Eur. Phys. J. A **25**, s01, 155–157 (2005)
DOI: 10.1140/epjad/i2005-06-143-8

EPJ A direct
electronic only

Recoil decay tagging study of ^{146}Tm

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Received: 20 January 2005 /
Published online: 10 August 2005 –

Abstract. Gamma-rays from the odd-odd transitional proton-emitting nucleus ^{146}Tm have been observed using the recoil-decay tagging technique. A rotational band similar to the $h_{11/2}$ decoupled band in ^{147}Tm has been observed. The particle decay of ^{146}Tm has been measured with improved statistics. A new decay scheme for ^{146}Tm is discussed with reference to prompt and delayed γ-rays detected in coincidence with particle decays.

PACS. 23.20.Lv γ transitions and level energies – 23.50.+z Decay by proton emission – 27.60.+j $90 \leq A \leq 149$

1 Introduction

The phenomenon of one proton radioactivity occurs from odd-Z nuclei which are situated beyond the proton dripline, that is they are unbound to the emission of a proton from their ground state. Proton emission offers a unique laboratory in which to gain information on the structure of nuclei beyond the proton dripline. The combination of highly segmented double-sided silicon strip detectors (DSSD) with large high-efficiency Ge arrays allows detailed information on the excited states of proton-rich nuclei to be established.

The thulium proton-emitting isotopes ^{145,146,147}Tm lie in a region of predicted shape change [1], moving from a prolate shape for ^{145}Tm to an oblate shape for ^{147}Tm. Fine structure has been observed in the decay of ^{145}Tm [2], with a branch to the first 2^+ excited state of the daughter nucleus ($E_p = 1728(10)$ keV and $t_{1/2} = 3.1(3)\,\mu$s, $E_p = 1393(10)$ keV and $t_{1/2} = 3.1(3)\,\mu$s, respectively). A total of 5 separate proton transitions were observed in ^{146}Tm [3,4]. Excited states in ^{147}Tm have been observed using the recoil decay tagging (RDT) technique with a modest array of Ge detectors [5].

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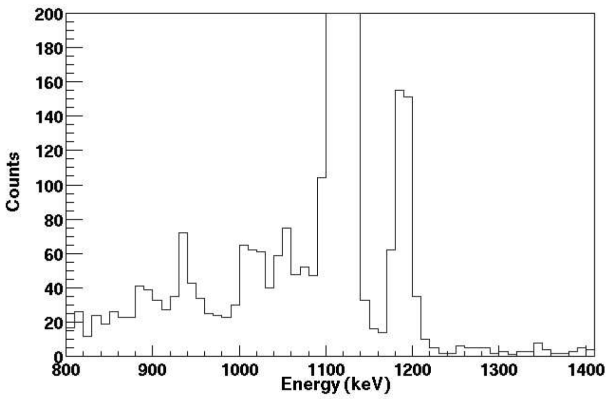

Fig. 1. Decays in DSSD within 500 ms of $A = 146$ implant.

2 Experimental results

In a recent RDT study a ^{92}Mo beam from the ATLAS accelerator was used with a ^{58}Ni target to produce ^{145,146,147}Tm via the 1p4n, 1p3n and 1p2n fusion-evaporation channels, respectively. The GAMMASPHERE Ge array was used in conjunction with the standard FMA and DSSD setup at Argonne National

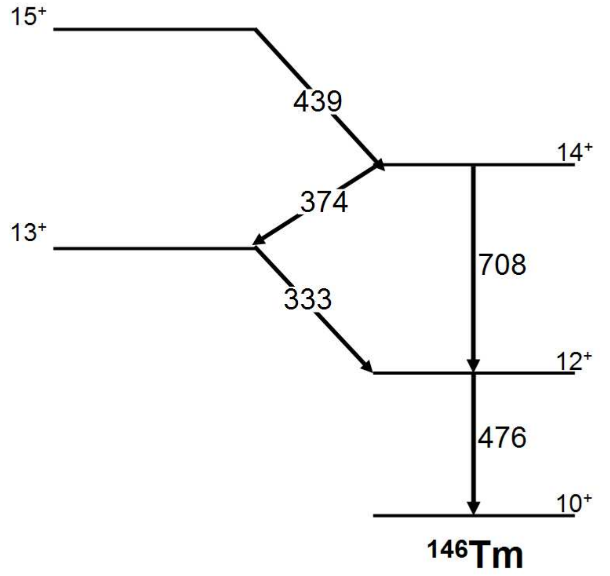

Fig. 2. Proposed level scheme for ^{146}Tm showing tentative spin and parity assignments.

