Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Invited talk presented at the 5th International
Conference on Nuclei Far from Stability,
Rosseau Lake, Ontario, Canada, September 14-19, 1987

**Decay Studies of Neutron Deficient
Rare Earth Isotopes with OASIS**

J. Gilat, J.M. Nitschke, P.A. Wilmarth,
K. Vierinen, and R.B. Firestone

September 1987

DECAY STUDIES OF NEUTRON DEFICIENT RARE EARTH ISOTOPES WITH OASIS*

J. Gilat,** J.M. Nitschke, P.A. Wilmarth, K. Vierinen*** and R.B. Firestone
Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

ABSTRACT

We report results on the decay of ^{124}Pr , $^{124,125}\text{Ce}$, $^{124,125}\text{La}$, $^{134-136}\text{Eu}$, $^{134-136}\text{Sm}$, $^{134-136}\text{Pm}$, ^{144}Ho , $^{141,142,144}\text{Dy}$, $^{140,141,142,144}\text{Tb}$, $^{140-142}\text{Gd}$, and $^{140-142}\text{Eu}$, produced by $^{92}\text{Mo}(\text{H.L., xpn})$ reactions at the Berkeley SuperHILAC, and studied with the OASIS on-line mass separator facility. Half-lives, delayed proton branching ratios, γ -ray energies and intensities, partial decay schemes and several J^π assignments are presented. Level systematics of the even mass Nd and Sm isotopes and of the $\nu_{h1/2} - \nu_{s1/2}$ isomers for $N=77$ are discussed.

INTRODUCTION AND EXPERIMENTAL

The OASIS on-line mass separator facility at the Berkeley SuperHILAC¹ is imminently suited for the study of highly neutron deficient, short-lived nuclides. The salient features of the system are shown in Fig.1. The ready availability of a wide variety of heavy ion beams from the SuperHILAC, including sufficiently intense beams (about 0.1 particle microamperes) of light isotopes of the first transition metal group (e.g. ^{58}Ni , ^{54}Fe , ^{52}Cr , ^{46}Ti , etc.) provides the means of producing, via the compound nucleus mechanism, adequate quantities of highly neutron deficient species, even though their production cross-sections are often less than 1mb. The high temperature ($>2800^\circ\text{C}$) surface ionization ion source, high ionoptical transmission and computer stabilized H.V. and magnet power supplies of the mass separator permit a rapid and interference-free separation of the desired mass chain. Unknown masses are extrapolated from known, stable isotopes via an NMR mass meter. Finally, the electrostatic ion deflector and fast programmable tape transport system enable time resolved studies of the desired species by an array of particle, x-ray and γ -ray detectors, in singles and coincidence modes, under relatively low background conditions in a shielded spectroscopy laboratory.

In the framework of a systematic investigation of neutron deficient rare earth isotopes, we have observed and characterized about 60 isotopes and isomers, ranging from $Z=57$ (La) to $Z=71$ (Lu) and with $124 \leq A \leq 152$. About half of these species were previously unknown. For the others, the body of available decay data has been substantially extended.

In this brief report we present results for about 30 of these nuclides, produced by the interaction of a variety of beams with enriched ^{92}Mo targets. The assignment of different decay modes and half-lives observed in a given mass chain to the relevant species is based, in all cases, on the observation of appropriate characteristic x-rays. The results include half-lives, γ -ray energies and relative intensities and, for some cases, partial decay schemes and delayed proton branching ratios.

* This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

** On leave from Soreq Nuclear Research Center, Yavne 70600, Israel.

*** On leave from University of Helsinki, SF 00170, Finland.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

1. SuperHILAC BEAM	9. EXTRACTION AND FOCUSING	17. MAGNETIC TAPE
2. TARGET	10. ANALYZING MAGNET	18. DETECTOR BOX
3. INSULATORS (BeO)	11. FOCAL PLANE DETECTOR BOX	19. N-TYPE Ge DETECTOR (52%)
4. ION SOURCE ANODE (Ta)	12. ELECTROSTATIC MIRROR	20. N-TYPE Ge DETECTOR (24%)
5. ION SOURCE CATHODE (Ta)	13. ELECTROSTATIC QUADRUPOLE	21. HPGe DETECTOR
6. CAPILLARY TUBES (Ta)	14. TRANSFER LINE	22. 718 μm Si DETECTOR
7. EB FILAMENT (Ta)	15. CONCRETE SHIELDING	23. 13.8 μm Si DETECTOR
8. EXTRACTION ELECTRODE	16. TAPE DRIVE (IBM 729)	24. 1mm PILOT F SCINTILLATOR

