Low-lying level structures in the transuranic n-rich $Z = 93$ nuclei ^{243}Np and ^{244}Np

P. C. Sood and R. Gowrishankar
Department of Physics, Sri Sathya Sai Institute of Higher Learning, Prasanthi Nilayam (AP) 515134, India

(Received 28 July 2022; accepted 20 October 2022; published 4 November 2022)

Low-lying level structures of the neutron-rich transuranic Z=93 isotopes, namely, odd-mass ^{243}Np and its odd-odd neighbor ^{244}Np, are investigated with a view to characterize the respective ground state (gs) and to identify any long-lived isomer (LLI). For ^{243}Np levels, we critically examine all the available information from three sources, namely, experimental, systematics from isotopic and isotonic neighbor, and theoretical results from microscopic Nilsson model calculations. Our investigations conclude ^{243}Np gs J$^{\pi}$ and configuration to be 5/2^{-}[523 ↓] on all counts. For the odd-odd ^{244}Np, we employ our well-tested three-step two-quasiparticle rotor model (TQRM) to identify and evaluate excitation energies of low-lying (E_x $\leqslant$ 400 keV) 2qp bands and respective I(I+1) rotational levels. These calculations yield ^{244}Np gs to have J$^{\pi}$ and 2qp configuration as 2^{+}{p:5/2^{-}[523]⊗ n:9/2^{-}[734]} while confirming the earlier reported 7^{-}{p:5/2^{+}[642]⊗ n:9/2^{-}[734]} 2.29 m high-spin isomer (HSI) to be an excited state placed around E_x $\sim$ 100 keV. We also briefly discuss the earlier reported ^{244}Np β-decay branches of the K$^{\pi}$=7^{-} isomer and the admissible main β branches of K$^{\pi}$=2^{+} gs to the various levels in ^{244}Pu.

DOI: 10.1103/PhysRevC.106.054307

I. INTRODUCTION

As a part of our long-continuing investigations of low-lying level structures of odd-odd actinides [1,2], we report here the results of our critical study on such level structures of the transuranic n-rich Z=93 isotopes, namely, ^{243}Np and ^{244}Np. In this context, we have earlier reported the results of our similar investigations on the lighter Z=93 isotopes, namely, ^{236}Np [3], ^{238}Np [1,2], ^{240}Np [4], and ^{242}Np [5], and also of the N=151 odd-odd actinides ^{246}Am [6], ^{248}Bk [7], and ^{252}Md [8]. Against this background, primary motivation for the present study originates from the critical evaluation and incisive remarks by the respective nuclear data sheets (NDS) evaluators [9,10] highlighting the inconclusive, and often contradictory, suggested configuration assignments even to the ground state of these two Np isotopes.

Specifically, NDS2014 (A=243) evaluators [9] list, under ^{243}Np adopted levels, "t$_{1/2}$=1.85 m, J=(5/2) gs from systematics; π=+ for the lighter Np nuclei; however π= $-$ from possible gs band (gsb) assignment of 5/2[523] in ^{244}Pu(pol t, α) by Flynn *et al.* [11]." Taking due note of this contradictory (5/2+ or 5/2−) possible assignment (as also listed in NUBASE 2016 [12]) for the ^{243}Np core constituent of the odd-odd isotope ^{244}Np, the NDS2017(A=244) evaluator [10] considers information for ^{244}Np gs J$^{\pi}$ as "tentative," explicitly pointing out that "theoretical work [13] and systematics along with the Gallagher-Moszkowski rules [14] suggest either J$^{\pi}$=2^{+} or 7^{-}" as ^{244}Np gs configuration. The present study aims at finding definitive configuration assignments in each case following a critical and detailed examination of updated [15] available information coupled with results from application of various criteria, including experimental, theoretical (microscopic [16] and also model calculations), and systematics data. Preliminary results of these investigations have been reported earlier by us in the DAE (India) symposium [13] and cited in the arguments of the NDS evaluator in Ref. [10].

In Sec. II we take up in detail the spectroscopic information with respect to the odd-mass ^{243}Np isotope, focusing on the character of its ground state while taking note of the updated experimental data, level systematics in neighboring isotonic and isotopic sequences, and theoretical calculations of level energies in this domain. Section III includes a brief outline of our well-tested TQRM for odd-odd nuclei [2,17,18] and its applications to identify low-lying 2qp bands in ^{244}Np and evaluation of the respective bandhead energies. Section IV deals with analysis and discussion of our results in comparison with available experimental data. Summary and conclusions are presented in the last section.

