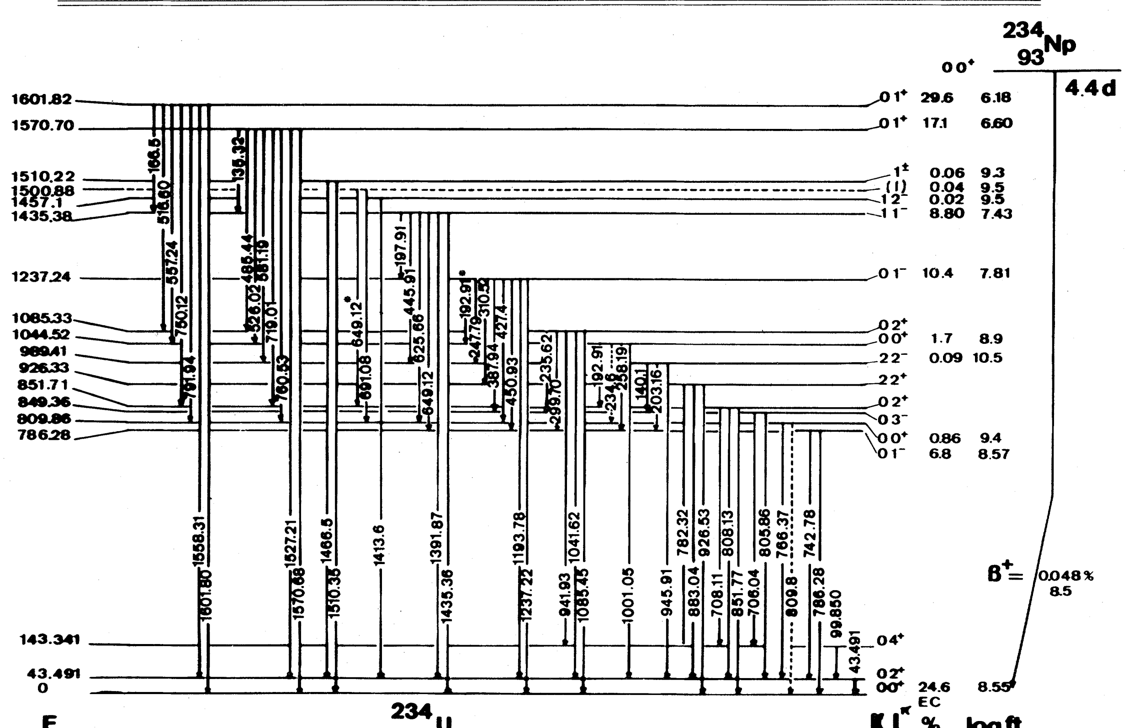

FIG. 3. Proposed decay scheme of ^{234}Np: the energy is given in keV. Dashed lines are E0 transition from Hansen *et al.* (Ref. 16). *: γ placed twice.

TABLE II. Energies and EC population of the ^{234}U levels fed in the ^{234}Np decay.

Present work				Hansen *et al.* (Ref 16)		
Level energy	KI^{π}	EC (%)	log*ft*	Level energy	EC (%)	log*ft*
0.0	00^+	24.6	8.55		33 ±8	8.4
		0.048(β^+)	8.5	0.0	0.084(β^+)	8.25
43.491(9)	02^+			43.4	0.4±0.4	
143.341(13)	04^+			143.31		
786.28(4)	01^-	6.8	8.57	786.1	6.2±1.4	8.6
809.86(5)	00^+	0.86	9.4	809.8	1.6±0.5	9.2
849.36(6)	03^-					
851.71(5)	02^+			851.4	0.4±0.4	
926.33(7)	22^+					
989.41(6)	22^-	0.09	10.5			
1044.52(4)	00^+	1.7	8.9	1043.5	0.9±0.4	9.2
1085.33(5)	02^+			1085.6	−0.4±0.4	
1237.24(2)	01^-	10.4	7.81	1237.4	8.3±1	7.8
1435.38(2)	11^-	8.80	7.43	1435.4	7.5±1	7.5
1457.1(3)	12^-	0.02	9.5			
1500.88(8)	$(1^{\pm})$	0.04	9.5			
1510.22(12)	$1^{\pm}$	0.06	9.3			
1570.70(2)	01^+	17.1	6.60	1570.3	15 ±2	6.7
1601.82(2)	01^+	29.6	6.18	1601.5	26 ±4	6.2