Fig. 1. A simplified representation of the OASIS mass separator online at the Lawrence Berkeley Laboratory SuperHILAC. The separator and tape system are approximately to scale. The major components are highlighted above.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

RESULTS

1. Mass 124

^{124}Pr , ^{124}Ce and ^{124}La were produced via the $^{92}\text{Mo}(^{36}\text{Ar}, \text{xpy})$ reaction at 174 MeV, with $x = 1, 2$, & 3 and $y = 3, 2$, & 1 respectively.

^{124}Pr : This new delayed proton precursor is produced with a very low cross section, so we could only measure its proton decay half-life of 1.2(2) s and assign one γ -ray of 142 keV to its decay². Our interpretation of this γ -ray as the $2^+ \rightarrow 0^+$ transition in ^{124}Ce is confirmed by recent in-beam data³.

^{124}Ce : In ref. 4, a 6(4) s decay of La x-rays was attributed to ^{124}Ce . We assign γ -rays of 120, 253, 544 and 560 keV to this decay. The intensity of these γ -rays is quite low with respect to the ~ 6 s component of the 511 keV annihilation peak or the La K_α and K_β x-rays. This indicates that the even-even ^{124}Ce decays predominantly to a low spin (1^+ ?) lanthanum isomer, not observed in our experiments.

^{124}La : Our measured half-life of 30(2) s agrees with that quoted by ref. 4. The following γ -rays (energies in keV, relative intensities in brackets) are associated with this decay: 229.8 [100], 421.2 [95], 576.3 [63], 694.5 [11], 1033 [~ 10] and 1262 [~ 10]. The first four lines correspond, respectively, to the $2^+ \rightarrow 0^+$, $4^+ \rightarrow 2^+$, $6^+ \rightarrow 4^+$ and $8^+ \rightarrow 6^+$ transitions in the ground state rotational band of ^{124}Ba , while the other two establish a second 2^+ level at 1262 keV. This decay pattern, shown in Fig. 2, is a clear indication of the high spin nature (7^+ ?) of the parent ^{124}La . No direct evidence for the decay of the low spin (1^+ ?) isomer produced in the decay of ^{124}Ce could be found.

Fig. 2. Decay of ^{124}La . 2. Mass 125

The reactions $^{92}\text{Mo}(^{36}\text{Ar}, 2\text{pn})$ and $^{92}\text{Mo}(^{36}\text{Ar}, 3\text{p})$ at 152 MeV were used to produce ^{125}Ce and ^{125}La . The analysis of the data is incomplete, and only preliminary results are presented.

^{125}Ce : Bogdanov et al.⁴ attributed a La x-ray activity decaying with a half-life of 11(4) s to ^{125}Ce . In ref. 2 we reported a delayed proton branch in ^{125}Ce and measured its half-life as 10(1) s. From the proton branching ratios to the 2^+ , 4^+ and 6^+ levels in ^{124}Ba we assigned a spin of $5/2^+$ to the ground state of ^{125}Ce . The γ -ray spectrum attributed to this decay is very complex: over 70 γ -rays between 50 and 2550 keV were tentatively identified by half-life analysis and coincidence with La x-rays. The strongest γ -rays at 194, 325, 370 and 379 keV decay with a half-life of 14(1) s, rather than 10(1) s obtained from delayed proton and La x-ray decays. This difference of half-lives is probably due to an isomer feeding the same set of levels in ^{125}La , but its exact nature has not yet been elucidated.

^{125}La : Our half-life of 70(3) s agrees with that of ref. 4. In addition to the 43.7 and 67.2 keV γ -rays assigned in ref. 4, we have identified 30 γ -rays between 70 and 1270 keV. The transitions at 98.8, 134.0, 168.6, 216.7, 232.7 and 384.4 keV were also observed in ref. 5 and attributed to the $h_{11/2}$ and $g_{7/2}$ rotational bands.

3. Mass 134

The reactions $^{92}\text{Mo}(^{46}\text{Ti},\text{xpy})$ with $x = 1, 2 \text{ \& } 3$ and $y = 3, 2 \text{ \& } 1$ at 212 MeV were used to produce ^{134}Eu , ^{134}Sm and ^{134}Pm . Only a 4s tape cycle, optimized for the study of ^{134}Eu , was used, so that only an estimate of the half-life of ^{134}Sm could be obtained, and the half-life of ^{134}Pm could not be measured.

