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RADIOACTIVITIES WITH $146 < A < 152$ INVESTIGATED AT THE OASIS FACILITY; EVIDENCE FOR ^{147}Tm β-DECAY

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A collaborative program, involving researchers from the Lawrence Berkeley and Oak Ridge National Laboratories, has now been in progress at the SuperHILAC OASIS on-line facility[1] for more than two years. In these investigations properties of short-lived nuclei near the 82-neutron shell have been studied, their decays being assayed with particle, γ-ray, x-ray, and positron detectors. Nuclides investigated so far were produced in ^{58}Ni bombardments of ^{96}Ru, ^{94}Mo, and ^{92}Mo. They are shown in Fig. 1 where a portion of the periodic chart for $N < 84$ and for $64 < Z < 72$ is displayed. Note that for nuclei with less than 84 neutrons α-particle emission is not observed due to the 82-neutron shell since this closure drastically lowers Q values available for α decay. However, as shown in Fig. 1, because of the proximity of the proton drip line and the large Q_{EC} values, both β-delayed and direct proton emission are observed. Table I lists the isotopes we have investigated and summarizes some of the information obtained.

The focus of the study has been primarily two-fold: 1) to gain insight into the nature of the sharp peaks seen in the delayed-proton spectra that accompany the β decays of $N = 81$ even-Z precursors, and, 2) to investigate low-lying states in nuclei near $N = 82$, levels whose structures should be describable by shell-model analyses. Much of the accumulated data have been described in recent publications. Interested readers are referred to these papers for a discussion of the following: 1) experimental and calculational decompositions of the ^{151}Yb (Ref. 2) and of the ^{148}Ho, ^{150}Tm, and ^{152}Lu (Ref. 3) delayed-proton spectra; 2) systematics[4,5] of single-particle states in $N = 81$ and $N = 82$ isotones compared with predictions from HFB calculations; and, 3) a description of decay properties of $A = 152$ (Ref. 6) and $A = 150$ (Ref. 7) nuclides. Here we will discuss data from a recent experiment that examined $A = 147$ nuclides produced in ^{58}Ni bombardments of ^{92}Mo.

On the basis of proton coincidences with positrons, x rays, and γ rays, we have shown[2] that the structured and statistical components of the ^{151}Yb delayed-proton spectrum are associated with the isotope's $s_{1/2}$ ground state and $h_{11/2}$ isomeric β decays, respectively. The structured component has also been observed in the delayed-proton spectra of two other $N = 81$ precursors, i.e., ^{147}Dy and ^{149}Er (see e.g. Ref. 8). Because it persists for ^{151}Yb the implication is that it reflects a region of low density of 1/2 and 3/2 levels in all three β-decay daughters as a consequence of the $N = 82$ shell with the effect of the $Z = 64$ subshell being minimal.

