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DECAY STUDIES OF NEUTRON DEFICIENT RARE EARTH ISOTOPES WITH OASIS*

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ABSTRACT

We report results on the decay of ^{124}Pr, ^{124,125}Ce, ^{124,125}La, $^{134-136}$Eu, $^{134-136}$Sm, $^{134-136}$Pm, ^{144}Ho, ^{141,142,144}Dy, ^{140,141,142,144}Tb, $^{140-142}$Gd, and $^{140-142}$Eu, produced by ^{92}Mo(H.I.,xpyn) 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 $\nu h_{11/2}$ - $\nu s_{1/2}$ isomers for N=77 are discussed.

INTRODUCTION AND EXPERIMENTAL

The OASIS on-line mass separator facility at the Berkeley SuperHILAC[1] 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 °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.

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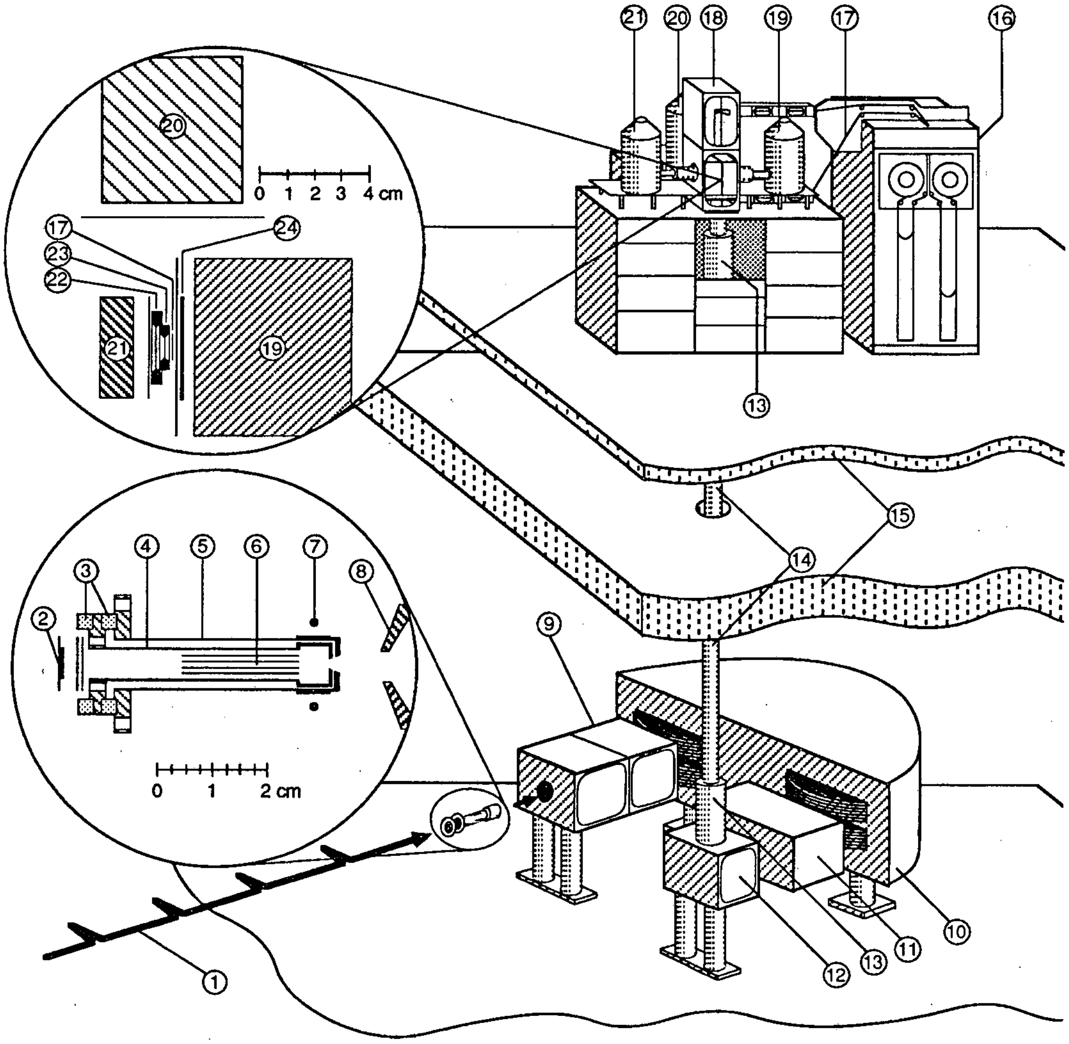