II. LOW-LYING CONFIGURATION IN ^{243}Np

A. Experimental

The first identification of n-rich Z=93 isotope was reported in a 1979 paper from Los Alamos National Laboratory by Flynn *et al.* [11] in a ^{244}Pu($\overrightarrow{t}$, α) reaction wherein "twenty-two energy levels were observed in ^{243}Np, a nucleus previously unreported." Further using the analyzing power measurements, they "suggested the most likely spin assignments" for a number of ^{243}Np levels. In particular, they *uniquely determined* a (l-1/2) J$^{\pi}$ assignment for "the lowest excitation energy state" and hence concluded that "the 5/2^{-}[523 ↓] may indeed become the gsb here," and that "the gsb of lighter Np isotopes (namely 5/2^{+}[642 ↑]) is no longer the gs in ^{243}Np." In this context, it is significant to

TABLE I. Observed [15] excitation energy E_x (in keV) of two lowest levels in n-rich Pa (Z=91) isotopes.

$E_x(\mathrm{p}_i) \rightarrow$	E_x(keV): p orbital	
$^{A}\mathrm{Pa}_N$ $\downarrow$	$3/2^{-}1/2[530]$	$1/2^{+}[400]$
$^{231}\mathrm{Pa}_{140}$	0	(287)
$^{233}\mathrm{Pa}_{142}$	0	169
$^{235}\mathrm{Pa}_{144}$	0	19
$^{237}\mathrm{Pa}_{146}$	90	0

note that of all the expected or observed low-lying orbitals in ^{243}Np, namely, $5/2^{+}[642\uparrow]$, $5/2^{-}[523\downarrow]$, $1/2^{+}[400\uparrow]$, and $1/2^{-}[530\uparrow]$, only $5/2^{-}[523\downarrow]$ is the one with (l-1/2)J$^{\pi}$; all other three orbitals have (l+1/2)J$^{\pi}$, thus uniquely confirming J$^{\pi}$=$5/2^{-}$ gs assignment on the basis of these ($\vec{t}$, α) experiments.

The only other experiment "claiming discovery of ^{243}Np without quoting the work of Flynn *et al.* [11]" was reported eight years later from GSI (Germany) by Moody *et al.* [19]. They deduced ^{243}Np half-life $t_{1/2}$=1.85(15) min based on observing "an intense γ line at 287.7 keV corresponding to a $5/2[622\uparrow] \rightarrow 7/2[624\downarrow]$ transition in ^{243}Pu following ^{243}Np β-decay."

B. ^{243}Np gs J$^{\pi}$ from systematics

In the absence of any direct information on gs J$^{\pi}$ assignments, it is normal procedure to examine the corresponding data in neighboring isotopes/isotones. In the present case, systematics of single-particle (1qp) orbital energies [16] clearly indicate that the choice of ^{243}Np gs J$^{\pi}$ is limited to $5/2^{+}[642\uparrow]$ or $5/2^{-}[523\downarrow]$. Moody *et al.* [19] had concluded that "from the systematics of odd-proton actinides, it is impossible to state whether the gs Nilsson configuration of ^{243}Np is $5/2^{+}$ or $5/2^{-}$. NDS2014 evaluators [9] had also remarked that $5/2^{+}$ is favored from systematics of light Np nuclei, whereas $5/2^{-}$ is favored from (t, α) reaction studies [11]. Under these circumstances, we look for guidance from systematics observed in Z=91 (Pa) and Z=95 (Am) isotopic sequences on either side of the Z=93 (Np) isotopic sequence and also in the N=151 isotonic sequence in this domain.

1. Z=91(Pa) isotopic sequence

In an 1977 proton pickup (t, α) reaction study partly aimed at "studying the effect of increasing neutron number (N) on proton single-particle orbitals of $_{89}$Ac and $_{91}$Pa isotopes," Thompson *et al.* [20] had concluded that "due to increase in deformation with neutron number N, [the] ground-state (gs) configuration of Pa isotopes changes from $3/2^{-}1/2[530\uparrow]$ to $1/2^{+}[400\uparrow]$ as A increases." As seen in Table I, changes in gs configuration are observed near the end of the isotopic sequence with the crossover of the adjacent p orbitals as N increases.

2. Z=95(Am) isotopic sequence

In the Z=95 (Am) isotopes, crossing between the $5/2^{+}[642\uparrow]$ and $5/2^{-}[523\downarrow]$ is seen in going from A=239 to A = 245, as shown in Fig. 1. This crossover, seen in ^{245}Am with ϵ_2=0.22, "seems to be the result of a slight decrease in deformation," as pointed out by Jain *et al.* [16].

