Description and prediction of Long-lived Isomers in the $_{101}$Md Isotopic Chain

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As a part of our continuing investigations on level structures of the odd-odd deformed nuclei, including the occurrence and characterization of long-lived isomers (LLI) therein, we have lately focused on nuclei of the heavy actinide region. In this report, we briefly present the results of such investigations for the even mass [A=246 (2) 258)] isotopes of first transfermium species, namely Mendelevium (Z=101). A similar exercise on this topic was carried out over 30 years ago [1]. A factual summary of the first identifying experiments on each Z > 100 nuclide (including all the Md isotopes) and the later experiments confirming their discovery, has been recently presented by Thoennessen [2]. The first identification of a Z=101 nuclide (^{256}Md) was reported from Berkeley in 1955. Subsequently isotopes with A=254-258 and with A=248-253 were discovered [2] in 1970 and in 1973 respectively. However, even after 45 years, level structures (even for gs) remain elusive in each of these nuclei. Presently available data on LLI in even-A Md isotopes from the current data bases [3] is summarized in Table 1. A critical examination of these data leads us to following observations.

Table 1: ENSDF/XUNDL (August 2018) based listing of long-lived isomers in even-A (246-258) $_{101}$Md isotopes.

^{A}Md	$t_{1/2}$	E_x	J^π
246(a)	0.9 s	0+x	?
246(b)	4.4 s	0+y	?
248	7 s	0.0	?
250	52 s	0.0	(7^-)
252	2.3 m	0.0	(1^+)
254(a)	10 m	0+x	?
254(b)	28 m	0+y	?
256	77.7 m	0.0	(1^-)
258(a)	51.5 d	0	(8^-)
258(b)	57 m	0+x	(1^-)

a) In 5 (out of 10) known LLI, no J^π (and hence no configuration) has been mentioned.

b) For each of the other 5 LLI, a tentative J^π has been *suggested* from 'analogy to (A-1) isotope/isotone and GM rule ordering' [3], with no experimental or theoretical inputs.

c) LLI pairs are known in only 3 (out of 7) isotopes under consideration; the relative energy spacing is not known (or even estimated) in any of them. Whereas eight 2qp options are listed [3] for low lying levels in ^{254}Md, for low-spin ^{258}Md four different configurations and even a different J^π are suggested [4].

We present here the characterization of known isomer pairs, and prediction of LLI in other cases. Firstly we report our results on the characterization [6] of known isomer pair in ^{254}Md. Next we present a detailed step wise calculation of level energies leading to prediction of higher-lying high-spin isomer in ^{252}Md. Finally we present the case of ^{250}Md wherein detailed calculations lead to a revision of the gs spin-parity.

We evaluate the bandhead energies of all the physically admissible 2qp GM doublets within specified energy domain using our well-tested 3-step Two Quasiparticle Rotor Model {TQRM} [5,6] employing the expression:

$$E(I,K) = E_0 + \left(E_p + E_n\right) + E_{rot} + < V_{np} >;$$

$$E_{rot} \approx -\frac{\hbar^2}{2I}(2\Omega_<)\delta_{\mathrm{K,K^-}};$$

$$< V_{np} > = -\left[\frac{1}{2} - \delta_{\Sigma,0}\right] E_{GM} + (-)^I E_N \delta_{K,0}. \quad (1)$$

^{254}Md: The bandhead energies of the physically admissible 2qp states were evaluated using our TQRM analysis. Critical examination of the results rules out high-spin assignment to both the isomers and instead leads us to the following assignments for the LLI pair with the 10 m isomer being designated as the gs of ^{254}Md [6]:

10 m gs $1^-0\{p:1/2^-[521]\otimes n:1/2^+[620]\}$
28 m 0+x $3^-3\{p:7/2^-[514]\otimes n:1/2^+[620]\}$

^{252}Md: The latest data sheets (NDS) [3] lists only a 2.3 m isomer as ^{252}Md gs with possible $1^+\{7/2^-[514]\otimes n{:}9/2^-[734]\}$ assignment. In Table 2, we list all the physically admissible 2qp bands for $(E_p+E_n)\leq 350$ keV and the TQRM calculated energies of these 8 lowest ^{252}Md bands are plotted in Fig 1. Our analysis thus predicts the existence of a high-spin $K^\pi=8^+$ LLI at ~150 keV and possibly another shorter lived $K^\pi=4^+$ isomer at ~ 100 keV.

