Nanosecond isomers in near-spherical ^{142,143}Pm

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In-beam measurements of nanosecond lifetimes have been undertaken for some of the excited states in near-spherical nuclei ^{142,143}Pm using the pulsed-beam γ coincidence technique and the generalized centroid-shift method of analysis. The ^{133}Cs(^{13}C,xn) reaction with a 60 MeV pulsed beam of ^{13}C was used to populate the excited states in the respective nuclei. The measured mean lifetimes have been compared with corresponding single-particle estimates.

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The prediction and discovery of the high-spin yrast traps around ^{146}Gd in the late 1980s [1] led to the belief that an island of high-spin isomers exists in the region $64 \leqslant Z \leqslant 71$ and $N \geqslant 82$. As a result of limitations in experimental arrangements, isomers with $T_{1/2} \leqslant 20$ ns could not be observed in the earlier measurements. Very recently, a number of new high-spin isomers have been reported [2] for Eu and Sm nuclei with $Z=63,62$ and $N=82,83$ which exhibit interesting systematics in their excitation energies, half-lives, and spins. It is suggestive of the likely extension of the predicted island of isomers below $Z=64$ and warrants similar measurements in the neighboring Pm nuclei with $Z=61$. We have recently investigated the high-spin states in ^{142}Pm [3] and ^{143}Pm [4] using the ^{133}Cs (^{13}C,xn) reaction and extended the level schemes considerably, which depict an irregular yrast sequence, typical of near-spherical nuclei. It is observed that the intensity balances of feeding and deexciting γ rays for some of the states in ^{143}Pm are not consistent, though their placement could be fixed up from the observed intensities in the relevant gated spectra. This discrepancy may be attributed to the presence of unobserved γ rays as well as isomers at moderate and high spin and excitation energies. In order to explore the scenario, we have undertaken in-beam measurements of nanosecond lifetimes in ^{142,143}Pm excited states using ^{13}C pulsed beam and the reaction ^{133}Cs(^{13}C,xn) at $E=60$ MeV.

The present experiment was performed at the BARC-TIFR 14UD Pelletron Accelerator at Mumbai. The target was prepared by vacuum evaporation of ultraspecture (99.99%) $CsNO_3$ on gold backing (5 mg/cm^2) in a controlled condition [5]. The target thickness was ≈ 800 μg/cm^2. The beam pulsing system [6] consists of a double-drift harmonic buncher at low energy and a rf sweeper at the high-energy end. These are phase locked with respect to a master oscillator using an amplitude and phase control unit. The system provided ^{13}C pulsed beam with a period of 213 ns and a typical beam width of ≈ 2 ns. A prompt time resolution [full width at half maximum (FWHM)] of ≈ 12 ns, without any energy selection, was obtained in this experiment with a Ge clover detector. The data were acquired in list mode and sorted off line into a (4096×512) add-back energy-time matrix, from which the background-subtracted time distributions were projected against various γ rays of interest, already known from our earlier studies [3,4]. The time distributions were analyzed for most of the cases by means of the centroid shift method [7], except for a few cases, where the spectra have substantial delayed component. The half-lives were determined by the slope method for the said cases and compared with the previous measurements in order to test the reliability of the present mesurements. Figure 1 shows a typical delayed time spectrum corresponding to 234.9 keV γ ray in ^{143}Pm, which dexcite the levels at 1898.3 ($15/2^+$) keV (cf. Fig. 5 of Ref. [4]). In the same figure, the prompt time distribution corresponding to 535.6 keV transition, deexciting 5115.9 keV ($31/2^-$) level, is shown for comparison. The half-life extracted for the 1898.3 keV level by the slope method corroborates well within error with the same obtained from earlier measurements and adopted in Nuclear Data Sheets [8]. In extracting lifetime information from the first moment of the time distributions, necessary steps, as described in Ref. [7], were followed. Unlike conventional $\gamma\gamma$ delayed concidence measurements the interpo-

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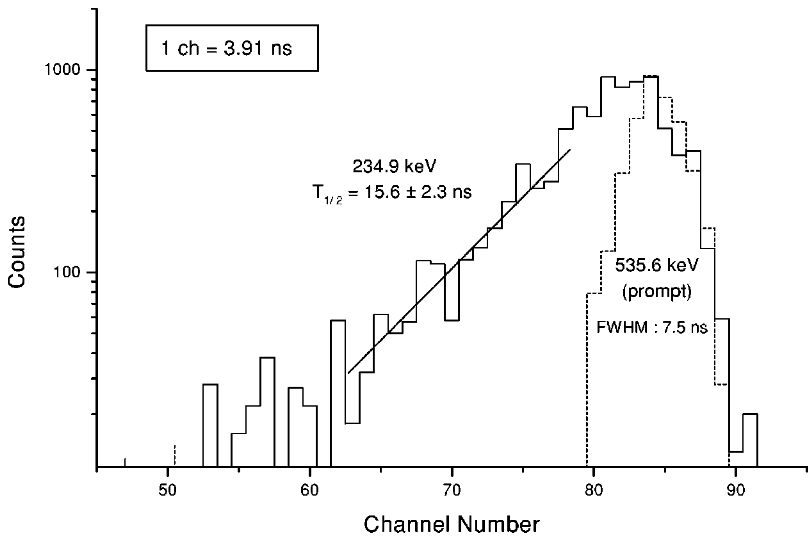