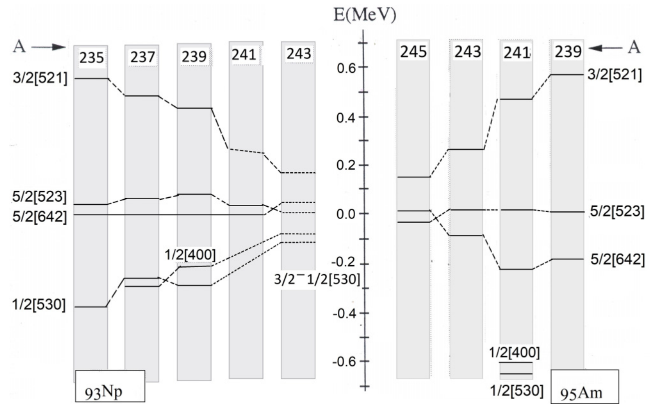


FIG. 1. Single-particle Nilsson orbitals in the odd-A Np isotopes (on the left) and odd-A Am isotopes (on the right), indicating the crossover of the $5/2^{+}$ - $5/2^{-}$ levels in the respective N=150 nuclides.

3. N=151 isotonic sequence

Rezynkina *et al.* [21] have explicitly brought to attention a similar occurrence of crossover of n single-particle orbitals in N=151 isotonic sequence close to the Fermi surface with the decrease of Z from 102(2)94 (with corresponding increase in N/Z ratio). The $9/2^{-}[734\downarrow]$ n orbital is observed as gs in all the known Z=94(2)104 odd-A nuclei. As shown in our Fig. 2, whereas a $5/2^{+}[622]$ n orbital is observed as the first excited state in all the N=151 isotones from ^{253}No through ^{247}Cm, with $7/2^{+}[624\downarrow]$ lying above it, the two-orbital crossover with $7/2^{+}[624\downarrow]$ observed as the first excited state, and $5/2^{+}[622\uparrow]$ shifted upwards in going from $^{247}_{96}$Cm to $^{245}_{94}$Pu.

C. ^{243}Np levels from theory

We now examine how the Nilsson single proton orbital energies are affected by the change in quadrupole deformation parameter (ϵ_2), which may come into play as we move away from the line of stability in this mass region. For this purpose, we look at our Fig. 3, which is an extract from Fig. 7 of Jain

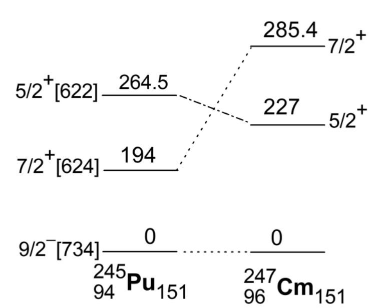


FIG. 2. Experimental [21] excitation energies (in keV) of the two lowest excited states in the ^{245}Pu and ^{247}Cm N=151 odd-A isotones clearly depicting the crossover of the $5/2^{+}$ and the $7/2^{+}$ orbitals as we proceed to the extremity of the N=151 isotonic sequence.

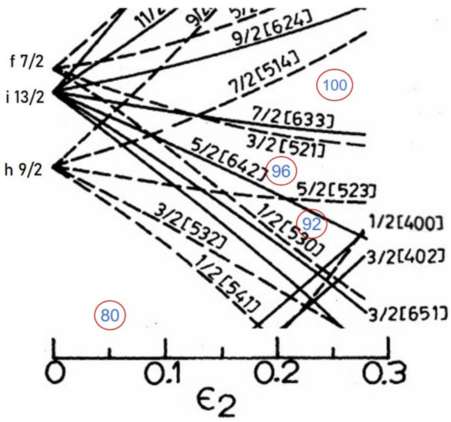


FIG. 3. Plot of proton eigenvalues [16] as a function of deformation using the classical modified harmonic oscillator (MHO) of Nilsson-Gustafson *et al.* [22] potential in the Nilsson [23] single-particle Hamiltonian.

et al. [16] highlighting the variation of energies of p orbital with $\epsilon_2 = 0$–0.28 and $\epsilon_4 = 0$ in the Z=93–95 region.

Looking at the total picture as of now, we observe the following:

(a) Flynn *et al.* [11] "uniquely determined (l-1/2) J^π assignment for the lowest energy state" and that "the $5/2^-[523\downarrow]$ may indeed become ^{243}Np ground state."
(b) Examining the relevant Fermi surface environment [16], we find that $5/2^-[523\downarrow]$ is exclusively the only (l-1/2)J^π state in this domain, while all the other low-lying orbitals, e.g., $5/2^+[642\uparrow]$, $1/2^+[400\uparrow]$, $1/2^-[530\uparrow]$, etc., have (l+1/2)J^π.
(c) Considering "systematic" evidence, we find that the ground state and nearby first excited state cross over with increase in N in both $Z = 93 \pm 2$ ($_{91}$Pa and $_{95}$Am) isotopic sequences, bringing about a change of gs character in n-rich (frontier) isotope.
(d) A similar crossover between low-lying levels is evidenced in the N=150 odd-A isotonic sequence with increase in N/Z ratio.
(e) Microscopic Nilsson model calculations aimed at Fermi surface level ordering with change of deformation parameter ϵ_2 also witness the crossover of the $5/2^-[523\downarrow]$ and the $5/2^+[642\uparrow]$ orbits within the Z=92–96 domain.

