Investigations of Long-lived isomers in transuranic actinides

R. Gowrishankar* and P.C. Sood
Department of Physics, Sri Sathya Sai Institute of Higher Learning, Prasanthinilayam - 515134, A.P., INDIA
** email: rgowrishankar@sssihl.edu.in*

Observation of Islands of Long-Lived Isomers (LLI), corresponding to ΔI≥4 between the ground state (gs) and the excited state had played a vital role in establishing the validity of magic numbers and the (spherical) nuclear shell model more than 6 decades ago. Similar occurrences have been found for the nuclei of the deformed region. During recent years, several global compilations of nuclear isomers have been undertaken [1-3]. An early survey of LLIs in deformed nuclei [4], examined the single particle (1qp) Nilsson level diagram for transuranic (deformed region) nuclei, shown in Fig. 1. They concluded that, whereas for odd-A (both for odd-Z and odd-N) nuclei of this region ΔI ≤ 3 (and hence absence of LLI with $t_{1/2} \geq 1$ sec), several low-lying 2qp (p⊗n) neighbouring states have ΔI≥5 thus resulting in the absence of gamma decay and hence in the ambiguity for the energy placement or even ordering of the isomer with respect to the corresponding gs in odd-odd nuclei.

In case of even-even nuclei, as briefly discussed earlier [5], high spin K-isomers (K ≥ 6) are expected for $E_x > 1$ MeV and $t_{1/2} << 1$s. A critical examination of current data [6] confirms occurrence of 2qp $K^{\pi} = 6^+$:nn[$5/2^+ \otimes 7/2^+$] high spin isomers in N=148 isotones and $K^{\pi} = 8^-$:nn[$7/2^+ \otimes 9/2^-$] in N=150 isotones (barring 1198 keV 1.9s $K^{\pi}=8^-$ isomer in ^{250}Fm). A similar 2qp $K^{\pi}=8^-$: pp[$7/2^- \otimes 9/2^+$] isomer has been observed at 1295 keV in $^{254}_{102}No_{152}$

From detailed examination of the then available experimental data, Sood and Sheline [4] discussed specific features of 12 known LLI pairs wherein gs was defined for only 3 cases. Further, they predicted occurrence of such LLI pairs in several other nuclei of this region. A critical survey of the presently available data [6] reveals that no significant progress in respect of proper characterization of the known LLI pairs of this region has been made over the past 30 years. For instance, although known for over 60 years, ^{236}Np ($t_{1/2} > 10^5$y) LLI has not been characterised.

Over the years, Sood and collaborators [4,7-10] have developed a 3-step Two Quasi-particle Rotor Model (TQRM) to address this situation. The modle involves scanning the 1qp orbitals, enumerating the admissible 2qp GM doublets and evaluating the 2qp bandhead energies with the inclusion of residual n-p interaction. We propose to summarize some of the significant findings from this pursuit.

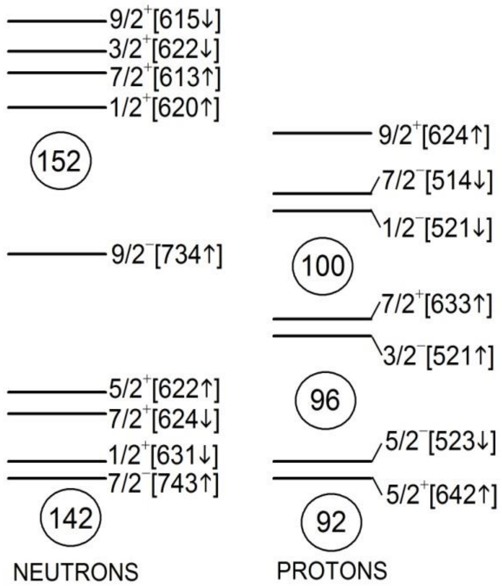

Fig. 1: Schematic (not to scale) single particle Nilsson level diagram for actinides.