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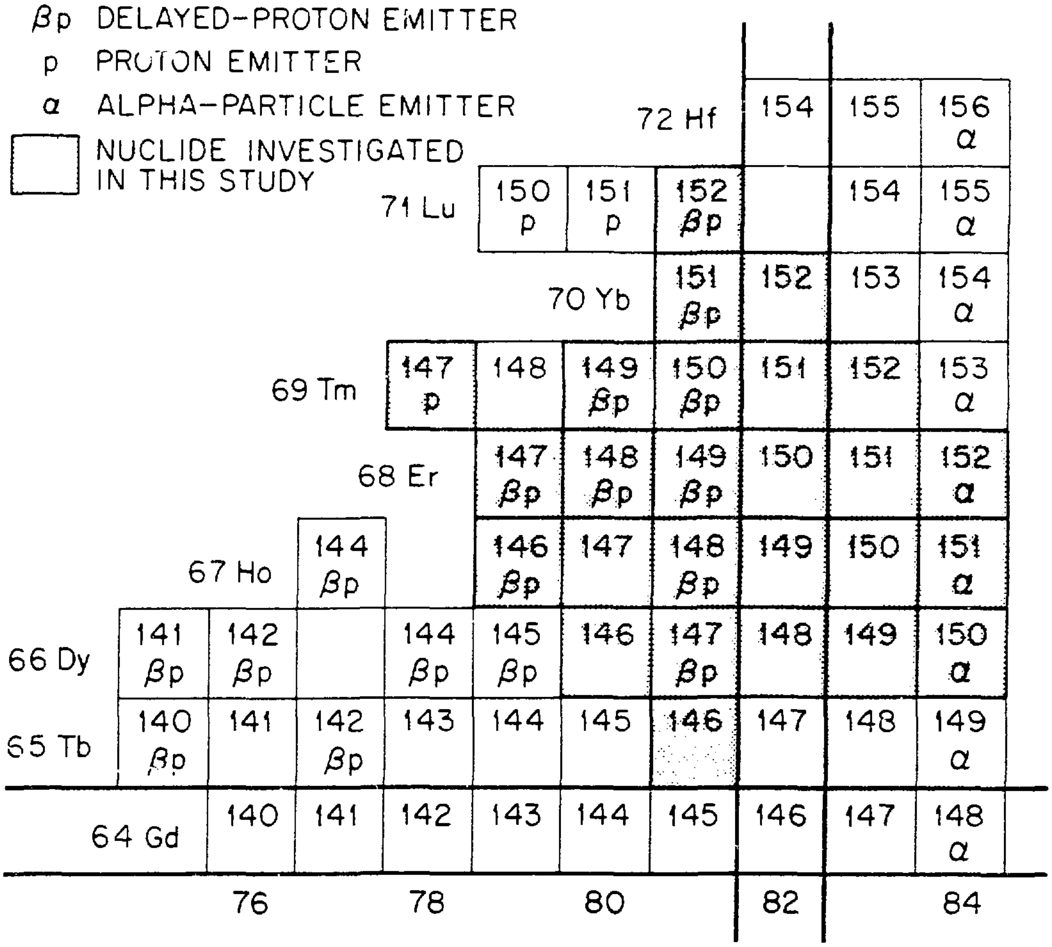


βp DELAYED-PROTON EMITTER
p PROTON EMITTER
α ALPHA-PARTICLE EMITTER
☐ NUCLIDE INVESTIGATED IN THIS STUDY

72 Hf								154	155	156 α
71 Lu					150 p	151 p	152 βp		154	155 α
70 Yb							151 βp	152	153	154 α
69 Tm				147 p	148	149 βp	150 βp	151	152	153 α
68 Er					147 βp	148 βp	149 βp	150	151	152 α
67 Ho			144 βp		146 βp	147	148 βp	149	150	151 α
66 Dy	141 βp	142 βp		144 βp	145 βp	146	147 βp	148	149	150 α
65 Tb	140 βp	141	142 βp	143	144	145	146	147	148	149 α
64 Gd		140	141	142	143	144	145	146	147	148 α
		76		78		80		82		84

Fig. 1. Portion of nuclidic chart; investigated isotopes are indicated by shaded squares.

To provide further evidence for this suggestion we performed a decomposition of protons emitted by the N = 79 precursor ^{147}Er ($T_{1/2}$ = 2.5 s); the main difference here, vis-à-vis the N = 81 isotones, is that one is now two neutrons further removed from N = 82.

Data were taken in 4-s counting cycles to emphasize ^{147}Er activity, and in 160- and 1.28-s cycles to provide information on the contributions of ^{147}Dy and ^{147}Tm, respectively. While these results are still being analyzed, two points have emerged. First, both low- (probably $s_{1/2}$) and high-spin (probably $h_{11/2}$) precursors contribute to the ^{147}Er delayed protons, and second, neither the total spectrum (studied also by Schardt et al.[8]) nor the spectrum in coincidence with positrons (it should probe lower excitation energies in the β-decay daughter) exhibits any intense peaks.

The existence of two proton-emitting states in ^{147}Tm has been established (see e.g. Ref. 9). Cross-section measurements and barrier-penetration half-life calculations suggest that the $s_{1/2}$ state ($T_{1/2}$ = 360 μs) is a pure proton emitter but that the $h_{11/2}$ state ($T_{1/2}$ = 560 ms) has a large β-decay branch which as yet has

Table I. Isotopes investigated in this study.

