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Study of the N = 77 odd-Z isotones near the proton-drip line

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Abstract. The evolution of the $\pi h_{11/2}\nu h_{11/2}$ and $\pi h_{11/2}\nu s_{1/2}$ isomeric configurations was studied for the $N = 77$ isotones near the proton drip line. The decays of metastable levels in ^{140}Eu, ^{142}Tb , and ^{144}Ho were measured by means of X-, gamma- and conversion electron spectroscopy at the Recoil Mass Spectrometer at Oak Ridge. The sequence of isomeric levels in ^{140}Eu was experimentally determined. The half-life of the $\pi h_{11/2}\nu h_{11/2}$ state in ^{142}Tb was remeasured to be 25(1) μs. The spins and parities of 5^- and 8^+ for the $\pi h_{11/2}\nu s_{1/2}$ and $\pi h_{11/2}\nu h_{11/2}$ ^{142}Tb isomers, respectively, were established from measured multipolarities. No evidence for the expected 1^+ ground state was found in the ^{144}Ho decay data.

PACS. 21.10.Hw Spin, parity, and isobaric spin – 21.10.Tg Lifetimes – 23.20.Lv γ transitions and level energies – 27.60.+j $90 \leq A \leq 149$

The interpretation of the structure of proton-emitting nuclei often suffers from the lack of data on nuclei next to the proton drip line. For an odd-odd $N = 77$ isotone ^{146}Tm, two proton-radioactive states are known and both exhibit fine structure in the proton emission spectra [1,2,3]. However, there was an ambiguity in the spin and configuration assignment and even a possibility of a third proton emitting state was considered [1]. In order to understand the evolution of the proton-neutron states beyond the proton drip line, we have studied the $N = 77$ even-mass isotones next to ^{146}Tm, namely ^{144}Ho,^{142}Tb, and ^{140}Eu. These nuclei were produced at the HRIBF in fusion-evaporation reactions between ^{54}Fe projectiles, at 225 MeV, 250 MeV and 315 MeV, respectively, and a 98.7% enriched, 1 mg/cm^2, ^{92}Mo target. Recoiling ions were separated according to their mass to charge (A/Q) ratio by means of the RMS [4]. After passing the position sensitive MCP detector [5], the recoils with desired A/Q were implanted into a collection foil or a tape [6] in front of the X-ray, gamma and conversion electron detectors assembled in a CARDS array [7]. For the ^{142}Tb studies involving conversion electron counting with a high resolution BESCA [6] spectrometer, a degrader foil (2.3 mg/cm^2 Cu) was placed in front of the implantation point. This foil slowed the 70 MeV ^{142}Tb ions to about 10 MeV, resulting in an implantation depth of ~ 3.3 μm. Electrons with energies below 20 keV emitted at this depth were stopped in the tape, and measured energies of 85 keV electrons were shifted down by about 3 keV. The signals from all RMS detectors were processed using 40 MHz Digital Gamma Finder XIA modules [8,9].

^{140}Eu: a metastable state ^{140m1}Eu, $T_{1/2} = 125$ ms, was previously reported [10]. We identified a second isomeric level, ^{140m2}Eu [11], with $T_{1/2} = 302(4)$ ns. The results were in agreement with two independent studies [12,13]. Figure 1 displays the 175 keV and 185 keV transitions, known from the ^{140m1}Eu decay, in the γ-energy spectrum following the 302 ns activity within 200 ms. It shows experimentally the sequence of levels, with the 302 ns ^{140m2}Eu being above the 125 ms ^{140m1}Eu as was suggested in [12,13].

^{142}Tb: there were two isomeric levels reported for ^{142}Tb, the 15(4) μs ^{142m2}Tb at 620 keV [14] and the 303 ms ^{142m1}Tb at 280 keV [10]. We had more statistics than [14], thus we obtained a half-life of ^{142m2}Tb of

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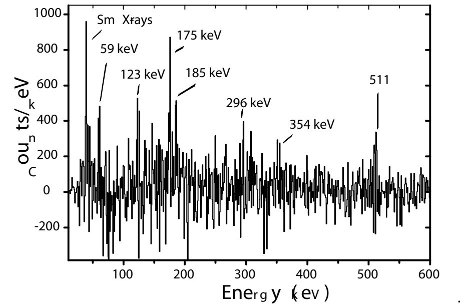

Fig. 1. Gamma rays following the decay of the 302 ns isomer (^{140m2}Eu) within 200 ms less those following by 200–400 ms. The presence of the 175 and 185 keV lines indicates that the 302 ns ^{140m2}Eu activity feeds the 125 ms ^{140m1}Eu. All labeled peaks are believed to be random statistical correlations except for the 175 and 185 keV peaks.