FIG. 1. Typical beam–γ-time spectra corresponding to 234.9 keV (delayed) and 535.6 keV (prompt) gates.

lated background time distributions cannot be regarded as prompt in the present case. Hence, the prompt distributions were obtained from the projections against known uncontaminated prompt γ-ray deexcitations belonging to ^{142,143}Pm and other beam-related well-known prompt γ rays. These time distributions were analyzed to extract their centroids. A numerical fit of these prompt centroids gives the so-called "zero-time line," which is shown in Fig. 2. In the same figure, other centroids, which show reasonable deviation from the said line and are classified as delayed, have also been plotted. From the measured difference between the time centroid and the corresponding interpolated value, obtained from Fig. 2, the mean lifetimes of the levels, corresponding to the γ-ray deexcitations, have been deduced, which are tabulated in Table I. The information with regard to the level schemes on ^{142,143}Pm are taken from Fig. 2 of Ref. [3] and Fig. 5 of Ref. [4]. As there is underlying delayed contributions due to positron and positronium lifetimes in the target and its surrounding, arising from 511 keV annihilation γ rays, we have quoted only upper limits in the mean lifetime for some cases where the corresponding time distributions may have contributions from positronium decay. Those truly do not reflect the actual lifetime of the levels. The Weisskopf estimates are made using the standard formulas [9] in order to get an idea on the enhancement and retardation of the transitions under consideration.

From the available data [10,11] on the neighboring $N=81$ isotones of ^{142}Pm, it is noticed that the low-lying level structures of these nuclei are not known beyond spin 10 in most cases and, hence, there is not much of systematics available for the states in these nuclei. For ^{142}Pm, the level scheme above the 8^- 2 ms isomer at 883.0 keV has been extended recently by us [3] up to 5.085 MeV. The negative parity level sequence, above the 8^- isomer, according to Ref. [3], necessitates the inclusion of a higher-seniority configuration, which is supported by the large basis shell model calculations for the neighboring singly closed ^{143}Pm [4]. It is observed that multiparticle excitations to $1h_{11/2}$ orbital is necessary in order to reproduce the level scheme of ^{143}Pm above spin $19/2^+$. The neutron hole in ^{142}Pm being rather

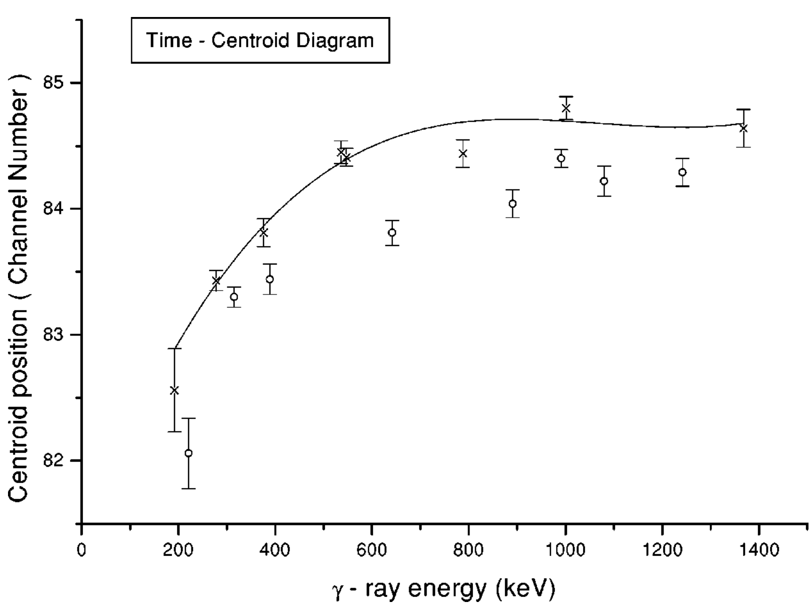

FIG. 2. Centroid positions of the time distributions for ^{142,143}Pm transitions. Crosses ($\times$) denote positions belonging to known prompt transitions, which give the zero-time line, and circles (o) denote the delayed ones.

TABLE I. Measured mean lifetimes of excited states in ^{142,143}Pm, produced by the reaction ^{133}Cs(^{13}C,xn) at $E=60$ MeV.