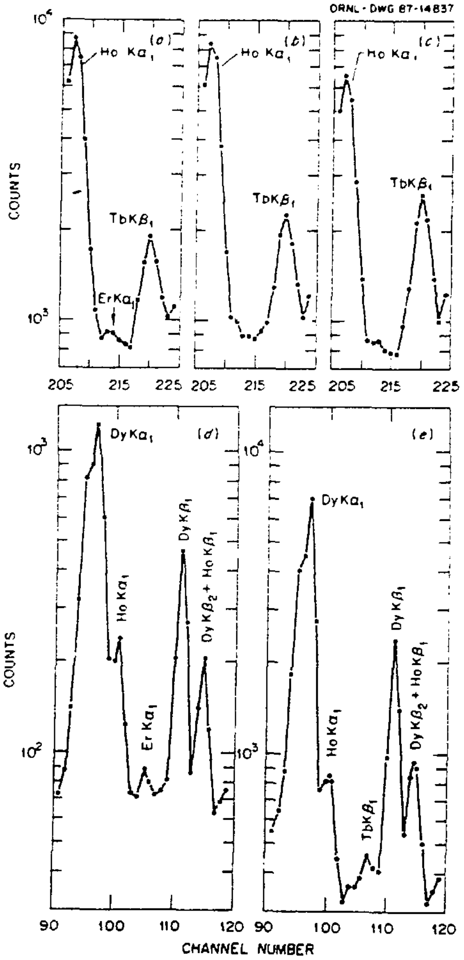
Isotope	J^{π}	$T_{1/2}$(s)	Delayed protons
^{146}Ho		3.6(3)	Yes[a]
^{146}Dy	0^+	29(3)	
^{146}Tb	1^+	~ 8	
^{147}Tm[b]	$(11/2^-)$	0.65(7)	
^{147}Er	$(11/2^-)$	2.5(2)	Yes
^{147}Er	$(1/2^+)$		Yes
^{147}Ho	$(11/2^-)$	5.8(2)	
^{148}Er	0^+	4.4(2)	Yes[a]
^{148}Ho	(6^-)	9.7(3)	Yes[a]
^{148}Ho	(1^+)		Yes[a]
^{149}Tm[c]	$(11/2^-)$	0.9(2)	Yes[a]
^{149}Er	$11/2^-$	9(1)	Yes
^{149}Er	$1/2^+$		Yes
^{149}Ho	$11/2^-$	21(1)	
^{149}Ho	$1/2^+$	54(5)[d]	
^{150}Tm	(6^-)	2.2(2)[d]	Yes[a]
^{150}Tm	(1^+)		Yes[a]
^{150}Er	0^+	20(1)	
^{151}Yb[c]	$11/2^-$	1.6(1)	Yes[a]
^{151}Yb[c]	$1/2^+$		Yes[a]
^{151}Tm	$11/2^-$	4.3(2)	
^{151}Tm[c]	$1/2^+$	~ 11	
^{152}Lu[c]	(6^-)	0.7(1)	Yes[a]
^{152}Yb	0^+	3.1(2)	
^{152}Tm	(2^-)		

[a] Delayed-proton emission observed for the first time.
[b] Beta-decay branch of nuclide identified.
[c] New isotope or new isomer.
[d] New half-life.

not been observed experimentally. Despite a low production cross section (predicted to be ~ 0.2 mb) the 1.05-MeV proton group[9] of the $h_{11/2}$ ^{147}Tm state was clearly seen in our experiment, and, primarily in the 1.28-s data, there was evidence for this level's β-decay branch. The decay curve for the annihilation radiation had a small component of ~ 0.5 s, the delayed protons showed a growth and decay pattern consistent with a 2.5-s decay (^{147}Er) being fed by a 0.6-s radioactivity, and, Er K x rays were observed.

Figures 2(a) and 2(b) are portions of singles x-ray spectra taken during the first and second halves of the 1.28-s cycles; fig. 2(c) was accumulated during the first 0.5 s of the 4-s cycles. A weak Er $K\alpha_1$ peak is seen in (a), but only vestiges of it are visible in (b) and (c). Also, Er $K\alpha_1$ x rays were observed in coincidence with the annihilation radiation peak in the 1.28-s [part (d)] but not in the 4-s [part (e)] cycles. Preliminary estimates indicate that the ^{147}Tm $h_{11/2}$ level has a β-decay branch of ~ 90%.

Fig. 2. Portions of K-x-ray spectra measured for A = 147 nuclides in ^{58}Ni irradiations of ^{92}Mo: (a) and (b) singles spectra taken during first and second halves of 1.28-s counting cycles, respectively; (c) singles spectrum accumulated during the first 0.5 s of 4-s cycles; (d) and (e) spectra measured in coincidence with the annihilation radiation peak in 1.28-s and 4-s counting cycles, respectively.



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