which yields $z_1 = -0.0285^{+0.005}_{-0.006}$, with the sign opposite to the z_0 value calculated for the 1237.24-keV level. Thus, for the amplitude mixing of these bands, we deduced the value

$$a = (-z_0 z_1)^{1/2} = 4.94\times 10^{-2}\ ;$$

the Coriolis matrix element, evaluated as

$$\langle 1^- || H_c || 0^- \rangle = | aE_c | = 9.7\ \text{keV}\ ,$$

is in agreement with an analogous value, i.e., 13 keV, calculated in ^{236}U by Lederer.[31] Moreover, assuming for the 197.96-keV interband transition $E2$ multipolarity and identical reduced probability to the $2^+_{\text{g.s}} \rightarrow 0^+_{\text{g.s.}}$ transition, we could deduce the half-life of the 1435.38-keV level: With the adopted values $\alpha_T = 724$ and

$$T_{1/2}(2^+_{\text{g.s.}}) = 0.252\times 10^{-9}\ \text{s}$$

(Ref. 20), for the 1435.38-keV level we found

$$T_{1/2} = 4.1\times 10^{-13}\ \text{s}\ ;$$

the 1435.36-keV γ partial half-life was derived, and then the corresponding hindrance factor:

$$F_W = T_{1/2}(E1)_{\text{exp}} / T_{1/2}(E1)_W = 9.2\times 10^3\ .$$

TABLE III. Squared amplitudes of $\Delta T = 1$ isospin forbidden EC transitions in ^{234}Np decay.

		C^2	
KI^{π}	E (keV)	Experimental value	Theoretical value
$0_1 0^+$	0.0	3.5×10^{-7}	
$0_2 0^+$	809.86	4.5×10^{-8}	1.25×10^{-5}
$0_3 0^+$	1044.52	1.6×10^{-7}	

The log*ft* value (7.43) of the EC branch feeding this state corresponds to an enhancement factor of 14 compared to $KI^{\pi} = 01^-$ levels at 786.28 keV, which is interpreted from the unique quasiparticle structure

$$\{\tfrac{7}{2}^-(743)_n - \tfrac{5}{2}^+(633)_n\}$$

deduced by Bjørnholm *et al.*[1] from pick-up reactions studies. Ivanova *et al.*[29] also predicted a two quasiparticle structure with this dominant configuration (63%); the corresponding EC transition

$$\tfrac{5}{2}^+(642)_p \rightarrow \tfrac{7}{2}^-(743)_n$$

is classified $a1u$ with $\Delta N = 1$, $\Delta n_z = 0$, $\Delta\Lambda = 1$; a similar value (log*ft* = 6.8) is observed for the same EC transition in ^{32}Np decay.[32]

The $I^{\pi} = 2^-$ state of this band, earlier observed at 1463.6 keV in ^{235}U(d,t) reactions[1] and at 1457.5 keV in ^{234}Pa^m decay,[15] is tentatively introduced in this decay scheme since we measured a weak 1413.6-keV γ transition to the 2^+ state of the g.s. band.