Laboratory [6]. A parallel semi-Gaussian shaping amplifier and fast delay-line amplifier system was used to instrument the DSSD allowing recoil-decay correlations to be observed for times down to 1 μs [7].

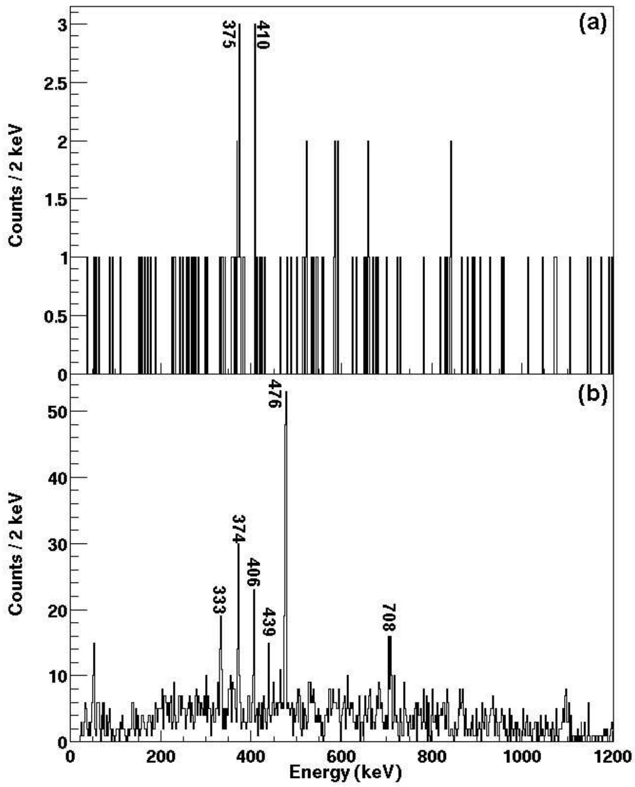

Fig. 3. Recoil-decay tagged γ-rays for (a) 890 keV proton transition and (b) 1122 keV proton transition.

3 Results and discussion

The five previously observed proton transitions in ^{146}Tm were remeasured with improved statistics, fig. 1. The energies of the transitions were found to be in good agreement with previous measurements. New, more precise values were measured for the half-lives of the five transitions. A proposed rotational band feeding the high-spin isomer emitting 1122 keV protons is shown in fig. 2. The spin and parity assignments are based on the systematics of similar rotational bands observed in the $N = 77$ isotones [8]. The energies of the transitions are very similar to those of the ground state band in ^{147}Tm [5] which is based on the $h_{11/2}$ proton state. ^{146}Tm is an odd-odd proton emitter which lies in the transitional region between predicted deformed and near-spherical shapes. It is potentially a rich source of information regarding the role of the odd neutron in proton decay. The improved statistics in this experiment allow some of the long-standing difficulties with the level scheme of ^{146}Tm to be addressed. The most intense $\sim$ 200 ms 1122 keV transition is assigned as an $l = 5$ transition from a $(10^+, 9^+, 8^+)$ state based on the $\pi h_{11/2} \nu h_{11/2}$ configuration, which agrees with previous work. High spin isomer states are strongly populated in fusion-evaporation reactions in this region.