1. SuperHILAC BEAM
2. TARGET
3. INSULATORS (BeO)
4. ION SOURCE ANODE (Ta)
5. ION SOURCE CATHODE (Ta)
6. CAPILLARY TUBES (Ta)
7. EB FILAMENT (Ta)
8. EXTRACTION ELECTRODE
9. EXTRACTION AND FOCUSING
10. ANALYZING MAGNET
11. FOCAL PLANE DETECTOR BOX
12. ELECTROSTATIC MIRROR
13. ELECTROSTATIC QUADRUPOLE
14.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

RESULTS

1. Mass 124

^{124}Pr, ^{124}Ce and ^{124}La were produced via the ^{92}Mo (^{36}Ar, xpyn) 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 decay[2]. Our interpretation of this γ-ray as the $2^+ \rightarrow 0^+$ transition in ^{124}Ce is confirmed by recent in-beam data[3].

^{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.

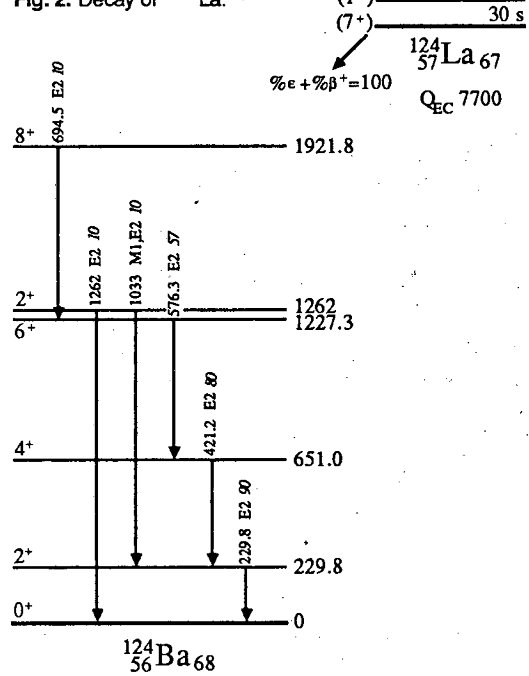

Fig. 2. Decay of ^{124}La.

2. Mass 125

The reactions ^{92}Mo(^{36}Ar,2pn) and ^{92}Mo(^{36}Ar,3p) 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.

<u>3. Mass 134</u>

The reactions $^{92}Mo(^{46}Ti,xpyn)$ with x = 1, 2 & 3 and y = 3, 2 & 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.

<u>4. Mass 135</u>

^{135}Eu, ^{135}Sm and ^{135}Pm were produced by $^{92}Mo(^{46}Ti,xpyn)$ with x = 3, 2 & 1 and y = 0, 1, & 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 $\sim 5\times10^{-4}$ 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 species[8], 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.

<u>5. Mass 136</u>

The reactions $^{92}Mo(^{46}Ti,pn)$ and $^{92}Mo(^{46}Ti,2p)$ 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 $2^+ \to 0^+$, $4^+ \to 2^+$, $6^+ \to 4^+$ and $8^+ \to 6^+$ transitions in ^{136}Sm, indicating a high (7^+?) J^π assignment for the parent. Excess intensity of the $2^+ \to 0^+$ 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 $4^+ \to 2^+$ transition decays with a significantly shorter half-life than the $2^+ \to 0^+$. We are thus led to postulate two ^{136}Eu species: ^{136m}Eu (J^π = 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}Mo(^{54}Fe,xpyn) 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}Mo(^{52}Cr,3pn).

^{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 $2^+ \to 0^+$ and $6^+ \to 4^+$ transitions respectively. The $4^+ \to 2^+$ 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 $8^+ \to 6^+$ 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 ^{140g}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.