Nucleus	Level energy (keV)	J_i^π	E_γ (keV)	J_f^π	Multipolarity	Measured mean lifetime (ns)	Single-particle estimate (s)
^{142}Pm [a]	2069.7	13^-	142.9	11^-	$E2$	12.82 ± 6.25	3.11×10^{-7}
	2291.2	15^-	221.5	13^-	$E2$	4.05 ± 1.34	3.48×10^{-8}
	1198.0	9^-	315.0	8^-	$M1+E2$	< 1	1.02×10^{-12}
	1874.7	10^-	991.7	8^-	$E2$	1.19 ± 0.65	1.93×10^{-11}
^{143}Pm [b]	1898.3	$15/2^+$	234.9	$11/2^+$	$E2$	22.51 ± 3.38 [c]	2.57×10^{-8}
	2287.3	$17/2^+$	389.0	$15/2^+$	$M1$	< 1	5.40×10^{-13}
	2229.8	$19/2^-$	642.5	$17/2^-$	$E1$	2.81 ± 0.58	1.35×10^{-15}
	4280.9	$25/2^+$	891.2	$23/2^-$	$E1$	2.60 ± 0.67	5.04×10^{-16}
	6657.7	$(33/2)^-$	1080.0	$(31/2^-)$	$M1+E2$	1.84 ± 0.78	2.52×10^{-14}
	5628.4	$31/2^+$	1242.3	$27/2^+$	$E2$	1.46 ± 0.82	6.21×10^{-12}

[a]Information on level scheme taken from Fig. 2 of Ref. [3].
[b]Information on level scheme taken from Fig. 5 of Ref. [4].
[c]Measured by the "slope" method.

inert, the transitions in ^{142}Pm between states at corresponding spin regime are thus decided by the available proton configurations. The measured mean lifetimes for the few cases in ^{142}Pm (cf. Table I) do not indicate significant enhancement, except for the 13^- level at 2069.7 keV which decays by the 142.9 keV ($E2$) transition. The order of the retardation factor for the 315 keV transition is consistent with the systematics, corroborating the $M1$ assignment for the transition.

Because of the low yield of ^{143}Pm in the present work, the statistical uncertainty in the measured mean lifetimes is rather high. However, it is observed that within experimental uncertainty, the transitions appear to be highly retarded. On the basis of the shell model calculation for ^{143}Pm [4,12], the dominant configurations contributing to the 4280.9 keV ($25/2^+$) level are 62% $\pi[(1g_{7/2})^7(2d_{5/2})^2(1h_{11/2})^2]$, 20% $\pi[(1g_{7/2})^5(2d_{5/2})^4(1h_{11/2})^2]$, and 15% $\pi[(1g_{7/2})^6(2d_{5/2})^3(1h_{11/2})^2]$. It is further observed that with respect to negative parity states, there exists good correlation between ^{143}Pm and ^{142}Nd states up to $J^\pi=19/2^-$, as the unique parity $1h_{11/2}$ orbital does not influence much the ^{142}Nd core states. However, above $19/2^-$ states, the multiparticle shell model states are influenced by the corresponding core-coupled states, arising out of coupling of either a $2d_{5/2}$ or a $1g_{7/2}$ proton with the 8^- to 14^- states in ^{142}Nd. Under this influence, the predicted shell model states at ($23/2^-$) are likely to be perturbed by the 8^- and 9^- states in ^{142}Nd around 3.5 MeV. According to Wirowski *et al.* [13], the said 8^- and the 9^- states in ^{142}Nd possess a likely configuration $\pi(d^1_{5/2}h^1_{11/2})$ and $\pi(d^2_{5/2})_0\times\pi(g^{-1}_{7/2}h^1_{11/2})$. It is, therefore, suggested that the observed 3389.7 keV ($23/2^-$) level is the one having the predicted shell model configuration: 59% $\pi[(1g_{7/2})^7(2d_{5/2})^3(1h_{11/2})^1]$ and 24% $\pi[(1g_{7/2})^5(2d_{5/2})^5(1h_{11/2})^1]$. This means that the 891.2 keV ($E1$) transition between the 4280.9 keV ($25/2^+$) and 3389.7 keV ($23/2^-$) levels is effected by single-proton transitions, involving $1h_{11/2}$ and $2d_{5/2}$ orbits. Such a transition is expected to be retarded which is reflected in the measured meanlife of the 4280.9 keV level.

From the estimated centroid shift for 1080 keV γ ray, which is suggested [4] to have originated from the decay of the probable high-spin isomer around 8 MeV in ^{143}Pm, an upper limit of 2 ns as the mean lifetime of the said isomer may be suggested. This is reasonably consistent with the known systematics of high-spin isomers in the neighboring $N=82$ isotones of ^{143}Pm [2]. From the suggested shell model configuration of 6657.7 keV ($33/2^-$) level [12], the 1080 keV transition seems to be contributed mostly by single-particle transitions of the type $2d_{5/2}\rightarrow1g_{7/2}$ and $2d_{3/2}\rightarrow3s_{1/2}$. A more definitive conclusion about the said high-spin isomer would be possible if the nucleus ^{143}Pm could be produced at still higher excitation energy and spin using a suitable target-projectile combination.

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