^{134}Eu : This new delayed proton precursor was produced with a very low cross section, so we could only measure its half-life of 0.5(2) s. Based on production cross section systematics, this is probably the high spin ($\pi h_{11/2}$) member of the isomeric pair typical of most even mass Eu isotopes.

^{134}Sm : Our estimated half-life of 10(2) s is consistent with the value of 12(3) s of ref. 6. The following nineteen γ -rays were assigned to this decay (energies in keV, relative intensities in brackets): 51 [1.6], 105 [3], 107 [1], 110 [11], 112 [7], 117 [3], 119 [100], 130 [2], 141 [3], 162 [11], 186 [7], 219 [28], 224 [2], 229 [12], 257 [6], 280 [14], 299 [18], 380 [16], 419 [9], and 15 of them placed in a decay scheme with levels in ^{134}Pm at 112.4, 118.9, 229.0, 280.0, 304.9, 409.5, 419.0, 537.5 keV. Since they are populated in the decay of the even-even ^{134}Sm these are presumably low ($J=1,2$) spin states.

^{134}Pm : Twenty one γ -rays between 290 and 1750 keV were identified with this decay; eighteen were placed in a decay scheme comprising levels in ^{134}Nd at 294.4(2⁺), 735.9(2⁺), 789.3(4⁺), 1089.1(3⁺), 1318.8(4⁺), 1384.0, 1420.5(6⁺), 1541.8, 1605.9, 1669.4, 1697.7, 1956.4 and 2231.9 keV. The levels at 294, 789 and 1421 keV are members of the ground state rotational band; the levels at 736, 1089 and 1319 keV appear to belong to a γ -vibrational band. This part of the decay scheme is in agreement with that recently proposed by Kortelahti et al.⁷, but our placement of some of the higher lying levels differs from theirs. The population of the 6⁺ level in ^{134}Nd suggests a $J^\pi = 5^+$ for the 25s ^{134}Pm parent. No direct evidence for the decay of the low spin ^{134}Pm species produced in the decay of ^{134}Sm was observed.

4. Mass 135

^{135}Eu , ^{135}Sm and ^{135}Pm were produced by $^{92}\text{Mo}(^{46}\text{Ti},\text{xpy})$ with $x = 3, 2 \text{ \& } 1$ and $y = 0, 1, \text{ \& } 2$ respectively, at 192 MeV.

^{135}Eu : A half-life of 1.5(2) s for this new isotope was determined from the decay of the Sm K x-rays, and a weak γ -ray at 120.8 keV was assigned to its decay. Delayed proton emission, though energetically possible, was not observed, consistent with the systematics of other even N precursors.

^{135}Sm : Our measured half-life for this isotope is 10(1) s, in agreement with ref. 6. The following 22 γ -rays were assigned to this decay (energies in keV, relative intensities in brackets): 49 [15], 55 [100], 77 [50], 105 [70], 116 [6], 124 [5], 127 [68], 160 [2], 182 [17], 190 [77], 237 [80], 286 [67], 313 [16], 341 [12], 351 [15], 363 [65], 418 [20], 428 [54], 543 [20], 573 [35], 755 [35], 1132 [17]. From our data we extract a delayed proton branching ratio of $\sim 5 \times 10^{-4}$ for this isotope. The $2^+ \rightarrow 0^+$ 294 keV transition in ^{134}Nd (but not the 495 keV $4^+ \rightarrow 2^+$ transition) was observed to be in coincidence with the protons. This indicates a low spin (1/2 or 3/2) for the parent ^{135}Sm .

^{135}Pm : About 40 γ -rays between 100 and 1200 keV were assigned to the decay of ^{135}Pm . The tape cycle of 40 s optimized for ^{135}Eu was too short for a reliable half-life determination. However, two distinct decay patterns of the strong γ -rays could be discerned: The 199 keV γ -ray, identified as an $11/2^- \rightarrow 9/2^-$ transition in ^{135}Nd and associated with the decay of a high spin ($11/2^-$) ^{135}Pm species⁸, decays with a single component half-life of ~ 50 s. Most other γ -rays, such as 129, 208, 245, 263, 270 and 398 keV exhibit a complex growth-decay pattern, and are probably associated with a low spin Pm species produced in the decay of the low spin ^{135}Sm .