All these observations lead us to conclude, as remarked by Flynn *et al.* [11], that $5/2^-[523\downarrow]$ is *indeed* the ^{243}Np ground state.

III. MODEL FORMULATION AND EVALUATION

A. Model outline of TQRM formulation

In the Nilsson model for odd-A deformed nuclei, each single-particle (1qp) state is labeled by the asymptotic quantum numbers $\Omega^\pi[Nn_3\Lambda\Sigma]$ with $J^\pi = \Omega^\pi$. In the case of odd-odd nuclei, each 2qp configuration (Ω_n, Ω_p) gives rise to two bands with $K^\pm = |\Omega_p \pm \Omega_n|$. In accordance with the GM coupling rule [14], the parallel spin triplet band K_T is placed lower in energy than its antiparallel spin counterpart singlet band K_S. In our TQRM approach, which is a three-step process, we first identify the available single-particle (1qp) configuration space within a specified energy range by examining the experimental excitation spectra of the nearest neighbor odd-A isotope and isotone. As our second step, we enumerate the physically admissible 2qp bands for the odd-odd nuclei from the coupling of the 1qp p and n orbitals. Finally, we evaluate the bandhead energy for each (Ω_p, Ω_n) 2qp state using the following expressions [2,17]:

$$E(K : \Omega_p, \Omega_n) = E_0 + E_p(\Omega_p) + E_n(\Omega_n) + E_{rot} + \langle V_{pn}\rangle, \tag{1}$$

where E_p and E_n are the observed excitation energies of the corresponding Nilsson orbitals in the adjacent odd-A isotope/isotone, and

$$E_{rot} \approx \frac{\hbar^2}{2I}[K^\pm - (\Omega_p + \Omega_n)] = \frac{\hbar^2}{2I}(2\Omega_<)\delta_{K,K^-}\,, \tag{2}$$

$$\langle V_{pn}\rangle = -\left(\frac{1}{2} - \delta_{\Sigma,0}\right)E_{GM} + (-)^I E_N \delta_{K,0}\,. \tag{3}$$

The last term in Eq. (1) represents the contribution from the residual n-p interaction, which includes E_{GM}, the GM splitting energy for each doublet, and E_N, the odd-even Newby shift only for the K=0 bands. The term $\hbar^2/2I$ in Eq. (2) is the usual rotational band inertial parameter. While these model parameters can be evaluated theoretically, in our semiempirical approach, these are derived from the experimental data of any odd-odd neighbor wherein specified 2qp band has been identified. This is based on the assumption that these parameters are only configuration specific and not nuclei dependent. The parameters thus deduced are used as inputs in Eqs. (1)–(3) along with E_p and E_n values from the latest available data files [15].

B. Evaluated level energies in ^{244}Np

In the present case of ^{244}Np, the single-particle orbitals have been obtained from the observed levels in the Z=91, 93, and 95 isotopic sequence for the protons as discussed previously. With respect to n orbitals, the experimental 1qp levels within an energy range $E_x < 300$ keV, as observed in the N=151 isotones, are considered. The physically admissible 2qp bands arising from the coupling of the 1qp p and n orbitals are listed in Table II. Finally, using the data from Table II as inputs, the 2qp bandhead energies have been evaluated using Eqs. (1)–(3). The plot of the physically admissible 2qp bandheads and their model calculated energies (up to 400 keV) is shown in Fig. 4, serving as location guides.

IV. ANALYSIS AND DISCUSSION

Even before the first identification of ^{244}Np was reported [19], we [6] had critically investigated its next immediate odd-odd isotonic neighbor ^{246}Am by mapping its low-energy 2qp intrinsic structures, evaluating the relevant 2qp bandhead energies and its various other features. It turns out that the low-lying level scheme of these two isotones have very similar, albeit occasionally contrary, features. Both

TABLE II. Physically admissible 2qp GM doublet bands in $^{244}_{93}Np_{151}$ arising from coupling of the 1qp *p* orbitals (top row) and the *n* orbitals (first column). Numbers beside p_i/n_j are E_x(keV), and those within parentheses are summed $[E(p_i)+E(n_j)]$ energies in keV.