Table 2: Physically admissible 2qp GM doublet bands (K_T & K_S) in ^{252}Md for $(E_p+E_n) \leq 350$ keV.

p_i E_p \ n_j E_n	n_0 0 $9/2^-[734\uparrow]$		n_1 200 $5/2^+[622\uparrow]$	
p_0 0 $7/2^-[514\downarrow]$	1^+	8^+	1^-	6^-
p_1 55 $1/2^-[521\downarrow]$	4^+	5^+	2^-	3^-

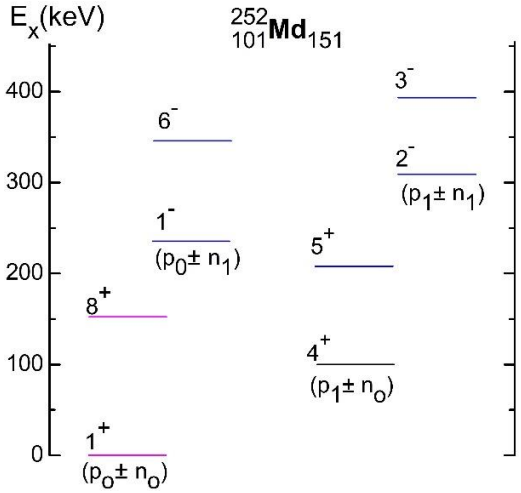

Fig 1: Calculated bandhead energies of the low-lying eight 2qp states in ^{252}Md using notations of Table 2.

^{250}Md: As given in the latest NDS [4], straightforward coupling of the 101st p orbital $7/2^-[514]$ and the 149th n-orbital $7/2^+[624]$ yields $K^\pm = 7^-$ & 0^- as GM doublet bands, with GM rule placing spins-parallel $K_T = 7^-$ lower (and hence ^{250}Md gs). However, as evident from our Eq. (1), there are 2 additional energy contributions specifically for the $K^\pi=0^-$ band. As detailed in

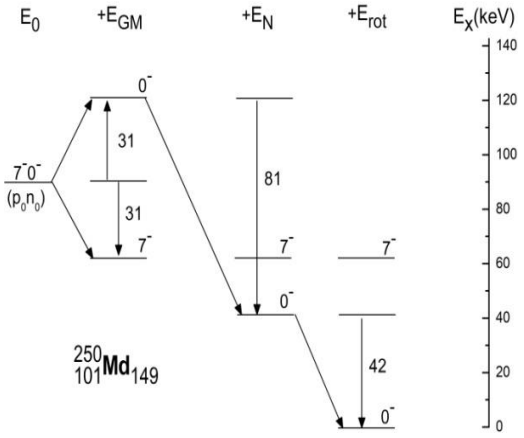

Fig. 2: The term-wise contribution to the bandhead energies of the gs GM pair showing the placement of $K_S = 0^-$ below the $K_T = 7^-$ state.

our reference [7] and illustrated in Fig. 2 here, these contributions bring the $K^\pi=0^-$ level below the $K_T=7^-$ level thus making the $K^\pi=0^-$ as ^{250}Md gs. The $K^\pi=7^-$ level appears as a higher-lying (~60 keV) high-spin longer-lived isomer.

Possible occurrence of isomer pairs in the other two Md isotopes, namely ^{248}Md and ^{256}Md are being investigated. For example, the latest (2017) NDS assigns $I^\pi K=1^-0\{7/2^-[514]\otimes n{:}7/2^+[613]\}$ to the 78 m ^{256}Md gs with no mention of the location of its $K^\pi=7^-$ GM counterpart. This surely constitutes a longer lived higher-lying high-spin state in ^{256}Md, a mention of which is made in NUBASE 2016 [3].

References

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