5. Mass 136

The reactions $^{92}\text{Mo}(^{46}\text{Ti},\text{pn})$ and $^{92}\text{Mo}(^{46}\text{Ti},2\text{p})$ at 192 MeV were used to produce

^{136}Eu and ^{136}Sm .

^{136}Eu : Twenty eight γ -rays between 100 and 1500 keV were assigned to the decay of ^{136}Eu ; the lines at 255 [100], 432 [34], 535 [9] and 576 [10] represent respectively the $2^+ \rightarrow 0^+$, $4^+ \rightarrow 2^+$, $6^+ \rightarrow 4^+$ and $8^+ \rightarrow 6^+$ transitions in ^{136}Sm , indicating a high ($7^+?$) J^π assignment for the parent. Excess intensity of the $2^+ \rightarrow 0^+$ transition indicates however that a low spin ^{136}Eu species is also present in high abundance. This conclusion is borne out by the observation that the $4^+ \rightarrow 2^+$ transition decays with a significantly shorter half-life than the $2^+ \rightarrow 0^+$. We are thus led to postulate two ^{136}Eu species: ^{136m}Eu ($J^\pi = 7^+?$) with a half life of 3.2(5) s and ^{136g}Eu ($J^\pi = 1^+?$) with a half life of approximately 5 s. The copious production of the low spin member in a heavy ion reaction suggests an IT path between the two species, but the relevant transitions have not been identified. Both species appear to be delayed proton precursors. Analysis of the γ -rays associated with this decay indicates a γ -vibrational band based on a second 2^+ level at 713 keV in ^{136}Sm .

^{136}Sm : The tape cycles, optimized for ^{136}Eu , were too short for a half life determination for this isotope. About 40 gamma transitions between 90 and 800 keV were assigned to its decay, most of them of low energy and roughly the same low intensity. The only exception is a strong line at 114.5 keV, about equal in intensity to the sum of all other lines. A $J^\pi = 1^+$ assignment to the 114.5 keV level in ^{136}Pm is indicated by the strong GT β^+ branch to this level. This, in turn, establishes the ground state of the ^{136}Pm species as 2^+ , which is not identical with the 1.8 m 5^+ species reported in ref. 8. The existence of a $5^+/2^+$ isomeric pair is not unexpected for Pm isotopes.

6. Mass 140

^{140}Tb , ^{140}Gd , and ^{140}Eu were produced via the $^{92}\text{Mo}(^{54}\text{Fe}, \text{xpn})$ reaction at 298 MeV with $x=3,4$ & 5 and $y=3,2$ & 1. The analysis is incomplete, and no absolute normalizations are yet available. ^{140m}Eu was also produced by $^{92}\text{Mo}(^{52}\text{Cr}, 3\text{pn})$.

^{140m}Tb : Proton emission has been assigned to this isotope on the basis of coincidence with Gd K x-rays. The absolute proton branching ratio is $7 \pm 2 \times 10^{-3}$. γ -rays of 328.4 and 627.8 keV were observed and assigned as the $2^+ \rightarrow 0^+$ and $6^+ \rightarrow 4^+$ transitions respectively. The $4^+ \rightarrow 2^+$ transition is known to exist at 508 keV and was obscured by an intense annihilation peak. The 328.4 keV transition is twice as intense as the 627.8 keV γ -ray and no evidence of an $8^+ \rightarrow 6^+$ transition was found. We tentatively assign the isomeric decay to a 6-isomer, predicted by systematics. The half-life of 2.4(2) s is adopted for this isotope. No evidence for a low spin ^{140m}Tb was observed.

^{140}Gd : 38 γ -rays between 160 and 1150 keV have been assigned to the decay of ^{140}Gd . A half-life of 15.8(4) s is adopted for this isotope. A partial decay scheme is shown in Fig. 3.

Fig. 3. Decay of ^{140}Gd .

^{140m}Eu : 174.8- and 185.2 keV γ -rays are observed with a half-life of 125(2) ms. The 174.8 keV transition is strongly populated by ^{140}Gd decay and is presumed to

deexcite a 1^+ level of that energy. The 185.2 keV γ -ray is only weakly populated by ^{140}Gd decay and is not in coincidence with the 174.8 keV γ -ray. The 185.2 keV γ -ray is intense and must deexcite to the ground state. We thus presume that both levels are populated by unobserved low-energy transitions from an isomer with a half-life of 125 ms.