p_i → n_j ↓	p_0:0 5/2⁻[523 ↓] K_T K_S	p_1:28 5/2⁺[642 ↑] K_T K_S	p_2:76 1/2⁺[400 ↑] K_T K_S	p_3:105 3/2⁻1/2[530↑] K_T K_S	p_4:154 3/2⁻[521 ↑] K_T K_S
n_0:0 9/2⁻[734 ↑]	2^+ 7^+ (0)	7^- 2^- (28)	5^- 4^- (76)	5^+ 4^+ (105)	6^+ 3^+ (154)
n_1:194 7/2⁺[624 ↓]	6^- 1^- (194)	1^+ 6^+ (222)	3^+ 4^+ (270)	3^- 4^- (299)	2^- 5^- (348)
n_2:265 5/2⁺[622 ↑]	0^- 5^- (265)	5^+ 0^+ (293)	3^+ 2^+ (341)		

nuclei each have a high-spin (J^π=7⁻) isomer and also a low-spin (J=2) isomer with similar 2qp configurations. Our present analysis takes due note of ^{246}Am level assignments and their characterization [24]. Our TQRM has presented in Fig. 4 complete 2qp intrinsic level structures in ^{244}Np up to a specified excitation energy. These results are open to confirmatory and other exploratory studies. However, at the present state of our knowledge, herein we confine ourselves to the characterization of already identified 2.29 m HSI and to ascertain the existence of a low-spin isomer (LSI) which may also be its ground state. Observed and admissible β decay of these isomers to ^{244}Pu levels is also discussed.

A. 2.29 m ^{244}Np HSI

In 1987, Moody *et al.* [19] had newly identified the transuranic Z=93 *n*-rich β-decaying nuclide ^{244}Np. Experimentally observing a cascade of γ's populating ground-state rotational band levels with J^π as high as 8^+ in the daughter nucleus ^{244}Pu, they concluded the parent state to be a high-spin isomer with $t_{1/2}$ = 2.29 min. Further considering the constituent *p* and *n* orbit configuration, they opined that this HSI might have J^π = (7⁻). This pioneering study reported over 35 years ago and constrained by then-available limited information had specifically pointed to the need for further exploratory investigations at each step; a few of these explicit pointers are briefly mentioned below.

(a) We *cannot exclude* the existence of a shorter-lived isomer.
(b) The odd neutron is *probably* in the 9/2⁻[734] orbital.
(c) Spin of the observed ^{244}Np nuclide *might be* J^π = 7⁻.
(d) We *assume* that the 681-keV γ-ray feeds the 8^+ member of the ground-state band.
(e) There is *probably* a level in ^{244}Pu at 1218 keV.
(f) We *tentatively* assign J^π = (7,8⁺) to the 1218 state.

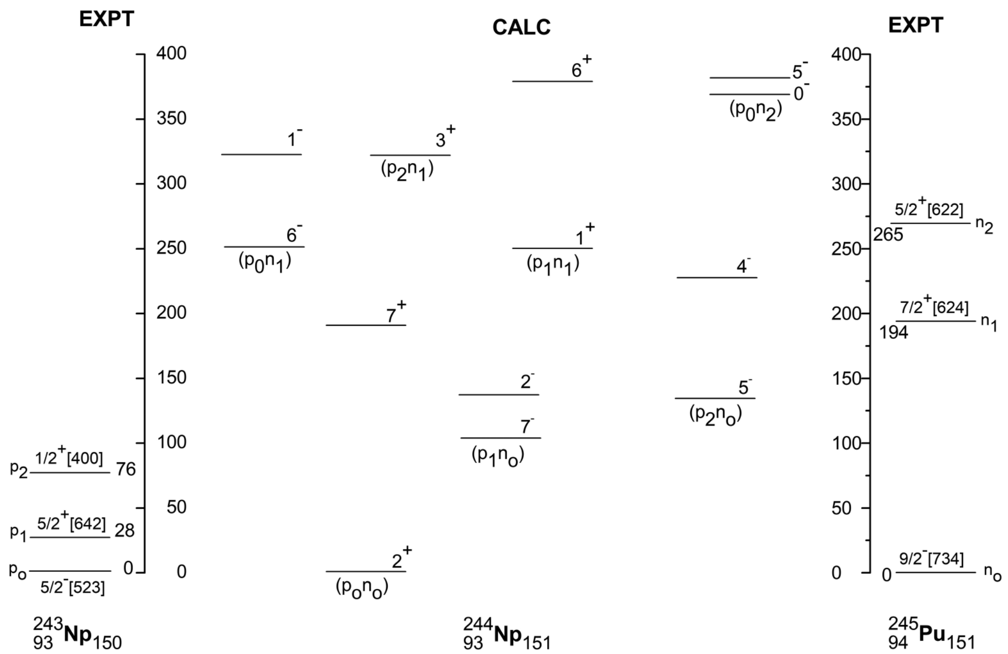
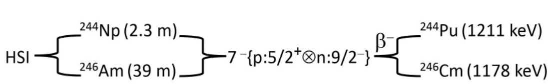


FIG. 4. Plot of model calculated energies of 2qp bandheads up to 400 keV in ^{244}Np (center) constructed from the experimental proton 1qp orbitals (on left) and the neutron orbitals (right).