1570.70- and 1601.82-keV levels. These two $I^{\pi} = 1^+$ levels previously known from ^{234}Np and ^{234}Pa^m decays[13,15,16] are observed here, strongly fed by EC feeding, with log*ft* values of 6.60 and 6.18, respectively. Present data (Table IV) confirm their deexcitation to 0^+ and 2^+ members of the g.s. band, and add new transitions towards 0^+ and 2^+ of both $K = 0$ excited bands at 809.96 and 1044.52 keV; the reduced transition probabilities to these bands rule out the definitive $K^{\pi} = 0^+$ assignment for these two levels (Table III). Two weak transitions are measured outfeeding to the two quasiparticle level at 1435.38 keV. Consequently, we tentatively assigned the configuration $\{\tfrac{5}{2}^+(633) - \tfrac{5}{2}^+(622)_n\}$ for either level, which is the only $K^{\pi} = 0^+$ configuration suggested by Soloviev and Siklos[33] in this energy region (1.6 MeV). In addition, several excited $K^{\pi} = 0^+$ bands were predicted in the recent calculation

TABLE IV. Comparison of ratios of reduced transition probabilities in ^{234}Np decay with predictions of the Alaga rule.

Initial level		Final level		Transition	Reduced probability ratio		
E_i	$K_iI_i^{\pi_i}$	$K_fI_f^{\pi_f}$	E_f	multipolarity	Expt.		Theor.
786.28	01^-	00^+	0	$(E1)^a$	0.51 ± 0.03		0.50
		02^+	43.491	$E1^a$	1		1
849.36	03^-	04^+	143.341	$(E1)^a$	1.25 ± 0.15		1.33
		02^+	43.491	$(E1)^a$	1		1
851.71	02^+	00^+	0	$(E2)^a$	1.27 ± 0.15		0.70
		02^+	43.491	$E2+E0^a$	1		1
		04^+	143.341	$(E2)^a$	1.00 ± 0.12		1.80
926.33	22^+	00^+	0	$E2^a$	0.51 ± 0.07		0.70
		02^+	43.491	$E2^a$	1		1
		04^+	143.341	$(E2)$	0.47 ± 0.11		0.05
1085.33	02^+	00^+	0	$(E2)$	0.10 ± 0.02		0.70
		02^+	43.491	$(E2)$	1		1
		04^+	143.341	$(E2)^a$	2.74 ± 0.38		1.80
		01^-	786.28	$(E1)^a$	0.82 ± 0.15		0.67
		03^-	849.36	$(E1)^a$	1		1
1237.24	01^-	00^+	0	$E1^a$	0.34 ± 0.02		0.50
		02^+	43.491	$E1^a$	1		1
1435.38	11^-	00^+	0	$E1^a$	2.56 ± 0.15		2.00
		02^+	43.491	$E1^a$	1		1
						$K=1$	$K=0$
1500.88	$(1^\pm)$	00^+	809.86	$E1$ or $M1$	$1\ \pm0.15$	2.00	0.50
		02^+	851.71	$E1$ or $M1$	1	1	1
1510.22	$1^\pm$	00^+	0	$E1$ or $M1$	0.70 ± 0.10	2.00	0.50
		02^+	43.491	$E1$ or $M1$	1	1	1
1570.70	01^+	00^+	0	$M1^a$	0.41 ± 0.02		0.50
		02^+	43.491	$M1+E2^a$	1		1
		00^+	809.86	$(M1)$	0.12 ± 0.2		0.50
		02^+	851.71	$(M1+E2)^a$	1		1
		00^+	1044.52	$(M1)$	0.38 ± 0.14		0.50
		02^+	1085.33	$(M1)$	1		1
1601.82	01^+	00^+	0	$(M1)^a$	0.45 ± 0.04		0.50
		02^+	43.491	$M1$	1		1
		00^+	809.86	$(M1)$	0.49 ± 0.08		0.50
		02^+	851.71	$(M1)^a$	1		1
		00^+	1044.52	$(M1)^a$	0.54 ± 0.08		0.50
		02^+	1085.33	$(M1)^a$	1		1

[a]Reference 20.

of Sørensen[7] and Ragnarsson and Broglia[8]; below 2 MeV, on the eight expected levels from the pairing isomer theory,[8] only one configuration is possible if we require that EC feeding not be quasiparticle forbidden:

$$\{\tfrac{5}{2}^+(633)_{n1};\tfrac{5}{2}^+(622)_{n2}\}$$

at 1.468 MeV. Other configurations, such as $\{\tfrac{5}{2}^+(622)_n\}^2$ at 1.582 MeV, need a change of more than one particle orbit and thus should be forbidden.