In particular, a recent analysis [8] predicts the occurrence of of $K^{\pi}=7^-$ and $K^{\pi}=0^-$ isomer pair in ^{250}Md bringing to light another case of violation of the GM rule. In our investigation on ^{240}Np levels [9], we conclude that the two isomers of ^{240}Np constitute a GM doublet with the 2qp configuration 5^+\{p5/2[642]±5/2[622]\}0^+, with the $K^{\pi}=5^+$ spins parallel band identified as 62m ^{240}Np gs while the higher-lying 7.2m isomer is assigned a low spin $J^{\pi}K=1^+0$ configuration. Similarly, in our investigation [10] of the level structures of doubly odd heavy actinide ^{254}Md, we characterize the two known isomers and suggest the 10m ($J^{\pi}K=1^-0$) isomer as the gs of ^{254}Md with the 28m ($J^{\pi}K=3^-3$) isomer lying closely above it.

Table 1: Presently known [6] long-lived ($t_{1/2}$>1s) isomer pairs in doubly odd transuranic actinides.

${}^{A}_{Z}X$	Longer lived			Shorter lived		
	$t_{1/2}$	I^{π}	E_x	$t_{1/2}$	I^{π}	E_x
${}^{236}_{93}Np$	153x10^{3} y	(6-)	0.0	22.5h	1( )	?
${}^{240}_{93}Np$	61.9 m	(5+)	0.0	7.22 m	(1+)	?
${}^{242}_{93}Np$	5.5 m	(6+)	?	2.2 m	(1+)	0.0
${}^{236}_{95}Am$	3.6 m	5-	0.0	2.9 m	(1-)	?
${}^{242}_{95}Am$	141y	5-	48.60	16.02h	1-	0.0
${}^{244}_{95}Am$	10.1 h	(6-)	0.0	26m	1+	88.6
${}^{246}_{95}Am$	39 m	(7-)	0.0	25 m	2(-)	30
${}^{248}_{97}Bk$	>9y	(6+,8−)	?	23.7 h	1(-)	?
${}^{250}_{99}Es$	8.6 h	(6+)	0.0	2.22 h	1(-)	200(150)
${}^{254}_{99}Es$	275.7 d	(7+)	0.0	39.3 h	2+	84.2
${}^{256}_{99}Es$	7.6 h	(8+)	?	25.4 m	1+,0-	0.0
${}^{246}_{101}Md$	4.4 s	?	?	0.9 s	?	?
${}^{254}_{101}Md$	28 m	?	?	10 m	?	?
${}^{258}_{101}Md$	51.5 d	(8-)	0.0	57 m	(1-)	?

We have examined the experimental results as entered in the current NNDC database [6] to find that 14 isomer pairs, as listed in Table 1, are presently known in the odd-odd transuranic actinides. In this table, all uncertain assignments of spin-parity are shown within brackets while the undetermined energies are denoted by question mark. As evident therein, even today unambiguous spin-parity and 2qp configuration assignments of the many known LLIs and their relative energy placements remain elusive.

In this talk, we address these questions and highlight some of the distinctive features of these isomers unique to this mass region. In this process, we first outline the method by which we characterise the isomer pairs and their relative placements. Our investigations also suggest occurrence of an 'Island of Long-Lived Isomers' in the region just below N=152 deformed shell closure. Specifically, our analysis points to the existence of an LLI pair in each of the 12 nuclides having N=147(2)151.

References

[1] G. Audi et al., Chin. Phys. C (HEP&NP), **36** (2012) 1157.

[2] A. K. Jain et al., Nucl. Data Sheets, **128** (2015) 1.

[3] F. G. Kondev et al., At. Data Nucl. Data Tables, **103–104** (2015) 50.

[4] P.C. Sood and R K Sheline, Nucl. Instr. Methods **B24/25** (1987) 473.

[5] R. Gowrishankar et al., Proc. DAE Symp. Nucl. Phys. **57** (2012) 330.

[6] ENSDF, XUNDL, and NWC data bases at NNDC, August 2017 version.

[7] P. C. Sood *et al.*, At. Data Nucl. Data Tables **58** (1994) 167, and references therein

[8] P. C. Sood, *et al.*, Intl. J. Mod. Phys. **E9**, (2000) 309.

[9] P. C. Sood, R. Gowrishankar and A. K. Dora, Phys. Rev **C89** (2014) 034308.

[10] P. C. Sood and R. Gowrishankar, Phys. Rev. **C95** (2017) 024317.