Surprisingly, even though ^{244}Np appears in numerous α-decay chains of several transfermium and superheavy nuclei, not a single report is available [25] investigating the properties of the nuclei. Herein we report the results of a ^{244}Np level scheme using our well-tested three-step TQRM while incorporating the related updated data from neighboring nuclei. Our considered pointwise response to the above-mentioned pointers is as follows:

(a) Our analysis concludes the existence of a shorter-lived lower-lying isomer ($K^\pi = 2^+_g$ discussed in the next section), as conjectured by Moody *et al.* [19].
(b) The N=151 odd neutron is found to occupy the $9/2^-[734\uparrow]$ orbital in all odd-n even-mass isotopes.
(c) Spin parity of the ^{244}Np 2.29-m HSI is confirmed to be $J^\pi = 7^-\{5/2^+[642\uparrow] \otimes 9/2^-[734\uparrow]\}$.
(d) In the current level scheme of ^{244}Pu [15], the 681-keV γ is experimentally (not assumed) established to connect the 1211-keV ^{244}Pu level to its 530-keV 8^+ gsb rotational level.
(e) There is a well-established (not probable) level at 1211 keV in ^{244}Pu which has the two-neutron configuration $J^\pi K = 8^-8\{9/2^-[734]_n \otimes 7/2^+[624]_n\}$ and isomeric ($t_{1/2}$ = 1.75 s) character due to large K hindrance (ΔK = 8). Very similar 8^- configuration states have been experimentally observed around the same energy range in N=150 even-even isotones ranging from Z=94(2)102 nuclei.
(f) Moody *et al.* had deduced log ft = 6.3 for the 2.29-m (7^-) ^{244}Np $\rightarrow$ 1218-keV ^{244}Pu level and found it consistent with a 1f transition value. Accordingly, they have tentatively assigned $J^\pi = (7,8^+)$ to the daughter state. Presently this tentative assignment is seen to be incorrect; as discussed above, the 1211-keV ^{244}Pu daughter state has firmly concluded $J^\pi = 8^-$ assignment.

Taking into consideration the presently available information and our above analysis, we conclude that the previously identified 2.29-m $J^\pi = 7^-$ ^{244}Np state is not its ground state but is placed around $E_x \sim 100$ keV above the LSI ($K^\pi = 2^+$) gs, which is discussed in the next section below. We confirm the spin parity and configuration of HSI as $7^-\{5/2^+[642\uparrow]_p \otimes 9/2^-[734\uparrow]_n\}$. This HSI primarily β decays, populating the $8^-\{7/2^+[624]_n \otimes 9/2^-[734]_n\}$ 1211-keV ^{244}Pu level as shown in Fig. 5. Due to highly K-forbidden (ΔK = 7) character, there is no observable direct β feeding to the (6^+, 8^+) levels of the $K^\pi = 0^+$ gsb of ^{244}Pu. It is of interest to take note of occurrence of a similar HSI in the next odd-odd isotonic nucleus ^{246}Am which has the same spin-parity 2qp configuration and similar decay feature, as illustrated below.



B. ^{244}Np low-spin isomer and gs

The current data sheets for A=244 [10] lists the ^{244}Np gs as $J^\pi = 7^-$, using the analogy that the 93rd proton is probably in the 5/2[642] state similar to A=235(2)241 Np isotopes. However, in light of the arguments presented in our Sec. II and on the basis of our TQRM calculations, we unambiguously establish the gs configuration of ^{244}Np as

$$^{244}\text{Np (gs)}: 2^+\{\text{p}:5/2^-[523] \otimes \text{n}:9/2^-[734]\}.$$

As discussed in the previous section, we conclude that the $2^+(p_0n_0)$ constitutes a low-spin isomeric state as conjured by Moody *et al.* The probable β decay of this gs (LSI) to some of the levels of ^{244}Pu is elucidated below.

Examination of the data for the listed levels of ^{244}Pu in the current data sheets [10] reveals that $5/2^-[523]$ is a common constituent of the 2qp structure between the ^{244}Np gs $2^+(p_0n_0)$ and ^{244}Pu gsb. Hence β decay of the ^{244}Np gs to the $K^\pi = 0^+$ and $I^\pi K = 2^+0$ of the ^{244}Pu gsb is probable. Thompson *et al.* [26] had reported a level at 957 keV with a $I^\pi K$ assignment of 3^-2 in ^{244}Pu. Robinson *et al.* [27] in their experimental studies on the $K^\pi = 2^-$ octupole bands in N=150 isotones observed that the major component of its wave function is the $2^-\{9/2[734] \otimes 5/2[622]\}$ two-neutron configuration. With the 9/2[734] being a common constituent between this level and ^{244}Np gs, one could expect a β branch.