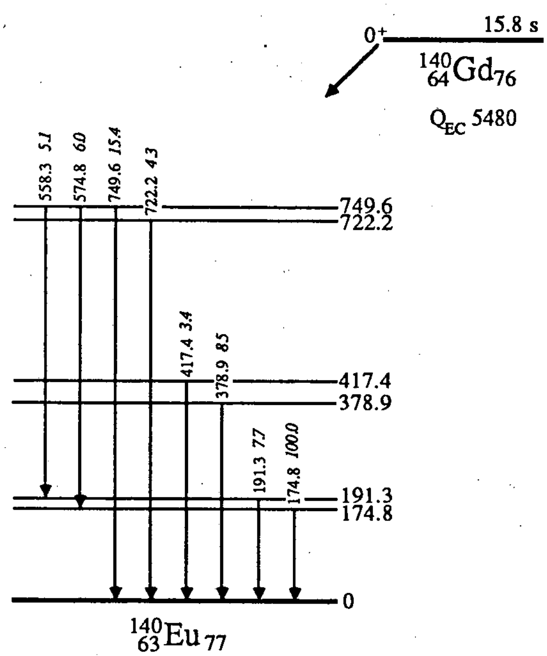

Fig. 3. Decay of ^{140}Gd.

^{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 ^{140g}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.

^{140g}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 ^{140g}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 ~20s ^{140m}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}Mo(^{54}Fe,xpyn) 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}Mo(^{52}Cr,2pn) and ^{92}Mo(^{52}Cr,3p) 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 β^++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.

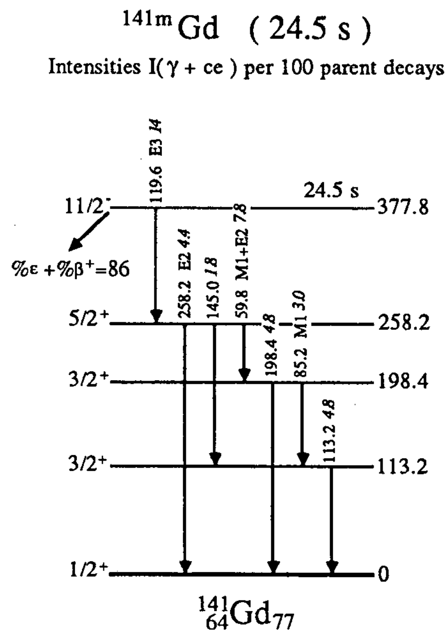

Fig. 4. IT decay of ^{141m}Gd.

^{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 β^+ + 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 β^+ + EC to the $5/2^+$ ground state of

^{141}Eu. The half life of ^{141g}Gd is about 20 s; a more precise value is difficult to extract from our data. The decay schemes of the two isomers are shown in Fig. 5. Thirty six of the forty γ-rays assigned to these decays have been placed with no overlap between the decay of the two species. The delayed protons that were observed in the decay of ^{141}Gd appear by half life analysis and lack of coincident γ-rays to originate from the low spin ground state, with a branching ratio of 3±1 x 10^{-4}.

^{141}Eu: Our data on the decay of the 40 s ^{141g}Eu agree almost completely with those of Deslauriers et al.[11], and will not be elaborated here. The results regarding the $11/2^-$ isomeric state at 96.4 keV, however, differ significantly from those of Ref. 9. Our half-life value is 2.7(3) s compared to 3.3(3) s[11], but, more importantly, the β^+ + EC branching ratio is only about 7% instead of 67%, resulting in a logft value of 5.1 for the $\pi h_{11/2} \rightarrow \nu h_{11/2}$ β transition, rather than the unusually low value of 4.1 suggested by ref. 11. Since in our work ^{141}Sm is produced only by decay of ^{141}Eu, the activity ratio ^{141m}Sm/^{141g}Sm is a direct and reliable measure of the above branching ratio.