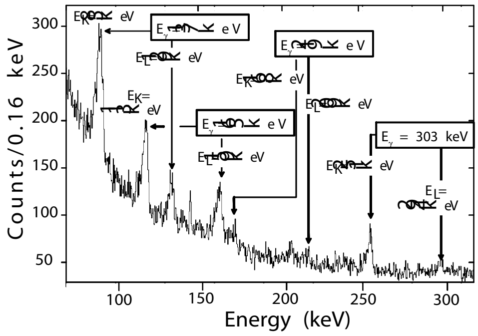

Fig. 2. ^{142m2}Tb conversion electron data measured with the BESCA detector within 90 μs after ion implantation.

Table 1. K/L ratios and deduced transition multipolarities for some of the isomeric decays in ^{142}Tb.

E_γ	K/L	K/L (calc)		Multi-
(keV)	(exp)	$E2$	$M1$	polarity
137	4.9(7)	1.74	6.89	$E2, M1$
165	4.5(6)	2.24	6.91	$E2, M1$
303	4.1(3)	4.04	7.02	$E2$
182	5.4(3)	2.53	6.92	$E2, M1$
212	2.56(7)	2.96	6.93	$E2$

25(1) μs based on the decay pattern of 37, 137, 165, 219 and 303 keV lines with a total number of counts of about 1.25×10^6 in the first 210 μs. The observed K-to-L ratio of intensities for respective electron lines, see fig. 2, allowed determination of the multipolarities of 137, 165, and 303 keV transitions, see table 1. From the gamma intensities balance, the multipolarities of $E1$, $M1$, $M2$ and $E3$ were deduced for the 37, 84, 68 and 98 keV lines, respectively. The multipolarities of the transitions indicate a spin and parity of 5^- for the $\pi h_{11/2} \nu s_{1/2}$ ^{142m1}Tb (see fig. 3). The sequence of derived multipolarities, the $E2$ and $E1$ for the 303 keV and 37 keV, respectively, allows assignment of 8^+ to the $\pi h_{11/2} \nu h_{11/2}$ ^{142m2}Tb. The mixed multipolarities of $M1/E2$ observed for the 137 keV and 165 keV lines agree with the level scheme and properties displayed in fig. 3.

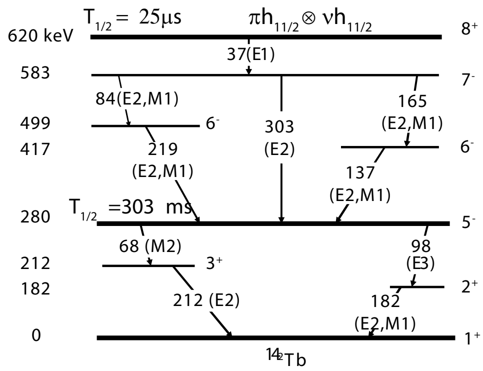

Fig. 3. ^{142}Tb decay scheme.

^{144}Ho: we measured the half-life of ^{144m}Ho to be 455(77) ns, in agreement with 500(50) ns [15]. In addition to the known transitions, we observed a 40 keV transition with a sub-microsecond half-life, but we were unable to assign it to the ^{144}Ho level scheme due to the lack of γ-γ coincidence statistics. Shorter or longer recoil-gamma correlation times did not reveal new activities. Since there are only up to three gamma lines following the decay of the high-spin (7^+,8^+) $\pi h_{11/2} \nu h_{11/2}$ ^{144m}Ho [15], there is no clear evidence for feeding of a possible 1^+ ground state. A 1^+ ground state of ^{144}Ho can be expected from the simple extrapolation of the level systematics of the neighboring lower-mass $N = 77$ isotones, ^{140}Eu and ^{142}Tb. Our observation might indicate that the 1^+ configuration does not minimize the energy of $N = 77$ even-mass isotones at the proton drip line, and the moderate spin $\pi h_{11/2} \nu s_{1/2}$ level becomes the ground state [1,2,3].

In summary, the systematic study of the p-n configurations in odd-odd $N = 77$ isotones was started. The spins and parities 8^+ and 5^- of $\pi h_{11/2} \nu h_{11/2}$ and $\pi h_{11/2} \nu s_{1/2}$ states in ^{142}Tb were established, and the level schemes of ^{140}Eu and ^{144}Ho were verified. The level scheme of ^{144}Ho to resembles the properties of ^{146}Tm, with an apparent absence of the 1^+ ground state known for lower-mass $N = 77$ isotones. Further work is needed to explain the evolution and relative energies of the 1^+ state *versus* the higher spin isomeric configurations.

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