Thompson *et al.* [26] also reported a collective state at 1015 keV. Based on the comparison of B(E2) and B(E3) values, they assigned a spin parity of $J^\pi = (2^+)$ to this level. A β branch to this level from ^{244}Np gs can thus be expected. These physically admissible β branches from levels of ^{244}Np to the levels of ^{244}Pu are depicted in Fig. 5.

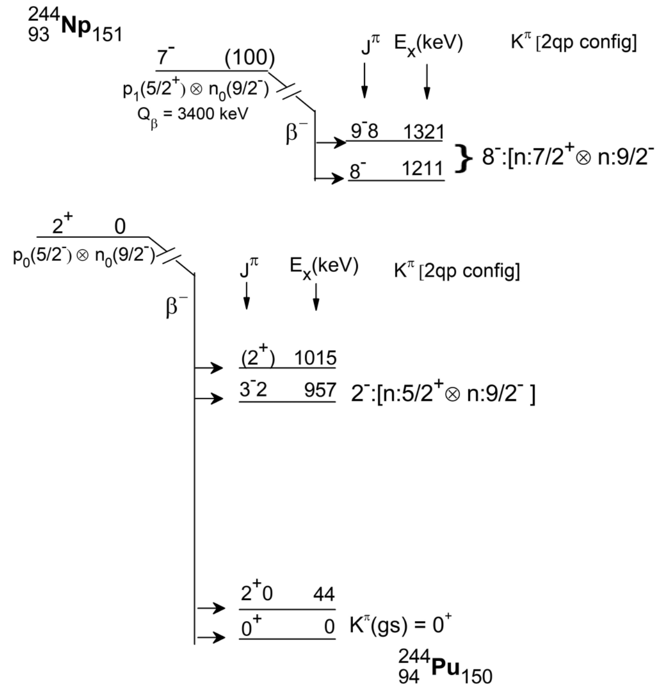


FIG. 5. Schematic plot of the admissible β branches from ^{244}Np to the levels of ^{244}Pu.

V. SUMMARY AND CONCLUSIONS

As a part of our continuing program of elucidation of low-lying (including ground-state and long-lived isomers) levels of transuranic nuclei, we have presented herein the results of our investigations of level structures of the odd-mass Z=93 nucleus ^{243}Np and its immediate odd-odd neighbor ^{244}Np. In respect of $^{243}_{93}$Np$_{150}$ levels, we particularly focused on the characterization of its ground-state spin parity J$^{\pi}$ and Nilsson model asymptotic quantum number configuration. In the process, we have critically examined all the available information under three heads, namely, experimental, systematics, and theoretical. Based on this analysis, we firmly conclude that ^{243}Np gs J$^{\pi}$ with a configuration of 5/2^{-}[523 ↓], with its neighbor 5/2^{+}[542 ↑] appearing as an excited state.

With respect to ^{244}Np, we have employed our three-step well-tested two-quasiparticle rotor model (TQRM) to evaluate the bandhead energies up to ≈ 400 keV excitation of all the admissible 2qp (p$_i$ ⊗ n$_i$) structures and also considered the respective I(I+1) dependent rotational level energies. Our investigations confirm the occurrence of already reported 2.29-min high-spin isomer [15,19] with the assigned 2qp configuration J$^{\pi}$K = 7^{-}7{p$_1$:5/2^{+}[642] ⊗ n$_0$:9/2^{-}[734]}, which, however, does not correspond to ^{244}Np gs but is an excited state with E_x ∼ 100 keV. We conclude that the lower-lying low-spin isomer with 2qp configuration J$^{\pi}$K = 2^{+}2{p$_0$:5/2^{-}[523] ⊗ n$_0$:9/2^{-}[734]} is the ^{244}Np gs, as conjectured by Moody *et al.* [19].

Taking note of the latest ENSDF [15] data (particularly of ^{244}Pu level characterizations), we conclude that the primary β-decay branch from 2.29-m ^{244}Np HSI with J$^{\pi}$K = 7^{-}7{p$_1$:5/2^{+}[642] ⊗ n$_0$:9/2^{-}[734]} populates the 1211-keV ^{244}Pu level with J$^{\pi}$K = 8^{-}8{n$_1$:7/2^{+}[624] ⊗ n$_0$:9/2^{-}[734]}, in contrast with J = (7,8^{+}) suggested [19] to the postulated 1219-keV daughter level in ^{244}Pu. Further, β decay of the proposed 2^{+} gs of ^{244}Np could populate the low-spin rotational levels of K$^{\pi}$ = 0^{+} gsb of ^{244}Pu. In addition, β-decay of ^{244}Np 2^{+} gs can be expected to populate 957-keV 3^{-}2 rotational level of the octupole band and the 1015-keV (2^{+}) collective state of ^{244}Pu.