^{140}Eu : A half-life of 1.51(2) s was adopted for this isotope. 18 γ -rays between 190 and 2000 keV have been assigned to its decay and 15 have been placed in a decay scheme comprising levels in ^{140}Sm at 531, 991, 1246, 1442, 1599, 2283, 2309 and 2482 keV. The γ -rays populated in this decay are also observed in equilibrium with ^{140}Gd decay, consistent with production from a low-spin ^{140}Eu parent. However, the decay scheme is dominated by feeding to the 2^+ level at 531 keV and to excited levels which deexcite through the 2^+ but not the ground state. The 4^+ level is only weakly populated by γ -ray deexcitation and no evidence for excited 2^+ states was obtained. We cannot reconcile the ^{140}Eu spin at this time; the most likely values are 0^- , 1^- , or 2^- with considerable unobserved decay intensity accounting for the apparent 2^+ feeding. Such a spin would be inconsistent with the systematics of the heavier Eu isotopes and might indicate a breakdown in the $Z=64$ semi-magic shell. No evidence could be found for a $\sim 20\text{s}$ $^{140\text{m}}\text{Eu}$ reported by Habs et al.⁹, presumably due to an erroneous assignment of ^{140}Gd .

7. Mass 141

^{141}Dy , ^{141}Tb , ^{141}Gd and ^{141}Eu were produced by the $^{92}\text{Mo}(^{54}\text{Fe}, \text{xpn})$ reaction at 276 MeV, with $x = 2, 3, 4$ & 5 and $y = 3, 2, 1$ & 0, respectively. ^{141}Gd and ^{141}Eu were also produced by the $^{92}\text{Mo}(^{52}\text{Cr}, 2\text{pn})$ and $^{92}\text{Mo}(^{52}\text{Cr}, 3\text{p})$ reactions at 210 MeV.

^{141}Dy : This 0.9(2) s delayed proton precursor was reported in an earlier publication.² No further details of its decay features could be observed, due to the low production cross section.

^{141}Tb : The half life of this new isotope was determined as 3.5(2) s, and 35 gamma transitions between excited levels of ^{141}Gd were assigned to its decay, and fitted to a decay scheme comprising levels at 113, 198, 258, 378, 492, 514, 552, 646, 662, 753, 758, 895, 940, 990, 1100 and 1132 keV. The lower portion of this level scheme can be seen in Fig. 4. Most of the levels populated by the $\beta^+ + \text{EC}$ decay of ^{141}Tb , decay to the $11/2^-$ isomeric state at 378 keV, and only very few transitions cross this level to the low spin structures near the ground state of ^{141}Gd . This establishes the high spin nature of the 3.5 s Tb species. No indication of a low spin ^{141}Tb could be found in the data.

Fig. 4. IT decay of $^{141\text{m}}\text{Gd}$.

^{141}Gd : Redon et al.¹⁰ recently reported the discovery of ^{141}Gd with a half-life of 22(3) s, assigned six γ -rays to its decay and proposed a partial decay scheme. Our much more comprehensive data clearly show the presence of two distinct species: a 24.5(9) s high spin ($11/2^-$) isomer at 378 keV, decaying by both $\beta^+ + \text{EC}$ (86%) to (mostly) the $11/2^-$ 96 keV isomeric state in ^{141}Eu and by an isomeric transition (14%) a low spin ($1/2^+$) ground state, which decays by $\beta^+ + \text{EC}$ to the $5/2^+$ ground state of

with Tb K x-rays². The absolute proton decay branching ratio is $\sim 8 \times 10^{-3}$. A 181.9 keV γ -ray, deexciting a level of the same energy was observed with an absolute intensity of 4.3 ± 1.2 per 100 decays. The total EC/ β^+ ratio for ^{142}Dy decay is 0.111 ± 0.005 . A half-life of 2.3(3) s is adopted for this isotope.

^{142m}Tb : This isotope decays by IT with a half-life of 303 ± 7 ms. γ -rays of 181.9 (also seen in the decay of ^{142}Dy) and 211.6 keV are associated with this decay. The decay scheme for this isotope is given in Fig. 6.

^{142g}Tb : Proton emission was assigned to ^{142g}Tb on the basis of coincidence with Gd K x-rays. The absolute proton decay branch from this isotope is $\sim 3 \times 10^{-5}$. A partial decay scheme for this isotope is shown in the figure. The absolute intensity of the 515.3 keV γ -ray is 24.9 ± 1.7 per 100 decays. The total EC/ β^+ ratio for ^{142g}Tb decay is 0.033 ± 0.004 . A half-life of 597(17) ms is adopted for this isotope.