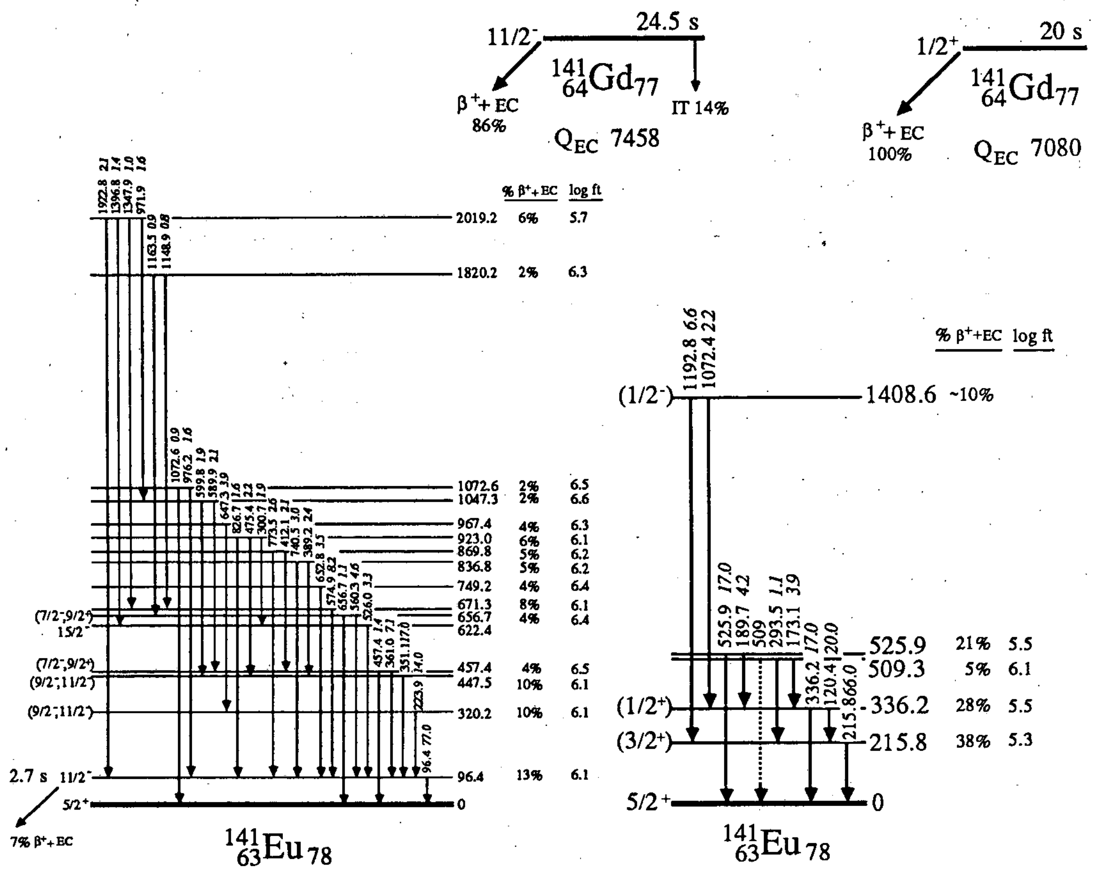

Fig. 5. Decay of ^{141g}Gd and ^{141m}Gd.

8. Mass 142

^{142}Dy, ^{142}Tb and ^{142}Gd were produced via the ^{92}Mo(^{54}Fe,xpyn) reaction at 250 MeV with x=2,3,4 and y=2,1 & 0 respectively. ^{142g}Eu was obtained from the decay of ^{142}Gd. ^{142}Tb was also procuded by ^{92}Mo(^{52}Cr,p3n). These isotopes formed a series of equilibrium pairs which together with K x-ray and annihilation data allowed the determination of absolute EC, β^+, and γ-ray intensities.

^{142}Dy: Proton emission was assigned to this decay on the basis of coincidence with Tb K x-rays[2]. The absolute proton decay branching ratio is ~8x10^{-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 ~3x10^{-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 known[12] 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.