Other levels. A 1500.88-keV level is tentatively proposed on the basis of two transitions which depopulate it to the 0^+ and 2^+ members of the β band; it was also found to be fed in ^{234}Pa^m decay.[14] In addition, if we identify it to the 1501.9-keV level observed in pick-up reactions on ^{235}U[1], negative parity could be expected for this level.

A new 1510.22-keV level is suggested, deexciting to the 0^+ and 2^+ members of the g.s. band; the corresponding reduced probability ratio is in agreement with the $K=0$ assignment (Table IV). The high logft value observed for this level could indicate a $1h$ EC transition, i.e., a negative parity state.

Although two $K^\pi=0^-$ configurations were predicted by Soloviev at this excitation energy,

$$\{\tfrac{5}{2}^-(752)_n-\tfrac{5}{2}^+(633)_n\}$$

at 1.7 MeV and

$$\{\tfrac{5}{2}^+(642)_p-\tfrac{5}{2}^-(523)_p\}$$

at 1.6 MeV, the identification at the above levels is excluded from quasiparticle forbiddenness arguments.

The γ transition of 1738.0 keV should arise from a 1780-keV level ($KJ^\pi=00^+$) (not shown on the level scheme), as observed in ^{234}Pa^m decay,[14] but no other argument supports the existence of this level.

TABLE V. Coupling between collective positive parity bands: $K^{\pi}=0_1^+$, 0_2^+, 0_3^+, and 2_1^+ are, respectively, the g.s., β, 1044-keV, and γ (at 926.33 keV) bands.

Transition ratios $\frac{K_iI_i\to 0_1I}{K_iI_i\to 0_1I'}$	Theoretical $(BE2)$ ratios	Correction factors	Experimental $B(E2)$ ratios	Calculated coupling parameters ($\times 10^{-3}$) From ^{234}Np decay	Others
$\frac{0_22\to 0_10}{0_22\to 0_12}$	0.70	$\frac{(1-6Z_\beta-12\xi_{\beta\gamma})^2}{(1+12\xi_{\beta\gamma})^2}$	1.27±0.20	$Z_\beta=-24\pm4$; $\xi_{\beta\gamma}=-7\pm4$	$Z_\beta=18(\xi_{\beta\gamma}=0)^a$
$\frac{0_22\to 0_10}{0_22\to 0_14}$	0.39	$\frac{(1-6Z_\beta-12\xi_{\beta\gamma})^2}{(1+14Z_\beta-2\xi_{\beta\gamma})^2}$	1.26±0.38		
$\frac{0_32\to 0_10}{0_32\to 0_12}$	0.70	$\frac{(1-6Z_0-12\xi_{0\gamma})^2}{(1+12\xi_{0\gamma})^2}$	0.32±0.06	$Z_0=46\pm8$; $\xi_{0\gamma}=3\pm4$	$Z_0=37,5\pm10,5^c$; $\xi_{0\gamma}=8\pm10$
				Mean average value: $Z_0=43\pm6$; $\xi_{0\gamma}=4\pm4$	
$\frac{0_32\to 0_12}{0_32\to 0_14}$	0.555	$\frac{(1+12\xi_{0\gamma})^2}{(1+14Z_0-2\xi_{0\gamma})^2}$	0.22±0.03		
$\frac{2_12\to 0_10}{2_2\to 0_12}$	0.70	$\frac{(1-Z_\gamma+2Z_{\beta\gamma})^2}{(1+2Z_\gamma-2Z_{\beta\gamma})^2}$	0.51±0.07	$Z_\gamma=29.5\pm3.5$; $Z_{\beta\gamma}>-19$	$Z_\gamma=25\pm12^b$; $Z_{\beta\gamma}\simeq-7$; $Z_\gamma=34(Z_{\beta\gamma}=0)^a$

[a]Phenomenological value (Ref. 34).
[b]In ^{238}Pu (Ref. 35).
[c]From ^{234}Pa^m decay (Ref. 14).

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