^{142}Gd : 42 γ -rays between 100 and 1800 keV; were assigned to this decay and placed in a decay scheme comprising levels in ^{142}Eu at 178.8, 280.3, 284.4, 496.7, 503.1, 526.2, 585.8, 591.3, 614.5, 619.8, 631.7, 660.9, 935.7, 1412.7, 1438.4, 1480.8, 1485.8 and 1779.1 keV. The 178.9 keV γ -ray has an absolute intensity of 11.2 ± 1.1 per 100 decays. The EC/ β^+ ratio for ^{142}Gd decay is 1.08 ± 0.11 per 100 decays. A half-life of 70.2(6) s was adopted for this isotope.

^{142m}Eu : The previously known¹² decay scheme for this 2.4(2) s isotope was confirmed. The absolute intensity of the 768.0 keV γ -ray is 10.2 ± 0.7 per 100 decays and the total EC/ β^+ ratio is 0.112 ± 0.018 .

Fig. 6. Decay of $^{142g+m}\text{Tb}$.

9. Mass 144

^{144}Ho , ^{144}Dy and ^{144}Tb were produced by the $^{92}\text{Mo}(^{58}\text{Ni}, \text{xpy})$ with $x=3, 4$ & 5 and $y=3, 2$ & 1 respectively and by the $^{92}\text{Mo}(^{56}\text{Fe}, \text{xpy})$ reaction with $x=1, 2$ & 3 and $y=3, 2$ & 1 , respectively. The decays of ^{144}Ho , ^{144}Dy , and $^{144m+g}\text{Tb}$ were investigated. K x-ray and annihilation intensities and equilibrium information were exploited to determine absolute γ -ray intensities. Apart from minor differences, the results agree with those of refs. 10, 13 and 14

^{144}Ho : Proton emission was assigned to this isotope on the basis of coincidence with Dy K x-rays. The half-life for the protons was $0.7(1) \text{ s}^2$.

^{144}Dy : A half-life of $9.1(5) \text{ s}$ was determined for ^{144}Dy . Proton emission was assigned to this isotope on the basis of coincidence with Tb K x-rays². The absolute proton decay branching ratio is $6 \pm 1 \times 10^{-3}$. 21 γ -rays were identified with ^{144}Dy decay populating levels at 0, 196.5, 298.7, 396.7, 469.5, 532.2, 615.9, 620.0, 774.4, 793.3, and 1237.2 keV. The absolute intensity of the 298.7 keV gamma ray is 13.7 ± 1.1 per 100 decays.

Fig. 8. Level systematics of even Nd and Sm isotopes.

REFERENCES

1. J.M. Nitschke, Nucl. Instr. and Meth. **206**, 301 (1983)
2. P.A. Wilmarth et al., Z. Phys. **A325**, 485 (1986)
3. K.L. Ying et al., J. Phys. G: Nucl. Phys. **12**, L211 (1986)
4. D.D. Bogdanov et al., Nucl. Phys. **A307**, 425 (1978)
5. J. Gizon et al., Z. Phys. **A285**, 259 (1978)
6. D.D. Bogdanov et al., Nucl. Phys. **A275**, 425 (1977)
7. M. Kortelahti et al., Z. Phys. **A327**, 231 (1987)
8. C.M. Lederer and V.S. Shirley, Table of Isotopes 7th ed., Wiley (1978)
9. D. Habs et al., Z. Phys. **A250**, 179 (1972)
10. N. Redon et al., Z. Phys. **A325**, 127 (1986)
11. J. Deslauriers et al., Z. Phys. **A283**, 33 (1977)
12. G.G. Kennedy et al., Phys. Rev. **C12**, 553 (1975)
13. D.C. Sousa et al., Phys. Rev. **C25**, 1012 (1982)
14. E. Nolte et al., Z. Phys. **A306**, 223 (1982)
15. I. Ragnarsson et al., Nucl. Phys. **A233**, 329 (1974)
16. G.A. Leander et al., Phys. Lett. **110B**, 17 (1982)
17. J.A. Cizewski et al., Phys. Lett. **175**, 11 (1986)
18. J. Deslauriers et al., Z. Phys. **A325**, 421 (1986)