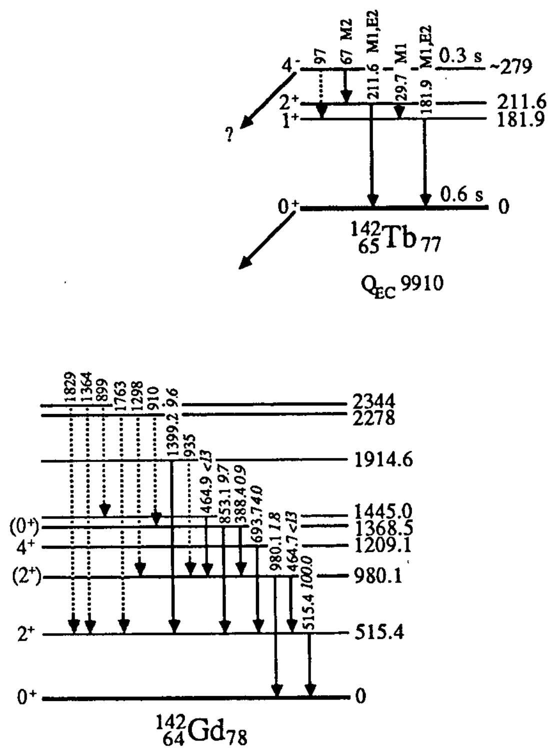

Fig. 6. Decay of $^{142g+m}$Tb.

9. Mass 144

^{144}Ho, ^{144}Dy and ^{144}Tb were produced by the ^{92}Mo(^{58}Ni,xpyn) with x=3,4 & 5 and y=3,2 & 1 respectively and by the ^{92}Mo(^{56}Fe,xpyn) reaction with x=1,2 & 3 and y=3,2 & 1, respectively. The decays of ^{144}Ho, ^{144}Dy, and $^{144m+g}$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) s[2].

^{144}Dy: A half-life of 9.1(5) s was determined for ^{144}Dy. Proton emission was assigned to this isotope on the basis of coincidence with Tb K x-rays[2]. The absolute proton decay branching ratio is 6±1x10^{-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.

^{144m}Tb: This isomer was determined to decay by IT (62%) and EC+β^+ (38%), with a half-life of 4.1(1) s. No evidence for proton emission was observed. 15 γ-rays were assigned to ^{144m}Tb decay. The absolute intensity of the 743 keV γ-ray is 38±3 per 100 decays of ^{144m}Tb.

^{144g}Tb: Decay to levels at 0(0$^+$), 743.0(2$^+$), 1877.2(2$^+$), and 1886.8(0$^+$)keV was observed. The 1144 keV γ-ray deexciting the 1886.8 keV level was determined to have an absolute intensity of 5.3±0.3 per 100 decays. No half-life for ^{144g}Tb could be determined because it was produced in equilibrium with both ^{144}Dy and ^{144m}Tb.

CONCLUDING REMARKS

The experiments summarized in the foregoing section have yielded a large body of new spectroscopic data on previously unknown or poorly characterized highly neutron deficient rare earth isotopes. Almost all of the odd mass and odd-odd isotopes studied exhibit isomerism due to the prominence of the $h_{11/2}$ neutron and proton shells in this mass region. The heavy ion induced reactions, which are the only practical means of producing these isotopes, exhibit a strong preference for the production of the high spin member of each isomeric pair. However, our practice of simultaneously following several members of a given isobaric decay chain, in and out of equilibrium, enabled us to study also the low spin species or, at least, infer their existence. The nuclear structure information underlying our data has not yet been fully elucidated. A pertinent problem is the persistence of the Z=64 closed shell as one moves away from N=82 shell, or the predicted onset of prolate or triaxial deformation below N=78[15–17]. The apparently anomalous J^π of the ground state of ^{140}Eu suggested by our data may indicate such an effect. In contrast, Fig. 7 shows the systematics of the $\nu h_{11/2}$ - $\nu s_{1/2}$ isomers for N=77. Our newly established levels in ^{141}Gd follow closely the systematics of analogous levels in the other isotones[8,18]. This indicates that the Z=64 shell has little effect on the spectroscopy of these neutron levels. However, the B(E3) transition rate for the 120 keV $11/2^- \rightarrow 5/2^+$ transition is only ~9x10^{-4} Weisskopf Units, i.e. about 5-10 times slower than the rate observed for the other three isotones.

