Characterization of ground states of $^{243, 244}$Np

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As a part of our long-continuing investigations of low-lying level structures of odd-odd actinides we report here the results of our study on the level structures of transuranic n-rich Z=93 isotopes, namely ^{243}Np and ^{244}Np. The primary motivation for the present study originates from the critical evaluation and incisive remarks by the respective Nuclear Data Sheets (NDS) evaluators [1,2], highlighting the inconclusive, and often contradictory, suggested configuration assignments even to the ground state (gs) of these two Np isotopes. Specifically, the NDS2014 [1] evaluators list j=5/2 from systematics for the gs of ^{243}Np with both possibilities for the parity. Taking note of this contradictory $5/2^+$ or $5/2^-$ assignment for the ^{243}Np core constituent of the doubly odd ^{244}Np, the NDS2017 [2] evaluator considers information on ^{244}Np gs as 'tentative'. The present study aims at finding definitive configuration assignment in each case following a careful and detailed examination of updated [3] available information coupled with results from various criteria including experimental, theoretical and systematics data.

The first identification of n-rich Z=93 isotope was reported in 1979 by Flynn *et al.* [4], wherein, using the analysing power measurements they uniquely determined (*l*- ½) J^π assignment for the lowest excitation energy state. They hence concluded that '$5/2^-$[523↓] may indeed become the gsb' and that the 'gsb of lighter Np isotopes $5/2^+$[642↑] is no longer the gs of ^{243}Np'. It is significant to note that, of all the observed low-lying orbitals in ^{243}Np, namely $5/2^+$[642↑], $5/2^-$[523↓], $1/2^+$[400↑] and $1/2^-$[530↑], only $5/2^-$[523↓] is the one with (*l*-½)J^π, all other three orbitals have (*l*+½)J^π, thus uniquely confirming J^π=$5/2^-$ gs assignment on the basis of their experiments. In the absence of any direct information on gs J^π assignments, it is normal procedure to examine the corresponding data in neighbouring isotopes/isotones. In the present case the systematics of single particle orbital energies (1qp) restrict the choice for ^{243}Np gs to $5/2^+$[642] or $5/2^-$[523]. Inconclusive results from Moody *et al.* and remarks from NDS evaluators makes us look for guidance from systematics observed in Z=91 (Pa) and Z=95 (Am) isotopic sequences on either side of Z=93 (Np) isotopic sequence and also in the N=151 isotonic sequence.

In an 1977 proton pickup (t,α) reaction study [5], Thompson *et al*. had concluded that 'due to increase in deformation with neutron number N, gs configuration of Pa isotopes changes from $3/2^-$1/2[530] to $1/2^+$[400] as A increases'. As seen in Table 1, changes in gs configuration is observed near the end of the isotopic sequence with the crossover of the adjacent p-orbitals as N increases.

Table 1: Observed [3] excitation energy Ex (in keV) of two lowest levels in n-rich Pa (Z=91) isotopes.

p-orbital $I^\pi K$	$^{231}_{91}Pa_{140}$	$^{233}_{91}Pa_{142}$	$^{235}_{91}Pa_{144}$	$^{237}_{91}Pa_{146}$
$3/2^-$ 1/2[530]	0	0	0	90
$1/2^+$[400]	(287)	169	19	0

Similarly, In the Z=95 (Am) isotopes, crossing between the $5/2^+$[642] and $5/2^-$[523] is seen in going from A=239 to A=245. This cross over, 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.* [6]. On the other hand, we find similar occurrence of crossover of n-single particle orbitals in N=151 isotonic sequence close to the Fermi surface. As explained by Rezynkina *et al*. [7], whereas $5/2^+$[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] lying above it, the two orbitals crossover in going from ^{247}Cm to ^{245}Pu.

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. 1, which is an extract from Fig. 7 of Jain *et al*. [6] highlighting the variation of energies of p-orbital with ε_2 = 0 to 0.28 and ε_4 = 0 in the Z=93-95 region. As seen in Fig.1, the crossover of the two orbitals in question is evident.

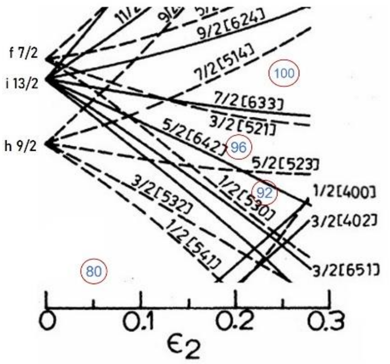

Fig. 1: Plot of proton eigenvalues as a function of deformation (extract from [6]).

In the light of the above observations, we confirm the following configuration assignment for ^{243}Np gs: **^{243}Np (gs): 5/2$^-$[523↓]**

Turning our attention to the doubly odd n-rich ^{244}Np, we use the well-tested Two Quasiparticle Rotor Model (TQRM) to determine the low-lying levels. For this, first we map the relevant 1qp configuration space from the neighbouring odd-A nuclei for the p and n orbitals and enumerate the 2qp GM doublet bands arising from the coupling of these p and n orbitals. A partial list of the physically admissible 2qp bandheads is given in Table 2.

Table 2: Physically admissible 2qp GM doublet bands (K_T & K_S) in ^{244}Np.

p_i E_p	p_0 0 5/2$^-$[523↓]		p_1 28 5/2$^+$[642↑]		p_2 76 1/2+[400↑]	
n_j E_n	K_T	K_S	K_T	K_S	K_T	K_S
n_0 0 9/2$^-$[734↑]	2$^+$	7$^+$	7$^-$	2$^-$	5$^-$	4$^-$
n_1 194 7/2$^+$[624↓]	6$^-$	1$^-$	1$^+$	6$^+$	3$^+$	4$^+$

Next, we evaluate the bandhead energies using the TQRM expressions [8]. Fig. 2 shows the plot of the model calculated bandhead energies.

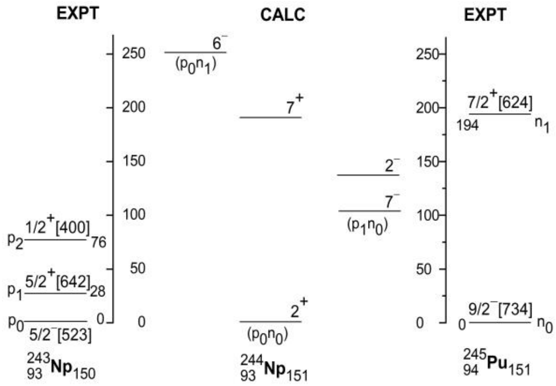

Fig. 2: Plot of model calculated energies of some of the low-lying 2qp bandheads in ^{244}Np.

In conclusion, our analysis unambiguously establishes the gs configuration of **^{244}Np as 2$^+${5/2$^-$[523]⊗ 9/2$^-$[734]}.** The current data sheet for A=244 lists only 3 beta branches for the decay of ^{244}Np to the levels of ^{244}Pu. These beta radiations are supposedly originating from the beta decay of the 7$^-$ (gs) as listed in the NDS2017 [2]. However, our analysis reveals that the 7$^-$ {5/2+[642]⊗9/2-[734]} state lies around 100 keV above the gs which, in the absence of gamma decay to the 2$^+$ gs, will be a β-decaying isomeric state. Our investigations also point out that there could be at least 6 beta branches originating from ^{244}Np to the levels of ^{244}Pu. Detailed level scheme indicating admissible β-branches is under preparation. We hope that our analysis provides valuable guidance for further studies on these two isotopes.

References

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