Thus our TQRM evaluation of the low-lying intrinsic 2qp spectrum and the respective level energies of the odd-odd n-rich transuranic nuclide $^{244}_{93}$Np$_{151}$ brings into focus several new features for the first time after over 35 years of its initial identification. This nucleus also appears in the α-decay chains of transfermium and superheavy nuclei. As such, further exploratory and confirmatory studies of these phenomena shall be keenly awaited.

ACKNOWLEDGMENTS

We gratefully acknowledge the involvement and certain contributions over the years by K. V. Sai, K. Jena, and A. Shekhar to this project.

[1] P. C. Sood and R. N. Singh, Nucl. Phys. A **373**, 519 (1982).
[2] P. C. Sood, D. M. Headly, R. K. Sheline, and R. W. Hoff, At. Data Nucl. Data Tables **58**, 167 (1994).
[3] P. C. Sood, Z. Phys. A **318**, 111 (1984).
[4] P. C. Sood, R. Gowrishankar, and A. K. Dora, Phys. Rev. C **89**, 034308 (2014).
[5] P. C. Sood, Phys. Scr. **29**, 540 (1984).
[6] P. C. Sood, Phys. Rev. C **29**, 1556 (1984).
[7] P. C. Sood and R. N. Singh, Z. Phys. A **314**, 219 (1983).
[8] P. C. Sood, P. M. Jodidar, and R. Gowrishankar, Phys. Rev. C **103**, 014310 (2021).
[9] C. D. Nesaraja and E. A. McCutchan, Nucl. Data Sheets **121**, 695 (2014).
[10] C. D. Nesaraja, Nucl. Data Sheets **146**, 387 (2017).
[11] E. R. Flynn, D. L. Hanson, and R. A. Hardekopf, Phys. Rev. C **19**, 355 (1979).
[12] G. Audi, F. G. Kondev, M. Wang, W. J. Huang, and S. Naimi, Chin. Phys. C **41**, 030001 (2017).
[13] R. Gowrishankar, K. Jena, A. Sekhar, K. Vijay Sai, and P. C. Sood, in *DAE (India) Symp. on Nuclear Physics* (BARC, Mumbai, India, 2015), Vol. 60, p. 76.
[14] C. J. Gallagher and S. A. Moszkowski, Phys. Rev. **111**, 1282 (1958).
[15] *Evaluated Nuclear Structure Data File (ENSDF) and XUNDL* (May 2022 Version), continuously updated data files (NNDC, Brookhaven, NY).
[16] A. K. Jain, R. K. Sheline, P. C. Sood, and K. Jain, Rev. Mod. Phys. **62**, 393 (1990).
[17] A. K. Jain, R. K. Sheline, D. M. Headly, P. C. Sood, D. G. Burke, I. Hrivnacova, J. Kvasil, D. Nosek, and R. W. Hoff, Rev. Mod. Phys. **70**, 843 (1998).
[18] D. M. Headly, R. K. Sheline, P. C. Sood, R. W. Hoff, I. Hrivnacova, J. Kvasil, D. Nosek, A. K. Jain, and D. G. Burke, At. Data Nucl. Data Tables **69**, 239 (1998).
[19] K. J. Moody, W. Bruchle, M. Brugger, H. Gaggeler, B. Haefner, M. Schadel, K. Summerer, H. Tetzlaff, G. Herrmann, N. Kaffrell *et al.*, Z. Phys. **A328**, 417 (1987).
[20] R. C. Thompson, W. Wilcke, J. R. Huizenga, W. K. Hensley, and D. G. Perry, Phys. Rev. C **15**, 2019 (1977)
[21] K. Rezynkina, A. Lopez-Martens, K. Hauschild, I. Deloncle, S. Peru, P. Brionnet, M. L. Chelnokov, V. I. Chepigin, O. Dorvaux, F. Dechery *et al.*, Phys. Rev. C **97**, 054332 (2018).
[22] C. Gustafson, I. L. Lamm, B. Nilsson, and S. G. Nilsson, Ark. Fys. **36**, 613 (1967).
[23] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat. Fys. Medd. **29**, 16 (1955).
[24] E. Browne and J. K. Tuli, Nucl. Data Sheets **112**, 1833 (2011).
[25] *Nuclear Science Reference* (May 2022 Version), comprehensive Source of Nuclear Physics Bibliographic Information (NNDC, Brookhaven NY).
[26] R. C. Thompson, J. R. Huizenga, and T. W. Elze, Phys. Rev. C **12**, 1227 (1975).
[27] A. P. Robinson, T. L. Khoo, I. Ahmad, S. K. Tandel, F. G. Kondev, T. Nakatsukasa, D. Seweryniak, M. Asai, B. B. Back, M. P. Carpenter *et al.*, Phys. Rev. C **78**, 034308 (2008).