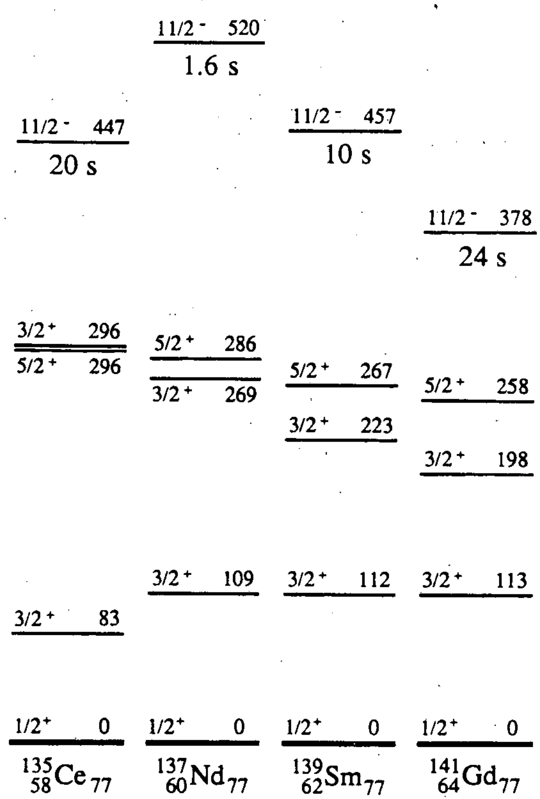

Fig. 7. Level systematics of N=77 isotones.

Fig. 8 shows the systematics of low-lying levels in even Nd and Sm isotopes. A smooth downward trend with increasing deformation is observed for both the ground state rotational band and for the γ-vibrational band. The only significant deviation is the position of the second 2$^+$ level (and the associated γ-vibrational band) in ^{132}Nd. This is in contrast with the smooth behavior of the samarium isotopes and throws a considerable doubt on the interpretation of the ^{132}Nd spectrum, recently proposed by ref. 7.

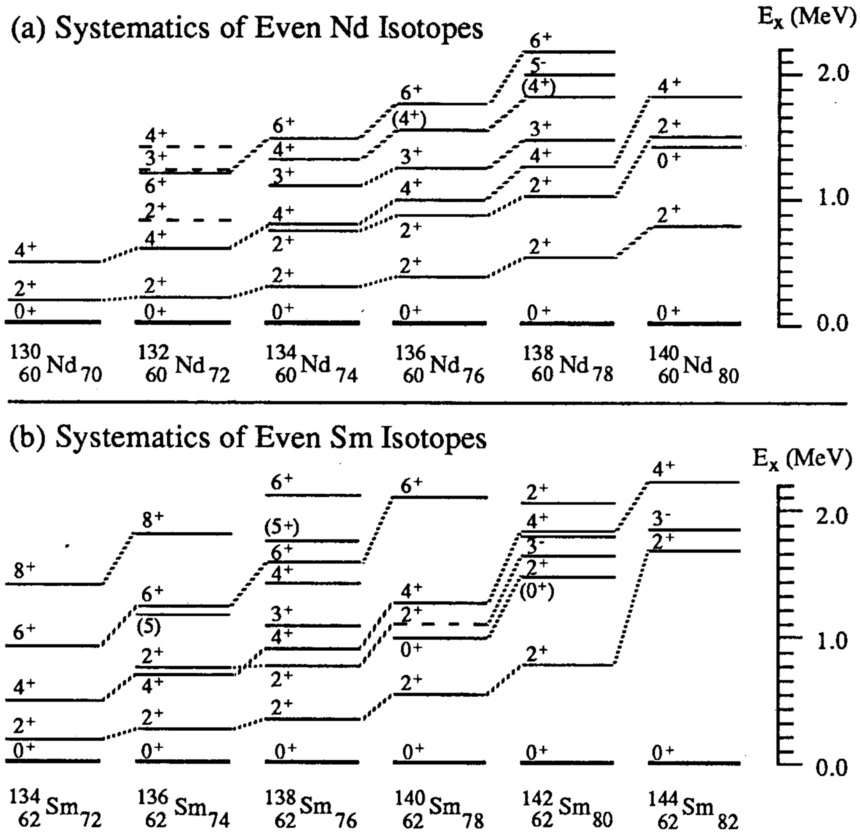

Fig. 8. Level systematics of even Nd and Sm isotopes.

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