From the half-life measurements it appears that the 937 keV, 1010 keV and 1192 keV transitions occur from the same state with a weighted half-life of 82(4) ms. As in previous work the 1192 keV transition is assigned as an $l = 5$ transition from a $(6^-, 5^-)$ state based on the $\pi h_{11/2} \nu s_{1/2}$ configuration to the ground state of ^{145}Er. The neighboring $N = 77$ isotones have a number of low-lying $3/2^+$ and $5/2^+$ states below the $11/2^-$ state. On the basis of this, and the delayed γ-rays seen in coincidence with the 937 keV and 1010 keV transitions, the 937 keV and 1010 keV transitions are assigned as decays from the $(6^-, 5^-)$ state in ^{146}Tm to low-lying states in ^{145}Er. This is the first example of decay to 3 states in the daughter nucleus from a proton emitter.

The placement of the 890 keV transition is more problematic. It has previously been assigned as a decay from the (10^+) isomeric state in ^{146}Tm to a $9/2^-$ state in ^{145}Er [4], however this assignment would require a significant admixture of the $\pi f_{7/2}$ orbital to the emitter wave function. An alternative assignment could be the $l = 0$ decay of a low-lying (1^+) state in ^{146}Tm to the ground state of ^{145}Er. A similar state is seen in neighboring odd-odd isotopes.

The half-life measured here suggests that the 890 keV transition occurs from a third state with a half-life of 155(20) ms. This would seem to favor decay from a low-lying 1^+ state in ^{146}Tm to the ground state of ^{145}Er. The recoil-decay tagged γ-ray spectra for the 890 keV transition and the 1122 keV transition are shown in fig. 3. Despite the low statistics in the 890 keV spectrum it is clear that the most intense 476 keV transition from the 1122 keV gated spectrum is not present, again suggesting that the decays occur from two separate states in ^{146}Tm.

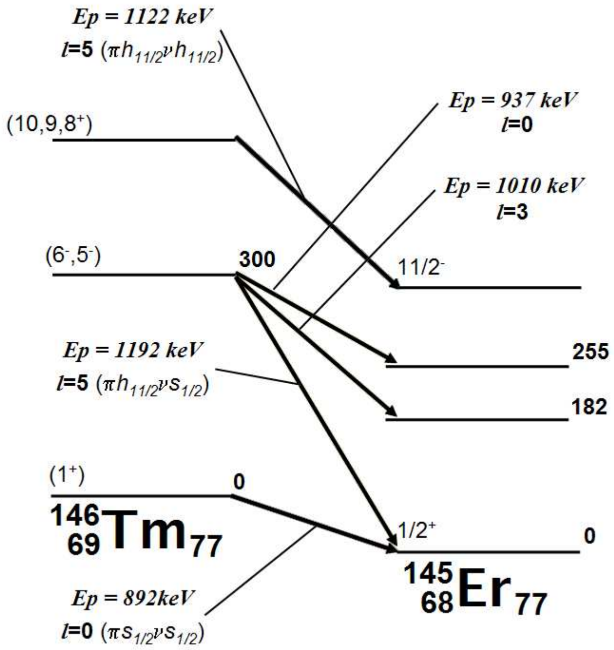

Fig. 4. Proposed ^{146}Tm decay scheme.

The absence of delayed γ-rays in coincidence with the 890 keV transitions suggests that the decay is to the ground state. As such the transition is assigned as decay from a low-lying 1^+ state to the ground state of ^{145}Er. The proposed decay scheme for ^{146}Tm is shown in fig. 4. A comparison of experimental partial proton decay half-lives with detailed theoretical calculations is needed to fully determine the structure of ^{146}Tm.

4 Summary

The combination of the FMA-DSSD system with GAMMASPHERE provides a powerful tool for studying excited states in proton-rich nuclei. The excited states of ^{146}Tm have been observed for the first time. Improved particle decay statistics have allowed all the observed proton transitions from this nucleus to be placed in a decay scheme for the first time.

This work was supported by the U.S., D.O.E., under Contract No. W-31-109-ENG-38. A.P.R would like to acknowledge funding from EPSRC. P.J.W would like to acknowledge receipt of an EPSRC research grant.

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